The Climate Imperative and Innovative Behavior: Encouraging Greater Advances in the Production of Energy-Efficient Technologies and Services

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Abstract

This white paper examines why a larger array of innovative institutions, behaviors, technologies, and services is needed – specifically in the context of what we call "the climate imperative." We explore possible mechanisms that can encourage the more robust development of innovative programs and policies within the State of California, with special attention to the activities of the California Public Utilities Commission. The potential for future innovation is described in the context of California's impressive past technological and institutional achievements, especially as they impact energy efficiency improvements and energy policy more broadly. Notwithstanding its past achievements, we contend that if the Golden State is to meet the climate imperative head-on it will need to promote significantly greater levels of innovation in the development of new ideas, new services, and new technologies – and to do so at a scale that has not been previously imagined or managed. This will demand innovation in all of the four stages of the technology development pipeline. This paper is divided into four sections. The first two are the introduction and history of energy efficiency-related innovation in California. The main body of the paper identifies five large themes: (i) advancing ideas throughout the entire four-stage development pipeline, (ii) providing a compelling narrative, (iii) encouraging collaboration and interaction, (iv) exercising "solution swarming" techniques, and (v) directing what we might call "purposeful innovation." All are relevant to addressing the climate imperative. We further contend that a full exploration of these five themes can yield valuable additional insights for the state of California. We conclude with five specific "next-step" recommendations derived from this larger review.

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1. Introduction – The Climate Imperative

The average temperatures in the earth's atmosphere are on an upward trajectory that is largely irreversible over the next century. The trend is driven almost exclusively by the rising concentrations of greenhouse gas (GHG) emissions, primarily carbon dioxide emissions (CO_2), which are generated by the combustion of fossil fuels. This trend has profound implications for the world's climate. Leading U.S. climatologist James Hansen and his colleagues (2008) say that current global CO_2 concentrations are now at about 385 parts per million (ppm) and could rise to 550 ppm or more by the year 2100. They raise the alarm, suggesting that the concentrations need to be slashed to 350 ppm if "humanity wishes to preserve a planet similar to that on which civilization developed" and to which life on earth has adapted. The obligation of human beings to reduce our emissions of greenhouse gases in order to stabilize their atmospheric concentration at 350 ppm – or whatever level that climate science suggests is safe – we term "the climate imperative."

There is also convincing evidence we are approaching "the sunset of the oil era in the first half of the 21st century" (Rifkin 2008). Peak oil production may well come within the next decade or two. With that inevitability, there will be a huge shift in the way most of humanity interacts with the global energy system. The realization of imminent limitations on our fossil fuel resources has generated a rush of interest in energy efficiency and renewable energy technologies while aggravating the financial and investment pressures that are necessary to maintain the integrity of the world energy market.

At the same time that we face critical environmental and energy challenges, the United States is on the verge of losing its competitive edge. Competition from rapidly growing countries with employees marching up the skill ladder is a big reason for America's economic strain, but not the only one. Inspired by its uniquely democratic political culture, the U.S. economic growth miracle has been nurtured by its openness to new ideas. For over two centuries, the United States has catalyzed an array of new institutional and technological innovations. Yet, as the great jurist Clarence Darrow said in a metaphor that applies to nations and states as well as species: "It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change." (Darrow 1988). Thus, it is especially troubling when a number of observers are suggesting we may be losing our resourcefulness – especially against the backdrop of these multiple challenges. As former Chief Technology Officer at Cisco Systems, Judy Estrin (2008) observes: "To be honest, we had a problem with innovation [in this country] even before the [current climate, energy, and] economic crisis. . . We're focusing on the short term and we're not planting the seeds for the future" (see, also Rae-Dupree 2008, Florida 2004, and Holdren 2006). Harvard professor and award winning physicist John Holdren (1999) asks pointedly, "can we afford 'business as usual' any more?"

Astute observers from across the country are calling for policy intervention by state and federal government to encourage a greater entrepreneurial activity within the U.S. Governments regularly intervene in the economic process, and for good reason (Block 2008). According to

Coburn and Brown (1999), the states themselves are "natural channels of technology deployment and commercialization, because they are attuned to the needs and structural of local and regional industry and have strong and direct political incentives to produce tangible economic results in the form of new wealth and employment gains." Prindle et al. (2003) underscore the role of states which have "long been known as 'laboratories of democracy' in the U.S. federal system."

In California, the United States, and around the globe, there is a clear need for real, affordable, short-term alternatives that can reduce our inefficient use of energy resources. More productive and cost-effective investments in greater levels of energy efficiency can reduce the upward pressures on and the volatility of energy prices as well as reduce the GHG emissions burden (Laitner 2009). Furthermore, energy efficiency investments can do all this while maintaining the production of the many goods and services demanded by our economy, and according to many analyses, actually increase net employment opportunities (Laitner and McKinney 2008, Eldridge et al. 2009, and Neubauer et al. 2009).

Although energy efficiency is seen by many stakeholders as a highly effective investment, it also tends to be viewed as a short-term resource. This view is now changing. California Public Utilities Commissioner Dian Grueneich has stated that energy efficiency is her state's highest priority energy resource (Grueneich 2008). Indeed, it is being increasingly seen by forward-looking utility regulators such as the California Public Utilities Commission (CPUC) as the first choice in the loading order for new a new generation of energy resources. This emerging perception has been instrumental in the selection of energy efficiency as a cost-effective resource for energy utilities (Eldridge et al. 2008).

The good news in all this, however, is that energy efficiency may well prove to be a more dynamic and long-term resource than many now assume (Knight and Laitner 2009), and there is a strong historical record to suggest that it can provide perhaps the largest single wedge of GHG emissions reductions (Laitner et al. 2009; see also American Physical Society 2008, Committee on America's Energy Future 2009, Ehrhardt-Martinez and Laitner 2008, McKinsey 2007, and McKinsey 2009). As we describe more fully below, by expanding the many on-going innovation investments to include a broader array of efficiency-related technologies and institutions (many of which have yet to be invented), California can further capitalize upon its rich history of regulatory and technology innovations in the energy field.

We explicitly include both institutions – organizations, laws, policies, and culturally-embedded behaviors – as well as technologies in our review. Energy-efficient technologies, in the end, are what will allow us to address the climate imperative through cost-effective energy bill savings, but efficiency-related institutions will play an equally important role: enabling the smart applications of technology and acting as a powerful force for or against new innovations. Innovation expert John Hagel (2007) defines institutional innovation as that which "redefines roles and relationships across independent entities to accelerate and amplify learning and reduce risks." Both efficiency-related institutions and technologies are often treated as more or less fixed when they are, in actuality, fertile ground for newer levels of innovation. As we argue later in this paper, institutional innovations such as "swarming" are redefining the innovation landscape.

Over the past three and a half decades, California has built up a strong record of innovation in both energy efficiency-related institutions and technologies. In the sections that follow, we first summarize some of California's most notable achievements in its relationship with the development of its energy resources, including several instances where the state appears to promote energy efficiency as the truly dynamic resource that it can be. We then suggest why there is some reason for concern; that these efforts may be insufficient in light of the rapidly emerging climate imperative. The balance of this paper is devoted to five critical themes that we believe should be further explored by the state to promote institutional and technological innovations related to efficiency. These themes range from observing the innovation process as occurring throughout the technology pipeline and emphasizing the importance of cooperation and knowledge sharing, to exploring new innovations by tapping the "swarming" intelligence of experts and the public alike, building on the importance of narrative, and finally engaging in more directed and purposeful innovation. We conclude by suggesting five "next-steps forward" based on these themes. The suggestion is that, by incorporating these elements more proactively into its management strategy, the Golden State may both replenish and enhance its resources which might help to dissolve the climate imperative.

