GEOPOLITICAL FACTORS AND INCREASINGLY TURBULENT SUPPLY AND DEMAND SCENARIOS IN ENERGY MARKETS: MODELING REJUVENATED INTEREST IN BIOMASS ENERGY SOURCES

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ABSTRACT

As the peak of global oil production approaches, increasing competition resulting from increasing demand in emerging economies challenges traditional energy market relationships. Recent events underscore additional disruptions and uncertainty in energy markets, resulting from random fluctuations introduced by wars and natural disasters. This paper proposes a modeling approach to understanding and predicting the impacts of these combined factors in the context of turbulent market conditions.

The model is capable of capturing price, yield, unit transformations, capacity and other important data. It also proposes the use of the model to examine the role of alternative fuel technologies in smoothing the transition from the fossil fuel era. An example of biomass ethanol is provided. The model employs generalized network optimization methodology and provides a general structure with data from 2004 as a base case. A brief tutorial on generalized network formulations in the energy context is included.

PROBLEM STATEMENT

Turbulent shifts are occurring in the world's oil driven energy markets. Large new players such as China, India and Brazil have appeared on the demand side. The energy demand among emerging economies is likely to equal or exceed first world economies by 2025 (Figure 1). Furthermore, larger players such as China will introduce uncertainties into traditional market relationships. China has already begun to compete with the United States and Europe for Canadian, Venezuelan and Russian oil.

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Figure 1: World marketed energy consumption by region, 1970-2025

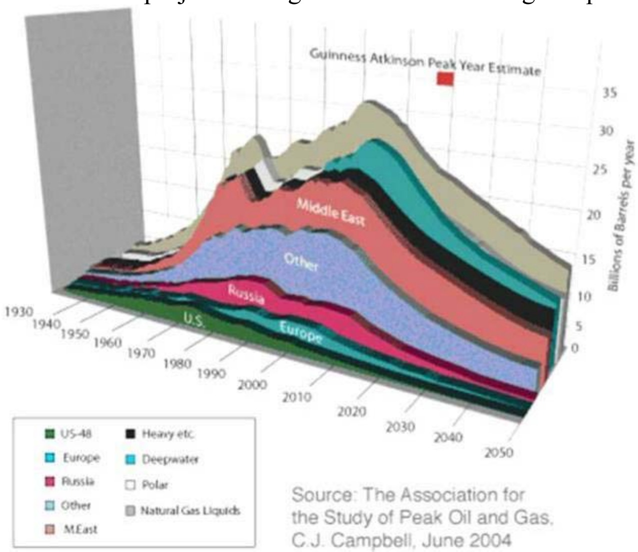
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

The increase in competition is complicated by the onset of the limitations associated with a finite resource in the context of increasing demand. The "End of Oil" or "Peak Oil" can be viewed as the point where world production will cease to increase at an increasing rate. It will then continue to increase at a decreasing rate. Ultimately it will peak and then, finally, decrease. "Peak Oil" occurred in the United States in the1970s. This peak was precisely predicted by M. King Hubbert's model in 1962. Globally, we are already beginning to see signs of the early stages of the approach of "Hubbert's Peak" (Figure 1). The onset can be characterized by ever increasing, highly unstable and fluctuating oil prices. Also, in 2005, global spare capacity reached a near 20 year low of 1 million barrels per day. Consequently, there is virtually no safety net as there had been in the past. Some argue that 2005 is the beginning of the peak; although, most estimates of peak production vary from 2026 to about 2039. The latter estimate was made by the U.S. Department of Energy's Energy Information Administration (EIA).

Hubbert's model was based on D.F. Hewett's (1929) statistical models of the depletion of non renewable resources. While accurate at the time, it may be too simplistic as the global peak approaches. Sources of variation resulting from conservation programs and the implementation of alternative fuels technologies may significantly affect depletion. Additional uncertainties in supplies due to conflicts in the Middle East, such as the Iraq war, further muddy the waters. Finally, significant unexpected random variations in supply and refining capacity can occur as a result of natural phenomena, as in the case of hurricanes Katrina and Rita.

