GIGATON THROWDOWN

Redefining What's Possible for Clean Energy by 2020

Job Growth
Energy Security
Climate Change Solutions

FULL REPORT
JUNE 2009

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A Letter from the Cleantech Community

Dear Colleagues:

Out of our garages came the innovations that launched the information technology and biotech revolutions. From those beginnings, we have built a trillion-dollar IT economy and a biotech industry. As investors, entrepreneurs, and business leaders, we recognize a similar economic opportunity in clean energy technology. And this prospect isn't just about economic growth. Our security and prosperity and that of future generations depend on energy independence and a stable climate, which clean technology can ensure.

FOR THE FIRST TIME, WE HAVE A ROADMAP OF HOW TO SCALE CLEAN ENERGY TO HAVE MAJOR IMPACT BY 2020

As this report shows, clean energy can reduce greenhouse gas emissions by the gigatons required to address climate change over the next 20 years. For an entrepreneur, what can be imagined sets the bounds for what can become real. We can now imagine gigaton scale for clean energy technologies, and entrepreneurs can starting building the leading clean energy companies of tomorrow.

ACCELERATION WILL REQUIRE POLICY ENGAGEMENT

All of the technologies that can make major carbon dioxide emissions reductions — energy, buildings, transportation, forestry, and agriculture — have historically had market rules established by local, regional, national and international policy decisions. The future will be no different.

FOR INNOVATION TO FLOURISH, POLICYMAKERS MUST LAY OUT FAIR AND STABLE RULES OF THE ROAD

Scaling up clean energy industries requires coordinated action by the entire supply chain. Companies will expand capacity only when there are clear market signals for expected growth. Such signals are also required to increase demand for renewable energy and low-carbon alternatives.

The energy and carbon policies being decided now in the U.S. Congress and in December at the 15th Conference of the Parties (COP-15) in Copenhagen can lay the foundations for decades of massive innovation and growth in clean energy. The central reform must be a comprehensive carbon policy that puts a price on carbon for the long term. Without such a policy, cleantech energy pathways will grow slowly and in most cases fail to affect climate change. With such a policy, we can achieve gigaton scale by 2020, stabilize the climate, and create a new industry.

While we did not prepare this report, we agree with its basic findings and encourage our colleagues to use it as a framework for thinking about how to achieve scale in cleantech energy industries. We encourage policymakers to take to heart its central conclusions.

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Executive Overview

Introduction

The Gigaton Throwdown Initiative Team has spent the past 18 months evaluating what it would take to scale up clean energy aggressively so that it has a major impact on job growth, energy independence, and climate change during the next 10 years. We now see two possible worlds for 2020 and beyond.

In one world, clean energy markets expand dramatically. Private investment in renewable energy and energy efficiency more than triples, revitalizing the economy with green jobs in manufacturing, construction, and technology. Our energy economy becomes a source of investment in science, engineering, and technology, all of which drive national economic growth. Simultaneously, our investments deliver energy security and address climate change.

In the other world, clean energy markets remain a polite concession to the sustainability movement. Demand for renewable energy grows at the modest rate of 7% annually that many national agencies forecast. At this growth rate, these technologies will meet less than 2% of total global energy demand in 2020. Some jobs will be created, but the opportunity to build a global industry and advance U.S. leadership in technology will be lost. Meanwhile, the U.S. will remain dependent on imported oil and other fossil fuels, and climate change will continue unchecked.

The pace of innovation and private investment in clean energy is now making it possible to envision the first world. On the current trajectory, however, we end up in the second. The U.S. will miss a huge economic opportunity and squander the chance to address the climate problem and deliver jobs, economic growth, and energy security.

Key Findings

1. **The clean energy sector is growing rapidly but could grow significantly faster and sustain this growth for decades.**

2. **An aggressive scale-up is needed for clean energy technologies to fulfill the promise of economic and job growth, energy security and independence, and solutions to the climate problem.**

3. **Clean energy technologies could add 5 million direct jobs to the global economy, strengthen energy security by reducing dependence on foreign oil, and abate more than the total carbon dioxide equivalent (CO_2e) emissions currently projected to be necessary for 2020 climate stabilization goals.**

4. **Immediate, stable policies and increased investment are needed to support the necessary, aggressive scale up in clean energy.** Annual private investment must grow by more than 3X in the next 10 years to scale up renewable energy technologies to meet climate stabilization goals. This level of growth is feasible, but policy action is needed immediately to support it.

5. **Sound, stable policy is needed to guide investment:**
   - The supply chains for clean energy technology take years to ramp up capacity and require clear policy signals to attract investment today.
   - Past experience shows that investment in efficiency — the cheapest form of energy savings — requires policy action.
   - Stable policy that establishes a meaningful price on carbon is the single most important action that will encourage investment across the clean energy sector and ensure that capital flows to the most cost-effective technologies. Although clean energy is already providing solutions and attracting significant investment — private investment totaled more than $450 billion during the past 5 years with $135 billion invested in 2008 — a large amount of private capital remains on the sidelines or is currently diverted to supply fossil fuel energy.

Gigaton Throwdown Initiative

The Gigaton Throwdown Initiative was launched to educate and inspire investors, entrepreneurs, business leaders, and policy makers to "think big" and understand what it would take to scale up clean energy massively over the next 10 years. A unique group from the business community — investors, entrepreneurs, and executives — teamed up with leading academics for the throwdown. The team investigated what it would take to reach gigaton scale for 9 technologies currently attractive to investors.

