SANDIA REPORT
SAND2009-8205
Unlimited Release
Printed December 2009

Laboratory Directed Research and Development Program Report

Models for Evaluation of Energy Technology and Policy Options to Maximize Low Carbon Source Penetration in the United States Energy Supply

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Models for Evaluation of Energy Technology and Policy Options to Maximize Low Carbon Source Penetration in the United States Energy Supply

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Abstract

An initial version of a Systems Dynamics (SD) modeling framework was developed for the analysis of a broad range of energy technology and policy questions. The specific question selected to demonstrate this process was "what would be the carbon and import implications of expanding nuclear electric capacity to provide power for plug in hybrid vehicles?" Fifteen SNL SD energy models were reviewed and the US Energy and Greenhouse gas model (USEGM) and the Global Nuclear Futures model (GEFM) were identified as the basis for an initial modeling framework. A basic U.S. Transportation model was created to model U.S. fleet changes. The results of the rapid adoption scenario result in almost 40% of light duty vehicles being PHEV by 2040 which requires about 37 GWy/y of additional electricity demand, equivalent to about 25 new 1.4 GWe nuclear plants. The adoption rate of PHEVs would likely be the controlling factor in achieving the associated reduction in carbon emissions and imports.

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NOMENCLATURE

ALTSIM	Liquid Transportation Fuels Cost Model
ANL	Argonne National Laboratory
BDM	Biofuels Deployment Model
CAFÉ	Corporate Average Fuel Economy (Standard)
CEM	China Energy Model
CIMS	Computer Integrated Manufacturing System
CNG	Compressed Natural Gas
DIS	Disruption Impact Simulator Model
DOE	US Department of Energy
EIA	Energy Information Agency Models
ENPEP	Energy and Power Evaluation Program
GASCAP	Wellhead Gas Productive Capacity Model
GCAM	Global Climate Assessment Model
GDP	Gross Domestic Product
GEFM	Global Energy Futures Model
GEM	The Global Electricity Module
GENSIM	Electricity Production Cost Model
GHG	Greenhouse Gas
GREET	Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation Model
GWOB	Global World Oil Balance Model
H_2SIM	Hydrogen Production cost Model
IEGHG	India Energy and Greenhouse Gas Model
IEGGM	India energy & GHG Model
ISTUM	Industrial Sector Technology Use Model
LDRD	Laboratory Directed Research & Development program
LNFCC-PC	Levelized Nuclear Fuel Cycle Cost Model
LVD	Light Duty Vehicles
MARKAL	Market Allocation Model
MiniCAM	Mini Climate Assessment Model
NEMS	The National Energy Modeling System
NREL	National Renewable Energy Laboratory
NRG-H_2O	Energy Water Nexus Model
ORNL	Oak Ridge National Laboratory
PCINM	International Nuclear Model – Personal Computer
PHEV	Plug In Hybrid Electric Vehicle
PNNL	Pacific Northwest National Laboratory
PPMM	Propane Market Model
SAGE	The System for the Analysis of Global Energy Markets
SD	System Dynamics
SGM	The Second Generation Model
SNL	Sandia National Laboratories
SOP	String of Pearls
SNAPPS	Short-Term Nuclear Annual Power Production Simulation

SPR	Strategic Petroleum Reserve
STHGM	Short-Term Hydroelectric Generation Model
STIFS	Short-Term Integrated Forecasting Systems
SWUSIM	East Asia Model
TEA	Technoeconomics of Algae
TEM	Transportation Energy Model of the World Energy Projection System
UMM-PC	Uranium Market Model
US	United States
USEGM	US Energy and Greenhouse Gas Model
USESM	US Energy Security Model
WECS	Water, Energy, & Carbon Sequestration
WEPS-PC	World Energy Projection System
WORLD	World Oil Refining, Logistics, and Demand Model

1 INTRODUCTION

The current reliance on fossil fuels and imported sources introduces significant economic, environmental and security concerns for the US energy supply. The inevitable transition to a more diverse and sustainable mix of energy sources will require a more sophisticated energy infrastructure and innovative end use strategies. Energy policy makers at all levels need to be informed with credible analyses of options and alternatives. The purpose of this Laboratory Directed Research & Development program (LDRD) project was to develop a systems dynamics framework for the analysis of a broad range of energy technology and policy questions which leverages our existing system dynamics capabilities, and demonstrate an initial version of this System Dynamics (SD) framework on an illustrative energy question on low carbon energy source penetration into the energy supply mix.

1.1 Objectives

Sandia has developed numerous systems dynamics models over the past 10 years that could be useful in the analysis of future energy policy issues. Typically these energy related models were developed under the Laboratory Directed Research and Development (LDRD) program or another customer funded program to address a specific issue. Although some of these models and databases are potentially useful in addressing a broader range of questions, the effort to reestablish the model at a later date, and adapt the model to the new issue is often a significant barrier to reuse. As a result, most SNL SD models have a finite life, and are generally retained and reused primarily by the author(s). A more integrated and flexible framework for energy policy analysis that could leverage the existing tools and the investment that has already been made could be a significant benefit in future studies. The first objective was to identify a framework for this more comprehensive analysis approach and identify the relevant Sandia SD models that could be useful. The second objective was to establish an initial version of this framework utilizing existing SNL models and apply this initial model to address a low carbon energy source question.

Most energy policy questions generally involve how best to achieve some overall societal objective where energy is one of the key elements. Addressing these questions can include functional or performance goals, economic objectives, environmental constraints, energy security issues, and potentially other considerations. These goals or objectives are often interrelated, and require consideration of a complex combination of interacting factors. Systems dynamics analysis of various energy supply and demand scenarios is an effective approach to examine the interaction and implications of various energy policy and technology options. The specific question selected to demonstrate this process was “what would be the carbon and import implications of expanding nuclear electric capacity to provide power for plug in hybrid vehicles?” This question was representative of the types of energy policy questions being asked in current discussions.

1.2 Approach

The major tasks identified to accomplish these objectives included:

1. Develop an initial list of the types of relevant energy policy questions to illustrate the range of technologies and analytic capabilities that need to be considered.
2. Review the relevant SNL systems dynamics models and assess applicability of these existing models to these types of questions. (A brief assessment of external models was also performed).
3. Identify the scope of questions current models can address and the gaps in capabilities.
4. Identify an initial (illustrative) question related to low carbon energy source penetration.
5. Develop or adapt a preliminary set of SD models to address the question and form the basis for further evaluation.
6. Analyze the economic and carbon implications of this initial proposed strategy.

2 ENERGY POLICY AND TECHNOLOGY QUESTIONS

A key element in developing a more comprehensive energy system perspective is understanding the range and types of energy policy and technology questions that need to be considered in the discussion of United States (US) energy alternatives. Example policy issues could include strategies and technologies to maximize the contribution of renewable or carbon free energy sources at the earliest time, evaluation of the implications of various mixes of synfuels, the role of hydrogen or electrification in transportation, evaluation of the benefits of local generation and storage on grid stability, and end use strategies to maximize compatibility with renewable sources.

An initial set of energy policy and technology questions was assembled to illustrate the range of issues that must be addressed and the different perspectives that generate these questions. This limited effort was not intended to be comprehensive but would provide a sufficient list to establish a first order classification of the types of questions that need to be considered, and therefore the types of tools that are needed. The output objectives must also be defined. What form and level of answers are needed to effectively communicate these results with the intended audience? This high-level effort was intended to illustrate the process of formulating the key questions, developing an appropriate tool to perform the analysis, and displaying results in a transparent presentation that provides effective communication.

The initial list of policy questions was developed through an informal process of soliciting inputs from SNL experts in different energy technology and policy areas. The perspective provided by these diverse questions was used to evaluate the types of SD models that would be needed to structure a quantitative analysis on energy and infrastructure options that maximize the penetration of low carbon sources in the US energy supply as a function of time and conditions.

2.1 Energy Policy Objectives

The types of energy policy issues and questions that are being considered relate to how best to achieve some overall goal or objective where energy is an important element. Examples of these higher level objectives include:

- Economic objectives – ensure low enough energy costs to support economic goals, provide energy price stability, avoid inhibitors to Gross Domestic Product (GDP) growth, create jobs, etc.
- Environmental objectives – explore energy policy and technology options that reduce carbon emissions, minimize other air emissions or pollution, minimize hazardous waste, support appropriate land use, etc.
- Energy Security – reduce dependence on imported oil and gas, provide a diversity of supply, resist disruption, promote sustainable alternatives, etc.
- Functional objectives – provide sufficient energy to support demands, promote reliable supplies, ensure availability at peak demand times to avoid outages or rationing, etc.

These types of objectives are often interrelated, and require consideration of a combination of factors, with feedback and interactions that make the projection of any particular policy outcome difficult. Implementing policies directed at one set of objectives may have unintended

consequences in other areas, often with significant time delays before the ramifications are fully understood.