New more sensitive and reactive tools to assist decision makers are needed. These tools could be used to assist in developing effective energy strategies to cope with increasingly turbulent supply and demand scenarios in energy markets. The technique presented in this paper employs a modeling approach. It evaluates the strategic role of biomass and related technologies as the new energy mix shifts. The transition period encompasses biomass; hydrocarbon based non-conventional oil, enhanced oil recoveries and existing capacities. The eventual mix is likely to include mainstream biomass, nuclear, hydro, wind, solar, new oil, coal and natural gas based technologies.

Figure 2: Hubbert curve projection of global oil and natural gas liquids production



LITERATURE REVIEW

Energy Modeling

Early statistical models of depletion of non-renewable resources can be traced to D.F. Hewett. Hewett visited and gathered data from 28 European mining districts in 1926. Hewett's 1929 paper resulting from the visits was the basis for M. King Hubbert's model (1962), which correctly predicted the year of peak US oil production.

Energy modeling was fueled in the 1970s by the OPEC oil embargo and the apocalyptic report by the Club of Rome, *Limits to Growth* (1972). The short term dire consequences didn't come to pass. However, many of the statistical predictions regarding energy resource depletion were quite accurate as strategic energy issues came to light. Energy specific modeling efforts followed at the Stanford Research Institute (SRI). Nesbitt led the development of the SRI Gulf Model (1974) and the SRI-World Energy Model (1976). The term "energy modeling" is broad, encompassing exploration and refinery modeling, local consumption modeling, and a wide range of other specific definitions. This review will limit itself to optimization models, associated macro supply/demand, and price/technology policy issues.

During the 1980's provided approaches for solving and optimizing non-linear complex systems at the Department of Energy and developed the MFUELS Model (1984). Hogan and Weyant (1992) examined methods and algorithms for energy model composition3. Devine, Kumin and Aly applied a system of optimization and stochastic process techniques to solar energy systems (1983). Numerous researchers including Dembo & Zipkin (1982), Yakin (1983) and Bloom (1983)] applied optimization procedure to a variety of facility optimization issues (e.g. power plants and refineries). PETNET (1983) was developed by Farina and Glover under a grant from the Solar Energy Research Institute (1982), now the National Renewable Energy Laboratory – NREL.

Fariña and Glover employed generalized network (GN) methodology (Glover , Klingman et. al. 1978, 1979) in the development and implementation of the PETNET model. PETNET addressed the question of evaluation of biomass technologies for replacement of hydrocarbon-based technologies in the fuel and petrochemical industries. It only took into account raw dollar comparative costs. Up to that point, it was the first time that powerful high speed GN algorithms were brought to bear on the problem of alternative fuel technologies.

From the late 1980s through the 1990s, modeling efforts shifted from emphasis on petroleum replacement to analysis of greenhouse emissions. The shift was partially due to a decrease in the real price of oil. In the United States, greenhouse related models have been centered at the National Center for Atmospheric Research in Boulder (NCAR) as well as at Stanford. Recent European efforts have included VLEEM, the Very Long Term Energy Environment Model (2002). European models also included SAPIENTIA, (Systems Analysis for Progress and Innovation in Energy Technologies for Integrated Assessment, 2001). SAPIENTIA is a large-scale dynamic equilibrium model of an energy system. Other models model, MARKAL (1999) and MARKAL-LITE (2000), satisfy useful demands or energy services, under resources availability and environmental constraints on both global and urban levels level.

The United States government, Energy Information Administration (EIA), has a wide range of energy market topic model modules grouped under the National Energy Modeling System (NEMS) (1992). The module most relevant in the context of our effort is the International Energy Module (IEM, 2004).