To attain gigaton scale, a single technology must reduce annual emissions of carbon dioxide and equivalent greenhouse gases (CO_2e) by at least 1 billion metric tons — a gigaton — by 2020. For an electricity generation technology, this is equivalent to an installed capacity of 205 gigawatts (GW) of carbon-free energy (at 100% capacity) in 2020.

The 9 technologies we analyzed are examples of the potential to scale up clean energy technology:

- **Biofuels**
- **Building efficiency**
- **Concentrating solar power**
- **Construction materials**
- **Geothermal**
- **Nuclear**
- **Plug-in hybrid electric vehicles**
- **Solar photovoltaics**
- **Wind**

Gigaton Scale is Attainable in the Next 10 Years

We found that 8 of the 9 clean energy technologies we analyzed can each feasibly reach gigaton scale in the next decade. Together they would abate a total of more than 8 gigatons of dioxide equivalent (CO_2e) emissions in 2020. Of these 9 technologies, 7 are ready to scale up aggressively today: building efficiency, concentrating solar power, construction materials, nuclear, biofuels, solar photovoltaics, and wind. One technology, geothermal, needs an intense period of research, development, and deployment of pilot plants for new enhanced geothermal systems (EGS) in order to reach gigaton scale. Combined, these 8 technologies can meet more than 60% of new global energy demand during the next 10 years with reliable, clean, low-carbon sources.

Although continued investment in plug-in hybrid electric vehicles (PHEVs) is important for emissions reductions beyond 2020, achieving growth in PHEVs sufficient to reach the gigaton target faces serious challenges. To reach the gigaton goal, the industry would need an estimated 300 million PHEVs on the road in 2020. This is equivalent to the total number of new cars to be added to the fleet worldwide in the next 10 years. Although this might be feasible technically, the disruption to current operations, junking of existing vehicles, and sheer amount of capital needed for this transition make this pathway infeasible by 2020 in the estimation of the Gigaton Throwdown Team. Therefore, we do not include PHEVs in our gigaton projections.

One of the technologies, wind, is already growing fast enough to achieve gigaton scale by 2020. The wind industry has been growing at an annual rate of 28% over the past decade and will soon reach 150 gigawatts (GW) of installed capacity globally. At currently projected growth rates, it will exceed half a terawatt (TW) of installed capacity by 2020 and deliver close to 1.5 gigatons of CO_2e emissions reductions. Building efficiency technologies, solar, biofuels, and nuclear have all been tested and deployed and can scale more rapidly than their current projections. These are not laboratory curiosities. They are active technologies that are supplying power in multiple markets. With sound policy support, they will do much more.

In addition to the technologies analyzed in this report, others, from carbon dioxide sequestration to novel enzymes, to fuel-switching have the potential to achieve gigaton scale. With the right policies, many other businesses that have gigaton-scale ambitions can flourish.

Gigaton-Scale Clean Energy Can Drive Economic Growth and Create Millions of Jobs

Growth in clean energy is already stimulating regional U.S. economies and adding manufacturing, construction, and technology jobs.

