Integrated Assessment of Technology Options

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We have initiated development of analysis tools designed to assist in the analysis of consequences of various technology development possibilities. The goal is the development and use of a comprehensive analysis system, including mathematical models, which (a) could be used on a continuing basis for assessments of the probable significance of technological options and (b) would serve as a basis for assessments of options designed to speed up diffusion of technologies once developed. Analyses will include estimations of greenhouse emission (carbon dioxide, other significant greenhouse gases, plus aerosols) baseline projections from various significant sources, ranges of uncertainty, and evaluations of reductions in emissions that could reasonably be expected from the various technological options over time, if successful. Analyses will include both micro-level technology estimates and larger scale estimates of the possible evolution of the entire energy system.

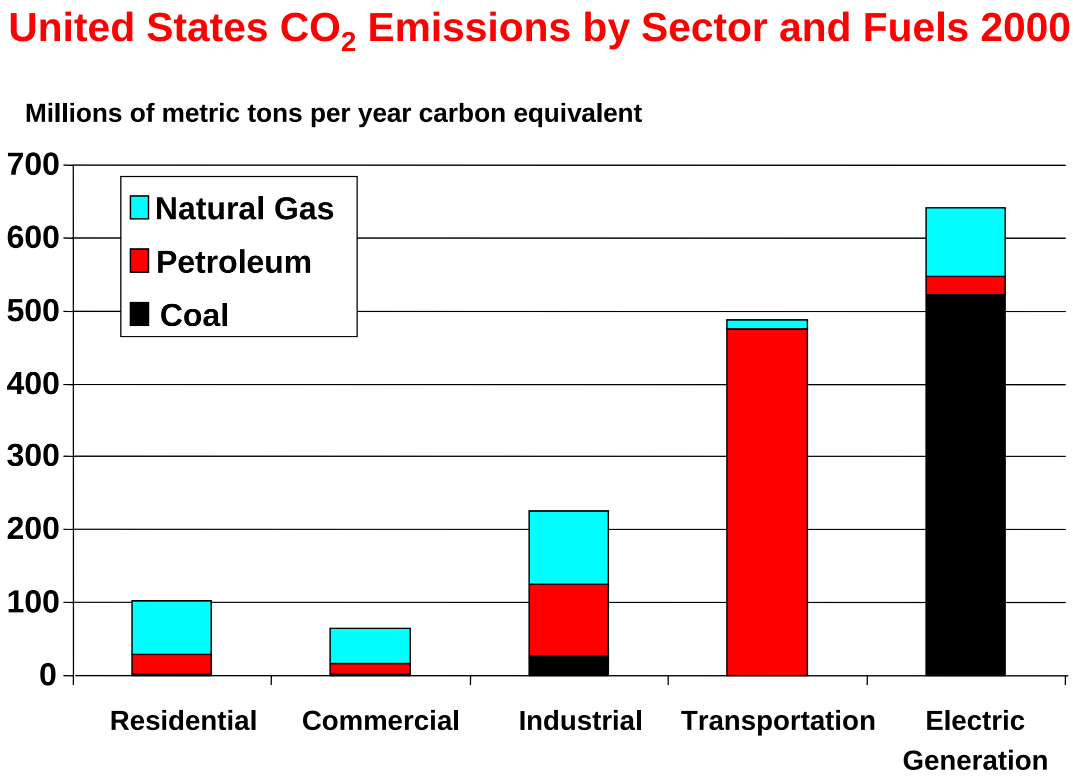
The research agenda is driven by a set of key questions for the various technology areas, assuming that the research and development turns out to be successful:

- Do we expect the new technologies to be broadly adopted?
  - Will the private sector pursue their introduction?
  - Will they compete in the market place?
  - Are governments likely to help or hinder their adoption by corporations and individuals?
  - Are there other important barriers to their wide-spread adoption?
- If adopted, how much might the new technologies reduce total greenhouse gas emissions?
  - How broad is the sector where they could be competitive? Could the technologies be competitive for the transportation sector, electricity generation, residential or industrials uses?
  - In what regions of the world could they be expected to compete? Are the potential uses very country specific, limited to rural uses, limited to only developing countries are to only highly developed countries?
  - What is the expected intensity of greenhouse gas emissions from the new technologies relative to technologies they are expected to replace?

