SAND2007-5690P

Energy Economics and Models

Peter H. Kobos

Economist, Ph.D.
Geotechnology and Engineering Department

Acknowledgements: A. Baker, D. Borns, T. Drennen, L. Malczynski and many others.

Setting the Stage: Economics, Energy Economics

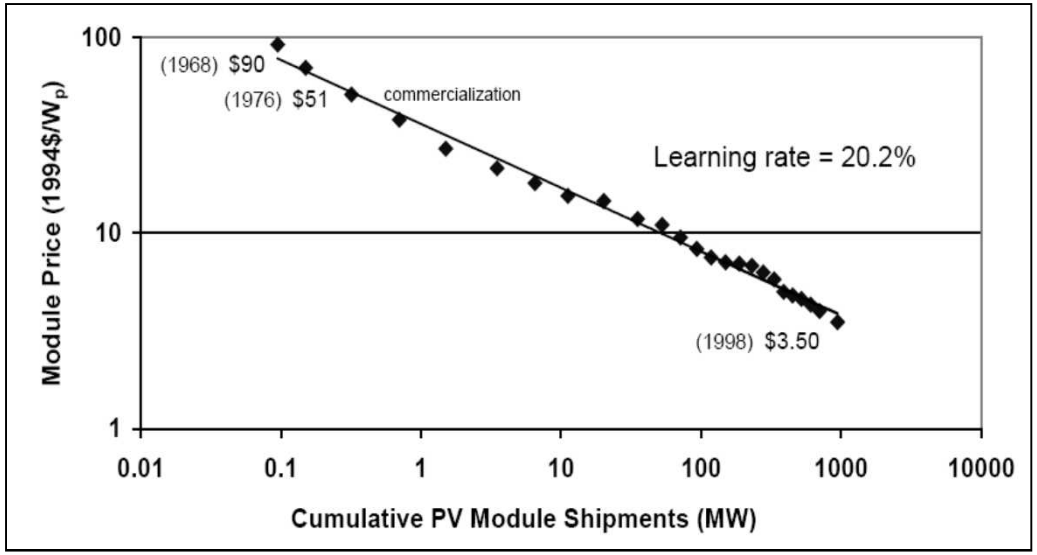
- **Economics**
  - **Social Science studying the production, distribution and consumptions of goods and services**
    - » **Can use $, or other means to track components of the economy**
    - » **Generally Divided into two main fields**
      - ¤ **Macroeconomics**
        - **(e.g., interest rates of the Federal Reserve System)**
      - ¤ **Microeconomics**
        - **(e.g., market behavior at the user's level such as with technology adoption, purchases, etc.)**

Setting the Stage: Economics, Energy Economics

- **Energy Economics**
  - **Subfield of Economics which focuses on the energy ties within the economy**
    - » **$ / Btu equivalent → Production Cost & Energy footprint**
    - » **Microeconomic analytical techniques can help with efficiency analyses, technology adoption (energy elasticity, income elasticity, market penetration)**
  - **The International Association for Energy Economics (IAEE) gives a good overview of the field (www.iaee.org)**

Modeling Technology Learning and Cost Reductions

- **Learning Curves:**
  - **Describe the *cost reduction* of technology due to a *doubling of capacity* (e.g., Harmon, 2000)**



Source: Adapted from Harmon (2000). Learning Rate (LR), costs decrease by 20% for every doubling of capacity.

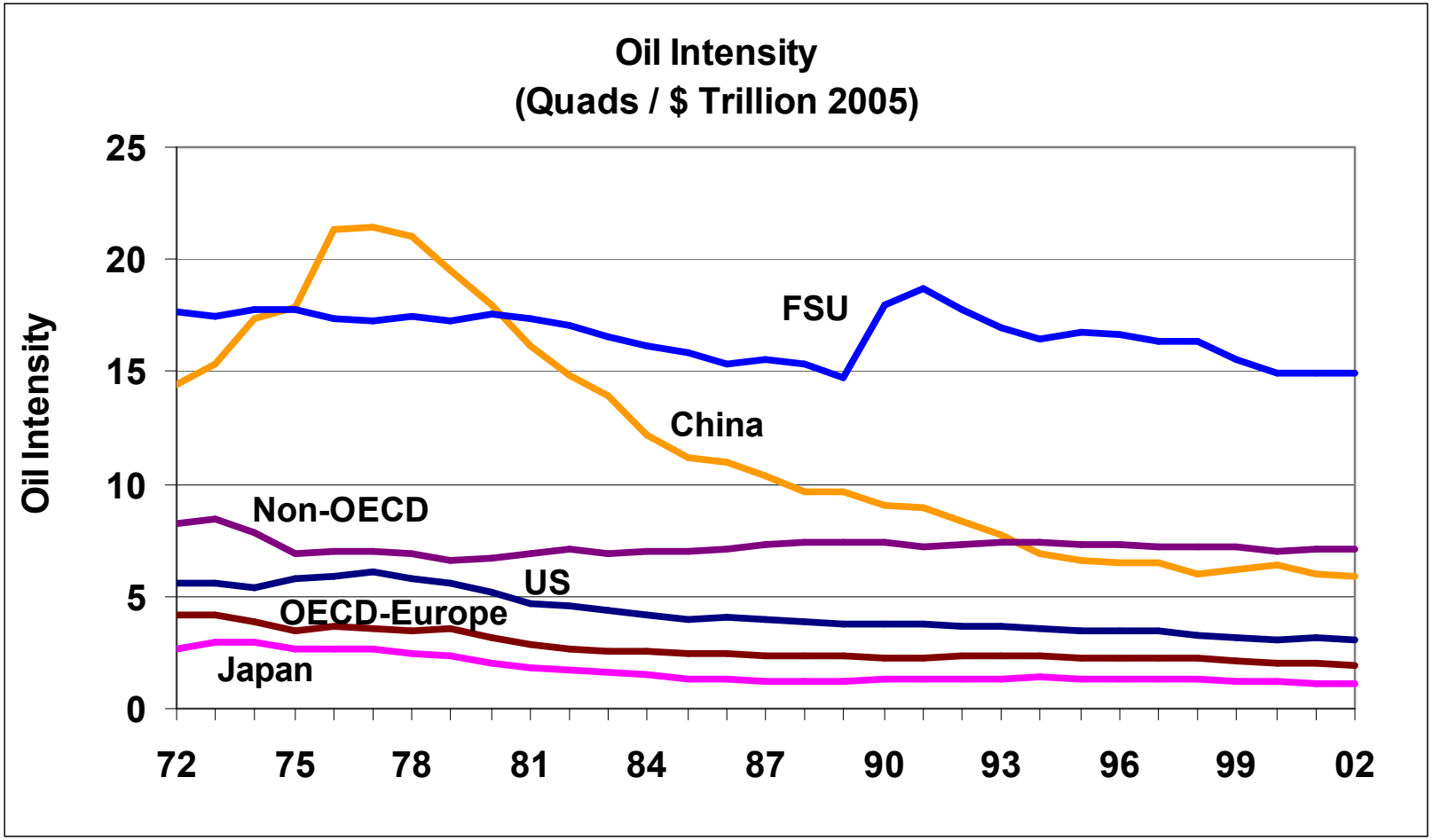
Energy Policy: The Bottom Line

- **"Throughout this decade, oil will remain the single most important commercial fuel, while such other primary and secondary energy sources as natural gas, coal, nuclear power, electricity, and energy from renewable sources must be relied upon increasingly."**

- **"Reducing demand for energy and securing access to oil while developing other sources will continue to be the major energy preoccupation of the United States and other governments."**

Atlantic Council's Energy Policy Committee Report, *"U.S. Energy Policy and U.S. Foreign Policy in the 1980s."* Written in 1981.

The Role of Oil in Economies



Source: Part I: IEA Statistics; Energy Balances of Non-OECD (and OECD) Countries, 1972-2002. CD-ROM(s).

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Efficiency vs. Equity

- **Efficiency: When the economy's resources and output are allocated in such a way that no reallocation can make anyone better off without making at least one person worse off. This requires a 'free market' competitive market place.**
  - ***Said to result in a Pareto Optimum, in which all resources are allocated efficiently***

- **Equity: Fairness or justice – judgments about the manner in which output is distributed and/or costs/prices are paid. Equity should not be confused with equality since one need not imply the other.**

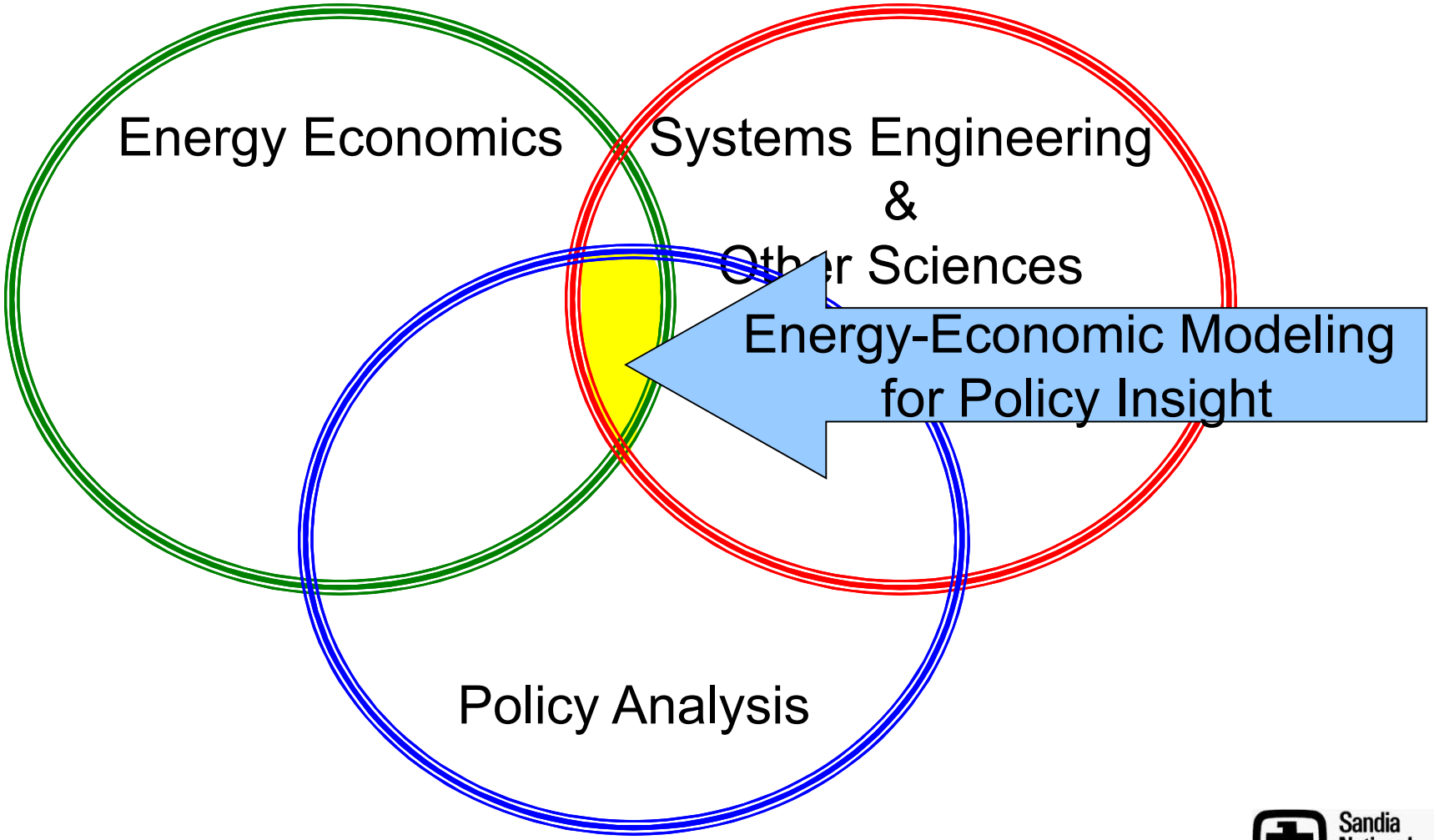
- **Efficiency does not necessarily lead to equity, and vice versa.**

Source: Adapted from Pearce, 1992.

The Role of Government

- **Can enhance efficiency by, among other things,**
  - **Removing market barriers/impediments**
  - **Internalizing externalities (e.g., pollution)**
  - **Providing public goods (e.g., national security)**
- **Can enhance equity by, among other things,**
  - **Providing/removing taxes and subsidies**
  - **Altering market resource allocation**
- **Governments try to balance both, though typically**
  - **Not very well**
  - **May sacrifice efficiency for equity**

Energy-Economic Modeling: Science & Technology-based Policy Insight



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Mathematical Modeling Approaches for Energy Policy Planning

- **Top-down**
  - **Energy sector, economy-wide, Computable General Equilibrium (CGE)**
  - **Useful for simulating taxes and externalities for economic costs**
  - **e.g., Input-Output Analysis, Jorgenson-Wilcoxen Model (CGE)**
- **Bottom-up**
  - **Simulation / optimization, technology descriptive**
  - **Useful for selecting fuel and technology choices**
  - **e.g., Least-Cost optimization models, MARKAL, MESSAGE, NEMS**
- **Hybrid / Integrated Assessment Models**
  - **Builds on the strengths of both Top-down and Bottom-up methods (economic tools, technology, builds the systems view from several sets of detailed components)**
  - **Useful to develop technology rich analysis modules combined with economic/policy insight**

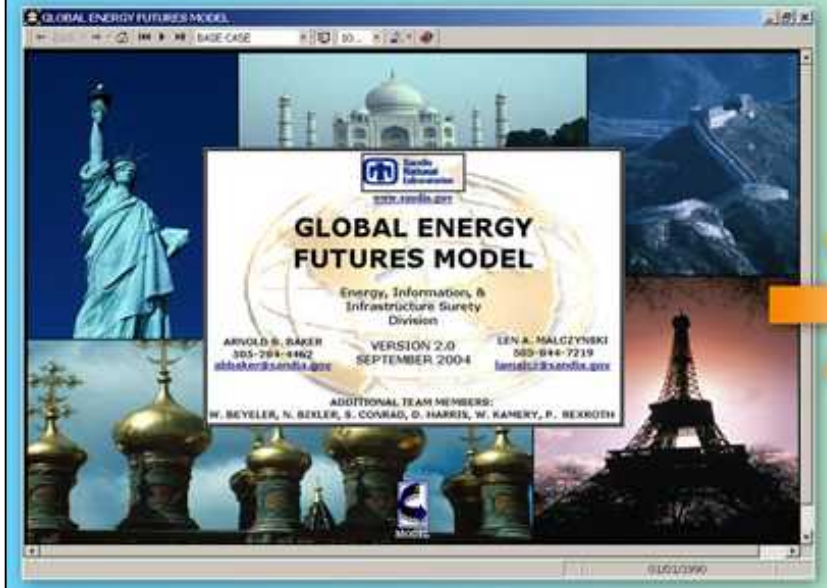
Sources: IEA, 1998; IIASA, 2005

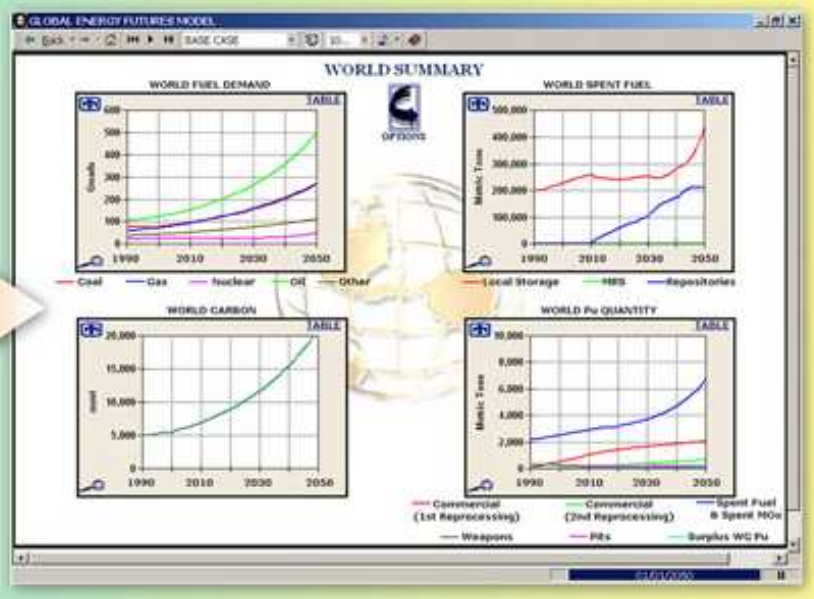
Topical Approaches to Select Economic/Energy/Technology Models at Sandia

