

The Development of an Energy Resources Accounting Module for a Global Energy Optimization Model

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Table of Contents

Abstract.....	1
Introduction.....	2
Method and Materials.....	4
Data Section.....	7
Results.....	8
Discussion and Conclusions.....	11
Acknowledgements.....	12
References.....	13

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Geologic assessments of world energy resources and projections of world energy demand indicate that the world will have depleted half of its conventional oil resources by the year 2020. The United States currently depends on oil as a primary energy resource for its economy, especially for transportation. Because of this trend, the United States and other countries will have to develop new sources of energy and new methods of fuel production or processing in order to supply the needs of their economies in ways that do not threaten the global environment. A model representing the process of resource production and depletion was constructed to better comprehend and analyze the effects of energy policies to protect the environment, promote economic growth and ensure adequate energy supplies for world economy. The optimization model consist of an excel workbook containing: 1) data on the world's fossil energy, 2) a model of resource extraction and depletion, including cost of production by region, 3) representation of the processes for converting energy into fuels, 4) energy demands along with the drivers of those demands, and 5) the technological changes affecting all components. A market model will find equilibrium between the supply and demand. In this study, the resource extraction and depletion accounting model was developed to observe production and consumption of the world's energy resources.

Introduction

The United States currently depends on oil as a primary energy resource for its economy, especially for transportation. Summer of 2000 gas prices sky rocked to almost two dollars in some regions because of the unexpected cut backs with OPEC oil production. To this day, gas prices have not been reduced to less than 1 dollar since 1999. Because of this trend, the United States and other countries will have to research and develop new sources of energy and new methods of fuel production or processing in order to supply the needs of their economies in ways that do not threaten the global environment.

Alternative energy, such as hydro-electricity, ethanol produced from biomass and other renewable energy sources have been introduced in the market to replace fossil fuels. However, supplies of these resources remain limited and have not been able to resolve all of the needs of an oil-based economy. In the near future, unconventional oil will become the mainstream supplier along with better, more efficient energy-using technology, which will reduce conventional consumption rates. The natural hydrogen deficiency or carbon richness of conventional petroleum sources may well become the largest barrier to widespread use of unconventional fossil resources in a Greenhouse Gases emissions-constrained future (Rogner 1997).

As present inhabitants of the earth, it is unjustifiable to diminish resources available for future generations. The increase in population, economic growth and transportation demand in the world regions will require more fossil fuel energy such as conventional oil than the world is presently producing. If the world continues to consume without trying to replace the oil in the reserves, then future inhabitants will be hit hard with high costs for energy. Not only would the economy suffer from shortages of depleted fossil fuels, it would make the other energy resources more expensive.

In order to prolong our existence on earth, one must start evaluating how we are destroying it. All we firmly know now is that human activities are changing the chemical composition of the atmosphere. Changing what is in the air will likely change the climate. (Ausubel 2001). The exact time and how the climate will drastically change are not determinable. So, one does not know how at-risk they are. We do know that the current technology that is used today is a major contributor to the carbon in the atmosphere today. The constant use of fossil energy resources adds to our problem with emissions of Greenhouse Gases. The most common greenhouse gas is Carbon Dioxide (CO₂). Carbon Dioxide is a product of fossil fuel combustion as well as other processes. It is considered a greenhouse gas as it traps heat (infrared energy) radiated by the Earth in to the atmosphere and thereby contributes to global warming (Griffin 2000). Technology such as carbon sequestration among other measures is suggested to prevent the release of large amounts of additional carbon into the air.

Studies on the long-term prospects for energy development in the world and its regions were started in a number of countries and international organizations, significantly in the 80's and 90's. Prior to that, the organization Club of Rome's intense research lured world attention to the impending shortage of fossil energy resources on earth. The so-called energy crisis of oil prices in 1973 and 1979 was a stimulating factor for the energy sector (L. S. Belyaev 2000).

As research interest increases, the studies are now focusing on the energy problems pertaining to human evolution towards sustainable development. According to the International Atomic Energy Association (IAEA) studies, global and regional analysis should be conducted to assess potentialities and conditions of energy formations. Energy policies are factored into this research.

