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From Religion to Reality

Energy Systems Transformation for Sustainable Prosperity

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"Green growth" has arrived at a critical time. Progress on emissions reduction has lagged far behind our understanding of the damage potential of unchecked climate change, and this is unlikely to change anytime soon. International climate negotiations have faltered, and it remains unclear how a deal sufficiently ambitious to address the emissions problem can be enforced. Domestically, the 2008 financial crisis reduced nations' willingness and ability to pay for emissions mitigation at home. With austerity in vogue, rich countries have also lost what little enthusiasm they had to pay for ambitious emissions reductions in emerging markets abroad. As the effects of the recession have slowly faded, emissions have resumed their upward trajectory, aided by rapid development in the emerging markets.

These difficulties make the newfound popularity of green growth unsurprising. The notion of green growth suggests that the investments required to mitigate the worst effects of climate change could become sources of sustained economic growth rather than burdens. Were green growth to become a reality, it would bypass the myriad problems of climate change mitigation: who should pay, how much, and when. If green growth were possible then, as with large-scale technological transformations of the past, the shift to a low-emissions economy might catalyze a wave of investment, innovation, and job creation that could sustain and pay for itself. Rich countries could base renewed economic competitiveness on an array of new "green" industries, while emerging markets could support their ongoing development on a foundation of new low-emissions technology.

Unfortunately, green growth today remains more "religion" than "reality." Most arguments for green growth today take on faith the link between investment in low-emissions technology and the creation of durable economic growth. Moving green growth beyond faith, however, appears difficult. In isolation, the gains from any specific investment in green energy are likely to be limited and short term. Instead, with some exceptions, green growth has to date functioned largely as a justification for changes to energy systems we might want to take for other reasons, such as emissions reduction or energy security.

This book looks beyond near-term investment to long-term sources of growth. We believe that translating the array of isolated investments required for emissions reduction into sustained economic growth may occur only if those investments can catalyze systemic changes in the energy system itself. Such a low-emissions energy systems transformation may then reveal new sources of employment, goods, services, and productivity growth inaccessible in today's fossil fuel–based, high-emissions energy systems.

We begin by asking two questions about the potential sources of green growth: first, *where* might this growth potential of low-emissions technologies come from, and second, *what* would allow economies to discover and maximize this potential. In this chapter and in Chapter 2, we argue that effective emissions reduction will require, in effect, a transformation of modern energy systems. That transformation will require parallel and complementary changes to the technological, economic, and political determinants of how we produce, distribute, and use energy in modern industrial societies. Most green growth arguments anticipate that this transformation will lead to durable economic growth. Inventing new energy technologies, deploying new energy infrastructure, and improving energy efficiency will, of course, require investment from, and generate employment in, sectors ranging from capital-intensive manufacturing to construction. The transition may provide, for the near term, new economic opportunities that can partially offset the cost of a transition necessary for mitigating climate change.

But whether that transition can support sustained economic growth is a separate and more difficult argument. Conceived solely in terms of jobs and investment from renewable energy, the scope and duration of opportunity are very narrow. As Chapter 3 shows, most low-emissions-related investment and employment will substitute for, rather than add to, employment in fossil fuel industries. Moreover, at least in the near future, low-emissions energy will probably cost more than equivalent fossil fuel capacity, potentially crowding out other potentially productive investment. Nor should we place broad hopes on export-led growth either. There will, of course, be countries that capture comparative advantage in green technologies and exploit those advantages to grow through exports abroad. But comparative advantage in green technologies will likely cluster in countries with specific industrial and innovative capacities that other countries will find expensive to replicate (Huberty and Zachmann 2011). Such green growth will thus not be widely shared. Of equal concern, the notion of export-led green growth threatens a new "green mercantilism" born of a perceived zero-sum game for control of green export markets.

