Implications of a Low-Carbon Energy Transition for U.S. National Security

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Introduction

Climate change and the secure supply of energy are among the biggest challenges of the twenty-first century. The problem is immense: While global greenhouse gas (GHG) emissions are still on the rise, they will have to be halved by the middle of this century in order to prevent the most dangerous effects of global warming. And while energy-related emissions are already responsible for the largest share of GHG emissions, global energy demand is estimated to rise by 50 percent or more between now and 2030.[1] Climate change and energy security can be seen as Siamese twins insofar as they can only be sustained with concern for one another: 80 percent of global energy supply is produced from fossil fuels which, in the United States, Europe, Japan and other important U.S. ally countries, are increasingly imported and therefore are at the core of their increasing energy dependence. The burning of fossil fuels also emits CO_2, and energy-related CO_2 emissions are responsible for about 60 percent of man-made climate change.[2]

The security impacts of climate change and our dependence of fossil fuels have been much debated. It is in the national interest of the United States to address both issues vigorously. There has been little academic and political discussion, however, about the security impacts of a transition of our economy to one that is built on a low-carbon energy foundation. What are the foreseeable material input demands and what human capacities are needed for such a transition? This paper addresses these questions under a particular scenario in which the United States commits to GHG reductions as party to an international climate change agreement.

1. Climate Change and Energy Security in the 21st Century[3]

There are radical changes ahead of us regardless of whether we act on climate change and energy security or not. In both cases, our environment, our economies, our domestic and foreign politics, our societies, and our individual lives will change dramatically. However, they will change in very different ways. The Intergovernmental Panel on Climate Change (IPCC) states that global warming is by now unequivocal. If emissions continue to grow unchecked, climate model projections reviewed by the IPCC indicate a further temperature rise of 1.1 to 6.4°C (2.0 to 11.5°F) during this century. The global effects would be a sea level rise of 110 to 770 millimeters (0.36 to 2.53 ft), more frequent warm spells, heat waves, and heavy rainfall, possibly followed by a dramatic increase in inland floods. There would be more droughts, more intense storms, and more extreme high tides. Up to 30 percent of plants and animal species would already be threatened in a low temperature increase scenario.[4] Already, the modest climate change that occurred between the mid 1970s and 2000 is estimated to have caused an annual death toll of over 50,000 lives. At continued emission trends, this number is likely to double by 2020.[5]

The United States has seen an increase in frequency of weather-related events since the 1950s.[6] The Southwest has experienced severe drought conditions since 1999. The 2007 heat waves in the western, central, and eastern parts of the country were record-breaking events: Drought conditions had terrible effects on farming and destroyed the harvest in vast areas. Fires of unprecedented sizes caused up to 100 human deaths and great destruction of property. The devastating floods of the recent past have led to the evacuation of thousands of homes. There is also evidence suggesting that the annual numbers of tropical storms, hurricanes, and major hurricanes in the North Atlantic have increased over the past 100 years.[7] Concerning the future, moderate climate change in the early decades of the century might increase the productivity of rain-fed agriculture in some northern regions, but decrease productivity in other parts of the country. Further warming in the western mountains is projected to cause decreased snow pack, more winter flooding, and reduced summer flows, exacerbating competition for already over-allocated water resources. Heat waves and droughts are projected to have increasing impacts on forests, with an extended period of high fire risk and large increases in area burned. Cities already experiencing long stretches of high temperatures are expected to be further challenged by an increased number, intensity, and duration of heat waves with direct health impacts. Many of America's major cities are located directly on the coast. These locations could face major land and habitat loss. Particularly for Florida, but also for the Northeast, sea level rise might become a major threat. If the intensity of tropical storms further increases, so will the human and economic losses. In 2003, a heat wave of unprecedented magnitude struck large parts of Europe, the United States' most important ally, causing the death of 35,000 people.[8]

For more than three decades, experts have called for widening the concept of national security to include a far broader range of threats to peace than traditional inter-state conflict, namely global resource scarcity and environmental pollution. However, only recently has "environmental security" entered the international political debate at the highest level; some of the key players of contemporary world politics have declared climate change the most serious global challenge of this century.[9] Climate change can aggravate the risk of intrastate conflict and interstate war over fertile land, food, water, and other resources. Both incremental climate change and rapid weather disasters can worsen living conditions to an extent that they cause people to flee their homes, exacerbating population pressure on neighboring regions. In 2005, increasing sea-level rise left 500,000 Bangladeshis of Bhola Island permanently homeless. The IPCC expects 150 million climate refugees predominantly from regions in Africa, Latin America, and Asia by 2050.[10] These migrants will also knock on American and European doors in their search for shelter. Former UN Secretary-General Kofi Annan stated: "Climate change is not just an environmental issue, as too many people still believe. It is an all-encompassing threat. It is a threat to health […]. It could imperil the world's food supply. […] It could endanger the very ground on which nearly half the world's population live."[11]

With the devastating effects of global warming becoming as clear as the economically disastrous effects of exploding energy prices, the debate to date has been often misleading. Fast and ambitious action on climate change and energy security is often considered to be an "option." As a matter of fact, however, there are no sound alternatives to it. It is in the national interest of the United States, mandated by environmental, security, and economic concerns, and, as such, a patriotic imperative. The same can be said about energy security. For example, an increasing number of experts believe that the maximum rate of global petroleum production has already been or is soon to be reached. After this "oil peak," they expect global production to enter a phase of ultimate decline.[12] The escalating shortage would further increase the price of petroleum. Are we going through this phase already? After all, oil production has not increased for years now despite rising demand and escalating prices. No one really has an answer to this question because there is no reliable data on remaining resources and, due to the OPEC cartel that determines supply rates, prices are manipulated and not the result of a free market. It is clear, however, that oil prices which have broken historical records recently, have and will continue to have enormous negative implications for the global economy as well as for prosperity in those regions which are net importers, including the United States. The profiteers of a continuation of the current energy system will be the biggest oil and natural-gas exporting countries. In a business- as-usual scenario, they will gain both in terms of capital and in influence. It is more plausible than not that these countries, which are quite aware of their powerful situations, will employ more radical methods if they believe their national interests are at risk.[13] Some commentators speculate that rampant energy prices bear a number of high security risks, including wars for resources, particularly oil; state failure and disintegration if the economies of already fragile states end up in complete disarray; and nuclear energy related problems because growing use of nuclear energy in response to the diminishing oil reserves also increases the danger of reactor accidents and the proliferation of weapons-grade plutonium.[14]

The success of climate and energy policy begins with the awareness of a problem of unprecedented dimensions: that our economies are fundamentally built on the burning of fossil fuels. Our entire transportation, agricultural, and industrial systems depend on their affordable supply. So the first link between both challenges, securing energy supply as well as an intact climate, lies in the joint root of the problem: that our dependence on fossil fuels is responsible for both a warming planet and a scarce energy supply. Our dependence on fossil fuels creates an unstable world by threatening our environmental, economic, political, and security systems through climate change and energy scarcity. The second and related link is on the solution side. We will only succeed in solving both problems if we manage to, first, change our consumption patterns, i.e., instead of continuing to squander our energy, consume it far more efficiently and, second, transform our energy production patterns, i.e., achieve a large scale alteration of our energy mix.

2. The Applied Scenario: U.S. Contribution to a 450ppm Pathway under an International Treaty

In the absence of exact knowledge of the complexion of a future global climate deal and the commitments of individual countries therein, we employ a scenario in this paper in which the United States agrees to GHG cuts on the order of 17 percent by 2020 and 85 percent by 2050 as part of an international treaty. We further presume that all major emitting countries agree to comparable efforts according to their national circumstances: while other industrialized countries commit to targets similar to those of the United States, emerging countries would commit to limit their per capita GHG emissions, e.g. to 4.5 t CO_2 in the case of China. The main timeframe we focus is the present day to 2030. In the *World Energy Outlook 2009*, the International Energy Agency (IEA) outlines a global energy scenario from 2007 to 2030 along the lines of these assumed emission trajectories. In this scenario, long-term GHG concentrations stabilize in the atmosphere at 450 parts per million CO_2-equivalent, a level at which there is a 50 percent chance that temperatures will not rise above 2 degrees Celsius (3.6 degrees Fahrenheit) from pre-industrial levels.[15] Although, according to the IPCC, there is no specific temperature threshold for dangerous climate changes, and the negative effects are gradually increasing, over one hundred countries have adopted this "2°C target" in order to contain global warming and its risks and consequences.[16] In order to include in-depth climate and energy trend projections, we will use the IEA's "450 Scenario" ("the Scenario") in discussing security implications for green technologies in the United States. It is important to stress that this scenario is a minimum for what has to be done in the United States to put the world on a "non-dangerous climate path." We will also stress the fact that greater scale-up of green technologies and practices than is outlined by the IEA, is technically and economically possible and preferential given the uncertainty of the costs of dangerous climate change on our nation.

