BUSINESS

THE BUSINESS OF INNOVATING: BRINGING LOW-CARBON SOLUTIONS TO MARKET

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

by

Andrew Hargadon
University of California, Davis

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FOREWORD Eileen Claussen, President, Center for Climate and Energy Solutions

Innovation is key to addressing climate change, and businesses are the engines of innovation. As the United States recovers from a deep and prolonged recession, many economists view innovation, particularly innovation in low-carbon energy, as a key pathway toward sustained economic growth. Business innovation can provide solutions that reduce greenhouse gas emissions, at the same time as they bring bottom-line value in terms of cost reduction, enhanced performance or competitive edge.

Yet there is uncertainty regarding the precise shape and timing of current energy policies and future action on climate change, particularly in the United States. This creates challenges for companies to efficiently allocate resources and make strategic bets on bringing to market products and services that will provide value for customers in the long term. Leading companies, in the face of this uncertain policy landscape, are developing and launching low-carbon technologies and solutions that provide value for customers in terms of cost, reliability and competitive advantage, in addition to carbon emission reductions. In this report, author Andrew Hargadon explores how to accelerate the business innovations needed to achieve carbon emission reductions while maintaining economic growth, and profiles effective methods used by leading companies to bring low-carbon technologies to market. The strategies of the companies studied in this report share certain key attributes:

- **A commitment to low-carbon innovations is critical to the success of a company's long-term innovation strategy.** Companies surveyed and interviewed for this study emphasized the importance of strong leaders or internal champions to articulate the value of low-carbon innovations to the bottom line and future growth.
- **Involving public policy expertise early in the development of corporate strategy helps to effectively manage uncertainty.** In the opinion of corporate executives surveyed and interviewed for this study, successful companies rely on managers with policy expertise when strategic decisions are made, and work with regulators, government agencies, industry groups, and other key players to shape those policies.
- **No new low-carbon innovation will survive in the marketplace if it fails to maximize customer value along multiple dimensions.** Reductions in carbon emissions alone will not make low-carbon innovations successful in the marketplace; the innovations must also bring bottom-line value in terms of total cost reduction, enhanced performance, or competitive edge.

We would like to thank Stuart DeCew, William Ellis, Daniel Esty, Andrew Hoffman, and Chris Trimble for their comments on an earlier draft of the report; Alstom SA, Daimler AG, HP and Johnson Controls, Inc. for their partnership on the case studies; and the many member companies of our Business Environmental Leadership Council and other participating companies that completed the Low-Carbon Business Innovation Survey and that provided comments and guidance during the research process. We would also like to thank HP for its generous support of this project.

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EXECUTIVE SUMMARY

Climate change—and efforts to mitigate it—are creating an increasingly uncertain future for businesses. The long-term effects of a warming climate are enormously difficult to predict. In the near term, however, new policies, technologies, and market preferences are already altering the competitive landscape of entire industries. That is creating opportunities for companies that effectively produce and manage low-carbon innovations in their markets—and threatening those that, by choice or circumstance, do not.

Today's policy environment, particularly in the United States, is creating an extraordinarily uncertain environment for business decision-making. In the face of such uncertainties, corporate executives must still make decisions that affect their company's strategy and competitive opportunities for years. The challenge is to walk a narrow line, investing in low-carbon innovation strategies that keep them competitive without moving too far ahead of the curve. Some companies, like those in the transportation sector, have some regulatory certainty in the form of fleet fuel economy standards, which enables them to commit to low-carbon innovations. But without such industry-wide standards in many sectors, the demand for low-carbon innovations is less clear.

Opportunities for low-carbon innovations exist throughout the economy, especially anywhere that energy is used in the manufacture, delivery, and consumption of goods and services. And with world energy consumption expected to grow by 40 percent in the next two decades,[1] these opportunities are growing. The replacement value of today's aging global energy supply infrastructure is estimated to be $12 trillion, and that of existing energy consuming technologies is even larger.[2] Global revenues from new low-carbon energy solutions, energy efficiency technologies and services, and other climate-related businesses reached $530 billion in 2009, and are projected to surpass $2 trillion by 2020.[3] Moreover, between 2010 and 2020, the projected cumulative total investment in clean energy generation alone is expected to reach $2.3 trillion.[4] Companies able to bring low-carbon innovations to market quickly and at scale will gain early advantages over competitors, such as product leadership, higher market share, and influence over emerging policies and standards.

Leading companies are already bringing low-carbon innovations to a wide range of markets, offering valuable lessons for others facing similar opportunities and uncertainties. This report documents the challenges and best practices of these companies, distilling insights for other businesses pursuing low-carbon innovation strategies. It was developed by the report author, by Center staff, and with members of the Center's Business Environmental Leadership Council (BELC). The project included a detailed survey of BELC members and other leading companies, in-depth case studies of eight innovation projects from four companies, a series of workshops, and broader research on innovation.

This report describes the particular challenges faced by companies pursuing low-carbon innovation strategies, including the different nature of innovating in mature markets versus emerging markets; the need to simultaneously achieve scale, reliability, and profitability; the risks and uncertainties from technology, market, and regulatory changes; and a bias, among some policy makers, that focuses attention and investments on radical technology breakthroughs, instead of on the innovative deployment of known solutions.

The report summarizes seven best practices that companies use to bring low-carbon innovations to market (**Table ES-1**). These best practices include: (1) integrating existing and possible future policies into corporate strategy; (2) setting a clear direction, with a firm commitment, from company leaders; (3) focusing on multi-dimensional customer value propositions; (4) creating innovative new business models; (5) organizing and reorganizing critical business relationships, a task called nexus work; (6) pursuing robust innovation strategies; and (7) strategically using partnerships, investments, and acquisitions. These best practices are often less important, or even absent from, other types of business innovation.

This report has four primary components: an introduction to the opportunities for low-carbon innovations and an outline of the challenges that are unique to low-carbon innovation efforts (Sections II and III); a description of the seven best practices identified in the case studies, workshops, and survey (Section IV); conclusions (Section V); and a presentation of detailed case studies (Section VI).

Taken in its entirety, the report presents a set of practical lessons for organizations pursuing low-carbon innovation strategies. The results should be of interest to corporate decision-makers who are developing or considering low-carbon innovation strategies and to others seeking to understand how companies can effectively bring low-carbon innovations to market, including financial analysts, institutional investors, state and federal officials, non-governmental organizations (NGOs), scholars, and participants in international efforts to address climate change.

In the effort to reduce carbon emissions, it has been said often that there is no silver bullet, only silver buckshot. The best hope for reducing carbon emissions in the near term lies in the pursuit of innovations from firms in a wide range of industries and markets. This silver buckshot will bring not only incremental improvements across many different technologies, but also the seeds of major breakthroughs as organizations and entire industries reorganize around the new opportunities and challenges of climate change.

TABLE ES-1: Seven Keys To Low-Carbon Innovation

1. MANAGING POLICY UNCERTAINTY IN INNOVATION STRATEGIES
The ability to account for public policy uncertainty in strategic planning enables companies to better identify and pursue opportunities for low-carbon innovation. Monitoring prevailing energy and environmental policy trajectories at the local, federal, and global levels enables corporate leaders to both guide innovation strategies and, when possible, shape policy development.
2. CLEAR DIRECTION AND COMMITMENT FROM LEADERS
Strong leadership has always been a hallmark of effective corporate innovation. This is even more critical in the pursuit of low-carbon innovations, where investments must be sustained in the face of unprecedented uncertainties and long term market shifts.
3. USER-FOCUSED VALUE PROPOSITIONS
Successful low-carbon innovations not only reduce carbon emissions, they also bring such additional benefits as lower operating costs, increased flexibility, or distinctive competitive advantages. Although emissions reduction is an overarching societal goal, the ultimate success of each innovation hinges on its broad adoption and use in the market which, in turn, hinges on a development process attuned to the multidimensional needs of customers and partners across the value chain.
4. BUSINESS MODEL INNOVATIONS
To bring low-carbon innovations into broad use, new business models are often more important than technical inventions. Especially for large companies, the success of these innovations depends on a firm's ability to reimagine and realign its business models to launch new technologies or services.
5. NEXUS WORK
Pursuing low-carbon innovations requires creating new commercial, financial, legal, and social relationships from within and outside the dense network of established suppliers, partners, customers, and regulators that constitutes the current energy system. Nexus work involves organizing or reorganizing the necessary networks that will enable new innovations to take hold.
6. ROBUST INNOVATION STRATEGIES
In a highly competitive and rapidly changing environment, a company's chosen strategy rarely plays out as originally planned. To be robust, an innovation strategy must advance the company's competitive advantage in the short run while preserving enough flexibility to respond to changing technologies, markets, and policies in the long run.
7. PARTNERSHIPS, INVESTMENTS, AND ACQUISITIONS
Promising new technologies have often failed to bridge the divide between scientific breakthrough and commercial success. Established corporations can meet the changing needs of their market by engaging with early-stage efforts and, through partnerships, investments, and acquisitions, can integrate newly developed technologies into their products and services.

I. INTRODUCTION

BACKGROUND

Long before the full effects of climate change are known, efforts to mitigate or avoid the worst of these effects bring new policies, technologies, and market preferences that are altering the competitive landscape of entire industries. That, in turn, is providing opportunities for companies that create and manage low-carbon innovations in their markets—and threatening those that, by choice or circumstance, do not. In the coming decades, existing markets will change dramatically and new markets will emerge that did not exist before.

These changes are creating extraordinary opportunities across a wide range of markets. The potential for low-carbon innovations exists throughout the economy, especially anywhere that energy is used in the manufacture, delivery, and consumption of goods and services. With an aging infrastructure in developed countries and world net energy consumption expected to increase by 40 percent in the next two decades, these opportunities are growing. Companies able to bring low-carbon innovations to market quickly and at scale will gain early advantages over competitors, such as product leadership, higher market share, and influence over emerging policies and standards. A wide range of new products and processes—from solar and wind power, to advanced batteries and biofuels—are already reshaping industries and markets, and creating new ones. As in any transformation, companies that gain leadership positions early can enjoy advantages that last for decades.

At the same time, today's policy environment, particularly in the United States, is creating extraordinary uncertainties in the business environment. Companies must make decisions that may affect their strategies and competitive opportunities for years to come. Depending on how the policy environment shifts, investments in low-carbon innovations may or may not pay off. Corporate executives must try to stay competitive without moving too far ahead of the curve. Some companies, like those in the transportation sector and to a certain extent in the buildings sector, have some regulatory or market certainty from fleet fuel economy standards and building codes. Those standards help push the creation and adoption of low-carbon innovations. But without such industry-wide standards in many sectors, the markets for low-carbon innovations are less clear.

Leading companies are responding to the opportunities and uncertainties by making strategic commitments to generating, developing and introducing low-carbon innovations. Many are also prepared to make strategic commitments to low-carbon innovations in countries that value low-carbon solutions, particularly in rapidly growing, urbanizing developing markets. Yet these opportunities aren't always easy to spot. Companies that miss the opportunities may be blindsided; but even those who see them correctly may still fail to meet the distinct challenges of innovating in fossil fuel-based industries. The innovation process for low-carbon products and services shares many of the challenges of the traditional innovation process. But it also presents new challenges, such as the need to navigate an uncertain regulatory landscape and an entrenched and rigid energy infrastructure. Low-carbon products and services may also require greater scale, reliability, and capital than many other innovations.

A number of companies have already successfully identified, developed, and launched low-carbon innovations, and their experiences offer valuable lessons for others with similar opportunities. This report draws on the experiences and perspectives of a range of corporations and distills seven best practices for effectively managing low-carbon innovations.

PURPOSE

This report looks at the best practices of corporations that have successfully brought low-carbon innovations to market in the face of unprecedented technological, political, and market uncertainties. The purpose is to inform corporate executives from a wide range of industries about effective practices that might benefit their own low-carbon innovation strategies. The underlying research sought to understand the challenges that are particular (or particularly salient) to low-carbon innovations, and to understand how companies identify, develop, and successfully introduce new low-carbon solutions. The results should be of interest to corporate decision-makers who are developing or considering such strategies and to others seeking to understand how companies can effectively bring such innovations to market, including financial analysts, institutional investors, state and federal officials, non-governmental organizations (NGOs), scholars, and participants in international efforts to address climate change.

METHODOLOGY

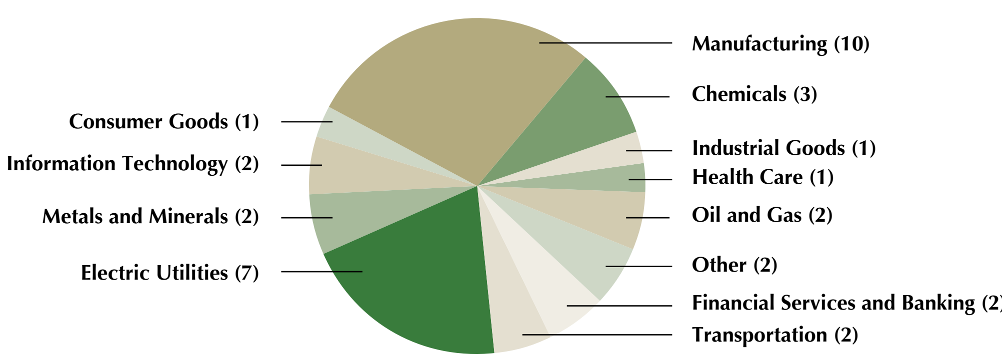
The research for this report used three data-gathering methods. The first was a 27-question survey of corporate executives at 35 companies, ranging in size from $600 million to $285 billion in annual revenues and with a median annual research and development (R&D) expenditure of $575 million. The survey was designed to gather key quantitative information and understand business strategies for developing low-carbon products and services, with a particular focus on how companies manage the associated risks and uncertainties. To explore best practices among industry leaders, the survey sample was weighted toward large, publicly-held corporations with global operations that are active in climate policy (**Figure 1**).[5]

The second method was an in-depth study of eight low-carbon innovations from four large multinational corporations (**Table 1**). These companies are members of the Center's Business Environmental Leadership Council (BELC).[6] The author conducted in-person and telephone interviews with key executives and managers, including Vice Presidents for Research & Development; Directors of Engineering, Marketing, and Policy and/or Government Relations; and R&D personnel. The author asked a consistent set of questions to assure comparability among case studies and, where relevant, augmented the data gathered with information from secondary literature.

Third, the Center held a series of BELC workshops in the fall and winter of 2010-2011 that brought together leading businesses (including from outside of the BELC), members of the financial community, and government officials to explore particular challenges and opportunities of low-carbon innovations.

For the purposes of this report, low-carbon innovations are defined as those goods and services that, in their manufacture, delivery, use, and disposal, have lower greenhouse gas (GHG) emissions *for the equivalent output* than the products or services they replace (see Sidebar: Defining Low-Carbon Innovations, page 3).

FIGURE 1: Number of Companies Responding to the Survey in Each Industry Sector



Source: Center survey (2011).

Defining Low-Carbon Innovations

Innovation describes the generation, development, and successful market introduction of new products or services, or new ways of delivering existing products.

Low-carbon technologies are those that produce fewer greenhouse gases (GHG) than other technologies that perform that same function. They include, for example, low-carbon energy sources such as wind, solar or geothermal power, and biofuels as well as other products that can substitute for more GHG intensive alternatives. The potential for GHG reductions can be large in the near term when efficiencies or improvements to existing technologies can be easily introduced and rapidly diffused through current markets and industries, such as electric generation, transportation, buildings, agriculture, and manufacturing.

Low-carbon innovations are those new products or services that emit significantly less GHGs per equivalent output than the products or services they replace (e.g., by using different power sources or materials, or by using less energy). These products or services are considered innovations if they are new to particular markets and needs, though they may be existing solutions, or combinations of existing solutions, adapted from elsewhere.

OVERVIEW AND ORGANIZATION OF THE REPORT

This report consists of the following main sections:

- **The Case for Low-Carbon Innovation** summarizes the motives and opportunities for low-carbon innovation, and then describes how companies pursue innovation strategies in the face of a broad set of challenges.
- **The Challenges of Low-Carbon Innovation** outlines four unique characteristics that distinguish low-carbon innovation efforts from other types of business innovation.
- **Keys to Low-Carbon Innovation** describes seven best practices for pursuing low-carbon innovations.
- **Case Studies** present eight low-carbon solutions from four companies: Alstom SA, Daimler AG, HP and Johnson Controls, Inc (**Table 1**). No single case showed all seven best practices, but no case contradicted the value of any of the identified practices. These best practices were often interdependent and mutually supportive of each other.

TABLE 1: Case Study Companies and Their Low-Carbon Innovations

ALSTOM SA	
Supercritical and Ultrasupercritical Boilers	Alstom is developing supercritical and ultrasupercritical steam power plants that are more efficient than conventional subcritical boilers because they are able to operate at higher steam temperatures. Such plants emit 8 to 17 percent less carbon dioxide (CO_2) than conventional plants.
High-Speed Rail	Alstom Transport is one of the leading manufacturers of high-speed rail locomotives, railroad cars, and power systems. Such train systems emit 20 to 25 percent of the CO_2 of automobile and air travel, per passenger mile.
DAIMLER AG	
BlueTEC Diesel	Daimler's BlueTEC technology is a diesel engine exhaust treatment that reduces emissions of traditional air pollutants, making it possible to use fuel-efficient diesel engines in a variety of cars and trucks. BlueTEC-equipped vehicles reduce CO_2 emissions by 20 to 30 percent compared to similar-sized gasoline-powered vehicles.
Freightliner Cascadia	In 2007, Daimler's Freightliner division introduced the new Cascadia truck, completely redesigned from the ground up with the BlueTEC diesel exhaust technology, new engine controls, improved aerodynamics, and a range of other innovations. Truck models with BlueTEC now have traveled more than 600 million miles, saving approximately 105 million gallons of fuel and 100 million tons of CO_2 emissions.
HP	
Visual Collaboration[7]	Visual Collaboration is a videoconferencing system—software and hardware—that successfully substitutes for many forms of business travel. Using the system, HP and its customers saved an estimated 66,000 metric tons of carbon dioxide-equivalent (CO_2e) greenhouse gas (GHG) emissions in two years, and HP reduced its own employee business travel by more than 43 percent.
Managed Print Services	Through its Managed Print Services, HP works with corporate customers to design, implement, and manage an imaging and printing infrastructure. For one customer with 10,000 employees, HP has reduced the energy consumption associated with printing by 66 percent. The results suggest that Fortune 500 companies could avoid about 2.3 million metric tons of CO_2 annually by reducing printing.
JOHNSON CONTROLS, INC.	
Private-Sector Building Efficiency	Johnson Controls has recently focused on innovative approaches in the commercial, private-sector buildings markets, where considerable opportunities for growth and environmental impact lie outside their traditional business in public-sector projects. Johnson Controls is a leader in reducing the energy consumption and associated GHG emissions of buildings. The company performs retrofits, installs and maintains both energy efficient and renewable energy technologies, measures and verifies performance, and arranges financing.
Start-Stop Battery Power Solutions	Automakers are rapidly adopting new "start-stop" battery systems from Johnson Controls that turn passenger and light-duty vehicles' engines off rather than allowing them to idle when the vehicles stop. The systems can improve the efficiency of traditional internal combustion engine vehicles by 5 to 12 percent. Since transportation accounts for nearly one-quarter of global GHG emissions, the opportunity for impact from such improvements is significant.

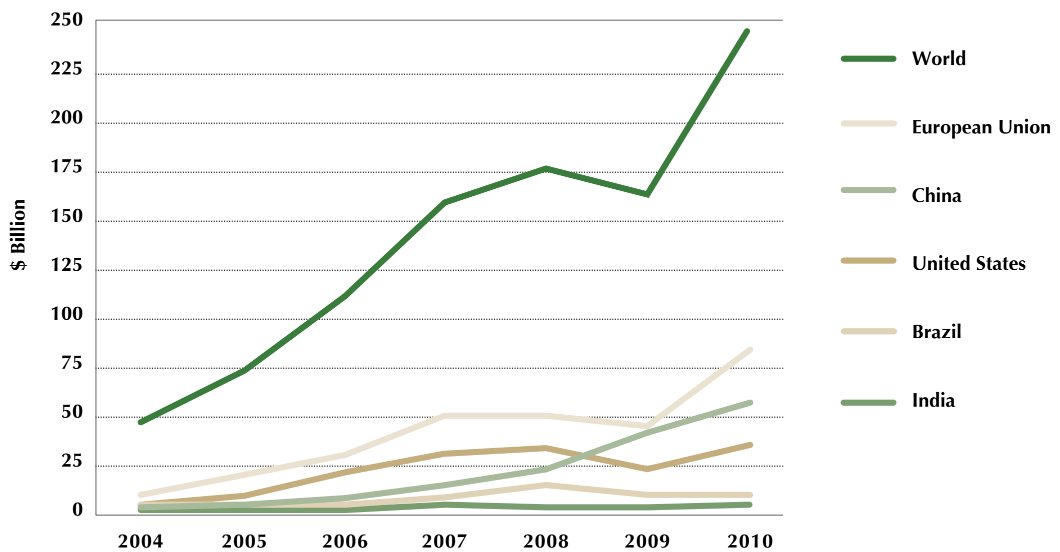
II. THE CASE FOR LOW-CARBON INNOVATION

MARKET GROWTH AND OPPORTUNITIES FOR LOW-CARBON INNOVATIONS

Opportunities for low-carbon innovations are growing, driven by policy changes, market shifts, and continued growth in energy consumption. While highly visible actions like the Copenhagen Summit of 2009 and efforts to pass U.S. national climate legislation may have fallen short, governments around the globe are taking steps to drive the adoption of low-carbon innovations.[8] These steps range from more stringent vehicle fuel economy standards in the United States to a proposed carbon price in Australia. Governments are pushing for a low-carbon economy to create jobs, to help end the economic recession, and to cut rising energy costs—in addition to trying to reduce carbon emissions. Meanwhile, consumers are increasingly buying low-carbon technologies to reduce their own energy bills, to reduce dependence on fossil fuels, and to help fight climate change.[9]

These trends, plus an expected 40 percent growth in world energy consumption over the next two decades, mean that there are significant market opportunities for companies with innovative low-carbon products and services. The replacement value of today's aging global energy supply infrastructure is estimated to be $12 trillion, and the cost of replacing existing energy-consuming technologies is even larger. Global revenues from new low-carbon energy solutions, energy efficiency technologies and services, and other climate-related

FIGURE 2: Global New Investment in Clean Energy Technologies, 2004-2010



Source: Bloomberg New Energy Finance (2010).

businesses reached $530 billion in 2009, and are projected to surpass $2 trillion by 2020. The market for environmentally friendly building products alone, for instance, has grown from just 2 percent ($10 billion) of overall construction in 2005, to 15 to 20 percent ($36 to 49 billion) in 2008, and is expected to climb to between $96 and $140 billion by 2013.[10] And the U.S. market for energy efficiency innovations between now and 2020 is estimated to average $50 billion per year.[11]

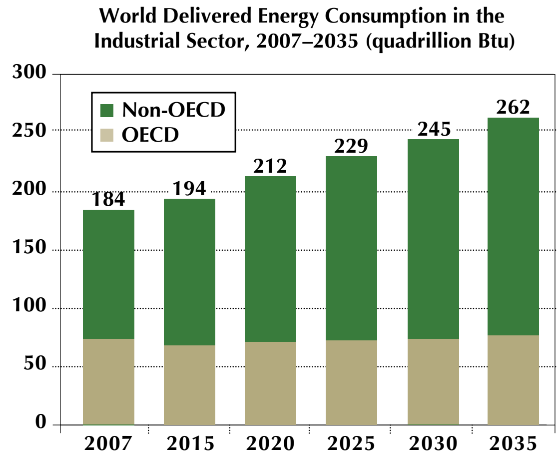
These opportunities are prompting forward-thinking companies to invest in low-carbon innovations (**Figure 2**).[12] By 2020, total investment in clean energy—everything from renewable power to technologies that improve efficiencies, like the smart grid—is expected to reach $2.3 trillion.[13]

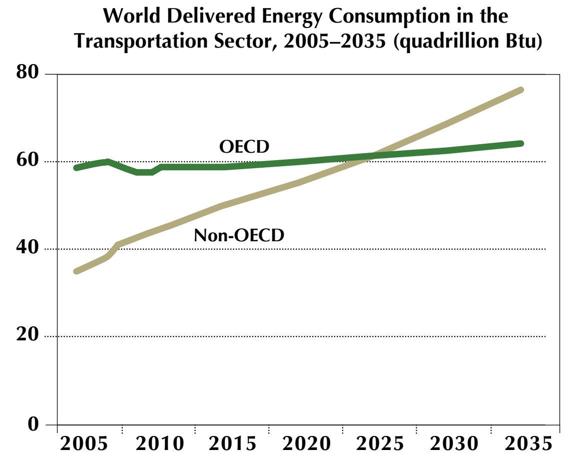
Not surprisingly, executives at the companies surveyed for this study believe that low-carbon innovations are becoming more important. They rank the importance of such innovations to their own business growth at 7.5 (on a 10-point scale with 10 being the highest) over the next 5 years, at 8.2 over the next 10 years, and at 8.7 over the next 20 years.

Low-carbon innovations aren't just new products and technologies. They also include new services and processes in such industries as information and communications technology (ICT), chemicals and materials, agriculture, and even law, accounting, and consulting.[14] Here are a few examples:

- In 2009, consumer electronics retailer BestBuy launched a sustainability strategy that involves offering low-carbon products. For instance, the company has partnered with General Electric (GE) to bring new home energy management systems, smart appliances, and renewable energy products to market more rapidly. "Our sustainability strategy," says CEO Brian Dunn, "is embedded in our business model."[15]
- ICT company HP met its goal of reducing the energy consumption and associated GHG emissions of all its products by 40 percent below 2005 levels by 2011, in part by helping customers cut their energy and paper use with HP's Managed Print Services. HP works with corporate customers to design, implement, and manage an imaging and printing infrastructure tailored to the specific needs and requirements of each customer, helping to avoid unnecessary materials and energy use.
- Accounting software giant SAP saw a business opportunity in helping companies track, manage, and report their carbon footprint data. The company introduced its Carbon Impact OnDemand 5.0 carbon management software in 2010, becoming a leader in the emerging $1.3 billion Enterprise Carbon Accounting (ECA) marketplace.[16]
- In 2005, international law firm Morrison & Foerster LLP began a practice focused on clean technology after recognizing the increasing need for "clean-tech" legal and regulatory advice. Billings have risen from $6 million in 2006 to around $100 million in 2011. The firm offers corporate and litigation services, along with technical expertise in intellectual property, energy, and environmental law.
- Bayer Material Science, with partners, developed an innovative process, called depolarized cathode technology, which reduces the energy needed to produce chlorine, an essential basic chemical. The technology was first used to extract chlorine from hydrochloric acid, but the next generation of the process produces chlorine from common salt, reducing energy consumption and GHG emissions by up to 30 percent. Bayer also has developed a method of seeding rice that reduces methane emissions 30 percent while saving water, reducing fertilizer use, and increasing plant yields.
- Several banks, including Citi, Morgan Stanley, JPMorgan Chase, Wells Fargo, Bank of America, and Credit Suisse, have put in place a carbon-focused due diligence process for any future lending for coal-fired power or other carbon-intensive projects. Bank of America also plans to reduce GHG emissions in the projects it funds in the utility sector, and has publicly disclosed that it is using a $20 to $40 per ton cost of carbon in evaluating loans.
- In 1995, chemicals company BASF added microscopic flakes of black graphite to its 50-year-old Styropor thermal insulation material. The resulting material, Neopor, was 20 percent more insulating yet used up to 50 percent less raw material. Rising standards for energy efficiency in buildings ensured that there would be a growing market for the new material.
- Procter & Gamble, the world's largest consumer-packaged goods company, committed in 2009 to sell $50 billion worth of "sustainability-driven" products

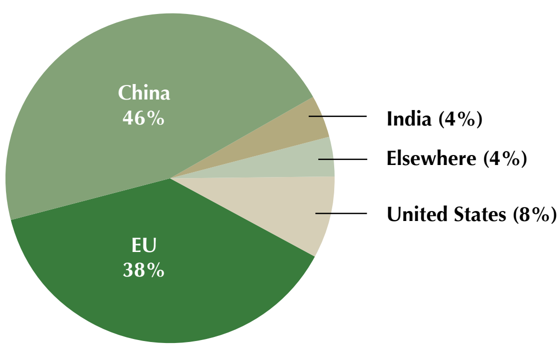
FIGURE 3: Projected Regional Growth in Energy Consumption





Source: U.S. Energy Information Administration (2010).

FIGURE 4: Country or Region with Best Business Climate Today for Domestic Low-Carbon Innovation



Source: Center survey (2011).

by 2012. The company also set goals to replace 25 percent of the petroleum in its products with sustainable materials, to reduce packaging materials by 20 percent, and to increase the use of renewable energy by 30 percent. "We don't treat environmental sustainability as something separate from our base business," explains CEO Bob McDonald.[17]

Companies are also recognizing that different regions around the world present different opportunities for low-carbon innovations. Developed economies offer markets for more efficient or lower GHG-emitting products and services, and for low-carbon energy generation that links to the existing infrastructure. In contrast, developing countries, particularly China (**Figure 3**), offer huge opportunities for new construction and new solutions. In fact, 93 percent of the estimated 40 percent global increase in energy consumption through 2030 is expected to come from non-OECD economies, where often favorable energy efficiency and clean energy policies are encouraging business investment in low-carbon innovations.[18] A large majority of surveyed corporate executives say that China and the European Union have

Defense and Other Government Procurement Policy

Government procurement—particularly military spending—has driven the development and initial deployment of many of the technologies that gave rise to new industries and markets. The impacts of military procurement include Napoleon's 1795 challenge to invent a method of preserving food that would feed his troops, giving rise to canned foods; the initial deployment of radar and penicillin in World War II; the early uses of transistors in the 1950s; and the launch of the Internet (first as the ARPANET) and global positioning systems in the 1960s. These technologies found their initial applications within the military but, once established and proven there, rapidly found new uses in commercial markets.

The nature of military procurement in developing new and disruptive technologies comes from the combination of sheer scale and unique needs. In and of itself, the U.S. Department of Defense (DOD) represents both a sufficient investor in and significant market for promising new technologies. Moreover, the military's needs are often unique enough to pay a premium for innovations. This enables suppliers to achieve production sooner and, once there, eventually move down the cost-curve to the point that these innovations become competitive in other markets. Thus, the DOD is uniquely positioned to help bring new low-carbon solutions to wider public and private applications.

In terms of the sheer scale of both its research and development (R&D) spending and procurement budgets, the DOD spends vastly more than any other single agency. R&D spending totals approximately $80 billion.[19] A former Pentagon official cited $20.2 billion as the annual cost of providing air conditioning for soldiers in Iraq and Afghanistan.[20] Overall, the DOD accounts for about 1 percent of the nation's total energy consumption, and the military's gasoline expenditures have increased 225 percent in the last decade.[21] As one of the largest aviation and logistics fuel users in the world, the DOD has the ability to greatly influence the adoption of new and promising technologies, from biofuels and smart grids to advanced batteries and insulation materials.

In addition, the Department's unique set of operational needs—typically more stringent performance requirements and fewer cost constraints—for bases, facilities and mobile uses make it ideal for early adoption of new and promising technologies. The "fully-burdened costs of energy" can range from $15 per gallon of gasoline when delivered in convoys to as much as $400 per gallon when delivered by helicopters to troops several hundred kilometers inland.[22] Moreover, there is an estimated one American casualty for every 24 fuel convoys in the wars in Iraq and Afghanistan, and more than 3,000 personnel and contractors were killed or wounded protecting those convoys in 2007.[23] As a result, the DOD is aggressively seeking to reduce its dependence on fossil fuels. Fewer fuel convoys and less fuel use increases troop agility and range, thus improving fighting capabilities, while alternative fuel options decrease the risks associated with protecting vulnerable oil supply lines. The DOD's latest review of its strategies and priorities, the 2010 Quadrennial Defense Review, for the first time addressed "energy security" as a strategic priority for national security, "having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational needs."[24]

Finally, federal directives are creating significant initiatives associated with energy use and developing potential low-carbon alternatives. Federal energy laws and multiple Executive Orders call for federal agencies—including the DOD—to meet a collection of low-carbon performance targets, GHG emissions reduction targets by 2020, and zero-net-energy federal buildings by 2030.[25] Yet this opportunity for companies supplying the DOD is not without challenges: while the Department's vast procurement needs can accelerate low-carbon innovation, at the same time, the DOD's enormous size can also mean a very slow procurement and adoption process. But as early adopters of low-carbon innovations, federal agencies as "test-beds" for innovation can help prove technologies, drive down production costs, and make them more available and accessible for civilian consumer markets.

the best overall business climate today for low-carbon innovations due to government policy support and, in China's case, a rapidly growing market (**Figure 4**). According to survey respondents, supportive government policies include a national cap-and-trade system, a long-term and transparent integrated energy policy, or ease of permitting. Government procurement policies are another significant driver of low-carbon innovations that can have lasting implications for the trajectory of technologies and industries (see Sidebar: Defense and Other Government Procurement Policy, previous page). For companies, competing in these high-growth economies is important for gaining market share or experience with emerging technologies.

Becoming a leader in low-carbon innovations can bring competitive advantages not just to individual companies, but also to entire economies. Thanks in part to government support, China has become the world's leading manufacturer of solar panels and wind turbines, building nearly 50 percent of the world's supply for both technologies. Similarly, Danish wind manufacturers now produce approximately 22 percent of annual global installed wind capacity.[26] As discussed later in this report, many companies are finding that the dynamics and transformation within these emerging markets make it imperative for them to engage with these markets to acquire the capabilities to commercialize low-carbon innovations.

PURSUING INNOVATION STRATEGIES

Companies able to bring low-carbon innovations to market quickly and at scale will capture these opportunities and gain early advantages. These advantages include product leadership, greater market share, revenue growth, and influence over the policies and standards that will shape the markets in the future. Johnson Controls, for example, expects that 70 percent of automobiles in Europe by 2015, and 70 percent of U.S. cars by 2025, will be equipped with "start-stop" technology that shuts engines off when they stop, saving fuel. To be ready, the company began developing its product over a decade ago. Now it expects to be a market leader, especially as stricter emissions limits and rising fuel prices increase demand. "Global trends toward a greater focus on long-term, sustainable solutions play to our competitive advantage," says Alex Molinaroli, president of Johnson Controls' Power Solutions business. "Our ability to be the first mover in start-stop [vehicle technology] is a huge advantage." Similarly, in 2005, GE launched an entirely new initiative—called 'ecomagination'—aimed at making the company a leader in products that tackle a variety of environmental problems (see Sidebar: Pursuing a Low-Carbon Innovation Strategy at GE, page 11).

The strategy for low-carbon innovations at Cummins, Inc., the world's largest independent engine manufacturer, takes four important macro-trends into account: emissions standards are becoming more stringent; demand for energy is outpacing supply; more people need power and vehicles than ever before as a result of globalization; and infrastructure is evolving. Cummins is responding to these trends in five different ways. The company supports and participates in the development of national, long-term energy policy. It educates policymakers about the importance of regulatory clarity, stability, and consistent enforcement. It forms public-private partnerships. It takes a holistic approach to innovation that maximizes value for a customer's entire system rather than promoting individual innovations. And it maintains a balance between creating common product platforms and building in enough flexibility to customize products for customers.

Innovation, in this report, includes the generation, development, *and* successful introduction of new products (both goods and services), or new means for delivering existing products, that provide competitive advantage.[28] The innovations that receive the most visibility are often the breakthrough technologies that emerge from university and corporate R&D laboratories. Yet innovations also can be existing products or processes adapted for new markets, or incremental improvements that, when applied to millions of units (e.g., new battery technologies for vehicles or smart meter capabilities for electric grids), have significant impact.

Innovations can take many forms, but they largely fall into four categories:[29]

- **Product Innovations.** Companies can develop new products and services, increase the performance or reduce the cost of existing products, or adapt existing products to new markets or uses. Toyota's Prius hybrid electric vehicle, Johnson Controls' start-stop battery, and Morrison & Foerster's clean-tech legal services represent new product innovations.

- **Process Innovations.** Companies can improve the efficiencies or capabilities of existing business processes, or create wholly new ones. For instance, process innovations in manufacturing are enabling companies like Suntech to dramatically reduce its production costs for solar panels.[30] Process innovations can also occur in marketing, distribution, sales, or accounting.
- **Firm-level Innovations.** Companies can capture more value from a product (and its enabling processes) by integrating higher-value outside activities into the firm or by *dis*-integrating lower-value activities out of the firm. Firms may take over downstream distribution, sales, or customer service, for example, or outsource manufacturing. When HP developed its Managed Print Services offering, the company integrated services and support traditionally done by customers or vendors.
- **Network Innovations.** Companies can capture value by constructing new external networks of distributors, manufacturers, retailers, or service providers. They can also license patents, establish joint ventures, or acquire product lines and whole businesses. The value of the resulting products then emerges from the network rather than from individual companies. For instance, it made more sense for automakers Nissan and Toyota to form joint ventures with particular suppliers to develop and manufacture battery packs for electric vehicles than for either company to do it alone. In addition, some innovations, such as developing high-speed rail, are so complex that they require partnerships between different types of companies, including those building rail infrastructure and trains, operating the rail service, and financing the project.

In practice, innovation involves elements of each category. Novel products often co-evolve with new processes. Similarly, changes within a firm are often supported by new connections outside the firm.

Innovations can also be described in terms of their origins and their impacts. In terms of origins, *incremental innovations* are minor departures from the existing technologies and approaches an organization already knows how to do, while *radical innovations* represent significant departures. In terms of impacts, *sustaining innovations* strengthen existing firms and relationships in today's markets, while *disruptive innovations* overturn existing markets or create entirely new ones.

An innovation's origin, however, does not determine its impact. Apple's iPod and its iTunes music store, for example, represented relatively incremental technological changes, but they disrupted the entire music industry. In contrast, Radio Corporation of America (RCA) used its capabilities in manufacturing, distribution, broadcasting, and content generation (which had been developed for radio) to successfully introduce a breakthrough technology, the television.

When companies pursue product and process innovations simultaneously, they are pursuing significant changes in both their offerings and the activities of their organizations. This is described as *business model innovation*. It brings both increased risk and greater potential for impact. Business model innovations play a critical role in shaping how, and how fast, low-carbon technologies come to market. Indeed, as will be discussed in detail later, rethinking business models may be the most effective means for commercializing low-carbon innovations.

Pursuing a Low-Carbon Innovation Strategy at GE

In 2005, General Electric (GE) launched a strategy called 'ecomagination' to "address critical challenges, including the need for cleaner and more-efficient sources of energy, reduced emissions and abundant sources of clean water." The strategy emphasized that GE's business growth would increasingly depend on products and services that solved global environmental challenges, and serves as an example of how companies recognize and pursue new opportunities. GE set up a specific product and marketing initiative—ecomagination—to make the effort more visible. It set revenue targets for ecomagination products. It committed specific financial resources to the initiative, and used its venture capital arm to help provide a pipeline of innovative ideas and technologies. GE has now invested over $5 billion in clean-tech R&D, launched 110 ecomagination products, and earned over $85 billion in revenue from those products (roughly 10 percent of the company's total revenue). Even during the 2009 economic downturn, ecomagination annual revenues grew 6 percent to $18 billion.

GE's ecomagination products include the WattStation, which rapidly charges electric vehicles, and the North American Evolution Series Locomotive, which consumes 6 to 7.5 percent less fuel per horsepower-hour than existing locomotives, saving customers between $48,000 and $60,000 per year and reducing CO_2 emissions by 200 to 248 metric tons per train per year. A third example: energy efficient light-emitting diode (LED) lights, which have been adopted by such big customers as Wal-Mart.

GE's success offers several lessons. First, developing low-carbon products takes years, even when they build on existing technologies. Take GE's LEAP-X (Leading Edge Aviation Propulsion) jet engine, which reduces airplane fuel consumption and CO_2 emissions by 15 percent, saving customers $1.6 million per airplane per year.[27] The project was launched in 2005, but the new engine wasn't introduced until 2011. Second, low-carbon innovations are more likely to succeed if they offer important benefits in addition to reduced GHG emissions. As GE's ecomagination 2010 Annual Report explains, offerings should "significantly *and* measurably improve customers' operating performance or value proposition and environmental performance." (Emphasis added.) That means that the criteria by which such innovations are identified, evaluated, and ultimately promoted must carefully balance the achievement of significant emission reductions with these other benefits.

Third, working closely with universities and emerging ventures can help identify and develop new low-carbon technologies. GE's venture capital group has made investments in smart grid and renewable energy companies. Some examples: Synapsense, whose mesh-networking and operations management technologies improve energy efficiency, cutting power and cooling costs in data centers; Soladigm, whose energy-efficient dynamic glass switches from clear to tinted on demand in buildings, reducing cooling and heating costs; and Ciris Energy, whose biotechnology converts coal to methane for cleaner energy.

GE plans to double its clean-tech R&D investments to $10 billion and increase its ecomagination revenue at twice the rate of total company revenue growth over the next five years. GE's strategic commitment in 2005 gives it an early lead in establishing the organizational capabilities to remain a major player in what will be a dramatically shifting competitive landscape.

III. THE CHALLENGES OF LOW-CARBON INNOVATION

While innovation presents common challenges across all markets and technologies, companies pursuing low-carbon innovation face four unique challenges. Companies typically must compete in mature markets, often against incumbent energy and infrastructure systems that are entrenched and highly subsidized. They must develop innovations that can be quickly scaled up while remaining reliable and profitable. They must manage risks and uncertainties not typically found in other types of innovation. And they must avoid pursuing tantalizing breakthroughs when less enticing known solutions offer more potential. This report describes these challenges and then presents the set of capabilities that companies have developed to effectively overcome the challenges.

MATURE VERSUS NEW MARKETS

Many of the opportunities for low-carbon innovations require competing in mature markets like energy, transportation, and construction. That presents different challenges than innovating in less established markets, such as the personal computer in the 1980s, the Internet in the 1990s, and smart phones or social media today. Mature markets are typically large. They have long-established practices and technologies, specialized assets like power plants or buildings that have lifespans of many decades, large numbers of entrenched customers and competitors with deep-rooted business relationships, and extensive government regulation and subsidies. Moreover, energy is usually a low-cost commodity, requiring low-carbon innovations to compete on cost. As a result, successfully introducing innovations such as renewable energy sources, energy-efficient computers, or high-speed rail systems into mature markets is far more difficult than launching products into new and emerging markets.