Obtaining the technologies required for a low-emissions energy systems transformation poses equally difficult problems. Virtually no one disputes the idea that such a transformation will require an array of innovation in new and existing technologies and their widespread commercial adoption. Who will make the investments in developing these technologies remains controversial. Venture capital has been entangled with and supported other technological systems transformations, most notably the Silicon Valley brand of information technology. Countries around the world, and particularly the United States, have perhaps understandably hoped that venture capital could drive the creation of green energy technologies.

But as Kenney and Hargadon argue in Chapter 4, venture capital will likely fall short of repeating its earlier success. Energy technologies for the most part lack the rapid growth, high turnover, and low capital costs that underpinned the huge returns enjoyed by venture capital investments in ICT. Rather, the energy sector remains focused on capital-intensive, highly reliable technologies capable of integrating with preexisting, complex, economically vital systems. These characteristics run contrary to the needs of successful venture capital–financed green industry. Historically, venture capital has made an array of small investments in fast-growing sectors in the hope that one will become a massive payoff like Google. Here, however, they must make a series of much larger investments in slow-moving, capital-intensive industries, with the knowledge that more than one might become a Solyndra — a massive loss with little upside spillover. Given these incentives, the venture capital model is unlikely, on its own, to drive the innovations required for low-emissions energy systems transformation.

In light of these difficulties, we argue that enduring green growth will have to come from the potential created by a low-carbon energy systems transformation for the economy at large. Past transformations — whether in energy, as in the electrification of cities and factories in the early nineteenth century, or elsewhere, as in the ICT revolution — of course generated investment and employment in their own narrow sectors. But the explosive growth we associate with those earlier transformations derived mostly from how they changed what was possible in the broader economy. The impact of computers went well beyond replacing adding machines, and that of electrification went well beyond simply replacing gaslight. They initiated, among other changes, the radical restructuring of assembly lines and the long-distance transmission of information. These transformations became sources of growth and productivity with far greater scope and impact than the narrow electrical or semiconductor sectors themselves.

We cannot know, of course, whether the low-emissions technology revolution will deliver a similar array of changes. But we emphasize that the growth opportunities of earlier transformations were not always obvious either. History is replete with failed prognostication by even the most sophisticated technologists, often about their own technologies.

Instead, moving green growth from religion to reality will require creating the economic and market space in which firms and consumers can discover the growth potential in this transformation. That, we argue, suggests a role for governments that goes beyond the limited role of setting emissions prices and supporting basic research and development. Indeed, earlier transformations demonstrated that the state has regularly played a more expansive role, even in revolutions that, like ICT, have since been heralded as triumphs of free-market innovation. Determining, then, how to repeat these past successes while avoiding the obvious risks of distortion and capture — either by today's fossil fuel industry or tomorrow's clean-technology sector — remains the primary challenge for green growth policy makers.

Transforming the energy system will, though, require making difficult choices amidst serious political conflicts. The transition we consider in the first part of the book requires a process of technical, economic, and regulatory experimentation. The experimentation, in turn requires sustained political support to survive the inevitable failures, setbacks, and misdirection. But the process of energy systems transformation will create numerous opportunities for conflict and endless reformulation of the policy environment. Even accepting the common threat of climate change, the transformation of today's fossil fuel–based economies will force difficult choices. Even if one can imagine that an energy systems transformation might be able to support green growth, it will invariably benefit some and impose costs on others. Abandoning otherwise functional fossil fuel–based energy assets will of course bring opposition from their owners, who will undoubtedly claim they made their investments in good faith to satisfy an energy-hungry society.

Rebuilding the systems of energy transmission and distribution will require state interventions in land use planning, capital investment, and regulation of monopolistic markets. Transforming energy efficiency will touch every business and household. Each of these goals, moreover, will be weighed against an array of other priorities for investment dollars. The political task of managing the conflicts about how we structure the transition and manage its costs and benefits thus becomes as important as the economic task of structuring a smooth, efficient, and cost-effective transformation. The second half of the book examines how a variety of countries — from small, rich states in Northern Europe, to giant emerging markets in Asia — have approached these technical and political challenges.

