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The importance of advancing technology to America's energy goals

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ABSTRACT

A wide range of energy technologies appears to be needed for the United States to meet its energy goals. A method is developed that relates the uncertainty of technological progress in eleven technology areas to the achievement of CO_2 mitigation and reduced oil dependence. We conclude that to be confident of meeting both energy goals, each technology area must have a much better than 50/50 probability of success, that carbon capture and sequestration, biomass, battery electric or fuel cell vehicles, advanced fossil liquids, and energy efficiency technologies for buildings appear to be almost essential, and that the success of each one of the 11 technologies is important. These inferences are robust to moderate variations in assumptions.

1. Introduction

Simultaneously achieving national goals for greenhouse gas mitigation and energy security poses a transformational challenge for the U.S. energy system (Barrett, 2009). Doing it at a price society is willing to pay will likely require major advances in energy technology and in many cases advances in the underlying fundamental science (Richels and Blanford, 2007, p. 22; Clarke et al., 2006; Edmonds et al., 2007; International Energy Agency (IEA), 2008; Intergovernmental Panel on Climate Change (IPCC), 2007). Both technological breakthroughs and market acceptance are inherently uncertain (National Research Council (NRC), 2005).[1] Most energy models are designed to analyze trade-offs between costs and societal objectives conditional on assumptions about technological progress. Uncertainty about technological progress is addressed by means of scenario analysis (e.g., Nakićenović et al., 2000; IEA, 2008; U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA), 2008).

The method used in this report assumes that technologies will either succeed or not, enumerates all possible sets of successful technologies, uses the Kaya (1990) equation to identify those sets that enable national energy goals to be met and applies probability theory to derive insights. It does not consider economic trade-offs or behavioral change. As Richels and Blanford (2007) observed, "insights can be obtained from analyses that analyze the implications of uncertain technological success, conditional on cost-effectiveness, as well as from analyses of cost-effectiveness conditional on technological success."

The method is used to evaluate the prospects for achieving the following energy goals:[2]

(1) reduce U.S. carbon dioxide emissions from energy use by 50–80% by 2050 compared to 2005,
(2) reduce the costs of U.S. oil dependence to less than 1% of GDP with 95% probability by 2030 (Greene, in press),

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[1] Solution of such problems also requires policy and sometimes behavioral change, but these are not the subject of this paper.

[2] Developing sustainable energy sources is a fourth energy policy goal but as yet does not have a measurable definition.

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(3) at costs society is willing to pay (in the vicinity of \$50–\$100/ tCO_2 and an oil premium of approximately \$25–\$50/barrel).

The authors identified eleven broad areas of energy technology with the potential to contribute to national energy goals. Based on existing studies, the ability of each technology to reduce CO_2 emissions by 2050 and oil use by 2030 relative to the Energy Information Administration's Frozen 2008 Technology projections were estimated (U.S. DOE/EIA, 2008). Initially, technologies were assumed to either "succeed" or "fail" (have no additional impact beyond the reference projection). All possible combinations were generated and their impacts on CO_2 emissions and oil use estimated.

Given the "successful" technology sets, inferences can be made about the number of technological advances likely to be needed to achieve both goals, the required likelihood of success in advancing technology, and the impact of each technology's success on achieving national energy goals. The assumption that technologies will either succeed or fail with a fixed impact is then relaxed, and Monte Carlo analysis is used to test the robustness of the inferences.

2. The energy goals

It is assumed that the United States establishes a national objective of reducing CO_2 emissions from energy use by 50–80% by 2050 (IPCC, 2007). The costs of different levels of greenhouse gas emission mitigation, conditional on the success of energy technologies have been estimated elsewhere, demonstrating the value of technological progress to solving the climate problem (Edmonds et al., 2007).

