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Governments, Markets, and Green Growth:
Energy systems transformation for sustainable prosperity

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I. INTRODUCTION[i]

There are compelling and varied arguments for moving to low-carbon, high-efficiency energy systems: mitigating climate change, securing energy supplies, and resolving the imbalance of payments caused by energy imports. The hope is that investment in pursuit of these policy goals will also generate sustained economic growth.
We address three aspects of this problem:

1. What are the proper roles for markets, prices, and governments in the move to a new energy system?
2. Which policy interventions can become investments in a productive future, and which are just costs that we must bear to achieve our other policy objectives?
3. Can the shift to low-carbon, high-efficiency energy drive "green growth" and business opportunity?

The concept of an *energy systems transformation* helps us answer each of these questions. The energy supply system is a *system*, consisting of separate elements that are complementary to one another and inter-linked. Changes to most of these parts, in ways that maintain their linkages and complementary relationships is required to establish a low carbon, high-efficiency economy. This set of coordinated changes can be called a *systems transformation*. Policy must seek a shift from today's high-carbon, low-efficiency energy system to a low-carbon, high-efficiency alternative. Understanding the demands of such an energy systems transformation is crucial to addressing the connection between energy policy and growth.

First, the concept of a system means that significant changes to patterns of energy use require a shift to a different trajectory of energy development, not merely improvement of the existing system. More efficient light bulbs, or better gas mileage for vehicles, can improve the efficiency of today's energy system. However, those changes will not fundamentally transform our dependence on carbon energy. Instead, policy must target an altogether new systems trajectory, and to that end promote innovations that in a new and integrated manner create a low carbon system to produce, distribute, and use energy in new ways.

Second, a new energy system will require suites of interoperable technologies, not just one-off technological breakthroughs. For instance, advances in wind power technology must be matched by developments in the power grid and energy use to accommodate wind power's fundamental intermittency. Likewise, an efficient, reliable electric car will require substantial increases in electricity supply from low-emissions sources, and a new network of refueling stations, even as it promises to radically reduce the role of oil in transportation. These problems demonstrate the importance of energy as a system, and inform against approaching treating the problem as one of isolated solutions. [3]

[3] This system transformation will require difficult changes in three distinct domains, 1) Energy efficiency can reduce demand, but those demand reductions make planning harder and diminish the requirements for new capital investments potentially embodying low carbon technology. 2) Renewable electrical energy sources are intermittent, creating new demands for grid management. Biofuels require significant alteration of fuel distribution systems; and 3) Decarbonizing existing fuel sources, as well as introducing renewables, comes at the price of

Consequently, policymakers must judge which interventions in the energy system have the greatest potential to shift the system onto a new trajectory. Observation of other technological systems demonstrates the power of the network itself to shape the evolution of the rest of the system. Earlier energy systems transformations were facilitated in part by changes to the transportation infrastructure: the railroad for coal, or the pipeline for oil. Similarly, the ICT revolution has been sustained by innovation in data and telecommunications networks.

We propose for the sake of discussion that the structure of the energy system makes the electric power grid the best analogue to the rail and telecommunications networks, and the leading candidate for transformative policy intervention. Modernization of the power grid offers great leverage for creating an energy system transformation and establishing an energy innovation platform. Policy can help drive a grid modernization based on open standards – standard communication protocols for different classes of devices on the grid, access for devices and energy sources, and the communication capacity to link it all together as a system.

II. AN EARLIER TRANSFORMATION

The opportunities and challenges of the energy system transformation can be clarified by considering energy in light of an earlier systems transformation. As we've noted, information technology proved both a transformative communications technological and a growth-generating general technology. Why did the digital revolution happen so quickly, and so smoothly? *First*, the semiconductor industry developed as an entirely new sector. No legacy system existed to constrain the choices made in this period of experimentation. *Second*, that experimentation was heavily underwritten by the United States Defense Department, which during the Cold War had effectively bottomless pockets. *Third*, the emergence of dynamic new firms like Intel or Cisco depended on antitrust provisions that prevented AT&T, who then dominated the networks, from controlling the microelectronics or semiconductor markets. *Fourth*, DARPA and the NSF supported the standard protocols and open network communications paradigms that became the Internet. *Finally*, deregulation of the telecommunications markets required network owners to offer open access to their monopoly-controlled networks, fracturing the system and permitting the entry of a variety of new players.