Green growth simultaneously represents enormous promise and real challenges. A low-emissions energy systems transformation that delivers broad economic growth would remove many of the roadblocks to effective climate change mitigation. But, as we endeavor to show in this book, the obvious sources of that growth are limited and finite, and the sources of transformative growth are unclear. At present, then, green growth provides a valuable creed for policy makers who desire to make progress on climate change in times of austerity. But sustaining progress over the long term will require moving green growth from political religion to economic reality.

A FIRST STEP TOWARD REALITY: GREEN GROWTH AND ENERGY SYSTEMS TRANSFORMATION

The discussion of green growth first requires that we clearly define the terms used in the book. We define *green growth* as the use of climate policy to create economic opportunity.[1] This definition, however, departs from those implied in today's debate. That debate covers at least three different concepts of green growth, all shorthand for myriad policies with diverse, and at times contradictory, goals:

1. The use of climate change mitigation policy to create jobs and other forms of economic opportunity
2. The changes required to make economic growth compatible with environmental sustainability
3. The restructuring of capitalist production to resolve both perceived inherent instability and social and ecological injustices in the system

We also depart from most analysts in how we identify the sources of growth and the tasks required to achieve it. Contrary to most green growth arguments, we find little reason to believe that the jobs and investment required for emissions reduction alone can generate significant long-term economic growth. Rather, we argue, growth can only come, if at all, through what a low-emissions energy system makes possible for the broader economy.

Making green growth a reality will therefore require exploiting the opportunities of a broad shift from today's high-emissions energy systems to low-emissions alternatives. Assessing whether this is possible requires that we first consider the unique challenges posed by this transformation. As Chapter 2 discusses at length, widespread adoption of renewable energy will introduce energy sources with fundamentally different physical characteristics from today's fossil fuels. Maintaining the reliability of a system built around the behavior of fossil fuels will thus require a range of technological changes that go well beyond just switching energy sources.

Physically, fossil fuels offer energy-dense, geographically centralized, constant supplies of power. Each successive generation of fossil fuels — coal, oil, and gas — provided denser, more easily stored, and more easily transported fuel sources. The ability to store ever-larger amounts of energy in the same place has encouraged more concentrated, centralized electricity generation. These highly centralized production systems serve diffuse households and businesses via a distribution grid designed to move geographically dense production to diffuse consumers. Finally, the system permits precise control of power generation as long as fossil fuel supplies are available. This precise control permits the system to supply consumers, who operate in markets that provide little information and few incentives for flexibility, with highly reliable power.

A switch to renewable energy sources, which deliver little or no net emissions over their entire life cycle, poses at least three technical challenges. First, the geographic dispersion of renewable energy sources will require downstream changes to best incorporate low-emissions energy into the power system. The best locations for wind, sun, geothermal, and other renewable energy sources are often located far from existing power plants, and they have far lower generation capacity per unit area. Widespread adoption of renewable energy will therefore require significant changes to a power grid designed to move power from centralized, concentrated producers to diffuse consumers. Instead, the grid will need to evolve to concentrate and redistribute power from low-density, dispersed renewable energy generation. This constitutes a major restructuring of critical infrastructure.

These changes to the grid must also confront a second challenge: intermittency. Renewable energy sources — particularly wind and solar electricity — depend on flows of sun and wind that vary minute by minute, seasonally, and over a period of many years. This variation leads to intermittency: fluctuations in the power available from renewable energy sources. This intermittency stands opposed to the assumption of constant and precisely controlled power supplies that underpins the stability of the rest of the energy system. Consequently, at sufficiently high shares of renewable energy,[2] this intermittency can destabilize the balance of supply and demand critical to the operation of the electric grid. Maintaining the stability of the energy system in the face of intermittency will require substantial changes to systems of energy transmission and distribution. Expanding the grid's geographic coverage can help level out the peaks and valleys of power supply across regions. Energy storage can provide similar services by capturing excess power at peak production periods for use during supply lulls. Demand-smoothing innovations can help support these supply-smoothing changes. "Intelligent" grids may be able to prioritize and adjust energy consumption in parallel with supply fluctuations, enabling significantly more efficient energy consumption. Regardless of which of these options proves feasible, though, any of them will require an array of new innovations and substantial capital investment to adapt the power transmission and distribution system to the new properties of energy supply. The transformation thus goes well beyond the simple adoption of renewable energy.

