

## 2.11 Reducing US Oil Dependence Using Simulation

### Reducing US Oil Dependence Using Simulation

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**Abstract.** People across the world are addicted to oil; as a result, the instability of oil prices and the shortage of oil reserves have influenced human behaviors and global businesses. Today, the United States makes up only 5% of the global population, but consumes 25% of the world total energy. Most of this energy is generated from fossil fuels in the form of electricity. The contribution of this paper is to examine the possibilities of replacing fossil fuel with renewable energies to generate electricity as well as to examine other methods to reduce oil and gas consumption. We propose a system dynamics model in an attempt to predict the future US dependence on fossil fuels by using renewable energy resources such as, nuclear, Wind, solar, and hydro powers. Based on the findings of our model, the study expects to provide insights towards promising solutions of the oil dependency problem.

#### 1.0 INTRODUCTION

Oil shortage is affecting various facets of our lives, such as the economy, the environment, national security, government policies and human behaviors. According to the Energy Information Administration report 2009, U.S. fossil fuel consumption decreased by 4.2%; however, the major petroleum product especially gasoline did not decline, in fact, the average annual consumption is predicted to increase by 20,000 bbl/d and 90,000 bbl/d in 2010 and 2011, respectively [1]. The report implies that oil will continually be produced and imported at increasing rates in order to meet the rising consumption levels while oil reserves are limited. As a result, the health of our future will ultimately depend on all available energy resources to include oil, and renewable energies.

Investing in alternative energy sources has become popular in the recent decade. The main reason behind such investments is to decrease American oil dependency on imported foreign oil by generating substitutable energies for power generation from different avenues, such as from wind turbines and natural gas. In this paper, we propose a system dynamics model that represents the US energy consumption,

generation, and use of alternative energy sources focusing mostly on electricity generation from alternative renewable sources. The aim of this paper is to examine the future US oil dependence by using renewable energy sources. The study expects to provide insights towards promising solutions of the US oil dependency problem.

#### 2.0 PROBLEM STATEMENT

Recently, researchers have been focusing on creating and generating alternative renewable energies which can reduce the amount of imported foreign oil. This could provide advantages in term of employment rate, environmental sustainability, technological development and local economies; however, such strategies require a huge investment and support from both the private sector as well as the government. In this study, we propose a simplistic model of energy generation and consumption in the US focusing on electricity generation from alternative renewable energy sources. In order to examine the model, the data collection have been retrieved from the Energy Information Administration Independent Statistics and Analysis. The influenced factors include oil

production and consumption, gas production and consumption, electricity consumption and generation, oil consumption to electricity generation, alternative energies consumption and production (hydropower, nuclear, wind, thermo, solar), electric car and light bulb (CFL). The data will be analyzed quantitatively and conclusions will be drawn according to the model's results.

### 3.0 MODEL CAUSAL LOOP

One of the intentions of the proposed model is to predict the behavior of the transition from traditional non-renewable to renewable sources of energy. In consequence, we take into consideration the three main non-renewable sources used nowadays: oil, gas and coal. As it has been evident through the years, the demand for energy is constantly increasing. In our model, we consider the demand from four main sectors: transportation, commercial, industrial, and residential. The high increase in the demand for energy and the decrease, since many years ago, in the petroleum extraction have alerted the world about the critical need to find and use alternative energy sources. In this model, we consider the main renewable sources that are starting to emerge and become important in electricity generation for some countries; including The United States. The renewable sources considered in this paper are: wind, nuclear, hydro, thermo and solar sources. Furthermore, another way to preserve and optimize the use of petroleum is by utilizing more efficient technologies that use less energy and provide the same benefits. Therefore, in this model we consider the impact of using technologies such as: LED's and electric cars, which help in reducing the amount of energy that is currently obtained from fossil sources.