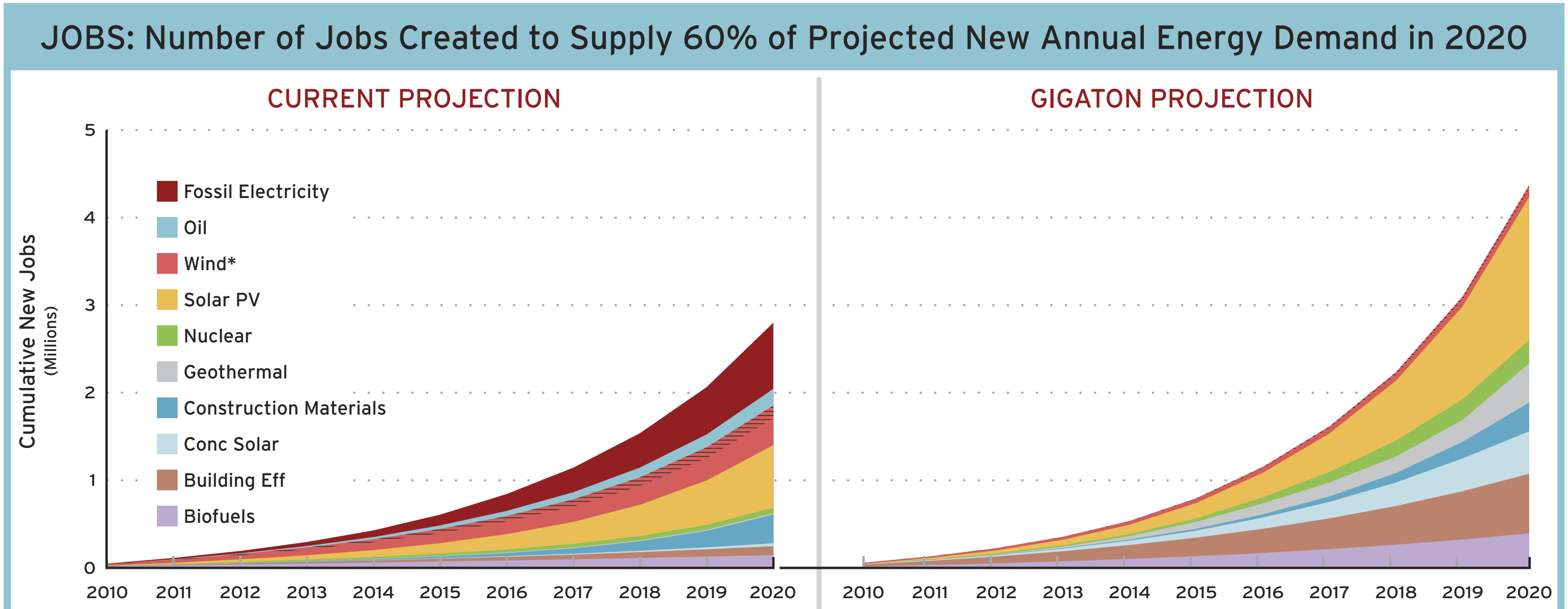

FIGURE 1. Expanding these 8 clean energy technologies to gigaton scale to meet new energy demand would create close to 4.5 million direct jobs, compared to fewer than 3 million under current projections. Both projections (current and gigaton) show jobs created for the same amount of energy (55 quads in 2020, which is approximately 60% of new global annual energy demand). Under current projections, the majority of new energy demand is met by fossil-fuel-based generation and adds significantly fewer jobs. Source of jobs data: Engel and Kammen, 2009.[1]

* Wind is currently projected to exceed gigaton scale and add approximately half a million direct jobs.

Clean energy has the potential to add several million new jobs over the next 10 years.[2]

The ethanol industry, for example, has created tens of thousands of jobs across the U.S., in Nebraska, Iowa, Illinois, and Michigan. In 2004, ethanol production generated more than 150,000 jobs. For every billion gallons of production, the industry adds between 10,000 and 20,000 new jobs in the U.S. This sector alone has the potential to create 1 million jobs in the next 10 years.

Other renewable-energy technologies are also strong jobs providers. Wind-industry jobs in the U.S. took off in 2006 and grew until late 2008 when the credit crisis struck and stalled wind developments. Industry-wide, wind energy employment is at 85,000, with 35,000 jobs added in the past year. A third sector — building efficiency — has the potential to add jobs in all 50 states. Based on past increases in jobs attributable to the building efficiency sector in California, for each 1% annual gain in efficiency, approximately 400,000 jobs are created. Similarly, the solar installation and utility business has added substantial numbers of jobs in a number of states, including Arizona, California, Nevada, and New York.

Clean energy sectors are typically more labor intensive than traditional fossil-based sectors, so gigaton-scale deployment would accelerate job growth around the world. Figure 1 shows the jobs created, over the next decade, by the 8 feasible technologies analyzed in this report.

Gigaton-Scale Clean Energy Can Meet 2020 Climate Stabilization Targets

In early 2009, both the Intergovernmental Panel on Climate Change (IPCC) and McKinsey reported that significant emissions cuts are needed in the next 10 years if the world is to have a chance of stabilizing the climate.[3,4] For the stabilization target of 450 parts per million (ppm) of CO_2e that is the focus of current U.S. legislative discussion, this amounts to reducing

