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Energy for Change
Creating Climate Solutions

ENTREPRENEURIAL SOLUTIONS TO GLOBAL CHALLENGES

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John P. Holdren

Energy for Change

Introduction to the Special Issue on Energy & Climate

Without energy, there is no economy. Without climate, there is no environment. Without economy and environment, there is no material well-being, no civil society, no personal or national security. The overriding problem associated with these realities, of course, is that the world has long been getting most of the energy its economies need from fossil fuels whose emissions are imperiling the climate that its environment needs.

Compounding that predicament are emissions from land-use change, above all deforestation in the developing countries of the tropics. Like society's choices about energy supply and use, this process has been driven by powerful economic and political forces insufficiently moderated by understanding or consideration of the environmental component of societal well-being.

This is no longer a hypothetical or distant issue. It is real and it is upon us. The climate is changing markedly nearly everywhere. The air and the oceans are warming, mountain glaciers are disappearing, permafrost is thawing, sea ice is shrinking, the great land ice sheets on Greenland and Antarctica are slipping, and sea level is rising. And the consequences for human well-being are already being felt: more heat waves, floods, droughts, and wildfires; tropical diseases reaching into the temperate zones; vast areas of forest destroyed by pest outbreaks linked to warming; hurricanes and typhoons of greater power; and coastal property increasingly at risk from the surging seas.

All this is happening faster than was expected. Sea level is rising at twice the average rate for the 20th century. The volume of sea ice in the Arctic (its area times its average thickness), which reaches a seasonal minimum every September, appears to have been smaller in September 2008 than in any year of the last 30—the period in which we've been able to estimate this variable. In that same 30 years, the average area annually burned by wildfires in the Western United States has quadrupled.

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Nor is the primary cause of these changes any longer in serious doubt. The primary cause is the emission of carbon dioxide and other heat-trapping pollutants from our factories, homes, offices, vehicles, and power plants, and from land clearing. We also know that failure to curb these emissions will bring far bigger impacts from global climate change than those experienced so far. Drastic changes in weather patterns, sharp drops in the productivity of farms and ocean fisheries, a dramatic acceleration of species extinctions, and inundation of low-lying areas by rising sea level are among the possible outcomes.

> Without energy, there is no economy. Without climate, there is no environment. Without economy and environment, there is no material well-being, no civil society, no personal or national security. The overriding problem associated with these realities, of course, is that the world has long been getting most of the energy its economies need from fossil fuels whose emissions are imperiling the climate that its environment needs.

But we also know what we can and must do to avoid the worst of these possibilities. We must work together—East and West and North and South—to transform our technologies for supplying and using energy from polluting and wasteful to clean and efficient. We must create new incentives and agreements to accelerate this transformation, and to bring deforestation and other destructive land-use changes to a halt around the world. And we must invest in adaptation, to reduce our vulnerability to the degree of climate change that can no longer be avoided.

We can do this together. And when we do, we will benefit not only by avoiding the worst damages from climate change, but also by reducing our perilous overdependence on petroleum, alleviating the air pollution that afflicts our cities, preserving our forests as havens for biodiversity and sources of sustainable livelihoods, and unleashing a new wave of technological innovation—generating new businesses, new jobs, and new growth in the course of creating the clean and efficient energy systems of the future.

The key question on which we now need to heed what the science of climate change is telling us is how much progress we need to make with these measures, and how quickly, to have a good chance of avoiding climate changes more extreme than our adaptation efforts will be able to manage. And the science is increasingly clear in pointing to the conclusion that it will be essential to hold the global average temperature increase to no more than 2 degrees Celsius if we are to keep climate change to a manageable level.

It is likewise clear that if we are to have a good chance of meeting this goal, global emissions of carbon dioxide and other heat-trapping pollutants must level off by about 2020 and decline thereafter to something like 50 percent of the current levels by 2050, with continuing declines after that. Allowing for the larger historical responsibility and much higher current per capita emissions of the industrialized countries and for the development trajectories and aspirations of the developing ones, the most likely way to achieve this goal would be for the industrialized world to level off its emissions by 2015 and reduce them thereafter to around 20 percent of current levels by 2050, with the developing countries following after a lag of about a decade, leveling off their emissions by about 2025 and reducing them after that.

These are targets that we can meet. As the content in this special edition of *Innovations* illustrates, the solutions to our climate challenge aren't just "out there," they are right here—before your eyes, in your hands. Climate solutions are in California, which thirty years ago charted a course toward energy efficiency that other states are only now beginning to follow. They are in Brazil, which generates 50% of the fuel used in its cars from home-grown sugarcane. They are in New Hampshire, where a company started by a former nuclear engineer is working to develop the carbon capture and storage technologies that will be essential for a cleaner coal future. They are in Hawaii, where plug-in electric vehicles are quietly becoming a reality. And they are in Arkansas, where the world's biggest company—Wal-Mart—is establishing standards for energy use and carbon reductions that will apply not only to its global operations but to its entire supply chain.

These and the other innovations described in this special issue are not isolated anecdotes. Nor are they elements of any single grand plan. They are simply a few of the many pathways to progress created every day by citizens, by the businesses that serve them, and by the governments that represent them. Such pathways derive from another other type of energy vital to addressing our climate challenges: the creative energy of people who, through ingenuity, partnerships, and collaborations, are able to cut through complexity to arrive at practical solutions. We can ask for no better guides than they toward the prosperous and secure future to which we all aspire.

CONTENTS OF THE SPECIAL ISSUE

The publication before you is as thorough a survey of energy and climate solutions as has yet been compiled. Like other issues of *Innovations*, it is organized into four sections: lead essays; cases authored by innovators (each accompanied by a commentary); integrative analytic papers; and perspectives on policy.

Lead Essays

The lead essays are authored by a formidable group of energy and climate policy veterans.

First among them is Thomas Schelling, recipient of the Nobel Prize in Economics in 2005 (jointly with Robert Aumann) and chair of the first committee of the National Academy of Sciences to study global warming. Schelling makes a compelling case for a new institutional architecture to support international collaboration to address the climate challenge. Specifically, Schelling points out that the countries most likely to suffer adverse impacts from climate change are also, in most cases, the ones least well equipped to adapt their energy infrastructures to reduce carbon emissions. Advanced industrialized countries have an opportunity to reduce adverse impacts from climate change while improving welfare for the majority of the world's population by both increasing and better structuring energy and climate assistance to developing countries.

The second lead essay is authored by Vinod Khosla, a founder of Sun Microsystems, a general partner at the venture capital firm of Kleiner Perkins Caufield & Byers and the founder of Khosla Ventures, a major investor in energy technologies. Khosla applies the deal-making acuity that has made him one of America's most successful private-equity investors to the task of proposing a way forward with climate negotiations that would be acceptable both to developed and developing countries. Khosla makes the case that even when countries agree on the urgency of the climate challenge and on the most efficient mechanisms to achieve needed carbon reductions, potentially deal-breaking disagreements may exist about the fairness of different approaches for defining and sharing responsibility. He proposes an approach aimed at aligning the objectives of carbon reduction and economic growth, while at the same time allocating responsibility for progress in an equitable manner.

The third lead essay is by Eileen Claussen, President of the Pew Center. Focusing on policy at the national level in the United States, Claussen emphasizes the benefits to business of policy certainty during the transition to a lower-carbon economy. She quotes George Nolen, president and CEO of Siemens Corporation: "Businesses need to plan. The absence of a price signal for carbon in the U.S. stifles planning and creates a competitive barrier to investment in technology." Creating a price signal for carbon, she argues, is a prerequisite if the U.S. is to realize the job-creation and growth gains that will accompany the shift toward clean technologies.

The third lead essay is written by Bill Drayton, founder and chairman of both Ashoka: Innovators for the Public and of Get America Working. Drayton is today best known as a leading figure in the field of social entrepreneurship. Three decades ago, however, Drayton made another contribution directly relevant to the theme of this volume. At the Environmental Protection Agency, he set up the world's first system for emissions trading. Others had floated the idea, but Drayton took the lead in implementing it. Today, the same principle of emissions trading has been accepted throughout the world as the best approach for achieving targeted reductions in emissions while maximizing economic efficiency. Like Claussen, Drayton emphasizes the need to get prices right. He focuses on the tax system, arguing that it makes no sense to subsidize the use of machines by keeping energy prices low while penalizing the use of labor through payroll taxes. Urging structural changes in the economy to "favor people, not things," he advances a proposal to both create jobs and meet climate goals by reducing the tax on employment and increasing the tax on gasoline.

Cases Authored by Innovators

The second section of this issue features four cases authored by innovators. Each of these addresses a different domain of energy and climate solutions. The first two describe initiatives spanning decades that have had large-scale impacts in California and Brazil, respectively. The second two describe new ventures that hold promise for the future.

The first case narrative is by Arthur Rosenfeld, a pioneer in the design and implementation of policies to encourage energy efficiency whose "laboratory" for this work has been the State of California. (That per capita electricity demand stayed constant in California over the past three decades while rising 50% in the rest of the United States is widely known as "the Rosenfeld effect".) In a fascinating retrospective, Rosenfeld describes how energy efficiency was first "invented" as a concept relevant to public policy and then embedded into a set of strategies for dramatically shifting the trendline of energy consumption in the nation's largest state—still perhaps the greatest success story during the past 30 years of U.S. energy policy.

The discussion of the California experience in achieving efficiency gains is written by Ralph Cavanagh, Energy Program Co-Director at the Natural Resources Defense Council. Cavanagh starts with a wonderful anecdote: "Late in 2006, soon after Governor Arnold Schwarzenegger signed into law California's path-breaking curbs on greenhouse gas emissions, a reporter asked California Energy Commissioner Arthur Rosenfeld when statewide reductions would start showing up. 'Around 1975,' he replied." The point is clear: Future carbon reductions in California—and, Cavanagh, argues, elsewhere in the U.S.—are not only possible, they are to be expected as direct extensions of past successes. Other regions and countries can achieve substantial carbon reductions with a minimum of creativity or risk-taking simply by following the strategies—such as electricity and natural gas rate "decoupling"—employed successfully in California.

The second case narrative in the issue is by José Goldemberg, a professor at the University of Sao Paulo who has held many positions of national and international distinction over the span of his fifty-year career as a scientist and public servant. He is among the world's most respected voices on energy policy. Goldemberg's case narrative describes the origins and evolution of Brazil's world-leading biofuels program, of which he was among the principal architects. Placing Brazil's experience in a global context, Goldemberg describes the potential that exists for Brazil and other developing countries to create jobs and contribute to meeting carbon targets by producing ethanol for export.

Melinda Kimble, a senior vice president at the UN Foundation, offers a discussion of the Goldemberg case. Kimble, who oversees the foundation's International Biotechnology Initiative and who previously served as an Assistant Secretary of State, emphasizes how Brazil's success in shifting its energy mix derived from its creativity in finding multiple uses for sugarcane and its by-products. The central lessons to be learned from Brazil's experience, according to Kimble, pertain not to ethanol itself, but rather to the value that can created by policies encouraging market flexibility and resource optimization.

Next in the issue is the story of Powerspan, a company that develops and sells carbon capture technologies. The company's founder and the author of the case, Frank Alix, describes with clarity both why carbon capture and storage (CSS) technologies are of potentially great importance in meeting carbon-reduction targets and how the development and widespread deployment of CSS technologies represent a complex business challenge. At the same time that he describes a significant climate solution, Alix also offers a compelling entrepreneurial narrative. Here is a man who, trained as a nuclear engineer and about to embark on a career building submarines for the Navy, is faced with the end of the Cold War and a sudden, wholly unexpected decrease in his professional prospects. Looking for new opportunities, Alix eventually rededicated himself to a new challenge vital to national security: the reduction of carbon emissions from coal-powered energy plants. The result, after over a decade of entrepreneurial perseverance, is the company that today is Powerspan.

The discussion of the Powerspan case is authored by Granger Morgan who leads the Department of Engineering and Public Policy at Carnegie Mellon University and is one of our country's most thoughtful experts on energy policy. Morgan offers a concise and lucid exposition of the challenges that must be overcome before CSS technologies can contribute significantly to meeting the climate challenge. Observing correctly that the very existence of markets for environmental-control technologies is predicated upon regulatory action, Morgan summarizes the dimensions of public action required before the potential benefits of CSS technologies can be realized. He concludes that "while technical innovation will be a critical part of the successful large-scale deployment of CCS, innovation in public policy and law will likely be as or more important."

The last among the case narratives tells the story of a new company with a big vision—Better Place, which seeks to make electric vehicles a wide-spread reality. As described in this case narrative by the company's founder, Shai Agassi, Better Place has undertaken new approaches to developing and deploying electric-vehicle driver services, systems, and infrastructure. In the Better place models, subscribers and guest users have access to a network of charge spots, switch stations, and systems that substantially increase driver convenience while minimizing environmental impact and cost.

Dan Kammen founding director of the Renewable and Appropriate Energy Laboratory (RAEL) at the of the University of California-Berkeley and the co-Director of the Berkeley Institute of the Environment offers a discussion of Agassi's case. Kammen begins by pointing to the regrettable failure in the U.S. to make headway on vehicle efficiency for a period of two decades from the mid-1980s to roughly 2005. Clearly, Kammen points out, the time has come to get the ball rolling again. The question is, along what path? Kammen summarizes the alternatives. He then encapsulates the challenge that Agassi and his team at Better Place face in bringing about the system change required so that electric vehicles are competitive not only with today's conventional vehicles, but also with the improved internal combustion engines and hybrid-electric cars that are on the horizon.

Analytic Essays

The case narratives in the issue cover four areas of potentially great significance to creating climate solutions: improving energy efficiency, creating substitutes for oil, enabling coal to be burned more cleanly, and developing the infrastructure to make electric vehicles a reality. The analytic essays address two more: creating the safeguards and building the institutional capacity to enable a next generation of nuclear power, and combining standards and innovation to dramatically improve the efficiency of energy use in buildings.

The future of nuclear power is the subject of a set of four essays respectively authored by. Matthew Bunn and Martin Malin of Harvard's Kennedy School of Government; Tariq Rauf and Zoryana Vovchok of the International Energy Agency; Charles McCombie, formerly scientific and technical director of Nagra, the Swiss Cooperative for the Disposal of Radioactive Waste; and Roger Howsley, Director of Security, Safeguards and International Affairs (SSIA) for British Nuclear Fuels Ltd. The authors of these essays are professionals with nearly a century of combined experience related to nuclear energy and security policy — people who understand well the particular characteristics that make nuclear power simultaneously one of humanity's most promising and most contentious creations. As a large-scale energy-production technology that generates zero carbon emissions in use, nuclear power is in the midst of a potentially welcome resurgence. The growth in the use of nuclear power and the contributions that such growth could make to addressing the climate challenge are at risk of being cut short, however, if accidental or deliberate catastrophes (another Chernobyl, use of civil plutonium in a nuclear weapon that explodes in a city) cannot be avoided. The nuclear industry and all of us share an interest in driving the risk of such catastrophes as close to zero as possible. This collection of essays describes improved nuclear safety, security, and nonproliferation controls—including new institutions and agreements—whose implementation could enable the nuclear industry to grow responsibly and safely.

Multiple authors with deep experience in energy policy collaborated to produce a set of essays on strategies to improve efficiency in buildings—what my colleague, Secretary of Energy Stephen Chu, has described as the "low-hanging fruit" in our efforts to reduce carbon emissions both at home and abroad. Jim Turner, former Chief Counsel for the Science Committee of the U.S. House of Representatives, has joined with Ellen Vaughan, Policy Director of the Environmental and Energy Study Institute, and Colin McCormick, an energy specialist with the Federation of American Scientists, in examining this claim by showing the magnitude of possible savings from buildings, the current state of energy efficiency knowledge and use in the United States, and the changes that must occur before we can start realizing the large reductions in carbon emissions that are possible through the more efficient use of energy in buildings. A second essay written by Franz Beyeler, the Chief Executive Officer of Minergie, his colleague Nick Beglinger, and Ursina Roder of the Embassy of Switzerland to the United States describes Switzerland's success in improving the energy efficiency of the built environment through voluntary energy standards. In a third essay, Henry Green, the President of the National Institute of Building Sciences, describes how his organization is helping craft standards to enable a future of high-performance buildings that are not only far more energy efficient than today's, but that also incorporate significant advances in safety, security, and accessibility.

The last of the three analytic essays is authored by Hunter Lovins, the founder of Natural Capital Solutions and one of America's most expressive voices on the topic of benefits attainable through improved energy efficiency. Lovins provides a systematic survey of initiatives that companies and municipalities have undertaken unilaterally to address the climate challenge. Along the way she describes what she terms "the economic case for climate action." Lovins notes that leading U.S. companies including DuPont, GE, Alcoa, Caterpillar, and PG&E, acting as members of the U.S. Climate Action Partnership (USCAP), have called for national legislation to cap carbon emissions, stating, "In our view, the climate change challenge will create more economic opportunities than risks for the U.S. economy." Lovins further describes how cities, states, campuses and others are implementing climate protection efforts, and in so doing "cutting their costs, creating jobs and enhancing their economies by reducing their carbon footprint."

PERSPECTIVES ON POLICY

In the final section of the energy and climate issue, two pairs of authors take a step back from specific innovations in practice to offer their perspectives on the design and implementation of climate policies.

Daniel Kammen, introduced above, and Felix Creutzig, a postdoctoral fellow and associate at the Technical University Berlin, have co-authored an essay that emphasizes the need for adaptability in international accords to ensure that different geographical regions are able to realize fully the societal benefits that they can derive from a transition away from carbon. To exemplify the need for such an approach the authors focus on two domains: rural regions in Africa and cities in the industrialized world. The authors argue that putting a future international climate accord into a local context and relating mitigation measures to "co-benefits" of a carbon transition will not only increase political acceptance of any accord reached but will also advance other important sustainable development objectives.

In a second perspective on policy, William Bonvillian of MIT and Charles Weiss of Georgetown University focus on the challenge of undertaking large-scale innovation in energy and other established sectors of the economy that are complex and capital intensive. The core metaphor of their essay is a colorful and illuminating one: Americans know well how to bring real and metaphorical "covered wagons" West and built on frontiers of various types; however we have less experience, and are arguably less adept, in taking those same covered wagons East—that is, innovating in established technological and social domains. Our energy systems, like our healthcare systems, are complex and interconnected. In such settings, success in addressing futures challenges and realizing future opportunities may require a new innovation framework—one vision of which is offered by the authors.

CHANGE THAT SURROUNDS, CHANGES THAT PROPEL

The many impressive innovations and visionary ideas described in this volume are all the more inspiring as one comes to understand that they are but a few of many. Just as we are surrounded by evidence of a changing climate, so are we surrounded by climate solutions in the making. There was not room in this issue to come close to covering them all, with wind, geothermal, advanced solar-electric technologies, the smart grid, direct solar-to-liquid-fuel conversion, better biofuel options, new battery technologies, resource-conserving urban and transport-system design, and advanced manufacturing technologies among the innovations getting short shrift here.

Meeting the energy-climate challenge—supplying the expanded energy services required to create and sustain economic prosperity for everyone on the planet without wrecking the global climate on which well-being equally depends—is likely to be the toughest task that science, technology, and innovation policy will face in this century. But I have no doubt that with education about the stakes and opportunities, the political will created thereby, and the ingenuity and entrepreneurial spirit exemplified by the stories and ideas in this special issue of *Innovations*, we will find that "Yes, we can."

Thomas C. Schelling

International Coordination to Address the Climate Challenge

Climate change is real, but its future is marked with uncertainties. We cannot predict the kinds of societies that will be faced with the most severe impacts of climate change fifty years or a century from now: What sort of lives will people lead? What kinds of technologies will they use?

Still, we do know some things about the future effects of climate change, and with high confidence. Above all, we know that "developing" countries will experience the greatest impacts from climate change. (I put "developing" in quotes because many of the places to which this term refers are, in fact, not developing: today they are, regrettably, simply poor.) For the countries most vulnerable to climate change, the most reliable defense lies in economic development itself. The advanced industrial countries that have been primarily responsible for bringing about climate change will most likely not experience its most severe impacts. They have a responsibility to assist both poor and genuinely developing countries to find a path of development that does not exacerbate global harm. More urgent, it is unlikely that China, India, Brazil, Indonesia, and other large emitters of greenhouse gases can be induced to participate in massive changes in energy supply and use without substantial assistance from the countries that can afford to assist.

Bilateral aid is probably not the right approach for mobilizing such aid and directing it toward the most promising investments. For example, a bilateral relation between China and the United States to help finance Chinese energy improvements would probably get tangled in other issues like Taiwan, North Korea, civil rights, exchange rates and trade policy. Institutions that isolate energy and climate from other politics will certainly be preferred.

Thomas Schelling is the Lucius N. Littauer Professor of Political Economy, emeritus, at Harvard University and a Distinguished University Professor, emeritus, at the University of Maryland. From 1948 to 1953 he worked in Europe and with the Executive Office of the President in support of the Marshall Plan in Europe. During the Carter administration he was selected to chair a committee of the National Academy of Sciences on global warming. In 2005 he received the Nobel Prize in economics, shared with Robert Aumann, for "having enhanced our understanding of conflict and cooperation through game-theory analysis."

We can learn from a few from models of actual international cooperation. The purpose of this essay is to describe precedents for such collaboration, and how it might be structured to best address the climate challenge.

WHAT WE KNOW AND DON'T KNOW ABOUT THE IMPACT OF CLIMATE CHANGE

Unique to our solar system, Earth has a combination of carbon dioxide and water vapor that keeps the planet both warm and cool enough. Atmospheric moisture doesn't freeze solid, nor does it become so hot that it all evaporates. We have known for a century that Mars, lacking a greenhouse atmosphere, is too cold for water to exist as a liquid. Venus's dense greenhouse atmosphere has the opposite effect: water exists only as steam. Furthermore, we've known that if you shine an infrared light through a chamber full of carbon dioxide, less of it comes out of the other end. An observer can monitor a proportional difference between the reduced infrared light and the rise in temperature of the carbon dioxide in the chamber.

> For the countries most vulnerable to climate change, the most reliable defense lies in economic development itself.

Of course, climate change is a much more complex phenomenon than is suggested by this experiment, and by the formerly dominant term, "global warming." What is more, even when we talk about "climate change" we are really talking about change in hundreds of climates around the world, all different from each other, all potentially affected by concentrations of greenhouse gasses in different ways. Some places will get hotter as a consequence of climate change, a few will get cooler; some will get cloudier, some will get sunnier. Some will get more storms, some will get fewer storms; some will suffer drought and some will suffer flooding, some may suffer both. Climates differ between east coasts and west coasts of continents, between high altitudes and low altitudes, between northern and southern hemispheres.

From the standpoints of both science and policy, global averages do not tell the whole story. The way that climate change affects very specific places has enormous implications for future human well-being. For example, we know very little about what kind of climate change will occur above 3000 meters. Only a few Tibetans and Bolivians live at such altitudes. However, a great deal of the water that irrigates agriculture around the world depends on snow that falls in the winter in the high mountains and then melts gradually, beginning in late spring and continuing through the summer irrigation season. If, above 3000 meters, what used to fall as snow now falls as rain, farms lose that moisture unless they can rely on a huge infrastructure to capture it. And if it falls as snow but melts too early in the spring, farmers can't use it for irrigation because it has already flowed to the oceans. Thus, what happens at high altitudes will affect few people directly, but it will have a crucial impact for the more than three billion people who live in China, India, and Southeast Asia, and in Peru, Chile, and Argentina, not to mention California and Colorado.

That significant uncertainties exist regarding the dynamics of climate in the long term should come as a surprise to no one. While the science underlying the phenomenon of climate change has been well understood for a century, the interdisciplinary field of climate science has developed only during the last couple of decades. However the biggest uncertainty, I believe, arises not from our understanding of the climate itself, but from our vision of the kinds of societies that will exist in the second half of this century—the societies that will experience the most significant impacts of climate change. To consider the effects of climate change on human populations over time, we are compelled to consider how a changing planet will affect the way people live and work in the second half of this century.

> We should not compel developing countries to drastically transform their energy sectors in order to slow climate change, but we must offer them coordinated and well-considered assistance to do so.

To illustrate this idea, imagine that we are in the 1920s, when I grew up, and consider the climate challenge from the point of view of people living then. What sorts of concerns would they have projected upon us, the people of the future? Clearly people in the 1920s would have been far less interested in hotter summers than warmer winters. In the United States, especially, many would have worried about what would happen to roads. How much mud would a change in seasons bring about? Back in the 1920's, automobile tires measured about two and a half inches in diameter. Pumped up to 60 lbs. per square inch, they felt and acted like wood. One of my uncles made money every summer using a team of horses to pull automobiles out of the mud in the road near his house.

So we remain uncertain, even in our imaginations, of how people will earn their living, even how they will entertain themselves, not only in the United States but in Sub-Saharan Africa, Southeast Asia, and the Andes.

Developing countries will see the worst damage. People in the developing world depend on outdoor activity—particularly agriculture—to a far greater extent than do people in advanced industrialized countries. Agriculture in the United States and in most of the rest of the developed world—whether in France, Germany, Japan, Israel, or Norway—accounts for less than five percent of gross domestic product. Whatever happens to agricultural productivity, Americans will likely be able to afford higher-priced food. Today, so few American farmers make their living from agriculture that the Census Bureau has stopped counting them. If the cost of food goes up as a consequence of climate change, the world's poor will suffer most. Americans, by the time all of this happens, will likely have doubled their per capita income. The developing world is particularly vulnerable to climate change. Their best defense against climate change is their own development.

> Among the ideas that I do not believe will get serious attention in Copenhagen is one I see as critical to addressing the climate challenge: creating a new institutional structure to coordinate assistance from advanced industrialized countries toward developing countries with the objective of transforming the way that people in the developing world produce and utilize energy.

We should not compel developing countries to drastically transform their energy sectors in order to slow climate change, but we must offer them coordinated and well-considered assistance to do so. Anything that slows down their own development will worsen their situation as climate change occurs.

Conversely, potential donor nations have been reticent to fully endorse efforts to stop climate change at the expense of their own economic growth. In 1997, at the time of the Kyoto Conference that led to the draft treaty about climate change, the U.S. Senate unanimously passed a resolution: it would not ratify any climate treaty in which the major developing countries did not participate fully. As president, Bill Clinton said that he would not submit the treaty to the Senate for ratification until diplomacy had brought China and India and other major developing countries into compliance with a Kyoto-type program. That administration did nothing. Then we had a president who either didn't believe in climate change or pretended not to. I think we now have a president who does believe in it and who takes it seriously, and Congress has begun to take it seriously as well.

As for international action, I'm not optimistic about anything of great substance coming out of the upcoming Copenhagen Conference. If there were substantial agreement among major parties, worked out over the preceding six months, Copenhage might generate the finishing touches. But the participants in the conference cannot accomplish much new work over only two weeks in Copenhagen.

Among the ideas that I do not believe will get serious attention in Copenhagen is one I see as critical to addressing the climate challenge: creating a new institutional structure to coordinate assistance from advanced industrialized countries toward developing countries with the objective of transforming the way that people in the developing world produce and utilize energy. If we want China, India, Brazil and others to transform their energy sectors drastically, they must engage in costly and systemic transformations of their energy infrastructures. The array of actions they must take will include removing carbon from the emissions of power plants and putting it underground permanently, developing wind or solar power on a large scale, and converting from coal to oil or natural gas. To make such changes will require assistance from advanced industrialized countries.

A PROPOSAL AND ITS PRECEDENTS

Rich countries will need to negotiate how they will share the cost of contributing resources to the developing world. Countries within the European Union, the United States, Canada, Japan, Australia, and New Zealand will need to find a way to agree upon how much they will put up to help major countries in the developing world to transform their energy economies, and how they will share the costs of transferring resources to the countries that most need to transform their use of energy.

We will also need some kind of institution within which the major developing nations that will have the greatest impact on the greenhouse problem (China, India, Brazil, Indonesia and a few others) can decide how they will share in whatever resources the rich countries make available for the purpose of transforming their energy sectors.

The recipients should also declare what they will commit themselves to do in return for the kind of help they may get. Ideally, potential recipients within the developing world would negotiate among themselves on how to share the money made available by the rich countries. Of course they may not agree at first; after all, India and China battled barely 45 years ago and they still have military confrontations in the Himalayas. The institution would provide a forum where they can at least attempt to reach an agreement on how they would share what the rich countries have made available.

A third institution would channel funds to the developing world, acting as an intermediary between the donor countries and the receiving countries that does not rely on bilateral relations. We will need this intermediary agency to monitor what recipients do with all of the funds, to create an entire climate-oriented investment program in each recipient country. The recipient countries must have a coherent program for making changes in their energy sector, and a subsequent plan to channel the internationally transferred funds to specific projects. Donor countries should not simply finance one or two particular investments that substitute for what the country itself might have done.

I can't think of any precedent in the last 50 years for what I suggest. However, the Marshall Plan provides a model whose potential has intrigued me for years. During the early years of the Marshall Plan, beginning in April of 1948, the United States first contributed $5 billion for a 15-month period to the 15 countries of Western Europe that constituted the Organization for European Economic Cooperation (OEEC). The initial $4 billion per year represented about two percent of the U.S. gross national product—a lot of money. The United States divided it up among the recipient countries of Western Europe. For the second year, spanning 1949 to 1950, the United States said it would appropriate a lump sum for the Europeans to divide among themselves.

That was quite a challenge. The OEEC had to develop detailed questionnaires that every recipient nation filled out in order to indicate how much aid it qualified for and how much it requested out of the forthcoming total. This involved making up national accounts, something that was brand new in the United States and no economist in Greece knew anything about. They suddenly had to figure out how to allocate their gross national product—relative to Marshall Plan funding—between public investment, private investment, and private consumption. These investments could take the form of anything from repairing roads and railroads and dredging canals to building schools and homes and hospitals. The nations even had to decide how to ration gasoline, meat, and butter.

I can't think of any precedent in the last 50 years for what I suggest. However, the Marshall Plan provides a model whose potential has intrigued me for years.

They spent six months developing this program, essentially a claim for a part of the resources that the U.S. would make available. At the ministerial level in Paris, they negotiated for about six weeks, cross-examining each other and bearing in mind that more for one country meant less for the rest of them. They negotiated peacefully, on a first-name basis and in good will, and reached nearly final agreement. Then the Secretary General of the OEEC and the Belgian delegate — Belgium didn't ask for any portion— went off to Fontainebleau and spent a weekend preparing a proposal for how to share the funds among the 14 countries that had applied. They came back and presented it to the ministers of the 14 countries, and the delegates unanimously accepted the division.

This is the only precedent I have ever found of countries getting together and, in gentlemanly fashion, negotiating how to share a crucially large lump sum of resources, available only if they could find a way to divide it among themselves.

Have recipient countries ever agreed on how to share their own contributions to a joint project? A few precedents do exist, again from 50 or 60 years ago. In 1951 the Marshall Plan became the Mutual Security Program and aid became tied to the burdens that European countries would bear if they would share in NATO defense. Again they went through something like what had happened with the Marshall Plan division in 1949-50, the "Burden-Sharing" Negotiation. In 1951, the United States made aid to Western Europe available only in connection with commitments that the recipient countries would undertake, such as the number of men they would raise for the armed forces, the number of months they would train them, and the amount of time they would serve. Commitments also included the their expenditures for military equipment and ammunition, and provision of real estate for military maneuvers, NATO pipelines, military housing, and the like.

The NATO treaty differs significantly from most climate change treaties in that the NATO signatories declared what they would do, instead of stating results 20 or 30 years down the road. The Dutch didn't say, "We will contribute to retarding a Soviet invasion by two and a half days." And the French didn't say, "We will contribute enough to reduce the likelihood of a Soviet attack by two and a half percent." Instead, they committed themselves to the troops they would raise, the money they would spend, and the real estate they would make available. Therefore they knew whether or not they kept their commitments—and so did everybody else. You could look and see what they had done. And in fact NATO commitments were substantially carried out. That suggests to me strongly that a treaty or an agreement on what to do about reducing greenhouse gas emissions has greater odds of success when countries commit to actions they will take rather than to results in the year 2030 or 2050.

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To say that we will reduce greenhouse gas emissions by 50% by 2030 or by 80% by 2050 doesn't indicate what steps we need to take. Along the way no one will be able to say whether our completed activities will contribute to what needs to happen by the long-term target.

In response to this issue I see another precedent, the one set in 1946 by the Bretton Woods negotiation, which established the International Bank for Reconstruction and Development and the International Monetary Fund, both of which required contributions to their capital assets. Both institutions had to sell bonds to accumulate funds and then lend out the funds for reconstruction and development or financial solvency, and they needed capital assets. The capital assets had to come from the countries that could afford to contribute, and donor countries had to negotiate to determine how much and in what currencies the various contributing countries would make their contributions. They managed to arrive at an agreement. The IMF and the World Bank did get funded and established, and have operated for more than a half a century.

On the other hand, some other precedents warn us to be cautious about agreements to share costs or revenues. Consider the League of Nations after World War I. Seeking an appropriate model to replicate, it found one in the International Postal Union of 1874, which taxed its participants for shares in the funds that the union needed. The league ultimately experienced the same results as the union had. The Postal Union formula involved geographical size, population size, and a few other variables, none of which corresponded to any notion of "ability to pay" or likely benefits from the union.

And consider the United Nations. After World War II, it tried to establish something analogous to a progressive income tax: countries with a higher per capita income would contribute a higher share of the UN budget. It largely turned out that way, except that the UN had a special problem: the United States played such a huge role in the world economy that almost any reasonable formula would require it to contribute more than half of all the funds. Not only did the U.S. find that unacceptable; most other countries felt it would create a dominating situation for the United States. The U.S. ended up with a share of slightly more than one third of the total. The UN also engages in separate negotiations for specific programs like peacekeeping; different countries negotiate shares of the costs depending on where the peacekeeping occurs. These and other myriad examples illustrate the problems that a new multi-lateral institution may confront.

USES OF A GLOBAL FUND

How would the resources gathered by such a fund be spent? To fully enumerate the options for each place, and speculate on priorities, is well beyond the scope of this essay. Other contributions to this special issue of Innovations provide some ideas. I believe it important to identify the aid with specific projects. Pure financial transfers are likely to appear as bribery or extortion. Here I offer just two illustrative examples.

Countries like China or India, with a vast wealth of natural resources and a steep curve of improvements in industrial infrastructure expansion, will require a huge number of investments, and large ones. Wind power is an attractive source of energy that involves no greenhouse gas emissions in its operation. However, wind power depends on the wind blowing fairly regularly. And the turbines cannot lie too far from the electricity's destination because transmitting that electricity does cost something, especially if it has to go a few thousand kilometers. China has an exceptional potential for developing wind energy, especially in northeast China and Manchuria. Tibet has an enormous amount of steady wind, but Tibet lies far away from the areas that most need electricity. If China had the funds to reduce its dependence on coal, wind power might present itself as a more than viable option.

China has advanced significantly in developing ways to convert sunlight directly into electricity, but by nature that technology requires huge installations and lots of investment.

A second example is capturing carbon dioxide as factories emit it, which has spurred a great deal of interest recently. Carbon capture and sequestration takes the carbon dioxide that comes out of a smokestack, separates it from the rest of the gases, converts it into a liquid-like substance (called its super critical form), and subsequently requires transport to sites that can handle deep storage underground. (See the case narrative authored by Frank Alix in this issue.) Oil companies have used this technique for 30 or 40 years to get more oil out of depleted wells. This could mean that China, which has enormous coal deposits and is building coal-fired electric power plants at the rate of more than one a week, can exploit its valuable coal resources, separate out much of the carbon dioxide, and inject it underground to seal it in. That will require a lot of geological exploration and experimentation. The process is expensive because it includes constructing a whole plant to capture the carbon dioxide and the pipelines to inject it underground.

CONCLUSION

Who will lead in creating the sort of institution I have tried to describe? To my knowledge, no part of the U.S. government is currently focused on ensuring we have the institutional structure we will need: one that will allow the rich countries to coordinate their climate assistance to developing countries, and allow the developing countries to determine how to allocate funds toward the projects with the highest global return, and that can monitor and account for the way the aid is invested.

To address the climate challenges we must find mechanisms so that those countries in the developing world that are most likely to contribute to growth in carbon emissions over coming decades can upgrade and transform their energy infrastructures in ways that do not cripple their own development. The multilateral nature of the climate impacts demands that solutions come about through a multilateral process. Though we cannot know the particular paths by which we will avoid the most severe consequences of climate solutions, we can act now to lay the foundation.

Vinod Khosla

Whose Rules?

Terms of Discussions Around a Global Cap and Trade System

Global climate change is accelerating like a runaway truck. The conventional wisdom is simple: the U.S. does not want to participate in a global treaty, because India and China don't want to participate. But is that really an accurate assessment, or is it that they don't want to participate based on Western rules of engagement? What are those rules, and who makes them? The countries with the biggest bulk and heaviest sticks? And do we use moral and ethical principles? If so, whose ethics and morals? Do we consider a given country's ability to pay, its natural resources, and its rate of economic development? Many proposals have been made for carbon cap and trade, but many do not explicitly consider the above issues.

Beyond the heaviest sticks and issues of local ethics is another complex matter: the political reality in each country. What is politically acceptable, both locally and regionally, becomes even more critical in the democratic world where the politics of today far outweigh considerations of the planet's needs in 2050. In addition, we have learned a critical lesson from recent experience: we must manage global climate risk both prudently and flexibly. We need to achieve currently defined targets but must also respond to changing targets quickly as new information comes becomes available. Considering all these issues, I suggest four criteria that any carbon emissions control system must achieve. It must meet CO_2 reduction targets, be morally acceptable, be politically acceptable in most countries, and be able to adjust to dynamic targets.

I believe that the single best way to measure progress is based not on CO_2 emissions as a whole, but rather on creating incentives for the developing world to increase its carbon productivity of GDP. That means producing more, but reducing the carbon emissions associated with each marginal dollar of GDP growth. This concept is also known as the carbon efficiency of GDP. Researchers at the McKinsey Global Institute, among many others, have created a set of global reduc-

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tion targets and estimations of how quickly the world's GDP carbon efficiency must grow to meet those targets.[1] This approach is significantly easier for the developing world than many others that have been suggested, and should be more politically palatable. It does not ask them to slow their growth, but rather to improve the efficiency of that growth, especially in conjunction with flows of CDM (Clean Development Mechanism) funding. From a fairness standpoint, it does not unduly punish nations for their rates of growth, but rather aligns incentives so that efficiency and growth become common goals.

If we accept that increasing carbon efficiency is the key, the next question is where and how the developing nations can work towards this goal and how the CDM mechanism can be used to guide it. I believe that access to cheap capital (and thus lower financing costs) is vital; in fact the cost of capital may be the most critical tool in developing a lower carbon GDP economy. Developing nations may be able to lower the cost of capital by leveraging relatively low-interest loans to invest in low-carbon power generation, be it electricity or biofuels. In the rest of this article I describe these ideas and show how they might work in combination.

CONSIDERING METRICS

John Holdren, director of the White House Office of Science and Technology Policy, summarized the current situation in a recent talk:

> We have a global climatic disruption and serious harm is already occurring. Mitigation, adaption and suffering are our only options and the more we have of the former two, the less we will have of the latter. The key question is whether we can we avoid catastrophic interference.[2]

In light of the current situation, it is clear that mitigation must happen everywhere to make a material difference. But how should the burden of mitigation be allocated? The proposals so far have been dominated by Western points of view and mostly consist of tradeoffs between the various Western constituencies including business, labor, agricultural and environmental groups. The proposals don't work with the priorities of many developing countries like India and China, which have mostly distanced themselves from the discussions. Is it possible to craft a set of proposals that are more likely to be acceptable to this constituency?

The first step toward responding to these questions is reviewing emissions and economic data. Figures 1 and 2 show (1) total annual CO_2 emissions by country, and (2) CO_2 emissions per capita, by country, color-coded by GDP per capita on a PPP basis.[3] Discussions in the West turn almost exclusively to one idea: reducing carbon in percentage terms from the 1990 level. While this is in line with scientific recommendations as a global target, reviewing the charts below raises further questions on how to allocate this goal among all nations. Examining Figure 1, is it reasonable to compare the cumulative emissions of two countries, one with a billion people and one with a million? Reviewing Figure 2, is it reasonable to ask a country whose per-capita income is $1,000 to meet the same percentage carbon

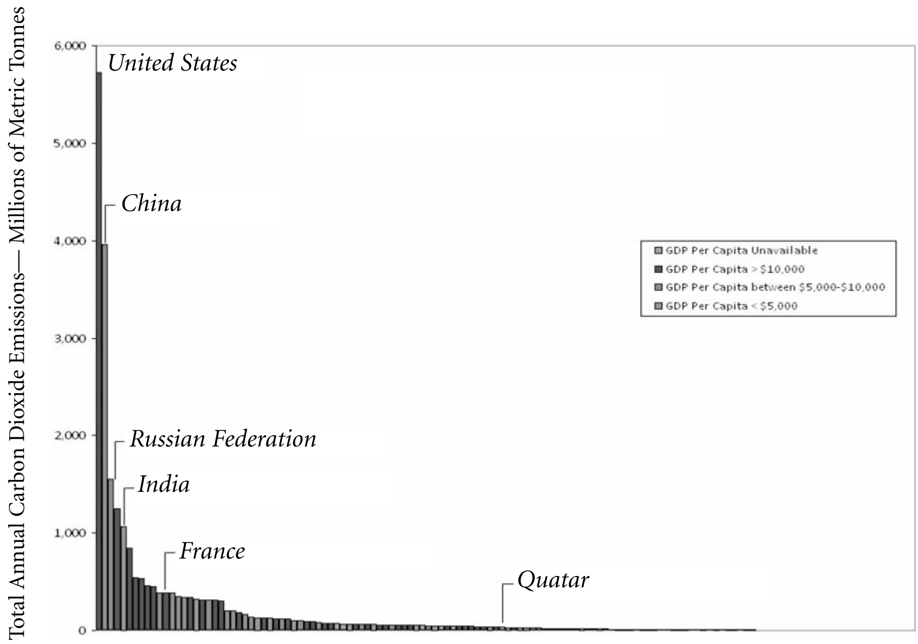

Figure 1. Total Annual Carbon Dioxide Emissions, in Millions of Metric Tons, 2003

Source: World Resource Institute, citing IEA data.

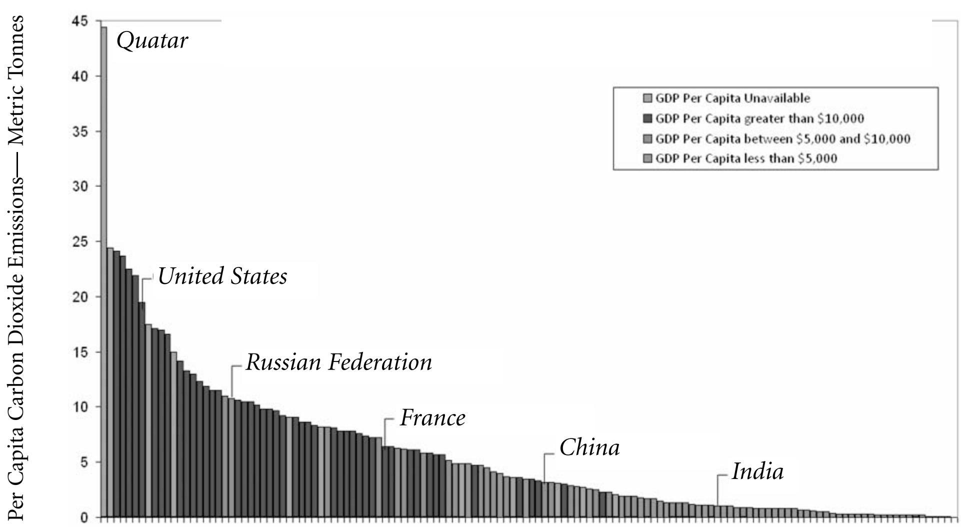

Figure 2 Per-capita Carbon Dioxide Emissions in Metric Tons, 2003

Source: World Resource Institute, citing IEA data.

reduction as one whose per-capita income is $40,000? Should a country with a per-capita income of $1,000 and an economic growth rate of 2% achieve the same reduction as another with the same per-capita income and a 10% growth rate? Who decides where to draw the lines? What protocols are used to assess fairness and what standards apply?

Even if a definition of fairness can be established, what is fair and what is pragmatic often do not correspond, especially in democracies. Perhaps the only morally defensible—fair—thing to do is to give every human being an equal right to pollute the air. That means an equal per-capita emissions quota. Being strictly fair, using the closest thing to a universal moral code, would suggest that the per-capita allocation should be based on the total cumulative stock of carbon emissions through history rather than an equal current annual flow of carbon emissions per capita. In computing the stock of carbon emissions they have emitted per capita over time, developed nations would include their historical emissions, potentially starting at the dawn of the industrial revolution in 1750 or so.

But the answer this leads to is impractical from the scientists' perspective of total atmospheric carbon. Though carbon calculations can get convoluted, it is important to realize that emissions during the last fifty years are the dominant culprits by virtue of their magnitude. As of 2006, the population of the OECD, approximately 1 billion persons, was emitting roughly as much carbon dioxide equivalent as the remaining 5.5 billion people.[4] Hence developing nations argue, quite reasonably, that it is only fair that the OECD and the developed world bear the principal burden for reductions, especially since they have the highest incomes and greatest capability to invest in reducing their carbon footprint.

Unfortunately this fair formula does not work well for the planet, or for much of its politics, given the heavyweight clout and self-interest of the Western world, which would have to radically change its carbon emissions and hence its energy-use profile, draining investment funds and causing significant business dislocations. Moreover, the common refrain, even within some environmental circles, is that India and China don't want to do their part to reduce global carbon emissions, and that no coordinated action can possibly succeed without them. Of course, every country wants to continue its development priorities while offsetting the burden of carbon abatement to the "commons"—this is the classic "free rider" problem. However, I believe that most countries will participate in a scheme that they can still sell to their people.

In that vein, India's Prime Minister Manmohan Singh has stated categorically that India would sign on to a cap-and-trade system that allocates equal carbon emissions to every human being. India has also stated that its per-capita carbon emissions will never exceed those of the developed world. But even with that promise, the Western world will not sign on to a system that allocates every human being an equal right to pollute. Meanwhile, what India and China are refusing to sign up for is something different: a system devised by the environmental groups in the developed world that makes it harder for them to get to the same level of per-capita GDP as the developed world and its concomitant energy consumption, even assuming they could get to similar levels of energy efficiency per dollar of GDP. India and China are not currently at the same level of efficiency that the developed world has achieved, and would have to work harder and invest more than they do currently to get to similar efficiency levels. But, as we will see, in this situation lies one potential fair and universal solution.

The question is not whether India and China would participate, but rather the terms on which they—and others—would do so. The United States will have its own ideas of what system works best, though even it is deeply divided on the issue politically. Europe, which has lower per-capita emissions than the U.S., may be the most flexible and committed to carbon reductions (and have significantly greater political support for reductions). Russia and the Arab world may have other geopolitical interests, including the use of their strategic energy assets. Brazil may be most focused on its land assets, and its recent discovery of large oil fields off the coast could change its priorities. Africa may give the issue less priority given the various other challenges it faces. Clearly, any formula will have to include some country-specific considerations. As many critics have pointed out, the U.S. has a larger land mass and a lower population density than most countries, and thus longer average distances to travel. Thus, by its very nature, the U.S. will use more fossil fuels for travel compared to its higher-density European counterparts.

> The basic terms of the discussion around carbon cap and trade must change and new formulas must to be devised to share the pain of carbon emissions reductions between the world's citizens, with allowances to deal with factors like density and climate (a colder country will use more fossil fuel for heating)... What allocation of responsibility for carbon reduction might be acceptable to most countries, whether they are developed or developing?

Given all these facts, it is not hard to conclude that the basic terms of the discussion around carbon cap and trade must change and new formulas must to be devised to share the pain of carbon emissions reductions between the world's citizens, with allowances to deal with factors like density and climate (a colder coun-

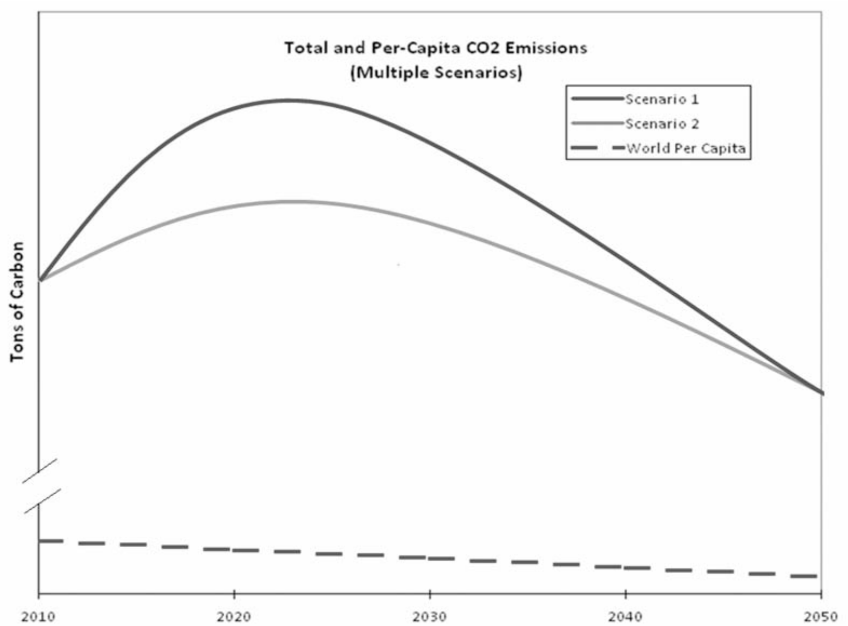

Figure 3. Figure 3: Annual Total and Per-Capita Global Carbon Emissions Scenarios

try will use more fossil fuel for heating). There is a general consensus that emissions reductions are needed and that our responsibility is to avoid the tragedy of the commons. What allocation of responsibility for carbon reduction might be acceptable to most countries, whether they are developed or developing?

CONSIDERING SCENARIOS

Figure 3 shows two hypothetical scenarios as approximate trend lines. These are two potential pathways for achieving the most widely—if not universally—accepted per-capita emissions target. The target is to return to two tons of carbon per year (2tc/yr) per person by 2050. Those pathways would reduce carbon emissions on different trajectories and achieve different levels of carbon in the atmosphere. The long-term goal, though still subject to considerable debate, is often set at stabilizing atmospheric carbon at approximately 450 parts per million (ppm) of carbon dioxide equivalent by 2050. The Intergovernmental Panel on Climate Change (IPCC) says that doing so would give us a 50% probability of limiting temperature increases to about 2 degrees Celsius,[5] though experts such as James Hansen (at NASA) and others have suggested ranges between 350 ppm and 550 ppm.[6]

The simplest way to look at these trajectories is to understand that each level of carbon in the atmosphere results in a different level of risk of catastrophic or runaway climate change: the higher that atmospheric carbon content, the greater the risk we face. The science on the magnitude of the change at each level of carbon in the atmosphere is uncertain but recent indications point to the "safe" levels being lower than was generally accepted even a few years ago.

Thus we understand the need to combine both prudence and flexibility. Not only must we achieve the above targets; we must also be willing and able to respond to changing targets quickly as new information comes becomes available. What we know about the impact of climate change is important, but what we don't know—and will learn over the next few years and decades—is even more crucial. Thus, the principles behind a global cap and trade deal should allow for dynamic adjustment, as opposed to a new multi-year Kyoto style negotiation among almost 200 countries. The need to respond flexibly to changing information on climate change and carbon emissions is evidenced by the significant changes in the history and near- term forecasts of global emissions.

Forecasting is an inexact science—as multiple examples over the years have shown. In particular, much economic forecasting is essentially a regression of old data; it cannot account for technological evolution, shifts, and shocks because these cannot be predicted.

For example, in 2002, in its GLOBE report, the IEA forecast that emissions in 2008 would be 42 gigatons (GT) per year and that they would double from 2008 to 2050 under scenarios of business as usual.[7] Only five years later, an updated IPCC report, relying on 2004 data, predicted that 2008 emissions would be 55 GT, or more than 30% higher.[8] Why did these numbers grow so much in the short span of five years? The answer is uncertainty. In addition to growth, there are large uncertainties around measurement, and the projected growth rates for India and China have increased dramatically, thus changing their forecasts for energy consumption and carbon emissions.

Thus, econometric models are only as good as the research and assumptions upon which they are based—and in my view, the assumptions made so far are extremely tenuous. Projecting the growth rate of India or Russia in 2050 is like projecting the world's 2008 growth rate in the early 1900s. With the accelerating rate of change in society and heightened global dynamics, it is nearly impossible to make accurate predictions. Of course it is also unrealistic and unwise to abandon modeling entirely, but given its inherent limits, we must recognize these limits and treat the output accordingly. The key point is not that forecasts are inaccurate but that the global response must be dynamic and flexible. Thus the system must adapt as the results come in without requiring political negotiations at each stage.

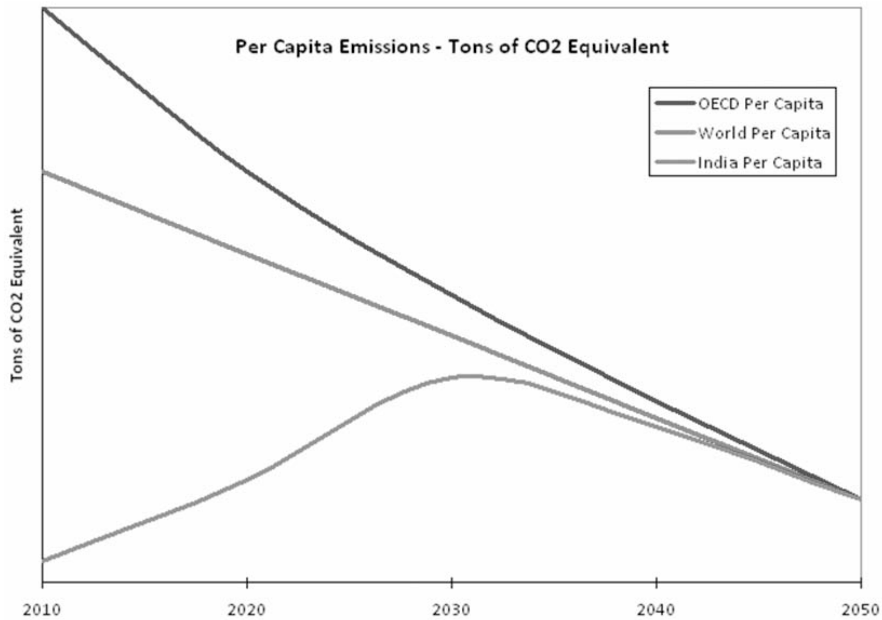

Figure 4. Hypothetical Scenario of Required Per-Capita Carbon Emissions Trends

Developing technology to allow for rapid response is critical but we must also allow for a rapid, maybe even automatic, policy response.

FORECASTING, AND BLACK SWANS

Forecasting is an inexact science—as multiple examples over the years have shown. In particular, much economic forecasting is essentially a regression of old data; it cannot account for technological evolution, shifts, and shocks because these cannot be predicted. One of the more famous examples is McKinsey's 1980 estimation of the mobile phone market in 2000 for AT&T: it forecast a market size of approximately 1 million phones. The actual market in 2000 exceeded 100 million—an error by a factor of 100. Similarly, the Energy Outlook Retrospective from the Energy Information Administration (EIA) noted that on average, its forecast of average oil prices had been off by 52%; natural gas prices were off by 64%, and coal prices were off by 47%.[9] The fundamental problems here are those of forecasting: gaining false precision at the expense of accuracy, obscuring underlying assumptions, and inputting what is measureable while ignoring what is not. Furthermore, most forecasts fail to recognize that extreme events with high unpredictability are responsible for most of society's evolutions—what author Nicholas Nassim Taleb calls a "Black Swan." Three features characterize a Black Swan event:

1) It is an outlier before it happens, as traditional expectations from the past do not predict it.
2) It carries a significant impact.
3) Despite being previously unpredictable, after the fact observers derive explanations to justify it. To summarize: "rarity, extreme impact, and retrospective (though not prospective) predictability."[10]

Technology shocks are one of the best examples of this maxim in action: ranging from the internet, to the agricultural revolution, to the rise (and demise) of the traditional telecommunications infrastructure. Forecasting is an inexact science; its errors are further compounded by dramatic changes in inputs and assumptions, often rendering history a poor base from which to extrapolate.

To summarize all I have said so far, I see four key criteria that any carbon emissions control system must achieve:

It must meet global CO_2 reduction targets. Any scheme must converge upon this target value, be it 350, 450, or 550 ppm worldwide.

It must be politically acceptable in most countries. No scheme is likely to be acceptable to every country, but we must strive for an approach that is politically viable for most sovereign entities and thus minimizes the number who opt out or become "free-riders."

It must be morally acceptable. While the concept of fairness is open to debate, any system must be fair in assigning the responsibility for the problem in rough proportion to the primary pollution caused historically and prospectively by each country, especially considering their current per-capita income. Pragmatically, fairness will have to be defined in a way that is maximally but not universally acceptable.

It must be dynamic. From a policy perspective, any emissions control system must have the flexibility to revise safe targets and goals as better information and research becomes available, without requiring a new set of negotiations. From a technology perspective, working towards carbon reductions now is important, but the primary goal is to work towards significant carbon reduction capability in the future (even at some cost in terms of emissions today). Thus investing in technology that can reduce carbon emissions in the future offers greater benefits than simply reducing emissions today.

CONSIDERING APPROACHES

How might the carbon emissions reduction proceed? Figure 4 shows one hypothetical pathway, with the OECD working to reduce its per-capita emissions of CO_2, while countries like India experience a temporary increase in those per-capita emissions, but level off around an acceptable per-capita emissions level, which is likely to be about 2 tons of CO_2 equivalent (CO_2e) per year. In this scenario, countries like India and China could offer to go beyond their responsibility to have their per-capita emissions equal the world's average. They could accept an additional constraint by agreeing not to exceed the per-capita emissions of the OECD countries. India's prime minister has made such an offer, but that will not be sufficient to achieve global carbon reduction targets. One current thought among developed country planners, as highlighted in the recent Stern report,[11] is that by 2050 the developed world would be required to reduce its carbon emissions by an agreed-upon percentage relative to 1990 levels with some interim goals set for 2020. Within this thinking, some suggest giving the developing world until 2020 to start making reductions in absolute carbon emissions.

Is this basic approach, as outlined above, fair? It may or may not be, depending upon the country involved. Should the same date for capping carbon emissions be used for all countries even if they are in very different stages of development, just because the developed world needs them to cap emissions? If we concede that different countries are on different developmental trajectories, who decides what the date should be for each country to start capping its total emissions? We need objective criteria that are smooth and continuous in their demands on countries to invest in carbon reductions. Those criteria must apply to every country as uniformly as possible as they become capable of investing in the carbon commons. This approach may be fair for China but not for India; or it may be fair to require India to reduce emissions but not Bangladesh.

One thing is clear: we need concrete measures from countries like India and China because they will very soon constitute a majority of the carbon emissions flow—if they have not already. According to some reports, China may already be the world's largest CO_2 emitter,[12] another point of contention for many in the West who see no pragmatic value in any scheme that does not require Chinese reductions. Even if the Chinese have substantially lower per-capita emissions and a lesser ability to respond to the need for carbon mitigation because of their lower per-capita incomes, should we still require them to reduce carbon emissions? Despite these issues, and the potential for forecasting and measuring discrepancies, it is still clear that by 2050, almost every country must approach the global per-capita target of 2tc/yr/person. If India and China are outside of a cap-and-trade treaty, fairness will not matter. Higher total worldwide carbon emissions could potentially condemn the world to Professor Holdren's "suffering" option outlined earlier. Is there an option that better fulfills most of our criteria, while still offering enough incentives for the heavyweights, both developing and developed, to participate?

I believe such an approach does exist. Pragmatically, the developed world has been the primary cause of greenhouse gas (GHG) emissions, and will continue to release higher per-capita emissions than the per-capita quota. If it wants to continue to do so, it can afford to pay the developing world for this privilege. One instrument to facilitate this is the clean development mechanism (CDM). The CDM sets up a trading contract in which the developed world pays the developing countries to execute carbon reduction projects. Developing nations get credits for reducing emissions beyond the business-as-usual scenarios, but they are not penalized if they fail to achieve specific targets. This approach is a win-win. The developed world can reduce its carbon footprint by reducing emissions in the developing world where it might be cheaper to do so, essentially by outsourcing its carbon mitigation responsibilities. Meanwhile, the developing world gets more carbon-efficient investment opportunities, accelerating its development and generally reducing its energy needs. Many will agree on the equity of this arrangement, but it isn't likely to be enough. We still need additional approaches.

In addition to CDMs, what could the developed world offer to developing countries, to give them greater incentives to reduce carbon emissions? What could it offer that would not be too costly to the developing world's development goals? Before discussing additional options, it is important to look back at previous efforts such as the Kyoto protocol. The Kyoto protocol divides the world's nations into two groups. Annex 1 countries include members of the OECD, as well as countries with economies in transition including members of the former Soviet Union and several other Central and Eastern European states. All others are non-Annex 1 countries. The criteria for being a "developed" (Annex 1) country or a "developing" one are somewhat arbitrary.

Given these criteria, where should the cutoff be in per-capita GDP? Absolute carbon caps based on 1990 carbon emissions penalize fast-growing countries, and are especially unfair for those countries with low per-capita emissions. They are even worse for the slow-growth, very poor economies in some of the African nations. Eritrea's per-capita emissions are 1% of those in the U.S. (0.2 tons of CO_2 per capita) and its per-capita income is $900.[13] Should it be responding in any way to the need for carbon mitigation?

Politics and economics confuse the issue too. As a result of politics in western countries, internal negotiations with environmental groups, and a western failure to understand local politics and values in the developing world, impractical solutions are often proposed that are more suited to fast-developing countries. Economics is a principal driver for the adoption of technology and business practices: because of risk adjustments, the cost of capital in the developing world is generally higher than in the developed world, so many solutions that work in the latter are not viable in the former. If we keep the Kyoto definition of Annex 1, there is still the issue of the cost of capital which may contain solutions that meet the separate and common goals of both the developed and developing worlds. The most often cited questions of fairness are the need for shared pain and wanting countries like India and China to do more than just commit to good intentions. What could fairly and flexibly quantify this effort to reduce emissions and make the process measurable?

MY PROPOSAL: A CARROT AND A STICK

This leads us into my primary proposal: offering a carrot and a stick for the developed world, beyond just CDMs. For the developed world, an approach based on CDMs carries significant advantages, primarily in the degree of control it has over

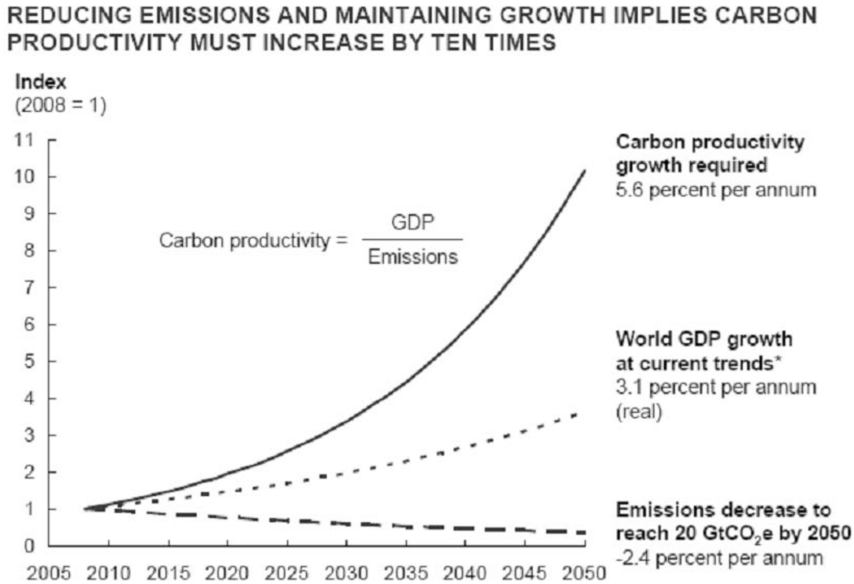

Figure 5. Figure 5: Scale of Emissions Productivity Required

Source: McKinsey Global Institute, p. 17.

the funds allocated through it. This leverage can be directed towards requiring the recipient nations to make a hard, measurable commitment on carbon emissions. Any approach must meet the developing world's need to not limit its growth, while at the same time providing actual incentives towards reducing carbon emissions. What measurable makes sense? The most advantageous way to measure progress is not based on CO_2 emissions as a whole, but rather on creating incentives for the developing world to increase its carbon productivity of GDP: producing more, but reducing the carbon emissions associated with each marginal dollar of GDP growth. This is the concept of carbon efficiency.

Given a 3.1% world GDP growth rate, researchers at McKinsey and Co. have estimated that the carbon efficiency of the world's GDP needs to grow at about 5.6% per annum to meet the set of global reduction targets they recommend.[14] This increase in carbon efficiency can become the measurable that the developed world can ask developing nations to meet in return for CDMs and any other incentives. As Figure 5 shows, a moderate increase in efficiency, sustained over time, provides exponential benefits. This approach is significantly easier and more politically palatable for the developing world than a hard carbon emissions cap might be: it asks nations not to slow their growth, but rather to improve the efficiency of that growth, especially in conjunction with flows of CDM funding. The exact percentage for improvement in carbon efficiency should be subject to negotiation. From a fairness standpoint, it does not unduly punish nations (as in the Eritrea example cited above) that are not achieving stratospheric levels of growth, but rather aligns incentives, so that efficiency and growth become common goals. With the developed nations working towards this goal themselves, and the developing nations having incentives to do the same through the suggested mechanisms, we would have a pathway towards meeting GHG reduction targets worldwide.

If we accept that increasing carbon efficiency is the key, the next question is where and how the developing nations can work towards this goal and how the CDM mechanism can be used to guide it. Earlier I noted that access to cheap capital, along with lower financing costs, is vital. In fact, the cost of capital may be the most critical tool in developing an economy with a lower carbon GDP, since the amortized cost of energy or energy consumption (like cost per mile driven for transportation) often depends materially on it. Paying an additional fee up front (e.g., for solar power capital costs or an electric car) can lead to significant savings in fossil fuel over time; the resultant cost of a KWh or a mile driven depends a great deal on the cost of capital. For developing nations, one approach to lowering the cost of this capital may be leveraging the relatively low-interest sovereign loans that they are granted and applying them towards the capital costs of low-carbon power generation (be it electricity or biofuels). Essentially, developing nations would be utilizing the cheaper access to capital of a developed nation (which is lending its balance sheet) to develop lower-cost energy.

> The most advantageous way to measure progress is not based on CO_2 emissions as a whole, but rather on creating incentives for the developing world to increase its carbon productivity of GDP: producing more, but reducing the carbon emissions associated with each marginal dollar of GDP growth. This is the concept of carbon efficiency.

For example, it has been estimated that the cost of solar thermal power in 2013 would drop from $0.169/KWh to $0.136/KWh if the cost of capital dropped from 8% to 3%, a rate not uncommon in sovereign lending.[15] Alternatively, institutions like the World Bank or the IMF could become facilitators of the move to low-carbon GDP growth in the developing world. One could even demand that under the CDM, the developing world utilizes the best available low-carbon technology that can be economically justified, for projects that depend on these lower-cost loans for low-carbon development.

This becomes an even more attractive proposition if we recognize that, as Arthur C. Clarke put it, technology is rapidly expanding the art of the possible and that the technologies we are likely to use in 2030 have probably not been invented or even thought of today. The developing countries could accept these low-carbon loans voluntarily, based on conditions set by the loan-providing institution (like the IMF, World Bank, or Asian Development Bank). This formulation also solves the related issue of technology transfer. Since most low-carbon technology resides in private hands and is not subject to transfer at the whim of the western governments, lower-cost funding would create the incentive for these innovative technology providers to undertake projects in the developing world.

How might efficiency improve? Figure 6 shows the gains in efficiency over time from the perspective of the U.S., the OECD, and India—with more rapid improvement to come from countries (like India and China) where relatively easy marginal gains can be had. As the technology improves, the use of this "best available technology" condition would drive its adoption. The benefits from substantial energy security and lower energy prices would accrue to all economies because of the slower growth in demand.

If the world's economic growth increased beyond 3%, the world's need for carbon efficiency improvements would also increase, but that increase would apply equally to all countries without major new negotiations—assuming that the system is capable of a dynamic response. Ideally, we would still keep the other constraints like caps on total carbon emissions in the developed world. Then, all Annex 1 countries would accept additional constraints: an agreed-upon reduction (many scientists recommend at least 75%) from 1990 levels by 2050 and hopefully additional targets for 2020 to ensure that we are on course to meet our 2050 targets. It would also behoove us to require that the non-Annex 1 countries do not exceed the average per-capita carbon emissions of the Annex 1 or OECD countries and that they remain below the hopefully declining per-capita emissions of the developed countries.

Clearly, what is fair is in the eye of the beholder, but this approach comes as close as possible to using a definition of fairness that is likely to appeal to a majority of the world's population. Though it is imperfect, a focus on carbon-efficient GDP improvements largely uncouples the requirement for carbon reductions from GDP per capita and GDP growth rates. This is critical to the politics of the developing world, and an important first step, but it may not be enough by itself. For selected global industries, additional constraints such as sector-specific caps may be needed to make the system politically acceptable in the developed world; the Stern report notes that steel and cement are possibilities.[16] Political realities in the west will forestall the adoption of policies that cause widespread losses of employment, especially if the jobs in question are outsourced to the developing world. The sector-based approach offers an alternative by encouraging innovation across the spectrum, instead of encouraging industry to find the country that is most willing to turn a blind eye to pollution.

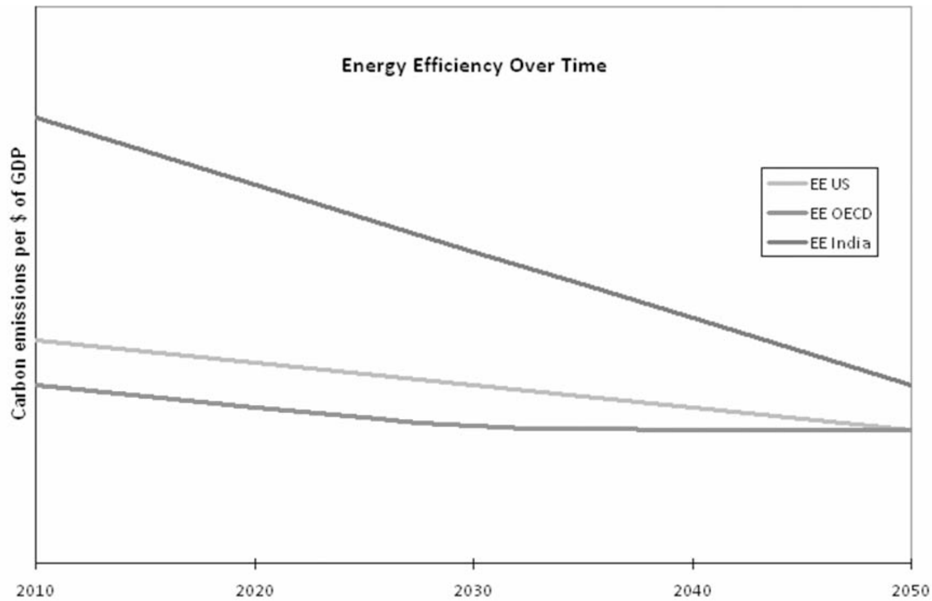

Figure 6. Hypothetical Scenario of Energy Efficiency Improvements Required

CLOSING THOUGHTS

No overarching global cap-and-trade scheme will be easy to create and administer, from either a political or an economic perspective. In Tom Friedman's words, "We're having a Green Party, not a Green Revolution."[17] Revolutions produce dislocations, and winners and losers; people and institutions get hurt. The situation is complicated further by the basic drive of the capitalistic system to economic efficiency. But this very drive can be turned on its head and the capitalist system can be used to more efficiently achieve the goals of a carbon-constrained world. Some aspects of this process will not appeal to individuals in the environmental community. They have been key in identifying and alerting the world to this potentially catastrophic problem, but they have also promoted impractical solutions, often by disregarding the importance of economic gravity which dictates that the cheapest solutions win in developing countries. Economics, not environmental whims, must drive global solutions. Given the scale of capital needed, public funding will not be sufficient; the key is attracting private capital, motivated by profit rather than social goodwill.

We must be pragmatic. For example, from a grid perspective, every nuclear plant the environmental community stopped was likely replaced by an even dirtier coal plant. The environmentalists may be more responsible than the power industry for causing more coal plants to be built, thus increasing carbon emissions: nuclear energy releases almost zero carbon! Today, we must again be wary of uneconomic solutions to significant problems, such as the idea that hybrid cars

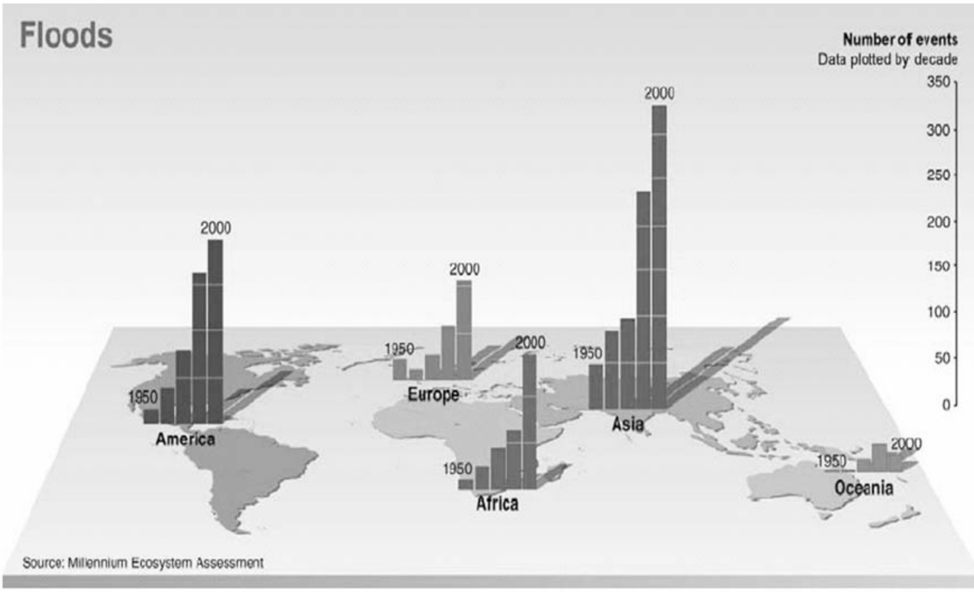

Figure 7. Number of Flood Events by Continent and Decade Since 1950
Source: Millennium Ecosystem Assessment

constitute a large-scale solution: a recent McKinsey & Co. report noted that hybrids have a carbon abatement cost of approximately $90 per ton, making them the most expensive large-scale solution.[18] Are hybrids or some other low-carbon transportation technology likely to be adopted in 80% of the next billion cars we ship on this planet? In a world with limited investment dollars, the case for green technology has to make economic and environmental sense, and we must lower the risk of adopting new technologies. Consumer preferences are only part of this risk.

Also, any fair compromise must include another source of carbon emissions: deforestation. Here we need a carrot-and-stick approach, rewarding a reduction in deforestation with carbon credits that have at least equal economic value to the land holders, and penalizing countries that don't achieve deforestation targets. For example, WTO accords could be appended to make it possible to prohibit agricultural exports, or at least biofuel exports, from countries that don't meet deforestation reduction targets, in addition to the carbon incentives to preserve forests.

But, as Tom Friedman said, it will not be easy. Today, approximately 2.5% of the Gross World Product (GWP) is spent on defense; the U.S. spends closer to 5% of its GDP. Estimates indicate that avoiding the catastrophic consequences of climate change and (re)creating a low-carbon world will not be free.[19] For example, the Stern report estimated that doing so will cost approximately 1% to 2% of GWP; mid-range IPCC estimates are about 0.5% to 1% of GWP. But these estimates suggest it will be cheaper than our "impact-weighted" defense costs if we consider the relatively high probability of catastrophic change and the rapidly rising cost of events related to extreme weather. For example, the U.S. General Accounting Office noted that "claims paid on weather-related losses totaled more than $320 billion between 1980 and 2005" and that "climate change may increase losses by altering the frequency or severity of weather-related events."[20] Weighing the costs of these consequences, it may well feel like a bargain to avoid them if we act in a timely manner. Figure 7 shows the effect of one specific weather-related event over time.

In my opinion, climate change is a far more critical and potentially more catastrophic problem than national defense, terrorism or nuclear proliferation, even though all those problems are urgent and potentially catastrophic. Some of the costs of insurance (much like the costs for defense and anti-terrorism efforts) are warranted to mitigate the risk of the calamitous damage we face. But it may be cheaper to implement a global mechanism to work towards reducing carbon emissions. In any case it is vital, and a working cap-and-trade system offers one tool for aligning the interests of a disparate group of countries, industries, and people.

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Eileen Claussen

Deploying Our Clean Energy Future

> As for the future, your task is not to foresee, but to enable it.
>
> — Antoine de Saint-Exupery

The United States and the rest of the world face a momentous choice. It is a choice that will determine the nature of our economies and our climate for generations to come. One option is to continue down our current energy path—relying to a substantial degree on fuels and technologies that will result in ever-increasing levels of atmospheric GHGs. The other option is to chart a new path—a path by which we protect the climate and rebuild our economies by developing and deploying clean energy technologies.

The choice is obvious: we must pursue a clean energy future.

The consensus among scientists who study the issue is that if we hope to avoid the worst effects of climate change, emissions of carbon dioxide and other GHGs must be reduced worldwide by 50% to 85% from 2000 levels by 2050. In order to do this we must start now, and we must be aggressive.

Transitioning to a low-carbon economy in the time frame required will not be easy. If we remain on our current path without significant changes to the way we generate and use energy, global energy-related carbon dioxide emissions are projected to increase 39% by 2030. Over the next two decades, U.S. emissions, which currently account for about 20% of the world's total, will continue to grow. Meanwhile, emissions from developing countries are projected to increase by 40%. So, how do we create the impetus for broad, across-the-board emissions cuts while still meeting our goals for development and economic growth?

Here is what we know. First, and most immediate, we know that a collection of

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market-ready technologies already exists that, accompanied by innovative policies, can start us down a more climate-friendly path and play a substantial role in reducing emissions. Second, we know that we need a low-carbon economy by mid-century. Third, we know that we cannot and will not achieve a low-carbon economy if we continue on a "business-as-usual" trajectory.

We need policies that trigger investment and propel new technologies into the marketplace. This means putting a price on carbon, such as through a cap-and-trade system, and implementing complementary policies that create incentives to develop and use new technologies.

Our challenge over the next decade is to chart a new path that leads to action on this issue across all sectors of the economy, from electricity and transportation to agriculture, manufacturing, and buildings. We need policies that trigger investment and propel new technologies into the marketplace. This means putting a price on carbon, such as through a cap-and-trade system, and implementing complementary policies that create incentives to develop and use new technologies. The need for technological innovation is non-negotiable. To succeed, we need to take strong action that moves us away from the dirty fuels of the past and toward clean, safe energy sources to power our future.

THE NEED FOR POLICY CERTAINTY

Since the energy crisis of the late 1970s, the federal government has promoted clean energy alternatives in fits and starts. This inconsistency has kept many innovative companies from placing big bets on an uncertain clean energy future. Today, amid tough economic times, concerns about foreign energy supplies, and growing risks of climate change, businesses are looking to Washington to deliver long-term regulatory certainty in climate change and energy policy.

In testimony during the first House Energy and Commerce Committee hearing on climate change this year, CEOs of a dozen large industrial companies were unanimous in making the case that regulatory certainty is critical to unleashing substantial investment dollars. The CEOs said they will invest billions of dollars in the research, development, and deployment of new clean energy technologies—creating jobs and helping to rebuild the economy in the process—once they have clarity on the regulatory rules of the road.

"I believe that this may be the single greatest opportunity to reinvent American industry, putting us on a more sustainable path forward," said DuPont Chairman Charles Holliday, Jr. regarding legislation on climate change and clean energy that passed the U.S. House in June. "A federal climate program has the potential to create real economic growth through innovation."

Jim Rogers, president and CEO of Duke Energy, the nation's third-largest coal-burning utility, said, "Long-lasting climate change legislation must be based on three equal tenets—protecting the environment, the economy, and consumers. The sooner Congress acts on climate change to provide the regulatory clarity business and industry needs to move ahead with major capital projects, the more rapid our economic recovery will be."

Examples of past policy efforts offer good guidelines for providing this regulatory clarity. A 2003 Pew Center report looked at historical U.S. technology and innovation policies to see what lessons could be learned for addressing climate change. One of the key insights was that past government policies that go beyond R&D—to promote downstream adoption of technologies and learning by doing—have greatly influenced technological change.