METHODOLOGY

Objectives

The purpose of the model presented in this paper is to provide broad based decision support in the context of turbulent market conditions. It assists the decision maker in addressing questions regarding competition among the world's consumers for a finite resource that is reaching its production peak globally. It also allows for the examination of the role of ethanol as an alternative fuel technology. More precisely it might provide the lowest mix of explicit and external costs, the most flexible reaction and best strategic protection against disruptions in domestic supply.

Additional issues the modeling approach is capable of addressing are: exploding demand for petroleum in emerging economies in the context of the limits associated with affordable price per barrel. Co-product credits/debits can be effectively evaluated with the model for each alternative technology. Also, second order impacts of the alternative co-products on their markets can be investigated. Finally, environmental costs (e.g. biomass waste) and the impacts of renewed conservation efforts on energy supplies and prices can be evaluated.

Method

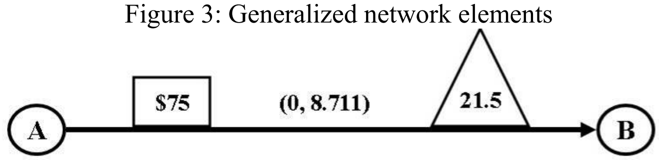
The IEM addresses the petroleum supply and demand aspects this paper considers. However, the IEM model is limited to simulation, which provides non-optimal solutions to these problems. The generalized network (GN) optimization algorithm developed by Glover and Klingman et. al. (1978) is a specialized form of mathematical programming. GN can provide solutions hundreds of times faster than conventional linear programming algorithms. Furthermore, it allows for graphic formulation and presentation of the problems. Graphic presentations are far more palatable than matrix oriented formats. The method's only relative disadvantage can be that it is static as opposed to the dynamic nature of simulation. This drawback can be resolved through a multiple scenario approach.

In a GN formulation, each arrow or arc between model nodes represents a variable, while each node represents a constraint. Flow out of nodes must equal flows into nodes. GN methodology facilitates transformations across arcs, enabling the modeling of yields (e.g. gallons of gasoline per barrel of crude) and unit transformations (e.g. barrels to gallons). GN can also model upper and lower limits as well as process or costs. Therefore each arc can incorporate:

- Price or cost per unit (e.g.$/barrel);
- Minimum flow allowed (e.g. minimal economic lot size);
- Maximum flow allowed (e.g. max. capacity);
- Transformations including examples such as:
    - Process yields – such as gallons/ton of ethanol or gallons/acre sugar cane;
    - Unit changes – such as gallons/barrel;
    - Efficiency ratios - such as biomass/fossil fuel input;
    - Currency exchanges – such as Brazilian Reals/USD.

The graphic representation with symbols for a variable can be found in Figure 3.

Figure 3: Generalized network elements



The circles or nodes identify the distribution point A, for example, Saudi Arabia and receiving point B, for example, the United States. The arrow or arc between nodes A and B identifies the path along which some resource may flow (or travel) from A to B, or in this case, from Saudi Arabia to the Untied States.

The number in the box along the arc represents the unit cost or price of the art flow (i.e., the cost of sending each unit of resource across the arc), in this example of $75/barrel.

The numbers 0 and 8.711 in parentheses indicate the minimum (lower bound) and maximum (upper bound) permissible quantity *of the resources in millions of barrels per day to flow along the arc.*

The quantity 21.5 in a triangle represents the multiplier of the generalized arc. This multiplier literally multiplies the flow in barrels of crude oil that enters the art at A to produce a yield and new quantity of flow in gallons of gasoline, which the art transmits to B. Thus, for example, if 1 unit of flow is accepted by the art from its originating endpoint (A), then 21.5 units of flow will be delivered by the art to its terminal end point (B).

Software used for a simple aggregate model, such as, the example presented in this paper can be solved using EXCEL template software. More detailed complex models at the refinery and barrel fraction level require more sophisticated software, such as Glover's proprietary (*GN2PC*) GN software.