The context for the analysis starts with estimations of greenhouse emission (carbon dioxide, other significant greenhouse gases, plus aerosols) baseline projections, including the ranges of uncertainty. These will be developed from various significant sources.

Current estimates of carbon dioxide emissions in the United States by sector and by fuels are available from the United States Environmental Protection Agency. Those data are included in the following graph, Figure 1.

Although carbon dioxide emissions are associated with each of the sectors in the graph -- residential, commercial, industrial, transportation, and electric generation -- the transportation sector and the electric generation sector are most important. In the transportation sector the dominant source of carbon dioxide emissions is associated with the use of petroleum; and electric generation sector the dominant source is coal-based emissions. Therefore, all else even, these two combinations of fuel and sector provide particularly interesting technological opportunities to reduce the emissions of carbon dioxide.



Source: U.S. EPA Inventory of Greenhouse Gas Emissions, April 2002

Figure 1: U.S. Emissions of Greenhouse Gases

The US Environmental Protection Agency has developed similar estimates of emissions of greenhouse gases other than carbon dioxide. Most of these sources are from sectors other than the energy sectors, particularly agriculture. John Weyant, through the Energy Modeling Forum, is working with personnel from the US Environmental Protection Agency in order to help other modelers understand the magnitudes of these emissions and to incorporate them into mathematical models.

Analysis of particular technologies will involve micro level analysis of technologies, and a macro level analysis of the energy system for assessing the value of new energy technologies. These will be described in separate subsections of this document.

Micro Level Cost and Impacts Analysis

The micro level analysis of technologies starts with mathematical models which build up estimates of the unit costs that could be expected for the various technologies. These models incorporate estimates of the major components of cost, including the capital depreciation and amortization, feedstock costs, costs of electricity or other energy inputs, costs of separating carbon dioxide from the gas stream, costs of sequestering carbon dioxide, and operations and maintenance costs. Consistent assumptions about economic conditions, interest rates, electricity costs, and carbon prices (if any) are used across the various technology estimates.

The first group of such models is currently under construction. Rather then examining all classes of low-carbon dioxide technologies, we are developing the first group of models to examine the production, transportation, and dispensing of hydrogen for use in automobiles. Such models are currently being created under the supervision of James Sweeney for the National Academy study "Alternatives and Strategies for Future Hydrogen Production and Use". The models currently exist in preliminary form and include estimates of costs that would be incurred if current technologies were utilized. The data in these models will be updated over the next several months to include cost estimates conditional upon technological advances. We expect that the results from these models will be incorporated into the National Academy study. The models, as incorporated into the National Academy study, will be further refined with the goal of making them more user-friendly and more amendable to detailed technological analysis.

Linked to this the first group of cost models will be models designed to examine the quantitative impacts of various technologies if successful. The first such model under construction is a relatively simple vintage capital representation of automobile use of fuels. The model uses as an input the fraction of new vehicles in any future year which would be fueled by hydrogen. This model then keeps track of the projected number of vehicles produced in any year, the capital stock of automobiles from the various vintages, the average fuel efficiency of each vintage, the fraction of vehicles from each vintage that would be fueled by hydrogen as opposed to gasoline, the differential fuel efficiency of new hydrogen vehicles, the vehicle miles traveled, and the resulting consumption of hydrogen and gasoline. These consumption estimates can be combined with estimates of carbon dioxide emissions from gasoline-based consumption and the carbon dioxide emissions from the various hydrogen-producing technologies in order to estimate how implementation of various hydrogen production technologies might decrease or increase the emissions of carbon dioxide into the atmosphere and the quantities out of carbon dioxide sequestered. Similarly, based on estimates of the cost of producing hydrogen from various technologies, the model can be used to provide quantitative estimates of changes in the total cost of fuel for vehicles, conditional on implementation of the various hydrogen-production technologies.

Carbon dioxide releases would be reduced however, if hydrogen were generated using photovoltaics, wind turbines, nuclear power, or biomass. However each of these technologies currently appears to be very costly. With sequestration, however, the fossil fuel-based technologies could significantly reduce the amount of carbon released into the atmosphere. To do so, however, would require a large amount of carbon dioxide to be sequestered.