Indeed, the lesson from history is that competing with entrenched industries is almost always more challenging than breaking new ground. Consider how France and Holland were slow to adopt rail travel in the 1800s because they already had effective transportation networks—canals.[31] Today's high-speed rail projects must compete not only with established highways and airports, but also with the entrenched interests of the airlines. Similarly, Edison struggled against the established infrastructure, and incumbent interests, of the gas-lighting industry, ultimately compromising his system of electric lighting in order to gain adoption.[32] Other new products and processes must integrate within the existing infrastructure, hobbling their potential. Today's solar power technologies, for example, must gain entry either as small-scale (rooftop solar) or large-scale (utility-scale) projects, even though neither approach is necessarily the best scale for commercial success.

New and emerging markets have fewer such constraints. The opportunities for low-carbon innovations are greater in rapidly growing countries like China, which are less encumbered by established infrastructure. China was able to leapfrog the construction of a traditional copper wire telephone network by moving directly to cellular communications in the 1990s. Now China is rapidly embracing high-speed rail, and nuclear and solar power. Yet the challenges, particularly in emerging markets like China's, are to bring new technologies to scale rapidly, and at the same time create the disparate necessary elements of the infrastructure, markets, and standards that support safe and reliable ongoing operations.[33]

SCALABILITY, RELIABILITY, AND PROFITABILITY

The success of low-carbon innovations often requires producers to be able to rapidly scale their innovations while maintaining reliability and, at the same time, remaining profitable. While these interdependent criteria are typical of many types of innovation, they are especially important for low-carbon innovations.

Because many low-carbon innovations address already mature and large markets—from household appliances and industrial motors, to power plants and trucks—companies must be able to rapidly *scale* the production of successful new products or processes. Tesla faced this challenge introducing its electric car. Unveiled in 2006, the first production car wasn't delivered until 2008, and in the next two years Tesla struggled to deliver the first 1,000 vehicles.[34] Quality problems prevented Tesla from meeting promised production volumes and schedules: early transmissions failed in the field, and a faulty rear hub required a safety recall of the first 345 units produced. By contrast, due mainly to its previous experience and established capacity, Toyota quickly scaled up to make 18,000 Prius vehicles in 1998, the year it was introduced. By 2004 that number had grown to 125,000, triple the vehicles sold the year before. Similar challenges face suppliers of new electric vehicle batteries, solar energy components, and smart meters—they must develop not only a novel product but also the ability, should the market embrace it, to rapidly scale production. This challenge often follows a different trajectory in new markets, where production often starts small as few customers yet exist, and both the product and production capacity grow and evolve along with the market.

One of the difficulties of scaling rapidly is the loss of *reliability*, or product quality, that often follows when new products are produced and put into use for the first time. In new markets, early adopters and relatively niche uses support a relative tolerance for unreliability. The early days of the computer industry, for example, were characterized by frequent system crashes, hard-disk failures, and other reliability issues. However, mature markets and mainstream users have less tolerance. Indeed, in the energy and transportation sectors, unreliability is even regulated against. Such a need for reliability drives customer purchase decisions, and depends on both the dependability of the technology and of the manufacturer who provides it. For example, Wal-Mart's recent decision to purchase LED lighting for its parking lots depended more on the long-term savings in the maintenance costs of replacing bulbs (LED lights have a longer theoretical life than traditional metal halide lamps) than on the energy savings of the bulbs themselves. Wal-Mart thus chose GE, rather than smaller startups selling LEDs, to ensure that the company would be around as long as the 12-year warranty (matching the LED's useful life).[35]

Companies pursuing low-carbon innovation must also be able to scale *profitably* (at least remaining solvent), an uncertain bet because of the interdependent challenges of scalability and reliability. Scaling production while maintaining reliability for low-carbon innovations can be extremely costly and take years of preparation and investment. Wendy Graham, an executive at Air Products and Chemicals, Inc., which provides industrial gases and other process technologies for power generation, emphasized,

> "There is a real scale difference between typical innovation and low-carbon innovation, especially the need to establish reliability and incentives for low-carbon solutions before energy industry customers will adopt them. Utility customers are interested in large-scale projects that have been demonstrated, and that [effort] can take hundreds of millions of dollars."

Moreover, the need to scale quickly to large production volumes can bring unexpected material, operational, and warranty costs. These liabilities put pressure on the later stages of innovation—product engineering and development (including prototyping and product validation) and manufacturing (process validation, quality control). The corporate executives surveyed for this study viewed these later stages as the sources of greatest internal uncertainties in developing low-carbon innovations.

The challenge of scale, reliability and profitability is that they must be achieved together. The rapid market acceptance and deployment of novel wind turbine designs, for example, led to problems with newly installed turbines—cracks and other quality issues—that proved extremely costly to manufacturers Clipper Wind, Sinovel, and Suzlon Energy.[36] Such problems are typical of initial production units, yet the costs were magnified by the rapid deployment of these units in the field.
In the transportation industry, the CEO of Daimler Trucks North America, Martin Daum, summed up these challenges when describing the introduction of the redesigned Freightliner Cascadia long-haul trucks: "You have to make the technology mass-production capable, and then you have to test and make sure it is absolutely 100 percent reliable… The customer in our industry expects nearly 100 percent reliability."

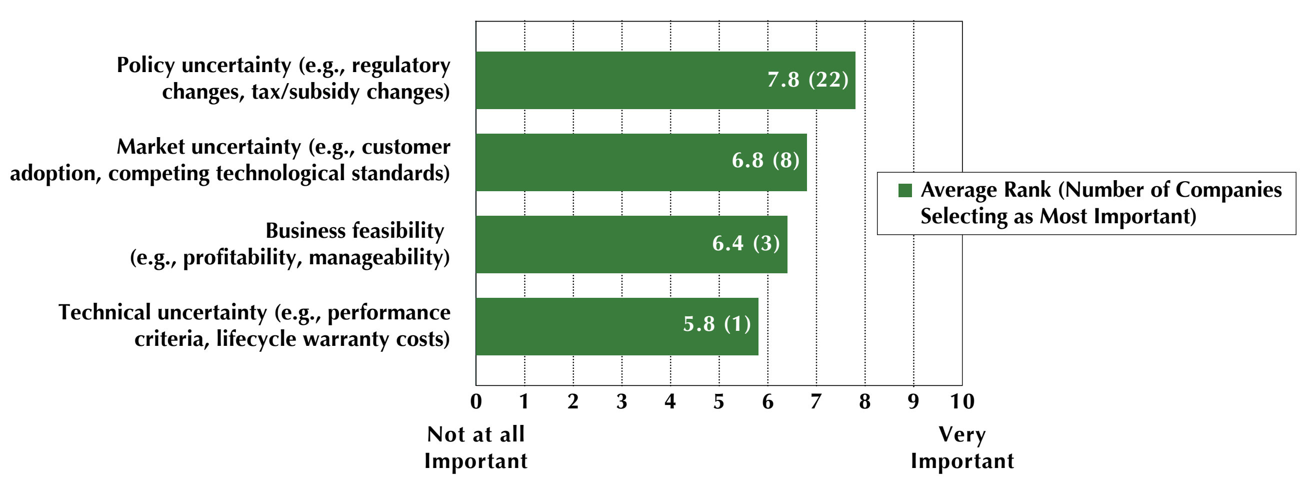
RISK AND UNCERTAINTY

Innovation is risky business. Not all risk is created equal, however, as the term actually refers to two very different types, probabilistic risk and uncertainty. Probabilistic risk is the type you get with actuarial tables or loan portfolios, and can typically be estimated and hedged against. Uncertainty, on the other hand, is when the true costs and benefits—the size of the actual investments required, the ultimate returns, even the rules of the game—are unknown and may change, sometimes exponentially, depending on how events unfold. Low-carbon innovations are especially risky because they often face greater uncertainty. The companies that participated in the Center workshops and survey said that their most significant challenges came from the uncertainties about public policies and customer acceptance (**Figure 5**). Success can be a moving target, as one survey respondent stated: "Profitability is [the] main metric for all [low-carbon innovation] projects, yet sustainability issues are constantly changing the rules for [that] calculation." A majority of corporate executives surveyed for this study believe that innovation in low-carbon products is different from other types of innovation and due, in large part, to uncertainty. The greatest source of this uncertainty? Sixty-five percent of the companies named government policy, while 25 percent said that market uncertainty is the most significant.

"The potential and perceived value of new energy technologies can change quickly," explained a United Technologies executive, "and is significantly impacted by domestic and global public policy." Such policies can take many forms, from emissions curbs to tax credits or subsidies.[37] For example, the U.S. Department of Energy's loan guarantees—such as $465 million to electric automaker Tesla—are meant to reduce the risks of lending to these particular firms but, in the process, create even greater uncertainty for other competitors and investors in the same markets. Some incentives may be predictable and provide greater certainty; others may be unpredictable and increase uncertainty. Policy uncertainty also acts more indirectly, by shaping the availability of raw materials for manufacture and use, shifting the regulatory environment of customers or suppliers, or supporting (or tolerating) nationally subsidized industries. For a deeper discussion, see the Sidebar: Predictably Unpredictable: Policy Uncertainty in Low-Carbon Innovation on the next page.

The second major source of uncertainty is market acceptance. Will customers pay more for electric cars and other highly fuel-efficient vehicles, for instance? The answer may change depending on fuel prices, the state of the economy, government policies, or attitudes towards energy security and climate change. Customer preferences regarding climate change shift across market segments and across time as competing alternatives emerge from within or outside an industry. Customers' decisions are also driven by their own uncertainty about the direction of public policy. For manufacturers supplying the automobile market, the customers are the automakers whose decisions hinge on upcoming emission standards and other policies (and particularly how they will be measured). The same holds for electric

FIGURE 5: Relative Importance of Risks or Uncertainties Associated with Low-Carbon Innovation



Source: Center survey (2011).

generating equipment and the policy uncertainties that utilities, as customers driven by their local utility commissions, will face over the life of the plant. Similarly, building owners considering adopting energy efficiency innovations face a range of uncertainties regarding the technical and financial outcomes of such investments (a more detailed discussion of the uncertainties for adopting low-carbon innovations in buildings appears in the Johnson Controls case study).

Uncertainties about policy trajectories and customer acceptance have a significant effect on how and when companies will pursue low-carbon innovation opportunities. With the ability to identify and manage or resolve policy and market uncertainties, companies can act on growing opportunities sooner and with more commitment; without that ability, companies often adopt a wait-and-see posture that follows, rather than leads, changes in their industries.

THE "BREAKTHROUGH BIAS"

For the past several decades, U.S. public investments and policies toward low-carbon innovations have focused on technological invention and scientific discovery—based on the assumption that breakthroughs would set major energy transitions in motion. Yet the pursuit of radical breakthroughs often diverts attention away from investments in commercializing known solutions which,

Predictably Unpredictable: Policy Uncertainty in Low-Carbon Innovation

Some policies can drive innovation; others can have the opposite effect. Regulations, subsidies, and standards create a dense network of policies within which companies must compete. These include federal and state mandates, codes, standards, R&D programs, taxes, tax incentives, subsidies, loan guarantees, procurement programs, and rebates designed to promote energy innovation generally, or the development and adoption of particular energy technologies. Below are four policy-related challenges for companies in the United States:

1. A state-by-state policy environment. Several sectors, such as the electricity sector, are regulated both at the federal and at the state level by policies that often vary state-by-state. States play an important role as policy laboratories, and have filled a federal policy vacuum, for example through state Renewable Portfolio Standards requiring utilities to procure a percentage of their electricity from renewable sources. However, the resulting "patchwork quilt" of regulations, and a lack of coherent energy policy at the national level, make it more challenging for companies to pursue the long-term strategic planning and capital investment required for low-carbon innovations. In contrast, Germany has developed a national energy policy supporting solar and wind and, as a result, has created robust public and private investments. The United States has made progress toward a coherent national energy policy with new fuel economy standards for vehicles through 2025. These steps enable companies to make long-term commitments to innovation.

2. Short time horizons. U.S. energy policy can change quickly. For example, after its first seven years, the national Production Tax Credit (PTC) for wind energy has expired every one to three years. Even though the credit usually has been renewed or reinstated, the uncertainty has created a "boom and bust" investment history in wind power. Moreover, national priorities shift with elections. President Clinton's clean car initiative, which aimed to address fuel efficiency, safety, and emissions, gave way to a hydrogen fuel initiative under President Bush. Now, President Obama is focusing on electric cars.

3. No long-term policy framework. U.S. policymakers can't decide whether or not the country should have a climate policy. Not knowing what the long-term policy will be makes it difficult for companies to justify investments in low-carbon innovations.

4. Incumbent policy inertia. U.S. energy policies reflect over a century of support for now-incumbent energy industries. The support includes direct subsidies and tax breaks for energy exploration and production, and indirect subsidies in the form of land and mining rights, insurance, and guarantees. These policies contribute to a "breakthrough bias," described in the next section, which diverts attention and resources away from a clean energy economy and low-carbon innovations.

paradoxically, are often ultimately more disruptive. This problem is known as the "breakthrough bias." The challenge for executives: to invest in developing and deploying known solutions despite the uncertainty presented by countless "breakthroughs" described as just around the corner.

In his influential 1945 report, *Science: The Endless Frontier*, Harry Truman's science advisor Vannevar Bush argued that basic research creates technological breakthroughs which then move downstream through development, demonstration and deployment.[38] This emphasis on breakthroughs shaped not only government research but also R&D in corporate labs, where scientists focused more on novel innovations than on technical problems like those on the manufacturing floor.[39] This schism increased as manufacturing was outsourced, resulting in R&D organizations focused on developing novel breakthroughs rather than incremental improvements to current organizational challenges.

Yet incremental advances, relying on existing technologies, may have far greater impacts than novel innovations, particularly if the surrounding infrastructure isn't yet there to support them.[40] Henry Ford's Model T was neither the first automobile nor the first product to be mass-produced, for instance (see Sidebar: Henry Ford and the Revolution of Mass Production, this page). The development of modern wind power technology reflects this bias. In the 1970s, while U.S. technology policy pursued breakthroughs with large investments in R&D, Danish companies focused on putting existing technologies into practice and evolving the technologies based on lessons learned in use. Now, Danish wind companies and technologies are the world leaders.[41] Huge energy savings are now possible with existing energy efficiency technologies, according to both a 2009 National Academy of Sciences report and a McKinsey Global Institute study.[42] The limiting factor thus may not be our ability to generate novel technologies, but rather to bring together the technologies that are already developed.

Much of a new technology's productivity growth (and resulting impacts) are realized *after* it is put into practice—often after the initial decade when the innovation first takes hold. In many cases, the locus of innovation lies not in an initial breakthrough, but in the demonstration and deployment of existing innovations over time and across companies.[43] When successful iterations of an innovation take hold in the market, they dramatically reduce the uncertainty for *all* participants by validating new business models, technology platforms, and market needs. This in turn spurs new investments in complementary innovations. Until such certainty emerges, the next waves of researchers, investors, and other entrepreneurs often wait on the sidelines or engage in a widely diffused and often contradictory range of efforts. One historical example is the rapid improvement in the entire electricity sector that took place after the electric light bulb was successfully commercialized (see Sidebar: Innovation in the Electric Age, next page).

Today's possibilities need not be sidelined by the breakthrough bias. Known and incremental solutions able to be deployed broadly in the short term can be pursued alongside novel solutions that have the long-term potential for breakthroughs.

Henry Ford and the Revolution of Mass Production

When Henry Ford introduced his Model T in 1908, commercial automobiles had been available for more than two decades, but the market remained tiny and Ford's share, at 5 percent, even tinier. Seven years later, Ford was selling 265,000 cars per year—out of an overall market of 500,000 cars. Such a broad-reaching transformation was possible because Ford and his engineers built a car, and a system of mass production, that didn't require any breakthroughs. Instead, he combined people, materials, and manufacturing equipment from the bicycle, carriage, granary and brewery, and meatpacking industries. This allowed the company to scale production dramatically, while maintaining reliability and profitability. Moreover, to sell and support the cars in the market, Ford exploited the emerging infrastructure of roadways, gasoline distribution, and railroad supply lines. As Henry Ford admitted: "I invented nothing new. I simply assembled into a car the discoveries of other men behind whom were centuries of work."

Innovation in the Electric Age

Most of the efficiency and productivity gains of a new technology come after it is introduced and proven commercially viable. Electricity offers a good example.

While electricity and electric lighting had been around for nearly 50 years before Edison opened the nation's first commercial power plant (the Pearl Street Station) in 1882, the technology had evolved little in those decades. The next 25 years, however, brought a cascade of innovations in both generation and use. These changes were enabled—indeed driven—by the successful commercialization of electricity, which showed that providing electric light and power could be profitable.

The demonstrated commercial feasibility of electric power generation then drove investments in rapidly developing and deploying innovations that would otherwise remain laboratory experiments or conceptual possibilities. These deployments were replicated, and improved upon, as they diffused across urban markets. In use, the products and processes of electric lighting changed dramatically within the first several decades and the efficiency of light bulbs jumped fourfold. Edison's direct current transmission was replaced by higher efficiency alternating current, dramatically reducing energy losses in transmission and the amount of copper wiring needed to distribute power.

Perhaps most profoundly, steam engines in power plants were replaced by steam turbines with higher efficiencies. The first steam turbine, introduced in 1884 by Sir Charles Parson, was only 1.6 percent efficient (less than the 2.6 percent efficiency of Edison's steam engines).[44] Within a decade, however, Parsons built a 1 megawatt turbine with approximately 5 percent efficiency, and within another decade, efficiency had climbed to 25 percent. About the same time, in 1888, Nikola Tesla developed his first electric induction motor, converting electrical energy into mechanical energy with efficiency and precise control. Within a decade, these motors had replaced steam engines as the prime movers of industrial power. Improvements continued throughout the next century. Between 1909 and 1955, a series of incremental changes reduced the cost of the incandescent bulb by 96 percent and increased the efficiency by 175 percent.[45]

This pattern of rapid improvements would be repeated in the development of the integrated circuit, where innovations in semiconductor manufacturing, transistor and integrated circuit designs, and computing needs fueled exponential growth in performance and equivalent reductions in cost in computing. As it becomes clearer which technological and business opportunities to pursue, in what forms, and with what expectations for profitability, rapid but incremental changes can transform entire industries.

IV. KEYS TO LOW-CARBON INNOVATION

This section describes seven key practices found in companies that have successfully conceived, developed, and introduced low-carbon innovations in a wide range of industries. These practices are not intended to be a recipe so much as a menu of capabilities, strategies, and perspectives that have proved valuable to business executives in their pursuit of low-carbon innovations.

1. MANAGING POLICY UNCERTAINTY IN INNOVATION STRATEGIES

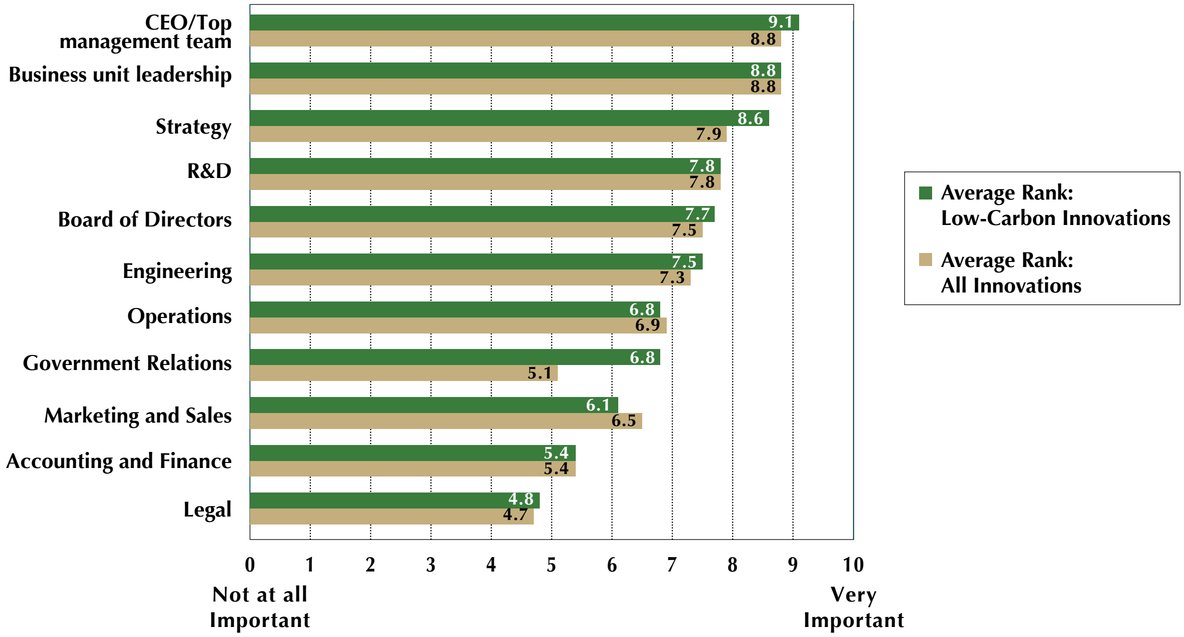
The companies in this study manage policy uncertainty by closely monitoring, and proactively engaging in, energy and environmental policy issues. Public policy can make or break most low-carbon innovations. As emphasized by business executives in the survey and workshop discussions, the ability to manage these policy uncertainties, more so than technical or market issues, influence whether and how companies pursue low-carbon innovation strategies. Especially for companies not already embedded within the energy sector, navigating these dense networks presents considerable uncertainties. To be successful, companies must be able not only to anticipate and react to policy directions, but also to engage with policy makers to shape regulations, standards, incentives, and other crucial policies that help low-carbon solutions succeed in the market. In addition, they must also be able to integrate their understanding of policy with their own internal capabilities in manufacturing, marketing, and engineering.

The companies in this study have all developed in-house capabilities to manage policy uncertainty in the same way that they manage other critical aspects of their environment, from R&D and manufacturing to marketing and compliance. Individuals or groups are responsible for assessing the potential impact of current and upcoming policies on their business, their supply chain, and their customer's business, exploring how differing policy scenarios may create new opportunities or risks. One example is Daimler's Office of Certification and Regulatory Affairs. During the development of Daimler's clean diesel cars for the U.S. market, members of this office traveled regularly between the U.S. Environmental Protection Agency's Ann Arbor, Michigan, office and Mercedes-Benz's Stuttgart, Germany, engineering offices to ensure that any solutions Daimler developed would be acceptable to regulators. The discussions also enabled engineers to design the vehicles to meet tightening standards over the cars' seven-year lifespan.

Research on effective organizational structures shows that those corporate functions best able to manage the greatest uncertainties—whether technical, marketing, financial, or manufacturing—come to hold more powerful positions within companies and have greater influence over decision-making.[46] The huge impact of policy on low-carbon innovations makes policy and regulatory capabilities much more important for that type of innovation, according to the executives surveyed for this study (**Figure 6**). The case studies illustrate the important strategic role of this function. In some companies, public policy departments altered their charters to provide more guidance on product development and innovation strategy. In other companies, new groups emerged from within R&D or strategic functions and developed the capacity to monitor and engage with regulatory and public policy issues. At Johnson Controls, for example, a separate group, run by a vice president, is responsible for overseeing both policy and mergers and acquisitions. This group focuses on integrating energy and sustainability strategy, policy, and innovation, and has been instrumental in identifying and incubating low-carbon innovations.

Policy, technology, and strategy co-evolve, and the interaction among them is critical to establishing the associated industry standards, infrastructure and common practices. At Daimler in the 1990s, the policy office predicted that emission standards would tighten significantly over the coming 20 years. At the time, the company was trying to decide whether to continue to make periodic, incremental adjustments to its existing vehicle platforms, or commit to a more radical vehicle design capable of incorporating multiple low-carbon

FIGURE 6: Relative Importance of Business Functions to Low-Carbon Innovation versus All Types of Business Innovation



Source: Center survey (2011).

technologies in the longer term. The policy office's influence was crucial in convincing the board of directors to commit to the new clean diesel engine platform.

Policy groups also work outside the company to influence policy makers, stakeholders, and industry standards and practices. For many large corporations, this often means protecting their interests by seeking to preserve the status quo. A strategic policy capability, on the other hand, involves working with policy makers and others to better enable innovation. While Alstom has a Vice President of Government Affairs, for instance, the company's senior engineers and scientists within R&D also participate on and help lead industrial standards committees that heavily influence the direction of innovation. Johnson Controls has created a separate group, the Institute for Building Efficiency, to provide key decision-makers in government, NGOs, and business clients with important information on next-generation technologies and solutions.

Recommended practices for managing policy uncertainty in innovation strategies include:

a. Give groups or individuals (possibly including board members and advisors) formal responsibility for identifying, monitoring, and managing critical policy uncertainties.

b. Ensure those groups or individuals assess the potential impacts of policies on current products and processes, on the supply chain, and on customers.

c. Ask crucial questions, such as: Under what policy scenarios will new opportunities for innovation emerge or current products be threatened? What international, federal, state, and local policy changes will affect the company's performance?

d. Finally, develop a plan to educate policy makers, as well as suppliers and customers, to shape the opportunities, issues, and standards associated with low-carbon innovations.

2. CLEAR DIRECTION AND COMMITMENT FROM LEADERS

While strong leadership has always been a hallmark of effective corporate innovation, this strength is even more critical to pursuing low-carbon innovation strategies, where investments must be sustained in the face of unprecedented uncertainties. In the survey, an executive at a global metals and minerals company notes, "New technologies require time and often financial support to reduce risk to the point where decision-makers are comfortable to select them," and Mark Proegler, Director of Climate and Transport Energy Policy at BP, points out: "Developing low-carbon innovations is a long-term issue that requires a patient and extended outlook, approach, and commitment" from leaders. Research on innovation highlights the critical role of an "innovation champion" who lends his or her experience and support to emerging innovations. The more radical the innovation, the more important it is that this role be filled by someone with considerable power and influence in the organization.

Business literature notes that strong leadership can begin anywhere within the corporation, but to be successful it must garner support at other levels, including the board of directors, the top management team, business unit leaders, and especially program and project managers.[47] In the survey, Kristin Zimmerman, Manager of Advanced Technology Infrastructure at General Motors, maker of the Chevy Volt, remarked: "High level champions are required, with high levels of investment along all phases of the design, build, and sell value chain—and with an excellent ability to listen to external stakeholders." Consider the following examples:

- In September 1993, Honorary Chairman Eiji Toyoda encouraged R&D Executive Vice President Yoshiro Kimbara to create "G21," a committee to research cars for the 21st century. Within two years, the company revealed a hybrid concept car at the 31st Tokyo Motor Show. Two years later, the hybrid Prius went on sale in Japan (two years ahead of any other manufacturer). Toyota has now sold more than three million hybrid vehicles.
- In the mid-1990s, Daimler's top executives made the decision to develop a clean diesel platform that created "a shift in the mentality about sustainability right from the Board. It is a strategic decision, and we did it in the early phase and then it goes from top to bottom to get the whole team motivated," as one manager noted. Daimler now sells clean diesel cars and trucks around the world.
- At HP, the early development of its Visual Collaboration videoconferencing system received critical support during the economic recession in 2009 when top management drove the use of videoconferencing tools by sharply restricting internal travel.
- Lockheed Martin's energy efficiency services business was initiated by a "unique talent," Thomas Grumbly, within the company's Information Systems & Global Services group. He saw the potential to grow the "information services" business into an "energy services" business, and pulled together a team to make it happen. The company's power engineers had been providing expertise and services to energy users such as the U.S. Navy for 50 years. These talents just needed to be redirected by an internal champion with a vision.

"Top management recognition of the strategic importance of managing carbon risk is essential to identifying a portfolio of opportunities," as Jeff Williams, Director of Climate Consulting at Entergy, describes. This recognition can come from engaging with customers, from observing new technical solutions being developed by the company or by competitors, from assessing the company's own climate-related business strategy and carbon emissions from its products in use, or from effectively managing energy and environmental policy uncertainty.

For example, HP first conceived of its Managed Print Services business when its Imaging and Printing Group heard concerns from several key customers about the spiraling costs, redundancies, and complexities of their organizations' printing activities. Those concerns led HP to assess the energy use and carbon emissions of all printers and copiers on the market since the 1980s. (HP has since expanded this analysis to include all computers and monitors.[48]) The exercise identified large cost and environmental benefits that would come from streamlining an office's printing capabilities, and led to a whole new service for accomplishing that streamlining.

Once leaders recognize the need for managing carbon risk and potential opportunities, the next challenge is developing an effective strategy. Volumes have been written on how to create effective innovation strategies. A key difference with low-carbon innovations is the added importance of managing policy uncertainties (see

Section IV.1. "Managing Policy Uncertainty in Innovation Strategies").

Once developed, innovation strategies must be articulated well. Successful change hinges on "the ability to articulate and convey a focused sense of purpose, a clear statement of values, and a consistent set of themes,"[49] explained David Lawrence, who as CEO led Kaiser Permanente through challenging regulatory and economic changes in the health care industry during the 1990s—not unlike what many industries face with the move to a low-carbon economy. A good example of a well-articulated vision is Daimler's mantra of a diesel engine "cleaner than gasoline." Similarly, HP's corporate policies on environmental issues, internal goals and programs addressing such issues as packaging, recycling, renewable energy and GHG emissions, demonstrate its clear vision for pursuing low-carbon innovations.

Strategies work best when they recognize the long time frames involved in commercializing low-carbon technologies. Establishing clear criteria for investing in low-carbon innovation requires matching the sometimes slow pace of technology, market, and policy changes, and fosters steady and consistent investments in the necessary capabilities and projects. Toyota, Daimler, HP, and GE (see sidebar, page 12) made commitments to innovations that took several decades to bring to fruition. It takes strong leadership to invest in innovations and organizational capabilities that extend beyond the typical quarterly and annual time horizons of modern public corporations.

Setting specific, quantifiable goals also helps articulate the strategy and motivate employees. For instance, Dow Chemical Company has set a goal to double its percentage of sales to 10 percent by 2015 for products that provide solutions to customers that help address sustainability challenges, including climate change. The company uses its Sustainable Chemistry Index to publicly track progress against the goal. When asked what measures defined success in low-carbon innovations, 50 percent of corporate executives surveyed selected business growth (in terms of profitability, ROI, sales or revenue generated, the same as for other types of innovation), while 34 percent mentioned reductions in products' energy use and/or carbon footprints. The carbon footprint metric refers to reduction in carbon emissions from the product's use. These calculations are compared against the company's previous product models as well as against competitors' performance.

Once commitments are made and goals set, implementing a low-carbon strategy requires having the right people and resources in place. When Johnson Controls decided to pursue the large but more challenging private sector building market, for instance, leadership hired several senior managers from the energy finance sector—a field relatively new to Johnson Controls but critical for success in this new endeavor. At Daimler, managers worked closely with a critical supplier, Bosch, as well as with government agencies in Europe and the United States, to ensure their support of clean diesel technologies. DuPont announced in 2006 that by 2015 it would double investment in R&D programs (to $640 million) that bring quantifiable environmental benefits, and would aim to grow annual revenues by at least $2 billion from products that significantly reduce customers' energy use or GHG emissions.

Finally, success in all innovation processes hinges on the passion and commitment of the people who must turn ideas into reality. This passion and commitment, in turn, can be enhanced by such incentives as management recognition, higher compensation, and professional growth opportunities. Fifty-two percent of the corporate executives surveyed for this study say that their companies offer incentives to participating in low-carbon innovation. At Baxter and Entergy, successful achievements with low-carbon innovation projects bring greater attention and recognition from top management and external stakeholders. At Air Products & Chemicals and United Technologies, participation in low-carbon innovation often presents opportunities for professional growth. At Bayer AG, employees who participate in nine high-profile "Lighthouse Projects" (which are designed to support the company's strategic business goals and its policy on climate change) get recognition and visibility for being involved in programs that are regularly reported to top executives in Bayer's sustainability governance structure. Other companies, such as Exelon and Intel, explicitly link participation in low-carbon innovations to performance reviews and/or compensation levels for employees in relevant functions.

Respondents described how policy uncertainty can undermine the passion and commitment of their employees, who fear low-carbon innovation projects might be derailed by external policy shifts unrelated to their efforts and opportunities. Others cited greater cost management pressures associated with ventures that are seen as potentially risky undertakings at the company. Under these circumstances, clear and long-term commitments by senior leadership help allay fears that such projects might be short-lived.

Recommended practices for establishing a clear direction leadership include:

a. Create clear and tangible strategic objectives for low-carbon innovations, with quantifiable goals that match the pace of technology, market, and policy changes.

b. Clearly communicate the objectives and goals, with specific timeframes and criteria, and back the commitment up with steady and consistent investments.

c. Identify the networks of partners, suppliers, and initial customers—inside and outside the company—that will increase the chances of success for low-carbon innovations, and make sure those networks are created.

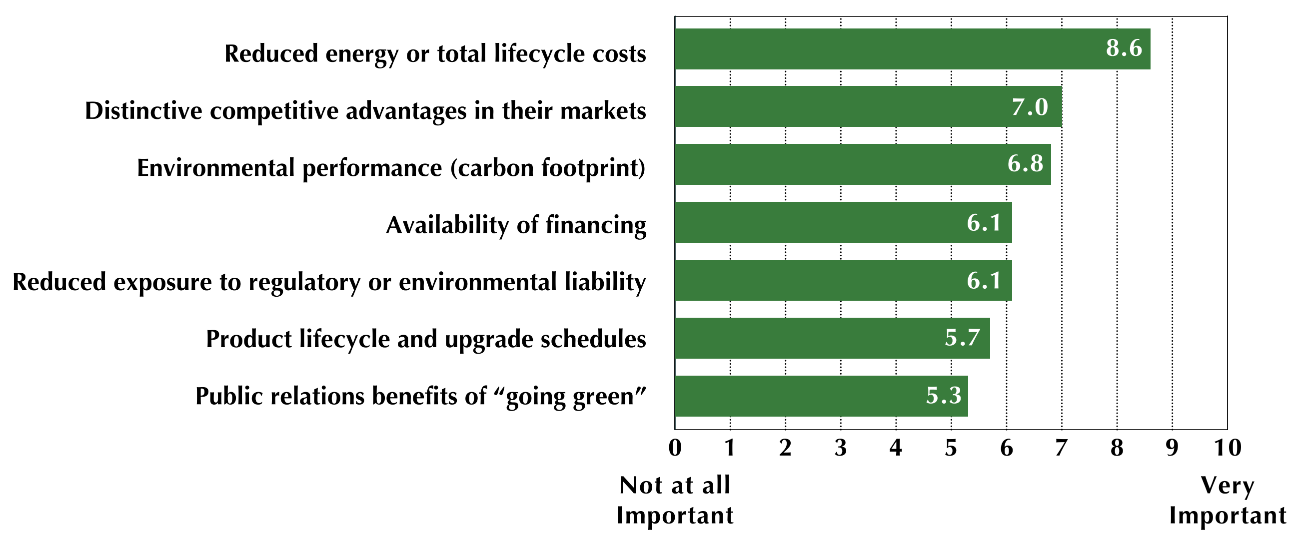
d. Ensure that a company's formal and informal incentive structures reward employees for pursuing low-carbon innovations.

3. USER-FOCUSED VALUE PROPOSITIONS

No new product or service will survive long in the marketplace if it fails to offer compelling value. Such an observation seems obvious, yet companies often neglect this imperative as they race to match competitors' offerings, reduce manufacturing costs, add features or, in the case of low-carbon innovations, struggle to meet new industry or regulatory standards.[50] User-focused value propositions are developed through an in-depth study and understanding of customers' costs and benefits for adopting low-carbon solutions.

Executives at every company studied for this report were quick to emphasize that reductions in carbon emissions alone would not make low-carbon innovations successful in the marketplace; the innovations must also bring bottom-line value. "At the end of the day," one Alstom executive noted, "fuel savings is the economic benefit that [our customers] can take to their bottom line today, the side effect is carbon reduction." Indeed, the surveyed companies reported that cost reduction was the most important factor in customers' decisions to adopt a particular low-carbon product or service (**Figure 7**). And these innovations provide customers with carbon reductions "without compromise in underlying product performance," explained Thomas Catania, Vice President of Government Relations at Whirlpool. The second most important factor was providing competitive advantage. One survey respondent noted

FIGURE 7: Relative Importance of Drivers for Customers' Adoption of Low-Carbon Innovations



Source: Center survey (2011).

Customer Uncertainties and the Adoption of Low-Carbon Innovations

One of the barriers to successful commercialization of low-carbon innovations most cited in the survey of corporate executives is customer uncertainty about the innovations' costs and benefits. There is "strong preference for readily available, highly reliable, readily maintainable technologies over alternatives with additional technological risk," explained an executive at a metals and minerals company. Customers worry, for instance, that higher than expected construction or operating costs for large capital projects like power plants could eliminate any chance for profits. Attempts to launch high-speed rail projects in the United States face debilitating uncertainties around both construction and operating costs that, if underestimated, would burden state budgets for decades. Such worries played a major role in the decision of Florida's then-Governor Rick Scott to decline federal funding for a high-speed rail project connecting Tampa to Miami. Scott warned that the state's budget might be burdened by an expensive, unprofitable enterprise. "The biggest uncertainties that are holding back transportation in general in North America are around cost overruns and subsidies to maintain or operate," observed one Alstom executive, rather than concerns over whether a new system will work. (Such uncertainties are sharply lessened in Europe and Asia, where states typically subsidize rail transport.)

Customers are also particularly sensitive to uncertainties about product performance, quality, and reliability. Johnson Controls knows that it must overcome automakers' concerns over whether new batteries for electric vehicles, plug-in hybrids, and start-stop engines will work as well as expected, and over the expected life of the battery. Automakers also worry about battery suppliers' abilities to scale up from building 10,000 batteries per year to making 10,000 per week, should vehicle sales climb, without compromising quality.

Shifting policy environments create more uncertainties. Utility companies and merchant generators that are considering investing in new fossil fuel power plants express concerns about the possibility of regulations governing the use of such fuels over the 40 or 50 years that they will own and operate the plant. These executives worry that something considered acceptable today could become a liability in the future—similar to asbestos or cigarettes. Thus a user-focused value proposition must not only optimize the true benefits and costs, it must also reduce the uncertainties to customers.[53]

that the advantage of a successful innovation is to be the "technological leaders in the[ir product] category." The adoption of low-carbon innovations, in other words, is driven by the total value proposition of the innovations.

The value proposition represents a customer's experience of the costs and benefits of purchasing a product or service. So understanding the customer value proposition involves carefully analyzing customers' costs and benefits. It also means recognizing that customers can discount the costs and benefits because of their uncertainties about the performance, durability, or ultimate market acceptance of any particular technology.[51] As a result, the value proposition is most accurately portrayed as a function of costs, benefits, and the risks associated with each, where risk represents both probabilistic risk and uncertainty (see Sidebar: Customer Uncertainties and the Adoption of Low-Carbon Innovations, this page). The challenge for companies developing low-carbon innovations is keeping their focus on delivering value to customers in the face of internal pressures and distractions like project deadlines, cost limitations, competing products, and revenue projections. These distractions loom even larger when low-carbon innovations are motivated by corporate sustainability goals or subject to public policy pressures.

In this study, companies used three approaches to help clarify and increase the value propositions of their low-carbon solutions: a *user-centered design* process; an explicit focus on clarifying and *managing customer costs, benefits, and uncertainties*; and *attention to all "customers"* in the value network.

The *user-centered design* process focuses on the needs, wants, and limitations of the users of a product. This approach entails a careful analysis of user needs and end-use scenarios in order to generate a set of hypotheses for the key criteria shaping a value proposition, and close interaction with users to test these hypotheses in real world settings. Following a user-centered design process, the needs of current customers act as a first filter on commitments to pursuing particular innovations.[52] As HP developed its Visual Collaboration videoconferencing system (now owned by Polycom), the company's product team began by working closely with an early and willing customer, and by bringing together a group of anthropologists, designers, sociologists, and social linguists to understand why users would embrace or reject the new technology. This study of the needs of users led the company to set a challenging, yet simple, design goal, which project manager Mark Gorzynski described as: "Design an experience comfortable enough that a manager would willingly discuss an idea, present an argument, or have a conversation on which his or her career depended." Once that goal was set, HP could use its technology, engineering talent, and resources to solve the technical challenges of creating such an experience.

Another way to understand user needs is to find true early adopters—customers who can benefit from an innovation in ways that the mass market cannot yet. With their fleets of tens of thousands of trucks, companies like Waste Management and UPS can test alternative energy vehicles safely and profitably—and far more quickly and thoroughly than individual buyers can (see Sidebar: Using Early Adopters to Develop and Demonstrate the Value Proposition, this page). Working

Using Early Adopters to Develop and Demonstrate the Value Proposition

It is difficult to determine the true costs and benefits of new alternative energy vehicles, such as electric vehicles, compressed natural gas (CNG) vehicles, or hydrogen or fuel cell vehicles. These new technologies lack the broad supporting infrastructure of existing vehicles. As a result, developing and testing the value proposition becomes an exercise in hypotheticals about when and how such supporting infrastructures might take shape.

In this situation, early adopters provide a useful means for testing the value of an innovation. Waste Management and UPS are two such early adopters. They have large fleets of vehicles that are used locally and are supported by proprietary fuel and maintenance infrastructure. Such conditions allow manufacturers to see the true value of vehicles in use.

Waste Management, Inc. (WM) is leading the adoption of natural gas-fueled trucks. The company is one of the nation's largest comprehensive waste management companies, operating over 367 collection operations, 355 transfer stations, 273 active landfills, 16 waste-to-energy plants, 134 recycling plants, 111 beneficial-use landfill gas projects, and six power production plants. The company serves close to 20 million residential and commercial customers, and has 21,000 collection and transfer vehicles. The combination of thousands of trucks, abundant natural gas (from landfills), central locations (transfer stations), and regular maintenance done by in-house, trained mechanics makes WM a good test case for natural gas-fueled vehicles. The company found that the natural gas-powered trucks had a range of benefits: it reduced fuel costs, maintenance costs and truck noise, and resulted in a one-year payback on their added costs. In one year of use, WM expects these 1,000 natural gas trucks to displace eight million gallons of petroleum and eliminate 45,100 metric tons of GHG emissions.[55]

UPS is another early adopter and test bed. In 2007, the package delivery company partnered with Eaton, the U.S. Environmental Protection Agency, International Truck and Engine Corporation (ITE), and the U.S. Army to test a new hydraulic hybrid diesel truck. Hybrid technology makes sense for UPS because its delivery trucks make frequent stops and can capture lots of braking energy. UPS now has about 50 such delivery trucks on the road. The results are encouraging. UPS's hybrid trucks are 60 to 70 percent more fuel efficient than typical UPS trucks and emit 40 percent less carbon dioxide. UPS has found that the $7,000 higher price per truck for hybrid technology pays back in fuel savings in less than three years. UPS is also an early adopter of information technology solutions that optimize routing and tracking, also reducing fuel use and GHG emissions.