Model Development

The model presented in this paper employs a GN formulation reflecting current conventional and alternative fuel technologies. It is capable of capturing cost-benefit relationships of co-products, as well as environmental costs and benefits.

The model incorporates current demand data relating to emerging energy consumers such as China. It also measures the impacts of new oil and alternative fuel producers such as Brazil. The example presented in Tables 1 & 2 represents the current base case. Other scenarios easily addressed could evaluate impacts of conflicts such as those in the Middle East, and political shifts as in Venezuela.

Inputs related to conservation, as successfully predicted in the 1970's, (Lovins, 1976), can be included. In addition, the model has the benefit of yield and efficiency data from experience with ethanol (1996, 1998, and 1999) at both NREL and the United States Department of Agriculture (USDA). The recent developments and experience with ethanol, flex fuel technologies and bio-diesel technologies in Brazil (2004,

2005) provide new model inputs. Domestic trials with LPG and hybrid vehicles provide additional information. Environmental and social issues can be simultaneously evaluated in the context of conventional technologies (Khosla, 2006). Some examples involve food supply-fuel tradeoffs (Post, 1991) and pollution (NREL, 2000.2001) on the negative side. Others represent reduction of greenhouse gases (Splash, 1989) (Stevenson & Godden, 1991) (Smith, 1991) (Sitarz,1993) on the positive side.

The initial GN formulation (Figure 4) uses the supply and demand values for petroleum by country presented in Table 1. Ethanol supply inputs are included only for Brazil and United States. The two countries produced 97% of the world's ethanol in 2003. China, India and France have dramatically increased ethanol production in 2004. Brazil is the major exporter. Table 2 [18] shows 2004 production of ethanol by country. The gross ethanol outputs can be a bit misleading since, for example from a land efficiency standpoint, since, for example, ethanol yields per acre for French sugar beets and Brazilian sugarcane are roughly double those for American corn.

Table 1 :2004 Oil Production and Consumption

	Oil Production - 2004 by Country		Oil Consumption – 2004 by Country	
RANK	COUNTRY	barrels/day	COUNTRY	barrels/day
1	Saudi Arabia	8,711,000	United States	19,650,000
2	United States	8,054,000	Japan	5,290,000
3	Russia	7,286,000	China	4,570,000
4	Iran	3,804,000	Germany	2,813,000
5	Mexico	3,590,000	Russia	2,595,000
6	Norway	3,408,000	Brazil	2,199,000
7	China	3,300,000	Korea, South	2,140,000
8	Venezuela	3,080,000	India	2,130,000
9	Canada	2,738,000	France	2,026,000
10	United Arab Emirates	2,566,000	Italy	1,866,000
11	United Kingdom	2,541,000	United Kingdom	1,710,000
12	Kuwait	2,270,000	Canada	1,703,000
13	Nigeria	2,256,000	Mexico	1,507,000
14	Iraq*	2,200,000	Spain	1,497,000
15	Brazil	1,561,000	Saudi Arabia	1,452,000
16	Algeria	1,520,000	Iran	1,277,000
17	Indonesia	1,451,000	Indonesia	1,045,000
18	Libya	1,429,000	Taiwan	988,000
19	Oman	963,800	Singapore	700,000
20	Qatar	864,200	Turkey	619,500
21	Argentina	828,600	Belgium	595,100
22	Egypt	816,900	Egypt	562,000
23	Kazakhstan	798,200	Venezuela	505,000
24	Angola	742,400	Argentina	486,000
25	India	732,400	Malaysia	460,000
25			South Africa	460,000
25			Iraq	460,000
Data source: 2004 CIA World Fact book				

Table 2: 2004 Ethanol Production

RANK	COUNTRY	Source	billion gallons	Ratio to Fossil fuels used
1	Brazil	Sugar Cane	4.0	8 to 1
2	United States	Corn	3.5	1.3-1.6 to 1
3	China	Wheat (and corn)	1	no -data
4	India	Sugar Cane	.5	Up to 8 to 1
5	France	Sugar Beets & wheat	.2	2 to one

Figure 4: GN formulation: Crude Oil & Ethanol Supplies & Demands 2004: All Countries producing or consuming 1 million barrels per day or more. "Other" includes the rest.