The GEM-10R, Global Energy Model-10 Region, developed by the Siberian Energy Institute of Siberian Branch of Russia Academy of Science is a precursor to current optimization models. Its purpose is to study the World energy system over time till the end of the 21st Century. This model has multi-function processes that cover with sufficiently detailed presentation, technologies for the whole cycle of energy production, conversion, transport and consumption. Ecological constraints are incorporated, i.e. Greenhouse Gases and cost of regional energy development and operation (L.S Belyaev 2000).

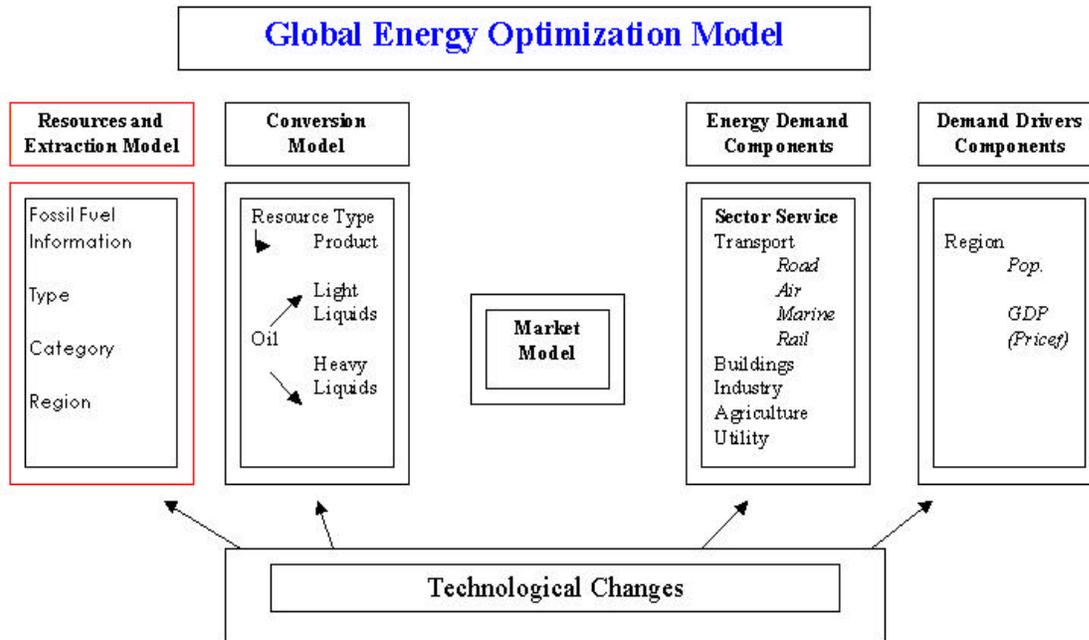
Traditional economic forecasting models do not consider resource constraints, and so can appear to evaluate energy problems over time, but may give an inaccurate picture of what lies ahead in the future. In working with resource constraints, forecasted scenarios must be consistent with the resources available regionally and globally (Parikh 1997). The usefulness of energy scenarios and models relies on the caution taken to make them guarantee a factual and consistent outcome. If this is not taken into consideration, false alarms can cause the world economy a sense of discomfort and create mistrust in statistical information in the future. The model will point out that our fossil resources are finite and run out with time. Realizing this, improved technology can redefine and enhance the resource bases.

This study's scope was to blueprint a model representing the process of resource production and depletion to better comprehend and analyze the effects of energy policies to protect the environment, promote economic growth and ensure adequate energy supplies for world economy. This model is designed to "optimize" an energy market solution for 11 world regions given exogenous forecasts of population and economic growth. It will accomplish this with five component models (See Diagram 1) designed to maintain the supply and demands of the optimization model.

Each component's functionality is dependent upon the other. The optimization model consists of the following: 1) data on the world's fossil energy, 2) a model of resource extraction and depletion, including cost of production by region, 3) representation of the processes for converting energy into fuels, and 4) organization of the energy demands along with the drivers of those demands, and forecasts of technological changes affecting all components. A market model finds equilibrium between the supply and demand.