A similar pathway to an energy systems transformation is not yet apparent. Differences from the ICT story are immediately obvious:

1. The energy system in the advanced countries is fully built-out, and new capacity will only be added slowly. Consequently, new approaches to energy must be implemented by retrofitting the existing system.
2. That retrofit must occur while preserving an uninterrupted supply of energy to the economy.
3. Both the public and private sector have limited resources relative to the scale of investment required compared with the initial era of semiconductor and ICT innovation

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higher energy costs. Those costs must be borne directly by energy users, but the benefits are quite diffuse.

4. In many countries, certainly the US, the networks belong to a diverse set of owners operating in many different regulatory jurisdictions, frustrating attempts to enforce interoperability for new grid capabilities and open access for new technologies and market players.
5. The investment horizons don't support rapid adoption or iterated innovation. Investments in ICT depreciated over months or years, creating consistent demand for new innovation. Investments in energy depreciate over decades.[ii]
6. Renewable energy does not, for the most part, offer immediate competitive advantage to early adopters the way ICT investments did.

These differences point to the challenge facing policymakers. The importance of the state to the ICT transformation implies an even more important role in the more complicated energy systems transformation. As with ICT, that role will require multifaceted intervention in research and development, regulation, coordination, and financial support.

III. GREEN TECH AND GREEN GROWTH

Whether and how an Energy System transformation translates into sustained economic growth depends on two fundamental issues. Any attempt to link systems transformation to growth must reckon with the challenges they pose. First, building out individual pieces of a new energy system—new windmills or better buildings or more efficient cars—will certainly create business opportunities, jobs, and technological innovation. But as isolated efforts, these opportunities may simply replace "brown jobs" with "green jobs", generating little additional growth.[4] Second, an energy systems transformation will create growth only if it creates pervasive opportunities throughout the economy beyond the immediate substitution of green for brown jobs. The basic question facing policymakers is whether these two issues will confound attempts to link energy systems and growth.

Systemic investment in disruptive technological innovation can create new opportunities throughout the economy. Industrial history provides many examples of situations where innovations in one sector or technology domain enabled dramatic growth in the rest of the economy. These examples underpin much of our understanding about the connection between disruptive technologies and long-term economic growth. A few examples[iii] will suffice:

- Steam power, which dramatically altered the amount of power that could be applied to a given task and created a platform for innovation in economic production and transportation

[4] The number of jobs created by greenhouse gas mitigation policies being discussed in California and the US generally is the subject of some debate. On the one hand, renewable energy technologies are typically somewhat more labor-intensive than fossil fuel technologies and therefore generate more jobs per unit of energy produced. On the other hand, insofar as renewable technologies remain somewhat more expensive than existing fossil fuel technologies, their adoption can lower the growth in employment Raising energy efficiency, however, contributes to economic growth (the same output of goods and services can be attained with less energy input) and therefore raises employment.

- Railroad transportation, which significantly lowered the cost of transportation and tied local markets into national economies. Railroads shrank time and space, creating much larger markets for goods that justified wholly new modes of firm organization and capital investment.
- Electrification, which enabled the reorganization of factories, and made possible the introduction of myriad new devices simply not possible with coal or gas.
- The internal combustion engine, which provided the energy efficiency and intensity necessary for the transportation revolution.
- Semiconductors and information networks, which enabled the information revolution and spawned entirely new forms of value creation based on information as a good. The internet changed fundamentally the ability to aggregate, access, process, and use information.