For decades, the market for clean energy alternatives has lacked sufficient demand to promote the wide-scale supply and use of technologies required to reduce GHG emissions to the level that scientific findings demand. An economy-wide price signal on GHG emissions and consistent and substantial public investment in clean energy are key ingredients to ramping up these technologies. Policymakers face the challenge of employing a suite of innovative policy tools to craft an environmentally strong, cost-effective regulatory environment to induce significant private sector commitments in a low-carbon future.

INNOVATIVE POLICY SOLUTIONS

Just as there is no single technological solution to reduce GHGs, there is no one policy "silver bullet" for transitioning to a clean energy economy. Both strong inducements for technology development and deployment and strong emission reduction requirements are needed. In January 2009, the Pew Center joined with the other members of the U.S. Climate Action Partnership (USCAP) in endorsing a detailed framework for legislation to address climate change. As noteworthy as the contents of the framework were the constituencies that put it forward: a coalition of leading businesses and non-governmental organizations.

A decade ago, it would have been unimaginable for companies ranging from Alcoa and John Deere to Dow Chemical to agree on an agenda advocating federal action to achieve dramatic reductions in U.S. emissions. But the USCAP *Blueprint for Legislative Action* is part and parcel of a campaign that has engaged CEOs and other leaders of Fortune 500 businesses to become active and very visible supporters of climate solutions. Their plea for strong action and regulatory certainty on this issue has found a receptive audience in Washington and has provided a vital push for Congress.

The USCAP *Blueprint* calls for a federal cap-and-trade program that sets targets for GHG emissions and allows companies the flexibility to trade emission credits to achieve their targets. In addition, USCAP advocates complementary policies for many other efforts: technology research, development, and deployment; carbon capture and storage technology deployment; lower-carbon transportation technologies and systems; and improved energy efficiency in buildings, industry, and appliances. These policies, including subsidies like tax credits or performance standards to speed deployment, can reduce the cost of low-carbon technologies and thereby accelerate the spread of emission reductions. The two approaches—the policy pull of cap-and-trade combined with the policy push for clean energy technologies—are more powerful in tandem than either one can be alone.

> For three decades, efforts to advance clean energy solutions have fizzled under ineffective, inconsistent policymaking. Now, the risks from climate change and the benefits of a new energy transformation make significant action an urgent imperative.

Federal policies limited to financial support for new energy advances have largely failed to produce meaningful results. For example, the Synthetic Fuels Corporation created under President Carter was quashed within six years by the Reagan Administration, which viewed it as unnecessary interference in the free market. The Synfuels Corp. was established to help create a market for domestically produced synthetic oil or gas made from coal, and less conventional sources such as tar sands and oil shale, as an alternative to imported fuels. Designed to provide substantial subsidies to the private sector for commercial-scale projects, the initiative fell far short of its production goals.

More recently, the FutureGen project for carbon capture and storage was a major technology initiative under the Bush Administration. FutureGen was set up as a public-private partnership to construct a near-zero emissions coal-fueled power plant. Later suspended under President Bush, FutureGen has been revived by the Obama Administration; a decision on whether to build the plant is expected to come in 2010. Whatever FutureGen's outcome, the years of delay in constructing a full-scale CCS demonstration plant underscore the shortcomings of a technology-only policy approach. Without support for technology R&D and a clear price signal on carbon, development and deployment of major new energy technologies is largely inconsistent and ineffective.

The businesses that are part of USCAP believe very strongly in the potential for strong policy to spur new investment in the climate-friendly technologies we need.

Consider this comment from Tim Fitzpatrick, vice president for marketing and communications with FPL Group, the parent company of Florida Power and Light, which has become a leading generator of carbon-free electricity worldwide:

> America's energy economy has already suffered from a lack of business certainty—simply witness the annual ritual over whether tax credits in support of wind energy will be renewed. Over the years, numerous wind projects have been put on hold while Washington dithers over whether to renew this vital support mechanism. … The lesson for U.S. policymakers is clear: Put a predictable price on carbon so that U.S. companies can invest with confidence.

Another perspective comes from George Nolen, president and CEO of Siemens Corporation, the U.S. subsidiary of Siemens AG:

> Businesses need to plan. The absence of a price signal for carbon in the U.S. stifles planning and creates a competitive barrier to investment in technology.

For three decades, efforts to advance clean energy solutions have fizzled under ineffective, inconsistent policymaking. Now, the risks from climate change and the benefits of a new energy transformation make significant action an urgent imperative.

NO SILVER BULLET: THE TECHNOLOGIES WE NEED

Transforming the world's fossil fuel-based energy system to one centered on low-carbon alternatives is an unprecedented undertaking. The fact is that no single technological silver bullet will be sufficient. The ultimate success of a climate change strategy—at both national and international levels—will hinge on the innovation and commercialization over time of a broad spectrum of technologies that can compete in a carbon-constrained world. That includes changes in how we produce electricity, how we get from one place to another, how we farm and manage our forests, how we manufacture products, and even how we build and operate our buildings.

A quick sector-by-sector overview illustrates the collection of market-ready technologies that, accompanied by innovative policies, can start the United States down a cost-effective low-carbon path.

- In electricity, we need to improve efficiency while shifting the supply mix to lower-carbon energy sources such as renewable and nuclear power and advancing carbon capture and storage to reduce emissions from coal combustion.
- In the transportation sector, we must focus first on using oil more efficiently while making the transition away from petroleum-based fuels to running cars and trucks on electricity, next-generation biofuels, and hydrogen.
- In the building sector, which accounts for nearly 40 percent of U.S. energy consumption, more efficient building designs and equipment can deliver enormous energy savings without sacrificing comfort or quality of life.

- And in manufacturing, we need to take a hard look at changing inputs, redesigning production processes, reworking the product mix, and, wherever possible, reusing and recycling products so they don't have to be produced again.

The low-carbon technologies available now, if deployed at a more rapid rate, would significantly reduce GHG emissions. But these technologies will not be enough. New breakthrough technologies will be essential for the world to meet its immense appetite for energy without endangering the global climate.

We have seen a certain amount of progress in all of these areas, but it's been largely hit-or-miss. Consider carbon capture and storage. Despite extensive planning, the United States has spent nearly a decade talking about but not building a commercial-scale demonstration plant with CCS. We need to provide producers with the incentives to build cleaner-burning plants as soon as possible—to bring down the costs of capturing carbon from conventional plants and to prove to policymakers, investors, and the public that large-scale CCS is an effective, safe technology.

Simply waiting around for these technologies to make their way from the laboratory into mainstream use is not an option. We don't have the luxury to sit and watch this process evolve ever so slowly, as if we're watching *American Idol* week after week to see who wins in the end. We need to speed the process along. Without picking winners, we need to enact policies that provide incentives to help commercialize new, viable technologies.

THE BENEFITS OF CLEAN ENERGY TECHNOLOGY

Developing and deploying these new technologies will have benefits beyond reducing GHG emissions. President Obama has stated very strongly that tackling energy and climate change will not only get the United States firmly on a path to economic recovery, but also will provide a new foundation for strong, sustainable economic growth. The economic stimulus package the president signed in February included more than $80 billion in new spending and incentives for everything from smart-grid technologies to renewable energy development to energy efficiency improvements and mass transit.

Of course the White House is not alone in highlighting the multiple benefits associated with the development and deployment of clean energy technologies. Mayor John Fetterman of Braddock, Pennsylvania set out to debunk the notion that reducing U.S. emissions through a national cap-and-trade program would cause industrial communities like his to lose jobs. "People here desperately want to work, and a cap on carbon pollution will generate jobs in industries like steel," he wrote this year in *The Dallas Morning News*, noting that it takes 250 tons of steel to make a wind turbine.

The U.S. manufacturing sector would greatly welcome a shot in the arm. Its struggles began well before the recession hit, and the new products and processes needed to build the clean energy economy and address climate change will be a boon to many American workers. Representing 850,000 manufacturing workers, United Steelworkers President Leo Gerard believes that "addressing climate change and ensuring the strength of our nation's manufacturing sector can be compatible goals."

Many governors—both Democrats and Republicans—also recognize the great potential that energy technologies can play in turning around their states' economies. In May, a bipartisan coalition of 27 governors signed an agreement supporting federal energy and climate change legislation that will help create clean energy jobs and industries and accelerate technology deployment. And nearly two thirds of U.S. mayors believe that addressing climate change with technological innovation represents an "enormous" economic opportunity, according to a 2009 U.S. Conference of Mayors survey of 140 mayors from 40 states.

These calls for action to spur the deployment of new, low-carbon energy technologies are backed by a wide-ranging cast of clean energy economy boosters from *New York Times* columnist Thomas Friedman to the businessman T. Boone Pickens. Supporting these views are growing signs of the economic opportunities that await leaders of a new energy future.

For instance, in a recent 10-year period, U.S. clean energy jobs grew nearly 2.5 times as fast as jobs overall. This growth rate, documented in a state-by-state analysis of clean energy jobs between 1998 and 2007 published this year by The Pew Charitable Trusts, demonstrates that good opportunities exist to spur new jobs, businesses, and investments in clean energy if supported by the right policies. Over the ten years studied, clean energy jobs grew at a national rate of 9.1% compared to the 3.7% growth rate in traditional jobs.

Several other recent studies cite substantial job growth opportunities in clean energy. For instance, the *2008 Green Jobs Report* for the U.S. Conference of Mayors found that increasing renewable energy use and implementing efficiency measures could generate 4.2 million U.S. jobs by 2038 and account for 10 percent of total new job growth over that period. Private investors are well aware of this growth potential. In 2008, $5.9 billion in private investment—15 percent of global venture capital investments—went to U.S. businesses in the clean energy economy. But this amount pales in comparison to the cost of transforming to a low-carbon energy system. The International Energy Agency estimates this transition will cost $45 trillion globally between now and 2050. Major investments to drive the development and commercialization of new energy technologies largely hinge on implementing appropriate policies.

The opening letter to the Deutsche Bank Group report *Investing in Climate Change 2009* captured this critical need. Kevin Parker, global head of asset management for the group, wrote,

> The aim must be to create a clear long-term regulatory regime that determines a market-driven cost of carbon while at the same time encouraging the development of alternatives. If governments recognize the neces-

> sity of creating the right regulatory environment, investors will recognize the opportunity and step in.

A growing number of parties—from senators and CEOs, to governors and venture capitalists—understand what's at stake. They believe in the power of current and emerging technologies to reduce GHG emissions in the United States and around the world. At the same time, however, they understand that these technologies will not be deployed in the marketplace at the scale and in the time frame needed to address climate change without an explicit and unprecedented set of policies from government.

A new path is needed to reduce emissions and advance clean technologies across the economy. It requires a carbon price signal to help level the playing field for clean energy technologies combined with substantial, consistent public investments to propel critical solutions from the laboratory to the marketplace. The pull of an emissions price tag in tandem with the push from technology policies provide a solid framework for engineering a low-carbon transformation—without dampening the competitive ingenuity that is a key driver of the world's most innovative economy.

Bill Drayton

People, Not Things

When we think about fighting climate change, the first things that naturally occur to us are that we need to cut or offset greenhouse gas emissions, or perhaps set in motion some other strategies that will mitigate their impact on the climate. Logically, the next step in the thought process is to consider the myriad ways of doing so, ways that range from using new energy technologies to launching carbon-trading markets, to stimulating innovative solutions, to lowering the costs of abatement, to helping end the north-south impasse.

All this is essential. But it is not enough. We need a larger conceptual framework if we are going to solve the problem. By refocusing on the larger balances and imbalances in our world, we can bring bigger, simpler and faster forces to bear on the climate challenge. Significantly, these forces are political as well as social, economic, and environmental.

The most basic balance, the first tradeoff society makes, is between the two primary factors of production. Should we use more labor or more natural resources (energy, materials and land)?

For decades, we have been tilting the scale ever more steeply in favor of using things, not people. We define "productivity" in terms of how little labor we can use in production, rather than thinking about how we can maximize value by changing the mix of inputs. In the U.S., more or less by accident, we have sent a giant "use things, not people" price signal as payroll taxes have increased from 1% to almost 40% of federal revenues over the last several generations. And now, in some of the current proposals to finance health care reform, we are considering further increases.

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As a result of this drift towards using things more and people less, the global system is consuming natural resources very aggressively. With our natural resources already significantly overleveraged, exploiting them no longer offers a promising avenue to greater growth. At the same time, our excessive use of them is a major cause of our climate problem—as well as a major opportunity to cure it.

On the opposite side of the equation is labor. Even as they encourage rapid exploitation of natural resources, our current policies so discourage labor demand that available labor resources are dramatically underutilized.

The result is madness. Not using labor is enormously costly and destructive (exactly the reverse of what holds true for natural resources). Official unemployment, now roughly 10%, is at historic highs and still climbing, and will be a political problem for a long time to come. And that official 10% represents only a fraction of the adult population that is not working; the total figure is closer to 40%.[1]

Looking closely at the numbers, it's possible to discern that at least 75 million full-time-equivalent jobs that we would need to employ our people are missing from the U.S. economy. This isn't immediately apparent from the official unemployment statistics, because periodically, they are adjusted to reduce the number of people counted as not working.[2] In 1994, for example, the Labor Department decided not to count those out of work for a year or more (4 million people at the time). The Clinton Administration also reduced household sampling in the inner cities, which probably leaves us further undercounting unemployment among minorities. Such practices are still in place today.[3]

But despite this, we can still detect the 75 million missing full-time jobs in either of two ways. One way is an aggregate analysis of who isn't working and who isn't officially counted as unemployed. Another way is to add up the number of jobs needed to provide work for those groups most afflicted by today's hidden unemployment: older people, young people, people with disabilities, many groups of women, minorities, legal immigrants, those who formerly were institutionalized, and those affected by shifts in the economy due to trade or technological changes.

Both methods point to some 75 million Americans who could and would work given the opportunity, but who aren't—*five times* the number counted as officially unemployed. In most of the rest of the world, the rate of hidden unemployment is even worse, and payroll taxes are higher, often much higher.

Hidden mass unemployment, in the U.S. and around the world, is the world's biggest orphan issue. It is also a latent economic, social, environmental, and political force. Once effectively engaged and led, it could create an irresistible, sustained political alliance that would drive deep change in a dozen fields—climate being a crucial one.

By themselves, the environmental constituency and organizations are weak. Why has environmental progress been so uncertain since Earth Day in 1970? A prime reason is the fact that those who want environmental action are a diffuse force whose members irritate, and impose costs on, almost every organized constituency.

But we could transform this situation by marrying the already closely linked issues of jobs and climate change, and making the decision to use more labor and fewer natural resources. Almost every major constituency will benefit in crucial ways, as will society as a whole. Every group—from young people to older people, from those with disabilities to immigrants and minorities—would gain jobs. Having work is immensely important to them, and to anyone who cares about them. Once the current 40% overhang of sidelined labor has been absorbed back into the workforce, more workers will be earning more, fueling economic growth. All but a very few companies will benefit from higher growth, lower costs for security and other services, and lower labor costs. The cost of the natural resources that companies use may go up and partially offset some of those savings; on the other hand, their rates of natural resource consumption will usually go down.

> Imagine what would happen in the U.S. if we made a complete switch, eliminating all payroll taxes, and compensating for the lost revenue so there was no budget deficit. Without payroll taxes the cost of hiring workers would decrease over 16%. At the same time, we could increase the cost of using natural resources by a similar but smaller amount. In other words, we could change the relative price of labor, compared to the price of things, by roughly 30%. That is a big price signal, one that would create roughly 40 million new jobs.

The other big beneficiary is the environment. It will benefit hugely from powerful conservation incentives and from the backing of this extraordinary alliance—an alliance with almost no enemies.[4] Who opposes robust, sustainable growth and more jobs? Conservatives, and especially libertarians, recognize that people have little freedom unless they have the opportunity to work in a decent job.

The most effective step toward a healthy mix of using more people and fewer natural resources is to send a simple price signal: make employment cheaper and natural resources dearer by shifting taxes away from payrolls and onto the use of natural resources.

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Such a price signal would not only be effective; it would also be welcome across the ideological spectrum. It does not require a bureaucracy. No one would choose winners and losers. There would be no delay and no need to worry about corruption. It can be configured in politically attractive ways: we need not tax gasoline, but could choose among a wide array of possible taxes to offset the loss of payroll tax revenue. For example, we could look to a non-labor Value Added Tax, or to an Energy Inefficiency Tax on the least efficient cars, appliances, and/or commercial buildings, or we could directly tax pollution such as carbon.

The national nonprofit group, Get America Working! analyzed 25 such taxes and found that, even at modest rates, they would yield two and a half times the revenue of all today's payroll taxes.[5] In other words, the political system has plenty of room to maneuver to find the least painful and most environmentally useful options.

Implementing such a tax switch would send even bigger price signals and have proportionately larger impacts in the many countries where payroll taxes are higher than in the U.S. The precise impact on any country is hard to predict, since most economic models are built from historical data on small and usually short-term shifts, and this is a big, new, long-term shift.

But there is no doubt that they would be hugely effective. Consider the following precedents: In the U.S. in the 1970s, when the energy crisis pushed commodity prices up and held labor costs down, the proportion of Americans who were working increased for the first time in decades. In OECD countries, there is on average an 11.5% difference in the proportion of the population working in countries where payroll taxes are higher (over 40%), compared to countries where they are lower (below 30%).[6]

We can predict that such a tax shift would be hugely powerful in terms of both policy and politics, because it achieves multiple and multiplying benefits for society:

- It accelerates growth sustainably as it puts to work society's one huge underutilized resource: people, and the enormous human capital invested in them.
- It sharply reduces today's tremendous costs—to individuals, families, business, and government—of supporting all those who are not working.
- It cuts away many of the root causes of today's hugely expensive social ills. To cite one example, researchers find that the rates of illness are sharply higher among people who stop working, once they control for personality and prior health. Work seems to keep people healthy.[7] Another example: fuller employment can address the cycle of drugs, crime, and fear.

- It gives everyone a big incentive to conserve. For example, farmers facing a tax on agricultural chemicals will do more composting and spend less on chemicals. Homeowners will hire people to insulate their houses, so they consume less heating oil.
- It gives those who work the gift of being useful—along with other gifts, like building skills, understanding, and contacts. And they will experience personal independence and greater ability to help others. (Those without work deteriorate on all these fronts).

So tax switching offers both a tax cut and an opportunity to do more. It expands the labor force and tax base while shrinking the high costs of unemployment, freeing the economy to grow, citizens to work and government to be effective.

> The chief remaining barrier to enacting a tax switch is resistance to an idea that is new and represents a different conceptual framework. To embrace it, people have to look beyond the old and ever-narrowing definition of "unemployment" and see the larger reality of who is and isn't working, who could be, and how more labor utilization could reduce natural resource consumption and protect the climate.

To fight climate change effectively, we need to unleash the extraordinary power of this alliance of diverse interests and goals—jobs, growth, equity and environment together, conservatives and liberals alike. The fight will require very heavy lifting—far more than the environmental community can do alone. But tax switching could help realign these issues and constituencies, so they work together.

Such a realignment may already be underway. Most European countries, and now increasingly those in Asia and Latin America, have begun to cut payroll taxes. Even international financial institutions have begun advising nations, for example in Eastern Europe, to cut payroll taxes as a way to increase employment.[8]

The U.S. has lagged behind in this trend. Historically, one reason is that the biggest payroll tax is for Social Security, and politicians have feared giving their opponents the smallest grounds to attack them here. But worries over the political dangers of touching Social Security's financing—the so-called "third-rail" problem—are surmountable. One could counter it in many ways, for example by cutting other payroll taxes first; or by issuing an offsetting credit, as several U.S. cities have already done—an attractive option because sending a check is so visible.

In any case, over the last five or so years, the "third-rail" taboo against touching Social Security has largely fallen away. Members of both parties have long since advocated cutting payroll taxes. Recent advocates of offsetting payroll tax cuts with taxes on gasoline or carbon emissions range from Charles Krauthammer to Thomas Friedman, Al Gore to Richard Lugar and T. Boone Pickens. This year Rep. Bob Inglis (R-SC) and Rep. John Larson (D-CT) both introduced climate change bills that recycle over 90% of carbon pricing revenues into payroll tax cuts. Robert Shapiro, President Clinton's Undersecretary of Commerce, argues for this approach. Bruce Bartlett, deputy assistant Treasury Secretary under President George H. W. Bush, recently proposed cutting the Medicare portion of payroll taxes coupled with a non-labor Value Added Tax to finance health care reform. The Obama White House 2010 budget proposal envisioned using 85% of the $645 billion in projected carbon trading permit revenues to extend the Making Work Pay payroll tax credit, initially created as a stimulus measure.

As fear itself fades, the chief remaining barrier to enacting a tax switch is resistance to an idea that is new and represents a different conceptual framework. To embrace it, people have to look beyond the old and ever-narrowing definition of "unemployment" and see the larger reality of who is and isn't working, who could be, and how more labor utilization could reduce natural resource consumption and protect the climate. This is doubly challenging since it combines transformations in two major spheres: climate and jobs. But the two need one another on several levels.

There is positive synergy between them. Allowing the economy to fly will make it far more likely that society will face up to climate change and make the very large investments required to deal credibly with it. And, given that our economic challenges far transcend transient business cycle economics, facing up to climate change also entails confronting the fundamental need to increase demand for labor, *structurally* and very significantly.

There is also negative synergy between jobs and climate. If we do not stop climate change quickly, the consequences will be enormously destructive to society and the economy. In some of the darker climate change scenarios, economic dislocation might reduce global per capita consumption by 20%. By the time that happens, we will probably have missed our chance to keep climate change within manageable bounds.

We need to muster the vision and determination to get the jobs/climate synergy working in a positive direction now, or we risk losing the opportunity to ride their spiral upward, and may find ourselves being ground down as job loss and climate change feed each other in a deadly downward spiral.

Fortunately, we still have the opportunity to press them forward together, and to reap the benefit of a very powerful combined uplift. Creating jobs and fighting climate change both entail large shifts in research, science, technology, skills, infrastructure, and systems, which together can set in motion profound cycles of innovation and investment. Innovation explosions on both fronts will feed one another, bringing prosperity, job creation, and the growth that comes with combined work and investment. When societies grow faster than expected, unity and community-mindedness arise (and we should not forget that the reverse is equally true).

Today's two giant imbalances—in climate and in jobs—are in fact a single, giant opportunity. If we break out of the narrow conceptual frameworks around them, if we allow ourselves to see and act in terms of all the forces at play, this moment in history offers us a chance to create an unstoppable, probably permanent, alliance of everyone with the spirit to help the world change.

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1. According to data from the Bureau of Labor Statistics, on the 2008 current and potential U.S. workforce, of the non-institutionalized adult U.S. population of 216.5 million, 63.5 million were not considered part of the labor force at all, and another 8.9 million were officially unemployed (at present, that number is about 15 million). Only 119.5 million, or about 55% of adults, were considered part of the full-time labor force. Of those considered in the full- and part-time workforces, many were out of work during at least some of last year.
2. The Bureau of Labor Statistics figures (Employment Situation Summary, Sept. 4, 2009) for August 2009 reported the unemployment rate at 9.7%, but only reported 14.9 million as "unemployed." The BLS summary notes that an additional 9.1 million Americans are working "part time for economic reasons"; i.e., they were unable to find a full-time job. These workers could be working as little as an hour per week. Still uncounted in the BLS numbers are the millions who have given up or do not look because they think they cannot find jobs with flexible schedules that would work with their lives, given responsibilities for childcare, eldercare, etc.
3. For commentary on the inadequacies of the current reporting of the unemployment rate see www.workinglife.org/
4. Early in its design, John Gardener, former U.S. Secretary of Health, Education, and Welfare, advised Get America Working!, a citizen group formed to encourage fuller employment policy and build a broad coalition of supporters. At Stanford Business School in the late 1980s he told me, "These policies bring great value to everyone and will help create the sort of standing alliance between constituencies that was key to the progress we made" when he was secretary of HEW.
5. Get America Working! background paper "Job Creating Tax Options."
6. Robert Walker, 2007, Declining Payroll Taxes: The European Example www.getamericaworking.org/europeanexperience Note that this comparison involves only differences in payroll tax levels. It does not include the other half of a tax switch: increasing the taxes on natural resources.
7. There is considerable empirical evidence that older people who continue working beyond "retirement age" live longer and are far healthier than those who stop working. For example, a study done in North Carolina showed that a 1% decline in labor force participation among people over 65 translated into a 7.29% increase in the rate of hospitalization. The author of the study, David Weaver, Ph.D., a researcher at the Social Security Administration, concluded, "policies encouraging labor force participation [among the elderly] will dampen the demand for hospital care." A study published in The British Medical Journal found that men aged 40-59 "who became unemployed or retired for reasons other than illness had a significantly raised risk of dying compared with continuously employed men, which suggests that non-employment even in apparently healthy men was associated with increased mortality."
8. Germany and Canada cut payroll taxes earlier this year as an economic stimulus in response to the downturn. Italy, France, Sweden and Australia have also vowed to cut theirs. The European Commission called for its member states to do likewise, and the World Bank recommended that Central European nations cut payroll taxes to stimulate jobs.

Arthur H. Rosenfeld with Deborah Poskanzer

A Graph is worth a Thousand Gigawatt-Hours

How California Came to Lead the United States in Energy Efficiency

Innovations Case Narrative

Humans burn fossil fuels to provide energy for our needs, including heat, light, transportation, refrigeration, and industrial processes. Our continued dependence on combustion produces carbon dioxide, contributing to the increasing concentrations of greenhouse gasses (GHGs) in the earth's atmosphere. Although energy efficiency alone will not likely be enough to reverse this trend, currently it is by far the fastest, cleanest, and cheapest energy resource available.

This article will discuss how my colleagues and I have promoted energy efficiency over the last 40 years. Our efforts have involved thousands of people from many different areas of expertise. The work has proceeded in several areas:

- Investigating the science and engineering of energy end-use
- Assessing the potential and theoretical opportunities for energy efficiency
- Developing analytic and economic models to quantify opportunities
- Researching and developing new equipment and processes to bring these opportunities to fruition
- Participating in the development of California and later federal standards for

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energy performance in buildings and appliances
- Ensuring that market incentives were aligned with policies
- Designing clear and convincing graphics to convey opportunities and results to all stakeholders

Here I tell the story of how we developed and combined these efforts by developing a conceptual framework, calculating costs and benefits, and deploying our findings in a way that would achieve maximum persuasive impact. During this time I have served in various capacities: as a physics professor at the University of California, a researcher at Lawrence Berkeley National Lab (LBNL), an advisor at the federal Department of Energy, and most recently a Commissioner on the California Energy Commission.[1]

Technological innovation has been and will continue to be an important component of efficiency improvement. However, legislative, regulatory and market innovations have also been a critical and challenging part of our effort. Our work covers a broad range of interconnected efforts: the ability to coordinate and align the work in all these sectors is at the core of my definition of "innovative."

Technological innovation has been and will continue to be an important component of efficiency improvement. However, legislative, regulatory and market innovations have also been a critical and challenging part of our effort. Our work covers a broad range of interconnected efforts: the ability to coordinate and align the work in all these sectors is at the core of my definition of "innovative."

This article is built around a collection of favorite graphs that my colleagues and I have used over the years to support the campaign for efficiency. I begin with two graphs that illustrate general concepts of energy efficiency and energy intensity in order to illustrate the amazing savings available from improvements in energy use. Next, a series of figures chronicle how we used and continue to use technical and economic data to substantiate our arguments for an effective energy efficiency policy. I have chosen several examples of innovation that have contributed substantially to efficiency improvements over the long term: refrigerators, electronic lighting ballasts, computer applications that simulate building energy performance, and valuation methods for conserved energy. These cases are not necessarily the most recent—some are based on research performed many decades ago—but each one illustrates the complex web of challenges in engineering, economics, and policy that is typical of the efficiency field, and each one continues to bear fruit.

The cases discussed in this article all originated in my home state of California before they went on to influence energy efficiency strategy at the national or global level. California has been, and remains, the main arena for my efforts, and after four decades of innovation we are a leader in energy efficiency. The gap between our lower per capita electricity use and national consumption has been dubbed the "California Effect." How much of this effect can be credited to our efficiency efforts, as opposed to advantages in climate and industrial mix, is a point of debate. I will give my own analysis here, and the article that follows, by Ralph Cavanagh, will also discuss the issue.

In conclusion I will describe an exciting new policy development that represents the culmination of many years of multi-pronged, interdisciplinary groundwork. In September 2008, the California Public Utilities Commission (CPUC) released California's Long-Term Energy Efficiency Strategic Plan, which was followed in September 2009 by the announcement of a $3.1 billion budget for the first three-year stage of implementation.[2] The Strategic Plan is a crucial component of the state's effort to roll back GHG emissions to 1990 levels by the year 2020. Achieving this goal, as was set forth in the landmark Global Warming Solutions Act of 2006 (Assembly Bill 32), will bring California into near-compliance with the Kyoto Protocols. More importantly, the Plan's detailed and entirely feasible program of increased energy savings, paired with job creation, provides a much-needed road map for a nationwide "green economy" stimulus.

ENERGY EFFICIENCY: CONCEPTS AND DEFINITIONS

Energy efficiency is defined as the amount of useful output derived from primary energy input. We encounter the idea of *end-use efficiency* every day when we calculate how many miles per gallon our cars achieve, or how much our electricity use drops when we replace an old refrigerator with a better one. Obviously, the greater the efficiency of our equipment, the less fuel we need and the lower our impact on climate change. The goal of energy *efficiency* is to use technical and process improvements to our appliances, buildings, and vehicles to deliver the same, or comparably satisfactory, levels of performance for less primary energy input.

To track the macroeconomic significance of efficiency gains we can index the *energy intensity* of an economy. Energy intensity is defined as the amount of primary energy needed to produce a unit of gross domestic product (GDP): lower energy intensity indicates a more energy-efficient economy. The good news is that in general, energy intensity improves through normal technological progress. This is intuitively obvious when we think about the efficacy of cooking over a wood fire compared to a modern range. Or to be more quantitative, lighting has progressed

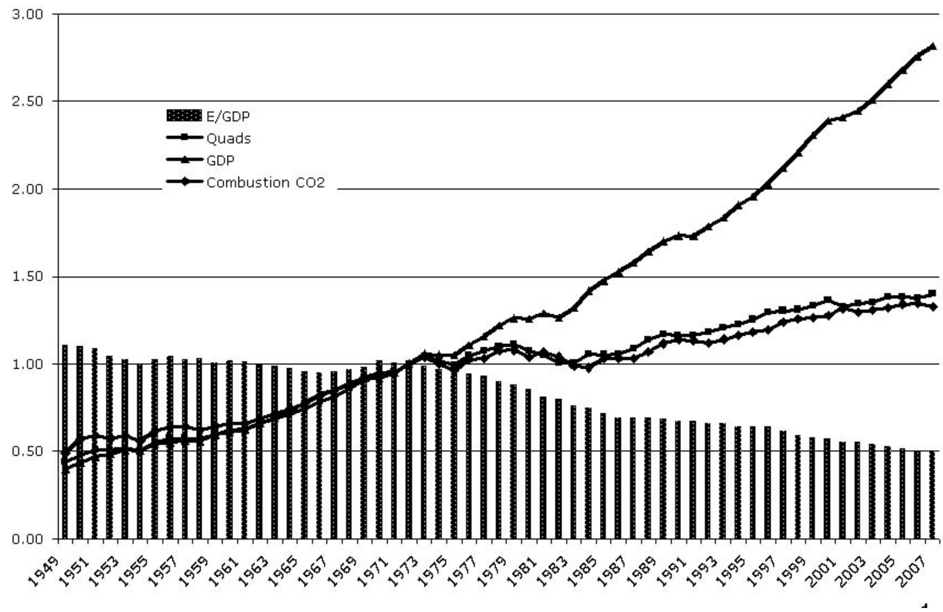

Figure 1. Index of U.S. Energy Use, GDP, Energy Intensity, and CO_2, with 1972 = 1

from candles producing one lumen for every six watts of candle or wax burned, to incandescent electric bulbs producing 17 lumens with each watt of electric input, to fluorescent lighting that produces 100 lumens per watt.

Figure 1 displays various energy and economic data for the U.S., indexed to a 1972 baseline.[3] These data include: Quads (10^15 Btus) of primary energy; Gross Domestic Product (in constant dollars); CO_2 emissions; and Energy Intensity (energy divided by GDP). In the high-growth decades following World War II, primary energy use, gross domestic product (GDP), and CO_2 emissions from combustion increased nearly in lockstep. Between 1949 and 1973, energy intensity barely changed, as seen from the unvarying height of the columns depicting energy intensity (E/GDP). In the years preceding the first OPEC oil embargo, the American consumer had not just scarce but *diminishing* motivation to reduce energy usage. The average retail price of electricity hovered below 2cents/kWh through the late 1960s and early 1970s; in fact the real price (in fixed 2000 dollars) actually declined.

Beginning in 1973, however, the rising price of oil changed the U.S. perspective on energy, spurring California and then other states to adopt energy efficiency standards for buildings and appliances. After 1973, as Figure 1 shows, the GDP and energy consumption kept increasing, but the gap between the rates of increase widened dramatically: energy use grew much more slowly than the GDP, and energy intensity improved rapidly. Many factors contributed to these changes, including the rapidly increasing cost of energy and federal Corporate Average Fuel

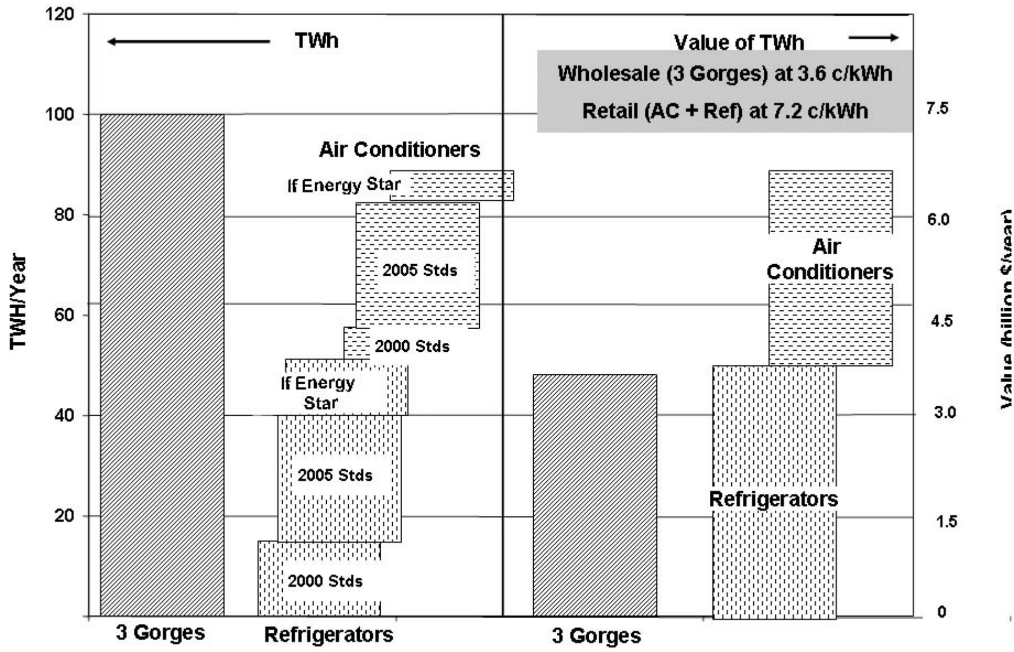

Figure 2. Comparison of Three Gorges Dam in China to Refrigerator and AC Efficiency Improvements.

Savings calculated ten years after standard takes effect. Calcluations provided by David Fridley, LBNL.

Economy (CAFE) standards in the transportation sector. We also note that even as energy intensity was improving, U.S. energy use and emissions were increasing though at nowhere near the rate of the 1950s and 1960s.

A central concept of energy efficiency is that it can be measured as a *source* of energy. Every unit of energy we avoid using thanks to a more efficient device has its equivalent in a unit of fossil fuel that need not be prospected and combusted, or on a macro scale, a power plant that need not be built. Fleshing out the bare concept of *avoided use* with sound methodology and data has been a core part of our work. Figure 2 shows an especially dramatic example that reaches far beyond California.[4] The Three Gorges Dam in China is the largest hydroelectric power station in the world, completed in 2008 at a cost of $30 billion. The left side of Figure 2 shows the amount of energy the dam can generate, compared to the amount of electricity that will be avoided once all the refrigerators and air conditioners in China meet current Chinese appliance performance standards for, respectively 2000, 2005, or the U.S. Energy Star label. The right side of the graph compares the dollar value of generation and saved or avoided electricity. We spotlight China because the Chinese example points to the amazing opportunities for energy efficiency. The quantity of energy that will be saved or avoided when refrigerators and air conditioners meet more stringent performance standards in China will nearly equal the output from the nation's largest hydroelectric power station. And the "value" of the electricity saved will be nearly double that of the power station.

Energy efficiency is *one* weapon in the arsenal against over-dependence on GHG-emitting fossil fuels. I believe efficiency is the *best* weapon: cheapest, safest, and most immediately achievable. The technological barriers to efficiency improvements are negligible. Efficiency is truly the low-hanging fruit of the alternative energy scene. I now turn to the story of how, beginning in the early 1970s, we worked across many different fields to convince others that significant gains in efficiency could, in fact, become a reality.

"INVENTING" ENERGY EFFICIENCY

The price spikes of the 1973 OPEC embargo drew nationwide attention to energy end-use, but in rapidly-growing California, already sensitized to environmental issues such as smog and water shortages, the problem caused particular concern. I can't claim any great personal prescience: at the time of the crisis my data set on energy consumption consisted of exactly two points, both gleaned from my European colleagues. First, European cars got an average of 27 miles per gallon, compared to our average of 14 mpg. Furthermore, Western Europeans used on average half as much energy per capita as their American counterparts, but I knew that they weren't "freezing in the dark" (the typical phrase used at the time by anti-conservation naysayers). I had stumbled upon the idea that per-capita energy use could be reduced without deprivation.

My learning curve spiked in 1974 when I served as a co-leader of a month-long workshop on energy efficiency, convened by the American Physical Society (APS) at Princeton University. Our first realization, which soon became a slogan for the field, was 'what's cheap as dirt gets treated like dirt.' In the world's other advanced economies, a higher dependence on expensive imported fuels made energy costs a critical factor in long-range economic strategy (on tax policy, balance of trade, and national security). Consumer psychology was also affected by higher energy prices: whereas Americans made their purchasing decisions largely on *first cost* (sticker price), the Europeans and Japanese were more likely to incorporate *life-cycle cost* (sticker price plus future operating costs) into their decisions. The soaring price of energy had a silver lining as a teachable moment: people could now realize that adopting better efficiency practices would be equivalent to discovering huge domestic oil and gas fields which could be extracted at pennies per gallon of gasoline equivalent.

The APS summer study was organized as a mixture of briefings by practitioners from commercial sectors where energy consumption was a salient concern (construction, manufacturing, transportation, utilities, etc.), and analytic sessions led by physicists and chemists to discuss the state of research. Our overriding concern was to focus on efficiency improvements achievable with current technology, rather than theoretically elegant but impractical research. We published our findings and recommendations in *Efficient Use of Energy*, for many years the best-seller of the American Institute of Physics.[5]

The volume set the tone for much of the energy efficiency work to follow, with its mixture of pure and directed research, its incorporation of social and economic factors into the engineering analysis, and its emphasis on feasibility. We were also aware that we had to illustrate our findings with concrete examples that would convey the importance of efficiency to a non-expert public (and government). For example, one third of *Efficient Use of Energy* was devoted to discussion of recent advances in window technology, such as thin films of low-emissivity (low-E) semiconductor material; when applied to the inside surface of double-glazed windows, they doubled the thermal resistance.

Like much of the volume, this section was highly technical and inaccessible to the lay reader, and yet it contained highly practical implications that we wanted to convey to the public. It was written just as the last environmental objections to the Trans-Alaska Pipeline were overruled in favor of construction. The section's authors calculated that low-E windows, installed nationwide, would save the equivalent of half the oil produced in the Prudhoe Bay oilfields. In combination with other modest efficiency measures, these windows could have eliminated the need for the pipeline; it was this simple memorable fact, rather than the painstaking calculations, that became the public angle for the book.

STATE AND SCIENCE IN CALIFORNIA

Returning to California after the APS Efficiency Study, I took what was intended as a temporary leave from particle physics in order to teach, conduct research, and proselytize about energy efficiency. It seemed logical to focus on buildings and appliances rather than the transportation sector, since the latter was already under the oversight of the Department of Transportation, whereas work on the former was virtually *tabula rasa*. After a few years it was clear that my sabbatical from physics had turned into a permanent defection. Worse yet, I coaxed a number of other scientists away from traditional career paths in physics or chemistry, in favor of the risks of an upstart field. Colleagues including Sam Berman, Will Siri, Mark Levine, and Steve Selkowitz joined me in the process of redirecting our skills from basic research to the mixture of science, economics and policy that efficiency work entailed. My most promising physics graduate students, David Goldstein and Ashok Gadgil, also joined us.

I do not wish to suggest that California was the only locus of innovation in energy efficiency. Colleagues in other parts of the country made the same career shift and did important early work, including Marc Ross at the University of Michigan, and Rob Socolow at Princeton. The critical difference was that we were graced with optimal conditions for our ventures. Lawrence Berkeley National Laboratory (LBNL) had recently come under the fresh leadership of Andrew Sessler, who signaled the lab's intention to engage with society's most pressing problems by creating a new Energy and Environment Division as his first act as director in 1973. The division was a natural host for my Energy Efficient Buildings Program (later known as the Center for Building Science), and sheltered it from much of the instability and administrative strife faced by similar programs at other institutions. At the same time, the University of California at Berkeley launched a doctoral program in Energy and Resources under the visionary leadership of John Holdren. Because this unique program created a talent pool with the necessary interdisciplinary skill set in policy, economics, and science, we were able to take on more ambitious projects than other institutions.

Finally, and most importantly, our California community of efficiency scientists formed just as the state's first efficiency legislation came into effect. A proposal to establish state oversight of energy supply and demand had been languishing on Governor Reagan's desk since 1973, opposed by utility companies, appliance manufacturers and the building industry. However, in the atmosphere of crisis following the OPEC embargo, the governor was compelled to act, and the Warren-Alquist Act was signed into law in 1974. The Act established the California Energy Commission (CEC) with the authority to approve or deny site applications for new power plants, to write energy performance standards for new buildings, to fund research and development and to support investment in efficiency programs. Soon thereafter the commission's mandate was expanded to major appliances. The first generation of state appliance performance standards (Title 20) was published in 1976, followed in 1978 by a building standard (Title 24).[6]

The establishment of the CEC created a market for our research, which in turn made the commission effective. This fortunate convergence of policy requirements and scientific knowledge was a key factor behind California's leadership in energy efficiency. In the years before the commission's in-house research capability was developed, it relied upon local scientists for data, forecasts, testing protocols, and analytic tools. One example was the creation of a computer application to simulate the thermal performance of buildings. In early drafts of Title 24 (residential building standards), the commission proposed limiting window area to 15% of wall area, based on the (erroneous) belief that larger window areas would waste heat in winter or 'coolth' in summer. No allowance was made for the compass orientation of the windows; indeed I don't think the sun was even mentioned.

The staff had used a computer simulation that ran on a "fixed-thermostat" assumption, maintaining indoor temperature at 72° F (22° C) year round. Keeping to this exact mark required heating or cooling—or *both*—every day of the year! We saw the need for a simulation that allowed a "floating temperature" mode, permitting indoor temperature to rise slightly during the day, as solar heat entered and was stored in the building's mass, and then float down at night, as the house coasted on stored heat. Such a model could demonstrate that in many situations, expanded window area would actually lower energy demand, supporting the inclusion of passive solar methods in the state building code. Unfortunately, the existing public-domain programs were too awkward and bug-ridden to handle more complex and realistic thermal simulations. I immediately sat down with my colleague Ed Dean, a professor of architecture, to write a residential thermal simulator which we dubbed Two-Zone, because it distinguished between the north and south halves of the house. The CEC was soon convinced to drop the proposed limit on non-north-facing windows, and the concept of passive solar heating was included in Title 24, years before the term itself was in common use.[7]

Two-Zone became the progenitor of a generation of public-domain building performance simulators. When the federal Department of Energy (DOE) was formed in 1976, it funded further development of the software through a collaboration of the national labs at Berkeley, Argonne, and Los Alamos. Since that time, the program, known as DOE-2, has been an essential tool for evaluating energy use in complex systems. Although similar proprietary programs were also developed, the public availability of DOE-2 allowed extensive feedback, which fed the increasing sophistication of the model. While enabling tools such as DOE-2 do not in themselves save energy, without them it would not be possible to write appropriate state and federal buildings standards, or to establish high-profile certification programs such the Green Building Council's Leadership in Energy and Environmental Design (LEED).[8]

Improved HVAC (heating, ventilation and air-conditioning) performance in buildings has been one of the most profitable and uncontroversial ways for society to save energy and money.

Improved HVAC (heating, ventilation and air-conditioning) performance in buildings has been one of the most profitable and uncontroversial ways for society to save energy and money. It would be tedious to calculate exactly how much of these savings can be attributed to the DOE-2 program, since standards were implemented gradually across the states, and some technical improvements occurred independently of implementation. My own guesstimate is that annual U.S. savings in buildings energy use (compared to pre-standards performance) are roughly $10 billion per year, and that the modest allocation of public funds to support the creation of a viable public-domain modeling tool advanced the adoption of standards by one to three years.[9]

THE POLITICS OF DEMAND FORECASTING

Another early task of the California Energy Commission was to determine an appropriate balance between increasing generation capacity through granting permits for new plants, and extracting more "service" from the existing supply. Often as not, these decisions took place against a politically charged backdrop.

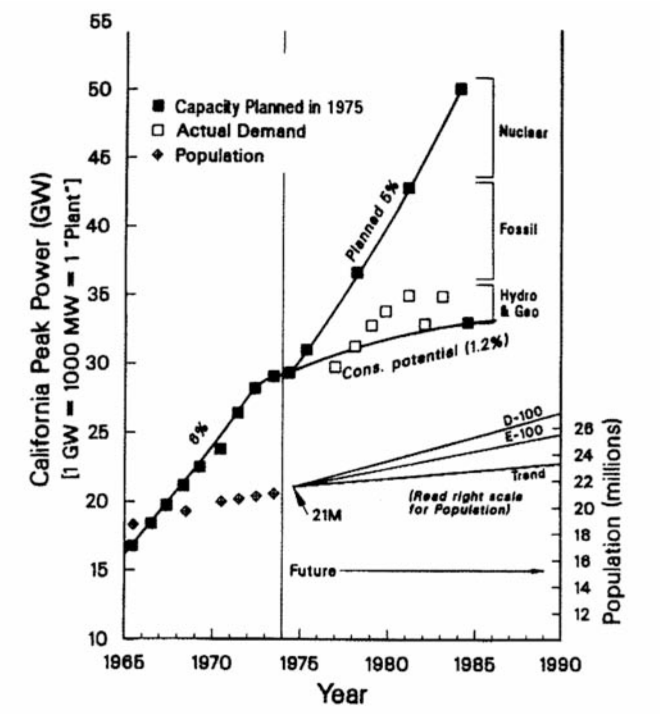

Figure 3. 1975 Projections of California Power Demand: Business as Usual vs. Goldstein & Rosenfeld Efficiency Scenario

Proposition 15, scheduled to go to California voters in March 1976, proposed to halt the construction of all nuclear power plants. My graduate student David Goldstein and I were determined to cut through the noise surrounding this hot-button issue with the first rigorous study of peak demand forecasts, shown in Figure 3.[10] We hoped that if the rising demand for electricity could be slowed through more efficient performance standards then the contentious issue of new power plants might be avoided.

The left side of Figure 3 shows the actual supply curve during the high-growth decade leading up to 1974, when peak production capacity reached about 30 gigawatts (GW). The right side of the figure compares two future (post-1974) scenarios. Under the "business as usual" (BAU) scenario assumed by the utilities, demand would continue to grow at 5% per annum, requiring the construction of an average of two large (1GW) power plants every year, mainly nuclear or fossil fueled. More than half of that new electricity (i.e. more than one plant per year) would be used to supply electricity to new construction. In the days before Title 24, two of the most egregious sources of waste were widespread electric resistance heating in residences, and 24/7 lighting in commercial buildings. When we calculated the potential savings from eliminating these practices, we came to the remarkable conclusion that the state's annual growth rate could drop to 1.2%. This scenario would eliminate the need not only for the contentious nuclear plants, but also for planned fossil fueled plants. When we demonstrated our findings at a State Assembly hearing in December 1975, the utility companies were so skeptical that Pacific Gas & Electric (PG&E) called Director Sessler to suggest that I be fired on the grounds that physicists were unqualified to forecast electricity demand.

Over the course of the later 1970s and early 1980s our vision was slowly vindicated and the hostility of PG&E was gradually replaced with a productive collaboration. After 1975 the actual growth of peak demand dropped to 2.2% per annum, much closer to our forecast than to that of the utilities. (For purposes of comparison, we later added this actual growth curve to the original version of Figure 3.) The fall from favor of nuclear power plants due to a combination of public opposition and unexpectedly high costs is well known, but in fact no application to build *any* kind of large power plant (nuclear, coal, or gas) was filed in California between l974 and 1998.[11] Demand continued to grow during that time, of course, but new supply came from small independent producers and co-generators, from renewables (hydroelectric, geothermal, and wind resources), and from sources outside the state. Improved efficiency was the largest single source of new electric services during that period.

After the deregulation of California's energy supply system in the late 1990s, and the ensuing electricity "crisis" of 2001, policies were put in place to encourage the procurement of a "reserve margin" large enough to guarantee reliability. In response to state incentives, investments in both power plants and efficiency accelerated. Fortunately the benefits of efficiency were not forgotten in the rush to increase capacity. In 2003, the CPUC and the CEC issued the first Energy Action Plan (EAP I)[12] to guide energy policy decisions. A major function of EAP I, and subsequent updates, has been to prescribe a "loading order" of energy supplies whenever increased demand needs to be satisfied. For immediate demand crises, demand response (e.g. shutting off unnecessary load) should take precedence over costly purchase of peaking generation from the market. For longer-term supply planning, investments in efficiency should "load" into the supply system before investments in generation; when new generation is necessary, renewable generation should load before fossil generation. From 2001 to 2009, over 15,000 MW of generation resources, including renewables, have been built in California, yet efficiency investments are increasing.[13]

INITIATING APPLIANCE STANDARDS IN CALIFORNIA

Whereas gaining acceptance for state oversight of building energy standards was relatively straightforward, creating a state appliance standard proved more controversial. Since manufacturers usually sold to the national market, federal responsibility looked more appropriate and effective to most people. In addition, the appliance industry was more concentrated and organized than the construction sector, and thus better able to mount opposition to changes. This did not deter David

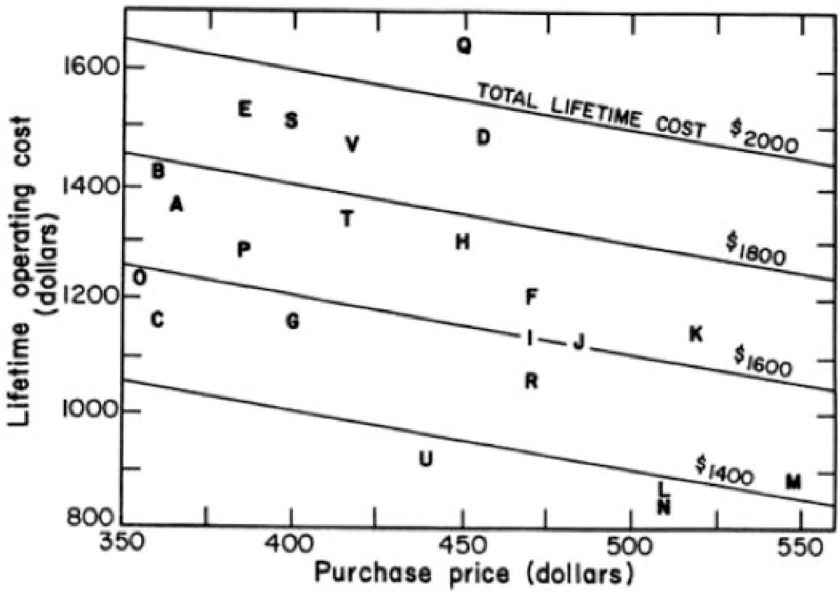

Figure 4. Supporting Appliance Standards: Lifecycle Operating Cost of 1975 Refrigerator Models

Goldstein and me from satisfying our curiosity about the correlation between refrigerator price and efficiency. Our interest in the refrigerator was motivated by its place as the most energy-thirsty appliance in the family home: in the 1970s it accounted for more than a quarter of the typical residential electricity bill. We tested 22 units from model year 1975, expecting to see some correlation between higher sticker price and higher performance, defined as the cooling service delivered per energy input. In other words, if we could establish a correlation between sticker price and efficiency, we could support informed consumer choices based on payback time (how long it takes to offset a high purchase price with lower energy bills) and life-cycle cost (purchase price plus lifetime operating costs).

Figure 4 displays the results of our refrigerator tests as a 'scatter chart,' the only feasible choice of format given that the data were truly scattered![14] Despite our efforts to control for every factor imaginable (volume, door configuration, options, etc) there was very poor correlation between purchase price and performance. Some of the lowest priced models (C, O) showed the same or even cheaper life-cycle costs than models costing $100 to $200 more (I, J, K). We quickly realized that if the less efficient half of the model group were deemed unfit for the market, the consumer would not perceive any change in the market range of prices or options, while being "forced" to save on average $350 over the 16-year service life of a refrigerator. Presumably as performance standards spurred further technical improvements, these savings would grow. The macroeconomic conclusion was even more exciting: since statewide energy use by refrigerators alone already accounted for about 5 GW, implementing even mild state standards could avoid

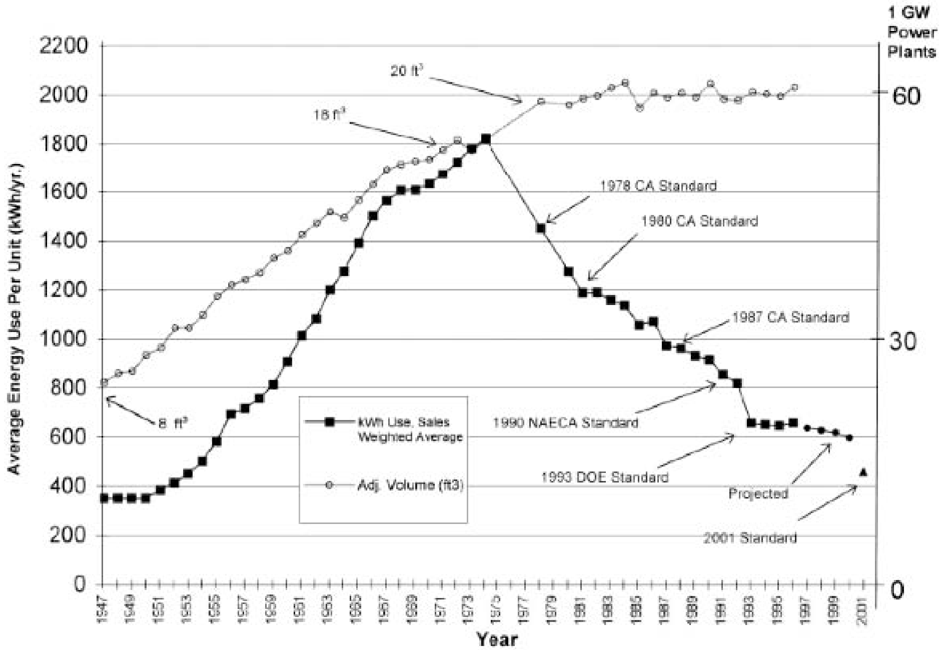

Figure 5. U.S. Refrigerators 1947-2001: Energy Use, Volume, Savings

the need to construct numerous power plants.

In 1976 California Governor Jerry Brown was looking for a way to avoid approving Sundesert, the only application still pending for a 1GW nuclear power plant. I took advantage of a chance meeting at the Berkeley Faculty Club to sketch out Figure 4 for him on a napkin. Thinking our findings too good to be true, the governor called Energy Commissioner Gene Varanini for corroboration. I believe his exact words were, "Is this guy Rosenfeld for real?" Commissioner Varanini vouched for us, Sundesert was cancelled, and California's Appliance Efficiency Regulations (Title 20) were implemented later that year.

REFRIGERATORS: AN EFFICIENCY SUCCESS STORY

The dramatic improvement in refrigerator energy efficiency over the last half-century is illustrated in Figure 5, which shows electricity use by new U.S. refrigerators for the model years 1947–2001.[15]

The heavy line with dark squares represents the annual kWh use of the sales-weighted average new refrigerator. Note that the energy consumption of new models has declined steeply in absolute terms, even though this line is not adjusted for increasing volume. In fact the volume of the average model grew from 8 cubic feet to 20 during this period, as shown by the line marked with open circles; if the consumption line were adjusted for volume, the efficiency gains would look even more impressive. The right-hand scale shows the number of large (1 GW) base-load

(5000 hours/year) power plants required to power 150 million average refrigerator-freezer units. The difference between the annual energy consumption of an average 1974 model (1800 kWh) and an average 2001 model (450 kWh) is 1350 kWH. The energy savings from this 1350 kWh/year difference, multiplied by 150 million units, is 200 TWh/year, equivalent to the output of 50 avoided 1 GW plants. The monetary savings of course depends on the price of electricity, which varies considerably. To give a rough sense of the magnitude of savings, at 8 cents/kWh, the avoided annual expense to consumers is $16 billion.

The other factor contributing to the sudden drop in refrigerator energy use in the mid-1970s was the advent of a new manufacturing technology, blown-in foam insulation. The coincidence of California's first performance standards with the market entry of better-performing models began a positive reinforcing cycle that continues to this day. Targeted, government-assisted R&D helps make possible the introduction of increasingly efficient new models, which themselves become the basis for tightening the efficiency standards, because they demonstrate that meeting a tighter standard is technologically feasible. When California standards were tightened in 1980 and 1987, followed by federal standards in 1990, 1993, and 2001, manufacturers were able and willing to meet the challenge, an example of government-industry partnership that has served society very well.

BRINGING THE UTILITY COMPANIES ON BOARD

Turning the utility companies from opponents of energy conservation into stakeholders was a key part of California's innovation in energy efficiency. As mentioned earlier, the encouraging results of initial efficiency policies gradually changed a contentious relationship into a collaborative one. High oil prices lasting through the late 1970s until 1985 helped PG&E and other companies perceive that their interests might lie in supporting affordable conservation rather than in pursuing expensive new energy supplies. However, telling utilities to promote efficiency was essentially asking them to sell less of their primary product, and thus to lose revenue, at least according to a traditional business model.

A new business model aligning market incentives with policy objectives was needed. The CEC, the CPUC, and the Natural Resources Defense Council created a new utility business model disconnecting profits from the amount of energy generated. A compensatory revenue stream from public good charges was awarded to companies that agreed to promote efficiency through consumer education programs or fluorescent light bulb subsidies. The technique of disconnecting utility company revenue from sales became known as "decoupling." Working out the details of decoupling was, and remains, a complex process, described more fully in the following article by Ralph Cavanagh, one of its chief architects.[16]

One serious obstacle to the innovation of decoupling was the inability to easily compare conventional energy supplies with the potential of conservation. The value of the utilities' efficiency programs could not be established without a stan-

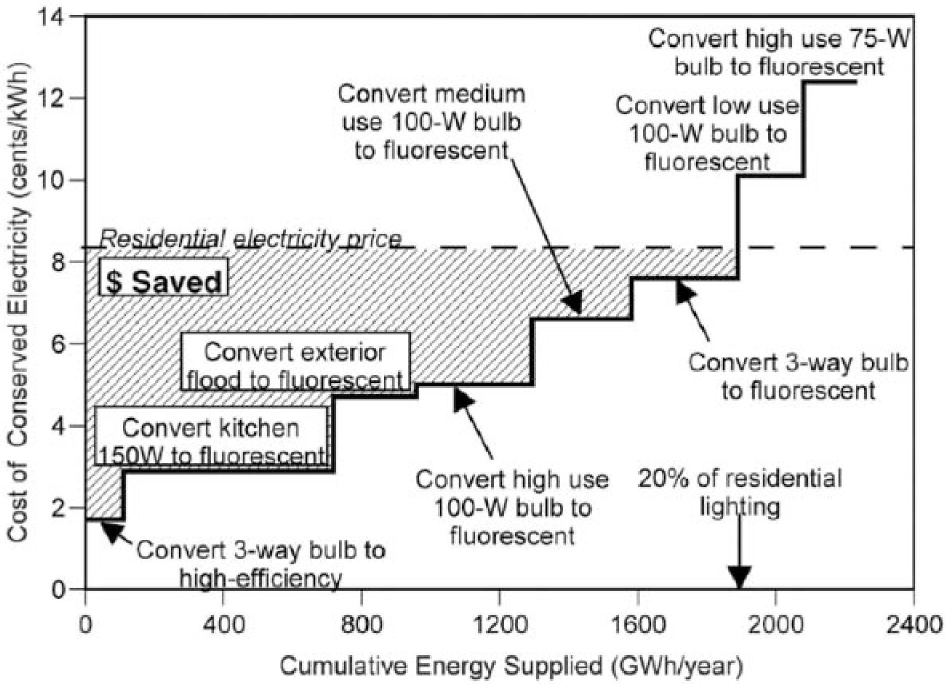

Figure 6. SupplyCurve of Conserved Residential Lighting

dardized way to set equivalencies in cost and scale. Conventional energy supplies tend to be large and concentrated, thus easy to measure, whereas conservation practices tend to be small and diffuse, thus difficult to measure in aggregate. Our task as scientists was to provide data to counter the skeptics who argued that the granular nature of efficiency—a lightbulb here, a new refrigerator there—could not possibly add up to a significant "supply." Alan Meier and Jan Wright of the Lawrence Berkeley National Labs (LBNL) unraveled this tangled methodological problem in the late 1970s by standardizing "bookkeeping" methods for avoided use, and creating a new investment metric, "the cost of conserved energy."[17] This allowed us to aggregate the energy and cost impacts of scattered conservation steps into a unified supply curve. The basic assumption when calculating the cost of conserved energy (CCE) is that any conservation measure begins with an initial investment, which then creates a stream of energy savings for the lifetime of the measure. Thus:

CCE = [annualized investment cost]/[annual energy savings]

The equitable yearly repayment to an investor (e.g. the utility) should be the annualized cost of energy conserved. In the case of avoided electricity use, the energy savings can be expressed in units of $/kWh, or in other cases in units for gas ($/MBtu), or wind, or geothermal. Since the CCE does not depend on a particular local price or type of displaced energy, the comparisons have the virtue of "portability" across and regional price variations and types of supply.

Figure 6, "Supply Curve of Conserved Residential Lighting,"[18] demonstrates the application of rigorous efficiency bookkeeping methods to one sector of energy end-use, residential lighting. The costs of eight different steps to improve lighting efficiency are plotted against the electricity that each measure would save (measured in gigawatt hours per year), and then compared to the actual retail price of electricity. Thus the savings derived from, say, Step 2 ("fluorescent kitchen lighting") are shown by the area between step 2 and the "price" line, that is, a savings of \$0.05/kWh X 600 GWh = \$30 million. The great virtue of this conceptually straightforward approach was that the cost effectiveness of various methods was clear at a glance. For example Steps 7 and 8 of Figure 6 are clearly not worthwhile. Furthermore, the supply curves of conserved energy provided a simple way to compare proposed new energy technologies with energy-saving actions.[19] The challenge of creating reliable supply curves is that deriving sound 'macro' estimates from the 'micro' contributions of individual changes rests on the painstaking collection of data on population, household size, and consumer purchasing practices, along with lightbulb cost, performance, and life span, and much more. Working out the proper energy accounting methods is the core of this work.

ELECTRONIC BALLASTS

The development of electronic ballasts for fluorescent lamps is the key technical innovation behind the recently burgeoning use of compact fluorescent lights (CFLs), which has resulted in tremendous energy savings. The story of electronic ballasts (also known as 'high-frequency' or 'solid state' ballasts) is a typical example of how innovations in engineering, policy, and commerce need to be aligned to achieve efficiency improvements. A ballast is a current-regulating device required to jump-start a fluorescent bulb with a surge of power, and then maintain a steady current for safe operation. Traditional ballasts were magnetic, constructed from passive components such as inductors, transformers, and capacitors.

At the APS Efficiency Summer Study in 1974, we considered the feasibility of creating an electronic ballast that would boost current to 1000 times that delivered by the power line. We knew that such a device would increase the efficiency of fluorescent lights by 10% to 15%, and also eliminate the annoying buzz that was a major obstacle to replacing quiet but wasteful incandescent bulbs in residential settings. Moreover, electronic ballasts would enable miniaturization, dimming, remote control, and other user friendly, energy-saving features not possible with magnetic ballasts.

Around that time, the major ballast manufacturing firms did in fact consider developing an electronic ballast, but rejected the idea due to the substantial capital investment required and the losses from early retirement of existing infrastructure. As is often the case in overly concentrated sectors—two large firms accounted for 90 percent of the ballast industry—the market provided more disincentives than incentives for innovation. It was clear to us that the impetus for R&D would

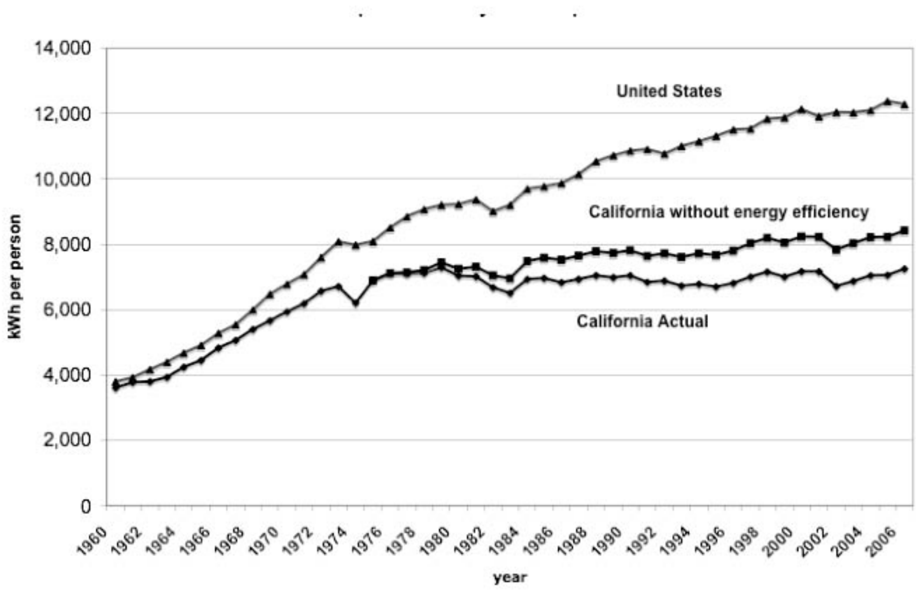

Figure 7. The California Effect? California vs. U.S. Per Capita Electricity Consumptsion 1960-2006

have to come from elsewhere. In the wake of the APS study, Sam Berman resigned a tenured post at Stanford University to lead LBNL's research on solid-state ballasts (as well as the low-E windows discussed earlier).

Fortunately the newly-formed DOE included a small Office of Conservation and Solar Energy, which was willing to fund both these projects. From 1977 to 1981, the DOE supported the development, evaluation, and introduction of electronic ballasts into the U.S. marketplace. Basic research took place at LBNL and two subcontracting laboratories. Three small, innovative firms new to the ballast field were awarded cost-sharing contracts to carry out development.[20] Berman shepherded the prototypes through UL certification, and persuaded PG&E to host a critical field test in its San Francisco skyscraper, which demonstrated electricity savings of greater than 30% over magnetic ballasts.

When the first electronic ballasts came to market in the late 1980s, they were so clearly superior that the major lighting manufacturers felt compelled to adopt and continue to develop the technology. Philips, in particular, reasoned that if large electronic ballasts were effective for traditional tubular fluorescent lamps, they could miniaturize ballasts to produce very efficient CFLs. The appearance of products such as Philips' 16-watt CFLs, radiating as much light as a 70-W incandescent light and lasting 10,000 hours instead of 750, was a turning point in the penetration of fluorescent lamps into the residential market.

The risk and expense of converting lighting plants to manufacture a new generation of ballasts was an important difference from the earlier case of improving refrigerators. Converting to blown-in foam insulation was comparatively simple,

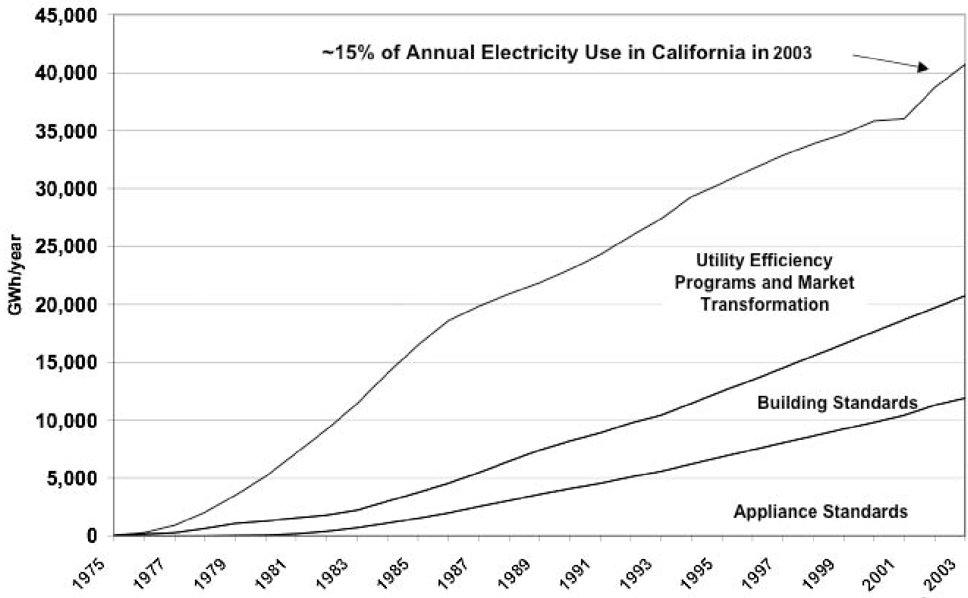

Figure 8. California's Annual Energy Savings Attributed to Efficiency Measures

and invisible to the end-user, so it required no consumer re-education. It is unlikely that the large manufacturers would have taken this step without the assurance of market success afforded by DOE-funded research. In the case of electronic ballasts, it was much harder to launch a positive reinforcing cycle of tightening standards and making technological improvements. States did promulgate efficiency standards for fluorescent ballasts (California in 1983, New York in 1986, Massachusetts and Connecticut in 1988, and Florida in 1989). By themselves, however, state standards could not drive market transformation, since they could be satisfied by conventional magnetic ballasts (which, not coincidentally, improved once the electronic ballasts were developed). The experience suggests that in some cases the seeding effect of publicly funded research is essential for market transformation.

IS THERE A "CALIFORNIA EFFECT"?

There is little doubt that California's energy efficiency policies have been successful. How successful, exactly, remains an open question. There is an ongoing debate about how much of California's lower per capita electricity consumption is due to policy differences, and how much to climate or the comparatively low level of heavy industry. As the need to reduce energy consumption and CO_2 emissions becomes more urgent, the so-called "California Effect" is coming under increasing scrutiny. Whether or not to emulate California's efforts hangs on the question of their efficacy. Figure 7 shows the difference in per capita electricity consumption between California and the U.S. for the period 1960 to 2006. In 1960, California's

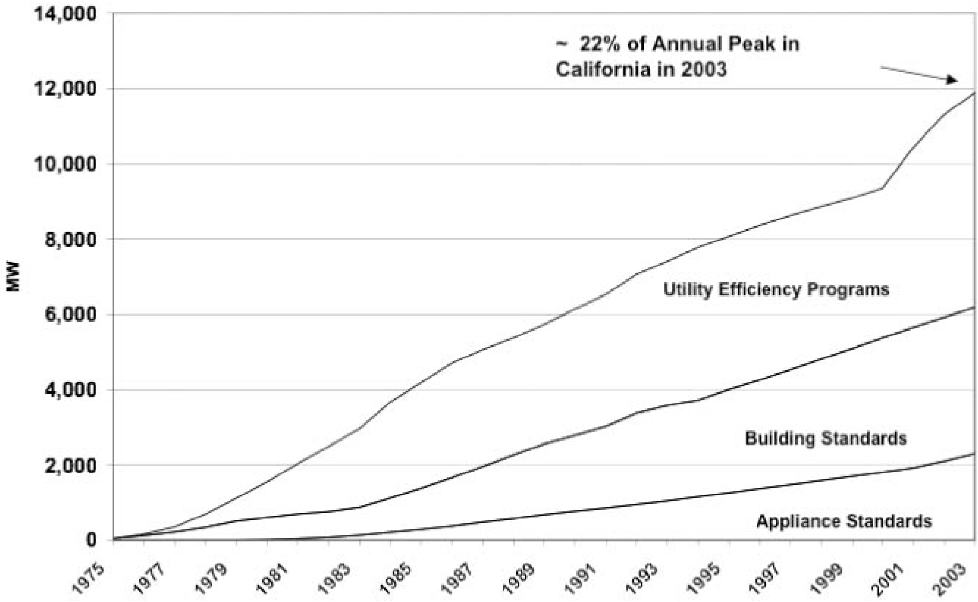

Figure 9. California's *Peak* Annual Energy Savings Attributed to Efficiency Measures

per capita consumption was within 5% of the national average. The curves gradually diverged between 1960 and the mid 1970s, but the difference was still only about 15% at the time of the OPEC embargo. By 2006, however, Californians were using over 40% less electricity per capita than the national average—and only about 10% more than they had in 1975.

Calculating the proportion of electricity savings directly traceable to our efficiency efforts is a complicated task. Our best conservative estimate, shown by the middle line in Figure 7, is that at least 25% of the observed difference can be directly attributed to policy—an estimate that does not include any secondary effects due to changes in building practice and appliance markets. Differences in climate and industrial mix, electricity price, demographic trends and other factors help explain some of the difference,[21] but other trends have been at work as well. In California, for example, building standards and electricity prices have discouraged the use of electric water heating in favor of natural gas, which reduces electricity consumption compared to the national average.

At the same time, most new housing has been built in the hotter inland valley and desert areas, dramatically increasing energy consumption for air conditioning. Also, most appliance standards initiated in California were eventually adopted nationally, so the policy impacts of appliance standards also affect the national per capita consumption average, an effect that is not captured by the difference in per capita consumption. Thus, for a variety of reasons, electricity use in California has been essentially flat and should either continue or even decrease as California extends standards to new devices, accelerates building performance requirements, and expands programs aimed at improving efficiency.

Figures 8 and 9 show California's savings in greater detail, breaking down the part of the consumption gap that can be attributed to efficiency efforts.[22] Performance standards for buildings and appliances, which as noted have been progressively strengthened every few years, account for roughly half the savings. The other half has resulted from utility company programs that promote adoption of energy efficient technologies, such as commercial lighting retrofit incentives and residential appliance rebates. Through 2003, these measures have resulted in about 40,000 GWh of annual energy savings and have avoided 12,000 megawatts (MW) of demand—the same as twenty-four 500-MW power plants (the MW data is not shown in the graph).[23] These savings have reduced CO_2 emissions from the electricity generation sector by nearly 20 percent compared to what otherwise might have happened without these programs and standards.[24] This equates to an avoidance of CO_2 emissions in the state as a whole of about four percent due to historical energy efficiency programs and standards.[25] These savings will only continue to grow.

The effect of efficiency policies is even more pronounced at peak load. Peak loads are a serious concern in California, as in other Sunbelt states and many fast-growing economies around the world. Air conditioning loads on hot afternoons can greatly increase system demand—as much 30% in California. Reducing the magnitude of these warm-season spikes is one of the most pressing items on the efficiency agenda. Building standards that focus on minimizing heat gain and thermal transfer and appliance standards that set minimum efficiency levels for air conditioning equipment can reduce peak demand. This in turn lowers the customer's immediate cooling costs as well as the system-wide costs of maintaining underutilized peaking capacity year-round; both measures contribute to lower bills.[26] Figure 9 repeats Figure 8's breakdown of savings derived from standards and utility programs, but for peak demand. The 12,000 MWs of capacity provided by efficiency measures have effectively avoided the need to build additional power plants to meet that demand.

FROM "INNOVATION" TO "BUSINESS AS USUAL": THE LONG-TERM ENERGY EFFICIENCY STRATEGIC PLAN

When the campaign for energy efficiency in California began four decades ago, the goal was simply to reduce the expense, pollution and political turmoil resulting from over-dependence on generating energy from fossil fuels. However, as awareness of the climate-changing effects of GHGs grew, so too did recognition of efficiency as a low-cost, low-impact, reliable source of energy. Now that our environmental concerns must share the stage with the current economic crisis, efficiency has suddenly become something of a mantra. Since efficiency investments have some of the fastest payback times in the "green economy," and since efficiency improvements are based on currently available technology, implementation offers a uniquely practical opportunity to stimulate economic growth and reduce GHG emissions at the same time.

A year ago, the California Public Utilities Commission (CPUC) issued California's Long-Term Energy Efficiency Strategic Plan, mapping out the steps toward meeting the state's GHG reduction goals by 2020.[27] The commission estimates that the Strategic Plan will create energy savings of close to 7,000 gigawatt hours, 1,500 megawatts and 150 million metric therms of natural gas. This is roughly equal to the avoided construction of three 500-megawatt power plants. Avoided emission of GHGs is expected to reach 3 million tons per year by 2012, equivalent to the emissions of nearly 600,000 cars. It is hoped that new efficiency programs will create between 15,000 and 18,000 jobs, in areas ranging from construction to education. The Plan has four "Big and Bold" goals:

- All new residential construction in California will be zero net energy by 2020.
- All new commercial construction in California will be zero net energy by 2030.
- The Heating, Ventilation, and Air Conditioning (HVAC) industry will be reshaped to ensure optimal equipment performance.
- All eligible low-income homes will be energy efficient by 2020.

The budget for just the first three years of the Strategic Plan was recently set at $3.1 billion, making it the largest-ever state commitment to efficiency. Funding will support a wide variety of programs in pursuit of the overarching goals, including the four examples below:

- CalSPREE, the largest residential retrofit effort in the United States, will cut energy use by 20 percent for up to 130,000 existing homes by 2012.
- $175 million will go to programs to deliver "zero net energy" homes and commercial buildings.
- $260 million will go to 64 local agencies (city, county, and regional) that would otherwise lack the expertise to create more energy-efficient public buildings.
- More than $100 million will go to for education and training programs at all levels of the education system.

From my perspective as a veteran of the efficiency campaign, the Strategic Plan presents a fascinating combination of old lessons and new ambitions. Although the overall scope of the plan is far more comprehensive and coordinated than anything yet seen, clearly the content of the programs is based on many years of experience in buildings and appliance standards. Furthermore, the plan was developed in collaboration with more than 500 stakeholder groups, including the state's major investor-owned utilities (IOUs): Pacific Gas and Electric Co., San Diego Gas and Electric Co., Southern California Edison, and Southern California Gas Co. The IOUs will be responsible for actually implementing the programs in their respective regions. The budget for the programs comes from the increased public goods charges authorized by the CPUC, on the condition that the funds be invested in efficiency. The slightly increased costs to ratepayers will be quickly offset by their reduced consumption. Of course, this process of coordinating best engineering practices with policy goals and utility market mechanisms has its origins in our forays into collaboration in the early 1980s.

The most ambitious and innovative aspect of the Long-Term Energy Efficiency Strategic Plan is its insistence on re-branding the practice of energy efficiency as normative behavior rather than crisis response. Commissioners Michael Peevey and Dian Grueneich have frequently spoken of "making efficiency a way of life." If successful, this would mean a reversal of the prevailing mindset. For many years, my graphs of energy supply/demand forecasts displayed competing scenarios labeled respectively "with efficiency measures" and "business as usual." Business as usual was understood to mean "without efficiency measures." If California's Strategic Plan succeeds, the comprehensive approach to energy efficiency that we have been pursuing for over 30 years will have finally become "business as usual."

