A Possible Turning Point for Climate Change Solutions:

How Innovations in Investment, Technology and Policy Are Needed for Emissions Stabilization

A White Paper Prepared for the Montreal Strategic Climate Change Workshop on Sub-National Strategies for Clean Energy Investment, Technology Deployment and Innovation*

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* This paper is intended as a springboard for discussion for the Montreal Strategic Climate Change Workshop on Sub-National Clean Energy Investment, Technology Deployment and Innovation, to be held at Château Vaudreuil, Montreal, from October 3–5, 2005. It is expected that the outcomes of the workshop will be incorporated into this white paper, which will in turn be presented as input to the sub-national conference at the Eleventh Conference of the Parties (COP-11)/First Meeting of the Parties (MOP-1) to the United Nations Framework Convention on Climate Change.

Clean Energy Group (CEG) is a leading non-profit advocacy organization, active in the U.S. and internationally on a variety of clean energy and climate change issues. CEG works directly with various public fund managers, private investors and business academics to develop more effective and transferable models for change in the clean energy sector. In 2002, CEG was instrumental in the formation of a new alliance of U.S.-based, public clean energy funds, the Clean Energy States Alliance, or CESA (www.cleanenergystates.org). This 12-state coalition includes 16 clean energy funds that will invest nearly $4 billion in the next ten years to support clean energy technology markets.

CEG is the non-profit manager of CESA, and assists CESA member funds in multi-state strategies to develop and promote clean energy[1] technologies and to create and expand the markets for these technologies.

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[1] Each member has its own definition of eligible technologies that controls their individual activities, but for purposes of CESA, "clean energy" is defined to include energy production from solar, wind, small hydro, biomass, ocean thermal, tidal and wave, fuel cells, and related energy storage and conversion technologies.

Introduction

We stand at a crossroads for climate change policy. A timely series of events has transpired over the summer of 2005 that, through a combination of disparate forces, could provide the necessary momentum and direction to move forward on international climate stabilization solutions through technology-based agreements.

Much like a tipping point, this confluence of elements suggests a new environment for collaborative action on climate change--one that is grounded in achieving low-carbon climate solutions on economic development terms through policy, investment and clean technology innovation & diffusion--not only at the international level, but also at the sub-global level.

Over the past few years, a growing body of academic literature and theories on technology- and investment-based climate agreements developed in parallel to the often tumultuous negotiations of the Kyoto Protocol. Rather than focusing exclusively on *results* by setting targets and timetables for greenhouse gas emissions reductions, these technology-finance-policy approaches focus on investment and innovation *actions* to mitigate climate change. Whether by intention or later interpretation, many of these "alternative" approaches were initially viewed by some as a strategic threat to the Kyoto Protocol. Some felt that recognition or adoption of a model other than Kyoto would weaken international commitment to the climate treaty. Others maintained that many of these theories would have been complementary to the "targets and timetables" approach embraced by the Kyoto treaty.

With the mounting recognition[2] that much deeper cuts in emissions[3] will be required beyond Kyoto measures to achieve climate stabilization, these technology-investment-innovation-based approaches to climate mitigation are again in the spotlight. This call for innovative strategies has recently been echoed in the outcomes of the G8, as well as in statements and publications from other diverse parties, ranging from the British House of Lords to the European Environment Agency to one of the most conservative members of the U.S. Senate. Taken together, these events signal a sea change in the willingness of the international community to move toward adopting such a technology-investment-innovation-based approach to climate.

It is clearly evident that there is a new swell of interest in complementary approaches to climate change mitigation. However, recent developments attest that no one in the climate community has yet to comprehensively figure out <u>how</u> to approach the critical elements of what a technology-investment-innovation-based climate protocol might look like. There are many pieces to this complex puzzle:

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[2] We will not replicate the full list of various climate stabilization arguments vis-à-vis Kyoto measures here, as the need for deeper emissions cuts is well-documented. For example, Scott Barrett of the Johns Hopkins University School of Advanced International Studies states in a recent paper (Barrett, 2005), "One thing is clear: Kyoto will not stabilize concentrations at any level, let alone one that avoids 'dangerous interference' with the climate...Stabilization will require deeper cuts, by more countries; and these will need to be permanent. By design, Kyoto's importance lay in creating a foundation upon which *further* emission reductions could be achieved. Kyoto was intended to be a first step."

