The Investment Consensus

Literature Review Reveals Expert Consensus on Need for Large Public Investments into Energy Technology Innovation to Stabilize the Climate

A Report Prepared for the Nathan Cummings Foundation by the Breakthrough Institute

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Summary

A review of more than two-dozen comprehensive, peer-reviewed academic studies on energy and climate policy reveals a strong expert consensus that stabilizing the climate will require governments to establish a price for carbon, implement new regulations to encourage technology innovation, and make large, long-term investments into clean energy technology innovation.

The following report summarizes these findings in the words of the energy experts themselves. The focus of this report is on the strong consensus for large increases in public investment into energy innovation.

There is strong agreement about the reasons for the lack of innovation in the energy sector and what should be done about it. As would be expected, there is some disagreement over how investments into energy innovation should be divided between various technologies, such as solar, wind, carbon capture and storage (CCS), nuclear, and geothermal. But even here there is widespread agreement about where greater advances in innovation can be made (e.g., solar and CCS), where greater basic-level research is needed (e.g., ocean power), and which existing technologies can most easily be scaled up at the lowest cost (e.g., wind).

Among policymakers and popular audiences there remains some confusion about whether low and zero-emission energy sources need technological breakthroughs or whether they can be scaled up. Among energy experts, however, there is widespread agreement that while many promising clean energy technologies already exist, it is imperative that, through R&D as well as deployment and procurement, these technologies quickly come down in price so that climate stabilization can occur without excessive costs to the economy.

This review includes major commission-based policy reviews and recommendations, such as the United Nations Intergovernmental Panel on Climate Change, the UK Treasury's Stern Review on the Economics of Climate Change, as well as reports by leading energy experts, such as John Deutsch (MIT), James Edmonds (University of Maryland), Michael Grubb (Cambridge), Martin Hoffert (NYU), John Holdren (Harvard), William Nordhaus (Yale), Richard Richels, as well as younger energy experts such as Gregory Nemet (U of Wisconsin - Madison), Richard Duke, and Karsten Neuhoff (Cambridge). The review is not exhaustive, but it is representative of the field.

I. Climate Change and the Need for Cheap Clean Energy

Dealing with climate change requires new technologies at a massive scale.

- "Reducing carbon emissions will undoubtedly require introduction of new energy technology on a vast scale – coal gasification, carbon capture and sequestration, alternative fuels for transportation, greater use of biomass feedstock, better energy efficiency in production, transportation and end-use, carbon free electricity generation from solar, wind, geothermal, and nuclear" (Deutsch 2005: 2).

Advanced clean energy technologies that can meet global energy needs do not yet exist.

- "Energy sources that can produce 100 to 300 percent of the present world power consumption without producing greenhouse emissions do not exist operationally or as pilot projects" (Hoffert *et al.* 2002: 981)

Massive technological improvement needed.

- The technical challenge, to invent and globally deploy energy systems that progressively release less CO_2, is unprecedented. The century-scale challenge implies that better technologies will be continuously needed in the near, middle, and long terms if costs are to be controlled" (Edmonds et al. 2007: 9).

- At the present time, there are insufficient supplies of low cost substitutes for high carbon emitting technologies. Currently we are limited primarily to fuel switching and price induced conservation, both of which will come with a sizeable price tag. To develop the technological wherewithal to do the heavy lifting in the future is essential for managing the costs of the transition. This will require both a sustained commitment on the part of the public sector upstream in the R&D chain and incentives for the private sector to bring the necessary technologies to the marketplace" (Richels *et al..* 2007: 14)

- "Efforts to mitigate global climate change will require technological innovations deployed on a massive scale… [S]ubstantial reductions in U.S.

CO_2emissions would require that the United States replace or retrofit hundreds of electric power plants and tens of millions of vehicles. In addition, appliances, furnaces, building systems, and factory equipment numbering in the hundreds of millions might also need to be modified or replaced. Technological change on this scale cannot happen overnight. Many of the technologies needed do not yet exist commercially or are too costly" (Alic et al.. 2003: 5)

- "Stabilizing greenhouse gas concentrations will require even greater technological change. That change will take dedicated resources; supportive policies, including those that facilitate technology innovation, development and deployment; emissions mitigation policies; and the adoption of a timeframe that is consistent with the climate change challenge" (Edmonds et al. 2007: 32)

Non-incremental technological improvements required.

- "Fundamental changes in the world's expanding energy system are required to stabilize concentrations of greenhouse gases in the atmosphere. Incremental improvements in technology will help, but will not by themselves lead to stabilization" (Edmonds et al. 2007: 11)

Clean energy alternatives still far more expensive than fossil fuels

- "At present, we have insufficient economically competitive substitutes for high carbon emitting technologies. The development of low- to zero-emitting alternatives will require both a sustained commitment on the part of the public sector upstream in the R&D chain and incentives for the private sector to bring the necessary technologies to the marketplace" (Richels *et al..* 2007).

Scaling up clean energy requires major cost reductions through innovation.