- **High-level Models (2)**
  - Focus on the Total Fuel Demand and Associated Economic Issues
- **Technology-Cost Options Models (2+)**
  - Focus on Electricity Generation, Innovative Fuel Supplies
- **Systems Models (2+)**
  - Focus on Carbon Sequestration Technology, Scale up Issues, and the Associated Infrastructure
- **Others throughout the Lab**

High-Level Modeling: Understanding Long Term Energy & Environmental Options

Global Energy





- Provides a global/regional perspective on trade-offs for economic growth, energy demand and environmental emissions to 2050, including the full nuclear fuel cycle and related materials

- Links oil, gas, coal, nuclear, and renewable energy to GDP growth, energy intensities, carbon emissions, and twelve other measures of environmental impact for five regions of the world

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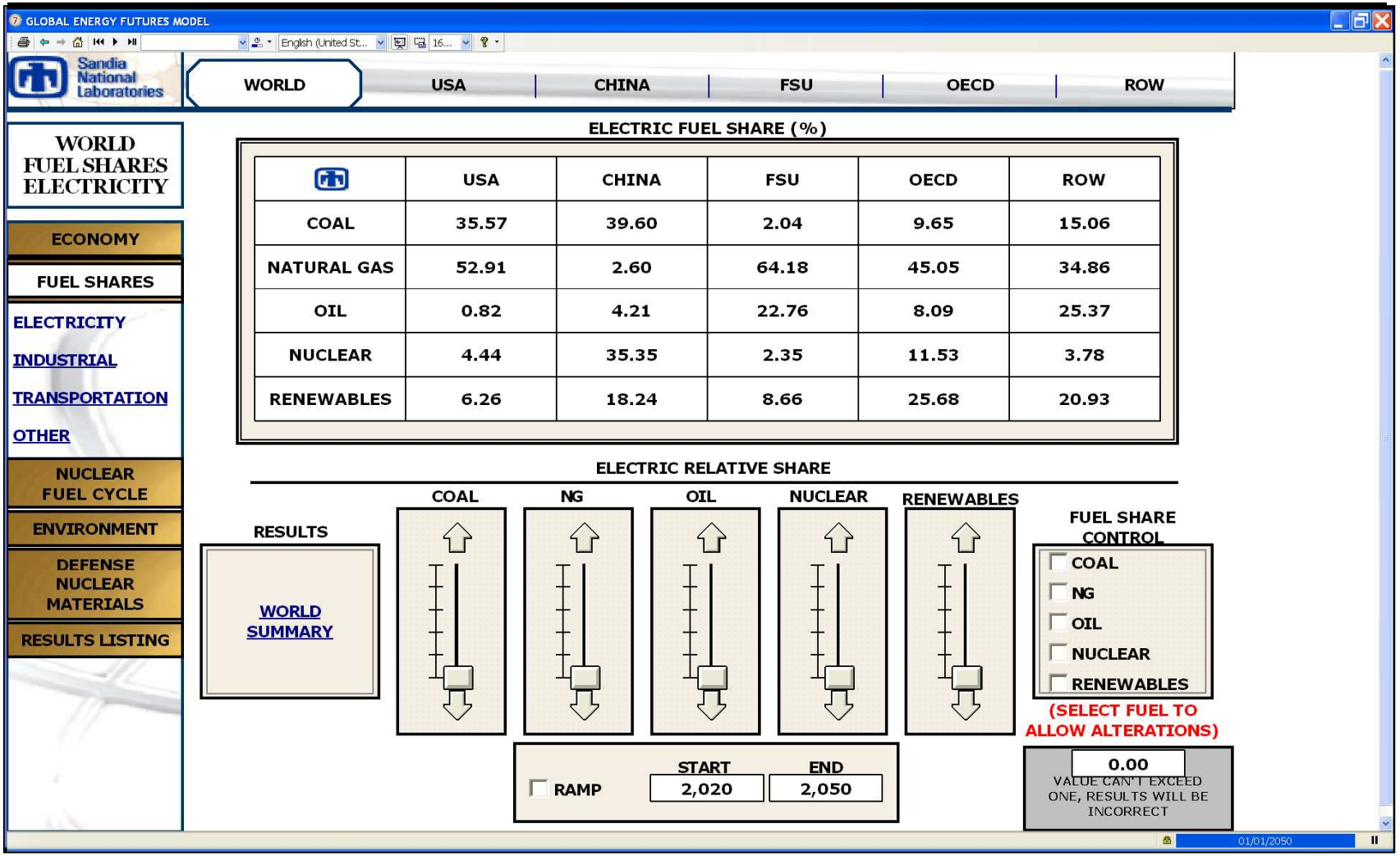
Global Energy Futures Model



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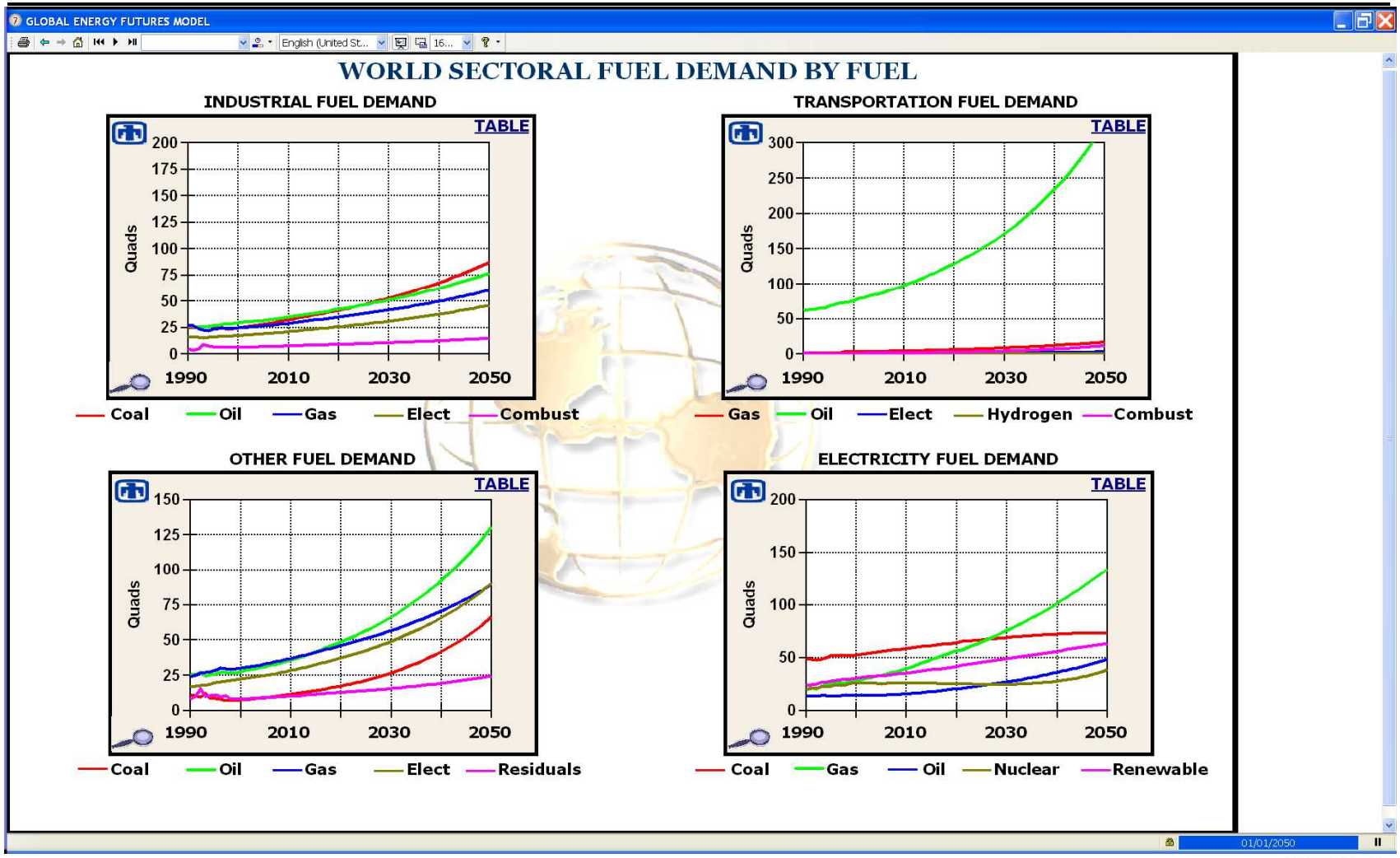
Global Energy Futures Model



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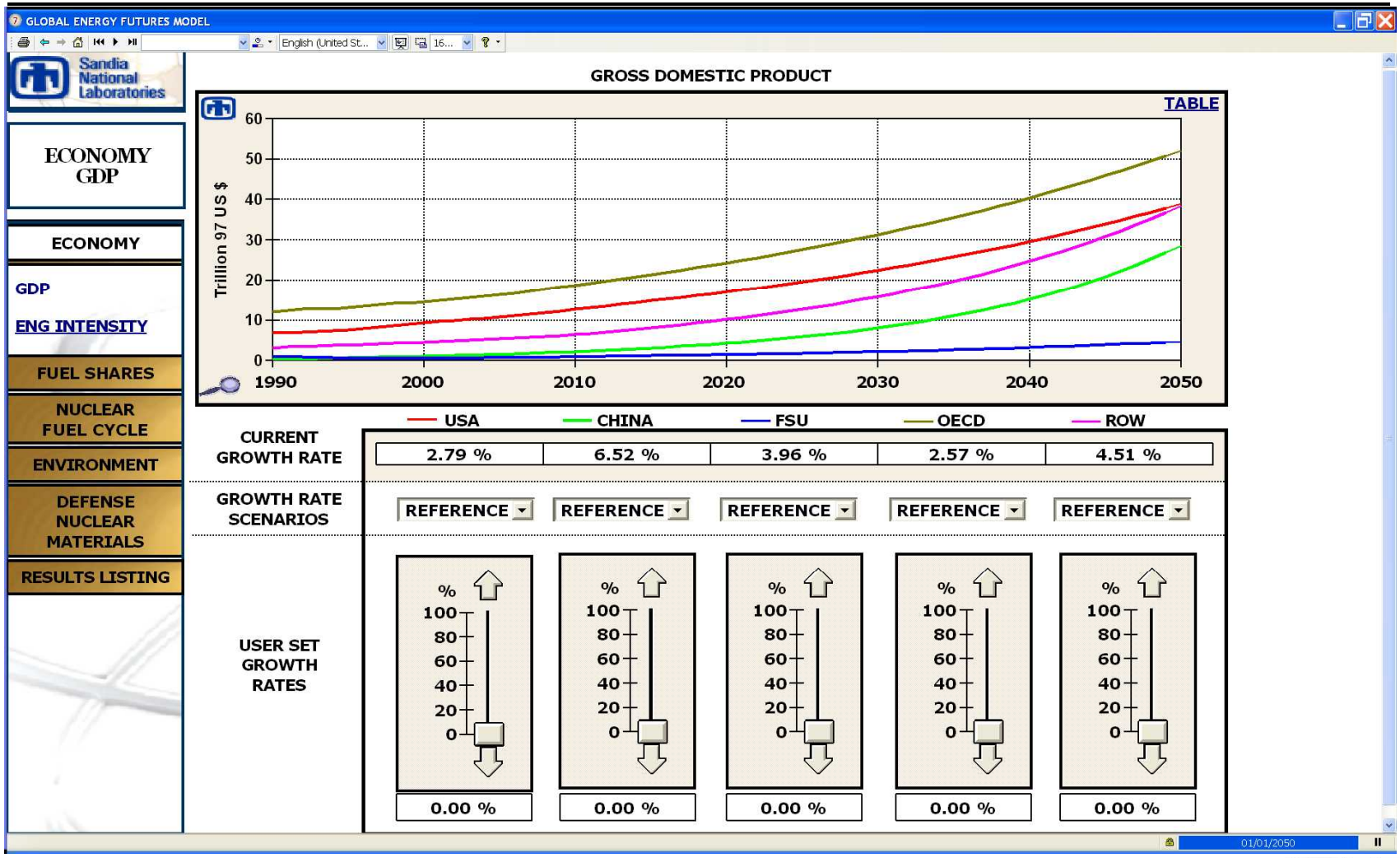

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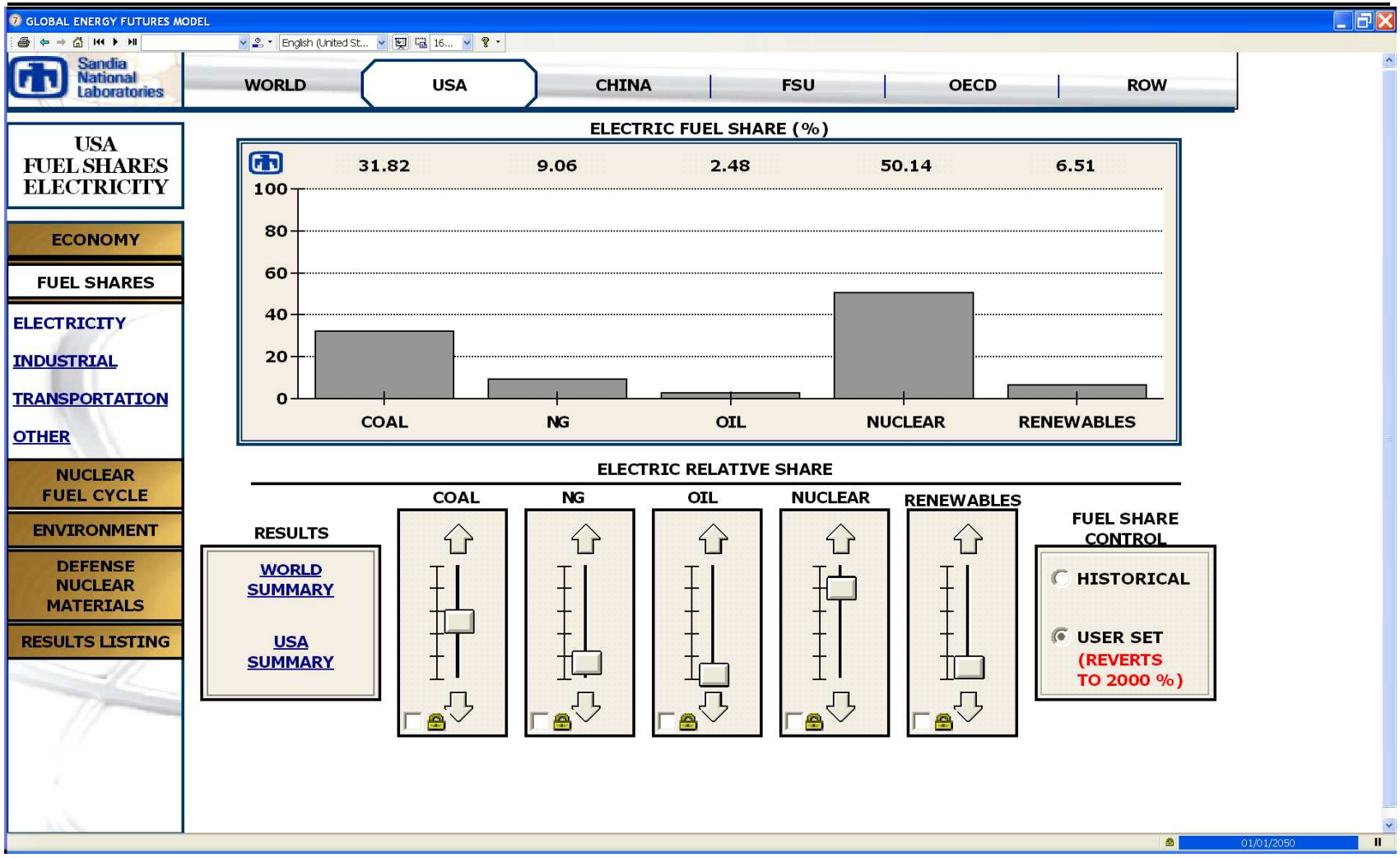
What if the U.S. increased the nuclear fuel share to 50% of electricity production?