[3] In March 2005, the European Environment Council recommended climate stabilization levels of 15-30% below 1990 levels by 2020 and 60-80% below 1990 by 2050.

- How do we achieve mainstream commercialization of low-carbon technologies?
- How do we link commercialization strategies among various technologies to leverage deep emissions reductions?
- How do we integrate an economic development approach within technology-investment-innovation-based climate strategies to ensure success?
- How do we better coordinate joint activities among current and future clean energy investors and practitioners to greatly accelerate clean energy commercialization?
- How do we apply technology innovation principles to clean energy and climate activities?
- How do we create complementary and synergistic relationships between federal, state, international and private sector low-carbon technology investment-innovation-diffusion activities?
- How do we rapidly create new dedicated streams of capital for low-carbon technologies?

This list represents only a starting point for discussion. As we contemplate avenues for a technology-investment-innovation-based climate regime, are there models that already combine elements of investment in low-carbon technologies and deployment strategies that could be explored for lessons and options?

We think so. Several models of clean energy investment, technology deployment and collaboration are already working at the sub-global level--in states, provinces and regions--that could provide options for climate action going forward.

In the U.S. alone over the last five years, state clean energy funds have invested and obligated more than $1.5 billion through a growing variety of public finance instruments including grants, rebates, loans and equity investments to spur the development and deployment of clean energy technologies. In the coming decade, these state funds are currently budgeted to invest another $2.5 billion. Some states are also focusing their technology investment activities to take advantage of related economic development and technology innovation opportunities by investing directly in clean energy companies.

We believe these emerging investment models could inform any future technology-investment-innovation-based climate protocol, especially an agreement based on collaborative investment and technology innovation for low-carbon technologies. Yet we also recognize that far more discussion is needed, especially in the area of technology innovation, if we are to develop investment-innovation-diffusion strategies that will lead to climate stabilization. Indeed, we face a massive gap between clean energy technology commercialization and deployment strategies and an operational framework for climate stabilization.

Furthermore, we believe the complexity of the problem and the nature of the solutions requires that this debate should take place at various levels (international, sub-national, etc.) and within multiple frameworks (i.e., fora for sub-national stakeholders as well as the United Nations Framework Convention on Climate Change or the G8 Dialogue on Climate Change). To be clear, our aim is <u>not</u> to challenge the approach or institutions agreed to under Kyoto or the G8 action plan on climate change; rather, we believe there is a distinct role for sub-national actors, such as the state clean energy funds, to inform these processes.

Now is the time to work together to discover how investment and commercialization strategies for clean energy technologies could play a part in any future technology-investment-innovation-based agreement aimed at climate stabilization. It is in this spirit that we hope others will join us in our effort to chart out options and answers for this complementary approach.

Prevailing Factors--The G8 and Other Recent Developments in Context

There is now a well-developed academic literature on technology-investment-innovation-based approaches to achieve climate stabilization. This work comes from various scholars and diplomats including Scott Barrett at the Johns Hopkins School of Advanced International Studies, Carlo Carraro and Barbara Buchner at Fondazione Eni Enrico Mattei, Thomas Schelling and Richard Benedick at the University of Maryland, Robert Socolow and Stephen Pacala at Princeton University, and Jonathan Pershing and Robert Bradley at WRI, among others. In short, this growing body of writing recognizes the importance of strategically incorporating technology solutions into the climate end-game. These authors support the viability of a new approach to climate change policy grounded in low-carbon technology innovation and diffusion.

Some of their key findings include:

- ✓ The Kyoto model is linear, with one agreement following the last in succession. A better approach, in my view, would be to adopt a number of different, mutually reinforcing protocols--agreements that would need to be adjusted and amended over time. To make a difference to the climate, a treaty has to create incentives for long-term technical innovation (Barrett, 2005).

- ✓ [Various papers explore] the idea of replacing international cooperation on greenhouse gas emission control with international cooperation on climate-related technological innovation and diffusion... More radical proposals are based on the observation, largely shared by climate scientists, that without a real technological breakthrough it will be very difficult to achieve the stabilization of GHG concentrations. Therefore, an effective climate regime should be based on measures that enhance climate friendly technology innovation and dissemination (Buchner and Carraro, 2004).

- ✓ When the OECD countries do get serious about climate change, they should focus on actions – policies, programs, taxes, subsidies, regulations, investments, energy technology research and development … (Schelling, 1997).