Finding such customers is not easy, but they provide unique ways to develop and test the value proposition of low-carbon innovations long before any required infrastructure can be present in the larger markets.

closely with such early adopters, innovators can try out potential product features. The true costs and benefits quickly become clear.[54] Companies also can serve as their own early adopters. For example, Johnson Controls decided to use its Glendale, Wisconsin, headquarters campus as a test bed for such efficiency and low-carbon technologies as geothermal heat pumps, photovoltaic panels, and underfloor air distribution systems with individualized controls.

The second approach is clarifying and *managing the particular costs, benefits, and uncertainties* of potential new offerings. For example, when Johnson Controls reorganized its energy retrofit business to serve private sector customers, the company found that the value proposition for these customers differed, sometimes dramatically, from its traditional public sector customers. As Johnson Controls carefully explored these differences, it discovered that commercial customers face noticeably different financial constraints, in the form of shorter acceptable returns on investment and higher costs of capital, than those faced by public institutions. So the company hired managers from the utility and energy industries with relevant commercial financial experience to help customers up the learning curve. Ultimately, this helped the company to develop financial and contracting features, such as the ability to profit from the onsite generation of energy through feed-in-tariffs or tax credits, that reduce the costs and uncertainties of making long-term energy retrofits. Similarly, Lockheed Martin created Integrated Product Teams (IPTs), groups of multidisciplinary executives that meet monthly to share information and recognize when ideas from across their multiple customer and technology sectors can bring new value to emerging opportunities and products. The purpose is to guide the development of high-performance, dynamic products, for both its defense and non-defense customers (see Sidebar: Lockheed Martin: Managing the Costs, Benefits, and Uncertainties of Potential New Offerings, next page).[56]

Since most innovations rely on a network of suppliers, development partners, regulators, and distribution partners, the value proposition must *respond to the needs of all of the "customers" in the network*. Designing a high-speed rail system, for example, requires maximizing value for a wide range of critical partners—passengers, rail operators, infrastructure managers, and federal and state agencies. As Guillaume Mehlman, Managing Director for Alstom Transport in North America, explains, the success of a high-speed rail (HSR) system relies largely on the company ultimately operating the system, not on the manufacturer:

> "If the operator does not operate its trains with a high level of availability and maintain its corridors, then the fleet won't be profitable. It will just prove that high-speed trains cannot be profitable, that it has to be subsidized, and it will not fuel growth. Yet, the Paris to Lyon [HSR] service, which opened 30 years ago, was so profitable that they started buying mountains of trains, hundreds of trains just on that line."

Some of these partners will be driven by profits, others by the desire for growth, impact, or the public welfare. Understanding and meeting these different needs will be critical to designing low-carbon products and services around which viable networks can be assembled.

Recommended practices for ensuring user-focused value propositions include:

a. Task a multi-disciplinary team with defining the strategic value proposition of a low-carbon innovation opportunity by assessing potential customers' costs, benefits, and uncertainties.

b. Ensure that designers engage directly with end users in creating the initial product specifications, or even the initial product concept. Bring in outside help (such as anthropologists to study meetings or sociologists to help understand energy consumption behavior) where necessary to better understand the needs of users and others in value chain.

c. Conduct rapid experiments to generate and quickly test new concepts that may improve the value proposition. One useful approach is working with early adopters that have the most to gain from an emerging innovation. Another is to find opportunities for internal projects that demonstrate the customer experience.

d. Ensure that the team explores the value propositions for all critical partners. Develop a comprehensive value-chain analysis that identifies and clarifies the value propositions (costs, benefits, risks, and uncertainties) to all relevant actors in the value chain including, for example, the customer and consumer, distribution and development partners, suppliers, and regulators.

Lockheed Martin: Managing the Costs, Benefits, and Uncertainties of Potential New Offerings

Headquartered in Bethesda, MD, Lockheed Martin is a global security company that employs about 126,000 people worldwide and is principally engaged in the research, design, development, manufacture, integration and sustainment of advanced technology systems, products and services. While the company serves both domestic and international customers with products and services that have defense, civil, and commercial applications, the principal customer is the U.S. government. In 2010, 84 percent of their $45.8 billion in net sales were made to the U.S. Government and approximately 60 percent of those net sales were made to the DOD. In addition to meeting its own performance benchmarks to reducing its water use, waste and emissions, the company is advancing low-carbon technologies and practices, including in biomass, solar, wave, and ocean thermal energy; smart grid solutions; and energy savings performance contracting across defense, civilian and intelligence markets.

To help alleviate customer concerns regarding the technical and financial viability of a new solution, Lockheed Martin conducts pilot projects internally, as its own "end-user," to test technologies before commercialization. It built its own biomass power generation facility in Owego, New York, before earning a contract to build a similar structure for the U.S. Department of Veterans Affairs. The company's consolidation of 4,000 data servers saved 26 million kWh of electricity. A separate data center consolidation project at its own facilities provided a quantitative and qualitative performance record that was a crucial element to winning a bid with the Department of Energy in August 2011 to conduct such projects across federal agencies, as part of achieving the White House's goal to close 800 government data centers by 2015, estimated to save $3 billion in energy costs. Lockheed Martin expects its demonstrated success to continue and be applicable to new project opportunities in the private sector.

To help identify and magnify the value proposition of its offerings to customers, Lockheed Martin's IPTs are used to cross-pollinate ideas and expertise between its many defense and non-defense divisions. One such opportunity generated by IPTs is Lockheed Martin's ocean thermal energy conversion (OTEC) research and development. OTEC can provide near-zero carbon emission energy generation by harnessing the temperature difference between warm surface water and cold deep water to drive a steam-like cycle that turns a turbine, with potential capacity on the scale of 500 MW per plant.[57] To develop OTEC, IPTs are leveraging knowledge across the company's Space Systems and its Maritime Systems and Sensors divisions. Advanced composite materials developed by Space Systems are used for OTEC's deep cold water pipes to sustain "wave-driven platform motions, ocean currents, and pressure forces" at depths of 1,000 meters. The friction stir welding process, previously used by Lockheed Martin for the development of the External Tank on the Space Shuttle and combat ships for the U.S. Navy, is being used to reduce ocean corrosion of the low-cost heat exchangers, which create the steam to drive the turbines. Awarded $15 million in funding over the last three years from the U.S. government, including the U.S. Naval Facilities command, the company plans to have a 10 MW pilot project in Hawaii online by 2012-2013, with commercial size plants of 100 MW or greater online by 2015. Lockheed Martin anticipates that this DOD-driven project will not only help the U.S. Navy fulfill its goal of obtaining 50 percent of its energy from alternative sources by 2020, but also sees significant private market potential for OTEC, for example, off the coast of Florida and in the Gulf of Mexico to power the mainland U.S. electrical grid. The RAND Corporation estimates that this region could accommodate the deployment of 100 to 300 100-MW plants, which could power five million to 18 million homes.[58]

4. BUSINESS MODEL INNOVATIONS

New technologies are vital for reducing carbon emissions and driving business growth, but revolutionizing business models may be even more important for bringing low-carbon innovations to market. Many innovations (from the light bulb and the transistor to mass production and online commerce) existed for years before the right combination of organizational resources, market structures, policy incentives, and/or complementary technologies enabled them to finally have a major impact. That is why business models are so important.

The term 'business model' describes particular combinations of products (goods or services) and processes (all of the business activities involved in delivering those products). More important, it describes how a given combination provides competitive advantage to companies. 'Business model innovation' describes a novel combination of changes in both a company's product offering and the internal process and external partnerships by which that offering is delivered.

Southwest Airlines provides a classic example of business model innovation in a mature industry. The airline successfully reduced the costs of air travel by using a uniform fleet of 737s with rapid gate turn-arounds, by creating a collaborative work culture, by choosing less-used airports, and by taking other steps that together created a tightly knit and functioning network. This type of innovation is typically more difficult to achieve in large, established companies because it involves changing, adding, or dropping current activities. These are difficult steps that can trigger significant resistance and even outright hostility within a company.

Business model innovations shape the way—and the speed at which—low-carbon technologies come to market. Each new low-carbon technology has distinct strengths. But when forced to integrate within larger industrial networks optimized around incumbent technologies and models, these new technologies often cannot play to their strengths. Without new business models to match the new technologies, low-carbon innovations such as solar, wind or biofuels must compete as commodities within established, mature industries.[59]

History shows that technological innovations can languish until the right business model comes along. When Edison introduced his electric light, the technology was already four decades old. Edison's key business innovation lay in adopting the product offering and processes of the existing gas companies. Instead of just selling generators, wiring, and lightbulbs, he reorganized to operate and maintain these systems, selling energy itself in the form of electricity.

Similarly, the companies in this study have identified, developed, and launched new business models to bring new low-carbon innovations to market. HP could have continued its traditional business of selling printers and ink. But it heard from customers that printing was getting too large and out of control. The company created a multidisciplinary team to develop a service that would manage a customer's diverse printing assets. The result was a new business, Managed Print Services, which entailed a shift in focus from selling printers and ink. HP expanded its boundaries to include everything from locating printers around an office, to managing the operations and maintenance of those printers, to finding ways to reduce their energy and materials consumption. Today, Managed Print Services reduces an average company's overall printing-related operating costs by about 30 percent. It reduces the customer's energy consumption from printing by 30 to 80 percent. And it cuts paper use by millions of pages. For HP, the benefits include strengthening customer relationships and gaining deeper insight into the changing nature of printing in offices. That insight could lead to new opportunities for innovation.

The idea behind HP's business model innovation came from listening to customers. But business model innovations can also be enabled by changes in policy. For example, Johnson Controls and other energy service companies were able to see the opportunities created by the 1985 Ohio School Facilities Commissions House Bill 264, which allowed public schools to finance energy retrofits based on future energy savings. Before the bill was passed, schools and other public institutions typically couldn't afford energy efficiency retrofits—even though the long-term energy savings would more than pay for the initial price tag. After the legislation was passed, however, energy service companies could offer more than a retrofit; they could also offer the required financing or take on the financing and maintenance themselves. That opened up a new business model for energy services, turning a commodity into a service.

Identifying the opportunities for business model innovation represents, in many ways, the easy part. The harder part is making the needed changes to current products and processes. Some of the companies studied were able to develop novel business models within their existing business units. However, many such innovations threaten, and are threatened by, existing operations. So companies also developed and launched business model innovations under the protective wing of R&D labs or similar groups.

Consider Johnson Controls' private sector building efficiency initiative, which reflects a business model innovation that involved significant product and process innovations. The company simultaneously developed new energy technologies (including renewable energy generation), new financial and contracting features, and new organizational capabilities (expertise in corporate financing and power purchase agreements). To accomplish these changes, Johnson Controls launched the business within its Global Energy Solutions Group, where the initiative could safely develop and prove itself before becoming a standalone business.

Business model innovations can make huge impacts on markets—particularly when the policy environment can adapt to accommodate those innovations. For example, Freightliner's Cascadia truck helped launch a new Daimler engine platform that will provide a clean diesel product line for decades. But in the process of developing the truck, Daimler's development team discovered that the greatest potential for further reductions in energy consumption and carbon emissions may lie not in the truck, but in changes to truck trailers and driving behaviors—operational elements that had been outside of the company's typical purview. In test drives of the Cascadia truck, the engineering team discovered that 40 percent of a 40-ton truck-trailer combination's fuel consumption is influenced by the aerodynamics of the trailer, traffic events, maintenance and, perhaps most significant, driving behavior. Current policy requires new engine efficiencies that are capable of only producing gains of 1 to 2 percent. Yet changes in these other factors—which could be accomplished through the development of different business models—could deliver 10 to 30 percent improvements. As a result, more innovations may lie ahead as Freightliner starts to tackle trailer design, maintenance, and driving conditions and practices—especially if policies begin to require such improvements.

In the electric power industry, heavy regulations and deeply entrenched players hamper the development of new business models. But outsiders like Silver Spring Networks (a smart metering and demand response company), IBM, Google, and Cisco are leveraging their broad technology expertise and political clout to change the game in smart meters. Such meters allow greater end-user control, efficiency, and connectivity with renewable energy sources, while providing new business growth for these companies.

Companies develop new business models by first identifying the opportunity—whether from emerging technologies, a customer preference, or evolving policies. Companies then incubate emerging businesses within internal labs or strategy groups, and provide the new businesses with the right support, resources, and guidance until they prove their value with customers and mature into self-sustaining businesses.

Recommended practices for rethinking business models include:

a. Assemble a multidisciplinary team with technical, marketing, organizational skills and, critically, public policy expertise. The team also must be able to pool this expertise in order to identify novel ways of reorganizing the company's current set of activities.

b. Observe and document the full set of activities associated with the manufacture, use, and disposal of the company's products or processes. Consider whether and how the organization might profitably incorporate and adapt each activity to enhance its offerings.

c. Carefully develop and launch promising business model innovations where they will have the chance to grow and prove themselves while remaining safe from competing interests inside the company.

d. Scout for business model innovations in other locations, markets, and sectors. Explore adopting and adapting those changes, and assess the potential profitability of pursuing such innovations.

5. NEXUS WORK

For low-carbon innovations to take root, companies must envision and develop not just the technical or business model changes, but also the necessary networks of external partners that enable them. The success of innovations like the smart phone, automobile, or train depends upon large networks of suppliers, developers, and other partners. In other words, the innovation process depends on nexus work.[60]

Nexus work involves envisioning, building, and maintaining the necessary business and technical systems that underlie innovations. These systems are complex, reflecting the interdependent relationships among diverse elements, each necessary but none sufficient to ensure the performance of the larger system. The best example of such nexus work is the role of producers in music, film, and theater, where diverse resources are identified and brought together in new ways to create each new product.[61] These same activities are found in many large organizations, particularly in innovation projects that span departments within organizations, external suppliers (and their suppliers), manufacturers, distributors, and users.

Nexus work is vital for the success of low-carbon innovations. Surveyed executives from Citi, DuPont, and TransAlta all cited the importance of building effective relationships across the organization and with critical external partners—especially those bringing competencies that the company does not have. In part, this is because modern products and services already reflect large and interdependent relationships between components and service providers that are both inside and outside companies. Brian Mormino at Cummins pointed out that improving the fuel efficiency of Cummins' large diesel engines requires managing changes across multiple critical subsystems, some designed and built within the organization, others by outside suppliers. These systems include electronic controls, combustion technologies, fuel systems, turbochargers, and exhaust treatment systems. Similarly, Herman D'Hooge, Innovation Strategist at Intel, explains, "Low-carbon innovations require a multi-function approach (among strategy, design, customers, government, policy, operations, sales), best when incorporated into standard business lines."

Nexus work can be divided into three activities: *seeing*, *building*, and *maintaining* new technological and business relationships. *Seeing* involves recognizing the critical partners, within an organization and outside, whose collaborations are required for success, and understanding the value proposition that would ensure their commitment. Take, for example, Daimler's clean diesel technology. Part of the challenge was technical—creating a clean diesel engine without sacrificing performance. But an equally important part of the challenge was organizing a network of suppliers, competitors, regulators, service stations, and distributors to ensure that the new engine design would be adopted as a market standard and would bring profits to all involved (see Sidebar: Nexus Work in Automotive Innovations: Daimler's BlueTEC, this page, and Daimler case study). Envisioning the new clean

Nexus Work in Automotive Innovations: Daimler's BlueTEC

To develop and deploy BlueTEC (a clean diesel engine system that enables automobiles with 20 to 30 percent better fuel efficiency than similar-sized gasoline-powered cars), Daimler worked effectively with a wide range of partners and at multiple levels of the business, creating a new set of partnerships and interdependent activities. Nexus work at Daimler begins at the earliest stages of projects, and involves working with development teams, suppliers, competitors, and regulatory agencies. The BlueTEC technology itself is an exhaust treatment system that uses an additive to create diesel engines capable of meeting strict pollution regulations. But the underlying technology intersects all aspects of a vehicle's design. As a result, moving BlueTEC from the R&D Group to specific product development teams required collaboration and interdependent changes across a dozen or more design teams.

To enhance collaboration, three R&D engineers followed the technology, joining the 97-member project team designing the vehicle. The project team, in turn, was divided into a number of subgroups. Each focused on one area, such as the engine, exhaust system, transmission, safety, cabin interior, or body. Decisions made in any one of these groups often affected the other groups—sometimes to their benefit and sometimes adversely. And decisions made at other levels had ramifications for the integration of systems in the car. For example, in response to regulators, the tank in one vehicle design had to be designed to hold enough additive to last through the average service interval of the vehicle. Such a large tank took up space that otherwise would have housed the spare tire, requiring the wheels team to ditch the spare tire and shift to 'run-flat' tires. This tire decision, including all of its ramifications, took a whole year to make.

Daimler also faced stiff challenges in trying to introduce an entirely new additive. It was important to both Daimler and the U.S. regulators that the clean diesel technology be widely used across manufacturers, to create a common platform and ensure one system. This entailed Daimler creating a dedicated Working Group to work closely with regulators, suppliers, and competitors to win confidence in this technology platform, to coordinate design specifications, and to ensure a shared infrastructure for all car models. That took time: representatives of the cooperating auto companies met with regulatory agencies every six weeks for 18 months. Such nexus work was critical to successfully developing and launching this innovation.

diesel opportunity at a purely technical level without considering system-level changes would be no more sufficient than envisioning the market-level changes without considering the necessary technical improvements. Similarly, the development of high-speed rail projects at Alstom involves determining, in the very initial stages of the project, which organizations will be the central partners in the construction, service, operating and maintenance, and financing of the resulting railway.

Successful companies begin by identifying employees who have technical or marketing expertise and the ability to engage in nexus work. In many cases, technical advances must be accepted and shared across the industry before customers can be confident in the results. That entails working with competitors to establish new standards for emerging innovations. The importance of these interactions requires that companies choose their most qualified individuals to represent them. As one Alstom R&D manager explained:

> "You have to [staff standards committees] with your best people because the best people from the other organizations are involved. You're dealing with Oak Ridge National Lab and so forth. If you don't have your best people...nobody has any reason to interact with you."

The next step is *building* new business and technical relationships across existing and new participants in mature markets. This requires both disentangling long established linkages (whether collaborative or competitive) and effectively constructing new ones. For example, the engineering and construction of advanced supercritical power plants requires bringing together a broad range of suppliers, regulators, utility customers, sub-contractors, and others. One Alstom executive explained:

> "As you stop vertically integrating your business and try [to] be master of all trades, you get involved in more complex, broad-reaching, government-involved projects, [and] no one company can do it all. You need to rely on other people to do things well in their particular areas. Your ability to bring those people together and manage that [collaboration] is a key piece of our success."

Forming new commercial and technical relationships requires significant investments—directly and in the form of the opportunity costs from not pursuing others. As a result, network partners want to be assured that others are making the same commitment. The Daimler executive team's strong commitment to its new clean diesel solution was critical in securing the commitments of suppliers, competitors, and new distribution partners.

Finally, there is the work of *maintaining* the new networks as they evolve during the period of commercialization and broad diffusion. The durability of a network depends on the network's original design, on how it was built, and on whether critical pieces were left out. At engine maker Cummins, the network behind the company's heavy-duty engine came together over decades, says Cummins' Brian Mormino. Innovations, adaptations, and accommodations took place in all the systems and suppliers that were involved. And it was important that each participant could profit from being involved.

It is also critical for those engaging in nexus work to set aside their egos and individual interests. As an Alstom executive noted: "You want to build the big asset and have your brand on it and say 'look what I've delivered.' But the reality is there are many different hands in [bringing a low-carbon innovation to market]." What is important and "the right thing for the customer" is "having the right hands in building" the solution, regardless of how credit for the project is attributed.

Recommended practices for engaging in nexus work include:

- **a.** Identify and develop those individuals within the organization who have both technical expertise and the ability to identify, build, and maintain collaborative relationships with outside partners.
- **b.** Create a team whose task it is to identify the critical partners *within* the organization whose support and commitment will be needed for a project's success. Consider their resources and interests and define the ways in which mutually beneficial connections can be established.
- **c.** Similarly, ask this team to identify the critical partners *outside* the organization, and consider the resources needed by these potential partners to establish mutually beneficial connections.
- **d.** Think beyond current innovation opportunities. Create a strategic plan that identifies the critical resources and sources of uncertainty in your environment. Then devise strategies for building relationships that enable access to these resources and help resolve the uncertainties.

6. ROBUST INNOVATION STRATEGIES

In highly competitive and rapidly changing environments, it is dangerous to presume that one chosen strategy will play out as planned. While some business authors have suggested that a tenacious focus on a single strategy is critical for success, the companies in this study demonstrate that flexibility—with what is called a 'robust' innovation strategy—is also vital.

Robust innovation strategies advance a company's competitive advantage in the short run while also preserving the flexibility to respond to the moves of competitors, suppliers, regulators, market conditions, and customers over the long term. The notion of robust strategies comes from a study of chess players by sociologist Eric Leifer. Before Leifer's study, it was thought that chess masters systematically map out all possible moves and counter-moves before making each of their moves. But Leifer found that players did not (and could not) rely on such detailed planning. Instead, players chose moves that simultaneously advance a particular strategic gambit yet preserve the flexibility needed to respond to their opponents' moves. Leifer described these moves as robust actions. Later, scholars generalized this concept to describe the effective actions of managers in organizations.[62]

A robust innovation strategy does not conflict with a tenacious focus, but rather complements it by continually exploring alternative technologies, strategies, and capabilities.[63] If conditions change, these alternatives can make a new approach possible. Consider Johnson Controls' automotive battery research programs. While the company was developing hybrid and electric vehicle battery designs in anticipation of growing markets for such vehicles, it also developed and began manufacturing mass-market quantities of a product—the start-stop battery—that offered a more immediate opportunity. This strategy prepared Johnson Controls to meet the evolving demands of its automaker customers. Focusing on a single battery technology would have left them at a disadvantage in responding to long-run changes in the market.

Alstom also recognizes the dangers of an inflexible strategy. "In our business, if you try to tell an electric utility that they're only going to have it one way, you [the provider] are not going to have anything," explained one executive. While focusing on core markets like boilers for fossil fuel power plants, Alstom is also expanding its capabilities in renewable energy and carbon capture and storage. Similarly, while Daimler has committed to clean diesel engines, it is also developing and manufacturing hybrid and electric vehicles.

The corporations in this study have been able to pursue robust innovation strategies that enable them to continually scan for, develop, and advance multiple competing technologies. Over time, as their markets evolve, they are able to selectively increase their investments in those technologies that the market is embracing while putting on hold, or abandoning, those that are no longer relevant. In fact, the companies in this study have inventories of available technologies that their R&D groups have already developed to the point of technical competency and that await the right price points or regulations for fuel efficiency, carbon emissions, or other factors.

Put another way, the companies in this report are pursuing robust innovation strategies that include three activities: *scanning, learning,* and *engaging. Scanning* involves keeping abreast of emerging relevant technologies. The companies in this study have given specific individuals or groups the responsibility for continuously monitoring the environment for novel or potentially valuable technologies, and for engaging with potential sources, such as universities, that are working on similar technologies. In the workshops and in the survey, companies noted that "first movers pay [a] penalty," and that you need to "know your market…and keep a good eye on disruptive technologies that can change the whole game." Alstom, for example, collects new technology ideas and quickly tests them to see if they are technically viable and make business sense. "In trying to come up with solutions that we envision for the customer's future needs, we are looking at a wide scope of approaches and a wide scope of technology," explained John Marion, head of Alstom Power's Boiler R&D unit. Such scanning and testing is vital, he added: "If you haven't done any homework [on emerging technologies], you have no hope."

Companies can monitor technological developments by working with startups, engaging with the inventors who often approach the companies, and working with universities. Daimler, for example, brings in university doctoral students to conduct their dissertation research within the R&D labs of the company. This ensures that the research is shaped by practical industry problems—and that cutting-edge academic ideas are shared with Daimler. HP similarly works closely with university researchers, often locating them in the company's R&D labs for specific projects.

When promising new technologies are spotted, *learning* activities begin. Companies must gain enough understanding to be able to decide whether to dismiss the new idea, monitor its progress, or begin developing it. Daimler has a variety of engine technologies that add cost and complexity to the vehicle design but, if necessary, can be added to meet customer or regulatory requirements. The ability to build such "inventories" of potential innovations requires the competence to evaluate a range of alternatives for both technical and business feasibility. This competence, according to the corporate executives surveyed, is crucial. It enables Alstom to bring promising technologies into larger systems in ways that the original inventors could not, for example. Entirely new technologies represent opportunities as well. Consider Alstom's investigation of oxygen membranes (which may enhance the performance of combined-cycle power plants). As John Marion at Alstom described:

> "We heard about oxygen membranes but didn't know a thing about them. So we identified one of the staff members to go out, look into oxygen membranes, and report [on] what they are, how they work, what could be done—and to do a kind of pre-study…with a hope that as a result…you're going to have ideas."

In addition to determining whether or not a technology works, companies need to ask if it fits with their business strategies: Does it open a new market or enhance an existing business line? Can it make money? It is economically attractive to customers? At Alstom, if the answer to all these questions is 'yes,' the R&D team will invest in exploring the new technology. As Marion explained,

> "The main reason [for] doing that is to compare. [For example,] right now we are comparing the oxy-boiler to using chilled ammonia or the advanced amine systems [to reduce carbon emissions from boilers or to capture carbon from flue gases] and we are determining which technology looks more economical for site-specific conditions and then we look at sensitivities of the technology to operating conditions. So [given] a market with certain site and operating conditions, then is one [solution] better than the other?"

Once a value proposition has been established, Alstom budgets for further experiments to better understand the capabilities and limits of the new technologies. After that, many of the technologies simply sit on the shelf awaiting favorable market conditions, as was discovered with the oxygen membrane technology, because the next steps in their development would be costly.

Finally, robust innovation strategies involve *engaging*—in other words, learning by doing. Learning by doing reflects the fact that considerable technological advances, as well as cost reductions, take place only after a company has begun manufacturing, selling, and supporting new products. Alstom, for instance, recognizes that it must jump quickly into key markets (which may be anywhere in the world) for any given technology, or risk falling behind as technologies and products evolve. As an Alstom Power Solutions executive described:

> "The hydropower business went through a couple of growth waves. First, all the big projects were in Brazil. If you weren't in Brazil you couldn't sustain your competencies, your people, your technology, or your R&D. So business had to move and you had to engage in Brazil. Then it was China. If you weren't in Asia and you didn't capture [project opportunities]… you weren't able to pay for all of your R&D, and you weren't able to maintain your competence."

Similarly, Duke Energy has been working closely with Chinese companies and government agencies for the past three years to stay ahead of the curve in clean energy technologies. China's rapidly expanding energy market provides Duke Energy with a cost-effective, low-risk opportunity to experience the learning that comes from deploying technologies in locations where there are fewer extant large-scale industries (see Sidebar: Duke Energy's Robust Innovation Strategies in China, next page).

Entergy CEO Wayne Leonard has also recognized the need for forward-looking strategies and investment in clean energy. In 2001, the company committed to stabilizing its CO_2 emissions at 2000 levels and established an Environmental Initiatives Fund (EIF). To date, $28 million in EIF funding has been dedicated to maximizing carbon reductions of Entergy-owned assets and to innovative external investments in a portfolio of carbon offsets. Through the EIF, Entergy has funded electric vehicle charging stations on college campuses

Duke Energy's Robust Innovation Strategies in China

In 2008, Duke Energy began a concerted effort to engage with the development and deployment of novel low-carbon energy technologies in China. Based in Charlotte, North Carolina, Duke Energy distributes electricity to over four million customers in the United States, and owns power-generating assets in the United States, Canada, and Latin America.

Because China has been deploying new energy technologies with what Duke Chief Technology Officer David Mohler calls "unimaginable" speed, scale, and scope, Duke saw an opportunity to obtain first-hand experience with installing and scaling low-carbon innovations, Mohler explains.[64] Duke Energy is leveraging opportunities in China as a low-cost research market, and the lessons learned could help bring clean energy to the United States more cheaply and quickly, and at lower risk. In the United States, there is relatively little demand for new installed capacity, so testing and deployment of these technologies is slower.

Mohler points out that the effort to build clean energy infrastructure in China is driven by three primary factors: state support (through Five Year Plan mandates) and funding is widely available, unlike in the United States where policies and funds are subject to frequent election cycles, and budget deficits constrain infrastructure investments. Permitting is easier and construction cheaper than in the United States. And market demand is huge. Of China's 1.3 billion citizens, 400 to 500 million are without electricity today, while 350 million are expected to move into cities planned for completion by 2030.

China presents a new market rapidly reaching the scale and complexity of the many mature markets in developed economies. In such an environment, Duke Energy can observe new technologies in use. As Mohler explains: "If we didn't pursue and observe this experience, we'd be left in the dust. What China does [with respect to energy innovation] will set the curve on what everyone else will do moving forward." At the same time, the company's experience managing the scale and complexity of the mature energy infrastructure in the United States provides valuable guidance for the Chinese power companies as they grow.

To gain firsthand experience and provide guidance, Duke formed a series of joint activities and partnerships with Chinese firms, government agencies, and leading universities. The activities cover a broad array of technologies, including energy efficiency, renewable energy, carbon capture and storage, clean transportation, energy storage, and smart grid solutions. In one partnership, Duke is working with Chinese energy company ENN Group to develop and test solar power generation, substation and community battery storage capabilities, grid management optimization, and residential energy management.

To capture the learning by doing from projects in China, Duke Energy established a Technology Group with 22 employees (two of whom are fulltime in China). The Group is responsible for maintaining and developing relationships with companies in China, and translating those into practical projects for Duke. The Group reviews over one thousand potential ideas each year, provides in-depth analysis of roughly one quarter of those, and validates approximately 150 through laboratory or field testing, before passing around about five of them into the business lines. As a technology adopter, Duke is not interested pursuing intellectual property (IP) for individual technologies, but rather wants to gain experience with the technology in use to bring Duke up the learning curve. As Mohler explains: "We are interested in the IP of scaling."

Even without a price on carbon emissions in the United States, Mohler feels that low-carbon innovation is part of the company's responsibility, and this strategy provides exposure and expertise with new technologies at a relatively low expense and low risk for Duke Energy's customers and shareholders.

in its service area, developed protocols for carbon sequestration from coastal wetlands restoration projects, and has voluntarily purchased over four million GHG emission reduction credits from bottomland hardwood reforestation, methane capture and utilization, geologic sequestration of CO_2, direct seed farming, among other projects.

On a smaller scale, companies are constantly learning by doing by moving first to prototypes, then demonstration projects, and finally small-scale manufacturing. HP, for example, moved quickly to prototype its videoconferencing offering, Visual Collaboration, and is similarly pursuing pilot-scale manufacturing and marketing experience with a promising sensor-based technology, CeNSE, that enables highly sensitive remote monitoring and data-intensive communication.

Recommended practices for developing and pursuing robust innovation strategies include:

- **a.** Task specific individuals or groups with continuously scanning the environment for novel or potentially valuable technologies. Identify and engage with groups, such as universities, where work is being done on similar technologies and problems.
- **b.** Establish a clear process for identifying and vetting potential technologies. Develop a common criteria and method for validating the technical, market, and financial uncertainties associated with each potential innovation, ensuring comparability across assessments. Stage the exploration of individual technologies to maximize learning and minimize costs, tranching (or dividing up risks of) investments in the investigation of any one potential technology.
- **c.** Where possible, evaluate each potential technology on technical, market, and business criteria in order to learn when a new technology might become viable. For automakers, for example, new engine technologies could be prioritized by their costs per gram of reduced CO_2 emissions.
- **d.** Monitor global markets for opportunities to engage with emerging technologies wherever they are being developed, manufactured, and used, experiencing first-hand the lessons from learning by doing and using. Because technologies and industries co-evolve rapidly in use, participating in this process provides a distinctly different perspective than laboratory testing.

7. PARTNERSHIPS, INVESTMENTS, AND ACQUISITIONS

Many emerging technologies fail to bridge the divide between scientific breakthrough and commercial success. Publicly funded energy R&D has developed a wide range of technological alternatives for the generation, storage, distribution, and consumption of energy. Yet few are ultimately commercialized and broadly adopted. Similarly, many recent and highly publicized new ventures, often backed by prominent venture capital funds, have developed proprietary technologies that have yet to be successful in the market. Moving technologies from university labs and garage startups to the marketplace requires overcoming significant barriers. The technologies typically can't succeed without large upfront investments, the existence of complementary infrastructure, the turnover of existing capital stock, and market re-organization. Large corporations can play a critical role in overcoming these barriers by partnering with such early-stage efforts, and sometimes investing in or outright acquiring them. Large corporations also have the capability of integrating newly developed technologies into products and services at the right scale, reliability, and profitability to meet market needs.[65]

In the development of early-stage, emerging technologies, the companies in this study partnered with other companies, worked with university (and national lab) researchers and inventors, and invested in and acquired promising new ventures. Large companies often partnered with each other to pool expertise and complementary assets for, and to share the risks of, developing new technologies in joint ventures. For example, Alstom and Dow Chemical Company jointly developed proprietary advanced-amine technology for carbon capture and sequestration, testing it on a coal-fired boiler at a Dow-owned facility in South Charleston, West Virginia. The pilot allows both companies to evaluate the technology operating under power plant conditions and provides the necessary data to design large-scale demonstration plants. Similarly, Catchlight Energy, a 50-50 percent biofuels joint venture between Chevron and Weyerhaeuser, brought Chevron's production and distribution expertise together with Weyerhaeuser's biomass feedstock. This arrangement leverages their mutual expertise, and also reduces the risks of running out of feedstock or not having adequate production and distribution to meet market needs. Johnson Controls' alliance with concentrating photovoltaic developer

Concentrix increased its ability to develop integrated utility scale solar projects.

Companies like Alstom, Daimler, and HP also regularly meet with inventors and academic researchers, as mentioned in Section IV.6., "Robust Innovation Strategies." An Alstom R&D executive noted:

> "Alstom, of course, gets approached by a lot of inventors. An idea can also come from the outside, so we evaluate it and decide whether it makes sense to look at. Enabling technologies are often brought in—such as a new material that has superior wear resistance—and we might see the opportunity to put that into our components. Or a new kind of firing technology or a new kind of emission sensor—these pieces of our product where there's a win-win."

Engaging with researchers has benefits in the other direction as well, by providing the researchers with an understanding of the challenges inherent in integrating new technology solutions into larger technical systems and existing markets. Professor Yet-Ming Chiang, a co-founder of battery manufacturer A123 Systems, once noted that "scientists work on one-dimension solutions. Industry deals with multidimensional problems." Making scientists aware of the larger issues and challenges can often result in changes in the focus of future research.

Large companies also partnered with, invested in, and sometimes acquired promising new ventures. Partnering can also take the form of joint ventures (or subcontracting relationships) between large companies and new players.[66] Customer uncertainties about performance claims, product reliability, or manufacturing capacity (even company longevity) can undermine customers' willingness to work with young companies, despite promising technologies. Through the larger corporations, small companies rapidly learn the intricacies of mature markets and benefit from the established firm's experience and reputation. Additionally, many small companies are focused on a single product or technology while customers want solutions integrating multiple technologies. When Johnson Controls was overseeing the Empire State Building project, they partnered with Serious Energy (formerly Serious Materials), a small firm that makes windows with dramatically higher thermal efficiency (see Sidebar: Empire State Building, next page). The partnership assured the building owner, the customer, that it was not only getting advanced windows, but also was working with a large company with a long track record managing energy retrofits. Moreover, the benefits of efficient windows were captured not only by energy savings but also by reduced capital and operating costs associated with installing a new and smaller HVAC system.

Similarly, partnerships can also be created through corporate investments in or outright acquisitions (often both) of smaller firms. In 2008, General Electric Energy, a division of GE, bought a majority stake in startup PrimeStar Solar, which is developing thin-film cadmium telluride solar cells that have a lower manufacturing cost than silicon panels, based on technology developed at the National Renewable Energy Laboratory. In April 2011, GE announced it had acquired the company outright and will invest $600 million in a solar business built around the new technology. GE plans to build a new 400 megawatt U.S. manufacturing facility that, according to GE, will be "larger than any existing solar panel factory in the country today."[68] In June 2011, GE announced it was taking a minority stake in solar thermal company eSolar and plans to include the company's technology in some natural-gas-fired power plants and solar farms.[69] Similarly, DuPont recently acquired Innovalight, a maker of silicon ink that boosts the efficiency of solar cells by several percent. And in 2010, DuPont acquired Danisco, a maker of industrial enzymes used in the production of biofuels.

Selecting these investments or acquisitions requires different skills than does licensing technologies or managing supplier relationships. The task is similar to venture capital or private equity investing, and often requires the ability to manage the external ventures. Yet in addition to financial returns or access to novel technologies, such investments in smaller ventures also provide opportunities to explore emerging business models and market shifts. An executive at PG&E Corporation explained that the utility's investments in two rooftop solar companies provide not just financial returns, but also insights into the companies' business model. In many ways, this approach is part of a robust innovation strategy, since it helps to identify and develop potential options. The companies surveyed estimated that, while 70 percent of original ideas for low-carbon innovations come from inside their companies, approximately 30 percent come from outside through acquisitions, corporate venture capital, and/or joint ventures. These outside ideas and offerings augmented their own R&D efforts and, at times, enabled them to provide a richer set of offerings to their clients.

Empire State Building

Johnson Controls led a $500 million upgrade of the Empire State Building (expected to be fully complete in 2013) that will result in one of the most energy-efficient commercial buildings in the United States. Working together with Jones Lang LaSalle, a global real estate services firm specializing in commercial property management, the Rocky Mountain Institute, and the Clinton Climate Initiative, Johnson Controls engineered and executed a broad range of renovations and retrofits to this landmark that, according to the company, included:[67]

- refurbishing on-site approximately 6,500 windows with new components that will substantially reduce summer cooling load and winter heat loss.
- adding insulation behind radiators to reduce winter heat loss and summer heat gain.
- upgrading tenant and common area lighting with controls and sensors to lower electricity costs and cooling loads.
- retrofitting chiller plants to improve efficiency.
- introducing individualized web-based power usage systems so tenants can manage their power consumption more efficiently.
- installing one of the world's largest digitally controlled wireless networks, enabling 24/7 monitoring and control of every steam valve, pump, louver, fan, and other elements of the building's HVAC system.
- integrating the Johnson Controls Metasys® building management system to monitor and optimize HVAC, lighting, and other building systems.

The project is expected to reduce energy consumption by 38 percent, cut CO_2 emissions by 105,000 metric tons over a 15-year period, and save the building owners $4.4 million per year in energy costs, with a payback based on incremental cost of 3.1 years. To reduce risk and uncertainties, Johnson Controls and the Empire State Building's owners entered into a performance contract guaranteeing the projected energy savings for the life of the project.

Companies established groups with direct responsibility to identify and manage formal partnerships with outside inventors, researchers, or companies, formalizing and developing the particular skills needed to work with external partners through joint marketing, engineering, and contracting efforts. This enabled them to make sure that those responsible had the requisite experience and could operate with sufficient resources and flexibility. The approach used by Johnson Controls combines the responsibilities for both public policy and mergers and acquisitions in the office of Clay Nesler, Vice President of Global Energy and Sustainability. That closely links these two strategic functions, ensuring that potential partnerships with technological promise also make sense in the policy environment.

Managing innovation through partnerships, investments and acquisitions depended on clearly understanding the company's core strengths and weaknesses (and strategic objectives) in order to target potential partners with valuable and complementary expertise, intellectual property, or capabilities. As Dawn Rittenhouse, Director of Sustainability at DuPont, asserts: "Know your market, find partners who can bring competencies that you don't have, and keep a good eye on disruptive technologies that can change the whole game."

Recommended practices for managing innovation through partnerships, investments, and acquisitions include:

a. Determine the company's core strengths and weaknesses in each market and formally identify potential partners that provide valuable complements. Assess both their strengths and weaknesses.

b. Develop and formalize the capabilities for partnering with other companies and university researchers, and for licensing from inventors. In other words, assess internal competencies in working with external partners in joint marketing, engineering, and contracting efforts. Are there specific individuals and offices tasked with partnerships, investments, and acquisitions? Do they have the requisite experience? And can they operate with sufficient resources and flexibility?

c. Invest in robust innovation strategies (see preceding section of this paper) that provide a mechanism for evaluating potentially disruptive technologies and enable the quick assessment of partnership opportunities.

d. Develop the organizational capabilities for investments and acquisitions, which entail often very different skill sets than do licensing and maintaining supplier relationships. Those skills are similar to those needed for venture capital and private equity investing (which often requires continuing involvement in the management of external ventures).

V. CONCLUSIONS

The threat of climate change is already altering markets, creating both new opportunities and new risks for companies. And the future is expected to bring additional (and potentially dramatic) policy changes, requiring new technologies, new business models, and new market priorities. In fact, the steps needed to combat climate change may radically reshape entire industries. Some companies, industries, and sectors will be more at risk than others—but all will be affected. Only companies that are prepared will thrive.

This report looked at the opportunities and challenges facing companies pursuing low-carbon innovations. It documented the increasing opportunities in a range of markets. It also distilled some of the unique challenges that companies face in bringing such innovations to market. Finally, this report documented the best practices of companies already at the vanguard. These companies have demonstrated their commitment and ability to lead change, successfully generating, developing, and introducing low-carbon innovations. Their lessons provide guidance for other companies looking to capture some of the same opportunities. The strategies of the companies studied in this report demonstrate the following attributes:

- **A commitment to low-carbon innovations as integral to a company's overall business strategy.** This commitment starts at the top of the company, and is supported by both broad visions and specific goals, by strategic and often long-term investments, and by formal and informal incentive structures for employees and managers. Companies surveyed and interviewed for this study also emphasized the importance of strong leaders or internal champions to articulate the value of low-carbon innovations to the companies' bottom lines and future growth prospects.
- **The involvement of public policy expertise at the highest level of corporate strategy.** Companies have created formal roles for individuals or groups not only to monitor the policy landscape, but also to effectively incorporate responses to policies into the appropriate levels of the company where strategic decisions are made. The companies also work with regulators, government agencies, industry groups, and other key players to shape policies and standards.
- **A focus on maximizing customer value along both carbon and non-carbon dimensions.** Companies emphasized that low-carbon innovations must present equal or greater value for customers than competing alternatives. Moreover, companies must also find innovative ways to reduce the risks associated with adopting new technologies.
- **A willingness—and an ability—to embrace business model innovation.** In many cases, the most effective way to bring a new innovation to market is to develop a new business model. Such a new model can mean changes in both the product offered and the way the organization brings that product to market. New business models may be essential for low-carbon innovations to compete against incumbent technologies.
- **An investment in nexus work.** Companies emphasized that a large number of formal and informal relationships must be envisioned, built, and maintained in order to successfully introduce a novel technology. This is particularly true for low-carbon innovations that occur in very mature, heavily regulated, and infrastructure-intensive industries, such as electricity generation, oil and gas production, and transportation. Successful companies identify their best managers who have both the technical and interpersonal skills to participate in these multi-stakeholder projects.
- **A balance of long-term vision and short-term profitability.** Companies able to successfully commercialize low-carbon innovations have a constant focus on core competencies and customer needs today, while also studying the changing technical, market, and policy landscape of the future. As executives in this study emphasized, companies that do not invest in learning about the next generation of

technologies or the shifting policy environment will be left behind. This does not mean that companies should pursue every avenue for low-carbon innovations, but rather that they have a formal process for constantly identifying and evaluating alternatives. As a result, when opportunities do arise, companies are prepared to recognize them and act quickly.

