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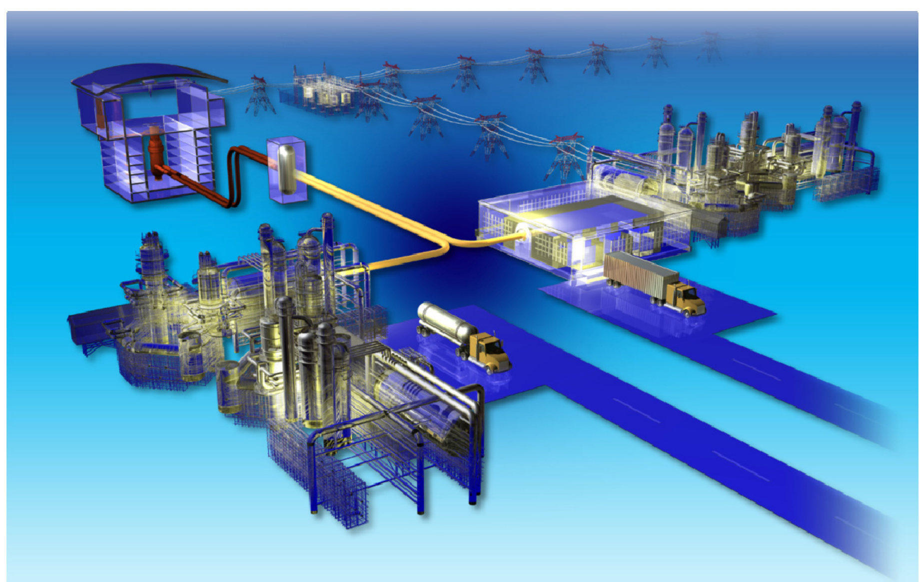
Plan

Validation and Verification Plan for 2050 Strategic Impact Model (SIM), Version 2.0



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REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	09/21/10	All	Newly issued Document
1	09/01/11	All	Updated software to next version (2.0).

SUMMARY

High-temperature gas-cooled reactors (HTGR) have the potential to help the nation meet strategic objectives defined in current legislation pending in Congress. The 2050 Strategic Impact Model (SIM) will provide an overall system understanding of the tradeoffs between building and using HTGRs versus fossil fuels and to test various HTGR application scenarios to meet future U.S. energy, economic and environmental visions, goals, and objectives. The tool will result in useful insights on system performance that U.S. Department of Energy and private industry can utilize to make decisions regarding if and how HTGRs can best be used as an alternative for meeting U.S. energy needs.

This validation and verification plan provides a rigorous and systematic approach to testing the 2050 Strategic Impact Model to ensure that it has been properly designed and constructed, that it operates appropriately and that it meets all Idaho National Laboratory (INL) software development standards applicable to Quality Level 3software.

CONTENTS

SUMMARY iv

ACRONYMS vii

1. OVERVIEW, PURPOSE, AND SCOPE 1

2. TASKS AND RESPONSIBILITIES 1
   - 2.1 Integrated Project Team 1

3. MODEL PURPOSES AND USE 1
   - 3.1 Model Inputs 2
   - 3.2 Model Requirements List 3
   - 3.3 Model Functionality 3
   - 3.4 Model Design Requirements List 4
   - 3.5 Model Implementation 12
   - 3.6 Model Implementation List 13
   - 3.7 Model Outputs 14
   - 3.8 Model Assumptions 15

4. MINIMUM COMPUTER HARDWARE REQUIREMENTS 15

5. MODEL QA/QC 15
   - 5.1 Software Design 16
   - 5.2 Software Testing 16
     - 5.2.1 Assess Source Data 17
     - 5.2.2 Assess Calculations/Projections 17
     - 5.2.3 Data Output, Display and Storage 17
   - 5.3 Model Test List 17
     - 5.3.1 Human Factors 21
     - 5.3.2 Documentation 21
     - 5.3.3 Operation and Maintenance 21
     - 5.3.4 Retirement 21

Appendix A 2050 SIM Assumptions and Bases 22

Appendix B 2050 SIM Test Approach 30

Appendix C 2050 SIM Test Results 40

1. Petroleum 48
   - 1.1 Sources for Actual Petroleum Quantities 48
     - 1.1.1 Baseline 48
     - 1.1.2 After Improvements 48
   - 1.2 Sources for Alternative Energy Quantities 49

1.2.1 Baseline 49
1.2.2 After Improvements 49
1.3 Calculation Methods 49
1.4 ESTIMATING PARAMETERIZED VARIABLES 53
1.4.1 Volatility of Oil Prices 53
1.4.2 Volatility of Alternative Energy Prices 53
1.4.3 Volatility of Natural Gas Prices 54
1.5 RESULTS OF COMPUTATION 56
1.5.1 Substitution and the Diversification Effect 56
1.5.2 Volatility of Effective Price 56
1.5.3 Decreased Call Option Prices 56

Appendix E Price Stability Test Case 57

ACRONYMS

BTU	British thermal unit
DOE	U.S. Department of Energy
DOE-NE	U.S. Department of Energy Office of Nuclear Energy, Science, and Technology
EIA	Energy Information Administration
GDP	gross domestic product
GHG	greenhouse gas
HTGR	high temperature gas-cooled reactor
IGCC	integrated gasification combined cycle
LWR	light water reactor
MPG	miles per gallon
NE	Office of Nuclear Energy, Science, and Technology
NG	natural gas
QA	Quality Assurance
SIM	Strategic Impact Model
VHTR TDO	Very High Temperature Reactor Technology Development Office

1. OVERVIEW, PURPOSE, AND SCOPE

High-temperature gas-cooled reactors (HTGR) have the potential to help the nation meet strategic objectives defined in current legislation pending in Congress (e.g., The *American Clean Energy and Security Act of 2009* and the *Clean Energy Jobs and American Power Act of 2009*). The 2050 Strategic Impact Model (SIM) will provide decision makers, and eventually stakeholders, with the ability to test various HTGR application scenarios to meet the future U.S. energy vision, goals, and objectives.

The primary objective of 2050 SIM is to provide an overall system understanding of the tradeoffs between building and using HTGRs versus fossil fuels (e.g., oil, natural gas, and coal) for providing energy (electricity, hydrogen, and process heat) to various sectors in the United States. Based on customer needs, this model will address the potential effects of deploying HTGRs on: greenhouse gases (GHG) production, dependence on foreign energy sources, energy price stability, and jobs creation. The potential effects of HTGR use in other countries will not be addressed in this model.

The use of the tool will result in useful insights on system performance that U.S. Department of Energy (DOE) and private industry can use to make decisions regarding if and how HTGRs can best be used as an alternative for meeting U.S. energy needs. 2050 SIM will model the input parameters and graphically depict the extent to which the benefits are realized based on the market penetration of reactor user applications into residential, commercial, industrial, and transportation sectors. This systems integration model will characterize energy supply and demand, depict optimized configurations for energy hybridization, and estimate the number of HTGRs necessary to meet established national energy imperatives.

2. TASKS AND RESPONSIBILITIES

2.1 Integrated Project Team

The integrated project team for this effort consists of:

- John Collins – Software project manager
- Brett Devine – Software design and economic analysis
- Ron Klingler – Project management plan
- Gloria Newberry – Software interface design
- Layne Pincock – Database design and data analysis
- Gerald Sehlke – Data collection and analysis.

3. MODEL PURPOSES AND USE

This project is funded by the DOE Office of Nuclear Energy, Science, and Technology (DOE-NE). DOE-NE requested that Idaho National Laboratory (INL) develop a desktop tool that would conduct qualitative and quantitative comparisons of various HTGR strategies with respect to:

- Energy production and use
- Energy production-related generation of GHG emissions
- Job creation

- Reducing foreign oil dependence
- Increasing energy price stability.

In addition, the model could be used to:

- Summarize data, analysis, and functionality of lower-level models developed to model unit operations (e.g., Aspen, spreadsheets)
  - Electricity production
  - Hydrogen production via high-temperature electrolysis
  - Coal to liquids
  - Oil extraction from tar sands
  - Oil extraction from oil shale
  - Ammonia production.
  - Co-generation
- Calculate economic and environmental effects for options selected in the model
- Quickly assess and evaluate, with reasonable accuracy based on available data, relative economic tradeoffs between a range of HTGR strategies
- Simulate feedback impacts from using HTGR technology for multiple uses.

Finally, based on the software design and the data being incorporated, functions could be added to the model to assess energy security, environmental footprint if there is sufficient interest, and funding is available.

3.1 Model Inputs

The model will utilize (1) U.S. Census Bureau population estimate data and project them through 2050, (2) existing Energy Information Administration (EIA) energy production and use data, (3) HTGR program-generated data, (4) additional information from peer reviewed literature; and (5) various assumptions (Appendix A) to evaluate the quantity and types of energy resources (e.g., transportation fuels and electricity) that are currently being produced and utilized, that project future energy demands and uses, and that assess the potential capability of HTGRs to displace current energy resources in various sectors (transportation, industrial, residential/commercial, and electricity generation) with a carbon-free energy source. In addition, it assesses the potential impacts of deploying HTGRs relative to reducing GHG emissions, creating new jobs, reducing foreign energy resources (primarily reducing foreign oil imports), and increasing prices stability, based on the relatively stable long-term costs of producing energy utilizing HTGRs. Finally, it assesses the potential for new light water reactors (LWR), coal-fired integrated gasification combined cycle (IGCC) electric plants, natural gas, and renewables (onshore wind farms, thermal solar plants and geothermal power plants) to displace fossil fuels thereby reducing GHG emissions.

To provide these analyses, all data utilized must be of a known quality and source (e.g., EIA energy data, HTGR program approved data or other peer-reviewed data/information). The data sets will be either complete or extrapolated through 2050. To increase comparability, the results are standardized to common energy units (British thermal units [BTU] or "barrels oil equivalent").

3.2 Model Requirements List

The model will meet the following requirements:

- R1. Evaluate the quantity and types of energy resources (e.g., transportation fuels and electricity) that are currently being produced and utilized
- R2. Project future energy demands and uses
- R3 Assess the potential capability of HTGRs to displace current energy resources in various sectors with a carbon-free energy source
- R4. Assess the potential impacts of deploying HTGRs (and other energy sources) relative to GHG emissions
- R5. Assess the potential for HTGR deployment to create new jobs
- R6. Assess the potential for HTGR deployment to reduce foreign energy resources (primarily reducing foreign oil imports)
- R7 Assess the potential for HTGR deployment to increase price stability
- R8. Assess the effect of new light-water reactors, coal-fired IGCC electric plants, natural gas, and renewables on the energy mix and GHG emissions in the U.S.
- R9. Assess the effect of projected energy efficiency/conservation efforts on the energy use/demand and GHG emissions in the U.S.

3.3 Model Functionality

The purpose of 2050 SIM is to analyze and display the tradeoffs between building and using HTGRs versus other existing energy technologies for providing energy (electricity, hydrogen, and process heat) to various energy-demand sectors in the U.S. This includes the potential effects of deploying HTGRs on the following: GHG emission, job creation, fossil fuels (oil, natural gas, and coal) demand and use, energy price stability, and other economic factors. The 2050 SIM model will allow users to input data, select a limited set of parameters/options for analysis, calculate and display data through a graphical user interface, allow the user to adjust those parameters, and view the corresponding outputs. Examples of user selectable inputs include:

- Referenced population data and growth rate assumptions through 2050
- EIA energy supply data and growth rates through 2050
- Energy demand data and growth rates for each energy sector (residential, commercial, industrial, and transportation) through 2050
- Production, lifecycle, and generation capacity information on existing U.S. LWR fleet (including life extension programs) and projected data for proposed new advanced LWR reactors
- Scenarios for anticipated energy savings relative to new energy conservation and energy efficiency technologies
- GHG emission data and goals

- Data on operations (e.g., from Aspen, spreadsheets) on electricity production, hydrogen production via high-temperature electrolysis, coal to liquids, and oil extraction from tar sands, and ammonia production.

Economic formulas will be developed and incorporated into the model to provide the capability to assess the relative economic tradeoffs between a range of HTGR strategies utilizing/constrained by the scenarios/assumptions (e.g., the number and use of various HTGR products and hybrid approaches).

The model will allow the user to input data and select and modify inputs (independent variables) by typing in the data via an input box and/or adjusting data via slider bar. The appropriate calculations will be initiated by clicking on a "run" button and the results will be available via graphs and tables. The model will select the appropriate energy dataset modules and formulas; and perform the appropriate calculations. The model will plot graphs and/or populate the tables with the appropriate results. The results will be visible on the computer screen either individually or with selected multiple output graphs and/or tables for comparative purposes. In addition, the resulting graphs and tables from each model run will be savable in electronic form or by printing hard copies of the results.

3.4 Model Design Requirements List

The model will be designed to perform the following functions:

- D1. Display data relative to the quantity and types of energy resources (e.g., transportation fuels and electricity) that are currently being produced and utilized in the U.S.
- D2. Display existing EIA data and projected EIA data for future energy demands and uses to 2050.
- D3. Estimate the potential energy sector penetration of HTGR products (and other energy sources) by calculating the effect on the energy sector balance (Figures 1-6). Display the results showing the number of plants built, energy created/used, and cost. The following plant/process options will be used (note: process number references are in square brackets):

  - Produce electricity using HTGRs [1].
    Process [1a] is an HTGR electricity plant that replaces coal electricity production.
    Process [1b] is an HTGR electricity plant that replaces natural gas electricity production.

  - Produce electricity and process heat (co-generation) using HTGRs [2].
    Process [2a] is an HTGR co-generation plant that replaces coal co-generation.
    Process [2b] is an HTGR co-generation plant that replaces natural gas co-generation.

  - Produce hydrogen via high-temperature electrolysis [3].
  - Utilize excess heat production for energy hybridization, e.g., converting:
    - Natural gas to ammonia [4]
    - Natural gas to diesel [5a]
    - Coal to diesel [5b]
    - Natural gas to gasoline [6a]
    - Coal to gasoline [6b]
    - Coal to natural gas [7]

- Produce oil from tar sands via steam assisted gravity drainage [8].
- Produce oil from oil shale deposits via HTGR assisted oil shale extraction [17]
- Estimate the potential to displace coal and natural gas by maintaining and sustaining the existing LWR fleet, potential reactor life extension programs, and by constructing new advanced LWR reactors [9].
  Process [9a] is an LWR electricity plant that replaces coal electricity production.
  Process [9b] is an LWR electricity plant that replaces natural gas electricity production.

- Estimate the amount of electricity that can be produced utilizing IGCC electric power plants with various degrees of carbon capture capabilities [10].
- Estimate the potential to displace coal and natural gas by building small modular reactors [16].
  Process [16a] is an SMR electricity plant that replaces coal electricity production.
  Process [16b] is an SMR electricity plant that replaces natural gas electricity production.

- Estimate the potential to displace coal and natural gas utilizing renewable resources including on-shore wind farms [11], solar plants [12] and geothermal plants [13].
  Process [11a] is a wind farm that replaces coal electricity production.
  Process [11b] is a wind farm that replaces natural gas electricity production.
  Process [12a] is a solar plant that replaces coal electricity production.
  Process [12b] is a solar plant that replaces natural gas electricity production.
  Process [13a] is a geothermal plant that replaces coal electricity production.
  Process [13b] is a geothermal plant that replaces natural gas electricity production.

- Estimate the amount of electricity that can be generated by new natural gas power plants [14].
  Process [14a] is a natural gas electricity plant that replaces coal electricity production.

- Estimate the effect of future MPG standards (for 2020 and 2050) on petroleum usage in the transportation sector.
- Estimate the effect of ethanol use on petroleum usage in the transportation sector.
- Estimate the effect of electric cars (and light trucks) on petroleum usage in the transportation and on the electricity sector.

- D4. Allow the user to specify a future energy strategy including the elements listed in D3 and estimate/calculate the effect on GHG emissions and cost. Display the number (and type) of plants built (including HTGRs) to carry out the user specified strategy.
- D5. Estimate the number of jobs (including HTGRs) over time created by a user specified energy strategy and display the results.
- D6. Estimate the effect of a user-specified energy strategy on the amount of foreign oil imports needed in the future (as well as natural gas usage) and display the results.