- ✓ Serious global climate change can be averted only if, first, we develop a new generation of cost-effective technologies that dramatically reduce dependence on fossil fuels and/or that capture and sequester carbon...What is needed now is a farsighted strategic vision that explicitly addresses issues of technology research, development, and diffusion, aimed an nothing less than a technological revolution in energy production and consumption (Benedick, 2001).

- ✓ Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. A portfolio of technologies now exists to meet the world's energy needs over the next

> 50 years and limit atmospheric CO_2 to a trajectory that avoids a doubling of the preindustrial concentration...Humanity can solve the carbon and climate problem in the first half of this century simply by scaling up what we already know how to do (Pacala and Socolow, 2004).

- ✓ ...There is arguably a need to look for other avenues for concerted action, provided such action is consistent with or complementary to the aims and processes of Kyoto. With this perspective in mind...constructive agreements should be explored at the sub-global level that would have the advantage of producing real emission reductions while at the same time paving the way for engagement at the larger global level by countries whose ultimate participation in a global regime is imperative (Pershing and Bradley, 2005).

As we will see, the idea of a technology-investment-innovation-based approach to climate is undoubtedly gaining ground with international climate change policymakers. The summer of 2005 has witnessed several new developments and directions that further solidify the need for an approach to climate change mitigation that is grounded in technology, economic development and innovation.

Climate as Economic Development

On June 22, 2005 as part of the U.S. Senate deliberations on the Energy Bill, the Senate voted against the passage of the McCain-Lieberman amendment on climate change.[4] This proposed legislation would have imposed limitations on greenhouse gas emissions in the United States through a cap-and-trade system. In lieu of this legislation, a Sense of the Senate Resolution on Climate Change was passed, stating that such legislation should be enacted at some point in the near future, and confirmed a majority view that action on climate change is needed.[5]

Our purpose here is not to discuss the merits or approach of this legislation. Instead, we call attention to a statement made by Republican Senator Mike DeWine of Ohio--one of the more conservative members of the Senate--that was offered during the McCain-Lieberman bill discussion. In a floor speech, Senator DeWine advocated a new willingness to take action on climate change through a progressive, technology-based approach:

> As the world's biggest emitter of greenhouse gases, the United States has an obligation to take the lead in efforts to control climate change. We have an obligation to be an engaged global player. We have an obligation to urge other nations to join efforts to lower emissions.

[4] The Climate Stewardship and Innovation Act of 2005.

[5] "It is the sense of the Senate that, before the end of the first session of the 109th Congress, Congress should enact a comprehensive and effective national program of mandatory, market-based limits on emissions of greenhouse gases that slow, stop, and reverse the growth of such emissions at a rate and in a manner that 1) will not significantly harm the United States economy; and 2) will encourage comparable action by other nations that are major trading partners and key contributors to global emissions." See the Congressional Record for additional debate on this issue: http://frwebgate.access.gpo.gov/cgi-bin/getpage.cgi?position=all&page=S7033&dbname=2005_record.

> It is time for our Nation to get into the driver's seat and take the lead in developing the technology and the alternate energy sources that will become an inevitable part of our economy. Right now, we are falling behind. Japan and Europe are well on their way to developing the very technologies that will be necessary to retrofit our power plants and make our cars environmentally friendly. We should be the ones developing that technology. We should be the ones designing and creating and inventing the tools we need to adapt and adjust to the future.
>
> Let me repeat: Climate change is happening, Mr. President, and a shift to a new global energy economy is also happening. We cannot avoid it. It is inevitable. And, without question, we are going to have to change operations and clean up our power plants and find alternatives to oil and gasoline. Do we want to be the buyers of the technology that gets us there? Or rather, do we want to be the sellers?[6]

We include the senator's statement here as further evidence of the acceptance of climate action through a technology-investment-innovation-based approach (and because he is not a member of the usual chorus of climate change policymakers). Senator DeWine's remarks are a bellwether for increased understanding of the importance of economic development and potential job growth related to what he terms the "transition to the new energy economy." This statement is a strong and timely signal that there is a momentous change taking place--we are moving beyond the stalemate of the uncertainties related to climate change toward a consensus view that there are significant economic development benefits that can stem from climate innovation.