Over the long term, those companies most able to adjust themselves and tailor their offerings to the new conditions will prosper. Innovations will be required across all markets. The opportunities will not be confined to the primary energy markets of energy generation, transportation, industrial processes, and energy use in buildings. Environmental effects and related policies will change energy prices, market preferences, and the competitive dynamics of seemingly distant markets, sometimes with surprising speed. No company can afford to assume it will not be affected.

The practices described in this report capture the experience of companies already developing low-carbon innovations to compete in their own markets, from energy generation to computing, and from financial services to industrial manufacturing. The next several decades will bring a critical turning point as environmental effects and global economic development meet head-on. Actions taken today can help companies thrive in industries and markets that are shifting in response to climate change, creating competitive advantage and business growth opportunities that will last for years to come.

ENDNOTES

1 U.S. Energy Information Administration, "Highlights," in *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010), http://www.eia.gov/oiaf/ieo/pdf/0484(2010).pdf. The growth in world net energy consumption represents the addition of goods and services associated with energy generation in the form of new power plants, transmission lines, drilling rigs, pipelines, refineries, and coal mines, as well as those associated with energy consumption in the form of buildings, appliances, cars and trucks, airplanes, and industrial machinery.

2 John P. Holdren, "The Energy Innovation Imperative: Addressing Oil Dependence, Climate Change, and other 21st Century Energy Challenges," *Innovations 1, no. 2* (2006). Expected energy consumption growth—not including the replacement of existing stock—represents over $9.6 trillion in new market opportunities. U.S. Energy Information Administration, *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010), http://www.eia.gov/oiaf/ieo/pdf/0484(2010).pdf.

3 Joaquim de Lima and Vijay Sumon, *Climate Change—September 2010 Annual index review: China Cleans Up* (HSBC, 2010), http://www.research.hsbc.com/midas/Res/RDV?p=pdf&$sessionid$=NpWx7KnQX3S7eidoBg6dF0t&key=fahW5blBFB&n=277980.PDF. HSBC calculates the climate revenues by summing all the reported revenues that each of the companies within their HSBC Climate Change Index derives from the 18 investable climate themes.

4 Center for Climate and Energy Solutions, *In Brief: Clean Energy Markets: Jobs and Opportunities, July 2011 Update* (Arlington, VA: Center for Climate and Energy Solutions, 2011), http://www.c2es.org/docUploads/clean-energy-markets-update2011_0.pdf.

5 The results and a brief analysis of the Low-carbon Business Innovation Survey conducted in winter 2010-2011 can be found on the Center's web-site at http://www.c2es.org/business-innovation/survey.

6 The Center's BELC is the largest U.S.-based association of companies dedicated to business and policy solutions to climate change. The 46 companies in the BELC represent $2 trillion in revenues and nearly four million employees. For more information, see: http://www.c2es.org/belc.

7 In June 2011, HP entered into a strategic relationship with Polycom, Inc., an industry-leading unified communications (UC) solutions provider. Polycom will serve as an exclusive partner to HP for telepresence and certain video UC solutions, including both resale and internal HP deployments. Under the terms of this agreement, Polycom acquired HP's Visual Collaboration business, while HP will continue to provide the networking and computing hardware that supports it.

8 For example, as of August 2011, 31 U.S. states had set standards specifying that electric utilities generate a certain amount of electricity from renewable or alternative energy sources.

9 See, for example, Joel Makower, *State of Green Business 2011* (GreenBiz Group Inc., 2011).

10 McGraw Hill Construction and Siemens, *2009 Greening of Corporate America: The Pathway to Sustainability-From Strategy to Action* (McGraw Hill Construction, 2009).

11 McKinsey & Company, *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve* (McKinsey & Company, 2009).

12 United Nations Environment Programme and Bloomberg New Energy Finance, *Global Trends in Sustainable Energy Investment 2010: Analysis of Trends and Issues in the Financing of Renewable Energy and Energy Efficiency* (United Nations Environment Programme and New Energy Finance, 2010). In total, approximately 50 percent of this investment was in asset financing, 20 percent in company investing, and the remaining 30 percent in mergers and acquisitions.

13 Center for Climate and Energy Solutions, *In Brief: Clean Energy Markets: Jobs and Opportunities, July 2011 Update* (Arlington, VA: Center for Climate and Energy Solutions, 2011), http://www.c2es.org/docUploads/clean-energy-markets-update2011_0.pdf.

14 For a more extensive discussion of the clean energy economy and a perspective on the types of activities that are included, see The Pew Center on the States and The Pew Environment Group, *The Clean Energy Economy: Repowering Jobs, Businesses, and Investments Across America* (Washington, DC: The Pew Charitable Trusts, 2009).

15 "Best Buy Launches Online Sustainability Report: 'Our World Connected'," *Best Buy*, July 15, 2011.

16 Pike Research forecasts the carbon accounting and management market to reach about $1.3 billion on a global basis in 2011, and grow to represent a $5.7 billion market opportunity over the next decade. "Carbon Management Software and Services," Pike Research, accessed 2011. In 2009, market research firm Groom Energy named SAP as a market leader in the emerging field. See "Enterprise Energy and Carbon Accounting Research," Groom Energy, http://www.groomenergy.com/eca.html.

17 "Procter and Gamble unveil 'sustainability vision' for 2020," *Beyond Beauty: Sustainable* (blog), February 11, 2011, http://www.blogbeyondbeauty.com/en/index.php/2011/02/11/procter-and-gamble-unveil-sustainability-vision-for-2020/.

18 U.S. Energy Information Administration, "Highlights," in *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010); see also BP, *BP Energy Outlook 2030* (London: BP, 2011). For example, coal-fired electricity generating capacity in China is expected to more than double from 2007 levels by 2035, and China's reliance on coal in its industrial sector will grow by 55 percent. As developing economies rapidly adopt today's OECD standards of living, they adopt the energy, transportation and other consumption patterns as well, opening up opportunities for adoption of low-carbon innovations and at a much faster pace than before.

19 John F. Sargent Jr., *Federal Research and Development Funding: FY2012* (Washington, DC: Congressional Research Service, 2011).

20 NPR Staff, "Among The Costs of War: Billions A Year in A.C.?," *National Public Radio*, June 25, 2011.

21 William J. Lynn, III and Sharon Burke, "DOD News Briefing with Deputy Secretary Lynn and Assistant Secretary Burke from the Pentagon on the DOD Operational Energy Strategy," *U.S. Department of Defense*, June 14, 2011, http://www.defense.gov/transcripts/transcript.aspx?transcriptid=4840.; William J. Lynn, III, "Remarks at the White House Energy Security Summit," *U.S. Department of Defense*, April 26, 2011, http://www.defense.gov/speeches/speech.aspx?speechid=1556.

22 Roxana Tiron, "$400 per gallon gas to drive debate over cost of war in Afghanistan," *The Hill*, October 15, 2009, http://thehill.com/homenews/administration/63407-400gallon-gas-another-cost-of-war-in-afghanistan-.; Deloitte, *Energy Security: America's Best Defense* (Deloitte Development, 2009).

23 Army Environmental Policy Institute, *Sustain the Mission: Casualty Factors for Fuel and Water Resupply Convoys. Final Technical Report* (Arlington, VA: Army Environmental Policy Institute, 2009); U.S. Department of Defense, *Energy for the Warfighter: Operational Energy Strategy* (Washington, DC: U.S. Department of Defense, 2011).

24 U.S. Department of Defense, *Quadrennial Defense Review Report* (Washington, DC: U.S. Department of Defense, 2010).

25 Exec. Order No. 13514, 74 Fed. Reg. 194 (Oct. 8, 2009).

26 Center for Climate and Energy Solutions, *In Brief: Clean Energy Markets: Jobs and Opportunities, July 2011 Update* (Arlington, VA: Center for Climate and Energy Solutions, 2011), http://www.c2es.org/docUploads/clean-energy-markets-update2011_0.pdf.

27 "Fuel, Cost Efficient LEAP Engine with Breakthrough Tech to Power Virgin America Planes," *GE Reports*, June 15, 2011, http://www.gereports.com/fuel-cost-efficient-leap-engine-with-breakthrough-tech-to-power-virgin-america-planes/.

28 While innovation is often used to describe the conception of novel possibilities, this report considers innovations as those novel products and processes that have been successfully introduced and put into use.

29 Innovation researchers have created a wide range of innovation categories; this section summarizes the main categories. For more discussion of innovation typologies and more detailed distinctions, see for example, William Abernathy and Kim Clark, "Innovation: Mapping the Winds of Creative Destruction," *Research Policy* 14 (1985):3-22.; Geoffrey Moore, *Dealing with Darwin: How Great Companies Innovate at Every Phase of Their Evolution* (Portfolio, 2005).; Joseph L. Bower and Clayton M. Christensen, "Disruptive Technologies: Catching the Wave," *Harvard Business Review* 73, no. 1 (1995): 43-53.

30 Kevin Bullis, "Chinese Solar Companies Thrive on Manufacturing Innovations," *Technology Review*, July 6, 2011, http://www.technologyreview.com/business/37954/.

31 Christian Wolmar provides an excellent and highly accessible description of the development and diffusion of railroads through the 19th century, and the impact of state policies on both the quantity and nature of the resulting rail systems, in *Blood, Iron, and Gold: How the Railways Transformed the World* (Public Affairs, 2010).

32 For example, Edison Electric Light Company introduced a 13-watt bulb to match the familiar, if dim, light of competing gas lamps; it relied on a meter that froze in winter, in order to charge customers in ways familiar to gas utilities; it organized under existing gas statutes, under which Edison buried its lines underground (as did gas) despite high power losses, frequent shorts, and occasionally electrified streets. For a deeper discussion of the need to design innovations for integration into mature markets, see Andrew B. Hargadon and Yellowlees Douglas, "When Innovations Meet Institutions: Edison and the Design of the Electric Light," *Administrative Science Quarterly*, 46, no. 3 (2001).

33 This challenge can be seen in recent accidents involving high-speed rail, improper building construction, or corruption that emerges through rapid growth not only in new technologies but in the requisite skills and control mechanisms in supporting industries such as construction, maintenance, or inspections.

34 Michael Kanellos, "Tesla Production Slower Than Expected," *Greentech Media*, May 15, 2008, accessed August 23, 2011, http://www.greentechmedia.com/articles/read/tesla-production-slower-than-expected-908/.; Jay Yarrow, "Tesla Recalls More Than 75% Of Its Roadsters," *Business Insider*, May 28, 2009, accessed August 23, 2011.

35 Josie Garthwaite, "LEDs Are Getting Ready for the Spotlight," *Technology Review*, January 12, 2011.

36 All three companies, and others, faced unexpected quality problems stemming from wide-scale deployment of new technologies and designs. See, for example, "Launching Liberty: Clipper addresses teething issues," *Renewable Energy World*, May/June 2008. According to the *Wall Street Journal*, in 2008, Suzlon Energy had to "strengthen or replace 1,251 turbine blades—almost the entire number it has sold to date in the U.S.—after cracks were found on more than 60 blades on turbines" installed and in use. See Tom Wright, "Windmill Mishap Weighs on Suzlon," *Wall Street Journal*, October 25, 2008, http://online.wsj.com/article/SB122485006026866321.html. According to Li Yuheng, an industry analyst at China Investment Consulting, "The exceptional growth of China's wind power industry has sown seeds for potential risks, especially in terms of quality." Analysts fear an eruption of wind turbine quality problems as the operating experience with these turbine designs has not been long enough to test the quality. See Liu Yiyu, "Wind power industry facing big challenges," *China Daily*, January 20, 2011, http://www.chinadaily.com.cn/business/2011-01/20/content_11889212.htm.

37 See Andrew Hargadon and Martin Kenney, "Misguided Policy? Following Venture Capital into Clean Technology," *California Management Review* (forthcoming).

38 Since its inception as a policy framework, economists and historians of technology have labored to unseat the linear model of "RDD&D". See, for example, Nathan Rosenberg, *Inside the Black Box* (New York: Cambridge University Press, 1983), but the language (and even accounting categories) has become institutionalized in federal policy.

39 Richard Florida and Martin Kenney, *The Breakthrough Illusion: Corporate America's Failure to Move From Innovation to Mass Production* (Basic Books, 1992), 18. As Richard Florida and Martin Kenney argue, during the second half of the 20th century, "R&D grew further and further estranged from factory production as companies moved their manufacturing plants to new low-wage, non-unionized locations and then relocated their R&D facilities to suburban campuses. As the gulf between the sites of innovation and production widened, it became increasingly difficult to transform the new technological marvels developed in R&D labs into viable commercial products."

40 For a good description of the recombinant nature of many breakthrough innovations, see Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1890* (New York: Viking, 1989).; Nathan Rosenberg, "Technological Interdependence in the American Economy," *Technology and Culture* 20, no.1 (January 1979).; and Andrew B. Hargadon, *How Breakthroughs Happen: The Surprising Truth About How Companies Innovate* (Cambridge: Harvard Business School Press, 2003).

41 Raghu Garud and Peter Karnøe, "Bricolage Versus Breakthrough: Distributed and Embedded Agency in Technology Entrepreneurship," *Research Policy* 32, no. 2 (2003): 277–300.

42 The National Academies, *Real Prospects for Energy Efficiency in the United States* (Washington, DC: National Academies Press, 2009).; Hannah Choi Granade et al., *Unlocking Energy Efficiency in the U.S. Economy* (McKinsey & Company, 2009).

43 As argued by the authors of a recent article, John Alic et al., "A New Strategy for Energy Innovation," *Nature* 466 (2010). "Although advocates see basic research as the wellspring of breakthroughs, many radical innovations, including the jet engine, the microprocessor and the Internet, stemmed mainly from incremental advances that were motivated by anticipated applications." Edmund Phelps, winner of the 2006 Nobel Prize in economics, once observed: "Once in a while there is a big leap which creates the ground for a surge of innovations to follow. Nowadays we realize that an awful lot of innovation just comes from business people operating at the grass roots having ideas on the basis of what they see around them. Nothing to do with science." From Howard R. Vane and Chris Mulhearn, "Interview with Edmund S. Phelps," *Economic Perspectives* 23, no. 3 (2009).

44 Efficiencies refer to the amount of useful energy derived from the chemical energy of the fuel. In the case of modern power plants, this refers to the amount of heat released during the combustion of a specified amount of fuel, and is quantified as the higher heating value (HHV).

45 Such incremental improvements included better metal alloys, improved vacuum technology, coiling the filaments, frosting the glass, and others. See William Abernathy and James Utterback, "Patterns of industrial innovation," in *Readings in the Management of Innovation*, ed. Michael L. Tushman and William L. Moore (HarperBusiness, 1988).

46 See for example, Paul R. Lawrence and Jay W. Lorsch, *Organization and Environment: Managing Differentiation and Integration* (Boston: Harvard University, 1967).; James D. Thompson, *Organizations in Action* (New York: McGraw-Hill, 1967).; see also Gerald R. Salancik and Jeffrey Pfeffer, "Who Gets Power – and How They Hold onto It: A Strategic Contingency Model of Power." *Organizational Dynamics* 5 (1981): 3-21.

47 As described in Section IV.5. of this paper, because most innovation projects take place across the boundaries of traditional disciplines, project leaders must be able to manage across these boundaries to integrate the needs of many, sometimes competing, stakeholders including internal manufacturing, marketing, engineering, and policy as well as external customers, consumers, regulators, suppliers, channel partners, lenders, and investors.

48 HP Carbon Footprint Calculator, available at http://h71028.www7.hp.com//enterprise/us/en/solutions/hp-carbon-footprint-calculator.html.

49 David Lawrence, "Leading Discontinuous Change," in *Navigating Change*, ed. Donald Hambrick, David Nadler, and Michael Tushman (Harvard Business School Press, 1998), 302.

50 For a broad and deep review of the literature on customer adoption decisions and patterns, see Everett M. Rogers, *The Diffusion of Innovations* (New York: Free Press, 1995).

51 Early in the emergence of new technology platforms, considerable uncertainty surrounds these decisions. Adopting the wrong technology, or even the right technology but the wrong materials and configurations, can be extremely expensive and time-consuming if it fails to perform as promised. Additionally, in this study, uncertainty derived from concerns over evolving market standards (i.e., which technology becomes the market standard will determine commitments from suppliers, competitors, customers, and consumers; investments in building capacity at all levels of the supply chain; continued advances in materials, configurations, and manufacturing; and performance improvements through use).

52 For a brief discussion on the role of user-centered design in the innovation process, see Tim Brown, "Design Thinking," *Harvard Business Review* (June 2008).

53 Additional uncertainties that a customer considers include supply chain risk. Integrating a particular innovation into original equipment or into business processes will succeed or fail only if the innovating supplier is able to meet and maintain the demands of the customer around product performance, cost and reliability. The uncertainty is around the ability of the vendor to manufacture product, or deliver a service, at the scale and with the reliability that the customer depends on, and to do so over the product's or service's projected lifecycle (or financing period or warranted life).

54 The surveyed companies, with their long interactions with the customers and markets they serve, were primarily driven by solving the needs of the particular markets they knew well, rather than developing new technologies first and then searching for places to apply them: 91 percent of the companies surveyed said they developed new technologies to serve particular markets while only 9 percent (two respondents) said they developed a technology first, then went looking for markets to apply them.

55 "Waste Management Adds 1000th Natural Gas Truck to Fleet," *World CNG,* July 15, 2011.

56 Maribeth Malloy, Cathy Snyder, and Greg Caplan (Lockheed Martin Company), interview by Center staff, June 2011.

57 For more information about this technology, see Lockheed Martin Corporation, *Next Generation Ocean Thermal Energy Conversion (OTEC): A White Paper Prepared for Alternative Energy Decision Makers* (Lockheed Martin Corporation, 2011).

58 Lockheed Martin Corporation, *Ocean Thermal Energy Conversion: Renewable and Stable Power for Energy Needs of Today and Tomorrow* (Lockheed Martin Corporation); "Lockheed Martin Looks to the Ocean as Global Energy Source" *The Monitor*, 5, no. 1, (2009); "Lockheed Martin Awards JI Contract on Ocean Thermal Energy Conversion Project," *Janicki Industries*, August 12, 2010, http://www.janicki.com/lockheed-martin-awards-janicki-industries-contract-on-ocean-thermal-energy-conversion-project; "Aloha, OTEC Heat Exchangers," *Lockheed Martin Corporation,* accessed September 6, 2011; "How–OTEC," Lockheed Martin video, 3:51, accessed September 6, 2011, http://www.lockheedmartin.com/how/stories/otec_player.html; "Ocean Thermal Energy Conversion (OTEC)," Lockheed Martin Corporation, accessed September 6, 2011; "Harnessing Ocean Power," Lockheed Martin Corporation, accessed September 7, 2011.

59 If the only business model available to commercialize solar and wind power is to supply utility-scale power, these emergent technologies must compete with incumbent energy sources like coal and natural gas solely on cost and reliability (price per kilowatt-hour). Similarly, biofuels must compete with gasoline directly on cost and availability, and energy efficiency investments must compete with inexpensive grid-distributed energy, directly on cost. Subsidies may change the relative costs of these competing technologies, but do not change the overall rules of the game, leaving the only advances heavily dependent on cost reductions.

60 Nexus work also enabled project teams, and entire companies, to raise the level at which solutions could be developed. For example, solutions for meeting emission requirements, when measured at the level of the diesel engine, are more limited than when changes involve the entire powertrain, cab design, cab and trailer combination, and even driver training and monitoring. Daimler found that driver behavior alone may be responsible for 30 percent of experienced efficiencies in its Cascadia truck.

61 Elizabeth Long Lingo and Siobhán O'Mahony, "Nexus Work: Brokerage on Creative Projects," *Administrative Science Quarterly* 55 (2010): 47–81. For a discussion of the work of building effective networks inside organizations, see David Krackhardt and Jeffrey R. Hanson, "Informal Networks: The Company Behind the Chart," *Harvard Business Review* (1993).

62 See Eric Leifer, *Actors as Observers: A Theory of Skill in Social Relationships* (New York: Garland, 1991). and Robert G. Eccles, Nitin Nohria, and James D. Berkley, *Beyond the Hype: Rediscovering the Essence of Management* (Watertown, MA: Harvard Business School Press,1992). The notion of robust strategic actions was also used to explain the rise to power of the Medici family in Florence. See John F. Padgett and Christopher K. Ansell, "Robust Action and the Rise of the Medici, 1400-1434," *American Journal of Sociology* 98, no. 6 (1993): 1259-1319.

63 Robust innovation strategies pursued by large corporations differ markedly from the strategies of smaller, less established firms. Startups in particular live or die by the success (or failure) of a single technical choice. That strategy is unlikely to work with low-carbon innovations, where such innovations are often associated with major infrastructure investments—and may be just one element of larger systems. As a result, it is rare for an individual technology or company to drive changes in mature markets with complex, interdependent business and technical systems already in place.

64 Kevin Leahy and David Mohler (Duke Energy), interview by author, July 2011.

65 This partnering model happens frequently in the pharmaceutical industry, where the investments required to move a promising drug through clinical trials are prohibitively expensive to small companies.

66 Partnering between large corporations frequently happens, and such partnerships helped mitigate risk for any one partner. In the companies studied, however, there was little discussion of such joint ventures and their role in driving low-carbon innovation.

67 For more information, see "Empire State Building," Johnson Controls, http://www.johnsoncontrols.com/publish/us/en/products/building_efficiency/esb.html.

68 Minh Le, "New GE Plant to Produce Thin Film PV Solar Panels Based on NREL Technology," *U.S. Department of Energy*, April 22, 2011, accessed May 20, 2011.

69 Cassandra Sweet, "GE Announces Investment In Solar-Thermal Company eSolar," *The Wall Street Journal*, June 7, 2011, http://online.wsj.com/article/SB10001424052702304432304576370462182476244.html.

CASE STUDIES

CASE STUDY: ALSTOM SA

CASE STUDY	ALSTOM SA Innovating Infrastructure: Reducing Carbon Emissions in Power Generation and Transportation
Headquarters:	Levallois-Perret, France
Industry:	Diversified Machinery
CEO:	Patrick Kron
Revenues (2010):	$26.8 billion
Average Annual R&D Spend:	€700 million ($991.4 million)
Employees:	96,000
Keys to Success:	• Nexus Work • Robust Innovation Strategies
Low-Carbon Innovations:	• **Supercritical and Ultrasupercritical Steam Power Plants** Alstom is developing the next generations of supercritical and ultrasupercritical steam power plants, which by operating at higher steam temperatures (540°C to 600°C and ≥ 600°C, respectively) than traditional subcritical boilers (≤ 540°C) will increase fuel and thermodynamic efficiency (alternatively "electric generating efficiency"). Boilers operating at subcritical temperatures have an average plant efficiency of approximately 34 to 37 percent; newer supercritical plants achieve approximately 37 to 41 percent efficiencies; and advanced ultrasupercritical plants promise to achieve 43 to 47 percent efficiency by 2020. These efficiencies reduce both the amount of fuel needed and carbon dioxide (CO_2) emissions over the lifetime of the plant: A supercritical boiler with 37 percent plant efficiency emits 8 percent less CO_2, and a plant that achieves 41 percent efficiency emits 17 percent less CO_2 than traditional subcritical power plants. • **High-Speed Rail** Alstom Transport is one of the leading manufacturers of high-speed rail (HSR) rolling stock (locomotives, railroad cars, coaches) and power systems. Alstom Transport offers the complete range of HSR products, including rolling stock, infrastructures, information systems, services and turnkey solutions that make up an HSR system. Prior generations of Alstom's TGV high-speed rolling stock system have been used in Europe for more than 30 years and the company has sold more than 670 high-speed trains worldwide. Today's HSR solutions emit 20 to 25 percent of the CO_2 of automobile and air travel, per passenger mile, and compete effectively for passenger business against both modes in the 200 to 500 mile range.

While replacing fossil fuel-based technologies with zero-carbon alternatives represents the best long-term path for significantly reducing greenhouse gas (GHG) emissions, opportunities for low-carbon innovations that improve existing and widely used products and processes can help reduce GHG emissions today. The electric power and transportation sectors represent two of the largest industries most affected by climate change policies, energy prices, and related forces shaping market risks and opportunities. The International Energy Agency (IEA) projects that, by 2030, global electricity demand will almost double and the transportation sector will grow by nearly 50 percent, corresponding to a roughly equal increase in the markets for energy generation and transportation capacity. Existing technologies are expected to play the dominant role in meeting that demand for capacity and, as a result, global dependence on fossil fuels for electric power generation and transportation will remain practically unchanged.[1]

In electricity generation, this demand is expected to outpace the introduction of low-carbon energy sources such as wind, solar, nuclear, and hydroelectric power and, particularly in developing economies, is driving the construction of new coal- and natural gas-fueled power plants. Net electricity generation from these two fuels is expected to grow 61 percent by 2030[2] and remain the dominant source (41 percent) of global CO_2 emissions over that time period. Increasing the efficiency of the power plants being brought on line in the next two decades represents both the most immediate opportunity for low-carbon innovations, and for meaningfully reducing global GHG emissions. In the face of coal's persistent global dominance as a fuel source, experts recognize that "a cost effective and readily available option to reduce CO_2 emissions per unit of electricity generated is to increase the generating plant's efficiency, so that less coal is burned per MWh [megawatt-hour] generated."[3]

In transportation, increases in personal travel will be the primary driver of rising energy use. Personal and commercial transportation is responsible for 27 percent of global energy demand and roughly 22 percent of total CO_2 emissions.[4] As with electricity generation, increasing demand for transportation creates similar needs (and opportunities) for low-carbon innovations as new capacity comes on line over the next two decades. Passenger rail represents a significant opportunity to meet this growing demand in a low-carbon way.

In these two established and mature markets, opportunities for low-carbon innovation over the next two to three decades will largely exist in incremental product and process innovations—those that improve the value of an existing product or increase the efficiency of its delivery. These innovations can be brought to market either through individual companies or through the construction of new networks of organizations, each providing complementary elements of the solution.

Alstom's efforts to increase the efficiency of coal-fueled power plants and to develop advanced high-speed rail systems provide unique insights into the challenges and opportunities of developing and marketing such low-carbon innovations. Both sectors are characterized by high capital costs, long asset life cycles and, once in place, high reliability requirements and operating costs relative to revenues. These special conditions bring unique innovation challenges.

COMPANY PROFILE

Alstom's history, dating back to 1928, is that of "an industrial and technological adventure which has continually carried the Group towards excellence."[5] Today, Alstom Power engineers, manufactures, and constructs power plants and their various components, including boilers, turbines, generators, and auxiliary equipment. Close to 25 percent of the world's electric power generation capacity relies on Alstom technology and services. Alstom Transport develops and markets the most complete range of systems, equipment, and services in the railway sector, including record-breaking very high-speed rail (reaching 357 miles per hour (mph)). Headquartered in Levallois-Perret, France, Alstom has more than 96,000 employees in over 70 countries. Sales in Fiscal 2010 totaled nearly €21 billion ($29.8 billion), of which Alstom Power represented €11.7 billion ($16.6 billion) and Alstom Transport €5.6 billion ($7.9 billion).

In response to (and to some degree in anticipation of) the demand for deep reductions in fossil fuel carbon emissions, Alstom has devoted considerable resources to pioneering alternative, and specifically low-carbon, energy solutions. The company spent €700 million ($993.2 million) on research and development (R&D) in 2010 and expects to continue this high level of investment, focusing on key low-carbon technologies in Alstom's Power Sector business (carbon capture and storage, renewables), in its Transport Sector (new very high-speed rail platform, products for developing countries), and its Grid business (ultra high voltage and smart grids).[6]

The main drivers of Alstom's focus on the environment come from a combination of market forces—customers defining the environmental solutions they need today and in the future; the broader societal mandate for all companies to behave in a responsible fashion towards the environment; and, in some countries, regulatory mandates to reduce carbon emissions. This focus is evidenced by actions and energy solutions rolled out over the last decade, including Alstom's $130 million investment in solar power company BrightSource Energy and joint construction of the 392 megawatt (MW) Ivanpah project in California's Mojave Desert—the world's largest solar power plant under construction today. Alstom is also conducting numerous development projects leveraging its proven technologies in wind turbines, transmission and distribution technologies, hydropower, and nuclear energy. Alstom publicly supports smart international climate and energy policy that would stabilize and reduce GHG emissions, and promote additional investment in low-carbon innovations.

Alstom is also working to improve the efficiency, and reduce the emissions, of existing technologies in power generation and in rail transport. To understand the immense challenges and practices driving low-carbon innovation in entrenched infrastructures, this case study looks particularly at two of Alstom's efforts to advance new technologies: Alstom Power's supercritical and ultrasupercritical power plant boilers, and Alstom Transport's development of high-speed rail systems, particularly in the United States.

SUPERCRITICAL AND ULTRASUPERCRITICAL STEAM POWER PLANTS

Global electricity demand is expected to nearly double by 2030, and the share of fossil fuels in electricity generation is projected to remain unchanged over that time, with the fastest growth in fuel sources through 2035 likely to be in coal and natural gas, largely in Asia. Coal currently accounts for approximately 42 percent of electricity generation worldwide (and a roughly equivalent share of global CO_2 emissions, at 12.6 gigatons (Gt)); natural gas accounts for approximately 20 percent of generation and of global emissions (5.8 Gt). In 2030, CO_2 emissions from coal and natural gas are expected to increase proportionately to 18.6 Gt and 8.0 Gt, respectively.[7] Given such trends, there is significant need, and opportunity, in the very near term for improving efficiencies and reducing emissions from these fossil fuel-based technologies.

The history of modern steam turbine development reflects the relentless pursuit of efficiency. Efficiency gains have been made by increasing the temperature and pressure of steam as it exits the boiler and enters the turbine, by improving blade aerodynamics, and by optimizing and integrating other power plant components for the fuel characteristics and power demands of a specific location (see Sidebar: The Evolution of the Steam Turbine, next page).

Over the last several decades, Alstom has developed new generations of supercritical (SC) and ultrasupercritical (USC) steam power plants. These plants increase fuel and thermodynamic efficiency (alternatively "electric generating efficiency") by operating boilers at higher steam temperatures (540°C to 600°C and ≥ 600°C, respectively) than traditional subcritical boilers (≤ 540°C). Boilers operating at subcritical temperatures have an average plant efficiency of 34 to 37 percent; newer SC plants achieve approximately 37 to 41 percent efficiencies; and advanced USC plants promise to achieve 43 to 47 percent efficiencies by 2020. These efficiencies reduce the amount of fuel needed and CO_2 emissions over the lifetime of the plant: A supercritical boiler with 37 percent plant efficiency emits 8 percent less CO_2, and a plant that achieves 41 percent efficiency emits 17 percent less CO_2 (**Figure 1**).[11] Put another way, compared to an average 500 MW coal plant in the United States emitting 2.72 million metric tons of CO_2 per year, a supercritical plant operating at 44 percent efficiency would produce 1.77 million metric tons CO_2, reducing emissions by 952,000 metric tons annually. The equivalent of five hundred 500 MW coal plants now operate in the United States alone. So switching to SC and USC technology could slash emissions by hundreds of millions of tons per year. In fact, the possible reductions in carbon emissions from SC and USC boiler designs between now and 2030 may rival the reductions that can be achieved from renewable energy sources.

Moving forward, the opportunity for plant efficiencies through the adoption of such technologies will continue to grow. Most of the projected growth in generating capacity will take place in developing economies, where demand is growing rapidly and renewable energy sources will not stem the growing consumption of coal

The Evolution of the Steam Turbine

Steam turbines are mechanical devices that convert the thermal energy in pressurized steam into rotary motion that drives electricity generators. Fuel heats a boiler, producing steam that powers a turbine, which turns a generator to produce electricity.

The modern steam turbine was first introduced in 1884 by Sir Charles Parson and has since driven the direction of innovation in the electric power industry. Parson's first model powered a dynamo (electric generator) that produced 7.5 kilowatt (kW) of electricity. It was only 1.6 percent efficient, yet it quickly replaced the piston-driven steam engine for electricity generation.[8] Within a decade, Parson built a 1 MW turbine with approximately 5 percent fuel efficiency. Within another decade, Parson produced a 25 MW turbine that was 25 percent efficient. And by the 1950s, steam turbines were capable of producing 1 gigawatt and reaching efficiencies approaching 40 percent.[9]

Since Parson's steam turbine arrived at the beginning of the modern electric industry, power generation (with the exception of hydropower) grew up around and depends upon it. The steam turbine today produces approximately 80 percent of the world's electricity and relies on a mix of fuel sources (approximately 40 percent coal, 20 percent natural gas and 20 percent nuclear).

The original pace of innovation—in which the efficiency of steam turbines increased fifteen fold within two decades—is no longer possible, and improvements in the steam turbine today are hard won. Because the efficiency of steam turbines ultimately depends on the temperature difference between the steam entering and exiting the turbine, increasing temperatures remains the predominant means for increasing efficiencies.[10]

Due to the high capital costs of building power plants, along with the plants' long asset life cycles and high operating costs, small changes in efficiency (including in operational "uptime"—the percentage of time that the plant is in a condition to function) can spell the difference between profitable and unprofitable operations.

and the corresponding increase in CO_2 emissions. And while carbon capture and storage (see Sidebar: Carbon Capture and Storage, page 52) promises to be a highly-effective means to dramatically reduce GHG emissions from coal-fired power plants, it is not expected to be commercially available until 2015 at the earliest (pending the construction and operation of demonstration projects, and the needed support of climate and energy public policies).

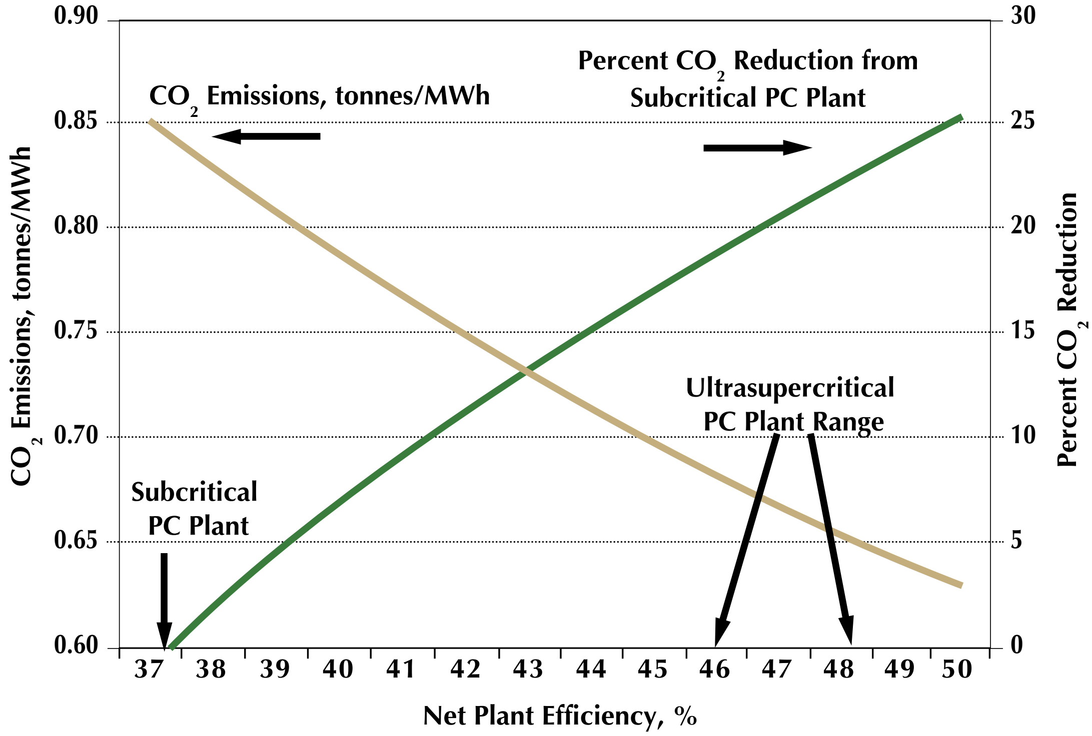
Alstom is seeking to pursue this growing demand from emerging markets, while activity in developed economies remains sluggish. This geographic shift in markets opens up "a new business phase" for the company.[17] In fact, 60 percent of the post-recession rebound in Alstom's customer orders for Fiscal 2010–2011 came from emerging markets, rising in just one year from 35 percent.[18]

To capitalize on this opportunity, Alstom must overcome a range of challenges in developing SC and USC power plants. First, the higher temperatures and pressures associated with SC and USC plants increase material corrosion in the boilers and turbines. That requires developing and testing more advanced materials, particularly new nickel alloys for boilers and steam turbines. These advances represent incremental product innovations and create a potential demand for radical materials and manufacturing process innovations by Alstom's suppliers.

Second, these innovations represent significant changes to power plant design. Customers, rightly concerned that new plants meet current standards for reliability and generating efficiencies, want to see these new materials and operational changes demonstrated at scale before contracting for their own plants. Because these plants represent hundreds of millions of dollars in capital costs, this creates the challenge of finding a first customer willing to make the commitment.

Third, such innovations must aim at markets that are three to five years out (at the earliest) and also ensure operational profitability for the next 40 or more years. As a result, projects often have long lead times. As John Marion, Director of Alstom Power's Boiler Research

FIGURE 1: Power Plant CO_2 Emissions vs. Efficiency



Note: PC = pulverized coal

Source: Booras and Holt (2004).

and Development, explains: "[Delivery of] a gas turbine combined-cycle [power plant] is under three years from the day that you place an order with any [manufacturer]. It's basically three years before you can flip the switch and make money. [Lead time for] a coal-fired plant is four to five years." Truly novel advances in the design of these technologies can require demonstration units to be built and deployed, which can add another three to five years to that schedule.

Fourth, power plant operators are reluctant to adopt a new technology that does not have the consensus validation of the largest players in the industry. In other words, in the power sector, a large-scale technological advance needs to be supported by Alstom and other power plant manufacturers before customers will consider adopting it. Company R&D engineers may identify and develop novel technologies, but the engineers must also work closely within industry associations to ensure that they and others in the field are moving in the same direction. Once the industry has decided on a consensus direction, individual companies can find ways to compete by offering their own variations of the same basic technological approach.

Within this context, Alstom continues to advance the development of SC and USC power plants. Today the company has 113 directly executed supercritical units in operation or under construction, representing 73,600 MW of direct worldwide SC capacity.

HIGH-SPEED RAIL

With transportation projected to increase globally by 45 percent by 2030,[19] passenger rail transport in general (and high-speed rail in particular) represents a

Carbon Capture and Storage

Carbon capture and storage (CCS) promises to be a highly-effective means to dramatically reduce GHG emissions from coal-fired power plants in the longer term. CCS describes a combination of technologies and a process for capturing CO_2 emissions from large sources (particularly fossil-fueled power plants) and then permanently storing (or sequestering) the captured CO_2, typically by injecting it into geological formations deep underground so that it does not enter the atmosphere. When deployed, CCS technology has the potential to reduce CO_2 emissions from a coal-fueled power plant by as much as 90 percent.[12]

While the component technologies—CO_2 capture, transport, and storage—are currently used at industrial scale for a variety of applications, CCS has not yet been deployed at a commercial-scale power plant and is not expected to be commercially available until 2015 at the earliest.[13] Governments around the world are funding large-scale CCS demonstration projects, including commercial-scale deployment of CCS at coal-fueled power plants.[14]

Deploying CCS at power plants requires substantial incremental capital investments and raises operating costs. The key driver behind any future widespread deployment of CCS technologies will be government policies to reduce CO_2 emissions to combat climate change. According to the IEA, if countries adopt policies to substantially reduce global CO_2 emissions, CCS could provide one-fifth of global CO_2 emission reductions from the power sector by 2035.[15] Government policies that place a cost on GHG emissions, or that otherwise limit GHG emissions, are crucial to spur CCS deployment.

The economic viability of CCS also depends on overcoming technical challenges and increasing the efficiencies of coal-based power generation to offset the additional energy costs of operating CCS equipment. Further, a more efficient plant would require less coal use for a given electricity output, thereby reducing the need for auxiliary equipment such as coal handling and emission control systems.[16]

To be truly cost-effective, CCS systems would be fully integrated into new power plant designs and construction. It is relatively more expensive to retrofit facilities. Yet before such a commitment by customers, new CCS systems must be adequately demonstrated (developed, constructed, and operated at capacity), which can cost over $500 million per project and require four to five years. Once CCS has been demonstrated sufficiently, a new plant equipped with CCS would require an additional four to five years before becoming operational. Government support for “first mover” CCS projects is crucial for bringing CCS technologies online at a more rapid pace.

Staying on the forefront of this market, Alstom is focusing special attention on what it believes are the two most promising CCS technologies: Oxyfuel Carbon Capture (which requires combustion of coal in nearly pure oxygen, rather than air, to facilitate CO_2 capture) and Post-Combustion Capture (which uses chemical solvents to separate CO_2 from the flue gas at a pulverized coal plant). It is the company’s belief that, when developed, these two approaches will be the most economically viable and sustainable solutions for new plants and be comparatively straightforward and economical to retrofit on existing power plants. Alstom is currently piloting and validating these technologies with partners in Germany, France, Norway, Sweden, and the United States.

lower-carbon alternative to the automobile and airplane. Despite its success in some markets, high-speed rail remains challenging to deploy because it is so expensive and can’t be accomplished without a complex collection of private and public sector partners working together. The uncertainty that surrounds its accomplishment and subsequent profitability for rail system operators renders HSR today a radical innovation, in the sense that each new project in each new market involves new partnerships, new customers, and the latest technologies.