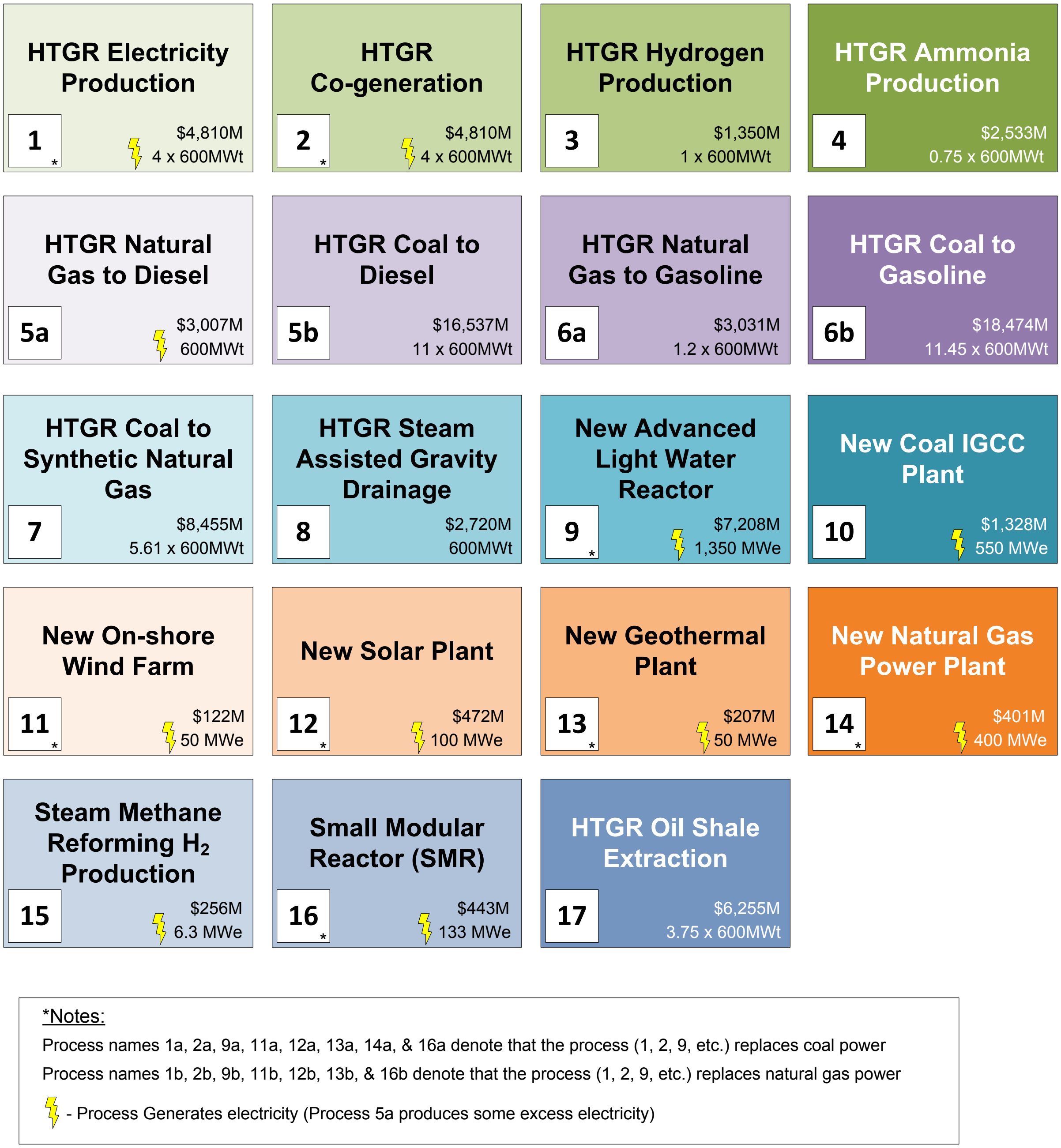


Figure 1. 2050 SIM Building Blocks.

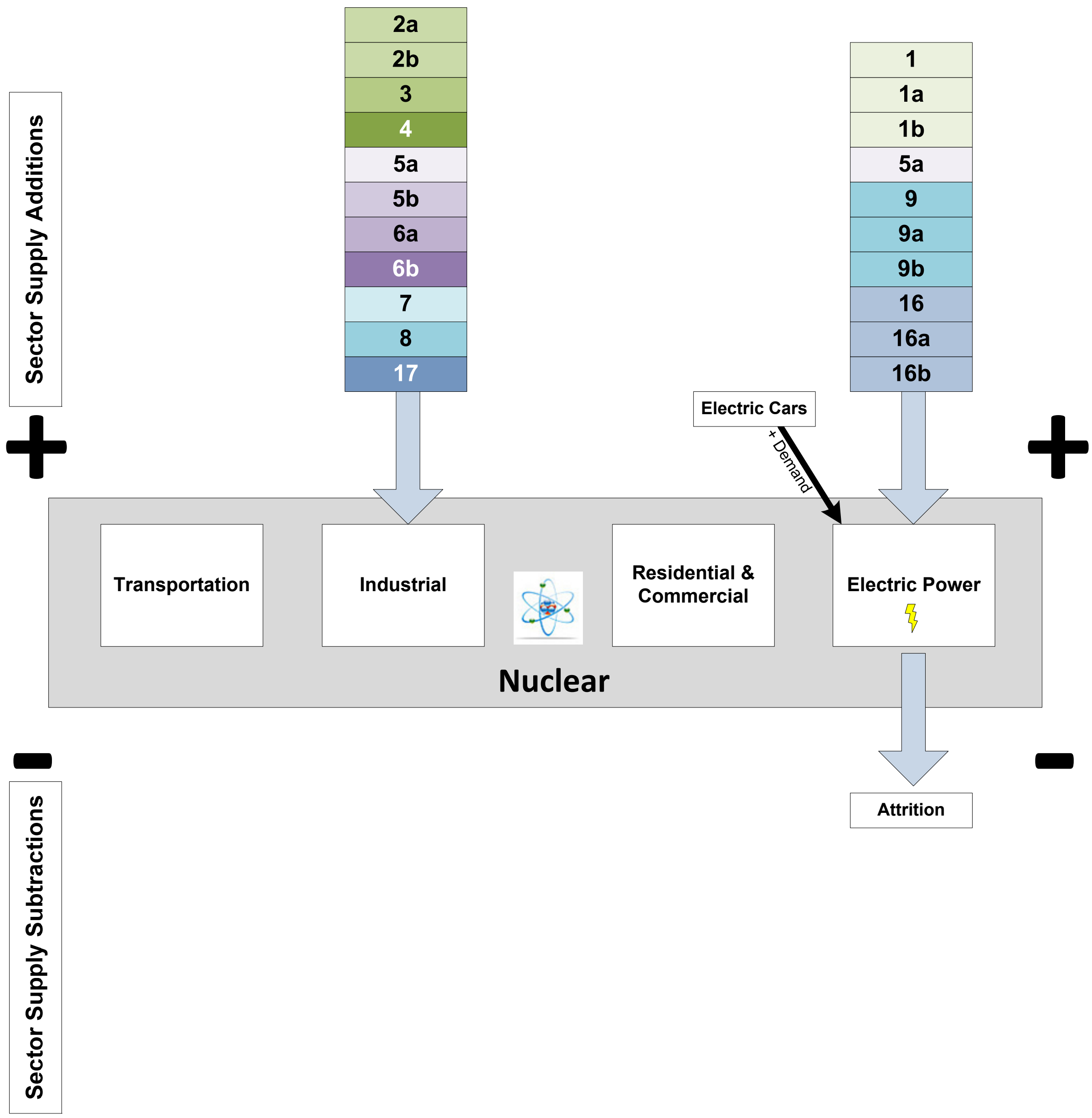


Figure 2. Nuclear Sector Inputs and Outputs.

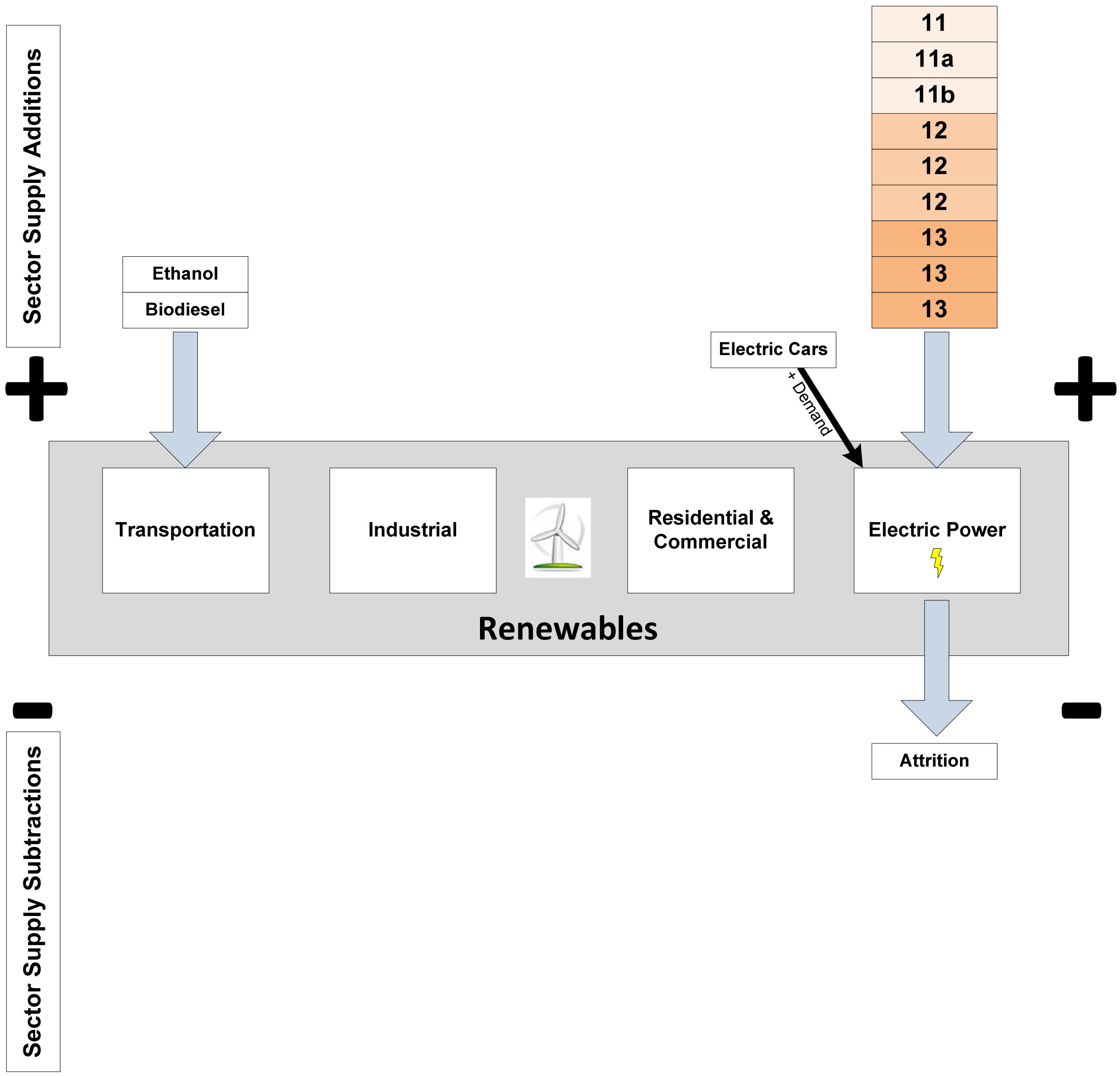


Figure 3. Renewables Sector Inputs and Outputs.

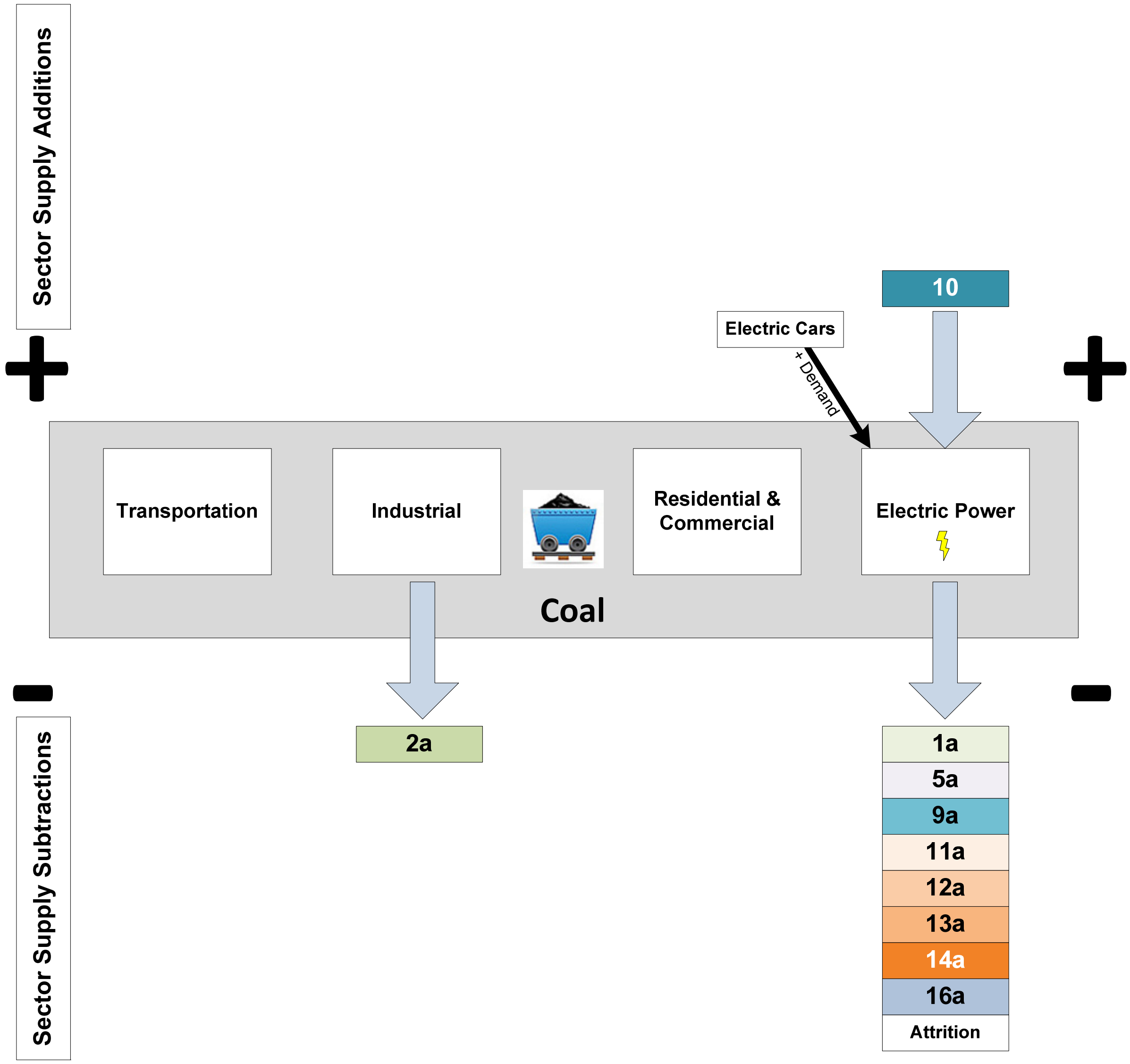


Figure 4. Coal Sector Inputs and Outputs.

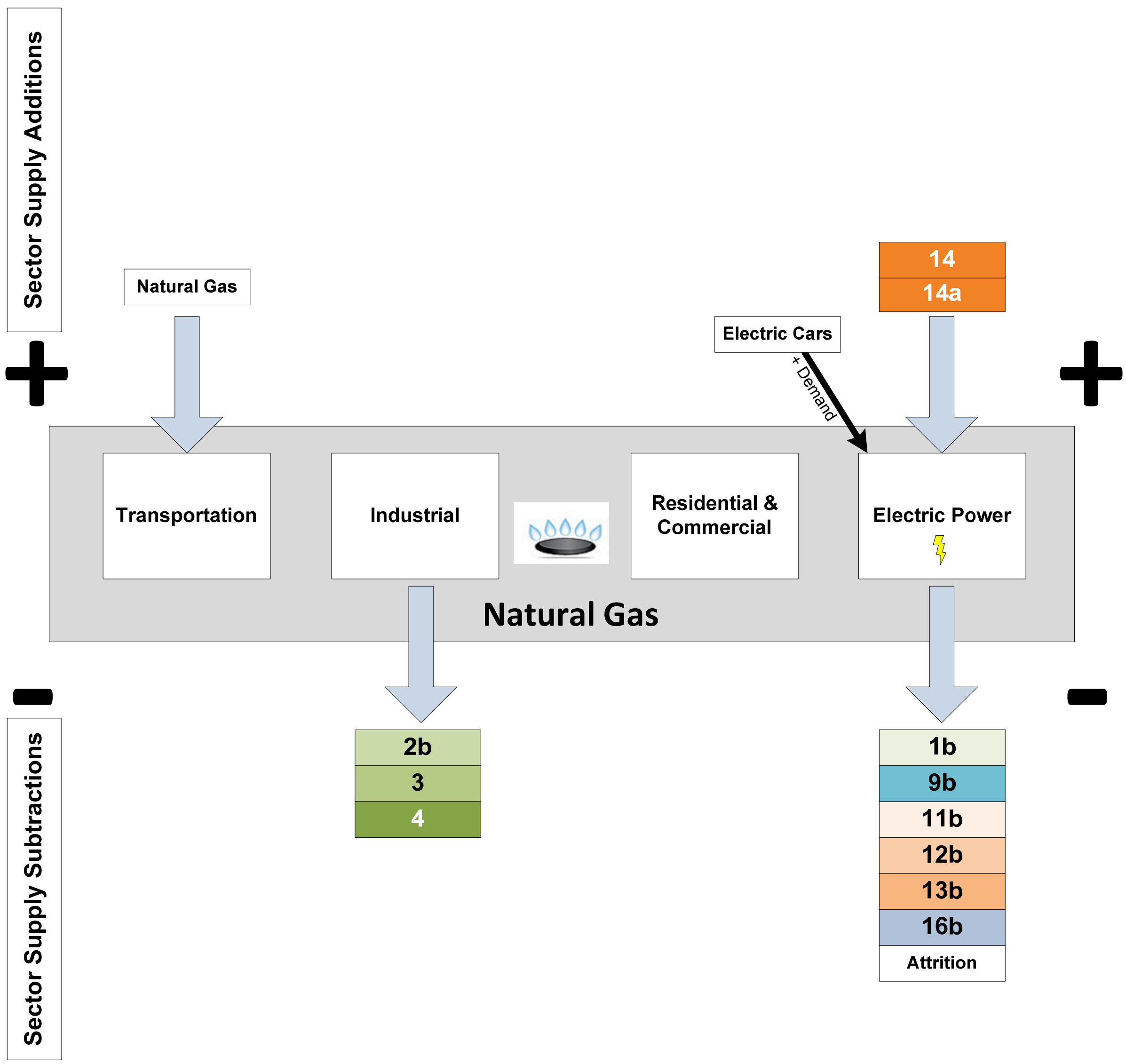


Figure 5. Natural Gas Sector Inputs and Outputs.