The G8 Connection

On July 8, a few days following the passage of the Energy Bill in the Senate, G8 ministers were unable to reach a new international (Kyoto-like) agreement on climate change at the Gleneagles Summit. However, the G8 issued an action plan and communiqué on climate change, clean energy and sustainable development affirming the obligation of the international community to find new means to finance the transition to cleaner energy. They also established a Climate Change Working Group to guide the action plan. The G8 ministers pledged at Gleneagles to:

> Support a market-led approach to encouraging energy efficiency and accelerating investment and the deployment of cleaner technologies which will help transition to a low-emission future; adopt, where appropriate market-based policy frameworks which:
>
> - support re-investment in capital stock turnover;
> - remove barriers to direct investment;
> - leverage private capital for clean development; and
> - use standards, or use pricing and regulatory signals to provide confidence in the near- and long-term value of investments, so as to reduce emissions of greenhouse gases and/or pollutants.

[6] Speech by Senator Mike DeWine, given on June 22, 2005; see http://dewine.senate.gov/pressapp/record.cfm?id=239322.

> We will promote dialogue on the role, suitability, potential synergies and timing of various policy approaches within the context of each country's national circumstances, including:
>
> - developing long-term sectoral, national or international policy frameworks, including goals;
> - market-based instruments including fiscal or other incentives for the development and deployment of technologies... (G8, 2005).

The G8 ministers' commitment to establish a formal dialogue to discuss these approaches is encouraging. Yet the lack of concrete measures identified in the G8 debates and resulting text, and the action plan's reliance upon global institutions such as the World Bank, the Global Environmental Facility and the International Energy Agency, (and their respective programs and investment mechanisms) to carry out this work is of concern unless a broader stakeholder process is incorporated into current plans.

Furthermore, and perhaps even more telling, the G8 directive does not provide for any new investment funds or new finance tools to support the work called for by the action plan. Without a new infusion of capital to support this work, it is difficult to envision that many concrete results will stem from these already capital-constrained programs, or that the critical innovative measures needed to move clean energy technology markets will be created by top-down institutions without a serious inclusion of other sub-global stakeholders. While the results of the G8 were a disappointment to many, these outcomes further support the need for new technology-oriented models and new forms of capital and collaboration to forge a climate stabilization agenda.

Another Call to Action from the House of Lords and the EEA

Two other recent publications echo the G8 outcomes and call for technology-based agreements to mitigate climate change. The first report, entitled "The Economics of Climate Change," was published by the British House of Lords Select Committee on Economic Affairs on July 6; the second report, "Climate Change and a European Low-Carbon Energy System," was released by the European Environment Agency (EEA) on June 29.

Respectively, the following key messages and conclusions from both reports provide further testament to this newfound willingness to adopt a technology-based approach to climate change:

> We are concerned that the international negotiations on climate change reduction will be ineffective because of the preoccupation with setting emissions targets. The Kyoto Protocol makes little difference to rates of warming, and has a naïve compliance mechanism which can only deter countries from signing up to subsequent tighter emissions targets. We urge the Government to take a lead in exploring alternative 'architectures' for future Protocols, based perhaps on agreements on technology and its diffusion (House of Lords Select Committee on Economic Affairs, 2005, from abstract).
>
> In our view, there is a real risk that the international negotiators will render their own efforts fruitless if they persist in an exclusive adoption of the targets-based approach...While the Kyoto Protocol should, in principle, encourage technological

> change, we are not convinced that it has sufficient focus on this central issue (House of Lords, 2005, paragraphs 131-132).
>
> It could be argued that it is late in the day to be suggesting a significant change of focus in the climate negotiations. But we fear that the present 'more of the same' approach, focusing on targets for emissions reductions, will fail. It is better to aim for cost-effective technologies, and the right balance between adaptation and mitigation (House of Lords, 2005, paragraph 136).
>
> There appears to be growing support for the idea that Kyoto-plus should focus on technology and research and development...International agreement on R&D in low or zero-greenhouse gas technology might help to lower future costs of these technologies at a rapid rate. In the same vein, the bigger the scale of the technological innovation, the lower the costs of adopting it (House of Lords, 2005, paragraph 141).

Admittedly, the report states, "we do not pretend to have worked through in any detail proposals of the kind outlined above. The important issue is to wean the international negotiators away from excessive reliance on the 'targets and penalties' approach embodied in Kyoto...there should be urgent progress towards thinking about wholly different, and more promising, approaches based on a careful analysis of the incentives that countries have to agree to any measures adopted," (House of Lords, 2005, paragraph 143).