These first micro level analyses will include sufficient information to estimate the quantities of energy inputs -- such as electricity, coal, natural gas, or wood -- needed per kilogram of hydrogen produced. And the will include sufficient information to estimate required capital investment and required sequestration quantities. They will provide estimates of total cost conditional on magnitude of implementation of the various technologies (if these technologies are successful). However, the first versions will not include much information about whether governments are likely to help or hinder their adoption by corporations and individuals. The will provide little or no information about what regions of the world the technologies could be expected to compete, not whether the potential uses are very country specific, limited to rural uses, limited to only developing countries, or to only highly developed countries. Such additional analysis will be left for later stages of the project.

Macro-Level Analysis for Assessing the Value of New Energy Technologies

Given estimates, developed from the micro-level analysis, or other sources, regarding the characteristics of the new energy technologies resulting from R&D (expressed via probability distributions over costs and performance at specific future dates of interest), assessments of the value of that new technology depend on what other new technologies have been developed, how fast existing technologies are improved, and conditions in energy markets. Conditions in energy markets are reflected in energy prices and depend on many factors including population levels, economic output, the structures of the world's economies, resource availabilities, energy producer (and especially oil exporter) behavior, the set of available technologies for producing, transforming and consuming energy, and government energy, economic, and environmental policies.

The key factors that determine the future value of new energy technologies are highly uncertain and the relationships between them can be quite complex. One approach to energy policy assessment is to run sensitivity analysis on external factors through large-scale (macro-) models of the energy system. Figure 4 and Figure 5 show the primary energy mix for 2100 projected by a number of prominent large-scale energy models for a reference case (a different modeler chosen reference case for each model) and a case in which the atmospheric concentration of CO2 concentration in the atmosphere is limited to 550 ppm.