This study focused on the development of the Resource and Extraction Accounting Model, designed to account for the production and of the world's energy resources by type of fossil energy. The accounting tool calculates the depletion of fossil energy resources and the resulting increases in production costs. This model helps explore when fossil energy resources are likely to be depleted and when a transition to new energy sources must be made.

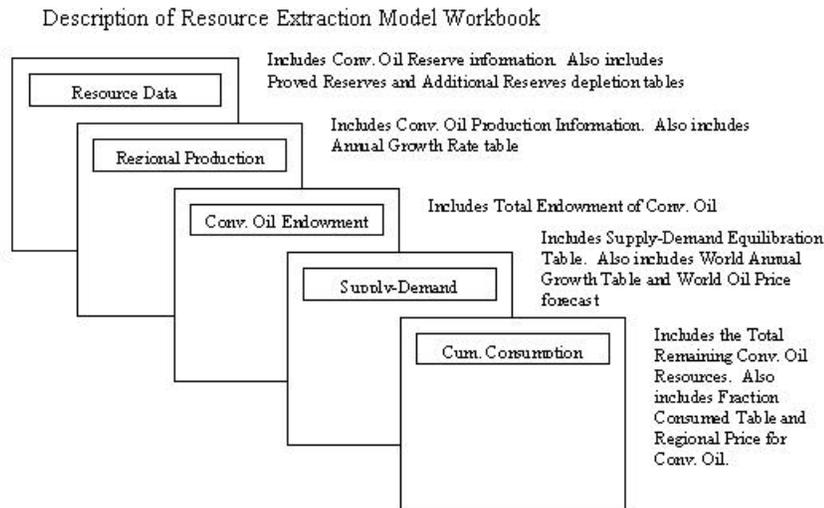
Diagram.1



Materials and Methods

A Microsoft Excel workbook was used for modeling the resource extraction process. Individual spreadsheets were required to collect and link data. (See Diagram 2).

Diagram 2



The Resource Data spreadsheet contained the foundation for all other spreadsheets. It contained Conventional Oil Reserve information. Pertinent tables inside this sheet were the Proved Reserved and Additional Reserves depletion tables. The Resource data was found using H.H. Rogner's figures categorized fossil fuels starting with oil occurrences (See Table 1).

Table 1. Estimates of oil occurrences, in Gtoe

		Conventional oil			Unconventional oil reserves and resources						
						Aggregate of shale, bitumen, and heavy oils					
		Proved	Estimated	Additional							
	Cumulative	Recoverable	Additional	Speculative	Enhanced	Recoverable		Additional			
	Production	Reserves	Reserves	Resources	Recovery	Reserves	Resources	Occurrences			
Region		I	II	III	IV	V	VI	VII	VIII	Total	
NAM	62.2	8.5	8.6	6.7	15.9	7.6	98.8	172.8	287.4	606	
LAM	17.5	17.4	8.9	15.5	18.9	2.6	91.5	160.1	270.8	586	
WEU	5.8	5.6	2.1	3.6	5.1	1.3	7.6	13.3	34.6	73	
EEU	1.9	0.3	0.2	0.6	0.7	0	0.5	1	3.8	7	
FSU	31.6	17.1	13.6	19.3	23.4	3.3	19.4	34	125.6	256	
MEA	85.1	87.9	17	21.9	56.2	22.3	39.6	69.3	279	593	
AFR	13.2	4	3.4	4.9	5.4	1.4	5.1	8.9	29.7	63	
CPA	2.1	5.1	4.7	8.2	7.4	2.3	42.2	73.8	118.7	262	
PAO	1.3	0.4	0.3	0.6	0.7	3.7	25.8	45.1	60.3	137	
PAS	5.6	2.9	1.6	2.5	3.4	0.6	4.8	8.3	23	47	
SAS	1.2	1	0.3	0.6	0.8	0.1	0.3	0.5	3.5	7	
World	227.5	150	61	84	138	45	336	587	1237	2638	