The global market opportunities for high-speed rail are significant. By 2020, 4.5 billion people, 60 percent of the world’s population, are expected to be living in cities. This urbanization is creating “megacities” (comprised of city centers surrounded by large suburbs and with populations greater than ten million) and the need for many people to travel quickly and reliably between them (see Sidebar: High-speed, Commuter, and Urban Rail Markets, this page). Across all geographic regions, it is estimated that countries will invest up to $824 billion in the next ten years on new rail infrastructure construction, and an additional $76 billion on rolling stock.[20] In the United States, the Obama Administration in 2008 proposed the construction of nine HSR lines, backing that proposal with $9 billion in government support. The U.S. Government Accountability Office (GAO) has estimated that by 2025, these lines, if built, would account for more than 25 billion passenger miles annually.

Alstom Transport is well positioned to pursue high-speed rail opportunities. Alstom is one of the leading manufacturers of HSR rolling stock (locomotives, railroad cars, coaches) and power systems, and has been bringing HSR to the global market for the last 30 years. Alstom Transport is present in over 60 countries, employs some 27,000 people, and last year recorded sales of a5.6 billion, despite the challenging economic environment.[22] It is the only manufacturer in the world to offer the complete range of HSR products including rolling stock, infrastructures, information systems, services, and turnkey solutions that make up an HSR system. Alstom's TGV high-speed rolling stock system has been used in Europe for more than 30 years and the company has sold more than 670 high-speed trains worldwide. In 2007, Alstom equipment set the world very high-speed rail record of 357 mph.

Despite its promise, high-speed rail in the United States faces significant challenges. Much of the political and economic uncertainty around HSR stems from the original divergence between the laissez-faire approach to managing rail networks adopted by England and the United States in the 1830s, and the more "top-down" management approach taken by continental Europe and Asia (see Sidebar: The Co-Evolution of Railroads and Rail Policy, next page). Without a history of, and precedents for, state-sponsored investments in railway construction and operation, the United States faces considerable challenges in finding and directing the necessary public funds to make HSR a broadly diffused reality. Established private interests stand to gain little by HSR relative to the initial rail connections offered in the 1800s (indeed, airlines often actively resist HSR proposals), and estimated revenues from passenger travel are difficult to anticipate. As the U.S. GAO explains:

> "While some U.S. corridors have characteristics that suggest economic viability, uncertainty associated with rider and cost estimations and the valuation of public benefits makes it difficult to make such determinations on individual proposals. Research on rider and cost has shown they are often optimistic and the extent that U.S. sponsors quantify and value public benefits vary."

Political uncertainty is reflected in the recent decision by Florida's Governor to forego $1.2 billion in federal funds to construct a high-speed rail between the cities of Tampa and Orlando (with a future extension to Miami), based on concerns of state obligations to pay for project cost overruns and ongoing operating losses. As evidenced by Florida's decision, long-term profitability of operations and the role of government are critical uncertainties to be faced by the public and private

High-speed, Commuter, and Urban Rail Markets

Passenger rail technologies comprise local rail (commuter and metro), serving commuters traveling *within* cities and their surroundings and typically displacing automobile traffic, and high-speed rail, which provides travel *between* major cities. HSR achieves speeds of 250 kilometers per hour (155 mph) or higher and competes most directly with short-hop airplane and long-distance automobile travel. The technology emerged in Europe and Japan in the late 1960s. Now, approximately 8,000 miles of HSR lines are in operation worldwide. China leads with 2,800 miles. Spain, France and Japan each have around 1,200 miles. Germany has 800 miles, Italy has 577, and the United States has 226.

HSR is most competitive with travel alternatives on distances of 200 to 500 miles, and has proved itself in Europe and Asia. For example, the introduction of the Madrid-Barcelona HSR line in 2008 reduced air travel between the two cities by an estimated 30 percent (from 5.0 million to 3.5 million air passengers). In France, HSR captured 90 percent of the Paris-Lyon combined air and rail traffic.[21]

The Co-Evolution of Railroads and Rail Policy

In 1830, steam-powered locomotives carried the first rail passengers on the new Liverpool and Manchester Railway (L&MR). Within the next two decades, railways would rapidly expand across the United Kingdom, United States, and Europe.

Two opposing principles quickly emerged that still organize today's rail technologies and opportunities in different markets. In Britain and the United States, individual rail lines were built based on local, private economic interests and resulted in largely unplanned and fragmented networks. The original lines were built where freight traffic already existed. On the European continent and later in Asia, however, rail networks were championed by the state to pursue social (e.g., economic development) and state (e.g., military) interests.[23] A century and a half later, these different organizing principles continue to influence the evolution of rail transportation technology.

As historian Christian Wolmar describes: "The British method, which was also adopted in the United States, was more organic, a bottom-up process driven largely by the obvious economic benefits to local towns and cities of better transportation connections … Right from the beginning, European governments on the Continent were aware that the railways were such an important part of their country's [sic] infrastructure, and would play such a vital role in economic development, that the states had to be involved."

The U.S. and UK initial "laissez-faire" approaches to railroad construction and operation allowed for greater experimentation, but often resulted in less efficient rail networks. The European nations, which pursued more centrally-planned and funded initiatives, tended to design more rational rail networks, though often with less profitable ongoing operations.

organizations investing in the construction, maintenance, and operation of a rail system.

Meanwhile, Europe and Asia continue to grow their HSR networks and Alstom's innovations in high-speed rail continue to focus on increasing the profitability of operations for its customers. Early commercial success within a region influences the diffusion of HSR: The more profitable the operation becomes, the larger the market for it grows. This profitability is best achieved by providing rolling stock with increased energy efficiency and increased reliability (so there is more "uptime," or time in use, compared to time in maintenance). Alstom has responded with innovations that improve both. The company has pioneered new technologies in distributed power and magnetics that make their trains lighter and allow them to move using less energy than ever before. It has also pioneered the use of lightweight composite materials to further reduce the mass of train cars. And it has designed these cars to be more aerodynamic, resulting in less drag and less noise.

For personal transportation, rail travel represents a significant opportunity to reduce global carbon emissions. High-speed rail emits 20 to 25 percent of the CO_2 of comparable automobile and air travel on a per passenger mile basis. Building such rail systems in the United States would thus result, by GAO estimates, in 29 million fewer automobile trips and 500,000 fewer flights, for an annual CO_2 emissions savings of 2.7 million metric tons.[24] As global demand for transportation grows, high-speed rail will be pursued for both economic and environmental objectives. Those companies engaging in the market today gain the capabilities and experience necessary to remain competitive in the future.

MANAGING LOW-CARBON INNOVATION

At Alstom, innovations advancing both HSR and more efficient power generation promise to make significant contributions to reducing global carbon emissions. Alstom's efforts illustrate a range of critical capabilities (activities and competencies) that companies in these markets must develop in order to innovate effectively. In Alstom's case, two capabilities stand out in stark relief: the ability to pursue robust innovation strategies and active engagement in nexus work.

Nexus Work

Nexus work lies at the heart of network-level innovations. Nexus work involves seeing, building, and maintaining the set of interdependent relationships that make up complex systems like high-speed rail. Network-level innovations represent functioning systems that deliver products and services (most often in combination) through a set of independent but tightly linked organizations. The organizations involved can be large and small, public and private, or for profit and non-profit. Each organization is necessary but not sufficient to ensure the performance of the larger system. The success of HSR, for example, has less to do with individual technical advances than with the alignment of public and private partners in ways that are economically and politically effective.

Nexus work lies at the core of Alstom's innovation efforts. It requires people who can comfortably understand and engage with other organizations, ultimately shaping their own company's participation in emerging "networks" of innovation and negotiating successfully with partners despite the almost certain presence of conflicting interests. One Alstom executive described the role of nexus work:

> "As you stop vertically integrating your business and try [to] be master of all trades, you get involved in more complex, broad-reaching, government-involved projects, [and] no one company can do it all. You need to rely on other people to do things well in their particular areas. Our ability to bring those people together and manage that [collaboration] is a key piece of our success."

Nowhere is the need for this nexus work more evident, and necessary, as in the work of Alstom Power and Alstom Transport to bring low-carbon solutions to customers in these industries.

Perhaps not surprisingly, the challenges for nexus work in HSR today would be familiar to the private developers and national planners of railways almost two hundred years ago: raising sufficient capital, obtaining land rights, bringing together diverse public and private parties in a common venture, and building an infrastructure that would enable a railway to operate profitably over decades. HSR systems are complex enterprises involving many different elements and players, including land rights and environmental impacts, infrastructure (bridge and tunnel works, track), stations, rolling stock (locomotives, carriages), operations, signaling systems, maintenance systems, financing, marketing procedures, management, and legal and policy issues. "If there is a [growing] demand for high-speed rail, who can step up to meet it?" asks Guillaume Mehlman, Managing Director for Alstom Transport in the United States. "It's not within the scope of a single big business. We're talking about partnerships between multiple businesses and state and federal partners."

Similar challenges exist for low-carbon innovations in power plants—even when advances take on the appearance of straightforward product or process innovations. Without industry-wide support for a particular technical innovation—including from competitors—it is unlikely to gain acceptance in the market. So even new product and process innovations require skilled nexus work from Alstom engineers to ensure they gain acceptance. As one Alstom Power executive explained: "There are industry standards and then there is the science that establishes those standards. In the science that establishes them you need your best people, [and] in the industry standards you also need your best people." Without creating and carefully building these systems to ensure each element performs well (and profitably), the system as a whole will not remain profitable and reliable for the 30 to 40 years it is expected to operate. Scott Sherin, Vice President of U.S. Business Development for Alstom Transport, recognizes the critical role that nexus work plays in piecing these elements together:

> "The fact is, you need to have people who are able to be part of their consortia with Virgin Trains [operating company] and VINCI [infrastructure construction and maintenance] and actually be good partners and manage [those relationships] and keep your interests associated and represented the whole way... It's a huge issue. It is, in my opinion, a required core competency of companies."

Such nexus work spans a wide range of capabilities from intensely technical to the almost purely political. At the technical level, Guillaume Mehlman explains, "everything that we do is an integration. Even…a train, you see a single stand-alone thing on wheels, but it is multiple sub-systems that all need to get integrated." Similarly, the competence in building technical systems drives innovation in power plants. John Marion, head of Alstom Power's Boiler R&D, identifies Alstom's competitive advantage as not just in individual technologies but also in understanding how those elements can work together in the most efficient and reliable way. The key, he says, is "the know-how we developed as a power company around the individual elements, and the way they fit together and work together as a larger system." The technical work is not done merely inside the organization. In fact, in many cases, technical advances must be shared across the industry in order for customers to achieve a degree of confidence in the results. This entails working with competitors to establish new standards around emerging innovations, Marion says:

> "You don't have influence if you don't have experts in the field (technologies and technology communities) engaged with other experts. It's the entire technology management proposition. You may need lobbyists in D.C. [working with government] but it is also important to engage at the industry level and to try to move the field in a different direction—the field has to move in the [same] direction before anybody cares to support you to do it."

Beyond the technical aspects, the ability to manage partnerships across organizations to develop, construct, operate, and maintain HSR is equally critical. Alstom's recent proposal for an HSR system in Florida, though prematurely denied, offers a good illustration of the many different partners involved in putting together a viable solution, and the challenges associated with managing the partners' diversity of interests. As Guillaume Mehlman describes of this project team:

> "Our team is Alstom [specializing in the manufacture of rolling stock and power equipment], Virgin Rail [specializing in the operation of railways] and VINCI [specializing in the construction and maintenance of transport infrastructure]. It was the first fully-implemented rail concession ever done in North America where you actually had an equity consortium stepping up and saying 'I'm going to build this, I'm going to put my own money at risk, I'm going to operate this,' and we're business people making a business decision on how to get this up and running."

The history these partners share also plays a role in their willingness to work together and in the level of comfort they share in entering such networks, says Mehlman:

> "Our team has all worked together. Everybody on the team has at least one or two relationships or prior contracts working together somewhere around the world. In the UK we supplied the rolling stock and Virgin runs and operates the trains. They took an ailing rail system and doubled ridership in around seven years, from six or seven million people to 12 million people a year."

Developing and maintaining these partnerships is critical as Alstom adapts its presence in key geographic markets. To seize expected growth opportunities in developing countries, Alstom plans to build up its industrial footprint and strategic partnerships to meet expected demand in Brazil, Russia, India, and China (the "BRIC" countries), while making capacity adjustment plans in Europe and North America.[25] Alstom initiated several partnerships in 2010 in Russia, India, and China, and announced its intention to create a joint venture with Shanghai Electric to become the world leader in boilers for coal-fired power plants. Alstom also spent over €500 million ($719.5 million) in capital to upgrade its existing footprint and to launch new investments in the BRIC countries.

Beyond the organizational partnerships, putting together capital-intensive projects like HSR requires public and private financing partnerships as well as strong partnerships with federal and state agencies. HSR can cost between $22 million per mile and $132 million per mile (depending, in part, on the value of the properties lying in the proposed corridor), with total project costs running in the range of $6 to $24 billion.[26] Similarly, electric power plant project costs range from approximately $1 per watt (natural gas combined-cycle, "NGCC") to $2 per watt (NGCC with CCS) to $3 per watt (coal-based generation) to $5 per watt (coal with CCS)—equating to typical project capital costs of $300 million to $1 billion.[27] Financing terms on such projects will determine profitability, so the ability to deal effectively with financial partners is crucial. Similarly, Alstom must work closely with public agencies to understand and manage land use rights and environmental impacts. As Scott Sherin explains: "There are a whole host of things that need to get done…before you can actually get into the work of building a line... [Alstom's] influence is kind of limited because it is a lot about politics and local stakeholders," as evidenced by the rejection of the project by Florida's state government.

Finally, nexus work is about the people—the individuals involved from Alstom and partnering organizations, industry associations, and public agencies. For companies to effectively participate and lead in moving partnerships and even entire industries toward a particular standard or solution, they must have the credibility of the people they are working with across these networks. In other words, Alstom recognizes the need to assign their best people to the nexus work that brings along their partnerships, says Sherin:

> "You have to [staff standards committees with your best people] because the best people from the other organizations are involved. You're dealing with Oak Ridge National Lab and so forth. If you don't have your best people...nobody has any reason to interact with you. You have to fight for your scope [of expertise], you have to deliver, and it has to reflect in a positive way for the company. One of the difficulties of these [projects] is that they do require your best people."

Alstom's commitment to engaging its best people in the nexus work necessary to build partnerships, described here in HSR and power plant businesses, reflects its recognition that nexus work is crucial to the company's business success and bottom line. It also reflects Alstom's recognition that modern energy systems are complex, highly interdependent systems involving diverse technologies, organizations, and public and private interests.

Robust Innovation Strategies

The notion of robust innovation strategies comes from an insight first generated by Harvard University sociologist Eric Leifer to describe the distinction between chess moves of masters and novices. Leifer found that chess masters did not choose and pursue singular strategies for winning a given game. Instead they chose 'robust' strategies that, at any moment, advanced particular gambits while preserving the flexibility to adapt to the uncertain responses of their opponents. Such robust strategies have been found effective in managing organizations: effective in the conditions of a relatively certain short run, robust action remains adaptive in the face of uncertain and evolving conditions over the long run.

In the highly-competitive environments of energy generation and HSR, Alstom recognizes the dangers of presuming its chosen strategy—or even the best technical solution—will play out as planned. One Alstom Power executive described the company's dependence, for example, on its utility customers: "In our business, if you try to tell an electric utility that they're only going to have it one way, you [the provider] are not going to have anything." In dealing with such large and integrated markets, Alstom's innovation strategy in both Power and Transport is to scan for, learn about, and develop a range of technologies that would, in the short run, advance the company's competitive advantage while, over the long run, also preserve its flexibility in the face of customer, market, and political uncertainty.

Because innovations in power generation and HSR involve complex systems, and their development cycles are long and expensive, a strategy that allows for flexibility is necessary to ensure that Alstom retains its leadership position as the market evolves. Alstom Power pursues a disciplined planning process that includes both a short-term market forecast and a long-term (10 to 30 years) visioning exercise. This long-range planning involves the larger technology community and other external stakeholders, and is important in a sector where R&D may take decades (often waiting for the market need to emerge), demonstration can take another three to five years, and the actual construction process another three years. It is as important to know where the rest of the market is going as it is to know what new technologies might be possible.

Over time, as the company's markets evolved, Alstom has been able to selectively increase its investments in those technologies that the market embraces while putting on hold, or abandoning, those that are no longer relevant. John Marion explains:

> "[The market] can't get off fossil fuel in this century. So that's core to our business, and it's where we're strong... At the same time, we're not completely betting the farm. And we want to have a strong position in other options, so we're the world's leading provider of hydro[power]. We have a nascent position in wind. We have a nascent position in solar. We look at biomass fuel utilization. And we have a strong position in nuclear on all of the components absent the reactor, and a good partnership with firms in this area."

Alstom pursues a robust innovation strategy by pursuing a set of activities that can be divided between *scanning, learning,* and *engaging.*

Scanning. Scanning involves keeping abreast of emerging technologies. As these technologies arise, Alstom devotes discrete resources to quickly exploring their potential. As Marion describes: "In trying to come up with solutions that we envision for the customers' future needs, we are looking at a wide scope of approaches and a wide scope of technology." More directly, he warns: "If you haven't done any homework [on emerging technologies], you have no hope." Working with startup companies provides useful insights into emerging technologies. Alstom is often approached by individual inventors and small technology companies. Alstom's R&D group will evaluate the technologies and determine whether they are worth further analysis. Many of these are enabling technologies, such as new materials that promise superior wear resistance, new combustion processes, new flue gas treatment processes, or new kinds of emissions control processes.

Learning. Within robust innovation strategies, learning activities involve developing enough understanding of promising new technologies to be able to incorporate them into development cycles if it appears that the market is ready for them. When Alstom sees an opportunity, the company is able to bring these technologies into larger systems in ways that the original inventors could not. Entirely new technologies represent opportunities as well. Consider Alstom's process of investigating oxygen membranes (to enhance the performance of combined-cycle power plants): "We heard about oxygen membranes but didn't know a thing about them," explains Marion. "So we identified one of the staff members to go out, look into oxygen membranes, and report [on] what they are, how they work, what could be done—and to do a kind of pre-study…with a hope that as a result…you're going to have ideas."

The first question to ask, in addition to whether a technology works, is whether it fits with Alstom's business strategy: Does it open a new market or enhance an existing business line? At the same time, the company attempts to understand the economics of the technology: Can it make money? From the customer perspective, it is economically attractive? If there is confidence in both the technology and in the economic value to customers, Alstom's R&D team will increase its investments in learning about and gaining a competency with the new technology. As one R&D executive explains:

> "The main reason for doing that is to compare technologies. [For example,] right now we are comparing the oxy-boiler to using chilled ammonia or the advanced amine systems [for CCS technologies] and we are determining which technology looks more economical for site specific conditions and then we look at sensitivities [of the technology to operating conditions]. So [given] a market with certain site and operating conditions, then is one [solution] better than the other?"

Once a value proposition has been established, Alstom budgets for further experiments, which enable its R&D staff to better understand the capabilities and limits of new technologies. At this point, many of these technologies simply sit on the shelf, awaiting the market conditions that will make them valuable to customers. For many of them, the next steps in their development would bring significantly higher costs.

Engaging. Finally, robust innovation strategies involve engaging with practice—in other words, learning by doing. Learning by doing reflects the recognition that considerable technological advances, as well as cost reductions, take place only after a company has engaged with the manufacture and use of its offerings. For Alstom, engaging involves participating in the current markets of any given technology, be it coal or gas combustion power plants, solar and wind, or high-speed rail. Often, these markets are spread across the globe, reflecting engagement in a variety of different conditions.

While Alstom was disappointed by the outcome in Florida, it believes the longer term potential for HSR in the United States remains strong. Meanwhile, Alstom is focusing on pursuing markets most likely to move forward in the relative near term and on making the case to policy makers and the broader public about the benefits of investing in HSR. As Guillaume Mehlman notes:

> "[In] Florida, the teams bringing the technology were all international. There is no U.S. company bringing its own technology—the rolling stock, the signaling and control systems, the know-how around operating and maintaining this type of system… It's just a legacy of not having done it before."

In many cases, the markets for low-carbon innovations have started on a relatively regional basis and migrate around the globe. As Mehlman adds: "You have to follow [a technology] around the world. All of the innovation is happening outside the United States, all the technical innovation, all of the learning by doing, learning by using."

In the 1990s, the European market was driving a lot of the innovation in HSR in power electronics and in the dynamic behavior of trains. This was when and where tilting trains were introduced and developed. All that learning was taking place, Mehlman explains, "in the 1990s as the networks were expanding in Spain, and the Italian high-speed line north-south and France and Germany were extending their networks." Alstom and other companies pursuing low-carbon innovations in such large and complex systems as power and transport recognize the need to be global, he adds:

> "Our investment in low CO_2 technologies could be first commercialized in the United States, but more likely in Europe. It could be in China, could be Brazil... We're looking at global markets and that gives us scope and resources, but it also means that's an advantage. In this game if you're not global you are probably are in trouble. Because somewhere in the world other than where you're located it will probably happen without you."

Thus one of the most crucial pillars of a robust innovation strategy is engagement with the market and understanding the associated political risks. It is not simply the ability to maintain possibilities but also to commit to a particular combination of technologies and markets at the opportune time.

CONCLUSION

Due to their significant contribution to carbon emissions and their heavy reliance on fossil fuels, the electric power and transportation sectors represent two of the most important industries that could be transformed with low-carbon innovations in the coming years. This case illustrates that significant reductions in the way we use energy are achievable through innovations that integrate into existing infrastructures. Yet the scale and maturity of these infrastructures present distinct conditions and challenges shaping the innovation and deployment processes. To successfully bring lower-carbon alternatives and technologies to these highly competitive markets, Alstom leverages specific competencies in both technical and non-technical areas. First, Alstom brings in its best people to create and negotiate partnerships—to build and manage networks of capabilities across multiple partners and technology platforms. The success of high-speed rail, for example, has less to do with individual technical advances than with successfully aligning complex financial, political, and commercial partners and capabilities. Second, the company's robust innovation strategy allows it to meet customer needs in the short-term while maintaining flexibility to respond to evolving customer needs in the longer term. That flexibility is particularly important to low-carbon innovation, to address evolving climate and energy policies, along with energy prices and other market forces affecting decision-making. This strategy is evidenced in the company's practice of scanning the market for and experimenting with potentially promising solutions and learning from a range of existing and promising technologies in use, from renewable energy generation to carbon capture and storage. This same flexibility is allowing Alstom to bring specific low-carbon innovation activities to those regional markets that have the greatest need and growth potential. While many of these practices are important for all types of innovation, they are particularly important to bring to bear in innovating the infrastructures of energy-intensive industries of unprecedented complexity and scale.

ENDNOTES

1 International Energy Agency (IEA), "IEA Statistics: CO_2 Emissions from Fuel Combustion, Highlights," 2010 Edition, http://www.iea.org/co2highlights/co2highlights.pdf. Trends for electricity demand vary greatly among regions and countries: the IEA projects that by 2030 demand for electricity will be almost twice as high as current demand, driven by rapid population and income growth in developing countries, by the continuing increase in the number of electrical devices used in homes and commercial buildings, and by the growth in electrically-driven industrial processes.

2 U.S. Energy Information Administration, *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010), http://www.eia.gov/oiaf/ieo/pdf/0484(2010).pdf.

3 János M. Beér, *Higher Efficiency Power Generation Reduces Emissions* (Cambridge: Massachusetts Institute of Technology, 2009), http://web.mit.edu/mitei/docs/reports/beer-emissions.pdf.

4 International Energy Agency (IEA), "IEA Statistics: CO_2 Emissions from Fuel Combustion, Highlights," 2010 Edition, http://www.iea.org/co2highlights/co2highlights.pdf; U.S. Energy Information Administration, "World Energy Demand and Economic Outlook," in *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010), http://www.eia.gov/oiaf/ieo/world.html. Both the U.S. EIA and the IEA estimate that transportation accounted for 22 percent of global CO_2 emissions from fossil fuel use in 2008.

5 "A Group with a long tradition," *Alstom*, accessed August 10, 2011, http://www.alstom.com/static/alstom-history/main_en.html.

6 Alstom, *Q&A: Annual Results 2010/11* (Alstom, 2011).

7 International Energy Agency (IEA), "IEA Statistics: CO_2 Emissions from Fuel Combustion, Highlights," 2010 Edition, http://www.iea.org/co2highlights/co2highlights.pdf; U.S. Energy Information Administration (EIA), "World Energy Demand and Economic Outlook," in *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010), http://www.eia.gov/oiaf/ieo/world.html. Much of the EIA's projected increase in coal use occurs in Asia, which will account for 95 percent of the projected increase in world coal use. Coal-fired generating capacity in China, for example, more than doubles from 2007 to 2035 and coal use in China's industrial sector grows by 55 percent. At the same time, the EIA predicts that renewable energy's share of global electricity generation will increase from 18 percent in 2007 to 23 percent in 2035.

8 In this context, "efficiencies" refer to thermodynamic or "electric generating" efficiency, which is the amount of useful energy derived from the chemical energy embedded in the fuel. In the case of modern power plants, this refers to the amount of heat released during the combustion of a specified amount of fuel.

9 Vaclav Smil, *Energy in World History* (Westview Press, 1994).

10 Gas turbines, which use combustion gases to directly turn a power turbine, emerged in the mid-20th century as an alternative and complement to steam-driven turbines. Indeed, the most efficient power plants, called combined-cycle power plants (CCPP) or combined-cycle gas turbine (CCGT) plants, employ gas turbines and are able to recover the waste heat from the exhaust to produce steam to power a second, steam-driven turbine.

11 George Booras and Neville Holt, *Pulverized Coal and IGCC Plant Cost and Performance Estimates* (Washington, DC: 2004), 5, Figure 1.

12 "Carbon Capture and Storage (CCS)," Center for Climate and Energy Solutions, accessed 2011, http://www.c2es.org/technology/factsheet/ccs.

13 "Alstom's carbon capture technology commercially 'ready to go' by 2015," *Alstom*, November 30, 2010, accessed April 25, 2011, http://www.alstom.com/australia/news-and-events/pr/ccs2015/.

14 Global CCS Institute, *The Global Status of CCS: 2010* (Canberra: Global CCS Institute, 2011).

15 International Energy Agency, *World Energy Outlook 2010* (Paris: International Energy Agency, 2010).

16 János M. Beér, *Higher Efficiency Power Generation Reduces Emissions* (Cambridge: Massachusetts Institute of Technology, 2009), http://web.mit.edu/mitei/docs/reports/beer-emissions.pdf.

17 "Alstom posted operational results for 2010/11 in line with guidance and achieved a marked increase of orders during the second half," *Alstom*, May 4, 2011, http://www.alstom.com/assetmanagement/DownloadAsset.aspx?ID=ce4086d3-86b0-453a-861a-4a73a62644bb&version=e0eece8023d245f1a346cc925e42d43c3.pdf.

18 Alstom, *Q&A: Annual Results 2010/11* (Alstom, 2011).

19 International Energy Agency (IEA), "IEA Statistics: CO_2 Emissions from Fuel Combustion, Highlights," 2010 Edition, http://www.iea.org/co2highlights/co2highlights.pdf.

20 Donald Ivan, *High Speed Rail – Urbanisation triggering demand for mass transit* (Frost and Sullivan, 2011), http://www.frost.com/prod/servlet/market-insight-top.pag?docid=227550507.

21 U.S. Government Accountability Office, *High Speed Passenger Rail: Future Development Will Depend on Addressing Financial and Other Challenges and Establishing a Clear Federal Role*, GAO-09-317 (Washington, DC: US Government Accountability Office, 2009), http://www.gao.gov/new.items/d09317.pdf. For travel times of two hours or less in Europe and Japan, HSR has traditionally won 90 percent of the market share. On the Paris-Marseille line, for example, rail travel held only 22 percent combined air-rail market before the high-speed train TGV Mediterranean went into service in 2001, but within five years rose to 69 percent. Japan's Shinkansen HSR service averages 75 percent of the combined air-rail market, and on its Tokyo and Osaka line accounts for about 88 percent of the market share. It is not until distances exceed 620 miles that air travel gains a higher market share.

22 Alstom's efforts take a holistic view of sustainability in all its parts. Roughly 98 percent of all their rolling stock is recyclable. According to Veronique Andries, Eco-conception Leader for Alstom Transport, the company strives to develop cleaner products by taking into account any environmental impact: energy consumption, materials, emissions of every kind including noise, electromagnetic radiation or particles, and landscaping.

23 Christian Wolmar, *Blood, Iron, and Gold: How the Railways Transformed the World* (Public Affairs, 2010), 19-20.

24 Edward L. Glaeser, "How Big Are the Environmental Benefits of High-Speed Rail?," *Economix* (blog), *The New York Times*, April 12, 2009, http://economix.blogs.nytimes.com/2009/08/12/how-big-are-the-environmental-benefits-of-high-speed-rail/; U.S. Government Accountability Office, *High Speed Passenger Rail: Future Development Will Depend on Addressing Financial and Other Challenges and Establishing a Clear Federal Role*, GAO-09-317 (Washington, DC: U.S. Government Accountability Office, 2009), http://www.gao.gov/new.items/d09317.pdf.

25 "Alstom posted operational results for 2010/11 in line with guidance and achieved a marked increase of orders during the second half," *Alstom*, May 4, 2011, http://www.alstom.com/assetmanagement/DownloadAsset.aspx?ID=ce4086d3-86b0-453a-861a-4a73a62644bb&version=e0eece8023d245f1a346cc925e42d43c3.pdf.

26 Edward L. Glaeser, "Is High-Speed Rail a Good Public Investment?" *Economix* (blog), *The New York Times*, July 28, 2009, http://economix.blogs.nytimes.com/2009/07/28/is-high-speed-rail-a-good-public-investment/.

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28 Eric Leifer, *Actors as Observers: A Theory of Skill in Social Relationships* (New York: Garland, 1991).

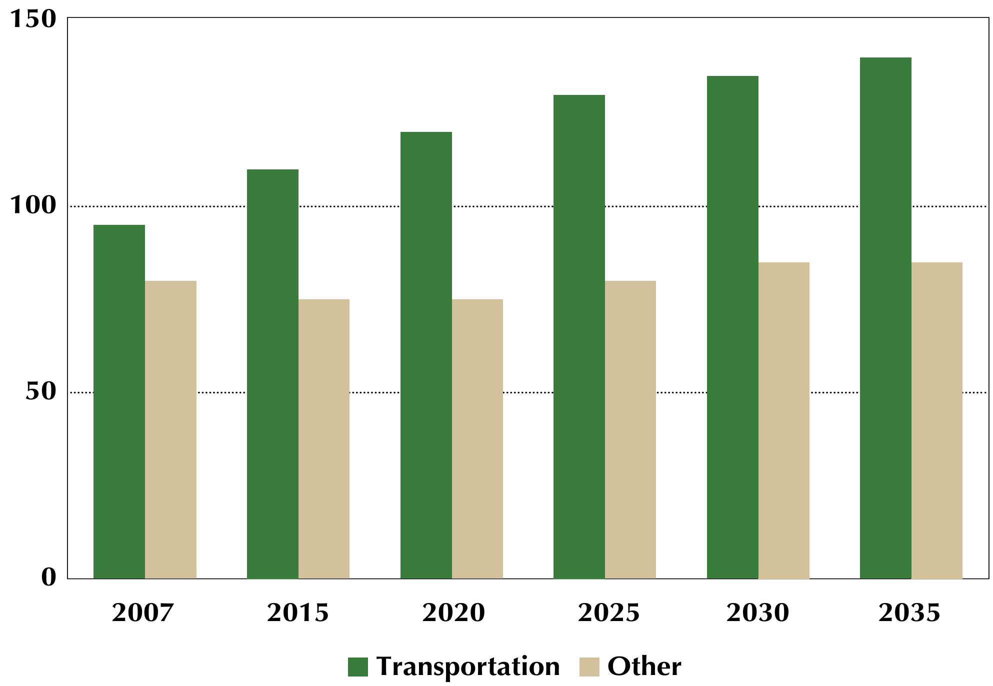
CASE STUDY: DAIMLER AG

CASE STUDY	DAIMLER AG Innovating Transportation: Managing the Move to a Low-Carbon Future
Headquarters:	Stuttgart, Germany
Industry:	Auto Manufacturing
CEO:	Dieter Zetsche
Revenues (2010):	€97.8 billion ($140.8 billion)
Average Annual R&D Spend:	€4.85 billion ($6.8 billion)
Employees:	260,100
Keys to Success:	• Nexus Work • Clear Direction and Commitment from Leaders • Managing Policy Uncertainty in Innovation Strategies
Low-Carbon Innovations:	• **BlueTEC Diesel** Daimler's BlueTEC technology is a diesel engine exhaust treatment that, using a urea-based[1] chemical additive, converts polluting nitrogen oxide (NO_X) emissions into harmless nitrogen and water, in addition to reducing soot, carbon monoxide (CO), and hydrocarbon (HC) emissions. This product innovation provides Daimler with both a significant reduction in regulated emissions and a means for the diesel engine to become more fuel-efficient. Daimler introduced this technology first to the European truck market in 2005 and then to the U.S. passenger vehicle market in 2007. The Mercedes-Benz E320 BlueTEC-equipped automobile was, according to Daimler, the first diesel vehicle in the world to meet California's strict exhaust emissions standards. BlueTEC-equipped vehicles get 20 to 30 percent better fuel efficiency than similar-sized gasoline-powered cars, with equivalently less GHG emissions. BlueTEC vehicles meet all 50 U.S. states' criteria pollutant standards, and federal greenhouse gas (GHG) emissions standards.[2] • **Freightliner Cascadia** In 2007, Daimler's Freightliner division introduced the new Cascadia truck, completely redesigned from the ground up with the BlueTEC diesel exhaust technology, new engine controls, improved aerodynamics, and a range of other innovations. The company created a next-generation freight truck with the best cost-to-performance ratio in the marketplace (the lowest total cost of ownership including vehicle, fuel, and maintenance costs). Over the last few decades, Daimler has refined its standard commercial vehicle diesel engine, improving fuel efficiency by over one-third. According to Daimler, 160,000 Mercedes-Benz heavy trucks (including Cascadia) and buses, Vario vans, and Setra buses have been delivered since the BlueTEC diesel technology for commercial vehicles was introduced in 2005. These models with BlueTEC have traveled more than 600 million miles, saving approximately 105 million gallons of fuel and 100 million tons of carbon dioxide (CO_2) emissions.

In the transportation sector today, new opportunities for low-carbon innovations are being driven by more stringent regulations, volatile fuel prices, and shifting market preferences. Transportation is and will remain vital to our economy and quality of life. But it is also the primary cause of oil dependency, responsible for 27 percent of the world's energy consumption and approximately 22 percent of global CO_2 emissions—the second-largest source after the electric power sector.[3] Daimler's 125-year history of leading automotive engineering, and its broad and deep relationships across the passenger and commercial vehicle markets, provide the company with the means to pursue low-carbon innovations across its core business lines.

In the long term, achieving dramatic reductions in CO_2 emissions requires developing alternative transportation technologies. Daimler has been developing such solutions as hybrid drive, all-electric, and hydrogen fuel cell vehicles that will help decouple transportation from fossil fuels. Yet the market adoption of such alternative technologies in the next two decades is projected to remain relatively low, while the growth of petroleum-fueled vehicles will continue. Passenger vehicle ownership is expected to double worldwide, and demand for transportation fuels is expected to increase another 20 percent from 2007 levels by 2035 (**Figure 1**).[4] Of the various transportation modes, passenger vehicles

FIGURE 1: World Liquid Fuels Consumption by End-Use Sector, 2007–2035 (quadrillion btu)



Although improvements in vehicle fuel efficiency, higher fuel costs, and government fuel economy mandates are expected to dampen demand for transportation fuels in developed economies, expected economic and population growth in developing economies and latent demand for personal mobility will more than offset efficiency gains.

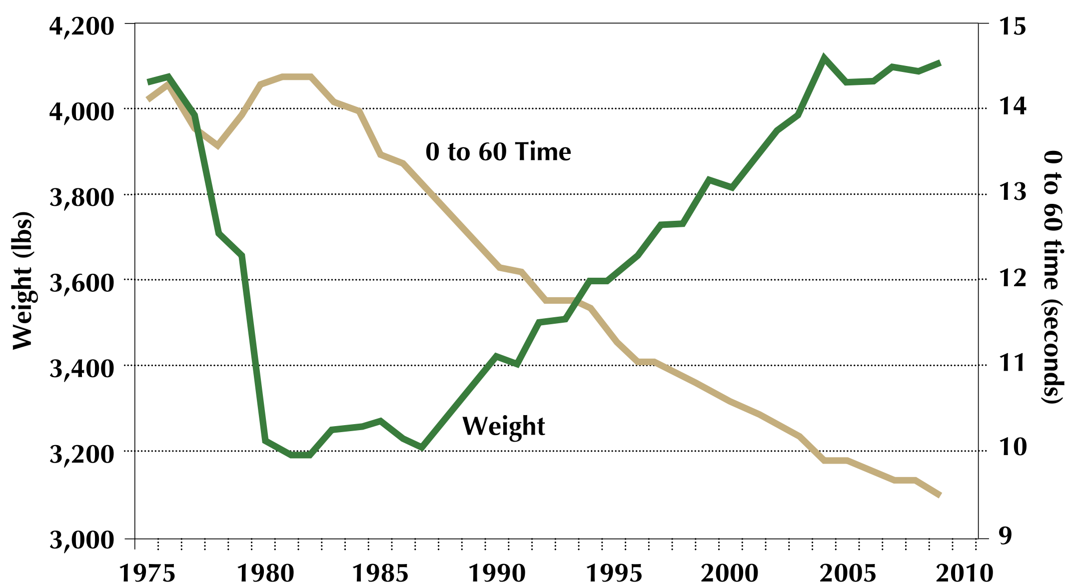
Source: U.S. Energy Information Administration (2010).

consume the most of that energy: In 2007, about two-thirds of transportation energy use in developed countries and 56 percent in developing nations was for passenger travel. In the nearer term, the best opportunities for emission reduction lie in advances in current internal combustion engine (ICE) technologies.

This projected rise in demand suggests significant opportunities for pursuing low-carbon innovations that reduce the fuel consumption and GHG emissions of cars and trucks in the next several decades. The last four decades witnessed considerable improvements in fuel efficiency; yet, due to consumer preferences for size, luxury, safety, and performance over fuel economy and the absence of encouraging public policies, these improvements were channeled into creating heavier vehicles with greater acceleration (**Figure 2**).[5] There is potential for even greater efficiency improvements in the next two to three decades that, with the relevant policy and market conditions, could further reduce CO_2 emissions per mile travelled.

Two low-carbon innovations at Daimler illustrate the potential to immediately reduce GHG emissions from the transportation sector through improvements in current technologies. The first is Daimler's BlueTEC technology, an innovation in diesel engine exhaust treatment that both reduces NO_X created in the combustion process[6] and increases the efficiency of fuel combustion to reduce CO_2 emissions. The second innovation is the design and introduction of the Freightliner Cascadia truck, which combines a series of innovations in engine and control systems (including a commercial version of BlueTEC) and truck design to improve the fuel efficiency and reduce emissions of commercial long-haul trucks. As these cases illustrate, Daimler's ability to achieve low-carbon innovations in a large, established, and heavily regulated industry derives from effectively managing policy, market, and technology uncertainties; from nexus work; and from acting with a clear leadership commitment.

FIGURE 2: Curb Weight and Acceleration Performance of New U.S. Light-Duty Vehicles, 1975–2009



Source: U.S. Environmental Protection Agency (2009).

COMPANY PROFILE

Daimler AG is one of the world's largest producers of passenger vehicles (cars and light-duty trucks), freight trucks, and buses. The company pioneered diesel engine technology in the 19th century and today is developing new diesel engine advances that reduce air pollution and emissions and increase fuel economy.

The company was built on a merger between two of the companies that originally founded the automotive industry. Daimler Motoren Gesellschaft (DMG) was founded by Gottlieb Daimler and Wilhelm Maybach in 1890 to build small, high-speed vehicle engines based on a stationary engine technology developed by Nikolaus Otto. Benz & Co. was founded in 1883 by Karl Benz, widely considered the "inventor" of the automobile for having created the Motorwagen, which was patented on January 29, 1886 as the first "automobile fueled by gasoline." (Previous automobiles were steam-powered modified carriages or coaches). Benz patented his work first and then patented all of the processes that made the ICE feasible for use in automobiles.

In 1926, DMG merged with Benz & Co. to form Daimler-Benz, which made Mercedes-Benz vehicles. The merger of the two companies was one of the most productive partnerships in automobile history. From the beginning, both Daimler and Benz were committed to the highest quality standards, a core company value to this day (as seen in the company's recent slogan: "The best or nothing"). Both men were deeply committed to innovation, and were responsible for imagining and solving problems that had no engineering precedent, from creating the first diesel engines to determining how to effectively steer four wheels. Their commitment still shapes the company's culture of innovation and industry leadership.

Diesel engines, first introduced by Rudolf Diesel in 1897, have an inherent efficiency advantage over gasoline engines. With a thermal efficiency[7] five to seven times greater than competing steam engines, these engines were rapidly adopted for a wide variety of industrial uses. Diesel engines use diesel fuel, which has a higher energy content than gasoline (10 percent more energy per unit volume), and use compression (rather than a spark) to ignite the fuel. The very high compression ratio[8] of the diesel engine gives it the highest thermal efficiency of any typical ICE, resulting in less fuel used, and less carbon emitted, per vehicle mile traveled.[9] Between 1910 and 1940, diesel engines were adapted for use in commercial and passenger vehicles; in 1924, Benz and Daimler partnered to build the diesel engine for the first commercial vehicles (two years before they merged to become Daimler-Benz) and introduced the first commercially successful diesel passenger car in 1936.

Daimler AG, 125 years later, is still one of the world's most successful automotive companies. In 2010, it sold 1.9 million vehicles, employed more than 260,000 people, and had revenues of $97.8 billion ($140.8 billion). Its divisions today include Mercedes-Benz Cars, Daimler Trucks, Mercedes-Benz Vans, Daimler Buses, and Daimler Financial Services, making the Daimler Group one of the largest producers of premium cars and the world's largest manufacturer of commercial vehicles. In addition to Mercedes-Benz, Daimler's car and truck brand portfolio includes Smart, Maybach, Freightliner, Western Star, BharatBenz, Fuso, Setra, Orion, and Thomas Built Buses. Daimler sells its vehicles and services in nearly every country and has production facilities on five continents.