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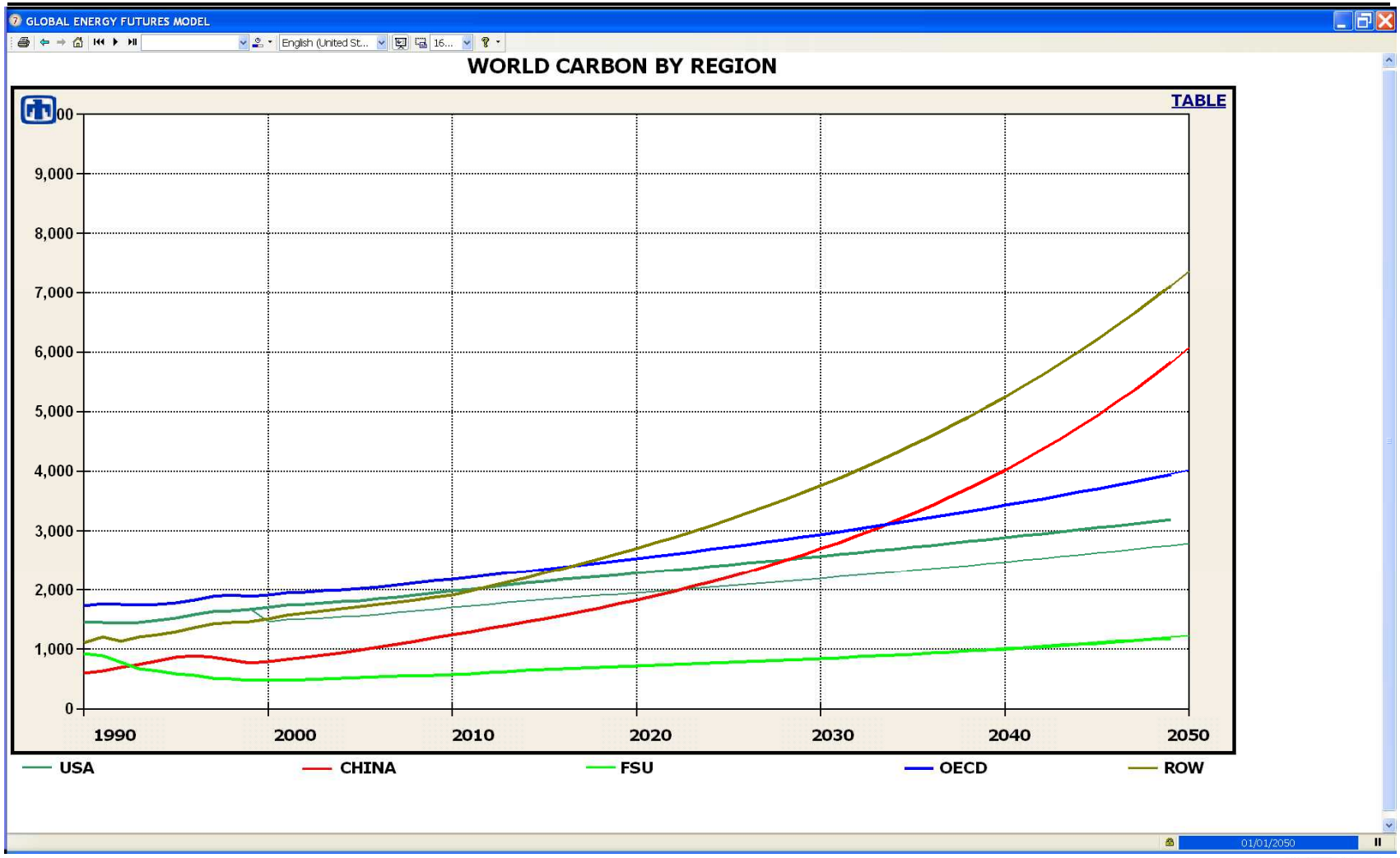
U.S. Carbon Dioxide Emissions Decrease, But Small Relative to the World's Emissions



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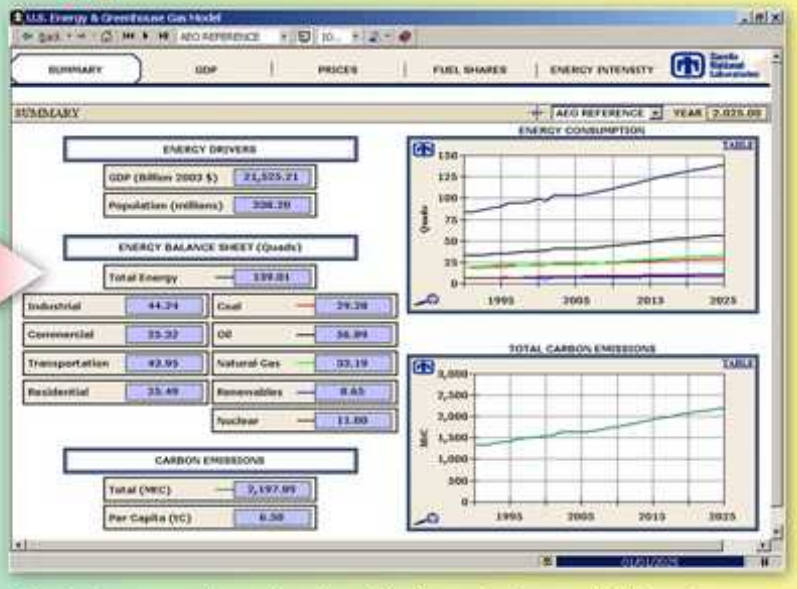
High-Level Modeling: Understanding Long Term Energy & Environmental Options

U.S. Energy



- Focuses on U.S. energy demand by economic and electric power sectors through 2025 to facilitate energy policy discussions
- Evaluates energy demand, carbon dioxide emissions, and oil import requirements, driven by gross domestic product, energy prices, energy intensities, and population effects

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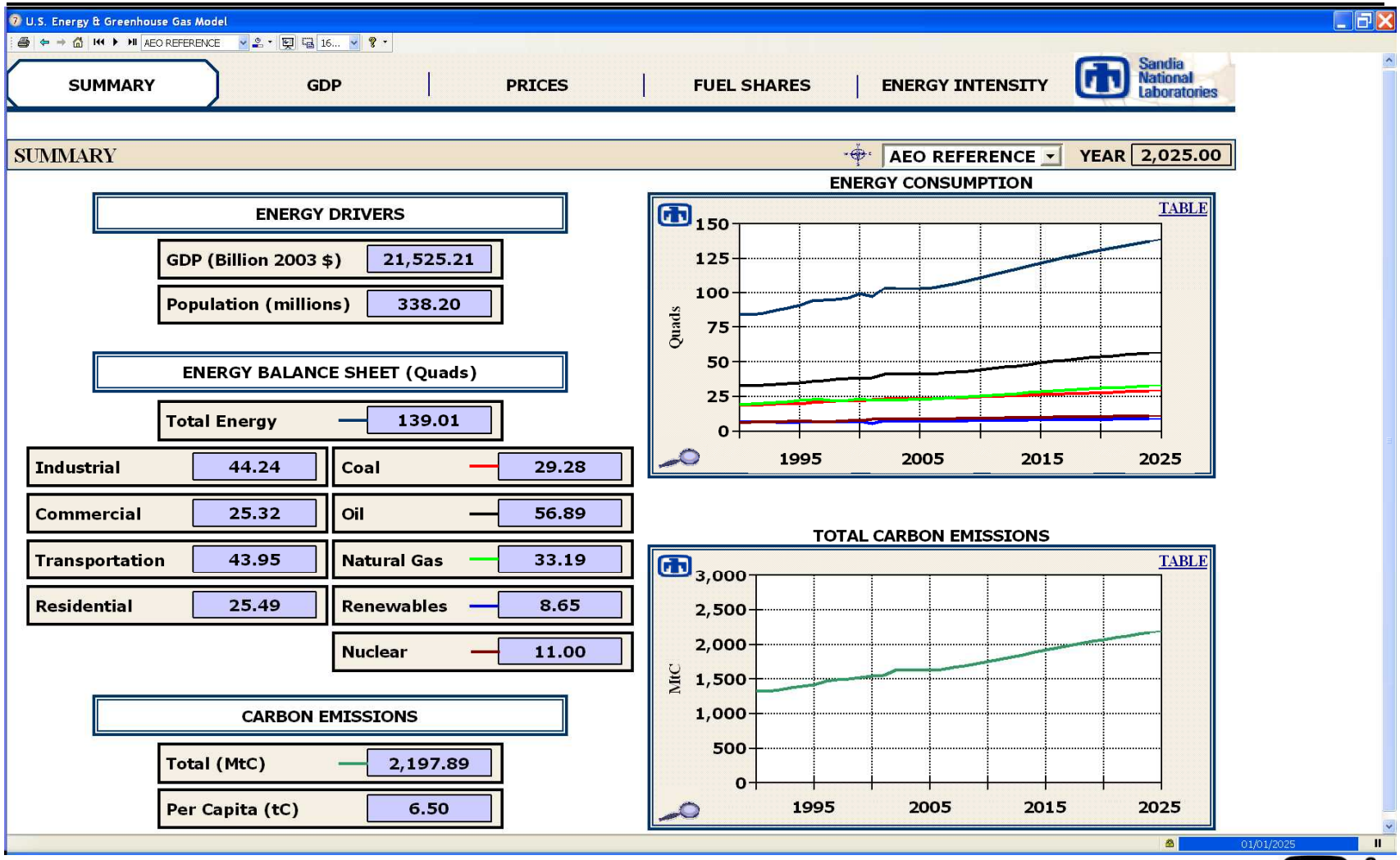
U.S. Energy and Greenhouse Gas Model



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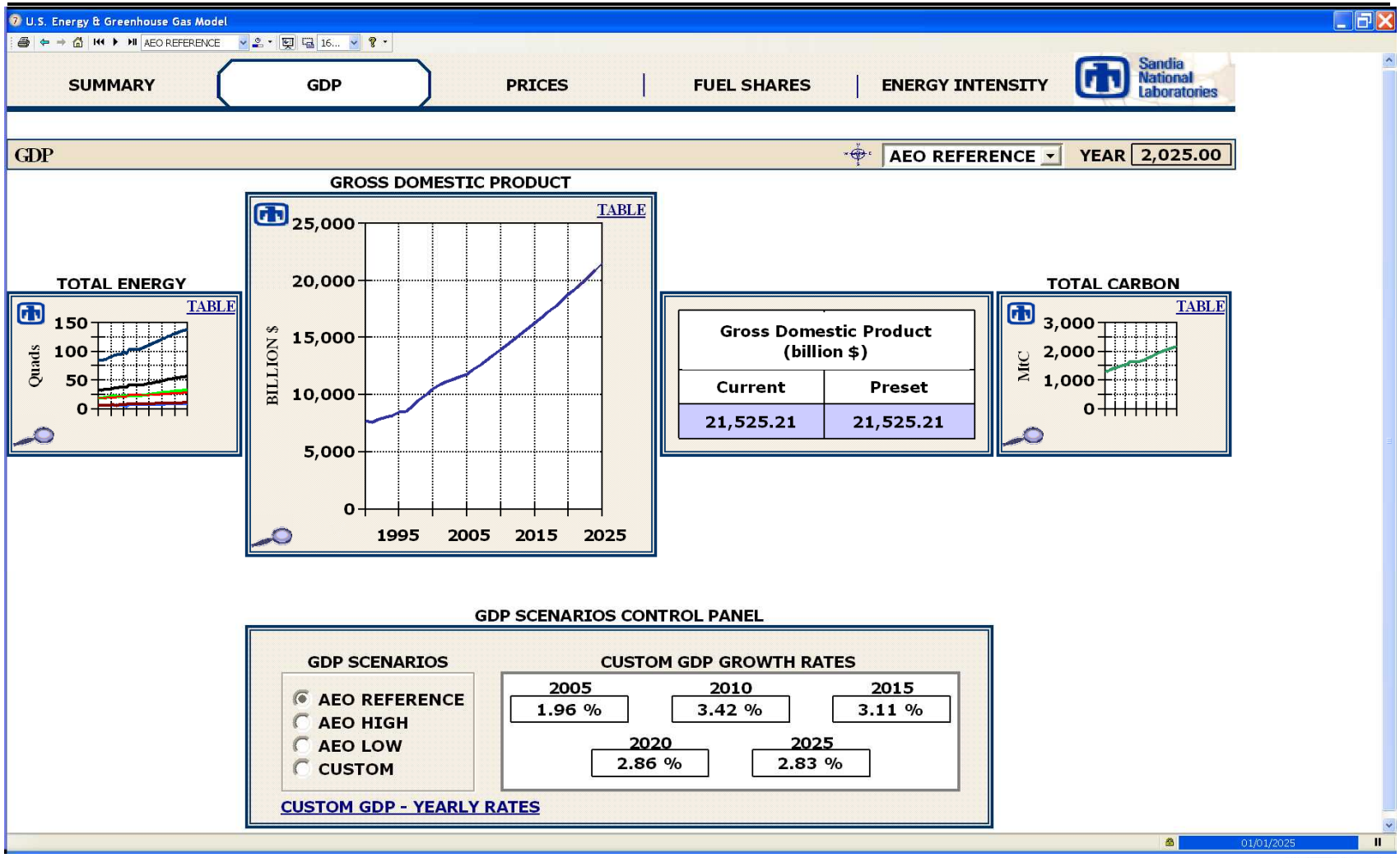