The assumptions underlying the Scenario include global projections of economic growth, demographics, fossil fuel prices, technological developments, and urbanization. The deployment of individual technologies reflected in the Scenario take into account projected financial incentives, market barriers, and technological and social constraints.[17] Some 75 percent of added capacity is in the form of renewable energy. (See Table 1.) Considered are mainstream renewable technologies which are already in use (biomass, hydro, photovoltaic, solar thermal, geothermal, on-shore and off-shore wind, tidal and wave). Fossil fuels will play a relatively decreasing but still important role. A significant amount of coal emissions will be absorbed by "carbon capture and storage" (CCS).

In the Scenario, despite falling GHG emissions, nearly 5,000 GW of power generation capacity is added globally. This new capacity will be installed across a much wider geographical spectrum as developing countries and other major economies build up their energy infrastructure. 38 percent of capacity additions occur in the United States or its traditional allies among the Organization for Economic Cooperation and Development (OECD).[18] A nearly equal share of additions (37 percent) occur in other major economies, including China, Russia, Brazil, South Africa, and Middle Eastern nations. Overall, the Scenario represents a marked shift away from both conventional sources of energy and the typical distribution of generation capacity in the world.

The U.S. population is projected to expand from today's 308 million to nearly 370 million by 2030.[19] This increase will require the United States to expand electricity generation capacity and efficiency. In a business-as-usual-scenario, i.e. in the absence of significant GHG limitation efforts, the IEA projects that electricity generation would need to grow nearly 1,000 Terawatt-hours (TWh) - a quarter of current generation.[20] If, however, reductions are agreed to at the order outlined above, the IEA predicts that the United States would only require another 500 TWh of generation to meet the country's energy demand – a result of carbon-mitigating technologies, energy efficiency improvements, and mobilized government action.[21]

In the Scenario, renewable sources of energy supply approximately 10 percent of the United States' primary energy demand in 2020 and 20 percent by 2030.[22] This will require the nation to greatly expand installation, operation and maintenance of wind, solar, geothermal, and tidal power. (See Figure 1.) Energy efficiency measures will also be a key action for the United States moving forward. Improvements in power plant efficiency as well as the efficiency of processes that require energy input will make up nearly 50 percent of the nation's emissions-abatement effort up to 2030. (See Figure 2.)[23] Finally, in order to build security in this new system of renewable energy and energy efficiency, the United States must also sustainably manage water inputs, improve the electricity grid, and supply the adequate human resources.

In our analysis, in addition to individual energy sources, we also look at transformational needs in the transportation sector as well as new technologies that will become necessary in the areas of energy storage, distribution and usage. The future transition of our energy system will also require a build-up of intellectual capital commensurate with the scale-up of green technologies.

3. Energy Production from Renewables

Wind

Wind currently generates slightly above 1.5 percent of the world's electricity. In 2008, wind power accounted for 42 percent of U.S. capacity additions and 36 percent of new additions in the European Union.[24] Because of wind energy's relatively low cost per unit of electricity supplied - at USD 0.84 per kilowatt-hour (kWh), wind is the cheapest of all zero-emissions energy technologies (See Figure 3.) – the increase in wind capacity is more dramatic than that of any other power-generation source.[25] The full life-cycle of producing wind power, from turbine manufacture to operation and maintenance, also causes far less greenhouse gas emissions than most other technologies. The industry average is only 21 grams of CO$_2$-equivalent per kilowatt-hour provided (gCO$_2$-e/kWh), while coal, natural gas, and photovoltaic power are rated at 993 gCO$_2$-e/kWh, 664 gCO$_2$-e/kWh, and 106 gCO2-e/kWh respectively (see Table 2).[26] Each of these factors is a boon to the nation's economic, energy, and climate security, and an argument for the ambitious development and deployment of wind technologies. In the Scenario, U.S. electricity generation from wind expands from today's 70 TWh to 265 TWh in 2020 and 500 TWh in 2030.[27] Wind increases in the electricity generation mix of nearly every region of the world, especially in OECD countries, China, and India. As a consequence, we expect significant international competition for the immense amount of materials which this scale up will require.

The predominant wind-power technology in the United States is a horizontal axis wind turbine (HAWT) consisting of three large blades mounted on a hub. A 5 MW commercial-scale HAWT has a typical height of 114 meters (374 feet) and a blade diameter of 124 meters (407 feet).[28] Primary materials in wind turbines include steel and concrete for the basal structures, glassfiber reinforced plastic (GRP) and carbon-filament reinforced plastic (CFRP) for rotor blades.[29] Concrete supply will remain abundant as its primary components – sand, gravel, and limestone – are widely available and recycling technology is well-established. Steel is also of minor concern due to well-established recycling technologies; in 2008, recycling rates for construction plates and beams reached nearly 100 percent in the United States. Rates this high are also possible for wind turbine parts. The United States typically imports no more than 20 percent of the iron ore that it needs to produce steel. The majority of imports come from Canada and Brazil, two reliable trade partners.[30] The greatest security risk for the wind industry going forward will be the global economics and availability of rare earth metals ("rare earths"), in particular neodymium, which is a primary element in the permanent magnet generators used in the newest commercial-scale wind turbines. (For a discussion of rare earths including neodymium, see Box 1.) These generators are now replacing gear-based generators due to their greater efficiency.[31]

Box 1. Rare Earth Metals & Neodymium[32]

According to the U.S. Geological Survey (USGS): *"rare earths are a relatively abundant group of 17 elements composed of scandium, yttrium, and the lanthanides… The elemental forms of rare earths are iron gray to silvery lustrous metals that are typically soft, malleable, and ductile and usually reactive, especially at elevated temperatures or when finely divided."* Rare earths are used in a wide range of applications including: electronics, chemical catalysts, computer monitors, lighting, televisions, automotive catalytic converters, glass polishing, and petroleum refining catalysts.

The US has proven reserves of rare earths, estimated at 13 million tons. (See Table 3.) Nearly 2 million tons of this reserve is neodymium oxide – far more than the estimated 40,000 tons needed for expanded wind capacity under the Scenario. However, rare earth mining in the US, concentrated in Mountain Pass, California, has stalled in the last decade due to pollution concerns. In the meantime, China's low labor and regulatory costs have pulled the lion's share of rare earth mining and production within its borders. As a result, China supplied 96 percent of the world's demand for neodymium in 2008. Thus, nearly all PM generators rely on China for their neodymium supply. In recent years, the People's Republic has actively controlled supply of neodymium to the global market and imposed duties on its rare earth exports. It has also made moves to secure a near-monopoly on the global rare earths mining and refining industries. In 2005, the Chinese state-owned oil company CNOOC attempted to acquire the United States' sole rare earth production firm, Molycorp. While the bid was turned down, it is a sign that China is highly aware of its current dominance of rare earths supply paired with the inevitability of demand growth.

Some possibilities stand out for reducing China's dominance in this sector. Further rare earth exploration could turn up previously unknown reserves. The USGS *Commodity Summaries 2010* states that "undiscovered resources are thought to be very large relative to expected demand." In fact, the U.S. government already seeks to boost its domestic rare earth industry. A bill has been introduced in the House of Representatives calling for an assessment of domestic resources, supply-chain support, and workforce development (the bill is called The Rare Earth Supply-Chain Technology and Resource Transformation (RESTART) Act of 2010). The U.S. Department of Energy has already launched an initiative to "assess ways of diversifying the global supply chain, developing substitutes for rare earth minerals, and promoting recycling, reuse and more efficient use of strategic materials."

Biofuels

Global biofuel production topped 81 billion liters - 66 billion liters of fuel ethanol and nearly 15 billion liters of biodiesel – in 2008, an increase of more than 36 percent over the previous year.[33] Biofuel production has increased more than 350 percent since the start of the decade and now makes up some 1.67 percent of the total world liquid fuel supply.[34] The United States produced nearly 35 billion liters in 2008, more than 43 percent of the global total.[35] Global biofuel production in the Scenario will increase about eightfold from current levels, almost one-third of which is U.S. demand. Biofuels will comprise an increasingly large percentage of U.S. transportation energy, rising from 2 percent in 2007 to 20 percent in 2030.[36] The U.S. has strong policy support for biofuels and currently mandates the blending of 136 billion liters of biofuels annually into conventional motor fuels by 2022 under its revised Renewable Fuel Standard.[37]

Expanding biofuels production will affect the production of other crops and livestock in ways that are not fully known but which are dependent on the types of biofuels produced—first versus second generation.[38] Increased biofuel use is contributing to the global conversion of land to agriculture for growing feedstocks.[39] The United States already devotes nearly 33 percent of its corn to fuel production, up from 6 percent in 2000.[40] By some estimates, pressure to expand biofuel production could increase the expansion of cultivated land by 20–40 percent by 2020, accelerating deforestation, biodiversity loss, and other problems, each of which can pose security problems in the wider sense.[41] For example, increasing biodiversity loss may limit human capacities to develop new medicines. The rapid growth in biofuels use in the past five years has also contributed to a sharp increase in the prices of food and feed grain.[42] The International Institute for Applied Systems Analysis looked at a series of stimulated biofuel scenarios and concluded that increasing biofuel production will lead to more hunger across the world.[43] Africa and Asia are expected to be hit the hardest, making up two thirds and three quarters, respectively, of the additional number of people experiencing food insecurity due to biofuel increases in 2020 and 2030.[44] Refugees from these areas will search help in richer countries including the United States.