Similarly, the new report from the European Environment Agency, "Climate Change and a European Low-Carbon Energy System," emphasizes that we need to go well beyond Kyoto measures to achieve climate stabilization. The EEA states that major investment in low-carbon technology is needed on top of a global carbon tax to reach climate stabilization levels:[7]

> There needs to be greater support for research, development and demonstration into sustainable energy technologies in order to support and promote innovation...R&D on the emerging sustainable energy technologies such as renewable energy, carbon capture and storage, energy efficiency, hydrogen and fuel cells could yield significant cost reductions and performance improvements over time. R&D expenditure should address a variety of low-carbon technologies on the supply and the demand side in order to keep different options open...Making commitments to innovation in low-carbon technologies would have the added benefit of introducing a new element to the international dialogue on policies for addressing climate change, which may appeal to some of the countries that are sceptical of the Kyoto Protocol. An innovation-oriented technology and climate action could also contribute to the creation of a lead market, resulting in future economic benefits ("first-mover advantage"), (EEA, 2005, p. 57).

Yet again, as is the case with the House of Lords report, the EEA findings fail to indicate a clear path for how the international community should go about developing investment and commercialization strategies for low-carbon technologies. Both reports indicate a willingness to move toward a technology-investment-innovation-based protocol but offer no substantive suggestions as to how that would be achieved. Furthermore, the reports do not place much

[7] The EEA report uses the European Environment Council-recommended climate stabilization levels of 15-30% below 1990 levels by 2020 and 60-80% below 1990 by 2050.

attention on the importance of going beyond R&D agreements to also focus on the critical funding needed for deployment and commercialization.

One step in the direction of outlining specific technology options is found in a new paper from Jonathan Pershing and Robert Bradley of WRI. "A Climate Solution Concept," which was released in conjunction with the G8 deliberations, offers three possible sub-global technology options for the new G8 Climate Working Group to consider. These include 1) loan guarantees for CO_2-capture-ready Integrated Gasification Combined Cycle (IGCC) plants, 2) promoting biofuels through the diversion of agricultural subsidies, and 3) stimulating the market penetration of highly efficient vehicles (Pershing and Bradley, 2005). Pershing and Bradley favor such sub-global approaches to both inform the G8 process, and serve as a testing ground for real emissions reductions and implementation of investment and technology deployment policies. They recommend that, "...action at the sub-global level should be explored with vigor and commitment."

A Closer Look at Options: Sub-National Strategies and Other Trends

Historically, the "laboratories of experimentation" have been most commonly found at the sub-global, or state, level. States often play the essential role of bringing R&D (developed at federal or state level) to the critical stages of deployment and commercialization.[8] Perhaps more importantly, a growing number of states already view economic development and climate protection through the same lens. In these terms, states see low-carbon technologies as a large market growth opportunity over the next decade. It could be the most significant energy growth sector in the medium term for U.S. and European generation and energy investment markets. Annual U.S. installations of renewable energy are expected to increase by a factor of five in the next ten years.

Decades of research and development advances, driven largely by government investments, have led to a proliferation of clean energy technologies. Recent growth rates of over 20 percent per year are common in the wind and photovoltaic industries. Fuel cell markets are also growing, with the technology providing reliable, high-quality power for critical facilities such as police stations and hospitals, among other applications.

These prospects for growth are attracting both public and private investment capital. In addition to states, venture firms, state pension funds and other private investors have begun to explore ways to invest. In 2004, $900 million was invested in U.S. energy technology companies from venture capital funds, increasing the share of all VC clean technology investing to 4.5 percent for that year. By comparison, 2003 levels were $428 million, or roughly 2.4 percent of all VC investment.

[8] For further reading on specific public finance mechanisms for clean energy and the role of states in clean energy technology development and deployment, see "Global Clean Energy Markets: The Strategic Role of Public Investment and Innovation," and "Clean Energy States Alliance Year One: A Report on Clean Energy Funds in the U.S. 2003-2004" at www.cleanenergystates.org.