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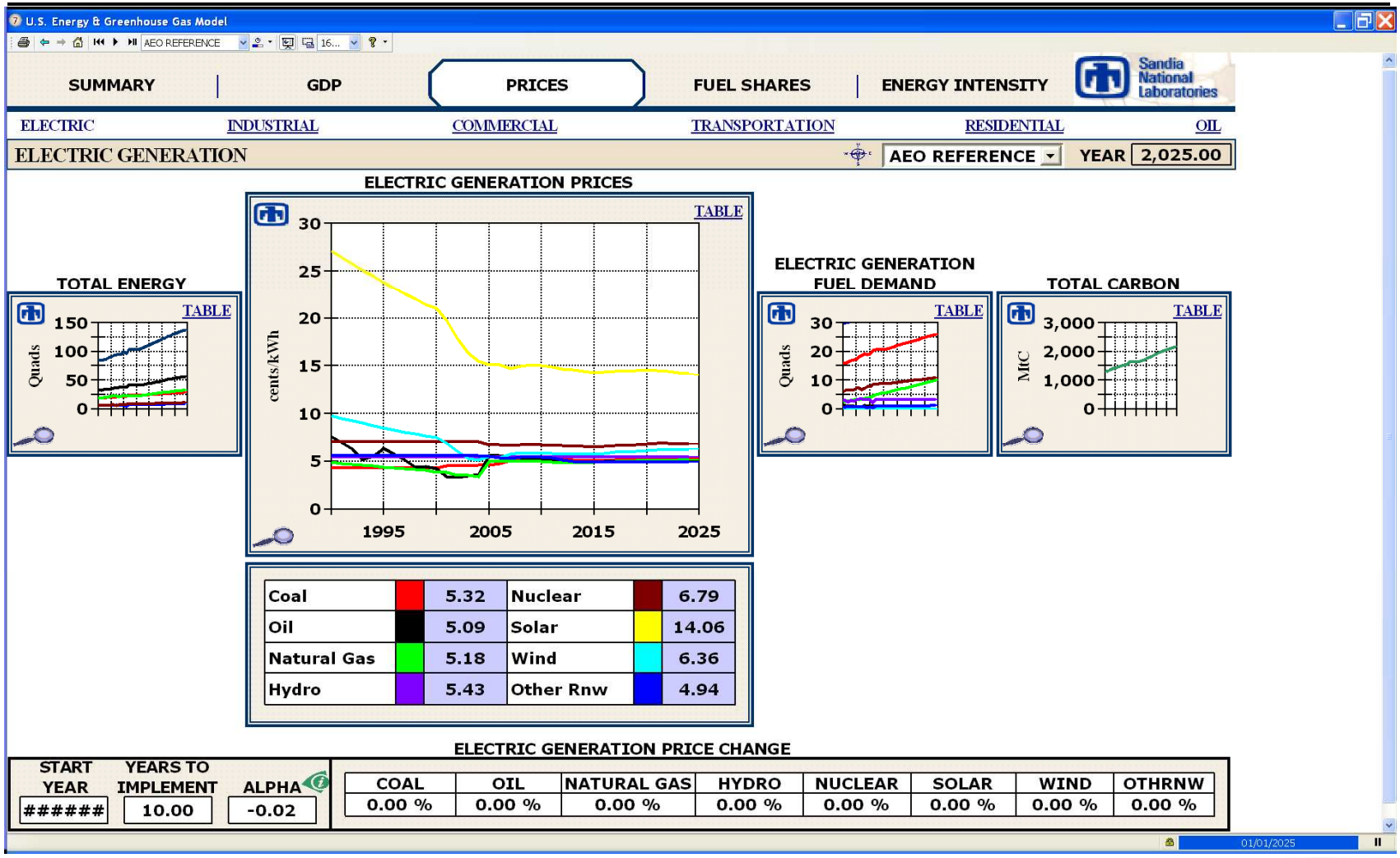

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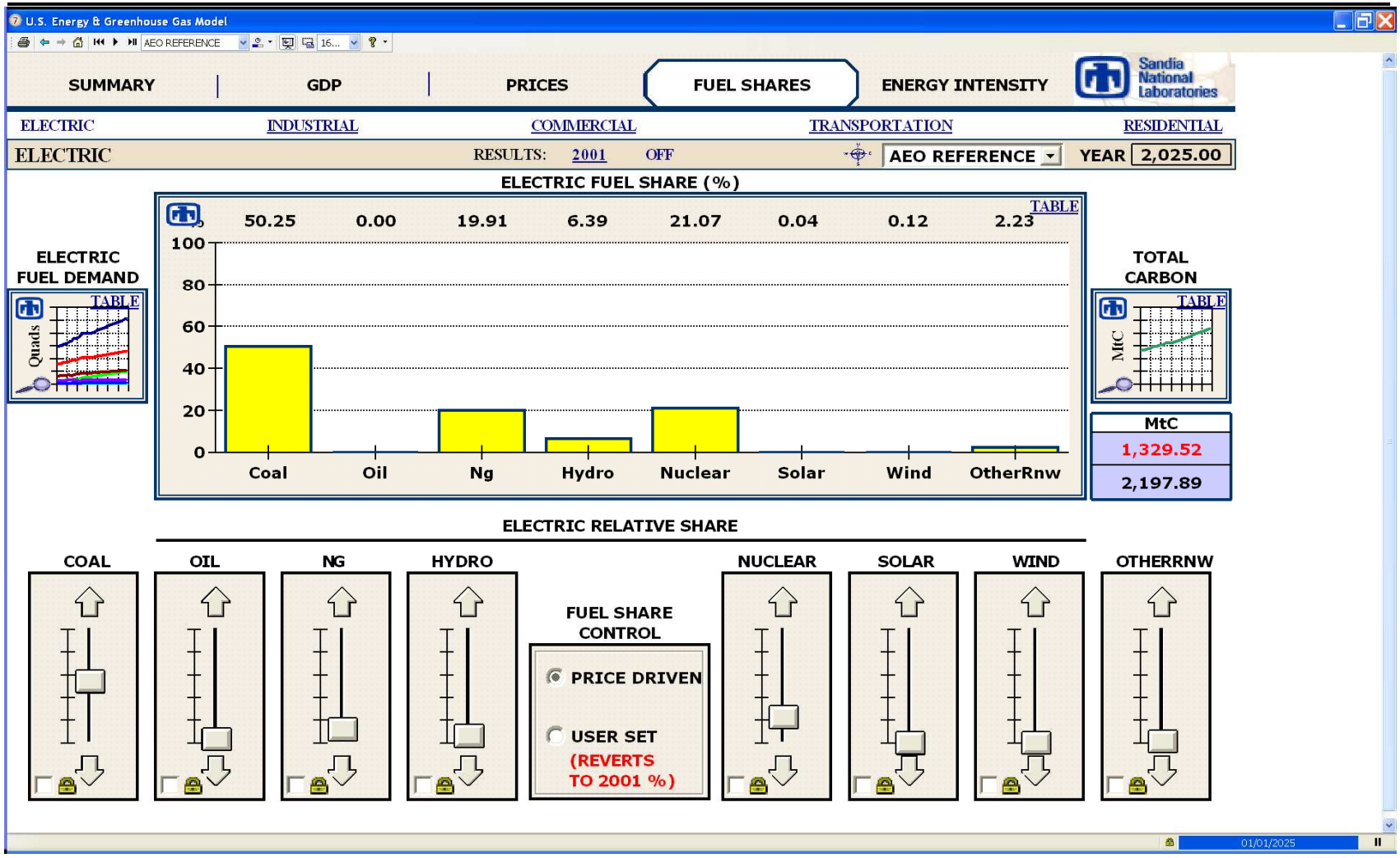

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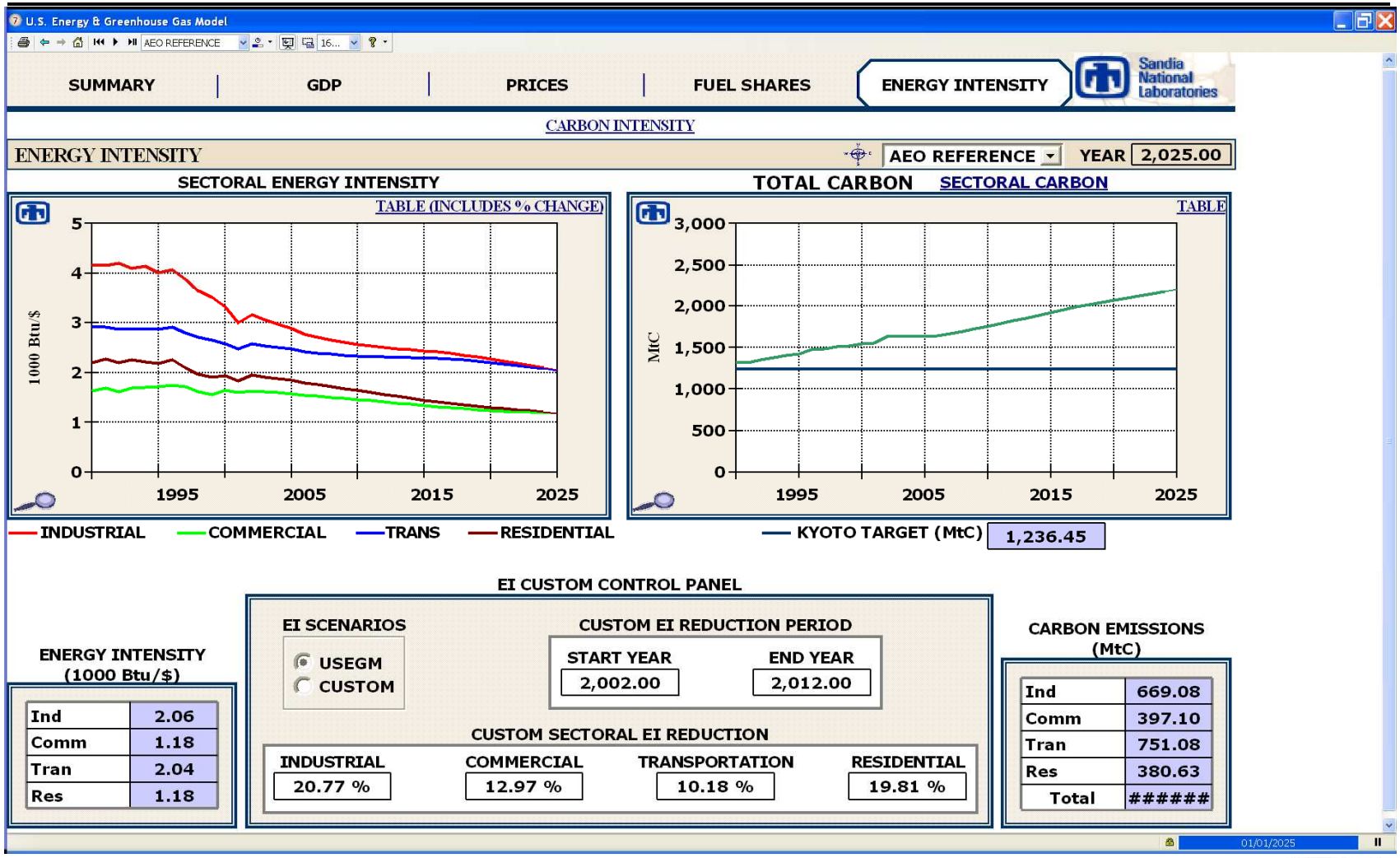

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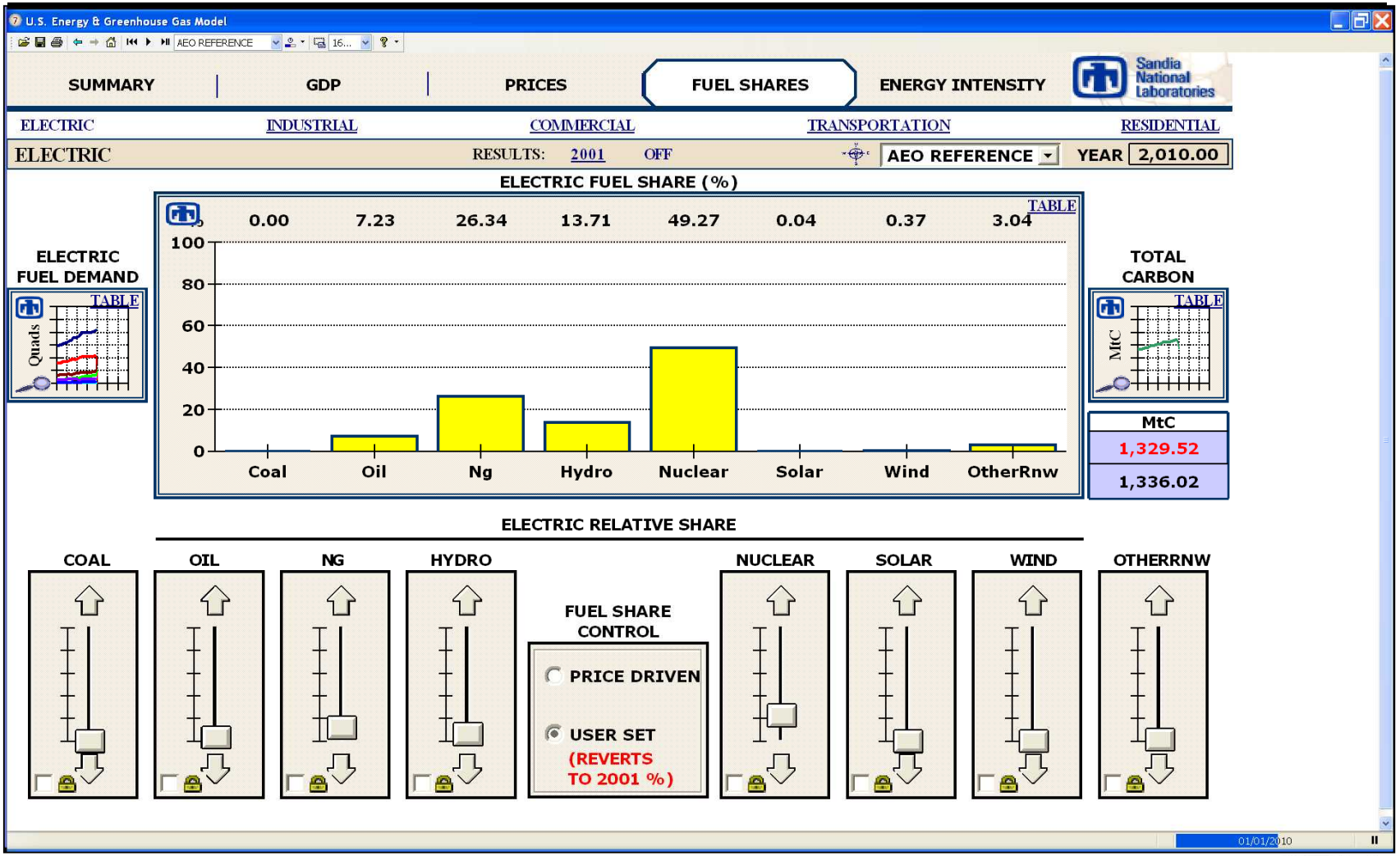
Scenario: What if in 2010 all Coal was eliminated (hypothetical case)



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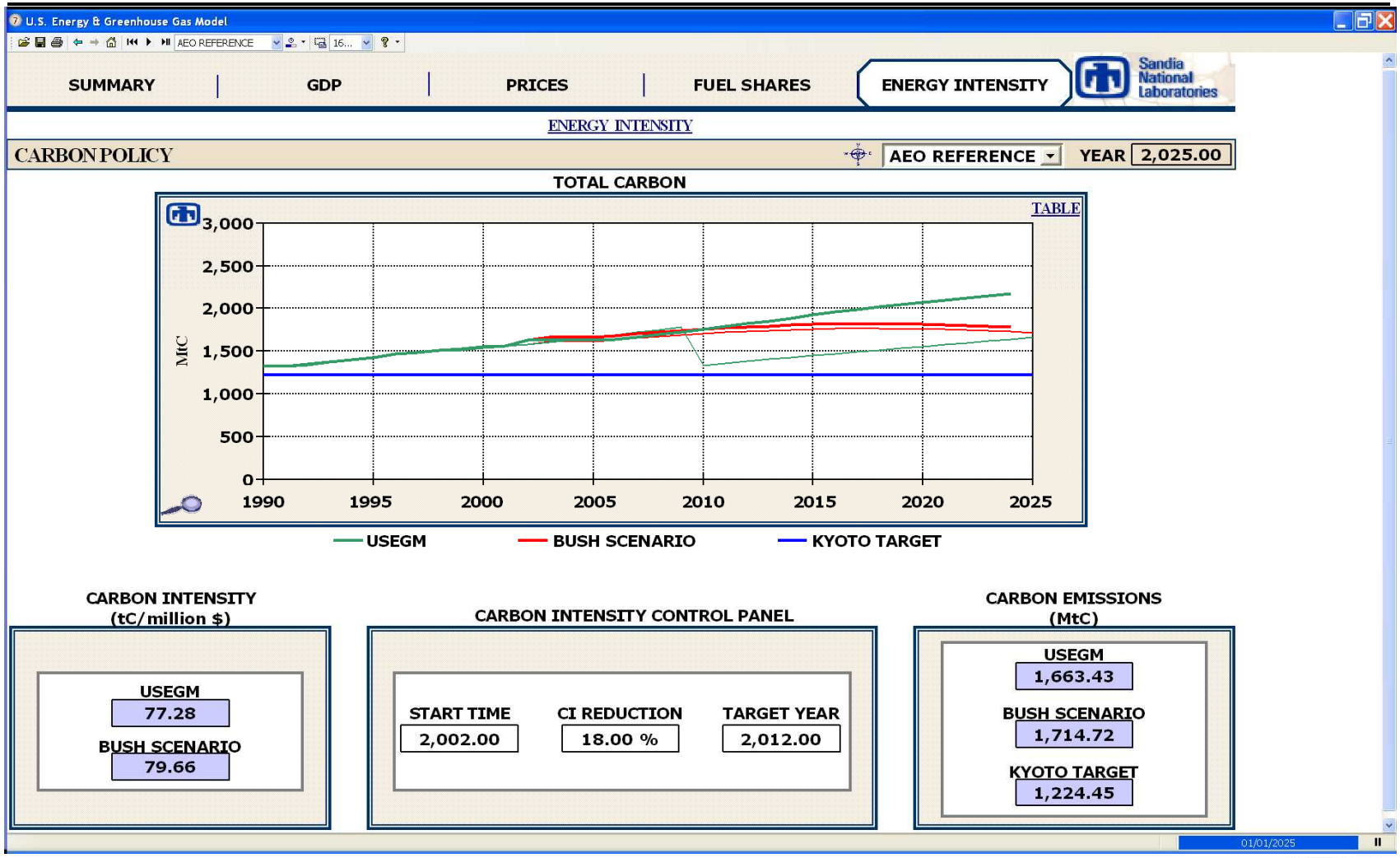
Scenario: Even if in 2010 all Coal was eliminated, the U.S. still would not meet Kyoto