Daimler is working on next-generation vehicle technologies and has enhanced its passenger car, van, and bus fleets with these innovations. Its heavy research and development (R&D) investment has resulted in demonstrated breakthroughs in alternative drive technologies such as the B-Class F-CELL, the Concept Blue Zero E-CELL PLUS, and the Vision S 500 Plug-in HYBRID. Since the end of 2009, Daimler has produced about 200 of the B-Class F-CELL hydrogen fuel cell vehicles, placing them in customers' hands in Germany and the United States at the end of 2010. Moreover, Daimler bought a 10 percent stake in Silicon Valley-based Tesla Motors (an electric car manufacturer), entered into a joint venture with German battery-maker Evonik Industries and, more recently, announced a planned joint venture with automotive supplier Bosch to develop electric motors for Mercedes-Benz and Smart electric vehicles starting in 2012.

In parallel, Daimler is pursuing innovations that increase the fuel efficiency of the ICEs on which we rely today. Daimler has a compliance obligation to meet air emission and fuel efficiency standards as European Union (EU) and U.S. Environmental Protection Agency (EPA) regulations become increasingly stringent. Both the EU and U.S. EPA standards for allowable particulate matter (PM) (a type of air pollution from fuel combustion) and NO_X emissions from commercial vehicles have tightened considerably over the past two decades

(**Figures 3 and 4**).[10] These regulations have driven many of the technical improvements in ICE technology during that time. Through innovations in its current vehicle and engine technologies, Daimler intends to reduce CO_2 emissions in its European car fleet by nearly 40 percent from 1995 levels by 2012, and 45 percent by 2016. In its trucking business, Daimler Vision 2020 sets a goal of reducing carbon emissions by 20 percent by 2020.

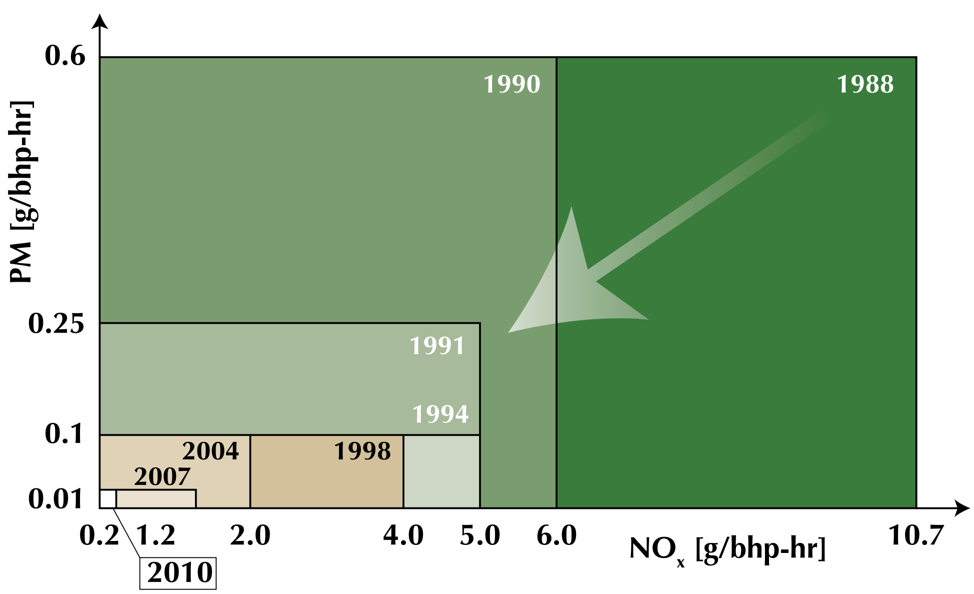
For a maker of premium cars, balancing regulatory compliance with the preferences of its primary customer base for luxury, exceptional quality, safety, service, acceleration, and high performance is not easy. But rising consumer demand for environmentally sensitive luxury cars and unprecedented fuel prices at the pump—along with increasingly strict emission standards—have encouraged Daimler to take a long view of the technological alternatives that would meet market and regulatory demands over the coming decades. As a leader in automotive innovation, Daimler looks to achieve dramatic growth, in part, by significantly improving the fuel efficiency of the almost two million vehicles it sells each year, reducing GHG emissions and helping customers save money. The BlueTEC diesel engine system and the Freightliner Cascadia commercial truck design represent two solutions that emerged from Daimler's commitment to meeting future emission requirements.

BLUETEC DIESEL

Vehicle manufacturers have, in many ways, exhausted the easy means for efficiency gains and emission reductions from the ICE, and are now considering advanced platforms that enable continued improvements to the ICE over the coming decades. Despite adding upfront costs to vehicles, these new platforms will continue to provide cost-effective pathways to reduce emissions while meeting market and regulatory demands (see Sidebar: The Potential of Existing Engines, page 68).

In the late 1990s, Daimler began considering the range of new technology platforms that would enable it to respond effectively to changing market conditions, technologies, and policies. The company considered the low-carbon alternatives available, including smaller

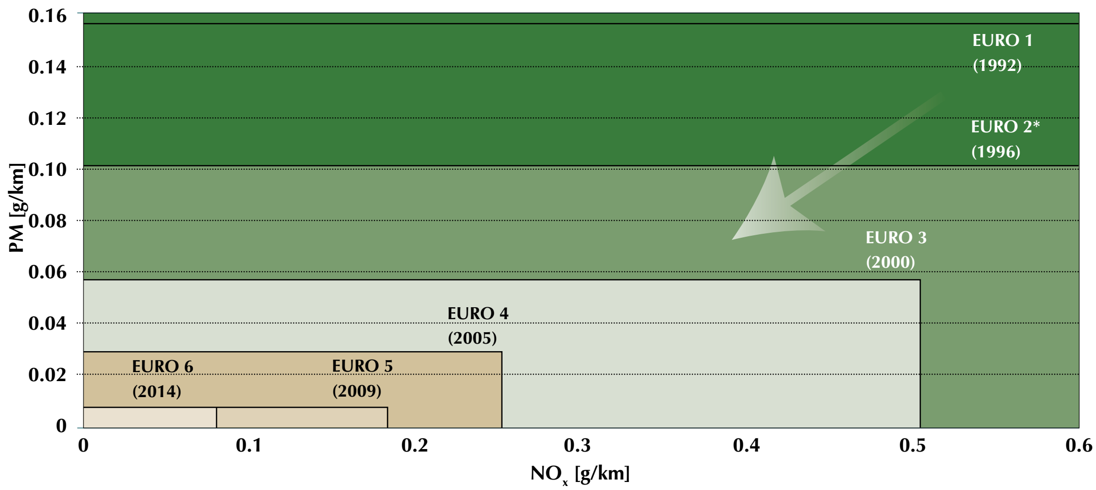
FIGURE 3: Evolution of U.S. EPA Emission Standards for Diesel Cars (1988–2010)



Note: U.S. EPA emission standards for diesel engines are measured in grams per brake horsepower-hour ("g/bhp-hr").

Source: Recreated based on an image provided by Daimler (2010).

FIGURE 4: Evolution of EU Emission Standards for Diesel Cars



* EURO 2 emission standards ranged from 0.08 g/km for indirect injection diesel engines to 0.1 g/km for direct injection diesel engines.

Source: International Energy Agency (2010).

engines, hybrid-electric vehicles, diesel engines, and "start-stop" batteries. It returned, in a way, to its roots in the diesel combustion engine. The inherent efficiency advantage of the diesel engine, the company decided, made it the best platform for pursuing low-carbon innovations over the next two to three decades. The fuel efficiency and higher torque (or power) of diesel engines provide two features that the company believed would remain critical for consumer preference—fuel economy and driving performance. The company saw the potential for further improvements in efficiency and emission reductions that would meet future, more stringent regulatory standards. While continuing to develop hydrogen fuel cell and electric vehicles for production, Daimler placed a large bet that the diesel engine would be the best platform to achieve its business and environmental goals for the next 20 to 30 years and developed the BlueTEC diesel exhaust system.

The deployment of diesel engines in the past was hampered by the NO_X and PM emissions associated with diesel fuel combustion. Worse, the two emission challenges seemed to conflict: Lower combustion temperatures cause incomplete combustion, increasing CO_2 and PM emissions. But raising combustion temperatures to boost efficiency increases the production of NO_X. Daimler engineers saw this seeming conflict as a significant opportunity for a paradigm shift. They returned to selective catalytic reduction (SCR)—a technology first patented in 1957 and used in stationary diesel engines since the 1980s—and began developing an exhaust treatment system that uses ammonia (derived from urea) to reduce NO_X emissions.[13] BlueTEC technology involves spraying small doses of urea into the exhaust stream, which reacts with NO_X to form diatomic nitrogen (N_2) and water (H_2O) (**Figure 5**).

The BlueTEC system decoupled NO_X emissions from high combustion temperatures and fuel efficiency. The BlueTEC system allows engineers to remove the NO_X gases in the exhaust system, allowing them to burn diesel fuel at higher temperatures and optimize the engine for fuel efficiency. Daimler first introduced BlueTEC in its long-distance trucks in 2005 and brought it to the United States in passenger vehicles in 2007 (when it was also introduced in passenger cars in Europe). As of July 2007, over 80,000 BlueTEC trucks were in use in the European market.[14] The next-generation solution, BlueTEC II, reduces NO_X emissions up to 80 percent below conventional diesel engines. It is the cleanest diesel engine on the market today.

The Potential of Existing Engines

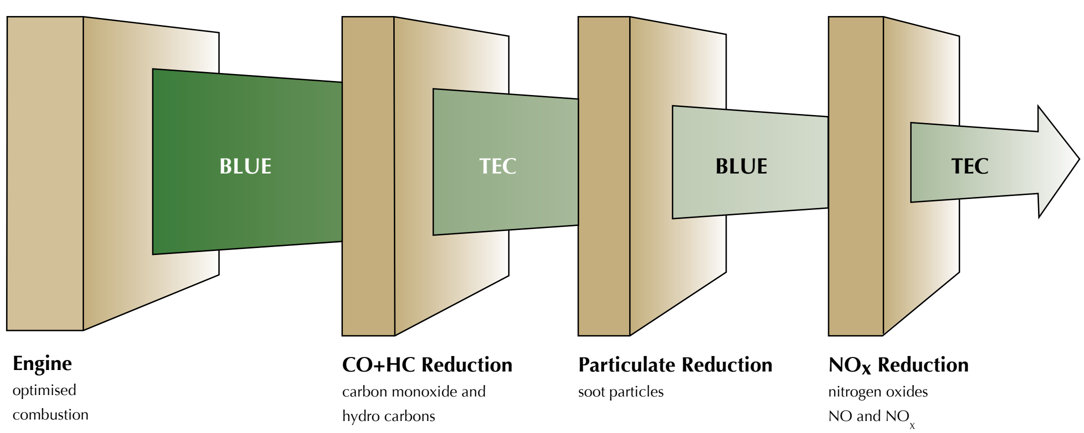
A range of existing low-carbon innovations is available for increasing the efficiency and reducing the emissions of ICE passenger cars and light-duty trucks.[11] It is estimated that ICE technologies alone can reduce CO_2 emissions by approximately 40 percent, and have the potential to improve fuel economy to over 50 miles per gallon (mpg), with hybrid vehicles using these technologies reaching 75 mpg, by 2035.

For the most part, these are "incremental" product innovations that auto manufacturers understand relatively well, that use existing technologies, that work within existing industry value chains, and that will likely meet regulatory requirements through 2020. These solutions still add between $100 to $2,000 to the price of a vehicle, and so await the appropriate price point to be brought to market, in terms of cost per vehicle, per reduced emissions, and per reduced fuel consumption ($/vehicle, $/%$CO_2$ and fuel use offset). Examples of such solutions for engines and vehicles include:

- Reducing the energy needed to move the vehicle, by reducing weight, aerodynamic drag, and rolling resistance (resisting force between tires and the road);
- Improving the efficiency and conservation of air conditioning and lights, using improved insulation, and changes in window glass;
- Improving drivetrain (engine and transmission) efficiency through, for example, start-stop batteries, improved thermal management, and downsizing engines. Turbochargers help maintain superior performance and have the greatest potential to decrease CO_2 emissions in diesel engines.

Conventional engine and vehicle technologies, when used in concert, can reduce CO_2 emissions by as much as 20 percent for a cost of $1,122 per vehicle and $58 per percentage point of CO_2 reduction. By contrast, battery pack costs for EVs are projected to fall sharply (approximately 69 percent from 2009 levels) by 2020, but to the consumer this still represents a cost of $9,600 per vehicle for a typical 20-kWh battery necessary for a pure battery electric vehicle (EV).[12] For this reason, low-carbon innovations for the ICE will likely reach the market before alternative options such as electric vehicles can compete on costs.

FIGURE 5: BlueTEC Exhaust Treatment System



Source: Recreated based on an image provided by Daimler AG (2010).

BlueTEC is not just clean compared to a typical diesel engine. According to Daimler, "it's one of the cleanest automotive options on earth." BlueTEC-equipped automobiles meet the strictest EU and U.S. emission standards and are now "the cleanest diesel cars in the world."[15] According to Daimler's benchmarking tests, only four gasoline vehicles on the market create fewer NO_X emissions than BlueTEC II vehicles. Daimler's BlueTEC technology is a scientific breakthrough in diesel engine exhaust treatment.[16] Rather than simply expelling emissions, the BlueTEC system drives the exhaust gases through several filters to a catalytic converter, where they mix with the urea-based chemical additive (called AdBlue in Europe and Diesel Exhaust Fluid (DEF) in the United States) to convert polluting NO_X into harmless nitrogen and water. The result is a significant reduction in soot and other air pollutants, making the BlueTEC engine smoother, more fuel-efficient, quieter, and more robust than its predecessors.

As Dr. Dieter Zetsche, Chairman of the Board of Management of Daimler AG and Head of Mercedes-Benz Cars, describes:

> "The modern four-cylinder diesel engine with BlueTEC emission control is a prime example of cutting-edge technology with a safe future. With our diesel strategy, we provide the answer to the questions of how fuel consumption—and thus carbon dioxide emissions—can be lowered, how all exhaust gas constituents including nitrogen oxides can be further reduced, and how superior motoring pleasure can be ensured at the same time. We are convinced that the modern diesel currently represents the best and most efficient solution in this respect."[17]

In 2007, when Daimler introduced this technology in passenger vehicles in the U.S. market, the E320 BlueTEC was, according to Daimler, the first diesel vehicle in the world to meet California's strict exhaust emission standards. Mercedes-Benz BlueTEC vehicles get 20 to 30 percent better fuel efficiency than similar-sized gasoline-powered cars, and can travel 600 miles—roughly from New York City to Detroit—on a single tank of fuel. BlueTEC vehicles already meet or out-perform the 2016 federal and California corporate average fuel economy (CAFE) standards, which require an average of 34.1 mpg.

FREIGHTLINER CASCADIA

Global freight traffic is expected to grow every year by an average 2.5 percent through 2030, roughly doubling in volume compared to the year 2000.[18] Growth rates may be even higher in road transport because of its flexibility relative to modes with more restricted access, such as rail. Several factors make the long-haul commercial trucking market particularly responsive to low-carbon innovations. Medium- and heavy-duty trucks consume 26 percent of liquid transportation fuels in the United States, and their consumption is increasing more rapidly—in both absolute and percentage terms—than consumption by other sectors.[19] Fuel costs are a dominant factor in the productivity and profitability of trucking operations. The relatively high fuel expense—both overall price and price volatility—in operating commercial trucks puts significant value on mileage improvements: Both fleet owners and independent truckers spend approximately three to four times as much on fuel costs and maintenance over the life of a truck as on the truck itself. While Daimler Trucks North America (DTNA) tests its vehicles for a ten-year useful life, commercial trucking fleets will often replace trucks approximately every four years,[20] ensuring enough market turnover to reward investments in new products that achieve efficiency gains.

Deploying technologies in commercial transportation is not without challenges. The production of commercial freight trucks is highly fragmented: The components of a typical long-haul truck (cab, engine, powertrain, and trailer) involve multiple manufacturers. The party responsible for the final truck configuration is often not well defined. The company that integrates the overall vehicle may be the manufacturer of record, but it may not design or even specify many of the essential parts of the truck, such as the engine and powertrain. For tractor-trailer combinations, the tractor and trailer are made by and often owned by different companies, meaning many tractors and trailers must be interchangeable. Many trucks are also custom-made for specific needs (the type and weight of the cargo, the terrain, and the expected routes), "literally one of a kind."[21] These other factors, many beyond the manufacturer's control—including engine design, trailer design, and driver skills—influence the truck's fuel efficiency as much as cab design. Thus, advancing low-carbon innovations requires cooperation with many different entities responsible for the truck's manufacture, maintenance, and operation.

Daimler's acquisition of commercial truck manufacturer Freightliner removed much of that fragmentation, allowing the combined company to design engines and trucks together for maximum efficiency. Since the acquisition in 1981, Daimler has refined its standard commercial vehicle diesel engine through technical improvements, cutting fuel consumption by over one-third and increasing performance (in terms of fuel and maintenance costs) by about the same degree. In 2007, Freightliner introduced the new, completely redesigned Cascadia truck line—a next-generation freight truck with the best cost-to-performance ratio in the marketplace. According to the company, the Cascadia "started with a clean sheet of paper and an open mind." Freightliner invested millions of dollars in researching the competition and conducting an extensive analysis of the strengths and weaknesses of its own trucks, identifying best practices that could be applied to the Cascadia. Numerous customers and drivers throughout North America participated in the truck's development, offering their insights and practical knowledge to the design process.

The Cascadia became one of the most thoroughly tested Freightliner trucks that Daimler had ever produced, ensuring its productivity, safety, durability, and comfort. The truck spent months in Freightliner's proprietary, state-of-the-art wind tunnel laboratory in an effort to understand and offset any barriers to maximum aerodynamic efficiency. Then thousands of miles were logged under actual operating conditions to test the truck's fuel-saving capabilities. Unlike so many conventional trucks on the market, the Cascadia is not just an enhancement of an existing model. Designed more like a sports car than a long-distance highway hauler, the Cascadia has the lowest coefficient of drag of any Freightliner truck currently available. Its aerodynamic bumper directs airflow into the radiator, around the tires, and under the chassis to reduce turbulence. Its grille optimizes cooling efficiency and helps air flow smoothly along the hood, fenders and curved windshield, over the truck and trailer. Many existing truck cabs have fairings, or extenders, that stick out backwards from the cab to cover the much of the gap between cab and trailer, reducing drag. In the Cascadia, the side extenders have been shortened to increase maneuverability, but are angled outward slightly to preserve aerodynamic performance. The result of such meticulous design is industry-leading fuel efficiency.

In addition to updating an aging cab design, Freightliner invested in engine and powertrain technologies that would position Cascadia, and the company, at the leading edge of the most fuel-efficient and emissions-compliant trucks on the market. While historically Freightliner trucks were available with several types of diesel engines, such as those from Cummins, Daimler's acquisition in 2000 of Detroit Diesel, a producer of truck diesel engines, integrated Freightliner's cab design capabilities with Detroit Diesel's engine manufacturing capabilities. This acquisition facilitated the introduction of Daimler's SCR-based engine technologies to the North American trucking market and provided Daimler with greater control over the truck's fuel efficiency. Achieving a dramatically more fuel-efficient truck required creating an exhaust system that, in order to meet EPA emission requirements, added 50 percent to the cost of the engine and, therefore, represented a clear leadership commitment to this new platform and confidence that the engineers could reduce these initial costs quickly as the truck came on the market.

Daimler uses BlueTEC diesel technology in commercial trucks to further increase efficiency and reduce GHG emissions: fuel consumption has been cut by between three and five percent, equivalent to nearly 2,000 liters (528.3 gallons) less diesel consumption per truck each year. According to Daimler, 160,000 Mercedes-Benz heavy trucks (including Cascadia), buses, Vario vans and Setra buses using the BlueTEC diesel technology have been delivered since 2005. These BlueTEC models have traveled more than one billion kilometers (600 million miles), saving some 400 million liters (105 million gallons) of fuel and avoiding 100 million tons of CO_2 emissions. However, Freightliner test-drives also demonstrated that only about 60 percent of the fuel consumption of a 40-ton truck-trailer combination can be directly attributed to engine technology. The rest is influenced by factors such as traffic events, topography, vehicle configuration (particularly the aerodynamics of the trailer), maintenance, and driving behavior. Thus, considerably more opportunity lies ahead as Freightliner develops solutions that encompass trailer design, maintenance, and even driving conditions and practices.

MANAGING LOW-CARBON INNOVATION

Innovations advancing the performance of BlueTEC diesel engines and Freightliner Cascadia trucks created new profitable product lines while reducing global GHG emissions. These projects illustrate a number of best practices for innovating effectively in large, established, and heavily regulated markets. At Daimler, several key factors stand out: the role of nexus work in introducing new and common technology platforms; the role of leadership commitments to these new platforms, both inside and outside the company; and the role of concurrently managing regulatory, technology, and market uncertainties.

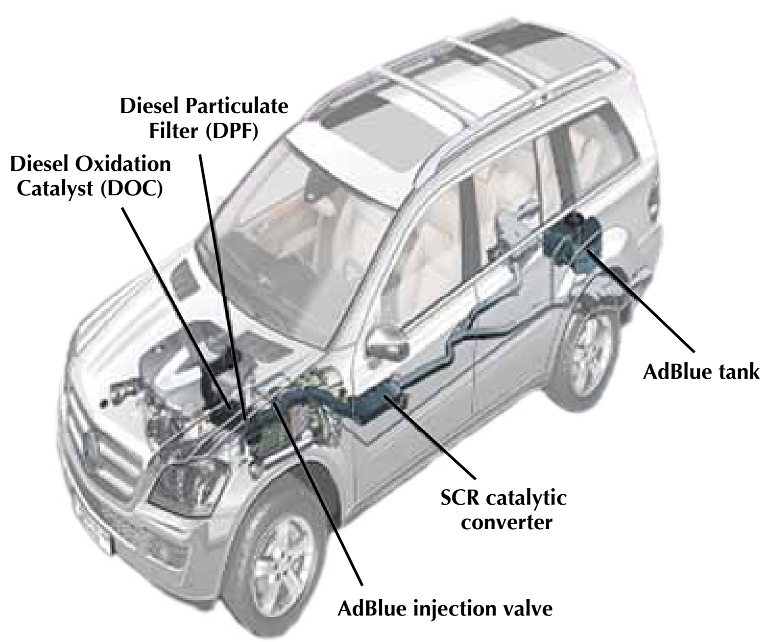
Nexus Work

Nexus work involves seeing, building, and maintaining the necessary technical and commercial networks that enable interdependent solutions to emerge. The complexity of these solutions is often obscured by their appearance as discrete "innovations" neatly packaged. In reality, these solutions represent complex webs of interdependent relationships between diverse interests. Each one of these components is necessary, but none is sufficient, to ensure the performance of the larger system. Daimler's successful introduction of the BlueTEC system in trucks and cars, first in Europe and then in the United States, illustrates this type of work.

Developing and deploying BlueTEC involved working effectively with a wide range of partners and at multiple levels of the business. BlueTEC involved creating new networks between the R&D Group, where the SCR technology was being developed for potential application in automobiles, and the Product Development Group within Mercedes-Benz, where it would be integrated into the particular engine design that would work within new car models. Networks also were created with the suppliers and competing auto manufacturers whose collaboration was necessary to establish an acceptable industry standard for the AdBlue (or DEF) additive, and with policy makers who would ensure that the technology—and engine designs that relied on it—would be accepted as delivering the promised emission reductions. How Daimler pursued this nexus work at each level offers valuable insights for other companies pursuing similar technical, market, and policy challenges associated with low-carbon innovations.

Moving BlueTEC from the R&D Group to specific product development teams may sound straightforward, but in fact required collaboration and interdependent changes across a dozen or more design teams, because

FIGURE 6: Integration of GL320 BlueTEC with AdBlue Injection in Vehicle



Source: Recreated based on an image provided by Daimler AG (2010).

the underlying SCR technology intersects all aspects of the vehicle (**Figure 6**). To enhance collaboration, the three engineers within R&D responsible for the SCR technology joined the 97-member project team designing the vehicle, itself broken into subgroups including engine, calibration, exhaust, transmission, safety, cabin interior, and body. Decisions made in any one of these groups often affected the other groups—sometimes to their benefit and sometimes adversely. And decisions made at other levels had ramifications for the integration of systems in the car itself. For example, BlueTEC passenger vehicle engines require an additional tank to hold the additive. Working with regulators, Mercedes-Benz decided that refilling the urea additive would be done by the service dealer, so the tank had to be designed to hold enough AdBlue (DEF) to last through the average service interval of the vehicle. But a tank that was large enough took up space that otherwise would have housed the spare tire, requiring the wheels team to shift to 'run-flat' tires. The decision to shift to run-flat tires was itself a one-year discussion.

In addition, BlueTEC was an extremely challenging innovation to commercialize because the technology required bringing an entirely new additive—AdBlue (DEF)—to the automobile market. Traditionally, there are only two additives that typical drivers need ever concern themselves with, fuel and motor oil (coolant, windshield washer fluid, and brake fluid are rarely needed). Daimler mitigated that problem by making the AdBlue tank large enough (15-25 liters) to last 10,000 miles—longer than the typical service interval—so that drivers need not worry about filling up the tank themselves. Introducing an entirely new additive meant also developing its supporting infrastructure. Daimler had to ensure that the additive was broadly available, requiring gas stations to inventory it and setting up a national distributor. Daimler also had to create industry-wide standards for the additive mixture and the design of the nozzle used to fill the tank. Those steps ensured that the costs and benefits of this new additive were borne by as many car companies and drivers as possible.

Equally important was that Daimler's suppliers and the competing auto manufacturers offering diesel engine vehicles, particularly Volkswagen (Audi) and BMW, would agree to use these same technology standards to ensure compatibility and market acceptance. It was important to both Mercedes-Benz and its U.S. regulators (the EPA and the California Air Resources Board (CARB)) that the SCR technology be widely used across manufacturers to create a common platform and ensure one system. This entailed creating a SCR Working Group to work closely with competitors to ensure their confidence in this technology platform, to coordinate design specifications, and to ensure a shared infrastructure for all car models. Some of the issues to be resolved included determining common components that would integrate into each manufacturer's engine designs, deciding on a common means of certifying engine performance, educating a shared base of suppliers, and even adopting common marketing language.

Both Daimler's Cascadia and BlueTEC passenger vehicle innovations also required working closely with policy makers, industry associations, and other stakeholders whose acceptance of the ultimate solution was critical. The main policy makers with which Mercedes-Benz's SCR Working Group engaged in the United States around introducing the BlueTEC technology were the EPA and CARB. Representatives of the cooperating auto companies met with these agencies every six weeks for 18 months. This was the first vehicle emissions innovation that the U.S. agencies had dealt with that required an entirely new additive, and so faced several significant challenges. First, the system could not add extensive new maintenance requirements for consumers. The additive needed to be available, it was agreed upon, within 20 miles of 80 percent of the diesel car owners in the country. This required partnering with Exxon, whose distribution network and gas stations would stock the additives. Second, the EPA insisted that, if the additive tank went dry, the vehicle could not continue operating (as it would no longer remain within the specified emissions limits) yet, at the same time, the vehicle could not strand a driver. This challenge was ultimately resolved with a countdown beginning when the tank is close to empty that provides the driver with 20 'starts' that, as used, involve increasingly intrusive warnings before finally preventing the vehicle from starting at all. This is an unprecedented solution, as it effectively gives policy makers the ability to prohibit non-compliant cars from running. In the case of the Freightliner Cascadia, the team spent considerable effort educating regulators about the interdependent nature of how efficiencies are gained through not only advanced engine design but through necessary improvements in multiple truck components.

At all levels, Daimler had to engage in nexus work—effectively managing complex systems and relationships—in order to introduce SCR technology sufficiently broadly in the market. This effort included building new product development networks to develop the BlueTEC vehicles, accomplished by integrating the R&D engineers with the vehicle design teams; new industry networks across competing auto manufacturers and suppliers to manage a collaborative design effort, accomplished by effectively partnering with common suppliers and industry associations;[22] and new networks across public agencies, accomplished with a dedicated SCR Working Group—members of the product development team working directly with policy makers to ensure that the design supported, and was supported by, regulators now and in the coming decades.

Clear Direction and Commitment from Leaders

With product development efforts taking three to five years and product lifecycles lasting another five to seven years, decisions made today shape an auto company's success into the next decade. Under these conditions, strong leadership provides a clear set of long-term values and objectives that help guide decision-making within the organization, and with suppliers and partners, in the face of evolving regulations, shifting market preferences, and increasing technical complexity. As Dieter Zetsche stated: "The invention [of the automobile] created by Daimler and Benz changed the world and affected virtually every aspect of daily life. Now we are inventing the automobile for the second time, and the effects will again be revolutionary."[23]

With the turn of the 21st century, Daimler's top leadership worked to develop a clear strategy for addressing the environmental impacts from the automotive industry while ensuring continued business growth. Secure in the belief that diesel engine technology, with its superior efficiency and performance relative to gasoline engines (including when used in future hybrid-electric powertrains), was the best solution for car and truck buyers today and in the near future, Daimler's leadership committed to building a new technology platform that would enable diesel engines to meet current and upcoming EU and U.S. EPA emission standards. This strategy led to the decision to move forward with BlueTEC and with Freightliner's Cascadia, which in turn provided critical certainty for the company and its stakeholders by defining the technology platforms that the company would leverage for the next several decades. As Martin Daum, President and CEO of DTNA, stated: "This engine should have the potential for meeting the underlying trends of the next 30 years."

This long-term commitment to diesel provided certainty in an otherwise uncertain business environment. In the development of both the BlueTEC system and the Freightliner Cascadia, strong leadership commitment was essential to empowering the rest of the organization—such as the engineers on the product development team—to make key decisions in bringing these products to market. Strong leadership was also essential to convincing suppliers, competitors, and new partners of the priority and support that Daimler was putting behind these low-carbon innovations. In both of these cases, top leadership at Daimler made clear, well-reasoned, proactive commitments to clean diesel technologies as a long-term strategic vision—as opposed to relying on multiple, short-term, reactive efforts that led to combinations of technical improvements and compliance fines. The resulting strategic vision to meet long-term market and regulatory demands reflects a turning point in the company's history, representing a proactive commitment to clean diesel technologies rather than relying on short-term, incremental efficiency efforts. Specifically, Daimler's leadership used three mechanisms to enable the company and its partners to move forward: an effective process for making and sharing this decision; clear and well-articulated goals; and regular, visible actions in support of these goals.

The process by which top leadership decided to develop these low-carbon innovations was deliberative and evolutionary. In the mid-1990s, responding to increasing regulatory pressure, Daimler invested in resurrecting and advancing clean diesel technologies like SCR for automotive use and particulate filters. By the early 2000s, increasingly stringent emissions requirements in the United States and Europe helped move these technologies into vehicle model designs, which were introduced in the United States in 2006. By April 2008, on the heels of yet further legislation for increasingly stringent emissions standards, the Daimler Board of Directors finally made a decision to commit fully to leverage diesel as one of the most robust technology platforms with the potential to cost-effectively manage these emissions requirements—while still responding to customer preferences for luxury cars of exceptional quality and performance. As one development manager emphasized: "It really is a shift in the mentality about sustainability right from the Board. It is a strategic decision, and we did it in the early phase and then it goes from top to bottom to get the whole team motivated." Following this influential decision, the company's top

30 managers held a workshop in April 2008 to jointly approve Daimler's overall "green" environmental strategy, including its commitment to diesel. The following September, the top 120 managers convened for a day and a half to discuss, ultimately approve, and determine how to execute this strategy.

Daimler's leadership then set clear targets to motivate and empower the rest of the organization around this strategy. The company set specific goals, including reducing CO_2 emissions in its European car fleet by nearly 40 percent by 2012 (from 1995 levels), and 45 percent by 2016 and, in the trucking business, reducing CO_2 emissions by 20 percent by 2020. These reflected more strategic goals for BlueTEC, including first, to successfully return diesel to the U.S. car market and second, to make diesel as clean as gasoline. These goals enabled the product development team to balance the difficult tradeoffs that inevitably emerged as they attempted to integrate the SCR system within the vehicles, and within the timeframes of upcoming emission standards. "It's really a long development process," an engineering manager described. "And to get this process started you need a Board management decision to say 'Yes, we want this.'" For example, integrating the additive tank, hoses, and intelligence into the vehicle required costly modifications to the body, the engine and exhaust designs, and even the tires (particularly displacing the spare tire). Top leadership's clearly communicated priorities for this technology ensured that such decisions had support in the organization. Top management's commitment to make Cascadia the lowest GHG-emitting truck on the North American long-haul market empowered similar decision-making for the engine and cab development. Both development teams understood these projects were to establish the technological platform on which Daimler would compete in diesel vehicles and trucks over the next three decades—providing support and long-term perspective to their missions.

The attention that these projects received at the highest level of the company demonstrated Daimler's commitment to this new technology platform. For example, progress reports from a global development group bringing SCR technology into Mercedes trucks in Europe were presented to the Daimler Board of Directors at each board meeting. Leadership supported these efforts with long-term strategic thinking. For example, to meet EPA emissions requirements, DTNA committed to designing into the Cascadia program a powertrain exhaust after-treatment system that initially added 50 percent to the cost of the engine—a decision that reflected both DTNA's commitment to the new platform, and confidence that their engineers would be able to reduce these costs quickly. Overall, Daimler invests €4.85 billion ($6.8 billion) annually in R&D, roughly half of which is now dedicated to developing technologies that reduce CO_2 emissions from its vehicles.

Managing Policy Uncertainty in Innovation Strategies

Effectively commercializing low-carbon innovations in such an energy-intensive and highly regulated industry depends on understanding public policies and trends that influence when to leverage existing capabilities, and when to transition to wholly new technology platforms. Make a transition to a new technology too soon and the company risks increased costs and complexities while competitors gain an advantage. Moving too late and failing to meet increasingly strict emissions standards can harm profitability and the competitive edge. To integrate innovation strategy with policy analysis, Daimler monitors and engages with policymakers, competitors, suppliers, and other stakeholders around issues in a range of global markets. This engagement helps ensure that these policy issues are represented at all stages of the low-carbon innovation process, from early-stage R&D to vehicle development and commercialization.

Daimler has a number of executive and management positions dedicated to monitoring and managing energy and environmental policy, and to integrating those considerations into the business. The Office of Certification and Regulatory Affairs works to facilitate learning and engagement between product development teams and regulatory agencies. During the development of the first U.S. cars to use BlueTEC, members of this Office traveled regularly between the EPA's regional office in Ann Arbor, Michigan, and Mercedes-Benz's Stuttgart engineering offices. At these meetings, design decisions were discussed, and changes made, to ensure that what was feasible was sufficient, and that what was sufficient was feasible. Decisions included the cost and availability of the AdBlue (DEF) additive and how to manage the warnings to drivers that a car could not start without sufficient additive. These positions and offices also educated the engineers on the design teams about current and future policy requirements that affected their work. Not only could engine designers therefore work toward meeting current emission standards, they also prepared their designs for the tightening of those standards over the seven-year lifespan of each car model.

Through long experience dealing with environmental and energy regulations, Daimler has learned to provide strong support for voices from those who monitor and manage policy issues within the company. These voices helped shape the thinking of the Board members who, recognizing the potentially significant new emission standards to come over the next 20 years, decided to pursue more robust vehicle designs capable of incorporating multiple low-carbon technologies. Without the Daimler Board's continual awareness of political and regulatory trends, these decisions would have been much more difficult to make and much harder to hold to.

Daimler has built the capacity to not only anticipate and react to policy directions, but also to proactively engage with policy makers to inform those directions. Engagement also ensures that policy makers recognize the full potential of existing technologies, which can be extensive, and do not unintentionally close off avenues for efficiency gains. For example, while Daimler was realizing opportunities to make diesel engines cleaner than gasoline engines, public agencies were considering eliminating diesel engines in passenger vehicles based on the poor NO_X and PM emissions performance of older, conventional diesel engine models. Without engaging and educating this key constituency, companies pursuing low-carbon innovations may find promising technological avenues prematurely closed off.

CONCLUSION

As a maker of premium cars and trucks, Daimler faced daunting challenges in balancing fuel efficiency and customer preferences for exceptional quality, safety, and service for passenger vehicles, and for a high weight carrying capacity and the ability to travel over different types of terrain, along with other demands, for trucks. Daimler's ability to achieve low-carbon innovations in such a large, established, and heavily regulated industry illustrates several capabilities for bringing new technologies and solutions to market. Daimler was able to bring AdBlue (DEF) to market by effectively managing relationships and partnerships internally through newly created product development networks, and externally within new industry networks of suppliers, competitors, and industry associations. Second, Daimler's senior executives set specific goals that empowered engineers to pursue low-carbon innovations and helped them to balance trade-offs. This is evidenced by the specific fuel-efficiency targets set for the car and truck businesses, supported by additional CO_2-specific goals within the company, as well as the board of director's involvement in guiding and monitoring Daimler's environmental strategy. Daimler's long-term strategic vision to meet evolving market and regulatory demands reflects a turning point in the company's history, representing a proactive commitment to clean diesel technologies rather than relying on short-term, incremental efficiency efforts. Finally, this case illustrates the time and resources that Daimler's regulatory affairs and product development teams invested in educating and engaging with the company's regulators to ensure the viability of its low-carbon solutions. These innovations created new profitable product lines, while also helping to manage the move to a low-carbon transportation future by significantly improving the fuel efficiency of a sizeable percentage of the almost two million vehicles that Daimler sells each year.

ENDNOTES

1 Urea is a non-toxic, organic compound that is highly soluble in water. It binds easily with nitrogen and is widely used in industrial and agricultural processes. The urea, hydrolyzed as ammonia, reacts with nitrogen oxide emissions to create nitrogen and water.

2 The U.S. National Highway Traffic and Safety Administration and the U.S. Environmental Protection Agency jointly set federal vehicle GHG standards and corporate average fuel economy (CAFE) standards—for fuel economy (miles per gallon, "mpg") and carbon intensity (grams of carbon dioxide-equivalent emissions per mile, "gCO_2e/mi"), respectively. The standards for 2012 to 2016 require passenger cars to meet an estimated combined average of 38.0 mpg and 224 gCO_2e/mi in 2016, and for light trucks to reach 28.3 mpg and 302 gCO_2e/mi by 2016. Combined, the vehicle standards will achieve 34.1 mpg and 250 gCO_2e/mi. In July 2011, the Obama Administration reached a deal with 13 automakers to increase U.S. fuel economy standards for cars and light-duty trucks to 54.5 mpg by 2025. The agreement will likely increase the fuel economy of the cars and trucks on U.S. roads by about 50 percent in 2035. For more information, see "Federal Vehicle Standards," Center for Climate and Energy Solutions, http://www.c2es.org/federal/executive/vehicle-standards.

3 International Energy Agency (IEA), "IEA Statistics: CO_2 Emissions from Fuel Combustion, Highlights," 2010 Edition, http://www.iea.org/co2highlights/co2highlights.pdf.; U.S. Energy Information Administration, "World Energy Demand and Economic Outlook," in *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010), http://www.eia.gov/oiaf/ieo/world.html. The majority of emissions (95 percent) from transportation are composed of CO_2, which is released during fossil fuel combustion; an additional 1 percent comes from methane (CH_4) and nitrous oxides (N_2O), also associated with fossil fuel combustion; the leakage of hydrofluorocarbons (HFCs) from vehicle air conditioning systems is responsible for the remaining 3 percent.

4 U.S. Energy Information Administration, *International Energy Outlook 2010* (Washington, DC: U.S. Department of Energy, 2010), http://www.eia.gov/oiaf/ieo/pdf/0484(2010).pdf.

5 U.S. Environmental Protection Agency, *Light-Duty Automotive Technology, Carbon Dioxide Emissions and Fuel Economy Trends: 1975 through 2009*, EPA420-R-09-014 (Washington, DC: U.S. Environmental Protection Agency, 2009), http://www.epa.gov/oms/cert/mpg/fetrends/420r09014.pdf.

6 Nitrogen oxides (NO_x) refer to compounds of nitrogen and oxygen that are regulated as contributing to smog, acid rain, and ozone depletion. One of these compounds, nitrous oxide (N_2O), is a GHG that is 296 times more potent than CO_2.

7 Thermal efficiency refers to the ratio between the energy input and the useful work output of a device. Friction, heat loss, and other factors reduce thermal efficiency.

8 In a spark-ignition engine, fuel and air mix before entry into the fuel combustion cylinder to prevent damage pre-ignition. Since only air is compressed in a diesel engine cylinder, and fuel is not introduced until later, premature detonation is not an issue and compression ratios are much higher.

9 According to the U.S. Department of Energy, diesel engines are more efficient overall than gasoline engines (45 percent versus 30 percent) and further advances are possible (up to 55 to 63 percent).

10 "Euro 5 emissions standards for cars," EurActiv, accessed August 1, 2011, http://www.euractiv.com/en/transport/euro-5-emissions-standards-cars/article-133325.

11 See, for example, Boston Consulting Group, *The Comeback of the Electric Car? How Real, How Soon, and What Must Happen Next* (Boston Consulting Group, 2011), http://www.bcg.com/documents/file15404.pdf. and David L. Greene and Steven E. Plotkin , Reducing Greenhouse Gas Emissions from U.S. Transportation (Arlington, VA: Center for Climate and Energy Solutions, 2011). http://www.c2es.org/docUploads/Reducing_GHG_from_transportation.pdf.

12 Boston Consulting Group, *Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020* (Boston Consulting Group, 2011), http://www.bcg.com/documents/file36615.pdf.

13 Selective catalytic reduction (SCR) is a means of converting NO_x, with the aid of a catalyst, into diatomic nitrogen (N_2) and water (H_2O). A gaseous reductant, such as urea, is added to a stream of flue or exhaust gas and is absorbed onto a catalyst. Urea is widely used in the industrial, chemical, and agricultural sectors as a safe and stable means for transporting ammonia and, as importantly, SCR has been in use since the 1980s to reduce NO_x emissions from stationary diesel engines. See Scott Fable, Fanta Kamakaté, and Shyam Venkatesh, *Selective Catalytic Reduction Urea Infrastructure Study*, NREL/SR-540-3268 (National Renewable Energy Laboratory, 2002), http://www.nrel.gov/vehiclesandfuels/apbf/pdfs/adl_urea.pdf.

14 Mercedes-Benz, *From Prechamber to BlueTEC HYBRID: The History of the Diesel Engine* (Mercedes-Benz, 2011).

15 Daimler, *Pioneers of Sustainability. Annual Report 2009* (Daimler, 2010), 83.

16 Daimler also credits the innovation and introduction of ultra-low sulfur diesel (ULSD), mandated for use in the U.S. market in 2006, with making the BlueTEC system possible. ULSD is a refined diesel fuel that has a much lower sulfur content than regular diesel fuel, which results in dramatic reductions in air emissions. ULSD is required for the precise engine and advanced exhaust treatment technology of all Mercedes-Benz diesel vehicles.