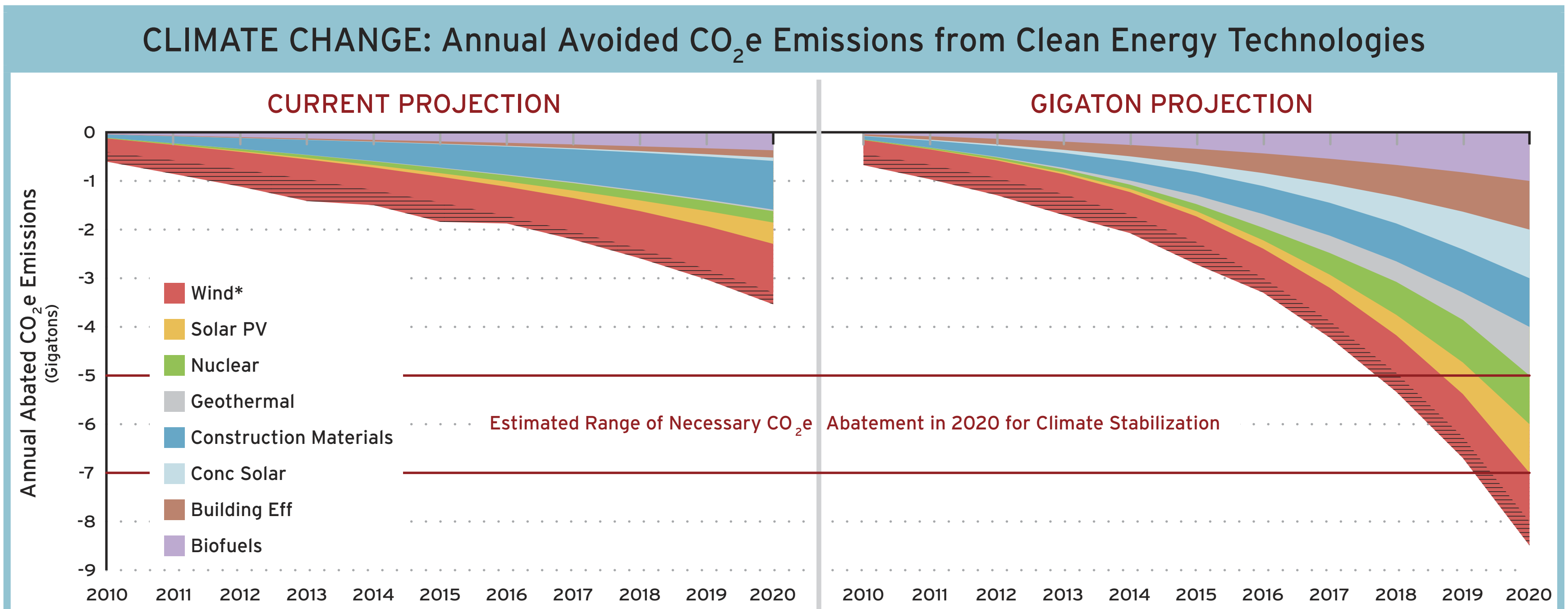

FIGURE 2. At gigaton scale, these 8 technologies could provide CO_2e reductions in excess of the 5 to 7 gigatons needed to hit 2020 climate stabilization targets, compared to the current projections that show these technologies falling short.[5] Under current projections, these 8 technologies abate close to 3.5 gigatons of CO_2e, with the bulk of the contribution from one technology, wind. (See report chapters for details on the current projections for each technology.)

* Wind is currently projected to exceed gigaton scale and abate 1.5 gigatons of CO_2e.

emissions from the global energy sector by an estimated 5 to 7 gigatons of CO_2e in 2020. Scaling the 8 feasible technologies by 2020 would more than meet this climate stabilization target (See Figure 2). Given that several technologies have the potential to deliver more than 1 gigaton of CO_2e reduction, the 450 ppm climate stabilization goal looks well within reach.

Gigaton-Scale Clean Energy Can Help Ensure Energy Independence and Security

Scaling up clean energy technologies to avoid 1 gigaton of CO_2e emissions has major implications for U.S. national security by reducing dependence on foreign oil as well as mitigating climate change and the associated social instability.

Reduced oil use through efficiency measures and scale-up of biofuels, for example, can put the U.S. on a pathway to energy independence. The U.S. imports a majority of the oil it uses, much of which comes from politically unstable regions. In February 2009, the U.S. consumed 524 million barrels of oil, of which it imported 60%. In periods of higher demand, imports account for an even greater percentage of consumption. A gigaton scale-up of biofuel production can reduce U.S. reliance on oil imports by as much as 25% in the next 10 years (See Figure 3). Distributed energy resources, e.g., small solar and wind installations, can also enhance energy security by reducing vulnerability to major power disruptions whether from oil shortages, natural causes, or terrorism.

Oil is currently such an essential ingredient in the U.S. economy that without it the nation would come to a virtual standstill. The dependence on oil leaves the U.S. vulnerable to price shocks when supply constricts, and sudden price increases harm consumers and can destabilize the economy. Even without price shocks, U.S. citizens pay for the costs of government and military activities to protect U.S. oil interests abroad. The nation is vulnerable to all disruptions in its supply, whether from piracy, terrorist attacks, or acts of war at key choke points for oil processing and transportation. In light of these vulnerabilities, the 2007 Energy Independence & Security Act recognized a decrease in oil dependence as a clear security objective.