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20. Energy Research at DOE: Was It Worth It? Appendix E, pp. 104-107. DOE's call for bids in 1977 received no responses from the major ballast manufacturers. Of the small firms that did receive a contract, one eventually developed into a significant, independent ballast manufacturer. At first, one of the large manufacturers of traditional ballasts actively sought to prevent the introduction of the electronic ballast by acquiring the technology from this firm and then preventing its dissemination. In 1990, after 6 years of litigation and a $26 million damage award, control over the technology was partially reacquired by the originating small business.
21. For a discussion of some of these factors, see Anant Sudarshan and James Sweeney, Deconstructing the 'Rosenfeld Curve.' Working paper, Stanford University, June 1, 2008.
22. Because California's population has been growing, the 25% of per capita effect in Figure 7 corresponds to the 15% effect on total consumption per year in Figure 8.
23. California Energy Commission, Implementing California's Loading Order for Electricity Resources, Staff Report, CEC-400-2005-043, July 2005, p. E-4.
24. This calculation is based on a marginal CO_2 emissions rate of nearly 0.5 tons per MWh for a natural gas fired power plant with a marginal heat rate of just over 9,000 btu/kWh.
25. Calculated from the product of 22% of the state's CO_2 emissions from electricity consumption and the reduction of 20% in electricity use due to standards and programs.
26. California Energy Commission, Implementing California's Loading Order, p. E-4.
27. CPUC and CEC, California Long-Term Energy Efficiency Strategic Plan, September 2008; www.cpuc.ca.gov/PUC/energy/electric/Energy+Efficiency.
    http://docs.cpuc.ca.gov/published/News_release/91027.htm
    www.californiaenergyefficiency.com/index.shtml
    www.reuters.com/article/topNews/idUSTRE58N70520090924

Ralph Cavanagh

Graphs, Words and Deeds

Reflections on Commissioner Rosenfeld and California's Energy Efficiency Leadership

Innovations Case Discussion:
California's Energy Policy

Late in 2006, soon after Governor Arnold Schwarzenegger signed into law California's path-breaking curbs on greenhouse gas emissions, a reporter asked California Energy Commissioner Arthur Rosenfeld when statewide reductions would start showing up. "Around 1975," he replied.

Showing how right he was would require an entire treatise, and happily a most compelling edition is already available to the public at no charge. In addition to the energy-efficiency achievements recounted in Commissioner Rosenfeld's article, a recently compiled *Green Innovation Index* adds five more California distinctions:

- Greenhouse gas emissions per capita, and greenhouse gas emissions per dollar of economic output, are less than half the average for the rest of the nation.
- California increased its renewable electricity production by 24% from 2003 to 2007.
- The state is home to 60% of US venture capital investment in "clean technology" companies. (Californians also captured almost 40% of all US solar energy patents from 2002 to 2007).
- It has the fifth lowest electricity cost, measured as a fraction of the state's economy, in the United States.
- Its residential gas and electric bills are well below the national average.[1]

A study at the University of California Berkeley, supplementing the index, also concluded that California's comparative advantage in energy efficiency had generated some $56 billion in net economic benefits since 1972, yielding an employment dividend of 1.5 million jobs.[2] And MIT's Energy Innovation initiative independently ranked California first among the states in sustained progress since 1980 in reducing residential sector energy use.[3]

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Some maintain that California has championed efficiency at the expense of its economy, and that its low energy consumption is primarily a function of high electricity rates.[4] However, as a fraction of its economy, California's electricity bill is a third lower than the national average and just over half that of Texas and Florida (the disparity between California's and Texas's electric bill, in relative terms, represents a $25 billion/year comparative advantage for California).[5]

Can this be explained by state-specific economic or geophysical anomalies? While California indeed looks different from the rest of the country in some important respects, these contrasts generally are not new and do not explain significant sustained divergences in consumption trends between California and most other states over the decades encompassed by what some have termed "the Rosenfeld Effect."

A study at the University of California Berkeley, supplementing the index, also concluded that California's comparative advantage in energy efficiency had generated some $56 billion in net economic benefits since 1972, yielding an employment dividend of 1.5 million jobs.

Over more than three decades, compared with averages for the rest of the nation, significant differences have emerged in how Californians manage their energy use. Although contributors include factors independent of energy policy, such as average household size,[6] few would dispute the enduring importance of integrating a three-part efficiency policy that involves utility incentives, government standards, and technology innovation. The results can be seen today in both the efficiency with which energy services are delivered and the behavior of those who use the services. For example, Californians are much more likely than their counterparts in other states to own and use programmable thermostats, or to shut off systems altogether when away from home.[7] California's efficiency regulators have been steadily tightening minimum standards for buildings and equipment, following a thirty-year pattern that is illustrated clearly in Commissioner Rosenfeld's graph of trends in refrigerator efficiency. In their first quarter century, California's building and equipment standards saved the equivalent of a dozen 500-megawatt power plants.[8]

An important part of the Rosenfeld Effect also involves the regulation and role of utilities. As of 2009, some states were still debating whether and on what terms to encourage utilities to invest in energy-efficiency improvements. Aggregate utility-initiated electricity savings nationwide totaled only about .3% of retail sales in 2008.[9] California's three major utilities achieved eight times this level of savings during that same year, reflecting a 150% increase in annual investments over four years (from $370 million in 2004 to $935 million in 2008). Over that same period, annual energy savings grew even faster (from 1,900 GWh in 2004 to 4,900 GWh in 2008). These programs continue to provide the cheapest resource available to meet California's energy needs, averaging 2-3 cents per kWh in 2008.[10] And in that year, California utilities accounted for about one-third of the entire US industry's efficiency investments.[11] The net benefits provided annually to customers by the California energy efficiency programs increased 160% from 2004 to 2008, and the cumulative net benefits over that five-year period were about $5.6 billion.[12]

These achievements have venerable antecedents. More than thirty years ago, California's utility regulators understood that traditional utility regulation had to change in order to put energy efficiency opportunities on an equal footing with generation alternatives. Writing for the majority in a 1975 case addressing the revenue needs of the Pacific Gas and Electric Company, PUC Commissioner Leonard Ross anticipated issues with which many states still wrestle today:

> We regard conservation as the most important task facing utilities today. Continued growth of energy consumption at the rates we have known in the past would mean even higher rates for customers, multibillion dollar capital requirements for utilities, and unchecked proliferation of power plants . . . Reducing energy growth in an orderly, intelligent manner is the only long-term solution to the energy crisis.
>
> At present, the financial incentives for utilities are for increased sales, not for conservation. Whatever conservation efforts utilities undertake are the result of good citizenship, rather than profit motivation. We applaud these efforts, but we think the task will be better accomplished if financial and civic motivations were not at cross purposes.
>
> The effort we expect is not limited to exhortation, advertising and traditional means of promoting conservation. We expect utilities to explore all possible cost-effective means of conservation, including intensive advisory programs directed at large customers, conservation-oriented research and development, [and] subsidy programs for capital-intensive conservation measures.[13]

Although few if any state utility regulators contest the objective of substituting less costly energy-efficiency savings for more costly alternative energy supplies, most utilities still automatically incur financial harm when electricity and natural gas use decline, and most utilities still are denied any earnings opportunities if they make cost-effective efficiency investments. The result is a broken business model: utilities typically suffer immediate losses with no prospect of gain if they try to help their customers achieve cost-effective energy savings, through either targeted incentives or improved government efficiency standards.

Commissioner Ross and his successors long ago grasped the need to prevent changes in customers' energy use from affecting utilities' financial health. Much of

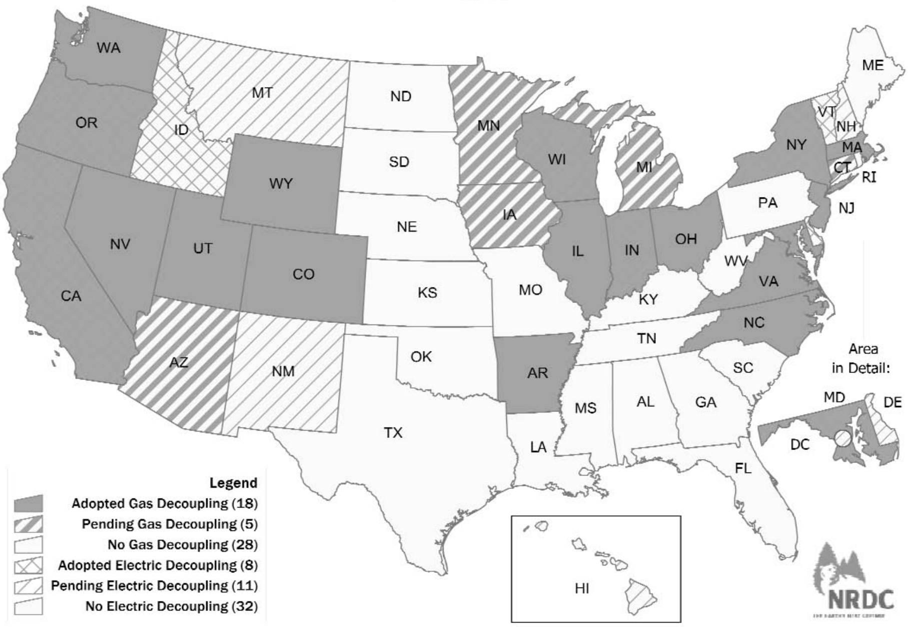

Figure 1. Gas and Electric Decoupling in the US (August 2009)
Source: Natural Resources Defense Council

a typical utility's cost of serving customers is independent of energy use (e.g., paying for generation, transmission and distribution equipment already installed). Since utilities recover most of their fixed costs of service through charges on electricity and natural gas use, increases or reductions in consumption will affect fixed cost *recovery* even though the costs themselves don't change. Fixing this problem includes making sure that fluctuations in sales (either up or down) do not result in over- or under-recovery of utilities' previously approved fixed costs; otherwise utilities and their customers have automatically conflicting interests on even the most cost-effective energy efficiency.

The immediate temptation is to respond by converting fixed costs into fixed charges; this would make the recovery of fixed costs independent of energy sales, but it also would significantly reduce customers' rewards for reducing energy use. That is a step in the direction of what might be termed "all you can eat" rates, which reduce or eliminate customers' rewards for saving energy by making the bill largely independent of total energy consumption.

Some contend that recovering utilities' fixed costs as part of volumetric charges for electricity is inefficient, because it makes additional consumption look more costly than it should. That amounts to contending that most utilities today are suppressing beneficial increases in electricity and natural gas use through their rate designs. Yet the rationale for energy efficiency programs and standards rests in part on the conclusion that extensive market failures continue to block energy savings that are much cheaper than additional energy production at *today's* electricity prices. What we need now is not rate designs that encourage electricity waste, but a strong move toward inverted rates, where the rule is "the more you use, the more you pay."

Of course, that means that utilities will go on relying on variable charges to recover all or most authorized fixed costs of service, which on the face of it creates a disincentive for utilities to promote energy efficiency. A straightforward solution, sometimes called "decoupling," is to use small, regular rate adjustments to prevent over- or under-recovery of authorized costs; the Appendix provides a detailed illustration. California had such mechanisms in place for both electric and natural gas utilities by 1982;[14] a nationwide debate is now underway over whether they should become the industry norm. As of September 2009, eighteen states had adopted decoupling mechanisms for one or more of their natural gas utilities; the comparable figure for electric utilities was eight states. (See figure 1.)

Although some have worried about the impact of decoupling on electricity and natural gas rates, industry experience shows minimal effects on short-term rates, and adjustments go in both directions. A comprehensive industry-wide assessment found that, of 88 gas and electric rate adjustments since 2000 under decoupling mechanisms, only one-fifth involved increases exceeding 2 percent. Typical adjustments in utility bills "amount[ed] to less than $1.50 per month in higher or lower charges for residential gas customers and less than $2.00 per month . . . for residential electric customers."[15] That represents about a dime a day for the average household, which hardly seems like dangerous rate volatility, particularly since it sometimes comes in the form of a rebate—and serves only to ensure that the utility recovers no more and no less than the fixed costs of service that regulators have reviewed and approved.

These simple automatic adjustments eliminate a huge financial disincentive, but they do not by themselves give utilities an opportunity to share in the net benefits of cost-effective energy efficiency investments. It's good not to lose money automatically when you help your customers save energy, but it's even better from the perspectives of both shareholder and society if management has a financial incentive to succeed. To sustain their excellence in efficiency, investor-owned utilities, which deliver three quarters of the nation's electricity and almost all of its natural gas, need more than just a guarantee against instant pain. California is one of about a dozen states that have responded with assurances that independently verified net energy efficiency savings to customers will also yield a reward for shareholders (see Appendix for illustrative operational details).[16]

The huge federal "stimulus bill" enacted in February 2009 includes an effort to encourage accelerated progress in utility regulatory reform. In section 410 of the American Recovery and Reinvestment Act (ARRA), Congress appropriated $3.1 billion for state energy grants, to be released "only if the governor of the recipient state notifies the Secretary of Energy in writing that the governor has obtained necessary assurances" from that state's utility regulators that they will "seek to implement" two conditions for gas and electric utilities over which they have regulatory authority:

- "A general policy that ensures that utility financial incentives are aligned with helping their customers use energy more efficiently;"
- "[T]imely cost recovery and a timely earnings opportunity for utilities associated with cost-effective measurable and verifiable savings."

In addition, these objectives are to be achieved "in a way that sustains or enhances utility customers' incentives to use energy more efficiently." And "to the extent practicable" utilities and their regulators are to be leaders in the ARRA implementation process. These provisions received broad support from environmental and business interests. Congress did not try to dictate ratemaking methodologies, beyond specifying that customers' incentives to save energy must not be impaired (ruling out the option of shifting fixed costs into fixed charges). And Congress did not try to impose final results on independent state regulatory commissions. Regulators in complying states certify only that they will "seek to implement" the conditions.[17] The ARRA conditions supply a strong nudge, not a straight-jacket. But states that want the benefits of accelerated energy efficiency progress now have added incentive to act swiftly.

For those who seek to suspend a dangerous global climate experiment while expanding global access to electricity services, California's precedents are of obvious and immediate interest. Many of America's leading physicists, business consultants and environmental visionaries have recently reaffirmed a common theme: energy efficiency is the fastest, cheapest and cleanest solution available for both overstressed power grids and an overtaxed atmosphere. Inexpensive ways to get more work out of less electricity are now understood worldwide as invaluable utility system resources, just like new power plants or enhanced distribution systems. Recent studies offer three particularly arresting conclusions:

- Energy efficiency measures in buildings and appliances could cut US global warming pollution by almost a billion tons a year by 2030 (CO_2 equivalent, or more than one-eighth of total current US greenhouse-gas emissions) at *negative cost* (McKinsey & Co.).[18]
- Energy demand from the entire US buildings sector (everything from houses to light bulbs to office towers to retail stores) would not grow *at all* from 2008 to 2030 if we deployed energy efficiency measures costing less than the energy they displaced (American Physical Society).[19]
- Closing the electricity efficiency gap between the 10 top-performing states and the other 40 would achieve electricity savings equivalent to more than 60 percent of US coal-fired generation (Rocky Mountain Institute).[20]

California's achievements make these projections more than hypothetical. Certainly the state has a gratifying number of fierce competitors, and its mission is hardly complete. Yet it remains the most fully realized effort to decarbonize an advanced economy in economically compelling ways. Precisely because its image is the antithesis of self-denial, California remains the most powerful rebuttal to claims that greenhouse-gas reductions cannot be achieved without personal privation and economic decline. Long live the Rosenfeld Effect, and its indomitable progenitor.

Acknowledgements

I gratefully acknowledge helpful comments from my colleagues James Chou and Lara Ettenson, and an excellent final edit by Helen Snively.

APPENDIX. HOW TO FIX THE UTILITY BUSINESS MODEL

I. Aligning Customer and Utility Incentives in Energy Efficiency

This illustration draws on the experience of the Idaho Power Company, Idaho's principal investor-owned electric utility.

- State utility regulators authorize recovery of $300 million in fixed costs for an electric utility over the next year and set its rates based on assumed electricity use for that period; those fixed costs represent half of the $600 million cost of providing service at that level of consumption, with the rest representing fuel and other variable costs.
- Despite energy efficiency efforts by the utility and its customers, retail electricity sales over the next year are one percent higher than regulators had anticipated, as a result of stronger than expected economic growth. Regulators respond by adjusting electric rates downward by just under half of one percent to return $3 million in excess cost recovery to the utility's customers ($3 million/$606 million).
- Or, alternativelyafter one year, strong energy efficiency efforts by the utility and its customers and other factors push retail electricity use one percent below the level that regulators anticipated when rates were set. Regulators then adjust electric rates upward by just over one half of one percent to make the utility whole for $3 million in under-recovery of authorized fixed costs ($3 million/$594 million).
- An index (tied to inflation or customer growth or some combination) is used every year to adjust authorized fixed costs up or down, until the regulators have an opportunity in the utility's next adjudicated "rate case" to reassess the utility's revenue requirements for fixed-cost recovery and other purposes, with opportunities for all interested parties to participate. The regulators then approve a new authorized fixed-cost target, and the process begins again.

II. Providing a Performance-Based Earnings Opportunity

That same electric utility demonstrates through independent measurement and verification that its annual expenditure of $20 million to secure cost-effective energy efficiency savings by customers avoided an annual expenditure of $40 million on alternative energy supply resources.

- Regulators authorize recovery of the $20 million in energy efficiency costs and allow the utility to retain 10 percent of the $20 million in net savings to customers.

- Customers' annual utility bill drops by $18 million as a result of the utility's energy efficiency expenditures, notwithstanding the utility's timely cost recovery and its earnings opportunity.

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1 See Next 10, California Green Technology Index (2009), pp. 4 (emissions per person), 17 (emissions per dollar of economic output); 33 (patents); 64 (electricity costs). The Index is available in full at www.nextten.org/next10/publications/greenInnovation09.html. See also US Energy Information Administration, Average Monthly Bill for Residential Electric Utility Customers (2008: www.eia.doe.gov/cneaf/electricity/esr/table5.xls), which pegs California's average residential electricity bill at $84.56, more than ten percent below the national average of $95.66. It also reports that the states with the nation's highest average residential electricity bills are Hawaii, Texas and Florida; each exceeds the national average by more than 30%.

2. D. Roland-Holst, Energy Efficiency, Innovation and Job Creation in California (Next 10, October 2008), p. 3: "Energy efficiency measures have enabled California households to redirect their expenditure toward other goods and services, creating about 1.5 million FTE jobs with a total payroll of over $45 billion, driven by well-documented household energy savings of $56 billion from 1972-2006." http://are.berkeley.edu/~dwrh/CERES_Web/Docs/UCB%20Energy%20Innovation%20and%20Job%20Creation%2010-20-08.pdf

3. R. Lester, A. Finan & R. Sakhuja, The Role of Energy Efficiency in Reducing Climate Change Risks (MIT Industrial Performance Center, March 2009), p. 11, compare states based on "annual change in residential delivered energy per capita, 1980-2006."

4. For example, K. Galbraith, in Deciphering California's Efficiency Successes (New York Times, April 14, 2009, Green Inc., http://greeninc.blogs.nytimes.com/2009/04/14/deciphering-californias-efficiency-successes) cites contentions that "California's electricity prices have risen far faster than those elsewhere."

5. See Next Ten, note 1 above, at p. 64.

6. "Larger households are able to attain economies of scale" in energy use "and California households on average now have about ten percent more occupants than the national average." A. Sudarshan & J. Sweeney, Deconstructing the "Rosenfeld Curve" (Precourt Institute for Energy Efficiency, Stanford University, June 2008), p. 7.

7. Sudarshan & Sweeney, p. 12.

8. California Energy Commission, 2005 Integrated Energy Policy Report (CEC-100-2005-007), p. 70.

9. G. Barbose, C. Goldman & J. Schlegel, The Shifting Landscape of Ratepayer-Funded Energy Efficiency in the U.S. ([needs publishing info] July 2009), p. 1. The near-term trend is encouraging, however; combined utility investments in electricity and natural gas efficiency improvements increased by 20 percent in 2008. Ibid., p. 3.

10. I am indebted to my NRDC colleague James Chou for the data summarized in this paragraph, which he assembled in August 2009 from reports and data submissions by California's three major utilities. The 2 cents/kWh is calculated from utilities' total investments and total lifecycle savings. Utility-reported levelized cost is 3 cents/kWh. The difference is that the utility estimate discounts the costs and savings. The 2006-2008 figures are from utility annual reports posted on the PUC website (http://eega2006.cpuc.ca.gov/) and individual data requests from the utilities. Data from 2004 and 2005 were compiled by NRDC from PG&E, SCE and Sempra Utilities' Annual Earnings Assessment Proceedings (AEAP) at the California PUC.

11. Barbose, Goldman & Schlegel, in The Shifting Landscape, p. 3, credit California with $831 million of $2.6 billion in electric efficiency investment in 2008, and $183 million of $529 million in

natural-gas efficiency investment.

12. Compiled by NRDC's James Chou from sources cited in note 11 above.
13. D. 84902 (September 16, 1975), quoted in B. Barkovitch, Changing Strategies in Utility Regulation: The Case of Energy Conservation in California (doctoral dissertation, University of California, 1987), pp. 134-35.
14. J. Eto, S. Stoft and T. Belden, The Theory and Practice of Decoupling (Lawrence Berkeley Laboratory, LBL-34555, January 1994), p. 21. The first formal decoupling proposal of which I am aware appears in testimony filed with the California Public Utilities Commission by William B. Marcus and Dian Grueneich (now a commissioner) in April 1981, as follows: "Total base revenues for forecast sales and base revenues resulting from actual sales would be compared on a quarterly basis.... The resulting undercollection or overcollection would be placed in a balancing account, rates would be adjusted to amortize the balancing account, and the balancing account would accrue interest at the prime rate." W. Marcus, California Energy Commission Staff Report on PG&E's Financial Needs, Application No. 60153 (April 21, 1981, Revised July 1981), p. 55.
15. P. Lesh, Rate Impacts and Key Design Elements of Gas and Electric Utility Decoupling: A Comprehensive Review (June 2009), p. 3. The report is posted on the website of the Regulatory Assistance Project, at http://www.raponline.org/showpdf.asp?PDF_URL=%22Pubs/Lesh-CompReviewDecouplingInfoElecandGas-30June09.pdf%22
16. See The Edison Foundation, Institute for Electric Efficiency, Performance Incentives for Energy Efficiency by State (May 2009), at www.edisonfoundation.net/iee/issueBriefs/IncentiveMechanisms_0509.pdf. For an admirably concise and compelling treatment of these issues for a mass audience, see T. Friedman, Hot, Flat and Crowded (2008), pp. 285-90.
17. Expressions of regulators' intent routinely launch a broad variety of utility proceedings; regulators' final decisions depend on weighing the views of all participating parties, applicable law and other factors.
18. McKinsey & Co., Reducing US Greenhouse Gas Emissions: How Much At What Cost? www.mckinsey.com/clientservice/ccsi/greenhousegas.asp, pp. x-xiv. Assessment includes "lighting retrofits, improved heating, ventilation, air conditioning systems, building envelopes, and building control systems; [and] higher performance for consumer and office electronics and appliances."
19. American Physical Society, Energy Future: Think Efficiency (September 2008). www.aps.org/energyefficiencyreport/
20. Natalie Mims, Mathias Bell, & Stephen Doig, Assessing the Electric Productivity Gap and the US Efficiency Opportunity (Rocky Mountain Institute, February 2009). http://ert.rmi.org/files/documents/CGU.RMI.pdf

José Goldemberg

The Brazilian Experience with Biofuels

Innovations Case Narrative

From a technical perspective there is nothing new in the renewed interest in using biofuels in the internal combustion engines on our roads. In the late 1800s, Henry Ford used ethanol to drive automobiles and Rudolf Diesel used biodiesel from peanuts to drive trucks. But these fuels were replaced by gasoline and diesel oil distilled from petroleum; in the early 1900s they became cheap and seemingly inexhaustible in the United States and a few other countries with easy access to oil. Meanwhile biofuels, particularly ethanol (also an alcoholic beverage), were expensive and produced in minor amounts compared to the huge quantities needed for large vehicle fleets.

Oil-poor countries, including Brazil, had a different experience. Since 1920 Brazilians have conducted technical studies on ethanol-run vehicles, including racing cars; because ethanol works so well as a fuel it makes a good alternative to imported gasoline. In 1931, a Brazilian law required that all gasoline include 5% bioethanol from sugarcane and the government regulated prices to make it possible. Over the years the blend remained almost constant and was slowly raised to 7.5%. Such blends did not require changes in the engines. In the early 1970s Brazil imported all of its gasoline and petroleum from abroad, at an annual cost of US $600 million. In 1973, with the first oil shock, imports rose to more than $4 billion annually, contributing greatly to the deficit in hard currency, and badly damaging the economy.[1]

Professor José Goldemberg earned his Ph.D. in Physical Sciences from the University de São Paulo in 1954, where he became a full professor and served as rector from 1986 to 1990. A member of the Brazilian Academy of Sciences, he has served as the president of the Brazilian Association for the Advancement of Science, as Brazil's secretary of state for science and technology, and as minister of state for education. He has conducted research and taught at the University of Illinois, Stanford University of Paris (Orsay), and Princeton University. From 1998 to 2000, he chaired the World Energy Assessment for the U.N. Development Program. Between 2002 and 2006, he was secretary for the environment of the state of São Paulo. He has authored many technical papers and books on nuclear physics, sustainable development, and energy, and is the 2008 recipient of the Blue Planet Prize.

Given this situation, the representatives of the sugar producers proposed ways to reduce Brazil's dependence on imported oil by increasing the amount of ethanol in gasoline. This move also made use of the idle capacity in sugar refineries, which can easily be converted to produce ethanol, and today most can produce both sugar and ethanol. In November of 1975, as a result of those proposals, the federal government established the National Alcohol Program (PROALCOOL) by decree, and set production goals of 3 billion liters of ethanol by 1980 and 10.7 billion liters in 1985.

Today Brazilians are driving about 24 million automobiles. Most of the pure-ethanol cars on the road—2.8 million in 2000—have been retired. Already seven million flex-fuel cars are on the road and their numbers are increasing rapidly. Ethanol to supply these cars is produced in 414 distilleries, of which 60% are equipped to produce both sugar and ethanol. In 2007, production reached 22 billion liters.

Earlier that year, President Ernesto Geisel had visited the Air Force Technological Center in São José dos Campos, São Paulo, and was very impressed by the work being done there by engineers, led by Urbano Ernesto Stumpf, on ethanol-driven cars using hydrated ethanol (95.5% pure ethanol and 4.5% water). Important changes in the engine were needed to use that fuel, which required a compression ratio of 12:1, compared to 8:1 for regular gasoline. The higher compression ratio meant higher efficiency, which partly compensates for ethanol's lower energy content. Combining all these factors, 199 liters of pure (anhydrous) ethanol can replace one barrel of gasoline (159 liters).

This change to engines meant a drastic change in auto manufacture, but under government pressure, local car makers adapted. Meanwhile, sugar producers welcomed these changes, which would let them divert more sugarcane to ethanol production, and better face oscillations in sugar prices on the international market. Also enthusiastic were nationalistic elements in the government who saw ethanol as an instrument of national independence—although Brazilian auto manufacturers could no longer export their cars. It was also a problem to drive Brazilian cars in neighboring countries (and even some states in Brazil) that did not have service stations selling hydrated ethanol. The production of these cars began in earnest at the end of the decade; between 1979 and 1985, they accounted for 85% of all new

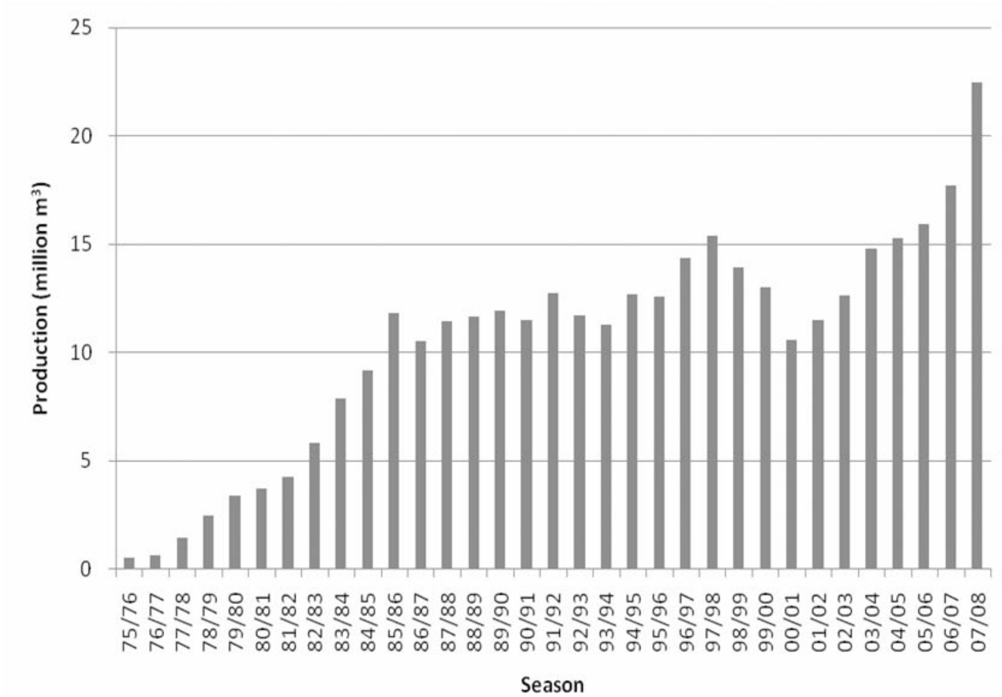

Figure 1. Evolution of Ethanol Production in Brazil

Source: UNICA (Sugarcane Industry Association) statistical database.
http://english.unica.com.br/dadosCotacao/estatistica/

car sales.[2] Over the same period the percentage of ethanol in gasoline reached approximately 20%.

Once ethanol was added to gasoline, MTBE was eliminated as an additive: ethanol has a higher octane number than gasoline and performs the same role as MTBE. Soon, two fleets of automobiles were circulating in the country, some running on gasoline, using a blend of up to 20% anhydrous ethanol and 80% gasoline, and others running entirely on hydrated ethanol. These goals were achieved through mandatory regulations and subsidies: Brazil was under an authoritarian government from 1964 to 1985.

In 1985 the scenario changed dramatically as petroleum prices fell and sugar prices recovered on the international market. Subsidies were reduced and ethanol production could not keep up with demand. By 1990, sales of cars running on pure ethanol dropped to 11.4% of the total and continued to drop.[3] The production of ethanol leveled off but the total amount being used remained more or less consistent because the blend was increased to 25% and more cars were using the blend (see Figure 1).

Then, after 2003, ethanol consumption rose again, as flexible fuel engines were introduced in the cars produced in Brazil. These cars are built to use pure ethanol with a high compression ratio (approximately 12:1) but can run with any propor-

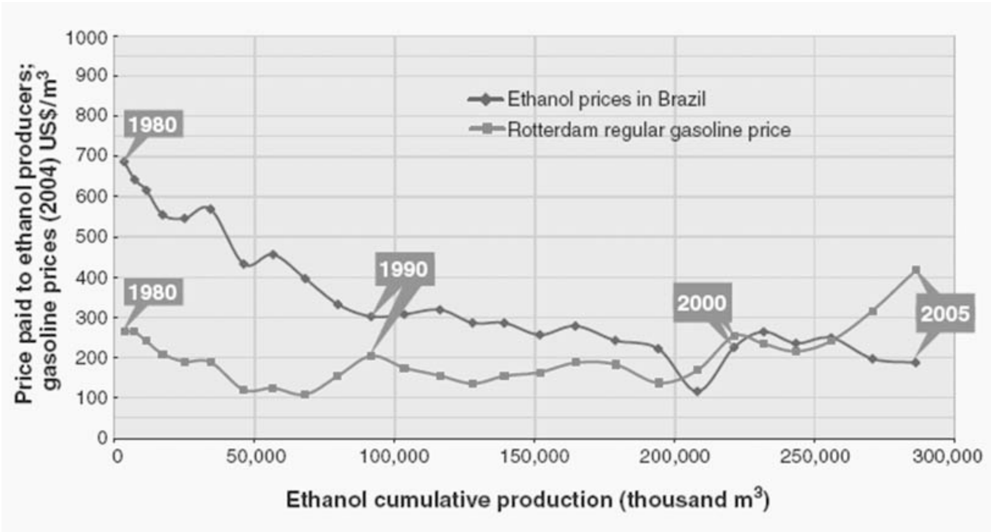

Figure 2. Economic competitiveness of ethanol fuel compared to gasoline

tion of ethanol and gasoline, from zero to 100%, as they have sensors that can detect the proportion and adjust the ignition electronically. Flex-fuel cars were an immediate hit; today they represent more than 95% of all new cars sold because they allow drivers to choose the cheapest blend on a given day.

Today Brazilians are driving about 24 million automobiles. Most of the pure-ethanol cars on the road—2.8 million in 2000—have been retired. Already seven million flex-fuel cars are on the road and their numbers are increasing rapidly.[4]

Ethanol to supply these cars is produced in 414 distilleries, of which 60% are equipped to produce both sugar and ethanol.[5] In 2007, production reached 22 billion liters. For 2008 the estimated production was 26.1 billion liters; assuming that the recent growth of 8% per year continues, it should reach 30.5 billion liters in 2010, using an area of approximately 4 million hectares of sugarcane. In 2008/09, 35 new distilleries were to start production, and another 43 are in various degrees of development. In 2015, production should reach 47 billion liters and the land required approximately 6 million hectares.[6] As Figure 2 shows, the cost of ethanol production in Brazil has dropped significantly over the years.[7]

In 1980 ethanol cost roughly three times as much as gasoline on the international market but by 2004 technological gains and economies of scale had made it competitive with gasoline. Productivity has increased almost 4% per year for the last 30 years. The number of liters of ethanol produced per hectare of sugarcane harvested increased from 3,000 liters/ha to more than 6,000 liters/ha, and today ethanol is fully competitive with gasoline without any subsidies.[8]

What drove this extraordinary expansion of ethanol production from sugarcane? Economic and strategic factors were crucial in reducing Brazil's dependence on petroleum, but environmental issues are also key. Ethanol does not have the impurities that gasoline does, such as sulfur oxides and particulates, which are the

Figure 3. Location of sugarcane plantations and distilleries in BrazilI.

Source: C. Macedo, 2005. *Sugarcane's Energy: Twelve Studies on Brazilian Sugarcane*. São Paulo: Berlendis & Vertecchia.

primary cause of poor air quality in large cities like Beijing, Mexico City, São Paulo and even Los Angeles. In São Paulo the air quality has improved remarkably as gasoline was replaced by ethanol; today it represents more than 50% of the fuel used in cars.

In addition, over its life cycle ethanol from sugarcane produces considerably lower amounts of CO_2 , the main contributor to global climate change, compared to gasoline. This is because sugarcane bagasse, the fibrous waste that remains after the plant is crushed, can provide the heat and electricity needed in ethanol production, including the crushing and distillation processes.[9]

The calculations mentioned above do not include emissions from changes in land use, including massive deforestation, which could cause increased emissions of greenhouse gases (GHG), as Fargione et al. (2008) demonstrated.[10] However, they looked at a worst-case scenario which is not currently occurring since biofuel production is not expanding into virgin tropical forests. If that did happen, of course, it would release a large amount of CO_2 but extensive studies have been conducted on the CO_2 releases resulting from other agricultural practices that do not involve deforestation, and the results are much less alarming.[11]

The whole issue of CO_2 emissions from changes in land use, as raised by Searchinger et al (2008),[12] is not really a matter of food versus fuel, but should more appropriately be called a problem of food versus climate, since it applies to the expansion of agricultural areas in general. In addition, in Brazil, sugarcane plantations are being expanded into degraded pasturelands and are not displacing other crops. They are also very far from the wet tropical Amazonia forest where sugarcane does not grow well, as Figure 3 shows.

In 2001, in the state of São Paulo, the average number of cattle per hectare was 1.28; as of 2008 it had increased to 1.56, because the expanding sugarcane plantations put pressure on cattle grazing. In the country as a whole the density is even lower, at closer to 1 animal per hectare.[13] The deforestation in the Amazon basin is linked closely with the raising of cattle for meat, for both domestic consumption and export; it is not linked with ethanol production. Today, Brazil has approximately 200 million head of cattle on 237 million hectares.[14]

The expansion of ethanol production has had important repercussions for the ownership and management of the sector which in Brazil is entirely in the hands of private groups. Although Petrobras, the state-owned Brazilian oil company, is beginning to invest in this area, it is still a very small player.[15] Traditionally, sugar-producing units were family-owned enterprises such as Costa Pinho, São Martinho, and Santa Elisa, but new ones are owned by Brazilian companies including Votorantim, Vale, and Odebrecht. Foreign companies entering the sugarcane business include French (Tereos, Louis Dreyfus), Spanish (Abengoa), British (British Petroleum), and Japanese (Mitsui, Marubeni) groups. The financial sector is also quite visible, including Merrill Lynch, Soros, and Goldman Sachs. The presence of foreign investors has given the sector a new dynamism and new concepts of management, but as of 2007, investments by foreigners were only 12% of the total.[16]

THE SUSTAINABILITY OF ETHANOL PRODUCTION FROM SUGARCANE

One crucial question surrounding the growth of ethanol production from sugarcane in Brazil is the sustainability of that growth. What are the issues regarding soil quality, water consumption, and agrochemical inputs, as well as the social impacts? Goldemberg et al. (2008) explored these issues exhaustively in a recent article,[17] summarized here.

Soil quality

Sugarcane culture has become more sustainable over the years as practices have been introduced to protect against erosion, soil compaction and moisture losses and to insure the appropriate use of fertilizers. In Brazil, some soils have been producing sugarcane for more than 200 years, with no reduction in yield. Sugarcane culture in Brazil is well known for its relatively small loss of soil to erosion, especially when compared to soybeans and corn.[18]

Definitions of first and second-generation biofuels

First-generation biofuels
First generation biofuels are those on the market in considerable quantities today. Typical first-generation biofuels are sugarcane ethanol, starch-based or 'corn' ethanol, biodiesel, and pure plant oil (PPO). The feedstock for producing first-generation biofuels may be crops that produce sugars, starches, or oils, or animal fats, most of which can also be used as food and feed; food residues can also be used. A first-generation biofuel can be blended with petroleum-based fuels, combusted in existing internal combustion engines, and/or distributed through existing infrastructure, or it can be used in existing alternative vehicle technology like flexible-fuel vehicles (FFVs) or natural gas vehicles. First-generation biofuels are produced commercially today: almost 50 billion liters annually. There are also other niche biofuels, such as biogas, which are derived through the anaerobic treatment of manure and other biomass materials. However, the relatively small volumes of biogas are currently used for transportation.

Second-generation biofuels
Second-generation biofuels are those biofuels produced from cellulose, hemicellulose or lignin. These biofuels can also be blended with petroleum-based fuels, combusted in existing internal combustion engines, and distributed through existing infrastructure; they may also be dedicated for use in slightly adapted vehicles with internal combustion engines, e.g. vehicles for Di-Methyl Ether (DME). Examples of second-generation biofuels are cellulosic ethanol and Fischer-Tropsch fuels; the latter technology synthesizes fuel from gases produced from the gasification of fossil fuels or biomass.

Source: IEA Bioenergy Task 39.
http://www.task39.org/About/Definitions/tabid/1761/languange/en_US/Default.aspx.

Water

Water is used in two ways in producing sugarcane and ethanol. First, great quantities of water are needed to grow the cane. The cane requires significant rainfall, in the range of 1500 to 2500 mm a year, ideally spread uniformly across the growing cycle.[19] Most sugarcane production in Brazil relies on rain, rather than irrigation, including nearly the entire Sao Paulo sugarcane producing region.

Large amounts of water are also used to convert sugarcane to ethanol. In 1997, this amount was calculated as 21 cubic meters per ton of cane. Of that, 87% was used in four processes: sugarcane washing and three other industrial processes of ethanol production. However, most of the water used is recycled, and water consumption has decreased substantially in recent years. Also, a dry process for washing cane is replacing the standard wet washing process.20 In addition, sugarcane is

70% water, which should provide enough for all the steps needed in ethanol production. Distilleries are being developed to be self-sufficient in their water consumption.[21]

Agrochemicals

Many inorganic compounds are introduced during the production of ethanol, including chemicals that kill weeds, insects, mites, and fungi, along with defoliants and other chemicals that help the cane to mature more quickly.

Fewer agrochemicals are used in sugarcane production than for some other crops. Pesticide consumption per hectare for sugarcane is lower than for citrus, corn, coffee and soybeans. On the other hand, sugarcane requires more herbicides per hectare than coffee, but still less than do citrus, corn, and soybeans. Also, comparing Brazil's major crops (those grown on areas larger than 1million hectares), sugarcane uses smaller amounts of fertilizer than cotton, coffee and oranges, and about the same amount as soybeans. It also uses less fertilizer than sugarcane crops in other countries; for example, Australian cane growers use 48% more fertilizer than Brazilians.[22] One practice that helps here is using industrial waste as fertilizer, especially vinasse, the byproduct of ethanol distillation process, and filter cake, which remains after cane juice is filtered and then goes through a process of fermentation/distillation leading to ethanol. This has led to substantial increases in productivity and in the potassium content of the soil.[23]

Genetic research, especially the selection of resistant varieties, has made it possible to reduce the diseases affecting sugarcane, such as the mosaic virus, sugarcane smut and rust, and the sugarcane yellow leaf virus. With genetic modifications, some now being field tested, plants are more resistant to herbicides, fungus and the sugarcane beetle. At present more than 500 commercial varieties of sugarcane are being grown.

Social Aspects

Brazil's labor laws are well known for their worker protection. Workers involved in sugarcane production experience better employee relations, and better protection of their rights, compared to those in other rural sectors. Overall, 40% of Brazilians are in formal employment; in comparison, in the sugarcane industry the rate is now 72.9% (up from 53.6% in 1992); it is 93.8% in São Paulo as of 2005 and only 60.8% in the north/northeast region.

Many of Brazil's sugarcane plantations are large, and almost 75% of the land in use is owned by large producers. However, in the southeast, around 60,000 small producers are organized in cooperatives. A long-established payment system based on the sucrose content in sugarcane has promoted significant growth in agricultural productivity. In the southeast, people working with sugarcane earn more than those working on coffee, citrus and corn, but less than those working with soybeans, as that work is highly mechanized, and the jobs more specialized. In the northeast, people working in sugarcane earn more than those in coffee, rice,

	US	Brazil	EU	Other Countries	Totals		Growth rate
	Billions of liters/year				Billions of liters/year	Millions of barrels of oil equivalent/day	
2006	20.7	14.4	1.7	-	36.8	0.4	
2015	56.8	31	-	-	87.8	1.1	2006-2015: 10.1%
2022	136	56.7	14.8	7.6	215.1	2.6	2006-2022: 11.7%

Table 1. Ethanol Consumption in Brazil, U.S., EU, other countries

banana, manioc (cassava) and corn; their income is about equivalent to that for citrus, and lower than for soybeans. However, the enforcement of labor regulations in some parts of the country could be improved.

INTERNATIONAL DIMENSIONS OF THE ETHANOL PROGRAM

The 2007 U.S. Energy Bill[24] set a target of producing 15 billion gallons (56.8 billion liters) of ethanol per year by 2015, from corn, using first-generation technologies, which will probably require an agricultural area of approximately 14 million hectares.

Further expansion of production is planned, up to 21 billion gallons (79.5 billion liters) a year, using cellulosic materials and second-generation technologies which are still in an experimental phase. By 2020 the European Union directive will require 3.9 billion gallons per year to replace 10% of the gasoline it uses, but today it produces only 2 billion liters per year, mainly from sugar beets.[25] Production of ethanol from corn, using first-generation technologies, will be at least 87.8 billion liters per year in 2015, up from 36.8 billion in 2006, as shown in Table 1.

There is an important difference between the production of ethanol from sugarcane, or from corn in the U.S., and from starchy feedstocks such as wheat and sugar beets in Europe. The industrial process requires external sources of energy (fuel oil or gas) to supply electricity and heat. In practical terms, in the U.S. and Europe ethanol is obtained by burning coal (the main source of energy in the region) to turn corn into ethanol; on the other hand sugarcane converts the sun's energy into ethanol through photosynthesis. The concept of energy balance is used to evaluate the use of fossil fuels in preparing ethanol: it is the ratio of the amount of energy contained in the ethanol to the amount of fossil fuel energy used to produce it. For sugarcane this ratio is 8:1 and for corn in the U.S. only it is 1.3:1.

Many studies have been conducted on this subject and the results are sensitive

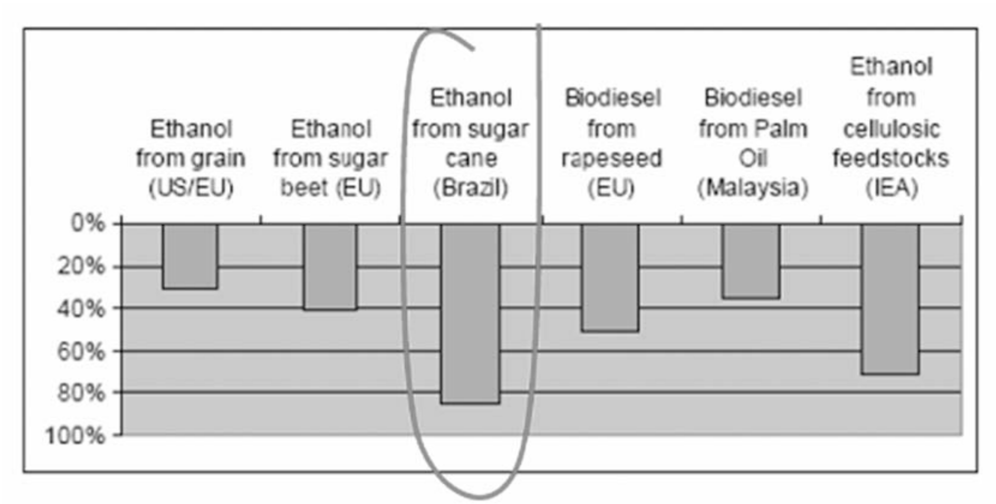

Figure 4. Reductions in GHG emissions per KM from biofuels, compared with gasoline and mineral diesel

Source: R. Doornbosch, and R. Steenblik, 2007. "Biofuels: Is the cure worse than the disease?" Presentation at OECD Roundtable on sustainable development, Paris, September, 2007, (p. 17) www.foeeurope.org/publications/2007/OECD_Biofuels_Cure_Worse_Than_Disease_Sept07.pdf .

to assumptions about the use of fertilizers, pesticides and other inputs. Still, a fair estimate is that compared to gasoline, ethanol from corn emits 30% less CO_2 and ethanol from sugarcane 82% less, as Figure 4 shows.

In the U.S., efforts to expand ethanol production from corn will face severe obstacles. Already 18% of the nation's corn, grown on a total of 37 million hectares, is being used for ethanol production, and that land use is cutting into soybean production. Production of ethanol from cellulosic materials, which could be a solution, is still facing technological problems that are not likely to be solved by 2015. However productivity increases, including genetic modification, might help to significantly reduce the amount of additional land needed.[26]

This large demand for ethanol, and the corresponding use of agricultural land to produce it, has generated a number of objections to the use of biofuels. Some argue that the competition between land for fuel (ethanol) and land for food, in both the U.S. and Europe, is causing famine around the world and leading indirectly to deforestation in the Amazon and other tropical areas.[27] The recent rise in the prices of agricultural products, after several decades of declining real prices, is often seen as a cause of famine, and led to the politically laden controversy of fuel "versus" food. In the aggregate, grain prices have more than doubled since January 2006, with over 60% of the rise since January 2008 closely following the price of petroleum; prices began to drop as the 2008 crop was harvested. In contrast, the point has been made that higher crop prices will not necessarily harm the poorest people; many of the world's 800 million undernourished people are farmers or

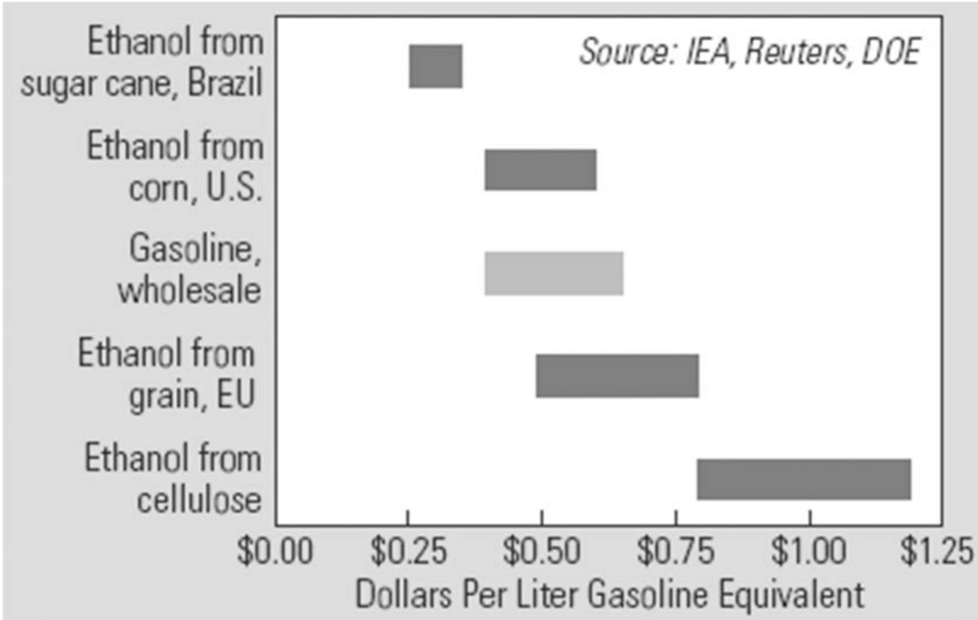

Figure 5. Cost ranges for ethanol and gasoline production, 2006

Source: World Watch, 2006. Biofuels For Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century (p. 2)
www.worldwatch.org/system/files/EBF008_1.pdf

farm laborers, who could benefit from higher prices.[28] More recently the price of agricultural products has decreased following the decline in petroleum prices.

To keep the issue in perspective, it is important to remember several facts. First, around the world, 93 million hectares are currently being used to grow soybeans and 148 million hectares for corn, while the amount used in the U.S. to produce ethanol is approximately 7 million hectares. Second, in general the prices of food commodities have been decreasing since 1975 but fluctuations frequently occur in those prices, as well as in the areas planted and the prices of crude oil. Those fluctuations, occurring for decades, result from an enormous number of factors and events.[29]

Worldwide, 1.5 billion hectares of the arable land is already being used for agriculture and another 440 million hectares is potentially available, including 250 million hectares in Latin America and 180 million in Africa. So the area currently being used for biofuels is only 0.55% of the land in use; even if it were to grow by an order of magnitude that would not be a very disturbing expansion.[30]

This problem has been extensively analysed in many reports, particularly by the World Bank,[31] which pointed out that several individual factors have driven up grain prices and in combination led to an upward price spiral. Among them are high energy and fertilizer prices, the continuing depreciation of the U.S. dollar, drought in Australia, growing global demand for grains (particularly in China), changes in some nations' import-export policies, speculative activity on future

	Ethanol			Biodiesel		
	Total, in US$ billions	Billions of liters	US $/liter	Total, in US$ billions	Billions of liters	$/liter
US	5.8	20.7	0.28	0.53	0.96	0.55
EU	1.6	1.6	1.0	3.1	4.43	0.70
Total	7.4	22.3	-	3.63	5.39	-

Table 2. Subsidies for biofuels in the U.S. and EU, 2006

Source: R. Steenblik, 2007. Biofuels – At What Cost? Geneva: The Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD). www.globalsubsidies.org/files/assets/oecdbiofuels.pdf

commodities trading, and regional problems driven by subsidies of biofuel production in the U.S. and Europe. For example, in the U.S., from 2006 to 2007, corn acreage grew 19% to almost 37 million hectares: an increase of 7 million hectares. Most of this expansion came at the expense of soybean acreage, which decreased by 17%, from 31 to 26 million hectares: 5 million hectares.[32] This is approximately 6% of the world's area used for that crop, and that change is helping to drive up prices.

Though these land changes were reversed in 2008, other countries had to expand their soybean production, possibly increasing deforestation in Amazonia. Such speculations about a "domino effect" are not borne out by the facts: the area used for soybeans in Brazil (mainly in Amazonia) has not increased since 2004.[33] The reality is that deforestation in the Amazon has been going on for a long time at a rate of approximately 1 million hectares per year[34] and recent increases are due not to soybean expansion but to cattle and are unrelated to ethanol production.

REPLICATING THE BRAZILIAN EXPERIENCE ELSEWHERE

Almost 100 countries are producing sugarcane, over an area of 20 million hectares (approximately 0.5% of the total world area used for agriculture). The 15 most important producers represent 86% of the total production of sugarcane.[35] It is easy to convert sugar plants to ethanol distilleries and most of the existing plants in Brazil have a dual purpose. This makes it clear that the production of ethanol from sugarcane could be expanded significantly if other countries follow Brazil's example, using a fraction of their sugarcane for ethanol.

The question then arises: why are other sugarcane-producing countries not using some of their raw material to produce ethanol which they could then export to the U.S. and Europe where production costs are significantly higher, as shown in Figure 5.

Biofuels and the World Trade Organization

The World Trade Organization (WTO) does not currently have a specific trade regime for biofuels. Therefore, international trade in biofuels falls under the rules of the General Agreement on Tariffs and Trade (GATT 1994), which covers trade in all goods, as well as other relevant WTO agreements such as those on agriculture, technical barriers to trade, the application of sanitary and phytosanitary measures, and subsidies and countervailing measures. Agricultural products are subject to GATT and to the general rules of the WTO insofar as the Agreement on Agriculture (AoA) does not contain derogating provisions.

Key trade-related issues include the classification for tariff purposes of biofuel products as agriculture, industrial or environmental goods; the role of subsidies in increasing production; and the degree of consistency among various domestic measures and WTO standards.

The AoA covers products from Chapters 1 to 24 of the Harmonized System, with the exception of fish and fish products and the addition of many specific products, including hides and skins, silk, wool, cotton, flax, and modified starches. The discipline of the AoA is based on three pillars: market access, domestic subsidies, and export subsidies. One of its main features is that it allows members to pay subsidies in derogation from the Agreement on Subsidies and Countervailing Measures.

The Harmonized System classification affects the way products are characterized under specific WTO agreements. For example, because ethanol is considered an agricultural product, it is subject to Annex 1 of the AoA. Biodiesel, on the other hand, is considered an industrial product and is therefore not subject to the disciplines of the AoA. Paragraph 3 (iii) of the Doha Development Agenda has launched negotiations on "the reduction or, as appropriate, elimination of tariff and non-tariff barriers to environmental goods and services." Some WTO members have suggested that renewable energy products, including ethanol and biodiesel, should be classified as "environmental goods" and therefore subject to negotiations under the "Environmental Goods and Services" cluster.

Sources:

FAO, 2007. *Recent trends in the law and policy of bioenergy production promotion and use,* FAO Legislative Study No. 95. Rome: FAO.

GBEP, 2007. *A review of the current state of bioenergy development in G8 +5 countries.* Rome: GBEP Secretariat, FAO. In FAO, 2008, The State of Food and Agriculture 2008. Biofuels: prospects, risks and opportunities. Rome: FAO. www.fao.org/docrep/010/a1348e/a1348e00.HTM.

The main reason is the high import duties imposed on ethanol imports in the U.S. and Europe to protect local industries which are heavily subsidized. Table 2 gives estimates of the subsidies in the U.S. and European Union which totalled almost $12 billion in 2006.

Country	Capacity (m³ ethanol/day)	Status
Colombia	150 x 5	In operation
Venezuela	700 x 4	In construction
Angola	1,000	Firm proposal
Colombia	1,000	Firm proposal
Bolivia	500	Firm proposal
Paraguay	700	Firm proposal
Colombia	300 x 2	Firm proposal
Colombia	100	Firm proposal
Colombia	150	Firm proposal
Colombia	200	Firm proposal

Table 3. Projects under Development

Source: J.L. Olivério, vice president of operations, Dedini Organization, personal communication.

Removing these subsidies is a topic of discussion in the Doha round of negotiations but prospects for progress in this area are poor (see Box 2). However, several countries in Central America benefit from their privileged access to the U.S. market. For members of the Caribbean Basin Initiative (CBI), the oldest group, up to 7% of the previous year's U.S. ethanol demand is exempt from import tariffs.[36] This agreement has been used mostly to allow these countries to import dehydrated Brazilian ethanol; in the past European hydrous ethanol was also included. Dehydration plants are located in Costa Rica, the Dominican Republic, Trinidad & Tobago, El Salvador and Jamaica. The U.S. imported 482 million liters from these countries in 2006 and 877 million liters in 2007, considerably less than the 1.3 billion liters that the 7% limit represents on ethanol imported from Caribbean countries.

CAFTA, the Central America Free Trade Agreement, signed in August 2004, immediately eliminated all tariffs and quantitative restrictions on 80% of manufactured goods in that market, including ethanol, with the remainder phased out over a few years. Nearly all of the 6 nations in CAFTA have already initiated plans to develop large-scale ethanol production. El Salvador is the most advanced; it has already drafted legislation to continue developing a local ethanol market and is beginning to invest in ethanol production. An old distillery that can produce 60 million liters a year is being revamped to double its capacity and is already exporting all its production. Similar initiatives are under way in Guatemala and Costa Rica.[37]

Across the Atlantic, two key elements of the EU's General System of Preferences are the *Everything but Arms* (EBA) initiative and the *Special Incentive Arrangement for Sustainable Development and Good Governance* (GSP+). EBA provides special treatment for 50 least-developed countries, giving duty-free access to imports of all products except arms and ammunition, without any restrictions on quantity, with the exception of rice and sugar up to October 2009.[38] At present, GSP+ benefits 16 countries, mostly in Latin America and the Caribbean.[39] Any GSP+ beneficiary country must be both "vulnerable," according to a definition established in the regulation, and have ratified and effectively implemented 27 specified international conventions in the fields of human rights, core labor standards, sustainable development and good governance. This program grants special duty-free access to the EU market for denatured or un-denatured alcohol.[40]

To benefit from such advantages, a few countries in Latin America and Africa are starting to divert some of their sugarcane to ethanol production and others, especially Venezuela, are expanding their sugarcane plantations. Table 3 provides a list of projects underway around the world.

This development represents a modernization of the sector which traditionally was in the hands of prosperous family groups that benefited from special relationships with the European Union, as described above, that let them sell sugar at far more than the international price; their price was based on the much higher price of locally-produced sugar from sugar beets or sweet sorghum. This comfortable situation discouraged them from entering into the ethanol business which required additional investments and know-how.

CONCLUSION

If second-generation technologies do not materialize until 2022, most of the ethanol required in the U.S. will probably have to be imported from countries in the Southern hemisphere such as Brazil where the expanses of land and good climate particularly favor its production from sugarcane.

If it were possible, worldwide, to place 10 million hectares into sugarcane cultivation, up from the 2.9 million hectares currently in use in Brazil, it would be possible to produce 70 billion gallons of ethanol; together with the U.S. production from corn, that would more than suffice to meet projected worldwide needs as of 2022. Carbon emissions would be reduced by at least 57 million tons per year.

In all likelihood, ethanol consumption, which represented 0.4 million barrels of oil equivalent per day in 2006 (1.2% of all gasoline in use in the world) will grow to 2.6 million barrels of oil equivalent per day in 2022, replacing 10% of all gasoline used in the world. Considering that current oil consumption is 85 million barrels a day and that it might grow to 100 million by 2012, ethanol would be contributing the equivalent of almost 3% of the world's consumption of oil. That is a significant amount and will help drive down the world price of petroleum.

As discussed above, neither the U.S. nor the European Union will be able to produce all the ethanol it needs; in all likelihood they will have to import it from

Brazil and other tropical sugarcane-producing countries. This could be a mutually beneficial solution, reducing the cost of fuel for consumers in the U.S. and Europe and generating hundreds of thousands of jobs in the developing countries.

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Melinda Kimble

It's Not About Ethanol, It's About Sugarcane

Innovations Case Discussion:
The Brazilian Experience with Biofuels

Brazil's decision to integrate sugar production with its energy system makes an interesting case study in optimization and economic flexibility. Dr. Goldemberg's first-hand experience with Brazil's policy of incorporating ethanol into the transport fuel mix offers important insights into the steps Brazil took to change fuel blends and encourage consumers' adoption. Dr. Goldemberg argues that an ethanol export industry could power development in other countries. While ethanol is part of an important Brazilian story, export-led development was not the driver. Rather, in finding multiple uses for sugarcane and its byproducts, Brazil systemically transformed its energy mix. This success in optimizing resources offers a rare example of low carbon growth.

Can other countries replicate Brazil's experience with low carbon growth and/or become ethanol exporters? The answer is not yet clear. To illustrate the challenges, this commentary briefly explores the experiences that Brazil and the U.S. had with ethanol as a transport fuel, the choices made by industry and policy makers and the economic and political forces that shaped decisions.

BRAZIL'S ETHANOL EXPERIENCE

Domestic economic policy was the original impetus behind the ethanol experiment in Brazil. When the military assumed political control in Brazil in 1964, it

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sought to expand the productivity of Brazil's major export products—coffee, sugar and citrus—and protect the development of a modern industrial sector. Two of these markets, coffee and sugar, were highly distorted and Brazil was vulnerable to volatile prices. The success of the command-and-control economy was illustrated by 10% annual growth rates in the early years of the military regime, backed by high tariffs and domestic programs that supported the development of a new industrial sector that produced steel, autos, cement and other products; meanwhile, agroindustry developed and the middle class expanded. Like most emerging markets of the mid-sixties, Brazil fueled much of its post-war expansion with cheap energy, primarily imported petroleum, to the extent that by 1974, it was importing 85% of its primary energy supply. In 1973-74, however, two events coincided to refocus the attention of Brazil's ruling elite on the potential of ethanol: 1) oil prices jumped sharply with the Arab oil embargo of 1973; and 2) sugar prices fell, leaving Brazilian producers with growing supplies and few markets.

> In finding multiple uses for sugarcane and its byproducts, Brazil systemically transformed its energy mix. This success in optimizing resources offers a rare example of low carbon growth. Can other countries replicate Brazil's experience with low carbon growth and/or become ethanol exporters? The answer is not yet clear.

In 1974, Brazil's oil import costs jumped from $769 million to $2.8 billion; the large oil import bill threatened the continued expansion of the economy.[1] Brazil had a long history, starting before World War II, of blending ethanol with gasoline as a thrift measure. Now sugar producers needed a new market, and the military dictatorship was concerned about the balance of payments and energy security. They seized an opportunity to expand blending requirements and stimulate a new domestic industry at the same time. One of the more ambitious features of this program was a decision to promote the manufacture of alcohol-only cars, an option few other sugar-producing countries had, or have.

The government actually bought cars and retooled the engines to prove that 100% alcohol engines would work. They also established price parity with gasoline to ensure that ethanol would remain competitive as petroleum prices fluctuated. This approach enabled policy makers to adjust the ethanol price to offset the petroleum producers' economies of scale when gasoline prices were low and to provide a smaller subsidy when gasoline prices were higher. The Brazilian government was responsible for the price mechanism and for establishing blending ratios while Petrobras, Brazil's national oil company, played, and continues to play, a central role in blending and distributing both gasoline and ethanol. These early decisions, made under a program known as *Pro-Alcool*, were consistent with the "Brazil first" philosophy of the ruling junta, which involved direct government intervention and large subsidies. Within five years, ethanol was an accepted consumer product; sales of alcohol-only cars grew through the late 1980s, especially in the State of Sao Paulo.

With the restoration of democracy in the mid-eighties, Brazil began the painful process of liberalizing a highly protected economy. Foreign and domestic debt incurred by the military regime weighed heavily on the economy. Domestic subsidies, including those for ethanol production and blending requirements, were eliminated. Initially, this shift posed only minor problems for sugar producers, who were selling sugar in more profitable international markets; still, ethanol was an important option given the long-range volatility in sugar prices.

In the 1990s, sugar producers, ethanol processors, and Brazil's new economic team began to reassess whether it would make economic sense to maintain an ethanol option in the domestic market. This review prompted consultations with Brazil's auto industry, which had virtually stopped producing alcohol-only cars by early 1992, due to a sharp decrease in the domestic ethanol supply and the consequent decline in consumers' confidence in the availability of fuel for their vehicles. In addition, as the international prices of oil eroded and the price parity with ethanol was eliminated, consumer preference shifted quickly towards gasoline vehicles, because of their higher engine performance and lower costs. Still, the experience of producing alcohol-only vehicles had paid off in expertise about ethanol engines. Volkswagen Brazil engineers had a simple solution when the government asked them if they could develop a low-cost engine modification that would permit the use of any combination of ethanol and gasoline. The flex-fuel modification proved commercially viable and most Brazilian manufacturers began adopting it. The Brazilian government helped offset manufacturing costs through consumer incentives, which gradually declined over time and encouraged consumers to opt for flex-fuel vehicles. Dr. Goldemberg has noted the success of this strategy, which has resulted in flex-fuel vehicles now comprising more than a third of the current fleet.

This policy secured the ethanol market, but sugar producers, who no longer had price supports for ethanol, realized that efficient processing systems would be essential to their long- term competitiveness, no matter the product. They had already started using bagasse, a waste product of sugar extraction, to fuel the processing plants. The next step they took was to cogenerate electricity. Then, the public utilities arranged to feed spare power into the grid. This systemic innovation created a win-win-win formula for sugar producers and Brazil's power sector, which gained a new domestic source of electricity. The contribution to power generation tipped the economic scale in favor of ethanol production (see Figure 1).

Whether by chance or design, Brazil's sugar industry has become a "strategic optimizer," and this market flexibility has encouraged a continuous search to

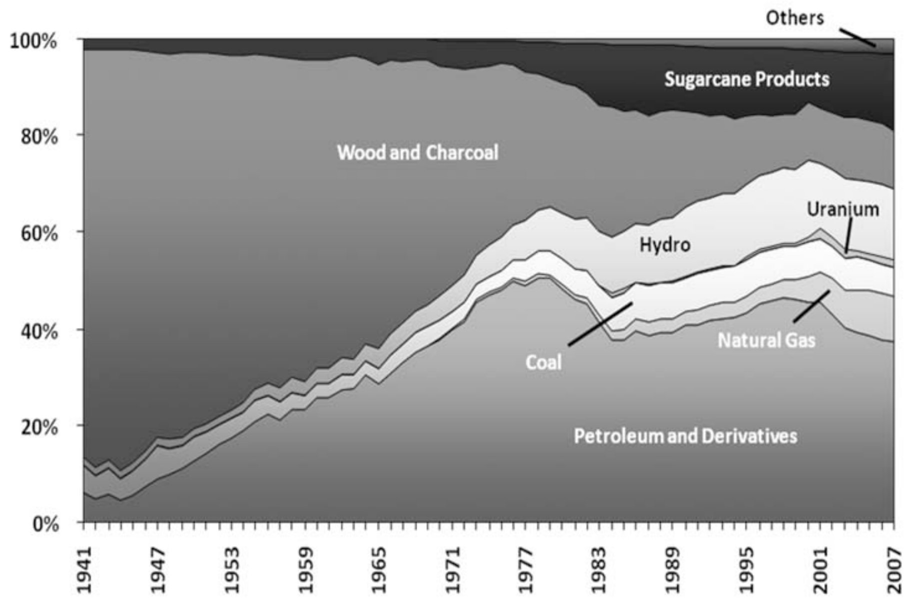

Figure 1. Brazil Energy Mix, by percentage, 1941-2007
Source: Ministry of Mines and Energy, Brazil, Balanco Energetico Nacional, 2008.

increase efficiency, productivity, and profits. This process of improving productivity through public-private research partnerships and systematic review of agricultural practices has extended to Brazil's other major agriculture crops, including citrus and coffee.

U.S. ETHANOL POLICY

Like Brazil's, the U.S. experience with ethanol has been shaped exclusively by domestic agricultural production and energy consumption. While the U.S. does export vast quantities of agricultural goods, ethanol was always envisioned as a domestic market, driven by domestic interests.

As the auto industry developed in the U.S. at the beginning of the 20th century, Henry Ford thought the most reasonable fuel would be grain alcohol. But that calculation changed as petroleum was discovered and John D. Rockefeller consolidated the petroleum industry. Rockefeller recognized that he needed a variety of markets for this new product, as the initial use for lighting was insufficient to sustain the investment required to exploit this resource. The new markets for electricity and personal mobility were ideally suited to creating demand for petroleum and the control Rockefeller exercised over supply made it possible to establish prices that many could afford and still remain competitive with alternative fuel options. By about 1920 the fortunes of the oil and automotive industries were firmly linked. As the U.S. was the largest producer of petroleum until after World

War II, its actions suggested a lack of concern about long-term energy supply.

This calculation prompted U.S. policy makers to ignore any potential renewable and alternative fuels, even though gasoline rationing had been imposed during WWII. After the war, major U.S. oil companies discovered far more oil in the Middle East, reinforcing the belief that supplies would be abundant and cheap. U.S. policy continued to reflect these early assumptions until the 1973 Arab oil embargo led to a rapid jump in global oil prices, to levels far above the historical trend, and touched off a global recession.

In response to new energy concerns, the Carter Administration launched a variety of programs to improve domestic energy supply, including a corn ethanol program. It put in place both a processing subsidy and a tariff on ethanol imports that remains today. As with sugarcane, ethanol served as an outlet for an oversupply of corn. While the costs of producing corn ethanol were similar to Brazil's during its early efforts, they were much higher than for the recently optimized Brazilian sugar-based ethanol. And U.S. ethanol, suffering from high production costs and lower energy density, could not compete with inexpensive gasoline in the 1981-2000 period. Unlike Brazil, the U.S. made no significant attempt to retool vehicle engines for ethanol.

Oil producers contended that oil was plentiful and would continue to be available, even though U.S. oil companies were producing much of the oil in the sensitive Middle East, and by 1979, state-owned oil companies had control of reserves and supply in Iran, Iraq, Saudi Arabia and Kuwait with international oil companies reduced to production contracts. Despite warnings that the U.S. or U.S. oil companies would have less and less control over international petroleum reserves, Congress found it too difficult to build a consensus on an energy policy that would promote conservation, efficiency, and alternative fuels.

In 1987, Ronald Reagan joined Margaret Thatcher in establishing the Intergovernmental Panel on Climate Change (IPCC) to examine the environmental implications of growing fossil fuel use and its impacts; still, few policy makers were convinced that a shift from conventional fossil fuel was either necessary or possible. These attitudes were generally reinforced in the 1990s as oil prices hit a low point for most of the decade. Even with the expertise of Vice President Al Gore on emerging environmental issues like climate change, the Clinton Administration was unable to build a legislative consensus to revamp domestic energy policy significantly (see Figure 2, next page).[2]

In 1997, the President's Committee of Advisors on Science and Technology (PCAST) made the energy security case again. It estimated that by 2015, 70% of internationally traded oil would come from the Persian Gulf region, and it argued that U.S. access would not necessarily be assured, especially given the rising consumption of gasoline.[3] In that report, the PCAST experts argued that an aggressive program using cellulosic biofuels from perennial crops could replace 2.5 million barrels of oil a day by 2030 (38 billion gallons of oil a year). Concurrently, the panel cautioned against a continued focus on corn ethanol as too costly and inefficient.

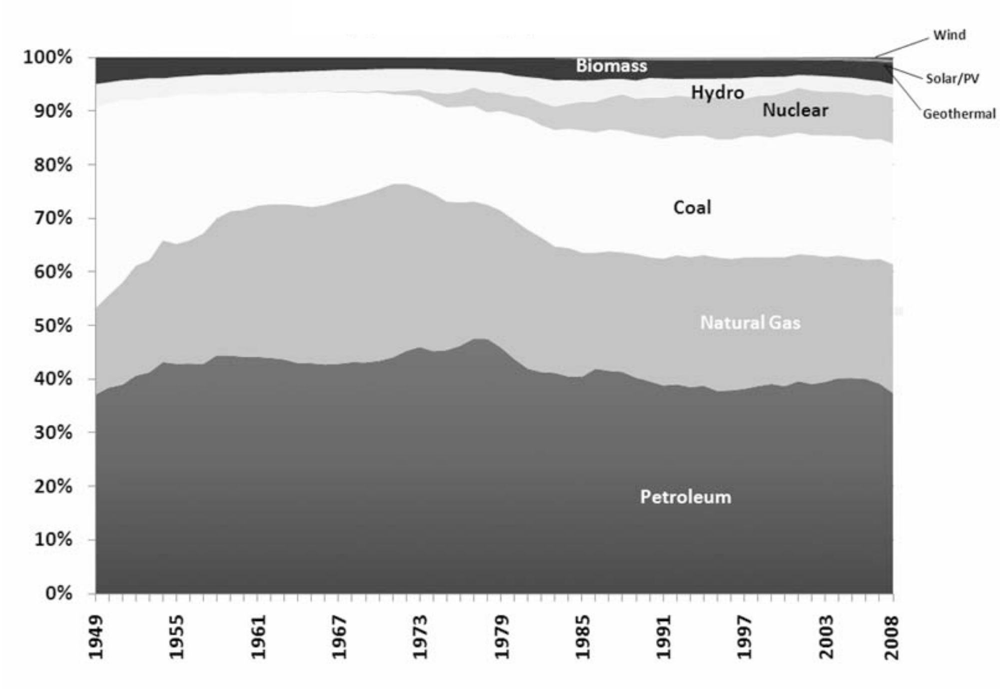

Figure 2. U.S. Energy Mix, by percentage, 1949-2008

Source: Energy Information Administration (EIA), Annual Energy Review 2008

In 1999, recognizing the need to understand how alternative fuels might affect greenhouse gas (GHG) emissions, Michael Wang, of the Argonne Laboratory, published his work on the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) fuel model, estimating the GHG balance for several fuels.[4] He demonstrated that ethanol produced from various feedstocks was less carbon intensive than gasoline, and had a lower lifecycle GHG balance. In these assessments, cellulosic and sugarcane ethanol produced the greatest reductions in GHG emissions, and corn ethanol had a 20% lower carbon profile than gasoline, keeping it within a viable range for an incremental low carbon transformation of the U.S. energy mix. These research results set a useful benchmark, but the study had limited impact until the September 11, 2001 terrorist attacks again raised the specter of dependence on Middle Eastern oil and reignited the ethanol discussion (see Figure 3).

In 2002, two bipartisan coalitions formed to examine energy, environment and energy security issues. One, the Energy Future Coalition, published an article in *Foreign Affairs* arguing that revamping U.S. energy use would transform long-term energy access in the U.S., strengthen the U.S. economy by accelerating and diffusing new technology, and speed international efforts to address the impacts of climate change.[5] This report was reinforced by the National Commission on Energy Policy, which called for a cap-and-trade system to price carbon emissions throughout the economy and use market forces to advance the transformation to cleaner

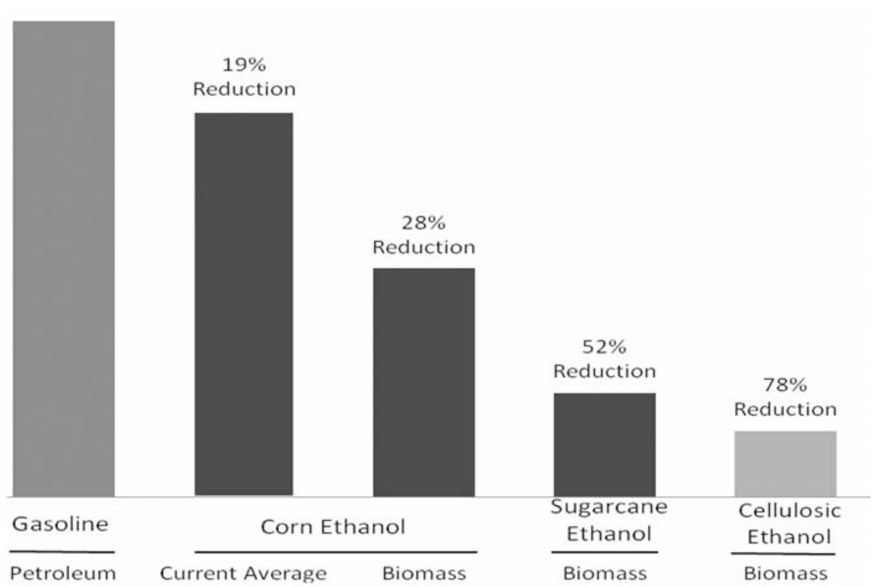

Figure 3. Lifecycle GHG Emissions Associated with Different Fuels, compared to Gasoline
Source: John Ferrell, U.S. Department of Energy, 2008

energy sources. The stage was set to revisit ethanol alternatives when yet another unexpected driver emerged.

Studies showed that MTBE (methyl tertiary butyl ether), a common fuel oxygenator widely used in the U.S., was contaminating soils and groundwater, prompting a number of U.S. states to ban MTBE from their fuel supply, beginning in 2004. Federal regulations required that gasoline be oxygenated for air quality reasons and ethanol replaced MTBE in a variety of gasoline blends in order to meet these standards. Individual states adopted different fuel blends within the larger federal air quality framework, using more or less ethanol depending on local circumstances. For example, California was concerned about nitrogen oxides (NOx) emissions, and unsuccessfully sought to eliminate MTBE without substituting ethanol. Despite this patchwork approach, MTBE bans did increase the use of ethanol nationally. While a federal ban on MTBE stumbled, Congress refused to provide MTBE distributors with liability protection against pollution damage suits, prompting the remaining distributors to switch to ethanol voluntarily in 2005 in order to limit their risk.

In 2005, driven primarily by concerns about energy security, Congress established the first federal renewable fuel standard, requiring that 2.78% of the U.S. fuel supply come from renewable sources (two decades after Brazil had started its effort). Lacking second-generation fuels made from cellulosic feedstocks, these mandates depended universally on corn ethanol and demanded increasing portions of the U.S. harvest. These moves led farm organizations to see ethanol as a

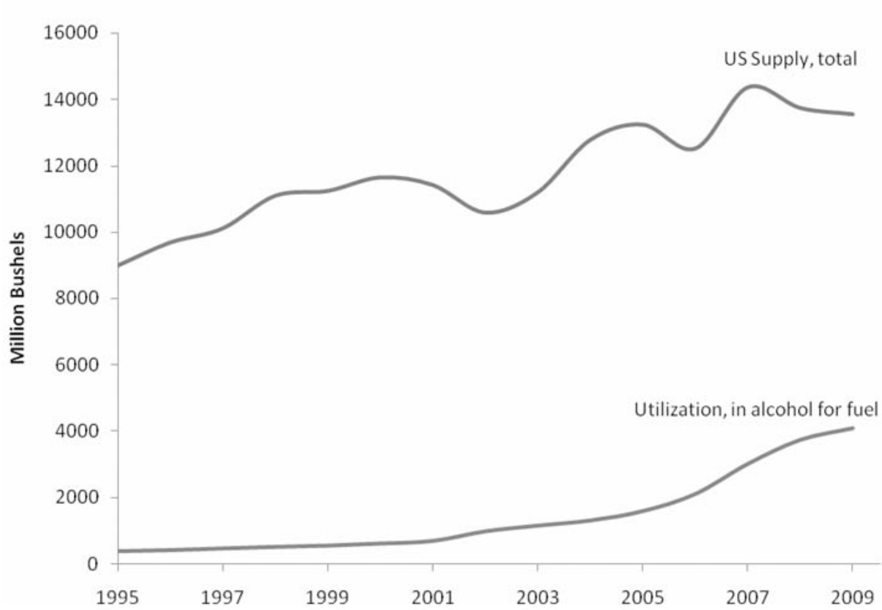

Figure 4. U.S. Corn Supply and Ethanol Demand, 1995-2009

Source: Feed Grains Database, Economic Research Service/USDA

new opportunity to restore prosperity in rural areas. They strongly backed efforts to create a market for renewable fuels. Despite the earlier recommendations of PCAST, corn ethanol production in the U.S. climbed to 5 billion gallons by 2006, up 20% from 2005.[6] U.S. corn farmers responded to the new demand by planting significantly more corn (see Figure 4).

In 1998, with little fanfare, U.S. automakers had begun selling flex-fuel vehicles that could run on gasoline or a mixture of gasoline and up to 85% ethanol.[7] Up to 2006, they mainly promoted these vehicles in markets like Iowa where state policy had encouraged the use of higher ethanol blends. Recognizing a new marketing opportunity, Ford and GM quickly expanded their marketing of flex-fuel cars, stressing first and foremost the opportunity for energy independence and secondarily, the technology. Response proved limited, however, especially as U.S. gasoline refiners and distributors were not prepared to offer higher blends of ethanol on a national scale. In 2006, despite the very rapid growth, ethanol still only represented 3.5% of motor vehicle gasoline supplies in the U.S..[8] As in Brazil, the U.S. focus was strictly domestic and the country retained its duties on imports and subsidies to processors.

