SAND2012-3587P

Exceptional service in the national interest

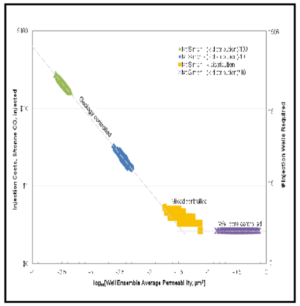
Sandia National Laboratories

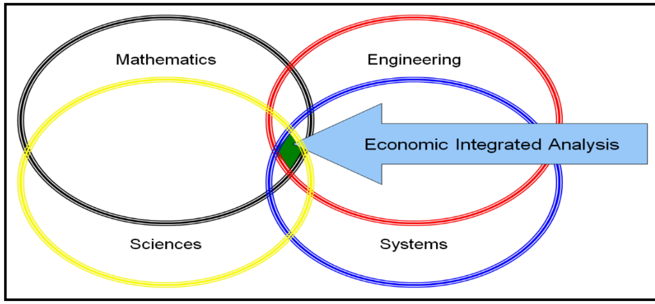
ENG 505 ENERGY SURETY AND SYSTEMS

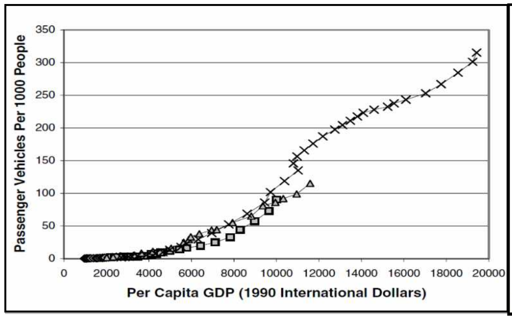
Energy Economics and Modeling

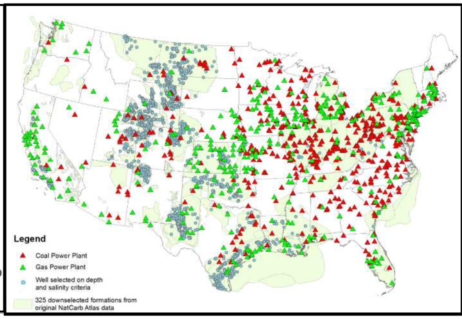
Peter H. Kobos, Ph.D.
Earth Systems Analysis
Sandia National Laboratories,
New Mexico (USA)

SANDIA REVIEW & APPROVAL NUMBER









U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline of Presentation

- Brief Biographical Note of Presenter(s)
- Complex Systems Construct Application to Energy Type
- Energy Economics
- Modeling Taxonomy
- Current Applications
- Summary Overview
- Question & Answer Session

Peter H. Kobos

- Education:
  - BS, Biology (Hobart College)
  - MS, Economics; Ph.D., Ecological Economics (Rensselaer Polytechnic Institute (RPI))
- Professional Experience:
  - Sandia Consultant (~ 5 yrs) + Post-Doc and Staff (~10 yrs)
  - International Institute for Applied Systems Analysis (IIASA), YSSP, Austria
  - Council Member: U.S. Association for Energy Economics (current)
- Past Sandia Projects
  - Solar (CSP & PV), Wind, Geothermal, Hydrogen and Fossil Energy (Coal), CO_2 Capture, Storage and Transportation
- Current Projects:
  - PI on National Energy Technology Laboratory (NETL) project(s)
  - Focusing on Electricity, CO_2 capture and storage, Water Use and Treatment from geological formations

Recall: What is a Complex System?

- A **complex system** is a system composed of interacting elements that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts
- Common Attributes
  - Multiple interacting phenomena
  - Heterogeneous element
  - Non-linear dynamics and effects
  - Adaptive behavior
  - Elements with memory
  - Large network of elements or nested complexity

Recall: Approaches* to Complex Systems

- Mathematics
- Physical-Cyber-Behavior
- Threat and Risk
- Systems Engineering
- Sandia Software Tools
- Sandia Disciplines

These represent approaches or resources that an analyst or engineer may apply to a systems engineering challenge. They are not intended to be a complete set, just one chosen to add structure to this course.

*Note: These approaches represent a simplified set of complex systems concepts chosen for the ENG505 systems lectures. Please see the initial two systems lectures for additional detail and expanded references.

Approaches to Energy Economics & Modeling

Mathematics

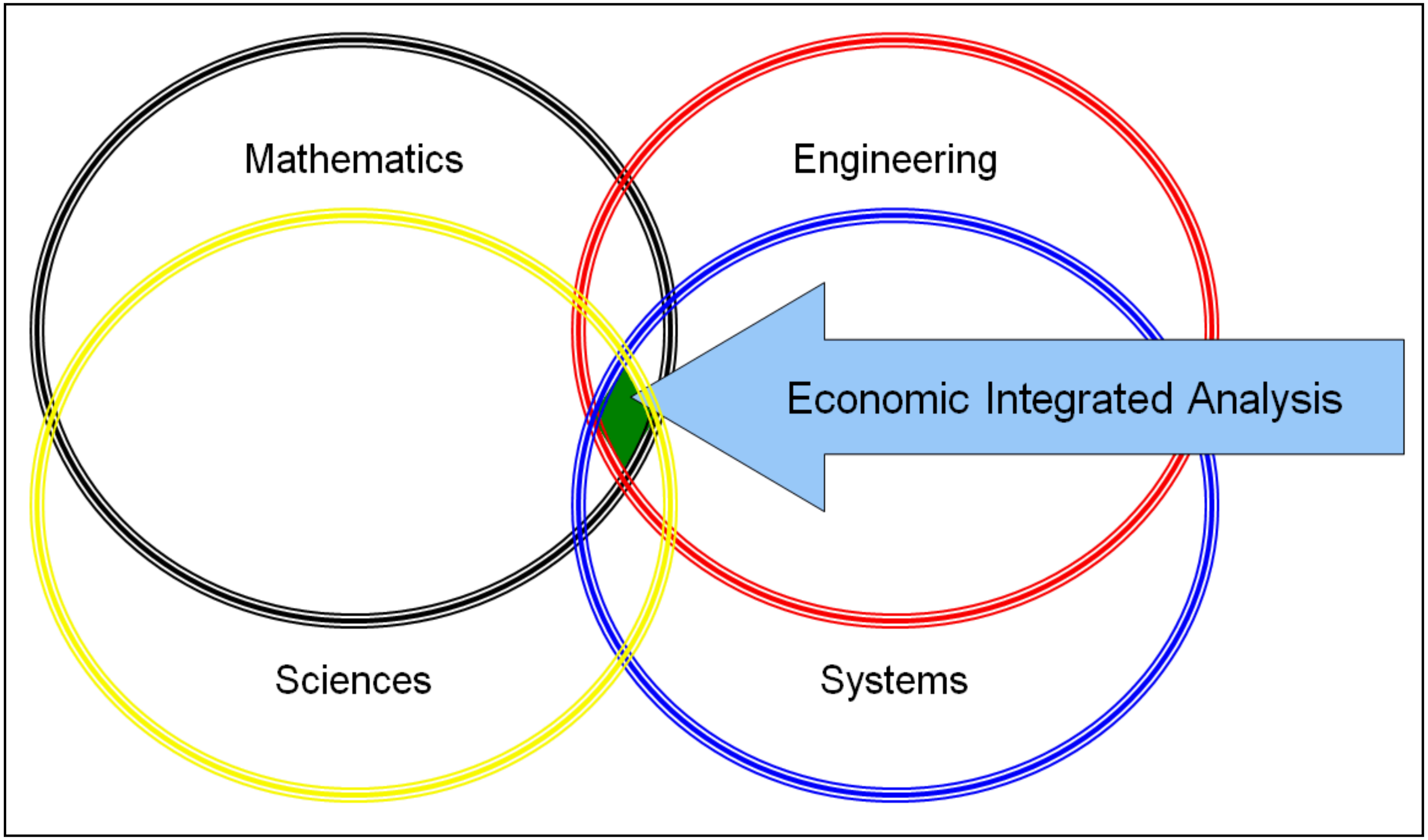
- Linear systems, non-linear systems, statistics, etc.
  - Optimization techniques (e.g., Linear Programming)
  - System Dynamics tools
  - Regression Analysis, Matrix manipulation

Sandia Disciplines

- This approach represents a number of methodologies used across the field of Energy Economics
  - Science & Engineering
    - Material costs, physical and theoretical limits of technologies (e.g., energy efficiencies for given materials), etc.
  - Economics
    - Modeling the Adoption of new or different technologies (e.g., via income elasticities), impact analysis, identify systems cost 'bottlenecks', etc.