Pension funds and other institutional investors are considering investments in clean energy technologies.[9] The recent $1 billion commitment by members of the Investor Network on Climate Risk to invest in clean technologies over the next year is indicative of the enormous capital potential these investors can bring to clean energy markets.[10]

There is similar low-carbon investment and innovation activity taking place across the globe at both national and sub-federal levels:[11]

- In Europe, organizations such as the Carbon Trust in the United Kingdom are fostering clean technology innovation through a range of grants and equity investments to move the UK toward a low-carbon economy.
- In Germany, states such as North Rhine-Westphalia and Schleswig-Holstein have supported renewable energy technology projects and companies through state support in addition to public support at the national level through the German feed-in tariff.
- In Canada, the new Climate Change Plan includes billions in new funding for climate change mitigation through the use of cleaner technologies. For example, the $250 million Partnership Fund will provide federal-provincial support for major technology and infrastructure strategic investments. Support for large Canadian greenhouse gas emitters will come through a long term Greenhouse Gas Technology Investment Fund to make strategic investments in new, innovative technologies or processes to reduce emissions.
- China is taking an economic development approach to clean energy through groundbreaking renewable energy legislation introduced in 2005. In addition to a feed-in tariff for renewable energy, China will support a technology fund for the development of clean energy projects and companies.

While these trends in clean energy investment and technology adoption are encouraging, the current scale for low-carbon technologies remains extremely small. While solar and wind power in the last five years have surged with over 30 percent annual growth, they still represent less than 1 percent of global electricity generation. Including small-scale hydroelectric and fuel cells, the overall figure for clean energy today is between 3–4 percent of total electric generation in the U.S.

A low-carbon future will not be self-executing. Even if a new technology-investment-innovation-based climate regime were to outlay major new sources of capital today, we currently do not have a sound strategy to invest those dollars tomorrow in the manner that would accelerate

[9] Several states are working together through a joint Clean Energy Group-Ceres Clean Energy Investor Working Group to explore the interests of pension funds, institutional investors and other fiduciaries in developing enhanced, environmentally responsive investment strategies in the clean energy subsector that can deliver competitive returns to participating investors.

[10] Two California state pension funds, CalPERS and CalSTRS, are leading a wave of institutional investors, having made commitments of $450 million in private equity investment in clean energy technologies. CalPERS has also approved $500 million in investment in environmentally screened stocks.

[11] A new report that provides a thorough assessment of sustainable energy finance mechanisms will be released by the United Nations Environment Programme Sustainable Energy Finance Initiative and CEG in fall 2005.

innovation of current low-carbon technologies--and yield future generations of those technologies--that would stabilize our climate. It may be necessary to develop a variety of complementary options that go beyond conventional environmental treaty-based agreements to achieve the level of action and investment required for change.

The Technology Commercialization and Innovation Challenge

Despite positive growth in clean technology deployment and uptake, most current technologies face daunting issues of power density, scalability and economics. In "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years With Current Technologies," Stephen Pacala and Robert Socolow of Princeton University identify a portfolio of existing technology "wedges,"[12] already in various levels of deployment that, with greater effort, could lead to climate stabilization.

These technology wedges include:

- renewable electricity and fuels
- energy efficiency and conservation
- fuel switching
- nuclear fission
- forests and soils
- CO_2 capture and storage

Pacala and Socolow maintain that we already know "what" technologies to use. The fundamental question then, if we indeed hold all the right technologies in hand, is "how" to overcome the multiple barriers that are hindering their commercialization. How do we set a strategy to bring these low-carbon bridge technologies to scale through near- and long-term approaches?

There are various options on the drawing board. Near term (3-25 year) global approaches could include efforts to:

- Stop expanded development of conventional coal plants.
- Expand use of natural gas.
- Commercialize integrated coal gasification combined cycle (IGCC) technologies.
- Increase terrestrial carbon sequestration.
- Conduct universal retrofit of existing diesel vehicles and widespread deployment of both hybrid drive systems biofuels.
- Maximize deployment and utilization of clean energy technologies such as renewables and fuel cells.
- Enhance the integration of "best practice" energy efficiency design elements into the power generation, transport, manufacturing and real estate sectors.

[12] A "wedge" is defined by Pacala and Socolow as an activity reducing the rate of carbon build-up in the atmosphere that grows in 50 years from zero to 1.0 Gt(C)/year.

Long term (2030-2050) technology strategies could include:

- A transition to low- or no-carbon mobility fuels (electricity, hydrogen, or hydrogen-rich liquids).
- Application of biotechnology to fuels production, $C0_2$ capture and mineralization.
- Operational deployment of widespread fossil energy system carbon capture and geologic sequestration.
- Deployment of very high efficiency fossil fuel generation technologies.
- Widespread use of renewable technologies (PV, wind, biomass) in distributed and central generation applications.
- Mainstream application of fuel cells in distributed generation systems.