Current and expected limitations in ethanol infrastructure and production may force the United States to rethink the future of biofuels in its energy mix.[45] One problem is a general lack of pipelines from major biorefineries in the Midwest to distribution markets on the East and West Coasts.[46] The properties of ethanol also make it difficult to transport through the existing petroleum pipeline infrastructure without significant modifications.[47] Another potential issue is the nation's ethanol blending limit, currently set at a maximum blend level of 10 percent ethanol into conventional gasoline (known as E-10). A higher-level blend of 85 percent (E-85) can only be used in specially modified engines and is sold at only a small number of filling stations across the U.S.[48] Expanding E-85 consumption would require new ethanol distribution channels, new storage facilities, and increased purchase of flex-fuel vehicles that can run on the fuel.[49] Other potential problems include biomass collection and storage. A cellulosic refinery producing 10-20 million gallons of fuel per year requires an estimated 700 tons of input per day.[50] Producing such large quantities will require advances in harvesting, collection, transporting, and storage.[51] The U.S. Departments of Energy and Agriculture estimate that 1.3 billion tons of biomass could be harvested sustainably each year to produce enough biofuels to replace 30 percent of the nation's oil consumption by 2030 while still meeting other needs such as food, feed, and exports.[52] The counted biomass includes 368 million dry tons of wastes from forests and logging, residues from wood, pulp, and paper mills, and construction and demolition wastes.[53] Another 998 million tons are available from agricultural production, including energy crops, crop residues, and animal manure.[54] Potential obstacles to meeting this yearly biomass goal include uncertainties with new energy crops, including yield variability, time to establish production, and harvesting requirements and timing.[55]

Concentrating Solar Power

In the Scenario, U.S. electricity generation from "other renewables" – concentrating solar power (CSP), solar photovoltaics, geothermal, wave and tidal, hydroelectric, and biofuels – increases from roughly 89 TWh in 2007 to 223 TWh in 2020 and 413 TWh in 2030. Utility-scale CSP plants currently represent less than 0.1 percent of the United States' electricity generation capacity, with 15 plants totaling 424 Megawatts.[56] However, more than 10,000 Megawatts of capacity are currently under development.[57] CSP plays an important role in the Scenario because it is considered the most commercially-scalable solar technology. It is both cheaper than solar photovoltaic generation and has the second least life-cycle carbon-dioxide emissions per kWh of any power-generating technology.[58] CSP plants require an array of mirrors that concentrate sunlight on a water-based liquid which then produces steam to drive electricity generation. Mirror inputs are fairly unsophisticated. Thus, material input for CSP is not an *international* security risk for the United States. However, water availability is a serious input concern for CSP. (See Box 2.) CSP plants are typically sited in desert-like landscapes but use a significant amount of water equivalent to that of a nuclear power plant.

Solar Photovoltaic

Today's PV capacity in the United States stands at 1.2 GW, around 0.1 percent of total electricity generation capacity. PV, currently at USD 21.2 per kWh, will be rather costly to scale up. However, it has immense GHG avoidance potential, at only 106 gCO_2-e/kWh for the full life-cycle.[59] PV modules can also take advantage of existing infrastructure when installed on building rooftops. Currently, three dominant technologies for generating PV power exist: crystalline silicon, "thin-film" PV panels, and concentrator PV cells.[60] Silicon sources are highly abundant and do not present an import strain for the United States. However, silicon PV electrodes require a significant amount of silver.[61] As 63 percent of the U.S. silver supply is currently imported from abroad (primarily Mexico, Canada, Peru, and Chile) at significant costs, it is predicted that silver needs will significantly hinder the ability to scale crystalline silicon PV to the terawatt level, unless the amount of silver required for PV panels is reduced, or alternative electrodes are developed.[62] Thin film PV requires an Indium-tin-oxide conductor layer. The United States is largely dependent on China for Indium supply stands in the way of a massive scale-up of the technology. Zinc-oxide alternatives for the conductor layer are currently under development. Most of these have to be imported as well but the main suppliers are Peru, Ireland, and Mexico making the United States less dependent on one individual exporter county. A similar situation exists for concentrator PV cells. They require germanium – a relatively scarce mineral imported primarily from Belgium and China. A shift to proven gallium arsenide (GaAs) alternatives would prevent over-dependence on these countries. However, this technology has not reached commercial scale.[63] American companies currently lead the way in production of PV modules, with First Solar ranking second in silicon-based cells (behind Germany's Q-cells).[64] First Solar and United Solar also lead the way in production of thin film modules.[65] With China as a main competitor in both consumption as well as production of solar PV technologies and also a major exporter of certain essential minerals, it is clear that the focal point for reducing risk in PV development lies with intellectual capacity. It is essential that the United States maintain its competitive advantage in photovoltaic research and development.

Geothermal

Geothermal currently produces only 0.3 percent of U.S. energy but is set to expand rapidly as early as 2013, with several major projects underway in California and Nevada. In 2009, the U.S. Department of the Interior authorized the installation of geothermal energy-production sites on federal lands. The Bureau of Land Management is planning for 12 Gigawatts of geothermal energy to be installed on its lands by 2025, a greater capacity than is envisioned for the whole OECD in the Scenario. Sources of geothermal energy in the United States include steam or hot water that occurs naturally underground, as well as hot areas of the crust that can be injected with water to create steam. Hot water suitable for geothermal energy is also produced at many oil and gas wells. This "produced water" is typically discarded as a waste product, but can provide a cheap and efficient source of geothermal power. One study calculates that over 70 GW of geothermal capacity could be established at existing oil and gas wells within the United States by 2030.[66] Expansion of geothermal power will present few concerns for international resource competition. Geothermal turbines are technologically similar to the steam turbines used in many conventional fossil fuel power plants and material inputs are fairly secure. However, the intellectual capacity for scaling up geothermal will come from abroad (mainly Iceland) until more Americans enter into the field. The National Renewable Energy Laboratory admits that a "major obstacle facing geothermal energy utilization in the US and worldwide is the shortage of people with experience and training in geothermal development and engineering."[67]

Hydroelectric and Wave & Tidal

Hydroelectric plants currently make up 78 GW, or 7 percent of existing generating capacity in the United States.[68] Due to widespread concern about the environmental and water resource impact of large dams, hydroelectricity is an unpopular option for meeting increased energy needs.[69] In the Scenario, hydro will increase to just over 100 GW by 2030, a minor increase compared to the capacity increase of nuclear, wind, and other renewables.[70] Therefore, construction needs will be few and will primarily require concrete and steel supplies which are economically secure.[71] Even so, provision of ample river-flow could be a security concern in the future, as changes to the nation's water cycle occur from an altered climate. (See Box 2.)

Some new wave and tidal power models call for permanent magnet generators, requiring rare earth inputs equivalent to those mentioned in the wind section above. However, as wave and tidal increases are relatively small over the next twenty years, rare earth security concerns will primarily affect other green technologies.

4. Non-Renewable Energy Production

Oil

The United States is the world's largest oil consumer, with petroleum constituting 39 percent of U.S. primary energy source demand in 2007. Ranked eleventh in world oil reserves, the United States imports about 60 percent of its oil. Due to high production levels, its proven oil reserves have declined by 46 percent between 1970 and 2006. [72] Tapped U.S. oil reserves—less than 20 billion barrels—can supply demand for about another decade at current rates of production, and less than a third of that time if the country had to supply its entire demand by itself. In 2000, the United States and Europe supplied 50 percent of domestic oil demand with domestic oil production. In a business-as-usual scenario, they will import more than 80 percent of their oil by 2030, competing for these resources with other regions, most importantly the booming economies in Asia.[73] Most of this additional supply would have to come from the Persian Gulf and, to a lesser degree, from the Caspian Sea and Russia. The result would be an ever-increasing Western dependency on these politically and strategically fragile regions.

In the Scenario, the United States sees a significant shift in its transport sector from conventional fuel vehicles to electric and biofuel-powered vehicles. The global share of transport powered by zero-carbon fuels rises from today's 19 percent to 32 percent in 2030. This shift is largely concentrated in OECD countries. So while U.S. oil import volumes in the Scenario actually decrease – from roughly 24 million barrels per day (mb/d) today to less than 8 mb/d in 2030, they will continue to rise in China and India.[74] Despite this and the anticipation that the Organization of Petroleum Exporting Countries (OPEC) increases production from today's 37 mb/d to 48 mb/d in 2030 (a greater increase than OPEC countries achieved from 1980 to 2008), the traditional security concerns around oil do not entirely disappear.[75] Global oil demand rises roughly 0.2 percent per year up to 2030, and with OPEC countries supplying much of this increase, its members will continue to gain power and influence internationally. It is more plausible than not that these countries, which are quite aware of their powerful situations, will employ more radical methods if they believe their national interests are at risk.[76] Reducing our oil dependence as swiftly as possible is one of the greatest efforts to contain our dependence on the import of "foreign oil," a key national security goal.