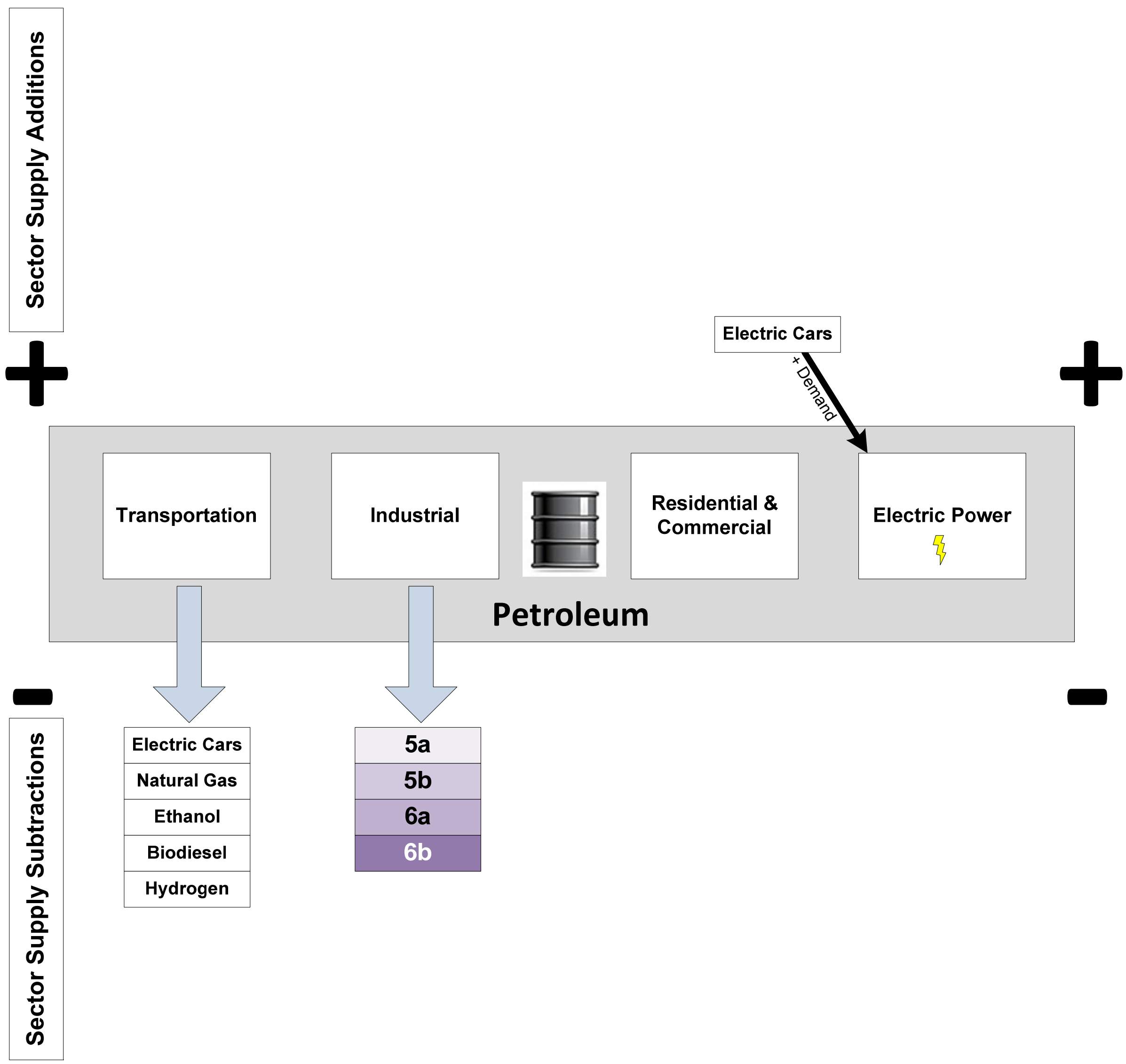
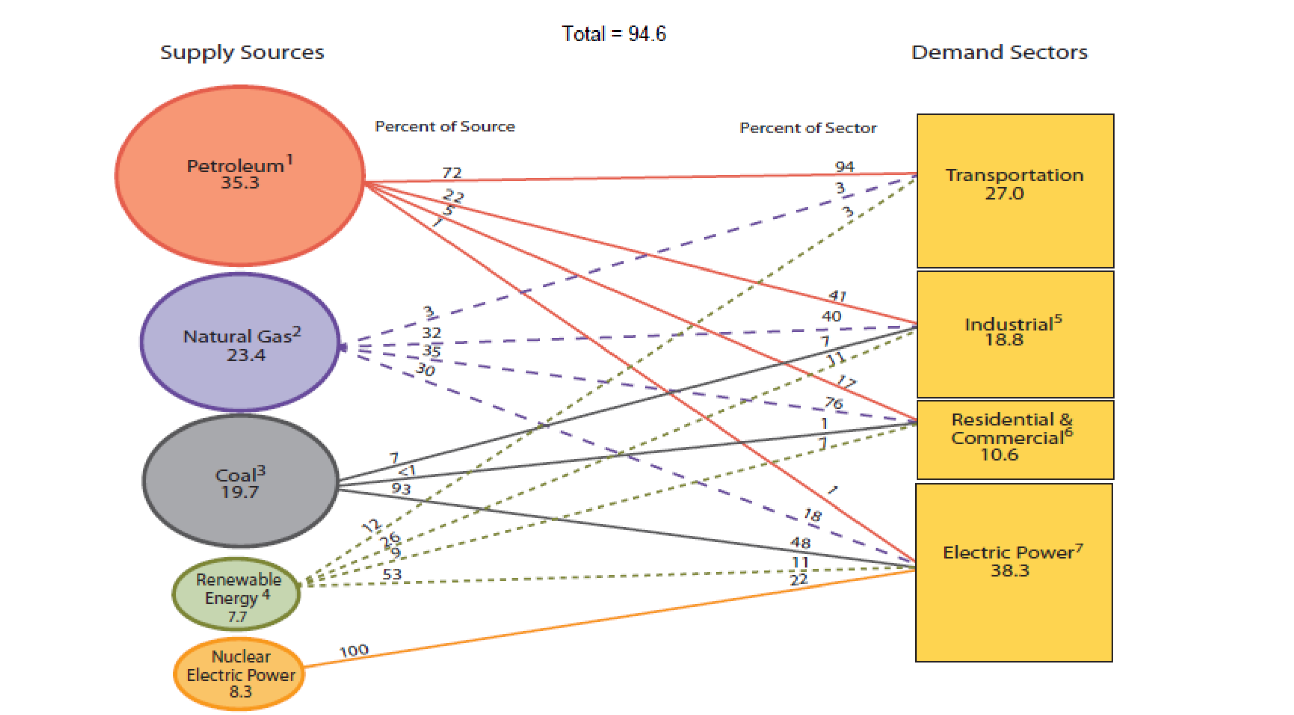


Figure 6. Petroleum Sector Inputs and Outputs.

- D7 Estimate the effect of a user specified energy strategy on the stability of the price of oil and natural gas and display the results.
- D8. Estimate the amount of new LWRs, coal fired electric plants, and natural gas fired electric plants needed to replace capacity that is expiring or going offline in the future. Calculate the necessary new power plants needed to achieve the user-specified goals for a given strategy (including LWRs, coal fired plants, wind farms, solar plants, geothermal plants, and natural gas fired plants). Calculate the effect of these new plants on the energy mix, GHG emissions, and cost.
- D9. Estimate the effect of projected energy efficiency/conservation efforts on reducing demand in all energy sectors and reduction of GHG emissions.

3.5 Model Implementation

The 2050 SIM model is based on the energy sources and sectors shown in Figure 7. This framework is organized by supply sources in Figure 1. The affect of each plant/process on the energy balance is displayed in Figures 1-6 as well. When a plant/process is built, its energy is added to the appropriate sector and subtracted from the sector it replaces or offsets.



¹ Does not include biofuels that have been blended with petroleum—biofuels are included in "Renewable Energy."
² Excludes supplemental gaseous fuels.
³ Includes less than 0.1 quadrillion Btu of coal coke net exports.
⁴ Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
⁵ Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
⁶ Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
⁷ Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

Note: Sum of components may not equal total due to independent rounding.
Sources: U.S. Energy Information Administration, *Annual Energy Review 2009*, Tables 1.3, 2.1b-2.1f, 10.3, and 10.4.

Figure 7. Primary Energy Flow by Sources and Sector[16], 2009 (Quadrillion Btu).

3.6 Model Implementation List

The codes that will be written to implement the estimates and projections, and display the results graphically and in tabular form relative to the design requirements above include:

- I1. The energy demand/use for each energy sector is calculated by multiplying the total energy for that sector by the percentage of energy in that supply source sector:

  For example, (Nuclear/Electricity Sector) = (Total Electricity Sector)*(0.22)

  This amount of energy is adjusted (in the appropriate years) by additions and/or subtractions (see Figures 1 through 6) depending on what plants are built and new energy sector percentages are calculated each year up to 2050.

- I2. The energy for each of the energy sectors in each supply source is calculated in tabular form before and after adjustments (additions and subtractions based on user strategy). Energy graphs are displayed in appropriate places in the output to show changes from 2010 to 2050.

- I3. Data/information for each plant/process is calculated in its own table in the spreadsheet. The list of information calculated for each process is:

  - Number of plants (spread over the specified years of operation)
  - Total project cost spread over the appropriate years for a given lead time
  - Amount of energy created in the appropriate units (BTU/yr) taking into account appropriate capacity factors
  - Amount of energy commodities not used (or additional commodities used) (e.g., amount of natural gas not used if building an HTGR to replace a natural gas plant).

- I4. Estimate the GHG emissions for a given strategy by using an "emissions per energy" conversion factor for each energy sector in each supply source. For example, for 2010 the total emissions for natural gas electricity were 408 million metric tons CO_2. The total energy supplied from that sector for 2010 was 7,040,197 billion BTUs. Dividing these gives 5.8×10^{-5} million metric tons CO_2 per billion BTU. This factor is used to calculate future emissions based on the adjusted amount of energy produced (I1) in the given year for a given sector.

- I5. Estimate the number of jobs (by year) for the given energy strategy by calculating the job breakdown into the following seven areas: (1) engineering, (2) manufacturing, (3) construction, (4) operations, (5) decommissioning, (6) induced operations; and (7) induced construction. Each of these job areas is assigned a timeframe and a yearly number of associated jobs. The operation duration is equal to the plant life and begins at the user-specified start year of operation. The construction duration is the lead time minus one year and occurs in the years leading up to operations. Engineering and manufacturing start at the beginning of the lead time and last one to three years depending on plant data. Decommissioning begins when operations is finished and lasts two years. Induced construction and operations jobs occur during construction and operations respectively.

- I6. Estimate the effect on oil imports by taking the projected import data from EIA and decreasing the import need based on the user-specified energy strategy. The plants/processes that affect oil imports are: HTGR natural gas to diesel, HTGR coal to diesel, HTGR natural gas to gasoline, HTGR coal to gasoline, HTGR steam-assisted gravity drainage, HTGR oil shale extraction, electric car usage, ethanol usage, and higher miles per gallon (MPG) standards. Natural gas usage is calculated in a similar manner, adding and subtracting from the projected EIA import data based on the user selected plants/processes that affect natural gas usage.

- I7. Estimate the effect on energy price stability by summing the variances of energy price returns weighted by the square of their respective energy types. Taking the square root of the result returns the volatility of the effective price of energy. The overall effective price of energy and its volatility are input, along with some user defined inputs, into the Black-Scholes Option Pricing Model. An "at-the-money" call option is priced to value the energy buyer's risk of volatile price increases. Price and volatility contribute to the call option price. Changes in the call option price will mostly be attributable to changes in the overall effective energy price level, and the effective energy price's volatility. Energy price data is taken from EIA records and forecasts. For the years 2035 to 2050 prices are estimated by linearly continuing the trend found in EIA's forecast data. Price volatilities are estimated using Excel's Standard Deviation function on data obtained from EIA, St. Louis Federal Reserve, and commodity exchange spot prices. Volatilities were estimated using the most recent ten years of annual price data.
- I8. Using data of the existing LWR fleet, estimate the amount of new LWR plants that will be needed to replace existing capacity going offline in the future. (Do the same calculation for coal fired electric plants and natural gas fired plants.) If the user specifies to renew licenses for the LWRs, extend those plants that have not already had a license extension by 20 years. As the user sets goals for the electricity energy mix, build plants as necessary to achieve the percentage goals. Assume that building is initiated in the first year the given plant can be built and increment out to 2050. If the goal is not reached for a sector when 2050 occurs, loop back to the first year and build more each year until the goal is attained.
- I9. Estimate the effect of projected energy efficiency by taking a user input of percent efficiency per year and applying that percent decrease to the overall demand for the U.S. (except for the transportation sector). The projected efficiency for the transportation sector is calculated by using the future MPG standards (for cars and light trucks) and a percent improvement for the remainder of the transportation sector. Estimate conservation by using energy consumption per gross domestic product (GDP) percent change per year factor (default 1.9% decrease per year). Or if demand is driven by population, estimate conservation by usage and energy consumption per capita percent change per year factor (default 0.3% decrease per year).

3.7 Model Outputs

The model will output data showing the scenario performance for a given set of model inputs. Model outputs will include (but not be limited to) showing the ability of HTGRs:

- To produce useful energy products (electricity, hydrogen, and heat) based on the various scenarios selected
- To displace fossil fuels in the industrial and electrical sectors
- Create jobs in the U.S. relative to construction and operation of new facilities
- Produce products that reduce U.S. dependence on foreign energy sources (primarily oil and natural gas)
- Increase energy price stability based on lower and more predicable long-term operational costs
- Produce carbon-free energy to reduce energy production-related GHG emissions in order to meet to U.S. GHG goals (e.g., Copenhagen Accord, the American Clean Energy and Security Act of 2009, and the Clean Energy Jobs and American Power Act of 2009)

Given sufficient time, funding, and resources, the model may be expanded to output data in graphic and tabular formats and printed reports showing the effects of various HTGR strategies with respect to energy security and its environmental footprint.

The model will output data in graphic and tabular formats and printed reports showing the economic tradeoffs between a range of HTGR strategies (e.g., the number and use of various HTGR products and hybrid approaches).

3.8 Model Assumptions

All models are simplifications of reality and, therefore, are based on assumptions. The assumptions utilized to develop 2050 SIM are documented in Appendix A.

4. MINIMUM COMPUTER HARDWARE REQUIREMENTS

The initial version of the HTGR 2050 SIM needs to be able to run as a standalone application on a personal computer with the following minimum system requirements:

- Intel Pentium 4 processor
- Microsoft Windows XP SP2 or newer
- 1GB RAM
- Microsoft Excel 2007.

If the 2050 SIM is deployed as a web-based application, the requirements for use will be a high speed internet connection and a web browser.

5. MODEL QA/QC

This project will be conducted in accordance with all INL project control and reporting requirements in accordance with "HTGR 2050 Strategic Impact Model Task Plan," PLN-3610.[a] According to PLN-3610, the HTGR 2050 SIM software has been designated as "custom developed," non-safety software. Software will be entered into Enterprise Architecture, and a safety software determination will be identified or developed. Software Quality Assurance (QA) will be performed to the requirements of INL PLN-2247, "General Software Management Plan" for the Very High Temperature Reactor Technology Development Office (VHTR TDO), and documented on INL Form 959-A (FRM-959-A),[b] "VHTR SMP Record Form." A software requirements traceability matrix will document the development and implementation through life-cycle stages of all requirements.

The quality level of the application and software type must be reviewed to determine the level of testing to be conducted for compliance. The 2050 SIM model has been evaluated and is considered to be a Quality Level 3 software application.