This year's Proved Reserves (q_t) is equal to last year's Proved Reserves (q_{t-1}) plus this year's Additions to Proven Reserves (a_t) minus this year's Production (p_t).

$$q_t = q_{t-1} + a_t - p_t$$

To forecast the depletion of Additional Reserves, the following equation was used:

This year's Additional Reserves (a_t) is equal last year's Production (p_{t-1}) divided by the Remaining Reserves two year's ago (r_{t-2}), then multiplied by last year's Remaining Reserves (r_{t-1}).

$$a_t = (p_{t-1} \div r_{t-2}) \times (r_{t-1})$$

The Cumulative Consumption spreadsheet played a key role in accounting the reserves. In order to figure out the Total of Remaining Conventional Resources, one had to calculate the prerequisite Remaining Conventional Resources.

The accumulated Remaining Conventional Resources (Q_{2000}) is equal to the sum of this year's Proved Reserves (q_t) plus the sum of this year's Additional Reserves (a_t).

$$Q_{2000} = \sum q_t + \sum a_t$$

The Extraction Price of Conventional Oil versus Percent of Conventional Oil Consumed was also calculated in the Cumulative Consumption Spreadsheet. This price depends on the fraction of the total reserves that have already been consumed.

This year's Fraction of Reserves Consumed (f_t) is equal to the difference of the accumulated Remaining Conventional Resources (Q_{2000}) subtracted by this year's Total Remaining Conventional Resources (y_t), then divided by Remaining Conventional Resources (Q_{2000}).

$$f_t = (Q_{2000} - y_t) / Q_{2000}$$

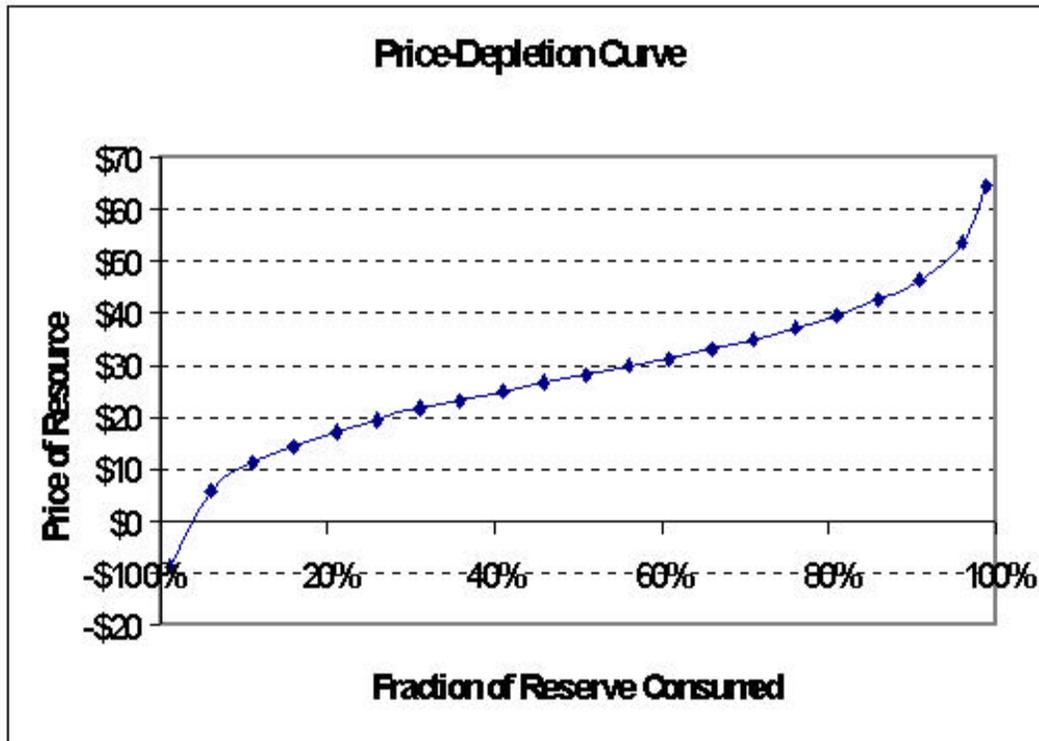
The Regional Extraction Price of Conventional Oil calculated using a logistic function. The concept of this function is to represent how, as a resource is depleted, the cost of extraction increases.