*Note: Additional detail and expansion around other approaches are included in the initial two ENG505 systems lectures. This is only a simplified template summary for use in ENG505 energy-focused classes.

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



Setting the Stage: Economics, Energy Economics

- "The fundamental challenge in economics is to allocate scarce resources across competing uses."
  - *Dahl, 2004, p. 43.*
- 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
  - Income elasticity, market penetration rates of technology
  - Other techniques include:
    - Econometrics (various statistical analyses, i.e., regression analysis)
    - Macroeconomics (structural changes throughout the economy, i.e., aggregated price indices)
    - Resource economics (resource extraction and rates of use, i.e., maximizing profit, addressing sustainability, etc.)

- Additional Information Resources on Energy Economics & Modeling:
  - International Association for Energy Economics (IAEE), www.iaee.org
  - National Bureau of Economic Research: Environmental and Energy Economics Division: http://www.nber.org/programs/eee/eee.html

General Topics in Energy Economics

- Competition, Monopolies and the Energy Industries
- Deregulation and Privatization of Electricity Generation
- Dominant Firm and OPEC (Organization of the Petroleum Exporting Countries)
- Transaction Costs
- Energy Futures and Options Markets for Managing Risks
- Externalities and Pollution
- Energy Resource Allocation Planning
- Supply and Cost Curves

Source: Adapted from Dahl, 2004.

Types of Costs & Factors Used in Energy Economics

Sandia National Laboratories

- **Capital Costs:** Represent the initial cash outlay (e.g., $)
- **Discount Rate:** The rate at which future benefits and costs are discounted because of *Time Preference* or because of a positive *interest rate*
- **Inflation Rate:** A sustained rise in the general price level
- **Nominal (current) dollars vs. Real (constant) dollar:** Real dollars account for inflation (e.g., $\$\mathbf{3{,}521}_{1970\$}/0.388_{1970CPI/100})*1.136_{1987CPI/100} = \$\mathbf{10{,}309}_{1987\$}$)
- **Present Value:** The worth of a future stream of returns or costs in terms of their value now
- **Levelized Costs:** include the energy technology's electricity output across time, discount rate, Operating Costs, & other factors including taxes, externalities, etc. (e.g., electricity costs in $/kWh)
- **Opportunity Cost:** The value of the forgone alterative action by committing to another one (exists when resources are limited and cannot meet all wants).

Sources: Pearce, 1996; Boardman et al., 1996.

Example: Capital Costs and Levelized Costs, What's the difference?

Sandia National Laboratories

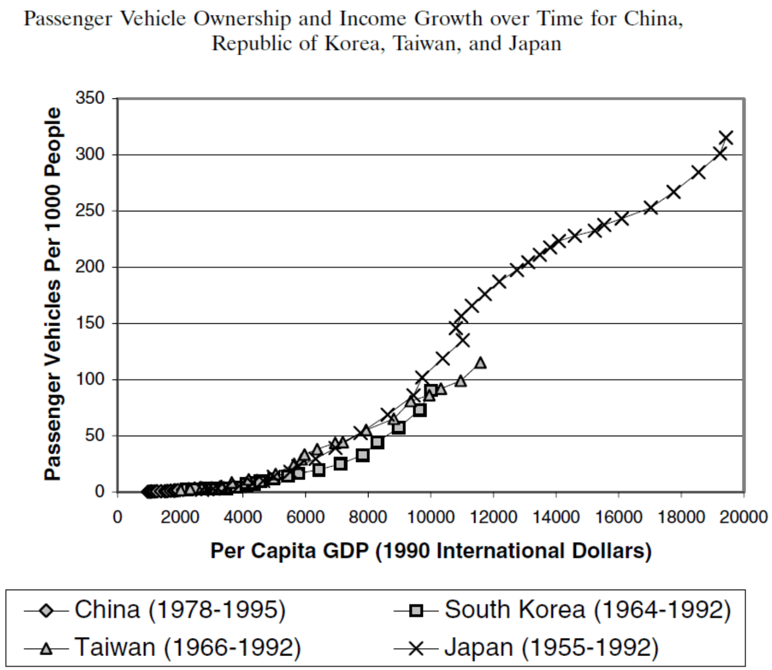
- Levelized Costs include the energy technology's electricity output across time, discount rate, and other potential factors including taxes, externalities, etc.
- Wind turbine hypothetical example
  - Initial Capital Outlay: **$450,000**
  - Installation Costs: **$125,000**
  - Turbine Operating (a.k.a., capacity factor): **25%** of the time
  - Size of the Turbine: **600 kW**
  - Life of the Turbine: **20 Years**
  - Real Discount (or interest) rate: **10%**

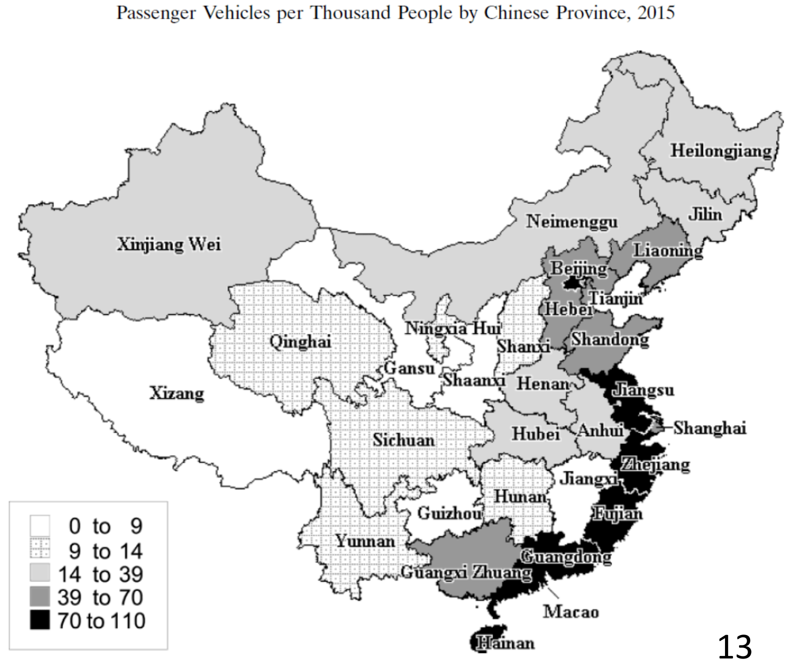
  - Thus, moving from Initial Capital and Installation costs ($) to levelized costs:
    - 600 * 24 * 365 * 0.25 = 1,314,000 kWh per year
    - $((\$450{,}000 + \$125{,}000)/1{,}314{,}000) \,/\, \left(\sum_{i=0}^{20} 1/(1+.10)^i \right) = \sim \$0.047$ per kWh

Sources: Dahl, 2004.