Natural Gas

In 2007, natural gas comprised 21 percent of world and 23 percent of U.S. primary energy demand. In the Scenario, the natural gas share of worldwide primary energy demand falls slightly to 20 percent in 2030, 17 percent below IEA business-as-usual projections. In the United States, however, natural gas share rises to a projected 25 percent in 2030, only 3 percent below the reference case. Natural gas for electricity generation in the United States increases from 21 percent in 2007 to 26 percent in 2030, a 29 percent increase over the reference scenario.[77] The United States has abundant natural gas reserves, and in 2007, overtook Russia as the world's leading natural gas producer.[78] These abundant resources will play a key role in helping the United States achieve a significant reduction of GHG emissions in the power sector. Based on current technology, advanced natural gas combined cycle power plants emit about 55 percent less CO_2 than even advanced supercritical pulverized coal or integrated gasification combined cycle power plants, and 63 percent less CO_2 on a per kilowatt-hour basis than the average U.S. coal plant.[79] The most recent estimates of the United States' natural gas supply estimate that the United States has 2,074 trillion cubic feet of technically recoverable natural gas, including shale gas and other unconventional resources. [80] Even if U.S. demand were to rise to 29,496 billion cubic feet per year, this represents a 70-year supply of gas, although scaling up production of new gas resources will not happen immediately, as state and federal regulators are still in the process of determining what safeguards will be needed to ensure gas development does not occur at the expense of local environmental quality. A significant increase in dependence on imported natural gas is only likely in the event that shale gas resources prove to have been dramatically overestimated or that imported liquefied natural gas (LNG) is cheaper than domestically produced gas. Gas producers abroad are not optimistic about the latter outcome, however. This year, Russian gas giant Gazprom shelved plans to develop the Shtokmann gas field, a project whose original intention was to supply a U.S. market for LNG that is no longer perceived to exist.[81] Some analysts have conjectured that rising U.S. production of unconventional gas will redirect LNG to Asia and Europe, diversifying the energy portfolios of these regions. Thus, while global demand and competition for natural gas will almost certainly rise in the coming decades, the United States, due to its immense domestic reserves, is unlikely to become dependent on foreign sources of gas.

The United States currently has a large, under-utilized fleet of combined cycle natural gas plants, representing a total nameplate capacity of 221 GW, but used at a capacity factor of only 35 percent.[82] The primary reason for this under-utilization has been the high fuel cost of natural gas relative to coal. In the Scenario, stricter regulation on power sector criteria pollutants, a potential price on carbon, and expected lower and more stable gas prices (i.a. because of the exploitation of unconventional gas reserves) in the future will help make natural gas a sustainable and cost-competitive alternative to coal. If the existing plants were operated at 80 percent capacity, they could theoretically generate about 1,554 TWh of electricity annually – more than enough to meet the projected demand for electricity from natural gas in the Scenario in both 2020 and 2030 (1,071 and 1,249 TWh, respectively).[83] Despite the large amount of existing efficient natural gas capacity, additional plants may need to be constructed depending on the geographic and temporal distribution of future electricity demand – demographic trends, state and local policies governing the power sector, the construction of new variable wind and solar capacity, the retirement of aging coal and gas plants, and many other factors. The main inputs in the construction of new combined cycle power plants are concrete, steel, iron, and aluminum; new pipelines to serve new capacities will require additional steel. [84] None of these input materials should be limited by significant shortages in the foreseeable future.

Although shale gas resources are located around the world, United States is far ahead of the rest of the world in the experience and technological expertise needed to develop those resources. Foreign companies including Norway's Statoil and France's Total have signed joint ventures with American producers in a bid to learn from U.S. shale gas production expertise. Last November, the U.S. government announced a U.S.-China Shale Gas Resource Initiative designed to share U.S. experience in shale gas with China.[85] U.S.-based consultants and service companies anticipate dominating international markets for some decades to come.

Coal

Roughly equal to natural gas, the United States covers about 23 percent of U.S. primary energy demand by burning coal. Coal consumption must decline sharply if the United States is to reduce greenhouse gas emissions 17 percent by 2020. Over 90 percent of coal consumption in the United States is by the electric power sector, which emits 82 percent of all electricity sector emissions and 33 percent of total U.S. emissions.[86] In the Scenario, U.S. demand for coal will decline from 1,122 million short tons in 2008 to 833 million short tons in 2020 and 498 million short tons in 2030, a 60 percent reduction relative to the 2030 business-as-usual scenario. Similarly, electricity generation from coal will decline from 1,700 TWh in 2007 to 1,692 TWh in 2020 and 1,106 TWh in 2030.[87] On the global stage, coal comprised 27 percent of worldwide primary energy demand in 2007. This is projected to fall to 18 percent by 2030 in the Scenario, a 47 percent decrease against the IEA's reference scenario, while coal for electricity generation will fall from 42 percent in 2007 to 24 percent in 2030, a 13 percent decrease against business as usual.

As the most abundant and evenly distributed fossil fuel in the world, coal is the least likely to pose a direct security of supply concern to the United States. As of January 1, 2009, the United States had an estimated 261 billion short tons of remaining recoverable coal reserves, or roughly 27 percent of the global total.[88] Other countries with significant coal resources include Russia, China, Australia, South Africa, and Kazakhstan. [89] U.S. supplies of coal could be enough to last for 230 years at current rates of consumption, although the National Research Council has estimated that U.S. coal resources may be closer to a 100-year supply.[90] However, due to tightening EPA regulations on coal plants' emissions of "criteria pollutants" (sulfur dioxide, nitrous oxides, ozone, mercury, and particulate matter), uncertainty about future carbon prices, and growing concerns about coal mining and coal waste disposal practices, coal generation is highly likely to become more expensive in the coming decades, losing its large cost advantage over other generating technologies. The amount of remaining coal generation possible under a scenario of 17 percent reductions in CO_2 by 2020 depends to a significant extent on the development of commercial carbon capture and storage technology.

Carbon Capture and Storage

CCS refers to processes of capturing CO_2 from a source such as a power plant and sequestering it into geologic formations such as deep saline formations, unmineable coal seams, and oil and gas reservoirs. CCS is considered a key technology to achieve the goals of the Scenario, but it is not projected to be deployed on a large scale until after 2020.[91] Currently, the integrated process of capturing, compressing, transporting, and storing CO_2 has not been done at a commercial scale in many places around the world, although according to the U.S. National Energy Technology Laboratory there are 135 active CCS demonstration projects worldwide, 47 percent of which are in the United States.[92] Government-led efforts to evolve CCS technologies have increased recently, with G8 leaders announcing plans in 2008 to undertake 20 large-scale demonstration projects by 2010 and a May 2009 U.S. announcement of USD 3.4 billion in new funding for CCS projects.[93] The Department of Energy's CCS goal is to develop, by 2012, systems that will achieve 90 percent capture of CO_2 at less than a 10 percent increase in the cost of energy services and retain 99 percent storage permanence.[94]

Although CCS has attracted great interest as a potential solution to reducing greenhouse gas emissions from fossil fuels, several constraints will limit the United States' ability to rely upon CCS. The first constraint is the availability of geologic formations suitable for CO_2 sequestration. The National Energy Technology Laboratory (NETL) estimates that North America has sufficient formations to store between 3,600 and 12,920 gigatons of CO_2, with most of the uncertainty surrounding the extent of suitable saline formations.[95] Even low end estimates predict sufficient storage capacity for centuries of CO_2 emissions. However, the portion of these potential storage sites within an economical distance of carbon point sources remains unknown. Second, carbon capture technology is still in early stages of development and could present risks or require inputs as yet unknown. In carbon capture, carbon dioxide is separated during the combustion of a fossil fuel through pre-combustion, post-combustion, or oxy-combustion capture. These technologies are likely to involve physical or chemical absorption on a variety of next generation membranes or sorbents whose inputs have not been determined.[96] After capture, CO_2 is compressed, a process which requires significant energy inputs, and transported through pipelines to storage sites. Finally, questions about permanence of CO_2 sequestration and the significant additional cost that CCS technology represents to plant owners continue to add uncertainty to the future of CCS. Because the IEA 450 Scenario relies on optimistic assumptions about the use of CCS technology by 2030, failure to achieve commercialization in this timeframe would force the United States to increase its generation from other low-carbon energy sources, in order to meet its emissions reductions targets, increasing competition and potential security risks associated with their resource inputs.