This year's Regional Cost (x_t) is equal to the natural log of (1/ this year's fraction of conventional oil consumed (f_t) minus 1) minus price variable (α), then divided by technological change variable (β).

$$\frac{\ln(1/f_t - 1) - \alpha}{\beta} = x_t$$

The price variable equation gives a general idea of how the price of oil will fluctuate with the consumption fraction (See Graph 1).

Graph 1

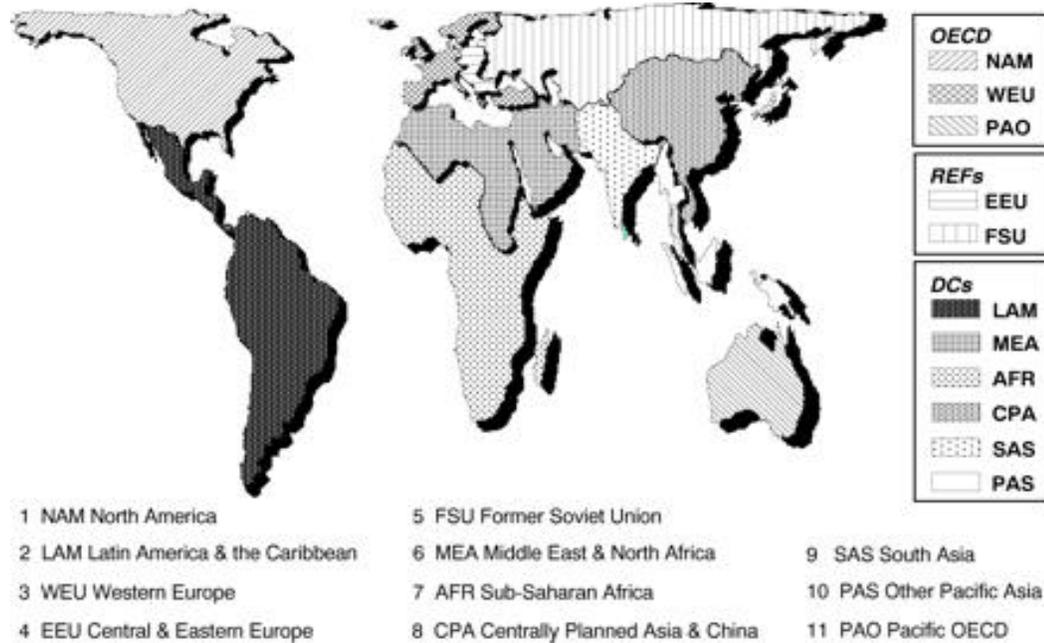


Data Section

The fossil resource information required had to be separation into regions or countries. Reason for such was to visualize the regions of Organization of Petroleum Exporting Countries (OPEC) and understand their transitions in the markets. The United States Geological Survey World Petroleum Assessment 2000, H.H Rogner's Assessment of World Energy Resources and the Energy Information Administration's International Energy Annual 1999 all qualified for potential information databanks. The USGS data was presented in overwhelming detail. The Survey had information separated by country as well as regions. Regional separation across the board varied in presentation. USGS separated their countries into 8 regions. Rogner separated his countries into 11 regions (See Graph 2). The EIA presented its regional information in to 7 regions.

Rogner's information was found suitable for a number of reasons. For starters, Rogner's data allocated the world regions in a reasonable figure giving the countries fair representation. Rogner's data also described every finite energy source; including the types of reserves they were stored. The categories of the reserves provided were quite helpful, which were used directly in the Resource Extraction Accounting Model. The USGS and EIA information was quite useful. The data from the alternative data bank provided a check and balance for Rogner's figures. The USGS provides uncertainty bounds for oil, which will be used in the future. The EIA provided a cumulative consumption datasheet that supplied the Conventional Oil Endowment for the accounting model.