These innovations made possible products and processes that simply did not exist before. The network innovations – railroads, the electric grid, the internet – all changed fundamentally the possibilities for the organization of the rest of the economy. The new market possibilities, and not just the networks themselves, generated economic growth.

There is a real question as to whether "Clean energy" generates pervasive opportunity in the same way. Spectacular success in adding renewable energy to the energy system means the energy user will notice no difference between electrons generated by coal and those generated by wind or solar. All the investment in storage, the smart grid, and new energy sources will go towards ensuring that today's patterns of energy use remain viable. It will do little to enable some new generation of energy uses. Even the invention of a whole new class of automobiles still only strives to produce a personal transportation device as good as automobiles available today.[5]

Energy innovation technologies may reduce energy costs or provide value by being "environmentally friendly". These benefits are largely about cost savings or avoidance of damage. These technologies do not, as of yet, promise radically different, more productive, more diverse forms of economic value creation.[iv] Thus green growth and the energy systems transformation on which it depends remain very different from these earlier epochs of transformative technological change.

These differences make it incumbent on those who advocate for green growth to demonstrate the systems advantages that would lead to repeated innovation in the private sector and that would drive growth through new possibilities for products, production, or productivity.[v]
We would point out that the economic significance of radical systems changes often comes in disguise. The advantages of a new energy system may not be evident immediately. In the 1960s, IBM famously thought that it would only sell a handful of its new mainframe computers. The enormous utility of the mainframe and its successors only became apparent through experimentation in the market. Microprocessors followed a similar pattern. Intel had to invest

[5] There could be some other transportation-related innovations that do improve on the quality of existing transportation services, such as smart parking lots with web-based information on parking space availability.

heavily in explaining to potential customers the possibilities of this new device. Indeed, its marketing manager at the time had a Ph.D. in electrical engineering—a necessary qualification for articulating the potential of this new technology for tangible economic benefits. Last but not least, the commercial power of the internet was hardly obvious at the beginning.
Similarly, the real advantages of "green" tech, and there may well be many, will be discovered in the marketplace. But the very different nature of this transformation, and the very large investments it will require, behooves the participants—private and public sector alike—to proactively identify the economic possibilities that may emerge from green energy. That discussion will prove a necessary precursor to policy that can go beyond merely driving the development and adoption of "green" energy, to enable the broader adaptation in the economy as a whole. That may prove the toughest trick of all.

IV. POLICY FOR "GREEN GROWTH" AND AN ENERGY SYSTEMS TRANSFORMATION

Thus both energy systems transformation and the green growth we hope that transformation will create represent special challenges to policymakers. Past experiences suggest the challenges but do not directly suggest solutions. Those solutions require that policymakers accomplish two separate, though ultimately linked, tasks. First, systems transformation requires policy to shift investment and technology development onto a fundamentally new trajectory. That shift will turn the energy system towards transformation. But, because it merely substitutes "green" investments and jobs for "brown" ones, it will make limited contributions to growth. There is a second, and more difficult task, which we do not address directly here. Policy must to explore how a green energy system can create possibilities and competitive advantage for products, processes, and services throughout the economy.

Shifting from one energy system to another will require more than just one-off innovation or a range of diffuse new products. The logic of the energy system places two demands on governments as they seek the right policies for the task.

First, innovation in new technologies for energy production, distribution, and use must produce an interoperable set of innovations that complement each other and that enable ongoing innovation. Public support for research, development, and deployment of new technology will of course be vital. Governments must go beyond traditional technology policy to sponsor coordination among a diverse set of private sector actors to assure interoperability and complementarity.

Second, to achieve sustained growth from green technology, the energy system transformation must shift the long-term private investment and innovation trajectory in a new direction. Policy must encourage a pervasive economy wide adaptation to the new energy regime. An appropriate policy framework will create the conditions for private investment to push the systems transformation to completion. Here, the Internet, though imperfect for reasons we've already discussed, provides a very relevant analogy. There, government policy sponsored innovation and established a competitive environment in which new firms and technologies could thrive. The private sector didn't invent the internet. Rather, they used its common standards and open networks as a platform for rapid, iterated, diverse innovation in technology and business models.