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a. PLN-3610, 2010, "HTGR 2050 Strategic Impact Model Task Plan," Rev 0, NGNP Project, August 2010.

b. FRM-959-A, 2010, "VHTR SMP Record Form," Rev 1, June 2010.

5.1 Software Design

All necessary data and formulas will be developed and tested in Excel spreadsheets. They will be tested to ensure that sufficient/appropriate data are available and incorporated and they will be assessed to ensure that they are properly linked relative to conducting the appropriate calculations, as described above. The data will also be assessed to properly support the appropriate graphics, tables, and printed reports, as described above.

Detailed 2050 SIM assumptions and scenarios will be formed and documented in the model as it is developed (Appendix A). For example, a model assumption for an HTGR may be that the capacity factor is assumed to be the same as the LWR requirements.

The data, numerical methods, formulas, logic, and data and/or process flow will be documented in accordance with "HTGR 2050 Strategic Impact Model Task Plan," PLN-3610.

5.2 Software Testing

Various types of testing will occur during the development of 2050 SIM. These include:

- Unit Testing – Unit testing will be conducted informally by the software engineers on an ongoing basis as work progresses. Each software engineer is responsible for testing each function and component as it is developed. In addition, software engineers will cross-check each others' work on a periodic basis.
- Component Testing – Component testing will be conducted informally on an ongoing basis as each component is completed. Typically this is conducted during weekly project meetings by having the software engineers demonstrate their latest results or modifications to the project team, including the software project manager.
- Performance Testing – Performance testing will be conducted by database design and data analysis personnel in order to provide an independent assessment of the penultimate product to ensure that the model operates as designed under normal operating conditions and load. This will include testing the model to ensure it meets users' expectations relative to the look-and feel of the inputs/outputs and from the screen navigation perspective. The results will be compared against the criteria specified in this plan and the model will be tuned as appropriate to bring the software within those limits.
- User Acceptance Testing – User acceptance testing will include the software engineer and/or software project manager demonstrating the final 2050 SIM model to the customer and making final adjustments as requested by the customer.

According to MCP-3058, the test documentation shall specify characteristics to be tested, test methods, and acceptance criteria. These tests will be conducted to ensure that the software produces correct results, adequately and correctly performs all intended functions, properly handles abnormal conditions and events as well as credible failures, does not perform adverse unintended functions, and does not degrade the system either by itself or in combination with other functions or configuration items.

The characteristics to be tested for 2050 SIM include source data, calculations, and projections; and data output, display, and storage. In addition, human factors will be assessed to ensure that the model used is intuitive and meets users' expectations.

5.2.1 Assess Source Data

- Show evidence that the model data sources are documented or referenced. Data for future projections should be referenced as well. In the case that projections go beyond 2035 to 2050, document how the projections were calculated (EIA data typically only goes out to 2035).
- Show evidence that all data are normalized to the appropriate units (e.g., BTUs, barrels of oil equivalent, and CO_2 equivalents).
- Show evidence that all data sets and formulas utilized are properly entered into the database/spreadsheet and properly linked to the user interface.

5.2.2 Assess Calculations/Projections

- Perform an independent check of all model calculations to ensure that they access the appropriate inputs and data sets/formulas, that they perform calculations appropriately, and that units are handled correctly
- Perform an independent check that all output data accumulate and are summarized appropriately with correct units.

5.2.3 Data Output, Display and Storage

- Show evidence that all data output graphics and tables display the appropriate data listed in Section 3.7
- Show evidence that the graphics and tables display appropriate labels and units
- Perform an independent check that all data out can be stored and retrieved appropriately.

5.3 Model Test List

The assessor/reviewer will conduct each test described below to ensure that the model properly performs all of the calculation described under "implementation" and meets all of the functions described under "design," above:

- T1. Set all user inputs to default (**Reset** button on "Control" sheet). Verify that the desired 2050 electricity mix percentages match the starting values: Nuclear 22.0%, Renewable 11.0%, Coal 48.0%, Natural Gas 18.0%, Petroleum 1.0%. Press the **Calculate** button on the "Control" sheet. Verify that the actual final energy mix percentages ("Control" sheet, cells I12 through I16) are within 1.5% of the desired percentages. (Because of differing plant sizes it is not possible to get an exact replacement of plants going out of service.)
- T2. Using the same user settings as set at the end of Test T1, change the nuclear electric sector goal percentage to 25.0, the renewable to 14.0%, the coal to 40.0%, and the natural gas to 20% (on the "Control" sheet). Calculate results and verify that the proper adjustments (nuclear electric went up, renewable electric went up, coal electric went down, natural gas electric went up) were made to the correct energy supply sectors (Adjustments to Supply Sources (Billion BTUs) section in "Sector_Supply" sheet) and verify that the 2050 percentages of each supply source are within 1.5% of the specified goal percentages ("Control" sheet, cells I12 through I16).

- T3. Reset all user inputs to default values (**Reset** button on "Control" sheet). Select the "DataTable" worksheet. Clear out all values from the interior of the main table (C5:AL65, so that no plants/processes are built). Enter a "1" in the 2025 line for each plant/process. In the "Processes" worksheet, verify that the total project cost (TPC) is calculated and spread over the specified lead time for each process (leading up to a 2025 operation start date). Also verify that the energy created is calculated correctly in the appropriate units and are connected to the appropriate energy sector supply source adjustments (Figures 1-6). Also verify that other energy commodities used/not used were calculated correctly for each process.
- T4. a. Reset all user inputs to default values (**Reset** button on "Control" sheet). On the "Control" sheet, change the nuclear electric sector goal percentage to 55.0, the renewable to 25.0%, the coal to 1.0%, and the natural gas to 18%. Calculate results and verify that the CO_2 emissions for coal (electricity) taper off to zero (or near zero) by 2050 (Electricity CO_2 Emissions graph on same sheet).

  b. On the "Control" sheet, change the nuclear electric sector goal percentage to 55.0%, the renewable to 25.0%, the coal to 18.0%, and the natural gas to 1%. Calculate results and verify that the CO_2 emissions for natural gas taper off to zero (or near zero) by 2050 (Electricity CO_2 Emissions graph on same sheet).

  c. Reset all user inputs to default values. Change the percent electric cars in 2050 input to 80% (Cell H25, "Control" sheet). Calculate results (**Calculate** button on the "Control" sheet), and verify that the emissions for petroleum decreased significantly (Transportation CO_2 Emissions graph) and electricity emissions increased significantly (see the Electricity CO_2 Emissions graph) thus showing the proper shift from petroleum to electricity.

  d. Reset all user inputs to default values. In the Industrial section of the "Control" worksheet, enter 30 for the number of HTGR Co-generation plants to build. Press the Calculate button and verify that the coal and natural gas industrial sectors both shrunk and the nuclear industrial sector grew in 2050 (looking at the pie charts in the expanded input section). The maximum needed energy limit should have been met for the co-generation market and the number of plants built should have been changed to 27 (which is roughly equivalent to 2 quadrillion BTUs). Also, verify that emissions decreased in 2050 for the industrial sector (see the Industrial CO_2 Emissions graph).

  e. Reset all user inputs to default values. In the Industrial section of the "Control" worksheet, enter 30 for the number of HTGR Hydrogen Production plants and 12 for the number of Ammonia Production plants. Press calculate and verify that natural gas emissions decreased for the industrial sector in 2050 (see the Industrial CO_2 Emissions graph).

  f. Reset all user inputs to default values. On the "Emissions" worksheet, note the value in Cell BE131 (which is the net emissions for electricity production). Manually calculate the emissions change for one HTGR electric plant replacing a coal plant by doing the following:

  - Emissions=(energy)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy)
  - (1032 MW)(0.9)(24 h/day)(365.25 days/yr)(10,460,000 BTU/MWh)
  - Take that result and divide by 1×10^9 to get billion BTU.
  - Take that result times (9.817×10^{-5}) million MT CO_2/Billion BTU to get the CO_2 change.
  - On the "DataTable" worksheet enter a 1 in the year 2040 for an HTGR electric plant to replace a coal plant (Cell C35). Now look at the value in cell BE131 in worksheet "Emissions" and

take the difference from before the one HTGR electric plant was built. Compare this to the manual calculation and verify the calculations match.

g. Reset all user inputs to default values. On the "Emissions" worksheet, note the value in Cell BG131 (which is the net emissions for natural gas [NG]). Manually calculate the emissions change for one HTGR cogeneration plant replacing a natural gas cogeneration plant by doing the following:

- Emissions = (energy)(percent thermal)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy) + (energy)(percent electric)(capacity factor) (hours/day)(days/year)(BTU/MWh)(emissions/energy)
- (2400 MW)(0.69)(0.9)(24 h/day)(365.25 days/yr)(3,412,142 BTU/MWh) + (2400 MW)(0.15)(0.9)(24 h/day)(365.25 days/yr)(10,460,000 BTU/MWh)
- Take that result and divide by 1×10^9 to get billion BTU.
- Take that result times (5.334×10^{-5}) million MT CO_2/Billion BTU to get the CO_2 change.
- On the "DataTable" worksheet enter a 1 in the year 2040 for an HTGR cogeneration plant to replace a natural gas cogeneration plant (Cell G35). Now look at the value in Cell BG131 in worksheet "Emissions" and take the difference from before the one HTGR electric plant was built. Compare this to the manual calculation and verify the calculations match.

- T5. Reset all user inputs to default values. Select the "DataTable" worksheet. Clear out all values from table (so that no plants/processes are built). Enter a 1 in the 2030 line for each plant/process. Go to the "Jobs" worksheet and press Update Job Data. Now go to the "Jobs Data" worksheet and verify that the jobs data was populated correctly in data block for each plant/process.
- T6. a. Reset all user inputs to default values. On the "Control" sheet, set each industrial process to built 1 of each plant. Press Calculate and verify that the correct plants were built (see "DataTable" sheet).

  b. Reset all user inputs to default values. Change HTGR Hydrogen Production to 50. Press Calculate and verify that industrial emissions decreased and that the number of conventional hydrogen steam methane reformer plants that were needed was less than the base case. Also verify that natural gas usage decreased.

  c. Reset all user inputs to default values. Change HTGR Assist Coal to Natural Gas to 90. Press Calculate and verify that coal usage went up from the base case.

  d. Reset all user inputs to default values. Change HTGR Assist Natural Gas to Diesel to 20. Press Calculate and verify that natural gas usage went up from the base case and that oil imports and usage went down.

  e. Reset all user inputs to default values. Change HTGR Assist Coal to Diesel to 20. Press Calculate and verify that coal usage went up from the base case and that oil imports and usage went down.

  f. Reset all user inputs to default values. Change HTGR Assist Natural Gas to Gasoline to 20. Press Calculate and verify that natural gas usage went up from the base case and that oil imports and usage went down.

  g. Reset all user inputs to default values. Change HTGR Assist Coal to Gasoline to 20. Press Calculate and verify that coal usage went up from the base case and that oil imports and usage went down.

h. Reset all user inputs to default values. Change HTGR Assist SAGD to 20. Press Calculate and verify that oil imports went down.

i. Reset all user inputs to default values. Change HTGR Assist Oil Shale Extraction to 20. Press Calculate and verify that oil imports went down.

j. Reset all user inputs to default values. Change HTGR Co-generation to 20. Press Calculate and verify that natural gas and coal usage went down. Also verify that industrial emissions went down.

- T7 a. Set all inputs to default values. Verify that when no improvements are made (e.g., nothing is done to offset oil use) then oil and natural gas equivalent energy should be zero or near zero. The price stability graph should show no change from baseline

  b. Set all inputs to values specified in Appendix E. Change the energy goal profile (as specified in Appendix E) and run the simulation. Verify that the Effective Oil Price Volatility graph shows a 26.6% reduction. Verify that the quantities of oil and natural gas equivalent energy are correct and from actual sources under consideration (as specified in detail in Appendix D and E). These outputs listed in Appendix E can be verified by “hand” calculations using the formulas in Appendix D.

- T8. a. Reset all user inputs to default values. Verify that the model built the correct number of new LWRs and new coal plants to maintain the current (2010) energy sector mix for electricity given the demand (see columns BV and CF in sheet “Sector_Supply”).

  b. On the “Control” sheet, change the nuclear electric sector goal percentage to 24.0%, the renewable percent to 12.0%, the coal percent to 44.0%, and the natural gas percent 19%. Select LWR & HTGR for New Nuclear. Calculate and verify that the model built HTGRs and LWRs to replace coal. Also, verify that the model built renewable plants to replace coal close to the specified proportions. Also verify that the model built some natural gas electric plants to replace coal. (See the “DataTable” worksheet.)

- T9. a. Go to the “Control” worksheet. Reset all user inputs to default values. Change Energy Reduction due to Efficiency to 1% per year. Calculate and verify that the energy demand and supply decreased appropriately (see Energy Supply graph on same sheet).

  b. Reset all user inputs to default values. Change GDP Projection % Change per year to 2.9%. Calculate and verify that the energy demand and supply increased appropriately.

  c. Reset all user inputs to default values. Change GDP Energy Consumption per GDP % Change per year to -2.4%. Calculate and verify that the energy demand decreased appropriately.

  d. Reset all user inputs to default values and select Driven by Population (for energy demand). Change US Population Projection % change to 1.2% per year. Calculate and verify that the energy demand increased appropriately.

  e. Reset all user inputs to default values and select Driven by Population. Change Energy Consumption per Capita % change to -0.8% per year. Calculate and verify that the energy demand decreased appropriately.

  f. Reset all user inputs to default values. On “Control” worksheet, set 2020 MPG to 35 and 2050 MPG to 55. Verify that the energy demand (due to efficiency) decreased appropriately (Energy Supply Breakdown graph). Also verify that the CO_2 emissions for petroleum decreased (Transportation graph for CO_2 emissions).

  g. Reset all user inputs to default values. On “Control” worksheet, set Transportation Efficiency to 1%. Verify that the energy demand (due to efficiency) decreased appropriately (Energy Supply

Breakdown graph). Also verify that the CO_2 emissions for petroleum decreased (Transportation graph for CO_2 emissions).

5.3.1 Human Factors

Perform a qualitative check to ensure that model use is intuitive and it meets users' expectations relative to the look-and feel of the inputs/outputs and from the screen navigation perspective.

5.3.2 Documentation

Ensure that all that data sources, growth rates, formulas, calculations, scenarios and assumptions are documented.

5.3.3 Operation and Maintenance

The 2050 SIM software will be documented including a description of systems requirements, system set-up, procedures for operating the software, information on fault recovery, emergency procedures, and diagnosis features. Documentation will also include contact information for obtaining software support.

5.3.4 Retirement

This software package is funded for delivery and use in September 2011. The software will be maintained and updated/modified if funding is provided by the customer; however, if it is not funded, the software will remain available to the customer, but without further upgrades or modifications.

Appendix A

2050 SIM Assumptions and Bases

A-1. General

- The model initially breaks down U.S. energy into sectors and supply sources according to Figure 7.[16]
- New plants/processes are built according to user-specified inputs, starting in the earliest year possible and then building in the next year until the user specified goals are met. If 2050 is encountered, then the model loops back to the beginning year and builds more plants stepping toward 2050 again.
- New electricity producing plants (e.g., HTGRs, LWRs, SMRs, renewable plants) can replace coal or natural gas fired plants according to the energy goals set by the user. No jobs lost or costs are tracked for a replaced coal or natural gas plant. If future energy demand is above 2010 levels for a particular electricity energy sector, new plants will be built to meet new demand and will not replace other energy sources such as coal or natural gas.
- The model uses the value 3,412,142 BTU/MWh to convert energy between metric and English units.
- The model uses 21,868,000 BTU/ton as an energy content for coal. This number is based on Illinois #6 coal.[9]
- Jobs data are broken down into the following areas: Engineering, Manufacturing, Construction, Operations, Decommissioning, Induced Construction, and Induced Operations
- Each job duration is calculated based on the following rules:
  - Each new plant/process is assigned a lead time and a plant life.
  - The construction time period is assumed to be the lead time minus one year.
  - The operational time period is assumed to be equal to the plant life in years.
  - Induced construction related jobs created are 50% of Engineering, Manufacturing, and Construction jobs and are spread over the construction time period.
  - Induced operations related jobs created are 100% of Operations jobs and are spread over the operational time period (for Nuclear Power).
  - Decommissioning is assumed to have the same number of operational jobs for two years after operations end.
  - Engineering jobs start at the first year (operational date minus lead time) and last a default of two years, but can be changed for specific processes.
  - Manufacturing jobs start at the first year (operational date minus lead time) and last a default of three years, but can be changed for specific processes.
- All capital costs (shown on the "Control" worksheet) are in 2010 dollars (constant).
- For oil imports, the model uses past import data from EIA up to 2010. For future data, a 0.3% reduction per year is assumed (based on EIA future projections).[1] This value could be changed to create a different scenario.

- For natural gas imports, the model uses past import data from EIA up to 2011. For future data, a 1.1% reduction per year is assumed (based on EIA future projections).[1] This value could be changed to create a different scenario.