Several metrics can be used to measure success. Economic objectives can be measured in cost of fuel or electricity per unit of consumption, the number of jobs created, etc. Environmental metrics could be carbon emission per unit energy, or waste or pollution generated per unit output. Energy security metrics can be more subtle, but could include more quantitative metrics such as the amount of imported oil replaced, percent domestic supply, or a combination of metrics – i.e. the cost per barrel of oil replaced, or the incremental cost per kWe per ton of CO_2 eliminated, etc.

2.2 Types of High-Level Questions

An initial list of energy policy and technology questions was developed to help define the broad categories of relevant energy policy questions. In the process of collecting a range of representative questions and attempting to organize these questions in some more general structure, several observations were noted – some obvious, some more subtle.

- Many (most) energy policy or technology issues could be thought of as a **supply and demand** question – how best to meet a demand scenario with various supply options, or how to modify a supply source to better match demand, within a given set of **constraints**.
- Energy policy questions are often **driven from the perspective of the entity posing the question.** They are motivated by one or a combination of objectives, but they may prioritize factors (cost, environment, security, reliability, etc) differently from other stakeholders.
- **Supply side questions tend to focus more on technology** – how do we achieve some performance criteria with a given energy source technology.
- **Demand side questions tend to involve policy options** – how do we alter a demand scenario in a particular sector?

Figure 2.1is a schematic illustration of one way to view this general supply and demand structure. Starting with a set of economic, environmental, or other objectives, similar energy policy questions can be asked from different perspectives. For example, from a supply perspective, the question may be how to mitigate or modify the characteristics of energy source technologies to better match a demand scenario, questions which tend to focus on technology issues. From the demand perspective, the question may be framed as how to modify demand requirements to take better advantage of available supply resources, or what are the implications of sources or sector demands for a particular criteria. For example, many energy policy questions today are posed as what are the carbon implications of a particular source technology or energy policy.

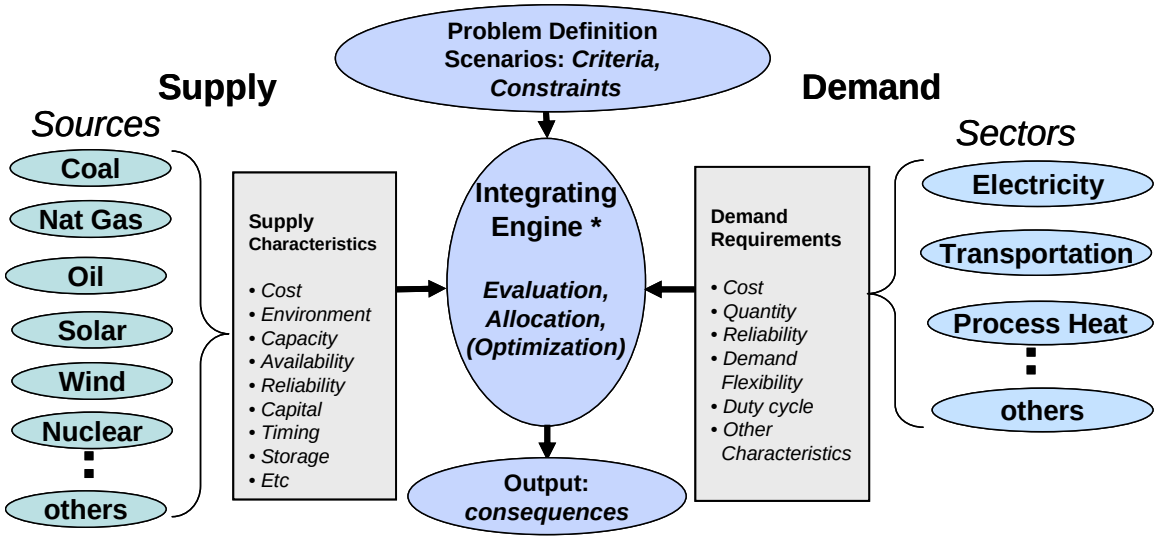

Figure 2.1 Energy technology and policy issues can often be represented in a supply and demand structure with constraints.

The same basic issue can be viewed from these different viewpoints, supply (utilities, vendors, resources), demand (industry, consumers), or constraints (regulators, policy makers) resulting in a different form of the question - depending on who is asking. It did not seem useful to try to define a single structure on the range of representative set of questions collected in this study, but it was instructive to list the questions from these different viewpoints (metrics, supply sources, or demand sectors).

2.2.1 Energy Policy/Technology Metrics Perspective

Carbon

- Carbon implications for different supply technology mixes:
  - What potential mixes of strategies are needed to lower carbon emissions to a desired target? The wedge analysis by Pacala and Socolow, in which they explored how implementation of a mix of efficiency programs and existing lower carbon technologies could stabilize CO_2 levels, [1] is an example of this kind of analysis.
  - What are the likely carbon emissions implications for a set of energy technologies?
    - What are the relative carbon emissions for transforming the transportation fleet from fossil fuels to electricity, biomass/synfuels, or hydrogen?
- Carbon Policy economics:

[1] Pacala, S. and Socolow, R. 2004 Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* 305, 968-972.

    - What would be an appropriate carbon tax?
        - How does one account for the cost of capture technologies?
        - What tax would be needed to achieve a given carbon reduction level?
    - What carbon management strategies could be used with acceptable economic impact?
    - How would carbon strategies change depending on various scenarios for GDP growth rate?

Cost

- What energy cost levels start to impact economic development? What areas would have the largest impact?
- How could the energy mix change to meet differing levels of future GDP growth (or contraction)?
- What are the potential energy market and economic impacts of the Low Carbon Economy Act of 2007 (S1766)?
- How much of a cost increase would be anticipated (or justified) to achieve a higher level of stability and availability?

Security

- Import Issues
    - At what rate should the US reduce dependence on imported oil to provide assurance that potential impacts due to resource limits or political uncertainties would be minimized?
    - What is meant by energy independence? What are the criteria and metrics (such as reduced imports, diversity of supply, control or flexibility of consumption)?
- Diversity of supplies, technologies
    - What combination of resources and utilization or policies would lead to greater national energy security?
    - What is the extent of the role that conservation could play in energy security?

Natural resources

- What are the relative land, water, and energy requirements for a suite of proposed technology pathways?
- How would utilization of different energy sources impact other natural resources?
    - How would biofuels impact water and land use?
    - What are the implications if certain kinds of land or crops are restricted due to regulations in other geographical areas?
    - What are the water requirements for refining or producing synfuels? What is the potential effect on water quality and supply?
    - Is there an adequate supply of key materials for a particular technology (such as battery storage or nuclear fuel)?

Labor

- How many jobs would be created by a particular initiative or project?

- What metric should be used to determine the net labor vs. cost benefit of one technology over others? Are additional jobs paid for by more expensive energy, or is there some additional leverage?

Infrastructure

- What infrastructure improvements provide the most leverage for energy security?
    - What "energy park" concepts might make the most sense given the geographical location and local resources?
    - What are the options for grid storage to enable higher renewable energy source penetration at the earliest times?
    - Is it feasible to capture CO_2 and make a biofuel using nearby crops?
    - What are the benefits or costs of creating multiple energy products with a single facility (such as nuclear electricity, hydrogen, process heat, desalinization)?
    - What combination of energy sources maximizes efficiency?

2.2.2 Demand Sector Perspective

Energy policy and technology questions often are posed as how to meet objectives for a particular sector demand scenario within a given set of economic, environmental or other constraints. Questions about these demand sectors could include comparisons of supply technologies, storage technologies, changes in demand scenarios driven by policy, etc. Examples of the types of questions that could be asked for the demand sectors are illustrated in the list below:

- *Transportation*

2.2.2..1 *Supply Issues:*

- What is the role of alternative fuels in the transportation energy supply?
- What mix of supply technologies would minimize carbon emissions, both near term and longer term, for a sustainable transportation strategy?
- What are the infrastructure implications of electrification, hydrogen, biofuels, etc? Considerations may include energy content, storage, infrastructure, vehicle performance and expectations for driving distance.
- What are the carbon and economic tradeoffs of liquid fuels vs. hydrogen-fueled vs. electric-powered vs. hybrid vehicles?

2.2.2..2 *Demand Issues*

- What is the impact of new vehicle characteristics (performance, cost, efficiency) on demand and use?
- Despite being a mature technology and the availability of fueling stations, why haven't (CNG) vehicles been more widely adopted?
- What are the different characteristics that motivate heavy-duty (industrial) vehicle vs. light-duty vehicle demand?

- What are the technology options (gasoline, diesel, biofuels, hydrogen, electricity) for better gas mileage for heavy duty vehicles?