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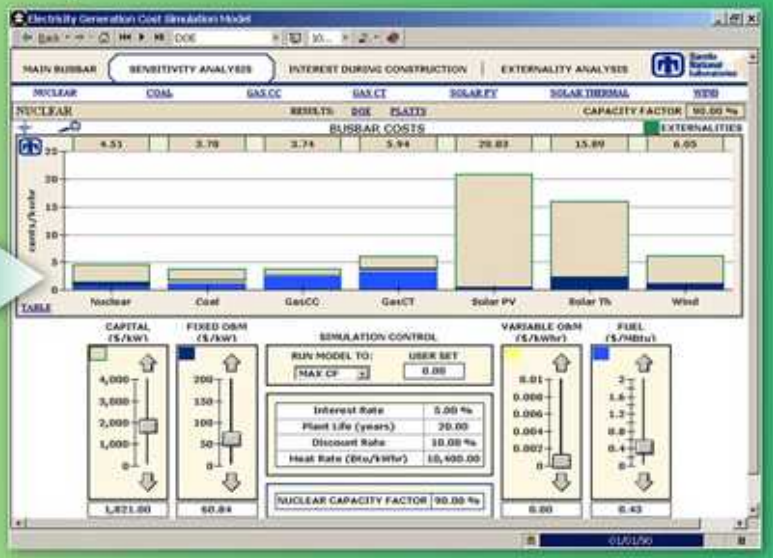
Understanding Technology Cost Options

Electricity



- Calculates electricity production costs for a variety of electricity generation technologies, including: pulverized coal, gas combustion turbine, gas combined cycle, nuclear, solar (PV and thermal), and wind

- Provides sensitivity analysis for key variables, including: capital, O&M, and fuel costs, interest rates, construction time, heat rates, capacity factors, and considers externality costs and pollution control options

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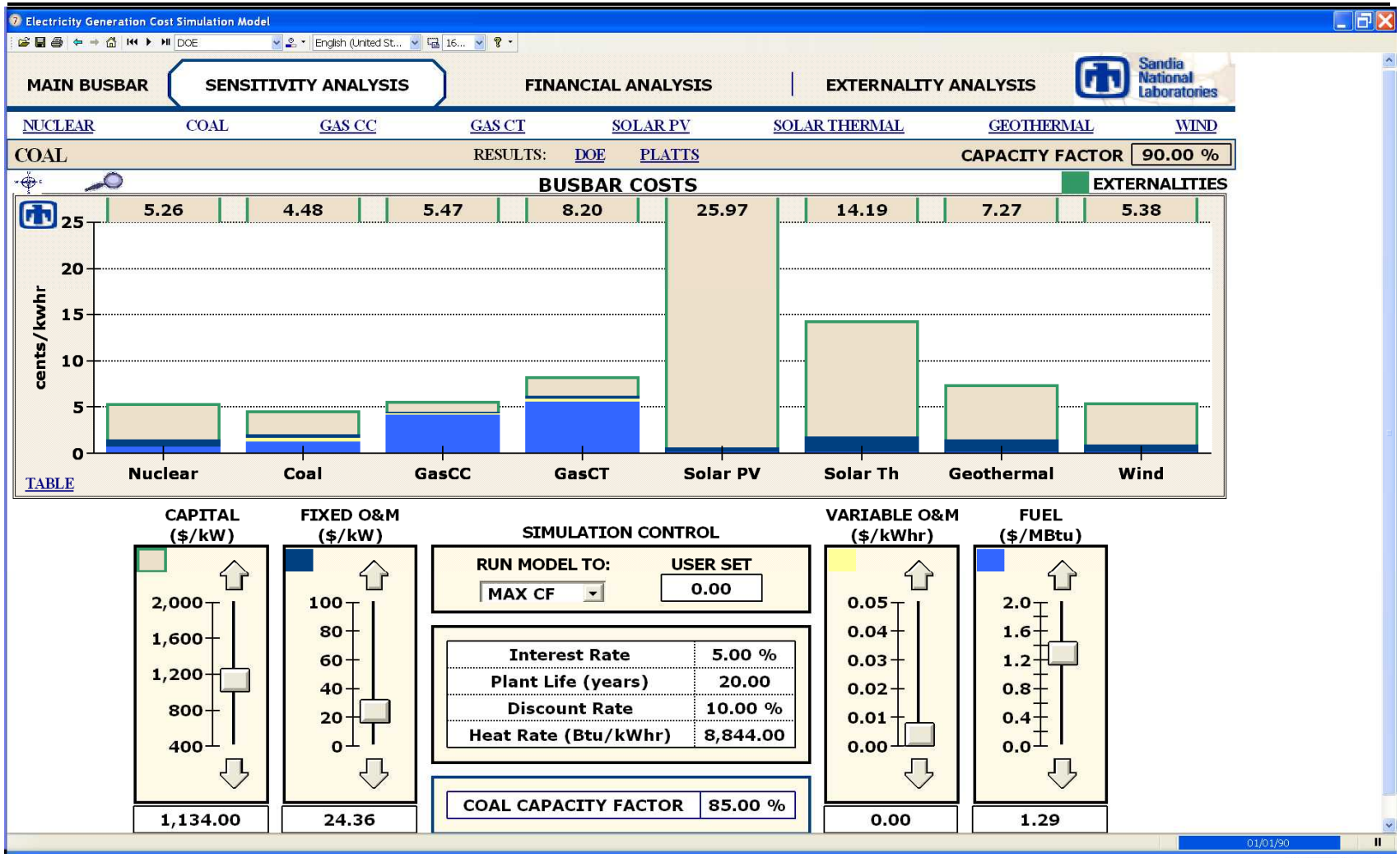
Electricity Generation Cost Simulation Model (GenSim)



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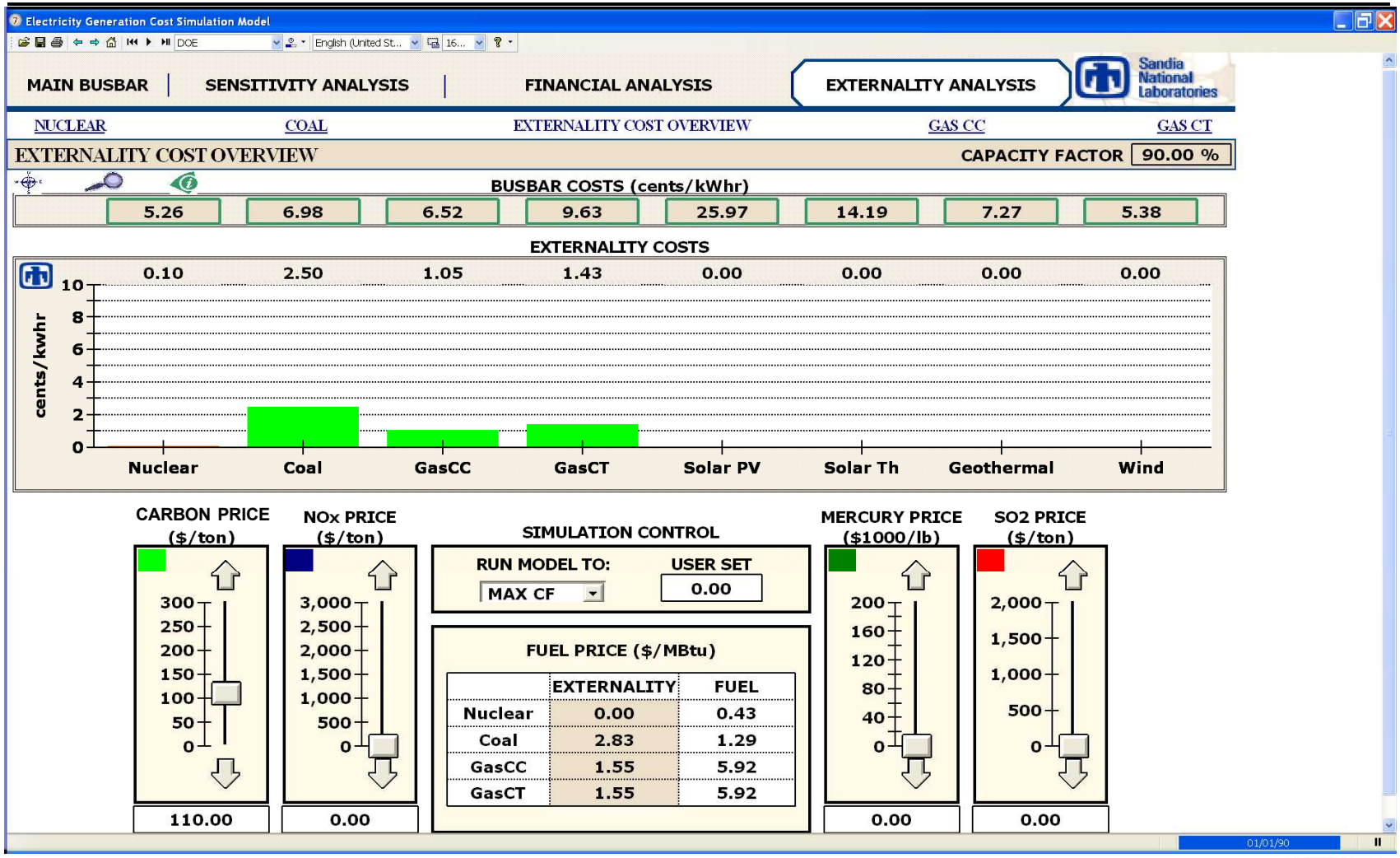

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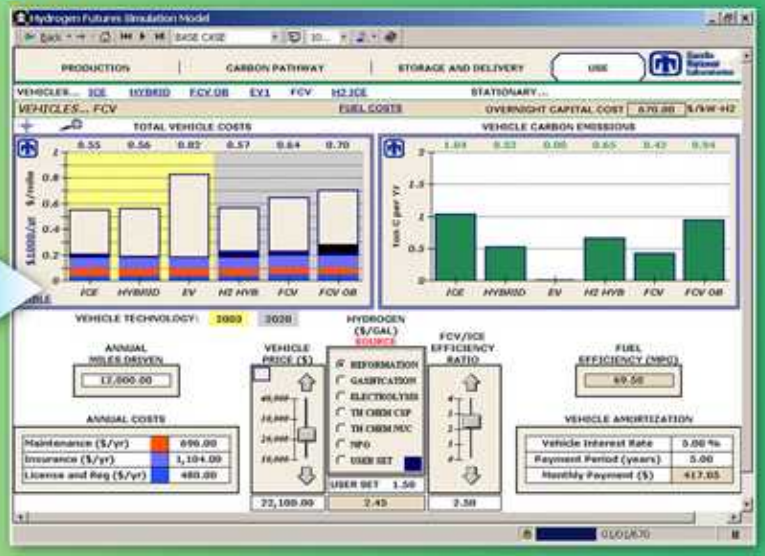
Understanding Technology Cost Options

Hydrogen



- Seeks to improve understanding of the economic viability and emission trade-offs of all stages of potential hydrogen pathways

- Calculates the production, storage, delivery, and end use costs associated with a future hydrogen economy

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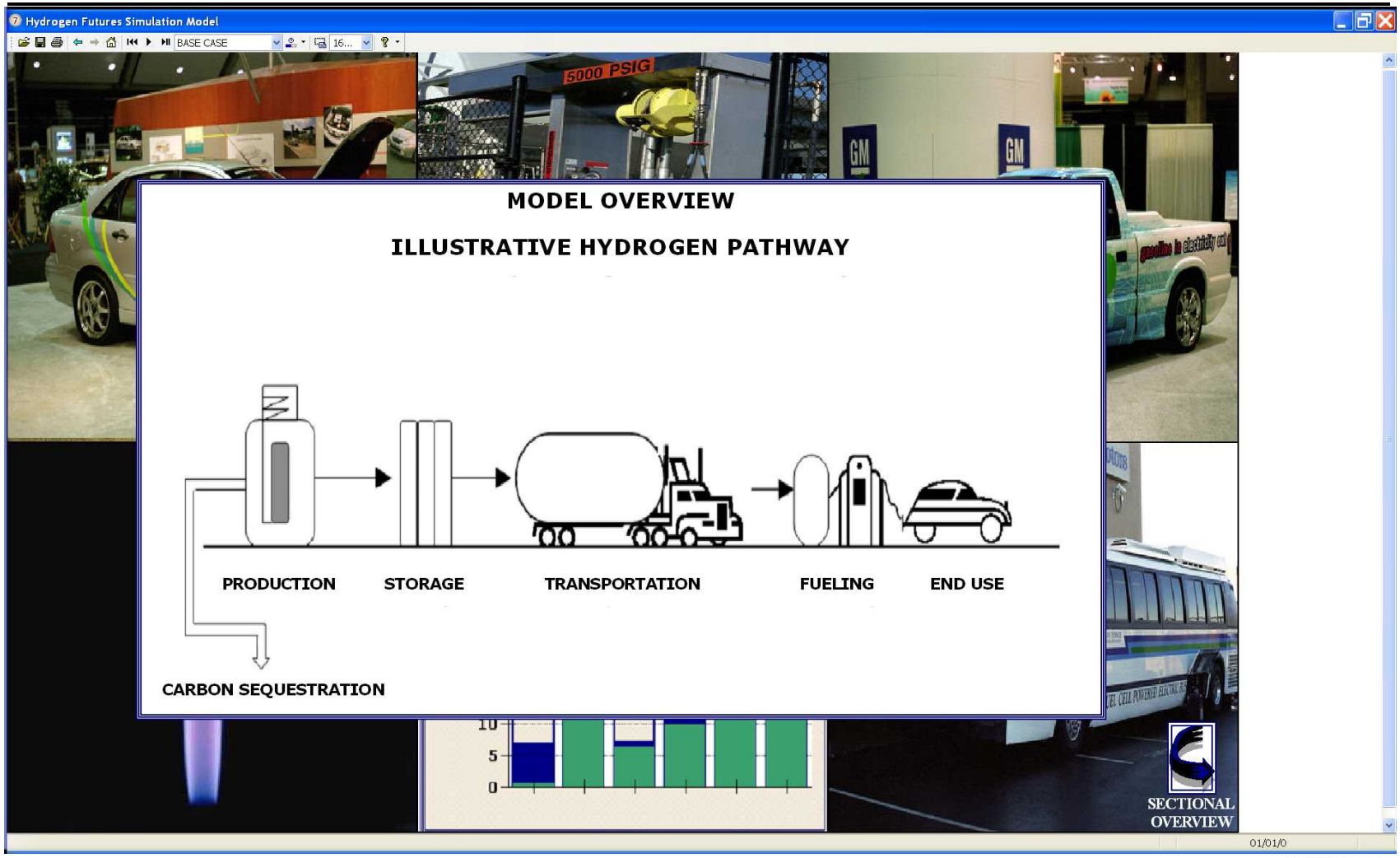
Hydrogen Futures Model (H_2Sim)