17 Dr. Dieter Zetsche (presentation, Geneva Motor Show, February 2007).

18 World Business Council for Sustainable Development, *Mobility 2030: Meeting the Challenges to Sustainability* (World Business Council for Sustainable Development, 2004), http://www.wbcsd.org/web/publications/mobility/mobility-full.pdf.

19 Transportation Research Board, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* (Washington, DC: The National Academies Press, 2010), 1.

After four years, long-distance trucks are often refurbished and re-used for local hauling and other activities, where fuel mileage and engine reliability is no longer as important. The useful life of the trailer, however, can be up to twenty years.

21 Transportation Research Board, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* (Washington, DC: The National Academies Press, 2010), 19.

22 These associations include, for example, the German Association of the Automobile Industry in the initial development of the SCR technology, and the American Trucking Association and the National Association of Truck Stop Operators (NATSO) in the rollout of SCR in the North American truck fleet.

23 Mercedes-Benz, *From Prechamber to BlueTEC HYBRID: The History of the Diesel Engine* (Mercedes-Benz, 2011), 65.

CASE STUDY: HP

CASE STUDY	HP Beyond Reduce, Re-use, and Recycle: Rethinking the Way We Do Business
Headquarters:	Palo Alto, CA
Industry:	Information and Communication Technologies
CEO:	Meg Whitman
Revenues (2010):	$126 billion
Average Annual R&D Spend:	$2.8 billion
Employees:	320,000
Keys to Success:	• User-focused Value Propositions • Business Model Innovations • Clear Direction and Commitment from Leaders
Low-Carbon Innovations:	• **Visual Collaboration** Visual Collaboration is a videoconferencing software and hardware—ranging from desktop solutions to immersive studios and from infrastructure to concierge services—that provide a high-quality, high-definition communication experience. The use of Visual Collaboration successfully avoids carbon emissions associated with business travel. In two years, between April 2007 and March 2009, HP and its customers saved an estimated 66,000 metric tons of carbon-equivalent (CO_2e) greenhouse gas (GHG) emissions using Visual Collaboration[1] and HP reduced its own employee business travel by over 43 percent. • **Managed Print Services** Managed Print Services is a solution through which HP works with corporate customers to design, implement, and manage an imaging and printing infrastructure (including network, processing, printers, paper and toner, and maintenance) tailored to the specific requirements of each customer and adaptable to changing needs. For one enterprise customer with 10,000 employees, Managed Print Services has reduced energy consumption associated with printing by 66 percent (539,666 kilowatt hours, "kWh") and reduced CO_2e emissions from avoided energy and paper consumption by 381 metric tons. These results suggest that the effective management of printing, if applied to just the Fortune 500 companies and their approximately 60 million employees, could cut carbon emissions by about 2.3 million metric tons.

How do you reduce the carbon footprint of your products in use when your industry (information and communications technology) is rapidly evolving and your main technology (the silicon chip) is doubling in performance roughly every two years, and has done so for the past fifty years? For HP, one answer is adding another R to the traditional "*Reduce, Re-use, Recycle*" mantra: *Rethink*. While reducing, re-using, and recycling are valuable strategies for pursuing greater efficiencies in current products and processes, *rethinking* considers entirely new and different ways of doing things.

HP has had a long history of involvement with environmental sustainability and its own carbon footprint, and its employees have begun to *rethink* the role the company's products play in customers' overall business processes, and particularly each product's energy consumption and carbon emissions *in use*. Two low-carbon innovations at HP illustrate the potential for this rethinking. The first is Visual Collaboration, a premium videoconferencing technology that, by enabling an extremely high-quality, high-definition experience to users, successfully reduces business travel. The second is Managed Print Services, which changes the way printing is done in the office environment by converting a business traditionally focused on selling printers and ink into a service that manages customers' printing needs and dramatically reduces their energy and materials consumption.

By leveraging its technology leadership in computing, imaging, and printing, as well as its history of environmental leadership, HP is able to rapidly develop and bring these low-carbon innovations to market, and to achieve significant reductions in both customer cost and carbon emissions. Through these innovations, their demonstrated success with reducing emissions, and the potential for yet more low-carbon innovations in the future, HP is positioning itself to reduce the carbon footprint of its hundreds of millions of customers, who range from individual consumers to the world's largest enterprises, across a wide range of applications. In an industry that puts a premium on product innovation and has product lifecycles that are vanishingly brief, companies that deliver technologies and services that are not only better and faster, but also more efficient, are able to maintain a competitive edge.

COMPANY PROFILE

HP is arguably the most successful garage startup in history. Founded in 1939 by Stanford classmates Bill Hewlett and Dave Packard out of a garage in Palo Alto (a spot that now boasts a California historical registry plaque as the "birthplace of Silicon Valley"), HP has grown to become the world's largest information and communications technology (ICT) company. In 2011, it ranked 11th in the Fortune 500, with more than 320,000 employees in 170 countries and revenues of $126 billion.

HP develops and manufactures computing, data storage, networking hardware, software, and ICT services. The company's product lines include personal computing (PC) devices, enterprise servers, related storage devices, and a diverse array of printers and other imaging products. The company ships more than one million printers per week, 48 million PC units per year, and one in every three servers sold worldwide. Like many successful technology companies, HP has widely changed its product and service offerings over the years, driven less by any particular "core offering" (HP's first product was an audio oscillator for use by sound engineers) and more by the need to continuously innovate in a rapidly evolving industry in order to help its customers succeed at what they do.

HP has achieved this success while consistently earning top "Greenest Companies" rankings from *Newsweek*, among others, and comprehensively linking its brand with its commitment to sustainability. This success emerges from its corporate culture: The legendary "HP Way" philosophy states, among other things, that the company has always been about something bigger than short-term profits. As co-founder David Packard said in 1947:

> "Many assume, wrongly, that a company exists simply to make money...the real reason HP exists is to make a contribution…to improve the welfare of humanity... to advance the frontiers of science...Profit is not the proper end and aim of management—it is what makes all of the proper ends and aims possible."[2]

Today, the company is committed to reducing the GHG emissions from owned and leased facilities to 20 percent below 2005 levels by 2013 on an absolute basis. HP continues to take responsibility for all of its products at the end of their functional life, and increasingly designs every new product to make it easier to reuse or recycle parts. Collaborating with the Lavergne Group, HP has kept more than 210 million HP ink cartridges out of landfills, while manufacturing more than one billion new ink cartridges with recycled plastic content. This alone has brought a 22 percent reduction in the carbon footprint of HP's manufacturing processes.[3] Combining HP's culture with its sheer volume of product (in 2010, HP shipped an estimated 3.5 products per second), and it becomes clear that few other technology companies have the same opportunity to capitalize on low carbon-innovations with a similar scale and scope.

In as rapidly evolving an industry as ICT, reducing the energy and associated carbon footprint of your products in use is both inevitable and challenging. On the one hand, the energy needs of computing devices and their associated carbon footprint have dropped dramatically *relative to performance*, as described by Moore's Law.[4] The increased computing power of each new generation of integrated circuits brings corresponding decreases in cost, space, and power consumption. The earliest computer—the UNIVAC I in 1951—required 125 kilowatts (kW) to perform 1,905 operations per second, or roughly 0.015 operations per watt-second. In June 2010, the most efficient supercomputer required just 1.29 watts to perform a billion operations per second, about 51.5 billion times more efficient.[5]

On the other hand, however, the *overall demand for power* in computing and related activities (such as printing, imaging, and communication) increases with the growth in computing devices and services. The world's computer networks today consume more than 100 billion kW of electricity annually, helping make the ICT sector, through the manufacture and use of its products, responsible for 2 percent of global GHG emissions, a share that is expected to reach 4 percent by 2020.

This puts companies like HP in a unique position. It is estimated that the ICT industry can apply its technology and expertise to cut global GHG emissions by as much as five times their own direct impact in this same timeframe.[6] To achieve such meaningful GHG reductions, low-carbon innovations from these companies will need to target carbon reductions both in their own sector as well as to generate a range of valuable innovations targeting energy and emissions reductions in other industries.

As the ICT sector's impact on global carbon emissions has become clearer, HP has directed considerable time, talent, and resources to better understanding its products' carbon footprints *in use* and to do what it can—a constantly evolving set of possibilities—to reduce those footprints. "Applying our rich expertise and know-how, we're creating more efficient, low-carbon technology solutions that help our customers save energy, resources, and costs," says HP's Vice President of Sustainability, Engelina Jaspers. This includes the specific goal to reduce the energy consumption and associated GHG emissions of all its products to 40 percent below 2005 levels by the end of 2011, a target the company achieved in March of 2011.

So how did HP achieve this goal? One of HP's stated objectives is to use ICT to "replace carbon-heavy behaviors and industries with alternatives that will use less energy and generate less carbon—all while increasing productivity and lowering costs."[7] To accomplish these goals, HP had to rethink the role its products play in its customers' overall business processes. Two low-carbon innovations at HP illustrate the potential for this rethinking: Visual Collaboration, which addresses a new opportunity for reducing customers' costs and carbon footprint, and Managed Print Services, which changes the way printing is done in the business environment.

VISUAL COLLABORATION

In addition to the financial cost of traditional face-to-face meetings in a global marketplace (airfare, hotels, food) there are significant environmental costs as well. As HP describes in its 2010 Global Citizenship Report: "A roundtrip flight between San Francisco and Singapore [8,500 miles one-way] can generate 3.3 metric tons of CO_2 emissions per passenger. Add the time and expense of an average trip and business travel comes with a big bill, both for companies and the environment." Companies have long sought to use videoconferencing to replace such resource-heavy business travel, but poor quality meant that few participants would willingly and comfortably discuss an idea, present an argument, or have a conversation on which his or her career depended. HP took on this challenge, designing a virtual meeting experience that would be considered an adequate replacement for face-to-face discussions that may require hours of plane and automobile travel, an overnight stay in a hotel, and the same commute home again, for a meeting that may last only an hour or two.

The result of this effort was HP Visual Collaboration, a virtual meeting space that allows for global interactive collaboration. This solution, first developed and used internally, increased HP's productivity (less time commuting, more time computing), reduced travel costs, and avoided the carbon emissions from business travel. Launched commercially in December 2005, HP's Visual Collaboration system provides far more than a typical videoconference. Visual Collaboration is based on a scalable encoding technology that supports high-definition video and includes a desktop client, executive desktop, and integrated conference room and A/V systems. Using state-of-the-art information and communication technologies, it seeks to replicate the experience of being together with people in a conference room, down to the table and chairs (**Figure**).

Visual Collaboration provides an experience for participants that sufficiently imitates being in the same room. Users are able to experience the deep social interactions that enable a productive meeting: People on screen are the same size as those actually in the room. The participants sit on opposite sides of an identical table in identical chairs. Users can look each other in the eye and see facial responses with enough clarity to distinguish between a tic and a wink, while the audio system's sound quality renders the technology essentially invisible.

HP developed Visual Collaboration in close cooperation with one of its key customers to support the demands of the customer's global creative teams. As HP's design team considered the potential markets for this technology, the team decided that the opportunities for connecting seamlessly and effectively through video were as significant as the trend towards globalization. As Mark Gorzynski, leader of the design team, described:

> "One main driver [for the development of Visual Collaboration] is the cost of doing business globally. [There are] direct benefits that are measurable, like the [reduced] carbon footprint. But I think, from small companies trying to ship things globally to large companies doing workflows globally, it's very hard to find a team now that is not trying to…work over distance, that is not trying to overcome the limits of urbanization."

In other words, social and economic wellbeing and productivity depend on teams collaborating effectively across traditional geographic boundaries, using

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FIGURE: Visual Collaboration in Use

Source: Image provided courtesy of HP (2010).

less carbon-intensive means. In this context, Visual Collaboration provided a means for connecting an increasingly fragmented world. As an HP executive described:

> "[We were] trying to help people have a broader set of capabilities. Do they need medical care? Do they need access to education? Whether from companies or local communities, there is a great need [for] building on this technology—what we saw in [our initial customer] was not just one company's need, it was a pervasive pattern."

The timeline for the project was aggressive. In 2003, the design team started working on development with the customer. By 2004, HP was rolling out units across its own offices and starting tests with select customers. By 2005, the team had conducted pilots with customers and was increasing the rollout across HP. Meanwhile, the customer that had helped inspire the project started using the technology as well. Soon, this incubation phase reached the point where the company felt the technology was proving its value. One of the first connections enabled by the technology was between HP's Singapore factory and its Corvallis, Oregon, engineering offices. Corvallis had a long history of working with Singapore, "burning a lot of carbon between the two sites," as one engineer put it. Rolling out Visual Collaboration not only reduced travel costs, jet lag, and carbon emissions, it also increased the frequency of collaboration meetings. The earlier videoconferencing systems that HP had bought typically sat unused, while the new system was booked throughout the day. As one engineer described:

> "We would go into [HP] sites and they would have videoconferencing centers there that were full of spider webs, storage boxes, and all kinds of things that people didn't use. We would tear that out and put our systems in, but not tell them anything. Just say, 'OK, got a new system there.' Suddenly, they'd be used eight hours a day, all full on business hours, without forcing."

As of May 2010, HP had over 26,000 teleworkers (employees who work exclusively from home) worldwide who use HP Visual Collaboration as an option to attend their company meetings from home or while traveling. In its first three years of use (starting in 2005) at HP, the first Visual Collaboration studio solutions "reduced business travel by 43 percent in some groups and eliminated it completely in others," the company found. This, in turn, avoided more than 175,000 metric tons of CO_2e—the equivalent of cutting fuel use by more than 18.7 million gallons or eliminating over 143,000 roundtrip flights between New York and London (or 53,000 of the original Corvallis to Singapore roundtrip flights that initiated the project).[8] New HP Visual Collaboration desktop and room solutions that bring video to more users, introduced in November 2010, are expected to increase that number substantially as more enterprises move to holding more meetings by way of high-definition quality desktop video.

MANAGED PRINT SERVICES

The printer business has traditionally been organized around selling more printers and, concurrently, more ink cartridges. It is the classic razor and razor blade business model. When faced with the challenge of reducing its customers' costs and carbon emissions, HP first introduced power management features across its printing product lines, reducing power consumption while printers were in use and, as importantly, while in standby mode. Traditional printers consume roughly 250 watts while printing and 15 to 30 watts while in standby and, as rule of thumb, standby power costs consumers $1 for each watt annually (at retail electricity rates). Given the amount of down time for printers, most typically consume twice as much power in standby mode as in use. The new printers HP released were able to reduce that standby power use to 1 watt—no small feat when printers are often connected to multiple computers and must be able to continuously monitor a network. While this innovation reduced the energy consumption of individual printers, the worldwide market for printers is increasing dramatically,[9] with printers appearing in every manager's office in some companies. Because each printer uses energy and printer cartridges, the reductions in energy and materials consumption were not keeping up with this increasing number of printers (and things being printed).

HP looked for more ways to reduce its customers' energy costs and carbon footprint, rethinking its printer business to come up with new sales and service solutions. About ten years earlier, HP had heard from customers that printing was getting too large and out of control—and they were asking what HP could do for them. An HP team responded by experimenting with a service that used HP's existing expertise to manage a customer's diverse printing assets. The result, Managed Print Services, was a significant shift in focus: from selling printers to selling the management of print services for an office or entire corporation. As Bruce Dahlgren, Senior Vice President of Worldwide Sales and Services for the Imaging and Printing Group, said when introducing the service, "It may seem counterintuitive that a printing company like HP wants to help customers print more efficiently but that's exactly our focus and intent—to help our customers print more responsibly and intelligently."[10] This service focuses on optimizing customer infrastructures, managing their printing environments and improving workflows through such steps as optimizing the location of printers to use fewer devices, using duplex printing to save paper, using staff ID cards to initiate and track print jobs, and remotely monitoring cost and usage information. In essence, Managed Print Services helps customers increase efficiency, reduce costs, and meet their business sustainability goals. The service has evolved to include a remote support team that works 24 hours and 7 days a week (some customers even have dedicated HP employees on-site) and is backed by a performance guarantee ensuring customers will meet the projected savings goals.

Managed Print Services will typically reduce an average company's overall printing-related operating costs by about 30 percent, reduce its energy consumption from printing by 30 to 80 percent, and reduce paper use by millions of pages through paper management policies. HP estimates the shift to digital commercial printing has the potential to decrease annual global GHG emissions between 110 and 250 million metric tons CO_2e by 2020. For HP, the benefits include strengthening customer relationships, and gaining insight into the changing nature of printing in offices, which could lead to further opportunities for innovation.

MANAGING LOW-CARBON INNOVATION

User-focused Value Propositions

The *sine qua non* of successfully commercializing low-carbon innovations is the value proposition such solutions offer to customers. Customers will not adopt low-carbon innovations unless the new products or services bring significant benefits, such as lower costs, increased flexibility, or competitive advantages, in addition to reduced carbon emissions.

User-centered design, or human-centered design, is a design philosophy and process in which a product's value proposition is pursued and defined in terms of the needs, wants, and limitations of end users. In today's markets, in which a producer is often separated from the end user by an extended chain of manufacturing, distribution, sales, and purchasing decisions, product and process designs often put top priority on the needs of these extended systems, neglecting the original and ultimate user. The distinguishing feature of user-centered design lies in re-orienting the product or service around how users can, want, or need to use it, rather than forcing users to change behavior to accommodate the product and process. Considerable attention is thus given to user needs, particularly at the earliest stages of development.

At HP, a focus on the needs of customers acts as an early filter on commitments to pursue an innovation. This critical need is present in the company's technology development processes (see, for example, Sidebar: CeNSE: A Low-Carbon Innovation on the Horizon, next page). And this was particularly so with Visual Collaboration, where user-centered design played a significant role in the product's success. Although using the latest and greatest information and communication technologies, HP's Visual Collaboration is only partially a technology-driven product. Indeed, what is most striking about the system to the average user, particularly before it is turned on, is the design of the room, with its customized table, chairs, and configuration of screens, rather than the high-end, powerful video processing backstage.

Several factors contributed to the success of HP's approach to innovation and to the development of Visual Collaboration in particular. HP's longstanding practice of designing new high-tech products to solve problems that the engineer at the next bench was facing originally led to its leadership position in electronic testing and measurement equipment. HP also had a test-bed to develop and validate a solution for telepresence: Because the company had engineering and manufacturing facilities all around the world, employees were constantly flying back and forth. Moreover, HP had a longstanding relationship with a key customer that relied on connecting talented contributors from across the country using significant computing power. As in most major multinational companies, every project within this firm had teams that were spread across the country and

CeNSE: A Low-Carbon Innovation on the Horizon

"You can't manage what you can't measure."

HP Labs and the Imaging and Printing Group are taking that old management adage to heart, developing an advanced sensor system that will allow for real-time measurements across a wide range of challenging applications, such as tracking facility-level energy consumption or water flow, monitoring for gas leaks, or sensing possible stress on a bridge.

According to HP in its 2010 Global Citizenship Report, these sensors are up to 1,000 times more sensitive than existing technology—so precise that they "can hear footsteps, detect an ammonia or gas leak, feel the speed and volume at which traffic moves along a freeway, or sense wear and tear on vital equipment." As important, this new system would be capable of meeting three seemingly paradoxical but necessary goals of broadly-distributed sensor networks: high precision, high volume, and low cost.

The Central Nervous System for the Earth (CeNSE) consists of highly intelligent networks of first tens of thousands, then millions and potentially billions of nano-scale sensors. These sensors would be integrated into buildings, transportation systems, agricultural fields, and other infrastructure to enable detailed monitoring of resource use, drive maintenance decisions, and even anticipate failures. In electricity applications, CeNSE could align supply with demand, decreasing waste and reducing risk in the electricity grid.

The biggest challenge for such a system is adapting each of the components to work effectively together. The data from hundreds, even thousands, of high-precision sensors (up to 60 gigabytes of data per second) can easily overwhelm a communications network, let alone the computers needed to process the information. As a result, the entire system must be designed together—from the sensors, to the "first mile" connecting those sensors to the larger network, to the broadband connection, to the data processing and storage—and the elements fine-tuned to work collectively with precision.

In addition to the challenges of tuning the entire system to work seamlessly, each part needs to be cost-effective and produced at sufficient scale. As Stan Williams, senior fellow at HP Labs, describes: "We're working towards developing a trillion inexpensive [sensors]… a very large volume of a very precise device." Stan and his team found the expertise they needed to design and manufacture millions of high-precision electronic packages very close to home: HP's Imaging and Printing business, which makes millions of ink cartridges every year.

HP recognizes, however, that while it would be a technological feat to make the sensors and the communication and computing networks that would surround, gather, process, and store the information collected, the technology alone is not enough to create a valued solution for its customers, the end-users. What's also needed is the means to analyze and apply the resulting information. The value for the customer, and the environmental benefits of this technology, will emerge through applications that others develop to exploit this new tool.

the globe. In order to keep projects on schedule, and to make sure critical questions were asked and changes coordinated when they first arose, this firm had a strong need for the best collaborative communication solution possible. These early users provided the design team with valuable feedback during development.

Yet the history of Visual Collaboration's development shows there was an element of the solution even more grounded in "low-tech" than the chairs, table, and stage props of the screen-wall. The lead designer of the system, Mark Gorzynski, was trained as a cognitive scientist. In many ways, he was the perfect choice because the essential challenges facing the team were never driven by the technology—most of which was developed already. The challenge, as Gorzynski described, was very different and yet very simple: "Design an experience comfortable enough that a manager would willingly discuss an idea, present an argument, or have a conversation on which his or her career depended." If this could be achieved, the system would be considered an adequate replacement for a face-to-face discussion.

Certainly there were critical technical challenges to make such an experience work, and HP had the engineering talent and resources to solve them. But more important, those talents and resources needed to be directed towards solving the right problem—in this case a non-technical one. The project team's initial challenge—making a videoconferenced meeting as socially and politically comfortable as an in-person meeting—meant first understanding what it was about the experience of meeting with others that made it comfortable or not for participants.

The team soon found there was a hierarchy of social needs involved in collaboration among people. As they describe, there is simple presence: "I know where you are." There is voice: "I can share voice and other things with you, I can share symbols and text." There is vision: "I can see your reactions, I can see your eyes furrow and study and smile, then I can see gesture awareness." And then: "I can see group dynamics. For example, I can see if my boss leans back and looks worried because of what you're saying." By working with sociologists and social linguists who understand the myriad aspects of how people communicate, the design team determined how this hierarchy of communication directly relates to the meeting facilitation that it needed the new product to accomplish.

Gorzynski and his team had come from the HP Imaging and Printing Group and they understood how print and display images differ from "real" images (for example, printed images of foods have to look different than real foods to appear appealing, let alone edible). So what was it about attending a meeting that made it a comfortable experience? The team members engaged with cultural anthropologists to make sure they truly understood the problem they were trying to solve: "the meeting." Their findings identified critical features of the system, without which they knew they would not succeed.

For example, they needed what they called "panoramic multi-point"—the ability of anyone in a "meeting" to be able to point at anyone else (or look directly at them) and have everyone else be aware of the gesture. This was one of a number of factors that people take for granted when meeting face to face. During a meeting in which your project, your reputation, and maybe even your career will be affected, it is absolutely essential, while you are talking, that you are able to see everyone else's face in the meeting, to look directly at any one of them to ensure you can read their non-verbal responses and, in turn, to see in their eyes whether they are listening and whether they are agreeing or disagreeing, expressing doubt or support, keeping up or confused. If someone in the room is doodling, on their smart phone, or exchanging glances with someone else across the room—you need to be able to notice that. And so does everyone else in the "room." If 90 percent of all communication is non-verbal, and if more is on the line than ordering a sweater or debugging a computer glitch, then a bad video connection is not going to work. In fact, it may be worse than no video. And it will be used for only the most basic of information-sharing tasks.

Making it possible to achieve the deep social interactions needed for a productive meeting was a considerable technical challenge. Gorzynski's engineering team began by translating their list of requirements into technical capabilities. First was the ability to make the people on screen appear the same size as those in the room, sitting on the other side of an identical table, with identical chairs, and to see the facial responses on the screen with sufficient clarity to distinguish between a tic and a wink. Second was making it possible to sit six people across one side of the table, and six across the other (or three pairs of two from three other locations), to look at any one of them in the eye, and as critically, to have them look directly back at you. And third was a sound quality that renders the technology essentially invisible.

Once the basic technology was developed, HP needed to test the design and demonstrate its value in use. In 2008—the year of the financial crisis—HP sharply restricted internal travel. HP employees were still able to travel to meet customers, but traveling for internal meetings was strongly discouraged. Visual Collaboration quickly gained users, providing designers with valuable end-user feedback from the product in use.

Business Model Innovations

The term 'business model' describes the particular network of relationships that a company establishes to, in essence, integrate available technologies (and other resources) and deliver them as a compelling solution to a market need. A business model is not just a strategy, not just a revenue model (how it makes money), not just a collection of technologies that power the company's offerings, and not just a description of how product features match customers' needs. Instead, a business model is the combination of all of those things. More importantly, it describes how all those factors work together as a single profitable, valuable, and defensible network. New business models break the traditional relationships between offerings, customers, and market structures, enabling emerging technologies to compete on their strengths.

Changing a business model can reshape the innovation process for low-carbon solutions and the way cleaner technologies come to market. Without new business models, emerging technologies must compete directly with old ones on their terms. With new business models, companies can take advantage of the distinct advantages that new technologies bring.

But these entirely new business models often challenge a company's existing ways of doing things and maximizing profit. HP's printing business has traditionally been organized around selling more printers and ink cartridges, so the easiest first step for the company was to rework existing products, making them more energy efficient in use. While this innovation reduced the energy consumption of individual printers, the market for printers continued to increase dramatically and printing's environmental impact continued to grow.

HP needed to look for ways to reduce its customers' energy costs and carbon footprint on a more significant scale, beyond incremental efficiency improvements. The company ultimately introduced a new service that transformed its printer and toner business into a service business, one that reduced consumption of both printers and toner. For a company like HP, this might border on heresy: It manufactures and sells more than a million new printers each week, and its printing business generated revenues of $7 billion in the first quarter of 2011 (up from $6.5 billion for the same quarter in 2010), with revenues continuing to grow. Creating such an innovative service business required a change in HP's printing business model.

HP looked at the best way to reduce the energy costs and carbon footprint of printers in use and made a significant leap—boldly rethinking the structure of its printer business. Could it continue to maximize printer and cartridge sales? Certainly this would be good for business in the short run, but the carbon shadow cast by more than a million new HP printers sold every week might ultimately become a liability.

Rethinking this business, HP developed Managed Print Services—a radical departure from HP's traditional business model in that it shifts the company's focus from selling printers to selling the management of print services for an office or entire corporation. The result? One of HP's early customers of this service, Viacom, a company of approximately 10,000 employees, was able to reduce 60 to 90 percent of printing-related energy consumption (an average across buildings of 66 percent, totaling 539,666 kWh); reduce the number of printers by 50 percent; and reduce printing by an estimated ten million sheets of paper. Overall, Viacom achieved a 40 percent savings in printing-related carbon emissions, or an estimated total annual reduction in CO_2e emissions of 381 metric tons. For HP, the benefits are different but no less dramatic. The printer business is rapidly becoming a commodity business. Yet HP, with Managed Print Services, can bring steep reductions in printing costs and a new service to its customers while, at the same time, strengthening those customer relationships. Having visibility and control over the printing process also provides HP's engineers with insights into the changing nature of printing in offices, which can point the way to new opportunities for further product and process innovations.

Managed Print Services illustrates that rethinking the business model, going beyond incremental or local improvements to current products, is a potentially valuable way to develop and bring profitable low-carbon innovations to market. While such innovations might be recognized at the level of the development teams creating the next generation of products, they require insight into the strategic directions of both HP and the marketplace. And they require commitment by leaders in the Imaging and Printing Group.

Clear Direction and Commitment from Leaders

In any industry, shifts in the external environment often drive the need for organizational change. Periods of relative stability and growth are interrupted by moments of substantial upheaval. Such moments, triggered by events outside the organization, include the emergence of new technologies, major regulatory actions, changing consumer preferences, shifting legal environments, and constrained capital markets. In such times, organizations often find their people, strategies, and operations misaligned with the demands and opportunities of these new circumstances, and must innovate accordingly.

Such innovation requires strong leadership that embodies both the vision of and commitment to a new strategic direction. This is especially critical in developing and bringing low-carbon innovations to market, where the organization's traditional technical capabilities, market strategies, and financial metrics must shift, sometimes dramatically, to take into account new environmental goals or imperatives, whether driven by changing social values or public policies. Low-carbon innovation projects require the vision and commitment of leaders to drive the organizational changes necessary to meet the needs and opportunities of a shifting competitive environment. Leadership requires recognizing the changing needs of customers and other constituents for low-carbon innovations, and the business opportunities those changes create. For HP—a leader in an industry that has experienced nearly 50 years of continual change, the challenge is not creating a culture of innovation or a new technology but rather redirecting innovation toward the most rewarding and profitable ends.

This commitment was expressed as a clear vision of HP's role in developing solutions to environmental challenges and was consistently communicated both within and outside HP. Shane Robison, Chief Strategy and Technology Officer, recognized the importance of low-carbon innovations at HP, stating:

> "As an industry, we have an obligation to continually improve our energy efficiency and carbon footprint, and we are making meaningful progress. But the greater opportunity is using IT to address the other 98 percent [of global GHG emissions]. This may drive the 2 percent [of GHG emissions in the ICT sector] slightly higher, but it will shrink the overall pie."[11]

For the Visual Collaboration business, one of the most visible and effective signs of this commitment by HP's leadership came in 2008 when, facing a market recession, the company sharply restricted "internal" travel among HP's many sites (roughly half of the company's travel), relying instead on its own Visual Collaboration tools.

HP has always had a strong leadership commitment to innovation and sustainability, illustrated in its strategy for product development. From its earliest days, HP has invested heavily in its central R&D operation, now called HP Labs, which conducts high-impact scientific research aimed at "the most important challenges and opportunities facing our customers and society in the next decade."[12] The Labs employ roughly 700 PhDs in seven locations around the world and are focused on eight broad themes: Cloud and Security, Information Analytics, Intelligent Infrastructure, Mobile and Immersive Experience, Networking and Communications, Printing and Content Delivery, Services, and Sustainability. HP Labs reports to the Office of Strategy & Technology, which includes corporate strategy and new business development, where emerging businesses can be incubated before moving into the traditional business units. When Visual Collaboration was first launched as a business (more than simply a promising technology), rather than being placed immediately inside one of the existing business units (which are organized to run large and stable product and service lines), it began within the Office of Strategy & Technology. There it could receive the attention and support it needed to develop and evolve.[13] This organizational structure gives new businesses time and support to develop and prove their business models.

Emerging innovations must earn such commitment from senior leadership. In the case of Visual Collaboration, earning and maintaining the commitment was challenging because, during its development and launch, HP had three different CEOs: Carly Fiorina, Mark Hurd, and Léo Apotheker. As Mark Gorzynski explains,

> "[A]t each stage of the program's development we had to have two things to get over that barrier [to securing continued commitment]. We had to have a psychological bonding with the value of the business; [the CEO] had to intuitively believe that it had value. And then, in the finances, whether the numbers looked good. HP is very strict about both of those."

The team managed to obtain this commitment from the CEOs and other top leadership by "getting them in the rooms, by having them use the systems. They became viscerally dependent on them. They became addicted to the efficiency of them." The second barrier was financial: showing the return on investment for this business and the measurable benefits to customers. Again, the team managed this commitment by working closely with early customers and demonstrating the clear value proposition of the solutions.

While HP's vision and commitment to innovation has been well established over the 50 years it has been a leader within its sector, the increasing emphasis on environmental and climate change concerns and energy costs is relatively recent. HP's leadership has had to come to a new understanding of the importance of energy and environmental issues to the company and of the uncertainties these issues create for the company's customers, as evidenced by the company's goal to reduce energy consumption and GHG emissions from products to 40 percent below 2005 levels by 2020. HP had to craft new strategies to integrate these customer needs and goals into the company's plans, and it had to make significant commitments to and investments in achieving new low-carbon innovations.

CONCLUSION

HP is one of few companies to set—and already achieve—a specific goal to reduce the energy consumption and associated GHG emissions of all its products. Through the introduction of such new products and services, HP is positioning itself to significantly reduce the carbon footprint of its hundreds of millions of customers. In as rapidly changing an industry as ICT, reducing the energy and carbon footprint of your products in use is a constantly evolving set of possibilities and opportunities. HP is capturing these by leveraging traditional innovation strategies that are particularly critical to low-carbon innovation. First, HP found that bringing low-carbon solutions to market requires having a very sensitive filter for and an understanding of the needs of end-users, and drawing on "non-technical" talent within the organization to help solve problems. Engaging top leadership and key decision-makers also proved invaluable, in order to obtain buy-in to create an entirely new business model and products—moving beyond incremental improvements—as a way to develop and bring profitable low-carbon innovations to market.

EPILOGUE

In June 2011, HP entered into a strategic relationship with Polycom, Inc., an industry-leading unified communications (UC) solutions provider. Polycom will serve as an exclusive partner to HP for telepresence and certain video UC solutions, including both resale and internal HP deployments. Under the terms of this agreement, Polycom acquired HP's Visual Collaboration business, while HP will continue to provide the networking and computing hardware that supports it. As the two companies stated:

> "This alliance combines HP's networking scale and global reach with Polycom's expertise in videoconferencing to provide customers world-class video and UC solutions through Polycom infrastructure deployed on HP networking and systems. This also allows customers to capitalize on the critical importance of networking as the foundation for a superior video experience and tap the global services of HP for turnkey communications solutions."

This outcome ensures that HP's Visual Collaboration solutions will be integrated, installed, and maintained as part of Polycom's unified communications offerings to customers of both HP and Polycom.

ENDNOTES

1 According to HP's calculations, the average round-trip flight generates 0.91 metric tons of carbon emissions. "HP Halo Benefits Business and the Environment," HP, accessed April 11, 2011, http://h20338.www2.hp.com/enterprise/us/en/halo/environment.html.

2 HP, *HP and the Environment* (HP Development Company, 2008), http://www.hpcollateral.com/Files/EcoCollateral_20091120_Pan_HP_Environment_pgjd.pdf.

3 In the mid-1990s, before the concept of recycling electronic waste (or "e-waste") had really caught on, HP built a state-of-the-art electronics recycling plant in Roseville, CA, to disassemble old computers and printers, extract metals and reuse the plastic in the manufacture of new products.

4 In 1965, Gordon Moore first predicted that the number of transistors fitting on an integrated circuit would double approximately every two years. Today, this trend is used to describe the enhanced capabilities and power of many electronic devices, and is used by industry to guide long-term planning and to set targets for R&D.

5 Performance per watt is a measure of the energy efficiency of computer hardware. Computing performance is measured in FLOPS, or floating point operation per second, and FLOPS/Watt measures the rate of computation that can be delivered by a computer for every watt of power consumed. Will Knight, "Taking a Trip Down Memory-chip Lane," *New Scientist*, June 19, 2005, http://www.newscientist.com/article/dn7536-taking-a-trip-down-memory-chip-lane.html?full=true.

6 The Climate Group, *Smart 2020: Enabling the Low Carbon Economy in the Information Age* (Creative Commons, 2008), http://www.smart2020.org/_assets/files/02_Smart2020Report.pdf.

7 Doug Oathout, *Recognize—and Address—the Need for Green IT with HP's Eco Solutions* (SAPinsider, 2010), http://h30507.www3.hp.com/hpblogs/attachments/hpblogs/663/41/1/Doug%20Oathout%20Article%20-%20SPI%2007-2010_Sustainability_HP.pdf.

8 "HP Announces High-definition Videoconferencing for Desktops and Conference Rooms," *HP*, November 17, 2010, http://www.hp.com/hpinfo/newsroom/press/2010/101117c.html.

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10 "HP Offers Payback Guarantee for Managed Print Services Customers," *HP*, July 13, 2009, http://www.hp.com/hpinfo/newsroom/press/2009/090713b.html.

11 Shane Robison, *Executive Viewpoint: Changing the Energy Equation* (HP, 2009), http://www.hp.com/hpinfo/execteam/bios/pdf/SR_Energy_execview_112009.pdf.

12 "Research," HP, last modified 2011, http://www.hpl.hp.com/research/.

13 By contrast, Managed Print Services began in the Imaging and Printing Group, emerging most directly from the expressed needs of HP's customers rather than from a particular new technology.

CASE STUDY: JOHNSON CONTROLS, INC.

CASE STUDY	JOHNSON CONTROLS, INC. Incremental Revolutions in Energy and Fuel Efficiency
Headquarters:	Milwaukee, WI
Industry:	Diversified Technology and Industrial Products
CEO:	Stephen A. Roell
Revenues (2010):	$34.3 billion
Average Annual R&D Spend:	$723 million
Employees:	150,000
Keys to Success:	• User-focused Value Propositions • Robust Innovation Strategies • Managing Policy Uncertainty in Innovation Strategies
Low-Carbon Innovations:	• **Private-Sector Building Efficiency** Johnson Controls is one of the leading energy service companies in the United States, providing energy retrofit engineering for buildings, project management, installation and commissioning, performance measurement and verification, ongoing maintenance and support, and financing via performance contracting. Johnson Controls has recently expanded from serving institutional, public-sector customers and projects to innovative approaches in serving commercial, private-sector markets, where there are considerably greater opportunities for business growth and environmental impact but also considerably more challenging and complex customer requirements. As part of this effort, Johnson Controls has developed a significant renewable energy business, which enables the company to integrate renewable generation (such as solar or wind power projects) with traditional energy efficiency improvements, reducing customers' overall greenhouse gas (GHG) emissions and energy bills. Buildings represent a still largely untapped opportunity for emission reductions: Globally, the sector accounts for roughly 40 percent of energy consumption. In the United States, commercial and residential buildings accounted for nearly 40 percent of total energy consumption in 2008 and 38 percent of carbon dioxide (CO_2) emissions, and are expected to remain at that level through 2030.[1] • **Start-Stop Battery Power Solutions** Automakers are rapidly adopting a new "start-stop" battery system that is bringing low-cost fuel efficiency improvements of 5 to 8 percent to the operation of traditional internal combustion engines in passenger and light-duty vehicles. Those improvements could increase to 8 to 12 percent as vehicle and battery designs become more closely integrated. Johnson Controls' start-stop battery system turns a vehicle's engine off rather than allowing it to idle in stopped or parked conditions. More importantly for drivers, the batteries and electronic controls turn the engine on again in the time it takes the typical driver to move

	from the brake to the gas pedal or to manually put the car in gear. Johnson Controls expects the penetration of the start-stop battery technology in the European passenger vehicle market to be 70 percent by 2015, and to reach similar penetration in the U.S. market within the next decade. The opportunity for impact is significant: Transportation accounts for nearly one-third of global greenhouse gas (GHG) emissions, and passenger and light-duty vehicle transportation accounts for approximately 60 percent of global transportation energy consumption and CO_2 emissions.[2]

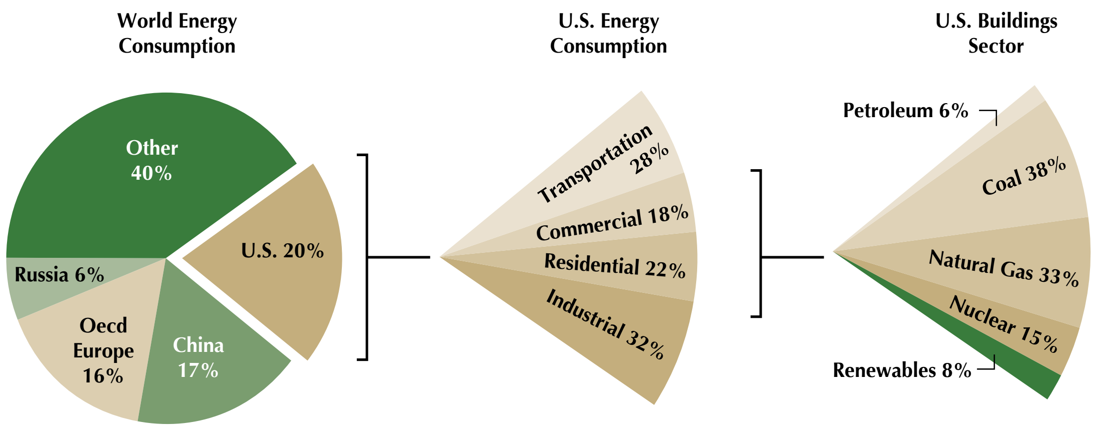
Johnson Controls, Inc. is on the frontier of low-carbon innovation in two sectors, building energy efficiency and automobile fuel efficiency. Johnson Controls is a global, diversified technology and industrial business with 150,000 employees, and with customers in nearly 150 countries. The company creates products, services, and solutions that optimize the energy and operational efficiencies of buildings. It also manufactures lead-acid automotive batteries and advanced batteries for hybrid and electric vehicles, and provides interior systems for automobiles. This case study considers two low-carbon innovation projects recently launched: a new business deploying building energy retrofit services to the commercial, private-sector market, and a new start-stop vehicle battery that increases the overall efficiency of the internal combustion engine (ICE) powertrain.

A company founded and grown on opportunities to reduce building energy consumption, Johnson Controls remains a leader in building energy efficiency. Buildings represent a still largely untapped opportunity for GHG emission reductions and energy cost savings.[3] Buildings represent nearly 40 percent of total U.S. energy consumption, dominated by fossil fuels (**Figure 1**). Energy use is expected to remain at that level through 2030, largely for space heating, ventilating, and air conditioning (HVAC) and lighting (**Figure 2**).[4] Moreover, because buildings have a typical lifespan of 80 or more years, their existing infrastructure—including HVAC, lighting, windows, and control systems—is often outdated and inefficient. In addition to ongoing efforts to raise efficiency standards for new building construction, reducing energy consumption and GHG emissions in buildings over the next several decades depends largely on retrofitting existing structures with low-carbon innovations. Johnson Controls is one of the few energy services companies (or “ESCO”)[5] with the expertise, experience, and size to bring such innovations to market at significant scale.

Annual revenues from the buildings energy retrofit business in the United States are an estimated $5 billion. Historically, this market has been primarily institutional customers—public facilities like government or municipal buildings, public universities, and schools and hospitals where the non-profit nature of customers, access to inexpensive public credit, and long-term ownership create a competitive return on such investments. The much larger commercial buildings market, however, remains largely untapped. Johnson Controls developed a new business model to pursue energy retrofits in the private sector. While much of the technology used to achieve the energy and emissions reductions remains the same, unique and different market requirements created the need to dramatically alter Johnson Controls’ business model to capture new growth opportunities.