With the standards not subject to competition, old firms were unable to use control of standards to monopolize markets; and new firms could count on the interoperability of their inventions with the rest of the system. In this environment, private investment and competition became the engine of transformation.

We return to the crucial question. Is there a point of leverage that can both shift the energy system to a new trajectory and drive a broader transformation in the economy? To provoke discussion, we hypothesize that the state can play its most crucial role in the networks that bind the energy system into a whole. The electrical distribution grid provides an instance of such networks. Today's power grid is widely regarded as a relic, one that Thomas Edison would recognize if he returned to life. There is widespread agreement that the incorporation of large amounts of renewable energy, the use of price incentives to help consumers make more efficient use of energy, and the replacement of fossil fuels for transportation with electricity all require a "smarter" grid that makes better use of real-time information on supply and demand to allocate capacity.[vi] That intelligence will bind production, distribution, and use even more tightly together in pursuit of efficiency and low emissions.

At present, however, much of that "intelligence" remains undefined: the design of that grid; the protocols that will support communication between appliances and power meters, utilities, and energy producers; and the regulatory framework that will structure the operating environment for firms and consumers.

This uncertainty is a disincentive to firms who might engage in widespread private innovation and deployment of new technologies to produce and use energy more efficiently. Without some degree of predictability around the technological and regulatory standards that will control access to the grid, firms and consumers face severe uncertainty as to the viability of their investments. Furthermore, in fractured regulatory environments, the prospect of many different standards, rather than some common standard, fractures the market for innovation and investment.[vii]
The grid therefore forms an important component of the energy transformation. It may also plays a critical role in achieving any kind of sustainable "green growth." Absent the kinds of innovation enabled by a more dynamic grid, firms lack the incentives to invest in a wide range of new innovation. Absent the standardization of that grid, they face fragmented markets and technical uncertainty. Today, these two shortcomings inform against an energy systems transformation that can create self-sustaining momentum for private investment and consumption, and thus growth.

V. POLICY CHOICES FOR AN ENERGY SYSTEM TRANSFORMATION

The most vibrant policy debates today concern the role that each of these tools can play.

1. Carbon pricing to incentivize both technological development and low-emissions energy adoption;
2. Technology policy to support research and development;

3. Regulatory policy to change market rules to favor new forms of energy production, distribution, and use[6];
4. Direct state action for public infrastructure investment and industrial policy.

- **Carbon pricing**

  Advocates of carbon taxes or cap-and-trade regimes argue that prices alone can create the conditions to accomplish the systems transformation. In our view, there are two reasons that prices, while a necessary component of the policy mix, will not be sufficient.

  First, policy based on pricing mechanisms was successful in addressing emissions issues where the technologies required to reduce emissions *already* existed. That is not the case with the current effort to move to "green" energy. Where the needed technologies already existed, prices thus acted as an incentive for *adoption*, not *innovation*. Furthermore, adoption of those technologies required almost no downstream change to how energy was distributed or used.[viii] The United States used pricing to reduce emissions of acid-rain-causing sulfur dioxide. The policy was enormously successful at very low cost. It provided very clear incentives for firms to build cleaner plants, and to install technology to capture emissions on older ones. But these technologies were very well understood when the policy was implemented, and the cost of installation and operation were very clear. The scrubbers also had no effect on the properties of the electricity supplied by these cleaner plants. Thus the incentives for power generators were clear, and the downstream effects on electricity consumers limited.

  Second, carbon pricing has little political support in several major emitters, including the United States and China. Even if these countries managed to implement a carbon price, the lack of political agreement surrounding it reduces the long-run credibility of the price and thus its effectiveness as an incentive for firms to make major long-term investments in innovation or new capital.