Nuclear

In the Scenario, electricity generation from nuclear expands from 837 TWh in 2007 to 1,214 TWh in 2030 in the United States, requiring 54 GW of capacity more than is currently installed. Because most reactors in the United States are due for decommissioning in the next twenty years, more than 54 GW of new capacity must be constructed. Current loan guarantees offered by the U.S. Government will only support 7 to 10 new reactors with a capacity of roughly 1 GW each. As a result, nuclear power expansion in the Scenario would require more than 50 new reactors to be built over the course of the next twenty years - pointing to the nuclear industry's dependence on additional federal funding.

Fuel for these reactors will come largely from Australia, a country that produces more than half of the world's uranium ore, and from Russian stocks of highly enriched uranium.[97]. However, fuel cost-reduction proposals have called for reprocessing of already irradiated nuclear fuel. Though this practice is common in France, the United

States has traditionally maintained that reprocessing brings nuclear material closer to weapons-grade and has refrained due to proliferation concerns. Nuclear expansion in the United States remains highly risky. The considerable barriers to adding new nuclear capacity include stringent safety regulations, opposition of local residents, and most importantly high costs. In addition, there is a shortage of trained workers to run and maintain nuclear power plants since a large share of the nuclear work force in Europe and North America is rapidly approaching retirement age.[98]Beyond these input security concerns, an extension of nuclear energy in the United States poses well-documented, conventional security risks. These include, in addition to proliferation, the inherent continued encouragement of other countries to launch or intensify nuclear programs, and the risk of terrorist attacks on nuclear power plants, the effects of which would put the health of millions of Americans at risk.

Box 2. Water[99]

Water is a major input into almost all forms of energy production, and as water supplies are increasingly vulnerable to climate change and population pressures, water is a key component that needs to be considered when looking at future energy security. Too expensive to transport over long distances in large quantities, water is a highly localized resource, which means that security concerns about water do not involve international competition or vulnerability but rather the stability of the domestic energy supply.

Many, but not all, forms of low-carbon energy also have low water requirements. The emphasis on wind power in the IEA 450 Scenario is positive from a water standpoint. Wind energy is the least water-intensive method of energy production, with operational water use largely limited to the water required for cleaning the turbines.[1] As a result, the predicted increase in wind power should not be impacted by changes in water availability in the future.
The low-carbon energy technologies that are more problematic with regards to water requirements are concentrating solar power (CSP) and nuclear power. According to a 2009 Department of Energy report, nuclear power consumes around 720 gallons of water per megawatt-hour (gal/MWh) of electricity generated, in addition to the large amount of water withdrawn for cooling but ultimately returned to the source. In contrast, producing electricity from coal consumes 450 – 520 gal/MWh, and natural gas uses a mere 190 gal/MWh.

In the case of CSP (750 – 920 gal/MWh),[2] the water needs are particularly worrisome because the prime sites for CSP are in deserts with limited water availability. Already, several CSP plants planned for the Southwest U.S. have been put on hold due to concerns about water usage. Given the growing thirst of cities such as Los Angeles and Las Vegas, water could be the limiting factor in the development of CSP in this region. Similarly, nuclear power plants, which are often situated on river banks for easy access to cooling water, can be impacted as river water levels vary due to climate change. During the heat wave of 2003, France, which gets 75 percent of its electricity from nuclear power, was forced to shut down 4000 MW of production capacity (just over 6 percent of total nuclear capacity) because water levels in some rivers dropped so low that there was not enough water available for cooling.

Another major area of concern when looking at the energy-water nexus is biofuels. A recent study has shown that switching from petroleum-based fuels to biofuels or electricity for transportation in the United States will result in substantial increases in water requirements. Of particular concern is the expanded production of irrigated biofuel crops in the Great Plains, where groundwater levels are dropping, resulting in energy and food security concerns.

Energy security risks to the water supply can be mitigated through improved technology such as air-cooling, regulations about water usage, and by encouraging energy and water conservation efforts. Nearly 40 percent of U.S. water usage is related to the energy sector, making energy efficiency measures crucial to avoid stress on water supplies. Similarly, much of U.S. electricity use goes into purifying, transporting and heating water, so reducing water use can have a significant impact on electricity demand. However, unless energy and water policies are managed together, the availability of water can be a large risk factor for U.S. energy production in the near future.

5. Energy Consumption

Updated Transmission Technology

In order to optimize the useful energy provided by new renewable power plants and various new generating technologies, the system of cables and storage devices connecting the power sources must be updated. Since the current U.S. grid is optimized for electricity input from singular large-capacity sources, a ramp up of distributed renewable energy without reciprocal updates to transmission would present a risk to the nation's typically stable electricity supply. This requirement is already holding back renewable energy projects in parts of the country. For example, the California Independent System Operator (CAISO) has reported that significant changes to the California power grid are needed if the state is to meet its goal of 33 percent renewables by 2020.[100] High-Temperature Superconducting (HTS) cables could replace traditional copper cables in an upgraded power grid. These cables can transmit ten times the power of a conventional copper cable over long distances. Some leading superconductor research and manufacturing firms are located in the United States. One firm, American Superconductor, reports that material inputs, which include the rare earth yttrium, are not a major concern for security or expanded use of HTS cable in the grid.[101]

Upgrading the grid to improve energy efficiency and to accommodate increasing amounts of variable power supply will also require increased grid interconnectivity and integration of Internet-based digital communication and information systems. As a result, the potential reach of cyber-attacks by hackers seeking to disrupt the U.S. power supply could grow.[102] Foreign hackers have already demonstrated the ability to shut down power supplies to major metropolitan areas, while recent cyber-attacks on the U.S. grid system, purportedly from Russia and China, may have left behind codes that could be activated in the events of future hostilities. Distribution automation technologies, transmission systems, and smart meters have been cited as being vulnerable entry points in smart grid information systems.[103] These vulnerable systems are driving investment in cyber-security spending at power utilities. Pike Research projects that a total of USD 21 billion will be invested in global smart grid cyber security deployments by 2015.[104] Large IT system providers such as IBM, General Electric, ABB, Emerson Electric, Lockheed, Boeing and Raytheon will likely absorb smaller IT security firms currently developing relevant cyber-security technology. Japanese companies Kyocera Communications, Toshiba Corp., and Fujitsu may also become major players, as they are already contributing cyber security and communications technology research elements to a pilot smart grid project being conducted collaboratively by the U.S. and Japanese government in New Mexico.[105]

Electric Cars and Energy Storage

Hybrid electric vehicles currently account for 2.4 percent of new vehicle sales in the United States, and full electric vehicles far less than a percent.[106] By 2030, the Scenario predicts that electric vehicles – including hybrid, plug-in hybrid, and full electric vehicles – will be over 60 percent of passenger vehicle sales in the United States. The annual number of electric vehicles sold by 2030 could be as great as 10 million. The current fleet of hybrid electric vehicles uses a variety of battery types. However, the industry is focused on developing high efficiency lithium-ion batteries. It is estimated that a full electric vehicle with a range of at least 100 miles will require a sizeable lithium-ion battery. Lithium input could be as great at 10 kg per vehicle.[107] There are mixed signals for the security of lithium supply in the United States. On the one hand, the concentration of known lithium reserves in a very few countries presents a security risk. The United States currently relies almost entirely on Chile and Argentina for its lithium supply. Bolivia is also set to build significant lithium export capacity, though the industry there is still in its infancy. Another important producer is China. The United States will likely remain dependent on imports for at least 50 percent of its lithium supply unless a greater share of its own reserve base – 410,000 metric tons (two hundred times 2009 import levels) - is tapped.[108] The lithium-exporting countries could decide to tighten exports and raise costs of the material – as China has done with rare earth metals. The concentration of lithium sources also makes supply more vulnerable to natural disasters. The recent 8.8 magnitude earthquake near Santiago, Chile was felt over 700 miles north at the Salar de Atacama, one of the country's largest lithium resources. Had the earthquake occurred further north, the entire world may have entered a lithium supply shock.[109]

On the other hand, a positive sign for lithium security is the U.S. dominance of lithium-based product manufacturing. The USGS reports that in 2009, "[t]he United States remained the leading importer of lithium minerals and compounds and the leading producer of value-added lithium materials."[110] The United States may also take the lead in recycling lithium-ion batteries – a currently rather uncommon practice – which would reduce both costs and import requirements. The U.S. government has also launched a concerted effort to support the build-up of intellectual capacity to produce more efficient lithium-ion and alternative high-efficiency batteries. The 2009 American Recovery and Reinvestment Act has allocated USD 1.5 billion for advanced electric vehicle battery and manufacturing research and reports a goal of bringing the cost of lithium-ion batteries from USD 800 per kWh down to USD 300 per kWh by 2014.[111]