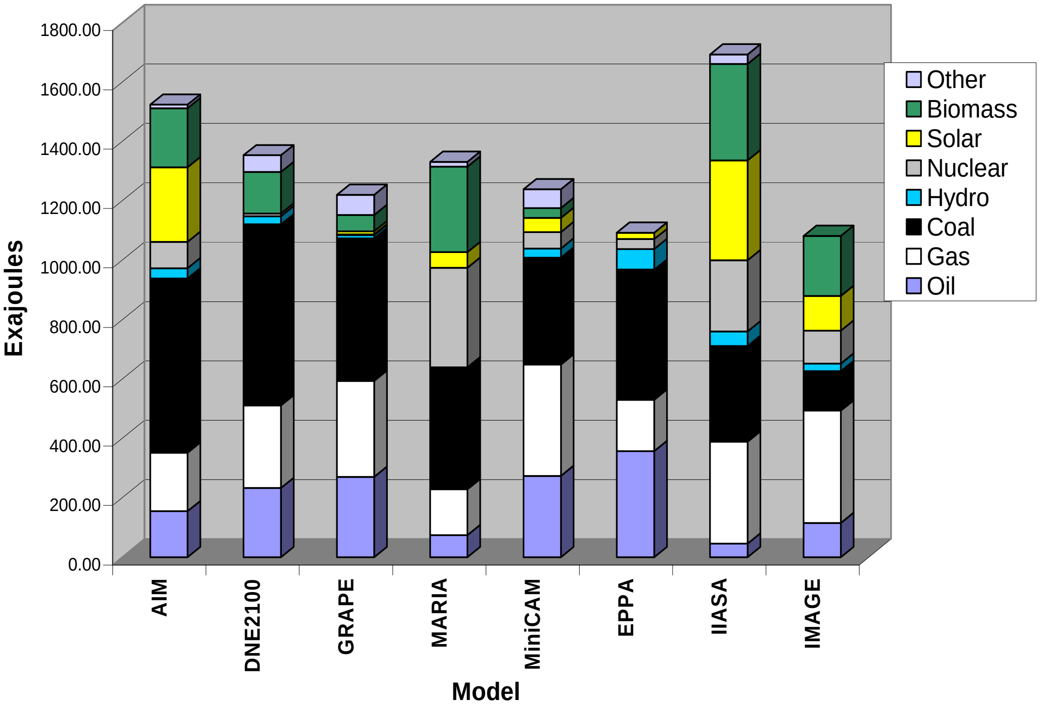


Figure 4: Reference Case World Primary Energy in 2100

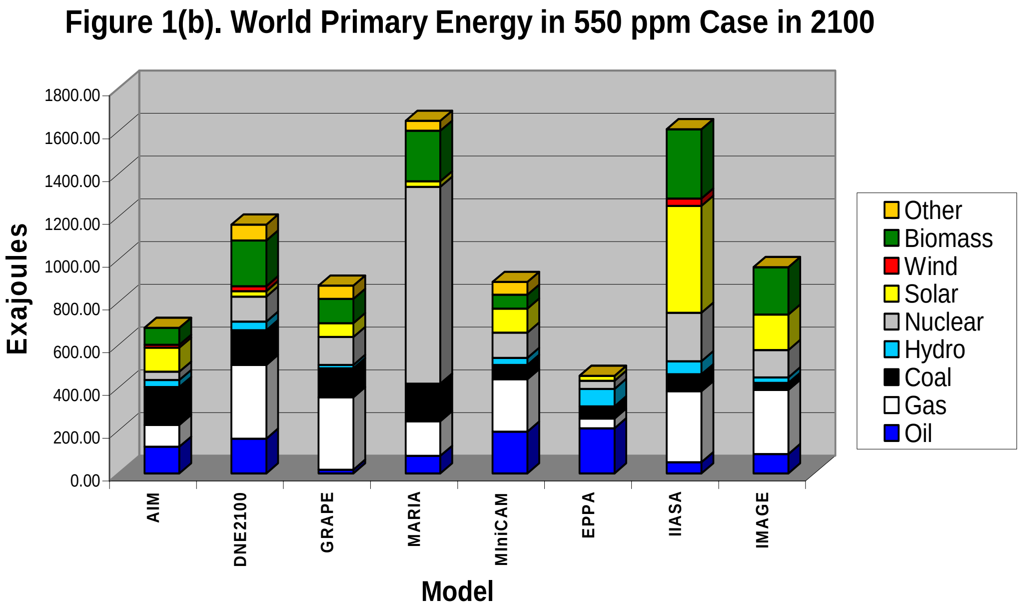


Figure 5: World Primary Energy in 550 ppm Case in 2100

The changes between the two diagrams are motivated by a tax on carbon that starts at about $10 per tonne of carbon in the early part of the century and reaches $200 to $400 per tonne by 2100 (depending on the model and its reference scenario). Results like these are illuminating, but consider only one reference scenario for one set of parameter values for each model. There are extremely large uncertainties about both over the course of a century and these uncertainties can have a significant impact on how we value the products of long-term R&D on new energy technologies.

The large-scale energy system models are often designed for purposes other than long-run energy technology assessment and, therefore, include enough complexities so as to make extensive sensitivity analyses, let alone formal uncertainty analyses infeasible. The approach here is to use reduced form energy models (calibrated to the more large-scale models, which in turn would be calibrated where possible to the micro-level models) as the central element of an uncertainty-oriented technology evaluation approach.

We will use literature reviews and expert assessments to develop probabilities distributions about key inputs to the models. This is crucial because these inputs are generally more important determinants of the values of the new technologies than many of the parameters included in the models.

Our past experience with thousands of energy system scenarios and hundreds of models over the years should enable us to identify the important drivers of the valuation equations and calibrate them to available modeling results. In addition, we can use our experience to determine what information to seek via expert assessments, e.g., ranges of possible economic growth rate assumptions, fossil fuel resource base estimates, evolution of conventional energy technologies, oil exporter behaviors, etc.

It will take some time to develop the full assessment system. In the interim, rather than working with all the uncertainties independently, we will work with a set of integrated probabilistic scenarios. These scenarios will represent a wide range of future states of the world and be mutually exclusive and collectively exhaustive so that probabilities can be assigned to them. This will enable us to compute a discounted present value for the new technologies across a wide range of possible technological and socio-economic futures. Figure 6 shows the key elements of the proposed energy technology evaluation system.