The rapid increase in production of both corn and ethanol drew renewed attention to questions of sustainability. Environmentalists contended that the rapid increase in U.S. corn production had negative domestic impacts: increased use of both fertilizers and water for irrigation, pollution of water with both nitrogen and phosphorus, and significant reductions in the acreages of conservation

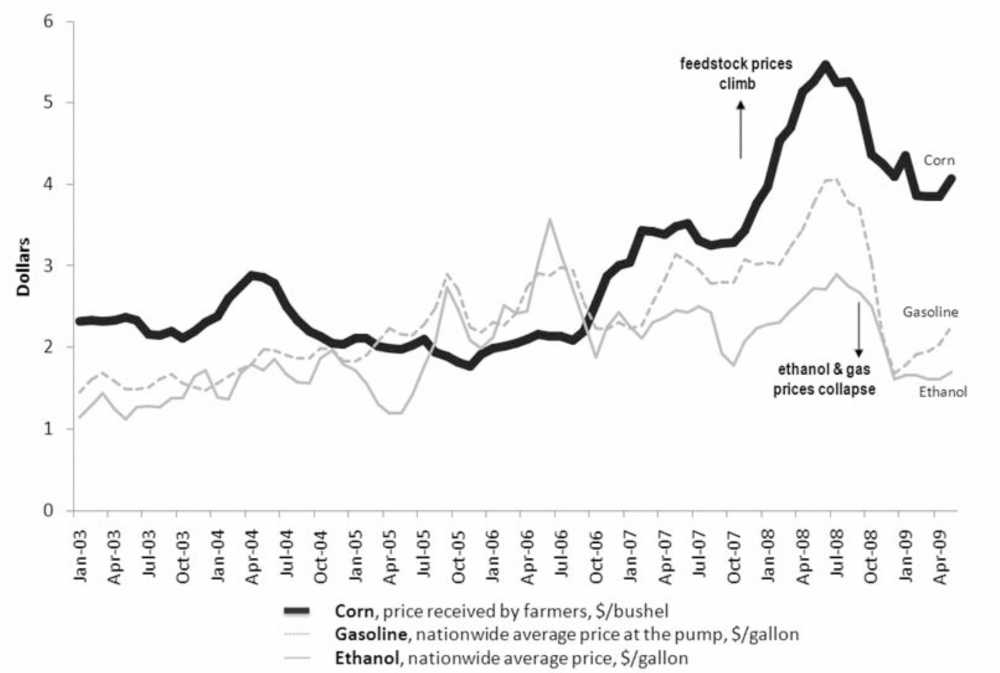

Figure 5. Ethanol, Corn and Retail Gasoline Prices 2003-Present

Source: EIA, Government of Nebraska, and USDA

reserves.[9] However, the key charge was that corn ethanol had no GHG advantage if life cycle analyses included indirect land use changes. In studies published in *Science*, researchers argued that using ethanol as a transport fuel would have no GHG benefits as long as deforestation in Brazil and other countries was driven by the diversion of U.S. corn acreage for ethanol.[10] This argument is often summarized simply: "U.S. corn production drove Brazilian soy producers to expand the agricultural frontier into the Amazon."

One of these researchers, Timothy Searchinger, estimated that, including direct and indirect land use changes amortized over 30 years, corn ethanol would produce 93% more GHG emissions than gasoline. He also challenged the positive assessment of sugarcane ethanol, by arguing that the expansion of sugarcane had displaced livestock producers, who also pushed into the Amazon. This research remains controversial and Dr. Goldemberg addresses its results from the Brazilian perspective, arguing that sugarcane expansion occurs so far from the Amazon that it is impossible to assume it has indirect impacts on deforestation. Searchinger's work, however, raised serious doubts in policy makers' minds about whether GHG reductions could be achieved with liquid biofuels, tempering the early enthusiasm.

But the environmental debate was quickly overshadowed by the economic debate. In mid 2007, global grain prices rose sharply and much of the increase was immediately blamed on biofuels, despite clear evidence that much of the increase in food prices resulted from a combination of factors including Australia's drought, increased global demand for meat, and controls on grain exports. The rising commodity prices made grain feedstocks, especially corn and wheat, more costly for ethanol producers and ate into their already slim margins. Humanitarian experts, nongovernmental organizations, and environmentalists called for a moratorium on biofuel mandates in the EU and the U.S. to relieve pressure on grain supplies.

As regulatory mandates became less certain, investment in the corn ethanol industry started to slow. The increase in production costs and decline in investments was just the beginning: petroleum prices declined in the second half of 2008, further eroding the economics of corn ethanol, and the financial crisis further constrained investment and credit. Over the winter of 2008, many U.S. plants were idled and some large producers went bankrupt. Meanwhile, sugarcane ethanol retained its market position in Brazil. Sugar prices spiked only briefly and cane-based ethanol remained competitive, even at lower oil prices (see Figure 5).

DEVELOPING COUNTRY PRODUCERS

Dr. Goldemberg highlights the ethanol export potential for developing economies based on legislative mandates in the U.S. and the European Union, particularly given the U.S. plan to expand renewable fuel use to 36 billion gallons annually by 2022. However, the size of the U.S. market for imported ethanol is constrained particularly by a Congressional preference to protect corn ethanol production. Other nations may find opportunities to enter this market if blending mandates outstrip domestic production, but past practice suggests that Congress would adjust the mandate rather than open the market to imports. Brazil will likely dominate any opportunities to supply the U.S. market, as it remains the high-volume, low-cost producer. Under the current trade regime, Caribbean and Central American producers are importing Brazilian ethanol and re-exporting it to the U.S. These countries can supply up to 7% of U.S. ethanol consumption and remain exempt from import duties under the Central America and Free Trade Agreement (CAFTA)[11] regime. Considering its fleet structure, the European market is primarily focused on biodiesel and is less likely to present major opportunities for ethanol exporters.

One cannot underestimate the scale of Brazil's investment to build the modern, highly efficient, and flexible sugar and ethanol industry it has today. Few other developing countries have the finance, infrastructure, agricultural expertise, car industry, or strong central government required to duplicate Brazil's experience. However, each country can center its innovation and low-carbon growth around its own assets and unique national circumstances. Sugarcane ethanol for domestic or export markets may or may not be the best opportunity; for example, palm oil may be a much more important feedstock in Africa, given the preference for diesel in Europe, Africa's traditional export market.

Ethanol may be part of the solution for countries with major gasoline requirements, large distances to cover, urban areas with traffic congestion, and appropriate resources. But ethanol is far from a perfect substitute for gasoline. It supplies less energy by volume and takes on water from the atmosphere—so it requires high-quality blending and careful storage. Processing must be done close to feed-stock sources and sugarcane, in particular, must be processed within a few hours after it is harvested. Creating an efficient ethanol production system demands careful placement of multiple local processing facilities. Most importantly, ethanol is highly volatile and its transport requires careful handling.

One option for developing countries, particularly smaller producers, may be to create regional markets for a single ethanol-gasoline blend and establish policies to support these initiatives. For example, they might require gasoline refiners and distributors to meet a common fuel standard. A Central American and Caribbean regional policy could combine the elimination of subsidized petroleum and expand the use of domestic ethanol. That would encourage national sugar industries to become more efficient, generate local employment, and reduce dependence on imported oil. A regional market in southern Africa could take advantage of South Africa's refining capacity and market and the agricultural potential of its neighboring countries.

Ethanol may be part of the solution for countries with major gasoline requirements, large distances to cover, urban areas with traffic congestion, and appropriate resources. But ethanol is far from a perfect substitute for gasoline.

Given the complexities of using ethanol as a transport fuel, it may not be an optimal energy investment choice for countries where less than half of the population has adequate access to modern energy services (energy services include lighting, cooking, heating and cooling, water pumping, refrigeration, transportation and communications). Instead, investments in renewable energy, including modern biomass fuel options, and in alternative energy technologies (solar, wind), are much more likely to expand energy access at the village level and to have greater impacts on livelihoods and on sustainable low-carbon growth. For example, in West Africa, more than 70% of the population has no access to electricity; their primary energy source is unrefined biomass, which is both inefficient and unsustainable.[12]

African countries could assess the potential to cogenerate electricity at sugar production facilities, sending it either to local communities or the national grid. They may also see opportunities to process some of the sugar wastes as high-protein animal feed, a practice that is common in Brazil. In the African context, ethanol gel cooking stoves are an attractive replacement for unsustainably harvested wood and charcoal. Many African countries could find it useful to adopt Brazilian agricultural practices, not just for sugarcane, but for a variety of crops.

Indirect Land Use Change (iLUC)

Heated exchanges on indirect land use change (iLUC) have occurred in the U.S. as the Environmental Protection Agency has undertaken life-cycle analyses of biofuels in compliance with the 2007 Renewable Fuel Standard; the California Air Resources Board has also recently published its analysis of fuels under California's low carbon fuel standard. Brazilian producers of sugarcane ethanol may have been frustrated to see analysts attribute Amazonian deforestation to their expansion, but U.S. corn growers were furious when they saw Amazonian deforestation via changes in soybean production attributed to their corn ethanol. The debate about how to accurately attribute indirect land use changes to particular biofuel feedstocks is somewhat intractable at this stage, critical though it might be to meeting the larger challenge of climate change mitigation in the transport sector. Data are scarce, methodologies diverse, and results are considered highly political. Pending the widespread availability of economically viable second-generation or cellulosic biofuels (and potentially even after their arrival, given global limitations on biomass production) the debate will continue to rage on how to best account for the full GHG impact of biofuel feedstocks.

To address findings about emissions from iLUC, Brazilian ethanol producers and academics have collaborated on their own research into this issue. They report that sugarcane production is so efficient that it limits the amount of new land that must be brought into use. Furthermore, they find that meat production is becoming more efficient on a per hectare basis, reducing its encroachment on forests. Finally, the rate of annual deforestation is now slowing, compared to the recent past. These analyses, while important, would be significantly buttressed by a full national accounting of greenhouse gas (GHG) production.

A national accounting system, includings sinks and sources, would eliminate the need to track or estimate the indirect impacts of the decisions by farmers or policy makers in the U.S., EU, or elsewhere. As Michael Obersteiner and others have argued, a full carbon accounting that covered all carbon-related components of terrestrial ecosystems would mirror "what the atmosphere sees."[13] In this model, international annual or bi-annual reports would track the flow of GHGs, both into sinks and out of sources. If Brazil were already producing a full carbon accounting on a regular basis, it would be significantly less open to accusations of rogue emissions. Brazil has fulfilled its commitments under the U.N. Framework Convention on Climate Change, producing a single National Communication with emissions data from agriculture, forestry and land use change up to 1994. A second National Communication is underway. This lack of firm data creates the opportunity for wide-ranging estimates of emissions and emission trends and attribution to a diverse set of drivers.

As sustainability criteria are established for biofuels, through regulatory or voluntary processes, Brazil and other larger producers would find that increased transparency is in their own interest, protecting both the larger biofuels market and their own reputations within it.

Optimizing the management of biomass to improve productivity and sustainable production and use could make the transition to modern energy services a foundation for the rest of the economy.

CONCLUSION

Dr. Goldemberg has advised developing countries to examine their current development and energy paradigm in light of potential opportunities and Brazil's historical experience. That experience is clearly relevant to any sugar-producing country. But the more important lesson is Brazil's overall investment in its agriculture sector, which is among the most efficient in the world. While Brazil remains a major exporter of agricultural commodities, it continues to expand its value-added processing systems. Much like the U.S. in the 1960s, Brazil is not only a major agricultural producer, but also an industrial powerhouse. Few countries, however, have a domestic market that can support initiatives like *Pro-Alcool,* and the start-up costs would likely be prohibitive.

The U.S. had many opportunities and the scientific research base to use various "oil shocks" to drive changes in its energy mix, but the status quo politics proved too powerful for such a shift to occur. This underscores how difficult the transition to lower carbon alternatives will be without resources and policies to underpin it.

Still, Dr. Goldemberg's examination of the role ethanol played in Brazil's economic course is important as it highlights the necessity of making new energy choices in this century. As the world moves from fossil energy to more sustainable and less carbon-intensive options, there are a range of choices. It is easy for sugar producers to also produce ethanol, but it may not optimize potential benefits unless other factors are in place, including a domestic market and refining capacity. It is vital that countries be able to analyze the options rather than pursue a single course of action. There are many lessons to be learned from Brazil's experience, but they are centrally about market flexibility and resource optimization rather than ethanol alone.

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Shai Agassi

World Without Oil

Better Place Builds a Future for Electric Vehicles

Innovations Case Narrative:
Better Place

So, how exactly would you run an entire country without oil?

Early in 2005, at the World Economic Forum for Young Global Leaders in Davos, someone asked me, "How would you make the world a better place by 2020?" No one would have thought to call me an environmental crusader back then, and I was more focused on my job as an executive at SAP. However, as I thought about my answer to the question, it became increasingly clear that ending our addiction to oil, and therefore running an entire country without it, would be the most significant progress we could make. That is why, eventually, I founded Better Place.

One needn't be an environmentalist to see the immense costs of oil dependence. First, it is economically and physically unsustainable. Oil is a finite resource whose price will only rise in the long run, compared to sustainable resources that are not finite and normally become cheaper over time. Further, it has a highly volatile price that, given the volumes and prices in question, can have massive impacts on the global economy (see Text Box 1). Even countries that produce oil seem to understand this: The United Arab Emirates invests all of its oil profits in sectors that will be sustainable in the long run, including tourism, financial services, media, education, and even alternative energy. Beyond the economic concerns,

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The macro-economic impact of oil

Switching from an oil-based transportation sector (and by extension, an oil-based economy) to an EV world would constitute the largest economic dislocation in the history of capitalism. That makes it vital to note the potential macroeconomic impact this switch might have.

In fact, a recent study at the University of California at Berkeley, published this June, analyzed our company model quite specifically.[1] The first step in determining our macroeconomic impact was to figure out roughly what sort of market share EVs would have, at both a baseline level of gas prices and a high-price scenario. Even at the baseline, they projected that EVs will have 44% of market share by 2025, and 80% if the high-price scenario develops. They further projected that the total cost of owning an EV would decline from roughly equal to an ICE at the current baseline-price scenario to less than half of that by 2030; the difference was even more stark with the high-price model.

One of the most important macroeconomic impacts this shift presents is in the balance of trade. Of the current U.S. trade deficit, 40% to 50% stems from oil imports; by 2030, in our model, those imports will fall 18% to 38% depending on the oil price scenario. This would have the same impact as eliminating all imports from Saudi Arabia and Venezuela: each year we would redirect between $90 billion and $260 billion back into the domestic economy.

Also essential to the shift is the impact on employment. Being at the forefront of the EV switch could be a way for currently struggling U.S. automakers to re-tool and regain their competitiveness. In addition, jobs will be gained in the sectors of battery production and charging infrastructure, while they are lost from service stations and parts suppliers. However, the study projected that this will lead to a net creation of 10,000 jobs in the U.S. alone.

The study even explores how much the U.S. would save on healthcare costs from a cleaner atmosphere and concluded that we would save $22 billion to $40 billion every year, roughly 1% to 2% of 2008 health care costs.

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we find that our addiction to oil also leads to the greatest transfer of wealth in history—mostly to countries that don't share our democratic principles. Ending our addiction to oil ends this immense geopolitical cost.

The final, and most important issue, is the impact that an oil-reliant economy has on the environment. CO_2 emissions have already caused catastrophic changes in climate that are well documented, and tragically those changes will continue even after we rein in the current rate of carbon emissions. Arguments about geopolitical and economic interests will be utterly irrelevant unless we significantly curb the steady flow of carbon into the atmosphere, and soon. Fifty years from now, in an oil-dependent economy, we will have one political issue: finding a way to make the planet habitable. Meanwhile, oil presents plenty of other environmental issues such as local air pollution (which causes immeasurable negative health effects, including death) and oil spills in the open ocean or other forms of contamination that destroy environments and are extremely costly to clean up.

The transportation sector accounts for nearly half of oil use worldwide, making it the natural place to start considering how to end our oil addiction. My project for Davos was to figure out a framework for ending our addiction to oil in our transportation system; I hoped not to rely on a government mandate or on technology that would require a scientific breakthrough to be feasible.

The Better Place business model starts with a fundamental rethinking of the role the battery plays in an electric vehicle and in the business model of personal transportation. From there, all major problems with electric vehicles are solved.

Electric Vehicle (EV) technology is here already, and completely implementing EVs would lead to a massive reduction in oil dependence. The only barrier between EVs and widespread adoption is a coherent plan that would allow them equal or better performance, usability, and affordability when compared to traditional internal combustion engine (ICE) cars.

The Better Place solution evolved from the understanding that people have a social contract with their vehicles and that a mass transition will occur only if the switch to EVs is a seamless one for the driver. Therefore the EV must be similar to an ICE vehicle in terms of size, driving experience, driving range and price (see Text Box 2). The Better Place business model starts with a fundamental rethinking of the role the battery plays in an EV and in the business model of personal transportation. From there, all major problems with EVs are solved. Car manufacturers have historically regarded the EV's battery as a fixed piece of the car. But what if they saw the battery as a separate component? Then the consumer would not necessarily have to own it. At Better Place, we view the battery as a consumable and as part of the infrastructure. We remove that cost from the consumer. We sell miles—or mobility—much as people purchase minutes for their mobile phones.

This facilitates the most important innovation of our model: switchable batteries that extend the vehicle's range, and can be switched at Battery Switch Stations (BSS) which will be installed along major highways. A driver can stop at one of these carwash-like installations and have a battery swapped out for a fully-

What kind of cars will they be?

To make a real difference, we need a solution that is scalable to the world. However, we cannot expect anyone to purchase an electric vehicle unless it can compare to an ICE car in terms of price, convenience, and performance. These basic demands essentially constitute a social contract as to what a car is and what it should provide, and if we fail to meet that social contract then the EV is not really a car at all. We cannot be selling a glorified golf cart. Therefore, I have always demanded that EVs must be more convenient and more affordable than what consumers currently get today with gas cars. So what exactly is that social contract for a car? I think there are five distinct elements:

"*It's my car.*" It needs to look like a real car, and be something you can actually be proud to call "my car." We are seeing that this is actually quite easy to achieve as Fisker, Tesla, and Nissan-Renault have all come up with EVs that look just like ICE cars.

Equal or better performance. EVs have all their torque available instantly, so the acceleration is linear and smoother than with an ICE. In fact, for normal driving, the acceleration is usually noticeably faster at lower speeds or in quick bursts, like a 0-to-60 push.

Sufficient space for cargo and passengers. If a normal sedan does not have five seats or room for a respectable amount of luggage, then it loses a lot of the freedom of transportation that cars are supposed to bring.

Affordability. Price is 85% of a consumer's decision at a dealership. Producing cars at scale and with our unique model should quickly solve the up-front price problem. As for operational costs, ICEs are twice as expensive to run per mile and the EV cost is likely to decrease over the years while the ICE cost only grows. Finally, the servicing is even cheaper.

Convenience. The average customer has to stop about 50 times a year for 5 minutes to fill up with gas. The EV has to, and can, be quicker. Charging reduces the frequency of stops, and switches have been performed in as little as 60 seconds. If we are not more convenient than an ICE in terms of the number or length of stops, we do not have a business.

charged one in less time than it takes to buy a tank of gas. This will give drivers essentially unlimited range, just like any ICE car now enjoys with the current infrastructure.

In addition to these switch stations, ubiquitous charge spots will exist in each major location where a typical consumer parks (at home, work, shopping malls, and downtown areas); these will allow people to continually charge their batteries in a way that renders moot the everyday range issues. Of course, a typical car is parked for 22.5 or more hours out of a 24-hour day, so the charge spots themselves will almost always be sufficient. Batteries have a range of roughly 100 miles, so people will only need to use a BSS when they are driving over 100 miles in just one leg, well beyond most normal commutes. The infrastructure costs of this plan are also smaller than one might imagine because the charge spots do not have all the "smart" technology (which is mainly stored in the car). The switch stations rely on a simple robot that moves in one-dimension; they do not need the comprehensive equipment and staffing of today's ordinary gas station. Finally, the switch stations will use renewable clean electricity (such as solar or wind), allowing each car to have a carbon footprint of zero.

Before January 2005, I knew very little about the issues presented by an oil economy. I started several software companies, the last of which we sold to SAP, and was in line to become CEO there one day. Even after the Davos conference, where I first proposed getting the world off oil, I never seriously thought it would become my livelihood and indeed my life.

While doing research in the lead-up to that conference, I had to decide what path to take towards my goal. The first step was to determine which sector to focus on. I looked across the board, from home energy usage to power generation. But transportation caught my eye: not only does it represent nearly half of world oil usage, but it is also widely regarded as the most difficult to address, given the entrenched need for infrastructure among other issues.

Various "solutions" to this problem have been getting play in the media over the last few years, leading to a lot of discussion about which solution will work in the end. I researched all the potential solutions myself, and the answer I came to was electric transport.

Ethanol was, a few years ago, the most talked about "solution" to the oil problem. Indeed, ethanol is renewable, and has the potential to replace oil. But it cannot solve the trickier issues related to oil—and is not entirely feasible. If every square mile of land on earth was covered in Amazonian rainforest that could grow sugar cane like that used to make ethanol in Brazil, the world would have enough ethanol-generating material. But the world does not have that amount of arable land—so ethanol is not feasible as a worldwide solution. Moreover, in ICEs, ethanol delivers fewer miles per gallon (mpg) than gasoline, and it does emit CO_2. Ethanol is not nearly as energy efficient as electricity: it takes energy to create it and ICEs are naturally inefficient. And ethanol is corrosive and cannot be transported through pipes, making it impractical. Finally—and most crucially—it distorts prices on corn, sugar cane, and related food goods, making it harder to feed the world.

Similarly, the "Hydrogen Economy" was championed by the previous administration—but it also faces problems. First, it has been the energy of the next decade for the last four decades, and is still decades away from being in any way a reality. Second, hydrogen fuel requires more energy to produce than it produces when burned; that's a negative energy equation. Finally, fuel cell cars are prohibitively expensive. The infrastructure issues are also massive, and would require a complete overhaul. Dr. Stephen Chu, the United States Secretary of Energy and a Nobel Prize winner in physics, recently rescinded all government funding for hydrogen.

Plug-in Hybrid Electric Vehicles (PHEVs) are now in fashion, epitomized by the recent Chevy Volt. Although PHEVs are indeed much more environmentally friendly than an ICE or a standard hybrid, the addition of the "range extender" in the form of an internal combustion engine and gas tank causes enough problems to doom it entirely. First, it does not remove us from the oil economy. Second, price is a deal-breaker: with a range extender, the car would cost twice as much as a similarly practical and capable car. Finally, it is debilitatingly heavy, making it harder to achieve efficient energy use and performance equal to ICEs.

We have even heard some noise lately about Natural Gas (NG) as a potential source of power for cars. But, like ethanol, it still emits carbon; like oil, it is a finite resource. It would require the same sort of overhaul of infrastructure that hydrogen would, but would not ultimately solve any of the problems related to oil. Therefore, at best, it is a "bridge" solution, but not one worth investing in if we have better technology already in place.

Electric cars, on the other hand, offer a full solution and the technology is already available. EVs use resources far and away more efficiently than any other system. The principal piece of infrastructure already exists: the electric grid. EVs emit absolutely no carbon, and they can be produced affordably at scale with no need for any technological advances. EVs are also cheaper to operate than ICEs, and even come with lower maintenance costs because the engines have fewer moving parts.

So why are people not already buying EVs? The two main reasons start with the battery: high upfront cost and a limited range.

At the moment, EVs cost significantly more up front than comparable ICEs, mostly due to the battery cost. Although this cost will drop over time as battery density improves (by roughly 50% every 5 years) and with scale, it will remain the single most expensive component in the car for the foreseeable future.

No matter how much battery density improves, however, it will always limit the range. Once the battery hits the end of its range, it must be recharged for hours if we regard the battery as a fixed unit. This "range anxiety," the driver's fear of reaching the end of the charge and not being able to go anywhere for hours, is especially prevalent in markets like the United States that have many long-haul routes and consumers accustomed to great mobility. "Range anxiety" is less of an issue in emerging markets like China and India, where people will be more than satisfied to have any range at all.

EV infrastructure is also far behind what is needed to encourage widespread adoption. Imagine a parallel: the cell phone revolution is peaking but we have no cell towers to transmit calls. The car is not a complete product in itself: the actual product is personal mobility. Therefore, the complete product relies on the infrastructure being in place before people start buying the cars themselves. If we wait until 100,000 people buy EVs before we build EV infrastructure, everyone will wait until they can be the 100,001st buyer, and we will never get there.

Also, EVs will likely have a substantial impact on the electric grid. If electricity flowed automatically to any EV at the second the owner requested it, that would create a load on the system throughout the day and often right at peak hours, like the minute the driver gets home from work. That would mean that electric companies would have to expand capacity to match every single new electric car, watt for watt.

Finally, many of our climate goals could be defeated by the tailpipe-to-smokestack effect. That is, if the extra energy produced to drive EVs is itself derived from fossil fuels and thus causes carbon emissions, we are not significantly cutting a car's carbon footprint. Emissions would merely move from the tailpipe of the car to the smokestack of the power plant that runs on coal, oil, or another fossil fuel.

For two years after the 2005 Davos conference, I spent whatever free time I had learning about the energy sector and researched solutions to the issues described above.

I started with the science, with what I actually had. Starting from that perspective led me to the conclusion that solutions other than electrons are neither short nor long-term solutions. Any time we turn energy into a molecule (such as oil) and then turn that molecule back into energy, we lose energy along the way to heat and other by-products that are useless to our end goal of propulsion. Electricity was scientifically ideal.

After evaluating technologies for fast-charging batteries and dismissing it as a possibility, I first had to find a way to eliminate the issue of range anxiety. For me, the "Eureka!" moment came when I concluded that the fastest way to gain a full charge would be to simply swap out the battery, much like swapping computer batteries during a long flight. Here, the car industry had made a conceptual error: regarding the battery as a fixed unit within the car, which could not be removed easily or quickly. In addition to the range and price impacts I mentioned above, I saw another consequence of having a battery that was non-removable and consumer-owned: What happens when a battery becomes obsolete and better ones have appeared on the market? Allowing easy transfer solved this smaller problem, as well as the two broader ones of range and up-front price.

The concern with obsolescence became even more important once I considered the rate of battery development. As I said above, the energy density of batteries typically improves by 50% every 5 years, or around 8% to 10% per year. This means that consumers would continually have obsolete technology with fixed batteries in a product (a car) that they ordinarily own for much longer periods of time than other consumer products with similar innovation curves.

Now it might be tempting to regard this improved density as a step towards expanding the range for all EVs, when in reality it could be much more usefully allocated towards a smaller, lighter, and cheaper battery. Most of us make few trips longer than 100 miles one way; the typical driver does it five times a year. Therefore, a longer range is not nearly as desirable as a lower cost option. Drivers would have no reason to pay a premium for a 300-mile-range battery if they could

The Oil Whiplash Effect

At its peak, in the first quarter of 2008, global oil demand stood at 87 million barrels per day (Mbbl/day).[1] Current predictions for global oil demand for 2009 vary from 82.6 Mbbl/day to 84.9 Mbbl/day, according to the International Energy Agency.[2]

The decreased demand is largely a result of the current economic crisis, with people driving and flying less often than they did before: Over the course of 2008 drivers of motor vehicles decreased their miles driven by up to 3.6% compared with their driving habits in 2007, and in the first four months of 2009 that figure dropped by an additional 1.1% compared with data from the same months in 2008.[3] Similarly, the number of flights taking off or landing in the U.S. in 2008 was 4.8% lower than in 2007, and the figures for the first quarter of 2009 were down more than 8.5%, compared with that quarter of 2008.[4]

Yet this decline in demand is predicted to be temporary, given the predicted growth in global fleet size, and the expected economic recovery. The UN predicts that by 2010 some 939 million vehicles will be moving along roads around the world, compared with only 751 million vehicles in 2002. It breaks down that growth as a 15% increase in the fleets of nations in the Organization for Economic Co-operation and Development (OECD), and a whopping increase of more than 73% in the fleets of the non-OECD nations, such as China, India and Brazil. It predicts that the global fleet will reach 1.26 billion vehicles by 2020, and 1.66 billion by 2030.[5] Considering that each 25 million vehicles require 700 million barrels of oil a year, or approximately 2Mbbl/day, we can expect oil demand to grow dramatically, by 26Mbbl/day, just to account for these new vehicles.

The trend toward increased demand in the very near future is troubling: Increased demand will drive up the price of oil, just as we are moving out of the current recession. Not only do prices affect the behavior of the end consumer; more importantly, the price of oil is linked with national and global economic growth and GDP. On the national level, meaningful oil price increases have preceded nine of the last ten recessions in the United States, including the current one. The one exception was the 1960 recession; see Figure 1.

These data demonstrate not only the link between the two but also the causal relationship between them: the increase in oil price *precedes* the drop in GDP, and thus supports the claim that these increases are one cause of the drop in GDP, and not the other way around.

The figure also shows an asymmetry in the impact of changes in oil prices. Increases in oil prices have a larger impact on GDP than do declines in oil prices.[6] Thus, the economy is hurt much more by price increases than it is helped by price decreases. This asymmetry means that the economy is subject to the disadvantages associated with increasing oil prices without getting nearly as many benefits from any potential declines.

The harmful link between oil prices and GDP puts our economy at risk and makes us more vulnerable to global economic trends. Because oil is a commodity that can be traded across the world, its price is affected by the economic and supply/demand trends of different countries. This means that with the anticipated fleet growth in India and China, demand for oil in the next decade is anticipated to rise substantially, and thus affect the national price of oil as well.

Indeed, many experts are predicting another price shock once the current recession eases. A report this spring by McKinsey and Co., "Why energy demand will rebound," indicates the potential for yet another price spike between 2010 and 2013.[7] Eliminating our dependence on oil will break this cycle and insulate the economy from this volatile market.

One key way to minimize the impact from increases in oil prices is to eliminate its use in the passenger vehicle sector by switching to electric vehicles. Given that over 60% of the oil demand in the U.S. was used for transportation and that the U.S. car fleet is growing dramatically, focusing efforts on that sector will provide the greatest leverage to break the link between oil price increases and recessions.

Electric vehicles are the only technology available today that could be mass-produced in a short time frame to promote the effort of decoupling our economy from oil. Reducing our dependence on oil will help secure our economy, while improving our air quality, reducing our carbon footprint, and increasing our national security.

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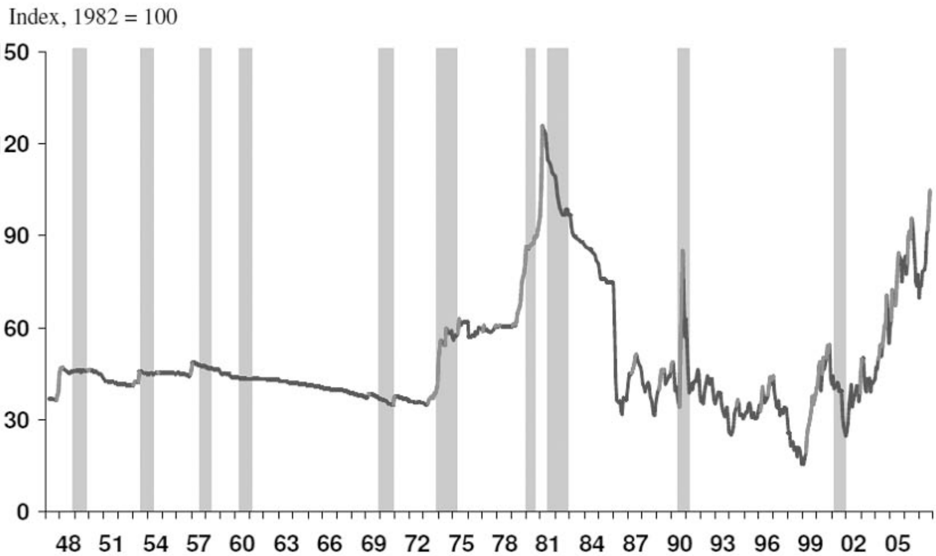

Figure 1. Figure 1: Real oil price (blue line, sustained price increases in red) and recession (shaded in gray)

Source: Stephen Brown, of the Federal Reserve Bank of Dallas, at 2008 Conference of the U.S. Energy Information Administration, "Globalization, Oil Prices and U.S. Economic Activity."

switch and have the same effective range.

Once I had completed my scientific research and innovation, I had to create a business model to implement these findings in a way that could actually have an impact on a worldwide scale. Since all the technology already existed, it was obvious what we needed: not a technological innovation but a business innovation that would set up a meaningful market shift.

At first, as I considered what organization would deploy the infrastructure and manage the network, I envisioned a governmental agency. The government traditionally controls matters of infrastructure and electricity, so an extension into EV networks seemed logical. But offering a competitive market solution would be much more effective in enticing customers and also had the potential to be profoundly profitable. It would also facilitate competition within the industry that might not be ideal from an individual firm's perspective, but would certainly help Better Place to eventually realize its goals.

Having decided that a private venture would be the best vehicle for conversion, I then had to figure out how to create a network that would not be prohibitively expensive to install yet would be comprehensive and thus fully functional for consumers. The first step would be blanketing the target region with charge stations. People tend to park in four key locations: their place of residence, their place of work, shopping districts and malls, and downtown areas. If we provided charge spots at all these locations, most consumers would always have a place to plug in and therefore maximize the benefit of using our network. To make this work that network would need to have approximately 2.5 charge spots per EV, so charge spots will need to be ubiquitous at full deployment. Switch stations would be located roughly 30 miles apart, mostly on highways between urban areas, to assist with commutes and long trips when needed.

But how could we roll out millions of charge spots if they were prohibitively expensive? We designed charge spots that are not stuffed full of computer equipment and instead put the computational and network power into the cars themselves and a network management hub. A consumer would flash a card at the charge spot, which would communicate with the on-board computer system, telling the charge spot to start charging based on the consumer's usage plan. This lets us build cheaper charge spots than in other models that build network software and credit-card-reading mechanisms into each and every spot. Also, as I said earlier, the simplicity of the BSS robot, with only one arm that moves in just one dimension, should keep costs down.

Where does the margin exist in our model, given the infrastructure costs? Quite simply, it comes from the fact that electricity is far cheaper than gasoline. Even the most expensive electricity (such as solar, which is steadily becoming cheaper) costs approximately 2 cents for a mile of EV usage in the U.S. Factoring in the cost of the battery, it costs roughly as much to operate an electric car as to operate an ICE vehicle on gasoline at $1.50 a gallon, with a barrel of oil costing about $25.

So where does the margin exist in our model, given the infrastructure costs? Quite simply, it comes from the fact that electricity is far cheaper than gasoline. Even the most expensive electricity (such as solar, which is steadily becoming cheaper) costs approximately 2 cents for a mile of EV usage in the U.S. Factoring in the cost of the battery, it costs roughly as much to operate an electric car as to operate an ICE vehicle on gasoline at $1.50 a gallon, with a barrel of oil costing about $25. That does not include maintenance costs or depreciation, two elements of operating costs that should also be favorable for EVs. Over the long term, oil prices will likely never again fall below $50 a barrel, and $1.50 a gallon is unheard of in the U.S., let alone Europe where the difference is even starker. Oil remains over $50 a barrel today, and that is in the midst of recessionary conditions. Once the economy recovers, oil demand (and therefore price) will recover with it (see Text Box 3). Consider some numbers. It costs roughly 16 cents a mile to operate an ICE car, and 8 cents a mile to operate an EV. When battery prices fall and clean energy is cheaper when produced at scale, the operating cost of an EV should be 4 cents a mile by 2015 and 2 cents a mile in 2020.

The next problem has to do with acquiring electricity. The problem of strain on the electrical grid is an important one, but can be avoided easily. Network management software can schedule car charging intelligently—around the low-demand periods of the day such as late at night when most people are asleep. That will let drivers take advantage of cheaper electricity that will be more readily available, and therefore not significantly increase the total capacity needs of the electric grid. For example, you might plug in your car at 5 pm when you get home, but it would not start charging until 10 pm or later, whenever the software determined that the network load was low and the costs cheaper. If you suddenly needed to run out on an errand, your car would likely still have enough energy to do what you need, but even if it didn't, you could find a switch station. If this sort of network management existed, electric grids would only have to expand their capacity by roughly 6%, which is relatively easy to do compared to the expansion necessary for non-managed charging.

Of course, it is essential to our goals that all this expansion of energy come from clean sources, such as solar and wind. We cannot guarantee that every electron in your car is clean, but we will guarantee that for every electron you use, someone will be generating a new one that is clean. Given that it would take about 10 years to switch a country from fossil fuels to clean sources, we are talking about expanding the grid with clean energy, by just half a percent per year.

Given that both solar and wind are intermittent, the EV actually solves yet another problem. Electric grids have remarkably little storage capacity. Reserves are kept for unexpected demand spikes and usually cannot be recovered when they go unused. However, if millions of EVs with large batteries were on the network, they would provide an excellent resource for energy storage. For example, wind is often at its most productive at night, but demand at night is often low. But combine EV batteries with the network management software, and all the excess electricity generated by wind power by night (or solar power by day) can be stored in EV batteries during non-peak usage times late at night and used as a buffer on the network. This solves a previously tricky problem in making renewable sources effective. More importantly, this is one more step in negating the tailpipe-to-smokestack effect.

Solar and wind energy are often criticized as being prohibitively expensive, and indeed they are more expensive than certain other non-renewable energy sources. However, in this context they should really be compared to the cost of gasoline, the comparable propulsion method for cars. To supply an entire nation's car fleet with enough solar and wind energy for the next 50 years would require the same amount of money it costs to import and refine crude oil for just one year. Viewed in this context, solar and wind are in fact remarkably cheap. In the U.S. we spend $300 billion a year on oil imports. To give an example from Israel, we asked the government if they would be willing to build a 2 gigawatt power plant in the desert. They were put off by its size, so I framed the question differently: What if we found oil in that exact same region? They said they had tried and knew there was none. I said I knew there was, and that I could prove it. Just let me drill *up*, build a power plant, and supply enough power for Israel's entire car fleet. Better yet, *this* oil will not run out.

By late 2006, I had figured out the technological kinks in the business but I saw my plan as no more than an innovative idea that someone else, be it a government or an entrepreneur, would eventually take up and make their own. In December of that year, Haim Saban kindly invited me to present my idea at his annual forum of American and Israeli leaders. After I gave my presentation, former President Bill Clinton had a provocative critique: the idea was good, but what about the Average Joe consumer who buys a well-used car, drives it into the ground, and buys another? That sort of person, a large segment of the market, is not likely to go for a car at the "new" price, and therefore not likely to switch at all.

> Only in the very last days of 2006 did I start thinking of making a career out of my plan. Shimon Peres, the President of Israel, called me at home as I had just gone to bed after the Saban forum. He said, "You have a good idea, Mr. Agassi, now what are you going to do about it? If you believe in it but do not do it yourself, why would anyone else jump on it?"

After the Saban forum, we further developed our model on the parallel to cellphones. The auto market as a whole actually has some striking parallels to the mobile phone market, where the network and the handset are independently useless but together necessary and ubiquitous. The product that operates on the network is (relatively) expensive in either case, and both systems charge for usage. Mobile phone networks are owned and operated by private companies, and they have a starkly different business model than auto companies currently do despite those similarities. First, they charge based on usage of their network. Second, they sign customers to long-term contracts in exchange for which they will subsidize their handsets.

This cellphone-based model of business allows for some extremely interesting innovations in the EV business model. Of course, it allows service providers to own batteries and thus allows for the all-important battery switching; at the same time, it lowers the price of the car by something like $10,000 to $15,000. It also allows the customer to pay on a usage basis, much as we all do now for gasoline, but with a network that is ideally cheaper, more ubiquitous, and easier to use. Drivers would have no reason to buy used, inefficient ICE cars when they could get brand new ones that are cheaper to buy and cheaper to operate. This model also allows for value-added services such as network management software and emerging management planning for drivers that can point each consumer in the direction of the nearest available BSS or charge spot, as needed. It could even send the customer an instant message saying that the car is fully charged or that the charging was unexpectedly interrupted.

It is telling that someone so closely involved with oil would not only allow for a switch but would boldly support it financially, and that will become a theme. About a year later Business Week quoted Ofer as saying, "If I did not do it, someone would. What is the point of fighting something that is inevitable?"

But only in the very last days of 2006 did I start thinking of making a career out of my plan. Shimon Peres, the President of Israel, called me at home as I had just gone to bed after the Saban forum. He said, "You have a good idea, Mr. Agassi, now what are you going to do about it? If you believe in it but do not do it yourself, why would anyone else jump on it?"

He was all too persuasive, and convinced me to leave my job at SAP to go off into the uncharted territory of my new idea. He also set me up with Ehud Olmert, then Israel's Prime Minister, who said the Israeli government would support my project if I lined up enough funding and a major automaker to back my plan.

Realizing that funding would be difficult to come by without at least a tentative agreement from an original equipment manufacturer (OEM), Peres helped set up meetings with them a month later at the Davos 2007 conference. Only two of the five we invited showed up. But that was enough.

My meeting with Carlos Ghosn, the CEO of Renault and Nissan, changed the course of Better Place. Finding him surprisingly supportive of my plan, I asked if he was interested in hybrids. He said, "Hybrids are like mermaids. When you want a fish you get a woman and when you want a woman you get a fish." He hit the nail on the head: if you want gas car performance from a hybrid, you get a watered-down version, and if you want a clean environment you are still giving off substantial emissions. Moreover, only one million of the 500 million cars sold in the last 10 years are hybrids: a market share of just 0.02%. Even worse, hybrids are only about 20% more efficient than comparable cars, and therefore have almost no meaningful carbon impact on the world scale.

Ghosn immediately responded to my ideas and business model, and seemed to really appreciate its implications. His company had been doing research on advanced batteries and was technologically well prepared for the challenge. He promised that down the road his company could make fully functional EVs, compatible with our solution, at scale (Text Box 2 describes the sort of car we are talking about).

With Renault-Nissan on board, my next task was to line up funding for what remained a fairly audacious venture. Michael Granoff, the President of Maniv Energy Capital, pointed me in the direction of Idan Ofer, the President of Israel Corp. Ofer's company is one of the largest owners of oil refineries in Israel, and therefore stands to be affected the most by the switch to EVs. After we had met for several hours, he stepped into the elevator with me, and said he would support my venture with $100 million. I was floored, and not sure I believed him, but Ofer was deadly serious. In fact, he would end up contributing a total of $130 million to the project. It is telling that someone so closely involved with oil would not only allow for a switch but would boldly support it financially, and that will become a theme. About a year later *Business Week* quoted Ofer as saying, "If I did not do it, someone would. What is the point of fighting something that is inevitable?"

From there, Granoff helped me get funding from his own Maniv Energy Capital, and we acquired substantial funding from VantagePoint Ventures and Morgan Stanley, totaling roughly $70 million. Now, with $200 million in capital, and a major OEM as a partner, we launched Better Place in October 2007. We lined up partners for the various pieces of the supply chain, most importantly battery production (with Automotive Energy Supply Corp. and A123 Systems), and began working on target markets.

Given the support we enjoyed from President Peres and Prime Minister Olmert, Israel was a natural place to start. In addition to the policy support, however, Israel is an ideal place for our solution, for several reasons. It is a transportation island (if your car is leaving Israel it has probably been stolen). The longest route one could possibly drive is 250 miles. Most importantly, the geopolitical costs of oil dependence are extremely clear to every consumer in the country. Israel even has a fairly aggressive gasoline tax. On top of that Israel has a favorable tax scheme, which was recently revised; it ensures an approximate 80% difference between the tax rates of ICE cars and EVs, and will maintain a substantial difference of at least 30% in the long term. We announced Better Place Israel in January of 2008.

Hardly two months later we announced our next market: Denmark. Again, the region presented a uniquely perfect fit for our business. Denmark has a relatively small and contained landmass, wind is a principal source of energy, gasoline is extremely expensive, and the difference in tax rates between an ICE vehicle and an EV is staggering: 105% to 180% depending on the price of the vehicle. Denmark's reliance on wind is a perfect example of EVs solving the problem of intermittent energy sources. In fact, Danes pay Germany to take some of the electricity they generate at night (the peak time for wind) because they have no method of storage and demand is not strong late at night. With millions of EV batteries and intelligent network management, the cars will be charged at night, providing a much more efficient usage of the energy generated around those hours. We managed to secure €103 million in funding as a seed fund for the Danish company, and quickly set up an office on the ground.

From there, we have announced Better Place operations in Australia (beginning in Canberra), the San Francisco Bay Area, and Hawaii. As Renault and Nissan approach mass-market volumes in 2012, our next step is to get the infrastructure into the ground as fast as we can to help speed up the transition. Government programs to encourage EV adoption are essential, either from the supply side, the demand side, or via regulation such as those making it easier to acquire permits for charge spots. With a little government help and with OEMs taking notice of Nissan-Renault's commitment, EV growth can only be limited by the rate at which we reach agreements with new regions and put the infrastructure into the ground. Countries around the world are rapidly starting to pass EV legislation, and are looking to show leadership in the field. China, especially, with its $9,000-per-vehicle EV credit, is showing the western world the sort of decisive action needed to transition quickly and effectively. Now it is up to the United States and others to show leadership by taking action on their own and encouraging OEMs to help and foster the trend.

Daniel M. Kammen

Incremental and Transformational Change

Innovations Case Discussion:
Better Place

Shai Agassi's story of his evolving personal interest in energy issues, and the evolving business plan of his electric vehicle company, Better Place, provides an important lens on the pace and drivers of innovation.

First, as Shai describes, his interest in energy issues evolved from great success in the software industry. At a successful entrepreneur, Shai became inspired by the imperative to change our energy economy, and his recognition that his background and drive might be a unique advantage in becoming an agent of innovation and change.

The transportation sector critically needed, and still needs, this sort of fresh look and novel business model. For a period in the late 1970s and early 1980s, average vehicle economy in the United States rose steadily, due to the requirements for greater fuel efficiency through the Corporate Average Fuel Economy (CAFE) standards and the lingering worries over oil prices from the two embargoes of the prior decade. After that, however, little changed in the transportation sector. In fact, looking at Figure 1 we can see a clear trade-off in the trends in vehicle efficiency and performance: gains in vehicle efficiency were sacrificed for performance. Perhaps improvements in both could have been achieved. Undeniable, however, is the decades of stagnation in improvements in energy efficiency, financial savings, or carbon savings.

The petro-politics of the 1980–2005 period were tumultuous: the Iran-Iraq war, the first and second gulf wars, and the ascension of Japanese car companies to a leading global position. Out of this period different nations and companies took

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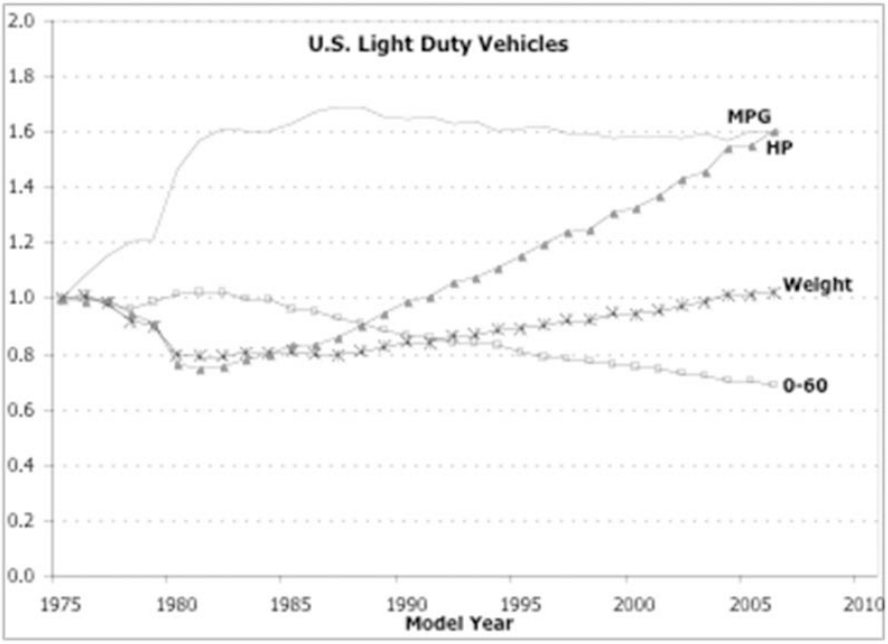

Figure 1. Changes in average mile per gallon (MPG), engine horsepower (HP), vehicle weight, and acceleration (0-60 speed).

The period of dramatic increase in vehicle efficiency from 1975–1983 (CAFÉ standards) can be seen clearly, as can long-term trends of improved performance despite increasing vehicle weight over the following three decades. These 'improvements,' however, clearly came at the expense of greater efficiency, which declined slightly over 30 years. Each of the data sets is referenced to a normalized baseline value of "1" in 1975.

very different lessons. The Japanese began to make greater efficiency—and then hybrid vehicle technology—part of their long-term plans. Meanwhile no clear message emerged from the US industry, beyond larger and larger vehicles and some interesting but largely short-lived efforts at developing electric vehicles.

All this can be seen, in retrospect, as a clarion call for new, fresh and innovative ideas. Shai Agassi is one of many entrepreneurs who took up the challenge. His model—leapfrogging over the emerging plug-in hybrid technology to go directly to pure electric vehicles—is notable and challenging at the same time. The benefit of pure EV technology, of course, is the complete removal from the car of internal combustion, and its associated ball-and-chain of engine and fuel weight. The drawbacks come in the form of a need to build market share today despite uncertainty over battery costs, battery charging standards, and battery technology that will surely evolve rapidly in the coming years.

In this new and changing landscape, Better Place planted its flag with a much-debated and questioned business model that is as innovative as the technology it embraces. Time will tell if the company can make this transition work; that may depend as much on the trends in oil prices and battery availability as the cleverness of the Better Place team. But the message is clear. While many are betting on improved internal combustion engines and greater efficiency standards, still more companies see the plug-in hybrid as the next new thing. Each of these views has merit: the incumbent technology—internal combustion engines—can clearly be made more efficient although such engines are ultimately limited by the thermodynamics of combustion. Plug-in hybrid vehicles offer a dramatic change—roughly two to three times the efficiency of internal combustion engines depending on the carbon content of the electricity supply used to charge the batteries.[1] By contrast, pure EVs, featured by Better Place and in other emerging models and business plans, offer a break from the vehicle designs of today, and could achieve even larger savings per vehicle, but they face the constraints of the logistics and costs of access to internal-combustion engine vehicles when needed.

In the end, in fact, this last point may shape the long-term success and popular judgment of the Better Place model: Can the infrastructure needs of the pure EV vehicle *systems* model be developed, disseminated and paid for in ways that make this business model a true challenger to a combination of improved internal combustion engine vehicles, plug-in hybrids, better mass transit, and improved planning? On this front the jury is out, but we vitally need a diversity of experiments, many of which we can hope will take hold in a low-carbon economy.

Endnote

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Frank Alix

Taking out the CO_2

Powerspan Helps Utilities Capture Carbon at the Source

Innovations Case Narrative:
Powerspan Corp.

As indications of global climate change and its inherent risks have become more apparent, the urgency to limit emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs) has grown. At the same time, rising worldwide demand for energy, driven by growing populations and improving living standards in the developing world, and by our increasingly electrified homes and businesses in the industrial world, has led to a steady growth in the use of fossil fuels. Today, fossil fuels account for 81% of the world's energy supply,[1] resulting in the release of 28 billion metric tons of CO_2.[2]

One of the largest sources of CO_2 emissions is coal-fueled electricity generating plants. Coal is the source of 49% of the electricity generated in the U.S.[3] and approximately 40% worldwide.[4] Economic, geographic, and political forces favor increasing use of coal as the most abundant fossil fuel, particularly in the US, China, and India; it also has the lowest cost, typically less than half of the cost of oil and natural gas per unit of energy.[5]

Experts agree that the only way to reconcile our increasing use of coal with needed CO_2 emission reductions is to deploy CO_2 capture and storage (or sequestration) systems (CCS) on coal-fueled electricity plants. The May 2007 MIT study, *The Future of Coal*, concludes that CCS "is the critical enabling technology that would reduce CO_2 emissions significantly while also allowing coal to meet the world's pressing energy needs."[6] The Intergovernmental Panel on Climate Change (IPCC) estimates that CCS will be needed to supply at least 15%, and perhaps as much as 55%, of the GHG emission reductions needed to stabilize the climate over the next century.[7]

Despite the recognized need for CCS, there are only a few commercial-scale CCS installations in the world today, and none are operating on a conventional

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coal-fueled electricity plant. The few existing CCS projects capture and store between 500,000 and three million tons of CO_2 per year.[8] This stands in stark contrast to the scale of CCS deployment needed to address climate change: the IPCC estimates that between 220 billion tons and 2,200 billion tons will need to be sequestered in the 21st century.[9] This scale is challenging for all three major aspects of a CCS system: CO_2 capture, pipeline transport, and geological storage.

The Powerspan story involves the most difficult and expensive aspect of CCS: CO_2 capture. The commercial CO_2 capture technologies that exist today are not well suited to conventional pulverized coal-fueled electric generating (PC) plants for several reasons: they are challenged by impurities normally present in the flue gas of the plant, they require up to 30% of the total plant output energy to capture and compress CO_2 for storage, and they add up to 80% additional cost to an already substantial capital investment. CCS costs are estimated to increase the cost of electricity from coal-fueled generating plants by 50% to 80%.[10] Therefore, the challenge is not only to commercially demonstrate CCS on the scale required, but also to develop a more economical approach to CO_2 capture for conventional coal-fueled electric generating plants. This objective is the focus of Powerspan today, but the road to this destination was anything but direct.

The challenge is not only to commercially demonstrate CCS on the scale required, but also to develop a more economical approach to CO2 capture for conventional coal-fueled electric generating plants.

WHAT MAKES CO_2 CAPTURE SO DIFFICULT?

It's hard to get your mind around the enormity of the task of CO_2 capture without some idea of the scale of a pulverized coal-fired electricity (PC) plant. A typical existing PC plant produces 600 megawatts (MW) of electricity at 35% thermal efficiency, while a new, state-of-the-art, supercritical PC plant (SCPC) would operate at near 40% efficiency. A supercritical plant would normally use between 200 and 300 tons of coal per hour, with flue gas flow resulting from coal combustion between 2,500 to 3,000 tons per hour, or 1.5 to 1.8 million cubic feet per minute. To give some perspective, the cross section of the ductwork carrying flue gas is nominally 15 x 30 feet and carries flue gas flowing at approximately 45 miles per hour. Another indication of scale is that the flue gas flow of a PC plant is roughly 20,000 times greater than the exhaust from a typical automobile.

The flue gas from a PC plant contains from 12% to 15% CO_2, with the balance mostly nitrogen, water, oxygen, and small concentrations of pollutants such as

Approaches for Capturing CO_2

The favored approach for capturing CO_2 from PC plants is thermal swing absorption, in which the flue gas makes contact with a solution that has an affinity for CO_2 and therefore absorbs the CO_2. Then that CO_2-rich liquid solution is taken away from the flue gas and heated, driving out the CO_2. Next, the heated solution is cooled back to flue gas temperature and returned so it can absorb additional CO_2. Finally, the CO_2 gas released from the heated solution is purified and compressed for transport and sequestration.

The cost of thermal swing absorption depends on several factors; the three most important are the speed with which the CO_2 is absorbed into solution, the amount of CO_2 absorbed into the solution (i.e., the capacity), and the amount of energy required to drive the CO_2 out of solution. Speed of absorption is important to minimize the size of the tower used to contact the solution with flue gas (approximately 70 feet in diameter and 150 feet tall for a 600 MW plant). It is vital to increase the amount of CO_2 absorbed into the solution and minimize the energy needed to release CO_2 from the solution as that energy would otherwise go toward producing electricity.

Powerspan's process utilizes ammonia in the CO_2 absorbing solution. Ammonia provides several benefits, including a high rate of CO_2 absorption, a high capacity for absorbing CO_2 into the solution, and a low energy requirement for releasing CO_2 from the solution. These benefits provide cost advantages. First, a high absorption rate minimizes the size of the equipment needed for CO_2 capture and the energy costs associated with moving large amounts of flue gas and liquid through that equipment. Second, because it can absorb more CO_2 and needs less energy to release CO_2 from the solution, ammonia reduces the heat requirements to approximately half what is needed in conventional amine-based capture solutions.

nitrogen oxides and sulfur oxides. The challenge of CO_2 capture is to economically remove and recover a large percentage (i.e. 90%) of the CO_2. That is, we need to reduce the CO_2 concentration to around 1% in a large gas stream moving at a substantial rate, then recover the removed CO_2 for sequestration. And since CO_2 is not a very reactive or soluble molecule, its capture becomes even more challenging.

Today, most efforts to develop CO_2 capture are focused on thermal swing absorption, which has been used in the oil and gas industry to reduce CO_2 concentrations in natural gas streams. The most popular solvents have been amine based; they offer rapid absorption of CO_2, but require great amounts of energy and the solvents degrade in the flue gas. Powerspan has focused on developing new solvents that retain the rate and capacity advantages of amines, but reduce the energy costs and solvent losses.

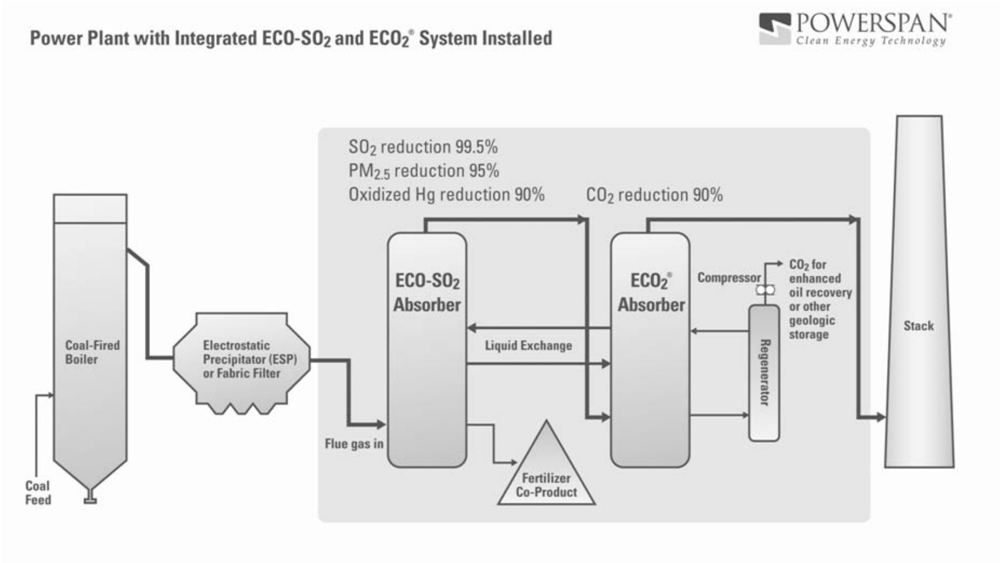

Figure 1. Power Plant with Integrated ECO-SO_2 and ECO_2 System Installed.

OVERCOMING TECHNICAL CHALLENGES

At this point our ECO_2 process is pretty well defined, but we faced several obstacles along the way. Our major technical challenge was to identify a CO_2 scrubbing solution and process conditions that maintained the benefits of ammonia in solution, did not overwhelm our ability to control the release of ammonia vapor to the flue gas, and did not produce a corrosive scrubbing solution as a result of the high concentrations of ammonia and CO_2. A secondary challenge was to develop a scheme for releasing the captured CO_2 from the solution while minimizing the heat input and the amount of gas processing needed to recover ammonia and water from the CO_2 gas stream.

Our 10 years of experience using ammonia for sulfur dioxide (SO_2) capture in our ECO process enabled us to identify the process conditions where we could control the ammonia vapor release from CO_2 capture by integrating the process with the sulfur dioxide removal process. Early patents for SO_2 removal using ammonia required that the pH be controlled low enough to minimize the formation of ammonia vapor, which could limit the efficiency of the SO_2 capture. Powerspan's innovation was to increase the pH to maximize the SO_2 capture efficiency, and then devise a means for controlling ammonia vapor, which earlier patents had considered too difficult or expensive. Our resulting expertise in controlling ammonia vapor would become an important part of our CO_2 capture process. Ammonia is a volatile compound and its vapor is released when the CO_2-absorbing solution is brought into contact with flue gas. We choose process conditions that will minimize the ammonia release, but some release is unavoidable and we need a way to capture the ammonia to keep it from escaping into the environment. Our process integrates CO_2 capture with the removal of sulfur dioxide, which is also present in coal-combustion flue gas and must be removed before we capture CO_2.

In our ECO process, sulfur dioxide is removed through absorption into an ammonia-water-sulfate solution, forming ammonium sulfate. When SO_2 is absorbed, the pH of the solution drops and more ammonia is needed to sustain the process. Rather than directly adding ammonia into the solution to raise the pH for additional SO_2 removal, in this process the low-pH solution makes contact with the flue gas exiting the CO_2 capture process that contains ammonia vapor (see Process Flow Diagram below). The low-pH solution captures the ammonia vapor, removing it from the flue gas while increasing the pH of the solution so it can remove more sulfur dioxide. This integration between the processes that capture SO_2 and CO_2 allows us to control ammonia vapor cost effectively and avoids the production of waste streams that require further processing.

Once we had established the basic process approach, we conducted extensive laboratory testing to identify and optimize the composition of the solution, and the conditions for capturing CO_2 and releasing it from the solution. As part of the testing we developed data on physical properties, including information on the vapor-liquid equilibrium, and the reaction rate data we needed to establish the requirements for contacting flue gas with the scrubbing solution. We built, and rebuilt, several test beds as we proceeded with the laboratory testing and gathered process information.

An equally important effort in the experimental work was developing sampling procedures and analytical techniques for accurately measuring the compositions of the scrubbing solutions, the treated flue gas, and the CO_2 product gas. We found that the available measurement equipment and techniques were inaccurate and inadequate, so we developed our own procedures and techniques to measure the compounds responsible for CO_2 capture, ammonium carbonate and bicarbonate, as well as undesirable compounds such as ammonium carbamate, and impurities that exist in and are picked up by the scrubbing solution when it makes contact with flue gas. This development work required several man-years of effort and included the testing and rejection of multiple measurement techniques, or in other words, a lot of failure.

Throughout the research and development work, we kept our focus on producing a process that could be deployed in commercial power plants, using available commercial equipment and construction techniques, and that could be controlled using measurement equipment that can survive in the power plant environment. Our initial pilot test results indicate that we are very close to achieving these objectives.

Overcoming the various technical barriers to CO_2 capture at conventional PC plants required the collaborative efforts of a strong, experienced, and cohesive team. The factors that went into building our company and the team behind it are as important as the evolution of the technology itself, and a story worth telling.

HUMBLE BEGINNINGS

After obtaining a degree in nuclear engineering from the University of Massachusetts at Lowell in 1979, I began my career building and testing nuclear submarines at Electric Boat in Groton, Connecticut, then moved to work at the maintenance and refueling of nuclear submarines at the Portsmouth Naval Shipyard in Kittery, Maine. In the early 1990s, after the end of the Cold War, the U.S. Navy began to downsize the nuclear fleet, and what started as an exciting career path at the forefront of technology innovation moved into a slow decline. In 1991, hoping to find an alternative career path, I entered the executive MBA program at the University of New Hampshire (UNH).

Early in my MBA studies, I had the good fortune to meet Bill Wetzel, who was my financial accounting professor. Bill had founded the Center for Venture Research at UNH where he pioneered research into the role of "angels," or self-made, high-net-worth individuals who provide seed capital and street smarts to the early-stage ventures that drive innovation and economic growth. Bill's passion for early-stage venture formation ignited a fire in me.

I decided to get directly involved in facilitating angel investments in new ventures. After a year of working diligently at this task as a "second job," I found that angel investors and entrepreneurs are generally not looking for a middleman to facilitate the venture process, particularly one with no experience. Despite my lack of success at this venture and the admonition of several advisors to "not give up my day job," I decided the next best thing to facilitating venture formation would be to start my own venture. So with $10,000 of personal funds and a great deal of optimism, I founded Zero Emissions Technology in 1994 along with Ed Neister, a physicist, and Nat Johnson, an electrical engineer. This company would eventually become Powerspan.

I had met Ed through a friend of Bill Wetzel and he was looking for an angel investor. He and Nat had come up with an innovative electrical filter for the power supplies of electrostatic precipitators (ESPs), which they called an "Arc Snubber." ESPs were being used by over 90% of PC plants to remove smoke particles from the flue gas. An ESP operates by slowing down the flow of flue gas and passing it between large grounded plates with high-voltage electrodes suspended in the center. The high-voltage electrodes charge the smoke particles and set up an electric field to attract them to the plates—which remove them from the gas stream. Our innovation was to filter the high-voltage power supply to remove high frequency noise and reduce sparking; because this improved the characteristics of the electric field it made the ESP collection more efficient.

Ed had convinced Public Service of New Hampshire to give the Arc Snubber filter a try on its local PC plant, and on the strength of this $50,000 order, I decided to jump on board, but kept my day job for the time being. The initial Arc Snubber modification was successful, which led to a second job, and finally our first outside investment by a real angel investor, Mort Goulder. Mort had founded the local angel investing group called the Breakfast Club, named after the breakfast meetings his group held at the Nashua Country Club to grill entrepreneurs and make its investment decisions. Mort was a 1942 MIT graduate with a degree in Applied Physics. He was one of the engineering managers who left Raytheon in 1951 to form Sanders Associates, where he was Director and Vice President for 22 years, growing the business to over $1 billion in annual sales.

After our first meeting Mort decided to invest $50,000 and joined our board of directors. He didn't perform any due diligence, other than asking questions to see if we knew what we were talking about. He trusted us. The deal was documented on a single page, part typewritten, part in his handwriting. Mort had made a lot of money as an entrepreneur and then spent the last 30 years of his life helping "give others a shot," as he would say. He definitely saw angel investing as part investment, part philanthropy… lucky for us, because what we were doing probably would not have held up under the intense scrutiny of a disciplined investment evaluation.

Mort's investment led to more angel investment and helped us grow the business to $2 to 3 million in annual sales and achieve profitability. However, after a few years we recognized that the Arc Snubber business was limited and we would have to expand our product line if we wanted to build a meaningful company. We were faced with the reality that we needed to "go big or go home."

BIGGER IDEAS REQUIRE VENTURE CAPITAL: WHAT DOESN'T KILL YOU MAKES YOU STRONGER

We thus began a series of development initiatives with the goal of expanding our proprietary product line in the air pollution control business using different gas processing techniques. We initially looked to expand further into ESP performance enhancement by developing a flue gas conditioning system based on sulfur trioxide (SO_3) injection. SO_3 injection had been shown to improve ESP performance in plants burning low-sulfur coal, and the two companies that were selling commercial SO_3 injection systems had done quite well in the market. Our particular innovation was to create SO_3 in situ from SO_2 in the flue gas stream using a non-thermal plasma oxidation device. We called this product the "SO_x Converter.

In order to fund our new R&D initiative, it was clear we would need venture capital because our existing products were not sufficiently profitable. We turned to Zero Stage Capital of Cambridge, Massachusetts, where I had had the good fortune to work part time over the two previous years while I had also been part-time CEO of Zero Emissions Technology. Based on our initial success with the Arc Snubber, and a personal relationship that I had developed with Gordon Baty, a Zero Stage founder, we were able to raise our first million dollars of venture capital.

But we were never successful in persuading any potential customers to buy our SO_x Converter, because they considered our approach too risky—a refrain we would hear again and again from prospective utility customers. But that didn't stop us. Instead, we saw the potential for our non-thermal plasma oxidation device to oxidize nitrogen oxides (NO_x) as well as SO_2, which would facilitate their downstream capture in an ESP or scrubber. This provided the opportunity to treat flue gas to remove multiple pollutants in a completely unique and innovative way: when nitrogen and sulfur compounds in flue gas are converted to higher oxides, they form aerosols that can be captured in particulate collection equipment. Our approach was to remove several gaseous pollutants in the same control device by first converting them to aerosols. Thus was born our multi-pollutant control technology, Electro-Catalytic Oxidation, or ECO®.

The ECO story would have been just another great idea with no commercial future if not for the interest of Ohio Edison in Akron, Ohio (later named FirstEnergy). Ohio Edison had a reputation for technology leadership as one of the first U.S. utilities to deploy SO_2 scrubbers on its Bruce Mansfield Plant in Pennsylvania. People there had also pilot-tested a number of unique air pollution control technologies and were intrigued by the potential of ECO. Two of their principal pollution control engineers, Dale Kanary and Morgan Jones, visited our lab test facility and became believers. Their CEO at the time, Pete Burg, met with us and was persuaded to invest, committing $5 million to fund ECO pilot testing at their R.E. Burger Plant near Shadyside, Ohio.

The ECO pilot test program did not go well initially, as most of the equipment we designed for this application was not sufficiently robust. That's a polite way of saying our plasma power supplies blew up and our plasma reactor bodies melted, but fortunately no one was hurt. However, we were able to "make a lot of mistakes fast," which became something of a mantra for us, and we eventually modified the pilot system to meet our performance objectives at just about the time we ran out of money. This resulted in the company's first layoff and what we now refer to as a "near death experience," which is common among venture-backed companies.

Inventors and company founders are by necessity quite optimistic and in some cases even naïve. We certainly were both at the start. But R&D is difficult to schedule and venture investors have limited patience. And therein lies the structural conflict that weeds out the weak and makes the survivors stronger. If we had known how hard this would be at the beginning, it's unlikely any one of us would have undertaken the journey. But once you start down the path, you end up doing everything possible not to fail.

In late 1999, when the emerging energy technology market was experiencing great investor interest (some call it a "bubble"), we were fortunate to catch the attention of Jeff Miller, one of the managing partners of the Beacon Group. He was one of the few in the energy investing space who still believed in the future of coal, and he made a bet on Powerspan as an emerging leader in the pollution control technology market for coal-fired plants. It helped that FirstEnergy and American Electric Power, two large potential customers, joined in the $26 million investment round. The purpose of the investment was to build a commercial demonstration facility for our ECO technology at FirstEnergy's Eastlake Plant. But once again, this didn't work out as we had planned.

Date	Amount Raised	Major Investors	Purpose of Funding
1997	$1.4 million	Zero Stage Capital, Calvert Group	Develop SO_x Converter for conditioning electrostatic precipitators.
1998	$5 million	FirstEnergy	Pilot-test ECO multi-pollutant technology at FirstEnergy's R.E. Burger Plant.
2000	$26 million	FirstEnergy, Beacon Group, American Electric Power	Install a 50-MW ECO system at FirstEnergy's Eastlake Plant, as commercial demonstration of ECO technology. Due to the anticipated sale of the Eastlake Plant, the project was moved to FirstEnergy's Burger Plant and started in 2004.
2003 - 2006	$35 million	NGEN Partners, RockPort Capital, Fluor, Angeleno Group, FirstEnergy, Beacon Group	Complete 50-MW ECO unit and associated performance testing in 2005. This marked the major transition point from ECO development to commercialization. In 2004, announced the CRADA with DOE for CO_2 capture technology development ("ECO_2").
2008	$50 million	George Soros, Tenaska Energy, AllianceBernstein, NGEN Partners	ECO_2 pilot test and commercial deployment. Fund early ECO projects (provide adequate liquidity to secure ECO commercial orders).

Table 1. Venture Capital Funding Timeline

After we had spent a good deal of money on design work for the ECO commercial demonstration unit (CDU), we realized that our pilot design was not readily adaptable to commercial-scale equipment. At about the same time, FirstEnergy reached an agreement to sell the Eastlake Plant, so we had to move the project. Once again, we had to move fast to come up with a new design that we could show was commercially viable along with a new location to build the CDU. Fortunately, we were able to accomplish both at just about the time we ran out of money again, which led to layoffs and near death experience number two.

The next funding round was a "down round," which means the price per share was lower than the price in the previous round. These are very unpleasant things. Completing this round would not have been possible but for the continued commitment of FirstEnergy, along with NGEN Partners, a new investor led by Steve Parry. This money was sufficient to build the ECO commercial demonstration unit and largely achieve the performance results we had promised. However, this did not immediately lead to commercial success.

Our next challenge was to overcome the risk aversion of this market. There are good reasons why power plant owners are so cautious. The power industry is the most capital-intensive business in the world, as measured by the ratio of invested capital to sales. Power companies only make money when their costly plants are running and meeting all requirements for air emissions. So in order to sell a new air pollution control technology, you not only have to be much better and cheaper than the competitors; the buyers also need a good reason to take on the technology risk. Providing that reason was much harder than we anticipated. That brings us to CO_2 capture.

GOOD FORTUNE PLAYS A ROLE

One myth I have come to reject is that of the great company founder or CEO who must have had a brilliant plan to create this amazing company, and then brought it forth with tremendous vision, courage, leadership, tenacity, etc. That's not how it really happens. Individual leadership is important, but the make-up and contributions of the whole team are far more critical to success. Having a plan is important, but the objectivity and flexibility to adjust the plan quickly matters more. Finally, circumstances that are completely out of your control play such a critical role in success. When you look at it all objectively, the reality is quite humbling compared to the conventional view of CEO as hero in the case of success, or loser in the case of failure.

So where have we experienced good fortune? In early 2004, the U.S. Department of Energy (DOE) National Energy Technology Laboratory contacted us to discuss research they were doing on CO_2 capture using ammonia. We were the only company in the U.S. developing wet scrubbing technology using ammonia as a reagent. They were wondering how we controlled the ammonia vapor and asked to visit our demonstration plant. We agreed to share our knowledge as long as they shared theirs. This meeting led to a cooperative research and development agreement (CRADA) with DOE to develop and commercialize their ammonia-based CO_2 capture technology; later, Powerspan acquired a license for the DOE patent once it was issued. We named this new process ECO_2®.

With that, we embarked on a multi-year R&D effort to develop the ECO_2 process in our labs. It would be four years before we were ready to build the ECO_2 pilot test unit in Ohio. Although we believed that at some point limits on GHG emissions would be imposed that would jumpstart the supplier market, it would be three years before we saw any meaningful movement on this front, despite periodic attempts by key members of Congress to garner majority support for federal climate legislation.

On April 2, 2007, the U.S. Supreme Court made a landmark decision. It ruled that, under the Clean Air Act, the EPA has the authority to regulate GHG emissions from automobiles, and that the agency could not abdicate its authority to regulate these emissions unless it could provide a scientific basis for refusing to do so. Although the court did not require the agency to regulate GHG emissions, the agency would face legal action if it did not. At the time, observers generally agreed that this decision marked the beginning of GHG regulation in the U.S.; apparently if Congress did not act, the EPA surely would.

So, it would be difficult to observe the confluence of events that led Powerspan to this moment and not feel fortunate. We thought we were way ahead of our time when we entered into the CRADA with DOE to develop CO_2 capture technology. Little did we know back then that we would be in exactly at the right place at the right time, which is where we find ourselves today in the emerging market for commercial CCS systems.

As the interest in CO_2 capture technology grows, we find ourselves well positioned for a few important reasons. First, this is one air pollution control technology that no one has installed on a PC plant, so there are no entrenched competitors or established technologies to overcome, which as we learned with ECO is no small thing. Next, the skill set needed to bring a technology from the lab to commercial scale is one we have developed and mastered over the last 15 years. To our knowledge, none of our competitors has this skill set. Lastly, the ECO system we developed as an integrated, multi-pollutant control system ended up as the perfect complement to an ammonia-based CO_2 capture system, though we had no idea it would become that when we started.

WHY POWERSPAN?

The rush to develop a cost-effective CO_2 capture technology for coal-fired electric plants has been compared to our nation's effort to put a man on the moon in the 1960s. On the campaign trail, President Obama compared development of clean coal technology to that famous effort: "This is America. We figured out how to get a man on the moon in 10 years. You can't tell me we can't figure out how to burn coal that we mine right here in the United States of America and make it work."

Several large companies are involved in this effort, including GE, Siemens, and Alstom. The resources available to these companies for R&D total in the billions of dollars annually, with GE alone committing $1.5 billion annually to clean energy research. By comparison, Powerspan's average annual engineering and R&D expense over the last 5 years was $6.5 million, orders of magnitude less than our competitors. So a reasonable question would be, with the tremendous importance of CCS as a climate mitigation tool, and with the anticipated worldwide CCS market of $1.3 to 1.5 trillion from 2010 to 2050, how could a company like Powerspan develop a leading technology position for post-combustion CO_2 capture? There are some important reasons why, some perhaps more obvious than others.

The first reason is that large companies generally make decisions based on conventional wisdom, which is often wrong. The innovations they bring to market are usually incremental improvements to existing product lines. Breakthrough innovations require one to think outside of convention and take risks, acting in ways that could threaten a profitable business line. As Clayton Christensen points out in *The Innovator's Dilemma*, the actions required to create disruptive technologies are nearly impossible for the well-established company to undertake.

A good example of conventional wisdom gone awry was the early rush to Integrated Gasification Combined Cycle (IGCC) power plants as the future of coal-based electricity production in a climate-constrained world. IGCC plants produce electricity by first gasifying the coal and then running the synthesis gas

The Makings of a Team

In venture capital, there is a saying that you "bet the jockey, not the horse." That means that the assumptions one makes about how a specific technology or market (i.e. horse) may evolve are invariably wrong. As the Nobel Prize winning physicist Niels Bohr stated, "Prediction is very difficult, especially of the future." However, the right team (i.e. jockey) will adapt to unexpected challenges and find a way to succeed.

How did we build the right team? It started with connections we made through the U.S. Naval Nuclear Propulsion Program (NNPP) and the University of New Hampshire (UNH). Powerspan's top technical leaders (Phil Boyle, Chris McLarnon, Dave Bernier, and myself) all started our professional careers in the NNPP, working together at Portsmouth Naval Shipyard through the 1980s and 1990s. The legendary Admiral Hyman Rickover, who founded the NNPP and served in its leadership role for over 30 years, established a well-deserved reputation for technical discipline. The program's tough standards are ingrained in participants at all levels, and the resulting culture of constant and sometimes pointedly direct questioning, challenging, and checking becomes second nature. Having this common background and approach to technical work and problem solving has been a key to our technical success. It has also helped us stand up well under the constant scrutiny of prospective customers and investors.

The UNH connection also facilitated building up the team. Our first directors of sales and manufacturing were MBA classmates of mine. Our Vice President of Communications and Government Affairs, Stephanie Procopis, was an MBA student referred by Bill Wetzel who started with Zero Emissions Technology as our Director of Marketing. Our CFO, Lynn Friedel, was a graduate of Plymouth State College in New Hampshire and came to us from the Breakfast Club (Mort Goulder). So the principal connections that brought the team together were from the Naval Nuclear Program and the local business school/angel investing network. What keeps the team together is harder to understand.

(syngas) through a combustion turbine.

Although coal gasification by itself is a well-established technology, there are only three commercial-scale IGCC plants in the world, each with about 250 MW capacity, and the consensus is that these plants are more costly, less flexible, and less reliable than conventional pulverized coal (PC) plants. However, despite these drawbacks, conventional wisdom held that IGCC plants would be able to capture CO_2 more easily than PC plants, and therefore they would be the low-cost option for coal-based electricity production when the cost of CO_2 capture was included. Because of this assumption, much of the early CCS research focus and funding was directed toward IGCC.

All the members of the management team had been very successful in their prior careers and had good employment opportunities outside the company. We recently sat down as a team to answer the question of what has held us together for so long. We recounted the occasions in our past when we had nearly run out of money. Twice we had to withhold a portion of employees' salaries while we awaited new financing. It so happens that in both cases, we obtained financing just before the end of the year and paid employees their back salary around Christmas. So we nicknamed this event the Powerspan "Christmas Club" (survival requires humor!) We also went through two substantial layoffs, a significant down round in venture financing that nearly killed us, and even a somewhat hostile takeover attempt by a large energy company, during which the board and management team split on the best path forward.

So what holds a team together through such turmoil when much safer and more rational employment alternatives exist? For one, our common background in the Naval Nuclear Program and UNH created a bond that went beyond common employment. Next, as we had weathered the storms, we had lost our false confidence based on ignorance or naiveté, and had gained real confidence based on surviving another battle and learning from it.

Most of us had come from modest, blue-collar backgrounds and worked our way through college, so the work ethic and commitment was deeply ingrained in us all. I was the middle child of thirteen (not a typo) and my father had a garage where he repaired cars. I started working for him at age 12 and continued until I went to college. I was never paid for it and was not encouraged to go to college. I just wanted something different for myself. Most of the Powerspan management team had similarly modest backgrounds, which led to a common drive to create something better, and a work ethic that never allows you to quit. This motivation is apparent not only in our leadership, but throughout the organization, and has enabled Powerspan to compete with, and in some cases surpass, the work of industry giants.

However, more recent studies have called this conclusion into doubt as the full cost of CO_2 capture in IGCC plants becomes better known and companies like Powerspan drive down the anticipated cost of CO_2 capture from PC plants. Another more obvious consideration is that over 99% of existing coal-based electricity production comes from conventional PC plants. These plants represent trillions of dollars in asset value and could not be readily replaced. Therefore, from the perspective of climate change mitigation, the primary need is for cost-effective CO_2 capture from PC plants, but it took conventional wisdom a few years to come back around to this obvious point.

Another reason for Powerspan's leading position in this market is that for decades, the suppliers of air pollution control equipment have not been in the technology development business. The basic technologies used to capture SO_2 and

NO_x from commercial PC plants—calcium-based scrubbing for SO_2 and ammonia-based selective catalytic reduction for NO_x—were first developed and commercialized in Europe and Japan over 30 years ago. The process engineering know-how and R&D skills needed to develop such technologies have largely disappeared from contemporary equipment suppliers. Today, the market for air pollution control equipment is a commodity market dominated by large companies with very little product differentiation.