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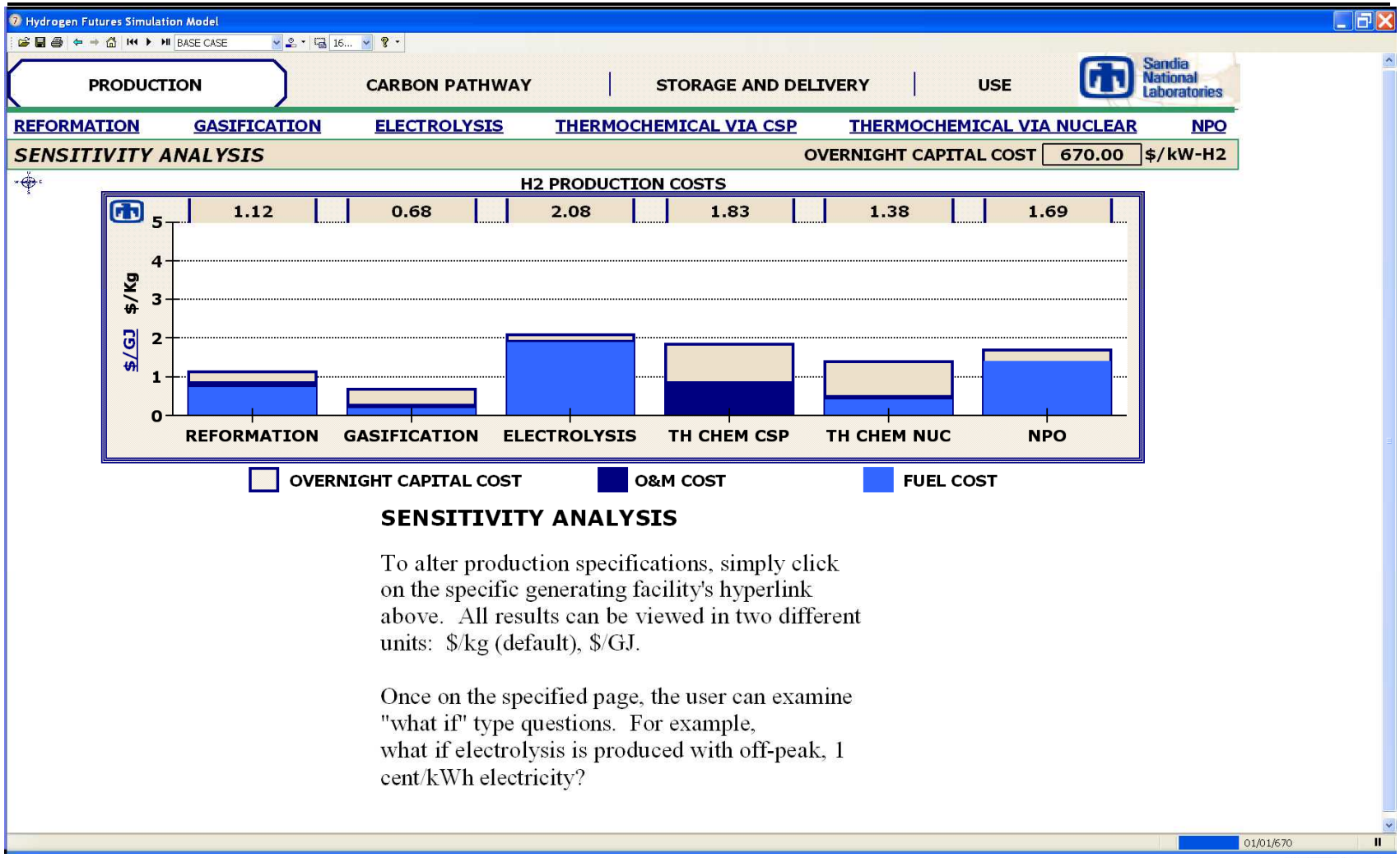

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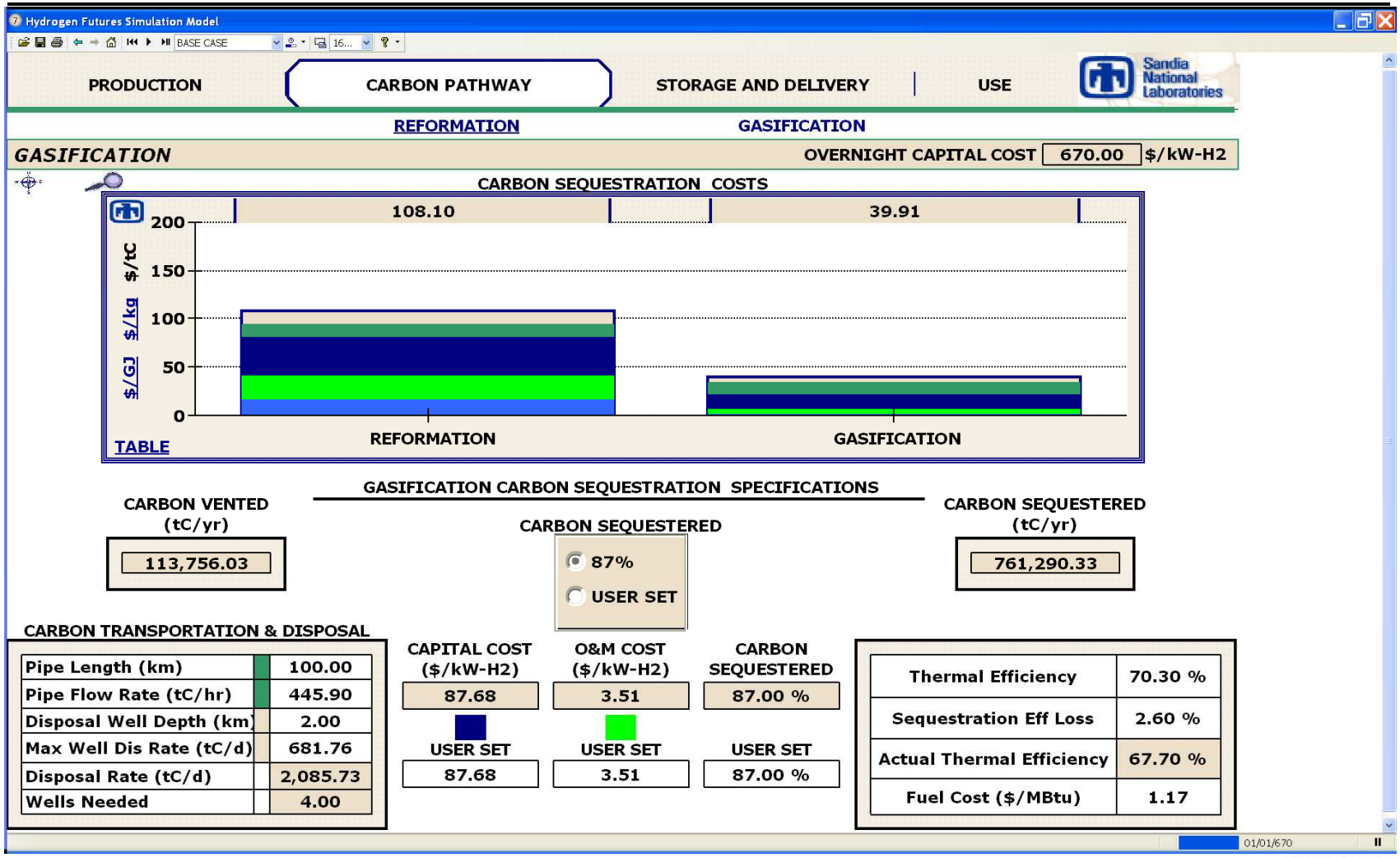

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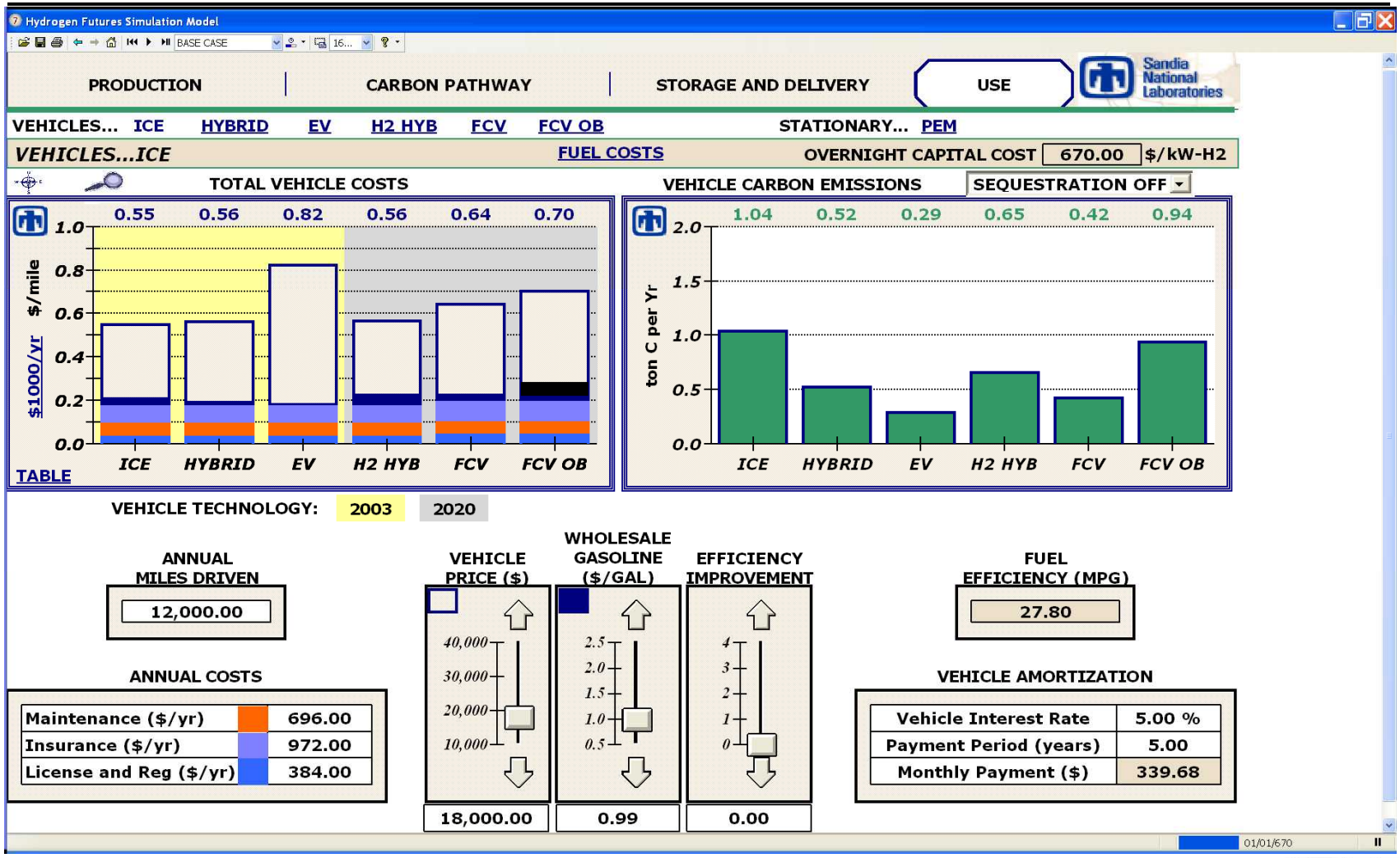

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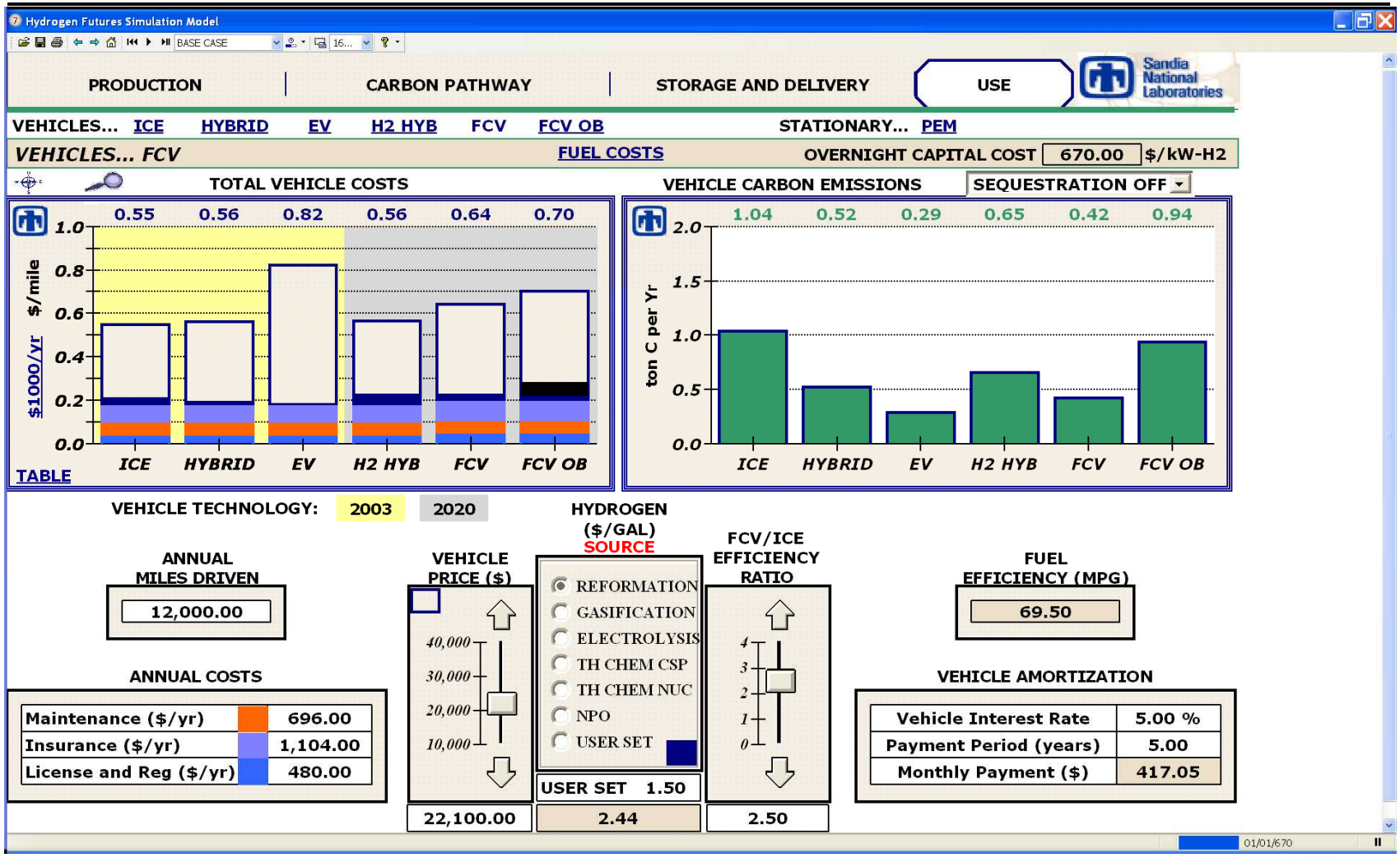