- "To be sure, achieving nearly every one of the wedges requires new science and engineering to squeeze down costs and address the problems that inevitably accompany widespread deployment of new technologies" (Socolow and Pacala 2006: 53)

- "Bernstein et al.. (2006) used simulation results to show that the effect on national energy expenditures of high penetration rates of renewables depends primarily on the relative technological change of renewables versus fossil fuels. But improvements to technologies require investment (Grubb, 2001)" (Nemet 2007: 2 – 3).

Innovation requires government investment.

- "Federal support to basic and applied research and for the creation of research facilities has a long history in this country. No other nation has remotely as successful an enterprise, and our practices are the model for the rest of the world. The hallmark of the U.S. approach is project selection according to merit, and, in general, flexibility in accommodating education as an important byproduct of funded research activity. The successful government manager in an agency that fosters technology creation is knowledgeable about advances in the field and attentive to outside expert opinion; direct support of R&D projects is the manager's major tool" (Deutsch 2005: 5)

II. The Need for Investment

Technology change has long been driven by government investment.

- "Public policies affecting technological change go back to the codification of the patent system in the Constitution. A federal grant in 1844 underwrote the demonstration of the telegraph. Financial guarantees, grants, and loans supported construction of a national rail network. Federal land grants underwrote the U.S. system of publicly financed colleges and universities, which became major players in R&D and innovation. Federal legislation in the 19thcentury also created an elaborate system to support technology adoption and learning-by-using in agriculture, spurring productivity growth and innovation in a vital sector of the economy. Government procurement during World War I transformed an infant aircraft industry that had produced a cumulative total of only a few hundred planes; by the war's end, U.S. firms had manufactured some 14,000 planes, with much concomitant learning. Government-spurred innovation accelerated in the post-World War II period. Despite the heterogeneity in federal policies—or perhaps because of it, given the high levels of uncertainty that characterize innovation—government actions have been remarkably effective" (Alic *et al.* 2003: 5)

- Digital electronics technologies emerged in the United States after World War II, supported by an R&D infrastructure created largely through federal spending. National security motivated most of the government's investments. The decentralized nature of U.S. policies allowed innovators to search for support in many different agencies and programs, even within DoD, helping domestic firms stay ahead of their rivals in other countries and leading to a competitive and rigorous "selection environment" that ruthlessly weeded out less effective firms and technical solutions" (Alic *et al.* 2003: 36)

Past energy tech innovation due to investment.

- "Past investments in [Energy Technology Innovation], public and private, led to large improvements over the course of the twentieth century in the performance of specific energy technologies, energy sectors, and the whole energy systems of nations and the world, as measured in increased technical efficiency, increased reliability, and decreased cost and environmental impact per unit of energy output and per unit of economic product" (Sims Gallagher *et al.* 2006: 227).

Government investment was crucial for wind and biofuels breakthroughs

- "Development of the Danish wind and Brazilian biofuels industries each required sustained government support over decades. The Danish subsidies totaled $1.3bn, and Danish wind companies now earn more than that each year (Carbon Trust, 2003). At current oil prices, Brazil may soon similarly recoup its investment in biofuel technology" (Grubb 2004: 26 – 27)

DoD buy-down of price of microchips and other policies helped create Silicon Valley

- "DoD procurement policies also had considerable influence on industry structure. Contracts stipulating that chips be available from at least two suppliers led to the sharing of design and process know-how, which encouraged new entries and accelerated interfirm technology flows. Together, the policies of DoD and DOJ expanded the number and diversity of alternatives explored during a period of significant technological uncertainty. They also fostered the intense competition and high labor mobility among engineers, scientists, and managers for which Silicon Valley would later be celebrated" (Alic 2003: 37).

Commercialization of clean energy requires public investment

- "Many of the technologies needed are already available or close to commercialization. But it will require substantial effort and investment by both the public and private sectors for them to be adopted by the market. Pathways need to be opened up to enable these technologies to deliver their full potential. Urgent action is needed to stimulate R&D, to demonstrate and deploy promising technologies, and to provide clear and predictable incentives for low carbon options and diverse energy sources" (Mandil/IEA 2006: 3)

Private energy firms underinvest in innovation.

- "Around the world, the energy sector's ratio of RD&D investments to total revenues is well below that for any other high-tech sector of the economy. In a $45 trillion world economy (calculated using purchasing power parities), fueled by circa $3 trillion worth of energy, total public and private investments in energy RD&D appear to be in the range of$15-20 billion, hence something like half a per- cent of energy expenditures and 0.03 percent of world GDP. These investments will need to be boosted at least 2-3-fold if the world is to meet the energy challenges it faces in the decades immediately ahead" (Holdren 2006: 20)

Private firms will fear knowledge spillover (e.g. through reverse engineering) and thus under-invest in innovation.

- "In the absence of sufficiently strong price signals, policy has tended to focus on specific support to certain technologies. A market view would assert that such support is unnecessary, since private actors would carry out the necessary technology development in response to expectations of future needs. However, there are reasons to suppose that investment in R&D will be lower than optimal in a market-based system because the learning gains from any individual company's investments will also accrue to its competitors (technology spillover). This may also apply at the country level, requiring international policy action to promote sufficient levels of government research and development of new technologies" (Blyth and Hamilton 2006: 11)

Current public and private investment levels are inadequate.