2. Energy Efficiency in California

Prindle et al. (2003) maintain that it may be no accident that states have been "laboratories of efficiency." To be sure, the states have "consistently demonstrated innovation and leadership in testing energy efficiency policies and programs. From the first wave of building energy codes and appliance efficiency standards in the 1970s, to utility efficiency programs in the 1980s, to climate change-driven initiatives in the 1990s, state legislatures, utility commissions, and executive agencies have led the way on efficiency policies and programs that often later found their way into federal policy." California, in particular, has implemented an assortment of energy programs and policies in an attempt to stimulate all phases of technological change, including research, development, demonstration, and diffusion policies in support of energy-efficient technologies. The benefits for California have been especially impressive because of the state's more concerted regulatory and financial commitment, and because it has built collaborative relationships between state government and its intrastate energy utilities as well as between state and municipal governments which have been useful for establishing and enforcing a variety of energy efficiency standards.

Overall, California's set of energy policies has placed it at the top of the American Council for an Energy-Efficient Economy's (ACEEE) 2008 "State Energy Efficiency Scorecard" (Eldridge et al. 2008). For example, its building and appliance standards were the first in the nation. California's Title 24 whole-building energy standards for new residential and non-residential construction have been in place since 1978, and in recent years efforts addressing energy use in the building sector have increased. Appliance standards in California were first established in 1976 and have been a remarkable and a publicly celebrated success. Among the most impressive policies have been the institutional innovations of the CPUC in its oversight and regulation of the state's investor-owned utilities (IOUs). Since the 1970s, the CPUC has used regulatory innovations such as decoupling and "decoupling plus[1]" to pave the way for ratepayer-funded energy efficiency programs. From 1975 to 2005, the CPUC directed the IOUs to spend over $5 billion[2] on efficiency programs, resulting in savings roughly equivalent to 15 percent of California's energy use (Rosenfeld 2009, Roland-Holst 2008).[3]

In 1998, realizing that the deregulated utility markets would not sufficiently promote innovation, IOU ratepayers began to fund energy research and development (R&D) programs more aggressively via a public goods charge – primarily through the California Energy Commission's (CEC) Public Interest Energy Research (PIER) program.[4] With an annual budget of around $80 million dollars, PIER is not huge. However, with collaboration and leveraging of funds from other stakeholders, it has an outsized impact. For example, the PIER program has played an important role in establishing the following research organizations at the University of California: the Center for the Study of Energy Markets, the California Lighting Technology Center, the Western Cooling Efficiency Center, the California Renewable Energy Collaborative, and the California Climate Change Center. Also, PIER funded the Demand Response Research Center at the Lawrence Berkeley National Laboratory. Once established, these centers attract additional funding from other public and private partners – such as Pacific Gas & Electric Company (PG&E) and the Davis Energy Group – leveraging the initial investment by the state.

Furthermore, while the efforts of innovators in California's private sector are not typically subsidized with public funds, the supportive policy climate creates positive spillovers that improve the odds of their success. Along these lines, the state also has a few other quasi-public and private sources of funds directed at energy innovation. These include the California Clean Energy Fund (CalCEF), the California Clean Tech Open, and the Energy Free Home Challenge. The California Clean Energy Fund is a $30 million dollar revolving public alternative energy venture capital fund funded through PG&E's bankruptcy. In the last few years, alumni of the business plan competition in the California Clean Tech Open have gone on to secure $125 million in start-up capital. The state is also home to some of the most successful and biggest thinking venture capitalists, such as those that contributed to the recent "Gigaton Throwdown" report.[5]

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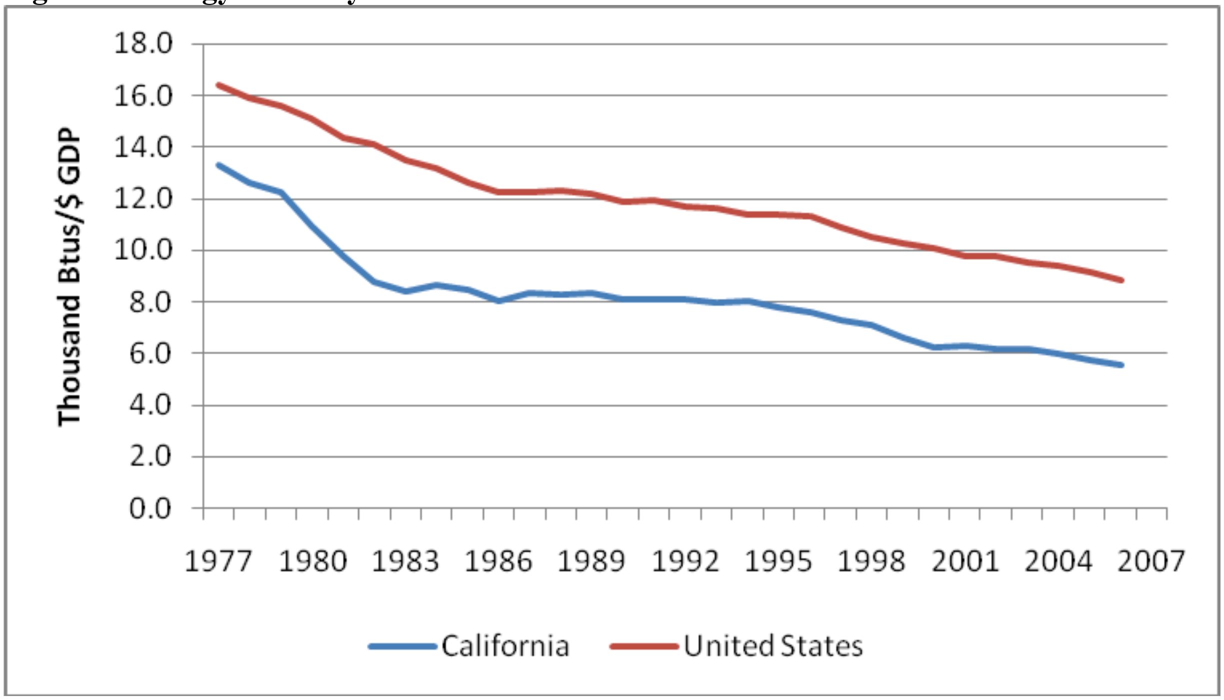
[1] Decoupling involves making a utility's profits independent of its sales to remove its disincentives to conserve energy. Decoupling plus adds rewards given to utilities when they meet conservation goals.
[2] This figure is a conservative estimate from "eyeballing" slide 39 in Rosenfeld's presentation
[3] As this report goes to press, ACEEE has just acknowledged California as the number one scoring state in 2009 as well (see, Eldridge et al. 2009).
[4] Because of other goals mandated through legislation (e.g., energy efficiency programs, low-income energy efficiency programs, renewable energy programs), not all of public goods charge spending goes towards research and development.
[5] The report can be found at http://www.gigatonthrowdown.org. We provide an extended discussion of this idea later in the text.

Figure 1. Energy Intensity Trends for California and the U.S.



The state's long history of public investment, regulation, and standard-setting has clearly had a major effect on steady improvements in energy efficiency (Roland-Holst 2008). Figure 1 above shows the number of Btus of energy needed to power each dollar of economic activity, both in California and the entire U.S. (measured in 2000 dollars of Gross Domestic Product). California was already 24 percent more energy productive than the U.S. in 1977, and 60 percent more in 2006.[6] Some, but not nearly all, of California's high level of efficiency can be explained in terms of policy independent characteristics such as its climate and its industrial mix. However, there is substantial consensus that California's efforts in utility regulation and standards have saved electricity and natural gas expenditures on the order of $56 billion from 1975 to 2003, a CEC estimate (Roland-Holst 2008).