- *Electricity*

2.2.2..1 *Supply Issues*

  - What storage technologies could mitigate renewable periodicity?
  - What renewable strategy would maximize penetration of low carbon, renewable electricity into the grid at the earliest times?
  - What are the innovative peaking power options (storage, natural gas, other low capital cost approaches, operational flexibility in coal or nuclear)? What are renewable source options?
  - How can smart grid technologies optimize the use of local vs. centralized renewable generation?
  - What is the value of multiple energy products from a single facility – such as nuclear electricity-hydrogen-heat? Could the output be shifted in periods of high demand or to increase revenue?

2.2.2..2 *Demand Issues*

  - What are the baseload vs. peak strategies?
  - What dispatchable load technologies and strategies have potential for mitigating peak requirements?
  - What are the appropriate energy efficiency requirements for residential and commercial uses?

- *Industrial (Process) Heat*

  - What are economically feasible combinations for electricity and process heat plants, district waste heat from power plants, nuclear process heat technologies, or waste heat with fossil or solar augmentation?
  - Industrial uses contribute approximately 20% of (US) carbon emissions. What are the low carbon strategies for process heat applications?
  - Is there significant potential for process heat efficiency improvement with co-located facilities, or improved process technologies?

2.2.3 Energy Source Perspective

An industrial entity (utility company, vendor, etc) may ask questions from the point of view of how to provide source options that better meet the criteria for a particular demand scenario.

- *Nuclear*

  - What are the options for increasing nuclear energy penetration across the transportation, electricity, and industrial heat sectors?

- What are the relative merits (cost, carbon) of using off peak nuclear electricity vs. biofuel strategies? What are the infrastructure requirements and what would be the timing of implementation?
- How do nuclear hydrogen for synfuels or refining vs. biofuel strategies compare?
- What would be the appropriate nuclear plant characteristics to maximize accommodation of periodic or intermittent low carbon sources (load follow vs. dispatchable loads)?
- How could higher nuclear baseload capacity be utilized? For example could plug in hybrids be used as storage with the associated reduction in peaking loads?

- *Fossil*

  - What would be the impact of carbon taxes or constraints on coal utilization?
  - What are the relative merits of coal to liquids vs. biomass strategies?
  - What coal utilization technologies could facilitate subsequent sequestration?
  - What would be appropriate carbon capture strategies?
  - Do we have capacity to support continued or expanded use of coal for electricity, is there enough capacity for economic sequestration (can you scale it up and is it economical compared to alternatives)?
  - What are the economic impacts of US cap and trade proposals, and what would be the economic impact on coal fired electricity?

- *Renewables*

  - What are the options for increasing the penetration of renewables into the energy mix?
  - What is the economic impact of 25% renewable portfolio by 2025?

- *Biofuels (alcohols or hydrocarbons)*

  - What are the economic and carbon tradeoffs between algae generated biomass fuels to other biomass?
  - What classes of biomass fuel options should be developed: cellulose, corn starch, wood residues, crops, waste, etc. (Cost, carbon, resource requirements, etc)?
  - What is the lowest carbon path for the biomass?
  - What is the appropriate geographical distribution for biorefineries for transportation fuels? Where should the biorefinery be located relative to feedstocks?
  - What are the infrastructure implications of biofuels (regionality of fuel use, infrastructure implications for adapting a new fuel type)?

- *Technology development/innovation*

  - What are the technical, infrastructure, or administrative solutions needed to optimize the use of available energy resources? Examples of key issues:
    - Coal – carbon control strategies, technologies – and cost impacts
    - Nuclear – waste solutions, safety, capital costs
    - Natural Gas – price volatility, cost, carbon
    - Solar – cost, periodicity
    - Wind – periodicity
    - Bio fuels – cost, infrastructure

As can be seen in the lists above, different perspectives can lead to the same basic question being asked in different ways. Questions will inevitably cut across multiple categories, and will require refinement to address the particular issues of interest.

2.3 System Dynamics Model Implications

Regardless of the perspective driving the question, evaluation of implications and alternatives will require energy models that can quantify the characteristics of energy sources, simulate the various demand scenarios or policy alternatives and evaluate implications according to a set of performance criteria. Figure 2.1was a schematic illustration of the types of models that would be required to address these types of questions. The next section poses a more specific question and illustrates the process of developing a set of models that can be used to evaluate a specific scenario.

3 ILLUSTRATIVE LOW CARBON SOURCE QUESTION

For the purpose of illustrating the process of developing a framework to address a current question, and performing the analysis to evaluate the alternatives and implications, the following example question was used:

Can a significant reduction in greenhouse gas emissions and oil imports be achieved by expanding nuclear electric generating capacity to provide power for plug in hybrid vehicles?

This question was selected because this approach could impact carbon emissions in the near term with minimal infrastructure changes or new technologies required. It also crosscuts transportation and grid sectors, and represents a combination of energy policy and technology questions that were identified above.

Using the Figure 2.1schematic to illustrate the models needed to address this question, Figure 3.1 shows the primary modules that must be included. Although this is a simplified set for the purposes of this LDRD, this exercise illustrated that some of these components are relevant to a wide range of questions, and can be assembled through defined interfaces to develop a basic set of SD models that can be linked to efficiently address a wide range of questions.

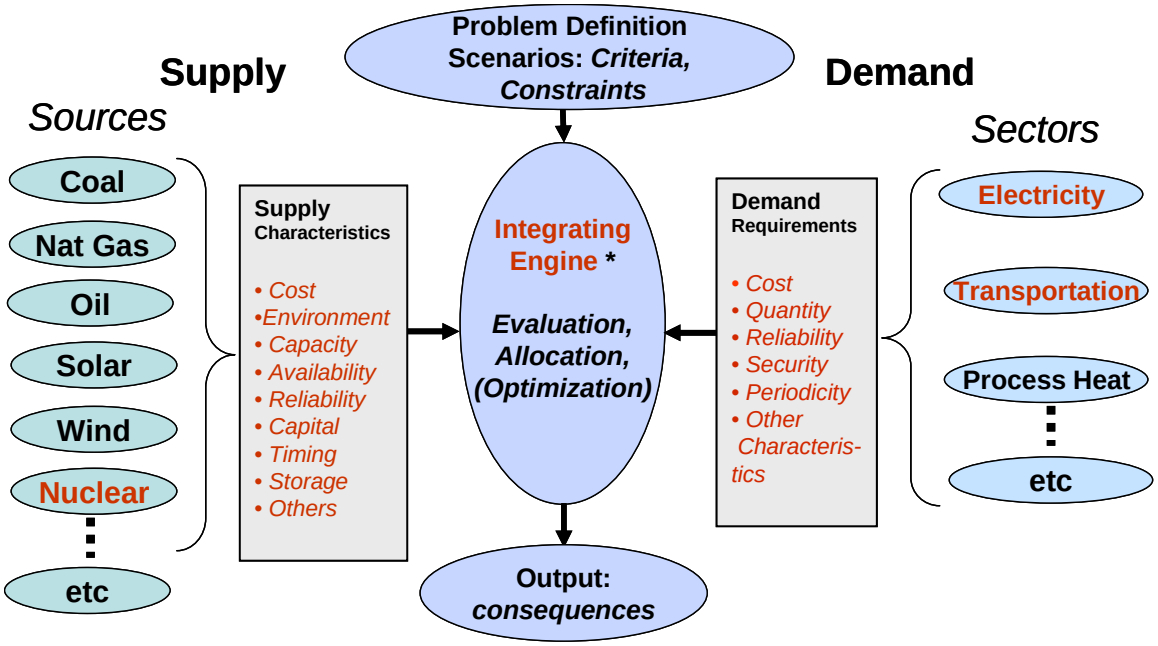

Figure 3.1 Models (highlighted in red) needed to address the question of the impact of using nuclear electricity to power a fleet of PHEVs.

The models identified for this LDRD illustrative question include a central model to compare carbon emissions, costs, and petroleum requirements for a range of energy supply options, a nuclear power module to define the characteristics of the expanded power source, and a transportation module to model the current light duty vehicle fleet and the adoption of new vehicle technologies. The integrating engine, the core model that evaluates the supply demand scenario against a set of performance criteria, is central to all of these types of questions. Although the modules selected or developed for this LDRD only needed basic functionality for this study, the models adapted provide more comprehensive capabilities which could be readily utilized in the next level of analyses.

To identify the most appropriate models for this study, an evaluation of SNL SD models was performed to determine which were most appropriate for this study and also which could be considered as building blocks for an expanded and more general set of tools for future use. The following section summarizes this evaluation.

4 ENERGY MODELS EVALUATION

A review of energy related Sandia systems dynamics models was conducted to identify existing models that could be useful in addressing current energy policy and technology questions of the types listed in Section 3. This evaluation included: the relevance to the current range of energy questions of concern, adaptability of the model for future use or modification, and identification of gaps or deficiencies in the SNL SD model portfolio. Being able to understand the code structure and logic in a straightforward manner greatly simplifies the process of adapting the model for future analyses. Basic code features such as protocols for data inputs, naming conventions, the logic structure of the code, and consistent practices programming techniques influence the ability to interface with other models.