A simple way to grasp our model is by reviewing the causal loop diagram (shown in fig.1) which; while avoiding to mathematically validate our predictions, is a summary of the factors considered that will

have an impact on the consumption, usage, and availability of fossil and renewable resources. According to the causal loop diagram, when the residential, commercial or industrial demand increases, the oil, gas and coal consumption also increases; therefore, the relation is positive. In the same way, if the oil, gas and/or coal consumption increases, then the oil, gas and/or coal resources decrease, respectively; in consequence, the relation is negative. Following the diagram, it is evident that if any of these resources decline; the non-renewable resources reservoir would decrease as well, implying a positive relation. Retrospectively, increase in consumption from alternative sources would yield a decrease in the non-renewable sources consumption (negative relation). Following the same logic, having more availability of alternate resources would allow us to have a higher electricity generation from renewable sources (positive relation) and reduce the consumption of fossil sources to generate electricity (negative relation). Finally, an increase in the use of saving light bulbs will also help to decrease the electricity generation from fossils (negative relation) in the same way that using more electric cars will allow us to reduce the consumption of oil for transportation (negative relation).

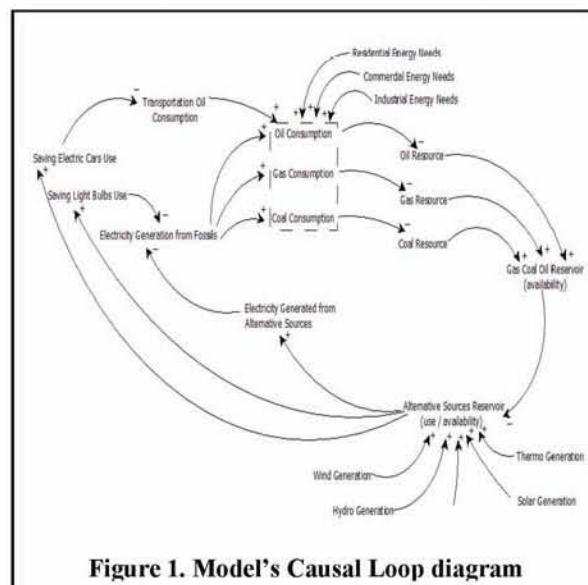


Figure 1. Model's Causal Loop diagram

The proposed model is created using GoldSim® version 10.10, a Monte Carlo simulation software based on system dynamic modeling [3]. In this section, we explain the technical details of the model we developed. The section is divided between Model Limitations and Model Technical Details.

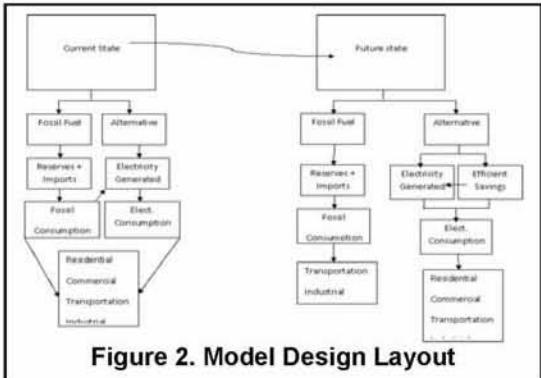
#### 4.1 Model Limitations

The model assumptions and limitations are presented below:

- a- The model is constrained within the time frame 1980-2035.
- b- High-Efficiency Light Bulbs were considered to yield 20% saving in electricity consumption when compared to standard light bulbs.
- c- Each electric vehicle was assumed to save an average of 600 gallons annually based on an average of 12000 travel miles per year with a consumption of 20 miles per gallon.
- d- Renewable resources were assumed to be installed upon demand without any limitations.
- e- Only 10% of the available area of the wind maps was considered for wind turbine installations.
- f- Solar panels were modeled without any limitations, such as size, locations, or available times.
- g- Increase in electric consumption due to electric vehicles was considered.
- h- Geothermal heat was modeled without any limitations.
- i- All modeling and simulation for future purposes was based on the year 2007 data.
- j- While the data in GoldSim is shown in bbl, it is actually in 1000 bbl. We did this for simplification of the graph readings.
- k- Nuclear plants take on average 10 years between being built and being commissioned, in order to start producing energy. Although we haven't modeled this important constraint, we adopted a lower percentage for nuclear reactors future production taking this delay factor into consideration.
- l- Although in real life the oil and gas reserves are rarely altered, we assumed that our reserves are in a tank (or reservoir to be more accurate) where the consumption is withdrawn from it and the import is added to it.
- m- In our model, we are assuming that the increase is constant (e.g. the same percentage increase of wind turbines and solar panels are added every year on the previous one).
- n- The future alternative energy sources are assumed to start at year 2007 and the data accuracy of the prediction is dependant on [4].
- o- The future increase of the energy produced by alternative energy sources starts from year 2007 and until 2035.
- p- Due to lack of data, future prediction for electric cars was based on the number of electric cars available in 2007 [4] consuming 150 watts/hr per car for total of 5 hours per day. In addition, we assume that based on the predicted rate increase in electric cars in the market, a similar decrease would be witnessed in fossil-fuel based vehicles. The fossil-fuel vehicles were assumed to consume an average of one gallon per 20 miles for a total of 12000 miles driven annually per car.

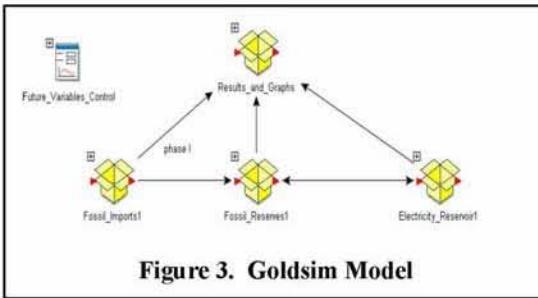
#### 4.2 Model Technical Details

The model is designed to reflect both the current and the future state of the energy production and consumption sectors. The current state represents the *no change* in culture "status quo" scenario, while the future state represents the implementation of alternative energy resources to include high efficiency systems. Below in fig. 2, is a layout that shows the blue print of our design.



**Figure 2. Model Design Layout**

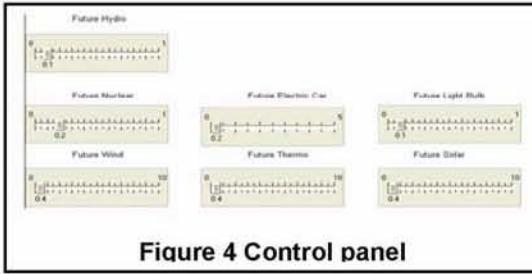
The initial high-level view of the model looks like fig. 3. The model is divided into four main containers and one control panel allowing the modeler to control the sliders of the future increases in alternative energy sources.



**Figure 3. Goldsim Model**

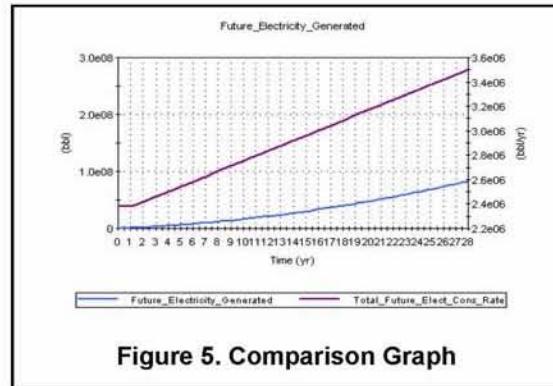
## 5.0 RESULTS AND ANALYSIS

When considering a constant increase approach for the future alternative energy sources, we compared the future electricity generation from alternative sources with the predicted electricity consumption. After increasing the future energy sources by certain percentages in the control panel (shown in fig. 4), we ran the system and compared the alternative electricity generation with the predicted electricity consumption. Note that we put the maximum amount for the variables in the control panel that according to our belief, are feasible.