Future policy actions by the state promise to save even more energy. Although the cap-and-trade legislation contained in Assembly Bill 32 (AB32), known more formally as the Global Warming Solutions Act, has not come into effect yet, stakeholders are beginning to scale their effort in accordance with the state's leadership.[7] In October 2007, the CPUC recommended that the state's goals for energy efficiency be 100 percent of economic potential (CPUC 2007). According to the CPUC's Long Term Energy Efficiency Strategic Plan, California's IOUs have

[6] Not immediately obvious, we can think of the inverse of energy intensity as a single-factor measure of energy productivity. Hence, California had an energy intensity of 13.3 thousand Btus per dollars of GDP in 1977 (measured in constant 2000 dollars). The inverse of that measurement suggests that California supported about $75 of economic activity for every one million Btus of energy consumed in that year. By comparison, the United States supported only $61 dollars of economic activity in 1977. That difference was more pronounced by 2006 when California supported $181 dollars of economic activity compared to $113 for the U.S. In short, California's economy is now about 60 percent more energy productive than the U.S. as a whole (with calculations based on data from Economy.com (2009) and the Energy Information Administration (2009)).

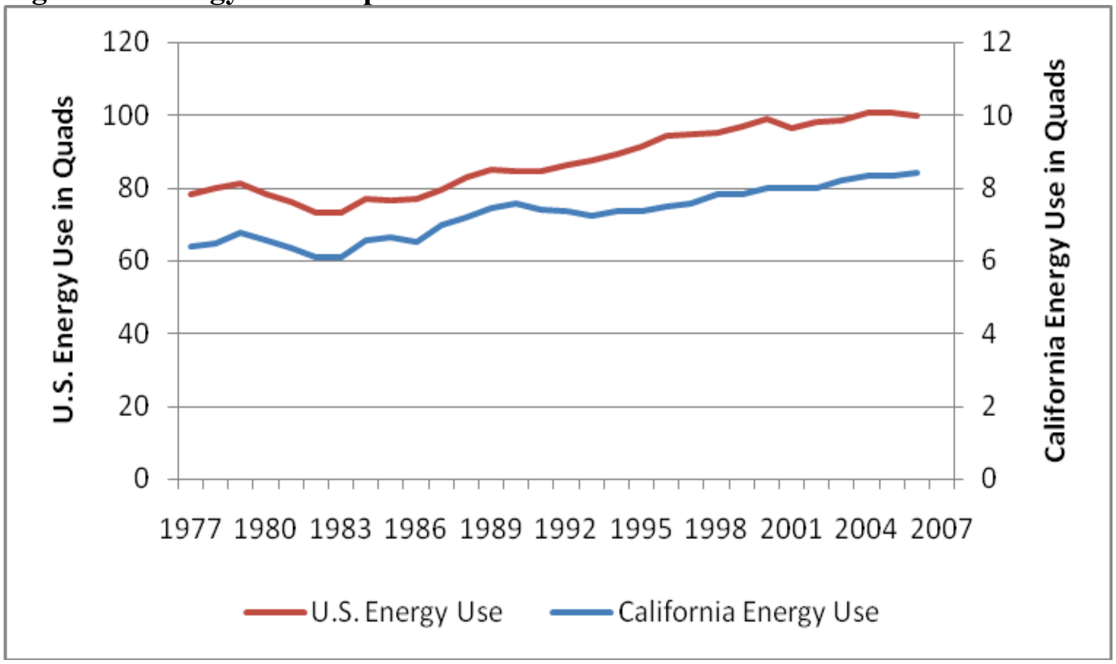
[7] AB32 was passed by the California Legislature and signed by the Governor on September 27, 2006.

proposed to spend over $3.7 billion on energy efficiency from 2009 to 2011 (with on-going approval of the CPUC) (CEC 2008). The Plan is one outcome of a flurry of recent collaborative activity by the CPUC and other stakeholders in California to prioritize energy efficiency. In mid-2007, the CPUC signaled its intention to work with other Western states on a National Action Plan for Energy Efficiency (CPUC 2007). The CPUC's rulemaking 06-04-010 in October 2007 to engage in unprecedented collaboration and planning for energy savings up to 2020 is another step in the right direction. It directs energy stakeholders in California to: "Establish new, collaborative processes with key business, consumer groups, and governmental organizations in California, throughout the West, nationally and internationally."(CPUC 2007). The CPUC also plans on creating an energy efficiency web portal to enhance information exchange with other efficiency policymakers and stakeholders (CPUC 2008b). The CPUC's pursuit of such collaborative actions builds momentum behind energy savings within and outside of California, but it will also help to promote innovation in the development and deployment of efficiency technologies through increased sharing of best practices and amplification of learning-by-using effects.[8]

But the question can still be asked whether the substantial institutional and technological innovations in California are enough when viewed in light of the climate imperative. While California's energy use per capita has stayed constant over the past several decades, its overall energy use has actually increased faster than the national average, growing 32 percent from 1976 to 2006, as shown by Figure 2 below. This slightly exceeds the growth rate of national energy consumption over the same period, which was 30 percent. Despite the tremendous policy effort to increase the economy's efficiency, GHG emissions have risen along with this increased energy use. A very big part of the reason may be the heavy share of transportation-related carbon dioxide emissions. While transportation fuels are 59 percent of total energy-related CO_2 emissions in California, for the U.S. as a whole they constitute only 34 percent of the total according to recent data from the U.S. Energy Information Administration (2009).[9] In fact, while non-electricity emissions from buildings and industry sector emissions have actually declined by about 4 million metric tons of carbon dioxide ($MMTCO_2$) over the period 1990 through 2007, electricity-related and transportation emissions have grow by 10 and 33 $MMTCO_2$, respectively. Hence, it is possible to cast some doubt on the extent and quality of public energy innovation going on in California – especially given the scale of emissions reductions that will be required by 2050 (Sullivan 2008).

[8] The idea of "learning-by-using" is expanded upon in the next section of the report.
[9] Emission estimates are based on energy consumption data from EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS) released Spring/Summer 2009 (http://www.eia.doe.gov/emeu/states/_seds.html).

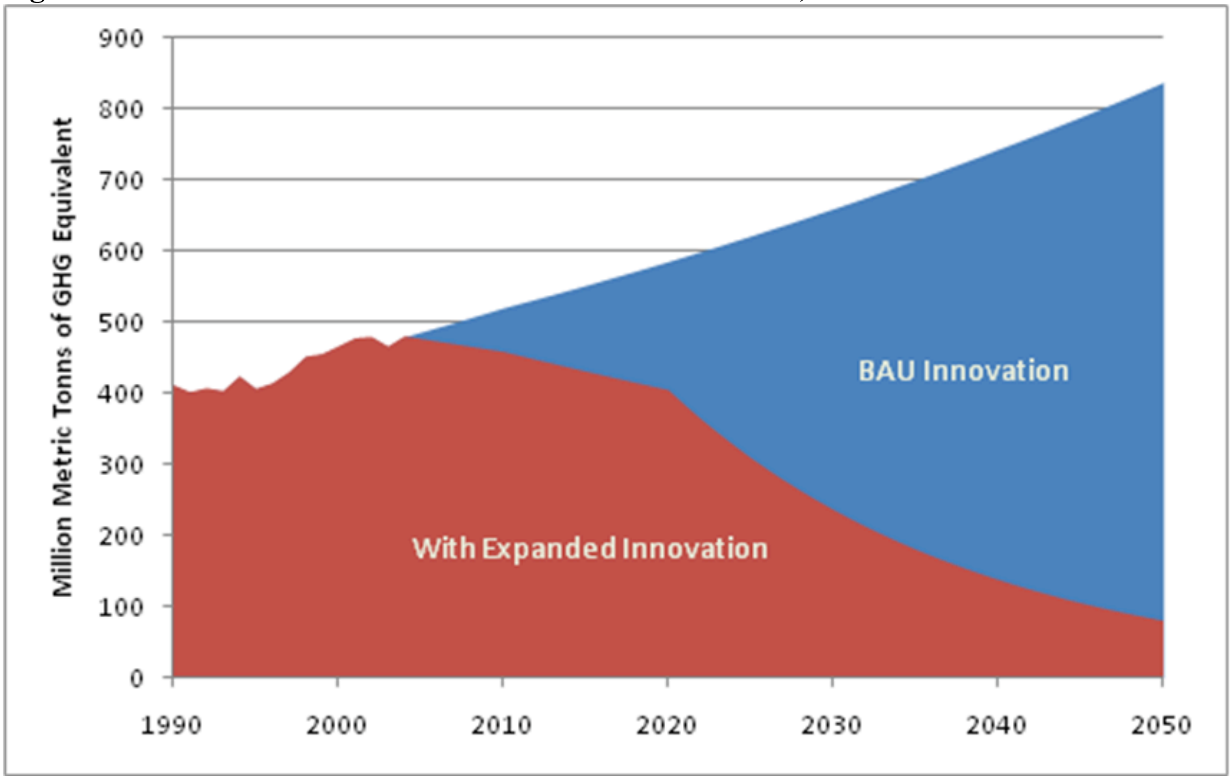
Figure 2. Energy Consumption Trends for California and the U.S.