The models that were reviewed in this LDRD represented a subset of the large number of models developed at Sandia. The selected models were generally developed more recently (last 5 to 10 years) and were based on current programming platforms. Most were developed in LDRD projects, and used the Powersim Studio system dynamics software platform. The models examined represented a wide variation in purpose, subject area, time horizon, level of detail, type of construction, reusability, and methodological consistency. In general these models were constructed for a specific application and purpose and at different times. There was no common model building process approach, programming style, or testing regimes. Models were identified that may have some relevance to the current study, but these were not formally reviewed due to the level of effort required to make the code operational again. Though this evaluation did not address external energy models in detail, a brief survey of some of the large number of non-SNL energy models was conducted as well.

Based on the evaluation results, the list of candidate models was then evaluated for relevance to the specific issue of achieving a significant reduction in greenhouse gas emissions and oil imports by expanding nuclear electric generating capacity to provide power for plug in hybrid vehicles. No existing Sandia model was found which could be adapted to the transportation issues posed so an additional aspect to the study was to build a simple vehicle fleet (park) model to describe the evolution of the US vehicle fleet as (PHEVs) are incorporated in the light duty vehicle fleet.

4.1 Model Review Approach

Modeling and simulation in Powersim Studio allows the creation of user friendly interface objects for changing model inputs and viewing model outputs. These interface objects give the end user access to the model via a “user interface” to explore a specific set of questions. However, the object oriented nature of Powersim Studio also allows the actual model code to be easily accessed, and if organized correctly, readily understood by users with familiarity with Powersim Studio or system dynamics modeling. The organization and explanation of model objects in the diagram view can be considered part of a “programmer interface” (structure of model code, inline comments in the code, and variable comments complete the programmer interface, but are not considered in this analysis). By taking advantage of Studio’s object

oriented structure, a well laid out programmer interface promotes first order model understanding at a glance and facilitates overall model accessibility by other modelers. The modularity of model structure can also aid in making modules or pieces of a legacy model available for use in later models. Having rigidly defined inputs and outputs and either using Studio sub-model functionality, or employing tab use and naming conventions can allow for plug and play type modularity which helps promote module use and reuse in evolving models. However, this level of modularity, sub-models, has only recently been employed at Sandia, and is not evident in any of the models evaluated below. Therefore, although it represents an important programming methodology and should be a goal of models going forward, modularity is not considered in this analysis.

This effort examined 15 energy relevant computer models which have been built at Sandia in terms of the relevance to current energy policy questions and the adaptability model.

4.2 Sandia Energy Models Evaluated

The Sandia SD models reviewed in this study are listed in Table 4.1 below.

Table 4.1 -- Sandia Systems Dynamics Models

Model Name	Description	Funding Source	Approx Date
WECS	Water Energy and Carbon Sequestration Model (WECS); combining CO2 sequestration and treating extracted water for power plant cooling.	NETL	2008-Present
String of Pearls	Southwest Regional Partnership on Carbon Sequestration; Source of CO2 from Power Plants in the SW U.S., matching with geological sequestration sinks.	NETL	2004-Present
The Energy Water Nexus	Calculates the water supply (hydrological assessment) and demand (power plants, agriculture, other uses) for the U.S. at the national, NERC region, state, county and watershed levels of detail.	LDRD	2006-Present
AltSim	Alternative Transportation Fuels Model; Calculates production costs of several alternative liquid transportation fuels (corn ethanol, cellulosic ethanol, biodiesel, and diesels derived from natural gas and coal	Late Start LDRD	~2008
India Energy and Greenhouse Gas Model	Calculates economic sector-specific energy demands, by fuel, with forecasted growth in India, calculates the associated emissions.	D.C. Customer	2005
GEFM	Global Energy Futures Model. Calculates worldwide electricity demands by country, fuel, and emissions.	LDRD	2004
China Energy Model	Calculates economic sector-specific energy demands, by fuel, with forecasted growth in China, calculates the associated emissions.	D.C. Customer	1998 - ~2007.
Strategic Petroleum Reserve	Demonstration / Program Development model for SPR Customer Visit	Internal Funds	2004
U.S. Energy and Greenhouse Gas Model	Calculates economic sector-specific energy demands, by fuel, with forecasted growth in the United States, calculates the associated emissions.	LDRD	2004
H2Sim	Hydrogen Futures Simulation Model; Calculates the costs to produce Hydrogen from various fuel sources (electrolysis, coal gasification, etc.).	LDRD	2004
GenSim	Electricity Generation Futures Model; calculates the cost to produce electricity from various fuel types (coal, oil, natural gas, nuclear, solar, wind).	LDRD	2003+
USESM	US Energy Security Model	LDRD	2004
Biofuel Deployment Model	General Motors funded look at the feasibility of cellulosic biofuel production in the continental United States.	External: General Motors	2008
TEA	Techno-Economics of Algae	DOE: OBP	2009
East Asia Model	Spent fuel management		

4.3 Current SNL SD Model Applicability to Broader Energy Policy Questions

These models can be generally grouped in five categories:

- **Supply/demand models –**
  - Global Energy Futures Model (GEFM),
  - US Energy and Greenhouse Gas Model (USEGM),
  - China Energy Model (CEM), and
  - India Energy and Greenhouse Gas Model (IEGHG)

All of these models project demand for energy by economic sector. These models also calculate the greenhouse gas emissions associated with the projected energy use, as well as other potential waste streams. GEFM models the world demand at the country level of resolution, and the others are country-specific. These models allow for "what-if" scenarios for projected energy demand based on input parameters such as GDP growth rate, population growth rate, and varying mixes of energy sources.

- **Cost models –**
  - GenSim,
  - H_2Sim, and
  - AltSim

These models calculate US projections for the cost of energy from a variety of sources. GenSim addresses electricity production, H2Sim addresses hydrogen production, and AltSim addresses a variety of liquid transportation fuels. These models allow for alternative scenarios for energy costs based on input parameters such as capital and operations & maintenance costs, interest rates, miles driven, fuel and conversion efficiencies, and fuel sources.

- **Carbon sequestration models** –
  - Water, Energy, & Carbon Sequestration (WECS),
  - String of Pearls, and
  - Southwest Partnership on Carbon Sequestration Model

These models enable various scenarios for mapping CO_2 sources to geological storage locations. These models were designed to guide decisions on the magnitude and location of CO_2 sequestration projects. Input parameters include CO_2 source output, rate of capture, and sink capacity.

- **Supply Feasibility models** –
  - Biofuels Deployment Model (BDM) and
  - Technoeconomics of Algae (TEA) Model

These examine the cost feasibility of biofuels production in the US. BDM addresses the supply side costs, resource utilization, and greenhouse gas emissions for cellulosic ethanol production at the state level. TEA addresses the economic feasibility of producing algae. These models enable projections of costs, resource requirements, and Greenhouse Gas (GHG) emissions for future scenarios given input parameters such as conversion efficiencies, feedstock availability and costs, and distribution requirements.

- **Resource supply and demand models** –
  - The Energy Water Nexus Model (NRG-H_2O)

This model examines water supply and demand at the national, regional, state, county, and even watershed level of detail. It enables mapping of supply and demand and elucidates mismatches between the two.

4.4 Summary of Sandia SD Model Review

Of the 15 SNL SD energy models examined for relevance and adaptability, most were considered to be relevant to at least some aspects of current energy issues, and several were found to be structured to facilitate adaptation to the broader range of questions. More recent models were generally developed in a more structured and documented approach, making them more easily adapted for use in a broader framework.

Sandia System Dynamics Energy Models address a broad spectrum of issues and often a specific aspect of the energy spectrum: e.g. cellulosic biofuels, hydrogen, algal biofuels, etc. in specific geographies. These models generally addressed the implications of specific energy sources and solutions. They generally utilize US Department of Energy (DOE) and other US government data sources and are consistent with projections from those sources. They are generally not optimization models, but evaluate 'what-if' or hypothetical scenarios.

Only a few models were considered directly reusable for the purposes of this study. In many cases, the characteristics of an existing model (specific objective, lack of documentation, etc) means that more effort would be required to reuse a model than was possible in this late start study. However, some aspects of these models (specific modules or databases) were still considered to be potentially reusable in future efforts.