Graph 2



For the model to function properly, it is essential that units for measuring energy be consistent throughout. This is done by converting different data from different units into common units of measure. The USGS information was represented into detailed American units such as Millions of Barrel of Oil (MMBO and Millions Barrels of Oil Equivalent (MMBOE)). Because the individual terms, it was difficult to convert. On the other hand, EIA's energy units were all grouped under one term, making it straightforward. The information was converted into Quadrillion British Thermal Units (Quad(10^{15})Btu) and also provide a simple conversion for the base unit. Rogner's information was not converted, leaving all energy resources in Giga Tonnes of Oil Equivalent (Gtoe), but problems did occur. Considerable time was spent trying to find a proper conversion for universal units to be translated (See Conversion Factors). Moreover, EIA's data history was used to complement Rogner's data in for Cumulative Production and 1999 Production Information. The Supply-Demand information and Resources and its sections were taken from Rogner.

Results

The results provided by the Resource Extraction Accounting Model can only be viewed as mock outcomes. The results are from sample runs made to test the operation of the model. This project's purpose was not to give accurate forecasts for oil depletion.

The time horizons of the Resource Spreadsheet display the depletion of reserves from 2000 to 2050. In the Proven Reserves table, one can see that the Central and Eastern Europe, Pacific OECD and South Asia will run out of conventional oil in their Proven Reserves before 2025. A graph that displays the production of Total World Reserves of Conventional Oil compared to Additional Reserves was constructed with Resource Spreadsheet information (See Graph 3).