With the climate imperative beginning to take center stage, California Governor Arnold Schwarzenegger signed Executive Order #S-3-05 in June 2005. This established significant GHG emissions reduction targets for the state. The Executive Order called for the reduction of all GHG emissions to year 2000 emission levels by 2010. By 2020 the state is to reduce total emissions to 1990 emission levels; and by 2050 to reduce total emissions to 80 percent below the 1990 Levels. At first glance, S-3-05 and the accompanying AB32 seem to provide a reasonable solution to reduce GHG emissions. However, high abatement costs and accompanying political backlash can undermine both the economy and the environment. From this perspective, ambitious policy measures such as these are foremost signs that sweeping innovations will be needed to successfully dissolve the climate imperative.

Figure 3 highlights both the "business-as-usual" (BAU) trajectory and the path the state will need to follow in order to meet the mandates set out in the Governor's Executive Order. Achieving this goal would result in a decrease in GHG emissions from over 450 million metric tons CO_2 equivalent (MMTCO_2e) in 2005 to about 80 MMTCO_2e in 2050. By contrast, extrapolation of historical trends of GHG emission growth suggests California will produce on the order of 800 MMTCO_2e in 2050.

Figure 3. California GHG Emissions Scenarios in Context, 1990-2050



Perhaps not immediately obvious, there is good deal of innovation that will be put to work just to hold GHG emissions to a mere doubling of quantities in 2050 compared to 1990 levels. Without further improvements in the carbon intensity, emissions could grow to perhaps 1400 million metric tons by 2050. Hence, "BAU innovation" (the blue shaded area in Figure 3 which includes the likely benefits of existing programs and policies) may be sufficient to hold the emissions to just over 800 million metric tons by 2050. But to bring total emissions down to the scale envisioned by the Governor's Executive Order, a substantially greater level of innovation activities will be required. Against the backdrop of the climate imperative, the current programs – even in a leadership state as California – may be insufficient.[10]

[10] We underscore a critical point that is embedded in Figure 3. The historical program efforts in California, even with the more recent ramping up of the overall funding levels, pale in comparison to the scale of effort that will be essential to achieving the 80 percent reduction by 2050. We hesitate to publish any specific number about the overall investment that might be required, especially given the huge uncertainties associated with both the mix of available resources and their ultimate costs. Yet, the range of even a first approximation is wide and deep. By slicing the problem from a number of different technology perspectives, and using a number of different cost assumptions, the analysis suggests the need for cumulative investments on the order of $800 billion to $2.3 trillion (or more) in technology and/or infrastructure improvements over the 40-year period between 2010 and 2050. With California's economy now hovering around $1,900 billion annually (Economy.com 2009), our estimate of needed investments is roughly the equivalent of devoting one-year of economic activity in California to achieving the 80 percent emissions reduction over that same 40-year period. The good news is that there will be a substantial return on that investment with the very real prospect of returns exceeding investments (Laitner et al. 2009). And further innovations may drive down those costs while adding to the overall benefits. The larger point is a simple one: the scale of innovation required to meet the challenge of the climate imperative is substantially larger than the state, the national, or the global economy has yet to confront. Perhaps another useful metric to better appreciate the scale of innovation that is required, the "gigaton throwdown" (if embraced as a strategy for California) should be sufficient

What can the state then do to promote innovation and climate leadership sufficient to confront the climate imperative? As the evidence strongly suggests, one crucial move will be to think of energy efficiency as substantially more than a "low-hanging fruit." If the state instead were to harness innovation in ways that build up the energy efficiency resource through the application of semiconductor-enabled technologies, increased broadband, the increased reliance on information and communication technologies (ICT), new materials, and new technology designs, the evidence points to an opportunity that might at least halve total emissions by its expanded capacity for gains in energy productivity. Expanding that capacity requires policymakers, business leaders and a full range of technicians and analysts begin to imagine a different scale of achievement. The balance of the paper describes and characterizes the kinds of themes, insights, and perspectives that might enable a greater capacity for innovation within the Golden State.

3. Five Themes to Guide Innovation in the Face of the Climate Imperative

A. Building Innovation throughout the Pipeline

A weblog discussion sponsored by the Institute for Innovation & Information Productivity (2007) suggests that innovation "is imaginative activity that produces outcomes that are both original and of commercial value." Similarly, a website sponsored by the Innovations Network (2008) defines innovation as nothing more than "people implementing new ideas to create value." But perhaps the most definitive inquiries into the innovation process were those of the Austrian economist Joseph Schumpeter. Schumpeter's studies of the stages of industrial and technological change highlighted the impact of "rule changing innovations." To Schumpeter, innovations required the introduction of revolutionary products and services by successful entrepreneurs, a transformation process that often destroys the power of established institutions and organizations. Schumpeter argued that an industry's economic power and structural influence were changes brought about from within. He named the process of industrial transformation through radical innovation as creative destruction, to wit: "Every piece of business strategy acquires its true significance only against the background of that process and within the situation created by it. It must be seen in its role in the perennial gale of creative destruction" (Schumpeter 1942).

Schumpeter's characterization of economic evolution divided the stages of technological change into four distinct phases or development pipeline (Rubin 2006). The first was invention, or the active conception of new ideas. Next was innovation, or the process that involves transforming new ideas into marketable products, processes and services; in effect, the instantiation of new ideas that create value. The third was adoption, when the new technology initially is absorbed into the market. The final was diffusion, a stage in which the new products and services gain widespread market share.

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to put the state on track for meeting the 2020 GHG reduction target. That is, abating a cumulative one gigaton of GHG emissions over the decade from 2010 through 2020 would help California reduce its annual emissions to approximately 1990 levels by the year 2020. But to reach the larger 2050 goal of an 80 percent reduction may require cumulative emission reductions equivalent to a 17 gigaton throwdown.

Most in the academic arena and many in the private sector have understood for years that, far from being a linear progression, Schumpeter's steps of invention, innovation, adoption, and diffusion are part of a dynamic process that encompasses many and often unexpected feedback loops and interrelationships. For instance, Rogers (1995) observes that innovation involves a complex set of factors, including uncertainty, information, and systems influence, all mediated through a process of social interactions. The policy relevance here is that the process of encouraging useful innovations is not just a matter of financial support. Yes, funding is critical, but to generate real value the financial resources should be used within a larger framework that promotes interaction, collaboration, and knowledge sharing so that stakeholders and participants can see and determine what works and what doesn't.

The most well-known innovations typically occur at the second stage, where new ideas from the first phase are first embodied in technologies or services that seem to have great potential. The public is frequently excited about technologies that do things faster, more easily, or more cheaply. But scholars of energy and environmental policy point out that innovation can occur throughout entire four phases of technological change. And if we take institutional and structural changes into account, then innovation occurs both inside and outside the pipeline (Alic et al. 2003). At the first stage, they occur simply when people think about situations in new ways. New products or services created within the second stage are further refined through feedback from incremental innovations induced through the technology adoption and diffusion process. Learning-by-doing is an example of this sort of incremental innovation. It is induced by the experience and insights gained as production continues to satisfy growing market demands.

