Long-Term Energy Scenario Models: A Review of the Literature and Recommendations

David L. Greene
National Transportation Research Center
Oak Ridge National Laboratory

February 28, 2001

Background

> "Long-term global energy futures are also no longer seen as geologically preordained....With continued exploration efforts and continuing technological progress, accessible and affordable reserves have increased, and this trend will continue to at least 2020. After that all scenarios move away from their current reliance on conventional oil and gas." (Grübler, 1999, p. 47)

But what primary energy resources will replace conventional oil and gas is far from clear. A key finding of the IIASA/WEC study is that the final energy demands of each scenario can be satisfied by a wide range of energy resource mixes.

> "Because of the long lifetimes of power plants, refineries and other energy investments, there is not enough capital stock turnover in the scenarios prior to 2020 to allow them to diverge significantly. But the seeds of the post-2020 divergence in the structure of energy systems sill have been widely sown by then, based on R&D efforts, intervening investments, and technology diffusion strategies. Decisions between now and 2020 will determine which of the diverging post-2020 development paths will materialize....This puts additional importance on near-term actions that can initiate long-term changes: technology and infrastructure investments are the most prominent examples." (Grübler, 1999, p. 47)

Review energy outlooks to 2020 and 2050 (EIA, IEA, WEC, IIASA, IPCC, others). Models through 2020 do not include resource depletion since it is not a critical issue through that point. Models to 2020 generally do represent resource depletion in some way and all conclude that conventional oil and gas depletion will be an issue. The conclusion seems to be that lots of energy exists in forms that can be transformed into the forms required to satisfy final demands. The questions then become those of environmental impacts and conversion technologies.

Model Requirements

1. Must represent cumulative resource depletion and its effects on primary energy markets;
2. Must allow introduction of new resources and transformation processes;

3. Must forecast to at least 2050;
4. Must simulate the market's equilibration of supply and demand via prices, and represent OPEC behavior;
5. Must represent global regions, including the U.S. and Canada;
6. Must provide measures of economic costs and benefits for alternative scenarios;
7. Must provide measures of environmental impacts, especially greenhouse gases;
8. Must allow analysis of energy security implications of alternative scenarios.

Modeling Approaches

Global Energy-Economic Models

Another major use of global energy models is for predicting global carbon emissions and the impacts of policies for mitigating greenhouse gas emissions. In an overview of a multi-model assessment of global carbon emissions models carried out by the Energy Modeling Forum, Weyant and Hill (1999) distinguished among five categories of models based on their representations of the energy sector and the economy (table 1). Although none of these models is suitable for the 2050 study purposes, the classification is useful because it describes the kinds of trade-off modelers typically make in weighing additional complexity against tractability.

The key trade-off is between the richness in representing the operation of economies and detail in representing energy sectors and the role of technology in the evolution of energy demand. The economy can be represented most simply by aggregate cost or production functions, but the ability to represent different economic sectors, such as transportation, is sacrificed. Multi-sector macroeconomic models allow the representation of sectoral interactions but, due to this added complexity, generally omit technological detail. Of the models that focus in detail on the consumption and supplies of fossil fuels and renewable energy sources, and explicitly include transitions to future energy technologies (types II and III), only type III models also represent individual economic sectors. And while several of the models allow fairly detailed consideration of energy supply technologies, only the AIM model represents energy demand and technologies at the end-use sectoral level. The AIM (Asia-Pacific Integrated Model) model

	Energy Sector Representation		
Economy Model	Fuel Supplies and Demands by Sector	Energy Technology Detail	Carbon Coefficients
Aggregate Production/Cost Function		II. CETA, MERGE3, GRAPE	I. FUND, RICE
Multisector General Equilibrium	IV. MIT-EPPA WorldScan G-Cubed	III. ABARE-GTEM, AIM, MS-MRT, SGM	

Multisector Macroeconomic	V. Oxford		

These models generally can represent OPEC behavior in some way. In general, they do not represent resource depletion.

Global Energy Dynamic Optimization Models

MESSAGE III : A dynamic linear programming model created by the IIASA and used for forecasting to 2050 and 2100. Used in the IIASA/WEC study of Global Energy Perspectives.

ERIS : Energy Research and Investment Strategy (ERIS) is a small-scale global energy model prototype. It was developed by the EU. The purpose of ERIS was to represent the important mechanisms relevant for analyzing and research and technology deployment policies with the goal of cost/benefit analysis and prioritization.