A-2. Data Sources

- Population data are from the EIA Annual Energy Outlook 2011[1] (which come from the Census Bureau). The future population to 2050 is estimated at about 1% per year growth which is fairly linear out to 2050.
- Future GDP projections are from EIA[1] (default 2.6% average growth per year to 2035).
- Energy consumption per GDP is based on EIA projections from the EIA Annual Energy Outlook 2011[1] (1.9% decrease per year default).
- Energy consumption per capita is based on EIA projections from Annual Energy Outlook 2011[1] (0.3% decrease per year default).
- Emissions are based on EIA 2010 data for total emissions for each energy sector. [1]
  The total emissions are divided by the total energy supplied for 2010 to get an average CO_2 per BTU release rate. As energy changes or is shifted from one sector to another, the change in emissions can be calculated using the average release rate.
- Current LWR fleet data are from EIA (including when licenses expire).[2]
- Transportation data are based on information from the "Transportation Energy Data Book,"[3] (1970 to 2007 data).
- For HTGR process applications, (such as coal to liquids, ammonia production, etc) the data used comes from the report "Integration of High Temperature Gas-Cooled Reactors into Industrial Process Applications,"[2] (and associated TEVs: TEV-666,[3] TEV-667,[4] TEV-671,[5] TEV-672,[6] TEV-674,[7] TEV-693,[8] TEV-704[9], TEV-1029[17]). The detailed TEVs were developed using Aspen modeling of each of the process along with a detailed economic evaluation.
- The data source for Carbon Capture and Storage (CCS) comes from "Carbon Dioxide Capture from Existing Coal-Fired Power Plants."[10]
- The data for new coal-fired power plants come from "Cost and Performance Baseline for Fossil Energy Plants."[11]
- The data for new LWRs, wind farms, solar plants, geothermal plants, and natural gas plants come from EIA.[1]
- Jobs data comes from:

  NGNP-HTGR Assisted Conventional Processes Jobs Creation and Energy Security Report, URS, 2010

  Labor Demand Analysis of a Stand-Alone HTGR Electric Power Plant, Letter from Martin Plum to John Collins, 2010

  New Nuclear Plants: An Engine for Job Creation, Economic Growth, NEI, 2008

  Jobs and Economic Development Impact (JEDI) models, NREL, 2009

Geothermal Technologies Market Report, DOE, 2008

A-3. Energy Demand

- The model assumes the energy demand for the U.S. is met.
- U.S. energy demand can be adjusted by the user and can be based on GDP or population.
- Demand can be decreased by adding in a yearly efficiency improvement percentage (the cost of this is currently not captured).
- Efficiency is accounted for in the model with the efficiency factor & future MPG. Conservation is accounted for with energy use per GDP or energy use per capita.

A-4. Electrical

- No new jobs are created for extending LWR licenses 20 years.
- The model allows the user to build various processes to achieve energy goals. The data used for most of the HTGR applications are in INL/EXT09-16942.[2]
- If the nuclear electricity goal is set to less than 18%, the model will set "Renew LWR Licenses" to false and set "Maintain LWRs" to try to achieve the goal.
- If building HTGRs, the default start date is 2021 but can be changed by the user. If building LWRs, 2016 is the earliest date a new LWR could be practically deployed.
- If building new renewables, 2014 is the earliest date a new renewable plants could be practically deployed.
- Current new process data used in model: Table A-1. (new plant data assumptions)
- The model will build new natural gas-fired electric power plants if the percentage of natural gas for the electricity sector is increased and as the current fleet of natural gas electric plants retire (assuming 50 year life).
- The model will build new coal fired electric power plants (with user specified CCS) to maintain the specified percentage of coal electricity production and as the current fleet of coal plants retire (assuming a 50 year life). The choices for CCS are: 0%, 30%, 50%, 90%.
- If selected, the model will build new small modular reactors (SMRs). The new SMR will be an average of the user selected list of six possible new SMRs (see Table A-1).
- The wind farms are assumed to be onshore and an average of 50 MWe each.
- The solar plants are assumed to be a mixture of thermal and photovoltaic and an average of 100 MWe each.
- If coal usage goes up in the selected scenario in the model, then the model calculates an additional infrastructure cost for coal distribution. This is based on the cost of new train cars and engines. Each train car is assumed to be able to carry 100 tons of coal and 30 shipments per year. Six train engines are needed for every 120 train cars. Each new train car costs $75,000. And each new train engine costs $2 million.
- As electrical demand and usage goes up in a given scenario, then the model calculates an additional infrastructure cost for electrical distribution (grid upgrades). The model assumes a cost of $960

million per 800 MWe of additional electrical demand. This is based on an average of recent electrical grid upgrade projects in the western United States.

- The model assumes that all hydroelectric plants continue the same as in 2010 with no new construction of dams and no demolition of any dams. This assumes that turbine replacement and other maintenance needs for these hydroelectric plants will be performed as needed in the future out to 2050.

A-5. Industrial

- For process applications that produce gasoline or diesel, equivalent energy is taken out of the industrial petroleum sector (for decreased crude oil refining) based on the energy used to refine oil: 3,388,626 BTU/bbl.
- All new cogeneration using nuclear energy (process heat and electricity) will be used in the industrial sector.
- The model builds new hydrogen steam methane reformer plants as needed to keep up with future hydrogen demand. As HTGR ammonia plants and HTGR hydrogen production plants are built, fewer conventional hydrogen steam methane reformer plants are needed. The influence diagram showing the logic the model uses for hydrogen supply and demand is shown in Figure A-1.

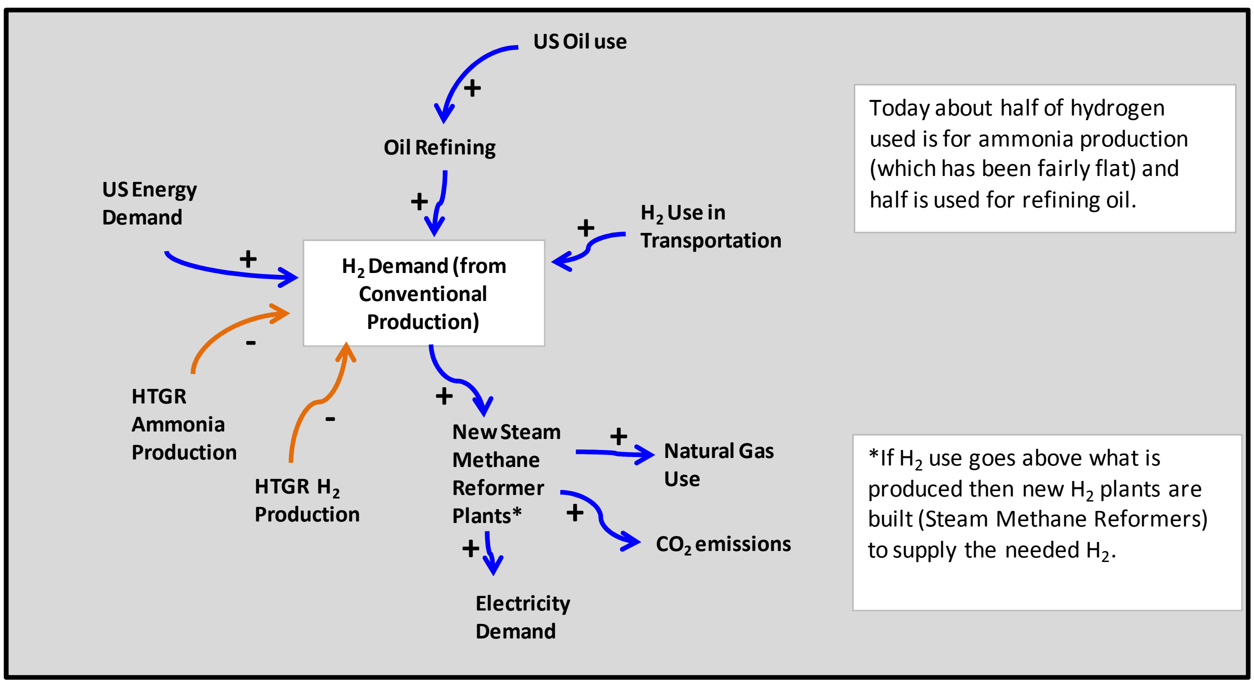

Figure A-1. Hydrogen supply and demand influence diagram.

- The user specifies how many HTGR assisted industrial process plants to build. The specifications of each plant are listed in Table A-1. The model assumes these are new processes and therefore the total energy supply breakdown could show total energy supply slightly more that the demand (because these are new processes not necessarily replacing existing processes).

- Linear treatment of industrial process applications approximates actual process operations.

A-6. Transportation

- Cost for electric cars is assumed to be absorbed by consumers and is not included in the total cost.
- Transportation data used for cars and light trucks includes number of registrations (to get number of vehicles currently in use),[12] vehicle miles traveled per year, fuel use, and fuel economy (MPG).
- Future vehicle miles traveled is set to a constant 12,000 miles per vehicle per year (based on past data, which has been close to 12,000 since ~1995).
- Future number of vehicles in use is based on a simple linear regression of past data (which is very linear).
- Future MPG (a national average) is specified by the user for 2020 and 2050 (calculated as linear growth from 21.0 MPG in 2010 to each of the input values).
- Future electric vehicle is a user input (% of total cars) that is calculated as a linear growth from 0% in 2010. The electric cars replace internal combustion engine cars, and energy is shifted from petroleum-transportation to electricity.
- Ethanol use can be specified by the user for 2022 and 2050 (calculated as linear growth from 3.3% in 2008, to each of the input values). This affects the cars & light trucks sector.
- Ethanol replaces gasoline use (based on the energy difference in fuels: 121,041 BTU/gal for gasoline & 84,041 BTU/gal for ethanol). The cost of building new ethanol plants is not included in the model at this time.
- Biodiesel use can be specified by the user for 2022 and 2050 (calculated as linear growth from 0.8% in 2008, to each of the input values). This affects the heavy trucks sector.
- Biodiesel replaces conventional diesel use (based on the energy difference in fuels: 138,690 BTU/gal for diesel & 119,216 BTU/gal for biodiesel). The cost of building new biodiesel plants is not included in the model at this time.
- Hydrogen can be used as a transportation fuel in the future. The user specifies a percentage of cars & light trucks that use hydrogen as a fuel in 2050. The model then calculates a linear growth from 0% to the user specified percent in 2050. Hydrogen demand is increased as shown in Figure A-1.
- If the user selects hydrogen to be used as a transportation fuel, then the cost of infrastructure to support hydrogen distribution is added into the overall capital cost. Using data from a presentation from the Argonne National Laboratory Transportation Technology R&D Center entitled “Cost of Some Hydrogen Fuel Infrastructure Options,” the hydrogen delivery infrastructure to serve 40% of the light duty fleet is likely to cost $500 billion. Using this as a data point, the model assumes a cost of $12.5 billion (for H_2 infrastructure) for each percent of the light duty fleet using hydrogen as a fuel. Then this cost is spread over the 40 years the model runs (from 2010 to 2050).
- Natural gas can be used as a transportation fuel in the cars and light trucks sector as well as heavy trucks sector. The percent of the sector that uses natural gas (in 2050) can be specified by the user (with default present day values of 0.17% for cars and light trucks, and 0.27% for heavy trucks). The natural gas use is calculated as linear growth to the user specified 2050 values.

- If the user ramps up natural gas usage as a transportation fuel, infrastructure cost for natural gas distribution is added into the overall capital cost. The model uses a cost of $2 million for each filling station built per each additional million GGE (Gallon Gas Equivalent) needed.
- The other transportation efficiency factor is the percentage increase of efficiency in the transportation sector for everything but cars and light trucks (e.g. trains, heavy trucks, airplanes, ships, etc.). The default value is 0.1% per year. The efficiency for cars and light trucks is accounted for with the projected average MPG for 2020 and 2050. The car and light truck portion of the transportation sector is assumed to be about 58% of the sector, leaving 42% for the “other” transportation portion of the sector. The other transportation efficiency factor also affects oil usage (and imports). The amount of energy saved (from efficiency) is converted to barrels of oil not used using the conversion factor 5.8 million BTUs per barrel of crude oil.

A-7. New Processes and Plants

The following table (Table A-1) shows a summary of New Processes/Plants the model builds to achieve energy goals.

Table A-1. New plant data assumptions.

Name	Size	Capacity Factor (%)	Lead Time (Years)	Plant Life (Years)	Unit Cap Cost (million $)
HTGR Electricity Production [1]	4 × 600 MWt	90	6	60	4,810
HTGR cogeneration plant [2]	4 × 600 MWt	90	6	60	4,810
HTGR Hydrogen production [3]	1 × 600 MWt	90	6	40	1,350
HTGR Ammonia Production [4]	0.75 × 600 MWt	90	6	40	2,533
HTGR NG to Liquids [5a]	600 MWt	90	6	40	3,007
HTGR Coal to Liquids [5b]	11 × 600 MWt	90	6	40	16,537
HTGR NG to Gasoline [6a]	1.2 × 600 MWt	90	6	40	3,031
HTGR Coal to Gasoline [6b]	11.45 × 600 MWt	90	6	40	18,474
HTGR Coal to NG [7]	5.61 × 600 MWt	90	6	40	8,455
HTGR SAGD [8]	600 MWt	90	6	40	2,720
HTGR Oil Shale Extraction [17]	3.75 × 600 MWt	90	6	40	6,255
H_2 Steam Methane Reformer [15]	6.3 MWe	80	3	40	256
New LWRs [9]	1350 MWe	90	6	60	7,208
Coal IGCC plant w/ CCS [10]	550 MWe	85	4	50	2,541*
New Onshore Wind Farm [11]	50 MWe	37.3	3	20	122
New Solar Plant [12]	100 MWe	37.3	3	30	472
New Geothermal Plant [13]	50 MWe	84	4	30	207
Natural Gas Electric Plant [14]	400 MWe	87	3	50	401
New Small Modular Reactors: [16]	*Avg:*	*90*	*3*	*38*	*433*
mPower	125 MWe	90	3	60	500
NuScale	45 MWe	90	3	60	180
HPM	25 MWe	90	3	10	50
PRISM	311 MWe	90	3	40	1,000
Toshiba 4S	50 MWe	90	3	30	125
EM^2	240 MWe	90	3	30	800

* $2,941 for Coal IGCC plant with 90% CCS; $2,906 for plant with 70% CCS; $2,822 for plant with 50% CCS; $2,753 for plant with 30% CCS; and $2,541 for plant with no CCS.

A-8. REFERENCES

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2. INL, 2009, "Integration of High-Temperature Gas-Cooled Reactors into Industrial Process Applications," INL/EXT-09-16942, Rev 1, February 2010.

3. TEV-666, 2010, "Nuclear-Integrated Ammonia Production Analysis," NGNP Project, Rev 2, May 2010.

4. TEV-667, 2009, "Nuclear-Assisted Methanol-to-Gasoline (MTG) Production Analysis," NGNP Project, Rev 1, May 2010.

5. TEV-671, 2010, "Nuclear Integrated Substitute Natural Gas Production Analysis," NGNP Project, Rev. 1, May 2010.

6. TEV-672, 2010, "Nuclear Integrated Coal and Gas to Liquids Production Analysis," NGNP Project, Rev. 1, May 2010.

7. TEV-674, 2010, "Power Cycles for the Generation of Electricity from a Next Generation Nuclear Plant," NGNP Project, Rev. 1, May 2010.

8. TEV-693, 2010, "Nuclear-Integrated Hydrogen Production Analysis," NGNP Project, Rev. 1, May 2010.

9. TEV-704, 2010, "Nuclear-Integrated Oil Sands Recovery Via Steam-Assisted Gravity Drainage," NGNP Project, Rev. 1, May 2010.

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11. NETL, 2007, "Cost and Performance Baseline for Fossil Energy Plants, Vol. 1, Bituminous Coal and Natural Gas to Electricity Final Report," DOE/NETL-2007/1281, May 2007.

12. DOE EERE, 2009, "Transportation Energy Data Book," ORNL-6984, Edition 28, 2009.

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Appendix B

2050 SIM Test Approach

The table below shows the 2050 SIM test approach.