At the adoption stage, innovations are rooted in multiple places, such as when consumers interact with products in novel ways, or through a more effective installation job, or through higher quality maintenance from contractors. When end-users and installers gain more experience with technology and become more accepting of it and more skilled at interacting with it, this is a form of innovation in its own right that can reduce the installed cost and increase a technology's market acceptance. But experience in the adoption phase also feeds back into product design routed through consumer feedback, for instance. This is termed learning-by-using (Alic et al. 2003). But this is just one example of a more general phenomenon: feedback occurs at numerous points along and within the technology development pipeline, from the scientists, the engineers, and the technologists themselves, to the early adopters who make possible and open up new markets, and then to the mass market which sustains and builds further opportunities. The feedback from any of these stages may result in technology alterations at any of these stages. This makes for a complex progression that opens up a significantly larger prospect for interaction that, in turn, can accelerate innovations at all levels – should California choose to do so.

Although most of the dollars spent in California's energy efficiency policies are targeted at later stages in the technology pipeline, this does not necessarily imply a shortcoming of technological innovation earlier in the process. In fact, beyond California's R&D spending, there have been a variety of the demand-side policies (policies occurring later in the pipeline) which have encouraged large-scale improvements in energy-efficient technologies (occurring earlier in the pipeline). California has done this perhaps most simply by setting energy performance standards. Setting standards encourages innovative behavior by firms by giving them a known performance target that they can try to meet as cost-effectively as possible. As but one of many examples over the last 30 years, the capital cost of a refrigerator in the U.S. has declined rather than increased – even as stricter energy efficiency standards for refrigeration have been implemented (InterAcademy Council 2007). Likewise, California's ratepayer-funded utility programs have promoted incremental innovations that through mechanisms previously referenced as learning-by-doing. The "learning" is manifest in real price declines associated with increased production experience (i.e., the result of the so-called cumulative production). Also, it has been shown that patenting activity for environmental technologies such as wind and solar energy systems responds to the later stage demand-pull policy mechanisms that California commonly employs (Taylor et al. 2006).

One step on the road to imagining efficiency as a dynamic resource is to recognize how the costs of saving energy can and do fall over time. In effect, energy-saving technologies become cheaper through mechanisms such as learning-by-doing, and also because contractors, service providers, and program administrators become more adept at installing – and arranging to install – these technologies in the adoption phase. Energy-efficient technologies, like energy conversion and end-use technologies in general, exhibit decreased cost with increased production from learning by doing. Laitner and Sanstad (2004) show that cost declines are common in energy-efficient end-use technologies such as selective window coatings and electronic ballasts. The effects of learning by using in energy efficiency are also exhibited in the energy efficiency programs of electricity utilities. A recent study by Hurley et al. (2008) documented that the saved cost of electricity by nationwide utilities through their various efficiency programs is negatively correlated with the percent saved of total sales. Such short-run effects are unlikely to be explained by learning-by-doing in technology production alone, but could well result from the increased experience of contractors and program administrators.

Standardizing the variable factors in the adoption phase can go a long way towards reducing uncertainty in the efficiency market. Outcomes at this late phase are highly influenced by the skill and honesty of the contractors, and with performance contracting, the terms of agreement. A good place for standardization to begin is the building retrofit market, which is likely to carry a heavy share of the requisite activity if California is to its climate goals. The state can build confidence in its dealers and service providers by creating a list of certified efficiency contractors, similar to the list of certified solar contractors the state makes available, and publicize best practice installation standards such as the Air Conditioning Contractors of America Quality Installation guidelines.[11] The state might also take steps to standardize procedures for estimating, measuring, and verifying energy savings. These practices will never be a science, but mandatory publicly-sponsored clinics for efficiency contractors that treat these subjects could help disseminate best practices.

The impact of the demand side management (DSM) programs of energy utilities on innovation is also a ripe topic for advanced study and further policy formulation. To the extent that DSM programs help build markets for energy-efficient goods, they can increase innovation throughout the technology pipeline. But programs that cut-off the technology pipeline at a certain point, or overlook the behavioral or psychological component of energy production and consumption (Swim et al. 2009), may have an adverse affect on innovation. An example here is the public

[11] The guidelines are located at this website: http://www.acca.org/quality/#QIVP.

benefit programs where utilities give away compact fluorescent light bulbs (CFLs). While the demand generated by the utility will probably lead to learning-by-doing in the production of the light bulbs, the consumers who accept light bulbs for free are not motivated for adoption innovation, which requires proper – or any – installation of the more efficient bulbs. Thus, the utility program is putting a gap between innovation through "learning-by-doing" in the production of CFLs and "learning-by-using" through adoption and consumption of those devices. A way to maintain the continuity of the efficiency technology pipeline is to task the utility with completing the technology pipeline from where it intervenes: in this case, going door-to-door and replacing incandescent light bulbs with CFLs. This way, contractors will gain more experience with installing products in buildings, and customers will gain more experience with properly installed products. The service provider might then also generate feedback to those working through prior stages of the pipeline which might inform producers about new insights and possible new uses in ways that might not be imagined within the laboratory or the shop floor. The widespread availability of information and communication technologies can greatly assist in the flow of information up and down the pipeline.

As California capitalizes on new smart-grid technologies with emerging policies that accelerate its deployment, it can create even greater levels of energy productivity outcomes within the development pipeline. Traditionally, energy efficiency innovation has occurred in all four of Schumpeter's technology phases. But after energy efficiency technologies are contracted for and installed, opportunities for innovation are sharply limited. The smart grid opens up the adoption phase, providing the tools that energy consumers need to decide whether to modify their behavior of not. When exposed to more complete information on electricity prices, they may decide to turn their air conditioners down or lights off, for instance. The behavioral change enabled by new smart grid technologies will then feed backward in the technology pipeline as another stimulus affecting how energy-efficient technologies are designed and diffused. The key for making this happen, however, is a set of policies that direct a structured but open-ended evolution of the smart grid in ways that distinctly emphasize energy efficiency as a first priority.

B. Motivating Through a Compelling Narrative

There are huge numbers of constituencies and diverse interest groups that can generate a form of policy gridlock as they vie for attention and advocate for different elements of desired policy outcomes. One useful approach for laying the foundation for a long-term innovation is to communicate the promise of smart policies within a narrative that connects them. One recent example is the work of Jeremy Rifkin (2008), president of the Foundation on Economic Trends. In a current project with the city of San Antonio, Texas, and now involving the Principality of Monaco, Rifkin envisions the enabling of what he calls a "Third Industrial Revolution" founded upon investments in energy-efficient technologies and systems. Previous industrial revolutions, Rifkin observes, have occurred with large shifts in both energy and communications technologies. This is no coincidence, as commerce relies just as much upon communication between its own producers and trading partners as it does on the ability to harness the energy needed to actually produce, move, and provide the needed goods and services. The first industrial revolution occurred with coal-fired steam engines and the advent of widespread text printing. The next occurred with the telegraph and the oil age. The third industrial revolution –

embracing the principles of long-term sustainability anchored by a foundation of greater energy productivity – is likely to be facilitated by productive investments in both renewable energy systems and a smart communications, transportation, and energy infrastructure.

It is not typical for American policymakers to speak of their policies in terms of their place within multi-century economic trends, but this may be one of the more critical innovations that can help to confront the climate imperative. Rifkin's theme of the third industrial revolution has had more success in Europe, where policymakers have been receptive to thinking in terms of narratives. The U.S. has also stood by and watched as Europe has treated climate change far more seriously than we have (Brunnée 2008). Certainly, there are complex reasons for Europe's climate leadership, but one thing that the religious history of humanity has taught is that people often seek to imbue their actions with a larger meaning. Two examples of this relevant to climate change discussions in the U.S. are the increased salience of the Christian ethic of stewardship on the one hand, and the talk of a duty to future generations on the other hand.[12] Clearly when many concerned Californians and Americans mobilize to protect themselves and their children from the ill-effects of climate change, they will do so within some narrative that makes sense to them. Perhaps policymakers should escape narrow "econ-speak" of the present value of future damages and more proactively contribute to the construction of this narrative as it applies to the climate imperative.