Third and finally, accommodating variable generation will become much easier if energy users can understand and respond to fluctuations in energy supply. Today, however, both the markets for energy and the technologies that consume it bury that information and inhibit consumer responsiveness. Improving this situation will necessitate a series of innovations that permit more efficient and responsive use of energy. The reach of these innovations promises to be very wide — from relatively centralized solutions like smart meters to diverse changes in appliances and consumer electronics.

These technological transformations must go hand in hand with a set of structural changes in the markets, business models, and regulatory structures that provide the framework in which these technical systems operate. As the country cases and the discussion of EU energy policy in particular make clear, the regulatory and market structures that worked for highly centralized and vertically integrated electricity markets will likely prove suboptimal for more decentralized and responsive low-emissions markets. Bringing an array of new energy technologies into the network may require changes in ownership and in control of networks, as well as the obligations of network operators. Demand-response pricing of energy will require significant changes to the pricing structures used in many energy systems, where users have come to expect constant prices over time. Funding the investments required for a new energy system will require changes to electric utilities' rate and capital investment structures. Finally, new "smart" grids will bring with them an array of new concerns about the use of the information derived from grid intelligence. Each of these changes will challenge firms and policy makers alike to reconfigure legacy structures to better exploit the opportunities and contain the dangers of new technological systems.

Despite the magnitude of the change implied by a low-emissions energy systems transformation, we should be cautious, if not skeptical, about its ability to drive a surge in economic growth. If this transformation proves enormously successful, it will result in an energy system that proves as capable, as reliable, and as economical as today's. But, apart from lower emissions, that system will offer few obvious advantages over the high-emissions system it replaced. In these terms, a low-emissions energy systems transformation offers few obvious material advantages to the broader economy. That reality raises real questions as to whether an energy sector, on its own, will become a catalyst for growth as well as a solution to climate change.

Green growth, if it is to become reality, will thus need to look beyond the obvious, but problematic, near-term investments a transformation will require. Instead, we should ask whether it is possible for such a transformation to provide opportunities for the broader economy on a scale that will represent significant returns on the investments that the transition will require. Other systems transformations have provided new opportunities for economic activity that were surprising in either their scope or magnitude. Those opportunities, in turn, became the engines that sustained transformations despite their costs. Whether green growth can do the same remains unexplored.

SYSTEMIC TRANSFORMATIONS AND ECONOMIC GROWTH

To better understand how systems transformation might catalyze broad opportunities for growth, we turn, by analogy, to an earlier instance of transformative economic growth driven by technological systems transformation. We observe that the network itself, rather than the technologies at either end, proved the transformative influence in shifting the trajectory of economic and technological systems. This result suggests that the power grid may provide opportunities to use energy systems transformation to catalyze growth. But these transformations also suggest caution in predicting that a low-emissions energy systems transformation will repeat their successes. As the following section details, low-emissions energy solutions may lack the technical and market conditions that contributed to the creation of economic growth in earlier periods.

We focus on the information technology revolution as a powerful example of how a transformative technology emerging in one sector of the economy can change goods and services and production throughout the economy, create new options and possibilities, and, in so doing, generate widespread growth. We might, of course, have chosen from an array of other instances of similarly catalytic technologies: the adoption of coal (Nef 1932; Sieferle 2001), electrification (Hughes 1979, 1983), or intermodal shipping (Levinson 2008). As with these alternatives, the history of ICT provides three important lessons for the transformation of energy systems: first, the network proved to be a significant enabling technology; second, the growth opportunities generated by the transformation came as much from the possibilities it created in the broader economy as they did from the IT sector itself; and third, regulatory intervention and public support played a co-equal role with private ingenuity in initiating and driving the transformation.