How do we radically innovate the current stable of low-carbon technologies and further catalyze a major technological shift in the interest of achieving climate stabilization? On the demand side, how can we improve uptake and adoption of these technologies? Can we better employ outside lessons on technology innovation to accelerate commercialization of low-carbon technologies? Are there approaches we can borrow from established innovation business principles?

Relatively little academic research has been conducted to apply historical models of technology innovation to low-carbon technologies. In one of the first publications to conduct such an analysis, [13] Andrew Hargadon, of the University of California at Davis, finds that successful development of clean energy will require attention not just to advances in basic and applied sciences, but also to the commercial dynamics that surround emerging technologies and represent the "tipping point" signaling rapid and widespread adoption (Hargadon, 2004).

> Technical advances alone are not enough to trigger rapid adoption. The revolution depends upon the slow accumulation and maturation of complementary technologies (whose recombination brings about new and innovative capabilities), but also depends upon the details through which they are ultimately introduces: the design of the new venture.
>
> To date, efforts to direct and develop alternative clean energy technologies have taken place largely within the domains of science and social policy. The need exists for better research aimed at effecting change through commercial ventures (Hargadon, 2004).

This leads to another fundamental question: If the international community indeed stands ready to develop a new technology-investment-innovation-based climate change agreement, how do we incorporate this critical missing link--the leap from technical possibilities to commercial application--into the equation?

In "Global Clean Energy Markets: The Strategic Role of Public Investment and Innovation," we outlined several suggestions to guide joint action:

[13] See "Clean Energy & Fuel Cells: Implications for Innovation Strategies from Historic Technology Transitions," at www.cleanenergystates.org.

1. **Develop global networks of clean energy practitioners.** Much greater coordination, cooperation and joint activities among clean energy practitioners are needed to accelerate clean energy commercialization. Rigorous networks of practitioners can begin to create the "social process" of clean energy innovation that is needed for global change.
2. **Understand processes of technology innovation for clean energy.** Coordination...will yield only uninformed chaos without a common understanding of our shared purpose. There is a vast wealth of knowledge about technology innovation that has not been applied to clean energy.
3. **Organize federal, state, international and private sector activities to create complementary and synergistic relationships.** Currently, various federal, state and private players in the U.S. and elsewhere are operating at different places in the technology innovation process. Each has a unique and valuable role, but there is little communication among the players to develop any complementary strategy for how these roles could work better together to leverage each other's success.
4. **Create new public and private funding streams and investment vehicles.** Any successful innovation network will require that more capital be mobilized to accelerate clean energy deployment. In order to bring about the billions of dollars in new capital required to bring clean energy to scale, new funding sources must be created (Brooks, Milford and Schumacher, 2004).

The massive gap between clean energy technology commercialization and deployment strategies must be addressed if we are to successfully employ technology-investment-innovation-based approaches to climate stabilization. We know that there is no "silver bullet" solution that is waiting to be discovered to guide the formation of such a climate protocol. We do know there are many questions to be answered and that it will take unprecedented work by different stakeholders to develop these technology-investment-innovation-based approaches.

We will need to go beyond the climate and clean technology community to engage other fields, most notably experts in finance and technology innovation, to develop solutions to bring about the massive technology and economic transformation needed to create a low-carbon economy.

Conclusion

To move beyond Kyoto requires new market, technology and finance solutions that are firmly rooted in an economic development approach. In essence, we are looking at a massive technology innovation leap, and a parallel finance revolution to mobilize unprecedented levels of public and private capital. No one has worked out a strategy for how that will happen.

To begin those discussions, we call upon academics, clean energy funders, leading business innovation scholars and NGOs to join with us to cross-pollinate the current practice of clean energy funding with ideas of a technology-investment-innovation-based approach to climate stabilization. We hope you will work with us to develop a framework to answer some of these fundamental questions:

- How do we achieve mainstream commercialization of low-carbon technologies?
- How do we link commercialization strategies among various technologies to leverage deep emissions reductions?
- How do we integrate an economic development approach within technology-investment-innovation-based climate strategies to ensure success?

We envision a bottoms up approach by focusing on what needs to be done to address these challenges and, most importantly, on the economic opportunities to advance these new low-carbon technologies.

It is not sufficient for countries to continue to linger in the middle of this conversation. The time is right to seize upon this willingness to try alternative approaches, and to set sights on developing concrete options that will yield real results. We hope this paper is only the beginning of this effort, and that the outcomes of our workshop in Montreal will further inform this process.

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