Conversion Factors

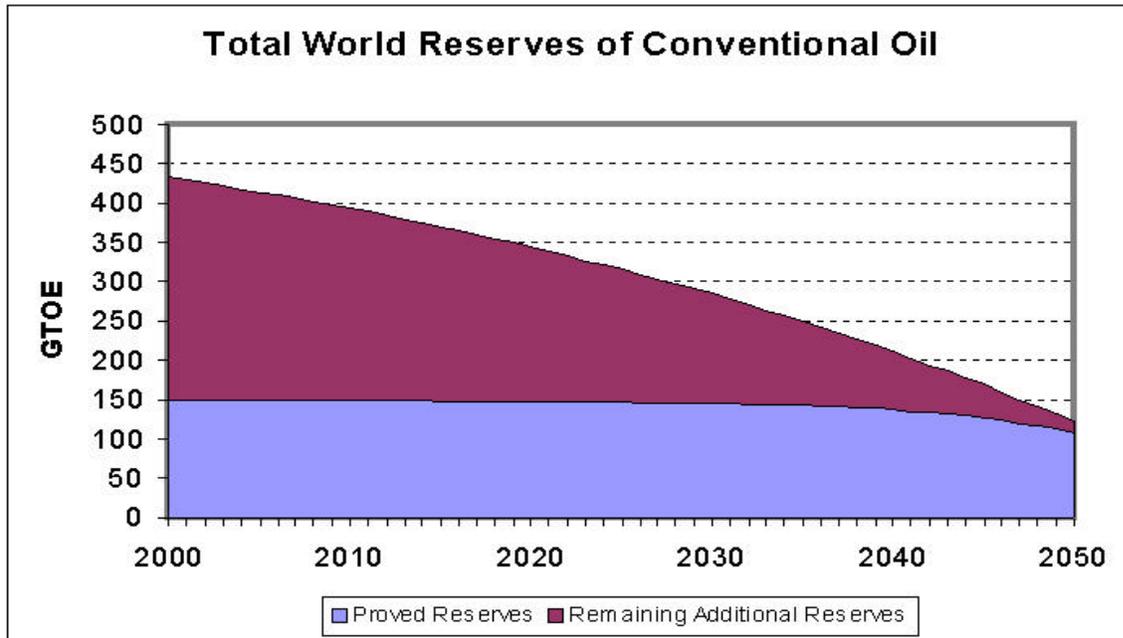
Table H2. Metric Conversion Factors

United States Unit	Multiply	Conversion Factor	Equals Metric Unit
Mass			
Pounds (lb)	X	0.453 592 37	= kilograms (kg)
Short Tons (2000 lb)	X	0.907 184 7	= metric tons (t)
Length			
Miles	X	1.609 344	= kilometers (km)
Energy			
British Thermal Unit (Btu)	X	1055.056 ^a	= joules(J)
Quadrillion Btu	X	25.2	= million tons of oil equivalent (Mtoe)
Kilowatthours (kWh)	X	3.6	= megajoules(MJ)
Volume			
Barrels of Oil (bbl)	X	0.158 987 3	= cubic meters (m ³)
Cubic Feet (ft ³)	X	0.028 316 85	= cubic meters (m ³)
U.S. Gallons (gal)	X	3.785 412	= liters (L)
Area			
Square feet (ft ²)	X	0.092 903 04	= square meters (m ²)

Note: Spaces have been inserted after every third digit to the right of the decimal for ease of reading. The Btu used in this table is the International Table Btu adopted by the Fifth International Conference on Properties of Steam, London, 1956.

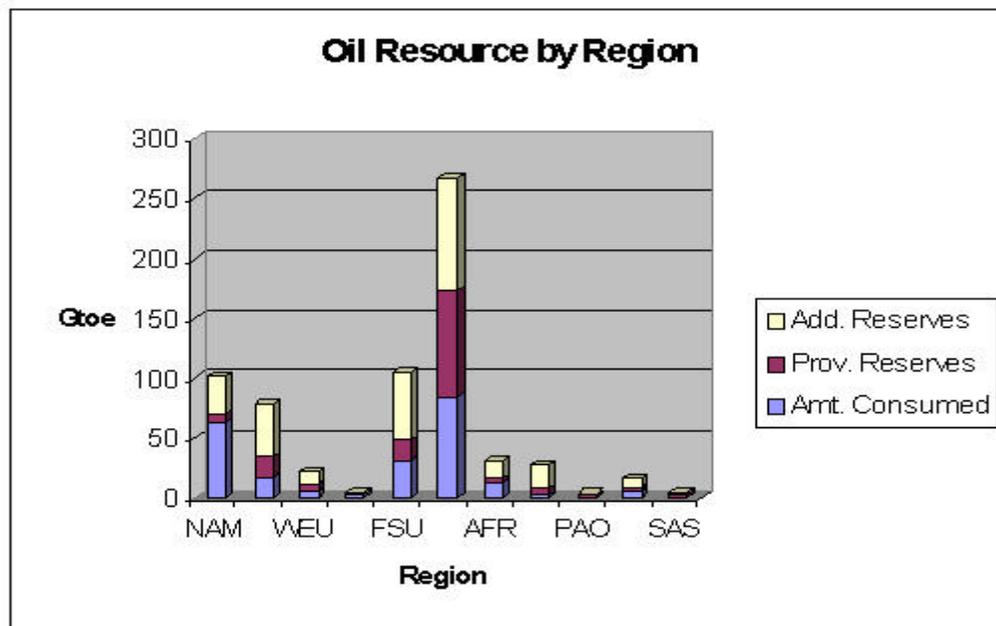
Source: Energy Information Administration (EIA), *Annual Energy Review 1999*, DOE/EIA-0384(99) (Washington, DC, July 2000), Table B1 and EIA, *International Energy Outlook 2000*, DOE/EIA-0484 (2000) (Washington, DC, March 2000).

Graph3



The Energy Resource Table provided an Annual Growth Rate of World Oil Production. Another graph was constructed to represent the regional consumption trend of Conventional Oil Endowment compared to Proven and Additional Reserves (See Graph 4).