Lighting: Compact Fluorescent Light Bulbs and Light Emitting Diodes

The Department of Energy estimates that efficiency gains brought by compact fluorescent light bulbs (CFLs) and light emitting diode bulbs (LEDs) could cut electricity demand for lighting in half by 2025, a reduction equivalent to more than 130 new power stations in the United States.[112] Both technologies are in line to replace inefficient conventional incandescent lighting. Regulations in major markets will phase out incandescent bulbs in the near future, most importantly in Europe by 2012 and the United States by 2014)[113] Currently, CFLs are the cheapest direct substitute for incandescent bulbs. CFLs use approximately 75 percent less power and last about ten times longer than incandescent bulbs. They costs more up-front but are cheaper on a life-cycle basis due to reduced operating costs. The biggest problems CFL technology faces are mercury content and consumer complaints over light quality as well as bulb aesthetics.[114]

CFL's main competitor are LED bulb technology, which is maturing and improving at a pace that fluorescent technology is unlikely to match.[115] Already, LED bulbs are generally as efficient as CFLs, but have longer life spans and avoid the environmental and health concerns raised by the mercury content of CFL bulbs. While high costs compared to CFLs will inhibit domestic adoption of LEDs in the near- to medium-future, LED life-cycle savings might make them economical options for businesses and other large organizations (which consume 75 percent of the electricity for lighting purposes) in the near term.[116] Future research pathways for both CFL and LED lighting will focus on increasing lumens per watt and improving manufacturing techniques to bring down costs.[117] The major leaders in LED and CFL technology (GE, Havells-Sylvania, OSRAM, and Philips) are all headquartered in the United States or Europe. Manufacturing, however, is mostly located in China. A lighting industry study conducted for the U.K. government predicts that dependence on Chinese lamp manufacturing will intensify as the transition is made away from incandescent lamps. However, lighting industry experts surveyed for the study do not view supply-chain constraints or material shortages as a concern for the production of future ultra-efficient lighting technologies.

6. Intellectual Capital and Human Resources

Workforce

Whether the U.S. possesses the intellectual capacity to support a low-carbon transition rests in large part on the quality and size of the U.S. energy-sector workforce. A number of studies with assumptions similar to the IEA's 450 Scenario forecast large increases in demand for technically skilled labor to construct, operate and maintain a low-carbon power system. One report estimates that a target of 20 percent renewables by 2020 would require an additional 185,000 direct jobs in the energy sector.[118] The Department of Energy estimates that over 215,000 direct and indirect workers would be needed to build, operate and maintain 20 percent wind-based electricity generation in 2030.[119] Expanding the energy workforce is a great challenge. The power sector workforce is aging, ensuring that it will need large numbers of new workers to maintain the status quo. At the same time, the training and education system is producing insufficient numbers of technically skilled power-sector workers. Prominently, the electricity utility sector and the nuclear industry, both of which must significantly expand their workforces to meet IEA 450 targets, are already facing labor shortages as high percentages of their workforce reach retirement in the coming years. Approximately 30 to 40 percent of electric power workers (about 400,000 employees) will be eligible to retire in the next five years,[120] while the Nuclear Energy Institute estimates that 25,000 more nuclear workers may be needed by 2014 just to maintain current employment figures.[121] Increasing the size of these workforces is made harder by low levels of enrollment in relevant engineering programs and a small number of power-engineering university programs. U.S. graduate power engineering programs currently produce about 500 engineers per year, compared to 2,000 in the 1980s.[122] The number of college graduates receiving degrees in science and engineering has steadily declined as well. According to current figures there are less than five very strong university power-engineering programs in the U.S.,[123] well below the number of similar graduate programs in Europe.[124] In the nuclear sector, a lack of modernized training facilities, the result of the 30-year freeze in US demand for new civilian nuclear power plants, is another important obstacle to increasing the industry's skilled workforce.[125]

R&D

Beyond the U.S. power sector workforce, assessing the state of U.S. low-carbon intellectual capacity must also consider the state of U.S. clean-tech research and development (R&D). Given that the potential market for low-carbon energy sources are considerable, with the IEA estimating that cumulative global investments in clean power generation technologies between 2010 and 2020 will total about USD 1.55 trillion, the development of a market leading U.S. clean-tech industry could have a significant impact on the national economy.[126] However, China and several European countries have already moved past the U.S. in their efforts to provide support for domestic demand and production of clean energy technologies. In 2009, China alone invested substantially more money in clean energy technologies than North America, announcing a ten-year, $400 billion clean energy technology investment program and enacting policies that help drive economies of scale and achieve cluster benefits in renewable energy industries.[127] In 2008, Europe led the world in clean energy investments, spending nearly $50 billion. Altogether, nearly 90 percent of today's market for new clean energy technologies is outside of the United States, primarily in Asia and Europe.[128]

Summary and Recommendations

Address the climate and energy security challenge. Fossil-fuelled energy generation is responsible for today's enormous global challenge of climate change and has lead to "an international energy crisis of unprecedented proportion."[129] In order to address these problems, we have to generate energy from alternative sources and use it more efficiently. Many experts on climate change and energy security have long seen the need for a reform of our energy production and consumption systems as a great opportunity for making our lives safer while growing the economy. While the necessary changes are so fundamental that the call for a Third Industrial Revolution seems justified, the chances generated by such a new industrial revolution have not been well communicated.[130] We have to develop strategies to get the public, the information multipliers, and the key decision-makers on board of this giant enterprise which is both without alternatives and highly valuable from a range of perspectives. If we do not succeed in altering the ways we produce and use energy, we risk running into a climate and energy catastrophe open-eyed.

Reduce U.S. dependency on foreign natural resources. The IEA's 450 scenario will reduce U.S. dependency on the import of resources such as oil and uranium. This will make the United States safer from both an energy, as well as a conventional security perspective. In the Scenario, we perceive a few possible new resource dependencies. However, these dependencies can be addressed in a rather straightforward manner. The primary areas in which these dependencies will occur are wind and PV electricity generation, as well as battery technology. Concerning wind, excessive dependency on China for supply of rare earths, particularly neodymium can be reduced by a two-prong effort to a) increase exploration for domestic rare earths, and b) advance R&D efforts for their substitutes in wind turbines. Regarding PV technology, the focal point for reducing risk in PV development lies with intellectual capacity. It is essential that the United States maintains its competitive advantage in PV R&D, especially in developing material alternatives to silver, indium, zinc, and germanium. A similar strategy needs to be employed in the sector of electric cars where the build-up of intellectual capacity to produce more efficient lithium-ion as well as alternative high-efficiency batteries can tackle possible dependencies on the import of lithium from a relatively small number of countries.

Stimulate a Competitive Clean-Tech Industry. The lack of a clear national low-carbon policy has hindered the development of domestic clean-tech demand, especially relative to many European countries and China. Until federal carbon mitigation legislation has been passed, individual state action as well as funding of R&D is the most significant government support to U.S. intellectual capacity in the clean-tech arena. While low-carbon R&D initiatives have increased recently, they are still surpassed by investments in China and elsewhere. Without increases in R&D and clear policy signals that foster domestic demand and production of clean energy technology at a larger scale, U.S. clean-tech companies will find themselves at a handicap vis-à-vis many of their foreign competitors.

Minimize low-carbon collateral damage. Increased penetration of low-carbon technology may increase the strain on other important natural resources, most importantly water and land. Nuclear and CSP are both highly water intensive generation sources. R&D should be committed to developing technologies such as dry-cooling CSP that decrease water demands without significantly raising generation costs. In a similar vein, pressure to expand domestic mineral exploration (e.g. to expand and diversify the supply of domestic rare earth metals) could threaten protected wilderness areas. Resulting biodiversity losses would potentially have grave security impacts of their own. Alternative energy strategies must be carefully crafted in order to lessen the impact on other important environmental resources.