- "Investments by both the private and public sectors in energy research, development, demonstration, and early deployment have been falling short of what is likely to be needed to meet the energy challenges confronting the nation and the world in the 21st Century" (NCEP 2004, xiv).

Lack of innovation due to lack of investment.

- "Probably the most significant barrier to ETI [Energy Technology Innovation] is inadequacy of funds, especially for R&D, in relation to the challenges that are faced by energy system" (Sims Gallagher *et al.* 2006: 221-222).

Conventional approach to energy innovation will not result in adoption of new technology.

- "The social cost of reducing carbon emissions in the long term requires major technical change. Currently, we -- the United States and the world -- do not have the necessary mechanisms in place and are not devoting the level of resources necessary to encourage the needed private sector adoption of new technology. Successful government action requires both more resources and a willingness to change the conventional approach to government's support for energy technology commercialization" (Deutsch 2005: 16).

Current public investment in energy innovation will not reverse growing dependence on imported oil or fossil fuels generally.

- "It is unlikely that DOE's current level of R&D funding or the nation's current energy policies will be sufficient to deploy alternative energy sources in the next 25 years that will reverse our growing dependence on imported oil or the adverse environmental effects of using conventional fossil energy. . . To meet the nation's rising demand for energy, reduce its economic and national security vulnerability to crude oil supply disruptions, and minimize adverse environmental effects, the Congress should consider further stimulating the development and deployment of a diversified energy portfolio by focusing R&D funding on advanced energy technologies" (GAO, 2006).
- "Combined public and private investment in ETI is not remotely commensurate, at present, with the magnitude of the energy challenges faced by individual nations and the world as a whole in the twenty-first century, even allowing for the improvements in innovation management and thus productivity that are likely to be possible with increased understanding and attention. Considerably higher levels of investment are warranted" (Sims Gallagher *et al.* 2006: 231).

Public investment needed because private investment into R&D is inadequate.

- "Support for R&D is especially important in the energy sector to address long-term challenges such as climate change, where the incentives created by demand-pull policy instruments on their own may be insufficient to motivate sufficient investment in early-stage technology development (Jaffe et al.., 2005). The need for R&D support may be especially acute for nascent technologies, e.g. energy storage, and infrastructure-based technologies, whose benefits private investors may find particularly difficult to appropriate" (Nemet 2007: 29)

Public investment will trigger private investment.

- "But the presence of a range of other market failures and barriers mean that carbon pricing alone is not sufficient. Technology policy, the second element of a climate change strategy, is vital to bring forward the range of low-carbon and high-efficiency technologies that will be needed to make deep emissions cuts. Research and development, demonstration, and market support policies can all help to drive innovation, and motivate a response by the private sector" (Stern Review 2006: 308)

- " It should also be noted that government investments in R&D in turn stimulate private-sector investments in innovation" (Sims Gallagher *et al.* 2006: 221-222)

- "Government support of innovation – both technology creation and technology demonstration – is desirable to encourage private investors to adopt new technology… Virtually every energy study recommends that the federal government mount technology research, development, and demonstration (R, D, & D) programs that require large and sustained budgetary support, of course, funded by the taxpayer" (Deutsch 2005: 1)

Private investment is overwhelmingly focused on short-term

- "Federal support of energy R&D peaked in the early 1980s at around $8 billion a year (in 2002 dollars). Since then, it has declined sharply and reached a plateau around $3 billion to $4 billion a year—a tiny fraction of the roughly $100 billion of total public research and development funding in the U.S. Public support for energy research is now inching up, but the effort falls short of that needed to tackle the climate challenge. Private energy R&D support is also rising a bit—witness Silicon Valley's investment in emerging "clean-tech" companies. Investors, however, tend to focus on technologies that are nearing commercial application and potential profit. In the past, the federal R&D tax credits have encouraged firms to spend more on new technology, but Congress has failed to renew the necessary legislation" (Victor and Cullenward 2007).

Advanced energy technologies needed to reduce cost of climate stabilization.

- "The key reason to develop and deploy advanced energy technologies is to control the cost of stabilizing greenhouse gas concentrations" (Edmonds et al. 2007: 9).

III. The Limits of Regulation Only

California can't meet emissions requirements with incremental improvements.

- "While it may be feasible to meet California's greenhouse gas emissions targets for 2010, and even 2020, through incremental efficiency improvements to the existing energy system, meeting the target for 2050 — 80 percent reductions from 1990 levels — cannot be met with incremental improvements to existing technologies" (Nemet 2007).

California will fall short in meeting renewables obligations because of out-clause.