Measuring how responsive quantities demanded & supplied are to prices $/or other variables

- An ‘Elasticity’ is a metric used to quantify the strength of a relationship between two entitites
- Demand, Supply, Income and Price Elasticities can be developed
- Income Elasticity = **% change quantity / % change in income**





Source: Adapted from Kobos et al., 2000.

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

Top-Down Example: *Input-Output Economic Modeling*

Sandia National Laboratories

Use the IO Model to Inform the Discussion: *What is the region's economic base?*

→

Translate policy issues into direct effects: *How many jobs are being gained/lost?*

→

Enter direct effects into the IO model: *What are the ripple effects across the economy?*

→

Interpret total effects: *What should be done? What is the contribution of the change?*

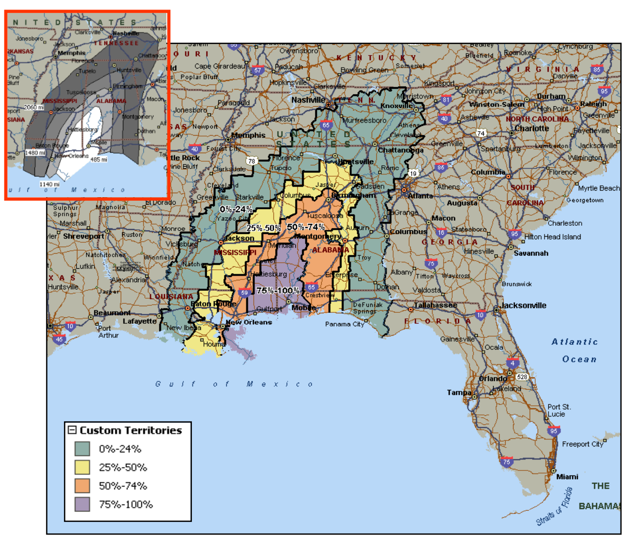
- Method of matrix analysis, economy is represented by a set of linear <u>production functions</u> that describe the <u>interrelationships</u> between sectors
- Total Economy's output is split into the amounts used in the production of all other commodities (intermediate production) and that which is finally consumed
- TAKE AWAY MESSAGE: Input-Output can identify the amount of output necessary from each sector to meet a given final demand

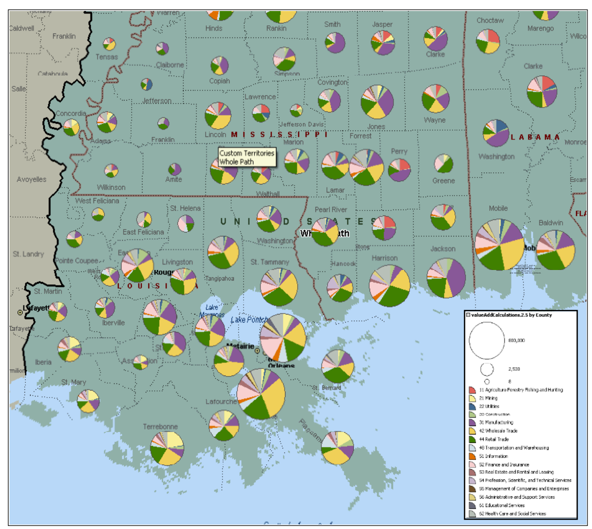
Source: Adapted from Pearce, 1996; EMSI, 2007.

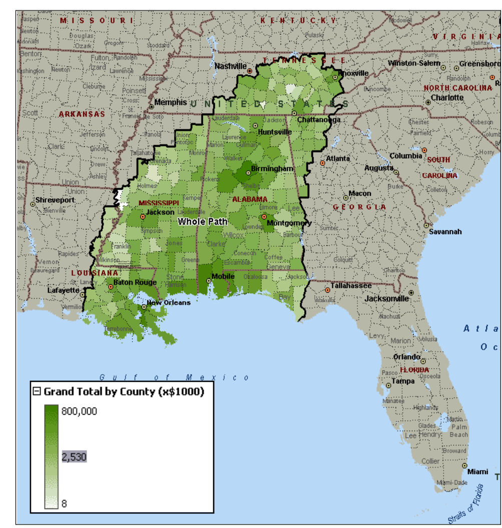
Input-Output Modeling at Sandia

- Historically used for ‘Impact Analysis’
  - Can expand Input-Output modeling to assess energy systems
- Sandia I-O Example: Regional Economic Accounting (REAcct)
  - Analysis tool used to rapidly estimate approximate economic impacts for disruptions due to natural or manmade events

Define the Impact Areas for a Hurricane Scenario → ***Compile the Economic Data*** → ***Estimating Impacts and Reporting Results***

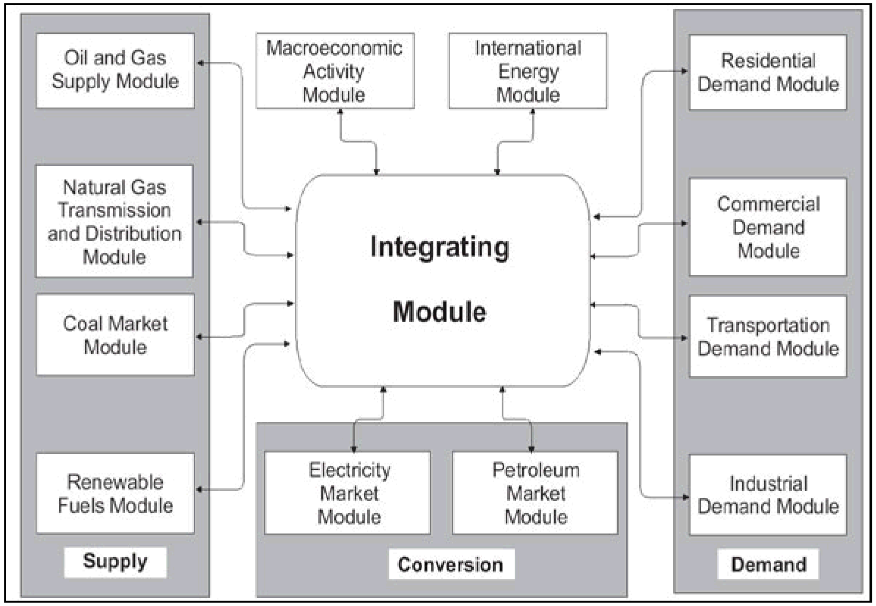


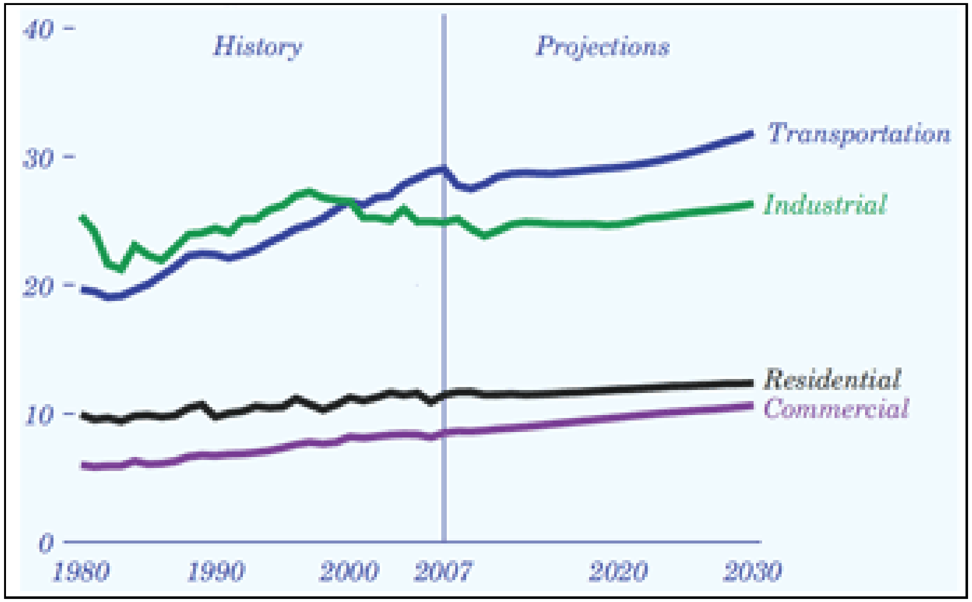




Source: Adapted from Ehlen et al., 2009.