Graph 4

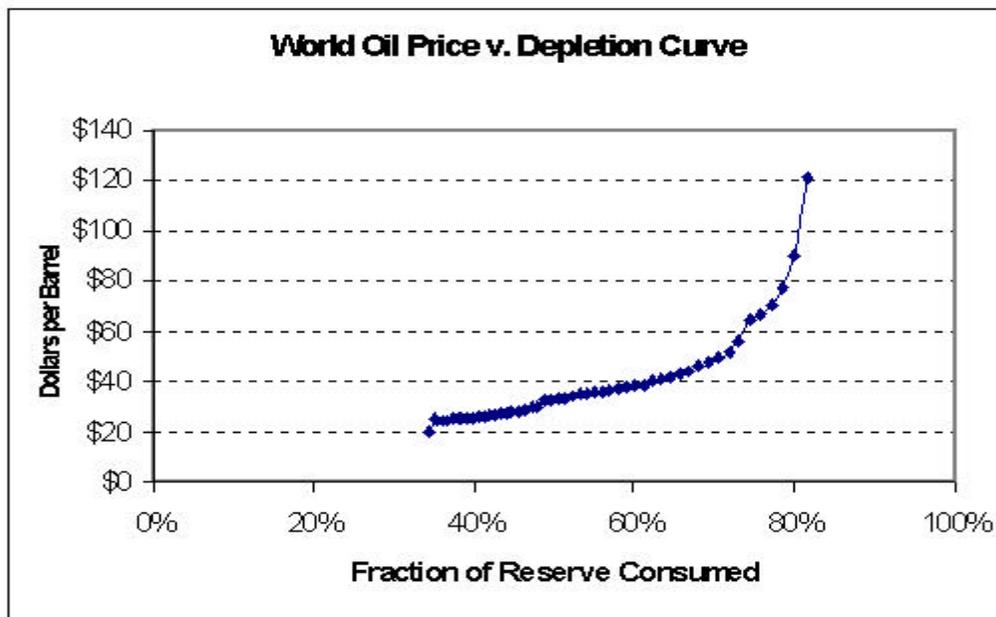


The Production Spreadsheet illustrates that Middle East, North America and Former Soviet Union regions were the largest producers in Oil in 1999.

The Short Run Supply information found in the Supply-Demand Spreadsheet delivered World Oil Prices with the Annual Growth Rate for World Oil Demand. In addition, a World Oil Bill was constructed displaying the cost of oil depending on the World Demand Rate.

The most significant spreadsheet of all is the Cumulative Consumption Sheet. From this table, one will observe the depletion of resources at a certain percentage as well as the price of production over a time horizon affected by the resource reduction. A detailed graph was constructed using the World Price of Resource (Conventional Oil) versus Fraction of Reserved Consumed (See Graph 5).

Graph 5



Discussion and Conclusions

So far, we are on the path to building a useful model, provided that more data for different types of oil are given, e.g. unconventional oil. Evaluating the results of the Resource Extraction Accounting model, one can see that the prices will increase as the oil reserves continue to deplete. A sample was shown that it is possible that the reserves will reach their midway marker by 2020. The time may not be exact, but through hypothesis; depletion will take place based on the world's current consumption trends. One thing is for sure, the more oil resources we use, and the potential warming will become prevalent in the future.

If unconventional oil information was included, one could evaluate how the economy would shift. If this is researched, hopefully retarding the conventional oil consumption, granted that the unconventional oil could produce fuels similar to conventional. The barrier to this goal is the limited information provided by databanks. Currently, there a little to no detailed information of unconventional oil located throughout the world.

Future work for this project would be to finely define what types of oils are borderline Additional Reserves. For the project, rough assumptions were made to group the data. When calculating for the Additional Reserves in the Resource Spreadsheet, Categories II-III was accumulated. Rogner's definition of Category IV appeared to qualify it to also be classified as Additional. This raises the question, how much of the additional reserves can possibly be made from conventional oils? Other questions that can be placed on the Energy Community Bulletin Board are:

Do we know the exact amount of the fossil energy resources? Once we find out the exact size, we will be one step away from determining the exact time of depletion.

When will we develop technology to extract unconventional oils at a reasonable cost? Will unconventional oil make a significant difference?

From this project, one is able to identify practical data representing the world's fossil energy resources by type, category and region. Reliable database building can be achieved by compiling data into common units for the model. Tasks such as constructing a detailed spreadsheet model can now be achieved giving a forecast of world energy demand, which will predict the price of production as it accounts for the depletion of energy resources by type. In the case of conventional oil, the model has been shown to function properly. The model will become a key building block for the world energy modeling system described in the project.

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