#	Requirements	Design	Implementation	Test
1	R1.Evaluate the quantity and types of energy resources (e.g., transportation fuels and electricity) that are currently being produced and utilized.	D1. Display in graphical and tabular forms EIA data relative to the quantity and types of energy resources (e.g., transportation fuels and electricity) that are currently being produced and utilized.	I1. The energy demand/use for each energy sector is calculated by multiplying the total energy for that sector by the percentage of energy in that supply source sector. For example, (Nuclear/Electricity Sector) = (Total Electricity Sector)*(0.22). This amount of energy is then adjusted (in the appropriate years) by additions and/or subtractions depending on what plants are built and new energy sector percentages are calculated each year out to 2050.	T1. Set all user inputs to default (Reset button on "Control" sheet). Verify that the desired 2050 electricity mix percentages match the starting values: Nuclear 22.0%, Renewable 11.0%, Coal 48.0%, Natural Gas 18.0%, Petroleum 1.0%. Press the Calculate button on the "Control" sheet. Verify that the actual final energy mix percentages ("Control" sheet, cells I12 through I16) are within 1% of the desired percentages. (Because of differing plant sizes it is not possible to get an exact replacement of plants going out of service.)
2	R2. Project future energy demands and uses.	D2. Display in graphical and tabular forms existing EIA data and project EIA data for future energy demands and uses to 2050.	I2. The energy for each of the energy sectors in each supply source is calculated in tabular form before and after adjustments (additions and subtractions based on user strategy). Before and after energy graphs are then displayed in appropriate places in the output to show changes from 2010 to 2050.	T2. Using the same user settings as set at the end of Test T1, change the nuclear electric sector goal percentage to 25.0, the renewable to 14.0%, the coal to 40.0%, and the natural gas to 20% (on the "Control" sheet). Calculate results and verify that the proper adjustments (nuclear electric went up, renewable electric went up, coal electric went down, natural gas electric went up) were made to the correct energy supply sectors (Adjustments to Supply Sources (Billion BTUs) section in "Sector_Supply" sheet) and verify that the 2050 percentages of each supply source are within 1% of the specified goal percentages ("Control" sheet, cells I12 through I16).

#	Requirements	Design	Implementation	Test
3	R3 Assess the potential capability of HTGRs to displace current energy resources in various sectors with a carbon-free energy source.	D3. Estimate the potential energy sector penetration of HTGR products (and other energy sources) by calculating the effect on the energy sector balance. Display the results showing the number of plants built, energy created/used, and cost.	I3. The data/information for each plant/process is calculated in its own table in the spreadsheet. The list of information calculated for each process is: a. Number of plants (spread over the specified years of operation). b. Total project cost spread over the appropriate years for a given lead time. c. Amount of energy created in the appropriate units (BTU/yr) taking into account appropriate capacity factors. d. Amount of energy commodities not used (or additional commodities used) (e.g., amount of natural gas not used if building an HTGR to replace a natural gas plant).	T3. Reset all user inputs to default values (Reset button on "Control" sheet). Select the "DataTable" worksheet. Clear out all values from the interior of the main table (C5:AL65, so that no plants/processes are built). Enter a "1" in the 2025 line for each plant/process. In the "Processes" worksheet, verify that the total project cost (TPC) is calculated and spread over the specified lead time for each process (leading up to a 2025 operation start date). Also verify that the energy created is calculated correctly in the appropriate units and are connected to the appropriate energy sector supply source adjustments (Figures 1-6). Also verify that other energy commodities used/not used were calculated correctly for each process.
4	R4. Assess the potential impacts of deploying HTGRs (and other energy sources) relative to GHG emissions.	D4. Allow the user to specify a future energy strategy including the elements listed in D3 and estimate/calculate the effect on GHG emissions and cost. Display the number (and type) of plants built (including HTGRs) to carry out the user-specified strategy.	I4. Estimate the GHG emissions for a given strategy by using an "emissions per energy" conversion factor for each energy sector in each supply source. For example, for 2010 the total emissions for natural gas electricity were 408 million metric tons CO2. The total energy supplied from that sector for 2010 was 7,040,197 billion BTUs. Dividing these gives 5.8×10^{-5} million metric tons CO2 per billion BTU. This factor is used to calculate future emissions based on the adjusted amount of energy produced (I1) in the given year for a given sector.	T4. a. Reset all user inputs to default values (Reset button on "Control" sheet). On the "Control" sheet, change the nuclear electric sector goal percentage to 55.0, the renewable to 25.0%, the coal to 1.0%, and the natural gas to 18%. Calculate results and verify that the CO2 emissions for coal (electricity) taper off to zero (or near zero) by 2050 (Electricity CO_2 Emissions graph on same sheet). b. On the "Control" sheet, change the nuclear electric sector goal percentage to 55.0%, the renewable to 25.0%, the coal to 18.0%, and the natural gas to 1%. Calculate results and verify that the CO_2 emissions for natural gas taper off to zero (or near zero) by 2050 (Electricity CO_2 Emissions graph on same sheet). c. Reset all user inputs to default values. Change the percent electric cars in 2050 input to 80% (Cell H25, "Control" sheet). Calculate results (Calculate button on the "Control" sheet), and verify that the emissions for petroleum decreased significantly (Transportation CO2 Emissions graph) and electricity emissions increased

#	Requirements	Design	Implementation	Test
				significantly (see the Electricity CO_2 Emissions graph) thus showing the proper shift from petroleum to electricity. d. Reset all user inputs to default values. In the Industrial section of the "Control" worksheet, enter 30 for the number of HTGR Co-generation plants to build. Press the Calculate button and verify that the coal and natural gas industrial sectors both shrunk and the nuclear industrial sector grew in 2050 (looking at the pie charts in the expanded input section). The maximum needed energy limit should have been met for the co-generation market and the number of plants built should have been changed to 27 (which is roughly equivalent to 2 quadrillion BTUs). Also, verify that emissions decreased in 2050 for the industrial sector (see the Industrial CO2 Emissions graph). e. Reset all user inputs to default values. In the Industrial section of the "Control" worksheet, enter 30 for the number of HTGR Hydrogen Production plants and 12 for the number of Ammonia Production plants. Press calculate and verify that natural gas emissions decreased for the industrial sector in 2050 (see the Industrial CO_2 Emissions graph). f. Reset all user inputs to default values. On the "Emissions" worksheet, note the value in Cell BE131 (which is the net emissions for electricity production). Manually calculate the emissions change for one HTGR electric plant replacing a coal plant by doing the following: - Emissions=(energy)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy) - (1032 MW)(0.9)(24 h/day)(365.25 days/yr)(10,460,000 BTU/MWh)

#	Requirements	Design	Implementation	Test
				- Take that result and divide by 1 × 109 to get billion BTU. - Take that result times (9.817×10^{-5}) million MT CO_2/Billion BTU to get the CO2 change. - On the "DataTable" worksheet enter a 1 in the year 2040 for an HTGR electric plant to replace a coal plant (Cell C35). Now look at the value in cell BE131 in worksheet "Emissions" and take the difference from before the one HTGR electric plant was built. Compare this to the manual calculation and verify the calculations match. g. Reset all user inputs to default values. On the "Emissions" worksheet, note the value in Cell BG131 (which is the net emissions for natural gas [NG]). Manually calculate the emissions change for one HTGR cogeneration plant replacing a natural gas cogeneration plant by doing the following: - Emissions = (energy)(percent thermal)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy) + (energy)(percent electric)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy) - (2400 MW)(0.69)(0.9)(24 h/day)(365.25 days/yr)(3,412,142 BTU/MWh) + (2400 MW)(0.15)(0.9)(24 h/day)(365.25 days/yr)(10,460,000 BTU/MWh) - - Take that result and divide by 1×10^9 to get billion BTU. - Take that result times (5.334×10^{-5}) million MT CO2/Billion BTU to get the CO2 change. - On the "DataTable" worksheet enter a 1 in the year 2040 for an HTGR cogeneration plant to replace a natural gas cogeneration plant (Cell G35). Now look at the value in Cell BG131 in worksheet "Emissions" and

#	Requirements	Design	Implementation	Test
				take the difference from before the one HTGR electric plant was built. Compare this to the manual calculation and verify the calculations match.
5	R5. Assess the potential for HTGR deployment to create new jobs.	D5. Estimate the number of jobs (including HTGRs) over time created by a user specified energy strategy and display the results.	I5. Estimate the number of jobs by year for the given energy strategy by calculating the job breakdown into the following seven areas: Engineering, Manufacturing, Construction, Operations, Decommissioning, Induced Operations, and Induced Construction. Each of these job areas is assigned a duration and a yearly number of associated jobs. The operation duration is equal to the plant life and starts at the year specified by the user as the start year of operation. The construction duration is the lead time minus 1 year and occurs in the years leading up to operations. Engineering and manufacturing start at the beginning of the lead time and last 1 to 3 years depending on plant data. Decommissioning starts at the end of operations and lasts 2 years. Induced construction and operations jobs occur during construction and operations respectively.	T5. Reset all user inputs to default values. Select the “DataTable” worksheet. Clear out all values from table (so that no plants/processes are built). Enter a 1 in the 2030 line for each plant/process. Go to the “Jobs” worksheet and press Update Job Data. Now go to the “Jobs Data” worksheet and verify that the jobs data was populated correctly in data block for each plant/process.
6	R6. Assess the potential for HTGR deployment to reduce foreign energy resources (primarily reducing foreign oil imports).	D6. Estimate the effect of a user specified energy strategy on the amount of foreign oil imports needed in the future (as well as natural gas imports/usage) and display the results.	I6. Estimate the effect on oil imports by taking the projected import data from EIA and decreasing the import need based on the energy strategy specified by the user. The plants/processes that effect oil imports are: HTGR Natural Gas to Diesel, HTGR Coal to Diesel, HTGR Natural Gas to Gasoline, HTGR Coal to Gasoline, HTGR Steam Assisted Gravity Drainage, HTGR Assist Oil Shale Extraction, electric car usage, ethanol usage, and higher MPG standards. Natural Gas imports are calculated in a similar manner, adding and subtracting from the	T6. a. Reset all user inputs to default values. On the “Control” sheet, set each industrial process to built 1 of each plant. Press Calculate and verify that the correct plants were built (see “DataTable” sheet). b. Reset all user inputs to default values. Change HTGR Hydrogen Production to 50. Press Calculate and verify that industrial emissions decreased and that the number of conventional hydrogen steam methane reformer plants that were needed was less than the base case. Also verify that natural gas usage decreased. c. Reset all user inputs to default values. Change HTGR Assist Coal to Natural Gas to 90. Press Calculate and verify that coal usage went up from the base case.

#	Requirements	Design	Implementation	Test
			projected EIA import data based on the user selected plants/processes that affect natural gas usage.	d. Reset all user inputs to default values. Change HTGR Assist Natural Gas to Diesel to 20. Press Calculate and verify that natural gas usage went up from the base case and that oil imports and usage went down. e. Reset all user inputs to default values. Change HTGR Assist Coal to Diesel to 20. Press Calculate and verify that coal usage went up from the base case and that oil imports and usage went down. f. Reset all user inputs to default values. Change HTGR Assist Natural Gas to Gasoline to 20. Press Calculate and verify that natural gas usage went up from the base case and that oil imports and usage went down. g. Reset all user inputs to default values. Change HTGR Assist Coal to Gasoline to 20. Press Calculate and verify that coal usage went up from the base case and that oil imports and usage went down. h. Reset all user inputs to default values. Change HTGR Assist SAGD to 20. Press Calculate and verify that oil imports went down. i. Reset all user inputs to default values. Change HTGR Assist Oil Shale Extraction to 20. Press Calculate and verify that oil imports went down. j. Reset all user inputs to default values. Change HTGR Co-generation to 20. Press Calculate and verify that natural gas and coal usage went down. Also verify that industrial emissions went down.
7	R7 Assess the potential for HTGR deployment to increase prices stability.	D7 Estimate the effect of a user specified energy strategy on the stability of the price of oil and natural gas and display the results.	I7. Estimate the effect on energy price stability by summing the variances of energy price returns weighted by the square of their respective energy types. Taking the square root of the result returns the volatility of the effective price of energy. The overall effective price of energy and its volatility are input, along with some user defined inputs,	T7 a. Set all inputs to default values. Verify that when no improvements are made (e.g., nothing is done to offset oil use) then oil and natural gas equivalent energy should be zero or near zero. The price stability graph should show no change from baseline b. Set all inputs to values specified in Appendix E. Change the energy goal profile (as specified in Appendix E) and run the simulation. Verify that the

#	Requirements	Design	Implementation	Test
			into the Black-Scholes Option Pricing Model. An "at-the-money" call option is priced to value the energy buyer's risk of volatile price increases. Price and volatility contribute to the call option price. Changes in the call option price will mostly be attributable to changes in the overall effective energy price level, and the effective energy price's volatility. Energy price data is taken from EIA records and forecasts. For the years 2035 to 2050 prices are estimated by linearly continuing the trend found in EIA's forecast data. Price volatilities are estimated using Excel's Standard Deviation function on data obtained from EIA, St. Louis Federal Reserve, and commodity exchange spot prices. Volatilities were estimated using the most recent 10 years of annual price data.	Effective Oil Price Volatility graph shows a 26.6% reduction. Verify that the quantities of oil and natural gas equivalent energy are correct and from actual sources under consideration (as specified in detail in Appendix D and E). These outputs listed in Appendix E can be verified by "hand" calculations using the formulas in Appendix D.

#	Requirements	Design	Implementation	Test
8	R8. Assess the effect of new light-water reactors, coal-fired IGCC electric plants, natural gas, and renewables on the energy mix and GHG emissions in the United States.	D8. Estimate the amount of new LWRs and coal fired electric plants are needed to replace capacity that is expiring or going offline in the future. Calculate the necessary power plants to build to achieve the user specified goals for a given strategy (including LWRs, coal fired plants, wind farms, solar plants, geothermal plants, and natural gas fired plants). Calculate the effect of these new plants on the energy mix, GHG emissions, and cost.	I8. Using data of the existing LWR fleet, estimate the amount of new LWR plants that will be needed to replace existing capacity that will be going offline in the future. (Do the same calculation for coal fired electric plants). If the user specifies to renew licenses for the LWR's, then extend those plants that have not already had a license extension by 20 years. As the user sets goals for the electricity energy mix, build plants as necessary to achieve the percentage goals. Start building in the first year the given plant can be built and increment out to 2050. If the goal is not reached for a sector when 2050 occurs, then loop back to the first year and build more each year until the goal is attained.	T8. a. Reset all user inputs to default values. Verify that the model built the correct number of new LWRs and new coal plants to maintain the current (2010) energy sector mix for electricity given the demand (see columns BV and CF in sheet "Sector_Supply"). b. On the "Control" sheet, change the nuclear electric sector goal percentage to 24.0%, the renewable percent to 12.0%, the coal percent to 44.0%, and the natural gas percent 19%. Select LWR & HTGR for New Nuclear. Calculate and verify that the model built HTGRs and LWRs to replace coal. Also, verify that the model built renewable plants to replace coal close to the specified proportions. Also verify that the model built some natural gas electric plants to replace coal. (See the "DataTable" worksheet.)

#	Requirements	Design	Implementation	Test
9	R9. Assess the effect of projected energy efficiency/conservation efforts on the energy use/demand and GHG emissions in the United States	D9. Estimate the effect of projected energy efficiency/conservation efforts on reducing demand in all energy sectors and reduction of GHG emissions.	I9. Estimate the effect of projected energy efficiency by taking a user input of percent efficiency per year and applying that percent decrease to the overall demand for the U.S. (except for the transportation sector). The projected efficiency for the transportation sector is calculated by using the future MPG standards (for cars and light trucks) and a percent improvement for the remainder of the transportation sector. Estimate conservation by using energy consumption per GDP percent change per year factor (default 1.9% decrease per year). Or if demand is driven by population, estimate conservation by using and energy consumption per capita percent change per year factor (default 0.3% decrease per year).	T9. a. Go to the "Control" worksheet. Reset all user inputs to default values. Change Energy Reduction due to Efficiency to 1% per year. Calculate and verify that the energy demand and supply decreased appropriately (see Energy Supply graph on same sheet). b. Reset all user inputs to default values. Change GDP Projection % Change per year to 2.9%. Calculate and verify that the energy demand and supply increased appropriately. c. Reset all user inputs to default values. Change GDP Energy Consumption per GDP % Change per year to -2.4%. Calculate and verify that the energy demand decreased appropriately. d. Reset all user inputs to default values and select Driven by Population (for energy demand). Change US Population Projection % change to 1.2% per year. Calculate and verify that the energy demand increased appropriately. e. Reset all user inputs to default values and select Driven by Population. Change Energy Consumption per Capita % change to -0.8% per year. Calculate and verify that the energy demand decreased appropriately. f. Reset all user inputs to default values. On "Control" worksheet, set 2020 MPG to 35 and 2050 MPG to 55. Verify that the energy demand (due to efficiency) decreased appropriately (Energy Supply Breakdown graph). Also verify that the CO2 emissions for petroleum decreased (Transportation graph for CO2 emissions). g. Reset all user inputs to default values. On "Control" worksheet, set Transportation Efficiency to 1%. Verify that the energy demand (due to efficiency) decreased appropriately (Energy Supply Breakdown graph). Also verify that the CO2 emissions for petroleum decreased (Transportation graph for CO2 emissions).