Bottom-Up Example: National Energy Modeling System (NEMS)



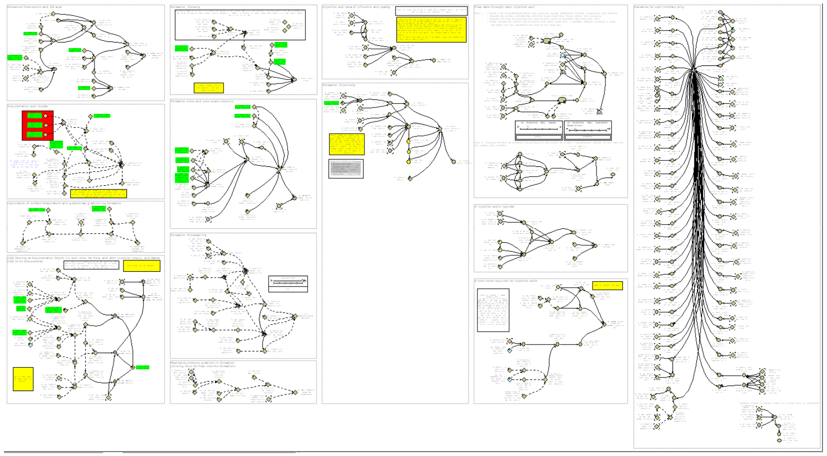


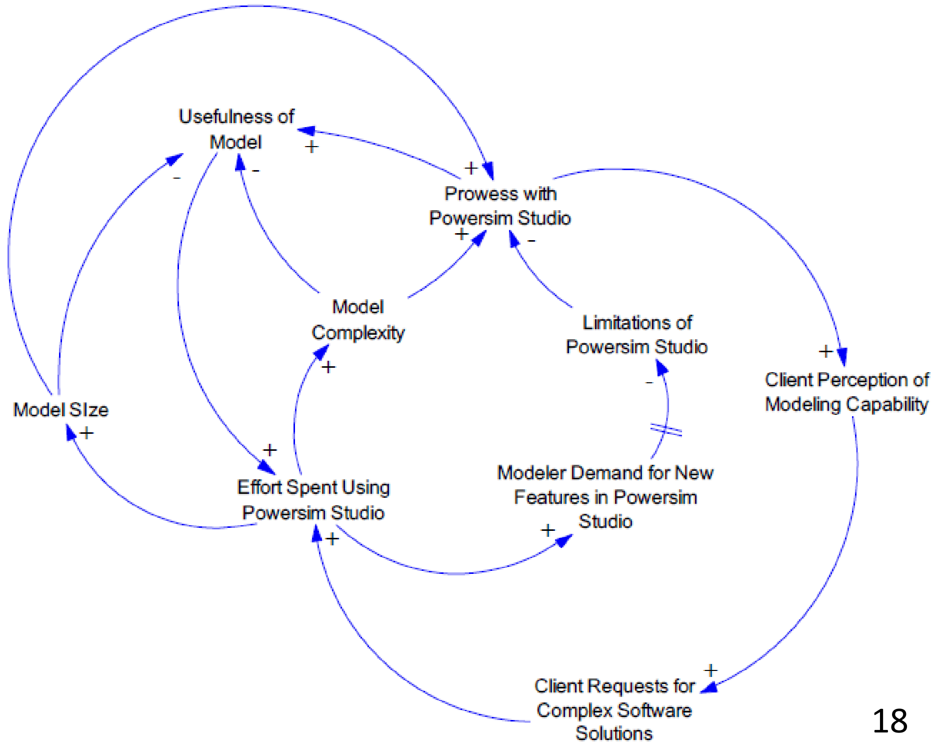
"The Annual Energy Outlook presents a midterm projection and analysis of US energy supply, demand, and prices through 2030. The projections are based on results from the *Energy Information Administration's* National Energy Modeling System." - EIA, 2009.

Sources: Adapted from the Energy Information Administration (EIA), 2009 As of March 9, 2009. http://www.eia.doe.gov/oiaf/aeo/assumption/introduction.html & http://www.eia.doe.gov/oiaf/aeo/overview/figure_2.html & http://www.eia.doe.gov/oiaf/aeo/overview.html & http://www.eia.doe.gov/oiaf/aeo/index.html

Integrated Assessment Modeling Example: System Dynamics

- System Dynamics tools focus on the system's interrelated dynamics
- Able to capture Engineered and Social Systems within one modeling methodology & tool
- Being careful to maintain the model's applicability (e.g., detail balance, time delays, technology attributes)
- Challenge to understand the positive or negative influences of factors across systems



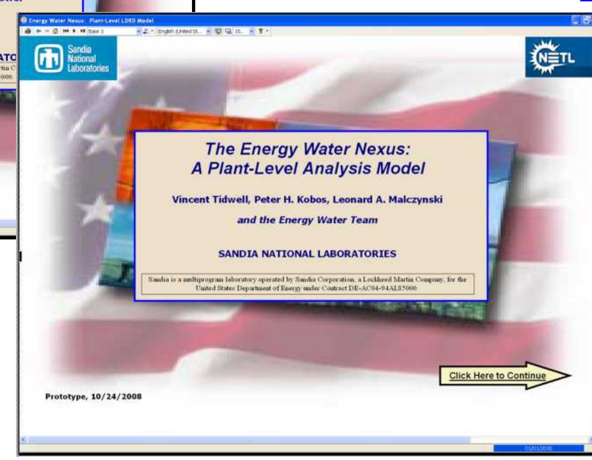


Source: Adapted WECSsim, 2011; Malczynski, L., 2011

Integrated Assessment Models:

Addressing Technological Progress and Policy Assessment

Sandia National Laboratories



Pilot Scale to Country Wide Technology Adoption & Assessment

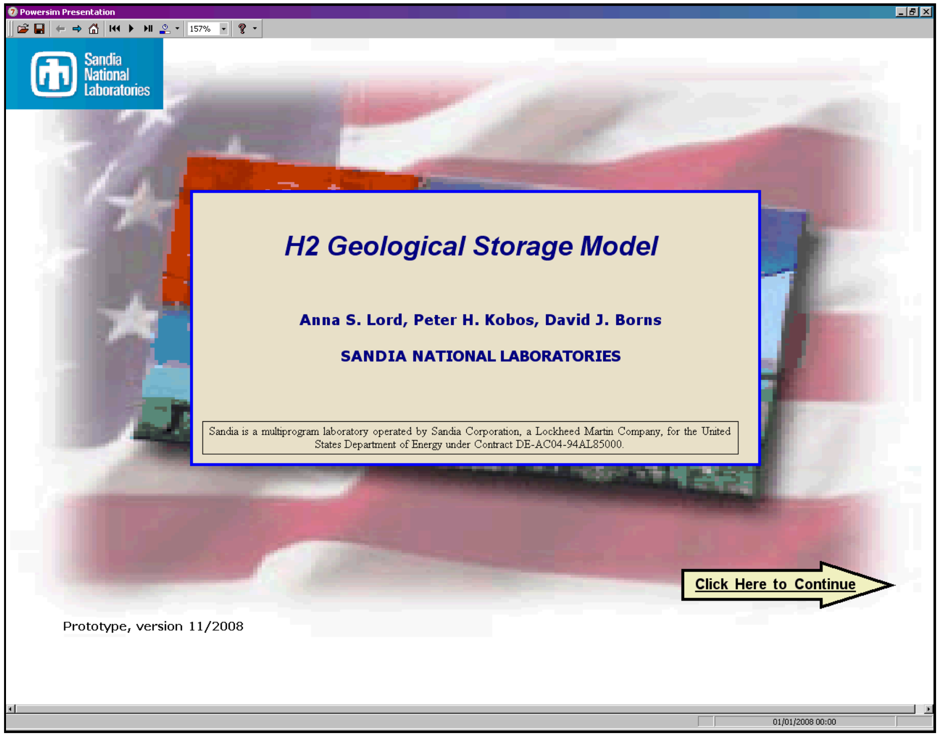
- → Electric Power and Efficiency
- → CO_2 Sequestration
- → Energy & Water Issues