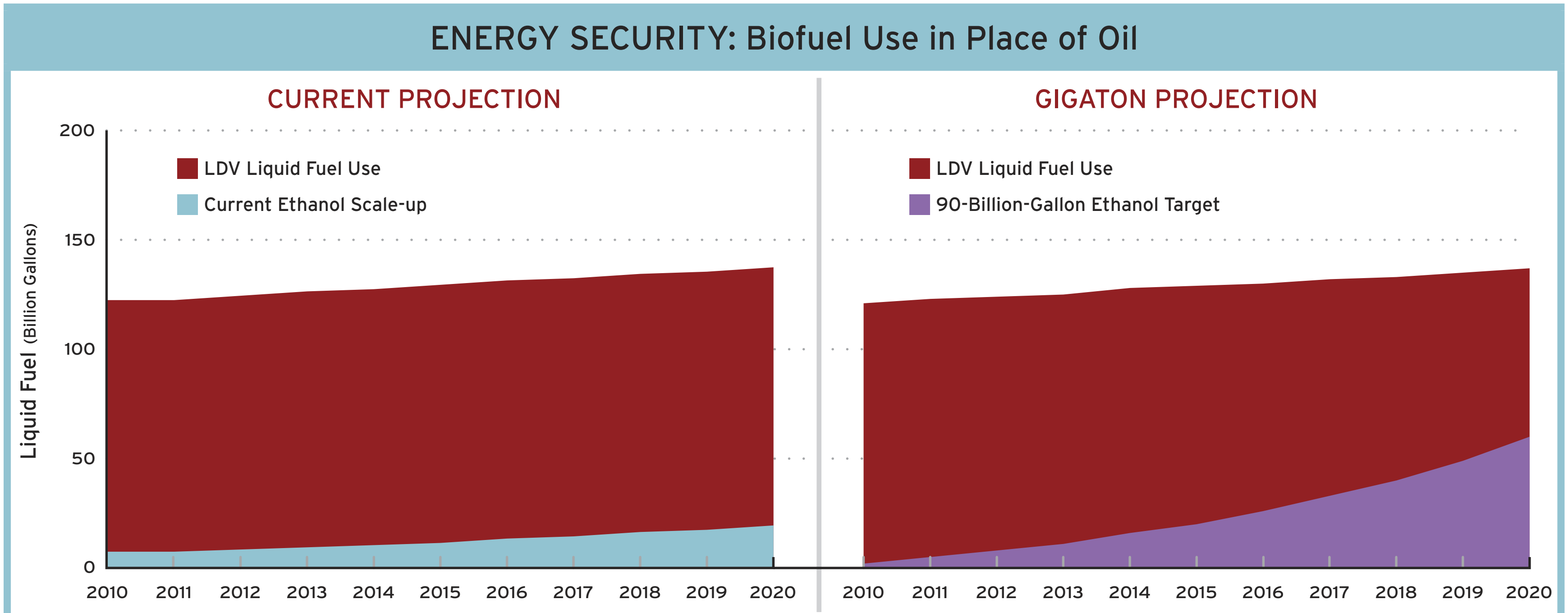

FIGURE 3. Gigaton-scale biofuel production in the U.S. can have a major impact on foreign oil dependence. An expansion of biofuel production to reach 90-billion-gallons in 2020 could displace close to half of the oil demand in the light duty vehicle (LDV) sector. The LDV sector is the largest oil-consuming sector in the U.S.

Climate change is the second threat to U.S. security that is addressed by scale-up of clean energy. Climate change poses a severe threat to global stability, with both direct and indirect implications for U.S. security. Unchecked, climate change is likely to create refugee crises worldwide as large populations are displaced by rising sea levels, increasingly intense storm patterns, prolonged drought, and resource scarcity leading to intense struggles for water and food and contributing to social instability. Conflict, loss of human life, and disruptions in trade could all have a significant impact on the U.S. The nation risks both needing to mount a humanitarian response and being drawn into conflict in order to protect national interests abroad as instabilities develop.

Gigaton-Scale Clean Energy Requires a 3X Expansion in the Current Rate of Investment

Deploying all 8 of the feasible gigaton-scale technologies in this report would require a significant increase in worldwide investment to $500 to $800 billion per year. At this scale, clean energy investments would be in line with fossil-fuel investments. Current global investment plans for maintaining and expanding energy infrastructure are on the order of $13 trillion globally over the next 10 years. In the U.S. alone, current planned investment is projected to be close to $1 trillion.

Shifting investment to the clean energy sector will not only benefit jobs, energy security, and climate change, but will create a new global industry. Twenty years ago, the U.S. had an information technology (IT) sector and a tiny internet and mobile phone sector. The nation developed these sectors by investing in technology and creating a marketplace where it could prosper. The IT sector has been propelled by more than $680 billion in direct investment in wired and wireless infrastructure between 1997 and 2008. Facilitated by stable and supportive government policy, this trillion-dollar sector now employs more than 1 million people directly in the U.S. and supports millions of additional service jobs. The investment oppor-