The phrase "all models are wrong, some are useful" captures the sense of this review. In the energy-economic-environmental sense of this study, the most adaptable and relevant models identified were:

- USEGM – US sector energy consumption, prices affect decisions
- GENSIM – cost estimates for electricity production
- GEFM – nuclear fuel cycle details
- BDM – constraints on feedstock, production, technology, prices
- USESM – use of economic Input/Output methodology

Some niche models also were identified as having useful constructs:

- String of Pearls – operations research code
- Energy-Water Nexus (NRG-H_2O) – multi-level detail (power plants, watersheds, counties)

The USEGM was identified as the most relevant SNL energy model to track carbon emissions, costs and petroleum requirements for a range of energy supply options and new types of PHEVs. The GEFM was identified as suitable to model electric generating capacity of the nuclear power fleet and future expansion. No suitable transportation sector models were available, so a simple US vehicle fleet model was created under this LDRD to model how the US fleet changes as PHEVs gain penetration with respect to gasoline usage, electricity usage, and greenhouse gas emissions.

5 EXTERNAL ENERGY MODELS SURVEYED

A brief survey of external energy models was conducted to examine the types and capabilities of energy related models that have been developed in other laboratories, government agencies, industry or universities. These models covered a range of applications and levels of sophistication. This brief survey was not intended to be comprehensive but was intended to provide some perspective on the models and approaches that other organizations are using for energy policy and technology analyses.

5.1 Energy Information Agency Models (EIA)

1. The National Energy Modeling System (NEMS) is a detailed computer-based, energy-economic modeling system for the U.S. energy markets. The NEMS model projects energy supply, demand, imports, conversion, and prices to the year 2030, subject to market assumptions such as macroeconomic and investment factors, world energy markets, fuel availability, technology cost, and performance characteristics of energy technologies.

Model's 2-13 are older (1990-2000) models used and maintained by EIA. Many of these are smaller, more specific models used to complement NEMS.

2. Disruption Impact Simulator Model (DIS)
3. International Nuclear Model — Personal Computer (PCINM)
4. Levelized Nuclear Fuel Cycle Cost Model (LNFCC-PC)
5. Propane Market Model (PPMM)
6. Short-Term Hydroelectric Generation Model (STHGM)
7. Short-Term Integrated Forecasting System (STIFS)
8. Short-Term Nuclear Annual Power Production Simulation (SNAPPS)
9. Transportation Energy Model of the World Energy Projection System (TEM)
10. Uranium Market Model (UMM-PC)
11. Wellhead Gas Productive Capacity Model (GASCAP)
12. World Energy Projection System (WEPS-PC)
13. World Oil Refining, Logistics, and Demand Model (WORLD)

14. WEPS+ is a system of sectoral energy models that provide a loosely linked, integrated equilibrium modeling system. It is used primarily to provide alternative energy projections based on different assumptions for GDP growth and fossil fuel prices. The WEPS+ common platform allows the models to communicate with each other and provides a comprehensive, central series of output reports for analysis.

15. The System for the Analysis of Global Energy Markets (SAGE) is an optimizing, technology-based model used for international policy analysis, which was used to produce energy consumption forecasts through 2030 for EIA's International Energy Outlook for IEO05 and IEO06. For each of 16 regions of the world, it estimates 42 end-use energy service demands based on economic and demographic projections.

16. The Global Electricity Module that is regional-based and used by SAGE for both electricity supply and demand.

17. GWOB -- Global World Oil Balance Model is used by EIA to make projections for world liquids production to reflect an assessment of world oil supply—based on current production capacity, planned future additions to capacity, resource data, geopolitical constraints, and prices—that is used to generate conventional crude oil production cases. The scenarios (price cases) are developed through an iterative process of examining demand levels at given prices and considering the price and income sensitivity on both the demand and supply sides of the equation.

5.2 National Lab Models

1. ENPEP Argonne National Laboratory (ANL) -- The model provides state-of-the-art capabilities for use in energy policy evaluation, energy pricing studies, assessing energy efficiency and renewable resource potential, assessing overall energy sector development strategies, and analyzing environmental burdens and greenhouse gas (GHG) mitigation options.
2. GREET (ANL) - Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
3. Oil Security Metrics Model at National Renewable Energy Laboratory & Oak Ridge National Laboratory (NREL/ORNL)
4. Fuel Economy Regulatory Analysis Model (NREL/ORNL)
5. North American Feebate Model (NREL/ORNL)
6. Hydrogen Transition Analysis Model (NREL/ORNL)
7. World Energy Scenarios Model (NREL/ORNL)

Models 3-7 are joint NREL/ORNL models used for transportation energy analysis.

5.3 Commercial Models (Some Originated with National Labs)

1. The Second Generation Model (SGM) is a collection of 14 regional computable general equilibrium models with an emphasis on energy transformation and consumption, economic activity, and greenhouse gas emissions. The SGM projects economic activity, energy consumption and greenhouse gas emissions for each region in five-year time steps from 1990 through 2050. The SGM contains a large set of parameters to simulate technical change over time for any given production process.

2. Markal -- MARKAL's primary uses are:
   (a) to identify least-cost energy systems
   (b) to identify cost-effective responses to restrictions on emissions
   (c) to perform prospective analysis of long-term energy balances under different scenarios
   (d) to evaluate new technologies and priorities for R&D
   (e) to evaluate the effects of regulations, taxes, and subsidies
   (f) to project inventories of greenhouse gas emissions
   (g) to estimate the value of regional cooperation

3. MiniCAM -- The MiniCAM is a long-term, partial-equilibrium model of the energy, agriculture, and climate system, a reduced form of the GCAM. It contains an emissions model that considers both energy and land use emissions and integrally runs the MAGICC climate model as a part of every run, so that climate implications of scenarios and management strategies are readily available. It considers the full range of greenhouse gases and the major new alternative technologies that are pertinent to questions about the future structure of energy supply. The MiniCAM is used for modeling over long time scales where the characteristics of existing capital stocks are not the dominant factor in determining the dynamics of the energy system.

4. CIMS (merged with ISTUM) -- CIMS focuses on detailed energy flows through technologies for modeling air quality and greenhouse gas emissions. Emission levels of all pollutants are technology specific; unless a model operates on an individual technology basis, as CIMS does, the emission estimates can only be approximated by economic activity.

5.4 External Model Observations

- EIA's NEMS is the most comprehensive model but it is difficult to use and requires huge amounts of input data. Thus, NEMS is not likely to be a practical option for addressing many of the types of questions in Section 2.2
- Argonne has a suite of energy/transportation models that are very useful and (mostly) publicly available. Since these are generally free to use and do not require a significant computing investment, these models should be considered for their utility in addressing a specific question.
- Pacific Northwest National Laboratory (PNNL), ORNL, and NREL also have specific energy and transportation models, but many of these were specific and therefore would be more difficult to apply to the level of questions identified in Chapter 2.
- University models also exist (e.g. UC Davis for biofuels) but are even more specific in what they analyze, making them more useful to plant and equipment decisions rather than high level issues such as those in Chapter 2.
- Commercial models also exist, but are expensive and in general would have the same types of features and limitations as the models described above.

6 SNL MODELS ADAPTED FOR LDRD QUESTION

In evaluating the most useful SNL energy models for addressing the types of questions identified in Chapter 2, both the relevance of the model for the question posed in this study, and the adaptability (structure, interfaces, inputs, etc.) of the model were considered. Since these models were not originally designed to be coupled in a framework, features such as input data capture, and output data analysis were not generally appropriate for the more integrated structure. The "gaps" included model capabilities for consistent interfaces, data inputs and outputs that would be needed to increase their value for future energy issue analysis. This initial assessment focused on the features and characteristics needed to address the PHEV – nuclear electricity issue posed in this study.

6.1 USEGM and GEFM

- USEGM (US Energy and Greenhouse Gas Model) was identified as most relevant SNL energy model to evaluate scenarios related to reduction in greenhouse gas emissions and oil imports from adoption of new technologies. The organization and interfaces were understandable and acceptable. The data in the model was from DOE-EIA sources and is consistent with US economic assumptions.

- GEFM (Global Energy Futures model) was selected to model nuclear electric generating capacity and future expansion scenarios. The organization was very good and it was readily interfaced with USEGM.

6.2 SNL Vehicle Fleet model

Existing models of the transportation sector were either not available or appropriate for this study. The decision was to develop a simple U.S. Transportation model (fleet or vehicle park model) to address U.S. automotive fleet evolution as PHEVs gain penetration. The Vehicle Park model accounts for the penetration of PHEV's into the 250 M vehicle US light duty fleet based on assumed adoption rates for PHEV's and transition rates for existing gasoline vehicles. Although the model can include a variety of assumptions for new technology adoption and vehicle expiration rates, the assumptions used in this study were based on current gasoline vehicle turnover data and adoptions rates based on the current gasoline hybrids (primarily the Toyota Prius).