By comparison, during all of the 15-plus years of Powerspan's existence, we have been in the product development business. As we moved to larger visions of our product offering, particularly our ECO technology, which we designed as an integrated system to compete directly with the best available control technologies for capture of SO_2, NO_x, mercury (Hg), and particulate matter, we necessarily had to develop critical skill sets in order to succeed. It is not easy to develop or acquire these skills: 1) a disciplined approach to lab testing, measurement, and analysis; 2) sophisticated process modeling, including the development of new models based on proprietary empirical data; and 3) critical thinking skills including the ability to find innovative solutions when the inevitable road blocks appeared. We believe this skill set is unique in our industry and we've been at it long enough to become quite proficient, easily surpassing the well-known 10,000-hour rule for mastering a profession (see Malcolm Gladwell's *Outliers: The Story of Success*).

HOW IMPORTANT IS CCS?

The importance of CCS cannot be overemphasized with respect to climate change mitigation. The Intergovernmental Panel on Climate Change (IPCC) estimates that CCS will be needed to supply at least 15%, and perhaps as much as 55%, of the GHG emission reductions needed to stabilize the climate over the next century.[11] According to the International Energy Agency (IEA), CCS is the only technology that can control CO_2 emissions from large-scale fossil fuel usage, and it will need to provide at least 20% of the reductions in GHG emissions required to meet the IPCC goal of cutting global emissions 50% from 2005 levels by 2050.[12]

The IEA has put forth a scenario that explores the least costly solutions to achieve the IPCC goal. Under this scenario, by 2050, 30% of all power will be generated by plants equipped with CCS.[13] In order to achieve this ambitious goal, CCS installations would be required in 55 fossil-fueled power plants every year between 2010 and 2050. Further, this same IEA scenario *without CCS* would have the highest emissions and would also have an annual incremental cost of $1.28 trillion in 2050, a 71% increase over the base scenario with CCS.[14] This underscores the importance of CCS in climate policies from the perspectives of reducing both costs and emissions.

As an alternative, many see renewable energy as the most important climate mitigation tool. However, a recent study conducted for a large California public utility estimated the levelized cost of avoiding CO_2, using solar power, at $230 per ton, while the cost for avoiding CO_2 using CCS was estimated at $59 to $63 per ton. In addition, renewable energy sources such as solar and wind power suffer from regional resource limitations, interruptions in supply, and transmission constraints.

Although no region has developed the comprehensive legal and regulatory framework necessary to effectively guide CCS, last year the G8—an economic and political organization consisting of Canada, France, Germany, Italy, Japan, Russia, the U.S., and the UK—endorsed the IEA recommendation that 20 large-scale CCS demonstration projects need to be committed by 2010, with broad deployment beginning in 2020.[15] The IEA believes that up to $20 billion will be needed to fund these near-term CCS demonstrations.

Lastly, CCS is needed to help sustain our lowest-cost electricity supplies and move us toward energy independence, since approximately half of the electricity in the U.S. is generated from domestically sourced coal. According to DOE's Energy Information Administration (EIA), 36% of our CO_2 emissions in 2006 came from coal consumption.[16] Broadly deploying CCS with 90% capture efficiency could potentially reduce those emissions to 4% or 5%. EIA predicts that CCS will have to provide at least 30% of the CO_2 emission reductions needed worldwide in order to stabilize GHG concentrations in the atmosphere. Since the transportation sector accounts for another 34% of U.S. CO_2 emissions,[17] transforming this sector with electric vehicles powered by low-carbon electricity sources could reduce U.S. CO_2 emissions by another 20% to 30%. Therefore, CCS could potentially provide over half of the emission reductions required to meet the nation's goals for climate change mitigation.

WHEN WILL CCS BECOME A COMMERCIAL REALITY?

CCS technology will be commercially available soon based upon successful completion of ongoing pilot scale test programs. The term commercially available means that qualified vendors are willing to sell commercial-scale CCS equipment with industry-standard performance guarantees. However, despite broad recognition of the pressing need for CCS technology, plant owners are not motivated to get large-scale CCS demonstrations up and running because they are very costly to build and operate, and the early projects carry considerable technology risk. It's the classic chicken-and-egg scenario. Most plant owners do not want climate regulations to force CCS installation until the technology is commercially proven. But owners will not proceed with early CCS installations to prove out the technology in the absence of either regulations or financial incentives. Therefore, the timing of when commercial CCS systems will begin operating depends on when the legal requirements, regulatory drivers, and financial incentives are established to motivate plant owners to proceed with the initial CCS installations. I discuss this issue in more detail later on.

Currently, a limited number of CO_2 capture pilot tests are being conducted at power plants worldwide to demonstrate ammonia-based, amine-based, and oxygen-fired technologies on a small scale. Pilot-scale testing of our ECO_2 technology began in December 2008 at FirstEnergy's Burger Plant in Southeastern Ohio. The ECO_2 pilot was designed to treat a 1-MW flue gas stream and produce 20 tons of CO_2 per day. Testing to date has demonstrated over 90% CO_2 capture efficiency with energy use in the range of our estimates. Future testing is focused on increasing CO_2 output and finalizing design parameters for our first commercial systems.

The ECO_2 pilot plant was built using the same type of equipment that we will use in commercial systems. Therefore, successful operation of the pilot unit will confirm our design assumptions and cost estimates for large-scale CCS projects. Although commercial-scale projects still have some risk, that risk is manageable because the major equipment used in the ECO_2 process—large absorbers, pumps, heat exchangers, and compressors—has all been used in other commercial applications at the scale required for CCS. The advanced technology in ECO_2 is innovative process chemistry. Commercial application of this unique technology involves no special challenges and therefore is highly likely to succeed.

Our experience in the emerging market for commercial-scale CCS projects supports our optimism. In 2007, Basin Electric Power Cooperative conducted a competitive solicitation for a post-combustion CO_2 capture technology to retrofit its Antelope Valley Station, a coal-fired power plant located adjacent to its Great Plains Synfuels Plant in Beulah, North Dakota. The synfuels plant currently hosts the largest CCS project in the world; it annually captures three million tons of $CO_{2,}$ which it sells for enhanced oil recovery (EOR) in the Weyburn fields of Saskatchewan. The Antelope Valley project will install CO_2 capture equipment on a 120-MW flue gas slipstream taken from a 450-MW unit. Basin Electric has targeted a 90% CO_2 capture efficiency rate in order to provide an additional one million tons of CO_2 annually for EOR. Six of the leading vendors of CO_2 capture technology responded to the Antelope Valley solicitation and after a detailed evaluation, Basin Electric selected Powerspan. This commercial CCS project is scheduled to start up in 2012.

Since Powerspan was selected for the Antelope Valley project, a feasibility study has confirmed that there are no technical limitations to deploying ECO_2 at the plant. The study estimated ECO_2 costs of less than \$40 per ton for 90% CO_2 capture and compression (in current dollars, with +/- 30% accuracy). A similar study of ECO_2 recently conducted for a new 760-MW supercritical pulverized coal plant estimates CO_2 capture costs of under \$30 per ton, including compression. A third engineering study focused on the scaling risk of ECO_2 determined that the ECO_2 pilot plant will provide enough design information so we can confidently build commercial-scale systems up to 760 MW, indicating that the ECO_2 technology scaling risk is manageable. Independent engineering firms led the feasibility, cost, and scaling studies for our prospective customers. As a sign of our confidence in the commercial deployment of ECO_2 systems, we will back our installations with industry-standard performance guarantees.

Worldwide, large-scale CCS demonstration activity is concentrated in the European Union, Australia, Canada, and the U.S. In the European Union, the European Parliament has approved a demonstration program of 10 to 12 large-scale CCS projects to be operational by 2015 in order to 'kick-start its urgent, wide-scale deployment.' Three hundred million European Union Allowances (EUAs) have been authorized to fund this initiative with an anticipated value of $6 to 10 billion.

In April 2008, the State Government of Victoria, Australia, announced a round of funding of AUD$182 million, of which AUD$110 million is available to support large-scale CCS demonstration projects. In December 2008, it issued a solicitation for proposals to be submitted by the end of August 2009. Selections are to be made in early 2010 and demonstrations are to be completed in the 2014-2015 timeframe.

In Canada, the provinces of Saskatchewan and Alberta are leading the effort to demonstrate CCS. SaskPower is currently evaluating three finalists, of which Powerspan is one, for a 140 MW CCS project (1.2 million tons of CO_2 capture annually) at its Boundary Dam Power Station in Saskatchewan. The final technology selection is scheduled for the end of 2009 with a construction start in 2011. The captured CO_2 will be used for enhanced oil recovery operations. Canada's federal government previously announced $240 million in support for this project.

In July 2008, the government of Alberta announced a $2 billion fund to accelerate the development of the province's first large-scale, commercial CCS projects, and in February 2009, legislation was passed that provides the legal authority to administer the $2 billion in provincial funding. The Carbon Capture and Storage Funding Act will enable the province to administer funding to support three to five large-scale CCS projects. The selected projects were announced in July 2009; by 2015, the governmentexpects, the projects will be reducing CO2 emissions by five million tons each year.

In the U.S., a limited number of large-scale CCS projects have been announced, including the Basin Electric project at Antelope Valley in North Dakota. The Troubled Assets Relief Program (TARP) bill, signed into U.S. law on October 3, 2008, contained provisions for investment tax credits and production tax credits for the capture and storage of CO_2. The American Recovery and Reinvestment Act (ARRA), signed into law on February 17, 2009, also includes unprecedented funding of $3.4 billion for CCS. While the rules for applying for U.S. government CCS funds have yet to be promulgated, these steps are encouraging.

On March 30, 2009, Chairman Henry Waxman of the U.S. House of Representatives Energy and Commerce Committee introduced a comprehensive climate bill, the American Clean Energy and Security Act of 2009 (ACES, H.R. 2454). On May 21, the committee passed the bill and on June 26, the House approved it by a vote of 219-212. The bill includes a greenhouse gas emissions cap-and-trade program to reduce emissions by 83% from 2005 levels by 2050. The bill also contains standards for renewable electricity and energy efficiency, along with provisions for clean transportation. At the projected allowance prices, ACES will invest over $190 billion through 2025 in clean energy and energy efficiency, $60 billion of which would be invested in carbon capture and sequestration technologies. Of that $60 billion, $10 billion would be generated through a small "wires charge" on electricity generated from fossil fuels. After 2025, 5% of allowances would be devoted to carbon capture and sequestration. The bill also creates a new carbon dioxide emissions performance standard for coal-based power plants.

WHAT IS NEEDED TO GET CCS DEPLOYED COMMERCIALLY?

CCS installations are expensive. In some regions, the use of captured CO_2 in enhanced oil recovery operations offers opportunities to offset a portion of the costs, but a power plant owner would still face a significant shortfall in covering the cost of this investment. Without a high enough price on carbon or adequate early incentives to cover the cost of projects, power plant owners cannot assume the financial risk of large-scale CCS demonstrations. Therefore, strong government action is needed to ensure timely deployment of CCS technology to support climate change mitigation goals. Government actions should focus on three areas: 1) a strong, market-based cap on GHG emissions; 2) a CO_2 emission performance standard for new coal-based power plants; and 3) incentives for early deployment of commercial-scale CCS systems. Incentives are needed to ensure the early deployment of CCS because CO_2 capture technology is not yet commercially proven and early CO_2 prices will not be high enough to offset CCS costs. Six aspects are most critical to the success of a CCS incentive program.

Competitive Award

CCS incentives should be awarded competitively based on a reverse auction (incentives awarded to the lowest-cost bidders per ton of CO_2 captured and sequestered) because this would preserve the primary objective of a cap-and-trade program, which is to minimize the cost of compliance, while also providing a market signal on the real costs for early CCS installations. Knowing the actual costs for CCS is extremely important to plant owners, technology developers, investors, and regulators as they evaluate future investment and regulatory decisions.

Funding the lowest-cost CCS projects will also favor those associated with enhanced oil recovery since those projects pay for the CO_2 and avoid the added cost of geological sequestration. This will have the added benefit of producing more domestic oil and reducing oil imports. It will also produce more jobs and the tax revenue associated with domestic oil extraction and sales.

In promoting early deployment of CCS through financial incentives, the U.S. could assume a leading position in this critical technology sector and create a thriving, high-tech export business, and the quality jobs that come with it. However, to make such an outcome likely, CCS incentives will have to be awarded competitively; otherwise we could not ensure that the lowest-cost technologies would be awarded incentives, and no clear signal would be sent on technology winners or actual CCS pricing.

Competitively awarding CCS incentives is consistent with the way that renewable portfolio standards are normally administered. Market participants—power suppliers, regulated distribution companies, and state regulators—understand this process. States set a standard for the amount and type of renewable energy desired, and the potential suppliers respond to competitive solicitations to provide the renewable energy. The federal government could effectively implement the same type of approach for CCS projects and associated incentive awards.

Long-Term Price Certainty

CCS incentives must provide long-term price certainty and factor in the value of CO_2 emissions allowances because CCS projects will likely be financed over 15 to 30 years. Current climate legislation proposals award CCS incentives over a fixed period of time (i.e. 10 years) that is too short to finance most projects.

CCS incentives would be most economical for the government if they factor in the increasing value of CO_2 emission allowances over time. As the value of these allowances rises over time, less government funding will be needed to support the CCS incentives. Current climate legislation proposals do not account for the added value of CO_2 emission allowances created by the CCS project or the fact that emission allowance values would be increasing over time. This approach creates a potential windfall profit opportunity for the early CCS adopters and unnecessarily increases the cost of CCS incentives to the government.

CCS Project Size

The primary objective of CCS incentives is to demonstrate CCS technology at commercial scale to accelerate market acceptance and deployment. In order to demonstrate CCS as commercially viable, minimum project size criteria should be established. Experts such as those at MIT and DOE have established a minimum size of 1,000,000 tons of CO_2 per year for CCS projects to be considered "commercial scale."[18] Once the minimum CCS project size is met, preference should be given to larger projects.

CO_2 Capture Rate

In order to meet the objective of stabilizing GHG concentrations in the atmosphere, large stationary CO_2 sources will need to capture and sequester a high percentage of their CO_2 emissions (i.e. > 90%). Therefore, CCS incentives should establish a minimum standard for CO_2 capture and should favor projects that capture higher percentages of CO_2. Available technology from leading suppliers has shown the ability to capture 90% CO_2. Therefore establishing a minimum CO_2 capture rate as high as 80% to 90% is technically feasible and commercially acceptable.

CCS projects will normally require at least four years to implement. An incentive program that encourages CCS to be demonstrated in sequential steps (e.g., 50%, then 80%) would unnecessarily delay deployment of the high-capture-rate CCS projects needed to combat climate change; it would also increase the cost of CCS incentives to the government.

Amount of CCS Incentives

The amount of CCS incentives in tons of CO_2 should be based on the need to demonstrate CCS at commercial scale in a number of different configurations for both plant type and geological storage type. All large industrial sources of CO_2 should be considered equally. However, the government should not try to pick technology winners and losers. The primary driver in CCS incentive awards should be the lowest cost per ton, with at least three different CO_2 capture technologies selected to promote technology diversity. This would facilitate the creation of a competitive supplier market of the most cost-effective technologies.

The amount of CCS incentives should be established to avoid early market responses to a CO_2 emission cap, such as a rush to gas-fired power generation, which may not be sustainable after CCS is commercially proven and CO_2 allowance prices rise to a level where CCS would be deployed without incentives. CCS incentives should also be spread out so that multiple CCS projects are awarded each year for at least five years, given the current fast pace of technology evolution; the CCS incentive program should take advantage of and benefit from this rapid pace of improvement.

Sequestration Issues

Several sequestration issues need to be addressed, such as legal and permitting requirements for geological sequestration, including standards for site selection, and requirements for measurement, monitoring, and verification. Although several states have been active in this area, a strong and consistent national approach would be beneficial. Among the issues to be addressed should be long-term liability for sequestered CO_2.

It is also important to create incentives for constructing CO_2 pipelines at optimum scale. CO_2 pipelines benefit from economies of scale up to about 24 inches in diameter. This size would provide CO_2 capacity for three to four large-scale CCS projects (nominally about 15 million tons per year; equivalent to about 2,000-MW capacity at 90% CO_2 capture). Therefore preference should be given to CCS projects that create extra capacity by constructing pipelines or other infrastructure that could be used by multiple projects.

SUMMARY

Climate change is a very real threat to our world. But carbon capture and storage (CCS), possibly the most important tool for climate change mitigation, is not in commercial operation on any coal-fired electricity plant. Subject to successful completion of ongoing pilot scale test programs, technology suppliers like Powerspan will be ready to provide needed equipment to implement CCS at commercial scale. CO_2 transport and storage needs further research, demonstration, and regulation, but over 20 years of experience in the U.S. with CO_2-based enhanced oil recovery, which currently injects over 40 million tons of CO_2 per year into depleted oil fields, has demonstrated that CO_2 transport and storage can be accomplished safely.

Independent studies show that early commercial installations of CO_2 capture technology are likely to succeed. The cost of widespread deployment of CCS technologies appears manageable, particularly when compared to the cost of other low-carbon electricity solutions. And once we gain commercial CCS experience, future costs will no doubt decrease substantially.

However, initial CCS installations will be expensive and the technology still carries substantial commercial risk. Without a price on carbon and adequate incentives to cover the cost of early CCS projects, power plant owners will be unable to assume the financial risk of building and operating large-scale CCS demonstrations. Therefore, strong government action is needed to ensure timely deployment of CCS technology to support climate change mitigation goals.

A benefit of early CCS deployment will be creation of jobs and economic growth. CCS projects require 3 to 4 years to implement and create significant economic activity over their duration. For example, a single CCS project would cost between $250 million and $750 million in capital expense and create up to 500 jobs at its peak, with the majority of materials and labor sourced domestically. But the government would not have to pay for the CCS incentive program until the project is completed and CO_2 sequestration begins. In addition, by incentivizing the early deployment of CCS, the U.S. can assume a leading position in this critical sector and create a thriving, high-tech export business, and the quality jobs that come with it.

The most important reason to promote early deployment of CCS is that post-combustion CO_2 capture technologies will preserve the huge investment in existing coal-fired power plants and allow us to effectively use abundant low-cost coal reserves in the U.S. and developing nations, even in a climate-constrained world. If we do not succeed in commercializing CCS technology in the near term, it will be difficult for the world to meet its long-term goals for climate change mitigation.

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M. Granger Morgan

Carbon Capture and Sequestration: How Can it Succeed Commercially?

Innovations Case Discussion:
Powerspan Corp.

In a market economy, people innovate because they think they can develop a comparative advantage selling a new product or service. This principle does not apply to environmental control technology, as its purpose is to limit a negative externality. Unless a regulation directly or indirectly places a price on that externality, there is very limited incentive to innovate.

Recent studies have shown that major innovation occurred both in the case of sulfur emissions control on power plants[1] and on motor vehicles[2] only after emission control regulations were passed, or it had become clear that they were about to be passed.

We have known for more than half a century that rising atmospheric concentrations of carbon dioxide (CO_2), and other greenhouse gasses, are trapping heat and changing the climate. Yet despite over a decade of talk, the US government still has not instituted emissions controls for CO_2. Several US states have established limits on the amounts of CO_2 that new power plants can emit. For example, California, Washington and Maine have all set limits on emissions from new plants to 1100lb per megawatt-hour. This level is high enough to allow new natural gas plants, but low enough to prevent the building of new conventional coal-fired plants.

Carbon dioxide is not like more conventional air pollution such as SO_2, NO_X or fine particles. Those pollutants only remain in the atmosphere for a few hours or days. In contrast, much of the CO_2 we emit remains in the atmosphere for over 100 years. Indeed, we are all still breathing molecules of CO_2 released to the atmosphere by Newcomen's and Watt's steam engines, Frick's coke ovens, and Carnegie's steel mills. For this reason, if we want to stabilize the climate system, we are going to have to do far more than stabilize the growing emissions of CO_2. Stabilizing the atmospheric concentration will require something like an 80% reduction in global emissions. That will require a profound transformation in the way we produce

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and use electricity, since the electric sector is the single largest source of CO_2.

Furthermore, coal is not likely to disappear quickly. Many people know little about where our electricity comes from; when they first hear these facts, they typically say "so, make it all with renewables." That simple and appealing prescription faces two problems. First, electricity generation and transmission is a capital-intensive business, involving physical plants whose useful economic lives span many decades. Today most of our electricity comes from coal (~50%), natural gas and a little bit of oil (~20%), nuclear (~20%), and large hydroelectric (~7%). Today, wind provides a mere 0.77% of total generation, geothermal 0.36%, and solar 0.01%. It will take decades to get the carbon out of such a capital-intensive industry. Second, renewables, such as wind and solar, are variable (e.g., no sun at night) and intermittent: along with the rapid fluctuations in wind, there are also "droughts." For example, in January 2009, for a period of 10 days, there was no wind at all across the entire Bonneville Power system. Even when distant wind farms are connected together, the remaining variability must be filled in with the use of gas turbines or quick-acting hydro power.

Major innovation occurred both in the case of sulfur emissions control on power plants and on motor vehicles only after emission control regulations were passed, or it had become clear that they were about to be passed.

All this means that, for decades to come, the U.S. will still need to use coal as part of a portfolio that includes improvements in end-use efficiency along with a mix of low-emission power generation technologies. This in turn means that Powerspan's strategy of developing a chilled ammonia clean-up system that could be added to the back end of large and relatively new coal plants makes great sense—*if* serious controls are instituted for emissions of CO_2. But that is a big if.

If a profit-maximizing firm is to adopt CCS technology for capturing and sequestering CO_2 in deep geological formations, the effective price on emitted CO_2 will have to be at or above \$50/tonne.[3] It is unclear whether or how soon the US Congress will manage to pass legislation to control CO_2 emissions, but when it does, it will likely work hard to hold the effective price of CO_2 below \$20 to \$30/tonne. That means that to be viable, the market for all types of CCS technology (Figure 1) will depend heavily on subsidies for at least the next several decades. New CCS power plants will cost upwards of a couple of billion dollars. Retrofits to existing plants, like those that Powerspan is developing, will obviously cost less, but we are still talking many hundreds of millions of dollars.

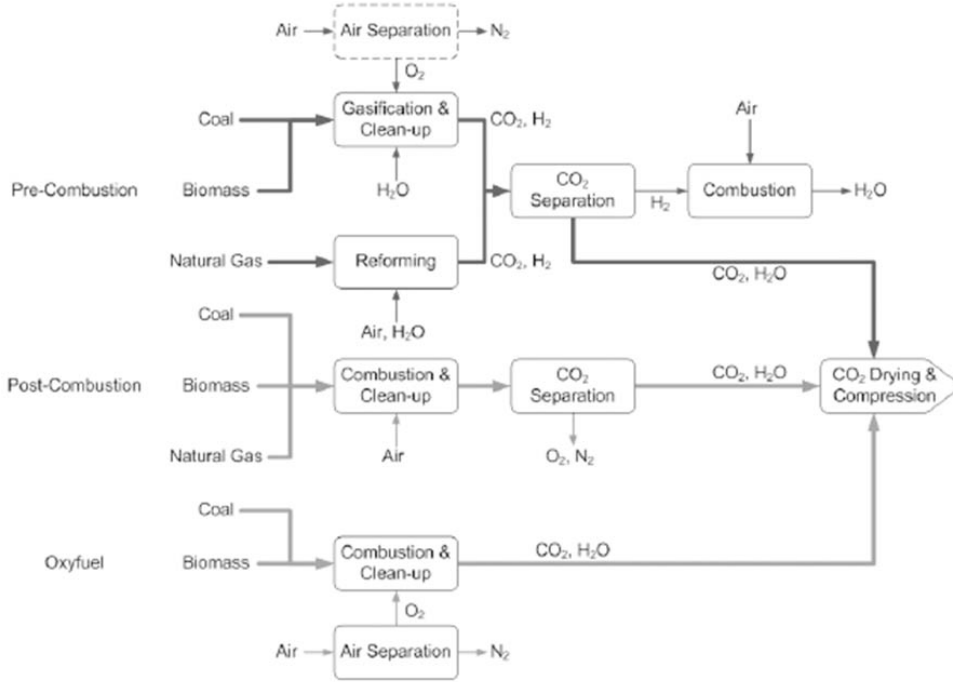

Figure 1. Three types of technology for capturing and sequestering CO_2 from a power plant.

Source: Figure adapted by Sean McCoy, from *IPCC Special Report on Carbon Dioxide Capture and Storage*, 2005. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, eds. B. Metz, O. Davidson, H.C. de Coninck, M. Loos, and L.A. Meyer. Cambridge, UK, and New York: Cambridge University Press

Three basic types of technology can be used to capture and sequester CO_2 from a power plant. Post-combustion scrubbing, shown at the top of the figure, involves removing CO_2 from a rather dilute steam of flue gas using a material to absorb the gas, such as chilled ammonia in the case of the Powergen system or various types of amines. This technology has an advantage: it can be used with existing plants, assuming physical space is available to build the additional clean-up train. In the second type, pre-combustion separation (middle of figure), the coal is first gasified, yielding a more concentrated stream of CO_2. The third alternative (bottom of figure) involves combustion in oxygen, which avoids the large volume of nitrogen present in post-combustion capture thus yielding a concentrated stream of CO_2.

We are accustomed to thinking about learning curves as starting high and decreasing monotonically as more and more units are built. In order to develop insights about how learning curves might evolve for CCS, Edward Rubin and his colleagues looked at how they are developed for SO_2, NO_x and fine particle control for large coal-fired power plants.[4] They found that costs rise over the course of the first several plants, while designers deal with unanticipated problems, and only start to decline after experience and refinements have accumulated from several early plants. This is another reason why it is essential to get some commercial-scale CCS plants built sooner rather than later.

After years of talking about CCS, the U.S. is finally showing signs of getting serious. Several bills in Congress would provide resources to get the first several commercial- scale plants built. With luck, companies like Powerspan will be able to hang on long enough to benefit from these subsidies. But subsidies may not last forever. If they start to phase out, we may see the emergence of a different kind of "valley of death": the gap between the moment subsidies start to tail off, and the time when effective CO_2 prices rise high enough to make CCS commercially attractive. On the other hand, once they are established, subsidies have a tendency to persist.[5]

Moreover, technology and cost may not be the largest obstacle. While CCS faces significant technical and economic challenges, in the U.S. the largest challenges may involve the regulations that govern deep geological sequestration of the CO_2 once it has been captured. Today, the U.S. injects large volumes of waste fluid underground. For example, the state of Florida injects roughly 3 billion tonnes of treated wastewater every year. All such injection is done under licenses granted by the US Underground Injection Control (UIC) Program, which is operated by the EPA (in many cases with delegation to states) under statutory authority provided by the Safe Drinking Water Act. Five different well types are regulated under the UIC program. EPA is working now to develop a sixth well type, for sequestering CO_2.

The problem is that the EPA's authority under the Safe Drinking Water Act does not allow it to address the two biggest obstacles to the wide commercial deployment of CCS: legal access to deep pore space, and long-term liability and stewardship for closed-out injection sites.

In much of the rest of the world, the state or "crown" owns the deep subsurface. In the U.S., the situation is much more complex and varies from state to state. Under the present UIC program, no one gets permission from surface property owners to inject waste fluids. However, given the enormous volumes that will be injected by commercial CCS operations, and the fact that the injectors will be big companies with deep pockets, it is a safe bet that as soon as large-scale injection of CO_2 begins, litigators claiming trespass will start appearing. If such suits were decided differently in different states, as they almost certainly would be, access to pore space could become impossibly complex and expensive.

Major insurance companies report that they are perfectly able to insure the operational phase of a CCS injection project. However, once a site is closed out, they are not willing to continue to provide liability coverage indefinitely.

These, and several other problems, are not likely to be addressed adequately without new federal legislation. To this end, the CCS Regulatory Project,[6] a joint effort by engineers and lawyers, has developed a set of six recommendations for new legislation:

- Declare that it is in the public interest to sequester carbon dioxide (CO_2) in geologic formations to mitigate the detrimental effects of climate change.
- Address the issue of access to and use of geologic pore space.
- Amend the Safe Drinking Water Act to direct UIC regulators to promulgate rules for GS that meet three goals:
  - Address all environmental, health and safety issues associated with deep geological sequestration (GS) of CO_2.
  - Be based principally on adaptive, performance-based standards, as opposed to design standards.
  - Include mechanisms to balance and resolve conflicts between multiple environmental objectives.
- Direct UIC regulators to coordinate with regulators in charge of greenhouse gas inventory accounting for the U.S.
- Obligate GS project operators to contribute on the basis of their operating performance to a revolving fund to cover long-term stewardship.
- Create an independent public entity (the Federal Geologic Sequestration Board) to approve and accept responsibility for appropriately closed GS sites.

Each of these recommendations is elaborated in a series of policy briefs developed by the CCSReg Project.[7]

Without elaborating further on such details, the key point is that developing a large US market for CCS will depend on not one but two new legislative initiatives:

1. New rules will have to limit CO_2 emissions with sufficient stringency to result in an effective price of ≥$50/tonne.
2. A new regulatory system must ensure that CCS is safe, comprehensive, environmentally sound, affordable, internationally compatible and socially equitable.

In short, while technical innovation will be a critical part of the successful large-scale deployment of CCS, innovation in public policy and law will likely be as or more important.

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Matthew Bunn and Martin B. Malin

Enabling a Nuclear Revival—And Managing Its Risks

As John Holdren points out in the introduction to this *Innovations* special issue, the world will need to produce huge quantities of energy in the 21st century to meet the needs of a growing world population, while also working to lift billions of people out of poverty. Providing this energy at a reasonable cost, without causing unmanageable climate disruption, security risks, or other environmental devastation will be one of the century's most daunting challenges. This challenge will be even more difficult to meet if nuclear energy does not play a substantial part. But achieving the scale of nuclear energy growth required while managing the risks of that growth will be a major challenge in itself, one that will require both technical and institutional innovations.

Consider the scale of growth that is needed for nuclear energy to make a meaningful contribution to mitigating carbon emissions. One oft-cited 2004 analysis broke down the problem of shifting away from a business-as-usual energy path into seven "wedges"—different technologies that would each grow to displace a billion tons of carbon emissions per year by 2050 (see Figure 1).[1] More recent science suggests that 10 to 15 such wedges are likely to be required, as business-as-usual emissions are higher than previously projected, the carbon-absorbing properties of the oceans appear to be weaker, and the atmospheric concentration of carbon required to avoid disastrous climate consequences seem to be even lower than once thought. For nuclear power to provide even *one* such wedge would require a

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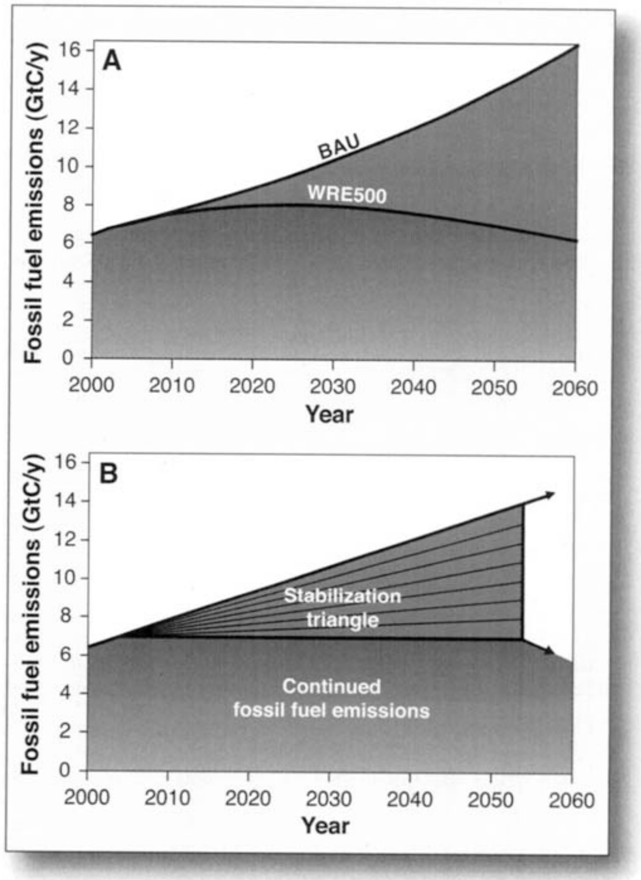

Figure 1. Stabilization Wedges

Source: Socolow and Pacala (2004) p. 969. "(A) The top curve is a representative BAU emissions path for global carbon emissions as CO2 from fossil fuel combustion and cement manufacture: 1.5% per year growth starting from 7.0 GtC/year in 2004. The bottom curve is a CO2 emissions path consistent with atmospheric CO2 stabilization at 500 ppm by 2125 akin to the Wigley, Richels, and Edmonds (WRE) family of stabilization curves described in (11), modified as described in Section 1 of the SOM text. The bottom curve assumes an ocean uptake calculated with the High-Latitude Exchange Interior Diffusion Advection (HILDA) ocean model (12) and a constant net land uptake of 0.5 GtC/year (Section 1 of the SOM text). The area between the two curves represents the avoided carbon emissions required for stabilization. (B) Idealization of (A): A stabilization triangle of avoided emissions (green) and allowed emissions (blue). The allowed emissions are fixed at 7 GtC/year beginning in 2004. The stabilization triangle is divided into seven wedges, each of which reaches 1 GtC/year in 2054. With linear growth, the total avoided emissions per wedge is 25 GtC, and the total area of the stabilization triangle is 175 GtC. The arrow at the bottom right of the stabilization triangle points downward to emphasize that fossil fuel emissions must decline substantially below 7 GtC/year after 2054 to achieve stabilization at 500 ppm."

tripling of global nuclear capacity by 2050, while simultaneously replacing nearly all the reactors now operating as they reach the end of their useful lives. This would entail increasing the pace of construction from four nuclear plants connected to the grid each year worldwide—the current rate—to 25 plants on average every year for the next 40 years. Since there is no possibility that rate of growth will be achieved in the next few years, the pace at the end of the period would have to be still higher, in the range of 30-50 reactors per year worldwide.[2]

To achieve this level of growth, nuclear energy must become dramatically more attractive to utilities, governments, and publics around the world. This would require reducing costs, preventing any substantial accident, avoiding terrorist sabotage, finding politically sustainable solutions to nuclear-waste management, and ensuring that nuclear energy does not contribute (and is not seen as contributing) to the spread of nuclear weapons to proliferating states or terrorist groups. Moreover, these challenges are interconnected and can only be addressed effectively in an integrated fashion. For example, we must take measures to improve nuclear safety and security that are also affordable, and we have to find acceptable ways of disposing of waste without increasing proliferation risks.

Nuclear energy must become dramatically more attractive to utilities, governments, and publics around the world. This would require reducing costs, preventing any substantial accident, avoiding terrorist sabotage, finding politically sustainable solutions to nuclear-waste management, and ensuring that nuclear energy does not contribute (and is not seen as contributing) to the spread of nuclear weapons to proliferating states or terrorist groups.

In short, nuclear safety, security, nonproliferation, and waste management are essential enablers for large-scale nuclear energy growth. It is very much in the world's interest—and the nuclear industry's interest—to drive the risk of catastrophe as close to zero as possible. Even a single catastrophe—whether a Chernobyl-scale accident, a successful sabotage (a "security Chernobyl"), or, worse yet, a terrorist nuclear bomb—would doom any prospect for nuclear growth on the scale needed to make a significant contribution to coping with climate change.

Although continued R&D on new technologies is important, the most critical near-term steps to reduce the risks from nuclear energy and to improve its chances of playing a major role in mitigating climate change will be institutional, not technical. For the long term, new reactor and fuel-cycle designs that are cheaper, safer, more easily secured, more proliferation resistant, and more appropriate for developing countries with modest electricity grids and technical infrastructures could have a major impact on nuclear energy's role in carbon mitigation. But even as low-risk new technologies come on line, the global risk of an accident or sabotage is likely to be dominated by a handful of facilities—those without the new safety and security features, and those in countries with weak safety and security regulations and poorly trained staff who cut corners on safety and security rules. Stronger global institutions and agreements are needed now to identify and remedy problems at the highest-risk facilities; greater international cooperation will be a necessary and essential part of a peaceful and vibrant nuclear futur[3]

In this section of the *Innovations* special issue, three authors outline particular institutional innovations now being pursued that could make a real difference for the future of nuclear energy and potentially for the planet. Tariq Rauf describes current efforts to establish an international "bank" for nuclear fuel, giving countries guaranteed fuel supplies without having to build their own plants to enrich uranium (plants that could also be used to produce more highly enriched uranium for use in nuclear weapons). Roger Howsley describes the recently established World Institute for Nuclear Security (WINS), designed to promote stronger nuclear security practices worldwide. Charles McCombie outlines the possibility of regional or international management of spent nuclear fuel or nuclear waste, avoiding the risks and costs of every country with even one nuclear power plant establishing its own nuclear waste disposal site laden with plutonium-bearing spent fuel – and potentially creating strong incentives for countries to rely on international fuel supplies, rather than building their own enrichment and reprocessing plants to produce and manage their nuclear fuel. In what follows we provide an overview of some of the innovations that must be put in place to enable future nuclear growth and to manage the resulting safety, security, and proliferation risks.

IMPROVING SAFETY

Nuclear plants today are dramatically safer today than they were in the days of Three Mile Island and Chernobyl.[4] But the 2002 incident at the Davis-Besse plant in the United States—where dripping boric acid ate away a football-sized hole in the reactor pressure vessel head before it was discovered—is a potent reminder that nuclear safety requires constant vigilance. Safety must continue to improve. Tripling nuclear energy capacity by 2050 without increasing the risks of a nuclear accident would require that the per-reactor annual accident risk be reduced by a factor of three compared to today's. Efforts to improve safety must focus particularly on identifying and addressing the least safe facilities, which are likely to dominate the global accident risks; these least-safe facilities are likely to be concentrated in three categories.

First, aging first-generation designs still pose significant safety risks that need to be addressed. (Remarkably, a dozen reactors with the same design as Chernobyl are still operating, for example; although a number of steps have been taken to avoid a repeat of that accident, these reactors still lack modern containment vessels and emergency core cooling systems.) Extending licenses and boosting the designed power output in existing plants may be desirable for carbon mitigation and profitable for the operators of those facilities, but such extensions must not be granted without ensuring that every necessary step has been taken to ensure that these reactors do not pose a substantially higher risk of a catastrophic radiation release than more modern facilities. Those that cannot meet that goal should be shut down.

Second, there is the problem of "newcomer" countries that do not yet have experience operating an effective nuclear regulatory system, building a sound nuclear-safety culture, or providing trained and capable personnel. A major effort will be necessary to help these countries put effective safety measures in place. One approach that should be considered would focus on small, factory-built reactors with high levels of built-in safety and security, which could be deployed at a site and generate electricity for 10-20 years with few staff members on site, an approach sometimes referred to as the nuclear battery. An international nuclear operating company could provide the initial staff and training for such facilities—an approach the United Arab Emirates hopes to follow in the early stages of its nuclear program.[5] Continued R&D, demonstrations, and institutional development would be needed to bring such a concept to fruition.[6]

Third, there are reactors where the staff has a poor safety culture and does not give safety measures the attention they require. While this category overlaps considerably with the first two, safety culture is a major problem even in wealthy developed countries that have been using nuclear power for decades. The Davis-Besse incident already mentioned, for example, arose because of a fundamental breakdown in the safety culture at the site and among regulators dealing with the site at the Nuclear Regulatory Commission, which allowed the site to postpone inspections and did not follow up on earlier indicators of a potential problem.[7] Even in the most advanced nuclear states, sustaining a strong safety culture as large numbers of new plants are built and thousands of new personnel enter the nuclear industry will pose a special challenge. China and India, with their near-term plans for rapid construction of large numbers of new reactors, will face this challenge acutely.

Operators of nuclear facilities, overseen by national regulators, are responsible for addressing such problems and ensuring nuclear safety. But the consequences of a major nuclear accident would extend far beyond national borders; the spread of that realization after Chernobyl led to the establishment of a broad international nuclear-safety regime. Today this regime includes international treaties such as the Convention on Nuclear Safety, a variety of agreements on liability in the event of a nuclear accident, a set of nonbinding international norms and standards, and a web of organizations that act to promote safety. The International Atomic Energy Agency (IAEA) has developed a series of safety standards and guides that do not carry the force of international law but are nonetheless widely followed. The World Association of Nuclear Operators (WANO), an industry organization that includes the operators of all the world's nuclear power reactors among its members, provides for exchanges of information on safety incidents, lessons learned, and best safety practices, and organizes international peer reviews of safety arrangements at member reactors. An IAEA program also offers peer reviews of safety arrangements at individual reactors, along with other programs that offer reviews of regulatory practices and other matters. The IAEA and the OECD's Nuclear Energy Agency manage a global safety incident-reporting system. There are also bilateral and multilateral nuclear safety assistance programs, international professional associations and conferences, and other groups focused on nuclear safety.[8]

This international regime has helped to achieve major improvements in nuclear safety over the more than two decades since the Chernobyl accident, but substantial gaps in the regime remain. The Convention on Nuclear Safety sets no binding standards for how safe nuclear facilities should be.[9] The IAEA peer reviews occur only when a state asks for one, and most of the world's nuclear power reactors have never had such a review. Hence, when asked the question "which reactors in the world pose the highest accident risks?" the IAEA has no real way of knowing the answer (though it can make some educated guesses). WANO peer reviews are closer to being universal, but they are far less rigorous than, for example, those of WANO's U.S. affiliate, the Institute of Nuclear Power Operations, and WANO promises its members that the results of these reviews will be kept confidential. If a WANO team finds a significant problem, WANO typically does not even tell the national regulator, unless the facility's operator agrees to do so. WANO officials have warned that some operators are not implementing all the recommendations of the peer reviews, so the same problems sometimes crop up on the next review.[10] Both WANO and the IAEA have warned that some safety incidents are not being reported, and some operators are not learning the lessons from incidents elsewhere, so that the same kinds of problems continue to occur.[11]

In 2008, an international commission convened by the IAEA recommended that (a) the IAEA should lead efforts to establish a "a global nuclear safety network" that would strengthen exchanges of safety-critical knowledge, experience, and lessons learned; (b) over time, "states should enter into binding agreements to adhere to effective global safety and standards and to be subject to international nuclear safety peer reviews"; (c) the IAEA and relevant states should greatly strengthen their efforts to help newcomer states "develop sound safety infrastructures"; and (d) the IAEA should expand its efforts to help states around the world assess and strengthen nuclear safety culture.[12] The commission argued that the IAEA's budget for nuclear-safety activities should be substantially increased to support this larger role.

STRENGTHENING SECURITY

Nuclear security requires even more urgent action. Terrorists are actively seeking nuclear weapons and the materials and expertise needed to make them, and have seriously considered sabotaging nuclear power plants.[13] The growth and spread of nuclear energy—and potentially thousands of lives and billions of dollars—will depend on the world's ability to prevent either of these threats from materializing. Achieving that goal will require major improvements in nuclear-security practices in many countries around the world.

A potential nuclear revival has quite different implications for these two threats. More nuclear reactors in more places need not increase the chance that terrorists could get their hands on the material for a nuclear bomb. Today, most nuclear power reactors run on low-enriched uranium fuel that cannot be used in a nuclear bomb without further enrichment, which is beyond plausible terrorist capabilities. These reactors produce plutonium in their spent fuel, but that plutonium is 1 percent by weight in massive, intensely radioactive spent-fuel assemblies that would be extraordinarily difficult for terrorists to steal and process into material that could be used in a bomb. If this plutonium is separated from the spent fuel by reprocessing, fabricated into new fuel, and shipped from place to place, that could increase the risk that terrorists could seize the material for a nuclear bomb unless operators take extraordinary security measures throughout the process. Fortunately, economics and counter-terrorism point in the same direction in this case: because reprocessing is much more expensive than simply storing spent fuel pending disposal, few countries that do not already reprocess their fuel are interested in starting, and some of the existing plants are running far below capacity or heading for shut down.

Nevertheless, many more nuclear power reactors in many more countries would mean more potential targets for terrorist sabotage—and more chances that some reactor's security would be weak enough that an attack would succeed in overwhelming built-in protections designed to reduce the risk of catastrophic dispersal of the reactor's radioactive core. A successful sabotage would be a catastrophe for the country where it occurred, and for its downwind neighbors. But the location of the reactor would determine the location of the damage; unlike readily transported nuclear weapons or materials, a successful attack on a reactor would not threaten lives in countries thousands of kilometers away.

Unfortunately, in many countries, the security measures in place to prevent theft of weapons-usable materials are demonstrably insufficient to defeat the kinds of threats terrorists and criminals have shown they can pose. As a result, theft and illicit trafficking of nuclear materials is not a hypothetical concern but an ongoing and current reality. The IAEA, for example, has documented 18 cases of theft or loss of plutonium or highly enriched uranium (HEU) – the essential ingredients of nuclear weapons – confirmed by the states concerned.[14] That reality was driven home in November 2007, when two armed teams simultaneously attacked the Pelindaba nuclear facility in South Africa, which contains hundreds of kilograms of HEU. One of the groups successfully disabled the security systems and the attackers made their way to the control room, shooting a security officer there, before any alarm was sounded. Although they did not seize any HEU, they escaped before external security reinforcements arrived and were never apprehended.[15]

Given incidents such as these and the major improvements in nuclear safety in recent years, the probability of a catastrophic release caused by malevolent human action—a successful sabotage or a terrorist nuclear bomb—may well be higher than the chance of such a release occurring purely by accident. If so, a radical change in nuclear security practices, culture, and regulation around the world is needed, for the emphasis in the industry today focuses overwhelmingly on safety and far less on security.

As with safety, nuclear operators themselves, overseen by national regulators, bear primary responsibility for providing effective security for nuclear weapons, weapons-usable materials, and facilities that might be vulnerable to a catastrophic sabotage. But the international community—including the global nuclear industry—has an overwhelming stake in ensuring that they carry out this responsibility effectively. Unfortunately, international institutions for nuclear security are substantially weaker than those for nuclear safety. Because the world has yet to witness a successful act of nuclear terrorism, complacency is widespread; many policymakers and nuclear managers around the world dismiss the danger or assume that existing security measures are more than sufficient. Most countries view nuclear security as an exclusively national responsibility, and shroud their practices in secrecy to avoid having potential adversaries learn about the kinds of defenses they might have to overcome.

The international conventions related to nuclear security, including the Convention on the Physical Protection of Nuclear Material and Facilities and the International Convention on the Suppression of Acts of Nuclear Terrorism, do not set specific standards for how secure nuclear materials or facilities should be, and include no mechanisms for verifying that states are complying with their commitments. U.N. Security Council Resolution 1540 legally obligates all U.N. member states to provide "appropriate effective" security and accounting for any nuclear weapons or related materials they may have, but no one has defined what key elements are required for a nuclear security and accounting system to be considered "appropriate" and "effective."[16] The IAEA has published physical protection recommendations, but these are still vague; in the case of a substantial stock of plutonium or HEU, for example, they call for having a fence with intrusion detectors but say nothing about how difficult it should be to get past the fence or avoid setting off the detectors. As in the case of safety, IAEA-led peer reviews of security are entirely voluntary; much less than half of the world's nuclear power reactors, and very few of the sites with HEU or plutonium, have ever had an international review of their security arrangements.

The Nunn-Lugar Cooperative Threat Reduction program and similar bilateral and multilateral cooperation programs have played a crucial role in improving nuclear security over the past 15 years, particularly in the former Soviet Union. The United States has invested billions of dollars in programs designed to help countries install and operate improved security and accounting systems, and to remove weapons-usable nuclear material entirely from a wide range of sites—for example, by converting research reactors to use low-enriched uranium rather than HEU. As a result of these efforts, nuclear security at scores of sites around the world has been markedly improved, and dozens of additional sites no longer have any weapons-usable nuclear material that could be stolen.[17] But there are still many important vulnerabilities to be addressed, and these international cooperative programs have so far not focused in depth on addressing the danger of sabotage.

The world needs a fast-paced global campaign to strengthen nuclear-security measures for all the sites and transports that handle nuclear weapons or weapons-usable material, or that could result in a catastrophic release of radioactive material if sabotaged. Plutonium and HEU that might be stolen reside not only in the stockpiles of states with nuclear weapons, but also in civilian facilities that reprocess and fabricate plutonium and in research facilities that use HEU in dozens of countries around the world. President Obama has pledged to lead "a new international effort to secure all vulnerable nuclear material around the world within four years."[18] Achieving that objective will take sustained high-level leadership, an effective and comprehensive plan, broad international cooperation, and adequate resources. The job will require convincing political leaders around the world that nuclear terrorism is a real and urgent threat to *their* countries' security, worthy of increased investment of their time and resources, not just a figment of overheated American imaginations.

As part of such a global campaign, a major effort is needed to reduce dramatically the number of buildings and bunkers where nuclear weapons and the materials needed to make them exist. States must also agree on and implement effective global standards for nuclear security, not only to prevent theft of nuclear weapons or materials, but also the sabotage of nuclear reactors, so that all are providing comparable levels of security against threats that terrorists have shown they can pose. Finally, to sustain nuclear security over the long run, those responsible for providing security at individual nuclear facilities must foster a strong security culture in the workplace.[19]

In this volume, Roger Howsley describes a new institution, WINS, which may play a key role in this effort. By providing a forum were nuclear security operators can exchange best practices and ways to resolve common issues, WINS has the potential to help strengthen nuclear security worldwide and to build up security culture, convincing operators and staff that the threats are real and can be addressed effectively without breaking the bank.

DEALING WITH NUCLEAR WASTES

As reliance on nuclear power increases, so too will the problem of how to deal with highly radioactive nuclear wastes. Nuclear waste is expensive to process or dispose of underground, politically unpopular to site, potentially vulnerable to sabotage when left in overfilled pools at reactor sites, and contains plutonium that could be reprocessed for use in nuclear weapons. Fortunately, the technology of concrete and metal dry-storage casks offers a cheap, safe, and proven means to store spent nuclear fuel for decades while more permanent solutions are developed. But the politics of waste storage and disposal remains a major problem, as President

Obama's recent decision to cancel the Yucca Mountain nuclear-waste repository, in the face of pressure from Senate Majority Leader Harry Reid of Nevada, makes clear. Here, too, institutions will be critical in building trust and public support for effective nuclear-waste management approaches.[20] As Charles McCombie writes in this issue, programs in which supplier states would "lease" fuel, taking back the spent fuel after it was used, and regional repositories could provide a critical means for small states to make use of nuclear energy without having to establish their own nuclear-waste repositories—and without leaving plutonium-bearing spent fuel scattered permanently in dozens of countries all over the world. "Shared disposal facilities for the spent fuel and highly radioactive wastes at the back end of the fuel cycle," writes McCombie, "should be one key component in a secure global [nuclear energy] system."

REDUCING PROLIFERATION RISKS

There is also much to be done to ensure that the growth and spread of nuclear energy will not contribute to the proliferation of nuclear weapons—another key to large-scale nuclear energy growth. The proliferation risks posed by nuclear reactors themselves are not zero—ordinary power reactors produce plutonium in their spent fuel and require large staffs of trained people who might later be turned to a nuclear weapons program, and substantial nuclear bureaucracies that may advocate for a weapons program. But the biggest risks come not from nuclear reactors but from the materials needed to make a nuclear bomb, plutonium separated from spent fuel or highly enriched uranium, and from the uranium enrichment and plutonium reprocessing facilities that could be used to make these potential bomb materials. A world of many more nuclear reactors will require more uranium enrichment or more plutonium recycling, potentially creating more challenges to safeguarding these materials, more companies working on enrichment technologies that might leak onto the nuclear black market, or more countries with facilities that could readily be turned to producing nuclear bomb material.

Moreover, the nonproliferation regime has suffered a number of major blows over the past several years. With North Korea becoming the first state to withdraw from the Nuclear Non-Proliferation Treaty (NPT) and test a nuclear bomb, Iran apparently seeking to come up to the edge of a nuclear weapons capability while staying within the regime, and the A.Q. Khan network peddling dangerous nuclear technologies across the globe, the need for action to strengthen the global effort to stem the spread of nuclear weapons has never been clearer. And nations aspiring to produce nuclear energy are not the only states that must renew their commitment to uphold the basic rules and principles of the nonproliferation regime. To gain international support for strengthened nonproliferation measures, the nuclear weapon states will have to be seen to be living up to their end of the nonproliferation bargain as well by pursuing nuclear arms reduction and disarmament in good faith.

Many steps will have to be taken to limit proliferation risks. Iran and North Korea present the first and most urgent challenges. The outcome of today's efforts to walk North Korea back from the nuclear brink and to persuade Iran to accept restraints on its fuel-cycle activities will have a major effect on whether nuclear energy will spread peacefully or will become a hedge behind which nuclear newcomers develop the necessary infrastructure to eventually build weapons. The United States and the other partners in relevant talks must engage directly with North Korea and Iran, with packages of promised benefits and punishments large enough and credible enough to convince these states that it is in their interest to give up their nuclear weapon ambitions.

Beyond those two cases, some of the most important means of limiting the risk of proliferation include phasing out the civilian use of HEU and minimizing civil plutonium reprocessing; forging new approaches to the fuel cycle that limit the spread of nationally controlled uranium enrichment and plutonium reprocessing facilities; building new approaches to police, intelligence, and export control cooperation to stop black-market transactions in nuclear technology; strengthening international safeguards; and strengthening enforcement when states violate their nonproliferation obligations.

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One approach that holds special promise as a nonproliferation tool is the proposed IAEA-sponsored fuel bank, which is described by Tariq Rauf in this issue. The idea is to provide a nonpolitical, nondiscriminatory mechanism for supplying nuclear fuel to any state that is in compliance with its nuclear-safeguard obligations. Having an assured backup if fuel supplies were ever cut off could strengthen states' incentives not to bother with the major investment required to build their own uranium enrichment facilities, thus limiting the long-term proliferation risks posed by such facilities.[21] In the future, as outgoing director-general of the IAEA, Mohammed ElBaradei, has argued, the goal should be a shift toward international or multinational control of all enrichment and reprocessing—perhaps starting with new facilities and eventually converting existing plants to some form of multinational ownership and control—"so that no one country has the exclusive capability to produce the material for nuclear weapons."[22]

New technologies and approaches to their use could raise significant future barriers to proliferation. Some of the small "nuclear battery" reactor concepts mentioned earlier, for example, are being designed to reduce proliferation risks through a combination of technological innovation (such as sealed reactor cores with no on-site access to the fuel) and new institutional arrangements (such as international firms to build, operate, and remove such reactors).[23] These concepts are still in development, however, and it remains to be seen whether the promise of real systems will match that envisioned while the reactors are still on paper. In particular, cost may be a major issue for these designs: the nuclear reactors on sale today are predominantly in the 1-1.6 gigawatt-electric (GWe) class because of economies of scale, and it remains to be seen whether very small reactors can make up in economies of production scale what they lose in economies of physical scale.

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But for decades to come, it will be institutional rather than technological innovations that contribute the most to stemming the spread of nuclear weapons.[24] The foundation of all the nonproliferation institutions is the Nuclear Non-Proliferation Treaty; all states except India, Pakistan, Israel, and North Korea are now parties. The NPT and the global nonproliferation regime have been largely unheralded success stories. There has been no net increase in the number of states with nuclear weapons in 20 years (South Africa dropped off the list, becoming the first case of real nuclear disarmament, and North Korea added itself to the list), an astonishing achievement, given that this 20 years included the chaos following the collapse of the Soviet Union, the operation of the A.Q. Khan network in its exporting phase, and secret nuclear weapons programs in Iraq, Libya, Syria, Iran, and North Korea. There are now more states that have started nuclear weapons programs and verifiably abandoned them than there are states with nuclear weapons—meaning that nonproliferation efforts succeed more often than they fail, even when states have already started down the nuclear-weapons road. But given the new pressures the regime now faces, even stronger nonproliferation agreements and institutions are needed to ensure continued success.

The IAEA is the primary international organization charged with overseeing compliance with nonproliferation rules. Its safeguards agreements with member states, for example, play a critical role in ensuring that the use of nuclear technology in states without nuclear weapons remains peaceful. But IAEA safeguards have important weaknesses, particularly in the difficult job of detecting undeclared activities at covert sites. The IAEA faces significant constraints in its access to sites, information, resources, technology, and the Security Council. There are also important issues of institutional culture that require constant attention; for example, balancing the need to maintain positive relationships with states – which is essential for the IAEA to do be able to do its work – with an appropriate investigatory attitude is a continuous challenge.

With respect to access to sites and information, the "Additional Protocol" to safeguards agreements, negotiated in the 1990s in response to the post-1991 revelation of the full extent of Iraq's nuclear activities, is a major advance. For those states that agree to it, the Additional Protocol requires states to disclose more information on nuclear-related activities, permits the IAEA access to an expanded set of sites, allows for short-notice inspections, and is intended to provide at least limited confidence not only that a state is not diverting nuclear material from declared nuclear facilities, but also that the state does not have secret, undeclared nuclear-related activities. However, many issues remain. First, there are dozens of states, some with significant nuclear activities that have not acceded to the Additional Protocol more than a decade after its adoption. Second, the Additional Protocol still focuses the IAEA's authority on sites involving nuclear material or the technologies to make such materials. When the IAEA wanted to visit, for example, Parchin in Iran, to investigate accusations that explosive experiments related to nuclear weapons might have taken place, there were no undisputed legal grounds for doing so.[25] To address some of these issues, former IAEA deputy director-general for safeguards, Pierre Goldschmidt, has suggested that the U.N. Security Council should pass a legally binding resolution that would impose a wide range of additional safeguards obligations on any state found to be in violation of its safeguards agreements, including broad-ranging inspections and a right for international inspectors to interview key scientists and other participants in nuclear programs in private.[26]

With respect to resources, the IAEA's budget for implementing nuclear safeguards worldwide is roughly the size of the budget of the Vienna police department, a situation that clearly has limited what the IAEA can hope to do, even as the demand for safeguards inspections is increasing. Unfortunately, the IAEA has been caught up in the broader politics of efforts to reform the U.N. system and restrain the growth of the budgets of U.N. agencies. At the same time, with the nuclear revival increasing demand for nuclear experts in the private sector and IAEA salaries and other personnel policies constrained by participation in the common personnel system for all U.N. agencies, the IAEA has had increasing difficulty recruiting and retaining the nuclear experts it needs to carry out its mission. Roughly half of all senior IAEA inspectors and managers will reach the agency's mandatory retirement age within five years.[27]

The IAEA and various of its member states are exploring a variety of new technologies that can contribute to the safeguards mission, from ever-evolving techniques for analyzing tiny particles taken in swipes from nuclear facilities to systems for monitoring the flow of nuclear materials in sensitive facilities in real time. Finding hidden nuclear facilities remains a fundamental challenge, however. Centrifuge enrichment plants, in particular, are small and potentially easy to hide; a facility capable of producing enough material for a nuclear bomb every year might not use any more power or cover any more area than a typical supermarket. And, in some cases, the challenge is not just to develop the technology but also to get industry to permit its use. The enrichment industry, for example, has so far refused to allow the IAEA to use equipment for continuous monitoring of the flow in their plants.

Finally, there is the question of the will and effectiveness of the U.N. Security Council in requiring states to comply with IAEA inspections, and in enforcing nonproliferation obligations more generally. When North Korea was found to be in violation of its safeguards obligations in the mid-1990s, the Security Council issued a statement but did nothing more. Meanwhile, the United States reached an accord with North Korea that postponed IAEA special inspections many years into the future. More recently, in the case of Iran, the U.N. Security Council passed legally binding resolutions requiring Iran to comply with IAEA inspection requirements, provide additional transparency to resolve key issues, and suspend its enrichment and reprocessing activities. Iran has ignored these resolutions, leading the Security Council to impose a series of mild sanctions against Iran that have not caused that country to change course.

In 2008, an international commission on the future of the IAEA called on states "to give the IAEA access to additional information, sites, and people, along with the money, qualified personnel, and technology that it needs to carry out its mission." The commission made a wide range of more specific recommendations, from universal adoption of the Additional Protocol to interpreting the agency's existing authority to give it the responsibility to "inspect for indicators of nuclear weaponization activities."[28]

The Nuclear Suppliers Group (NSG) is also an important international nonproliferation institution, but faces ongoing challenges to its effectiveness and legitimacy. Established in response to the 1974 Indian nuclear test, the NSG has traditionally operated by consensus and, as more and more states have joined, consensus on modernizing its rules has become more difficult to achieve. Most NSG participants, for example, strongly support making the Additional Protocol a condition for nuclear exports from NSG states, but Brazil (which has not accepted the Protocol) has resisted. Canada has similarly refused to agree that enrichment technologies be exported only on a "black-box" basis, i.e. without the recipient being able to have access to the technology.[29] Turkey recently objected to a proposal that would allow exporting states to consider proliferation problems in a recipient's geographic region when deciding whether to approve an export.[30] NSG members have held several rounds of discussions on strengthening export guidelines, but such objections have so far stalled these efforts. Some key states that may be worrisome sources of nuclear technology – including Pakistan, India, Israel, North Korea, and Iran, among others – are outside of the NSG. The NSG also has a problem of legitimacy, as a self-selected group: many developing countries believe the NSG is effectively a cartel that unfairly restricts nuclear trade, and is contrary to the NPT requirement to cooperate in the peaceful uses of nuclear energy.

The past decade has seen a variety of efforts at institutional innovation in the nonproliferation regime. With the advent of the Additional Protocol, the IAEA is in the process of a fundamental shift from simply measuring the nuclear material at declared facilities to a "state-level approach" that seeks to understand all the nuclear activities of each state, and to look for hints of secret, undeclared facilities. In the aftermath of the A.Q. Khan network and the 9/11 attacks, the U.N. Security Council unanimously passed Resolution 1540, which legally requires every U.N. member state to take a wide range of actions, from establishing "appropriate effective" export controls and security for nuclear stockpiles to criminalizing any effort to help nonstate actors with nuclear, chemical, or biological weapons. Unfortunately, however, no one has yet fleshed out what specific measures are required for export control or nuclear-security systems to meet the "appropriate effective" standard, and relatively little has been done to help states put effective systems in place.

Efforts to get states to work together to prevent proliferation without new treaties or organizations may also, over time, lead to building new institutions. After an embarrassing episode in which the United States found it had no authority to stop a ship and seize its cargo on the high seas, even though it was carrying North Korean missiles to Yemen (there was no agreement preventing Yemen from making such a purchase), the Bush administration launched the Proliferation Security Initiative (PSI), a voluntary grouping of countries that agrees to stop ships or aircraft carrying illicit nuclear, chemical, biological, or missile cargo when they are flying the flag of a participating country or in one of those countries' waters or airspace.[31] While the Bush administration went out of its way to avoid institutionalizing the PSI and the later Global Initiative to Combat Nuclear Terrorism out of a misplaced allergy to international institutions, President Obama has argued that because these threats are likely to be long-lasting, both should be turned "into durable international institutions."[32]

Some innovations were less positive or less successful. In 2005, for example, President Bush reversed years of international nonproliferation policy by agreeing to supply civilian nuclear technology to India, even while India continued its nuclear weapons program. The Nuclear Suppliers Group eventually blessed this new arrangement, creating a situation in which some non-nuclear-weapon states saw India getting all the benefits they received for being a party to the NPT without joining the treaty or even capping its growing nuclear-weapons stockpile, let alone giving it up. The Bush administration also called for a major international discussion of strengthening the safeguards system, but this effort collapsed in disarray with no agreement on even the most modest new steps.[33] Similarly, the 2005 review conference for the NPT fell apart without reaching any agreements, in large part because of the Bush administration's refusal to even discuss the disarmament commitments that all parties had agreed to at the previous review.

Fortunately, with President Obama's commitment to "a world without nuclear weapons," along with renewed support for negotiating deeper near-term reductions in U.S. and Russian nuclear arms, ratifying the Comprehensive Test Ban Treaty, and negotiating a verified cutoff of the production of fissile materials for weapons, the atmosphere in international nuclear discussions has changed dramatically, greatly improving the prospects for the next NPT review in 2010.[34] Of course, the goal of zero nuclear weapons is a long-term prospect, and it is not yet certain whether it can be achieved. But it is crucial to begin taking steps in that direction, reducing the nuclear danger at each step.

Fundamentally, strengthened nonproliferation measures are critical to a safe future for nuclear power, but they will not get international support unless President Obama and the leaders of the other nuclear weapon states make good on their NPT obligation to negotiate in good faith toward nuclear disarmament. Reducing existing arsenals may not have any effect on convincing North Korea or Iran not to want nuclear weapons, but it will have a major effect on convincing other countries to vote for stronger inspections, enforcement, export controls, and the like, all of which will help cope with the challenges posed by states violating the regime. A future of expanded reliance on nuclear power necessarily implies a future of much reduced reliance on nuclear weapons.

ENABLING A SAFE, PEACEFUL, AND VIBRANT NUCLEAR FUTURE

Creating the conditions for nuclear energy to grow on the scale needed for it to be a significant part of the world's response to climate change without posing undue risks is a global challenge. New steps to ensure safety, security, waste management, nonproliferation, and progress toward disarmament will be essential to success. All of these will require close international cooperation and stronger international institutions. In particular, achieving the safe, secure, and peaceful growth of nuclear energy will require an IAEA with more money, more authority, more information, more technology, more support from the U.N. Security Council.

With nuclear energy growth still proceeding at a modest pace and much of the industry focused on the inevitable difficulties of building the first few reactors of the new generation of designs, many policy-makers have been putting off the issues addressed here for a later day. But it will take time to build the institutions needed to guide a peaceful and vibrant nuclear future. It is essential that governments act in time, before an accident or terrorist attack shows us where and how we were too late.

1. S. Pacala and R. Socolow, "Stabilization Wedges," *Science*, August 13, 2004, pp. 968-972.
2. Pacala and Socolow envision 700 1-gigawatt nuclear plants substituting for efficient coal plants by 2050. The existing roughly 370 gigawatt-electric (GWe) of nuclear energy will also have to be replaced by 2050, for a total requirement to build over 1,000 1-GWe reactors in the next 40 years. Indeed, since the "business-as-usual" scenario presumably already includes a substantial amount of reactor construction, adding 700 reactors would require a still faster pace of reactor construction.
3. For a similar argument, see Commission of Eminent Persons, *Reinforcing the Global Nuclear Order for Peace and Prosperity: The Role of the IAEA to 2020 and Beyond* (Vienna: International Atomic Energy Agency, May 2008).
4. The authors are grateful to Andrew Newman for research assistance with this section.
5. See U.S. Department of State, "Nuclear Proliferation Assessment Statement: Pursuant to Section 123a. of the Atomic Energy Act of 1954, as Amended, With Respect to the Proposed Agreement for Cooperation Between the Government of the United States of America and the Government of the United Arab Emirates Concerning Peaceful Uses of Nuclear Energy" (Washington, DC: Department of State, April 2009), p. 4.
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Tariq Rauf and Zoryana Vovchok

Assurance of Supply: A New Framework for Nuclear Energy

The increase in global energy demands and pressing concerns over climate change are driving a potential expansion in the use of nuclear energy. Dozens of states have approached the International Atomic Energy Agency (IAEA) for guidance as they explore the possibility of building nuclear power reactors for the first time. With an expansion and spread of nuclear energy will come an expanded demand for nuclear fuel, and for the management of spent nuclear fuel. Where will the fuel supply for an expanded global reactor fleet come from? Will it remain in the hands of existing suppliers, with expanded capacity? Will new states develop their own national enrichment capabilities, adding to the number of states with the capacity to produce either fuel for nuclear power reactors or material for nuclear weapons? Or will multilateral nuclear fuel cycle facilities emerge to meet expanding demand? Many IAEA member states have expressed mounting concern over the risks that could be created by the further spread of technologies such as uranium enrichment or plutonium reprocessing—key technologies for the production of fuel for nuclear power reactors that could also be used to produce material for nuclear weapons.

The convergence of these realities points to the need to develop a new framework for the nuclear fuel cycle that provides reliable and predictable access to nuclear fuel and power reactors while strengthening the Nuclear Non-Proliferation Treaty (NPT) regime. Establishing a framework that is equitable and accessible to all users of nuclear energy acting in accordance with agreed nonproliferation norms will be a complex endeavor and should be addressed through a series of interlinked, progressive steps.

The first step would be to establish mechanisms that provide assurance of the supply of fuel for nuclear power reactors—and, as needed, assurance of the acqui-

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sition of such reactors. If states have assured access to fresh fuel for their nuclear power reactors, they will be less motivated to pursue own development of sensitive technologies for producing nuclear fuel. The second step would be to have future facilities for enrichment and reprocessing—the key technologies that make it possible to produce nuclear weapons material—under multilateral operation, rather than under purely national control. The third step would be to convert existing enrichment and reprocessing facilities from national to multilateral operations. In this context, it would be crucial to negotiate and implement a global, internationally verifiable treaty prohibiting the production of fissile material for nuclear weapons. Below we focus primarily on the first of these steps.

THE NEED FOR A NEW FRAMEWORK

The first notion of fuel assurances appeared in the Baruch Plan, a 1946 US proposal to the United Nations to provide international oversight of atomic energy development. Some 30 years later, the 1976 international nuclear fuel–cycle evaluation looked at multilaterally owned and operated nuclear frameworks. And, 60 years after the Baruch Plan, a special event at the IAEA's general conference held in September 2006 focused on several new proposals for multilateral approaches, such as commitments to supply enrichment services, international nuclear fuel centers, and even multilateral control over all nuclear fuel-cycle facilities.

In the more than half-century since the Baruch Plan, dual-use material and technologies have spread, with attendant risks of proliferation and nuclear terrorism. Such nuclear threats affect both the future of peaceful uses of nuclear energy and the prospects for nuclear disarmament.

The spread of nuclear fuel-cycle facilities and technologies is motivated in part by states' interest in ensuring reliable fuel-cycle services through indigenous capability. This, then, is the challenge: what must be added to the existing market for fuel-cycle services to provide enough assurance of supply to convince states that there is no need to invest in their own indigenous fuel-cycle facilities?

This question goes to the heart of the IAEA's mission. Not surprisingly, the IAEA must balance the interests of all of its member states. It needs to adequately represent the needs and interests of developing states, of nuclear supplier states, of states that are already relying on nuclear power, and of states that have plans to develop nuclear power in the future, all while minimizing the risk of proliferation, as stated in the IAEA Statute.[1]

THE ROLE OF FUEL ASSURANCES

Discussions both with nuclear supplier states and, more importantly, with consumer states have made abundantly clear that different states will choose different policies and solutions to meet their energy requirements. States' choices will depend on their specific situation, such as their geography, their technical abilities, and the individual preferences of policy-makers and members of the public. Thus, the IAEA must retain flexibility to respond to these demands.

The mechanisms for the assurance of supply are not intended to address commercial disagreements between suppliers and consumers but rather to prevent interruptions of the supply of nuclear fuel due to a supplier's political considerations that are not related to nonproliferation.[2] These concepts are intended to address two particular challenges. The first is to prevent supply vulnerabilities from dissuading states from initiating or expanding nuclear power programs. The second is to reduce vulnerabilities that might create incentives for states to build new national enrichment and reprocessing capabilities.

In other words, an assurance-of-supply mechanism is envisaged solely as a means of backing up the operation of the current normally functioning market in nuclear materials, fuels, technologies, and so on. This would not be a substitute for the existing market, nor would it deal with disruptions of supply due to commercial, technical, or other failures. Moreover, in this context, no state would be asked or expected to give up or abridge any of its rights under the NPT.

An assurance-of-supply mechanism is envisaged solely as a means of backing up the operation of the current normally functioning market in nuclear materials, fuels, technologies.

This point about rights is a critical one. In the debate outside of Vienna, the word "forgo" is used more often than not when describing the establishment of an IAEA fuel bank. Some officials and analysts have envisioned that states would agree to forgo their right to build enrichment and reprocessing facilities, and in return would gain access to an assured supply of nuclear fuel. In this day and age, however, few states are prepared to give up any rights, and one unexpected outcome of the proposals that have been framed in this way is that at least seven states have popped up saying that they may be interested in establishing enrichment plants in the future and are not prepared to compromise, dilute, or give up their right to do so. These states are Argentina, Australia, Brazil, Canada, Kazakhstan, Ukraine, and South Africa. This represents the greatest explosion of interest in enrichment in the nuclear age; it has been provoked in substantial part by well-intentioned efforts to prevent the spread of enrichment. Therefore, we need to frame the debate in a way that does not demand that states sign away their right to build enrichment and reprocessing plants, that helps states feel comfortable that they can maintain their rights while making sovereign choices to rely, for the present, on the international market for nuclear fuel. These choices must be backed up by a multilayered mechanism that includes both assurances and a physical reserve of nuclear material. Just as the word "forgo" has done more to undermine than to promote progress, loose talk of loopholes or an Achilles' heel in the NPT, or of a need to "reinterpret" the inalienable right to peaceful uses as recognized under Article IV of that treaty or in the Statute of the IAEA is at best unhelpful, at worst counter-productive.

As of summer 2009, three specific and more advanced fuel-assurance proposals were under discussion.[3] These proposals – the proposal of the IAEA Director-General on the establishment of an IAEA Low Enriched Uranium (LEU) Bank, the Russian Federation Initiative to establish a reserve of LEU for supply to IAEA for its Member States, and the Multilateral Enrichment Sanctuary Project (MESP) of Germany - which are complementary, range from providing backup assurance of the supply of LEU, to establishing an IAEA-controlled LEU reserve, to setting up an international uranium enrichment center where the IAEA would have some role in the decision-making.

STRUCTURING A NEW FRAMEWORK

A framework for assuring the supply of nuclear fuel could include three levels: first, reliance on the existing market, based on existing commercial and other arrangements; second, backup commitments provided by suppliers of enrichment and fuel-fabrication services, and their respective governments, to be used when predetermined conditions and criteria are met following a disruption of supply for political reasons; and third, a reserve of low-enriched uranium (LEU) stored in one or several locations under IAEA auspices, supported by agreements between suppliers of fuel-fabrication services and owners of fuel intellectual property rights, thus creating additional possibilities for fabrication.

The IAEA Statute, which entered into force on July 29, 1957, provides the IAEA the authority to carry out the activities necessary to establish and operate a nuclear material bank (in this case, one containing low enriched uranium). Under Article III of the Statute, the agency is authorized to acquire materials, services, and equipment, and to establish its own facilities and plants, in order to facilitate the practical application of nuclear energy for peaceful purposes. The legal authority for the receipt, custody, and supply of nuclear material lies, in particular, specifically in Article IX of the Statute, which provides for the supply of materials to the IAEA, and in Article XI, which outlines the authorized scope for IAEA projects.[4] In addition, Article X refers to the possibility of member states making available to the agency services, equipment, and facilities that may be useful in fulfilling its objectives and functions.

IAEA Director-General Mohamed ElBaradei, in his statement to the Board of Governors in March 2009, said he was convinced that multilateral approaches to the nuclear fuel cycle have great potential to facilitate the expanded safe and secure use of nuclear energy for peaceful purposes, while reducing the risk of proliferation.[5] The best approach, he argued, would be to start with a nuclear fuel bank under IAEA auspices, based on the following principles: (1) that any such mechanism should be nonpolitical, nondiscriminatory, and available to all states that are in compliance with their safeguard obligations; (2) that any release of material should be determined by nonpolitical criteria established in advance and applied objectively and consistently; and (3) that no state should be required to give up its rights under the NPT regarding any parts of the nuclear fuel cycle. The next steps, as noted earlier, would be to seek agreement that all new enrichment and reprocessing activities should be placed exclusively under multilateral control, and then to convert all existing facilities from national to multilateral control so that ultimately, as ElBaradei has said, no one country would have "the exclusive capability to produce the material for nuclear weapons."[6]

ESTABLISHING AN IAEA LOW ENRICHED URANIUM FUEL BANK

Among the leading proposals is one from the Nuclear Threat Initiative (NTI) that offers the IAEA $50 million on two conditions: (1) that IAEA member states raise an additional $100 million in material or cash donations, and (2) that the IAEA Board of Governors sets up an IAEA-controlled reserve of LEU as a last-resort supply in the event of a politically motivated supply disruption of nuclear fuel to an IAEA member in good standing. All other criteria for the fuel bank under the NTI proposal are left to the IAEA to define. Thus far, the United States has provided $49.5 million, Norway has pledged $5 million (and paid $1.5 million), and other pledges have come from the United Arab Emirates ($10 million), the European Union (Euro 25 million or about $33 million), and Kuwait ($10 million). The total will exceed the $100 million requirement once all the pledges are fulfilled. The NTI has extended its initial two-year deadline, which would have expired in September 2008, thus allowing more time for consensus to be built on the structure of the reserve and for the IAEA Board of Governors to take the decision for the establishment of such a bank. The following is a general description of how the bank would work.

The IAEA bank would contain a physical stock of LEU of standard commercial specification, with U-235 enrichment levels ranging up to 4.95 percent. This range of enrichment would provide the necessary flexibility to meet the requirements for subsequent fuel fabrication for most power reactors. The IAEA envisions making purchases of LEU using its standard procedures for open tender from vendors willing and able to provide the material free of conditions that conflict with the envisioned purpose of the fuel bank. The LEU would be made available to a consumer state at the prevailing market price at the time of supply, and the proceeds would be used to replenish the stock of LEU.

At current market prices, the $150 million pledged so far would be sufficient for the purchase of 60-80 tonnes of LEU and its delivery to the IAEA fuel bank located in a host state. This would be sufficient for one full core of a 1000-1500 MW(e) power reactor or for three annual reloads, and would be sufficient to meet the electricity needs of two million average Austrian households for three years. The annual cost to operate the bank, which would be incurred by the IAEA, would depend on a number of factors, including storage costs and the costs of other requirements associated with storage, such as safety and security measures. Ideally, such costs would be picked up by the host state.

The Russian Federation has proposed separately to establish an LEU reserve that the IAEA could draw on. Russia has indicated that it will create a physical reserve of 120 tonnes of uranium, in the form of UF_6, with an enrichment of 2.0% to 4.95%, of which at least 40 tonnes have an enrichment of 4.95 percent. Russia has committed to provide LEU that would meet the latest commercial specifications, and any future evolution of those standards.

The Russian Federation would, upon notification from the Director-General of the IAEA, deliver the LEU to the IAEA in St. Petersburg for supply to eligible IAEA consumer state(s). Eligible states would be those states for which the IAEA has drawn the conclusion that there has been no diversion of declared nuclear material and concerning which there are no issues under consideration by the IAEA board of governors relating to the application of IAEA safeguards. The LEU could be transferred to a non-nuclear-weapon state only when it has brought into force an agreement with the IAEA requiring the application of safeguards on all its peaceful nuclear activities. Russia has committed to issue all necessary export controls and other authorizations, "such that the shipment of material out of the country at the request of the Agency is guaranteed."[7] This would include the timely transfer of ownership to the IAEA for subsequent supply to an eligible member state, and arrangements for the physical shipment of the LEU out of Russian territory. The Russian Federation also would arrange for the prompt issuance of all necessary authorizations and licenses for the import of international licensed transport containers for the LEU, as well as for their transport within and from the territory of the Russian Federation. The Russian Federation would bear all expenses relating to the storage and maintenance of the LEU prior to notification by the Director-General of an impending shipment. The recipient country would pay the IAEA in advance for the specific quantity of LEU at the prevailing market price, and the IAEA would use the money to pay Russia to replenish the reserve.

It has been proposed, subject to the Board of Governors' approval, that an IAEA member state experiencing a disruption of its fuel supply would be required to meet certain conditions to receive fuel from an IAEA fuel bank. The supply of LEU from the bank or the reserve would be permitted to an IAEA member state only if (1) the state is experiencing a disruption of LEU fuel supply to a power reactor due to nontechnical, noncommercial reasons; (2) the IAEA has concluded in the most recent annual Safeguards Implementation Report that the state has not diverted declared nuclear material and that no specific report relating to problems with safeguards implementation is under consideration by the board of governors; and (3) the state has brought into force a safeguards agreement that applies to the LEU being supplied through the IAEA bank.

In the case of the Russian reserve, the receiving state would be required to have placed all of its peaceful nuclear activities under IAEA safeguards. Any other member state could also choose to establish a national LEU reserve that the IAEA could draw upon, subject to that state's own criteria. (The United States, for example, is also establishing an LEU reserve of some 300 tons, down-blended from up to 17 metric tons of highly enriched uranium (HEU) no longer needed for military purposes.[8]) However, the LEU reserves managed by the IAEA itself, as envisioned in the NTI proposal, would be subject only to criteria and rules agreed on by the IAEA Board of Governors; as currently envisioned, it would in principle be possible for a state that does not have full-scope safeguards to draw on the reserve, as long as it had met the criteria outlined above.

How would the decision be taken to go forward with a shipment of fuel? It has been proposed that the IAEA Board would agree in advance to follow this process:

A consumer state[9] that is experiencing a disruption in the supply of LEU that is not related to technical or commercial considerations and that fulfils the prescribed criteria, would submit a request to the Director General to provide a specified amount of LEU for a power reactor, along with an explanation of the circumstances in support of its request;

The Director-General would assess the nature of the disruption and determine whether the consumer state has fulfilled the criteria established by the Board and is thereby eligible to purchase LEU from the IAEA.

The Director-General, using a model agreement, would conclude an agreement with the consumer state requesting the LEU. The agreement would specify the obligations of the IAEA and of the consumer state, including all issues relating to the amount and specification of the LEU, liability, safeguards, and the cost of the LEU (including delivery, transport, and insurance costs) that would be paid in advance to the IAEA.