Besides serving to motivate stakeholders, narratives also have the advantage of helping focus one's vision on the opportunities ahead. For instance, it takes only a cursory review of California's economic and political resources to see that it is perhaps the state which is best positioned to capitalize upon semiconductor-enabled energy efficiency measures. As ACEEE has shown in recent research, the potential of semiconductor-enabled devices to save energy is tremendous (Laitner et al. 2009). The smart grid has been celebrated quite a bit, and utilities in California are among the forerunners in its deployment, but it is just one example of the convergence of the virtual with the physical infrastructure. The information and communication technologies that serve as the platform for virtual infrastructure can be embedded in most of the traditional infrastructure that we rely on today: buildings, roads, bridges, and mass transportation systems.[13] In all applications, distributed sensors collect data on relevant variables and transmit to monitor and control centers, where information is processed and action can be taken. A tremendous potential in vehicle-emissions heavy California would be using sensors to enable smart stoplights to reduce vehicle idling. One increasingly realistic possibility is that stoplight sensors could pick up on the GPS signals of mobile phones carried in cars, and adjust their timing accordingly.[14]

The dramatic innovation of converting California's old infrastructure to smart, energy-efficient infrastructure relies on many of the same information sharing and coordination measures that we

[12] For a useful example of the power of the Christian stewardship movement, see Banks (2006). And for an especially compelling review of the many psychological aspects of energy consumption and climate change, see Swim et al. (2009).
[13] See Watkin (2008) for examples of these ideas at UC Berkeley, and also the "Intelligent Infrastructure" page at the public-private UC Center for Information Technology Research in the Interest of Society, available at: http://www.citris-uc.org/research/themes/intelligent_infrastructure.
[14] Research suggesting this possibility is being carried out in the Mobile Millennium project at the California Center for Innovative Transportation at UC Berkeley. See their work at: http://traffic.berkeley.edu.

reference elsewhere in this paper. In the case of infrastructure, these measures would be directed towards vertical coordination between state energy and infrastructure agencies and the municipal organizations with which they work. As stated in the 2008 update to California's Energy Action Plan (CPUC 2008a): "Decisions about community planning and land use, as well as transportation infrastructure and electricity infrastructure, have a dramatic impact on our ability to decrease our greenhouse gas emissions. Many of these types of long-term infrastructure decisions are made at the local level and are not governed by our energy agencies. Truly reducing our greenhouse gas footprint will require new and strengthened partnerships with local governments, as well as developers and builders in the private sector."

C. Emphasizing Cooperation and Collaboration

Cooperation or the sharing of best practices is critical to the innovation process for both technologies and institutions; and yet policymakers often struggle with promoting it. It is easy, it seems, to get people to do something, but more difficult to get them to do something together or to share knowledge as they do it. This difficulty should not deter public leaders from making the effort.

Recent empirical work by social scientists has highlighted the importance of collaboration and communication in driving technological innovations. Andrew Hargadon (2003) shows that some of the most celebrated inventions of the modern age were not the product of lone geniuses. The light bulb and the transistor, for instance, were not thought up in isolation by Thomas Edison and William Shockley. These men built upon the work of many previous scientists and their own collaborators. They succeeded not only because they were intelligent, but because they served as "technological brokers" connecting the work of different firms, industries, divisions, and people. Within this paradigm, networks of skilled scientists, innovators and financiers come to assume primary importance. Indeed, this is the clustered and highly connected model that innovation centers such as California's Silicon Valley and North Carolina's Research Triangle are largely based on.

A different approach to discerning the nature of innovation by Block and Keller (2008) yields similar results, actually suggesting that networks have been becoming even more important to innovation in recent years. Their analysis of the different organizations and funding trails behind winning innovations from R&D 100 awards indicates that these innovations have changed in several key ways over the last 30 years. Large firms who act on their own actually claim a much smaller share of award-winning innovations in recent years. Innovations stemming from collaborations, with spin-offs from universities and federal laboratories, make up a much larger share. In the last two decades, most of the award-winning U.S. innovations have come from partnerships involving business and government – very interesting news for public private partnerships. Also, the number of innovations that are federally-funded has increased dramatically over the time period of study.

Based on their research, Block and Keller (2008) find that the U.S. innovation system has become much more collaborative in nature and suggest that technology policy should adapt to this. They think that, especially in light of the public sector's increasing importance over the time period, funding for the U.S. government's technology initiatives must be expanded and made more secure. This is particularly true for those initiatives that support partnerships among firms, universities, federal laboratories, and state governments.

There are several ways that California could capitalize on the work of Block, Keller, Hargadon, and many others. Communications and collaboration can be significantly enhanced at all stages in the energy efficiency product development chain. One end of the chain is in the lab where new more cost-effective or higher performance efficiency technologies are discovered and commercialized. Collaboration and information flow among the growing energy efficiency researchers should be significantly strengthened at institutions such as the Environmental and Energy Technologies Division at the Lawrence Berkeley National Laboratory (LBNL), the Energy Efficiency Center at UC Davis, and the Precourt Energy Efficiency Center (PEEC) at Stanford University. When appropriately incentivized, more interconnections at the early stages of research yield more opportunity for feedback and improvement.

Efforts can be made to establish more linkages between academic and government researchers and private sector institutions such as related Silicon Valley Venture Capital (VC) firms and technology start ups. At the same time, these connections should be used not only to rush products out of the labs through highly aggressive technology transfer mechanisms as the Cooperative Research and Development Agreements (CRADAs). When promising breakthroughs do occur within the labs that can make socially-valuable technologies commercially ready – for example, Light Emitting Diodes (LEDs) – they should also have non-VC options for further development of those technologies. One opportunity is to create more breakthrough occasions that might use publicly-subsidized technology incubators such as the San Jose Biocenter. Another is to use innovation grant programs such as the Small Business Administration's Small Business Innovation Research (SBIR) program or an expanded version of California's own PIER program. Highly promising technologies that are ready to go to market should have the luxury of shopping around for the right mix of VC and non-VC options. Competition should be preserved, but technologies should not be rushed to market if superior near-term alternatives can be deployed without significant "lock-in" effects.

Even when commercialized, energy-efficient technologies still require support for full deployment. The CPUC recognizes this, as can be seen from the billions it has helped utilities spend on the deployment of energy-efficient technologies over the last several decades. In coming years, this might be transformed into an even greater effort of making sure the latest and most efficient technologies are in line for deployment into residences and businesses. Better coordination with local high technology centers could result in utilities being the preeminent marketers of energy-efficient technologies. Given their unique relationship with customers who often are very reluctant to install efficient technologies, this evolution seems suitable. Overall, communication among the participants in the energy efficiency technology diffusion process should be increased. Studies of innovation suggest that knowledge transfer at the diffusion stage is a crucial "low cost and high impact" factor behind the successful deployment of new environmental technologies (Alic et al 2003; and Taylor et al 2006).

Perhaps one of the more valuable cooperative innovations that might occur is to enable realistic technology characterizations to flow smoothly from scientists and research analysts working at laboratories to energy modelers and policymakers – and back again. Efforts have already been underway at both ACEEE and LBNL, the latter through its Enduse Forecasting and Market Assessment division, to supply energy modelers with timely data about the cost and performance of energy efficiency technologies. However, recent experience at the Energy Modeling Forum at Stanford University, and with the procedures used in federal climate modeling at the U.S. Department of Energy's Energy Information Administration (EIA) and the U.S. Environmental Protection Agency (EPA), show that only a fraction of the needed work here has been done (Laitner et al. 2009). Efforts made to accurately characterize current market and technology cost curves for various energy end-uses, but also to project how these curves will change over the significant time periods often dealt with in climate change models, can greatly improve understanding about the positive benefits as well as costs of adopting new climate policies. If the economic policy models never reflect the potential of present and probable future energy-efficient technologies, then policymakers are likely to overestimate the costs of dealing with the climate imperative. This, of course, will slow enthusiasm for addressing the climate imperative.