Appendix B

Appendix C

2050 SIM Test Results

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
1	T1. Set all user inputs to default (Reset button on “Control” sheet). Verify that the desired 2050 electricity mix percentages match the starting values: Nuclear 22.0%, Renewable 11.0%, Coal 48.0%, Natural Gas 18.0%, Petroleum 1.0%. Press the Calculate button on the “Control” sheet. Verify that the actual final energy mix percentages (“Control” sheet, cells I12 through I16) are within 1% of the desired percentages. (Because of differing plant sizes it is not possible to get an exact replacement of plants going out of service.)				
2	T2. Using the same user settings as set at the end of Test T1, change the nuclear electric sector goal percentage to 25.0, the renewable to 14.0%, the coal to 40.0%, and the natural gas to 20% (on the “Control” sheet). Calculate results and verify that the proper adjustments (nuclear electric went up, renewable electric went up, coal electric went down, natural gas electric went up) were made to the correct energy supply sectors (Adjustments to Supply Sources (Billion BTUs) section in “Sector_Supply” sheet) and verify that the 2050 percentages of each supply source are within 1% of the specified goal percentages (“Control” sheet, cells I12 through I16).				
3	T3. Reset all user inputs to default values (Reset button on “Control” sheet). Select the “DataTable” worksheet. Clear out all values from the interior of the main table (C5:AL65, so that no plants/processes are built). Enter a “1” in the 2025 line for each plant/process. In the “Processes” worksheet, verify that the total project cost (TPC) is calculated and spread over the specified lead time for each process (leading up to a 2025 operation start date).				

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
	Also verify that the energy created is calculated correctly in the appropriate units and are connected to the appropriate energy sector supply source adjustments (Figures 1-6). Also verify that other energy commodities used/not used were calculated correctly for each process.				
4	T4. a. Reset all user inputs to default values (Reset button on “Control” sheet). On the “Control” sheet, change the nuclear electric sector goal percentage to 55.0, the renewable to 25.0%, the coal to 1.0%, and the natural gas to 18%. Calculate results and verify that the CO2 emissions for coal (electricity) taper off to zero (or near zero) by 2050 (Electricity CO_2 Emissions graph on same sheet).				
	b. On the “Control” sheet, change the nuclear electric sector goal percentage to 55.0%, the renewable to 25.0%, the coal to 18.0%, and the natural gas to 1%. Calculate results and verify that the CO_2 emissions for natural gas taper off to zero (or near zero) by 2050 (Electricity CO_2 Emissions graph on same sheet).				
	c. Reset all user inputs to default values. Change the percent electric cars in 2050 input to 80% (Cell H25, “Control” sheet). Calculate results (Calculate button on the “Control” sheet), and verify that the emissions for petroleum decreased significantly (Transportation CO2 Emissions graph) and electricity emissions increased significantly (see the Electricity CO_2 Emissions graph) thus showing the proper shift from petroleum to electricity.				
	d. Reset all user inputs to default values. In the Industrial section of the “Control” worksheet, enter 30 for the number of HTGR Co-generation plants to build. Press the Calculate button and verify that the coal and natural gas industrial sectors both shrunk and the nuclear industrial sector grew in 2050 (looking at the pie charts in the expanded input section). The maximum needed energy limit				

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
	should have been met for the co-generation market and the number of plants built should have been changed to 27 (which is roughly equivalent to 2 quadrillion BTUs). Also, verify that emissions decreased in 2050 for the industrial sector (see the Industrial CO2 Emissions graph).				
	e. Reset all user inputs to default values. In the Industrial section of the "Control" worksheet, enter 30 for the number of HTGR Hydrogen Production plants and 12 for the number of Ammonia Production plants. Press calculate and verify that natural gas emissions decreased for the industrial sector in 2050 (see the Industrial CO_2 Emissions graph).				
	f. Reset all user inputs to default values. On the "Emissions" worksheet, note the value in Cell BE131 (which is the net emissions for electricity production). Manually calculate the emissions change for one HTGR electric plant replacing a coal plant by doing the following: - Emissions=(energy)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy) - (1032 MW)(0.9)(24 h/day)(365.25 days/yr)(10,460,000 BTU/MWh) - Take that result and divide by 1 × 109 to get billion BTU. - Take that result times (9.817×10^{-5}) million MT CO_2/Billion BTU to get the CO2 change. - On the "DataTable" worksheet enter a 1 in the year 2040 for an HTGR electric plant to replace a coal plant (Cell C35). Now look at the value in cell BE131 in worksheet "Emissions" and take the difference from before the one HTGR electric plant was built. Compare this to the manual calculation and verify the calculations match.				

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
	g. Reset all user inputs to default values. On the "Emissions" worksheet, note the value in Cell BG131 (which is the net emissions for natural gas [NG]). Manually calculate the emissions change for one HTGR cogeneration plant replacing a natural gas cogeneration plant by doing the following: - Emissions = (energy)(percent thermal)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy) + (energy)(percent electric)(capacity factor)(hours/day)(days/year)(BTU/MWh)(emissions/energy) - (2400 MW)(0.69)(0.9)(24 h/day)(365.25 days/yr)(3,412,142 BTU/MWh) + (2400 MW)(0.15)(0.9)(24 h/day)(365.25 days/yr)(10,460,000 BTU/MWh) - - Take that result and divide by 1 × 109 to get billion BTU. - Take that result times (5.334×10^{-5}) million MT CO2/Billion BTU to get the CO2 change. - On the "DataTable" worksheet enter a 1 in the year 2040 for an HTGR cogeneration plant to replace a natural gas cogeneration plant (Cell G35). Now look at the value in Cell BG131 in worksheet "Emissions" and take the difference from before the one HTGR electric plant was built. Compare this to the manual calculation and verify the calculations match.				
5	T5. Reset all user inputs to default values. Select the "DataTable" worksheet. Clear out all values from table (so that no plants/processes are built). Enter a 1 in the 2030 line for each plant/process. Go to the "Jobs" worksheet and press Update Job Data. Now go to the "Jobs Data" worksheet and verify that the jobs data was populated correctly in data block for each plant/process.				
6	T6. a. Reset all user inputs to default values. On the "Control" sheet, set each industrial process to built 1 of each plant. Press Calculate and verify that the correct plants were built (see "DataTable" sheet).				

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
	b. Reset all user inputs to default values. Change HTGR Hydrogen Production to 50. Press Calculate and verify that industrial emissions decreased and that the number of conventional hydrogen steam methane reformer plants that were needed was less than the base case. Also verify that natural gas usage decreased.				
	c. Reset all user inputs to default values. Change HTGR Assist Coal to Natural Gas to 90. Press Calculate and verify that coal usage went up from the base case.				
	d. Reset all user inputs to default values. Change HTGR Assist Natural Gas to Diesel to 20. Press Calculate and verify that natural gas usage went up from the base case and that oil imports and usage went down.				
	e. Reset all user inputs to default values. Change HTGR Assist Coal to Diesel to 20. Press Calculate and verify that coal usage went up from the base case and that oil imports and usage went down.				
	f. Reset all user inputs to default values. Change HTGR Assist Natural Gas to Gasoline to 20. Press Calculate and verify that natural gas usage went up from the base case and that oil imports and usage went down.				
	g. Reset all user inputs to default values. Change HTGR Assist Coal to Gasoline to 20. Press Calculate and verify that coal usage went up from the base case and that oil imports and usage went down.				

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
	h. Reset all user inputs to default values. Change HTGR Assist SAGD to 20. Press Calculate and verify that oil imports went down.				
	i. Reset all user inputs to default values. Change HTGR Assist Oil Shale Extraction to 20. Press Calculate and verify that oil imports went down.				
	j. Reset all user inputs to default values. Change HTGR Co-generation to 20. Press Calculate and verify that natural gas and coal usage went down. Also verify that industrial emissions went down.				
7	T7 a. Set all inputs to default values. Verify that when no improvements are made (e.g., nothing is done to offset oil use) then oil and natural gas equivalent energy should be zero or near zero. The price stability graph should show no change from baseline				
	b. Set all inputs to values specified in Appendix E. Change the energy goal profile (as specified in Appendix E) and run the simulation. Verify that the Effective Oil Price Volatility graph shows a 26.6% reduction. Verify that the quantities of oil and natural gas equivalent energy are correct and from actual sources under consideration (as specified in detail in Appendix D and E). These outputs listed in Appendix E can be verified by “hand” calculations using the formulas in Appendix D.				
8	T8. a. Reset all user inputs to default values. Verify that the model built the correct number of new LWRs and new coal plants to maintain the current (2010) energy sector mix for electricity given the demand (see columns BV and CF in sheet “Sector_Supply”).				
	b. On the “Control” sheet, change the nuclear electric sector goal percentage to 24.0%, the renewable percent to 12.0%, the coal				

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
	percent to 44.0%, and the natural gas percent 19%. Select LWR & HTGR for New Nuclear. Calculate and verify that the model built HTGRs and LWRs to replace coal. Also, verify that the model built renewable plants to replace coal close to the specified proportions. Also verify that the model built some natural gas electric plants to replace coal. (See the “DataTable” worksheet.)				
9	T9. a. Go to the “Control” worksheet. Reset all user inputs to default values. Change Energy Reduction due to Efficiency to 1% per year. Calculate and verify that the energy demand and supply decreased appropriately (see Energy Supply graph on same sheet).				
	b. Reset all user inputs to default values. Change GDP Projection % Change per year to 2.9%. Calculate and verify that the energy demand and supply increased appropriately.				
	c. Reset all user inputs to default values. Change GDP Energy Consumption per GDP % Change per year to -2.4%. Calculate and verify that the energy demand decreased appropriately.				
	d. Reset all user inputs to default values and select Driven by Population (for energy demand). Change US Population Projection % change to 1.2% per year. Calculate and verify that the energy demand increased appropriately.				
	e. Reset all user inputs to default values and select Driven by Population. Change Energy Consumption per Capita % change to -0.8% per year. Calculate and verify that the energy demand decreased appropriately.				
	f. Reset all user inputs to default values. On “Control” worksheet, set 2020 MPG to 35 and 2050 MPG to 55. Verify that the energy demand (due to efficiency) decreased appropriately (Energy				

#	Test	Results	Meets Requirements (Y/N)	Date	Initial
	Supply Breakdown graph). Also verify that the CO2 emissions for petroleum decreased (Transportation graph for CO2 emissions).				
	g. Reset all user inputs to default values. On “Control” worksheet, set Transportation Efficiency to 1%. Verify that the energy demand (due to efficiency) decreased appropriately (Energy Supply Breakdown graph). Also verify that the CO2 emissions for petroleum decreased (Transportation graph for CO2 emissions).				

Appendix D

Energy Price Stability: Implementation

1. Petroleum

This section discusses the calculation of the volatility of effective oil energy prices.

1.1 Sources for Actual Petroleum Quantities

1.1.1 Baseline

The baseline calculations are a measure of the actual amount of oil being consumed for energy purposes under the "business-as-usual" system and form a basis for comparison. The following sheets are used with the associated cell references for the model-produced quantities and the associated accounting.
Baseline Source:

- Sheet: "Sector_Supply", Total Petroleum Demand (before efficiency and electric cars) column "S" starting at cell "S70."

1.1.2 After Improvements

Oil demand changes in the following ways:

- Efficiency and conservation ~ efficiency & conservation ↑⇒ oil ↓
- Transportation Sector ~ Shifts to alternative energy ↑⇒ oil ↓
- Industrial Sector ~ Cogen production of liquids ↑⇒ oil ↓

Pre-adjustment, Post-efficiency Demand for Oil:

- Sheet: "Sector_Supply", Total Petroleum Demand (after efficiency) column "S" starting at cell "S13."

Subtractions from Total Petroleum Demand (after efficiency)

1. Billion BTU from Transportation to Electric "Sector_Supply!DU"
2. Billion BTU from Petro-based Transportation to Renewable Transportation (Ethanol) "Sector_Supply!DT"
3. Billion BTU from Petro-based Transportation to Renewable Transportation (Biodiesel) "Sector_Supply!DX"
4. Billion BTU from Petro-based Transportation to Natural Gas Transportation (Cars & light trucks) "Sector_Supply!DY"
5. Billion BTU from Petro-based Transportation to Natural Gas Transportation (Heavy trucks) "Sector_Supply!DZ"
6. Billion BTU from Petro-based Transportation to Hydrogen Transportation (Cars & light trucks) "Sector_Supply!EA"
7. Natural Gas to Methanol to Gasoline HTGR Plant reduction to Petroleum Industry "Processes!I608"
8. Natural Gas to Liquids HTGR Plant reduction to Petroleum Industry "Processes!I408"
9. Coal to Liquids HTGR Plant reduction to Petroleum Industry "Processes!I508"
10. Coal to Methanol to Gasoline HTGR Plant reduction to Petroleum Industry "Processes!I708"
11. Petroleum Reductions from Nuclear Integrated SAGD (Barrels offset) "Processes!K908"

12. Petroleum Reductions from Nuclear Integrated Oil Shale Extraction (Barrels offset) “Processes!K1908”

1.2 Sources for Alternative Energy Quantities

1.2.1 Baseline

The baseline level of alternative energy is set to zero. At the baseline, only actual petroleum is used, hence “oil-alternative” energies are assigned as zero.

1.2.2 After Improvements

After model improvements, alternative energies replace oil in the various sectors
Alternative energy quantities are determined as follows:

- Electric ~ Conversion to electric vehicles ↑⇒ electricity use in transportation ↑⇒ alternative energy ↑
- Renewables ~ Conversion to renewable liquid fuels ↑⇒ alternative energy ↑
- Natural Gas ~ Conversion to NG vehicles ↑⇒ alternative energy ↑
- Hydrogen ~ Conversion to Hyrdogen vehicles ↑⇒ alternative energy ↑
- Conversions ~ Nuclear assisted energy source conversion ↑⇒ alternative energy ↑

Alternative energies above are summed each year as the substitute energy for oil used.

1. Billion BTU from Transportation to Electric “Sector_Supply!DU”
2. Billion BTU from Petro-based Transportation to Renewable Transportation (Ethanol) “Sector_Supply!DT”
3. Billion BTU from Petro-based Transportation to Renewable Transportation (Biodiesel) “Sector_Supply!DX”
4. Billion BTU from Petro-based Transportation to Natural Gas Transportation (Cars & light trucks) “Sector_Supply!DY”
5. Billion BTU from Petro-based Transportation to Natural Gas Transportation (Heavy trucks) “Sector_Supply!DZ”
6. Billion BTU from Petro-based Transportation to Hydrogen Transportation (Cars & light trucks) “Sector_Supply!EA”
7. Natural Gas to Methanol to Gasoline HTGR Plant reduction to Petroleum Industry “Processes!I608”
8. Natural Gas to Liquids HTGR Plant reduction to Petroleum Industry “Processes!I408”
9. Coal to Liquids HTGR Plant reduction to Petroleum Industry “Processes!I508”
10. Coal to Methanol to Gasoline HTGR Plant reduction to Petroleum Industry “Processes!I708”
11. Petroleum Reductions from Nuclear Integrated SAGD (Barrels offset) “Processes!K908”
12. Petroleum Reductions from Nuclear Integrated Oil Shale Extraction (Barrels offset) “Processes!K1908”

1.3 Calculation Methods

The calculation methods employed are the same for both the baseline and the projected change.

Definition 1.3.1 Oil and Alternative Energy Decomposition:
Let q_o be the barrels of oil consumed and q_a the quantity of alternative energy used in place of oil in barrel equivalent terms. Then

$$Q = q_o + q_a$$

where Q is the total barrel equivalent quantity of oil or alternative energy consumed in the period.

Computation 1.3.1:
"OilPriceStability!N*" = "OilPriceStability!L*" + "OilPriceStability!M*"

Definition 1.3.2: Crude Oil Weight and Alternative Energy Weight
The **crude weight** w_c and **alternative weight** w_a are defined as,

$$\mathrm{w_c} := \frac{q_o}{Q} = \frac{q_o}{q_o + q_a}$$

$$\mathrm{w_a} := \frac{q_a}{Q} = \frac{q_a}{q_o + q_a}$$

Computation 1.3.2:
Crude weight: "OilPriceStability!O*" = "OilPriceStability!L*" ÷ "OilPriceStability!N*"
Alternative weight: "OilPriceStability!P*" = "OilPriceStability!M*" ÷ "OilPriceStability!N*"

Definition 1.3.3: Total Cost and Effective Price
If p_o and p_a are the prices of crude oil and alternative energy respectively, then we define total cost C as,

$$C := p_o q_o + p_a q_a$$

and the effective price p_E can then be defined as

$$\mathrm{p_E} := \frac{\mathrm{C}}{Q} = \frac{p_o q_o + p_a q_a}{q_o + q_a}$$

Computation 1.3.3:
Total cost: "OilPriceStability!S*" = ("OilPriceStability!L*" × "OilPriceStability!Q*") + ("OilPriceStability!M*" × "OilPriceStability!R*")

Effective price: "OilPriceStability!T*" = "OilPriceStability!S*" ÷ "OilPriceStability!N*"

Definition 1.3.4: Volatility
If p is the price of a commodity and δ_p the annual percent change in p, then we define the **volatility** of p as the standard deviation of δ_p which we'll denote as $\sigma_\delta := \sqrt{\sigma_\delta^2}$ where σ_δ^2 is the variance of the random variable δ_p defined as,

$$\sigma_\delta^2 := \int_{-\infty}^{\infty} (\delta - E[\delta])^2 \cdot f(\delta)$$

where $f(\delta)$ is the probability density function for the distribution of δ, and E[δ] is the expected value, or mean of δ.