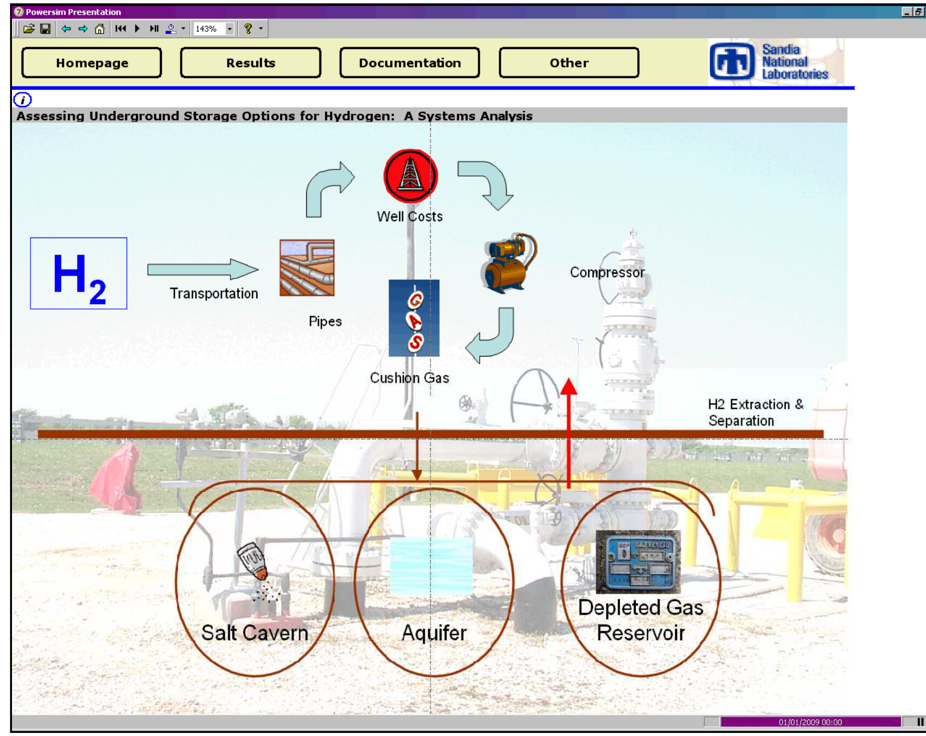
Fuel-Specific Technologies

- → Hydrogen Futures
- → Alternative Liquid Fuels
- → Electricity Generation

Life Cycle Cost Model Examples:

H_2 Geologic Storage Model





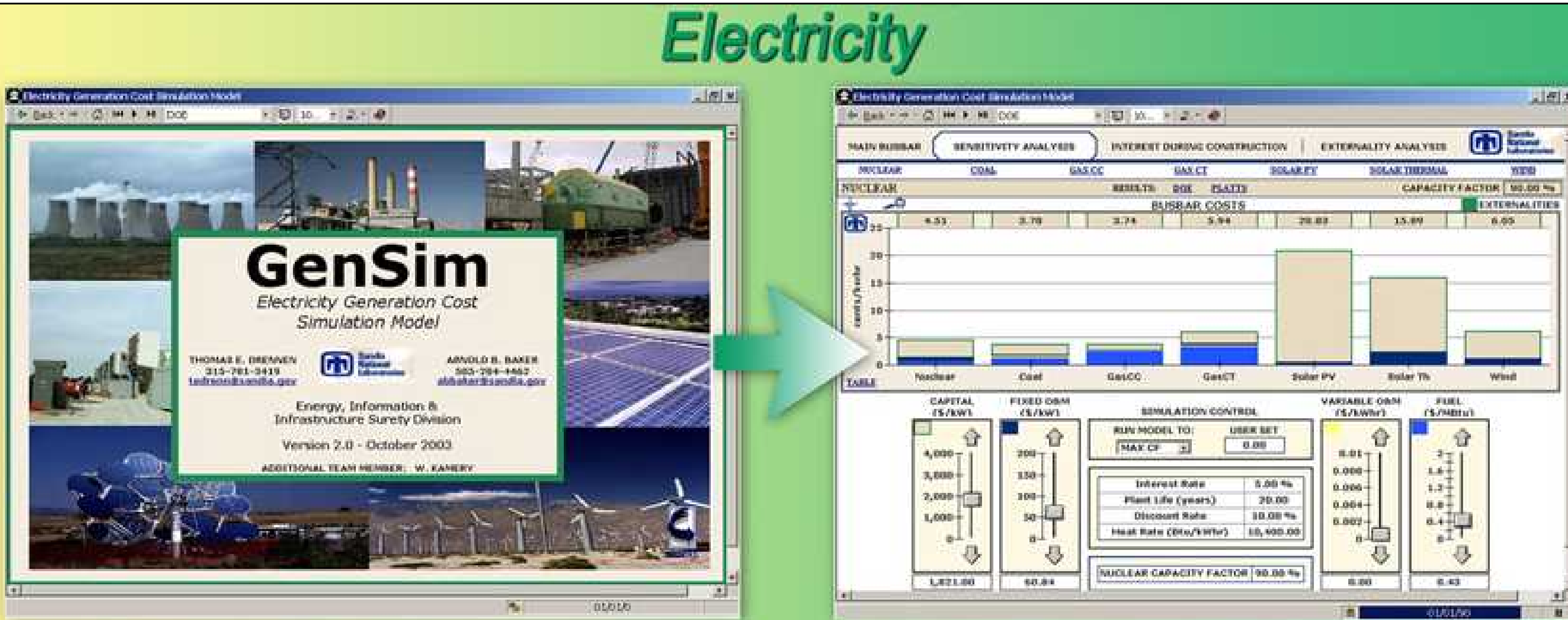
Hydrogen Geological Storage Model

Metrics of Interest

- *Scale of Potential Storage*
- *Costs Associated w/a Large-Scale System*
- *Engineering & Geological Constraints*

Life Cycle Cost Model Examples:

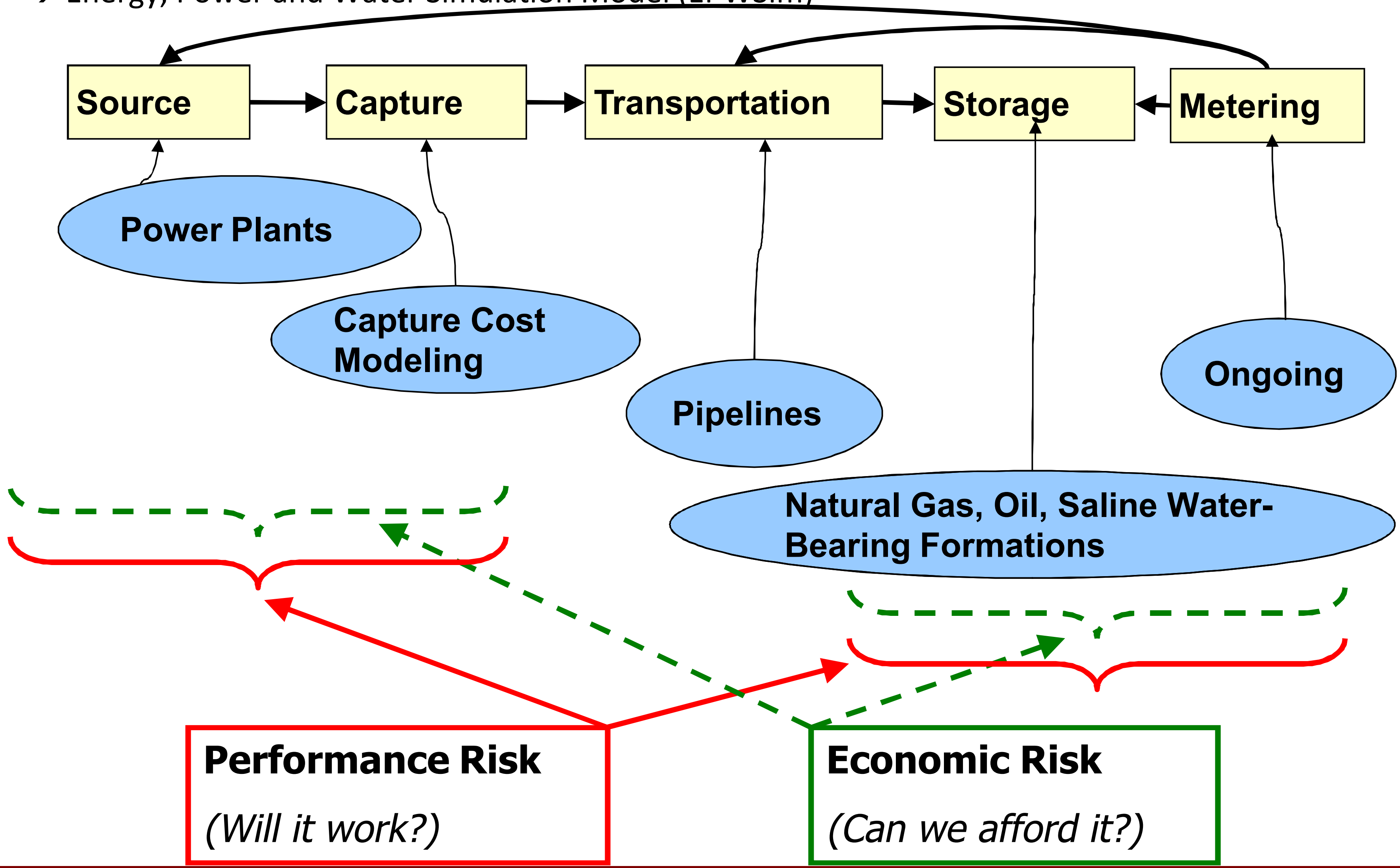
Electricity Generation Costs



- 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

Integrated Assessment Models: SNL examples

- → **'String of Pearls' (SOP)**
- → **The Water, Energy and Carbon Sequestration Model (WECSsim)**
- → Energy, Power and Water Simulation Model (EPWSim)

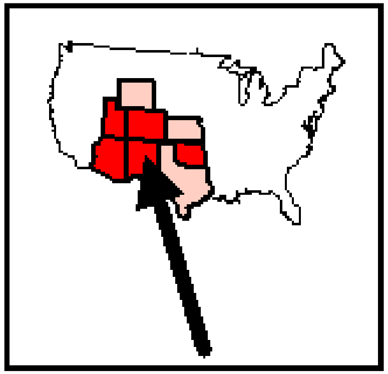


Systems Cost = Capture Cost $_{tCO2}$ + Pipeline Cost $_{tCO2}$ + Surface Piping and Well Costs $_{tCO2}$ + Measurement, Monitoring and Verification $_{tCO2}$

The String of Pearls:

Systems Model for the Southwest Regional Partnership on Carbon Sequestration

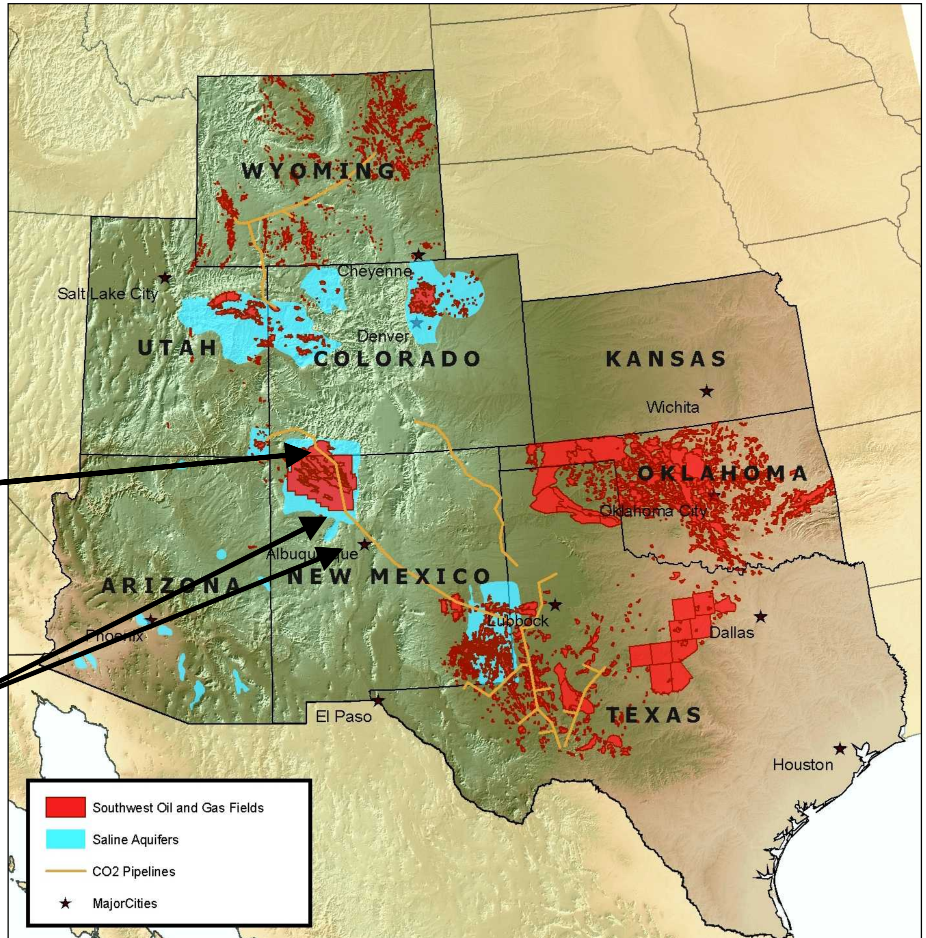
Sandia National Laboratories



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

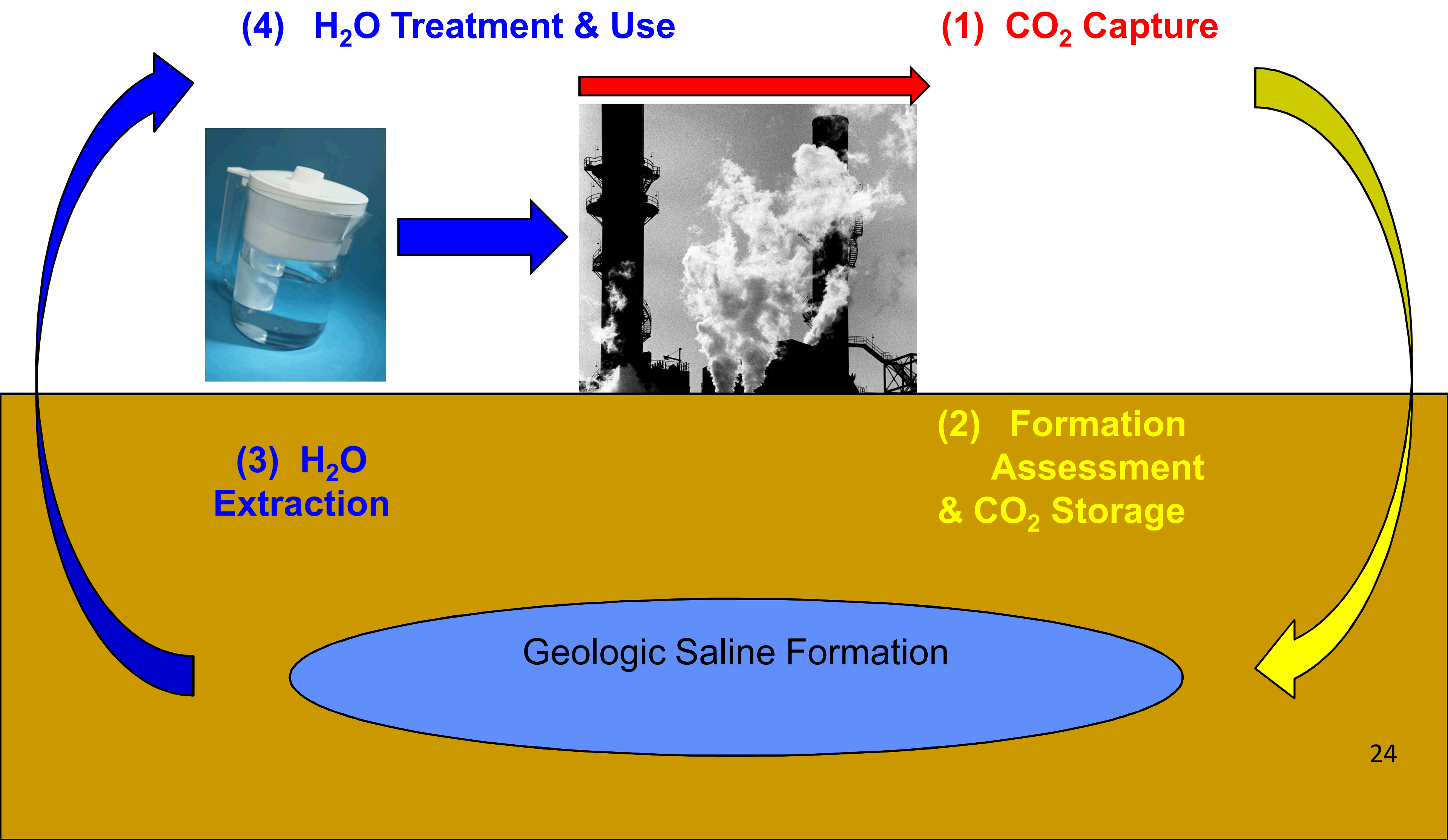
Potential Sequestration:

- Oil Fields
- Natural Gas Fields
- Saline Formations

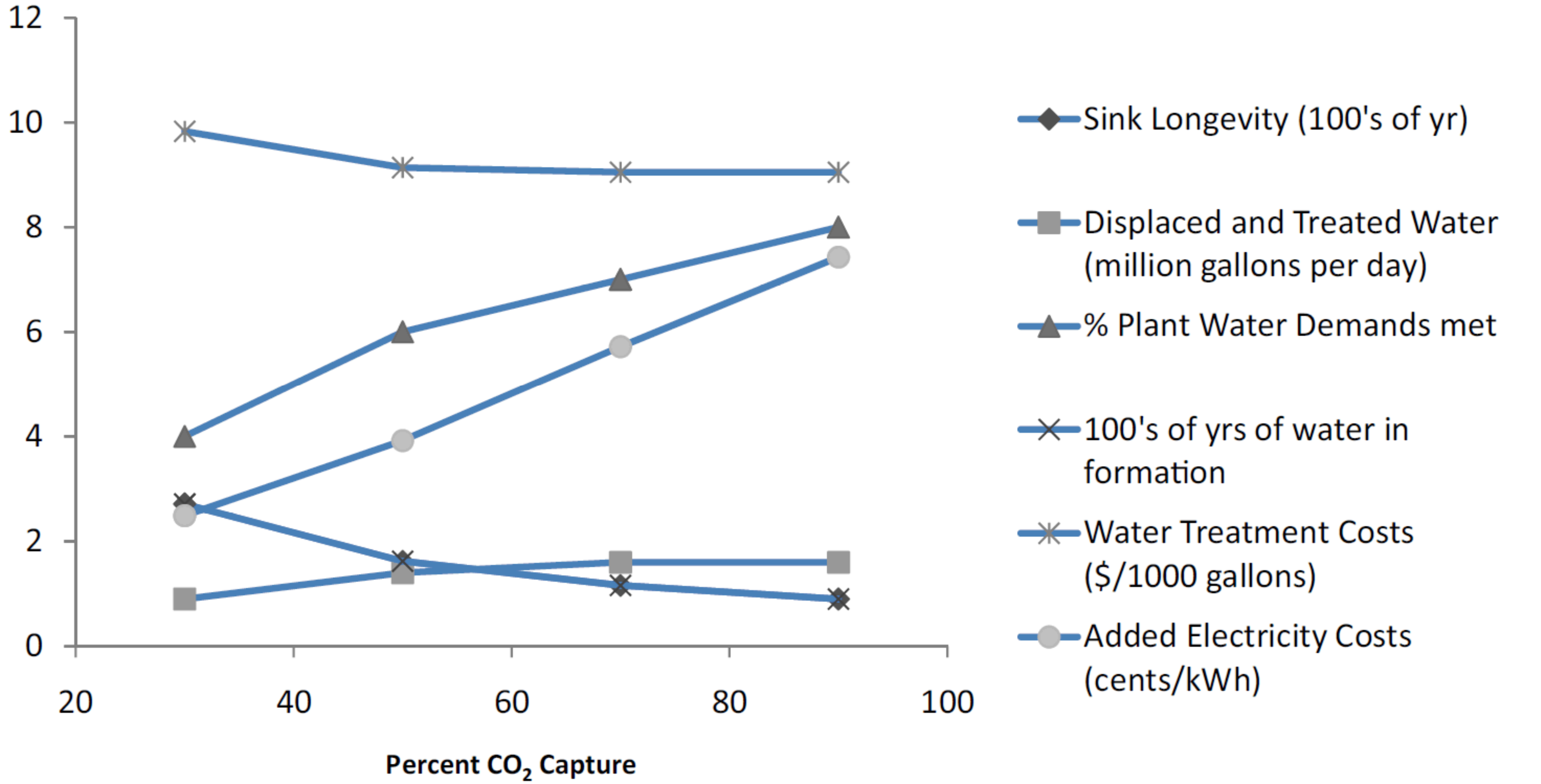


- ***One of seven*** regional partnerships throughout the U.S.
- Evaluating ***available technologies*** to capture and to reduce CO_2 emissions
- ***Source to Sink*** matching (Power plants to Geological Formations)
- String of Pearls Model ***'Tells the Story'*** for the SW Partnership
  - → Technology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

Water, Energy and CO_2 Sequestration Simulation Model (WECSsim):