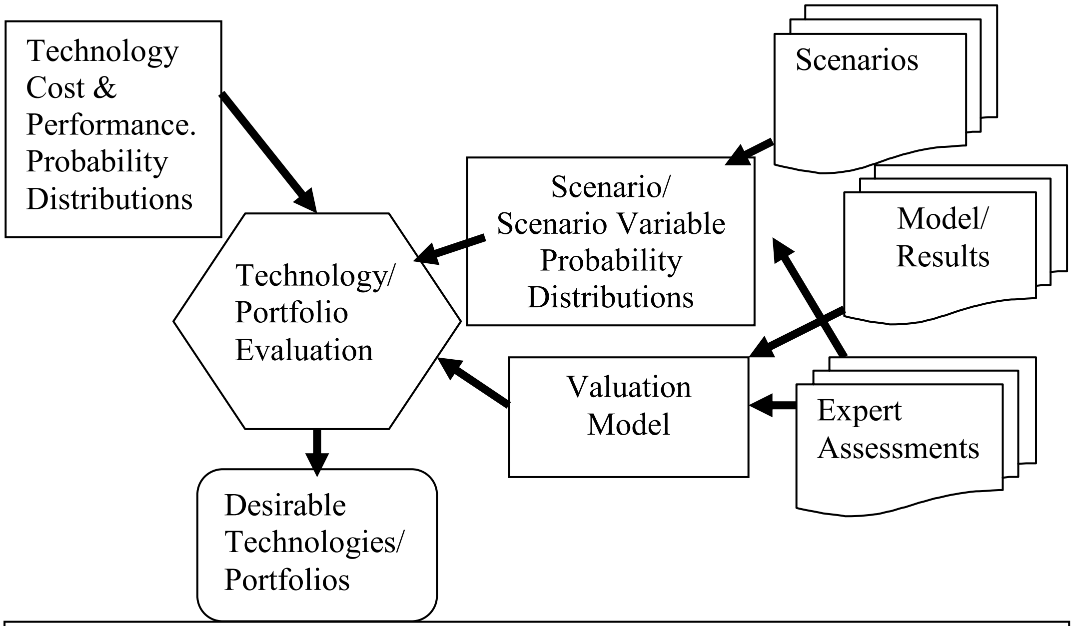


Figure 6: Schematic Diagram of Technology Evaluation Process

We will design scenarios to be as informative as possible about the efficacy of the GCEP R&D portfolio. For example, they will range from a (relatively low probability) case where there is no future concern about climate change to one in which (say twenty years from now) where climate change is perceived to be a (relatively low probability, but plausible) much more serious problem than currently expected. In the former case, only a small number of low-/non-carbon emitting technologies (e.g., perhaps advanced-technology combustion engines) will be adopted, whereas in the latter many low-/non-carbon emitting technologies that are more expensive than conventional carbon emitting technologies will be adopted. This comparison illustrates the "option value" associated with the development of new technologies. If new technologies are developed they can be introduced and diffused if they are needed, but kept "on the shelf" (and perhaps put into further development to make them more economical) if they are not needed.

The scenario part of the system will be implemented in the following stages with refinements made at each stage: (1) a range of initial evaluation scenarios combining assumptions for a number of external scenario variables, (2) a probabilistic set of scenarios, (3) a full probability treatment of all external scenario variables. The existing literature and expert opinion (our own and others) will be used to pick ranges of values for the key external scenario input variables. The valuation model will also evolve over time from a simple two sector, two or three region specification with sensitivities on parameter values to a more sophisticated system with greater detail and inputs calibrated to more complex models, estimated from primary data and/or obtained via expert assessments. Uncertainty about the cost and performance of the technology being evaluated and those of other new technologies will initially be represented by sampling from the probability distributions for those characteristics. Over time more sophisticated ways of incorporating the actual probability distributions into the analysis will be adopted, and the R&D effort will be broken down into stages reflecting the logical technical challenges that need to be met to bring the technology to fruition as well as the option to improve it over time. This information will allow us to look at the optimal R&D portfolio more fully as a sequential decision making problem over time where stages of the R&D on a particular technology may be pursued with subsequent stages either canceled or accelerated depending on how the energy system and the climate problem evolve.

Finally the technologies will be evaluated in groups in hopes of finding the most valuable portfolio(s) of technology options given the uncertainties about technology costs and performances, scenario variables, and valuation model parameters. Here we will consider using the whole portfolio as a hedge against future uncertainties as well as using individual elements of the portfolio as hedges against lack of technical or economic success in the other elements of the portfolio.

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