Concepts of energy security can be diverse, ranging from petroleum dependence to protection of pipelines or the reliability of the electricity grid. Here, only the problem of dependence on petroleum is considered. Following Greene (2010) it is assumed that foreign policy and national defense dimensions of oil dependence are a consequence of the *economy's* dependence on petroleum. Costs of oil dependence to the U.S. economy include transfer of wealth to oil exporting countries, and reductions in economic output due to higher than competitive market prices and oil price shocks (Huntington, 2007; Jones et al., 2004). Recognizing the inherent uncertainty in world oil markets, Greene (2010) proposed a quantitative national goal of insuring that the costs of oil dependence in any year would be less than 1% of U.S. GDP with 95% probability by 2030. Greene et al. (2007) showed that this goal could very nearly be achieved by the measures proposed by the non-partisan National Commission on Energy Policy (NCEP, 2004). To a reasonable approximation any combination of reduced petroleum demand and increased domestic supply that sums to approximately 25 exajoules per year (EJ/yr) or more would achieve U.S. oil independence as defined above. In the reference case, U.S. petroleum supply is 15 EJ/yr in 2030 and consumption is 45 EJ/yr.

3. The technologies

For this analysis, technology categories must be broad enough to have a major impact on greenhouse gas emissions or oil use. Keeping the number of categories small helps keep the computations tractable. With this in mind, the authors identified eleven important areas of energy technology. Each includes several technologies with different hurdles to overcome. Quantitative estimates of impacts on CO_2 emissions and the U.S. petroleum balance relative to the Frozen 2008 Technology Case are shown in Table 1. Detailed explanations and sources for estimates are provided in Greene et al. (2009).

Table 1
Impacts of the eleven energy technologies on carbon dioxide emissions and oil dependence.

Technology	Carbon dioxide emissions impact	U.S. petroleum demand and supply impact
Advanced fossil liquids	Without carbon capture and storage, increase the average energy intensity of liquid hydrocarbon fuels use by 15%	Provide additional domestic supply of liquid fuels of 10.6 EJ/yr from unconventional sources of petroleum, enhanced oil recovery and environmentally benign oil development in sensitive areas
Biomass energy	Increase biomass energy use by 3.9 EJ/yr of primary energy for electricity generation, 0.3 EJ/yr in industry, and 7.1 EJ/yr of biofuels for transportation, with a net reduction in well-to-wheel greenhouse gas emissions of 70% versus petroleum fuels	Displace an additional 7.1 EJ/yr of petroleum in transportation, 0.7 EJ/yr in industry by 2030, including both energy use and feedstocks
Carbon capture and sequestration	Reduce CO_2 emissions from coal and natural gas electricity generation by 90% but increase energy intensity by 10%. Reduce industrial CO_2 emissions from coal and natural gas use by 50% and increase energy intensity by 5%	No impact
Efficient electricity generation and distribution	Reduce system-wide energy intensity by 30% by 2050	Eliminate petroleum use in electricity generation, −0.9 EJ/yr
Electric drive vehicles	Reduce petroleum use by 13.9 EJ/yr and increase electricity demand by 7.0 EJ/yr	Displace 2.6 EJ/yr of petroleum in transportation and 0.2 EJ/yr in industrial sector by 2030.
Energy efficient buildings	Reduce the energy intensity of buildings energy use by 50% by 2050	Eliminate petroleum use in buildings, −2.1 EJ/yr
Energy efficient industrial process	Reduce energy intensity by 25%	Reduce the energy intensity of the industrial sector by an additional 10% by 2030
Energy efficient transportation	Reduce transportation energy intensity by 35% by 2050	Reduce the energy intensity of the transportation sector by an additional 16% by 2030
Nuclear energy	Increase nuclear share of primary energy use for electricity generation from 12% to 32% in 2050	No impact
Solar energy	Replace 15% of primary energy use for electricity generation in 2050. Solar energy use in buildings either increases energy efficiency or displaces grid electricity	No impact
Wind energy	Replace 18% of coal fired and 50% of natural gas fired electricity generation in 2050	No impact

*All impacts are incremental to the Frozen 2008 Technology Case.