D. Exercising Solution-Oriented Swarm Intelligence

Solving difficult problems often requires people with different perspectives and skills to work well together. Managing such collaboration can be extremely difficult without constraining the creative output of researchers. Recent research suggests, however, that doing away with the heavy-handed management of creative social processes may be the best way to arrive at solutions. The so called intelligent "swarming" approach to solving policy problems recognizes the extreme difficulty of arriving at useful solutions to problems with complexly interrelated economic, social, and technological aspects. Such insights are already being incorporated into the business world.

The concept of swarm intelligence is based on the emergent, collective intelligence of social insect colonies. Individually, one insect is clearly limited in its capacity to accomplish much. Collectively, however, social insects are highly proficient in achieving a great variety of things: building and defending a nest, foraging for food, taking care of the brood, allocating labor, and much more. The world has become so complex that no single human being can comprehend it. Swarm intelligence offers an alternative way of designing "intelligent" systems and outcomes (Bonabeau and Meyer 2001). Instead of relying on the simplification of an inherently complex task, swarm approaches allow the spontaneous interactions of experts who will appraise the problem according to their own knowledge and interests. What management there is, is present in order to "consult, facilitate, and to serve" the swarmers but not to direct them (Embley 2007).

Variations on swarming behavior are already evident in California. Given the highly-networked nature of the academic and commercial innovation centers in the state, and the presence of many experts on different issues, people are constantly coming together in informal environments to collaboratively solve complex problems. The CPUC's processes of soliciting review on rulemakings, holding workshops, and hiring issue-experts present elements of swarming. So does PIER's practice of collaborating with universities and research centers. In many ways, the political policymaking and rulemaking processes are the most common examples of swarming.

However, when carried out in overtly political environments such as legislative halls and rulemaking sessions, the interaction among experts will be shaped more heavily by power dynamics than may be optimal for so-called "swarm events."

California might improve on these practices to arrive at a swarming model that facilitates solutions that specifically confront the climate imperative. In this case, there is a demand for a very specific outcome – innovative solutions to counter the rapidly growing GHG emissions. The scale of this issue is larger than any one person can design and implement. Yet, there are strategic assets and personnel within the state that might "swarm" to a given task in a short period of time; and when a specific contribution is made, the individual or asset is returned to his or her original duties and/or responsibilities. To pull this effort together in a needed way, it is likely that it will have to be sanctioned by the Governor with each agency expected to contribute according to the nature of their personnel and/or resources. Much like jury duty obligations, individuals might be called forward to work on a specific task for some period of time; or in a self-organizing, emergent way, with the right narrative and incentives, they might simply volunteer. Sponsoring agencies would be expected to hold open the position and assign other personnel to take up the work in the expected short periods of time that might be involved in developing a recommended solution.

Following the enabling momentum established by the Governor (or presumably an agency head with supportive collaboration from other stakeholders and agencies), a convening body would lay out the problem and a set of rules by which the participants would proceed. As Bonabeau and Meyer suggest (2001), the most powerful and fascinating insights from swarm intelligence is that "complex and collective behavior can emerge from individuals following simple rules." The simple rules are designed to promote: (i) flexibility that allows the group to quickly adapt to new situations or new information and insights; (ii) robustness so that when one or more individuals and tasks inevitably fail, lessons are learned and the group can still perform their tasks, or even enhance the outcomes; and (iii) self-organization which requires little supervision but allows more productive outcomes to emerge. The convening managers might provide a reward system that empowers all participants to make decisions on their own assignments or undertakings but with very little top-down management. General George Patton said: "Never tell people how to do things. Tell them what to do and they will surprise you with their ingenuity."(Patton 1995).

Following the model of developing a new computer program, in effect we have the development of a concept and an initial design that convening managers might suggest. Teams of skilled people – ideally merging different technical and cultural perspectives (von Meier 1999) – are then brought in to assess, organize, and then complete different portions of the task. As they finish their individual responsibilities or assignments, the program segment that emerges is then subjected to an alpha test to review the viability and likelihood of success for that program element. Everything is open for discussion: how to cut costs, how to reduce mistakes, and how to unplug the inevitable bottlenecks. Once the full array of program elements is brought together, the integrated components are beta-tested through a game exercise or simulation. Following a successful review and beta test, the recommendation is made for full or modified implementation. Or the effort might be dropped in its current form, or even scrapped altogether – with the caveat that the lessons and insights from these scrapped or dropped efforts are in some way stored and potentially made available for another round of innovation solutions.

A Japanese variation of swarming behavior, known as "oobeya", structured largely along these lines, was instrumental in the successful redesign of Toyota's Corolla car model for the 2003 season. The company was aiming to keep the price of the new 2003 Corolla under $15,000 while reinvigorating the design and adding the high-tech options to win over young drivers. Toyota brought people together from all parts of the company – design, engineering, manufacturing, logistics, and sales – and continued to do so every month for the two years before the car went into production. Everyone in the room was an expert, and the result in this case was a spectacularly successful product (Warner 2002).

The state might also consider implementing a public-private swarm approach to energy problem solving. One blueprint of the organizational platform for a public/private swarm approach is the Energy-Discovery and Innovation Institute (e-DII). The e-DIIs are regionally-based "hub-and-spoke" networks of universities, industry, and government participants that work on energy and efficiency technology research, development, and demonstration (Duderstadt et al. 2009). The first e-DII-type institutions will come online soon. The American Reinvestment and Recovery Act provided grants to one-third of 46 energy research organizations called Energy Frontier Research Centers (EFRC). Six of the forty-six EFRCs are intended to be dedicated to energy efficiency work, including solid state lighting, efficient combustion, and superconductivity, and seven of them are in California.[15]

An example of more unstructured swarming in California is the recent effort of academics, venture capitalists, and entrepreneurs in the Gigaton Throwdown Initiative (Augustine et al. 2007). Driven by a realization of the huge scale implied by tackling the climate imperative and that they "could make a bunch of money but not a bit of difference," clean technology leaders banded together to research what individual technologies could prevent 1 billion metric tons (that is, one gigaton) of CO_2 equivalent emissions each by 2020. As it turned out, the Gigaton Throwdown Team, headed by leading venture capitalist Sunil Paul, discovered eight sets of such technologies which together could provide the equivalent of 55 quadrillion British thermal units (Btus) of carbon-free energy services by 2020. The team followed this research up with a series of policy recommendations that could turn this potential into reality. While this effort focused on the supply-side opportunities, a similar "efficiency throwdown" might generate equally valuable gigatons of energy productivity.

E. Directing Purposeful Innovation

With all of the proposed organizations, policies, and themes in this paper, a major challenge is how to set goals and timelines that deliver innovative outputs – without preventing researchers and program managers from capitalizing upon positive unintended consequences or otherwise constricting the free functioning of creative minds. As Dörner (1996) observes, "Few things are as important as setting useful goals. If we do not formulate our goals well and understand the interactions between them, our performance will suffer." As implied in the sections on swarm intelligence and collaboration, relatively unstructured, non-hierarchical, and highly-networked

[15] See the "Energy Frontier Research Center (EFRC) Awards" at http://www.er.doe.gov/bes/EFRC.html.

research environments can be some of the best for innovation. But the characteristics that make such environments productive for innovation also make them difficult to direct purposefully. In this section, we suggest that managing through a public mandate for innovation may be the best way to direct the creative juices of such highly innovative organizations.