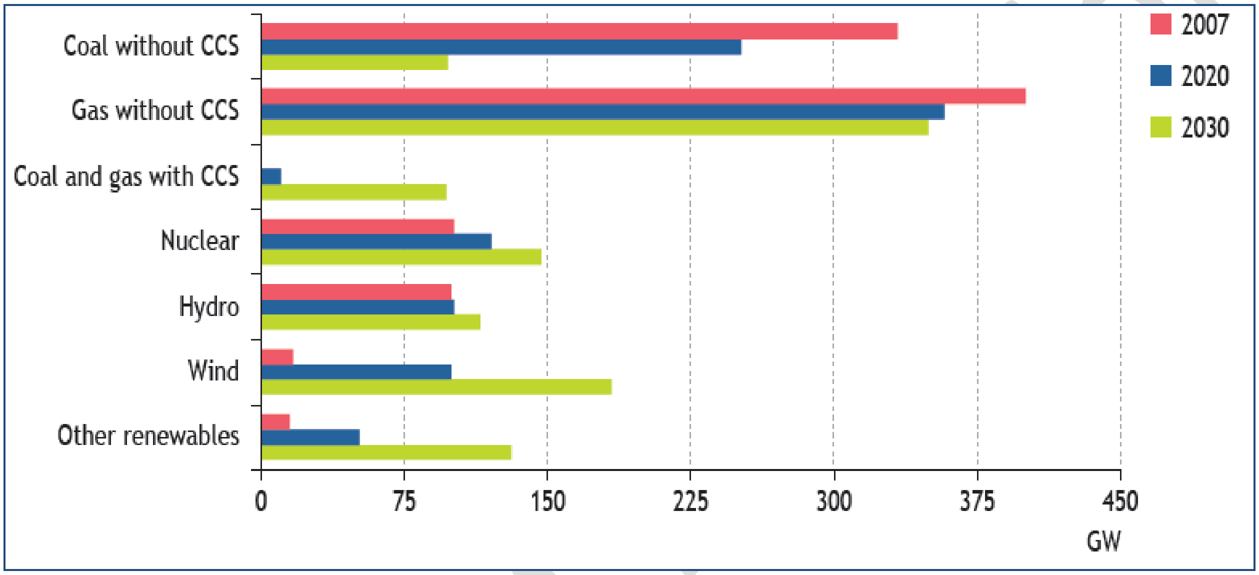
Address the risks of nuclear expansion. Nuclear expansion in the United States remains highly risky. The considerable barriers to adding new nuclear capacity include high costs, stringent safety regulations, and a shortage of trained workers to run and maintain nuclear power plants. While there are no long-term international uranium resource constraints, the pursuit of nuclear in the United States may cause traditional security risks. These include proliferation of nuclear technologies, the encouragement of other countries to launch nuclear programs, and the risk of terrorist attacks on nuclear plants on U.S. territory. If the United States commits to an extension of its nuclear capacities, it must undertake a serious effort to train a new generation of nuclear workers, seek to minimize the risks posed by civilian nuclear power proliferation, and design credible building protection measures for reactors.

Build the Workforce. The transition to the 450 Scenario could be made slower and more costly by a lack of well-qualified power-sector workers. New federal funding is being provided to support university efforts to build or expand energy science and engineering research and education capabilityes. However, further short- and medium-term efforts to boost the education and training of the energy-sector workforce will be needed to ensure a sufficient supply of highly-skilled technical workers required by the Scenario.

Avoid Green Mercantilism. In the Scenario, global markets for low-carbon technologies will be substantial and the rewards will be large for countries with competitive clean tech industries. However, the United States should help to pursue a national green policy path that creates competitiveness without overshadowing collaborative international approaches such as large-scale multilateral flagship projects, fast-tracking of international patents, or the installation of an international carbon market. The growth of a global green-tech market will not be zero-sum, and many nations stand to reap the economic benefits of the transition. Protectionism and "green mercantilism" would slow the pace and increase the costs of a transition to a new, sustainable energy path. International partnerships including climate policy and technology transfer agreements are clearly in the national interest of the United States.

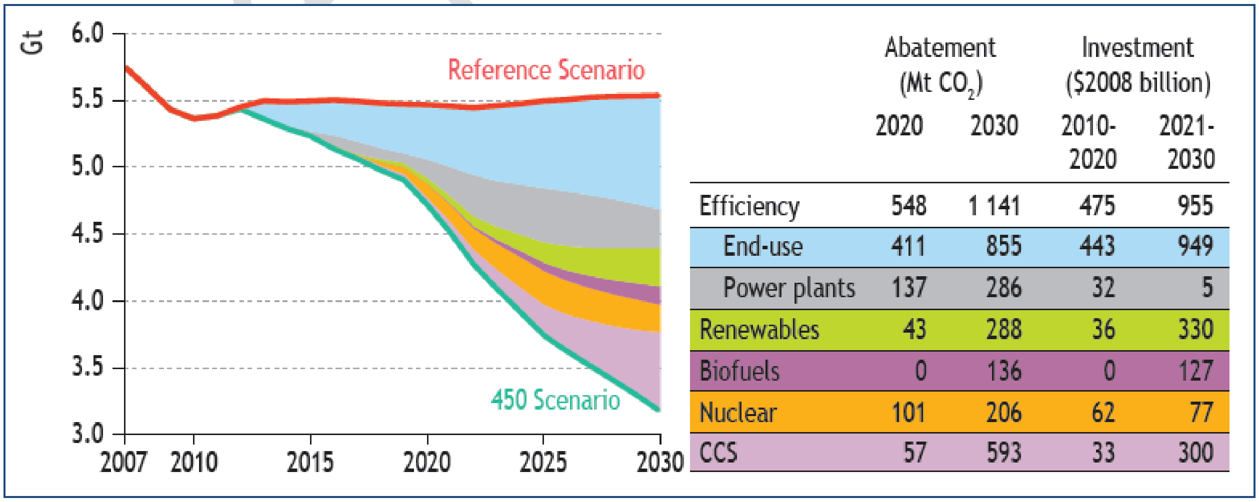
Appendix. Tables & Figures

Figure 1. United States power generation capacity in the 450 Scenario



Source: IEA *World Energy Outlook 2009*, Figure 9.13

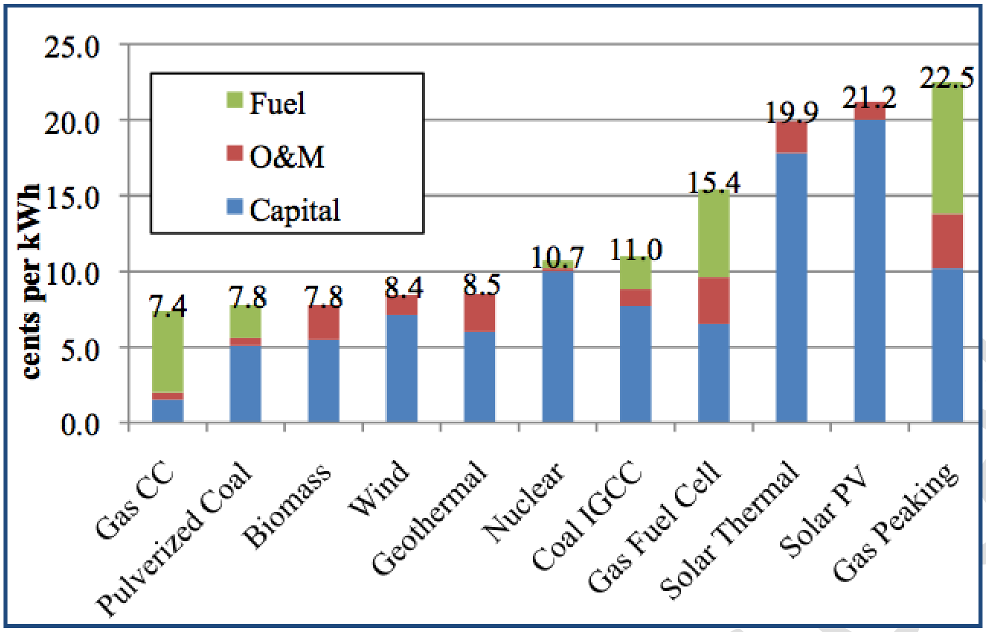
Figure 2. United States energy-related CO$_2$ emissions abatement, 2007-2030



	Abatement (Mt CO$_2$) 2020	Abatement (Mt CO$_2$) 2030	Investment ($2008 billion) 2010-2020	Investment ($2008 billion) 2021-2030
Efficiency	548	1 141	475	955
End-use	411	855	443	949
Power plants	137	286	32	5
Renewables	43	288	36	330
Biofuels	0	136	0	127
Nuclear	101	206	62	77
CCS	57	593	33	300

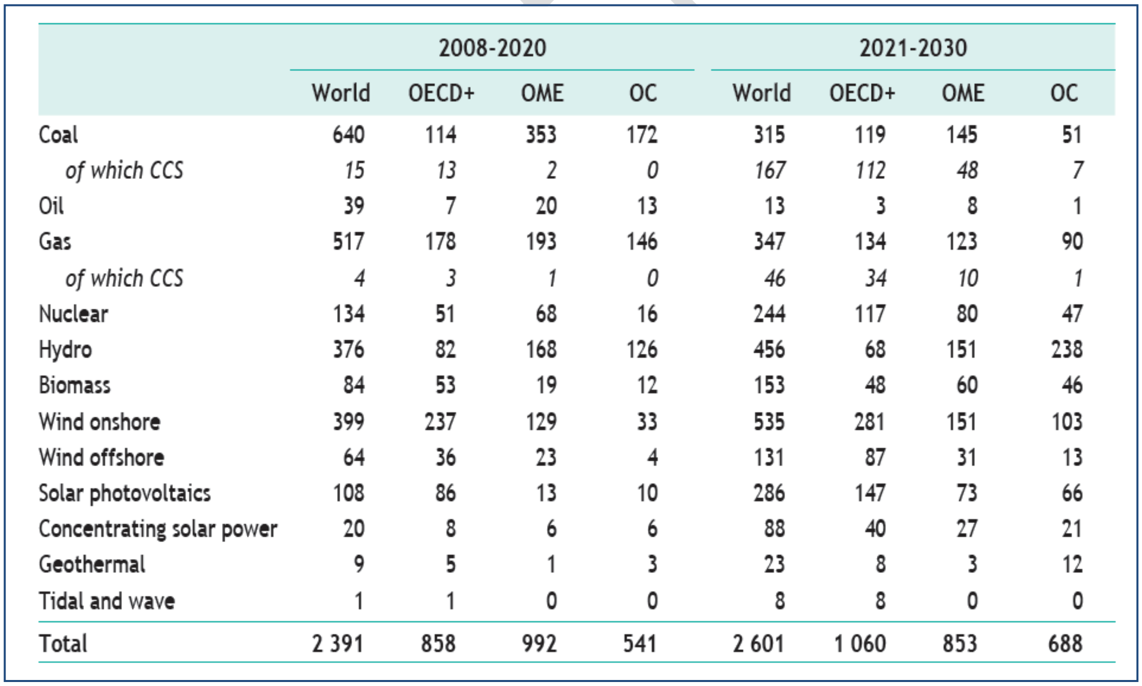
Source: IEA *World Energy Outlook 2009*, Figure 9.12