Following the entry into force of the above-mentioned agreement, the Director-General would authorize the transfer of the LEU to the consumer state.

The Director-General would keep the Board informed throughout the entire process. Note that there would be no requirement for consumer states to sign up ahead of time or to forgo any rights; the reserve would simply be available to be drawn upon if needed, reducing states' incentives to make the large investments required to develop their own enrichment capacity.

Why the focus on a bank of enriched uranium in the form of UF_6? According to the latest IAEA sources, there are now 13 enrichment facilities in 9 states versus 34 fabrication plants in 18 states.[10] This shows that fuel-fabrication services are more widely dispersed than enrichment services, thus justifying an initial focus on supply assurance of LEU and for fuel fabrication to be considered at a later stage. Moreover, attempting to establish a bank of fabricated fuel would be extremely difficult, as each reactor design uses a different set of fuel designs, and each fabricator has intellectual property in the particular fuel designs it fabricates; therefore, to have prefabricated fuel suitable for every reactor in the world would be prohibitively expensive. As noted earlier, however, the IAEA secretariat has explored concepts in which there would be prior agreements among the fabricators to step in and provide fabrication services in the event of a disruption from another supplier.

The bank would provide enriched uranium rather than natural uranium for two reasons: first, most of the world's reactors use enriched uranium, and second, natural uranium is available from a far wider array of sources since it is mined in dozens of countries. Currently, 48 nuclear power plants (11% of the world total) use natural uranium (44 pressurized heavy water reactors plus 4 MAGNOX reactors) and 388 nuclear power plants (89% of the world total) use enriched uranium.[11]

Germany has offered another proposal, suggesting that the international community set up a multilateral enrichment sanctuary project (MESP),[12] which would involve a group of interested states contributing the money, technology, and expertise to establish a new enrichment facility in a state that has not developed its own uranium enrichment technology.. The MESP would buy its centrifuges using a "black box" model, in which the state that provided the centrifuges would control and operate the centrifuge cascades while the other members of the group of interested states would control all other aspects of the operations. The MESP would provide enrichment services to the group and to the market, and could also provide LEU for an IAEA bank. It would be run on a commercial basis without government subsidies, and would have to operate on a profit-making basis in order to sustain its operations as a new producer. This would represent a new step in the direction of multinational control of enrichment facilities.

A CAUTIOUS APPROACH

To reiterate, establishing a new framework for the nuclear fuel cycle is a complex endeavor that will need time to develop. The IAEA secretariat is working to lay out the necessary legal and technical specifics, and to facilitate a full, frank, and comprehensive discussion with both consumer and supplier states. This preparatory work should make it possible for states to decide whether to establish an IAEA LEU bank or other multilateral mechanisms in the near term.

In his 1953 Atoms for Peace speech, President Dwight D. Eisenhower articulated a vision, shared by many world leaders, that would enable humanity to make full use of the benefit of nuclear energy while minimizing its risk. This vision led to the establishment of the IAEA. Much has changed since that time, and it is appropriate to take stock now of our successes and failures. Most important, we must resolve to take whatever actions are required, including new ways of thinking and unconventional approaches, to ensure that nuclear energy remains a source of hope and prosperity for humanity as envisioned in the NPT, and not a source of increased danger.

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3.See Tariq Rauf and Zoryana Vovchok, A Secure Nuclear Future, IAEA Bulletin (September 2009), Vol. 51, No. 1, p. 11.
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5. Mohamed ElBaradei, "Introductory Statement to the Board of Governors," March 2, 2009, http://www.iaea.org/NewsCenter/Statements/2009/ebsp2009n002.html (accessed July 13, 2009).
6. Mohamed ElBaradei, "Reviving Nuclear Disarmament," conference on Achieving the Vision of a World Free of Nuclear Weapons, Oslo, Norway, February 26, 2008.
7. Russian Federation, "Establishment, Structure, and Operation of the International Uranium Enrichment Centre," INFCIRC/708 (Vienna: International Atomic Energy Agency, June 8, 2007), http://www.iaea.org/Publications/Documents/Infcircs/2007/infcirc708.pdf (accessed 14 July 2009).
8. See IAEA document, INFCIRC/659 (September 29, 2009), http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc659.pdf; and Fact Sheet on U.S. HEU for a Nuclear Fuel Reserve, http://vienna.usmission.gov/np_nuclear.html, accessed 15 July 2009.
9. As noted above, only an IAEA member state could request supply of LEU.
10. International Atomic Energy Agency, *Nuclear Fuel Cycle Information System, A Directory of Nuclear Fuel Cycle Facilities* (2009 Edition), IAEA-TECDOC-1613 (Vienna: IAEA, 2009). See table 14 for a list of states with enrichment plants, and tables 17-22 for states with fuel fabrication plants.
11. This includes 92 boiling water reactors or BWRs, 2fast breeder reactors, or FBRs, 14 gas cooled reactors, or GCRs, 16 light water graphite reactors, LWGRs (including 12 Chernobyl-style, Russian-design reactors, and four very small Russian reactors at the Bilibino site), and 264 pressurized water reactors, or PWRs. One Argentine pressurized heavy water reactor, or PHWR operates with very slightly enriched uranium, i.e. 0.9% U-235 instead of natural uranium's 0.7%, but should the supply of enriched material be interrupted, it could operate on natural uranium.
12. See Federal Republic of Germany, "The Multilateral Enrichment Sanctuary Project: A Fresh Look at Ensuring Nuclear Fuel Supply," INFCIRC/735 (Vienna: IAEA, September 25, 2008), http://www.iaea.org/Publications/Documents/Infcircs/2008/infcirc735.pdf (accessed July 13, 2009).

Roger Howsley

The World Institute for Nuclear Security: Filling a Gap in the Global Nuclear Security Regime

In September 2008, a new international institution was born—the World Institute for Nuclear Security (WINS). Mohammed ElBaradei, then the director-general of the International Atomic Energy Agency (IAEA), said that "WINS fills an urgent gap in our need to strengthen the nuclear security system." But the key question is, what is that gap?

Cast your mind back to April 26, 1986, and the accident at Chernobyl that shocked the world and all but stopped further expansion of and investment in nuclear power. After that accident, "nuclear operators world-wide realized that the consequences had an effect on every nuclear power plant and international cooperation was needed to ensure that such an accident can never happen again." That statement is from the World Association of Nuclear Operators (WANO),[1] which was formed in May 1989 by nuclear operators worldwide to exchange operating experience and peer review so members could learn from one another's experiences, challenges, and best practices, the ultimate goal being to improve plant safety, reliability, and performance.

But WANO only handles nuclear safety. WINS was established to pursue similar objectives in improving nuclear security. In a world facing a global terrorist threat, we cannot afford to wait for a "security Chernobyl" before we take collaborative action to improve security.

WINS is designed to complement, not compete with, existing efforts to improve nuclear security around the world.

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The United States and other donor countries have done a great deal to finance the installation of improved nuclear security and accounting systems, to expand training programs, to strengthen regulatory efforts, and the like in the former Soviet Union and elsewhere. The Global Initiative to Combat Nuclear Terrorism is another effort that is entirely consistent with the WINS vision. Indeed, one of the Global Initiative's founding principles is the exchange of best practices in nuclear security, and WINS is designed to provide a forum for that exchange. The IAEA has a very successful security program, which drafts international recommendations and guidelines covering various aspects of nuclear security and organizes international reviews of particular elements of states' nuclear security approaches when states ask for such help. In November 2007, I had the honor to be asked by the IAEA to chair a review of its security program, looking back to 2002 when it first started and forward over the next few years. I concluded that the IAEA security team is doing a fantastic job.

The WINS vision is to help secure all nuclear and radioactive materials so that they cannot be utilized for terrorist purposes.

But there is no doubt that the global nuclear security regime is not as developed as the global nuclear safety regime. Individual states establish nuclear security rules for operators under their jurisdiction, but there are no international agreements that specify what kinds of security states should require for nuclear warheads or the nuclear materials needed to make them. The pervasive secrecy surrounding nuclear security means that no global mechanism is in place to identify the worst security performers and help them come up to the level of the best performers. It is important to understand that IAEA "safeguards," despite the name, are not designed to provide either safety or guarding. Instead, safeguards involve international inspections—typically ranging from once a month to once a year, depending on the type of material and other state-level factors—to ensure that the inspected state has not diverted material for military use. Hence, the fact that material is under safeguards does not mean that it is adequately secure.

The WINS vision is to help secure all nuclear and radioactive materials so that they cannot be utilized for terrorist purposes. But WINS can only undertake part of that immense challenge and it cannot address all of the issues facing the global nuclear-security regime. Indeed, given the secrecy that is an essential component of nuclear security, some aspects of the global nuclear-security regime that differ from the picture for nuclear safety are not likely to change in the near term. WINS does not aspire to set regulatory standards, or to act politically, speak on behalf of the nuclear industry, or promote or discourage any aspect of the fuel cycle. But it does aspire to make a difference.

WINS aims to provide an international forum for security professionals to meet, discuss, and decide how to implement best practices. Some of the meetings will be organized around international workshops to share best practices, others will be at the national level or among groups of individuals with common interests. There is no set or fixed approach; meetings will be driven by the needs of the members but with a focus on one thing: improving the implementation and performance of security. It really is time for the nuclear community to create more opportunities for the professional development of its security managers and staff, and to encourage the type of dialogue that is so taken for granted by our colleagues in the field of nuclear safety. We have a great deal to learn from their techniques of learning from experience, sustaining operational excellence, and promoting a strong safety culture.

WINS' focus is both broader and narrower than WANO's. It is broader in that WANO's members are predominantly operators of nuclear power reactors, while many other organizations, both nuclear and non-nuclear, contribute to nuclear security. While WANO is an industry organization, WINS must involve both security professionals from these organizations and the regulators who set the rules. In other words, WINS must be inclusive.

Its focus is narrower in that it does not presently plan to carry out international peer review of security practices as WANO does for safety practices. The IAEA peer-review program provides a good service for countries wanting such review; nevertheless, there would be advantages in expanding the scope of peer review to include the effectiveness of the managerial arrangements for overseeing and driving the performance of the security system. WINS may be better placed to do this than the IAEA.

WINS is particularly focused on ensuring that nuclear operating organizations take proper responsibility for security at all levels, up to and including the board of directors. We are keen to see nuclear organizations of all types embrace security as an issue of corporate governance in the same way they think about financial, safety, and environmental performance and risk management. Sound corporate governance and the right security culture are the keys to success, as demonstrated by improvements in nuclear safety and the reaction of industry leaders to Chernobyl. We have important things to learn from those working in nuclear safety and should be open to new ideas. We should begin to challenge whether all traditional aspects of security really need to be secret and isolated from mainstream corporate oversight. We should begin to unpack the "security box" to see what's inside and to determine what needs to stay inside to protect sensitive information.

In thinking about corporate governance, there are some basic questions to ask of boards of directors and other senior managers of both private and government organizations that have custody of and responsibility for the security of nuclear and radioactive materials. First, to what extent have the boards been briefed by their state authorities on the potential security threats to their operations—the so-called Design Basis Threat (DBT)? Some believe that discussing security and sharing details of the DBT could compromise security arrangements, but this has to be a false argument; how can operators trusted with day-to-day accountability for nuclear security sensibly address the risks if they are unaware of the threats they are facing?

Second, we need to ask if the board takes an active interest in assessing security by reviewing data on how well the security system is actually performing day-to-day. The boards of nuclear organizations likely have subcommittees that review safety, financial, and environmental performance, so why not security performance? The best companies conduct such reviews, but there may be gaps, and it is right and important that the best companies share their practices with those that are still developing their security approach. Security reports to boards should follow the same structure as those for other corporate functions, and include information on safety and environment; identify leading and lagging performance metrics that test program effectiveness; identify risks and actions to manage and mitigate the risks; provide a review of independent regulatory attitudes on corporate performance; and seek board approval for the overall policy of managing the security risk.

And, finally, it is increasingly common for companies to publish reports on corporate social responsibility that detail oversight and achievements relating to safety and environmental performance. Shouldn't they also publish information on how their boards oversee security arrangements? I am not suggesting that sensitive information should be published, but it cannot be considered sensitive to confirm publicly that the board receives reports on security performance. This information would provide an opportunity for companies to discuss and assess whether their security arrangements are sufficiently robust and able to protect the organization's assets and minimize its liabilities—duties that most boards have a legal responsibility to discharge. We must strive to achieve a situation where all boards feel confident that they have sufficient opportunities to oversee security risk so that they do not feel ignored by regulators, unaware of threats, or shocked by the poor performance of their security system if attacked.

WINS was founded in partnership with some of the key international players in nuclear security, including the U.S. National Nuclear Security Administration, which is responsible for securing a huge array of nuclear assets and provides more international nuclear security assistance than any other organization in the world; the Institute for Nuclear Materials Management, the leading professional society for experts in nuclear safeguards and security; the Nuclear Threat Initiative, the private philanthropic group making the most substantial contribution to nuclear security, led by former Senator Sam Nunn; and the IAEA. WINS is also supported by the Norwegian and Canadian governments, which pledged financial support, and is establishing new partnerships with nuclear and non-nuclear organizations that want to help promote effective security and address some of the key questions.

But WINS still faces significant challenges, which we have to confront head-on, in cooperation with our members and partners.

One challenge is countering the impression that individual states are solely responsible for all aspects of nuclear security. Of course individual states are responsible for establishing policy in relation to international guidelines and recommendations, setting regulatory standards, and conducting associated inspection and verification arrangements. What role is there for an international non-governmental organization such as WINS? There can be little doubt that helping operators find the most effective approaches to meeting state requirements is a useful role, one that goes beyond the responsibility of individual states.

In particular, unless those accountable for the management of the nuclear and radioactive materials in their custody feel fully involved in that process and understand their responsibilities, there will be a potentially serious gap that must be filled. Therefore, in planning its future activities, WINS will be focusing initially on corporate governance and associated assurance methodologies; how to promote security culture; how to learn from the lessons of nuclear safety and operational best practices; how to learn from other industries; and how to encourage members to share their best practices in facilitated workshops of likeminded people from across the world who want to make a difference and fill the gap. WINS has already held its first workshop in the U.K., which included policy-makers, regulators, operators, and security specialists. This exercise demonstrated the value of holding facilitated workshops to discuss security issues; other activities are planned through 2010.

A second challenge is addressing the impression that everything about nuclear security ought to remain secret and that discussing best practices in itself compromises secrecy and risks breaches of security. Theoretically, there may be a risk, but as John F. Kennedy said, "There are risks and costs to a program of action, but they are far less than the long-range risks and costs of comfortable inaction."

We need to remember that international bilateral meetings have taken place for many years to discuss security issues. I have taken part in many such meetings. But in general, I have not found them to be the most effective or efficient method for identifying sustained improvements to security.

While I was working with British Nuclear Fuels (BNFL), we conducted a national stakeholder dialogue over a six-year period from 1999 to 2005 that addressed many aspects of our operations. Some of the participants wanted a dedicated working group on nuclear security and we agreed to form one. The group, which included people with strongly held antinuclear views, met over a period of nearly two years. The resulting published report, which was a consensus of everyone involved in the group, included some 60 recommendations. As the executive responsible for BNFL security at the time, I can affirm that BNFL changed some of its security arrangements in response to these recommendations and that security at BNFL improved as a result. Despite the profoundly different positions held by members of the group this provided clear evidence that properly facilitated meetings can be very productive and need not compromise security in any way.

A third challenge is building the sense of urgency and commitment to nuclear security within the nuclear industry. Employees in the nuclear industry are trained to focus on safety from the first day of their careers. Organizations like WANO are successful because the industry recognizes that a major accident anywhere would be devastating for the entire industry, which gives all participants an overwhelming interest in helping the worst performers come up to the level of the best performers. Exactly the same can be said of security. Therefore, a key mission for WINS will be spreading that message and convincing the industry to take action before something terrible occurs. We want to provide industry with the practical tools and techniques to help them act, including some straightforward questions to help organizations understand more about their security programs: What do you spend on security? How much of that is discretionary and how much is required by regulations or other requirements? How much of your security program is subject to performance measures to establish its effectiveness?

Achieving the WINS vision of providing security for all nuclear and radiological materials, so that they cannot be utilized for terrorist purposes is an immense challenge. Success will require commitment and leadership from governments, operators, nongovernmental organizations, philanthropists, and others across the world. WINS offers a potentially important new forum in that struggle.

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1 World Association of Nuclear Operators, "What is WANO?" Rev. 5 August 2008, at http://www.wano.org.uk/WANO_Documents/What_is_Wano.asp (accessed 30 September 2009). [I modified the language in the original article draft to match the version now on the WANO web page.]

Charles McCombie

Responsible Expansion of Nuclear Power Requires Global Cooperation on Spent-Fuel Management

Nuclear energy growth on the scale needed to make a major contribution to mitigating climate change will remain wishful thinking unless some crucial requirements are satisfied. In addition to cost, safety, security, and peaceful use, there will have to be a sustainable solution for managing spent fuel and nuclear wastes—the so-called back end of the nuclear fuel cycle.

Highly radioactive spent fuel containing fissile plutonium should not end up in numerous locations scattered around the globe as more and more nations, both large and small, expand or introduce nuclear power. A small number of safely constructed and well-secured storage and disposal facilities must be the goal. The key challenge in this regard is the siting and construction of deep geological repositories for long-lived radioactive wastes. These repositories are expensive; even the smallest state-of-the-art deep facilities for high-level radioactive wastes (HLW) or spent fuel will cost several billion dollars. Even the much admired and most advanced small Finnish repository will cost around $4.5 billion,[1] and cost estimates in the several tens of billions have been published for large programs such as those in the United States and the United Kingdom.

Many small nuclear programs or countries starting out in nuclear energy do not have the technical or financial resources to implement a national repository in a timely fashion. They will have to keep their spent fuel in interim storage facilities; this could result in numerous sites all around the world where hazardous materials will be stored for decades to hundreds of years. There must be a better way.

One safer and more secure option would be for nuclear-fuel suppliers to take back the spent fuel under a fuel "leasing" arrangement, in which they would pro-

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vide fresh fuel and take it back after irradiation. They would then add this leased spent fuel to their own larger stocks to be stored for later disposal, or for reprocessing and recycling into new fuels. However, although there is fierce competition among nuclear suppliers to provide reactors, fuels, and reprocessing services, as yet there are few willing to pursue this leasing approach.

The concept was included in the Global Nuclear Energy Partnership (GNEP) program, which the Bush administration launched in 2006 with the goal of restricting sensitive nuclear technologies to a limited number of supplier states.[2] In fact, the prospect of being able to return spent fuel to the supplier could well be the only real incentive for small countries to accept restrictions on the peaceful use of nuclear energy like those proposed under GNEP — restrictions that go beyond those in the Nuclear Non-Proliferation Treaty. Unfortunately, the United States never made a serious offer to take back spent fuel in the GNEP discussions, and some other would-be supplier nations, such as France, even have national laws that prohibit taking back spent fuel unless the high-level wastes are returned to the user after reprocessing. The user country would therefore still require a geological disposal facility for these wastes. Moreover, if there were any cost savings in implementing an HLW repository rather than a spent-fuel repository, these would be far outweighed by the prices charged for the reprocessing service.

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Of all the nuclear suppliers, Russia has expressed the most support for fuel leasing and take-back. Russia's fuel-supply contract with Iran is a leasing contract, in which Iran is required to send the plutonium-bearing spent fuel back to Russia after it has been removed from the reactor. Current Russian law makes it possible to import foreign spent fuel for reprocessing and the return of wastes (as in France and Britain), but it also makes it possible for Russia to take back Russian-origin fuel without requiring return of the wastes, which appears to be the approach reflected in the contract with Iran.[3] Russia has not yet offered such services widely, however, and with the current underdeveloped status of waste-disposal projects in Russia itself, some countries (and also the European Commission [EC]) would have reservations about taking up any Russian take-back offer.

The most promising option that remains open for small and new nuclear power programs is to collaborate with similarly positioned countries in an effort to implement shared, multinational repositories. Cooperation among geographically contiguous or nearby nations to develop shared regional repository projects may be the most credible approach, although the possibility that some country may decide to offer international repository services on a commercial basis cannot be excluded. The national advantages in sharing technology and in benefiting financially due to the economies of scale in implementing repositories are obvious. The global safety, security, and nonproliferation benefits of helping all nations have earlier access to state-of-the-art repositories are also clear. The big challenge, of course, is in achieving public and political acceptance in countries where repositories are hosted. Is it conceivable that a country and a local community within that country would willingly accept being a site for imported wastes?

Recent experience with national siting offers hope. Siting initiatives in several countries for either HLW or for low-level wastes have shown that success can be achieved through a modern strategy, one based on open communication, transparent documentation of potential benefits to host communities, steady accumulation of trust by the organization developing the repository, and recognition of the necessity of local acceptance. In a few countries (e.g., Finland, Sweden, South Korea), this has even led to competition between communities that want to host a repository. At the multinational level, it is possible that the same strategy may also succeed; however, as with the successful national programs, this may take several years.

Over the past few years, significant progress in this direction has been made in the Strategic Action Plan for Implementation of European Regional Repositories or SAPIERR project. The project, funded by the European Commission, has carried out a range of studies that lay the groundwork for serious multinational negotiations on the establishment of one or more shared repositories in Europe. The studies (all available on the website www.sapierr.net) have looked at legal and liability issues, organizational forms, economic aspects, safety and security issues, and the challenges of public involvement. The proposal that resulted from SAPIERR is a staged, adaptive implementation strategy for a European Repository Development Organization (ERDO). The first step in the strategy was to establish a working group of interested countries to carry out preliminary work to enable a consensus model for ERDO, using the SAPIERR findings as a starting point. The project team, realizing that further progress required commitments at the political level, contacted the energy or environmental ministries of potentially interested countries in the European Union. At the January 2009 pilot meeting of potential participants in the working group, 32 representatives from 14 European countries were present, all of whom had been nominated by their national governments.[4] Also attending were observers from the International Atomic Energy Agency, the EC, and American foundations. Strong support for further activities was shown, dates and venues for further meetings were decided and all representatives undertook the task of formalizing the necessary agreements at the national level, which would enable the working group's activities the for the next one to two years.

ERDO will be established in 2010, providing that a sufficient number of partner nations agree to the final proposals. It will operate thereafter as a sister organization to waste agencies from European countries that have opted for a purely national repository program such as France, Sweden, Finland, and Germany.

By combining their resources in this way, the ERDO partners can also demonstrate to other regions of the world the feasibility of enhancing safety and security while increasing the economic attractiveness of nuclear power, even for small countries. ERDO also could act as a role model for regional groupings elsewhere. A number of Arab states have recently made clear that they intend to introduce nuclear power and have expressed a willingness to do so collaboratively. Close links being formed today between nuclear programs in Brazil and Argentina might usefully expand into a Central and South American grouping. In Asia, countries like Taiwan and South Korea have already experienced problems trying to implement disposal programs, and various other Asian states, such as Malaysia, Singapore, and Vietnam, have nuclear ambitions. An African regional grouping could also emerge, as various nations there are expressing interest in nuclear energy.

Joining forces to develop regional repositories could still have substantial advantages for small nuclear countries, even if the major nuclear powers at some stage reverse their policies and, for strategic or commercial reasons, offer to accept foreign spent fuel or radioactive wastes. By presenting a united front, and with the open alternative of a building a multinational regional repository, the partner countries would be much better placed in negotiations with potential large service providers over the economic and other conditions attached to any offer to take their spent fuel.

Nuclear power must be economically competitive to thrive. Disposal costs are not a major cost driver for large nuclear programs, but for a country with only one or a few reactors, the multi-billion-dollar cost and substantial technical demands of establishing a national repository may be substantial factor in decisions. Regional repositories can help to address that problem. Moreover, if the spread of nuclear energy production is to occur without increasing the risks of global terrorism and nuclear proliferation, there must be close international scrutiny of all nuclear activities. This will be easier if all sensitive materials in the nuclear-fuel cycle are handled, stored, and disposed of at fewer locations. Shared disposal facilities for the spent fuel and highly radioactive wastes at the back end of the fuel cycle should be one key component in a secure global system.

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1. See http://www.posiva.fi/en/final_disposal/total_costs_and_funding_for_final_disposal/.
2. The Obama administration has terminated GNEP's focus on near-term deployment of reprocessing facilities and fast reactors, but the fate of some of GNEP's proposed institutional approaches to the fuel cycle is less clear.
3. For a useful discussion of the potential value of fuel leasing and of regional or international repositories, and of the Russian approach to this topic, see Committee on Internationalization of the Nuclear Fuel Cycle, U.S. National Academy of Sciences and Russian Academy of Sciences, Internationalization of the Nuclear Fuel Cycle: Goals, Strategies, and Challenges (Washington, DC: National Academies Press, 2008), pp. 40-42.
4. The countries represented were Austria, Bulgaria, Czech Republic, Denmark, Estonia, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Romania, Slovakia, and Slovenia.

James H. Turner, Jr., Ellen Vaughan and Colin McCormick

Moving Toward High-Performance Buildings

At the end of May 2009, a group of sixty prominent scientists and other notables in attendance at the St James's Palace Nobel Laureate Symposium, including U.S. Secretary of Energy Steven Chu, declared that, to prevent irreversible damage to the world's climate, worldwide carbon emissions must begin to decline in just six years and be reduced by 50 percent by 2050. They believe that damage will occur if average global temperatures increase by more than two degrees centigrade. In developed countries like the U.S., the carbon footprint is stabilizing, but rapid growth in the use of fossil fuels in developing countries means the worldwide footprint has been increasing steadily by about one percent per year. Between 1980 and 2006, the U.S. share of the world's climate footprint decreased from 26% to 20% while the Asian share, led by China, doubled to 37%, with the largest growth in energy use in Asia and the Middle East. The United States is currently a heavy and wasteful energy user, but not as unique as some would have us believe. In 2006, the United States was second to China in total carbon footprint and 13th out of 207 nations in its per capita carbon footprint.

The St. James Palace group concluded that even a rise of two degrees centigrade in the global temperature will have adverse consequences, but that a bigger increase would create "unmanageable climate risks"; if total carbon emissions worldwide continue to rise after 2015, the cuts required to keep temperature increases at just two degrees centigrade would likely become unachievable. In light of these sobering facts, Professor Hans Joachim Schellnhuber, Director of the

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Potsdam Institute for Climate Impact Research, called for reductions by all nations and asked developed countries to aim for a reduction of 25% to 40% in carbon emissions by 2020.

The St. James Palace manifesto is a call for a major acceleration in international efforts to control global warming. It marks a dramatic change in U.S. policy, from being a leader of skeptical nations who want as little change as possible to joining those calling for the most urgent action. It was only 14 months earlier, on April 15, 2008, that President Bush chose income tax day to reject new taxes and trade barriers as part of the solution to climate change and to push back until 2025 the target date for stopping the growth of U.S. greenhouse gas (GHG) emissions, effectively giving U.S. utilities and industry an additional 10 to 15 years of GHG growth. He offered few specifics for achieving even that weakened objective. He expressed concern that Congress might pass climate legislation that would hurt the country's economic growth and encouraged accelerated development and deployment of new technologies, while pointing out that all countries including China and India would have to be a key part of any world approach to cutting greenhouse gases.

At the end of June 2009, the U.S. House of Representatives, with the support of President Obama, narrowly passed and sent to the Senate the American Clean Energy and Security (ACES) Act. ACES would put the United States firmly in the St. James Palace Group camp by setting goals of cutting global warming pollution by 17% compared to 2005 levels in 2020, by 42% in 2030, and by 83% in 2050; it also aims to set up a carbon trading system to enforce these levels. Virtually all Republican representatives opposed the legislation, along with many of the Democrats from states dependent on fossil fuels. Some of the conservative Democrats who voted for the bill in the House almost immediately drew new political opponents who are focusing on the consequences of this vote in districts that depend on fossil energy.

In the Senate, one does not achieve the 60 votes needed to move major legislation forward without bipartisanship and Republicans are currently unified in opposition, while Democrats are currently facing the same divisions as in the House. The Senate Republican Caucus, through its Chairman Senator Lamar Alexander, has floated an alternative approach. It features rapid expansion of nuclear power and energy research, two positions popular with Republicans and swing Democrats but given short shrift in the House-passed bill, and strongly opposes the House carbon-trading provisions which the House Democratic sponsors consider essential. How compromise will be reached at this time is unclear, but approximately 15 percent of the Senate would have to change their positions before a bill with a rigorous cap and trade provision could be passed. In recent years it has been the rule, rather than the exception, that major environmental legislation can take multiple Congresses to enact into law.

If the United States did reduce carbon emissions by 83 percent by 2050, this would be one of the most revolutionary changes in the way Americans live their lives in our nation's history. An American public that has grown comfortable with old transmission lines, inefficient appliances and vehicles, incandescent light bulbs, leaky, low-quality construction, and behaviors borne out of the belief that energy is cheap and abundant is being asked to make a significantly larger reduction than the worldwide average because its per capita usage of fossil fuels is over four times the world average. If the world carbon footprint is cut in half and the U.S. carbon footprint is cut by 83%, U.S. per capita carbon use would still be over 50% larger than the average world per capita use and the U.S. would find itself in the same relative position where the developed nations with the smallest carbon footprints—France, Sweden, and Switzerland—find themselves today.

But neither these countries nor the U.S. has had to face the proposed 50% worldwide reduction in carbon use which would have us getting by on half the per capita carbon that those European countries now use. The U.S. per capita levels of carbon emissions in 2050 would be below the current levels of Mexico and China, and total U.S. emissions would fall below current levels in India. Think pre-Henry Ford. To find a U.S. carbon footprint that small, we have to go back to the period from 1905 to 1910 when the U.S. population was around 90 million. In the debate to date, there has been little focus on just how big an 83% reduction in carbon emissions would be and what it would take to win public acceptance of the changes. Preserving a standard of living that Americans will accept while displacing this much carbon will require us to replace most current energy technologies. Cars will need to run on alternatives to fossil fuels, dramatic changes will be required in the industrial sector, and in the building sector we will need to employ highly efficient technologies and designs, renewable energy, and a conservation ethic at a level a yet unheard of in the United Staes.

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This is what leading scientists say we must do to save our environment, but George Bush's skeptical outlook on climate change still resonates with the public, depending on how polling questions are written. A March 2009 Gallup Poll survey recorded the highest level of public skepticism about mainstream reporting on global warming in Gallup's history of polling on the issue: 41% of respondents said the news media exaggerates the problem, a 6% swing in just one year away from concerns about global warming. Of the eight environmental issues polled, global warming came in as the least worrisome. In April 2009, a Rasmussen Poll showed just 34% of respondents feel that human activities are a factor in global warming, down from 47% a year earlier. In a June 30th Rasmussen poll, immediately after the House of Representatives vote, 42% of respondents felt that the bill's policies would hurt the U.S. economy and just 19% believed that they would help it. Other polls showed majorities feeling that the bill is a mistake. An August *Washington Post* Poll showed a small majority favoring the cap and trade provisions of the ACES bill with a hardening of Republican opinion against cap and trade, but this same poll showed that feelings on energy are less intense than those on health care and the economy. This is in keeping with the general rule that environmental concerns take second place to fiscal concerns in tough economic times.

The date for Senate consideration of the bill has slipped and may slip further as the ante is raised. On August 25, 2009, the *Los Angeles Times* reported that, despite an overwhelming consensus in the scientific community that global warming is real, the U.S. Chamber of Commerce is raising the stakes: it is calling on the Environmental Protection Agency to hold a public trial on global warming complete with witnesses, cross-examinations and a judge who would be asked to rule on whether human activities are a dangerous component in global warming before any efforts are made to regulate carbon dioxide under the Clean Air Act. Two other business groups, the National Association of Manufacturers and the National Federation of Independent Business, are starting to make major purchases of ads opposing cap and trade in states represented by swing senators.

If current trends continue and the Senate bill goes forward, it will be substantially changed from the House-passed version; it will take into consideration some of the views of the opposition, and it will require a substantial amount of time to work out differences with the House of Representatives. This means the Obama Administration will need to look to Executive Branch actions rather than those of the Congress if it wants to show attendees at the December international meetings on climate change in Copenhagen that the United States is committed to doing its share to meet worldwide 2015 and 2020 carbon reduction goals.

Assuming that the Nobel laureates of the St. James Palace Symposium are correct in stating that we have just six years to stop growth in the global carbon footprint, and we must begin significant reductions by 2020, then the carbon reduction goals in the ACES legislation must immediately be considered a national imperative. We cannot afford to wait for Congress to endorse them. Perhaps President Obama can use an executive order to make achieving the 2015 and 2020 goals official administration policy and to focus the Executive Branch on achieving them using available authority from existing law. If the Congress later succeeds in passing legislation on climate change or energy, the executive order and the implementation could be modified accordingly.

We would need strong leadership from our Executive Branch to explain this plan to the American people since success requires hundreds of millions of individual citizens making the right decisions about purchases of energy-efficient vehicles, appliances, and electronic equipment, while living in energy-efficient buildings, and practicing old- fashioned conservation. At the same time, improvements in building codes, appliance standards, efficient vehicle design and use, and a host of coordinated public policies must be put in place to support positive choices and phase out energy waste.

THE PROMISE OF THE BUILDING SECTOR: THE EUROPEAN VS. THE AMERICAN EXPERIENCE

While energy efficiency improvements will occur throughout all sectors over time, Secretary Chu has described the building sector, including residential housing, as the low-hanging fruit in efforts to reduce the worldwide carbon footprint. In the U.S., the building sector accounts for almost 40% of total energy use and carbon emissions, and 70% of electricity consumption. And unlike some of the most visible efficiency opportunities in the transportation and industrial sectors such as electric cars and advanced manufacturing techniques, key technologies for significant efficiency gains in buildings are already available and cost effective. Secretary Chu is correct that we must switch to low-energy buildings in new construction and perform energy upgrades on a large percentage of our installed building stock, as that is our best chance of meeting 2020 goals and creating momentum for the changes that are projected between 2020 and 2050. In the short term, achieving major improvements in energy use in the building sector could buy us time to improve building technology further and to make breakthroughs in other sectors with longer lead times and more dramatic need for new technologies. Therefore, the U.S. building sector is our focus in the balance of this essay.

It is generally understood that Germany, with its Passivhaus Standard, and Switzerland, with the related Minergie P Eco Standard, are among the nations that have surpassed the United States in several areas: understanding and constructing low-energy buildings, developing highly efficient windows and certain other building components, designing and operating buildings as efficient systems, and adopting a national environmental ethic. Although the earliest prototypes of low-energy buildings originated in the United States and Canada more than 30 years ago, they were taken more seriously and perfected abroad. In the United States, a small number of building scientists in and outside of government have the expertise to design and construct high-quality, low-energy buildings, but they face low expectations, financial barriers, and regulatory disincentives, while in Germany and Switzerland, increasing expertise finds a ready market.

Minergie is a voluntary energy efficiency standard that has been used over the past decade to certify over 14,000 Swiss buildings, each of which uses at least 60% to 80% less energy than a conventional building, for less than 10% additional building cost. This compares to savings of 20% to 40% for U.S. Energy Star homes; the rate per capita of Minergie certifications is over twice the Energy Star rate in the United States. In practice, though, Minergie's influence on Swiss building practices is much higher because many of Switzerland's cantons have offered financial incentives for Minergie buildings and have adjusted their energy codes to require energy efficiency at levels very close to the original Minergie level. In Switzerland, Minergie is the basic low-energy standard. A newer variant, Minergie P, incorporates traditional passive design and passive solar techniques, and Minergie Eco is Switzerland's green building standard. Minergie buildings always take into consideration the benefits of the earth as a heat sink, and aim to use solar energy and natural ventilation. If solar is not yet economical for a Minergie building, the building is designed to allow easy solar installation when the technology becomes economical. The highest efficiency buildings based on Minergie P go beyond the rated savings and are virtually off the grid.

> In the U.S., the building sector accounts for almost 40% of total energy use and carbon emissions, and 70% of electricity consumption. And unlike some of the most visible efficiency opportunities in the transportation and industrial sectors such as electric cars and advanced manufacturing techniques, key technologies for significant efficiency gains in buildings are already available and cost effective.

Passivhaus is an even more exacting German voluntary private-sector standard and design software that relies on very thick insulation, triple-glazed windows, air-tightness, heat recovery, elimination of thermal bridging and unintentional air changes, elimination of conventional heating systems, and careful optimization to reduce energy and building costs even further. Solar technologies are always considered for Passivhaus buildings. Worldwide, 15,000 buildings have been built to the Passivhaus standard, and experienced German designers and builders can now bring in these buildings at a cost only 3% to 5% above the cost of a conventional building. The designs are primarily oriented towards cold climates and it takes some work to apply them to other regions, but many of the Passivhaus principles have been shown to work with warm-weather buildings. The technology is sophisticated enough to require extensive training for both designers and constructors as well as extreme attention to detail by the designer and builder; it has led to the development of better windows and more sophisticated HVAC systems than can currently be purchased in the United States. Overall, both Switzerland and Germany have higher-tech construction industries than the U.S. and are moving steadily on the path to zero-energy homes.

Compared to the amount of energy used in the world's most energy-efficient buildings, in the U.S., the typical new or substantially remodeled building is an energy guzzler. Yet, based on the European experience and that of the few U.S. builders who have constructed buildings using Passivhaus, Minergie or other low/zero energy designs, there is clear hope that the U.S. building sector can contribute significantly to meeting the ACES 2020 and 2050 goals of carbon stabilization by eventually matching what world-class designers and builders can do today. Various projects in the United States have shown that extensive retrofits of existing buildings also can lower energy usage 25% to 40%. The big questions are whether our builders, remodelers, and building owners can change to take advantage of these opportunities, and whether as a nation, we will eventually have the political will to raise the bar in our building codes and require what is already technologically possible.

CONSIDERING THE WHOLE BUILDING

While energy is a primary driver of a high-performance building, other design objectives are very important. The average person spends most of his or her life in buildings, so it is important to design not just for energy efficiency and renewable technologies, but also for high performance building attributes including safety, security, accessibility, resistance to hurricanes and earthquakes, fitness for intended use, and ease of retrofit as technology improves and as building inhabitants age.

LEED® (Leadership in Energy and Environmental Design), one of the leading rating systems for green buildings, has received much attention in recent years, and many people think of a LEED building as the gold standard for a high level of energy conservation and even for high overall quality. In providing and promoting a system for evaluating the "greenness" of buildings, LEED has done much to raise the consciousness of the building industry and the American people regarding energy and environmental considerations such as choice of materials, water use, green roofs, energy efficiency and renewable energy. Many architects have become LEED accredited.LEED certifies design rather than building performance and sometimes LEED buildings use far more energy than expected; a 2008 study by the New Buildings Institute found that half of LEED buildings deviate by more than 25% from their designed energy use intensities. Through regular updates to LEED, the U.S. Green Building Council is working to overcome these and other problems, but LEED is still primarily an environmental rating system that does not give any credit for other important aspects of buildings.

This has caused some to look beyond green design to high-performance buildings. A good example of the potential of high-performance, factory-produced buildings is the Mississippi Cottage project of the State of Mississippi, Habitat for Humanity, and the Federation of American Scientists. After Hurricane Katrina, the project showed that modestly-priced housing units could be dramatically more energy efficient than earlier manufactured houses; they could also be environmentally sound, accessible to the disabled, and capable of withstanding hurricane-force winds. As described by its president Henry Green, the National Institute of Building Sciences (NIBS) is taking the lead in rethinking building standards for high performance; he hopes its work will lead to powerful design tools for identifying the win-win situations in energy conservation and overall usefulness of buildings that only optimizing for high performance can bring to the building sector. Another win-win situation would evolve if, after DOE fully funds and NIBS completes its work on assessing and harmonizing standards for high-performance buildings, the developers of the various green building rating systems use what NIBS produces as the technical basis for their rating systems.. This would help the rating systems become an effective performance measurement tool for achieving the intended performance of certified buildings.

THE STATE OF THE BUILDING INDUSTRY

In new construction, decisions on energy use are generally made by those who design and build buildings rather than those who use them, and savings in construction costs often trump even larger savings in operating costs. While major construction companies and a few architects and builders are able to use the most sophisticated software and employ business practices that can lead to world-class buildings, much of the industry is less sophisticated. In 2006, there were 883,000 construction establishments with 7.1 million workers in the United States; 65 percent of them employed fewer than five workers. The workforce may have little formal education regarding energy-related decisions since small construction firms are dependent on the job training or apprentice training conducted by experienced workers. Much work is carried out by subcontractors, so the workforce varies from one building to the next. In any given year, new construction adds only 1% to 2% to the installed base of buildings, so energy decisions made in a building's construction remain in effect for many years. Builder supply chains provide the materials and components that builders want, including builder-grade doors and windows that are lower quality than those sold as replacements to remodelers. Absent more stringent building codes or government financial incentives, energy efficiency is unlikely to happen in new buildings because contractors have no incentive to include energy-efficiency improvements that add to their costs but do not increase profits.

In contrast, the energy efficiency of retrofits, remodeling, and other home improvements depends on the level of sophistication of the building owners and whether they consider the operational costs of their buildings in their remodeling plans. Remodelers deal directly with the homeowners who pay the utility bills, so they are much more likely than home builders to use energy efficiency as a selling point. Also, builders rarely maintain a business relationship with the people who ultimately occupy the building and pay for its energy use, while some energy-oriented remodelers continue to monitor and "tune up" the performance of buildings they have worked on. These ongoing business relationships, which are not the case for all energy remodeling, can involve energy service contracts or other financial incentives for continued efficiency performance that are much more closely aligned with efficiency than in the case of builders.

BARRIERS TO HARVESTING THE LOW-HANGING FRUIT

Low-hanging fruit will remain on the tree as long as those making decisions about building construction, renovation, and operation are unaware of its value or do not have an easy way to harvest it. We need to re-engineer the building sector so that energy conservation happens routinely and easily. How do we get to a tipping point in public opinion so that the average person will be motivated to insist on living and working in low-energy buildings? Who are the players who can make this happen?

A major difference between the United States and Switzerland or Germany is the relative lack of precision in our buildings. European buildings are engineering-driven and their builders continuously look for improvements in energy efficiency through tighter fits, better materials, and manufacturing improvements. Because they look at the building as an integrated whole rather than as a collection of parts, they reap the associated energy savings. They pay attention to the details that save energy and measure precisely to make sure the savings will occur. In the United States, we seem to accept mediocrity, incorporate only minimum code requirements in most buildings, and focus on architectural awards rather than building performance. While the highest-quality buildings are significantly beyond code requirements, seven states do not even have building codes to set minimum standards for buildings and half of the states do not have up-to-date codes. Even when current codes are in place, they are ineffective unless they are enforced by properly trained code officials and inspectors. Differences between expectations and actual performance can be even larger in remodeling and retrofit where estimates of energy savings may be used as a sales tool but often no reliable measurements are available to determine whether or not the energy upgrades worked.

Another problem is public apathy, coupled with industry inertia. Most Americans do not understand that their homes, lighting, and appliances are inefficient, and typically the potential buyers of a new or used home have almost no knowledge of the energy performance of the homes they are considering, unlike vehicles (where MPG ratings are universally available) and major appliances (which often display an energy label). It is hard to find out how much energy a home has used historically, or what energy savings are possible through remodeling/retrofitting, which upgrades make economic sense, or how to get the work done. This translates into relatively low demand for low-energy homes and energy retrofitting, compared to Europe. With little public demand for better products and services, builders have little reason to change—and the same is true for those who design, construct, market, renovate and sell buildings. . Therefore, in terms of energy efficiency, most builders, real estate agents, lenders, and insurers are doing business much the same as they did years ago.

Unfortunately, we are also falling short of the challenge of developing the next wave of innovation that will be needed to meet carbon goals after 2020. Federal budgets for research into energy and energy efficiency soared in the second half of the 1970s when the American people were reeling from our first energy crisis.

These programs were cut back to perhaps 25 percent of their peak in the early 1980s when economic problems led to major cuts across the government, and they were not restored when times got better. Now, when we really need advanced energy technologies at competitive prices, we do not have them. Some observers have noted that we have lost our knowledge about using indigenous building materials. Just as we have much to learn from research and development, they argue, we have much to learn from those who came before us. Re-discovering, re-thinking, re-purposing, and re-combining low-tech and local resources can also be important sources of innovation and improvements.

WHAT CAN BE DONE TO BEGIN THE HARVEST?

We can meet the 2015 and 2020 carbon footprint goals only if millions of retrofits accompany a general upgrading of the energy efficiency of most new construction. This will require governments at all levels and the private sector to step up to the challenge; the White House, Department of Energy, and Department of Housing and Urban Development will have to play leadership roles. It will also require active participation by state and local government, code developers and officials, and the appropriate parts of the private sector. Some of the pieces already are in place but a major effort to scale up these efforts is needed as soon as possible. Several steps can be taken without waiting for the ACES legislation.

Show White House commitment

The direction we need to go is clear, but the will to act is not. A major thrust is necessary to overcome inertia and move forward. The State of the Union address or a major presidential speech to the American public would be a powerful way to kick off a national challenge, assuming that the president shares the conviction of the Secretary of Energy that the world absolutely must begin to reduce the world carbon footprint between 2015 and 2020.

Take advantage of the conservation dividend

Our best short-term hope is playing to the economic self-interest of individual building owners and of others in the real estate and construction business. In 2005, U.S. households spent $201 billion on utility bills and other building owners spent $150 billion more. Reducing the energy use of a year's worth of new buildings by 25% to 40% would save a billion dollars or more for those buildings' owners each and every year of the buildings' useful life. Yet, the much bigger pot of gold is in retrofits. If 25% to 40% of the total energy costs of existing buildings can be saved through cost-effective efficiency improvements using technologies currently available, an additional $85 billion to $135 billion per year is currently waiting to be claimed.

Additional savings are increasingly available from cost-effective use of renewable energy. Of course, investment is needed to claim these savings, but the payback periods are short enough to reward those who try to save energy. Other savings go begging despite government incentives to make the investment. To achieve these reductions we need to understand our behavior: Why are virtually all of us leaving significant amounts of money on the table each and every year by not making the buildings we own or control more energy efficient? Why have utility energy conservation programs, energy efficiency mortgages, and other innovative programs had such low levels of participation? And what can be done to make it easy for businesses to see the money we are wasting and devise profitable means of helping us claim it?

Benchmark the best solutions around the country and around the world

The United States has a large second-mover advantage in energy. Above we described how the Germans and Swiss are years ahead of us in thinking through high-performance, low-energy buildings. They also are ahead of us in setting up the infrastructure for bringing both new low-energy buildings and retrofits to the market. They have delivery systems in place. They have trained their construction industry. They have tried various incentives. Switzerland is one of a very few countries that have reached a tipping point: energy-efficient buildings are now so pervasive that the Swiss public demands them and the real estate market and the regulatory environment are responding. We need to study Switzerland and other progressive nations to figure out how they got to this point and which parts of their experience and their policies are applicable to the United States either regionally or nationally.

Also, some progressive communities across the United States have begun to require all new buildings to be energy efficient and/or have launched major programs to retrofit the least energy-efficient buildings in their communities. For instance, Austin, Texas created its own green building program in 1990 and recently enacted an Energy Conservation Audit and Disclosure ordinance to improve the energy efficiency of Austin homes and buildings that receive electricity from Austin Energy. The goal of the ordinance is by 2020 to reduce electricity bills for renters and owners of homes, multifamily properties, and commercial buildings through improved energy efficiency that is comparable to the original Minergie levels. In cities like Austin, builders and their suppliers have adjusted; now high-quality materials are readily available, real estate professionals have changed their marketing strategies, and inspections are effective and lead to energy efficiency improvements.

Other cities have adopted specific programs. The 2030 Challenge is a goal announced by the American Institute of Architects, and endorsed by the U.S. Conference of Mayors, to reduce building energy use and carbon emissions incrementally, and to achieve net-zero-energy buildings by 2030. The Cities for Climate Protection Campaign is a program from ICLEI-Local Governments for Sustainability to assist cities in adopting policies and implementing "quantifiable measures to reduce local greenhouse gas emissions, improve air quality, and enhance urban livability and sustainability."

And a growing number of local initiatives are too new to have any reliable measures of their success but show substantial promise. For instance, the City of Cambridge, Massachusetts, joined the Climate Protection Campaign and set a goal to reduce its greenhouse gas emissions by 20 percent by 2015. Cambridge is a dense, walking-oriented city with very little new construction, so smart growth was not the priority issue. Instead, retrofitting the city's large stock of 80-year-old buildings offered the best opportunity for energy savings. With partnership and funding from the Kendall Foundation, the city created a non-profit agency, the Cambridge Energy Alliance, to help residents and business owners invest in making their homes and buildings work smarter and more efficiently to save energy, water, and money. The city has been mobilizing volunteer climate activists to canvass neighborhoods and offer free basic energy audits and retrofit information to homeowners. Since the program started last August the number of residential audits has tripled and many retrofits have gotten underway. A dozen or more small businesses have also signed up. While the Alliance coordinates consumers, contractors, and banks, utility partner N-Star is monitoring energy use and beginning to measure success in terms of energy saved and carbon emissions reduced.

While these progressive city-scale programs are already having a local impact, their true power is in serving as test beds and models to inform and inspire other city- and town-level retrofit programs across the country. We need to capture the lessons learned from these early programs and make them available to other communities that are less familiar with energy issues and have shorter histories of energy-conscious behavior. The structures of the programs in Cambridge, Austin and elsewhere have important differences, including the relative involvement of the utilities, the role of various business and supply chains, the approach to auditing and verification, and the mechanisms for financing. These structural differences will presumably affect their relative success. We need to ensure that their lessons learned are captured in a coherent way that helps other communities avoid common mistakes and copy winning strategies. There are many places to start. Forty-two out of the 50 United States have taken formal steps to address climate change through some means, either by a statewide climate action plan or regional agreement. But without a coordinated effort to translate that emerging political will into practical programs, local governments will reinvent the wheel. This coordination must be led by the federal government, and must include a significant effort to study and synthesize the experiences of these local programs, and to communicate the lessons and best practices to the rest of the country.

Expand financing structures and explore innovative revenue streams

Innovation is often a matter of figuring out the appropriate financial structure to allow for a profitable investment. One of the most notable recent financial innovations is the use of property-assessed clean energy (PACE) programs, in which municipalities loan money to homeowners to install efficiency measures and/or renewable generation, and the homeowners repay the loans through additions to their property taxes. This approach has the benefit of tying the repayment of the loan to the home itself rather than the homeowner, since the ongoing benefits of reduced utility bills accrue to the current owner, who may not necessarily be the owner who arranged for the energy-efficiency improvements. Utility-based on-bill financing has also been used in a number of programs, in which loans for efficiency upgrades are repaid through the utility bill, with savings offsetting loan repayments in a format that homeowners can understand easily.

While direct savings on utility bills are the bulk of the returns from harvesting the low-hanging fruit of building efficiency upgrades, other revenues can be had through financial mechanisms that are almost completely unexplored. One of these is aggregating efficiencies from multiple building retrofits and selling them into carbon offset markets or forward capacity markets. The state of Maine is exploring how to aggregate carbon savings from low-income weatherization work for sale in carbon offset markets, and has noted that this class of offsets is particularly attractive to purchasers because they are unambiguously avoiding emissions that would otherwise have occurred, and they have a redeeming social aspect because they lower utility bills for low-income families.

An important development for this kind of alternative financing is last year's FERC Order 719, which explicitly permits aggregators of retail customers to bid demand response into forward capacity markets, paving the way for the possibility that large-scale retrofit work could be partly funded by revenues from installed demand-response measures. We also need to extend innovative financing to renewable energy, where powerful ideas are beginning to emerge, such as power purchase agreements that permit owners to lease photovoltaic equipment installed on their building and pay only for the power, rather than the entire capital equipment.

Make energy efficiency and cost-effective renewable energy a priority in government programs

Even in the absence of cap-and-trade legislation, the federal government is heavily involved in the housing sector and impacts the rest of the building sector as well. It is time to look comprehensively at ways to use existing authorities of the federal government: what steps can be taken through executive, departmental, and agency orders to take us closer to meeting the 2015 and 2020 goals? This recommendation is obvious enough that the Obama Administration has already begun to work on it, and it is one of the most important topics other than Cap and Trade in the ACES legislation.

For over 30 years, programs have been addressing energy efficiency in federal buildings, but it is time to go well beyond the *status quo*. Federal buildings are in a position to serve as demonstrations of energy conservation best practices and of how positively to affect construction supply chains, but they often fail to do so. A vital first step is for the federal government to overhaul its approach to efficiency in its own facilities, seizing opportunities to install all cost-effective retrofit measures; then it can use federal facility retrofits as a communications opportunity to advertise cost savings from and best practices for efficiency. This will require better resources for the government offices assigned to carrying out these programs; too often in the past, the Federal Energy Management Program (FEMP) and the agencies that support it were not considered mission critical, and had too few resources to implement even the existing executive orders for efficient energy management.

It will also be necessary to amend some federal accounting rules, which often constrain the options that agencies have for financing energy purchases. Ultimately, federal agencies should have access to an integrated set of best practices for planning, financing, implementing and publicizing energy efficiency upgrades at their facilities, since projects that lack any one of those components are missing opportunities to save energy and money while promoting efficiency beyond the agency's own properties. Leadership on this issue must come from FEMP, GSA, and the White House itself.

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The Department of Housing and Urban Development (HUD) is involved in providing housing for millions of people; it has been estimated that as much as $5 billion of its budget goes to pay utility bills in subsidized housing, some of which is in highly inefficient buildings. This happens partly because HUD allows landlords to pass on utility costs to tenants and the government without requiring the buildings to be energy efficient. It is time for HUD to add energy-efficiency requirements to the upgrades already expected of those who benefit from its programs and to require landlords to absorb utility costs if they do not upgrade their buildings. Fortunately, important steps in this direction are included in the Fiscal Year 2010 budget request and in legislation that Congress is currently considering.

The Department of Energy provides home retrofit services to low-income families around the country through the low-income Weatherization Assistance Program; through the Recovery Act, this program has received enough appropriations to increase its efforts several fold and reach hundreds of thousands of homes annually. While the increased weatherization is an excellent first step, it is clear that the expansion's most lasting impact could be stimulating the expansion of private-sector retrofit efforts by training weatherization specialists and by integrating and disseminating knowledge of retrofit engineering. This program is also an opportunity to explore different retrofit strategies on a large scale, effectively conducting in-the-field R&D on retrofit technology. By capturing this information and publicizing its knowledge base about what does and does not work in home retrofitting, this program could accelerate the entry of new private-sector retrofit companies into the industry; these companies could also use weatherization-trained workers to build their core competencies and expand their workforce rapidly.

Much of the federal government's support of the housing industry occurs through organizations that guarantee or subsidize home loans such as the Veterans Administration, the Federal Housing Administration, Department of Agriculture, and (as of recently) Fannie Mae and Freddie Mac. In fact, as reported in the *Washington Post* on September 7, 2009, the federal government now stands behind 86 percent of home loans, a dramatic change from just 18 months ago. These organizations think of themselves more as bankers than as institutions that can affect the quality of housing stock. However, the government has traditionally protected its investment by requiring that building defects be repaired before a loan on that building will be approved. Since the average home is sold every several years, curing "energy defects"—i.e. requiring a high level of energy efficiency—before loans are approved may be our best chance of encouraging the volume of retrofits needed to make a difference in the U.S. carbon footprint. If novel approaches for financing these repairs and upgrades, such as PACE, become generally available, the upgrade costs could be rolled into the mortgage or handled through property tax adjustments. Related strategies include energy efficiency rating and labeling similar to systems being implemented in Europe, and providing buyers with a recommended retrofit list beyond those made by the seller. These mechanisms would allow buyers to comparison-shop for energy efficiency and make it more likely that new homeowners would undertake retrofit work. Another strategy would be asking the lending institutions that benefit from federal insurance to make energy efficiency a condition of their construction loans and mortgages.

If implemented correctly, these approaches, and other variations on them, can contribute significantly to meeting energy conservation goals. Perhaps most important, this approach would reduce the chance of the purchaser defaulting, a key policy goal in the current economic environment, given that the efficiency improvements lower the net average monthly costs of operating a building. Unfortunately, the federal home loan agencies have not yet embraced this harmonization of energy and housing finance goals, as they are under immense pressure to minimize risk and are therefore averse to any kind of innovation in areas outside of their expertise. Actors within the federal government must figure out how to overcome this reluctance, both by enhancing the level of cooperation between the financial and energy-oriented agencies, and by clear White House leadership on the issue.

An added advantage of federal energy efficiency requirements is their educational impact on the building workforce. If architects, builders, permit issuers, inspectors, and real estate agents all have to become familiar with energy-efficient practices before they can qualify for federally-backed loans, this knowledge can spill over to other construction. If the building supply chain stocks energy-efficient products and components for the federally-backed market, then these products are also available to others remodeling their buildings. State and local governments have their own set of pressure points to encourage energy conservation and many of them will have to act if enough retrofits are to occur in time. However, given the magnitude of needed retrofits, state and local programs will not obviate the need for strong federal leadership.

Make better use of the power of codes, standards, and data. Give businesses the power of data and measurement

One key component in establishing new energy practices is developing strong standards and building codes and then assuring they are adopted. The current process of developing building codes relies on private-sector organizations to develop codes through a consensus process among their members. Consensus can lead to robustness because the concerns of all parties are considered, but it can also lead to weakness because the parties tend to adopt what is acceptable to a majority of participants rather than relying on the most advanced technology available. Then, the new versions of the model codes are adopted by perhaps half of the state and local governments, sometimes in modified form; this process has led to great variations in the minimum efficiency requirements around the country and a tenuous link between research on buildings and the implementation of research results in the field.

Fortunately, this situation may be improving, at least regarding energy efficiency. Earlier this year, Congress spoke clearly in the Recovery Act about setting a floor on building quality and energy use; for the jurisdictions that receive the state energy funding that the act provides, significant amounts of that funding will be contingent on their making progress towards adopting the current building codes. For this mandate to have its intended effect, the Department of Energy will need to take robust steps to track progress in implementing current codes and to help states and localities set up the infrastructure to ensure that these codes are followed, including supporting the training of code officials and building inspectors. This is a good starting point because our energy goals for buildings will not be met unless the heartland moves from an informal building culture to one with performance expectations.

The ACES legislation would build on this floor through provisions that require private-sector code developers to meet specified national targets for efficiency improvements in their building codes; if they fail, they face the prospect that federal mandates would supersede the energy portion of their codes. While this outcome is unlikely and not optimal, the threat of these provisions being enacted is already giving federal agencies the leverage they need to work with code developers to encourage them to regularly strengthen the codes' energy provisions in each revision cycle.

An important emerging supplement to stronger mandatory building codes is new efforts to develop voluntary codes, as guides for those who want to build buildings that exceed the minimum requirements. If the Swiss experience is any guide, these codes are likely to play an important role: they will also serve as initial drafts for the next round of minimum requirements, driving the cycle of continuous improvement and allowing progressive builders and localities to test various code approaches before they incorporate them into regulations. They also can serve as the threshold for various subsidy programs, allowing policymakers at all levels to link incentives to explicit code documents and guidelines. An important recent example of voluntary codes is the joint effort of the International Code Council, ASTM, and the American Institute of Architects to develop an International Green Construction Code.

This development increases the importance of the NIBS standards integration work described in President Green's article. While Passivhaus has shown us how to optimize a building for energy, the NIBS work will illustrate how to optimize whole-building performance; for code writers as well as architects, builders and their customers, it will provide a framework for understanding all aspects of what we need from buildings and for capturing that portion of energy savings that is only possible in optimally designed high-performance buildings.

Finally, it is important to be creative in looking for ways that the IT revolution can help achieve our goals. The advent of a smart grid is an obvious example and it should be developed aggressively. Geospatial databases also have a lot to offer; because a building is at a fixed location, it can be treated as a specific location in such a database. To enable this use of geospatial information requires standards for identifying buildings, and a promising effort towards that goal is now underway; the Open Standards Consortium for Real Estate and the Open Geospatial Consortium are developing open identifier data formats for buildings-related GIS information. This has the potential to be an extremely powerful tool, since it is now possible to mine geospatial databases for location-specific information on weather, geology, traffic patterns, neighborhood socio-economics, and hundreds of other geographic-specific inputs. The missing ingredient for this approach is the baseline for the building. If building permit records become automated we will have a wealth of information on a building's size, design, and suitability for upgrading that can be used to optimize original building designs and determine the likely economics of renewable and traditional energy systems at the property. Entrepreneurs are starting to see this data as a business opportunity. These databases should also prove valuable to local leaders and planners as they look beyond buildings to energy savings in communities by properly structuring transportation systems and locating key facilities and services in relation to concentrations of buildings.

Make it easy to opt for low-energy buildings by putting a low-energy infrastructure in place for builders, renovators, and building users

Reaching the 2015 and 2020 goals requires major action by three groups: designers and constructors of new buildings; individuals with authority to upgrade existing buildings; and owners and managers of existing buildings and residences.

Many builders do not build low-energy buildings because they do not have the knowledge, supply chain, or financial incentives to do so. As discussed above, the level of energy efficiency built into new buildings relates directly to the codes that are being enforced in building design and construction, but the final energy performance of new buildings also depends heavily on construction techniques and experience, so improving the skills of the construction workforce should be a priority. As small builders improve their skill sets, local jurisdictions should lower their resistance to adopting adequate building codes and using voluntary codes. One obvious partial solution is to have the Manufacturing Extension Partnership (MEP) of the Department of Commerce and the states move toward aiding builders. Home construction in many ways is a branch of manufacturing, and builders are increasingly using manufactured components and subassemblies. MEP has the ability to move the building sector toward adopting lean-six sigma and other techniques that have brought precision, cost reductions and energy savings into the manufacturing sector. Additional certificate and training programs can be set up within institutions of higher education and high school evening programs, perhaps in cooperation with manufacturers of sophisticated equipment and controls.

Financial incentives for contractors' first high-performance buildings may also be important. Builders make their profits on the difference between their costs and the sales price of the building. If it costs less to use a lower-grade window or insulation and the buyer does not complain, it is in the builder's financial interest to go with the cheaper alternative. The question becomes how to lower the price differential between an energy-efficient and an energy-inefficient building to the point where a buyer will pay enough of a premium for the energy efficiency so that the builder can make more money by building an efficient building. Demonstrations may show builders that they really can make money on low-energy buildings. A Michigan home builder who builds only Energy Star qualified homes that cost less to operate than conventional homes reported steady sales throughout the worst of the recession. Another possibility is to encourage volume sellers of building materials like Home Depot to buy quality products in volume and pass on savings and to offer training in how to use the products, perhaps in conjunction with Energy Star or federal procurement programs. If energy-efficient products are readily available and understood they are more likely to be used.

Another key driver is labeling, and other techniques for disclosing energy savings that encourage builders to advertise the fact that their energy efficient models will result in lower monthly operating costs for the building purchaser. It also may become necessary to remove the lower-grade products from the market. Just as the federal government establishes minimum efficiency standards for appliances, it could consider expanding this approach to building components. Since these components are manufactured assemblies, it would be possible to sample part of a production run and determine if a product meets these standards, similar to testing for appliance standards. One obvious complication is that acceptable performance levels for building components would vary by climate zone, an aspect of the regulatory framework that does not exist for appliance standards. Also, this authority does not currently exist and would require a legislative change. Still, as long as unambiguously inefficient building components are available on the market, they facilitate poor building energy performance, and a strong case can be made that these components should no longer be sold in a carbon-constrained world.

Finally, reaching rural areas can present a special challenge. The Department of Energy will have to work closely with the Farmers Home Administration and state rural development authorities and the Cooperative Extension Service should become involved in promoting energy efficiency.

> Government efforts must focus on allowing a private market, whether it is utilities or full service energy efficiency contractors, to expand quickly.

If we are going to expect millions of commercial building owners and homeowners to upgrade voluntarily, we must make it easy and desirable for them to do so. Large buildings are often managed professionally and building engineers handle the building's energy performance. Upgrading could be a company business decision or a decision by a condominium board wishing to save money. New laws, enhanced software, and new standards are making these decisions easier. California has just enacted a new law directed at benchmarking energy in existing commercial buildings and ASTM is beginning to develop a new standard, the Guide for Building Energy Performance Disclosure, to standardize the traditional real estate disclosures as to the condition of the property. The ASTM standard will cover a building's history of energy audits, energy and water usage, carbon footprint, building certifications and ratings, benchmarking against existing buildings, and applicable federal, state, local, and utility requirements. This will provide incentives for landlords and tenants to consider these elements and reach a contractual understanding on what renovations will be done and what price will be charged for the property. Additionally, the National Institute of Building Sciences has advanced its Building Information Modeling (BIM) software to the point where it has the potential to save, or replace with renewable alternatives, as much as 20 percent of energy use.

Homeowners will not have the patience to seek out an energy auditor, to locate the contractors who can do the recommended work, and to function as their own general contractors. They may also not have the financial means to pay for the improvements up front, even though the large energy savings would offer generous payoffs year after year. Therefore, government efforts must focus on allowing a private market, whether it is utilities or full service energy efficiency contractors, to expand quickly. This is the premise of the Rebuilding America effort: a public/private partnership with the goal of building up a retrofit market and putting thousands of people to work upgrading 50,000,000 homes by 2020. It is also worth considering the power of competition and the power of praise and to look for ways for communities or even subdivisions to compete against each other in saving energy and to honor those who have been especially successful in doing so.

The point of sale for homes is also an important window of opportunity for renovation and real estate agents are important advisors in deciding what upgrades are made. Perhaps governments at various levels can work with real estate agents to ensure that energy is a major consideration in these upgrades and in popularizing labels, energy warranties, and advertising a home's low energy usage to teach potential buyers that low energy use increases home value and reduces a homeowner's monthly costs. Also, home energy costs vary by as much as 20 percent depending on the owner's energy usage and conservation practices. It may be worth thinking about energy analogies to coupons and rebates, cell phone pricing plans, and gas station signs as we decide how to motivate consumers. These prove that, if they are marketed correctly, small rewards, pricing schedules, and prominent display of prices all affect consumer behavior and may have a role in getting large numbers of people to reduce their carbon footprints.

KEEPING ONE EYE ON 2020 AND BEYOND

We must keep in mind that the carbon reduction goals for the year 2020 and beyond are dramatic and represent one of the largest re-engineering challenges the United States and the world have ever faced. At some point in the process, perhaps as early as 2020, the remaining energy savings in the United States will cease to be low-hanging fruit and will make economic sense only if significant changes have been made in technology and government regulation, and the government has carefully developed incentives to save energy. These changes will be costly in terms of both money and political capital. We will need considerably better technological options—so it is crucial to revolutionize energy R&D now. In his Compton Lecture at MIT this year, Secretary Chu said that the American energy industry will have to move from being one of the least likely industries to invest in research and development to embracing the research spending levels and speed in adopting new technology that is now associated with information technology or biotechnology.

Worldwide, the challenges related to moving beyond fossil fuels will be greater because billions of people desperately need to improve their standards of living. Without a worldwide enforceable agreement on reducing carbon, the fossil energy not used in this country will be gobbled up by the developing world as it strives to meet these aspirations. Therefore, research and development into environmentally friendly technologies is as crucial there as in the United States. It is imperative, even if it is not possible immediately, to keep pushing for a strong, equitable, worldwide agreement on fossil fuel use which is then reflected in U.S. law, whether the mechanism for achieving the limits be cap and trade or an alternative mechanism that turns out to be more politically acceptable.

As the choices get tougher, strong public support will be crucial; this will not happen unless the American people feel that the cause is just and the means of achieving it worldwide is fair to them. In a democracy, it is impossible for governments to limit people's choices if they do not have the voters behind them, so it is important to plan ahead; we need an ongoing, honest, objective public debate about the severity of our environmental problems and we must collectively make intelligent decisions in response. The needed changes in laws, the market, and building codes will happen here in the United States once we cross the tipping point in public opinion and a majority of people feel strongly that reducing atmospheric carbon is the right thing to do. That is the Swiss experience, and it can happen here too.

Henry L. Green

High-Performance Buildings

The built environment forms a backbone that is critical to maintaining and enhancing economic growth, competitiveness, productivity, and quality of life. The construction industry in the United States contributes more than one trillion dollars to the yearly gross domestic product (GDP), but based on government statistics like those shown in Figure 1, it continues to stagnate or even lose productivity, unlike most other large-scale U.S. businesses.

The construction industry is characterized by a large number of small clients, vendors, designers and contractors who are often not in a position to provide leadership in adopting new technology and practice. Other industry segments, with different structures, have seen more rapid change and significant increases in the productivity of both design and construction. For example, in the process and power industry, the capital cost per kilowatt hour (KWH) of output from a power plant has declined steadily over the past decade.

The construction industry as a whole, and the government agencies that work with it, have not invested significantly in research and development (R&D), and have not adequately demonstrated the technologies that do exist. Often, new methods are tried out only on individual projects, and the result is slow adoption of new technology in the marketplace. Where new technology is developed, it is most often pursued to fill an identified market niche rather than being an industry-wide innovation.

In looking for the reasons for this low rate of productivity, performance, and adoption of technology, it is important to consider the role of codes and standards in building design and construction in maintaining the status quo. As currently structured, the industry is primarily driven by codes and standards that establish minimum requirements; these, in turn, are based largely on typical industry performance levels. Therefore, standards typically only prescribe minimum performance requirements that can be met by most of the design, construction and manufacturing community. An owner or builder who wants to do better than the min-

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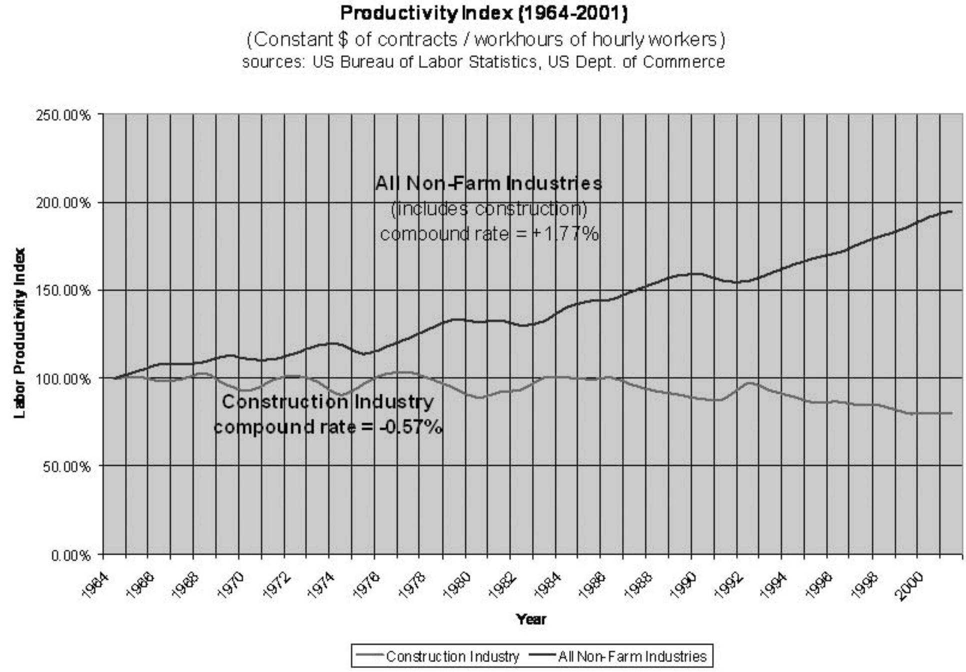

Figure 1. Productivity Index 1964-2001

imum will find little in the existing codes and standards to ensure that a building will, in fact, provide higher levels of performance.

Moreover, the nation's building community uses thousands of standards produced by hundreds of standards development organizations. While a few large organizations write multiple standards, most groups write only a handful. Standards do provide a degree of uniformity in a complex and sometimes fragmented industry. When master or guide specifications for a building refer to standards, they impact the entire design of the building, including the levels of quality and performance for selecting and procuring building materials, products, and systems under contractual agreements. When standards are adopted into building codes, they set the requirements for verifying that materials, products and systems meet a jurisdiction's minimum levels of performance for the safety, health and welfare of the occupants.

There are only a limited number of standards that significantly exceed the minimum requirements. If single building attributes like energy efficiency or safety are maximized without paying attention to other important attributes, the other attributes can end up sub-optimal. Thus new requirements are needed to optimize each attribute within the context of overall building performance. A suite of new high-performance standards would enable designers, developers and owners to produce buildings that focus on enhanced performance rather than minimum requirements. Not only will high-performance buildings use much less energy; they also have the potential to improve the health, comfort, and productivity of their occupants. The United States needs to develop an overall strategy to achieve high-performance infrastructure; that strategy must integrate and optimize all the major high-performance attributes including resilience, energy efficiency, sustainability, safety, security, durability, productivity, functionality, and operational maximization.

Owners in both the public and private sectors who seek a higher level of overall performance have not had access to criteria upon which they could base design solutions that will create and maintain greater performance. Perhaps more importantly, they have typically had no compelling reason to request designs or features that exceeded the minimum performance levels found in most U.S. codes and standards.

But high-performance standards open the door to enhanced value. That value may derive from reduced energy and operating costs, lowered maintenance costs, improved functionality and productivity, maximized protection and security, enhanced environmental conditions, sustainability, building durability, or capacity to continue operating after a catastrophic event. Whatever its source, that value has the potential to offer building owners dramatically greater returns on their investments. If high-performance standards permit the designers, builders, and operators of buildings to better understand the cost/benefit implications of design decisions, they can lead to owners deciding to make optional improvements to the building's performance, well above the requirements set by minimum codes and standards.

High-performance standards open the door to enhanced value... with potential to offer building owners dramatically greater returns on their investments.

It is clear, based on past programs to advance building design, that only a systems approach will achieve those goals in the future. Whether we are changing only one component or rehabilitating the whole system, effective approaches require advice from experienced practitioners of all types. And the value of our actions will be determined by the total performance that results. For all these reasons, the United States needs new metrics and benchmarks, as well as a new set of verification and validation standards, to ensure that we reach our overall performance goals.

At least seven key components of high-performance value must be considered while buildings are being designed and constructed:

1. Design should consider a building from cradle to grave and look for ways to reuse the existing parts in the next generation systems.
2. Design should stress for durability.

3. Design should aim for energy efficiency and efficient use of materials.
4. Design should make buildings efficient enough to justify the economic use of renewable resources.
5. Better tools and standards for validating and evaluating performance must be developed.
6. Commissioning must be used as a part of the design and construction process: from design intent, through the construction period and including some post-occupancy tests.
7. Predicted performance must be verified against actual data.

One of the most important attributes of a high-performance building is its inherent durability, i.e., its long-term performance. By appreciably extending the service life of buildings, owners can reduce life-cycle costs and achieve major savings from less frequent retrofits and replacements. A second critical consideration is the incorporation of appropriate passive energy efficiency and sustainability measures that lead to savings from smaller and less-expensive equipment and less fuel use.

The concept of high-performance buildings comes at a time when the design and construction community is being pulled in many directions and needs a framework for balancing competing interests. Several developments confirm that this is the right time to begin a paradigm shift in the production of the built environment: the increasing popularity of sustainable or "green" buildings, the need to address post-9/11 safety and security concerns, the new contractual and delivery methods available to builders, and the market mechanisms driving institutional investors to seek out energy and other efficiencies in their asset portfolios.

The emergence of the need for high-performance buildings provides a valuable opportunity to look deeply at some fundamental possibilities in terms of organization, procurement, research, and technology. We cannot afford to waste the current positive attention surrounding the linkages between the built environment and energy awareness, energy efficiency, sustainability, asset management, and technological feasibility.

The Energy Independence and Security Act (EISA) of 2007 established a new and aggressive plan for achieving energy independence in the nation's building stock by the year 2030. The act requires that federal buildings (both new buildings and renovations) reduce their consumption of energy from fossil fuels on the order of 55% by the year 2010 and 100% by 2030. The Act also requires that sustainable design principles be applied to the design and construction of federal buildings. Importantly, the Act defines high-performance buildings as those that integrate and optimize on a life-cycle basis all major high-performance attributes, including energy conservation, the environment, safety, security, durability, accessibility, costs and benefits, productivity, sustainability, functionality, and operational considerations.

We have little choice but to make the EISA timetable. The demand for natural resources is fast exceeding supply on this planet. Environmental preservation and economic, social and technological development must be seen as interdependent and complementary concepts, where economic competitiveness and ecological sustainability are complementary aspects of the common goal of improving the quality of life.

In many ways sustainability is at the forefront of the environmental movement: taking a holistic, systems approach to defining preferred performance; pushing the science of life-cycle assessment; asking the tough questions about environmental impacts; balancing environmental, economic and social considerations; and most importantly, responding to demand by providing and communicating the keys to responsible design. Environmental performance indicators cover the areas of siting/smart growth, energy, atmosphere, water efficiency, public health and well-being, environmentally responsible materials, and social responsibility. Better energy efficiency and decreased aggregate energy usage lie at the heart of sustainable buildings when compared with similarly benchmarked systems, because they can help reduce the use of fossil fuels.

Building functionality means how well a building can meet the needs and services of its users. Maintainability is its capacity to be serviced easily in terms of the functional requirements. Functionality establishes a building's basic characteristic or mission, and maintainability indicates its capacity to maintain that function over time. Today our society's focus is on environmental sustainability. But if we design highly sustainable buildings with poor functionality, that retards productivity, what have we really accomplished? Despite our many standards and protocols for maintainability, relatively little is in place on functionality. A family of useful functionality standards is emerging; though they are not yet widely used, a few federal agencies and large corporations have made a start.

Because so many of the nation's buildings suffer significantly from deferred maintenance, much of the building stock is functionally obsolete if not structurally deficient. We are not going to reach the EISA goals by improving these buildings with the best of existing technology. From a standpoint of design and engineering, transforming this building stock to high-performance buildings will require an unprecedented research effort that will allow us to insert in these buildings a whole new array of advanced materials and intelligent systems.

The deteriorated state of the nation's built environment has led the research community to look at using alternative materials that cost and weigh less, perform better, are more durable, and require less maintenance. Over the past decade, the industry and research institutions have developed a large variety of these new advanced materials and intelligent systems for buildings and for other purposes. This is an important step in the right direction and a foundation for further improvements. We will have to systematically take advantage of these new technologies and their successors from further research by moving aggressively to high-performance codes and standards and to accelerated research if we are to succeed in addressing the problem of deteriorating, obsolescent, unsustainable, and vulnerable buildings. A high-performance built environment must be our goal.

Franz Beyeler, Nick Beglinger and Ursina Roder

Minergie: The Swiss Sustainable Building Standard

Minergie is a sustainable building standard recognized globally for its effectiveness in achieving lower energy and resource consumption and a higher level of comfort regardless of building design or type. In Switzerland, where the standard was developed, over 14,000 Minergie buildings have been voluntarily certified and wide government backing across the cantons has led to market penetration of sustainable buildings unmatched elsewhere in the world. Also key to Minergie's success is Switzerland's vocational training system which has produced a construction industry workforce will the skills to take full advantage of the Minergie system.

Switzerland takes sustainability seriously. It is ranked No.1 in Yale's Environmental Performance Index[1] and is world-class in public transportation, recycling and organic food production as well as in buildings. Switzerland's success in the building sector is evidenced by comparing Minergie's penetration rates with LEED, a major U.S. green building rating system[2]. LEED has approximately 2,000 certified units. Minergie, in the roughly 100 times smaller Swiss market, counts over 14,000 certified buildings of many different types and sizes.

A Minergie building consumes around 60 percent less energy than the conventional Swiss building which in turn was built to one of the world's highest regulatory building standards. Such energy efficiency is attained through an integrated planning approach as well as a focus on lifecycle costs and quality benefits that involves the use of the Minergie standard from the very beginning of the planning process as well as Minergie solution modules that solve design problems in particular competence areas such as windows and ventilation. On a technical level, Minergie represents a combination of the following 10 key elements:

Franz Beyeler is a trained economist and communications specialist who since 1999 has served as Executive Director of MINERGIE through his firm, MKR Consulting AG. He also runs the Heat Pump Information Office for the Swiss Association for the Promotion of Heat Pumps. Nick Beglinger is a Management Board member of MINERGIE and a member of the management team at Maxmakers, Switzerland, which provides advisory services for sustainable real estate development. He is Co-Founder and CEO of the Foundation for Global Sustainability (FFGS). Ursina Roder works at the Office of Science, Technology and Higher Education of the Embassy of Switzerland in Washington D.C.