MARKAL (Various versions) : A dynamic "bottom-up" energy optimization model developed by the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA). It has been and continues to be widely used for greenhouse gas mitigation analysis and energy planning. It is now being adapted by EIA for international energy forecasting and analysis (Barry Kapilow-Cohen).

These models are generally very detailed in their representation of technologies in the energy and end us sectors, although they are flexible enough to be simplified in all dimensions. Representations of the rest of the economy are generally either non-existent or highly simplified. Their focus is on energy supply, conversion and end use. Recent development efforts have focused on endogenous technological change, among other methodological issues.

Issues

Comparison of economic versus simulation models. Generally only dynamic optimization models track resource depletion, and only IIASA's MESSAGE model has been used to do this in a major study. MARKAL could be used for this purpose, but would require some elaboration on the resource side.

Global models with regional representation generally involve thousands of endogenous variables and require months of set-up for a major new implementation.

A question is whether a much simpler model formulation could capture enough of the important energy market interactions. In particular, could a model focused on liquid fuels supply and conversion plus transportation end use, and minimizing detail for other energy sectors do an adequate job of representing the dynamics of the depletion of conventional oil resources?

The Champagne and POW models are spreadsheet models. Thus, a spreadsheet model would facilitate integration. Whether a spreadsheet model will allow adequate optimization capability remains to be seen.

Essential Elements of a Global Liquid Fuels Market and Resource Depletion Model

The model must represent both the supply and demand side, and must therefore have an algorithm for equilibrating the two via market prices. This algorithm must allow alternative representations of OPEC decision making.

Supply Side

World energy resources capable of conversion to liquid fuels for transportation must be represented quantitatively so that resource depletion can be accumulated over time. Key issues are how much regional detail in the distribution of resources is needed and how regional variations in the quality (cost of extraction) can be represented and, 3)

ENERGY SUPPLY SIDE

RESOURCES (Cumulative Depletion Calculated)
Conventional Oil Resources
    OPEC or OPEC+
    N.A. (U.S. and Canada separately?)
    ROW (OECD, Developing World)
Unconventional Oil Resources
    Regions
Gas-to-Liquids
    Regions
Renewables/Biomass
    Regions

CONVERSION/DISTRIBUTION PROCESSES

LIQUID FUELS SUPPLY ←> OTHER ENERGY SUPPLY

Issues:

1. Technological change in extraction and conversion exogenous or endogenous?
2. Fuel detail or just all liquids lumped together?
3. Cost as a function of depletion, region?
4. How to represent constraints on production capacity expansion and contraction?
5. Represent OPEC behavior exogenously or by algorithm?
6. Track imports and exports?
7. Make choices among energy sources exogenously or endogenously?

ENERGY DEMAND

Transportation Demand Drivers

Champagne Model
Canada, U.S.
Other Modes (Heavy-duty highway, air, rail, water, pipeline)

OECD

Developing world

Technology assumptions

World Energy Demand

Aggregation to world transport demand

Other world liquid fuels demands

Aggregation to world liquid fuels demands

Other world energy demands

EQUILIBRATION OF SUPPLY AND DEMAND

Questions:

1. How to harmonize N.A. and ROW technology and policy assumptions?
2. Should ROW transport demand be exogenous?
3. Should other liquid fuels demands be exogenous?

Recommendations

Options:

1. Create a new, special purpose model in Excel to interface with Champagne.
2. Adapt an optimization model like MESSAGE, MARKAL or ERIS
3. Wait for EIA to implement MARKAL and use or adapt EIA's version.
4. Other, such as adapt and expand existing spreadsheet models like OTT's POW.

References

Energy Information Administration (EIA), 2000. *International Energy Outlook 2000*, DOE/EIA-0484(2000), U.S. Department of Energy, Washington, D.C., March.

Grübler, A., 1999. "Global Energy Perspectives: 2050 and Beyond", pp. 41-61 in *Energy The Next Fifty Years*, OECD, Paris.

International Energy Agency (IEA), 2000. *World Energy Outlook 2000*, OECD, Paris.

Naki□enovi□, N., 2000. *Emissions Scenarios*, A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Seebregts, A.J., T. Kram, G.J. Schaeffer, A. Stoffer, S. Kypreos, L. Barreto, S. Messner and L. Schrattenholzer, 1999. "Endogenous Technological Change In Energy System Models", ECN-C-99-025, IIASA, Laxenburg, Switzlerland.

Weyant, J.P. and J.N. Hill, 1999. "Introduction and Overview", pp. vii-xliv in *The Costs of the Kyoto Protocol: A Multi-Model Evaluation*, *The Energy Journal*, Special Issue, J.P. Weyant, ed..