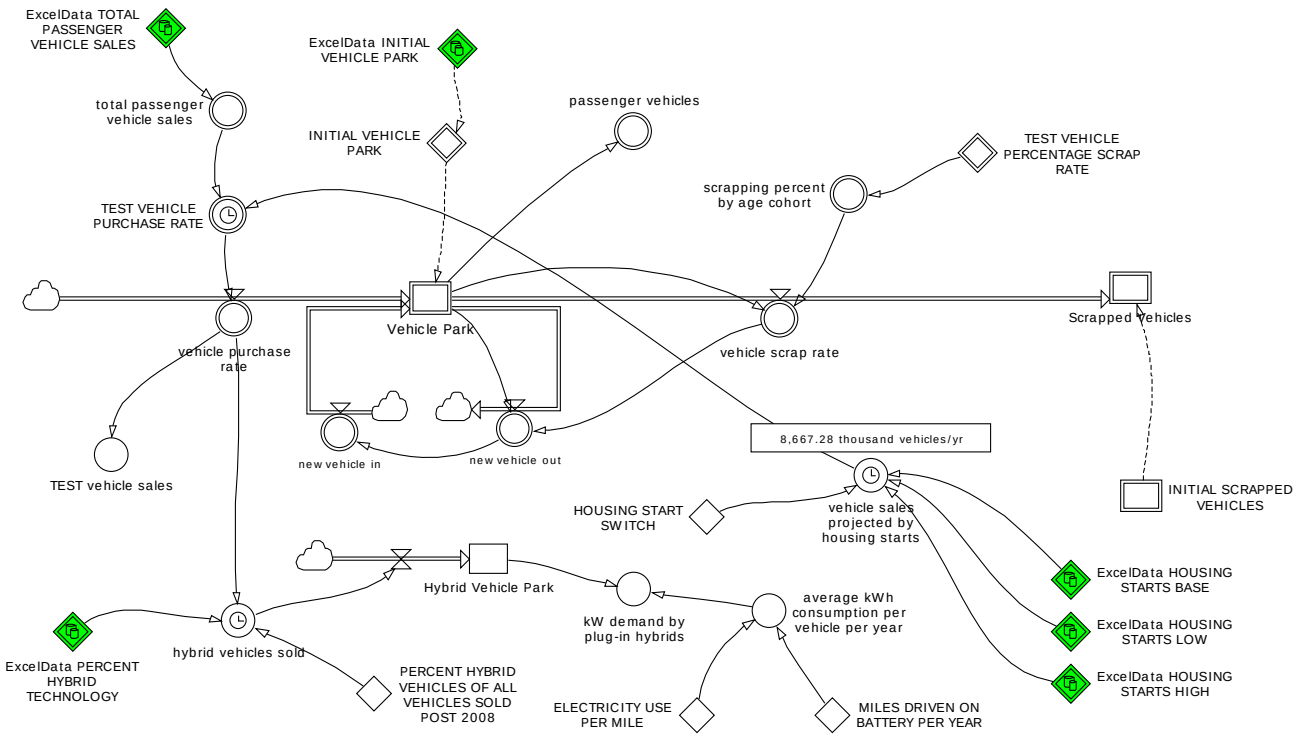

Figure 6.1 – A Vehicle Park (fleet) model was developed to describe the evolution of the US light duty vehicle fleet under a range of adoption assumptions.

6.3 Interfaces and Issues

A key issue identified in the various model evaluations was the need for an automated data input method. A consistent format (such as a spreadsheet) and a small program that can query a database (such as those provided by EIA) to populate the input data spreadsheets would greatly improve the utility of these models. Models such as USEGM have 100s of constants that need to be updated yearly (or every couple of years) with more accurate economic data. Doing this manually is a time consuming process that has to be repeated yearly to keep the model up to date. Automating the data capture process would make the models much easier to use. Further, the capture of output data from the models could also be streamlined into a standard format (again, a spreadsheet or a text data file). This output data format could then be used for post-processing on common commercial analysis programs (e.g. Matlab) to provide additional insight to the model results.

7 RESULTS OF ANALYSIS OF COST AND CARBON IMPLICATIONS

The USEGM, GEFM and new Vehicle Park models were used to conduct an initial analysis of the question posed in this study:

Can a significant reduction in greenhouse gas emissions and oil imports be achieved by expanding nuclear electric generating capacity to provide power for plug in hybrid vehicles?

This question was selected because this approach could impact carbon emissions in the near term with minimal infrastructure changes or new technologies required. It also crosscuts the transportation and grid sectors, and represents a combination of the energy policy and technology questions that were identified in Section 2.

7.1 Assumptions, Uncertainties, Approximations

The primary assumptions needed in this initial evaluation relate to the characteristics of the PHEV (efficiency) and the potential adoption rate in the US vehicle fleet. The approach taken in this study was to postulate a range of PHEV adoption scenarios and estimate the nuclear electric generation expansion that would be needed to support that adoption rate. Both the rate of PHEV adoption, the efficiency of the PHEV and the possible rate of nuclear electric expansion are uncertain but can be bounded by previous experience or otherwise reasonable assumptions.

Future PHEVs have been estimated in the literature to be as efficient as 136 watt hours/mile (equivalent to about 250 mpg), with some literature values even higher. Depending on vehicle size and other assumptions, estimates were found that ranged up to several hundred watt hours/mile. A value of 330 watt hours/mile was selected as a more reasonable estimate of the near term PHEV efficiency. Other values used in the analyses include:

- PHEV Assumptions
  - 1/3 miles on gasoline, 2/3 on battery
  - 0.33 kwh/mile on battery (about 110 mpg)
  - ~250 M Light Duty Vehicles in US (LDV)
  - ~3 E12 LDV miles/year

The rate of adoption will be dependent on several factors including PHEV efficiency, range, vehicle purchase and maintenance costs, the cost of alternative transportation fuels, and the overall economic climate. Given the uncertainty associated with these projections, adoption rates were parameterized in three scenarios:

- 3 PHEV adoption rate scenarios
  - ‘Anticipated adoption rate’ = historical conventional hybrid market penetration vs. time (data from 1999 to 2008 was used to establish the functional form). Since conventional hybrids represented approximately 8% of new vehicle sales after 9 years the lower adoption rate of a maximum of 10% was considered a reasonable lower adoption rate scenario.
  - ‘Some incentives’ = same functional form as ‘anticipated adoption rate’ but with 25% ultimate adoption

– ‘Aggressive incentives’ = same functional form as ‘anticipated adoption rate’ but with 50% ultimate adoption

The rate of nuclear electric expansion was treated as a dependent variable, but the rate of expansion for even the most aggressive PHEV adoption rate was on the order of two 1.4 GWe units per year, which is significantly lower than the nuclear power expansion rate in the 1970’s and 80’s.

7.2 Results of Preliminary Analysis

Based on the assumed PHEV adoption rate, the primary outputs from this initial analysis were:

1. Incremental electric power requirements to support the PHEV adoption rate
2. Number of nuclear plants needed
3. Carbon emissions implications compared to 2008 LDV levels
4. Potential reduction in oil imports
5. cost comparison to gasoline powered vehicles

The fraction of new car vehicle sales that would be PHEVs under the three postulated adoption rates are shown in Figure 7.1 for a 30 year period. The historical adoption rate for conventional hybrid vehicles (i.e. Toyota Prius) was used to define the functional form of the lower adoption rate which plateaus at 10% of new vehicle sales in the 2040 time frame. Higher adoption rates (assumed to be driven by government incentives or high gasoline prices) plateau at 25% and 50% of new vehicle sales.

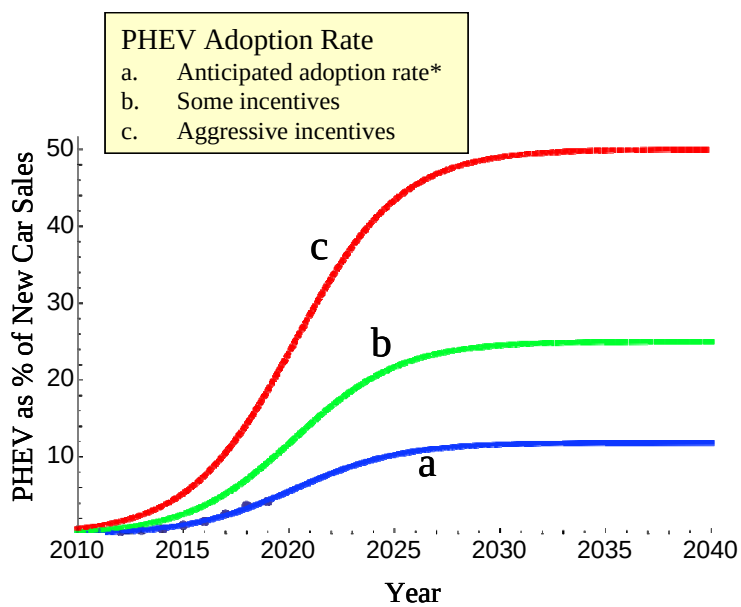

Figure 7.1 - Adoption rates assumed for PHEVs. a) – based on conventional hybrid rates (1999-2008), b) moderate incentives, and c) aggressive incentives

The fraction of the total US LDV vehicle fleet that would be PHEV as a function of time is shown in Figure 7.2 for the range of postulated adoption rates. By 2040, the percent of PHEVs on the road are starting to approach the 10, 25 and 50% levels implied by the new vehicle purchase rates.