  Thus, while emissions pricing can provide incentives for efficiency in some areas of the energy system, there is good reason to doubt that it can induce the broad range of investments required to effect the systems transformation we seek.[ix]

- **Technology policy to support research and development**

  Proponents of public support for research and development argue that these policies can achieve the goals that carbon prices cannot. Certainly the need for innovation in renewable energy, energy distribution, and energy efficiency will require significant public investment. How best to make those investments remains the subject of spirited debate.

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[6] These three elements of the energy system are configured differently in each country by regulation and ownership structure, creating distinct national dynamics of demand and supply. Hence there will not be one universal trajectory to a low carbon future and cannot be a single best regulatory strategy.

Traditional technology policy can take at least three forms: 1) intensive support of narrow innovation priorities, as in the Manhattan project: 2) diffuse support of research and development through research institutes and universities, and 3) policies to promote the adoption and diffusion of the new technologies. Manhattan Project-style efforts may be appropriate for capital-intensive, high-risk problems like nuclear fusion or carbon sequestration, but are of little use in delivering diffuse innovations for efficiency across a spectrum of sectors. Diffuse innovation, in contrast, is enormously successful when the standards for interoperability are already settled, and thus coordination among researchers is unimportant. Similarly, policies for adoption and diffusion of technologies, whether through public or private mechanisms, assume reasonably mature technology development. One must emphasize that technology policy does not necessarily constitute "industrial policy" since it need not determine technology choices in the market.

- **Regulatory intervention**

  Governments can successfully use regulatory incentives to drive the adoption of new energy technology where, again, the technological targets are well-understood and where the regulators have significant weight in the marketplace. Many countries or U.S. states have already done so, via Renewable Energy Portfolio requirements for power generators, energy efficiency programs for homeowners, and changes to energy tariffs. Regulation can affect the deployment and diffusion of technology, but does not necessarily create the framework for sustained private investment. Without considerable regulatory will the incentives to continue these programs may fade. Unless an energy systems change can be achieved, a phase shift from one system the impact of these regulations can be limited.

- Direct state action: infrastructure and industry policy

  Government, of course, may act in energy markets directly, as in building out new energy infrastructure or obligating private actors to do so. The question becomes whether energy systems transformation requires directed state action in addition to the less intrusive policies noted above. Importantly, infrastructure policy need not be directed industrial policy; it need not dictate or support the success of particular firms. Nevertheless, the classic questions arise of how to best organize state action, through administration, public companies or public-private partnerships. There will be a variety of national answers. Similarly, the issue, raised throughout this discussion, remains: which elements of the energy system, such as the electricity grid, if altered, will induce a significant shift in the energy system?

Appropriate pricing policy, technology strategies, regulatory programs, and infrastructure policies are essential. Each of these policy tools has a role to play. But none constitute a comprehensive solution on their own. Moreover, we emphasize that national variation in the regulation of the energy sector, the ownership structure of its firms, and the dynamics of finance create opportunities and constraints that will affect each of these three policy tools differently. Hence we should expect, and accommodate, distinct national solutions to systems transformation.

Given the complexity of these systems, policymakers face difficult choices about where to apply these policy tools. With limited resources, policymakers should seek points in the energy system where limited interventions can change the trajectory of development, by altering the choices of actors throughout the system. We have noted that the railroad and the telecommunications network played this role in past economic transformations. Do similar levers exist for energy, which if pulled would induce broad private investment to capture the diverse advantages of the new system?

Certainly there must be a debate about whether there is such a lever and what it might be. For the sake of discussion, we propose that governments should exploit the transformative potential of the power grid that we outlined above. The grid is central to choices about how to produce, distribute, and use energy. An appropriate grid is crucial both to the introduction of renewables and advancing efficiency and demand response programs. Consequently the grid provides significant leverage for policies intent on accomplishing energy systems transformation. Energy policy should use tightly focused technological innovation, coupled to regulatory reform and standards-setting processes, to develop and deploy a power grid capable of handling significant change to technologies for production and use. Development and deployment of standards-based grids both solves the initial investment problem and creates a platform on which private sector innovation can thrive. That innovation, in turn, can drive both the technological advances required for the adoption of new energy sources, and the investment and employment required for green growth.