The transformation wrought by digital technology has proceeded rapidly since the 1940s, impacting an array of sectors from insurance and banking to manufacturing and international logistics. But the consolidation of the digital age only truly arrived with pervasive networking. Throughout, the speed of the ICT transformation has been remarkable. Since 1940, computing power has increased by roughly 50 percent per year on average (Nordhaus 2007). More recently, the growth in networks has complemented this exponential growth in computational power. In 1991, the U.S. National Science Foundation opened to commercial activity the internal, distributed information network it had inherited from the Department of Defense. By 2000, this "internet" accounted for at least $100 billion in annual commerce and 2.5 million jobs in the United States alone, launched several firms in the Fortune 500, and laid the foundations for a second wave of innovation in social media, communications, and logistics that continue to this day. Thus, within 20 years of its commercialization, the internet had radically transformed not just information technology but the economy at large, generating significant economic growth and productivity improvements.

The speed and apparent smoothness of the ICT revolution derive, we argue, from two transformative phases—first in hardware and then in communications. These phases shared an important set of characteristics. Both merged private investment and innovation with public sector market formation and rule making. Neither proceeded out of some grand design but rather drew on general public support for innovation and investment and regulatory structures that encouraged early experimentation, policed monopolies, and sponsored network openness. Network openness, in turn, enabled rapid private sector experimentation both within and on top of these networks. This experimentation in turn drove a symbiosis between innovation and demand. Rapid improvements in technical capabilities supported widening demand for products, which in turn supported ongoing investment and innovation in the next generation of technology. That symbiosis between the ICT sector and the broader economy made the revolution self-sustaining.

The first phase of this revolution, which we might call the hardware phase, lasted from the invention of the transistor in 1947 to the introduction of the personal computer in the early 1980s. These years saw private sector innovation, buttressed by public support for research and development and strong military demand for new technologies. Innovation also benefitted from public sector antitrust restrictions on the ability of dominant market players to restrict the diffusion of new technologies. Much of this innovation originated in the laboratories of giants like AT&T and IBM. Left to their own devices, both firms might have used control of these technologies to generate rents, constrain market competition, and compete on the basis of access rather than features. Instead, both firms found themselves at the center of massive antitrust investigations that constrained their ability to pursue monopoly control of new technology. As a result, the transistors that came out of Bell Labs in the 1950s quickly diffused into the broader market. AT&T was also denied the opportunity to use its control of the communications network to limit access to competitors experimenting with the possibilities of emerging digital technology. Likewise, IBM was constrained by ongoing investigations into anticompetitive activity that spanned the formative years of the PC industry.

The second phase of the ICT revolution built on this hardware legacy and coupled information technology to communications. Here again, public action—this time in the role of standards-setter—played a vital role in the growth opportunities that evolved from the network at the heart of the revolution. Rapid growth in ICT depended on the predictable interoperability of a range of devices. Absent common standards, the large, positive network externalities of the internet might not have materialized. Indeed, had a network model along the lines of firms like America Online or Compuserve succeeded, competition might have come to focus on network access rather than end-user innovations. Instead, the emphasis, by both the Defense Advanced Projects Research Agency (DARPA) and the National Science Foundation, on open, redundant, standards-based communication networks provided the support for the open TCP/IP communications protocols that became the Internet. Coupled to antitrust restrictions on the control of telecommunications networks, those standards enabled a range of new competitors—from Cisco and Microsoft to Google and Facebook—to build entirely new markets atop networks otherwise dominated by legacy companies like AT&T. In time, innovation in those markets destabilized old competitors and provided opportunities for transformative growth.