**Figure 4 Control panel**

When looking at the results' graph (shown in fig. 5), we need to take into consideration that the future alternative sources start from year 2007 (i.e. reference year 0 on the graph) until the year 2035 (i.e. year 28 on the graph) meaning that at year 2035 for instance, we will generate  $75130280 * 1000$  bbl.



**Figure 5. Comparison Graph**

As observed, according to our study, when considering these 3 alternatives, i.e. wind, solar, and geothermal resources, it is not feasible to achieve, our objective and meeting the consumption demand. However, when Natural Gas was considered such as a simplistic optimization approach yields that it is a possibility to achieve our goal. Table 1 shows the parameters used to achieve the objective function and meet the energy consumption demand.

**Table 1. Parameters Used to Achieve Objective Function**

Resource	Preferential weight factor per sector <i>w</i>	% increase in annual production per sector
		<i>a/sector</i>
Wind	0.025	0.0625
Solar Panel	0.025	0.0625
Geothermal	0.025	0.0625
Nuclear	0.775	0.25
Hydro	0.025	0.16
Natural Gas	0.125	0.25

## 5.1 Optimization

In this section, a Non Linear Programming (NLP) Model was developed in Excel to quickly study the possible strategies for meeting future demand. For this reason we introduced two preferentiality factors i.e., strategy-variables, denoted as  $\omega$  and  $\alpha$ .  $\omega$  was used to limit the production of a given sector under a given percentage of the total output, where as  $\alpha$  was used to limit the annual increase in production of a given sector to a predetermined percentage. For the purpose of this paper we limited  $\alpha$  to less than 0.25 while we allowed Excel to determine  $\omega$ . It is understood that our results are strict to these conditions and that any change in the preferentiality factors would ultimately change them. Equations below were used to establish our optimization model.

$$Z = \sum_{j=1}^{j=6} P_j,$$

$$P_j = X_j + X_j * \partial_j * t_j$$

where  $P_j$  = Power output per Sector  $X_j$

$$\partial = \text{Production increase rate per annum} = \frac{P_{t+1} - P_t}{P_t}$$

Subject to the constraint of  $P_j * \omega_j$  for any sector  $j$

where  $\omega_j$  is a prefentiality factor per sector  $j$

The cost associated with installing additional units (not previously installed) can be calculated as such:

$$C_j = (\sum_{u=1}^{u=k} c_u) * (1+i)^t$$

$$X_j = \sum_{u=1}^{u=k} x_u$$

where  $c_u$  = cost per a single unit,  $x_u$ , of sector  $J$

$i$  = inflation rate or interest rate per year

$t$  = time to reach power output required

subject to the following constraints :

$$\sum_{j=1}^6 X_j P_j \geq \text{Predicted Energy Demand in 2035}$$

$$P_j = \text{Energy Production of sector } j = \sum_{u=1}^{u=k} p_u x_u$$

$$0 \leq t \leq 15$$

$$0 \leq \alpha \leq 25\%$$

$$\sum_{j=1}^6 \omega_j = 1$$

$$0 \leq \omega_j \leq 1$$

$$x_u \geq 1$$

$$1 \leq P_s \leq 0.1 * \text{Current No. Homes} * 4 \text{KWh}$$

$$1 \leq X_w \leq \frac{0.1 * \text{Total wind Area available}}{\text{Area of } x_w}$$

$$1 \leq X_H \leq 100 + (\text{Currently installed})$$

$$1 \leq X_N \leq 50 + (\text{Currently installed})$$

$$1 \leq X_G$$

$$\text{Currently installed} \leq X_{NG}$$

where w : wind Power Sector

H : Hydro Power Sector

S : Solar Power Sector

N : Nuclear Power Sector

G : Geothermal

and NG : Natural Gas

Some of the assumptions that were taken into accounts for building the model were:

- 10% of the total available wind land would be the maximum area to utilize.
- 10% of the residential homes would be assumed to install solar panels.
- Policies would not restrict or prohibit building of dams or solar panels or wind mills.
- There is assumed to be available resources to complete installation of any selected sector at any quantity.