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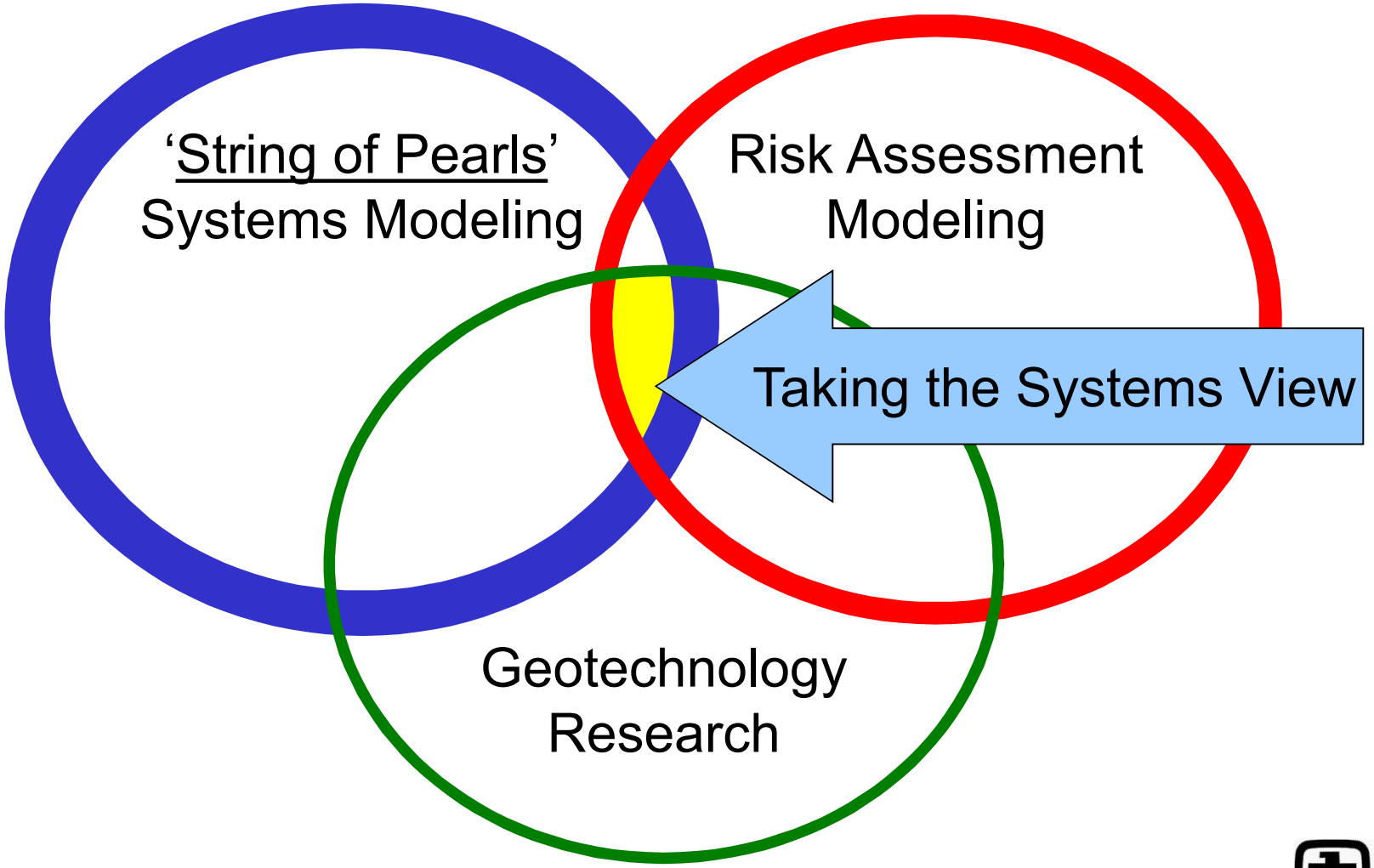
Systems Models: Carbon Sequestration Research



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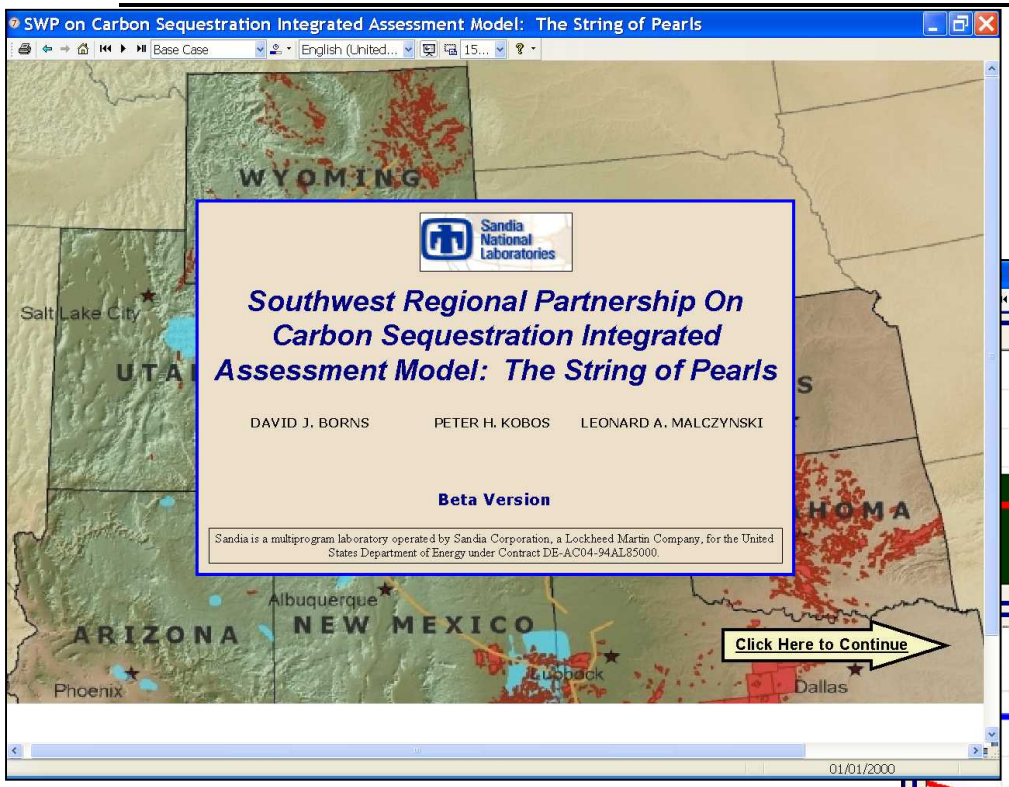
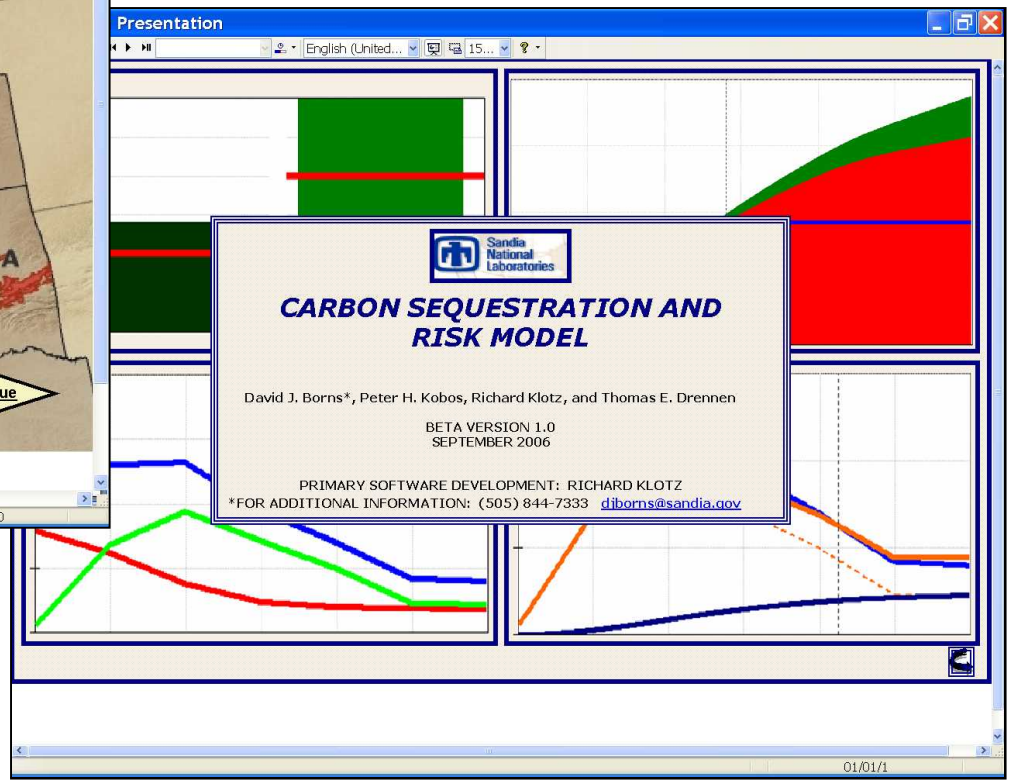
Systems Models : 'The String of Pearls' (SOP; The Carbon Sequestration and Risk (CSR)





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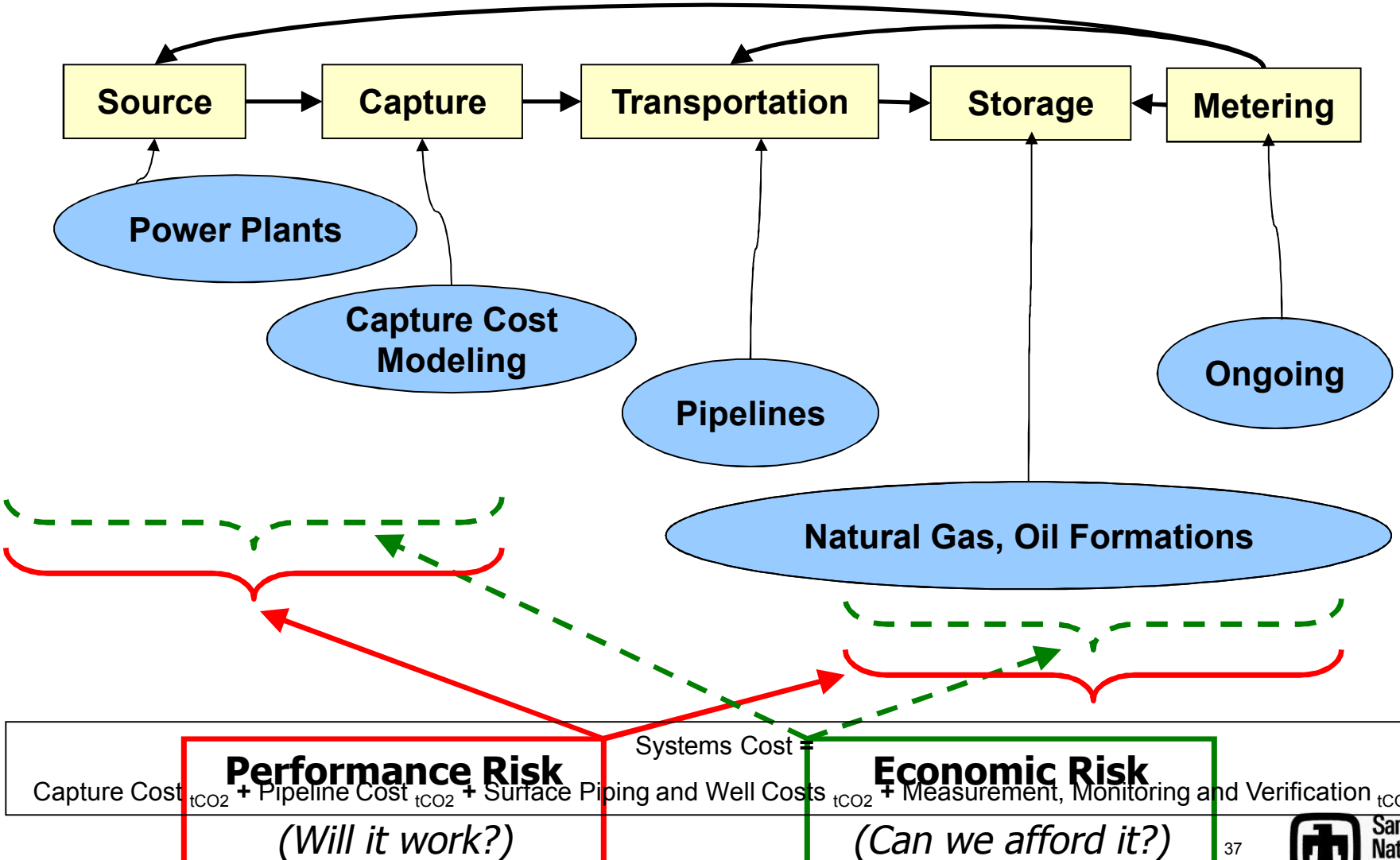
Systems Models' Structure (2)

-- > 'String of Pearls' (SOP)

-- > Carbon Sequestration and Risk (CSR)



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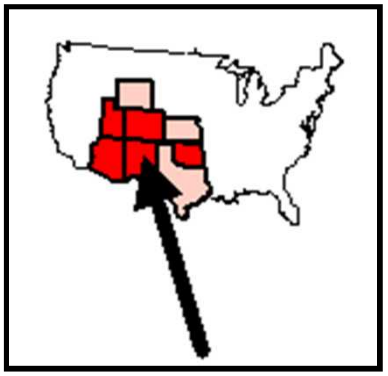
The Southwest Regional Partnership on Carbon Sequestration (SWP)

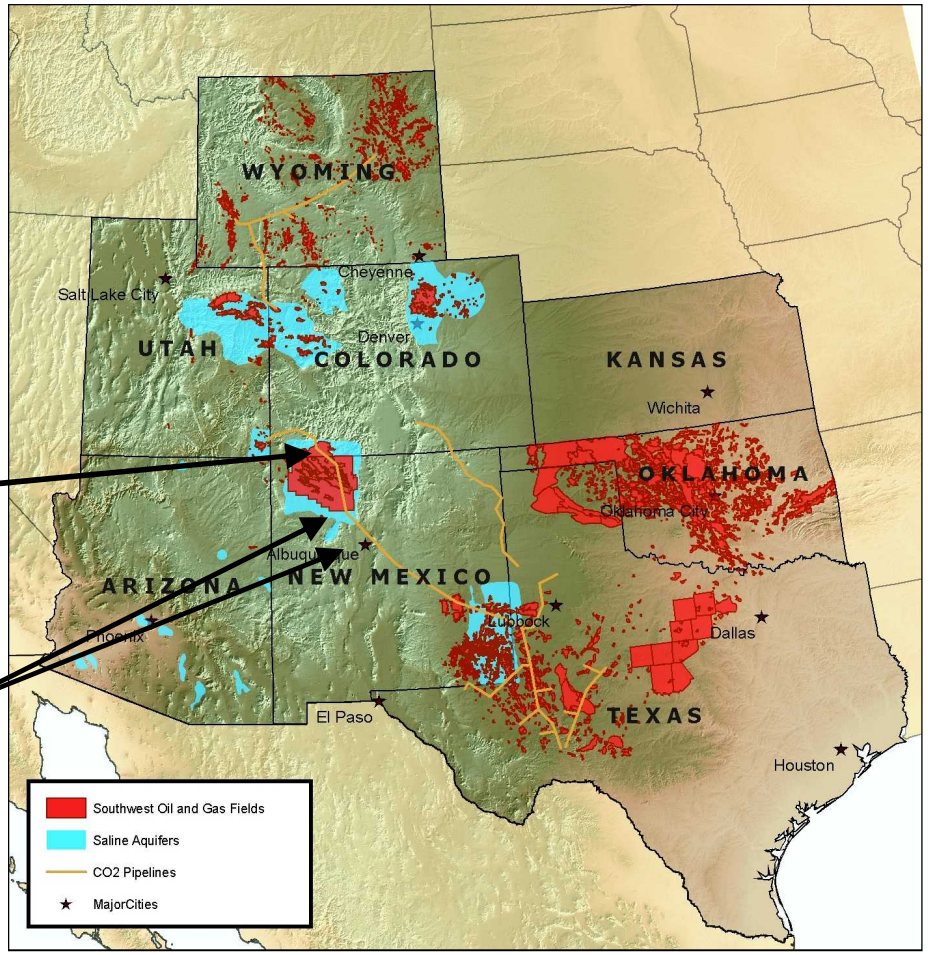
'The String of Pearls'