While the ICT revolution and the development of Silicon Valley are held up as icons of entrepreneurial capitalism and venture finance, the ICT revolution itself rested on and was supported by public policy. Antitrust policy, as noted above, assured space for such venture-backed firms as Intel and AMD in semiconductors. Early innovations benefitted from substantial public sector demand that supported firms until private markets became robust enough. In particular, the American aerospace and defense programs presented the nascent ICT sector of the 1950s and 1960s with bottomless budgets and bleeding-edge performance demands. These public sector customers made large purchases at high prices and enormous margins that underwrote waves of early innovation and experimentation among what later became ICT sector leaders. These purchases, moreover, followed on enormous public support for computational research during and after World War II. Hence, the foundation for the private sector ICT revolution, driven by ever-cheaper computers operating at ever-higher performance levels, found its roots in government sponsorship of both basic research and market formation.

The implications for green growth are clear. ICT's largest contributions to economic growth came in what it enabled rather than in the ICT sector alone. For instance, the radical transformation of finance, insurance, and media; the decomposition of production; and the emergence of global supply networks all grew from, and were unimaginable without, the capabilities created by the ICT revolution. Most recently, a new era of goods and services has opened, built on the organization of information and relationships by giants like Google and Facebook. Those innovations depend on the Internet, which grew out of the scientific research at DARPA and built upon the foundations of semiconductor innovation. In each generation, the value and productivity gains were generated by the *use* and *application* of ICT innovations, not just the innovations themselves. This symbiosis between ICT sector innovation and growth in the broader economy drove a virtuous cycle of innovation, demand, and investment that sustained repeated and ongoing waves of broad-based economic growth.

Moreover, while the transformative power of ICT appears obvious in retrospect, we should not forget the early doubts about its economic potential. In the early years of the hardware revolution, IBM, so the story goes, thought it would only sell a handful of its new mainframe computers.[3] 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 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 qualification Intel considered necessary for articulating the potential of this new technology for tangible economic benefits even to product developers in electronics firms.[4] Last but not least, the commercial power of the Internet was hardly obvious at the beginning. Whatever the power of systemic transformations for the creation of economic growth, the specific opportunities from any given transformation are often obscured at the outset.

We can distill six lessons from the transformative growth catalyzed by the ICT revolution:

1. Growth came from the transformation of existing industries as well as the creation of new ones.

2. Growth benefitted from substantial public as well as private support for research, development, and deployment of new technology.
3. Growth depended on supportive regulatory regimes focused on openness and competition.
4. Growth emerged from both the networks and the new opportunities created by network capabilities.
5. Growth and technological change became self-sustaining both by making existing tasks cheaper and easier and by making it possible to envision new tasks and forms of value creation.
6. Growth was not a foregone conclusion at the outset of the transformation. Rather, it required significant experimentation to discover the possibilities for growth that transformation created.

Thus, the ICT revolution was predominately a systems transformation, in two senses. First, it required a transformation of both the technologies for computation and communication, and the broader regulatory and market context that determined how firms and consumers adopted those technologies. Second, it generated massive spillover benefits by transforming the possibilities for economic activity in the broader economy. The economic growth generated by the ICT revolution was thus split between growth in the ICT sector itself, and ICT's impact in the economy writ large (van Ark, Inklaar, and McGuckin 2002). Achieving this kind of transformative growth required both private investments in new technologies and business models and public support for open, competitive, standards-based markets in which those investments could thrive. Finally, and perhaps most critically for green growth, creating growth through the information revolution required a long period of experimentation before the full potential of the systems transformation became clear. In the same sense, we should expect a period of experimentation with "green tech" before its potential becomes clear.

CHALLENGES TO GREEN GROWTH: EMPLOYMENT, MERCANTILISM, AND THE LIMITS TO SYSTEMS TRANSFORMATION

Advocates of green growth frequently argue that a low-emissions energy systems transformation can drive the same kind of innovation-led growth that has characterized the ICT revolution and its predecessors. To date, however, few policy makers or policy analysts have paid attention to whether the conditions that made ICT a revolutionary technology hold for the transformation to low-emissions energy systems. Instead, as the review of green growth arguments in Chapter 3 shows, most of the emphasis has concentrated on near-term benefits from job creation or capture of export markets in "green" goods.