- Compact building form
- Airtight construction of the building shell
- Very strong thermal insulation for walls and roof
- Very good windows with coated multiple glazing
- An energy efficient, draft-free ventilation system that provides a high quality indoor environment including plenty of fresh and filtered air
- Water-based heating and cooling featuring chilled/heated floors, walls, beams, and ceilings that results in even and efficient distribution
- Integration of renewable forms of energy such as geothermal, solar, wind, or wood
- Use of waste heat
- Careful selection of materials to avoid indoor and outdoor toxicity and to promote green values
- Efficient household appliances and lighting

MINERGIE BACKGROUND & APPROACH

The Minergie base standard was introduced in1998, with the more stringent Minergie-P and Minergie-P-ECO standards appearing later. Together they set performance criteria for materials and energy efficiency, as well as for comfort. The strategy of Minergie was not to certify a few "dream projects," but rather to achieve the greatest overall effect through a limited number of key performance indicators such as the specific energy consumption measured by the amount of energy delivered to the site. A large number of building owners could be attracted by positioning Minergie both as a performance standard that greatly exceeded the mandatory local building level and also as an economically competitive alternative to conventional buildings. Minergie adds higher performance criteria for the same factors that are found in local building codes, thus improving overall performance. In this way, Minergie now has a track record of over ten years of pulling the market towards more sustainability in buildings. Different from other standards, Minergie certification is not based on point scoring but on reaching a threshold level in all key performance indicators. This makes it impossible to achieve Minergie certification with critical factors such as energy efficiency unaddressed.

Minergie has shown that buildings can be both sustainable and economically competitive. Some buildings, such as IBM's new European headquarters building located in Zurich, have had less than a 1% Minergie investment cost premium. Smart design and the right combination of materials can lead to high levels of energy and emissions efficiency very economically. Our experience has shown that sustainability improvements in the building space indeed represent "low hanging fruit."

A major benefit of sustainable building, as is clearly demonstrated by Minergie, comes from the higher quality levels of the indoor space created. Indoor quality is very important on multiple levels. As city dwellers, we spend 90% of our time indoors, so our buildings largely determine the quality of air we breathe, as

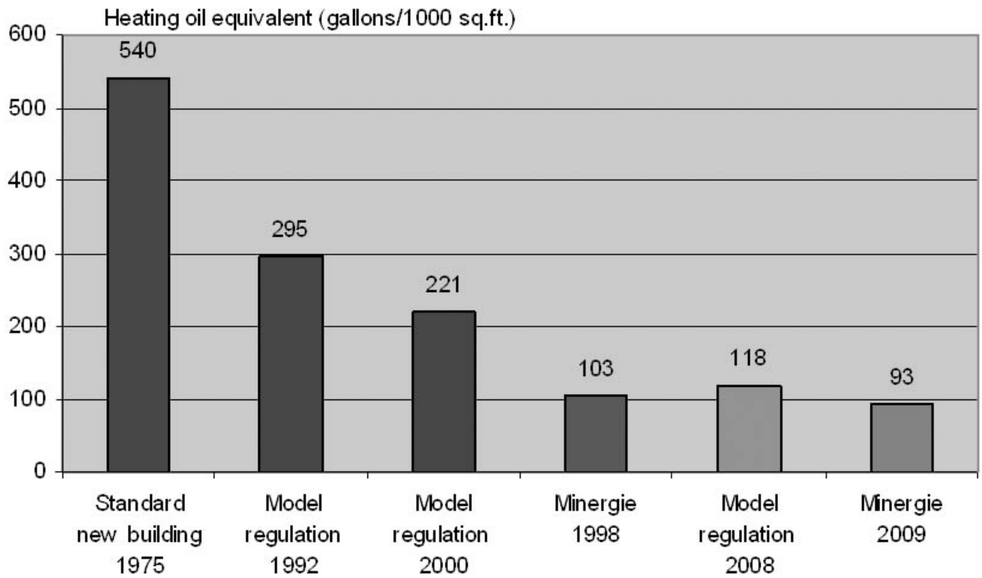

Figure 1. Heat Requirements of New Buldings

Source: Konferenz Kantonaler Energiedirektoren, 2009: http://www.endk.ch/kantone.html

well as the temperature, draft, and light quality we experience, which are important factors for our well-being and efficiency. At home, this means healthier sleep, better learning, and more comfort, all valuable, but hard-to-price benefits. At work it leads to more motivation, less sick-days, and the capability to work efficiently for longer periods of time. Since salaries represent by far the largest cost factor for the average commercial tenant, sustainable buildings create value that far exceeds the minor additional rental costs that may need to be charged for a very sustainable building.

DRIVING FORCE IN SWISS ENERGY POLICY

Minergie is a private organization and Minergie is a registered trademark owned by the nonprofit Minergie Association which permits clear legal protection of its certificates. The Association counts approximately 400 supporting members, including many architectural firms, construction and manufacturing companies, and banks. Minergie has a formal board, an executive strategy group, a technical agency, several competence centers and a network of licensed certifiers. Minergie is linked to almost 900 local businesses with first-hand experience in building to the standard. The Minergie brand provides a positive image and a high and long-term value to its customers. Leading companies such as SwissRE, IKEA, and IBM are among its members and have decided to construct all their new buildings in Switzerland according to the Minergie standard. Most remarkably: Credit Suisse, ZKB, Bank Coop as well as other Swiss financial institutions offer Minergie mortgages with favorable terms.

All 26 cantons (the Swiss equivalent of the U.S. states) are members of the Minergie Association and are integrated in the certification process. The large majority of cantons offer special subsidies to Minergie homeowners. In the case of Minergie-P, the average subsidies equivalent to 12,100 US dollars per new single-family home.

With 14,000 certified buildings, the Minergie standard has become a major factor in Swiss energy policy. It has been applied to a wide variety of buildings, ranging from single-family homes, to shopping centers and even historically valuable buildings with landmark status. Minergie buildings can be found in the desert as well as up high in the Alps. There are both Minergie huts and multi-million dollar Minergie villas. And the standard is widely regarded to be responsible for the performance improvements of the new Swiss cantonal building code (Model Regulation 2008) which approaches the level of the original 1998 Minergie standard.

Recently, Minergie started its international roll-out with the aim of sharing Switzerland's success with other countries and making a tangible contribution to sustainable development through leveraging the full potential in the building sector (and potentially urban planning, in the future). A pilot localization project is already running in Abu Dhabi (www.swiss-village.com). For all of its roll-out, Minergie is based on a partnership approach, seeking to work with local authorities and independent agencies to run a highly customized standard (regulatory environment, climate, know-how, and cultural factors), but one that is internationally comparable.

Minergie standards offer building users a higher quality of life as well as higher efficiency; and as a consequence the standards considerably increase a building's lifecycle value. At the same time, building owners, architects and planners enjoy freedom in design and selection of materials, as well as freedom regarding the internal and external structure of their building.

1. See epi.yale.edu
2. See www.usgbc.org

L. Hunter Lovins

The Economic Case for Climate Protection

> Climate change represents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen.
>
> —Sir Nicholas Stern[1]

> Creating the low-carbon economy will lead to the greatest economic boom in the U.S. since we mobilized for World War II.
>
> —Former President Bill Clinton[2]

Sir Nicholas Stern and Bill Clinton both have it right. Global climate change has been our greatest market failure. Now it is our greatest market opportunity. Market mechanisms are enormously powerful tools to apply to such challenges as climate change.

Solving the climate crisis is urgent. Perhaps more importantly, addressing it intelligently will unleash enormous economic opportunity. Mitigating greenhouse gas emissions will require a crash program to use energy more efficiently, and to use renewable energy sources. Doing this will cut costs and drive competitiveness, spread the use of clean energy technologies that already are cost-competitive and available, and deploy next-generation technologies in virtually every sector of the economy.

Capturing these opportunities will require investment, management attention, and determination. The fact that these resources are scarce goes a long way to explain why energy opportunities remain to be captured: without leadership and lacking a widespread recognition of the urgency, resources have been deployed elsewhere. Energy is typically a relatively small part of most organization's budgets, so investing time and money in cutting energy use has been a relatively low priority for a typical manager. Until the issue is elevated to the level of CEO concern,

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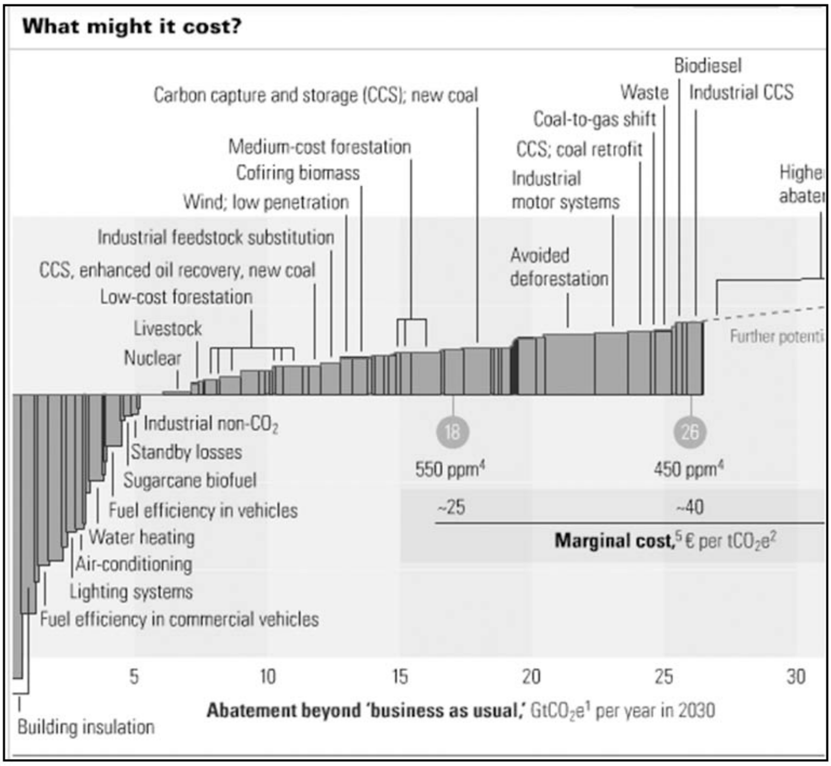

Figure 1. A Cost Curve For Greenhouse Gas Reduction

Source: Enkvist, Per-Anders, Naucler, Tomas, Rosander, Jerker, "A Cost Curve for Greenhouse Gas Reduction, The McKinsey Quarterly, 2007 #1.© McKinsey & Co.

it will be hard to get action in corporations or governments. In addition, as described below, there are myriad barriers to reducing energy use, even though doing so will save money quickly. Collectively these hurdles have created a hassle factor that for most executives, it's just not been worth surmounting—yet.

CAPTURING THE OPPORTUNITIES

The entrepreneurial opportunities of implementing a new energy economy will be unprecedented. Far from the crushing cost that some have called the price of climate protection, the investments in using energy more productively and in unleashing the new energy economy will deliver impressive returns.

In the past, the United States led the world in the development of "green" technologies. Solar electric cells and wind turbines were first developed in America. Today, due to intelligent government policies, countries such as Japan, China, Germany and Denmark have taken the lead in solar and wind power. Renewables now create more new jobs in Germany than any other industry.[3] Denmark aims to get 60% of its energy from renewables by 2010. Japan was first-to-market with hybrid vehicles. Toyota, which this year surpassed General Motors as the world largest car company, expects hybrid vehicles to rise from 6% of its U.S. vehicle sales in 2005 to 20% by 2012.[4] It is time again for the United States to become the world leader in developing the goods and services needed for low-carbon economic development worldwide.

The good news is that the transformation of the U.S. economy already is underway, and there is a strong business case for acting even more aggressively to protect the climate. Leading companies and communities are cutting their costs, creating jobs, increasing profits and strengthening shareholder value by doing just this. [5]

The McKinsey study profiled in Figure 1 is one of a growing number of studies are finding that the challenge can be met at little or even negative cost. McKinsey found that greenhouse gas emissions could be stabilized at current levels and reduced on the scale that scientists say will be necessary to protect the climate at costs less than the world spends on defense or insurance and around a third of the estimated impact of recent oil price rises.[6] Although individual numbers can be questioned (the study uses historic nuclear costs, not the marginal costs of building new plants, and almost no one expects that carbon capture and sequestration of carbon emissions from new coal plants can be brought on without doubling the cost of coal,) the shape of the graph is roughly right: most of the energy efficiency that by some estimates can cut energy use by at least half, comes on at a dramatic savings, and the measures needed to keep carbon emissions under 450 parts per million (the highest range that scientists believe the world can safely manage) are well within the range of acceptable investments.

"This is a hugely important message to policy makers everywhere, not least those in the United States Congress," the *New York Times* editorialized in May 2007. "Many of them have been paralyzed by fears…that a full-scale attack on climate change could cripple the economy."[7]

Many companies and communities aren't waiting. DuPont, GE, Alcoa, Caterpillar, PG&E, and others, acting as members of the U.S. Climate Action Partnership, or USCAP,[8] have called for national legislation to cap carbon emissions, stating, "In our view, the climate change challenge will create more economic opportunities than risks for the U.S. economy."[9] Pacific Gas and Electric, Exelon, Public Service of New Mexico, Nike and Apple have all resigned from the U.S. Chamber of Commerce in disagreement with the Chamber's opposition to the Environmental Protection Agency limiting carbon emissions.[10]

At the same time, farsighted leaders of cities, states, campuses and others are implementing climate protection efforts, cutting their costs, creating jobs and enhancing their economies by reducing their carbon footprint. As of October 2007 almost 750 American Mayors have pledged their cities to meet the goals set forth in the Kyoto Protocol or reduce their emissions of greenhouse gasses by at least 7% by 2012. Some have already met even more aggressive targets, ranging from a goal of 20% reduction by Portland to a goal of 42% reduction over the same time frame by Sebastopol, California.[11]

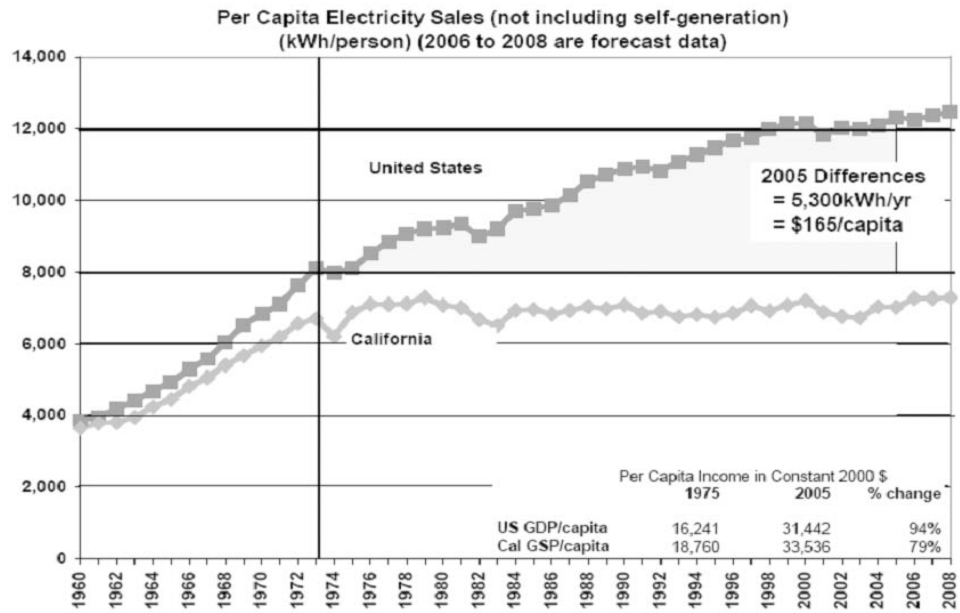

Figure 2. California vs. U.S. Energy Demand

Source: Arthur Rosenfeld, California Energy Commission

California, the world's sixth largest economy provides an example. Since 1974, Californians have held their energy consumption to zero growth while national per capita energy consumption grew 50%. The state's per capita carbon emissions have dropped 30% since 1975. (See case narrative by Arthur Rosenfeld in this issue of *Innovations.*)

By one estimate, the average family in California is paying about $800 less for energy each year than it would have had the state not actively pursued energy efficiency.[12] In 2004, California ranked 12th in the nation in energy prices, but only 45th in energy costs per person.[13]

Communities and companies that are implementing climate protection programs are finding that smart, comprehensive approaches to climate planning make them more competitive and put hundreds of billions of dollars back into the economy from savings. A local government Commissioner from Portland, Oregon stated, "We've found that our climate change policies have been the best economic development strategy we've ever had. Not only are we saving billions of dollars on energy, we are also generating hundreds of new sustainable enterprises as a result."

Programs to ensure that buildings use less energy, and to encourage the use of efficient cars, appliances and machines generate immediate energy savings, but they also deliver economic development in cities and states. They create new manufacturing companies, building retrofits, new, decentralized energy systems, new farm income, etc. and spur the creation of a dynamic, transformative clean energy economy that saves money, generates jobs and confers economic opportunity.

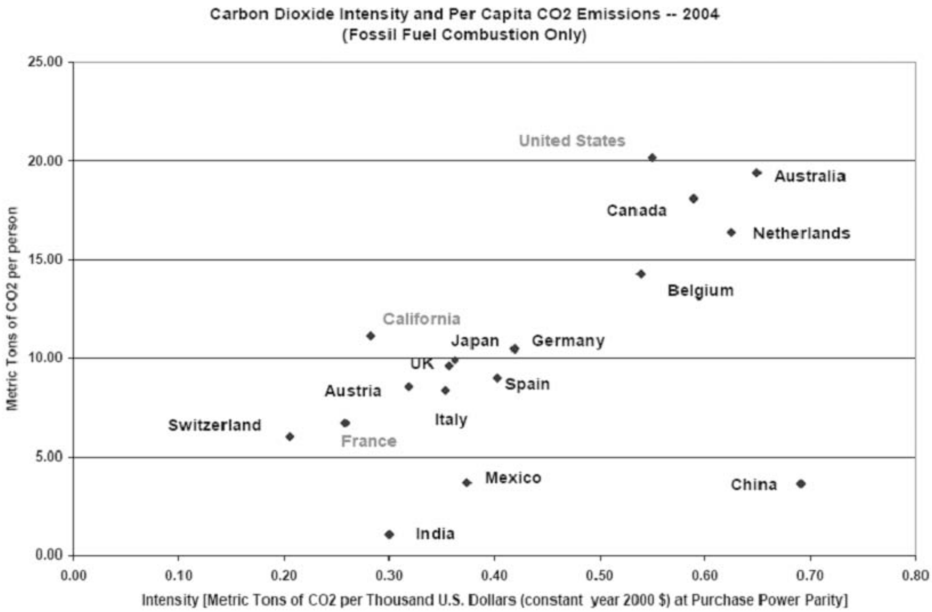

Figure 3. California and U.S. CO_2 Intensity

Source: Arthur Rosenfeld, California Energy Commission

THE BUSINESS CASE FOR CLIMATE PROTECTION

American businesses were among the earliest actors to undertake aggressive climate protection programs.

Gains for the environment realized through increased efficiency are free—or better than free (see text boxes on following pages). And they exist throughout American businesses. Even where achieving the energy savings that will protect the climate costs money, it is one of the best investments a company can make in the entire economy. Johnson Diversey projects 160 percent return on their Investments to cut their carbon footprint by saving energy.[14]

Given these examples of thoughtless waste, it should come as little surprise that American businesses use twice as much energy to produce a unit of GNP as do our competitors around the world.[15] But then all of the other nations in the world have signed the Kyoto Protocol, obliging them to save energy to cut carbon emissions. They are innovating to do this, saving money in the process and enhancing their competitiveness.

These companies realize that cutting carbon emissions, and other GHGs is a "no regrets" strategy. Using energy more efficiently not only reduces carbon emissions, it saves money.

Businesses can also profit from using and investing in carbon free renewable energy, now the hottest investment target in the economy. The venture capitalist John Doerr recently stated that such green technology could match information technology and biotechnology as a significant money-making opportunity. He

The Business Case for Climate Protection: Some Examples

- Researchers at Lawrence Berkeley National Laboratory estimate that an investment of more than $300 billion will be needed worldwide over the next 20 years to provide low-carbon electric power and equipment to1 billion people who now do not yet have access to electricity.[1] The World Bank estimates that an investment of up to $40 billion annually will be needed worldwide to adapt to climate change. This may sound like a lot, but the investment will do more to create jobs and stimulate the economy than any other options. Investments in renewable energy create 10 times the number of jobs that a similar amount invested in conventional power stations would.[2] Clean technology has become the fastest growing sector in venture capital and private equity investment, with a 2005 market valuation of $50 billion. The amount of global energy sector investment into renewables reached 10%. A survey that year of 19 venture capitalists investing in 57 European clean tech firms showed average annual returns since 1999 of almost 87%.[3]
- New low-carbon fuels are needed to replace the 85 million barrels of petroleum the world consumes each day and the 385 million gallons of gasoline burned daily in the United States[4] and the much higher fuel consumption projected for the future. Production of biofuels grew globally by 95% between 2000 and 2005 and should account for 5% of transport fuels by 2020. By 2015 this should create more than 200,000 new U.S jobs in ethanol production alone.[5] In contrast, current high oil prices represent one of the biggest transfers of wealth in history, redistributing 1% of world GDP each year. Oil consumers now pay $5 billion more for oil every day than they did 5 years ago. In 2007, $2 trillion will flow from customers to the oil companies and oil-producing nations.[6]
- There were 700 million "light duty vehicles" worldwide in 2000. That number is expected to increase to 1.3 billion in 2030 and to more than 2 billion by 2050.[7] New applications of urban design, mass transit and vehicle

called climate change "one of the most pressing global challenges" and said that the resulting demand for innovation would create the "mother of all markets."[16] One study estimated that investment in renewable energy projects market could skyrocket to nearly $50 billion by 2011, with double-digit annual growth rates.[17] In a separate report, the United Nations described, "A gold rush of new investment into renewable power over the past 18 months," which led the UN to conclude that clean energy could provide almost a quarter of the world's electricity by 2030. It reported that more than £35bn was injected into wind and solar power and biofuels in 2006, 43% more than the preceding year. Sustainable energy accounts for only 2% of the world's total but 18% of all power plants under construction are in this sector.[18]

efficiency are needed to prevent massive increases in transportation-related carbon emissions. Creating this infrastructure will revitalize aging downtowns and generate jobs.

- In December 2006, Mayor Michael Bloomberg announced a remarkable plan—PLANYC 2030—to create affordable and sustainable homes for nearly one million more New Yorkers, ensure that all residents live within a 10-minute walk of park, add public transit capacity for millions more commuters, upgrade energy infrastructure and achieve "the cleanest air of any big city in America"—all while reducing the city's greenhouse gas emissions by 30%.

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1. "Sustainable, efficient electricity service for one billion people," Fulkerson, Levine, Sinton and Gadgil, *Energy for Sustainable Development* Volume IX No. 2, June 2005, p. 26-34. The International Energy Agency estimates that 1.6 billion people worldwide now have no access to electric service.
2. Daniel Kammen, "Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?"http://www.berkeley.edu/news/media/releases/2004/04/13_kamm.shtml, and Sanders, Robert, "Investment in renewable energy better for jobs as well as environment", 13 April 2004 http://www.berkeley.edu/news/media/releases/2004/04/13_kamm.shtml
3. In the Black, A report by the Climate Group, August 2007, theclimategroup.org/index.php/resources/
4. U.S. Energy Information Administration at http://www.eia.doe.gov/neic/quickfacts/quickoil.html
5. In the Black, Climate Group
6. Mufson, Steven, "Oil Price Rise Causes Global Shift in Wealth," The Washington Post, 10 November 2007, http://www.washingtonpost.com/wp-dyn/content/article/2007/11/09/AR2007110902573.html?hpid=topnews. Americans use about 22 million barrels/day, times (say) $130/bbl. This results in around $3 billion per day spent. Based on the same usage rate, or about 7 to 8 billion barrels/year, at $130 Americans are spending about $1 trillion.
7. www.wbcsd.org/web/publications/mobility/overview.pdf

The European Union has established a goal of meeting 20 percent of its energy supply from renewable energy by 2020.[19] Delivering the capacity to do this is expected to provide up to 2.8 million jobs and create up to 1.1 percent of the GDP. The EU energy commissioner, Andris Piebalgs, stated, "This shows that benefits of renewables in terms of security of supply and fighting climate change can go hand in hand with economic benefits." Asia should do no less.

Vishal Shah, an investment analyst for Barclays Capital, has put it this way:

> As global economies take action to mitigate climate change, we expect an era of fundamental reshaping of the global energy infrastructure to create a prominent role for the renewable energy sector. Renewable electricity represented 2.5 percent of worldwide electricity generation in 2008

Interface Inc.

When Ray Anderson, CEO of the global carpet company, Interface, Inc., looked critically at his carpet operations and sustainability, he concluded that "nothing about our business was sustainable."[1] Anderson challenged himself, his employees, peers, and competitors to shift to sustainable operations. Innovating to cut waste, to redesign his products, Interface found that its commitment to sustainability enhanced every aspect of shareholder value. The savings accumulated from eco-efficiency measures paid for the entire sustainability commitment and enabled the company to remain profitable through economic downturns, gain market share and become the dominant player in its industry.[2]

Anderson goals were:

- Take from the Earth only what can be rapidly renewed by the Earth naturally;
- Take no oil from the ground for production and send nothing to landfill;
- Create no harm to the biosphere; and
- Goal: "Mission Zero" - 0 impact, 0 footprint.

The company's measured progress to date includes:

- Net GHG emissions are down 82% in absolute tonnage;
- Sales increased by 2/3;
- Profits have doubled;
- Fossil fuel usage is down 60%; Water usage is down 75%;
- Renewables and recycled materials are up 25%; Renewable energy use is up 27%;
- Interface diverted 74,000 tons of used carpet from landfills;
- The company innovated the first certified carbon neutral product; and
- Interface sold 85 million square yards of climate neutral carpet since 2004.

Interface is half way to its goal today. It anticipates meeting its goal of having zero impact and zero footprint in 2020. Ray Anderson, now Chair of the company, reports that Interface's sustainability quest has been the best thing he has ever done for the business.

Costs are down $4.5 million per year. The program has elicited unprecedented customer loyalty that saw the company through the last downturn. The savings from eliminating waste paid for all of the costs for transformation of Interface.[3]

1. Anderson Ray, Midcourse Correction, Chelsea Green Press, 1999, ISBN-13: 978-0964595354.
2. Personal communication, Ray Anderson, Wingspread meeting, 16 July 2008.
3. http://www.ted.com/talks/ray_anderson_on_the_business_logic_of_sustainability.html.

> and we believe it could represent more than 20 percent of worldwide electricity generation, as policies to promote renewable energy are implemented globally over the next 20 years.... Solar currently represents less than 0.5 percent of global electricity generation. However, as renewable electricity gains importance in the $1 trillion global electricity market, we forecast solar photovoltaic shipments to rise at a compound annual growth rate of 50 percent for the next four years.[20]

Renewable energy generation is being installed across Asia. The Government of India has announced plans to invest $20 billion to build a solar market and an Indian solar photovoltaic industry.[21] The plans include constructing 20 gigawatts (GW) of solar energy by 2020 with a total of 200 GW of solar generation by 2050. Currently, India has little solar generation, but by 2012 it expects to have 1 GW of solar power installed on the rooftops of public sector buildings and in local solar manufacturing parks.

Likewise, China is investing heavily in solar and wind power, reportedly investing $440 to $660 billion[22] in clean-energy industries over the next 10 years. Already one of the global leaders in wind power generation, with 100 billion yuan ($14.6 billion) committed to wind power generation by 2010,[23] China plans to increase wind generation from 12,000 megawatts (MW) to 30,000 MW. Shi Lishan, deputy director of renewable energy at the National Energy Administration, said, “Wind power is ‘vital’ as it is the cheapest form of renewable energy.”

Japan is investing to achieve a 20-fold expansion of installed solar energy by 2020[24] while South Korea is devoting $85 billion, or two percent of its GDP, in green industries and technologies over 5 years.[25] In contrast the U.S. is projected to only invest $10 billion annually in a clean energy economy, assuming that the American Clean Energy and Security legislation now languishing in Congress actually passes. Only $1.2 billion would be spent on research into low-carbon technologies.[26] Various observers believe that this is an opportunity for Asia to take the lead in creating a more sustainable energy future.[27]

Energy supply is not the only aspect of a clean energy industry. China plans to put half a million hybrids vehicles per year by 2011. Toyota projects 30,000 in Japan by 2012. In contrast, Ford Motor Company estimates that it will have produced only 120,000 by 2020. Unless America acts Asia will seize the center of the conversation in clean technologies.[28]

Enhancing the Integrated Bottom Line

Businesses that reduce their carbon emissions strengthen every aspect of shareholder value. The validity of this management approach is borne out by the recent report from Goldman Sachs, which found that companies that are leaders in environmental, social and good governance policies are outperforming the MSCI world index of stocks by 25% since 2005. Seventy two percent of the companies on the list outperformed industry peers.[29]

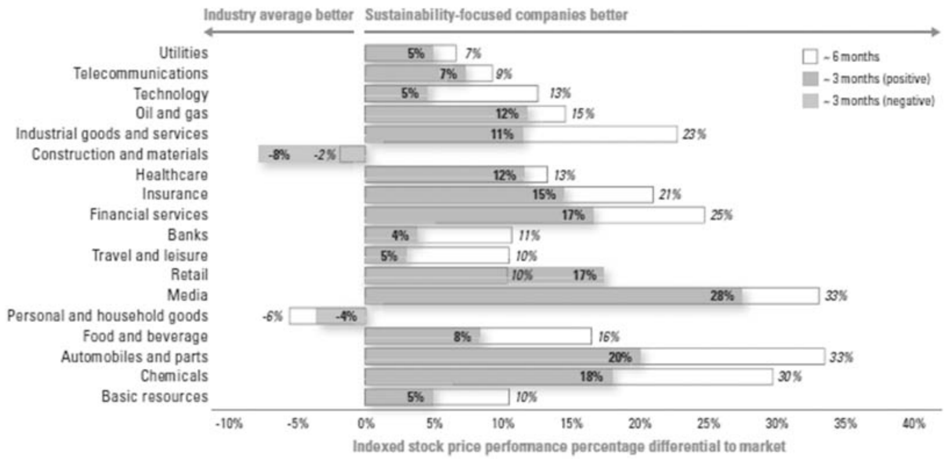

Figure 4. Performance of sustainability-focused companies.

Source: Mahler, Daniel, Jeremy Barker, Louis Besland, and Otto Schulz. "Green Winners," online article for A.T. Kearney, 2009, http://www.atkearney.com/shared_res/pdf/Green_Winners.pdf.

Even in the economic collapse, companies that make a commitment to behave more sustainably fared better than their peers in the same industry. From 2006 through 2007 companies on the Dow Jones Sustainability World Index performed 10 points above the S&P 500.[30]

In 2009, A.T. Kearney released the findings of their report, Green Winners, comparing the economic performance of companies with a commitment to sustainability to companies in the same industry without such a sustainability commitment. The report tracked the stock price performance over six months prior to November 2008 of 99 firms on Dow Jones Sustainability Index and the Goldman Sachs list of green companies. The results from the report showed that in 16 out of the 18 industries evaluated, businesses deemed "sustainability focused" outperformed industry peers over three- and six-month periods and were "well protected from value erosion." In the study period of three months the differential between the companies with and without a commitment to sustainability was ten percent and over six months the differential was 15 percent. "This performance differential," the Report stated, "translates to an average of $650 million in market capitalization per company."[31]

As shown below in Figure 2.13 from the ATOS study, a 2009 study of European companies, "There is a strong business case for environmental excellence. Companies with more mature sustainability programs enjoy higher profit..."[32]

Corporate managers are increasingly realizing that value returned to the owners, the real metric of success, derives from more than just attention to next quarter's profits—indeed the Financial Accounting Standards Board (FASB) has recently announced that it will revise its definition of "profit" away from this short-term fixation.[33]

Shareholder value is enhanced when a company grows top-line sales, cuts its costs, better manages its risks, enhances labor productivity, drives innovation, better manages its supply chains and stakeholders, etc. These constituents of what is now known as The Integrated Bottom Line[34] are all enhanced by saving energy and reducing greenhouse gas emissions. Companies that implement climate protection programs enhance financial performance from energy and materials cost savings in industrial processes, facilities design and management, and fleet management. It enhances core business value through sector performance leadership and first-mover advantage, gains greater access to capital, improves corporate governance, strengthens its ability to drive innovation, and improves government relations. Doing this helps a company retain competitive advantage, enhance its reputation and brand equity, increase its ability to capture market share and differentiate its product. Such programs increase a company's ability to attract and retain the best talent, increase employee productivity and health, improve communication, creativity, morale in the workplace, and better stakeholder relations.

Regardless of how severe the impact of climate change proves to be, and regardless of how drastically and how soon GHG come to be regulated at the federal level, these companies will be in a leadership position because by taking early action to deal responsibly with it, they cut their costs and got ahead of their competitors.

Cost reduction: The Walmart Experience

As DuPont showed, using less fossil energy by using energy more efficiently saves money, because it costs less to implement the energy savings measures than it does to buy and burn the fuel. In 1999, the company estimated that every ton of carbon it displaced saved it $6.

Walmart realized that changing the incandescent bulbs in its ceiling fan displays throughout its 3,230 stores (10 models of ceiling fans on display, each with four bulbs. Forty bulbs per store, 3,230 stores) could save the company $6 million a year. Said Chuck Kerby the Walmart employee who did the math, "That, for me, was an 'I got it' moment."[35]

In 2005, Lee Scott, then CEO of Walmart, committed the company to work with its more than 60,000 suppliers to deliver "affordable sustainability" to Walmart's 176 million customers in 14 countries. Walmart pledged:

- To be supplied 100 percent by renewable energy;
- To create zero waste; and,
- To sell products that sustain resources and the environment.

Scott announced that Walmart was "helping thousands of suppliers, millions of associates, and tens of millions of customers make billions of individual decisions that sustain themselves, their communities and, in turn, the Earth."

Scott announced goals to reduce energy use at Walmart stores 30 percent over three years, double the fleet efficiency of its vehicle fleet, build hybrid-electric long-haul trucks.[36] Walmart, which if it were a country would be the 20th largest in the world, is not making such pronouncements out of the goodness of its heart. In the two years after Walmart began its sustainability program savings were significant. Reducing unnecessary packaging by just five percent saved the company $11 billion globally.[37]

Walmart's challenge, like that of many retailers, is that it does not own or operate factories. "For instance," Lee Scott stated, "We were buying from a candy factory in Brazil that just did not have a good system in place for processing, recycling, and disposing waste. So our auditors sat down with the factory's management, explained that sustainability can be profitable, and made recommendations. These managers were skeptical, but they took on the challenge. The next time we visited the factory, we saw a new waste management program. And you know what? The factory managers proudly reported that their new program was generating $6,500 per year in new profits."

In October 2008, Walmart, which were it a country would be China's sixth or seventh largest trading partner, called its 1,000 largest Chinese suppliers to a meeting with representatives of the Chinese government, NGOs and others. Walmart executives described the aggressive goals the company has established to build a more environmentally and socially responsible global supply chain.[38]

The criteria required that the top 200 factories from which Walmart's sources its materials achieve a 20 percent improvement in energy efficiency by 2012. The company stated that by that date it would source 95 percent of its production from factories with the highest ratings in audits for environmental and social practices. It further revealed that Walmart China will design and open a new store prototype that uses 40 percent less energy.

To increase transparency and encourage sustainable development across its entire supply chain of 60,000 to 90,000 suppliers, Walmart asked the Carbon Disclosure Project (CDP) to survey suppliers in China to determine the carbon footprint[39] of factories, and to assess programs to reduce carbon emissions.[40] The CDP, which represents 315 global institutional investors with assets of $55 trillion, receives annual corporate carbon footprint reports from almost 80 percent of the Financial Times 1,800, the largest companies in the world. Institutional investors use the CDP database to make investment decisions based a company's greenhouse gas emissions, emission reduction goals and strategies to combat climate change.[41] Companies that do not responsibly manage their carbon footprint are deemed not worthy of investment.

Walmart was one of only two companies in the Dow Jones Industrial Average whose stock price rose in 2008—by 18 percent—and its sustainability efforts were credited in part with this performance.[42] When he announced the sustainability initiative, Walmart CEO Lee Scott observed that a corporate focus on reducing greenhouse gases as quickly as possible was just a good business strategy, stating, "It will save money for our customers, make us a more efficient business, and help position us to compete effectively in a carbon-constrained world."[43] In 2009, Reuters quoted the company's new CEO Mike Duke as saying that he wants to accelerate the sustainability efforts, saying, "I am very serious about it. This is not

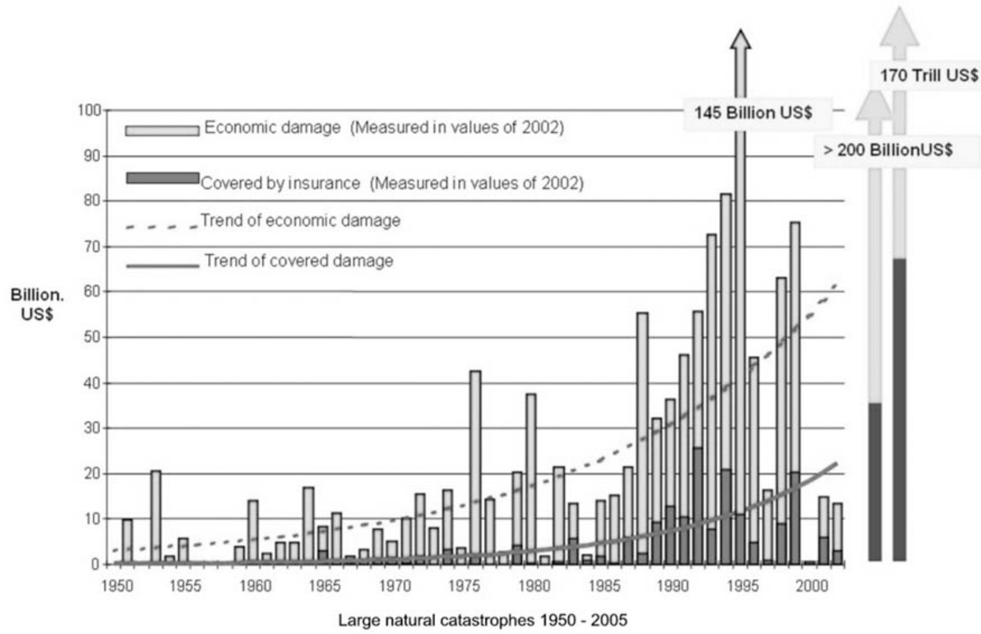

Figure 5. Evolution of economic costs, insured costs of natural disasters worldwide

Source: © 2003 GeoRisikoForschung, Müncheneruck

optional. It's not something of the past. This is all about the future."[44]

In July 2009 Walmart rolled the comprehensive environmental and social scorecard out to its several thousand largest suppliers, asking them to complete an environmental scorecard relating to product packaging and waste reduction to improve product design and delivery.[45] The first two questions ask suppliers whether they have measured their carbon footprint, and whether they report it through the Carbon Disclosure Project.

Walmart is not the only company now requiring its supply chain to document more environmentally responsible practices. Hundreds of major European and American companies are establishing supplier codes of conduct and hiring third-party verifiers to audit their factories to ensure compliance with social and environmental standards. As such companies recognize that their survival depends on behaving in more sustainable ways, they are changing how the world does business.

Risk management

Failing to reduce energy use and tolerating carbon emissions is a high-risk strategy for a business. Volatility of energy supply and increasing prices, overall volatility in the geopolitical and geostrategic environment, threats to business from extreme weather events, a growing risk of liability claims for failing to act and a host of other reasons make aggressive carbon reduction action simply good business (see Figure 5).

Corporate behavior that ignores such threats is coming to be seen as irresponsible. A 2003 *Columbia Journal of Environmental Law* article demonstrated the legal viability of lawsuits holding companies accountable for climate change. In July 2004, eight state attorneys general and New York City led the first-ever climate-change lawsuit against five of the nation's largest electric power generating companies to require them to reduce their CO_2 emissions. Though the effects of such litigation on companies' market value and shareowner value remain to be seen, the first such suits have already been filed.[46] The Environmental Protection Bureau of the New York Attorney General's office has studied whether polluters can be sued along the lines of the successful tobacco litigation by states in the 1990s.[47]

Climate change will have an impact on the value of investments and could cost U.S. public companies billions of dollars from decreased earnings due to cleanup costs and fines following the violation of environmental laws, increased operating costs due to changes in environmental regulations and higher management costs due to understated or undisclosed liabilities.

Conversely, an aggressive business posture to reduce greenhouse gas emissions is becoming a proxy for competent corporate governance. Climate protection programs can deliver better access to insurance, cost containment, legal compliance, ability to manage exposure to increased carbon regulations, reduced shareholder activism, and reduced risks of exposure to higher carbon prices.

The FTSE Index, the British equivalent of Dow Jones, states. "The impact of climate change is likely to have an increasing influence on the economic value of companies, both directly, and through new regulatory frameworks. Investors, governments and society in general expect companies to identify and reduce their climate change risks and impacts, and also to identify and develop related business opportunities."[48]

As described more fully below, the business and investment network CERES is working with institutional investors to require American companies to reveal the extent to which they may be more liable for lawsuits and other risks than their European counterparts because of their emissions of climate changing gasses. The New York Times stated, "Dozens of U.S. businesses in various climate-vulnerable sectors ... are still largely dismissing the issue or failing to articulate clear strategies to meet the challenge. Companies that disclose the amount of emissions of heat-trapping gases they produce and take steps to limit them cut their risks, including potential lawsuits from investors.[49]

In 2006, the United Nations Environment Programme (UNEP), working with CERES, announced a new Climate Risk Disclosure Initiative to create a global standard for disclosing climate emissions.[50] UNEP is developing Principles of Responsible Investment to align the long-term goals of sustainable development with the obligations of institutional investors. CERES and UNEP are also establishing a new international forum for collaboration and information sharing by institutional investors on climate risk.

Insurance

In 2003 The Wall Street Journal reported, "With all the talk of potential shareholder lawsuits against industrial emitters of greenhouse gases, the second largest reinsurance firm, Swiss Re, has announced that it is considering denying coverage, starting with directors and officers liability policies, to companies it decides aren't doing enough to reduce their output of greenhouse gases."[51] The following years showed the prescience of this statement: insurance companies are already being battered by losses from the increase in the violence of storms. 2005 was the costliest year on record for weather related damage, costing insurers over $65 billion, Claims from weather related disasters are now rising twice as fast as those from all other mishaps.[52]

In the *Fortune* Magazine article "Cloudy with a Chance of Chaos,"[53] author Eugene Linden reported:

> Already the pain of weather-related insurance risks is being felt by owners of highly vulnerable properties such as offshore oil platforms, for which some rates have risen 400% in one year. That may be an omen for many businesses. Three years ago John Dutton, dean emeritus of Penn State's College of Earth and Mineral Sciences, estimated that $2.7 trillion of the $10-trillion-a-year U.S. economy is susceptible to weather-related loss of revenue, implying that an enormous number of companies have off-balance-sheet risks related to weather—even without the cataclysms a flickering climate might bring.
>
> In 2004, Swiss Reinsurance, a $29 billion financial giant, sent a questionnaire to companies that had purchased its directors-and-officers coverage, inquiring about their corporate strategies for dealing with climate change regulations. D&O insurance, as it is called, insulates executives and board members from the costs of lawsuits resulting from their companies' actions; Swiss Re is a major player in D&O reinsurance.
>
> What Swiss Re is after, says Christopher Walker, who heads its Greenhouse Gas Risk Solutions unit, is reassurance that customers will not make themselves vulnerable to global-warming-related lawsuits. He cites as an example Exxon Mobil: The oil giant, which accounts for roughly 1% of global carbon emissions, has lobbied aggressively against efforts to reduce greenhouse gases. If Swiss Re judges that a company is exposing itself to lawsuits, says Walker, "we might then go to them and say, 'Since you don't think climate change is a problem, and you're betting your stockholders' assets on that, we're sure you won't mind if we exclude climate-related lawsuits and penalties from your D&O insurance.' " Swiss Re's customers may be put to the test soon in California, where Governor

> Arnold Schwarzenegger is pushing to restrict carbon emissions, says Walker. A customer that ignores the likelihood of such laws and, for instance, builds a coal-fired power plant that soon proves a terrible bet could face shareholder suits that Swiss Re might not want to insure against.

A single catastrophic event can cause insolvency or a precipitous drop in earnings, liquidation of assets to meet cash needs, or a downgrade in the market ratings used to evaluate the soundness of companies in the insurance industry.[54] Weather-related insurance losses in the United States are growing 10 times faster than premiums, the population, or economic growth, and many smaller events have not yet been included in official totals.[55] As the 2007 firestorms in Southern California showed, the convergence of climate change with rapid growth in population in some of the nation's most disaster-prone areas—and the accompanying real estate development and increasing real estate values—is leaving the nation exposed to higher insured losses. Hurricane losses are borne by private insurers and by two federal insurance programs established by Congress to provide coverage where voluntary markets do not exist: the National Flood Insurance Program (NFIP), which insures properties against flooding,[56] and the Federal Crop Insurance Corporation (FCIC), which insures crops against drought or other weather disasters.[57] Increasingly, private companies are taking steps to limit their catastrophic risk exposure, transferring some of the risk to policyholders[58] and to the public sector. Federal insurers may see losses grow by many billions of dollars in coming decades.

Property owners are suffering price shocks, as well as reduced availability of coverage. Highly vulnerable properties such as offshore oil platforms have seen insurance rates rise 400 percent in one year.[59] Homeowner premiums have risen 20 to 40 percent in many areas, and 10- to 20-fold in isolated cases.[60] Insurers have withdrawn coverage for hundreds of thousands of homeowners in Florida, Louisiana, Mississippi, New York, Massachusetts, Rhode Island, and South Carolina.[61]

The exodus of private insurers from hurricane-prone areas is, in turn, creating enormous financial exposure for state-operated insurance pools—intended to be "insurers of last resort"—that provide coverage for losses caused by weather-related events.[62] Federal, state, and local governments also are compelled to address events for which there is no insurance at all by way of disaster preparedness and recovery operations. NFIP and FCIC data indicate the Federal government already is more exposed to weather-related losses regardless of the cause. A General Accounting Office (GAO) study of weather-related losses between 1980 and 2005 notes that the number of NFIP policyholders has more than doubled since 1980, from 1.9 million policies to more than 4.6 million. Its exposure has quadrupled in the same period, nearing $1 trillion in 2005, and program expansion increased FCIC's exposure 26-fold to $44 billion.[63]

In spite of the growing risks, climate change also offers substantial opportunities to the insurance industry. A 2006 CERES[64] report notes: "As the world's largest industry ... with core competencies in risk management and loss prevention, the insurance industry is uniquely positioned to further society's understanding of climate change and advance forward-thinking solutions to minimize its impacts."[65] Indeed, a "vanguard of insurers" has begun to take concrete actions that generate profits while maintaining insurability and protecting their customers from extreme weather-related losses, in addition to reducing greenhouse gas emissions (see examples in Appendix A). Calling these examples an "encouraging start," the CERES report calls for far greater efforts from insurance companies and regulators to get more of these creative programs into the public arena.

In April 2007, the chief research officer of Risk Management Solutions, an industry risk forecaster announced that climate change is already increasing "financial losses from extreme weather catastrophes." A.M. Best, the historical voice of insurance, began a series in the August edition of Best's Review on the risks, regulatory issues and economic impact of climate change.

In September 2007 the Washington Post reported, "Nervous investors have begun asking insurers to disclose their strategies for dealing with global warming. At a meeting of the National Association of Insurance Commissioners, Andrew Logan, insurance director of the investor coalition, representing $4 trillion in market capital, warned that "insurance as we know it is threatened by a perfect storm of rising weather losses, rising global temperatures and more Americans living in harm's way." CERES cites estimates that losses related to catastrophic weather have increased 15-fold in the U.S. property casualty industry in the past three decades."[66]

Access to Capital

As investors evaluate corporations on the basis of their preparedness for the associated risks and opportunities of climate change they are increasingly recognizing that companies that do not adapt to a carbon-constrained world will be forced to compete with forward-thinking competitors ready to leverage new business models and capitalize on emerging markets in renewable energy and clean technologies. Large institutional investors are leading the way and have successfully waged shareholder campaigns urging companies to disclose climate risk and implement mitigation programs.[67]

The Investor Network on Climate Risk,[68] for example, includes more than 50 institutional investors that collectively manage more than $3 trillion in assets. Another group of 28 leading institutional investors from the United States and Europe,[69] who also manage over $3 trillion in assets, announced a 10-point action plan in 2005 that calls on investors, leading financial institutions, businesses, and governments to address climate risk and seize investment opportunities. The plan calls on U.S. companies, Wall Street firms, and the Securities and Exchange Commission to intensify efforts to provide investors with comprehensive analysis and disclosure about the financial risks presented by climate change. The group also pledged to invest $1 billion in prudent business opportunities emerging from the drive to reduce GHG emissions.

In October 2007 18 leading investors, including the $250 billion California Public Employees Retirement System, filed a petition to the Securities and Exchange Commission (SEC) asking the SEC to require companies to assess and disclose "material" financial risks from climate change. Such risks would include financial impacts from emerging carbon-reducing regulations, extreme weather and other climate-related physical events, or growing global demand for low-carbon technologies and products.[70]

The petitioners included $1.5 trillion of investor assets, including pension funds in California, Florida, New Jersey, New York, North Carolina and Rhode Island. The petition requests that the commission issue interpretive guidance clarifying that material climate-related information must be included in corporate disclosures under existing law. Dr Russell Read, then Chief Investment Officer of CalPERS stated, "CalPERS is interested in the sustainability of companies that may be threatened by climate change as well as those that can find new opportunities in a carbon-constrained market…. We want portfolio companies that are well positioned to avoid the financial risks associated with climate change and that can capitalize on new opportunities emerging from the regulation of greenhouse gases, including alternative energy technologies."[71]

In the United States, the Sarbanes-Oxley Act[72] makes it a criminal offense for the Board of Directors of a company to fail to disclose information, including such environmental liabilities as GHG emissions that could alter a reasonable investor's view of the organization. In France, The Netherlands, Germany[73] and Norway, companies are already required to publicly report their GHG emissions.

Even as early as 2005, such investor intervention and persuasion contributed to decisions by a number of large companies (Anadarko Petroleum, Apache, Chevron, Cinergy, DTE Energy, Duke Energy, First Energy, Ford Motor Company, General Electric, JP Morgan Chase, and Progress Energy) to make new commitments such as supporting mandatory limits on GHGs, voluntarily reducing their emissions, or disclosing climate risk information to investors.[74]

Since 2002, the British NGO, the Carbon Disclosure Project (CDP) has surveyed the Financial Times 500, the largest companies in the world. Initially, perhaps 10 percent of the recipients bothered to answer. In 2005, 60 percent answered. In 2006 70 percent participated, and in 2007 77 percent answered the survey. Ford Motor Company produced a major report detailing its emissions. Why the change? The threat of Sarbanes Oxley liability clearly played a role. But perhaps more significantly, the Carbon Disclosure Project represents institutional investors with assets of over $31.5 trillion, up more than $10 trillion since 2006 and now representing almost a third of all global institutional investor assets.

In September 2007 the CDP released its fifth annual report. It found that the world's major companies are increasingly focused on climate change and that many see it as an opportunity for profit. The report noted, however, that U.S. firms tend to view climate change as a risk to their bottom line. In the latest survey of a sample of members in the Financial Times 500 index, 77 percent of the Financial Times 500 (the 500 biggest companies on earth) responded, up from 72 percent a year earlier.

Nearly 80 percent of respondents around the world considered climate change a commercial risk, citing extreme weather events and tightening government regulations. Some 82 percent said they recognized commercial opportunities for existing or new products, such as investments in renewable energy. Overall, 76 percent said they had instituted targets and plans to reduce emissions, a jump from last year's 48 percent. Only 29 percent of U.S. respondents had implemented greenhouse gas reduction programs with timelines and specific targets.

The banking industry is also reducing its carbon footprint. In 2006 HSBC won the Financial Times' First Sustainable Banking Awards as the first bank to become carbon neutral. It not only provided financing for renewable energy companies, it purchased renewable energy, to cover its operations.[75] In 2007 JP Morgan Chase and the Socially Responsible Investment advisors, Innovest, announced the creation of the JPMorgan Environmental Index—Carbon Beta (JENI-Carbon Beta), the first high-grade corporate bond index designed to address the risks of global warming by tracking carbon footprint of companies. "Taking into account environmental and social issues isn't just about good corporate citizenship, its becoming an essential part of risk management for investors,"[76] In addition to reducing its own carbon emissions, the firm raised $1.5 billion of equity for the wind power market in 2006, making investments in renewable energy totaling $1 billion. The firm was also the lead sponsor of the C40 Large Cities Climate Summit in New York, in which mayors of the world's largest cities committed to move aggressively to reduce GHG emissions.[77] Citigroup Inc., Deutsche Bank AG, JPMorgan Chase & Co., UBS AG, and ABN Amro have committed $1 billion to finance the energy savings measures in municipal buildings in such cities as New York, Chicago, Houston, Toronto, Mexico City, London, Berlin, Tokyo, Rome; Delhi, India; Karachi, Pakistan; Seoul, Bangkok, Melbourne, Sao Paolo, and Johannesburg.[78]

In 2006, Goldman Sachs, the first Wall Street bank to issue an environmental policy, put $1 billion into clean-energy investments. It has also pledged to purchase more products locally.[79] Credit Suisse followed by forming a renewable energy banking group that has done more than 40 deals, including the first capital markets financings in the biofuel, wind and solar power industries. Lehman Brothers "renewables vertical" combined its natural resources and power banking groups.[80] Then in 2007, Citigroup committed $50 billion to an Alternative Energy Task Force to provide financing for solar, wind, biomass, ethanol and other renewable industries.[81] "Wall Street is waking up to climate change risks and opportunities," said Carbon Disclosure Project Chair James Cameron. "Considerably more of the world's largest corporations are getting a handle on what climate change means for their business and what they need to do to capture opportunities and mitigate risks. This all points to a continued elevation of climate change as a critical shareholder value issue for investors."[82]

In September 2007, Lehman Brothers published a climate change report that set forth its predictions of the likely future of climate change policies. Dr. John Llewellyn, Lehman Brothers' Senior Economic Policy Advisor, said "climate change policy will have to place the price mechanism at its core. In turn, investors and businesses that predict correctly the course of climate change policy should be able to anticipate the direction of asset prices."

Theodore Roosevelt IV, managing director and chairman of Lehman Brothers' Council on Climate Change, said, "We believe the U.S. Congress will enact legislation in the next few years, near term or by 2010, that will increase the cost of CO2 emissions. We look forward to working with our clients to develop the best strategies to address the economic changes that are likely to occur as a result of the new laws." Lehman Brothers believes the size of the carbon trading market will be $100 billion by 2020.[83]

Managing Supply Chains

In a global marketplace the threat of more frequent and more violent storms is a threat to companies that depend on products shipped from around the world. In September 2007 Walmart announced that it would begin to measure the amount of energy that it takes various suppliers to make and transport the products sold in its stores. Walmart will work with suppliers of such products as DVDs, toothpaste, soap, milk, beer, vacuum cleaners, and soda to enable these suppliers to reduce their carbon footprint.[84] As described above, Walmart hired the Carbon Disclosure Project to survey factories in China that are manufacturing products for the company. "This is an opportunity to spur innovation and efficiency throughout our supply chain that will not only help protect the environment but save people money at the same time," said Walmart's Chief Merchandising Officer John Fleming at a press conference at Merrill Lynch & Co.'s headquarters in New York. "We don't believe a person should have to choose between an environmentally friendly product and one they can afford to buy," he said. "We want our merchandise to be both affordable and sustainable."[85]

Labor Productivity

A suite of energy efficiency measures that can be implemented in buildings have been shown to increase worker productivity by six to 16 percent.[86] Even if energy savings are not sufficient to attract scarce management attention, labor costs, which are typically 100 times as high as energy costs, should. Even a one percent increase in labor productivity will dwarf the energy savings, but it was the attention to better energy efficiency that produced the labor saving.[87]

For example when Lockheed commissioned Building 157 in Sunnyvale, CA., the designers had to battle value-engineers who sought to delete the atrium around which they wrapped the building, calling it an expensive worker amenity. Declaring that the lighting feature, a "Literium," was structural, the designers preserved the daylighting features that enabled the building to use half the energy consumption of a comparable standard building. The extra $2 million to achieve this (good green features, if implemented by an experienced team now add nothing extra and can actually reduce costs) paid back in four years. The features achieved a 75% reduction in lighting energy, saving $500,000 a year worth of energy. Such metrics were predicted. What came as a surprise, however, was that the better lighting and the other green features led to a drop in employee absenteeism of 15 percent, and a productivity increase of the same amount. This enabled the company to win a contract, the profits of which paid for the costs of the entire building.

Boeing implemented a lighting retrofit that cut lighting energy costs by 90 percent. This investment returned itself with a less than 2-year payback, but because the workers could see better, the error rate went down by 20 percent—very good news for everyone who flies around on airplanes. It also avoided rework, increased on-time delivery, and increased customer satisfaction.

In the United States alone, roughly 6 billion square feet of buildings are constructed each year.[88] Buildings are the No. 1 cause of greenhouse gas emissions in the U.S. and must be made carbon-neutral as quickly as possible. This investment will cut healthcare costs and increase labor productivity. The current estimated decrease in productivity from "sick building syndrome," around 2 percent nationwide, resulting in an annual cost to the United States of approximately $60 billion.[89] Better indoor air quality, a frequent result of more energy efficient building technology has been shown to improve worker productivity by 0.5 to 5 percent, with estimated savings of $20 to $200 billion.[90]

Disproportionate Risks and Potential Benefits for Small Business

Small businesses are the economic engine of the country, generating more than half of non-farm private gross domestic product. They represent 99.7 percent of all employer firms, employing nearly 60 million workers, about half of all private employees. For the past decade they have generated 60 to 80 percent of net new jobs each year.

A June 2006 article in *Business Week*[91] pointed out that the 25 million small businesses in the United States stand to be among the hardest-hit victims of climate change. According to the Institute for Business and Home Safety, at least one-fourth of the small businesses closed by natural disasters never reopen.[92] It is also likely that small businesses will face increased government regulation if a mandatory program to reduce greenhouse gas emissions is implemented.

Small businesses consume half the electricity in the country, but only about a third have invested in energy efficiency. Less than half of the small business owners are aware that the EPA's Energy Star program can help them lower their energy usage. The Agency expends just $1 million and two staff positions on its programs to get information to small businesses.[93]

A number of programs show small businesses how to achieve the same sorts of savings that big companies like Walmart are enjoying. Natural Capitalism offers a web-based learning tool, Solutions at the Speed of Business, that shows small companies how they can benefit from programs to reduce carbon emissions. They can cut their own costs, and increase sales to others who are implementing emissions reduction programs.[94] There is a rapidly growing demand by consumers for environmentally sustainable choices in every line of consumer item, including foods, clothing, and household and recreational items.[95] As *Business Week* noted, "reducing energy waste in U.S. homes, shops, offices, and other buildings must, of necessity, rely on tens of thousands of small concerns that design, make, sell, install, and service energy-efficient appliances, lighting products, heating, air-conditioning, and other equipment. Small businesses can also save as much as 20-30 percent on their own energy bills by making their own workplace more energy-efficient."[96]

Energy efficiency and renewable energy can enable small businesses to become energy self-sufficient. On 14 August 2003 a tree branch fell across a power line in Ohio, setting off a cascading failure that blacked out the Northeast for up to 30 hours. The Wall St Journal estimated the cost to the region at $6 billion. Two thirds of business said that they lost at least a day of operation with a quarter losing more than $50,000 an hour.

Harbec Plastics a small upstate New York injection molding company had recently completed a comprehensive energy efficiency program, including a lighting retrofit, and more efficient motors. The company had constructed a LEED certified green building to add to its existing facilities, and added renewable energy including a wind turbine and photovoltaics. The company had improved its energy efficiency by installing a combined heat and power system to cut its soaring energy bill, which at 15¢ per kilowatt-hour was among the highest in the nation. The company was also tired of coping with the periodic power surges and outages to which it had been subjected.

Even before the blackout, Harbec had been pleased with its new energy efficiency, green building features and power supply. They cut costs and dramatically reduced temperatures on the shop floor, improving working conditions. When its systems enabled Harbec to continue operation all throughout the blackout the company was thrilled. Every year American businesses lose billions of dollars when blackouts, power surges and other interruptions force companies to shut down. Not having to shut down paid off the capital cost of Harbec's energy program. The company has since begun producing its own biodiesel, and bought fuel efficient vehicles.

Harbec worried especially about outages as they forced lost production time, wasted materials and made it unable to meet customers' needs, which risked sending its larger customers to suppliers overseas. President Bob Bechtold states, "I may be the only injection-molder in New York State who can go to his customers and talk about energy costs going down, in an industry where energy represents a significant portion of the cost of doing business. By reducing his energy costs, the leading reason that businesses are fleeing New York, Harbec has preserved jobs in an economic downturn, and created new business opportunities.[97]

Similar opportunities exist in rural America. The Straus organic dairy outside of San Francisco powers its operation from the methane from the manure from its 270-cow dairy herd. Its utility, Pacific Gas and Electric allows the dairy to run its meter backwards, selling renewable energy to the grid, and significantly reducing the emissions of methane gas, an even more powerful green house gas than carbon dioxide. The methane digester, which cost the dairy $280,000, is the fifth in the state, but 13 more are under construction, thanks in part to a state program that pays half the cost. The plant returns $6,000 a month in saved energy costs, giving Straus a two-year payback. The digester will strip 80 to 99 percent of organic pollutants from the wastewater generated from the farm. Heat from the generator will warms thousands of gallons of water used to clean the milking parlor. The resulting wastewater fertilizes the fields.[98]

American workers would benefit from building a new energy economy, according to the Apollo Alliance, a coalition of labor unions, environmental organizations, social justice and faith-based groups, businesses, and foundations. Industries improving the performance of the existing energy system, retrofitting buildings or installing new systems for energy efficiency, developing renewable energy sources, or building, improving, or maintaining transit systems will create large numbers of new high-wage jobs with good benefits, crossing a wide spectrum of industry sectors, from skilled craftsmen to designers and engineers, from public employees to laborers.[99]

"Renewable Energy and Energy Efficiency: Economic Drivers for the 21st Century," a 2007 report from the American Solar Energy Society, found that the renewable energy and energy efficiency industries currently generate about 8.5 million green collar jobs and almost $1 trillion in revenue. The number could increase to 40 million jobs and $4.5 trillion in revenues "with the appropriate public policy, including a renewable portfolio standard, renewable energy incentives, public education and research and development," the report found. As many as one in four workers could work in these fields by 2030. In the week that the report was released, General Electric Power Generation announced it would invest $39 million and hire 500 workers for a renewable energy division expansion in upstate New York.[100]

THE COMMUNITY CASE FOR CLIMATE PROTECTION IN THE U.S.

Business innovators are now being joined by thousands of large and small communities, counties, states, universities and communities of faith in cutting their emissions, and thus their energy bills.

States

With the Federal government abdicating responsibility on climate protection, states have taken up the challenge. The seven Northeastern states acted first, approving the Regional Greenhouse Gas Initiative, a mandatory regulatory scheme. Under Governor Bill Richardson, the state of New Mexico joined Chicago Climate Exchange, offsetting the carbon emissions of the State.

Over 20 states have either passed or proposed legislation on CO2 emissions, or have developed carbon registries. In 2006 California became the first state to impose mandatory GHG emission limits, requiring a 25% cut by 2020 affecting companies from automakers to manufacturers. The state is the 12th largest carbon emitter in the world despite leading the nation in energy efficiency standards.[101] In 2007, Arnold Schwarzenegger, the Republican Governor of California stated, "The debate is over. The science is in. The time to act is now. Global warming is a serious issue facing the world. We can protect our environment and leave California a better place without harming our economy."[102]

The Governor is right. A 2008 Study by the University of California found that California's programs to reduce energy dependence and increase energy productivity three decades ago directed a greater percentage of its consumption to in-state, employment-intensive goods and services whose supply chains largely reside within the state. This created a strong "multiplier" effect of job creation, generating 1.5 million FTE jobs with a total payroll of over $45 billion, saving California consumers over $56 billion in energy costs. Going forward, achieving 100% of the greenhouse gas emission reduction targets mandated by AB 32, the legislation that Schwartzenegger championed to reduce carbon emissions 80 percent by 2050, would increase the Gross State Product by $76 billion, increase real household incomes by $48 million, and create as many as 403,000 new efficiency and climate action jobs.[103]

Florida, one of the coastal states that could suffer from rising ocean levels as a result of global warming, has been hit hard by hurricanes, tornadoes, drought and wildfires. In his first State of the State address early in 2007, Republican Governor Charlie Crist, remarking on the extreme weather and skyrocketing insurance rates in his state, stated "I am persuaded that global climate change is one of the most important issues that we will face this century." He told the Legislature, "Yet, we have done little to understand and address the root causes of this problem, or frankly, even acknowledge that the problem exists. No longer."[104] Governor Crist commissioned a Republican task force to study what it would cost the state to implement measures to cut greenhouse gas emissions. Under the most optimistic projections of climate change, much of Florida floods. The Governor was surprised to find that implementing aggressive measures to reduce Florida's carbon footprint would add $28 billion to the state economy between now and 2025.

In November, 2007, Illinois, Iowa, Kansas, Michigan, Minnesota and Wisconsin, a region, which if it were its own country would be the globe's fifth-biggest producer of greenhouse gas emissions trailing only the U.S., Russia, China and India, signed a joint agreement setting greenhouse gas reduction goals and allowing companies to buy and sell pollution credits to meet the targets. A separate agreement commits all states in the region to promote the use of renewable energy. The governors agreed that wind power, water and other renewable sources will eventually provide up to 30 percent of the region's electricity. The region could "become the Saudi Arabia of renewable energy," stated Wisconsin Governor Jim Doyle. Iowa Governor Chet Culver called the move "a great opportunity for our country to come together and put partisan politics aside, and become an international leader on this issue." [105]

With this pact, nearly half of Americans will now live in areas covered by climate protection agreements mandating carbon emissions limits.

Counties

King County, Washington, the county surrounding Seattle has undertaken to reduce its carbon footprint 80 percent below its current levels by 2050. Calling global warming the defining issue of the 21st Century, King County Executive Ron Sims committed to make County communities resilient to expected loss in drinking water supply, more frequent floods and other impacts of climate change. Sims stated, "Communities that thrive in this new century will be the ones that take action now in response to the growing body of scientific evidence about global warming and its cause. The best way to protect the people, economy and environment of the region is to take specific actions to reduce greenhouse gases and invest the money needed to adapt to less snow in the mountains and more frequent more damaging floods."[106] Among many actions, the County implemented a broad scale citizens' education program, bought land throughout the County to serve as a "food-shed" in the event of global disruptions to food supply, encouraged public and private sector leaders to join the effort by setting their own climate stabilization goals, and joined Chicago Climate Exchange. Miami-Dade and Sacramento Counties have also joined CCX.

On Earth Day, 2005, Alameda County, California, commissioned a 2.3 megawatt solar powerplant, spread on roofs located throughout the County. The local utility paid for half of it, and the array will save the County $700,000 a year. Such use of distributed generation follows on the successful example of California's capital. In 1989, Sacramento, California shut down its 1,000-megawatt nuclear plant. Rather than invest in any conventional centralized fossil fuel plant, the local utility met its citizens' needs through energy efficiency and such renewable supply technologies as wind, solar, biofuels and distributed technologies like co-generation, fuel cells, etc. In 2000, an econometric study showed that the program had increased the regional economic health by over $180 million, compared to just running the existing nuclear plant. The utility was able to hold rates level for a decade, retaining 2,000 jobs in factories that would have been lost under the 80% increase in rates that just operating the power plant would have caused. The program generated 880 new jobs, and enabled the utility to pay off all of its debt.

Cities

Cities are home to half of the world's population and consume 75 percent of the world's energy.[107] Cities are even more aggressive in implementing climate mitigation programs. Although municipal budgets are strapped, over 730 cities have joined the call by Seattle Mayor Greg Nickels to commit their communities to aggressive climate protection campaigns.[108] For example, Kansas City in the Show Me State published a website stating, "Cities that have taken action to reduce global warming pollution are saving millions of taxpayer dollars while boosting real estate values, attracting new jobs and businesses, and improving community livability. Investments in mass transit; commitment to clean, renewable energy; improved public health from cleaner air; and new partnerships with the private sector all result in greater economic prosperity for citizens. They also make a city a cleaner, safer and more desirable place to live.[109]

The benefits Kansas City identified from its climate protection plan included:

- Reduced energy costs to households, recognized by a certified rating system, increases property values. Reduced energy costs also strengthen one of Kansas City's calling cards—low cost of living.
- Reduced energy cost to businesses would have similar effect and lower the hurdle for our ongoing Economic Development efforts to bring new business to Kansas City.
- Reduced economic dependence on oil, natural gas and coal and reduced vulnerability to market fluctuations.
- Economic benefits from the production and use of regional renewable fuels.
- Lower maintenance costs of alternative technologies such as efficient fluorescent lights, compared with conventional products.
- Increased worker productivity from improved indoor air quality, and efficient lighting.
- Less traffic congestion and the associated inefficiencies of time delays plus lower costs for infrastructure maintenance.
- Job creation through development and deployment of new technologies.
- Increased success in attracting business to Kansas City's overall low cost of operation and our clean environment.[110]

Some cities are implementing and succeeding at even more aggressive programs. Salt Lake City's Mayor Rocky Anderson stated in a letter to the Seattle Mayor:

> In Salt Lake City we have been working diligently since 2002 to meet the greenhouse gas emissions reduction goal set forth in the Kyoto Protocol. If every local and state government entity, every business, and every individual takes available, effective measures to significantly reduce greenhouse gas emissions, we can reverse the trend toward global warming. If we do not, the consequences will be devastating.

Salt Lake set a goal to reduce GHG emissions by 3% per year for the next 10 years, to reduce emissions in city operations by 21% below its 2001 baseline, by 2012. Its long-term goal is to reduce emissions 70% by 2040. By 2007 the city had achieved a 31-percent reduction in carbon dioxide emissions in its municipal operations over the 2001 baseline, surpassing its goal to meet the Kyoto Protocol standard by 148%, and seven years early. To achieve this, the City reduced its vehicle fleet, purchased alternative fueled vehicles, aggressively encouraged alternative modes of tranist, and offset the carbon emissions of City employees' air travel. Salt Lake required LEED silver for all new City buildings, purchased wind power, and implemented a comprehensive community education campaign. It increased recycling in the City by 85 percent, reduced water use by city residents 20 percent, replaced incandescent bulbs with compact fluorescent lamps, purchased open space, captured methane from land fills and the City's sewage operations, a year, and changed out all city traffic lights to LED's. These last three measures alone are saving the city $248,000 a year in energy costs.[111]

St. Paul, Minnesota saved $59 million in annual energy costs through measures such as energy retrofits in municipal buildings, recycling and waste reduction, and equipment and lighting upgrades. These actions reduced St. Paul's carbon emissions by 8% from 1988 levels by 2004. Toledo, Ohio saved $710,208 in the first year after retrofitting 20 city buildings with energy efficient lighting and replacing old HVAC units with new, digitally-controlled boilers and chillers. These efforts cut electricity use by nearly 6 million kWh and eliminated 5,250 tons of CO2.[112]

San Francisco Mayor Gavin Newsome introduced the City's Climate Action Plan saying that the city can reduce the pollution that causes global warming by using currently available technologies that also enhance economic development. It can promote energy efficiency, renewable energy, alternatives to automobile transportation, and recycling to help save money and create jobs that strengthen the local economy, and increase the livability of San Francisco's neighborhoods. To achieve this, the city has implemented renewable energy programs that promote power production from solar, wind, biomass, ocean wave, and bay tidal current sources. These will eliminate an estimated 550,000 tons of CO2. The city fleet has more than 700 clean-air vehicles; one of the largest municipal alternative fuel vehicle fleets in the nation, and by the end of 2007 will run all municipal trucks on biodiesel. Its mass transit fleet has 57 percent zero-emission vehicles and a goal of a completely zero-emission fleet by 2020. Installing LED, traffic signals across the city will reduce electricity use by an estimated 7.7 million kilowatt/hours and save the city $1.2 million per year. An expanded recycling program combined with methane capture at city-operated landfills to reduce emissions by about 300,000 tons of CO2. The programs have already saved the City money and energy. For example: six megawatts of electricity were saved by retrofitting lighting systems in over 4, 000 small businesses thanks to the Power Savers Program. The city's Peak Energy Program saved twelve megawatts by retrofitting residential and commercial buildings. Peak demand was reduced by 18 megawatts through successful programs operated by the SF Environment Department.[113]

In 1974, the Municipal Utility in Osage, Iowa, faced the need to build a new power plant to meet growing demand. Its general manager, Wes Birdsall, realized that building the plant would increase everyone's rates. He also understood that what his customers wanted was not more raw kilowatt-hours, but the energy "services" of comfort in their homes: shaft-power in factories, illumination, cold beer and the other services that energy delivers. People buy energy, but what they really want is the service that the energy makes possible. If people can get the same or improved service more cheaply using energy more efficiently or from a different source, they will jump at it. By meeting customers' desires for energy services at lower cost, Birdsall began one of the most remarkable economic development stories in rural America.

The Osage energy efficiency program saved over a million dollars a year in this town of 3,800 people and generated over 100 new jobs. A report on the program found that, "Industries are expanding and choosing to remain in Osage because they can make money through employees who are highly productive and through utility rates that are considerably lower than neighboring cities."[114] Birdsall was able to reduce electric bills to half that of the state average and unemployment to half that of the national average, because with the lower rates new factories came to town. That increased demand and necessitated more efficiency. But in this way Birdsall held electric growth level until 1984. The program was profiled in the Wall Street Journal, and replicated by other utilities. According to a USDA study of Osage, "The local business people calculated that every $1 spent on ordinary consumer goods in local stores generated $1.90 of economic activity in the town's economy. By comparison, petroleum products generated a multiplier of $1.51; utility services, $1.66; and energy efficiency, $2.23. Moreover, the town was able to attract desirable industries because of the reduced energy operating costs resulting from efficiency measures put in place. Energy efficiency has a long and successful track record in Osage as a key economic development strategy."[115]

A 2007 report by the Energy Trust of Oregon showed that per megawatt saved, economic output increases by over $2 million, wages increase by over $648,000, business income increases by over $125,000, and 22 jobs are created.[116]

Universities

The University of Colorado Student Union (UCSU) became the first student government in the nation to require that its student-run buildings become carbon neutral. In 2007, UCSU approved a $500,000 Energy and Climate Revolving Fund (ECRF) to pay for energy efficiency and other measures to reduce greenhouse gas emissions. The Fund adds to the existing $115,000-$125,000 Energy Efficiency Fund (EEF), which has already prevented the release of 125 tons of emissions, and reduced energy costs by over $30,000 per year.[117]

The University's Chancellor, G.P "Bud" Peterson, became one of the first 100 university presidents to sign the American College and University Presidents Climate Commitment. Now signed by over 300 University Presidents, it commits the University to integrate sustainability into its curriculum, support American energy independence, and develop a campus plan to achieve carbon neutrality.[118] CU responded by developing a Blueprint for a Green Campus, laying out the University's plan to achieve "zero climate impact" by 2025[119]

Middlebury College in Vermont adopted a goal of carbon neutrality by 2016. The Dean of Environmental Affairs, Nan Jenks-Jay, states, "Students were telling us, 'You're not doing enough'." Following the lead of CU, undergrads at dozens of schools are voting increases in activities fees to finance green initiatives. At St. Mary's College of Maryland, for example, 93 percent of students voted last spring for a $25 annual increase in fees, which will raise approximately $45,000 a year for the purchase of renewable energy.

Colleges are realizing that a commitment to climate protection enhances their recruiting efforts. "What message does a conventional campus send?" asks David Orr, Director of the Environmental Studies Program at Oberlin. "It sends the message that energy is cheap and plentiful." Orr sent a very different message by involving his students in the creation of the Adam Lewis Center for Environmental Studies. Powered entirely by photovoltaics, which deliver 30 percent more energy than the building consumes, the building treats its own wastewater in an Eco Machine, an artificial wetland that looks like a greenhouse, but costs less and works better. "You'd have no clue it's a wastewater system," says Orr. He credits the building with having helped to inspire hundreds of Oberlin students to choose professions in ecodesign, architecture and related fields. One such student, Sadhu Johnston, is now Director of Environment for the City of Chicago.[120]

Communities of Faith

Hundreds of churches, synagogues, mosques and other houses of worship are reducing their energy bills and their carbon footprints as a sacred duty. Spearheaded by the Regeneration Project, such communities see their task as deepening the connection between ecology and faith. The Project's Interfaith Power and Light campaign, representing over 1,000 congregation members in eighteen states, encourages a religious response to global warming in congregations through promotion of renewable energy, energy efficiency, and conservation. IP&L showed An Inconvenient Truth to over half a million people of faith in 4,000 congregations in all 50 states.

The Michigan chapter of IPL helped St. Elizabeth's Catholic Church conduct an energy audit and implement the suggested changes. The Church invested $150,000 in a new boiler, energy efficient lighting and appliances, window insulation, and a solar thermal hot water heater. Their annual savings are $20,000 a year, a 50% reduction in their annual energy budget.

Connecticut IPL organized green building projects or conservation upgrades for 22 organizations, including a kosher food store, 20 congregations and the association of non-profit building managers in the state. Their Lighten-Up CFL light bulb sale with 30 congregations sold approximately 3,400 bulbs. Currently, Connecticut IPL has 25 churches and synagogues, which have purchased clean energy, including nine that have conducted programs to encourage their congregants to become residential customers for clean energy. Two of the congregations have one or more congregants who have installed photovoltaics on their roofs. A third congregation is looking into this for their community's building.[121]

The Reverend Sally Bingham, Executive Director of the Regeneration Project states, "Global warming is one of the biggest threats facing humanity today. The very existence of life—life that religious people are called to protect—is jeopardized by our continued dependency on fossil fuels for energy. Every mainstream religion has a mandate to care for creation. We were given natural resources to sustain us, but we were also given the responsibility to act as good stewards and preserve life for future generations."[122]

Major changes in the economy—and even the introduction of significant new products—displace old technologies and the workers, businesses and communities that depend upon them. Personal computers replaced typewriters; vinyl records were replaced by tapes, which have been replaced by DVDs; horses were replaced by cars; wood was replaced with fossil fuels. Some households, business and communities will be less able to cope with the shift to a new energy economy—and some will be less able to cope with the effects of climate change. National policy must help.

"In developing climate policies, the incoming President has to be conscious of the need and clearly explain that the policies must be equitable," says Theodore Roosevelt IV, chairman of the Global Council on Climate Change at Lehman Brothers. "They should not impose an undue burden on the poor to the advantage of the affluent. The American public needs to be convinced that climate policies are fair."

ADVANTAGES OF ENERGY EFFICIENCY

Competent analyses hav shown consistently that efficiency costs far less than new supply. This conclusion was recently reaffirmed by a recent report by researchers from the U.S. Department of Energy, Oak Ridge National Laboratory, and Lawrence Berkeley National Laboratory. The study analyzed results from four recent engineering-economic studies of the potential for energy technologies to reduce greenhouse gas emissions, including a sector-by-sector assessment of specific technology opportunities and their costs, as estimated by the Five National Laboratories, the Tellus Institute, The National Academy of Sciences, and The Office of Technology Assessment.

It found that large carbon reductions are possible at marginal costs that are lower than the value of the energy saved. The report concluded that energy efficiency remains underused in every sector of the economy and is by far the cheapest option. New renewable supply, it found, has a net cost, but when combined with efficiency, can deliver climate protection at a profit. "In combination," the study concluded, "Large carbon reductions are possible at incremental costs that are less than the value of the energy saved." It called for an aggressive national commitment stating, "some combination of targeted tax incentives, emissions trading, and non-price policies is needed to exploit these carbon reduction opportunities."[123]

Good efficiency programs, such as retrofitting light bulbs, cost about 1 - 2¢ per kilowatt hour (kWh) saved, much less than the 4-6 ¢ it costs to generate a kWh in a coal plant. Building wind turbines, in good sites can cost as low as 3¢, competitive with just the running cost of coal. Running an existing gas plant typically costs 5-6¢. The average price of electricity from the grid is at least 9¢ per kWh, and building a new nuclear plant can cost as much as 20¢. These numbers do not count the cost from coal or gas plants of emitting carbon, mercury, other air pollutants and threatening the climate.

Obviously, it is in everyone's interests to pursue efficiency first, but few utility programs achieve this outcome. Until recently, utilities have tended to pursue only as much efficiency as regulators require them to. Various states have experimented with regulations to encourage utilities to meet customers' needs in the cheapest way. Programs like Integrated Resource Planning, which require utilities to compare the cost of building new capacity with the cost of meeting customers' needs through energy efficiency, sought to level the playing field, but because utilities are fundamentally rewarded based on how much power they sell, they have continued to seek to build new power plants.[124]

Only a few jurisdictions decoupled sales of electricity from utility profits, so utilities are no longer rewarded for selling more electricity nor penalized for selling less. Even better are states like Idaho that actively reward utilities for cutting their customers' bills through efficiency, by giving the utilities a share of the savings for their shareholders. When California implemented this plan (called the Batinovich plan, after the Public Utility Commissioner Robert Batinovich who first developed it) Pacific Gas and Electric, the country's biggest private utility, spent $150 million in 1991 to help make its customers more efficient. It kept 15 percent of the resulting savings, boosting its 1990 profits by $40-50 million. Doing this saved its customers nine times that much. The PUC found that between 1990—93 such efficiency measures saved customers a net present value of almost $2 billion.[125]

In the early 1990's there were a variety of experiments underway to help the market deliver utility customers better value. Eight states implemented programs to allow vendors to compete in an open auction for all ways to make or save electricity. Such auctions would typically ask who could make or save electricity at 1¢ per kilowatt-hour. The utilities would then sign contracts for the bids received. If they needed more capacity, they would then reopen bidding for efficiency or supply at 2¢ per kWh, then 3¢. At around 2-3¢ utilities would meet all of their required capacity, dramatically cheaper than building a new fossil fired plant.