- "The adoption of long term targets into law is encouraging. But they do not eliminate cause for concern. First, the strength of the incentives created by such policies depends not only on the targets themselves but also on the crucial details concerning implementation. For example, investor owned utilities (IOUs) in California have so far fallen short of their renewables obligations in 2003, 2004, and 2005 under the state's Renewable Portfolio Standard (RPS) (CPUC, 2007)… These IOUs are unlikely to meet the 2010 target of 20% renewables given the sum of all existing procurement contracts, even if all pending contracts are signed, all currently short-listed bids are accepted, and all expiring contracts are re-signed (Fig. 6.5)(CPUC, 2007). Assuming all these "probable" contracts end up providing power in 2010, these utilities together will fall short of the target by 2.5 terawatt-hours, or about 1.2 gigawatts of renewables capacity assuming they operate at 25% capacity factor. One might expect that this apparently aggressive target would prompt the development and adoption of new technologies, which, while possibly unproven or expensive, would enable the IOUs to meet the target. But the details of the RPS regulations contain another option. Utilities can simply pay a penalty…'an overall penalty cap of $25 million per utility annually'… a small price to pay relative to the cost of developing, building and operating renewable technologies" (Nemet 2007: 210 – 211)

Out-clauses in national global warming legislation will dampen private investment and innovation.

- "This dampening of the incentives created by out-clauses in future targets exists also for economy-wide programs addressing greenhouse-gas emissions, such as a proposed cap and trade program or carbon tax. In this case, some have suggested that the adoption of "safety valves"—limits on how high the price of carbon can go—would safeguard the macro-economy from excessively onerous costs and would make more stringent climate policy palatable to affected parties… Recent draft greenhouse-gas legislation in the Senate Committee on Energy and Natural Resources proposes a safety valve by limiting the price of carbon emissions credits to $7/ton in 2012 (Bingaman and Specter, 2007). With its proposed 5%/year increases thereafter, the cap in 2050 could reach approximately $15/year in year 2007 dollars, assuming 3%/year inflation. Again, this feature of the implementation of a target would reduce the incentives for investing in new technologies that might enable very large reductions in emissions, but whose costs are expected to be above the price cap. For example, recent estimates of the cost of carbon capture and sequestration (CCS) from coal power plants are in the range of $150–200/ton (Anderson and Newell, 2004). A price cap on carbon that is an order of magnitude lower may severely restrict the incentive for firms to build new coal plants, e.g. with gasification, which are amenable to sequestration later, never mind investing in improving the CCS technology directly" (Nemet 2007: 214)

Industry concern over higher costs results in less stringent incentives and inadequate private sector investment and innovation.

- "In previous cases, governments have backed down from ambitious long term targets once influential stake-holders protested that they faced an unfair burden in meeting them. For example, after passing a mandate in 1990 that 10% of new vehicles sold in 2003 must have no emissions, the California Air Resources Board abandoned the Zero Emissions Vehicles (ZEV) Mandate once automobile manufacturers sued the state (Dixon et al.., 2002; Shaheen et al.., 2002). Subsequently, the ZEV mandate shifted to a much less stringent set of incentives. This case may be especially pernicious, in terms of creating incentives for innovation, because it suggests that policies can change not only due to the vagaries of political priorities, but also because potential innovators decide that lobbying and litigating to soften government imposed targets may be a more effective use of their resources than investing in innovation to meet them" (Nemet 2007: 214)

Price for carbon will not be enough to drive innovation.

- "But a price on CO2 emissions on its own, may not be enough. Governments may need to stimulate the commercialization of low-carbon technologies to increase the number of competitive options available in the future. Examples include wind, photovoltaic power and hybrid cars. Also appropriate are policies designed to prevent the construction of long-lived capital facilities that are mismatched to future policy" (Socolow and Pacala 2006).

Cap and trade unlikely to price carbon high enough.

- "The desirability of the cap is debatable, but one should not expect a regime of stringent, but avoidable targets to stimulate investment in technologies that only pay off at high carbon prices. While a price cap on carbon limits the impact of carbon regulation on the economy, relying on it as the primary source of incentives also limits our ability to reduce emissions later if the impacts become more severe than expected, unless additional and complementary technology development policies are implemented" (Nemet 2007: 214)

Cap and trade will not be enough to drive innovation.

- "The emissions trading system will not be sufficient on its own to solve the problem, but it is a tool for creating the incentives for actions that will result in solutions. Investments in research and development must be focused and significantly increased in order to produce new technology that can replace or radically improve current methods for transportation and the generation of energy" (Josefsson 2006: 37).

If price of carbon remains low, clean energy tech subsidies will be crucial.

- "If the political influence of incumbent energy companies is likely to hold back moves to eliminate subsidies and internalise environmental impacts, then there is a strong case for subsidising renewable energy to prevent an on-going distortion in the choice of technologies that figure in future investment decisions" (Neuhoff 2005: 8).

Carbon price alone won't result in private firms making long-term investments in R&D that are needed.

- "It is sobering to note that true solutions to the carbon problem will require massive deployment of new energy systems that emit little or no carbon and yet are reasonably competitive with current methods [see "A Plan to Keep Carbon in Check," by Robert H. Socolow and Stephen W. Pacala; Scientific American; September 2006]. Getting those new technologies on line will require more than price signals because no company on its own will invest in the necessary speculative and costly research and development concepts To address this predicament, the federal government will have to fund the required research and engineering projects at corporate, university and federal laboratories. Such public-led investments have historically delivered huge, but hard-to-quantify returns to society. Other useful schemes include research tax credits and special mechanisms to reduce risks from uncertain and changing regulations" (Victor and Cullenward 2007).