- Environmental and other policy decisions could be represented by the preferentiality factor.

Other factors that were not considered:

- Operation costs of a plant
- Life cycle of a plant
- Decommissioning cost of a plant

What we now have, in fact, are two optimization objective functions that can be manipulated in the desired perspective. For instance, if cost is the main goal, which is not in our case, then minimizing the cost objective function would yield the sought after results, else our objective function Z is the answer.

One thing that must be kept in mind that all energy units have been represented on the basis of electricity equivalent. Since wind turbines, solar power, nuclear plants, and the remaining sector capacities are valued base on Kwh capacity. (The required 3.5E9 barrels/year in figure 5 was converted to MW). Input and constraints requirements and results for NLP model are given in tables 2 and 3 respectively.

**Table 2: Model Inputs and Constraints for Energy Optimization Non-Linear Program**

Source	Kwh/Unit/Yr	\$ Cost/Unit	Area require d ft <sup>2</sup>	Size/Numbers Constraints
Wind	3*10 <sup>3</sup>	10 <sup>6</sup>	84497	1.73052*10 <sup>12</sup> ft <sup>2</sup>
Residential Solar	1.4*10 <sup>3</sup>	36000	120/hou se	12.6*10 <sup>6</sup> houses
Geothermal	1.63*10 <sup>6</sup>	8.4*10 <sup>7</sup>	N/A	N/A
Nuclear	12.4 10 <sup>9</sup>	1.4*10 <sup>10</sup>	N/A	124
Small Hydro-electric	2.6*10 <sup>6</sup>	2*10 <sup>6</sup>	N/A	4139
Natural Gas	1.3*10 <sup>6</sup>	1.5*10 <sup>8</sup>	N/A	727

**Table 3: Results of the Optimization model**

Power Source	# of units	# units installed/a lready installed in 1" yr	Months to achieve goal	Total production MW	Total cost \$
Wind	1	1	5.63		
Solar	1	1	5.62		
Geothermal	2	2	5.62		
Nuclear	330	124	79.7	6.00E09	2.96E13
Hydro	4460	4139	5.8		
Natural Gas	1463	727	48.6		

The NLP optimization Model as demonstrated above shows that it is possible to meet the future demand of energy equivalent to 6E9 MW at a rough estimated cost of 2.962E13 over a period of 4 years.

## 6.0 CONCLUSION AND DISCUSSION

The purpose of this paper was to examine the future US oil dependence by using renewable alternative energy sources focusing on electricity. A simulation model was developed in which we considered wind, solar, and geothermal heat, as the only renewable resources available to generate electricity. Furthermore, we tested the effect of replacing light bulbs with high efficiency light bulb with respect to electricity consumption. Also, instead of using natural gas as the fuel of choice for transportation, electric vehicle technologies were considered for vehicles. No change in fuel consumption was considered for other modes of transportation, such as airlines, trains, large shipping trucks and maritime shipping.

After Setting up the modeling environment with the necessary functions and data, the renewable resources production rates were manipulated. The study concludes that it is possible to be energy independent from foreign oil but at an astronomical costs. A forcing policy must be implemented to entice *all* the private energy companies for seeking alternative energy sources.

#### **REFERENCE**

1. Administration, E.I., Energy Information Administration: Official Energy Statistics from the U.S. Government 2009, in Short Term Energy Outlook. 12 March, 2010.
2. Vuong, A., Tycoon's plan taps wind, in The Denver Post. 12 March 2010.
3. Associates, G. GoldSim. June 25, 2010]; Available from: <http://www.goldsim.com/>.
4. Administration, E.I., Forecasting and Analysis. 2010.