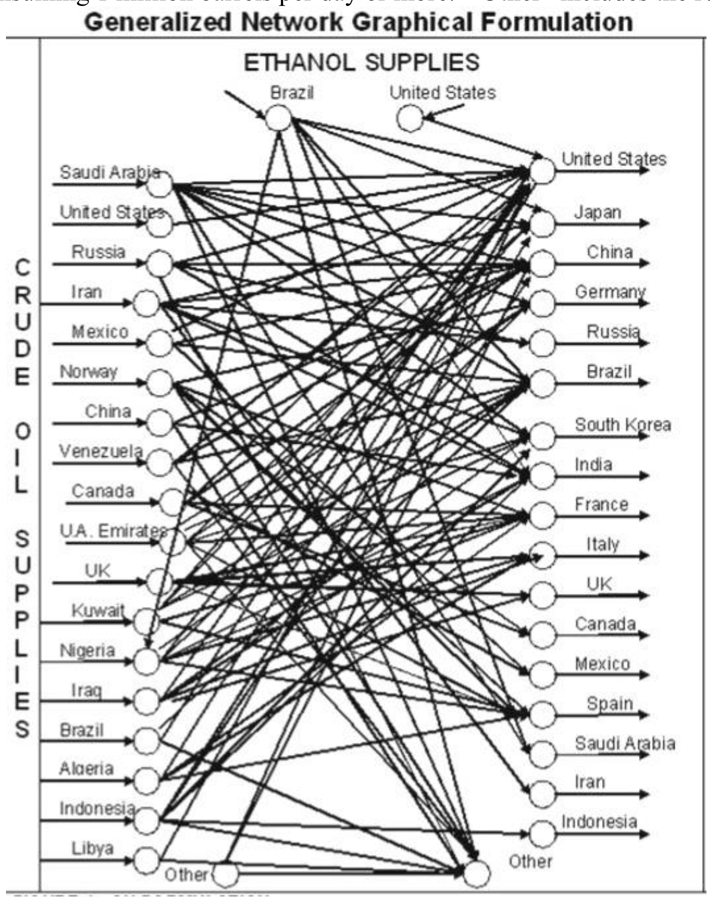
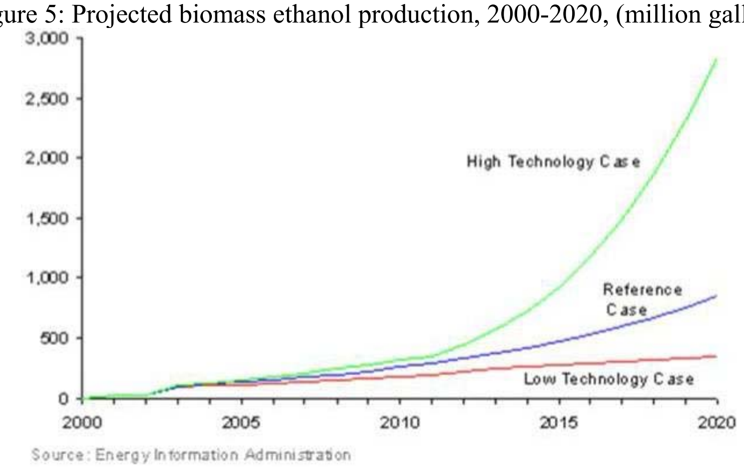


Figure 5: Projected biomass ethanol production, 2000-2020, (million gallons)



Model Application

As peak oil approaches, many argue that the United States and China are on a collision course in competition for the oil on world markets. China has already courted traditional U.S. suppliers such as Canada, Venezuela and Mexico. Furthermore, other emerging economies such as India and Brazil have dramatically increased their thirst for oil or possible substitutes. Among these substitutes is ethanol, which is included in this model, although, any other technology could be added.