Lack of innovation can't be reduced to absence of price for carbon.

- Ultimately, the belief that prices alone will solve the climate problem is rooted in the fiction that investors in large-scale and long-lived energy infrastructures sit on a fence waiting for higher carbon prices to tip their decisions. In fact, many factors stifle the implementation of novel low-carbon policies" (Victor and Cullenward 2007).

If U.S. had Europe's current price for carbon, little transition to low-carbon sources would occur.

- "If today's European carbon prices were applied to the U.S., most utilities would not automatically install new power generation technologies, according to a study by the Electric Power Research Institute. In much of America, conventional coal-fired power plants would still be cheaper than nuclear power, wind farms or turbines fired with natural gas. Raising carbon prices to perhaps $40 per ton of CO_2 or higher would encourage greater adoption of new technology, but that option seems politically unlikely" (Victor and Cullenward 2007).

Price on carbon alone would make climate stabilization unnecessarily expensive.

- If we want to bring about significant reduction in carbon emissions over the next half-century and stabilize greenhouse gas concentration thereafter, without greatly sacrificing economic growth, we must achieve tremendous technical change in the energy sector. Accomplishing this technical change in an efficient and timely way requires considerable government involvement. At present, the adequate resources have not been made available, and the capacity of the U.S. government to demonstrate usefully new technology is uncertain. If the government signals to the private sector that there is a significant cost for greenhouse gas emissions, such as CO2, there will undoubtedly be a market response of adopting new technology, deploying more energy efficient capital, fuel switching, and shifting to less energy intensive products and services. But progress, and especially technology adoption, will be slower absent an effective government program for technology creation and demonstration" (Deutsch 2005: 12 – 13).

A carbon price alone cannot drive down prices of new low carbon energy technologies.

- "Most of the policies listed earlier have an element in them to foster innovation. However, they frequently confound the aims of innovation policies with the aims of carbon pricing, which are to encourage the use of technologies that have already passed through their RD&D and commercial trial stages… By facilitating invention and reducing costs, such policies complement the pricing of carbon directly, and should pave the way to lower carbon prices in the long-term" (Anderson 2006: 41).

Public investment in innovation crucial to minimizing negative economic consequences of pricing carbon.

- "We find that investments in climate friendly technologies can reduce GDP losses to the US by a factor of two or more" (Richels *et al.*. 2007).

- "A technology strategy will provide value by reducing costs over a wide range of possible futures — an essential role, given the uncertainties in the science, policies, technologies, and energy resources" (Edmonds et al. 2007: 11)

Knowledge spillover and public benefits from R&D justify greater public investment

- "Public benefits of RD&D investments are bigger than the benefits captured by the private sector, justifying government support of RD&D… Mobilizing financing of incremental costs of low-carbon technologies is important" (IPCC 2007: 21)

Value of each new technology is in the range of $4 – 8 trillion.

- "Investing in research, development, and implementation in multiple technology areas will provide the foundation for deployment of a broad portfolio of advanced energy technologies. The large-scale deployment and use of these advanced energy technologies has the potential to reduce the cost of stabilization by trillions of dollars. Removing any one of them from the mix will increase cost. The value of this portfolio increases as technologies are added and improved…each individual technology can lower the cost of climate stabilization by $4 – 8 trillion — but the savings are significantly higher when a portfolio approach is implemented" (Edmonds et al. 2007: 20 – 21)

Future clean energy technology worth $17 trillion

- "We have determined that a low-cost and environmentally benign substitute for fossil fuels would be highly beneficial. We estimate that a low-cost zero-carbon technology would have a net value of around $17 trillion in present value. No such technology presently exists, and we can only speculate on it. It might be low-cost solar power, or geothermal energy, or some non-intrusive climatic engineering, or genetically engineered carbon-eating trees. While none of these options are currently feasible and environmentally benign, the net benefits of zero-carbon substitutes are so high as to warrant very intensive research" (Nordhaus 2008)

Long-term, cross-sectoral R&D investments needed

- "Policy makers need to understand that R&D has played a critical role in achieving key technical improvements, such as electrical efficiency improvements, and that it may need to play such a role in the future as well. Given the low levels of R&D investment noted above, government can play a role. Similarly, inter-sectoral spillovers have also helped drive down costs in the past and may also in the future, suggesting that efforts to support collaborative research across industries may bear fruit. Finally, acknowledging that a large share of the cost reductions arose from large and risky investments, which took years to payoff, implies that expectations about future demand, and thus about future policy, are critical to future cost reductions" (Nemet 2007: 198)

Public investments needed to ramp up renewables globally.

- "Overall, global studies by the IEA (2002) estimate that learning investments totalling $400bn over the next three decades could deliver low carbon electricity systems globally. This is less than a tenth of the sectors' projected needs for generation investment over the same period, and the IEA's 'alternative' high efficiency, low carbon scenario requires less total cumulative investment because the reduced electricity demand also reduces the need for infrastructure" (Grubb 2004: 28).