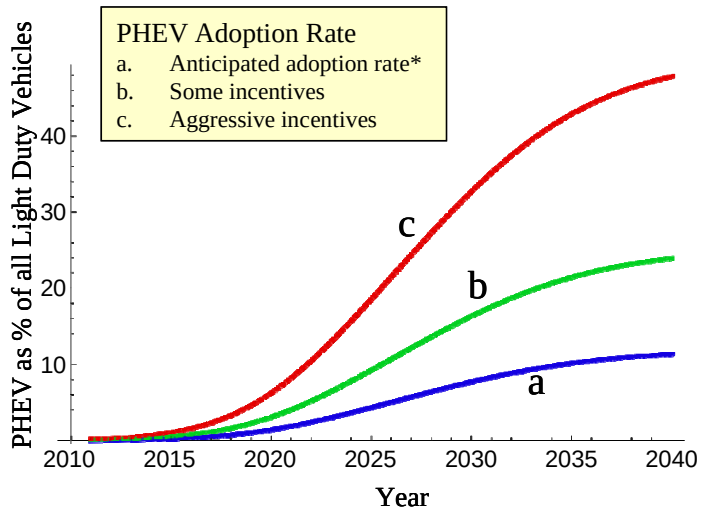

Figure 7.2-- PHEVs as a percent of the total number of US light duty vehicles for the various adoption rates.

The incremental electric energy needed to support the various adoption rates is shown in Figure 7.3. The total electric requirement is based on 12000 mile/year per vehicle, 330 watt hours/mile, and the assumption that 2/3 of the 12000 miles driven per year in a PHEV would be on battery. When estimating the number of nuclear plants required, it was assumed that the incremental electric energy required is supplied by new nuclear capacity. This would be the minimum number since plant duty cycles, and timing of vehicle charging has to be compatible with the overall demand on the grid.

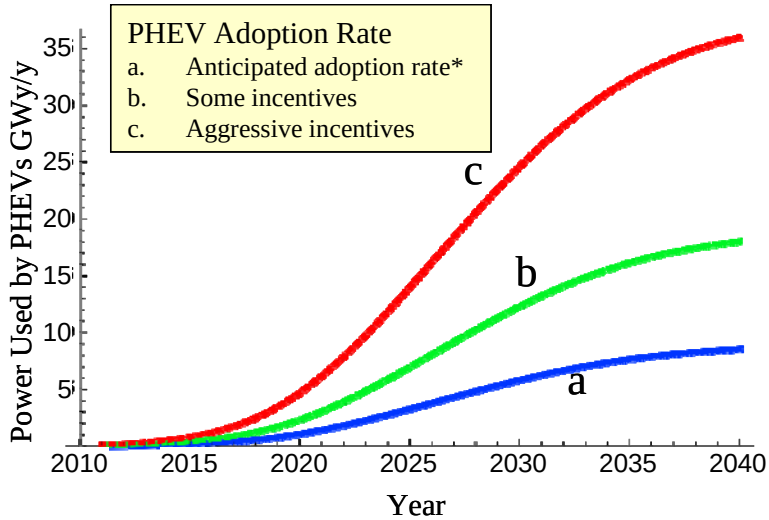

Figure 7.3 -- Total electric power requirement for the various PHEV adoption rates.

A more likely implementation approach would be to expand nuclear capacity beyond this incremental requirement to create excess off peak capacity, which could be used to power PHEV charging during the off peak hours. The additional benefit of the excess baseload capacity is the reduction in peaking power requirements which are generally supplied by higher cost natural gas combined cycle units.

The number of nuclear plants needed to provide the electric energy needed for the various adoption rates in shown in Figure 7.4. For even the most aggressive incentives, 25 nuclear power plants (at average of 1.4 GW/plant) are sufficient to meet annual PHEV electricity needs. This would not account for non-uniform charging rates (i.e., peak vs. non-peak charging, etc.).

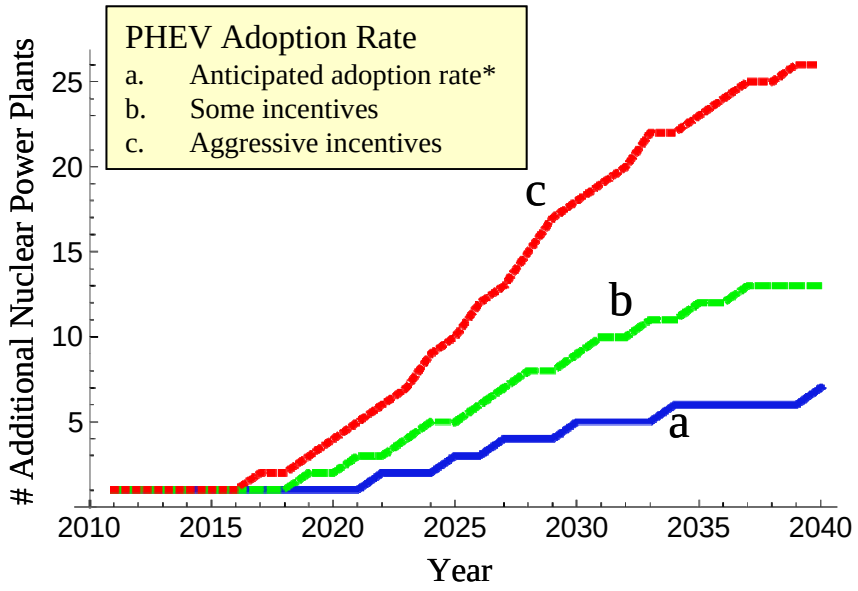

Figure 7.4 -- Number of 1.4 GWe nuclear plants required to supply the electric generation requirements for the various PHEV adoption rates.

In the most aggressive scenario, 25 plants would have to be constructed and brought on line in nominally 25 years. Even the peak rate of new nuclear plant construction in the most aggressive scenario is less than 2 plants per year. Although these construction rates seem ambitious based on a current perspectives, they are considerably lower than the rates during the 1965-1990 period when most of the 100 US nuclear plants were constructed. Given a stable regulatory environment, the rate of nuclear plant permitting and construction should not be the limiting factor in the scenario proposed in this study.

The carbon emission implications of the adoption of PHEVs powered by nuclear electricity are shown in Figure 7.5. Given that more than 40% of miles driven under the aggressive scenario in 2040 would be PHEV, the potential reduction in GHG and oil imports would also be in the range of 40% times 2/3 – or about 27% - to account for the assumption of 1/3 of PHEV miles being fueled by gasoline - if the efficiency of the gasoline component of the US vehicle fleet remained the same. In this study it was assumed that as older gasoline vehicles are retired, the replacement would be with vehicles that met the 35mpg corporate average fuel economy (CAFÉ) criteria.

Even without any PHEV penetration, the US LDV carbon emissions and oil requirements in 2040 would be significantly improved over 2008 levels based on the assumptions in this analysis. The comparison made in Figure 7.5 is to 2008 levels which are higher than the estimated levels in 2040 by about a factor of two. If the conventional gasoline LDV fleet does not evolve to as efficient a state in 2040 as assumed here, then the GHG percentage benefit would increase. Regardless of which scenario is used for comparison, significant GHG reductions from 2008 levels can be obtained within the 30 year period.

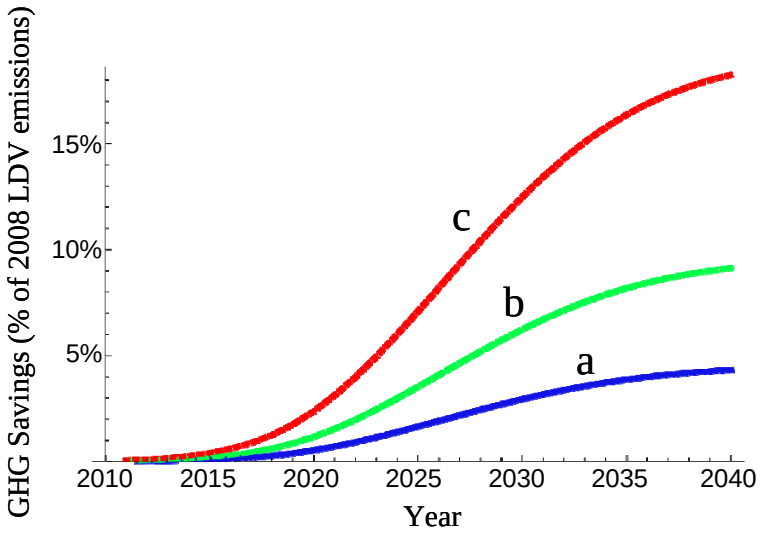

Figure 7.5 Reduction in GHG emissions for the various adoption rates in comparison to 2008 light duty vehicle emissions.