The model structure provides the energy strategist with a tool that can readily examine a virtually infinite number of scenarios. Some examples might include possibilities of energy impacts. These impacts might be associated with upheavals such as the Iraq war or natural disasters such as hurricanes Katrina and Rita. It can also capture different assumptions of when peak production might occur. GN methodology facilitates inclusion of price fluctuations and refinery capacity bottlenecks. Another issue under scrutiny could be the relationship between price and the relative ability of different countries to pay.

Finally, the model can provide valuable market information with regard to alternative fuels technologies. Ethanol is included as an example of such a technology. In an example, Figure 5 identifies three scenarios envisioned by the Energy Information Administration. In fact, there is considerable evidence that the high technology scenario is already happening. In 2004, 2% of the world's motor fuel was biomass ethanol. In isolated cases, dramatic changes are taking place. In Brazil, 40% of the motor fuel sold was sugar based ethanol. In 2003, a small São Paulo company developed "total flex" engine technology, further accelerating the transition.

Flex fuel vehicles embody existing technologies that can render the transition from petroleum based transportation fuels to alternatives relatively seamlessly. Flex fuel vehicles come in two general categories:

1. The basic flex fuel vehicle can run on either gasoline or pure biomass based ethanol, or mixtures of the two in any percentages. It requires no specific action from the driver.

2. The second type of flex fuel vehicle is the first type plus the enhancement of natural gas (NG) capability through the addition of an extra tank and specialized hardware. The driver must specifically select the NG option via a switch on the dashboard.

Estimates have been given that as many as 25 % of new vehicles sold in the United States have flex fuel capability.. This statistic, however, is illusory since little capacity to deliver ethanol or natural gas exists at the pump. Also, in fact, many of these vehicles are E85 or other specific mix technologies, not "total flex".

Only in Brazil has biomass ethanol been integrated into the system over an extended period. For thirty years, Brazil's national biomass alcohol agency, PROALCOOL, has developed the ethanol fuel supply infrastructure. It was accompanied by the domestic auto industry's development and production of alcohol vehicles. The program nearly became extinct in the late 1990's due to low oil prices. By September 2005, however, over 53 "total flex" models were available from virtually all of the manufacturers. Over 60% of the vehicles sold in Brazil (Fall 2005) were at least of the basic flex fuel variety (Khosla, 2006). The demand is market driven, given that biomass alcohol is almost exactly half the price of gasoline. While natural gas is on a par with alcohol, or slightly cheaper, it has found less favor in the marketplace, since the extra tank often takes up trunk space. The added weight affects the handling of the small Brazilian cars and presents an additional hazard.

Despite its growing fuel consumption, Brazil hopes to achieve energy independence as early as 2006. Its strategy is optimize domestic consumption and exports of its vast oil reserves discovered in the 1990's combined with its global predominance in ethanol production. The model presented in this paper could provide their energy strategy decision makers with an invaluable tool. One use could be the examination of a variety of global energy price, demand and exchange rate scenarios and their sensitivities.

The same could be said for the U.S. as it depletes its strategic petroleum reserve. It is clearly in need for a coherent energy strategy.

CONCLUSION

The GN model presented captures global crude oil flows under varying supply, demand, refining capacity, price, and ability-to-buy scenarios. In addition, it can analyze any or all of these variables simultaneously. This analysis can be done in the context of existing or hypothesized alternative fuel technology, resource availability and cost scenarios.

It can also help decision makers understand the costs of environmental benefits associated with ethanol and other alcohol fuels. All biomass fuels enjoy the environmental plus of returning to the atmosphere no more CO_2 than the plants, from which they are made, consume. On the minus side, care must be taken with regard to agricultural practices resulting in erosion, as well as deforestation and food /fuel tradeoffs. Finally, the model can examine impacts of random variations introduced by events such as wars and natural disasters.

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