$20 billion annually needed for energy R&D and $34 billion for deployment

- "Carbon pricing alone will not be sufficient to reduce emissions on the scale and pace required… Our modeling suggests that, in addition to a carbon price, deployment incentives for low-emission technologies should increase two to five times globally from current levels of around $34 billion. Global public energy R&D funding should double, to around $20 billion, for the development of a diverse portfolio of technologies" (Stern 2006: 347)

Public investment for clean energy cannot wait for carbon price

- "The urgency of the problem means that technology development may not be able to wait for robust global carbon pricing. Without appropriate incentives private firms and capital markets are less likely to invest in developing low-emission technologies" (Stern 2007: 352)

Uncertainty about the future is reason for technology investment

- "Uncertainties, both with respect to climate change and technology development, argue for investment in technology development. Uncertainties in irreversible investments argue for postponing policies until the uncertainties are reduced. However, uncertainties, especially with respect to technology development, will not be reduced exogenously with the 'passage of time' but endogenously through investment and the feedback and experience it provides" (Stern 2006: 360)

IV. The Need to Increase Investment in Clean Energy

History proves the importance of technology investment to innovation

- "Extensive and prolonged public support and private markets were both instrumental in the development of all generating technologies. Military R&D, the US space programme and learning from other markets have also been crucial to the process of innovation in the energy sector" (Stern 2006: 361)

- "Government support through financial contributions, tax credits, standard setting and market creation is important for effective technology development, innovation and deployment" (IPCC 2007: 20)

Increase in energy R&D required to develop *low-cost* clean energy

- "Global public energy R&D support has declined significantly since the 1980s and this trend should reverse to encourage cost reductions in existing low-carbon technologies and the development of new low-carbon technological options" (Stern 2006, 372).

- "The energy technology and policy options of industrial and developing nations are closely linked together in a global energy economy…. Many scientists have argued that emissions reductions of 70 percent or more are necessary to stabilize the atmospheric GHG concentrations at 550 or 450 parts per million. Achieving these levels would require a doubling or tripling, respectively, of the current rate of decarbonization. Without a sustained and diverse program of energy R&D and implementation, we are crippling our ability to make the necessary improvements in the global energy economy" (Margolis and Kammen 1999: 692).

Investment into R&D should reach new historic highs.

- "R&D efforts declined 10-fold in the UK over the past 25 years, 4-fold in the US, and 2-fold on average in the OECD countries (see Annex 7), a period when R&D expenditures in other sectors of the economy increased substantially… The task of mitigating climate change means that the R&D effort needs to be ramped up once again, perhaps to or above the levels that existed a generation ago. The challenges facing the energy sector today are far more demanding than they were then, and a much broader portfolio of low carbon technologies and practices needs to be developed further." (Anderson 2006: 40-41)

Energy R&D should be doubled

- "NCEP [National Commission on Energy Policy] recommends doubling of RD&D to $1.7 billion annually; investing $1.4 billion/annually into coal IGCC, biofueels, advanced nuclear, non-carbon production tax credit; auto manufacturer auto efficiency incentives; triple investment into international cooperation to $500 billion" (NCEP 2004, xiv).

Energy R&D should be tripled — globally — to $100 billion

- "For several decades it will be necessary to provide incentives for the development of new and emerging technologies… The overall requirements for investment in innovation of approximately £50 billion (~$100 billion) per year by 2015 and £70 billion (~$140 billion) per year by 2025 would be 2.5 and 3.5 times today's level, which Christ Taylor estimated is around £40 billion ($80 billion) per year. If indeed innovation were to reduce the average costs of [carbon] abatement from around £150/tonC ($300/tonC) for the current generation of investments to one third of this level, the benefits would be immense, amounting to £100/tonC ($200/tonC), such that for 10GtC of abatement by 2050 the cost savings would be £1 trillion per year" (Anderson 2006: 29)

Doubling of energy R&D insufficient

- "A 1997 study by the President's Committee of Advisors on Science and Technology and a 2004 report by the bipartisan National Commission on Energy Policy both recommended that the federal government double its R&D spending on energy. But would such an expansion be enough? Probably not. Based on Assessments of the cost to stabilize the amount of carbon dioxide in the atmosphere and other studies that estimate the success of energy R&D programs and the resulting savings from the technologies that would emerge, my research group has calculated that public funding of $15 billion to $30 billion a year would be required — a fivefold to 10-fold increase over current levels" (Kammen 2006b: 92)

$15 – 30 billion annually needed for energy R&D to stabilize the climate

- "Using emissions scenarios from the Intergovernmental Panel on Climate Change and a previous framework for estimating the climate-related savings from energy R&D programs (Schock *et al..*, 1999), we calculate that U.S. energy R&D spending of $15 – 30 billion/year would be sufficient to stabilize CO2 at double pre-industrial levels [550 ppm]" (Kammen 2006a: 4)

Carbon capture and storage (CCS) requires high carbon price…

- "We estimate that the price needed to jump-start this transition is in the ball-park of $100 to $200 per ton of carbon — the range that would make it cheaper for owners of coal plants to capture and store CO2 rather than vent it" (Socolow and Pacala 2006).