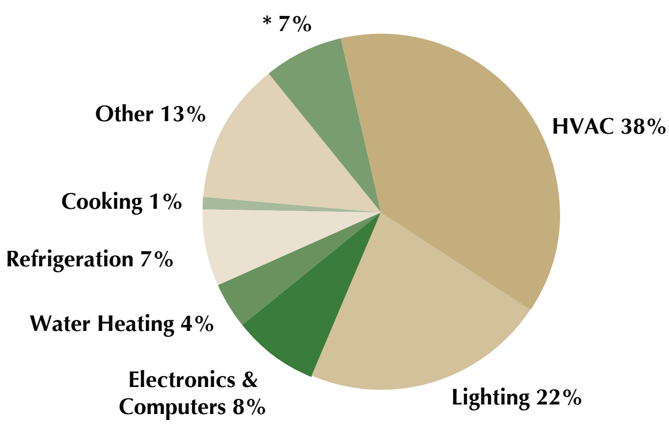
Similarly, as the transportation sector struggles to reduce energy consumption, dependence on fossil fuels, and GHG emissions, Johnson Controls—as a leading producer of lithium-ion batteries for hybrid and electric vehicles—also finds itself at the center of a low-carbon transformation in transportation. In particular, the start-stop battery and its surrounding system improve the efficiency of existing ICE vehicles in the range of 5 to 8 percent, with a commensurate reduction in CO_2 emissions. The improvement could reach as much as 8 to12 percent as new vehicle and battery designs become more closely integrated in the coming decade. Motivated by markets shaped by fuel economy and air pollution standards in the United States and European Union (EU), Johnson Controls introduced the start-stop battery in 2005 in Europe. The system has already captured approximately 50 percent of the EU passenger vehicle market (cars and light-duty trucks), and is likely to reach a 75 percent share by 2020. The U.S. market is also rapidly adopting this technology, and its penetration is projected to reach 75 percent by 2020. Over the next two to three decades, broadly commercializing the start-stop battery across millions of vehicles may have greater

FIGURE 1: U.S. Buildings Sector Energy Consumption (2008)



Source: U.S. Department of Energy (2011).

FIGURE 2: U.S. Commercial Buildings Energy End Use (2008)



*This pie chart includes an adjustment factor used by the EIA to reconcile two datasets.

Source: U.S. Department of Energy, (2011).

potential for reducing global energy consumption and CO_2 emissions than any other emerging low-carbon transportation technology.

COMPANY PROFILE

American journalist and essayist H. L. Mencken wrote: "The man who devised the thermostat…in my private opinion, was a hero comparable to Shakespeare, Michelangelo, or Beethoven." That man was Warren Johnson, a serial inventor and entrepreneur as well as a conservationist. Of the more than 50 patents he filed, most were for devices that tried to capture otherwise wasted power generated from air, steam, or water pressure. He experimented with electric storage batteries. He started a wireless telegraph business. He developed steam-powered vehicles, from luxury touring cars to the first postal service trucks. But the invention that launched his now 125-year-old company was a simple electric room thermostat. While a professor in Wisconsin, Johnson installed his "electric tele-thermoscope" in his classrooms to keep students more comfortable—and to end interruptions from the janitor checking the rooms' temperatures. The invention sparked public awareness, and launched an industry based on optimizing building performance and energy efficiency.

By the 1950s, thermostats were the building and construction industry standard. Large buildings had hundreds of thermostats, valves, dampers, and other control devices, each of which had to be checked for optimal performance several times a day. In 1956, Johnson Service Company introduced the pneumatic control center, which made it possible to monitor all of a facility's temperature control devices from one location. During the 1960s, the company expanded its technological capabilities through a series of acquisitions, including refrigeration and heating controls manufacturer Penn Controls in 1968, with plants and subsidiaries in Canada, the Netherlands, Argentina, and Japan. In 1972, Johnson introduced the first mini-computer system dedicated to building control, which could reduce fuel use by as much as 30 percent—a much-needed innovation as oil prices began to rise. In 1990, the company introduced the Metasys® building management system, which integrates management of a building's environment, energy use, lighting, fire safety, and security. In its current iteration, the system has Web and wireless connection capabilities. In 2005, the company acquired York International, a global supplier of HVAC and refrigeration equipment and services, effectively doubling Johnson Controls' Building Efficiency business. Today, Johnson Controls is a leading provider of equipment and controls for HVAC and refrigeration, and of building security systems. The company is also an ESCO, providing an array of cost-effective measures to achieve energy savings (see Sidebar: Johnson Controls' Building Retrofit Business, next page).

Expanding its technology and manufacturing expertise into the rapidly growing automotive business, the company acquired Globe-Union, the largest U.S. manufacturer of automotive batteries, in 1978. Three years later, company sales surpassed $1 billion. Expansion into the automotive business continued through 1985: The company entered the automotive seating and plastic container industries by acquiring Michigan-based companies Hoover Universal and Ferro Manufacturing, making Johnson Controls the leading independent supplier of automotive seats. The company's automotive interests evolved from components to seating systems to cockpit modules to complete interiors. The business greatly expanded in 1996 with the acquisition of automotive interiors and electronics maker Prince Automotive. By 2000, Johnson Controls was providing seating, overhead systems, electronics, and door systems for 35 million vehicles each year. The company's Power Solutions division has been the world's largest maker of lead-acid automotive batteries since 1985, and a pioneer in advanced battery technology. In a joint venture with French battery company Saft Groupe SA (a leader in high technology lithium-ion batteries), Johnson Controls-Saft is a global producer of lithium-ion cells and batteries for electric drivetrain vehicles.

This case study examines how Johnson Controls brought two low-carbon innovations to market: by developing a new business model to pursue building energy retrofits with a service offering for the private sector, and by developing and mass-producing the innovative start-stop automobile battery.

PRIVATE-SECTOR BUILDING EFFICIENCY

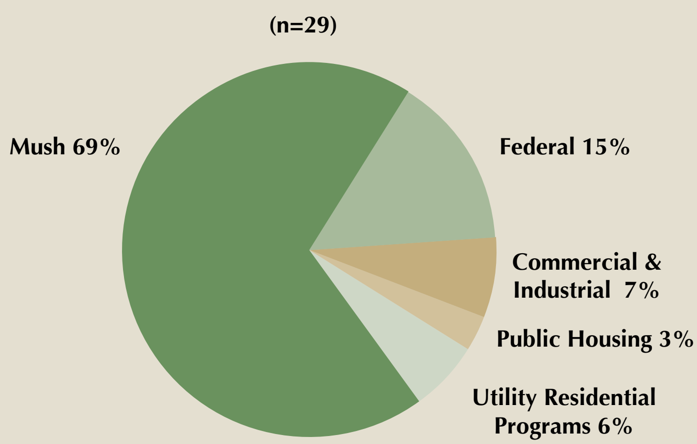
The existing stock of buildings is one of the largest end-users of energy, accounting for roughly 40 percent of global energy demand. And if the energy consumed in manufacturing steel, cement, aluminum, and glass used in construction is included, this number grows to more than 50 percent.[7] Buildings represent one of the

Johnson Controls' Building Retrofit Business

Johnson Controls' Building Efficiency division has generated over $19 billion in energy savings for customers, with over 1,000 active projects in federal, state, and local government facilities. Its current U.S. public-sector building efficiency projects with performance contracting are guaranteed to save more than $4.7 billion in reduced energy, water, and operational costs over the next ten years, and have offset more than 16 million metric tons of CO_2 since 2000. Johnson Controls has also developed a major renewables business, which enables the company to integrate renewable energy generation (such as solar or wind projects) with traditional energy efficiency improvements as customers seek to reduce their energy bills and their GHG emissions, or to capture potential revenues from renewable generation.

Johnson Controls' Building Efficiency retrofit business was in many ways created by the Ohio School Facilities Commissions House Bill 264 in 1985, which allowed public schools to initiate an energy retrofit contract that, when structured with a performance contract from a vendor, allowed them to borrow against the future energy savings. Public schools could replace aged windows, HVAC systems, lighting, and controls with more energy-efficient alternatives, and pay for those improvements out of the energy cost savings that would follow. This legislation provided the structure and precedent for financing public energy retrofit projects not only for schools but also for a variety of institutional clients, including military bases, state and federal agencies, along with municipal buildings, universities, school districts, and hospitals (collectively referred to as "MUSH"). The MUSH market accounted for $2.8 billion in ESCO revenues in 2008—about 69 percent of total industry activity (**Figure 3**).[6] Remaining energy efficiency opportunities in larger facilities in the MUSH market could produce annual energy savings of 160 million MMBTUs (million-British Thermal Units).

FIGURE 3: U.S. ESCO Industry Revenues by Market Segment (2008)



Source: Lawrence Berkeley National Laboratory (2010).

largest opportunities for reducing global energy use and related carbon emissions. Using existing technologies and practices, a 22 percent energy savings in commercial buildings could be cost-effectively achieved by 2020. That could create an additional $12 billion market annually over the next decade, and cut CO_2 emissions by some 128 million metric tons annually—equivalent to the annual emissions from 28 coal-fired power plants.[8]

Approximately 69 percent of the market for retrofitting existing buildings with energy-efficient systems and technologies has been driven by institutional customers known as MUSH (municipalities, universities, schools and hospitals). To date, Johnson Controls has been involved in more than 2,500 such projects around the world, which has provided essential experience with the technologies and solutions that offer the best financial return and GHG emission reductions for customers. Retrofits to aging buildings are typically more expensive—and involve greater technical and operational uncertainty—than installing energy-efficient windows, insulation, HVAC, and building controls when a building is first constructed. Yet the nature of institutional customers—who typically enjoy long-term ownership of their buildings and property, and have access to low-cost capital—helps create an attractive return on investment for energy retrofit projects.

Private-sector customers, on the other hand, represent a distinct set of challenges for low-carbon innovations. The market is characterized by highly-fragmented building ownership: 40 percent of commercial buildings and 32 percent of households are rented or leased.[9] In most commercial space, the owner, the property manager, and the tenant have different economic interests, and the costs and benefits of efficiency retrofits are not proportionately shared. The private-sector market often has more complex relationships to manage and more stringent financial requirements to meet (see Sidebar: Challenges to Energy Retrofits in the Private Sector, next page).

The greater complexity and the often-conflicting incentives of owners and tenants create opportunities for innovative new business solutions, and Johnson Controls developed a new strategic initiative specifically targeting the private sector. The market orientation of many private-sector customers has shifted to place stronger value on sustainability, environmental challenges such as climate change, and the economics of energy savings, leading to increasing customer requests for Johnson Controls to significantly expand its services and expertise to the commercial market. In response, the company augmented its business performance metrics (beyond energy efficiency) to include economic, social, and environmental impacts, and further oriented its offerings to focus on sustainability benefits as a whole.

While Johnson Controls' engineering and project management expertise from its public-sector work is useful for the private sector, the company faced three related issues that have a proportionately greater influence on private-sector decision-making: the need for different *financing mechanisms*, the challenge of overcoming competing *strategic priorities*, and the need to address critical *operations risks*.

First, most private-sector customers will finance a project internally or through existing credit lines rather than take on new debt that would weaken the balance sheet without proportionally improving their competitive prospects. Johnson Controls developed entirely new capabilities around project finance, such as the ability to profit from the onsite generation of energy through feed-in-tariffs or tax credits that were not as extensively available to its institutional customers.

For example, this initiative required new support for and adoption of financial models such as Property Assessed Clean Energy (PACE)[10] programs and Energy Services Agreements.[11] By leveraging the energy savings guarantees of performance contracting, these models address the specific financial barriers to funding commercial building retrofits. These models needed enhanced measurement and verification methodologies, requiring Johnson Controls to develop technology to monitor real-time energy consumption data and track performance over time. Guidelines for efficient tenant retrofits and lease structures that align building owner and tenant incentives for efficiency improvements also needed to be developed.

Second, among private-sector customers, most investments in reducing energy use or carbon emissions compete with other strategic priorities, such as investing in new product development, expanding into new markets, or developing marketing campaigns. A positive financial return, even on projects with short payback periods, must compete with the potential returns from, for example, new products or from increased sales due to new advertising. The competition between investments in retrofits and in traditional revenue-generating activities can reduce the value proposition for adopting even readily-available and proven low-carbon solutions.

Challenges to Energy Retrofits in the Private Sector

A variety of customer and market conditions make energy retrofits in the private sector a complex decision and undertaking, including:

Cost uncertainties. The financial cost and emission-reducing potential of energy efficient building solutions depend upon a wide variety of products and technologies, and the degree to which those technologies are utilized. Moreover, commercial building owners don't know whether they will capture the cost savings associated with lower energy use before the building is sold or again renovated.

Component versus system-level benefits. To be effective, energy efficiency projects need to be undertaken from a system-wide perspective. The wide range of energy retrofit choices, including improvements in windows, lighting, HVAC, renewable energy, and co-generation, are often interdependent: Better windows and lighting can reduce HVAC equipment needs and electricity costs yet, conversely, upgrading windows without downsizing the original HVAC equipment reduces the savings.

Competing strategic priorities. For companies that own their buildings, investing in energy efficiency, while a low-risk investment, competes with other business investments (such as adding manufacturing capacity, making acquisitions, purchasing materials, or hiring) for the limited amount of debt a company can take on.

Market barriers. In many commercial buildings, tenants pay the utility bills but have little control over building improvements, leading to 'split incentives' in which there is a disconnect between the party that owns or manages the building and those who pay the electricity and fuel costs. Property owners have little incentive to invest in improvements if tenants disproportionately gain through lower energy bills and, conversely, there is little incentive for tenants to invest when property owners disproportionately gain new long-term assets.

Knowledge barriers. Inadequate information about energy-saving opportunities and incentives, such as rebates and low-interest loans, can result in companies being unaware of, or reluctant to invest in, energy retrofits. Evaluating and planning energy retrofits requires considerable expertise, especially in planning for component versus system-wide improvements. Often the more visible solutions, such as solar power panels, result in less attractive economics relative to energy efficiency improvements.

Finally, investing in energy retrofits represents unknown risks associated with temporarily taking a factory offline or in other ways disrupting critical operational systems. For the $20 million energy retrofit of the iconic Empire State Building, Johnson Controls and its partners took a multi-year, phased approach to making improvements—very unusual for building retrofit projects. The windows were removed and replaced at night so that tenants would not be inconvenienced. Many tenants thought the windows had simply been cleaned rather than removed, upgraded, and put back in place. These improvements to occupied space were phased over a period of years to minimize disruption to the tenants, and to match lease periods and the fit-out of new tenant spaces. This project will save $4.4 million in the building's annual energy costs (a 38 percent energy reduction), with a payback based on incremental cost of 3.1 years.

START-STOP BATTERY POWER SOLUTIONS

Automotive batteries led a very quiet life until recent innovations in hybrid electric, plug-in electric hybrids, and electric vehicle technologies called for radical changes in the batteries' performance characteristics. These new uses require higher energy capacity, greater power for faster recharge and discharge, and more complex monitoring and control systems. At the same time, these performance characteristics continue to shift as automakers design and adapt new vehicles to their customers' evolving driving needs. Battery technology has moved into the spotlight as the linchpin of transportation innovations needed in the coming years, and is thus a critical challenge to address and an opportunity for commercializing fuel-efficient and low-carbon solutions. Johnson Controls' Power Solutions division is the global leader in manufacturing and distributing batteries for hybrid and electric vehicles, including lead-acid starting, lighting, and ignition (SLI) batteries, advanced lead-acid batteries for start-stop vehicles, and lithium-ion batteries.

Perhaps the biggest advantage of the start-stop battery, as a low-carbon innovation, is that it can be adopted by automakers almost immediately, giving it a competitive edge over solutions that may not come to market fast enough to appreciably change the fuel mix of the transportation sector before 2035. A range of lower-cost improvements to the ICE will enable it to remain competitive, on cost and under emission standards, for the next several decades (see Sidebar: The Emergence of the Electric Vehicle, this page). Automakers are rapidly adopting the start-stop battery system to bring low-cost fuel efficiency improvements of 5 to 8 percent compared to traditional ICEs, moving to 8 to 12 percent as vehicle and battery designs become more closely integrated. The start-stop battery system turns the engine off rather than allowing it to idle in stopped or parked conditions. More importantly for drivers, the batteries and electronic controls turn the engine on again in the time it takes the typical driver to move from the brake to the gas pedal or to manually put the car in gear. The technical challenges have been considerable: The requirements for start-stop battery performance increase as the number of stops increases from one start per trip to five to seven starts per trip. A short trip around town creates more starts with less time in between to recharge the battery. In addition, while the engine is off, the battery must maintain the electronic controls, lights, radio, and even air-conditioning.

Johnson Controls was able to develop and commercialize a technology that would overcome these challenges by building on its experience with maritime transport batteries, which share some similar use characteristics, and by adopting an existing but more expensive absorbed glass mat battery technology[13] that is better suited for the power needs of the start-stop use profile.

Based on this initial success, Johnson Controls is also developing a range of start-stop battery solutions that will meet its automotive customers' needs as alternative

The Emergence of the Electric Vehicle

The speed and scale at which electric vehicles will be deployed and substantially replace traditional ICE vehicles remains uncertain. Estimates suggest that electric vehicles will not have an appreciable impact on global carbon emissions for several years. "Electric vehicles" refer to a range of combinations under development, including hybrid-electric vehicles (HEVs) that rely on both electric motors and ICEs for propulsion; plug-in hybrid EVs (PHEVs) that have the ability to avoid onboard fuel consumption by relying entirely on battery power; and range-extended PHEVs that use an ICE for electricity generation rather than for direct propulsion.

The uncertainty about the pace of deployment of EVs reflects underlying questions about the direction of gas prices, public policies, advances in battery technology, customer preferences, and potential innovations in traditional engine technology. Today, battery systems needed for PHEVs represent an additional cost of as much as $9,600 per vehicle. By comparison, improvements in the efficiency of existing ICEs, such as reducing friction, adding the start-stop battery, and downsizing engines by adding turbocharging, will be more cost-effective at reducing CO_2 emissions in the next several decades, adding about $300 (for start-stop systems) and at most $2,000 dollars to the price of a vehicle. Moreover, several uncertainties make decisions around R&D investment, product development, and new vehicle models both difficult and risky, including the need for developing a broadly accessible vehicle charging infrastructure, concerns about consumer acceptance of driving range limitations, and whether tax credits for EVs will persist.

Current projections suggest that electric vehicles will achieve only a modest share—15 percent in one estimate, but only around 7.5 percent in another—of the global passenger vehicle market by 2020, with the majority being HEVs that rely on ICEs for propulsion.[12] Cumulatively, global sales as a percentage of vehicles sold are expected to be only 6 percent EVs and 9 percent HEVs. As much as 84 percent will continue to be gasoline- and diesel-powered vehicles.

power systems (which also include complementary regenerative braking, lighting, heating and air-conditioning, and console power solutions) become more widely adopted. The Johnson Controls-Saft joint venture is a leading global provider of advanced battery systems. The joint venture opened the world's first automotive lithium-ion cell manufacturing facility for hybrid-electric vehicles in 2008 in Nersac, France, where it currently builds the lithium-ion cells for Daimler's Mercedes S-Class hybrid. It also builds the hybrid battery system for BMW's 7 Series ActiveHybrid (which debuted in 2010), Azure Dynamic's Balance Hybrid Electric for commercial vehicles, and Ford's first plug-in hybrid electric vehicle, which will be available in 2012. The company built the first lithium-ion manufacturing facility in the United States—with a nearly $300 million grant from the U.S. Department of Energy in 2009—in Holland, Michigan, with an initial capacity of 15 million cells per year. Moreover, the Johnson Controls Battery Technology Center in Milwaukee, Wisconsin, is the largest automotive battery R&D, engineering, and validation facility in the United States. Its capabilities include cell design, system engineering, manufacturing, prototype assembly, testing, and integration. It has production and development contracts with automakers all over the world using plug-in hybrid and zero-emission technologies, and has received multiple government grants and contracts to further develop advanced energy storage solutions for vehicles.[14]

To automakers, the start-stop system is an extremely attractive near-term innovation because it achieves greater fuel efficiency and reduces emissions without requiring many changes to engine or vehicle design. According to Johnson Controls, a 50 percent market penetration of the start-stop battery system for light-duty vehicles in the North American market would avoid 38.1 million metric tons of CO_2 emissions cumulatively through 2020.[15] First introduced in Europe in 1997 by BMW, then quickly by Daimler and Peugeot, to help meet European fuel economy and pollution emissions standards, this technology is being rapidly rolled out by European and American manufacturers. Johnson Controls expects the penetration of the start-stop battery in the European passenger vehicle market to be 70 percent by 2015, and to reach similar penetration in the U.S. market within the next decade.

MANAGING LOW-CARBON INNOVATION

From these innovations, several clear insights emerge about effective practices for driving low-carbon business innovation in the context of market and technical uncertainties. Three practices in particular stand out: employing user-centered design in creating new services and business models; pursuing robust innovation strategies; and integrating public policy perspectives with corporate strategic planning.

User-focused Value Propositions

The development of both the start-stop battery and of the commercial building retrofit business was characterized by an explicit and comprehensive understanding of how the needs of Johnson Controls' customers were changing. In both cases, the overriding challenges facing its customers—automobile original equipment manufacturers (OEMs) and commercial building owners—were the technical and market uncertainties that clouded their decisions as to which technology or solution to adopt and how quickly to adopt it. An in-depth understanding of customer needs and technology adoption decisions served as a blueprint for guiding Johnson Controls' product and service development strategy.

First, Johnson Controls dedicated significant time and resources to understanding the value proposition for customers adopting new technologies and systems. In response to tightening fuel economy standards, automobile OEMs will consider adopting new battery technologies that increase fuel efficiency and reduce the overall GHG emissions of a vehicle. But adoption of the technology also requires that suppliers consistently meet (sometimes unpredictable) demand without compromising quality. And to be viable, a new solution must also seamlessly integrate into established vehicle production systems. Similarly, Johnson Controls' Building Efficiency division leveraged its long history of working closely with, and learning from, customers across many industries to develop and execute project financing deals and performance contracting terms that match each industry's unique energy use profile, operational demands, and financing requirements. In each case, Johnson Controls used in-depth research and surveys of its key customer segments to identify the different options and issues that determine how customers make decisions about adopting new technologies or services.

Johnson Controls has also demonstrated an ability and willingness to acquire, partner for, or develop the necessary tools and people to focus on the needs of customers. In Building Efficiency, as it became clear that commercial customers faced dramatically different financial constraints than public institutions, the company did not hesitate to hire managers from the utility and energy industries with relevant commercial financing experience to help move the business along the learning curve. Similarly, as automakers explore battery technologies, the Power Solutions division sought the best available, cost-effective technologies to meet customer needs, and eventually formed a partnership with Saft to manufacture hybrid vehicle batteries.

Finally, understanding the myriad trade-offs that companies face when adopting a new system or technology, Johnson Controls focuses its product and service development efforts on maximizing customers' system-wide performance rather than on the independent performance of its own innovations. In commercial building retrofits, the greatest benefits of adopting low-carbon innovations occur when projects make changes to multiple systems concurrently—like HVAC, windows, and energy controls—rather than making improvements in just one or two components. For the Empire State building retrofit, Johnson Controls and its partners tackled the project using a "right steps in the right order" approach for whole-systems optimization, reducing energy demand through the building envelope (via the windows and radiators) and through tenant energy use (via tenant space design and energy management), as opposed to only focusing on traditional HVAC equipment replacements.

Similarly, the Power Solutions business must be able to optimize a battery's performance for an OEM's vehicle system, which is not the same as building the perfect battery. The optimal performance of a start-stop battery depends on the choices for power needs, cycle life, costs, and technical specifications made by the team designing the battery for a particular vehicle model or platform. This customization at scale requires not just experience working effectively with individual automobile project teams, but also the ability to design for high-quality, large-scale manufacturing systems. A systems-level approach enables Johnson Controls to optimize a customer's overall business performance. Overcoming this challenge is a key strength of established corporations: With such extensive relationships and interactions with customers, Johnson Controls can come to market with solutions that are developed with a full understanding of customers' problems and decision-making criteria (see Sidebar: Its Own "Smart Buildings" Customer, next page).

Robust Innovation Strategies

An innovation strategy is robust when it strengthens the company's competitive advantage in the current market while preserving the ability to respond quickly and effectively to the moves of competitors, suppliers, customers, and regulators over the long term. The shifting market preferences, technologies, and regulatory policies associated with reducing GHG emissions add to the uncertainty that Johnson Controls' customers face when adopting low-carbon innovations. To remain relevant, the company must pursue a robust strategy that simultaneously provides customers with cost-effective low-carbon solutions available today while continuing to develop those that will meet market and policy environments over the coming decades.

Committing to one technology or solution at the expense of another runs the risk of prematurely abandoning what may become an industry standard. On the other hand, not sufficiently committing to a possible solution runs an equal risk of falling behind competitors. In battery technologies, automakers face a market that is only beginning to move to the new, relatively more expensive technology platforms of hybrid or all-electric vehicles. Yet at the same time, the policy environment is changing, as the United States and EU adopt increasingly stringent efficiency and emission standards. For today's market needs, Johnson Controls is leading the development and manufacture of start-stop batteries, while at the same time actively engaging with Saft to produce batteries for next generation hybrid and electric vehicles. In building retrofits, Johnson Controls is constantly evaluating and integrating emerging efficiency and renewable energy solutions as shifting technology, market, and policy conditions (such as subsidies and financing alternatives) favor one choice over others.

In addition to learning from customers, Johnson Controls spends significant effort educating customers on the range of alternative technologies and options available. In the Power Solutions business, the company engages in proprietary research and partnerships with other leading manufacturers and suppliers across industry to ensure they understand both the potential and limitations of particular technologies. The chemistry, materials, and structure of the battery technologies being developed in universities and corporate research labs today differ along with their performance characteristics. Some are better for start-stop systems and others for electric-drive systems; some are more easily integrated into OEM's existing electrical systems and others require new systems. As a leading supplier of batteries, Johnson Controls must anticipate the technologies its customers will need today and in the future—a challenging endeavor as the ultimate use environments and customer expectations for electric vehicles remains largely unknown. The partnership with Saft allowed Johnson Controls to rapidly develop its expertise in the emerging hybrid vehicle battery market.

The company also explores the current and future potential of alternative technologies through its R&D Groups and through its Institute for Building Efficiency, which applies the company's 125 years of global experience to addressing unique challenges in the buildings efficiency market. To bring innovative solutions to market, the Building Efficiency business works with a range of technology providers—new and established, small and large—that have developed potentially useful building retrofit solutions. It worked with Serious Energy (formerly Serious Materials), a maker of innovative window technology, in retrofitting the Empire State Building; with Verdiem, a computer energy management company; with several lighting controls companies; and with solar power manufacturer Concentrix. Working with companies involved in a wide range of innovations in various stages of development gives Johnson Controls a leading technological edge in its markets.

Its Own "Smart Buildings" Customer

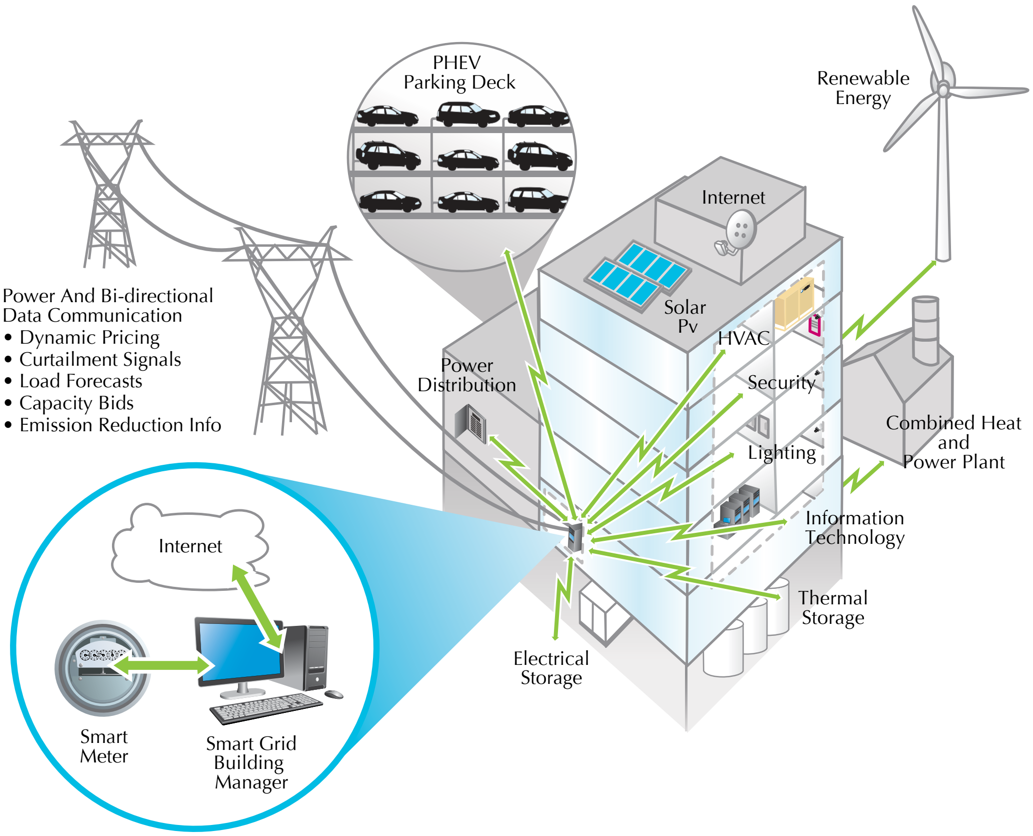
Johnson Controls uses its own facilities to test and demonstrate the potential of low-carbon innovations for customers. In 2008, the company met its goal to reduce global GHG emissions per dollar of revenue by 30 percent from 2002 to 2012. It has pledged to reduce its GHG emissions intensity by another 30 percent from 2008 levels by 2018. It is using the construction and expansion of its Glendale, Wisconsin, headquarters campus as a showcase of what is possible through building efficiency. In 2010, four buildings on the campus were awarded Platinum Certification from the U.S. Green Building Council for Leadership in Energy and Environmental Design (LEED),[16] making the campus the largest concentration of buildings to receive this recognition.

The 33-acre complex includes over 300,000 square feet of new and renovated office space. Two existing buildings were renovated for the corporate headquarters. Three new buildings were constructed: one for the company's Power Solutions business; another for a cafeteria, meeting rooms, and fitness center; and the third being a four-level parking structure for more than 400 vehicles, including space for plug-in hybrids. On the grounds, 1,452 solar photovoltaic panels make up one of the largest arrays in Wisconsin, delivering up to 250 kilowatts (kW) of electricity to the site.

Johnson Controls is no newcomer to green building: Its Brengel Technology Center in Milwaukee was one of the first LEED-certified buildings in the world. In the retrofit and construction of the campus, the company incorporated geothermal heat pumps, photovoltaic energy, and an underfloor air distribution system with individualized occupant controls. Skylights and larger windows increase the use of natural light and reduce dependence on artificial illumination. Snow and rainwater is collected and used to flush toilets. A parking lot surfaced with permeable pavers allows rain and snowmelt to filter through. The system-wide, "smart building" approach effectively connects and shares knowledge across a variety of existing technologies, systems, and sources to provide more intelligent control of energy use, cost savings, and productivity (**Figure 4**).

All the systems are connected using the Johnson Controls Metasys® smart building management system. These systems not only coordinate all energy-intensive activities across facilities, they also provide a single point of access to performance indicators to optimize building efficiency, comfort, and safety. As important, Metasys® systems also provide a dashboard that translates data into useful information for the management team, which can then make informed decisions about resource use in order to reduce costs and increase efficiencies. Such integration of building systems with information technology infrastructure into one intelligent network is an important part of Johnson Controls' sustainable business strategy.[17]

FIGURE 4: Smart Buildings: A Day in the Life



Source: Recreated from image provided courtesy of Johnson Controls, Inc. (2011).

This strategy of constantly evaluating new technologies and solutions, while educating business partners and customers, helps Johnson Controls remain competitive in the short run while maintaining options for business growth over time.

Managing Policy Uncertainty in Innovation Strategies

Low-carbon innovations are shaped not only by shifts in technologies and customer needs, but also by current and future political, regulatory, and legislative environments. To bring low-carbon innovations to market effectively, companies must be able to not only anticipate and react to policy directions, but also engage with policy makers to inform these directions. Policies that can significantly influence the development and success of innovations include national GHG emission standards (including the means by which such standards are measured), industry and market subsidies, tax breaks and loan programs, as well as state-level renewable energy standards, environmental policies, and local financing options. Mark Wagner, Johnson Controls' head of Government Relations, describes the company's business as an "ongoing co-evolution of policy and technology." Strategic planning is informed by developments in public policies and considers proactive policy engagement where appropriate.

In Johnson Controls' Power Solutions business, public policy most directly shapes OEM customers' decision-making via fleet limits on CO_2 emissions and air pollutants, and through such mechanisms as fuel economy standards and consumer tax credits for fuel-efficient vehicles. In the Building Efficiency business, public policy promoted the building retrofit market with the original Ohio House Bill allowing public schools to implement energy efficiency measures financed by future energy savings. Policies at local, state, and national levels—including feed-in-tariffs, tax credits, and building codes and standards—continue to shape retrofit project financing alternatives, operational revenues, and expenses. Managing low-carbon innovations in this context requires a strategic perspective on the challenges and opportunities presented by current and future regulatory environments.

Johnson Controls is turning these opportunities and challenges into business growth in several ways. It provides the people, resources, organization, and mandate to map new venture opportunities with business strategy and public policy trends. Recognizing the growing support for renewable energy from national and state policy makers, Johnson Controls built capabilities to provide clients with renewable energy solutions. Today, almost one in three energy efficiency projects includes a renewable energy component. Leveraging its experience in the public-sector retrofit market, the Energy Solutions business created a dedicated private-sector building efficiency team within its own group, and ultimately hired managers with project finance experience from the utility and energy industries to help navigate financing options and the public policies that influence those options.

In addition to recognizing and supporting policy expertise within the firm, Johnson Controls also tracks the diverse and complex policy environments of its markets by engaging directly with policy makers, customers, industry associations, and non-governmental organizations (NGOs). Policy makers tasked with setting new regulatory standards often turn to industry leaders and associations for a full understanding of the state of the art. Industry associations produce "joint comments" and "consensus agreements" that inform such policy-making, to which Johnson Controls contributes. Johnson Controls' ability to work closely with the U.S. Environmental Protection Agency (EPA) remains critical to deploying the start-stop battery as a valuable solution for U.S. customers. Current EPA vehicle fuel economy tests do not yet recognize the significant improvement in fuel economy that start-stop battery vehicles provide, in contrast to the tests in the EU, which do. The reason for the difference: The idle time used in EPA's test parameters is substantially less than that used for the EU test. It is therefore incumbent on Johnson Controls and other battery manufacturers to provide data to the OEMs and policy makers validating the fuel economy benefits for start-stop in the United States. Mark Wagner, Vice President of Government Relations, describes his role in understanding and communicating the value of the start-stop battery: "We have a new technology for start-stop batteries [and we need to work with] the EPA [to ensure they] take this into consideration when they write their regulations for emissions standards."

Just as building owners face an army of salespeople offering disaggregated solutions in solar, wind, lighting, heating, and air-conditioning—policy makers face industry advocates seeking focused support for particular technologies. As a system integrator and general provider of energy retrofits, Johnson Controls is uniquely positioned to help ensure that policies and subsidies provide real value to customers. In 2010, Johnson Controls dedicated significant resources and talent to establishing a framework for this effort in its buildings business, establishing the Institute for Building Efficiency. The Institute was designed to provide key decision-makers in government, NGOs, and business with research and educational resources. Some of its key objectives are tracking policy developments as they affect the company's markets and clients, engaging in research and education on upcoming policy decisions, and providing information on emerging technology and innovative financial models. Clay Nesler, Vice President of Global Energy and Sustainability, oversees the Institute for Building Efficiency and leads a global Center of Excellence responsible for energy and sustainability strategy, policy, innovation and NGO relationships. This management structure, which is focused on the integration of energy and sustainability strategy, policy and innovation, has been a key enabler in identifying and incubating low-carbon innovation opportunities for the company.

As organizations increasingly turn to low-carbon innovations for business growth opportunities, they find their technical and market choices shaped by policies that are uncertain and fluctuating, but that are also open to interpretation and shaping. Public policies can reward those who develop the resources to integrate the associated challenges and opportunities with the strategic management of the firm.

CONCLUSION

As a leader in providing fuel- and energy-efficient solutions to two of the highest GHG-emitting economic sectors, Johnson Controls stands to gain substantially by continuing to develop and market a wide range of low-carbon innovations and technologies that provide value to its customers. Like other companies in this study, Johnson Controls found that bringing low-carbon solutions to market requires investing time and resources in developing new technologies and management expertise, as well as developing new innovative approaches that apply existing technologies to capture opportunities in new market segments. The wide-scale adoption of incremental improvements in existing transportation technologies and the deployment of efficiency improvements to the existing building stock can have a significant—and immediate—impact on reducing GHG emissions and on business growth. As illustrated, Johnson Controls leveraged a strong investment in understanding the decision-making criteria of existing and potential customers, a robust innovation strategy maximizing technological flexibility in the short and long term, and the intellectual capital amassed by its financing and government relations experts to develop and deploy valuable low-carbon solutions.

ENDNOTES

1 U.S. Department of Energy, *2010 Buildings Energy Data Book* (Washington, DC: U.S. Department of Energy, 2011), http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2010_BEDB.pdf.

2 U.S. Energy Information Administration, "Transportation Sector Energy Consumption," in *International Energy Outlook 2010* (Washington, DC: U.S. Energy Information Administration, 2010), http://www.eia.gov/oiaf/ieo/transportation.html.

3 For an overview of the potential for emissions reductions in the buildings sector, barriers and challenges, and policy pathways, see "Buildings Overview," Center for Climate and Energ y Solutions, accessed 2011, http://www.c2es.org/technology/overview/buildings.

4 U.S. Department of Energy, *2010 Buildings Energy Data Book* (Washington, DC: U.S. Department of Energy, 2011).

5 An Energy Services Company ("ESCO") is a business that designs, develops, installs and arranges financing for projects that improve the energy efficiency and maintenance costs for facilities over a seven to twenty year time period. ESCOs generally act as project developers for a wide range of tasks and assume the technical and performance risk associated with the project. Services are bundled into the project's cost and repaid through the future dollar savings generated. What sets ESCOs apart from other firms that offer energy efficiency is the concept of 'performance-based contracting': the company's compensation, and often the project's financing, are directly linked to the amount of energy that is actually saved.

6 Andrew Satchwell et al., *A Survey of the U.S. ESCO Industry: Market Growth and Development from 2008 to 2011*, LBNL-2479E (Ernest Orlando Lawrence Berkeley National Laboratory, 2010).

7 World Business Council for Sustainable Development, *Transforming the Market: Energy Efficiency in Buildings* (World Business Council for Sustainable Development, 2009), outlines how energy use in buildings can be cut by as much as 60 percent by 2050.

8 Derek Supple and Olivia Nix, *Unlocking the Building Retrofit Market: Commercial PACE Financing, A Guide for Policy Makers* (Institute for Building Efficiency, 2010); B. Griffith et al., *Assessment of the Technical Potential for Achieving Zero-Energy Commercial Buildings*, NREL/CP-550-39830 (National Renewable Energy Laboratory, 2006).

9 Marilyn Brown, Frank Southworth, and Therese Stovall, *Towards a Climate-Friendly Built Environment* (Arlington, VA: Center for Climate and Energy Solutions, 2005), 17.

10 PACE is an innovative approach that would allow municipal governments to use funds from the bond market to help property owners finance energy efficiency retrofits and renewable energy arrays on their property. The property owners then repay the local governments, which in turn repay bondholders via assessments on their property tax bills over a set period of time. However, both existing and developing residential PACE programs have been slowed or halted in the past year entirely, due to opposition from Freddie Mac and Fannie Mae. Commercial PACE programs remain a viable solution for financing building retrofits.

11 Energy Service Agreements combine performance-based contracting methods that ESCOs use to secure financing for public-sector energy efficiency projects, with power purchase agreements that allow Johnson Controls to finance energy efficiency projects and receive payments based on the resulting kilowatt-hours (kWh) of avoided energy costs.

12 Boston Consulting Group, *Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020* (Boston Consulting Group, 2011), http://www.bcg.com/documents/file36615.pdf; Michael Omotoso, *Drive Green 2020: Alternative Powertrain Forecast* (J.D. Power and Associates, 2010), http://www.cargroup.org/documents/omotoso.pdf.

13 Absorbed glass mat (AGM) batteries are constructed differently from the traditional flooded battery and are almost immune to vibration. AGM sealed battery technology was originally developed and introduced in 1985 for military aircraft where power, weight, safety, and reliability were paramount considerations.

14 Johnson Controls is also the global leader in closed-loop, lead-acid battery recycling, leading the development of a system that limits the pollution that some recycling efforts can cause. Johnson Controls was also the first manufacturer to produce a recycled battery case made of plastic from old battery cases. As a direct result of the company's efforts, more than 97 percent of all lead-acid batteries are recycled (compared to 49 percent of aluminum soft drink and beer cans, 45 percent of paper, and 38 percent of tires), making lead-acid batteries the most recycled consumer product. The company is sharing this expertise in battery recycling around the world including in Mexico and China.

15 This estimate assumes a 50 percent market penetration of the start-stop system in light-duty vehicles in 2015 and increasing 5 percent annually to 70 percent through 2020; an average start-stop incremental fuel economy benefit of 8 percent; and that U.S. fuel economy standards in 2015 provide for 33.8 miles per gallon.

16 LEED is an internationally-recognized green building certification system that provides building owners and operators with a framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions.

17 Terry Hoffman, *Smart Buildings* (Johnson Controls Inc., 2009), http://www.johnsoncontrols.com/publish/etc/medialib/jci/be/white_papers.Par.88938.File.dat/SmartBuildings.pdf.

This report documents best practices in low-carbon business innovation and provides guidance to other companies seeking to develop new, or strengthen existing, low-carbon innovation strategies. The Center for Climate and Energy Solutions (C2ES) is an independent non-profit, non-partisan organization promoting strong policy and action to address the twin challenges of energy and climate change. Launched in 2011, C2ES is the successor to the Pew Center on Global Climate Change.

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