Figure 3. Levelized cost of energy from new power plants, 2008



Source: Lazard, "Levelized Cost of Energy Analysis – Version 3.0" (February 2009)

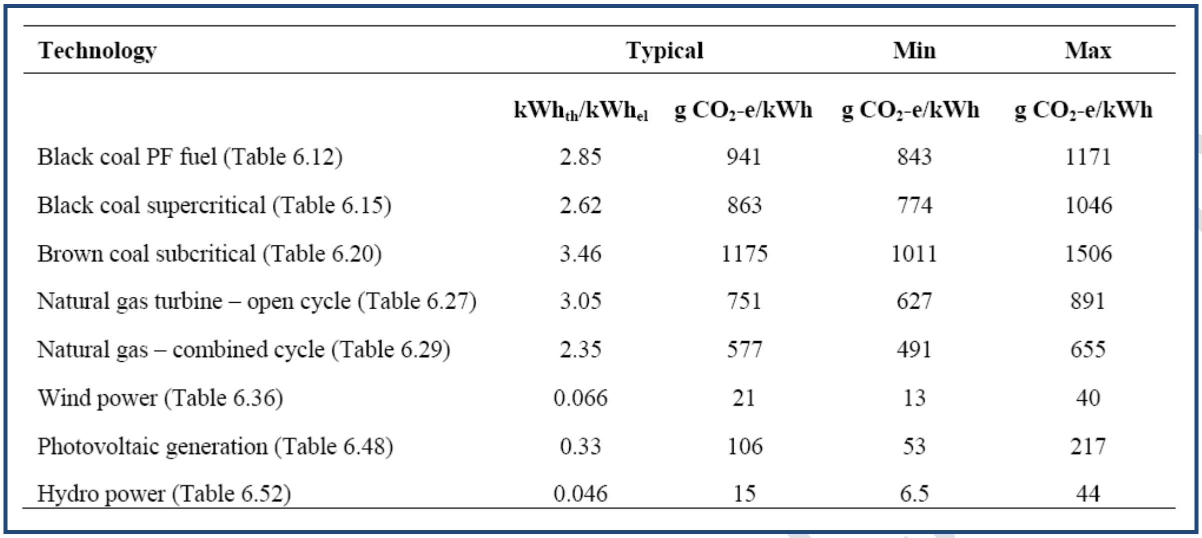
Table 1. Capacity additions by fuel and region in the IEA 450 Scenario (GW)



	2008-2020				2021-2030			
	World	OECD+	OME	OC	World	OECD+	OME	OC
Coal	640	114	353	172	315	119	145	51
of which CCS	*15*	*13*	*2*	*0*	*167*	*112*	*48*	*7*
Oil	39	7	20	13	13	3	8	1
Gas	517	178	193	146	347	134	123	90
of which CCS	*4*	*3*	*1*	*0*	*46*	*34*	*10*	*1*
Nuclear	134	51	68	16	244	117	80	47
Hydro	376	82	168	126	456	68	151	238
Biomass	84	53	19	12	153	48	60	46
Wind onshore	399	237	129	33	535	281	151	103
Wind offshore	64	36	23	4	131	87	31	13
Solar photovoltaics	108	86	13	10	286	147	73	66
Concentrating solar power	20	8	6	6	88	40	27	21
Geothermal	9	5	1	3	23	8	3	12
Tidal and wave	1	1	0	0	8	8	0	0
Total	2 391	858	992	541	2 601	1 060	853	688

Source: IEA *World Energy Outlook*, Table 6.2

Table 2. Greenhouse gas intensities of selected energy technologies

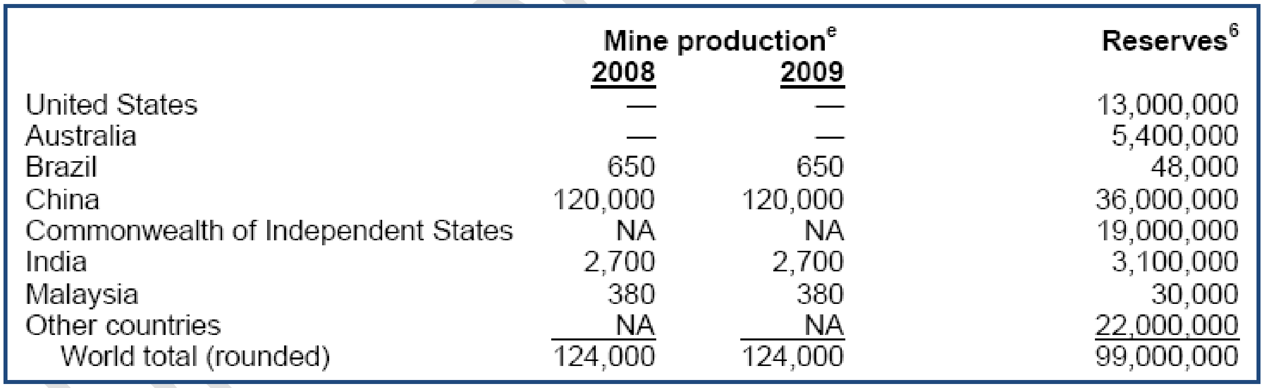


Technology	Typical		Min	Max
	kWh_{th}/kWh_{el}	g CO_2-e/kWh	g CO_2-e/kWh	g CO_2-e/kWh
Black coal PF fuel (Table 6.12)	2.85	941	843	1171
Black coal supercritical (Table 6.15)	2.62	863	774	1046
Brown coal subcritical (Table 6.20)	3.46	1175	1011	1506
Natural gas turbine – open cycle (Table 6.27)	3.05	751	627	891
Natural gas – combined cycle (Table 6.29)	2.35	577	491	655
Wind power (Table 6.36)	0.066	21	13	40
Photovoltaic generation (Table 6.48)	0.33	106	53	217
Hydro power (Table 6.52)	0.046	15	6.5	44

Source: M. Lenzen, "Life cycle energy and greenhouse gas emissions of nuclear energy: A review," *Energy Conversion and Management,* (Australia: 2008), Chapter 6.

Table 3. Rare Earths – mine production and reserves, select countries

Data in metric tons of rare-earth oxide. NA = Not Available. -- = zero.



	Mine production[e]		Reserves[6]
	2008	2009	
United States	—	—	13,000,000
Australia	—	—	5,400,000
Brazil	650	650	48,000
China	120,000	120,000	36,000,000
Commonwealth of Independent States	NA	NA	19,000,000
India	2,700	2,700	3,100,000
Malaysia	380	380	30,000
Other countries	NA	NA	22,000,000
World total (rounded)	124,000	124,000	99,000,000

Source: USGS, *Mineral Commodity Summaries 2010,* (Washington, DC: 2010), pp. 128-129.

Notes.

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[1] Alexander Ochs, “Overcoming the Lethargy: Climate Change, Energy Security, and the Case for a Third Industrial Revolution, AICGS Policy Report #34”, (Washington, DC: AICGS, July 2008), p. 7 - 15.

[2] Nader Elhefnawy, “The Impending Oil Shock,” in *Survival,* (2008): 37-66.

[3] This section follows, in part verbatim: Ochs, op. cit. note 1.

[4] Intergovernmental Panel on Climate Change, *Climate Change 2007:The Physical Science Basis - Summary for Policymakers.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Geneva: IPCC, 2007) and Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. *Summary for Policymakers.* (Brussels, April 2007); Numbers for sea level rise from John A. Church, et al., Executive Summary of Chapter 11 of IPCC, *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the IPCC.

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Material	Amount required (kg/MW of plant capacity)
Concrete	97,749

Steel	31,030
Iron	408
Aluminum	204

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