CO_2 pipelines in NM, TX, CO, WY, UT

Potential Sequestration:

- Oil Fields
- Natural Gas Fields
- Saline Formations



- ***One of seven*** regional partnerships throughout the U.S.
- Evaluating ***available technologies*** to capture and to reduce CO_2 emissions
- ***Source to Sink*** matching (Power plants to Geological Formations)
- String of Pearls Model ***'Tells the Story'*** for the SW Partnership
  - → Technology
  - → Economics
  - → Scale of the Issues

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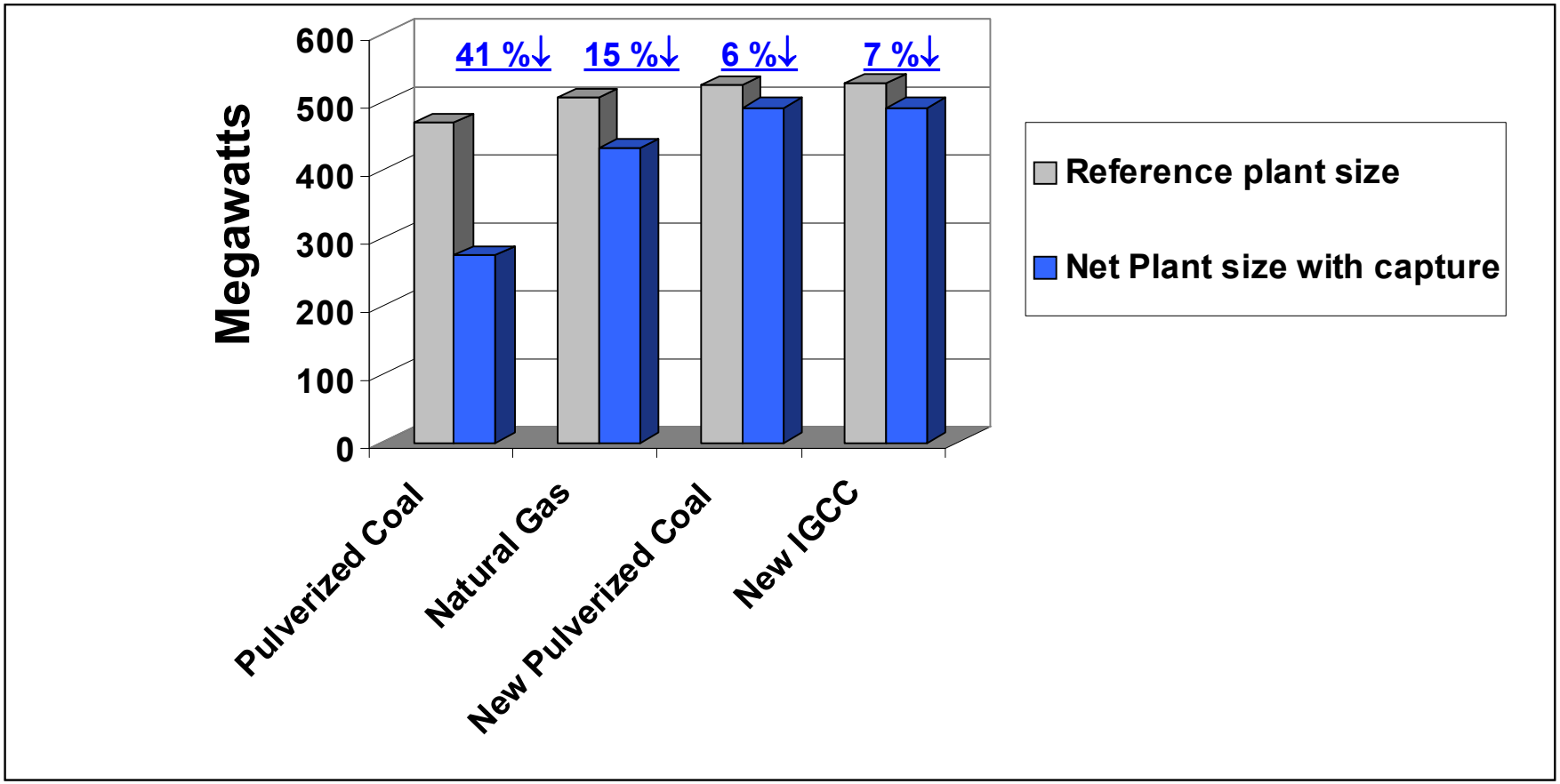
Parasitic Energy Losses: Power with current CO_2 capture Technology

Electricity Cost 291 %↑ 37 %↑ 61 %↑ 30 %↑



Sources: IPCC, 2005 (Rao and Rubin, 2002; Rubin et al., 2005)

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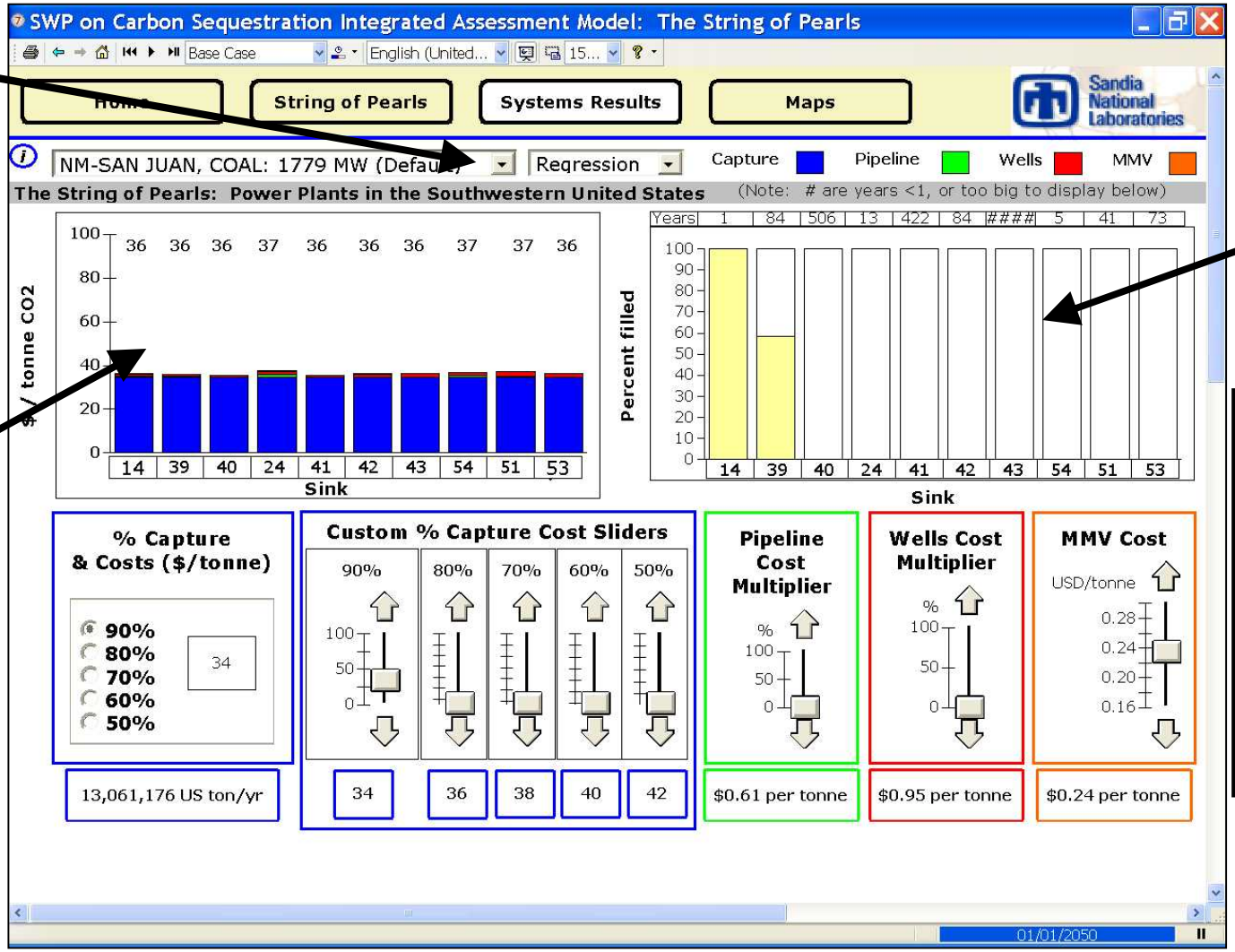
The String of Pearls Model's Working Interface

Select the Specific Power Plant in the SW U.S.

Stacked systems costs



Years of Useful Sink Fill Time

Potential CO_2 Source-to-Sink Matching Capacity of 100s of years (or more), but more work to be done

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A Model Scenario, Selecting only Oil and Gas formations & those ≥ 500 million metric tonnes

Results for the San Juan Power Plant (1779 MW)

Select only Oil & Gas Sinks ≥ 500 mmt

Only 6 sinks are ≥ 500 mmt in the SW Partnership's Oil & Gas database

500 mmt = ~ 60 years of fill capacity per sink for the San Juan Plant

SWP on Carbon Sequestration Integrated Assessment Model: The String of Pearls

Base Case | English (United... | 15...

Home | String of Pearls | Systems Results | Maps | Sandia National Laboratories

Region CO2 Totals | Plant Assumptions | Other

The String of Pearls: Choose a CO2 source (Coal, Gas, Custom), and watch or select the String of Pearls sinks.

Source: Select a Source

- Use selected Source (e.g., San Juan)
- Use custom Source (e.g., Lat., Long.)

NM-SAN JUAN, COAL: 1779 MW (Default)

Sinks: Select from the database of Sinks

- Arizona
- Colorado
- New Mexico
- Oklahoma
- Utah
- Coal Bed Methane
- Oil/Gas
- Saline Aquifer
- Pipelines

Maximum Distance from Source (km): 1,000

Minimum Capacity of Sink (mmtonnes): 500

Sink(s): Automatic String of Pearls, or Custom Sink Option

Electricity: 9.70 cents per kWh — *Note: illustrative electricity cost only*

Power Plant

Plant	Sink	Distance (km)	Cost ($/tonne)
Selected	53	81.2	39

Sinks

from Sink	to Sink	Distance (km)	Cost ($/tonne)
53	52	30.5	37
52	37	123.2	57
37	126	747.2	80
126	146	102.9	39
146	68	521.7	63
0	0	0.0	?
0	0	0.0	?
0	0	0.0	?

Note: The "0" for a Sink indicates the end of the string of pearls.

Click here to Select Specific Sinks

Click here to Show Regional Perspective

01/01/2000

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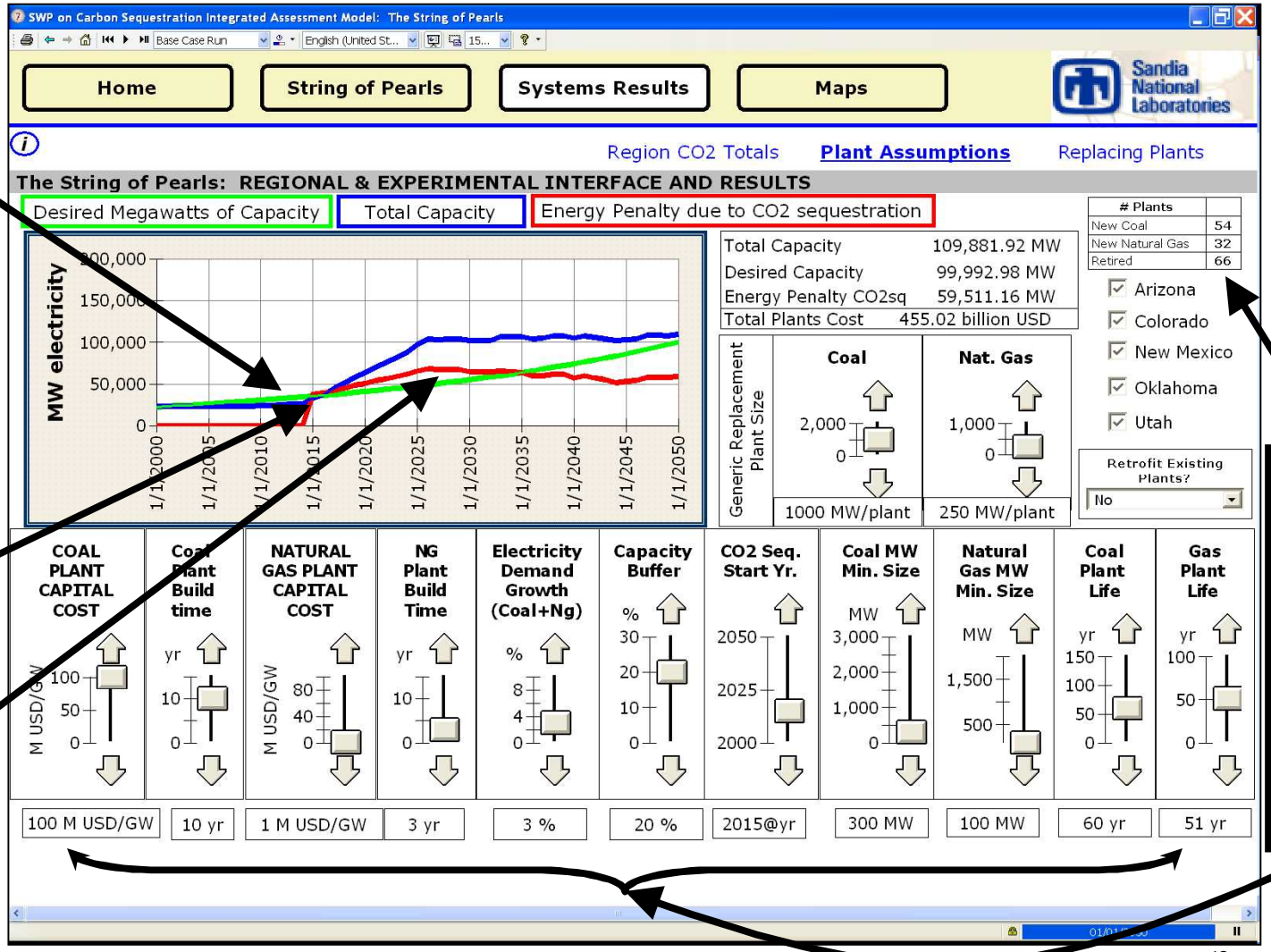
Prototype Total Installed Megawatts Regional Summary for the SWP under an Aggressive, Hypothetical Scenario.

Annual 3% growth rate in capacity (green line)

Total installed MW for the region (blue line)

Total energy needs due to carbon seq. (red line)



Coal and Natural Gas Power Plants (retired, replaced, new energy needs

Model User can Adjust the Plants' Parameters

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Select Energy Economics Modeling Community Members

- The U.S. Energy Information Administration (EIA)
  - Develop and Use the National Energy Modeling System (NEMS) model, is the basis for the Annual Energy Outlook (AEO)
- Pacific Northwest National Laboratory (PNNL)
  - The Joint Global Change Research Institute
- Stanford University
  - The Energy Modeling Forum (EMF)
    - » Collection of modelers (U.S. and abroad)
- The International Institute for Applied Systems Analysis (IIASA)
  - Research institute near Vienna, Austria; develop models for the EU community and beyond.
- The Environmental Protection Agency (EPA)
  - Use the MARKAL model to analyze technology options to address air quality issues
- Many others . . .

Energy Economics and Modeling

Thank You

Resources/References

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