INVESTMENT: Global Annual Investment to Scale Up Clean Energy Technologies

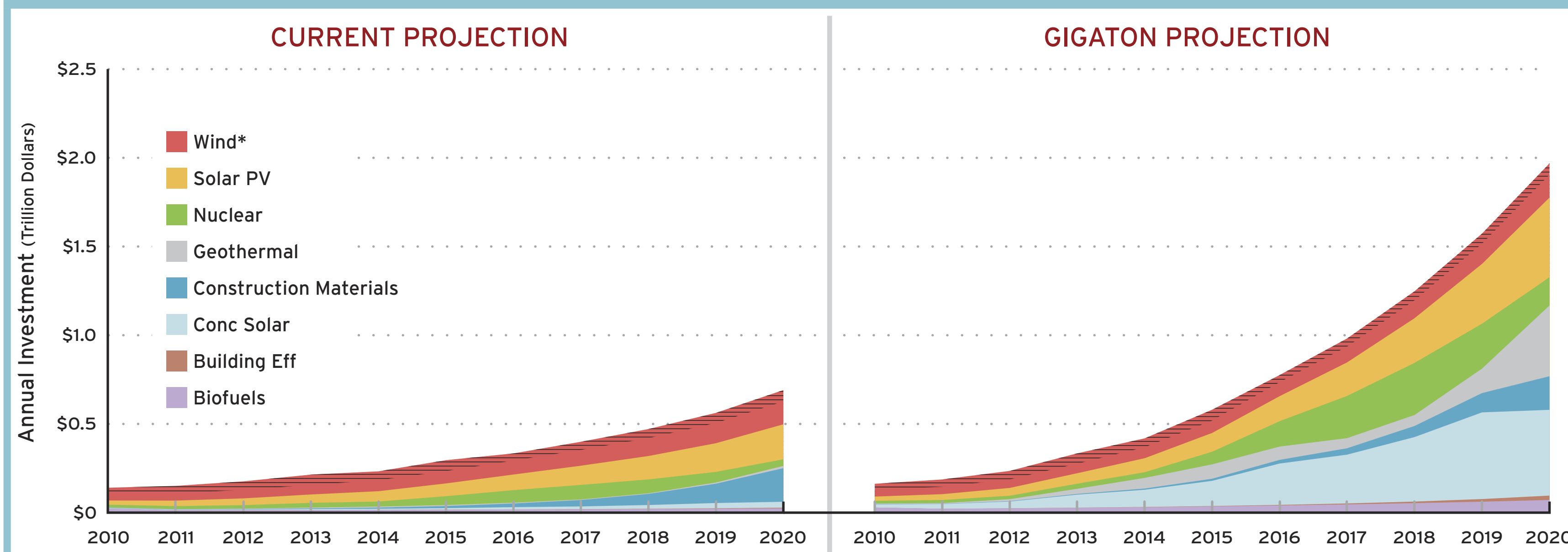

FIGURE 4. Private investment needs to accelerate by 3X for technologies to achieve gigaton scale over the next 10 years. The cumulative 10-year investment for gigaton scale-up of all 8 feasible technologies is $8.41 trillion, compared to currently projected investments in these technologies of $3.67 trillion. In 2020, annual investment levels reach $2 trillion (compared to $135 billion today), indicating a significant market opportunity.

* Wind is currently projected to exceed gigaton scale and attract $1.38 trillion in investment.

SPOTLIGHT: Companies with Gigaton Goals

Novozymes

Setting out an ambitious but achievable goal has a way of sparking creativity and new ways to solve a problem. Novozymes, an industrial biotechnology company, is an example of that creativity.

"We have set out as a corporate objective to enable our customers to reduce their CO_2 emissions by 75 million tons by 2015 through the application of our products," says CEO Steen Riisgaard.

Novozymes' carbon reductions come from the use of enzymes. "Enzymes are nature's engines of efficiency," says Riisgaard, "We apply them to industrial processes to increase efficiency and reduce greenhouse gases as well."

Novozymes sells more than 700 types of enzymes and microorganisms to the nearly $3 billion enzyme market. The company is one of the largest biotechnology and enzyme companies in the world with revenue of $1.5 billion in 2008.

The types of products Novozymes sells are as wide ranging as the industries they service. Paper pulp processing is only one example of the 40 different industries Novozymes serves. Less than half a kilogram of a particular enzyme can separate the fibers of more than 1 ton of wood pulp, saving energy and CO_2. If all thermo-mechanical pulp used this enzyme, the industry could eliminate 3 megatons of CO_2e per year.

Serious Materials

Two of the technology pathways reviewed in this report achieve significant CO_2e reductions by focusing on the built environment – building efficiency and construction materials. California-based Serious Materials, with manufacturing facilities across the U.S., recognizes both the immense business opportunity and potential environmental and social benefits of these two sectors.

CEO Kevin Surace observes, "The opportunity here is immense. Many building materials and technologies have not seen any innovation in the last century."

Serious Materials currently focuses on improving windows and drywall for energy efficiency, thereby reducing carbon emissions in two main ways: by developing and manufacturing building materials that are less energy intensive to make, which reduces up-front carbon emissions compared to other products by up to 80%, and by improving operating energy efficiency for buildings, thus continuing to reduce carbon emissions by up to 50% or more during a building's lifetime.

"Indeed, the environmental benefits of energy-efficient building materials are quite compelling, but the fact is that energy efficiency saves consumers money on their electricity bills and creates new domestic manufacturing jobs," says Surace. "We believe that scaling up our operations to reduce a gigaton of carbon emissions is not only feasible but can help the U.S. take the lead in an important and growing sector."

tunity in clean energy is much larger given the more than $4-trillion energy market.

The 8 renewable energy technologies that this study finds can feasibly achieve gigaton scale represent an investment opportunity of more than $8 trillion over the next 10 years, as shown in Figure 4. At this scale, clean energy — including efficiency improvements — would meet close to 60% of new global energy capacity requirements by 2020. The magnitude of investment needed to achieve gigaton scale varies by technology. The most capital-intensive technology we analyzed was PHEVs. The least capital-intensive technologies capable of gigaton scale include building efficiency, construction materials, and biofuels. Of particular note, the capital intensity of the building efficiency gigaton-scale pathway is 10 times less than for any of the generation pathways.

Expansion of clean energy in the developing world could benefit from accelerated U.S. investment to scale technology. The promise of inexpensive electricity and fuels has already encouraged venture capitalists in the U.S. to fund hundreds of clean energy start-ups; some of these companies could scale up over the coming decade to become large global suppliers. If the U.S. creates large, well-structured markets at home, these companies can continue to advance their technologies and reduce costs so that they can compete with fossil fuels even in the developing world.

Policy Action is Needed to Achieve Gigaton-Scale Clean Energy

To support the potential of gigaton-scale clean energy, the U.S. must enact and sustain policies to catalyze private investment, expand markets, and align incentives to produce society-wide benefits. Current policy does not take into account the negative effects of fossil-fuel-based energy use, nor does it motivate efficient energy use.

The three categories of policy important to achieving gigaton scale are: financial incentives, regulatory structure, and infrastructure development. In addition, the U.S. government should continue support for research and development (R&D) and lead the international community to create a global policy framework.

Policies must be stable if renewable energy technologies are to achieve gigaton scale. A carbon policy, for example, will not attract investment capital if the policy is subject to political manipulation in the short term or risks being revoked by a future congress or administration. No matter how robust a policy, investors are reluctant to bet on the staying power of a single policy by a single government because a shift in that policy can be catastrophic. The revoking of wind subsidies by California in the early 1990s, for example, caused the bankruptcy of almost every wind turbine start-up company in the U.S. and many around the world. The U.S. is no longer the world leader in wind technology largely as a result of such unstable policies. In short, unpredictable policy causes capital to flee; investors avoid categories of risk that they can't predict or understand. Investors and entrepreneurs are accustomed to analyzing uncertainty based on markets but are wary of uncertainty based on politics.