… ***and*** **subsidies**

- "The learning investment required for other supply technologies may be greater. RD&D totalling several $bn has brought IGCCs – which are a pre-requisite for most power-generation carbon capture and storage technologies – ready for 'small fleet' deployment requiring $0.5-7.5bn subsidy depending on the programme scale and instrument (Rosenberg et al., 2004)" (Grubb 2004: 27)

$20 - $100 billion required to bring down the price of solar.

- "Based on learning curve data, investment in the range of US $20-100bn could bring PV costs down to compete with bulk power supply at the point of end-use in many countries; the resulting strategic benefit-cost ratios are sensitive to assumptions but potentially high even without incorporating carbon prices (Neuhoff 2005; van der Zwaan, 2004)" (Grubb 2004: 27 – 28)

Public investment required at all stages of innovation process

- Industry funded R&D focuses on the domain of existing expertise and on improvements that can be leveraged in the short term (Anderson and Bird, 1992). This suggests that public funding will be the main driver for longer-term developments in new technology and production processes for existing renewables, exploration of untried renewable technologies, energy system integration, superconductivity, and non-hydro storage technologies. The innovation process is not linear but entails various feedback loops between market experience and research activities. This suggests that cost and efficiency improvements in existing renewable technologies (Luther, 2004) require a parallel increase in strategic deployment efforts and public research funding (Neuhoff 2005: 22)

Failures should be expected — and not used to justify inaction.

- "Government must remain engaged in technology policy, but it should try a variety of ways to structure policy in this area to minimize the known policy problems. Models are already working, such as public-private partnerships that subsidize research but retain significant elements of market forces in determining which technologies to pursue. Failure of some policy initiatives should be expected, and those failures should be used to terminate or improve particular programs, not to rationalize total inaction" (Jaffe et al. 2004: 21)

Government should procure solar to buy-down the price.

- "Governments need to stimulate bulk purchases and cost reductions of the renewable energy technologies by applying them to governmental safety and defense operations. In these kinds of ways governments can help to 'pull' the solar technologies into the market place, to complement the 'push' of their firm goals, policies and laws" (Aitken 2003: 53)

Need global technology investment into developing world.

- "[T]here is an opportunity to move forward by focusing international agreements and policies directly on technology development and use, facilitated, in the case of developing countries, by an expanded programme of international assistance, on the lines of the recent *Investment Framework* proposed by the World Bank, discussed below. As with other programmes of international assistance, direct investments need to be coupled with the development of national energy policies — in the developing no less than in the OECD countries" (Anderson 2006: 31).

- "A gap in the financing arrangements at the international level concerns the development and demonstration of new technologies. The Global Environment Facility, its Implementing Agencies and the multi-lateral and bilateral agencies are already involved in the application of established low-carbon energy technologies. The GEF alone already has a $15 billion portfolio of investments, including the investments directly levered by GEF grants. But there is a need to press the 'technology frontier' harder and move the technologies forward:
    1. Low carbon technologies and practices are fertile grounds for discovery and innovation—in biofuels, energy efficiency, PVs, the offshore resource, fuel cells, and hydrogen production, storage and use.

2. There are critical constraints to be addressed, especially (but not only) in energy storage technologies for both vehicles and stationary applications.
3. The education and training of scientists and engineers. The output of low carbon technologies will need to expand nearly 20-fold over the next 40-50 years, requiring new generations of engineers and scientists to work on energy technology development and use.
4. There is the need to involve scientists and engineers from developing countries in the task. Already China and India are each graduating 250,000 engineers and scientists each year—as many as in the US and in the European Union. A rich and copious source of discovery and innovation is emerging in developing regions" (Anderson 2006: 46).

Buying down the price could result in solar becoming 5 percent of developed world electricity by 2030.

- An optimal PV buydown would triple current demand subsidies and sustain declining per-unit support for over four decades. Such a buydown (initially targeting residential markets in industrialized countries) need never raise electricity rates by more than 0.5 percent while delivering roughly $50 billion in long-term net benefits (relative to a no-subsidy scenario) and allowing PV to provide over 5 percent of industrialized country electricity by 2030 (*vs.* less than 1 percent without subsidies)" (Duke 2002: iv)

Buying down the price of solar would allow knowledge spillovers to accelerate innovation.

- "Even if the industry starts with only one or a few firms, demand-pull programs encourage competitors to emerge to take advantage of the larger markets and lower industry-wide production costs catalyzed by the subsidies. It may also prove possible to design buydowns to actively promote spillover. Such a strategy would reduce the dual costs of divided learning and market power, ensuring that a competitive market structure emerges such that subsidies can be ultimately be phased out completely once the technology has become fully mature and has reached its long-term price floor" (Duke 2002: 27).

Solar buy-down needed even if there were a carbon price and R&D.

- [E]ven if adequate RD2 [research, development, and deployment] funding and perfect pricing of pollution externalities were in place, sustained buydown of the most promising clean energy technologies would remain essential. In the absence of these policies, the imperative to provide demand-pull support for clean energy technologies is that much more compelling" (Duke 2002: 207)

Long-term commitment to public investment required.

- "Long-term, consistent financing for technology development and demonstration is also essential. Much of the support for the early stages of this process will likely come from the public sector or other means of collective action" (Edmonds et al. 2007: 23).