Times at which public leadership has been strongest have been the most innovative. In 20th century American history, these periods include World War II and the Cold War most prominently. During these times innovation was emphasized, encouraged, and made purposeful. Scientists, policymakers, and everyday people have often responded to extraordinary circumstances with commendable out-of-the-box thinking. Current policymakers would do well to remember that innovation is a social process in which innovation is not only impelled by scientific search, but also by social needs and motivations (Freeman and Soete 1997).

A sensible place to start is an innovation mandate in energy-related government agencies (which may turn out to be almost or all of them). An innovation mandate reflects the reality that the innovative spirit must be planted in government first and only then will it have the best chance of spreading to the rest of the state and beyond. Government agencies should be directed to innovate in their own work, but most importantly to bring innovations into their collaborations with the private sector. Of course, commanding people to solve problems will not necessarily get the problems solved. It might, however, generate the political space for them to experiment.

For instance, a mandate for innovation could be grounds for the CPUC to continue with its regulatory innovations, and pursue them even further if necessary. One innovation would be to recognize that excess returns gained from supply side investments are just as much a hindrance to efficiency as are insufficient returns to efficiency investments. A solution is to cap the rate of return that public utilities can make off their supply investments at the general rate of return on equity capital, which is typically in the high single digits. Rates of return at these levels have been authorized by utility commissions in Arkansas, New Hampshire, and Canada (Marcus and Mitchell 2006). An even bolder action would be to spurn the idea that providers of a socially foundational good in a noncompetitive environment, i.e. the IOUs, should be run as investor-owned firms. A gradual transition could be made from investor to local ownership, with the transition happening gradually as utilities fail to meet the more and more aggressive savings targets that will occur in the coming years. Socialization would be aided by a well-executed P.R. campaign advertising the extremely generous efficiency benefits paid for by the public purse, such as the 12 percent rate of return the CPUC now offers for over performing efficiency programs. While some would characterize such a policy as harsh or even un-American, it seems pragmatic when viewed light of the seriousness of the climate imperative.

One detriment to the idea of encouraging purposeful innovation in the face of climate change is that such innovation has historically been motivated by an immediate existential threat. This is not an accident. Human beings are best at responding to crises, not secular trends, and often wait until crises affect them more or less directly before they act. During time periods without crises, politicians frequently try to rouse support for their initiatives, but they are rarely successful at significantly shifting public opinion. Because the effects of global warming are unlikely to be apparent to most of the American public for several decades at least, this would caution against trying to rely on public leadership to inspire anyone to action against climate change.

Yet, climate change policy provides the opportunity for a unique initiative, and with a compelling set of narratives about the necessity and opportunity to address climate change, it may be possible to motivate the public to support the necessary levels of innovation without resorting to war-time rhetoric and war-time levels of funding. For one, climate change is a well understood scientific phenomenon, unlike the “disasters” underlying most public policy initiatives. Scientific authority has special prestige in the United States, and especially in California, and thus is more of a credible backdrop for a call to action. Secondly, not all of the public will be innovating. It is primarily a small, well educated, segment of the population working in politics, policy, academia, and business that needs to be motivated (the Golden State does have some experience in motivating these groups already – look at the Gigaton Throwdown Initiative). These are the persons with the capacity to significantly further innovation in energy-efficient technologies and efficiency-related institutions. These are also the people most likely to be motivated by an argument based on science and long-term consequences.

4. Conclusions and Next Steps Ahead

In this white paper, we’ve briefly described the history of California’s innovations in energy-efficient technologies and efficiency-related institutions, and suggested how these achievements might be augmented with insights from the five themes we present on different aspects of innovation. The California state government is already a major leader in developing greater opportunities to promote energy efficiency, especially the CPUC. Hence, our suggestions build upon the capacities that already exist. Furthermore, with the arguable exception of implementing swarm-type intelligence gatherings, California is already known to be taking policy steps in these directions. The CPUC and CEC are particularly good at working cooperatively with businesses and research organizations in the state. With further reflection, however, California’s decision and policy leaders are likely to find room for improvement – especially when seen within the context of the climate imperative. Building on the insights emerging from this discussion, five specific suggestions appear to provide California with a logical set of five next steps forward:

1. Boost innovation in the adoption phase of the energy-efficient technology pipeline by implementing efficiency-friendly smart grid policies

The smart grid – indeed, a smarter infrastructure more broadly – opens up the adoption phase to innovation, providing the tools that energy producers and consumers need to decide how they might best modify their behavior. When exposed to more complete information on electricity prices, they may decide to turn their air conditioners down, or turn off their lights and other appliances, for instance. The behavioral change enabled by new smart grid technologies will then feed backward in the technology pipeline as another stimulus affecting how energy-efficient technologies are designed and diffused. The key for making this happen, however, is the set of policies that direct the evolution of the smart grid towards a greater emphasis on energy efficiency or energy productivity.

2. Energize the public sector and civil society with a compelling innovation narrative

Policymakers should capitalize upon the lessons of the private sector and European leaders by forming a compelling narrative that puts the climate imperative in a useful perspective in order to motivate innovation. As the efforts of broad thinkers such as Jeremy Rifkin have shown, powerful narratives from public figures can catalyze action in the face of climate change. This narrative may involve taking a longer term view of present climate policy than is typical. Such a viewpoint may be useful in motivating the population to embrace productive behaviors and attitudes, but also in focusing attention on high potential energy savings areas.

3. Promote knowledge sharing and cooperation among all elements of the energy efficiency supply chain

Running from energy research and development at labs and research universities, to the commercialization activities of start-ups, to the deployment actions of utilities, to the diffusion of technologies among consumer groups, to the technology modeling efforts of economists, government should come up with measures and support to increase knowledge sharing and cooperation along the energy-efficient technology supply chain. It is clear from its Long Term Energy Efficiency Plan that the CPUC already recognizes the importance of collaboration in promoting energy efficiency. The feedback effects that occur from the learning-by-using of energy-efficient technologies cannot be expected to improve technology design without a structured means to provide that feedback. By hosting information-sharing events and platforms with diverse stakeholders, the state can maximize the feedback that does occur.

4. Increase the use of swarm-type meetings in energy-related brainstorming sessions, possibly with a first experimental effort at the CPUC's upcoming smart grid meetings

Swarm-type events exploit the creative potential of experts who come together in a lightly managed and unstructured environment. A possible idea for testing out a swarm-type approach in California would be fitting more unstructured breakout sessions into the workshops and public meetings that the CPUC sponsors. The CPUC's upcoming meetings on the Smart Grid are a particularly attractive test bed. The best applications of the smart grid to save energy are not well understood, and the swarming of a variety of experts could produce unexpected and useful results. A productive personnel addition could be experts on distributed intelligence or on the implications of the convergence of virtual and physical infrastructure.

5. Make use of an innovation mandate to direct the actions of appropriate government agencies and personnel

California can capitalize on the historical evidence that shows that periods of great purpose often produce the greatest innovations. Given the prestige of science within California, an innovation mandate would resonate with the public, and would even furthermore motivate the educated stakeholders who are most vital to innovation. Perhaps anchored by a compelling narrative or vision of future opportunity, a structured innovation mandate will not only motivate innovation within the halls of government, but also in the collaborative activities of both government and the private sector.

None of these five recommendations is revolutionary, nor are they prescriptive in the sense that they either lock in or lock out future opportunities; but taken together they provide a reasonable portfolio of next steps forward that might catalyze purposeful innovation at the scale sufficient to address California and the global climate imperative. These next steps forward are based on a number of fundamental themes – such as increased levels of collaboration and the pooling of knowledge – whose importance to innovation is demonstrated in the emergence of smart technologies and creative institutions and is also documented in the literature. Applying and building on these insights can accelerate the development and deployment of a greater array of energy-efficient technologies and efficiency-related institutions. These next steps forward can enable energy efficiency to evolve from its current status as a low-hanging fruit to the dynamic, long-term resource that it could provide.

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