VI. CONCLUSIONS: NETWORKS AND GREEN GROWTH

Mitigating climate change, ensuring the security of the energy supply, and reducing the economic cost of energy all require major changes to today's energy systems. The successful pursuit of a high-efficiency, low-carbon energy system will require more than just one-off technological innovation or marginal attempts at energy efficiency. Rather, we must aim for an energy systems transformation that generates a sustainable trajectory towards ongoing efficiency improvements and emissions reduction. We have argued that this transformation can enable economic growth if it creates the preconditions for sustained private investment and innovation in the energy sector. An open power grid operating on common technological standards will play an important role in these preconditions and must be the focus of an energy policy. Whether it can sustain both energy systems transformation and economic growth remains an open question.

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[i]Many thanks to Michael Hanemann for helpful comments and deep insight into these issues.

[ii] Varun Rai, David Victor, and Mark Thurber make this point for carbon capture and sequestration in particular. The large financial and technological risks that CCS presents, coupled with the huge investment cost and regulatory uncertainty, promise to forestall innovation and investment. See Rai, Victor, and Thurber, "Carbon capture and storage at scale: Lessons from the growth of analogous energy technologies" *Energy Policy* 38(8), pp 4089-4098.

[iii] Carlotta Perez treats these as successive Kondratieff waves. We need not engage in the debate over the relevance of the Kondratieff concept to acknowledge that its core contention—that some technological innovations provide the foundation for a huge spectrum of subsequent growth—holds in each of these cases. See Perez, "Microelectronics, Long Waves, and World Structural Change: New Perspectives for Developing Countries" *World Development* 13(3), pp 441-463, 1985.

[iv] There may be some exceptions to this. Renewables such as solar and wind do permit decentralized energy production, reducing energy users' dependence on the grid. Whether this translates into radically new forms of production or the organization of production is as of yet unclear.

[v] The problem runs deeper than that. Only growth can sustain the energy systems transformation. No one believes that the policy goals of emissions reduction and energy security will be satisfied in the first generation of new energy technologies. Rather, it will require waves of innovation in energy production, distribution, and use. The scale and diversity of investment these goals will require can only come from a private sector that sees economic opportunity in ongoing energy innovation. Politically, commitment to energy systems transformation will only endure if it creates economic opportunities and not merely costs. Public investment must therefore set the foundation that enables this investment, by building a platform for growth along a low-carbon, high-efficiency trajectory. Only green growth along this trajectory can accomplish the energy systems transformation.

[vi] This point has been widely confirmed. For the American case, see *Accommodating High Levels of Variable Generation* (Princeton, New Jersey: North American Electric Reliability Corporation, 2009). That said, the specifics of how information and electricity supply will be integrated remains open to debate.

[vii] The importance of this for firm investment decisions is obvious. But consider the consumer who invests in a "smart" air conditioner in California or (Greece), only to move a few years later to Arizona (or Italy) where some other set of standards apply. Thus technical and regulatory uncertainty complicates consumption decisions as well as investment.

[viii] Acid rain mitigation policy achieved dramatic reductions in SO_2 emissions, at low cost, with carbon pricing. But emissions reduction technology already existed, and the costs of the technology were very well-known. Firms therefore faced little ambiguity about compliance costs, and the government knew exactly where the price had to be set to drive adoption. Obviously this does not apply to carbon emissions mitigation. See Michael Hanemann, "The Role of Emissions Trading in Domestic Climate Policy", *The Energy Journal* 30(2) 2009.

[ix] Indeed, one can do the thought experiment on the internet: if, in 1960, the US government had decided that it needed redundant, open communications networks, and chose to pursue it via raising the postage rate (thus giving incentives to pursue alternative forms of information transmission), how would firms and consumers have responded?