Investor-owned utilities, when rewarded for cutting bills, sold efficiency ever faster and more skillfully despite falling electricity prices. In 1990, New England Electric System captured 90% of a small-commercial pilot retrofit market in two months. Pacific Gas and Electric Company captured 25% of its entire new-commercial-construction market—150% of the year's target—in three months, so it raised its 1991 target…and captured all of it in the first nine days of January.

Making an informed, effective, and efficient market in energy-saving devices and practices can fully substitute for a bare price signal, and indeed can influence energy-saving choices even more than can price alone. That is, people can save energy faster if they have extensive ability.

During 1990–96, utility programs that gave customers information and enabled electric users in Seattle—which then had the cheapest electricity of any major U.S. city—to save electric load nearly 12 times as fast as citizens in Chicago, and electric energy more than 3,600 times as fast, even though Seattle electricity prices are about half of Chicago's. Seattle City Light achieved measured savings of 313 gigawatt-hours per year or 38 average megawatts—3.2 percent of 1996 energy sales and average load. Seattle's 1990–96 investments in demand-side management emphasized reducing energy use rather than peak-load.[126] By 1996, the nearly ten-fold larger Chicago utility Commonwealth Edison saved 51 peak megawatts (0.27 percent of its 19-gigawatt peak load), or an 11.8-fold smaller fraction of load. ComEd had made essentially no effort to save electrical *energy*, and only achieved savings of 800 megawatt-hours per year, or 0.00088 percent of its sales[127]—a 3,640-fold smaller fraction than in Seattle. Big customers in Seattle in 1996 paid 1.9 times less and small customers paid 2.3–2.4 times less per kilowatt-hour than in Chicago.

What this shows is that while economists would agree that in a free market energy prices should accurately signal to customers the full cost of using the resource, merely raising customers' rates will not necessarily achieve the reductions in energy use that economic theory might suggest. Similarly, giving people information, incentives and opportunity to act can elicit significantly greater reductions of energy use and carbon emissions than purely price-based theory might suggest.

COMBINING ENERGY EFFICIENCY AND RENEWABLE ENERGY

The most effective way to reduce greenhouse gas emissions is energy efficiency. But combining efficiency programs with renewable energy enables communities and companies to achieve truly large reductions. This combination is also key to unleashing the new energy economy of clean manufacturing and good jobs.[128]

Over 43,000 firms in the U.S. today are manufacturing and assembling renewable energy technologies. If the U.S. used renewable energy to stop global warming, such firms would create over 850,000 new, high-tech manufacturing jobs. Because of California's early commitment to climate protection and to develop clean energy technologies, the State will receive nearly 95,600 new jobs and $20.9 billion of investment to manufacture components to supply the growing national development of renewables.[129]

Toyota's Torrance, California, office complex, completed in 2003, combines energy-efficiency strategies such as roof color, photovoltaic solar electricity, an advanced building automation system, a utilities metering system, natural-gas-fired absorption chillers for the HVAC system, an Energy Star cool roof system and thermally insulated, double-paned glazing. The 600,000+ square foot campus exceeds California's stringent energy-efficiency requirements by 24 percent, but cost the same to build as a conventional office building.[130]

A recent article by utility regulator S. David Freeman, once Chair of the Tennessee Valley Authority, and Jim Harding of the Washington State Energy Office announced that the company Nanosolar is building a $100 million manufacturing facility in the San Francisco Bay area to produce solar cells very cheaply. That, they say,

> … would bring the cost to or below that of delivered electricity in a large fraction of the world." Backed by a powerful team of private investors, including Google's two founders and the insurance giant Swiss Re, Nanosolar announced plans to produce 215 megawatts of solar energy next year, and soon thereafter capable of producing 430 megawatts of cells annually.
>
> What makes this particular news stand out? Cost, scale and financial strength….
>
> Nanosolar is scaling up rapidly from pilot production to 430 megawatts, using a technology it equates to printing newspapers. …No one builds that sort of industrial production facility in the Bay Area—with expensive labor, real estate and electricity costs—without confidence.
>
> Thin solar films can be used in building materials, including roofing materials and glass, and built into mortgages, reducing their cost even further. Inexpensive solar electric cells are, fundamentally, a "disruptive technology," even in Seattle, with below-average electric rates and many cloudy days. Much like cellular phones have changed the way people communicate, cheap solar cells change the way we produce and distribute electric energy. The race is on.
>
> The announcements are good news for consumers worried about high energy prices and dependence on the Middle East, utility executives worried about the long-term viability of their next investment in central station power plants, transmission, or distribution, and for all of us who worry about climate change….
>
> Meanwhile, the prospect of this technology creates a conundrum for the electric utility industry and Wall Street. Can—or should—any utility, or investor, count on the long-term viability of a coal, nuclear or gas investment? The answer is no.[131]

Renewable options are now the fastest growing form of energy supply around the world, and in many cases are cheaper than conventional supply. Solar thermal is outpacing all conventional energy supply technology around the world. Modern wind machines come second, delivering over 15 gigawatts (GW) of new capacity a year, or three times what nuclear power did at the peak of its popularity. In 2007, the U.S. will add 4,000 GW of new wind to its grid, more cheaply than just the running cost of existing coal or nuclear plants.[132] The next fastest growing energy supply technology is solar electric, even at current prices.[133]

The Governor of Pennsylvania recently announced the opening of a factory to make wind machines. Creating 1,000 new jobs over the next five years, it is the biggest economic development measure for Johnstown, PA, in recent memory. California announced that it would spend over $8 million installing solar in 2006. The State created a $1.5 billion investment fund to help environmentally responsible companies that are developing cutting-edge clean energy technologies.

An analysis sponsored by the American Council on Renewable Energy found that in addition to eliminating the need for new coal or nuclear power plants over the next 20 years, renewable energy technologies could create $700 billion of economic activity and 5 million high-quality jobs by 2025.[134] The Apollo Project, a coalition of environmental, business and labor organizations, contends that an investment of $300 billion in Federal funding for low-carbon energy, infrastructure and urban development practices would add more than 3.3 million jobs to the economy, stimulate $1.4 trillion in new GDP, save $284 billion in net energy costs, and repay taxpayers in 10 years.[135]

REGAINING THE LEAD IN THE INTERNATIONAL MARKETPLACE 2

The United States was once the international leader in the technologies that will meet the world's need for energy and products in ways that don't cause catastrophic climate change. Almost all of the solar electric and wind power technologies were invented in the U.S. But in the 1980's perverse Federal policies prohibiting investment in commercialization of renewables let the progress of these technologies lapse in the U.S. Europeans and Asians picked up the opportunity and now lead in manufacturing.

The European Commission has projected that meeting its targeted energy cuts and renewable energy increases would save 60 billion Euros, create millions of new jobs, increase European competitiveness, and reduce Europe's carbon emissions by a third.[136] American businesses are already losing ground as their European competitors innovate to meet these goals. These renewables are the cheapest way to provide power to those around the world who don't have it, because these technologies don't require fuel, or investments in large central generating plants, transmission lines and other conventional electric infrastructure.

As gasoline prices have become volatile and public consciousness about greenhouse gas emissions has grown, it is the Japanese rather than U.S. automakers that were first to market with hybrid vehicle technology—just as in the 1970s the Japanese beat Detroit to the punch with compact cars that better served consumers seeking relief from high gas prices. Today, Australia, Japan, the European Union, Canada and China all have auto-efficiency standards higher than those in the U.S.

A confluence of rapidly developing factors is creating a worldwide opportunity for products, technologies, designs and practices that reduce greenhouse gas emissions. They include:

- Developments in various American states and internationally to place a price on carbon—whether through taxes or market mechanisms. Since the Kyoto Protocol came into force in February 2005, 141 nations have committed to limiting the amount of carbon that they emit. In November 2007 the Australian government fell, with the new government pledging to sign Kyoto, leaving the U.S. as the world's only major government to so-far refuse to ratify the treaty. As carbon is reflected in the price of energy and consumer products, low-carbon alternatives will become more competitive in the marketplace. Meanwhile, the growing international carbon market enables companies that make deeper reductions than required to sell their unused emissions capacity to companies unable to meet the limits. It is creating a de facto carbon currency. There are two ways to obtain a commodity/ currency: buy the credits or create them. Just as one can buy gold or mine it, one can create a carbon currency by reducing emissions. In such a market, companies will be invested in the new carbon currency, at best to forge wider margins on the rising costs of carbon fuels and at least to hedge their own exposure to the risks posed by the enactment of future legislation. Portfolio's (corporate, institutional and personal) of the future with carbon currency exposure can then be better positioned to mitigate the volatility of the new economy.
- The exploding demand for consumer products and energy technologies in rapidly developing nations such as China and India. Lester Brown of Earth Policy Institute points out that if China continues to grow at its current rate, and uses resources as efficiently as the U.S. (it is now four-fold less efficient) by 2030 it will want more oil than the world now lifts and likely can ever lift. It will also want more cotton, cars, concrete, and coal than the world now produces. And India is right behind. Both countries will be hard hit by climate change, with the melting of the Himalayan glaciers threatening water supplies throughout the region, the shifting of the monsoon patterns threatening agriculture, and the increased number and ferocity of cyclones already killing thousands of people each year. In 2007, China has passed the U.S, as the world's biggest emitter of carbon. In response, China has pledged to reduce energy intensity by 4 percent a year through the rest of the decade, and has set a target to reduce energy consumption per unit GDP by 20 percent during the 2006-2010 period.[137] In 2007, the Chinese announced the creation of over a billion dollars of funds to encourage energy efficiency and renewables[138]. The country is promoting biogas use, and investing in wind solar and other low carbon energy supplies. The world's first green billionaire now exists. He is a Chinese solar entrepreneur.
- The as-yet-unfulfilled aspirations of the billions of people in under-developed nations who need and deserve decent standards of living. An estimated 1.6 billion of the world's people lack convenient access to electricity. About the same

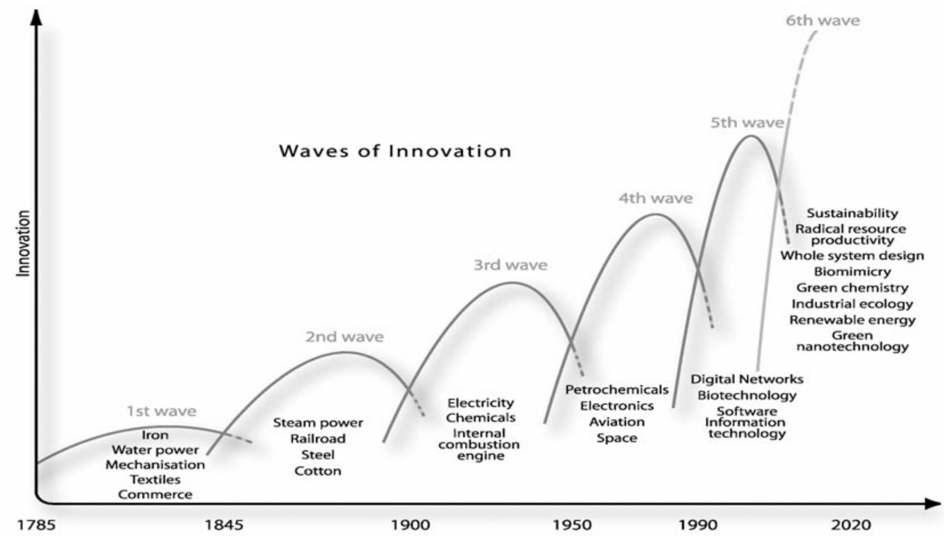

Figure 6. Waves of Innovation

Source: Technological "long waves" were long-ago described by Russian economist Nikolai Kondratiev. The version of long waves represented in this figure appeared first in *The Economist*. The image is courtesy of The Natural Edge Project, Australia, http://www.naturaledgeproject.net/, 30 October 2006.

number lack potable water. As the economies of these nations expand, pressures on the climate will become unmanageable without low-carbon technologies. At present, one-quarter of all development capital around the world is spent on carbon intensive power plants, whose electricity is unaffordable to the poorest, but whose economies are then taxed to pay for them. The only way that the half of the world's people who now live on less than $2 a day can afford to develop is to leapfrog to world best practice in sustainable ways to meet their needs for energy services, water, sanitation, transportation, housing, etc. These technologies can deliver genuine development more reliably and affordably than can the carbon intensive practices of the last century. One of the best ways to ensure that the world ramps its emissions down below the danger level at which we are now is to enable the whole world to unleash this new energy economy of efficiency and renewables.[139]

- The growing world population. If present trends continue, the world population will grow from more than 6 billion today to more than 9 billion before mid-century.

Business success in a time of technological transformation demands innovation. Since the Industrial Revolution, there have been at least six waves of innovation, each shifting the technologies underpinning economic prosperity. In the late 1700s textiles, iron mongering, water-power, and mechanization enabled modern commerce to develop.

The second wave saw the introduction of steam power, trains and steel. In both of these waves, Britain led the innovation, and rose to world prominence because of it, ruling the waves, and the global economy.

In the 1900s, oil, electricity, chemicals and cars began to dominate, enabling the production of cars and appliances. America led in this innovation, and by the middle of the century, was the dominant world power, continuing to innovate with petrochemicals, and the space race, along with electronics. The most recent wave of innovation saw the introduction of computers, and the rise of the digital or information age.

Which country will lead the next wave—the transition, described in this paper, to renewable, low carbon energy. As the industrial revolution plays out and economies move beyond i-Pods, industries and countries will suffer dislocations unless they drive innovation, implementing the array of sustainable technologies that will make up the next wave of innovation.[140] New York Times editorialist, Tom Friedman, warns that America is losing the race to lead this innovation. In he last two years, he points out, Applied Materials, a U.S. based company, has built 14 solar panel manufacturing facilities around the world, now earning Applied $1.3 billion a year. None are in America. Friedman writes,

> The reason that all these other countries are building solar-panel industries today is because most of their governments have put in place the three prerequisites for growing a renewable energy industry: 1) any business or homeowner can generate solar energy; 2) if they decide to do so, the power utility has to connect them to the grid; and 3) the utility has to buy the power for a predictable period at a price that is a no-brainer good deal for the family or business putting the solar panels on their rooftop.
>
> Regulatory, price and connectivity certainty, that is what Germany put in place, and that explains why Germany now generates almost half the solar power in the world today and, as a byproduct, is making itself the world-center for solar research, engineering, manufacturing and installation. With more than 50,000 new jobs, the renewable energy industry in Germany is now second only to its auto industry. One thing that has never existed in America — with our fragmented, stop- start solar subsidies — is certainty of price, connectivity and regulation on a national basis.
>
> That is why, although consumer demand for solar power has incrementally increased here, it has not been enough for anyone to have Applied Materials — the world's biggest solar equipment manufacturer — build them a new factory in America yet. So, right now, our federal and state subsidies for installing solar systems are largely paying for the cost of importing solar panels made in China, by Chinese workers, using hi-tech manufacturing equipment invented in America.
>
> Have a nice day.[141]

CONCLUSION: SEIZING THE ENTREPRENEURIAL IMPERATIVE

Crafting a policy to enable America to prosper while meeting its needs for energy services with ample and affordable supplies is a challenging task. But it also offers unparalleled opportunities. Americans will balk at rules, taxes, mandates and bureaucracy. But they will rise to an entrepreneurial opportunity. "A well-designed climate policy framework will create huge opportunities for innovative companies to flourish as new markets are created and demand shifts to more efficient, more advanced and higher-value-added products and services," according to a report from World Resources Institute.[142] British economist Sir Nicholas Stern, in his 2006 study commissioned by the UK government on the economics of climate action, estimates that by mid-century, the global market for low-carbon technologies could deliver up to $2.5 trillion a year in economic benefits. The Stern report puts the 2010 value of the global environmental market at $700 billion.[143]

There has never been a greater opportunity for America's entrepreneurs to do well by doing good, and for communities to enhance energy security, improve quality of life, and enable their citizens to join the transition of the renewable energy future. This is the sort of challenge that Americans are good at. All they need is a supportive Federal policy environment.

The growing frequency of corporate commitments—even on the part of former climate-change skeptics —is an explicit message that companies and communities that are not quickly and boldly following suit will fall behind the curve as others demonstrate visionary leadership, responsible action, and the ability to capture public goodwill and patronage. This is one arena in which the business and advocacy communities are working together. [144]

Climate change presents an opportunity for the nation's businesses and communities to reinvent themselves for the 21st Century, reinvigorating America's economy and workforce, creating millions of new jobs on U.S. soil, and reasserting American leadership in knowledge, ingenuity and technological innovation. As researchers at the University of California-Berkeley concluded, "All states of the Union stand to gain in terms of net employment from the implementation of a portfolio of clean energy policies at the federal level."[145]

The challenge for policy is to design a comprehensive approach to climate planning that ensures that America will capture all of the opportunities to make our building and car and appliances and machines as efficient as possible, transform our sunset industries from using dirty technologies from the last century and capture the opportunities to lead the innovation into renewable energy in ways that will make us more competitive, puts 100's of billions of dollars back into the economy from savings, and put Americans back to work. America can choose to invest in the approaches that generate economic development in cities and states, generate new manufacturing businesses, and create jobs retrofitting existing buildings. We can seize the opportunities to build and manage the new decentralized energy system, revitalize farm income from production of biofuels, and wind farms. Or we can allow our Asian and European competitors to become the new industrial leaders.

Traditional economists who use straight line projections to claim that acting to protect the climate will be costly should be challenged to show why unleashing the new energy economy will not, as President Clinton asserts, deliver the greatest economic boom since World War II.

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Taking Covered Wagons East

A New Innovation Theory for Energy and Other Established Technology Sectors

Frederick Jackson Turner, historian of the American frontier, argued that the always-beckoning frontier was the crucible shaping America society.[1] He retold an old story, arguing that it defined our cultural landscape: when American settlers faced frustration and felt opportunities were limited, they could climb into covered wagons, push on over the next mountain chain, and open a new frontier. Even after the frontier officially closed in 1890, the nation retained more physical and social mobility than other societies. While historians debate the importance of Turner's thesis, they still respect it.

The American bent for technological advance shows a similar pattern. Typically, we find new technologies and turn them into innovations that open up new unoccupied territories—we take covered wagon technologies into new technology frontiers. Information technology is an example. Before computing arrived, there was nothing comparable: there were no mainframes, desktops, or internet before we embarked on this innovation wave. IT landed in a relatively open technological frontier.

This has been an important capability for the U.S. Growth economics has made it clear that technological and related innovation is the predominant driver of growth.[2] The ability to land in new technological open fields has enabled the U.S. economy to dominate every major Kondratiev wave of worldwide innovation

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In this article the authors draw on the more extensive discussions of these ideas in their new book Structuring an Energy Technology Revolution (Cambridge, MA: MIT Press, April 2009).

since the mid-19th century.[3] Information technology and biotech are the newest chapters in this continuing story.

REVERSING THE COVERED WAGONS
LANDING IN OCCUPIED TERRITORY

While we appear to have a capacity for standing up technologies in open fields to form new complex technology sectors, we have not been as good at taking our covered wagons back east. We find it hard to go back over the mountains to bring innovation into the already occupied territory of established complex technology sectors. In typical American fashion, we'd rather move on than move back. This helps to explain why a cab ride over the highway system from New York's Kennedy Airport into Manhattan has a distinctly Third World feel, or why Thomas Edison would be very comfortable with our current electrical grid.

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Of course, the story is more complicated than Turner's frontier thesis about American culture. It's hard to reverse the covered wagons and go back to occupied territory. Over time, established technology sectors develop characteristics that resist change. The underlying technologies themselves become cost efficient through standardization and the phenomenon of "lock-in" sets in. Firms go through Darwinian evolution; the leading technology competitors survive, expand and become adept at fending off new entrants. They build massive infrastructure that is resistant to competitive models, and they form alliances with government to obtain subsidies, typically through the tax system, to tilt the playing field toward their model.

In other words, established complex sectors, often themselves the result of earlier waves of innovation, combine into a technological/economic/political paradigm that is very difficult to unseat;[4] they plant a series of sophisticated minefields to protect their model and resist its disruption. This pattern applies to highly complex sectors of the economy where technologies are a factor; examples are energy, health care delivery, transport, construction and physical infrastructure, education, and food and agriculture. A complex, established technology sector can be defined as one that involves products and platforms, that groups complex technologies in the way a car holds an internal combustion engine, drive train, battery, computers, fueling systems and tires. Complex sectors also have their own infrastructure, and are supported by established technologies, economic models, public policies, public expectations, patterns of technical expertise and trained workforces. In combination, these sectors become the technological/economic/political paradigm.

The concept of the complex sector is broader than that of complex technology introduced by Donald Kash and Robert Rycroft,[5] and is closer to Christopher Freeman's idea of technology clusters that dominate innovation waves.[6] The idea of such a sector has features in common with the idea of "dominant design," introduced by James Utterbach and William Abernathy[7] based on Raymond Vernon's product cycle theory:[8] once such a paradigm has set in, the emphasis shifts away from innovation in the overall system towards component innovation in technologies that can be launched on existing platforms.

To be sure, the U.S. is not the only nation to experience the economic and political barriers of complex established sectors. Japan's economy would be stronger if it could bring IT-driven retail efficiencies to a nation of small shops or to pursue large-scale agriculture, not simply small family farms. The frontier thesis aside, innovation in established complex sectors becomes even more complex once technological lock-in has set in.

LESSON FROM CHINA

The remarkable, sustained, double-digit growth of the Chinese economy is in due in part to the application of up-to-date technology to established sectors like transport, health care, construction and energy. Chinese strategy for catching up to the developed economies is based on a unique model that calls for moving to and even extending the technological frontier in these and other sectors, even as it applies well-known technology to huge projects that will modernize its infrastructure. It has organized its economy with large doses of capital, labor, innovation and stern political directives, relying on a rapidly expanding private sector using up-to-date technology to provide the resources to support an inefficient public sector that it will eventually supplant. China's model of pervasive technology advance throughout its economy, of course, has a precedent. in the economy-wide catch-up approach in postwar Japan and in Korea in the 70's and 80's.

There is a lesson here for the U.S. If innovation is key to growth, and if a nation is bringing innovation into many sectors—both established sectors and those at the technological frontier—then it may be able to boost its growth rate significantly. US growth might look different if we could find ways to cut the Gordian knots that tie up our ability to innovate in established complex technology sectors and bring innovation into those occupied territories, not just into the cutting economic edge of advances in new breakthrough technologies.

This might mean bringing innovation into our inefficient and expensive healthcare delivery system along with new biotech-derived drugs. It could mean bringing IT simulations and game-based learning into K-12 education, or new materials and information technology into our transportation or construction infrastructure, or e-government into the widespread delivery of government services. The list of possibilities is long. Perhaps we could even take our innovation covered wagon back east and bring innovation into our complex, deeply entrenched, heavily subsidized energy sector.

UNIFYING THE THREE MODELS OF INNOVATION

In order to contemplate stretching our scientific and technological capabilities to established sectors of the economy like energy, we need a working theory of innovation for these sectors. Its design depends on a clear concept of how technological innovation takes place in the sectors in response to market forces, and how this process can be influenced by public policy. We see three models of this process, each of them the product of a particular period of technological history.

The first of these models is the so-called pipeline or linear model, associated with Vannevar Bush,[9] in which basic research intended to push back the frontiers of knowledge leads to applied research, which in turn leads to invention, to prototyping, to development, and finally to innovation, by which we mean widespread commercialization or deployment. While subsequent literature showed that this process wasn't really linear—technology influenced science as well as the other way around[10]—"pipeline" is still the term generally associated with this technology supply approach.

This model was inspired by the World War II–era success of atomic energy, radar, and other technologies derived from advances in fundamental scientific knowledge;[11] it regained prominence in the 1990s from the example of the information revolution[12] and from the promise of similar revolutions in bio- and nanotechnology. In these examples, the government, and often the military establishment, played a prominent role in shepherding these technologies through the innovation process. This is a "technology push" model, with the government supporting R&D and to an extent helping push the resulting advances toward the marketplace.

The second of these models is the so-called induced innovation concept explored in detail by the late Vernon Ruttan,[13] in which technology and technological innovation respond to the economic environment. This concept holds that the technology in use in any economic sector—and, given enough time, the direction of development and research—responds to changes in the market, for example to price signals by minimizing the use of expensive inputs and maximizing the use of inexpensive ones.

By extension, this model would predict that technology and technological innovation would also respond to the policy environment, for example by improving worker and product safety and decreasing pollution as policies in these areas are tightened. The induced innovation model was one of several models that responded to the realization that nations that were superior in basic research, such as the Great Britain of the 1950s and 1960s, were not necessarily leading innovators, and that a majority of new products used existing technologies to meet new market needs—incremental advances - rather than emerging from basic research. This model involves "technology pull": the market inspires and pulls technology innovations from firms toward implementation in the market.

The third concept can be only sporadically glimpsed in the innovation literature.[14] However, we argue that innovation requires not only technology supply and a corresponding market demand for that technology, but also organizational elements that are properly aligned to link the two. There must be concrete institutions for innovation, and organizational mechanisms connecting these institutions, to facilitate the evolution of new technologies in response to the forces of technology push and market pull. We need this third element in our innovation model framework: the idea that innovation requires organizations anchored in both the public and private sectors, to form the new technology and to launch it, if innovation theory is to be practical, creating ideas we can actually implement.

These three theories fit into a historical context. The induced technology model was partly a product of the historical perspective of the 1960s through the 1980s, with advances derived largely from incremental gains in existing technology. Throughout that era, of course, the kind of innovation described by the pipeline model was humming along, bringing out an IT revolution in the 1990's after decades of government R&D inputs. While the induced model best fits incremental innovation, the pipeline model best fits breakthrough or radical innovation. Underlying both of these developments were organizational issues, vital for our innovation system, yet largely unexplored.

The induced and pipeline models have been viewed as separate and distinct paths, one led by industry, the other largely by government. We must combine and integrate these induced and pipeline innovation models if we are to adequately describe the innovation framework we will require for innovation in energy or other complex technology. The induced technology literature has rested primarily on market pull and the role of firms in filling technology needs based on changing market signals. It does not deal directly with the role of government. The pipeline literature, in contrast, discusses the government role. A focus on the organization for innovation offers us the opportunity to bring these separate strands together. Although the literature is limited, the organization of innovation at the institutional level reflects on connections between firms, the academy, and government entities like the Defense Advanced Research Projects Agency (DARPA).

Firms, universities and government organizations will be major players in new energy technology. What is more, the dominant literature on technological innovation in recent years has remained focused on the strengths and weaknesses of the pipeline model, because of the importance of the IT and the biotech innovation waves for which this model provides a good description. This pipeline literature pays too little attention to how the overall economic and policy environment affects technological innovation in complex networks of both related and unrelated technologies, and the induced model often pays too little attention to the governmental role.[15] To date neither has focused much on the third direction, innovation organization.

In sum, the literature on innovation policy, whether pipeline, induced or organizational, has not fully confronted the problems involved in complex technology sectors. These sectors require a very different analysis from the three separated strands that have been the focus of the American literature on technological innovation. Each of these models does helpfully describe aspects of the innovation process relevant to energy technology. But only by integrating all three in a unified approach can we move toward a better grasp of the task before us: innovation in a complex established sector. Indeed, in taking on this task we will be able to draw a new series of policy prescriptions quite different from the approaches that have been articulated to date in other sectors.

INNOVATION IN ENERGY: THE FOUR-STEP ANALYTIC FRAMEWORK

The most difficult step in developing and deploying new technology in energy and other complex, established sectors will be launching these technologies into extremely complex and competitive markets for technology. This "point of market launch" perspective is the basis for our argument that any program of government support for innovations in these technologies should be organized around the most likely bottleneck to their introduction to the market.[16] This goes beyond the long-standing focus of pipeline theorists on the valley-of-death stage between research and late-stage development.[17]

We start with the principle that public policies to encourage technological innovation should enable alternative technologies to compete on their merits; that is, they should be as technology-neutral as possible. This leads us to argue for an integrated consideration of the entire innovation process, including research, development, and deployment or implementation, in the design of any program to stimulate innovation in energy or any other complex, established technology. This requires drawing on both pipeline and induced innovation models. In addition, we see deep systems issues of organization for innovation that must be considered, because new organizational routines will be needed across both the public and private sectors to facilitate integrated policies to support innovation.

These considerations lead to a new framework for innovation policy, which we have worked out in some detail for energy technology. It requires a four-step analysis, which we propose as the basis for innovation policy in this area. We believe that a similar approach is likely to be applicable to technological innovation in sectors of comparable complexity.

The *first step* of this analysis requires assessing many promising technologies, based on the likely bottlenecks in their launch path, and classifying them into groups that share the same likely bottlenecks. For the energy sector, we found the following technology pathways.

Experimental Technologies. This category includes experimental technologies that require extensive long-range research. The deployment of these technologies is sufficiently far off that the details of their launch pathways can be left to the future. Examples include hydrogen fuel cells for transport, genetically engineered bio-systems for CO_2 consumption, and, in the very long term, fusion power.

Disruptive Technologies. These are potentially disruptive technological innovations[18] that can be launched in niche markets and that may expand from this base as they become more price-competitive. Examples include LEDs and wind and solar electric, which are building niches in off-grid power.

Secondary Technologies—Uncontested Launch. This group includes secondary (component) innovations that will face market competition the moment they are launched, but will likely be acceptable to recipient industries if their price range is acceptable. These technologies must face the rigors of the tilted playing field, such as a competing subsidy, or the obstacle of a major cost differential, without the advantage of an initial niche market. Examples include advanced batteries for plug-in hybrids, and enhanced geothermal and on-grid wind and solar technologies.

Secondary Technologies—Contested Launch. These are secondary (component) innovations that have inherent cost disadvantages, and/or that can be expected to face economic, political or other non-market opposition from recipient industries or environmental groups. They must overcome these obstacles in addition to those facing the technologies in the two preceding categories. Examples include carbon capture and sequestration, biofuels, and fourth-generation nuclear power.

All four of above categories segment evolving technologies into different launch pathways, so that relevant policies for each can be designed to support their launch. A significant majority of energy technologies now contemplated are component or secondary technologies, that fall into the third and fourth categories, above. This complicates the technology launch picture because component technologies will not land in open frontiers, but will land in existing systems or platforms—in occupied territory. While the potential for disruptive technologies that can open new energy frontiers will increase, that opportunity will take time to evolve.

There are two other categories that must be accounted for. These are crossovers because they include the above new technology categories as well as existing energy-related technologies:

Incremental Innovations in Conservation and End-Use Efficiency. For the energy sector, a focus on conservation and end-use efficiency can yield early and widespread gains. The implementation of these innovations is limited by the short time horizons of potential buyers and users, who typically refuse to accept extra initial costs unless the payback period is very short. Examples include improved internal combustion engines, building technologies, efficient appliances, improved lighting, and new technologies for electric power distribution.

Improvements in Manufacturing Technologies and Processes. These are improvements for which investment may be inhibited because cautious investors are reluctant to accept the risk of increasing production capacity and driving down manufacturing costs until they see an assured market. To drive down costs and improve efficiency will require advances in both manufacturing processes and technologies appropriate to the new energy technologies summarized above; support will also be required to scale up manufacturing so that efficient new products can move into the market more quickly.

The *second step* of our analysis is to classify support policies for encouraging energy innovation into technology-neutral packages, and then to match them to the technology groupings developed in the first step of the analysis. Here we see three policy elements.

"*Front-End*" *Technology Nurturing.* For technologies in all six of the categories above, technology support is needed on the front end of innovation, before a technology is close to being commercialized. This includes direct government support for R&D in both the long and short terms, and for technology prototyping and demonstrations.

"*Back-End*" *Incentives.* Incentives (carrots) to encourage technology transition on the "back end" may also be needed as a technology closes in on commercialization. Such carrots can encourage secondary/component technologies facing both uncontested and contested launch, along with incremental innovations in technology for conservation and end use, and technologies for manufacturing processes and scale-up. They may also be relevant to some disruptive technologies as they transition from niche areas to more general applicability. These incentives include tax credits of various kinds for new energy technology products, loan guarantees, low-cost financing, price guarantees, government procurement programs, buydown programs for new products, and general and technology-specific intellectual property policies. As one example, procurement by the Defense Department, the nation's largest owner of buildings and facilities, could offer potential energy cost savings to the department over time by using its facilities as an efficiency testbed, and could help ascertain the optimal approaches to building technology. However, there are challenges: How can abuses be avoided that may arise in deviating from lowest-cost procurement criteria? How could such procurement be reconciled with the technology-neutral strategy advocated here? Despite potential complications, this may be one of the better levers for lifting energy infrastructure out of the current technology "steady-state."

"*Back-End*" *Regulatory and Related Mandates.* Regulatory and related mandates (sticks), also on the back end, may be needed in order to encourage component technologies facing contested launch and also some conservation and end-use technologies. These include standards for particular energy technologies in the building and construction and comparable sectors, regulatory mandates such as renewable portfolio standards and fuel economy standards, and emission taxes.

Just as there is no "one-size-fits-all" R&D program, which requires R&D efforts to be tailored to particular technology categories, so particular "carrots" and "sticks" may fit one group of technologies but not another. Loan guarantees may work for major utilities building next generation nuclear power plants, but likely will not be useful to small firms and startups with limited capital access deploying new solar technologies. Analytical work is needed to evaluate the relative economic efficiency of particular back-end incentives or regulations. It should be noted, too, that in the energy sector, a system of carbon charges, such as a cap-and-trade program, can substitute for many (although certainly not all) of the back-end proposals listed above, both carrots and sticks, because it would induce similar effects.

As suggested in the previous section, the optimal approach to bringing innovation into complex, established sectors would bring to bear three models of the innovation process: the induced, the pipeline and the organizational models. A technology supply approach is unlikely to be effective unless it is accompanied by the demand-side price signals called for by the induced innovation model. Even when they are technically ready, new entrants cannot compete on price with existing mature, efficient and cheap energy technologies because the fossil fuel-based industry does not have to pay for the environmental and security externalities that it can now avoid. On the other hand, induced innovation depends on a robust technology supply program, supported by a strong pipeline innovation system, to enable the technologies that are needed to create alternatives and drive down costs to become available within a reasonable time. This is particularly true when the technology transformation being sought is as dramatic as the one we seek in energy. Innovation in a complex sector like energy is not either/or—both the induced and pipeline models are required.

Let's examine a concrete and current policy example for this balance. To induce an energy transformation, Congress has focused on a cap-and-trade approach intended to send pricing signals that increase demand for new energy technologies and efficiencies. It has preferred this approach to a carbon tax or to higher gas or other sector-specific taxes, which it considers to be more politically onerous. On June 26, 2009, the House of Representatives passed by a narrow margin a cap-and-trade bill, HR. 2454. As a result of political compromises with affected industries and interests, the economic pressures to reduce greenhouse gasses in the early years of the bill will be limited, because the "cap" tightens only gradually and the auctions scale up only over time. The House bill is also limited in its application of the pipeline model—i.e., on the technology-supply side—in that it provides only a marginal increase in energy R&D, and includes provisions for technology implementation that back only a limited range of technologies—namely, those sought by politically powerful industries: coal, oil refinery and automobile. The approach in the House bill, then, is tilted toward a gradually phased-in induced model, it is not balanced with a strong technology supply model.

The third element in the trio of models of the innovation process must now be introduced: the organizational model. The *third step* of our analysis, then, is to survey existing institutional and organizational mechanisms for the support of innovation, to determine what kinds of innovations (as classified by the likely bottlenecks in their launch paths) do not receive federal support at critical stages of the innovation process, and what kind of support mechanisms are needed to fill these gaps. This could be described as an institutional gap analysis. In energy, for example, we do not have the capacity to translate our research into innovation, to finance the scale-up of promising technologies, and to form an overall collaborative strategy between the public and private sectors to roadmap the details involved in developing and deploying new the technologies at scale.

Where complex technology sectors like energy are involved, we need to have Congress legislate standard packages of incentives and support across common technology launch areas, so that some technology neutrality is preserved and the optimal emerging technology has a chance to prevail.

The *fourth step* in our analysis is to recommend new institutions and organizational mechanisms to fill these technology gaps identified in the third step, by providing translational research, technology financing and roadmapping.

To summarize, the first of these four steps draws on pipeline theory, suggesting that support from the government pipeline will be important to creating, launching and enhancing a range of technology options. But since the technology streams will need to land in the private sector at a huge scale, the second step relies on induced innovation theory. It concentrates on the policy or demand signals that will induce the private sector to take up, modify, and implement the technology advances that originate from the innovation pipeline. Whether these come from a demand pricing system like the cap-and-trade scheme proposed for carbon-based energy, from technology incentives, or from regulatory requirements, they will need to be coordinated and, to the extent possible, will need to be technology-neutral. The third and fourth steps draw on the innovation organization theory we advanced here: that the gaps in the innovation system will need to be filled for the handoff to occur between pipeline and induced models, especially at the points where technology supply push meets market demand pull.

This proposed new integrated framework has implications beyond policy theory; it also leads to a different logic for the practical design of technology legislation. In effect, our discussion of steps one and two implies that the current legislative process for technology innovation in energy is exactly backwards. The incentive structure should be legislated first in a way that will preserve the fundamental technology neutrality needed in this complex technology area, rather than the present practice of legislating separately for each technology first, with a different incentive structure for each one. This unfortunate process has become a standard model for innovation legislation, for example in the major energy acts of 2005 and 2007.[19]

In contrast, where complex technology sectors like energy are involved, we need to have Congress legislate standard packages of incentives and support across common technology launch areas, so that some technology neutrality is preserved and the optimal emerging technology has a chance to prevail. Particular technologies can then qualify for these packages based on their launch requirements. It is important to get away from the current legislative approach of unique policy designs for each technology, often based on the legislative clout behind that particular technology.

APPLYING INTEGRATED INNOVATION ANALYSIS TO COMPLEX SECTORS

The American economy would be well served if it developed a capacity to move technological innovation more efficiently into established, complex economic sectors like energy. Our traditional model for innovation relies on launching innovation into open fields; we could improve our innovation-based growth rate if we learned how to drive our technology-laden covered wagons into old frontiers as well as new. This requires a new innovation framework, which integrates the three separate models for innovation we have articulated: the pipeline and induced models and the model for institutional organization of innovations, which backs them up. This framework requires a new focus on the moment of technology launch, as well as on the traditional focus of innovation policy on the "valley of death."

But even if we equip ourselves with a new model for innovation policy in complex established sectors like energy or health care delivery—for taking our technology covered wagons east—we should not underestimate the difficulty of the process for introducing new technology at the massive scale demanded. In energy, this process has eluded us for the last four decades. These complexities underscore the need for a comprehensive new theoretical approach.

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Felix S. Creutzig and Daniel M. Kammen

The Post-Copenhagen Roadmap Towards Sustainability

Differentiated Geographic Approaches, Integrated Over Goals

Climate change will bring economic, social and environmental costs at scales beyond any other human experience (IARU, 2009). Studies imply that humanity must reduce CO_2 below its current atmospheric concentration if we are to preserve a planet like the one we are now adapted to (Hansen et al., 2008). Considerable action has been taken since the Kyoto protocol was adopted in 1990 and ratified in 2005, but emissions continue to accelerate with potentially fatal effects. In fact, considerable ambivalence surrounds the Kyoto protocol. On the one hand, it is the only current substantial international effort to mitigate dangerous climate change. On the other hand, it lacks ambition. Its instruments mostly rely on complicated financial incentives, while mitigation focuses on single-source, context-detached, quantifiable and technology-oriented cases.

The result is a piecemeal approach. For example, as the single most relevant instrument under Kyoto, the European emissions trading scheme has succeeded in imposing a price on carbon but has also put windfall profits into polluters' pockets. Meanwhile, the Clean Development Mechanism (CDM) can reduce emissions at low cost, but does not contribute significantly to sustainable development (Olsen, 2007). At present, because the incentives are badly aligned, validation and verification of CDM projects cannot perform adequately and the additionality of a significant number of projects is in question (Schneider, 2007). In addition, the

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Kyoto framework requires single-source quantification, which is very difficult for some sectors, particularly transportation where it is very difficult to determine emission reductions, e.g. through reduced levels of motorization; other measures often have high transaction costs. For all these reasons, then, to achieve the required and ambitious reductions in emissions, the current piecemeal approach must be complemented by a more all-encompassing plan or program.

In response, we suggest a systemic approach in which mitigation measures are integrated across a set of sustainability goals, so they can be used to tackle local environmental, economic and social issues simultaneously, making them far more effective. Meanwhile, they should be specific to location, i.e. adapted to local geographical situations and cultural knowledge.

The beneficial side effects of climate change mitigation, the so-called co-benefits, are so persuasive that we cannot afford to ignore them. Mitigation policies nearly always affect other domains or interact with other policy dimensions. In the economic domain, for example, fuel efficiency standards will impact the automobile market and energy security. Equally important are the consequences for other environmental and social causes: Mitigation policies offer considerable benefits in air quality, biodiversity, and health, and they counteract energy inequality. In fact, in specific cases, the local or regional co-benefits outweigh the benefits of climate change mitigation by an order of magnitude. Because climate change mitigation is a public good, no single party takes on sufficient responsibility for it, and not enough is being done worldwide to protect the climate. From this agent-based perspective, co-benefits can be a game-changer for localized climate action: if the co-benefits of mitigation, such as improved air quality, manifest themselves locally, then they increase the incentives to act.

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Climate change mitigation and adaptation must also be seen in terms of development and alleviating poverty. Reconciling social justice with environmental protection and climate change mitigation will be crucial to effect global action (Baer, et al., 2000; Roberts & Parks, 2007). While OECD countries invest in mitigation policies, developing countries can gain the capabilities they need to choose low-carbon development paths. But development itself requires economies of scale that cannot be jump-started with meager development aid, often conditional on purchases and services from donor countries. Adaptation funds can overcome this financial barrier. For example, money raised from taxes on international air and maritime transportation and gathered by an international agency could be used to finance forest protection and adaptation measures.

When mitigation policies are designed and implemented from an integrated perspective, the regional or national population and electorate benefit directly. Not only does such an approach promote sustainability; in many cases, it also makes projects politically feasible. In fact, much of the mitigation action we are seeing at present can be attributed to local policies that are not necessarily motivated by climate change.

Mitigation action is also inherently spatial. The co-benefits are nearly always local or regional and differ from one place to another. Obviously, different geographic locations offer varying possibilities for renewable energies and different mitigation options. Because land-use patterns and population density are path-dependent, a differentiated approach is required. When technologies and infrastructures are adapted to the situation in a given area and become embedded in that context, they also become more useful because they are (re-)aligned with local cultural practices. In the rest of this paper we illustrate these points, using the examples of land-use change, small-scale and urban electricity supply, and the sustainable development of cities. Then we discuss the implications for a general framework of measurement and investment.

LAND-USE CHANGE AND FORESTS

Recent reports have illustrated that land use, and changes in it, is a major factor in the emissions and absorption of greenhouse gases (GHGs). Because land-use change has many causes and leads to a variety of consequences, it is hard to understand and act on it without understanding its context.

What is the issue? During the 1990s, deforestation accounted for about 25% of all anthropogenic greenhouse gas emissions (Houghton, 2005). These emissions are hard to measure, however; across all sectors, the uncertainty about the magnitude of emissions is highest for land-use change. Indeed, we are far from completely understanding deforestation, degradation and the changes in land use that cause GHG emissions. We do know that these emissions are probably high, so any effective climate regime must ensure that forest degradation is avoided. Of all the mitigation options related to forests, preservation has the largest and most immediate impact on carbon stocks in the short term. And preserving forests is more important than reforestation, as nothing can substitute for an intact ecosystem. Crucially, if forest degradation proceeds beyond a certain threshold, it may induce irreversible destruction of the rain forests.

Intact forests provide many co-benefits. They are more resilient against climate change, guarantee valuable biodiversity, and provide additional ecosystem functions such as water services (Noss, 2001). Forests also provide commercial prod-

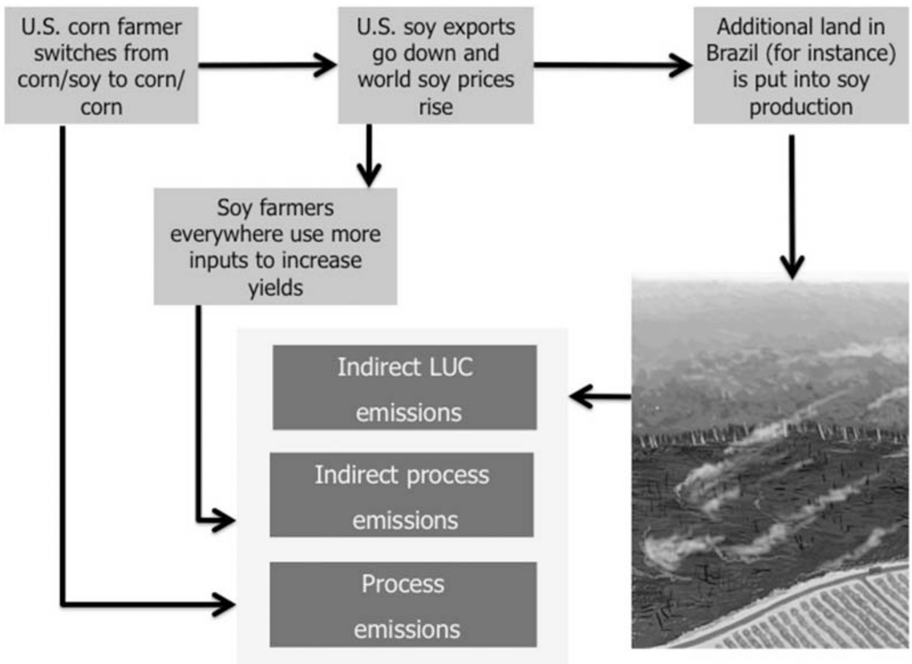

Figure 1. Changes in land use change may cause large emissions of GHGs.

ucts, such as timber, and provide opportunities for tourism, as well as non-commercial goods such as firewood for home use, drinking water, gums, resin, honey and fodder. Forests with watersheds purify water and protect downstream residents from floods, droughts and sediments, prevent erosion and provide wildlife for hunting. They can also store a significant amount of carbon and house significant biodiversity. Thus the potential commercial benefits of land-use changes in watersheds or other ecosystems must be weighted against a complete accounting of all the social benefits. These effects translate directly into macroeconomic loss when deforestation occurs. For example it is estimated that developing countries lose $15 billion each year due to illegal logging. That amount is eight times the total amount of international development aid to the forest sector.

What drives deforestation? The phenomenon of deforestation is entangled in both global and local market dynamics and institutions. On a global level, research emphasizes the indirect changes in land use that result from increased bioethanol production. For example, in response to higher prices, farmers worldwide have been converting forests to cropland to replace the grain that has been diverted to biofuels. The effects of this shift may be so significant that the net savings in GHGs will only occur after more than 150 years (Searchinger et al., 2008). The exact numbers are highly disputed, and there is a lot of uncertainty around the magnitude of indirect land-use change (iLUC) effects. However, there is agreement that iLUC can be very important and thus cannot be ignored. One specific aspect is that agrofuel production increases GHG emissions, mostly due to land-use changes when production begins, and thus has an immediate adverse impact on the climate (O'Hare et al., 2009). Some of the effects of this dynamic are summarized in Figure 1.

Furthermore, the current system of resource-intensive cheap meat production builds on the substantial demand for crops and may indirectly increase the pressure on primary forests and augment agricultural emissions. Local factors that drive deforestation include poverty, local demand for agricultural land and firewood, large-scale commercial cattle farming and dependency on exporting agricultural goods. Altogether, the decline in rainforestsis determined by a combination of various proximate causes and underlying driving forces (Geist & Lambin, 2002). Some of these causes are robust geographically, such as the development of market economies, but most are specific to their regions. Thus we must analyze cases individually.

Further scientific research is crucial in particular areas. The magnitude of the emissions related to land-use changes, combined with our lack of quantitative understanding about the interdependencies mentioned above, highlights the need to evaluate land-use systematically. Germany's Advisory Council on Global Change (WBGU, 2008) suggests three key areas for research:

- Enhance our base of knowledge about global land use, using high-resolution GIS data to determine vegetation cover, soil conditions and agricultural usage.
- Determine the amounts of GHGs that result from various land uses, including complete pathway analyses for particular uses, e.g. bioenergy.
- Investigate land-use competition and develop a land-use management system that takes into account different objectives, especially the basic need for food security.

It is widely recognized in science and politics that reducing or avoiding deforestation is a critical component of any international regime to reduce emissions. From the perspective we take in this article, two issues deserve particular emphasis. First, any deforestation agreement will address those countries that possess significant tropical rainforest cover, such as Brazil, Indonesia and Congo. However, with respect to a global framework on forests, the Annex I (industrialized) countries should not be relieved of their obligations—or deprived of the chance to use their potential. Russia, Canada and the U.S. have the world's largest primary forests, after Brazil. Some European countries are contributing significantly to GHG emissions because of land-use changes, e.g. by increasing their demand for wood. On the other hand, the U.S. can potentially sequester at least 150 million metric tons of carbon via reforestation (Rhemtulla et al., 2009). Hence, instead of only considering the deforestation of tropical rain forests, we should be applying an integrated concept of land-use change that includes the OECD countries (Mollicone et al., 2007). Second, a deforestation agreement clearly cannot solve all problems, but it will be effective only if the co-benefits and externalities are fully understood. In particular, it does not help to avoid GHG emissions only at one

How sustainable are biofuels?

Sustainable bioenergy has significant potential but also presents particular risks, as we show in this article. As the increased cultivation of crops for energy connects the rapidly-growing worldwide demand for energy to global land use, unregulated bioenergy development increases the likelihood of conflicts over land use. Some uses of land are essential, and irreplaceable, such as food production and the conservation of biodiversity and biogeochemical cycles; they must have priority over the production of biomass to generate electricity or transport fuels (WBGU, 2008). The utilization of waste and residues for energy generation is beneficial, causing very little competition with existing land uses, especially if energy crops are grown on land whose productive or regulatory function is limited. Furthermore, before cultivation begins, two conditions must be met: the interests of local population groups must be taken into account and the implications for nature conservation must be assessed. Cogeneration offers the most efficient use of bioenergy; in converting biomass to electricity it is more land-use efficient than biofuels (Campbell, Lobell, & Field, 2009). Policies that foster electromobility, i.e. support for electric cars, electric bicycles and appropriate infrastructures, are environmentally more beneficial than the current subsidies currently offered for biofuel production (Creutzig & Kammen, 2009).

specific point in time and space, if these emissions are then shifted to another place, or produced earlier or later; this phenomenon is called leakage. To avoid skewed incentives that encourage various parties to engage in gaming over emissions reduction within narrow system boundaries, a forest emission regime can be designed to promote the local co-benefits of forest preservation, i.e. by making everyone aware of the long-term economic value of forests rather than including only monetary incentives.

RURAL SETTLEMENT: SCALING UP SMALL-SCALE ENERGY SOLUTIONS FOR AFRICA

Small-scale technologies provide an often-underestimated potential for climate change mitigation both in cities and in rural areas; they can also promote low-carbon development.

Small-scale power generation, e.g. from solar radiation or biomass, can be efficient and produce little atmospheric carbon. At the same time it can be very important for local communities, by decisively combating energy poverty, reducing child mortality and providing crucial employment opportunities. Additionally, small-scale power generation is correlated with improved education and health services (Cabraal, Barnes, & Agarwal, 2005). Climate mitigation aside, these co-benefits provide sufficient reason to implement programs. However, there is no global silver bullet: successful solutions vary according to geographical location, latitude, needs and culture.

In this section we offer two concrete examples of small-scale power generation and co-benefits. First, solar electric systems, alone and especially as part of micro-grids, can provide substantial amounts of energy in rural areas and existing programs can be intensified. In Kenya, solar electrification has occurred at a faster pace than grid connection efforts; over 200,000 homes now have solar units and the figure is growing by 18% annually (Jacobson & Kammen, 2007). In other African countries, the rapid penetration of cost-competitive solar home systems is partially constrained by government subsidies on kerosene and propane fuels.

Second, biomass is an important source of energy, mostly consumed in cooking stoves. Worldwide, more than 90% of the bioenergy currently being used comes from traditional sources, such as wood and charcoal in cookstoves; 38% of the world's population depends on this form of energy, and 1.5 million people die each year from the pollution caused by open fires. Simple technical improvements to stoves can reduce many of the health risks posed by biomass use and meanwhile double or even quadruple the stoves' efficiency.

Newly designed charcoal stoves are far more efficient in both combustion and heat transfer than older models. Such cooking stoves, along with solar and plant-oil stoves, and other environmental management measures are not only beneficial in terms of energy efficiency; they can also lead to huge health benefits by reducing indoor air pollution (Ezzati & Kammen, 2002). Hence, these technologies address health, deforestation and greenhouse gas emissions at the same time that they provide energy at low costs. Even more importantly, improved and solar cookstoves can eliminate the emissions of black carbon, a crucial measure to reduce regional heating effects, particularly in the Himalayas. Hence, the large-scale deployment of cookstoves is very much in the interest of China, India and Southeast Asia, especially since they need to protect their long-term water security.

What does small-scale power generation look like from the grid perspective? Electricity consumption in Sub-Saharan Africa is only one 150th that of industrialized countries. Efforts to break up monopolies and liberalize energy generation and distribution in Sub-Saharan Africa increased the cost of the energy supply and contributed to energy inequality. Now, large-scale investments serving an elite minority receive the highest level of energy investments—at the expense of abundant, mature, and cost-effective small-scale renewable-energy technologies, such as solar energy, micro-hydro and improved biomass cooking stoves. However, innovative regulatory tools, including those for licensing, standards and guidelines, and metering and tariffs, have demonstrated the success of a new rural electrification regime (Kammen & Kirubi, 2008).

In these efforts, fee-for-service is a useful concept: An investor installs a micro-grid in a village and asks customers to pay fees for energy. In effect, the electricity provided is off-grid, the generation is small-scale, and the providers are individuals or communities. The costs are high but still lower than under the old regime as the grid does not need to be extended. For example, the Urambo Electric

Consumer's Cooperative in Tanzania outperforms the national utility in several respects: lower operation and maintenance costs, affordable tariffs, and improved customer service (Marundu, 2002).

Altogether, appropriate technologies for Africa are different than those for OECD countries. As most people have small incomes and little access to infrastructures, they can benefit greatly from technologies that are cheap, moderately efficient and simple to use; thus it is possible to reduce poverty with low-carbon technologies. In many cases, clever design trumps high-tech investment.

Although appropriate small-scale decentralized technologies have huge potential, however, they are only part of the equation. If economic well-being is to continue over the long term, the economies of scale must come with high productivity. Bringing economies of scale to Africa can be broken down into two tasks. First, economies of scale are usually reached in dense clusters of economic activity, mostly cities (Krugman, 1991). Such clusters of economic and academic activity also promote innovation, the key driver of economic well-being (Solow, 1957). An African center for appropriate technologies, such as one producing low-cost photovoltaics, could drive the economy of an entire region. Such a cluster would consist of a university, research laboratories, established companies, and funded start-ups. Substantial inputs of both financial and human resources from Annex-I countries could jump-start such an economy; local contribution should guarantee some sort of local ownership. Furthermore, trade agreements must be renegotiated to protect and foster these markets as the U.S. did in a far-sighted way to rebuild Europe after World War II (Jawara & Kwa, 2003). Second, economies of scale must be fostered as successful small-scale technologies are disseminated and deployed all over the continent.

ENERGY SUPPLY FOR CITIES IN INDUSTRIALIZED COUNTRIES

For OECD countries, the overall challenge is to overcome the reliance on carbon fuels, known as carbon lock-in, and to change structures so that a range of small and medium-sized technologies can be deployed, in a decentralized way, with the dominant contributors being wind farms, solar thermic and photovoltaic installations, geothermal power and (biomass)-cogeneration. Combined heat and power generation (cogeneration) is very efficient but still faces an adverse energy policy setting that favors large-scale, inefficient coal plants.

Also in OECD countries, small-scale technologies such as solar home systems, geothermal heat pumps and small cogeneration plants are already helping reduce the carbon intensity of electricity and heating, and increase energy security while providing additional employment opportunities. Soon, the price of electricity generated by photovoltaics (PVs) may drop enough to equal that of electricity from other sources, thanks to global investments of $200 billion (Farmer & Trancik, 2007); that would accelerate a huge market for renewables in all countries and on all scales. Smart-grid technologies will make it possible for the users of such systems to adjust loads, respond to unexpected demands, integrate power generated in decentralized locations, and become resilient to load fluctuations. These measures can make overall electricity usage significantly more efficient; the total monetary benefit is estimated to be $75 billion for the United States alone (Kannberg et al., 2003). In fact, changes in policy, such as pricing carbon according to such social costs, could help decentralize the energy supply even without further technological changes.

Large-scale technologies cannot be integrated into cities but they are part of their regional hinterland and are likely required to fulfill cities' energy needs. Three large-scale technologies can make a significant difference within the next decade: Wind parks, including off-shore wind; solar-thermal and/or PV; and geothermal. Wind is already competitive with conventional resources, so the private sector will invest in this technology as long as the financial market provides liquidity.

Solar thermal energy can contribute significantly to the near-term mix of energy from Africa, Europe, Iran, China, Australia, and the U.S. Once a reasonable price for carbon is established, solar thermal power plants will become viable in places as diverse as California and Botswana (Fripp, 2008; Wheeler, 2008). Concentrated solar power (CSP) has also been proposed and planned as the backbone of a transcontinental supergrid for the Middle East, Northern Africa and Europe.[1] A carbon price of only $14 per ton is enough to justify $20 billion in subsidies over ten years; by 2020 it can provide 55 terawatts (TWh) for EU-MENA (Europe, the Middle East, and North Africa) and make unsubsidized concentrated solar power competitive with coal and gas power generation (Ummel & Wheeler, 2008). Such supergrids will be more acceptable if local communities profit, e.g. with jobs, increased supplies of electricity, and desalinated seawater produced using waste heat from the power generation process.

Because geothermal energy can provide a baseload supply, that is, a constant, non-fluctuating energy supply, in contrast to wind or solar, it is attractive as part of the future renewable energy mix. Geothermal power, using conventional hydrothermal resources, can compete with coal, assuming moderate carbon pricing. For example, a project in Kenya has been able to reduce electricity costs for both generators and consumers (UNEP, 2008a). In the U.S., the world leader in installed geothermal capacity, enhanced geothermal systems can provide 100 gigawatts or 10% of the current electricity demand by 2050 (Tester et al., 2006). But reaching this goal will require $1 billion in funding for research and development, particularly to develop drilling techniques, power conversion technology, and reservoir development.

Renewable energies vary significantly with geographic location. Supply and demand often do not match very well; for example in China the best wind resources are in Inner Mongolia but the population is in coastal centers, such as Beijing-Tianjin. To get the energy from these new renewable sources to the consumer requires investments, both to develop and to deploy a grid backbone for clean energy commerce. Grid expansions can link clean energy resources with population centers, e.g. from CSP plants in Northern Africa to European cities or from wind generation plants in the U.S. Midwest to the more populated coasts. Large-scale inter-regional grid connection makes it easier to match supply and demand with renewable energies throughout the day (east-west connections) and year (north-south connections) (WBGU, 2003). To deal with natural fluctuations in the availability of renewable resources, particularly sun and wind, storage technologies will be required, such as melted sand for CSP plants and compressed air energy storage for wind generation. However, given the current mix of plants that can provide energy at the levels of base, intermediate, and peak loads, the grid can be made flexible enough so that wind energy can provide at least 20% of total energy at low grid integration costs (DeMeo et al., 2007). Hence, renewable energy can be expanded rapidly; it need not wait until better storage technologies become available.

Energy security would be a major benefit of a rapid switch towards a renewable energy mix. In fact, the European Union has been discussing the CSP-powered EU-MENA grid primarily in order to reduce its dependence on Russian fossil fuels. In fact, a group of European companies is pushing for the implementation of such an endeavor. In the U.S., becoming less dependent on Middle Eastern oil is a crucial motivation behind subsidies for agrofuels and the political pressure to provide electric and other more fuel-efficient cars.

Other grand-scale technology options are nuclear and carbon capture and storage (CCS). Nuclear energy is a mature technology and can be part of the future energy mix, though the cost of internalizing risks may reduce its financial viability. Crucially, other mostly renewable technologies and energy efficiency measures can be deployed on a sufficient scale to satisfy our future energy demand. It is important to foster research in CCS if we are to mitigate the emissions of existing coal plants in the future, especially in the U.S. and China. Doing so will require a strict and significant carbon price, along with high efficiency standards for power plants. Such a price will encourage the deployment of financially viable CCS. It is advisable to make the local externalities of coal, including air pollution and toxic landfills, an explicit part of an appropriate accounting.

SOLUTIONS FOR CITIES

With more than half the world's population now living in them, cities constitute a particular location where drastic reductions can be made in the energy needed for housing and transportation. Appropriate design of infrastructures and incentive schemes, along with technological innovation, can significantly reduce carbon emissions, and simultaneously improve the quality of life, e.g., by increasing accessibility and reducing air pollution. Given how important cities' scales and geographies are, it is worth focusing some of our energy efficiency discussion on them (Wilbanks, 2003).

Different aspects of cities' spatial dimensions provide insights into possible climate mitigation strategies. Carbon emissions and energy consumption are clearly a function of geographic circumstances. For example, in the U.S., January temperatures are negatively correlated with natural gas consumption and July temperatures are positively correlated with electricity consumption, reflecting heating and cooling needs respectively (Glaeser & Kahn, 2008). Other climate attributes, such as humidity, also contribute to the specificity of demands for energy.

Cities are never autonomous units; they rely on resources from their hinterland. In today's global economy, they also rely on resources from other continents, producing a global carbon footprint beyond their specific electricity and gasoline consumption. Indeed, in industrializing countries, much of the emissions stem from the production of goods for export to industrialized countries, but the reverse is not true (Suri & Chapman, 1998).

Cities also have their own spatial characteristics. Urban density is negatively correlated to gasoline consumption, and distance to the city center is positively correlated to it, indicating the negative impact that urban sprawl has on climate change. Dense Asian cities, and some European ones, perform better than U.S. cities that have fewer spatial constraints. Density is also related to the energy demand of buildings, one of the largest sources of GHG emissions. A city's form can also influence its micro-climate. For example, high levels of solar radiation from urban surfaces create urban heat-island effects, where the city temperature is significantly higher than that in the surrounding countryside.

These observations demonstrate that different cities face different energy needs and mitigation possibilities. According to its climatic region, a city may save energy by better and more appropriately regulating its heating and/or cooling systems, adapting them to factors such as the occupancy rates of office space and carefully avoiding overshoots in heating and cooling. With advanced smart control, millions of electricity-guzzling appliances, such as air conditioners and water heaters, can be fine-tuned and made to accommodate to rapid fluctuations in the renewable energy supply.

Dense cities can also reduce the GHG emissions in the transport sector by encouraging people to shift to public transportation; they can internalize the cost of auto transport by instituting city tolls and can implement low-cost but effective design measures to improve convenience and safety for pedestrians and bicycles. Crucially, the total social cost of car transportation in cities can exceed the climate costs by an order of magnitude. For example, in Beijing the costs and health consequences of congestion outweigh the climate costs by a factor of 15, as shown in Figure 2 (Creutzig & He, 2009).

Low-density cities face the syndrome of carbon lock-in, or the inability to develop low-carbon infrastructure due to adverse path-dependency. Still, ample opportunities exist to overcome this problem. For example, fuel efficiency measures and lighter vehicles can easily cut gasoline consumption in half; weatherization programs, such as insulating windows, can do the same for buildings. Convenient electric bicycles can satisfy a significant share of the need for transportation, and not only in Chinese cities. Innovative municipal instruments can

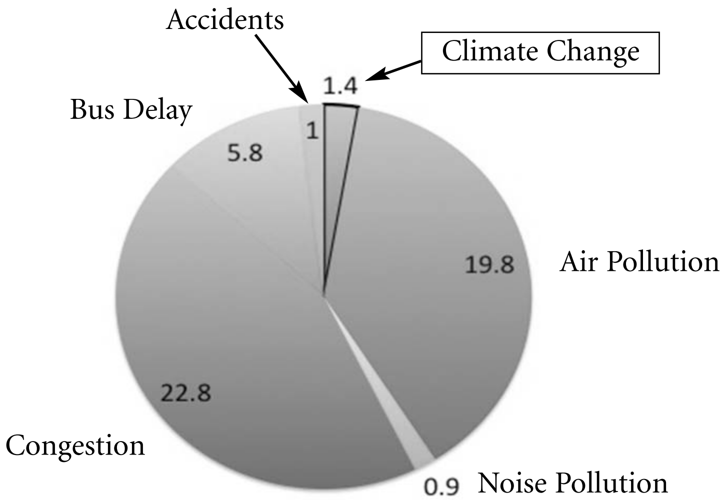

Figure 2. External costs of car transportation in Beijing. All values are in billions of RMB.

Source: Adapted from Creutzig & He, 2009.

successfully propel individual energy efficiency measures and increase the demand for decentralized renewable energy (Fuller, Portis, & Kammen, 2009).

At the same time, however, regulations and incentives should guarantee transit-oriented development and increase the housing density along public-transit corridors. We also need to redefine some concepts. For example, mobility should not be measured in miles travelled on concrete but in accessibility: how quickly can people access their work, stores, schools and hospitals? Accessibility can be improved by developing mixed-used neighborhoods that do not require highway construction. Even suburbs can be designed to facilitate car-free living when good streetcar connections are provided, as demonstrated by the Vauban quarter in Freiburg, Germany.

Finally, cities can be designed to adapt to their geographical location. Yazd, which lies in the Iranian desert, adapted to its climate by building wind towers that cool streets and houses with a refreshing breeze. Isfahan, another Iranian city located in an arid zone, has a historically well established water management system that can use scarce water resources for public gardens that cool the city. More generally, cool surfaces with a high albedo or reflectivity level, along with shade trees, can effectively mitigate both climate change and the urban heat island effect (Akbari, Pomerantz, & Taha, 2001). To go one step further, urban gardening can also help decrease resource dependencies and transportation costs. Many of these ideas are summarized in Table 1.

Approach	Location	Example	Co-Benefit
Fuel efficiency	Suburbs	Lighter materials & smaller cars	Cleaner air, energy security
Biofuels	-	Cellulosic waste, biomass cogeneration	Energy security
Transport Demand Management	Inner cities	Stockholm congestion charge	Faster, more reliable transport
Public transport	Inner cities	Beijing subway system	Mobility equality
Land-use research	Forests, food supply	Brazilian rain forest for soy production	Protection of biodiversity
Microgrids	Remote areas	Urambo, Tanzania	Reduction of energy poverty
Improved cooking ovens	Africa, India, China, Southeast Asia	Plant oil in Ghana	Improved respiratory health, decreased black carbon
Low-cost solar power	U.S., China, North Africa	Parabolic troughs in Andasol, Spain; PV on roofs	Energy security
Transmission	Across continents	DESERTEC	Facilitation of infrastructure
Smart grid	Buildings	Air conditioner control	Grid stability, jobs

Table 1. Potential solutions to global climate change: Locations, examples, co-benefits.

VISIBILITY AND MEASUREMENT: FROM GDP TO WEALTH ESTIMATION

The measures suggested above are motivated by a macro-economic perspective that considers social costs. But only if such a perspective becomes widely accepted will people fully embrace such measures. Here is where indicators can play a crucial role. Aggregate indicators are often used to judge government performance, so the choice of an indicator exerts considerable influence on the policy measures that politicians choose. The most notorious of all indicators is the gross domestic product (GDP). For more than 60 years, the GDP (or GNP) has been regarded as the single most dominant indicator of a nation's wellbeing. As a result, policy makers have focused on economic growth, or more precisely increased economic activity, arguing that other policy targets such as social stability would follow automatically. Though this argument has historically been justified by the high correlation of the GDP with more comprehensive measures of human well being, this logic collapses in eras like the present, with fundamental resource limitations and high global inequality.

GDP is an inappropriate measure for two reasons. First, it measures economic activity but not capital. Hence, a country's GDP could rise if economic forces are consuming the economy's capital, rather than reflecting productive wealth generation. Second, GDP only includes market goods, deliberately excluding human health, education, and—crucially— natural resources. A better index of well-being is wealth measured in accounting prices: the social value of resources and manufactured goods.[2] From this perspective, a society should strive to increase its wealth by producing positive genuine investment, i.e. increased wealth for its whole population. Genuine investments should also be used to evaluate policies, through a social-benefit analysis (Dasgupta, 2001).

In this framework, externalities are seen not as exemptions and deviations from the optimal market but as common features of real-world markets, particularly when natural resources are involved. Hence, markets function properly only if they can address externalities, an objective usually achieved by complementary regulations.

If we keep on measuring an economy predominantly in terms of its GDP, we may ignore the fact that its capital base is degrading quickly. In fact, the wealth of Sub-Saharan Africa has already degraded considerably in the last few decades (Arrow et al., 2004). Changing the accounting base will only slowly change consumption and production patterns. We must remember that the development and use of technology is path-dependent: as long as natural resources are underpriced, incentives favor the development of technologies that over-exploit them. Any change in the accounting base also has to overcome political barriers: owners and shareholders will not support change in accounting that do not favor their technologies. Also, customary habits of economic thinking are difficult to overcome. But the process of monitoring and measuring sustainability metrics and indicators can help as it both gauges and spurs sustainable development (Bossel, 1999; Meadows, 1998). Such a change in accounting would fit with a change in economic thinking which would then lead to changes in technology deployment that foster sustainability.

To make sustainable economics more visible and quantifiable, further research and actual on-the-ground deployment projects are needed in several methodologies for measurement and evaluation:

- We need a better methodology to determine the accounting prices for carbon stock, land uses, ecosystems, biodiversity, clean air, noise and other aspects of our environment. Accounting involves difficult issues such as the substitution of services, appropriate discounting over time, and the intrinsic value of biosystems. Further developing appropriate practices such as sensitivity analyses will make it possible to address the accompanying uncertainties. It would be helpful to make the process of dealing with soft, uncertain price estimation part of the economic curriculum.
- Ecosystem dynamics are usually nonlinear, so we need ways to understand the threshold values and catastrophic dynamics in more detail. Then, appropriate accounting prices can be adopted, or strict restrictions can be put in place if required.

- Research in behavioral and institutional economics is needed to determine which kinds of institutions can maximize wealth by handling natural resources properly.

How much weight can be given to indicators in general? How important is quantification? Quantitative science is needed to make decisions that are as informed as possible and can sharpen our intuition. But it is dangerous to rely only on those aspects that can be measured at a specific time and location. Often no data are available for a relevant set of measures, and other measures may be imperfect. Hence, only a small set of measures is left that is judged to be suitable—leading researchers, politicians and citizens to make the problematic assumption that a part truly represents the whole. This situation is aggravated by gaming behavior, in which managers act only to meet a specific target and underperform on important other tasks (Bevan & Hood, 2006). Hence, even a varied set of indicators should not be an all-exclusive measure of government performance. Instead, decision-makers must take a holistic view even when they are lacking some relevant data.

When decision-makers gain more information about ecosystem dynamics and social accounting, they can design economic institutions to foster sustainability. Fundamentally, this means that macroeconomics must shift to become a more empirical science. Also, just as economists systematically embrace ecological studies that involve a natural resource base, ecologists must investigate the impact that economic institutions have on ecosystems. Hence, from our point of view, both disciplines converge in an apparent reflection of their ethymologicy: the laws (*nomoi*) that we use to manage our global household (*oikos*) are based on its fundamental order (*logos*).

CARBON DIVESTMENT AND SCALING UP GREEN AID

What does this sustainable development framework imply for investment, particularly for multilateral investment banks? It is clear that investment strategies and decisions play a crucial role in a transition toward low-carbon technologies for energy production. Multilateral development banks (MDBs) play a crucial role as they have significant budgets and can function as cheerleaders for other banks and donor agencies.

An important question here is how much aid goes into *green* projects. Between 1980 and 1999, both bilateral and multilateral agencies significantly increased green aid and reduced the ratio of dirty to green aid. However, bilateral agencies perform better: they decreased their ratio of dirty to green aid from factor 10 to factor 3, i.e. bilateral agencies now only fund three times as many dirty projects (coal etc.) as 'green' projects. Multilateral agencies are slightly worse as they went from factor 10 to factor 4 and did not improve their spending ratio from 1992 onwards. Moreover, huge differences exist among the multilateral agencies. For example, the EU has increased green aid by 600% and the World Bank by 89% (Hicks, Parks, Roberts & Tierney, 2008). The World Bank is crucial as it is responsible for one third of all aid from multilateral banks and is considered to be a trustworthy first-mover, in many cases leveraging additional funds from other banks. This is important as multilateral banks, on average, have not reduced their dirty aid since 1999.

According to Friends of the Earth, in recent years the World Bank has increased its funding for oil, coal and gas projects. Like the World Bank, the European Investment Bank invested more than $3 billion into fossil-fuel related projects in 2007 (Lyman, 2008). In 2008, the World Bank approved a $450 million loan for a massive 4,000 megawatt coal project in India, expected to emit more emissions than some entire countries. By this measure, the World Bank was also leveraging more than $4 billion in overall funding. The Bank also plans to finance a coal-fired project in Mmamabula, Botswana. A reasonable shadow price for carbon would make this project less attractive and other technologies such as concentrated solar power (CSP) would become more competitive (Wheeler, 2008).[3] Central power plants also tend to increase energy inequality when rural areas cannot get access to a grid. Hence, a mix of a medium-sized CSP plant and seed funding for a market for microgrids is in many cases more appropriate.

The investment portfolios of MDBs can be made more sustainable. For example, accounting practice still regards environmental assessment as an add-on, rather than an integral part of project evaluation.[4] We suggest that donor governments withhold World Bank funds until it changes its incentives for personal advancement and its accounting practices. The bank should also establish carbon shadow prices for all its projects and explicitly evaluate land-use changes, e.g., through logging. It could consider a complete ban on fossil fuel projects, a step suggested in the Bank's own 2004 Extractive Industries Review. Also, personal advancement in development banks is sometimes based on the size and revenue flow of the funds an employee manages, thus promoting large-scale projects that are usually less sustainable. Internal career incentives could be structured around sustainability indicators.

Of course, divestment of carbon-producing systems is also required within OECD countries. For example, at present, Germany annually adds seven coal power plants, totaling about 8500 MW or 7% of current installed capacity. Investments in sustainable technologies do not mitigate climate change if dirty technologies continue to receive large-scale financing. Moreover, governments continue to subsidize the use of fossil fuels and need to rethink their policies to tackle climate change (UNEP, 2008b). OECD countries must also rethink their overseas development aid (ODA). Thus far, they are only providing 4% of the aid to mitigate climate change that they promised in 1992 at the Rio conference, and their total green aid is only 15% of what they promised (Hicks et al., 2008). These observations call for efforts to scale up green aid by a factor of ten. Some funding can come from scrapping dirty aid projects, but overall the aid must be doubled. It is crucial that projects integrate the needs of local communities and contribute to sustainable development—complementing the CDM where it fails to live up to its potential.

CLEAN ENERGY TECHNOLOGIES: NEEDED AND VALUABLE

Innovation is the main driver for new infrastructures and employment, but what drives innovation? Because it is a public good, governments must play a role in funding basic research to answer this question. Robert Solow (1957), the Economics Nobel laureate, estimated that over 90% of new economic growth results from public and private sector investments in innovation. A range of estimates using diverse methods from other researchers and government agencies supports this finding. While investment in research and development is roughly 3% of the U.S. GDP, it is roughly *one-tenth* of that in the energy sector. Careful funding of research is crucial to leverage high returns in terms of renewable energy deployment. For example, the market for CSP does not contain much room for investments into technology innovation, but moderate amounts of funding for research could help move CSP along the endogenous learning curve. The new U.S. administration has already indicated that it intends to increase R&D funding in energy research by a factor of ten, to $15 billion. Countries that seek to participate in future lucrative sustainable energy technology (SET) markets can follow suit. Above, in the section on technology options and cities, we pointed out specific areas of suggested research. But equally crucial research must go beyond specific energy generation or efficiency gains, for example considering appropriate demand management and ways to optimize infrastructure.

Government banks and development banks should also provide liquidity for large-scale wind and CSP projects and reduce the barrier created by high front-up costs. A boom in renewable energy projects can provide an urgently needed boost for job markets. Three to five times as many jobs were created when an investment was made in renewable energy compared to a similar one in fossil-fuel energy systems (Kammen, Kapadia, & Fripp, 2004; Kammen, 2007; Engel and Kammen, 2009). Furthermore, government and donor banks can take the risk of investing in uncertain projects, like geothermal exploration.

INSTITUTIONAL INTEGRATION IN AGENCIES AND IN THE BALI PROCESS

To utilize the wider economics and political opportunities of the co-benefits of climate protection with the direct message of climate risks will require a multi-sectoral dialog and set of metrics. Up to now, climate change policies have largely been a matter for environmental ministries that have had little authority over energy, housing, transportation, and commercial activities. This is a natural beginning, but in the long term it is not enough to design a few, or even many, well-structured programs. To confront climate change and to design a more sustainable energy system will require developing a set of goals, along with objectives for the public and private sectors; then they must be articulated, and applied fairly across the economy. Special attention must be paid to the situation of poor and disadvantaged communities (in *both* industrialized and industrializing nations), and to ways to encourage and disseminate innovative clean energy technologies, practices, and accords. Such a policy framework ideally would address basic research and the dissemination and diffusion of technology, and must include the energy and climate decisions made both by households and communities, and by national and international institutions.

What implications does our perspective have for an international climate regime?

Let us take the transportation sector and avoided deforestation as examples. The transportation sector has the fastest-growing GHG emissions, but has been widely ignored in the international climate regime. Investments and programs for mitigating its contribution to climate change have been disappointing, across both institutions and countries. For example, only 0.1% to 0.2% of all Certified Emission Reductions of CDM are attributed to transportation. The most important contribution to mitigation in the transport sector has been through unreported actions in developing countries. The current CDM framework focuses on single-source, context-detached, quantifiable, and technology-oriented measures, but for the transportation sector this approach entails high transaction costs and tough verification obstacles. However, if a system takes an Avoid-Shift-Improve approach to urban transport, that could lead to significant reductions in GHG emissions and huge co-benefits (Huizenga, Dalkmann, & Sanchez, 2009). In such a paradigm, future emissions are avoided as improved accessibility and better integration of transport and land-use planning reduce the need for travel. Thus travel is shifted to sustainable modes and both the transport systems and vehicles become more efficient.

For example, a city toll for Beijing (a la the congestion pricing in London), along with a synergetic expansion in bus rapid transit and non-motorized transport has been estimated to produce more than 10 billion RMB annually in co-benefits (Creutzig & He, 2009). Barriers to implementation often remain when no one measures the co-benefits and institutional segregation (Creutzig, Thomas, Kammen, & Deakin, 2009). An ideal way to support cities in non-Annex-I countries is a sectoral approach, such as sectoral crediting, that rewards successful measures to manage transportation demands.

In the area of avoiding deforestation, we suggest a combined effort by behavioral and institutional economists, biologists, ecologists and anthropologists, along with local, national and supranational stakeholders. Together they can design institutions that can successfully protect the forests. Instruments and institutions are appropriate if they follow five principles: environmental effectiveness, economic efficiency, distributional fairness, political feasibility and robustness against gaming and manipulation. The last requirement—robustness—is only instrumental with respect to the others but it is important to avoid outcomes like the current European trading scheme or the CDM scheme. As these schemes show, a design focused on market efficiency easily leads the market participants to engage in gaming behavior and vested financial interests can access it too easily. In particular, a purely monetary reward can crowd out community resource management regimes. To avoid deforestation and to preserve and enhance sustainable community management, we must focus on capacity building and land-use taxation and slowly phase in certificate trading in order to avoid compromising environmental effectiveness and the robustness needed for economic efficiency.

Two actions will make the future climate regime more acceptable and politically feasible: implement it in a variety of local contexts and relate mitigation measures to co-benefits. These actions are crucial if we are to make the change to a sustainable economy.

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Endnotes

1 www.desertec.org
2 An inclusive notion of human well-being would also consider civil and political liberties.
3 Note that the cost assumptions of this study can be disputed.
4 A standard argument is that more thorough accounting would be too complicated as it would increase transaction costs. However, an order-of-magnitude estimation of carbon emissions from a coal power plant can be done in a few minutes.

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