The corresponding reduction in oil import requirements (amount of oil displaced) is shown in Figure 7.6. As in the GHG analysis above, the comparison is to 2008 levels of oil imports. The 2040 oil import requirements in this analysis were assumed to be significantly reduced due to the replacement of current gasoline vehicles with more efficient models over the next 30 years.

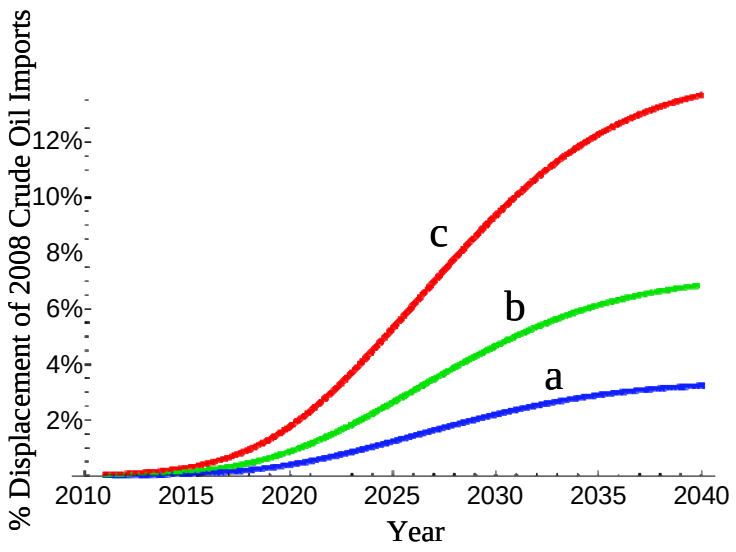

Figure 7.6 -- Reduction in oil imports (amount of oil displaced) for various PHEV adoption rates.

The cost of operating PHEVs based on a range of gasoline and electric energy prices are shown in Figure 7.7. The comparison in Figure 7.7 is to a 35 mpg conventional gasoline vehicle, a considerably more efficient vehicle than the average in 2008. In this study, PHEVs were assumed to use gasoline for 1/3 of the miles driven, so the price of gasoline still affects the cost of PHEV operation, but only 1/3 as much as conventional vehicles. The PHEV energy cost/mile is roughly ½ that of conventional vehicles for a range of electricity and gasoline cost assumptions.

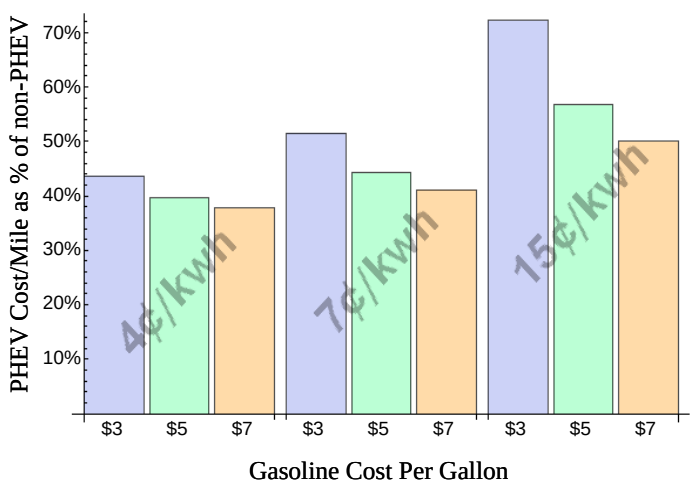

Figure 7.7 -- PHEV energy costs per mile as a percentage of a conventional gasoline powered vehicle operating at an average of 35 mpg..

7.3 Summary of PHEV – Nuclear Electricity Analysis.

- The incentivized adoption of PHEV's powered by nuclear electricity could make a significant impact on transportation greenhouse gas emissions and imported oil requirements over a 30 year period.
- For the most aggressive adoption rate, about 40% of light duty vehicles could be PHEV in 2040, with a corresponding 15% reduction in GHGs and imports when compared to 2008 levels. When compared to 2040 levels which are assumed to include a more efficient conventional fleet, the percentage reduction is would higher (approximately 2/3 of 40%) since total transportation carbon emissions are assumed to be lower in 2040.
- The rapid adoption scenario results in less than 37 GWy/y of additional electricity demand by 2040, equivalent to about 25 new 1.4 GWe nuclear plants. Only 7 additional plants are required in the low adoption rate scenario.
- PHEV energy cost/mile is typically about 1/2 of the conventional vehicle gasoline cost/mile for a range of electricity and gasoline cost assumptions. (based on a 35 mpg conventional vehicle).
- The reduction in LDV oil imports is similar, but since less than ½ of imported oil is for gasoline (diesel, jet fuel, other products), the percentage reduction in total imports is about 15% in the aggressive scenario.
- No technology breakthroughs are required to achieve a significant GHG and import reduction based on this approach.
- The most challenging aspect for this scenario is the rapid adoption of a new vehicle technology. PHEV efficiency, lifetime, cost and range will determine maximum penetration rates. The cost of gasoline will likely outweigh the influence of other incentives.
- Smarter grid technologies would be needed to allow optimized use of off peak power for lowest cost PHEV charging, but such off peak optimization is within near term technical capabilities.

8 CONCLUSIONS

8.1 Nuclear electric – PHEV observations

Rapid adoption of PHEVs or similar technologies powered by carbon free electricity can lead to significant reductions in transportation carbon emissions and oil imports with potential fuel cost reductions. No new technology breakthroughs are required, but evolutionary improvements (batteries, grid technologies) would increase the perceived benefits and increase adoption rates. There would probably not be any economic penalty in fuel costs as long as electricity prices do not increase rapidly compared to gasoline costs. However the cost and lifetime of PHEVs will strongly influence the penetration rate. The nuclear energy component is modest – with the required implementation rate for new nuclear plants well below the 1970's rates of construction. Nuclear electricity powered PHEVs would appear to be a useful and achievable component of the overall strategy to achieve US climate and energy security goals.

Although this initial analysis was primarily illustrative, it demonstrates that near term solutions can be implemented with no major fuel cost penalties. Clearly PHEV technology – or any other advanced vehicle (all electric) can make a significant impact on import and GHG objectives when powered by nuclear electricity. Extensions of this analysis could include additional nuclear powered dispatchable loads, such as hydrogen generation for liquid fuels, comparisons to alternative low carbon transportation schemes (biomass), and a more detailed assessment of the economic policy options to implement transportation alternatives.

8.2 Model Evaluation Implications

The example problem addressed in this study coupled two existing SNL SD models to address part of the problem and coupled a basic vehicle park model to expand the capability. In this process, some improvements to the existing models were accomplished, and the process for coupling existing models (and adding new ones) through a consistent interface was established. Several additional improvements were identified that could facilitate the integration of these models into a more comprehensive tool for future analyses.

It is recognized that there will always be new considerations in future studies, and that existing models or even a more integrated set of models may be not be appropriate for all aspects of a new problem. However, many aspects of energy policy and technology options evaluations have some elements in common. The models describing the characteristics of various energy sources, the description of energy sector demand characteristics, and the central integrating models that evaluate the options to match supply and demand requirements within a set of criteria are likely to be features of many energy policy and technology trade studies. In addition, establishing a more standardized, consistent and updatable set of databases for these models provides a means to take advantage of the information collected and validated previously as the starting point for future work. The relatively small effort involved in this study illustrates that there is potential to leverage existing capabilities to address new issues efficiently.

8.2.1 SNL model observations

There are some areas where appropriate existing models were not identified (transportation, process heat, alternate fuels and others), but for many problems of interest, the updated available models could form a capable framework or starting point for a wide array of questions. Such an effort would benefit greatly by doing some initial work to standardize and improve existing models. These standardized interfaces, databases, hooks for new models and standardized inputs could largely be accomplished in a small effort supported by student interns under the direction of SNL SD modelers.

8.2.2 Next Steps

Options for next steps could range from using this approach to develop a large, highly integrated model that would be capable of addressing a wide range of problems (long term, expensive effort) – to a more incremental approach of simply updating our collection of existing models to improve future utility. The former approach is long term and would require significant maintenance to remain useful, and would often not be optimum for a new problem. The latter approach would have limited impact on future studies. An intermediate approach would be to continue to update and integrate a suite of models that could serve as a framework for future simulations which seems beneficial for many applications. The steps suggested include:

- Develop guidelines or best practices that assure consistency and future utility, essentially improve the modeling practice
- Identify the types of near term questions that SNL management or customers are interested in to guide the initial version of this framework.
- Define interface criteria, input and database protocols and hooks for new energy supply or demand sector models
- Establish a limited effort to update selected existing models to facilitate application to a broader range of energy questions.
- Support an effort to provide a well documented basic framework of updated models, data, and displays that could be an efficient starting point for future efforts.

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