Financial Incentives

- **Carbon policy.** The single most important policy needed to support gigaton scale is a carbon pricing regime. A meaningful price on carbon emissions will drive investment into supply chains and spur innovation. The timing of this action is critical. It is needed now. Investment will lag the increase in potential market size. Supply chain ramp-up is particularly time sensitive. It can take 3 to 5 years for market opportunity to flow through to capacity investment, so the right signals must be given to private investors today if clean energy technologies are to achieve gigaton scale by 2020. Many innovations that could result in fast, cost-effective paths to gigaton scale will emerge rapidly with appropriate policies and investment.
- **Loan guarantees, early deployment, and tax credits.** These financial policies are important for the short term both because of the current shortage of capital and because of the special role of capital for clean energy. The cost of capital has a bigger impact on the price of clean energy sources than on the price of fossil-fuel sources. In general, clean energy has higher up-front costs and lower operating costs than traditional energy sources, and the "fuel" for clean energy is typically a free (renewable) source (e.g., sunshine or wind). Higher up-front costs make clean energy more sensitive to financing costs. Traditional lenders need examples of successful renewable energy plants operating at scale to provide favorable rates comparable to what is offered to fossil-fuel industries. Eventually these financial incentive programs can be phased out as clean energy ramps up and becomes more mainstream.
- **Government purchasing.** The government can be the market maker for early technologies as it has successfully done in the past. For example, federal purchases of buildings certified by Leadership in Energy and Environmental Design (LEED) helped pave the way for expansion of energy-efficient buildings.
- **Support for early scaling efforts.** A number of issues need to be resolved when a utility switches to a renewable energy source, including integration related to the timing of power supplies because many renewable resources produce electricity intermittently. Government should fund utility-scale pilot projects to test higher penetration of renewables.

Regulatory Policy

- **Decoupling.** Most utilities are regulated in a way that couples revenues and earnings. This gives utilities an incentive to increase the volume of electricity sales, which simultaneously increases revenues and earnings. In other words, regulation in this case dissuades utilities from pursuing or promoting efficiency. This is one of a set of market failures associated with overconsumption of energy in buildings. Decoupling of revenues and earnings for California utilities has enabled those utilities to increase support of efficiency programs.
- **Renewable Electricity Standards (RESs).** Requiring a utility to incorporate a minimum amount of renewable energy into its electricity mix guarantees a market for clean energy, which in turn stimulates investment. RESs are already in place in 49 jurisdictions (countries and U.S. states)

around the world, but our findings indicate that more aggressive standards are needed to facilitate gigaton scale.

- **Fuel standards.** Standards and minimum production levels for low-carbon fuels can play an important role in reducing oil dependence and addressing climate change. These fuels are not necessarily more expensive, but without standards there is limited incentive for investment in new fuel infrastructure.

- **Efficiency standards.** As illustrated in the McKinsey 2007 report, efficiency is the lowest-cost pathway to energy and carbon savings.[6] Because developers are not responsible for a building's utility payments, and car owners don't own vehicles long enough to benefit from higher mileage, these market participants have limited incentive to surpass current standards. Energy-efficiency upgrades in buildings are often inexpensive but may require training and restructuring on the part of industry. Efficiency standards can align incentives to help surmount these obstacles. New building standards can encourage fast-payback upgrades, and vehicle efficiency standards are a proven way to reduce energy dependence and limit CO_2e emissions. Regulatory intervention is needed to align incentives in the buildings and vehicle sectors.

- **Demand-side management support.** Managing when consumers use electricity, not just the quantity they use, is an important step to improving market functioning. Giving consumers options to shift the timing of their power consumption can relieve peak demand and lower electricity system expenses. Power costs more to produce during peak-use times. With modern information technology, it is possible to use price signals to shift consumption. As an example, time-of-use pricing gives consumers a true price signal so that they can opt to shift power consumption to lower-cost (non-peak) times. Employing time-of-use rates would open up a much larger market for technologies that provide intermittent or peak power such as wind and solar.

Infrastructure Policy

- **Transmission regulation.** Electricity grid enhancement will support all of the gigaton-scale generation technologies. Both long-haul transmission and local grids need enhancement. Prime renewable energy resources (wind, solar, geothermal, and biofuels) are mostly located in areas not connected to the grid; therefore, investment in infrastructure is needed to bring them to the power transmission network. Infrastructure build-out will enable long-distance electricity transmission that taps inexpensive sources of clean power. Investment is also required to improve grid intelligence. "Smart grid" enhancements enable distributed sources of power like rooftop solar, fuel cells, and small-scale wind and make the grid more efficient and resilient. The cost of grid enhancement is small compared to the cost of new generation capacity.

R&D and Education

The energy crisis of the 1970s sparked clean energy R&D in the U.S. and other countries. Many of the innovations developed and enhanced during that era are just now reaching utility scale. Future innovations can move more quickly to market with appropriate policies. Moreover, emissions cuts beyond the gigaton target will be necessary after the year 2020; continued R&D can smooth the way to those reductions and reduce their cost. R&D funding also supports training for the technicians, engineers, and scientists necessary to accelerate scaling of energy technology.