Computation 1.3.4:

The volatility of oil and alternative energy prices are estimated from data samples of oil prices, natural gas prices and interest rate and inflation rate history. The standard deviation of price/rate changes is estimated by the sample standard deviation.

Proposition 1:

If the volatility of oil prices and the volatility of alternative energy prices are independently distributed, then we compute the effective price volatility σ_E as

$$\sigma_{pE} = \sqrt{\sigma_{pE}^2} = \sqrt{w_c^2\sigma_o^2 + w_a^2\sigma_a^2}$$

Proof :

Let δ_{po} be the annual percent change in oil prices and let δ_{pa} be the annual percent change in alternative energy prices and let δ_{po} and δ_{pa} be independent. By definition of effective price it follows that

$$p_{\mathrm{E}} := \frac{p_o q_o + p_a q_a}{q_o + q_a} = \frac{p_o q_o}{q_o + q_a} + \frac{p_a q_a}{q_o + q_a} = \left(\frac{q_o}{q_o + q_a}\right) p_o + \left(\frac{q_a}{q_o + q_a}\right) p_a = w_c p_o + w_a p_a$$

where w_c is crude weight and w_a is alternative weight as defined previously. Assuming fixed weights throughout the year, it follows that

$$p_{\mathrm{E}} = w_c p_o + w_a p_a \Rightarrow \delta_{pE} = w_c \delta_{po} + w_a \delta_{pa}$$

Thus, by properties of variance, we can construct the variance of δ_{pE} as follows,

$$\begin{aligned}
\sigma_{pE}^2 &= Var(w_c\delta_{po} + w_a\delta_{pa}) \\
&= Var(w_c\delta_{po}) + Var(w_a\delta_{pa}) + 2Cov(\delta_{po}, \delta_{pa}) \\
&= w_c^2 Var(\delta_{po}) + w_a^2 Var(\delta_{pa}) + 0 \\
&= w_c^2\sigma_{po}^2 + w_a^2\sigma_{pa}^2 \\
\sqrt{\sigma_{pE}^2} &= \sqrt{w_c^2\sigma_{po}^2 + w_a^2\sigma_{pa}^2} \\
\sigma_{pE} &= \sqrt{w_c^2\sigma_{po}^2 + w_a^2\sigma_{pa}^2}
\end{aligned}$$

which is what we desired to show. ■

Computation of Proposition 1:

Effective price volatility: SQRT[(O*^2)×(U*^2) + (P*^2)×(V*^2)] where each reference is on sheet "OilPriceStability"
Alternative energies are a compound of nuclear assisted production of electricity, natural gas, nuclear assisted production of hydrogen, renewable electricity, biofuels and nuclear assisted liquid production. Natural gas has its own markets and an associated price and volatility. It may be expected that hydrogen, if turned into a storeable and tradeable commodity, would also have an associated price volatility. For this reason, the volatility of alternative energy prices is a combination of natural gas, hydrogen and all other alternative energy as a separate bundle. With this in mind we have the following definition.

Definition 1.3.5: Alternative Energy Price Volatility

Let σ_N be the price volatility of natural gas, σ_H the price volatility of hydrogen, and σ_E the combined price volatility of all other alternative energies. Then we define the alternative energy price volatility σ_A as

$$\sigma_A := \sqrt{w_N^2\sigma_N^2 + w_H^2\sigma_H^2 + w_E^2\sigma_E^2}$$

where w_N, w_H, w_E are natural gas weight, hydrogen weight, and other alternative energy weight respectively.

Definition 1.3.6: Alternative Energy Price

Let w_N, w_H, and w_E be natural gas, hydrogen and other alternative energy weights respectively. Furthermore, if p_N, p_H, and p_E are the prices of natural gas, hydrogen and other alternative energy respectively, then the alternative energy price of energy, p_A, is

$$p_A = w_N p_N + w_H p_H + w_E p_E$$

In order to calculate the 1.3.5 and 1.3.6 above, it is necessary to compute the relevant energy prices and volatilities into units that are equivalent to the energy in a barrel of oil. To this end we have the following conversions.

Converting Price per Thousand Cubic Feet of Natural Gas to Price per Barrel

We want to convert the price per thousand cubic feet of natural gas into the price of natural gas energy equivalent to a barrel of oil. Given that natural gas has approximately 1,027 btu per cubic foot and that a barrel of oil has approximately 5,800,000 btu, we have the following conversion:

Mcf = 1000 cubic ft. of natural gas.

1027 btu per cubic ft of natural gas ⇒ *btu per Mcf* = (1,000) · (1027) btu of natural gas.

So one thousand cubic feet of natural gas is energy equivalent to *Mcf* · (1,000) · (1,027)⁄5,800,000 barrels of oil.

This reduces to $\frac{Mcf\cdot(1{,}000)\cdot(1{,}027)}{(5{,}800{,}000)} = \frac{Mcf\cdot(1{,}027)}{(5{,}800)} = \frac{Mcf\cdot(1{,}027)}{(5{,}800)} = \frac{Mcf\cdot(10.27)}{(58)} \Rightarrow \frac{p}{Mcf} \approx \frac{p\cdot(58)}{Mcf\cdot(10.27)} = \frac{p}{Mcf}\cdot\frac{(58)}{(10.27)} = \frac{p}{Mcf}\cdot(5.6475) = \frac{p}{barrel}$

so price per energy equivalent barrel of natural gas is equal to (5.6475) $\cdot p$ where p is the price per thousand cubic feet of natural gas.

Converting Price per Kg of Hydrogen to Price per Barrel

We want to convert the price per kilogram of hydrogen into the price of hydrogen energy equivalent to a barrel of oil. Given the fact that hydrogen has 60,000 btu per pound and there are approximately 2.2 kg per pound, we summarize the following conversion:

Hydrogen has 60,000 BTU per pound and 2.2 kg per pound so it has 132,000 BTU per kg.

Then a kg of hydrogen is energy equivalent to $\frac{kg\cdot(132{,}000)}{5{,}800{,}000}$ barrels of oil.

This simplifies to $\frac{p}{\frac{kg(132{,}000)}{5{,}800{,}000}} = \frac{p\cdot(5{,}800{,}000)}{kg\cdot(132{,}000)} = \frac{p}{kg}\cdot\left(\frac{5{,}800{,}000}{132{,}000}\right) \approx \frac{p}{kg}\cdot(43.9394)$ so price per energy equivalent barrel of hydrogen is equal to $(43.9394)\cdot p$ where p is the price per kilogram of hydrogen.

1.4 ESTIMATING PARAMETERIZED VARIABLES

1.4.1 Volatility of Oil Prices

Volatility of crude oil prices is estimated from Cushing, OK WTI Spot Prices FOB (Dollars per Barrel) 1999 – 2009. The ten year volatility of oil price returns was estimated as 27.89%.

$\sigma_{p_{oil}} = 27.89\%$

Year	Price	Return	Average	15.82%
2000	30.38	57.08%	Variance	0.077761
2001	25.98	-14.48%	Standard Deviation	27.89%
2002	26.18	0.77%		
2003	31.08	18.72%		
2004	41.51	33.56%		
2005	56.64	36.45%		
2006	66.05	16.61%		
2007	72.34	9.52%		
2008	99.67	37.78%		
2009	61.95	-37.84%		

1.4.2 Volatility of Alternative Energy Prices

Volatility of alternative energy prices estimated from Consumer Price Index and Prime Bank Loan Rates 1999-2009. The ten year prime bank loan rate volatility was estimated as 29.79%. The ten year consumer price index volatility was estimated as 1.82%.

$\sigma_{p_{htgr}} = 29.79\%\ or\ 1.82\%$

Prime Bank Loan Rate Volatility:

Year	Rate	Return		
2000	8.50	9.68%		
2001	9.05	6.47%	Average	-2.19%
2002	4.75	-47.51%	Variance	0.09
2003	4.25	-10.53%	Standard Deviation	29.79%
2004	4.00	-5.88%		
2005	5.25	31.25%		
2006	7.26	38.29%		
2007	8.25	13.64%		
2008	6.98	-3.86%		
2009	3.25	-53.44%		

Consumer Price Index Volatility:

Year	Rate	Return		
2000	3.7	3.73%		
2001	3.2	3.25%		
2002	1.1	1.07%	Average	2.66%
2003	2.1	2.11%	Variance	0.00033
2004	3.3	3.27%	Standard Deviation	1.82%
2005	2.5	2.53%		
2006	4.3	4.32%		
2007	2.7	2.69%		
2008	5.0	5.02%		
2009	-1.4	-1.43%		

1.4.3 Volatility of Natural Gas Prices

Volatility of Natural Gas is estimated from EIA natural gas wellhead prices 1999-2009. The ten year natural gas price volatility was estimated at 38.43%.

$\sigma_{p_{ng}} = 38.43\%$

Natural Gas Price Volatility:

Year	Price	Return		
2000	3.68	68.04%		
2001	4	8.70%		
2002	2.95	-26.25%	Average	12.10%
2003	4.88	65.42%	Variance	0.147697
2004	5.46	11.89%	Standard	38.43%

		Deviation
2005	7.33	34.25%
2006	6.39	-12.82%
2007	6.25	-2.19%
2008	7.96	27.36%
2009	3.71	-53.39%

1.5 RESULTS OF COMPUTATION

1.5.1 Substitution and the Diversification Effect

The addition of alternative energy to the portfolio of petroleum energy uses and the portfolio of natural gas energy uses makes alternative energies like HTGRs a substitute for the other commodities. Resulting from the substitution is a reduction in the volatility of the effective price of joint consumption due to the effects of diversification. Diversification is an effect that is well noted in portfolio theory from financial economics. Two risky (high volatility) assets can be combined in an investment portfolio and the volatility of the entire portfolio will be less than the volatility of any one of the individual risky assets. Thus, the diversification reduces the volatility of the effective price of energy below that of oil or natural gas alone.

1.5.2 Volatility of Effective Price

The volatility of the effective price of energy is one of the main indicators of the improvements in energy price stability. As alternative energy becomes a greater portion of the joint consumption; the volatility of the effective price will drop. As the standard deviation of effective price returns (volatility) decreases, the price becomes ever more stable. The value of that stability can be measured by the call option price.

1.5.3 Decreased Call Option Prices

Substitution of alternative energy allows for greater diversification. Greater diversification generates greater improvements in the stability of effective energy prices. Holding the effective price level constant, decreases in effective price volatility are directly observable in the call option price. As stability increases, the value to an energy consumer of buying a call option decreases. When option prices go toward zero, prices are becoming more stable and the general price level is likely dropping. Increases in option prices signal an increase in either volatility, price level, or a combination

Appendix E

Price Stability Test Case

E-1. CALCULATION COMPARISON

An arbitrary simulation was computed in the model. Given the calculated quantities of oil, natural gas and alternative energies, the calculations involving effective price, effective price volatility and the Black-Scholes option pricing model were tested by hand calculation. The inputs for the test case scenario are shown in the tables below.

Energy Demand	
Future Energy Demand:	Baseline
Conservation:	Baseline
Efficiency:	Baseline

Electricity	
Nuclear	40%
Renewable	15%
Coal	26%
Natural Gas	18%
Petroleum	1%
Wind	65%
Solar	15%
Geo Thermal	20%
HTGR %	25%
LWR %	50%
SMR %	25%
1st Year HTGR Built	2021
Coal Plant CCS %	0%
Renew Existing License	TRUE
Build to Maintain LWR	TRUE

Transportation	
Other Transportation Efficiency	0.10%
% Electric cars in 2050:	30%
2010 MPG	21.0
2020 MPG	25.0
2030 MPG	34.0
% Biodiesel use in 2022:	0.8%
% Biodiesel use in 2050:	0.8%
% Hydrogen cars in 2050:	10%
Ethanol use 2022	3.3%
Ethanol use 2050	3.3%
% Natural Gas cars:	20%
% Natural Gas heavy trucks:	10%

Industrial	# of Plants
HTGR Hydrogen Production	3
HTGR Ammonia Production	3
HTGR Assist Coal to Natural Gas	3
HTGR Assist Natural Gas to Diesel	3
HTGR Assist Coal to Diesel	3
HTGR Assist Natural Gas to Gasoline	3
HTGR Assist Coal to Gasoline	3
HTGR Assist SAGD	3
HTGR Assist Oil Shale Extraction	3
HTGR Co-generation	3

E-2. Results for year 2030 oil price stability to be verified

1	+	Oil Demand (post efficiency)	3.510E+07	Billion(btu)
2	-	BTU from Transportation to Electric	2.073E+06	Billion(btu)
3	-	BTU from PetrolTrans to Renewable (ethanol)	0.000E+00	Billion(btu)
4	-	BTU from PetrolTrans to Renewable (biodiesel)	0.000E+00	Billion(btu)
5	-	BTU from PetrolTrans to Natural Gas Cars	1.545E+06	Billion(btu)
6	-	BTU from PetrolTrans to NG Heavy Trucks	2.477E+05	Billion(btu)
7	-	BTU from PetrolTrans to Hydrogen Cars	7.449E+05	Billion(btu)
8	-	Subtractions from Oil for Natural Gas to Gasoline	9.804E+13	BTU
9	-	Subtractions from Oil for Natural gas to liquids	1.179E+14	BTU
10	-	Subtraction from Oil for Coal to Liquids	1.175E+14	BTU
11	-	Subtraction from Oil for Coal to Gas	1.690E+14	BTU
12	-	Subtraction from Oil for Oil Shale Extraction	4.931E+07	Barrels
13	-	Subtraction from Oil for SAGD	4.931E+07	Barrels
		Total Oil Demand BTU from 1-11	2.998E+16	BTU
		Total Barrels of Oil from 1-11	5.169E+09	Barrels
		Less 12 and 13	5.071E+09	Barrels
		Total Oil Demand in Barrels	5.071E+09	Barrels

Total Oil Demand in Barrels located at “OilPriceStability!L75”

Alternative Energy

1	+	BTU from Transportation to Electric	2.073E+06	Billion(btu)
2	+	BTU from PetrolTrans to Renewable (ethanol)	0.000E+00	Billion(btu)
3	+	BTU from PetrolTrans to Renewable (biodiesel)	0.000E+00	Billion(btu)
4	+	BTU from PetrolTrans to Natural Gas Cars	1.545E+06	Billion(btu)
5	+	BTU from PetrolTrans to NG Heavy Trucks	2.477E+05	Billion(btu)
6	+	BTU from PetrolTrans to Hydrogen Cars	7.449E+05	Billion(btu)
7	+	Natural Gas to Gasoline	9.804E+13	BTU
8	+	Natural gas to liquids	1.179E+14	BTU
9	+	Coal to Liquids	1.175E+14	BTU
10	+	Coal to Gas	1.690E+14	BTU
11	+	Oil Shale Extraction	4.931E+07	Barrels
12	+	SAGD	4.931E+07	Barrels
		Total Alternative Energy 1-10	5.114E+15	BTU
		Total Altervative Energy Barrels 1-10	8.816E+08	Barrels
		Plus Barrels from 11 and 12	9.803E+08	Barrels
		Total Alternative Energy in Barrels	**9.803E+08**	Barrels

Total Oil Demand in Barrels located at “OilPriceStability!M75”

Total Barrels, Oil Weight, Alternative Weight

1	+	Total Barrels of Oil Demand		5.071E+09	Barrels
2	+	Total Barrel of Alternative Energy		9.803E+08	Barrels
3			Total Quantity	6.051E+09	Barrels
4			Oil Weight	0.8380	
5			Alternative Weight	0.1620	

Total Barrels of Oil Quantity located at "OilPriceStability!L75"
Total Barrels of Alternative Energy Quantity located at "OilPriceStability!M75"
Oil Weight located at "OilPriceStability!O75"
Alternative Weight located at "OilPriceStability!P75"

Alternative Price Calculation

1	+	Natural Gas Price	$41.28
2	+	Natural Gas Weight	0.31531
3		Hydrogen Price	$175.76
4		Hydrogen Weight	0.13102
		OthAltPrice	$129.63
		OthAltWeight	0.5537
		Alternative Price	$107.82

Alternative Price located at "OilPriceStability!BA27"

Alternative Price Volatility Calculation

1	Natural Gas Weight	0.31531
2	Hydrogen Weight	0.13102
3	Other Alternative Weight	0.55367
4	Natural Gas Volatility	38.43%
5	Hydrogen Volatility	1.82%
6	Other Alternative Volatility	1.82%
	Alternative Energy Volatility	12.16%

Alternative Energy Volatility located at "OilPriceStability!AR27"

Effective Price Volatility Calculation

1	Oil Weight	0.83800
2	Oil Price Volatility	27.89%
3	Alternative Energy Weight	0.16200
4	Alternative Energy Volatility	12.16%
5	Effective Price Volatility	23.45%

Effective Price Volatility located at “OilPriceStability!W75”

Effective Price Calculation

1	Total Barrels	6.051E+09
2	Oil Barrels	5.071E+09
3	Oil Price	$112.38
4	Alternative Barrels	9.803E+08
5	Alternative Energy Price	$107.82
	Effective Price	$111.64

Effective Price Volatility located at “OilPriceStability!T75”