Successful action depends on recognizing that global warming cannot be regulated away.

- "Combating global warming by radical restructuring of the global energy system could be the technology challenge of the century. We have identified a portfolio of promising technologies here—some radical departures from our present fossil fuel system. Many concepts will fail, and staying the course will require leadership. Stabilizing climate is not easy. At the very least, it requires political will, targeted research and development, and international cooperation. Most of all, it requires the recognition that, although regulation can play a role, the fossil fuel greenhouse effect is an energy problem that cannot be simply regulated away" (Hoffert et al. 2002: 986)

Bibliography

Aitken, Donald W. "Transitioning to a Renewable Energy Future," International Solar Energy Society, 2003.

Alic, John, David Mowery, Edward Rubin, "U.S. Technology and Innovation Policies: Lessons for Climate Change," Pew Center on Global Climate Change, November 2003.

Anderson, Dennis. "Costs and Finance of Abating Carbon Emissions in the Energy Sector," Imperial College London, White Paper Prepared for the Stern Review on the Economics of Climate Change, October 20, 2006.

Blyth, William and Hamilton, Kirsty. "Aligning Climate and Energy Policy: Creating incentives to invest in low carbon technologies in the context of linked markets for fossil fuel, electricity and carbon," Chatham House White Paper prepared for the Stern Review on the Economics of Climate Change, April 2006.

John Deutsch, "What should the government do to encourage technical change in the energy sector?" Center for Energy and Environmental Policy Research, March 2005.

Duke, Richard D. "Clean Energy Technology Buydowns: Economic Theory, Analytic Tools, and the Photovoltaics Case," Ph.D Dissertation, Princeton University, Woodrow Wilson School of Public and International Affairs

Edmonds, JA, Wise, MA, Dooley, JJ, Kim, SH, Smith, SJ Runci, PJ, Clarke, LE Malone, EL, Stokes, GM. "Global Energy Technology Strategy: Addressing Climate Change," Global Energy Technology Strategy Program, May 2007.

General Accounting Office, "Key challenges remain for developing and deploying advanced energy technologies to meet future needs," December 2006.

Grubb, Michael "Technology Innovation and Climate Change Policy: An Overview of Issues and Options," Keio Journal of Economics, 2004.

Hoffert, Martin, Caldeira, Ken, Benford, Gregory, Criswell, David R., Green, Christopher, Herzog, Howard, Jain, Atul K., Kheshgi, Haroon S., Lackner, Klaus S., Lewis, John S., Lightfoot, H. Douglas, Manheimer, Wallace, Mankins, John C. Mauel, Michael E., Perkins, L. John, Schlesinger, Michael E., Volk, Tyler, Wigley, Tom M. L., "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet," *Science*, November 1, 2002.

Holdren, John P. "The Energy Innovation Imperative," *Innovations*, Spring 2006.

Jaffe, Adam B. Richard G. Newell, and Robert N. Stavins, "A Tale of Two Market

Failures: Technology and Environmental Policy," Resources for the Future, October 2004.

Josefsson, Lars G. Vattenfall AB, "Statement given at the Ministerial Dialogue Meeting of the U.N. Commission on Sustainable Development," 2006-05-10

Mandil, Claude. "Foreward," *Energy Technology Perspectives*, International Energy Agency, 2006.

The National Commission on Energy Policy, "Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges," December 2004.

Karsten Neuhoff, "Large Scale Deployment of Renewables for Electricity Generation," Cambridge Working Papers in Economics #59, Cambridge – MIT, 2005.

William Nordhaus, *The Challenge of Global Warming: Economic Models and Environmental Policy*, forthcoming book, 2008.

Kammen, Daniel M. "Climate Change Technology Research: Do We Need a 'Manhattan Project' for the Environment?, Testimony before Congress, September 21, 2006.

Kammen, Daniel, "The Rise of Renewable Energy," *Scientific American*, September 2006.

Margolis, Robert M. and Daniel Kammen, "Underinvestment: The Energy Technology and R&D Policy Challenge," *Science*, July 30, 1999.

Nemet, Gregory. "Policy and Innovation in Low-Carbon Energy Technologies," Ph.D Dissertation, Spring 2007.

Richard Richels, Rutherford, Thomas, Blanford, Geoffrey, Clarke, Leon. "Managing the Transition to Climate Stabilization, AEI-Brookings Joint Center for Regulatory Studies, January 2007

Sims Gallagher, Kelly, Holdren, John P., and Sagar, Ambuj D. "Energy-Technology Innovation," Annual Review of Environment and Resources, August 25, 2006, pp. 193 – 237.

Robert H. Socolow and Stephen W. Pacala. "A Plan to Keep Carbon in Check," Scientific American, September 2006.

Stern, Nicholas. *The Stern Review: The Economics of Climate Change*, UK Treasury, October 2006.

Victor, David, and Cullenward, Danny. "Making Carbon Markets Work," Scientific American, September 24, 2007.

United Nations Intergovernmental Panel on Climate Change, "Summary for Policymakers," April 30 to May 4, 2007.