All of the gigaton-scale technologies produce jobs. In some categories, such as nuclear and solar, the Gigaton Throwdown Team identified a shortage of trained personnel, which might constrain gigaton-scale expansion. Government support of training and education can be a major help in providing the human resources necessary to scale up clean energy aggressively.

International Engagement

The bulk of growth in energy demand is occurring in countries outside the Organization for Economic Cooperation and Development (OECD), with more than 40% coming from China alone. The technology choices that OECD countries make will determine global energy markets and significantly affect future global CO_2e emissions. U.S. policy engagement and technology innovation can influence these choices. U.S. leadership can also ensure the competitiveness of innovative clean energy companies as they expand beyond the U.S. and OECD markets. First, the U.S. can serve as a receptive market to reduce the cost of these new technologies. Second, the U.S. can encourage adoption of similar policies in the developing world and other countries. Creation of a global carbon market would expand the opportunity for U.S. businesses that develop their technologies under a U.S. carbon regime.

Pathway Findings

Biofuels

- Biofuels can achieve gigaton scale by 2020 for an investment of $383 billion, creating 394 thousand direct new jobs and enhancing energy security by displacing foreign oil imports.
- Corn ethanol cannot deliver 1 gigaton of CO_2e reductions because of massive land-use requirements; next-generation biofuels (e.g., cellulosic ethanol) can scale to 1 gigaton.
- Biofuels are widely seen as a low-cost and rapidly deployable alternative for the transportation sector.

Building Efficiency

- Building efficiency can achieve gigaton scale by 2020 for an investment of $61 billion, creating 681 thousand direct new jobs.
- Building efficiency is the lowest-cost pathway (of the 9 in this report) to achieve 1-gigaton CO_2e reduction by 2020.
- New energy-efficient building designs show little to no up-front cost and more than 30% energy savings.

Concentrating Solar Power

- Concentrating solar power can achieve gigaton scale by 2020 for an investment of $2.24 trillion, creating 484 thousand direct new jobs.
- Solar resources are abundant in the U.S. and globally to meet new energy demand, and concentrating solar power is ideally situated to remote, high-insolation desert areas, so new transmission build-out is needed to bring CSP to high-population areas.
- Solar thermal systems with storage can provide consistent power and thus are attractive relative to intermittent power sources, e.g., solar photovoltaics and wind.
- Tested technology has been supplying cost-competitive solar thermal power in southern California for the past 20 years.

Construction Materials

- Construction materials can achieve gigaton scale by 2020 for an investment of $445 billion, creating 328 thousand direct new jobs.*
- Multiple gigaton-scale pathways exist in the construction materials sector; the biggest single opportunity for CO_2e reduction is low-carbon cement.
- No single country's building sector can achieve gigaton scale alone, with the possible exception of China if that country shifted to low-carbon cement production.

* *Jobs and investment numbers based on transformation of the cement industry.*

Geothermal

- Geothermal can achieve gigaton scale by 2020 – contingent on development of Enhanced Geothermal Systems (EGS) – for an investment of $919 billion, creating 448 thousand new jobs.
- EGS development will require an estimated $1 billion in R&D to be market ready.
- Major areas for technology support include transmission, drilling, reservoir stimulation, downhole pumps, energy conversion, and exploration.
- Geothermal will ramp slowly; each project requires roughly 5-7 years.

Nuclear

- Nuclear can increase by gigaton scale by 2020 for an investment of $1.27 trilllion, creating 269 thousand direct new jobs; this pathway faces major build out challenges.
- Nuclear power already displaces more than 1 gigaton of CO_2e annually.
- Major technical challenges to scaling nuclear include rapid expansion of the supply chain, including the build-out of large steel forges, and expansion of the workforce.
- Concerns surrounding weapons proliferation, waste disposal, and safety make nuclear uniquely challenging.

Plug-In Hybrid Electric Vehicles

- PHEVs cannot achieve gigaton scale by 2020; starting in 2010, every new car would have to be a PHEV to meet the gigaton goal by 2020, making this pathway all but impossible.
- An aggressive scale-up to 5 million PHEVs would create more than 204 thousand jobs in the battery industry, for an investment of $1.9 trillion.
- Innovations that reduce the cost of batteries and of vehicle retrofits would have a major impact on this pathway, as would business models to finance up-front costs of vehicles.

- The vehicle sector in general is by far the most capital-intensive sector of those examined in this report; it is also a source of major job creation.

Solar PV

- Solar PV can achieve gigaton scale by 2020 for an investment of $1.71 trillion, creating 1.63 million direct new jobs and enhancing energy security through distributed power generation.
- At current growth rates solar PV is on track to abate half a gigaton CO_2e by 2020 and be cost competitive with current electricity prices within the next 5 years.
- Solar PV is already price competitive for peak power rates in a number of markets.
- Successful policies, grid integration, and storage are critical to scaling PV.

Wind

- Wind is on a pathway to exceed gigaton scale by 2020 and attract $1.38 trillion in investment, creating 452 thousand direct new jobs.
- Current projections show wind delivering close to 1.5 gigatons of CO_2e reductions in 2020.
- There is enough wind resource available for more than 4 times projected annual global energy consumption in 2010.

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