Single Power Plant to Single Geologic Storage Site

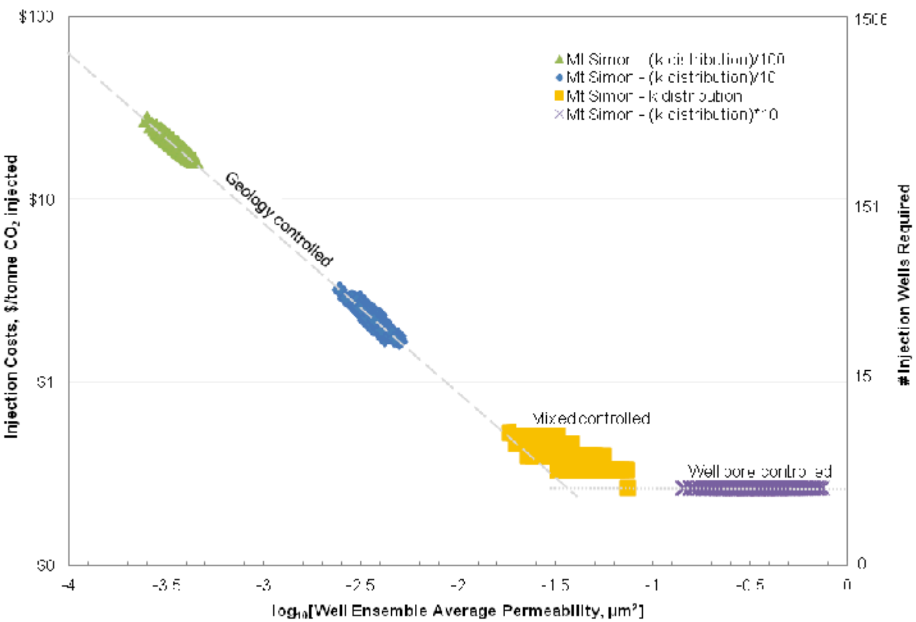


Source: Kobos et al., 2011, Combining power plant water needs and carbon dioxide storage using saline formations: Implications for carbon dioxide and water management policies, *International Journal of Greenhouse Gas Control*, 5, 899-910.

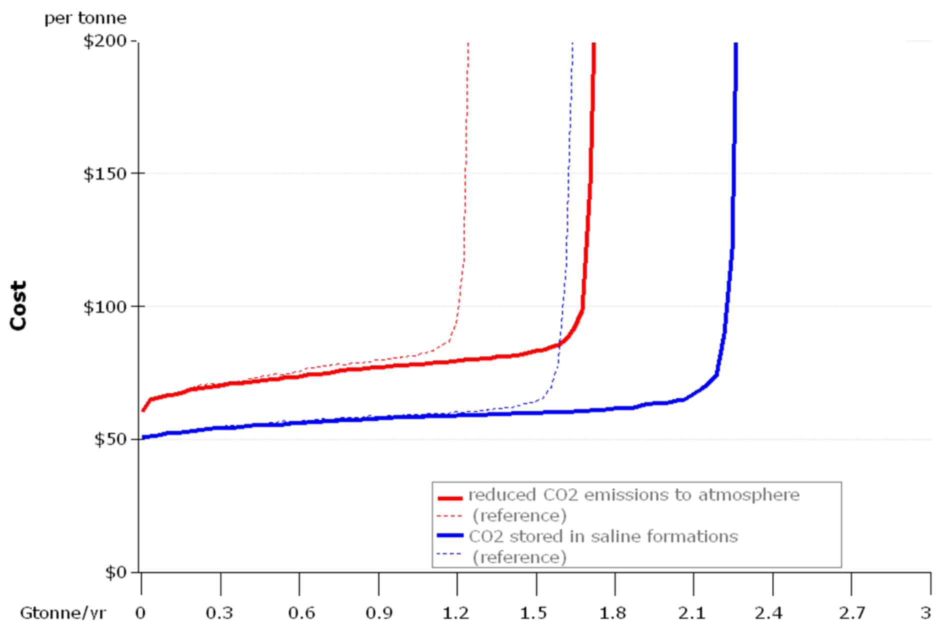
Cost Drivers & Supply Curve:

Interactive CO_2 Storage Analysis …

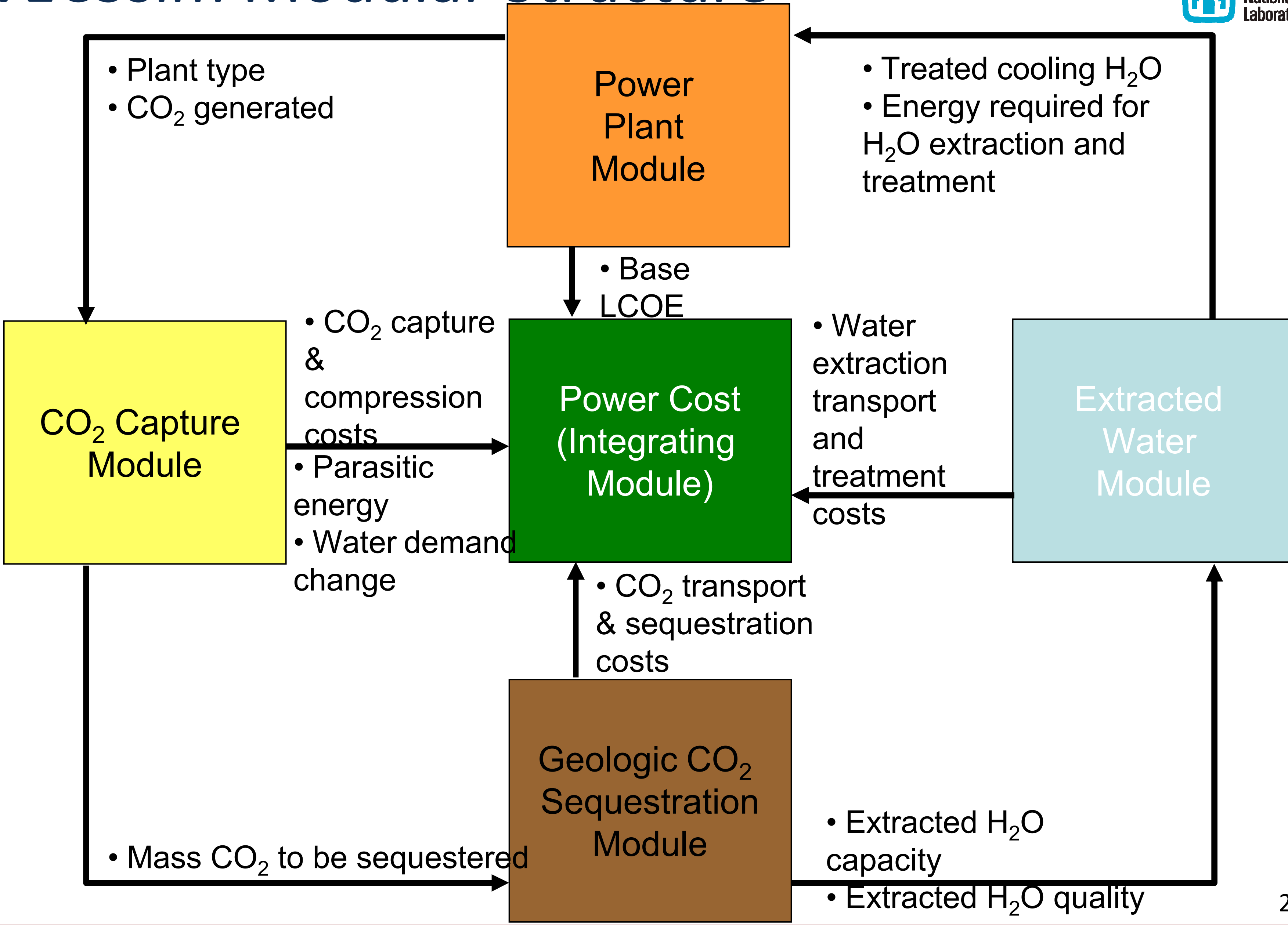
Permeability ↑ = Well Costs ↓



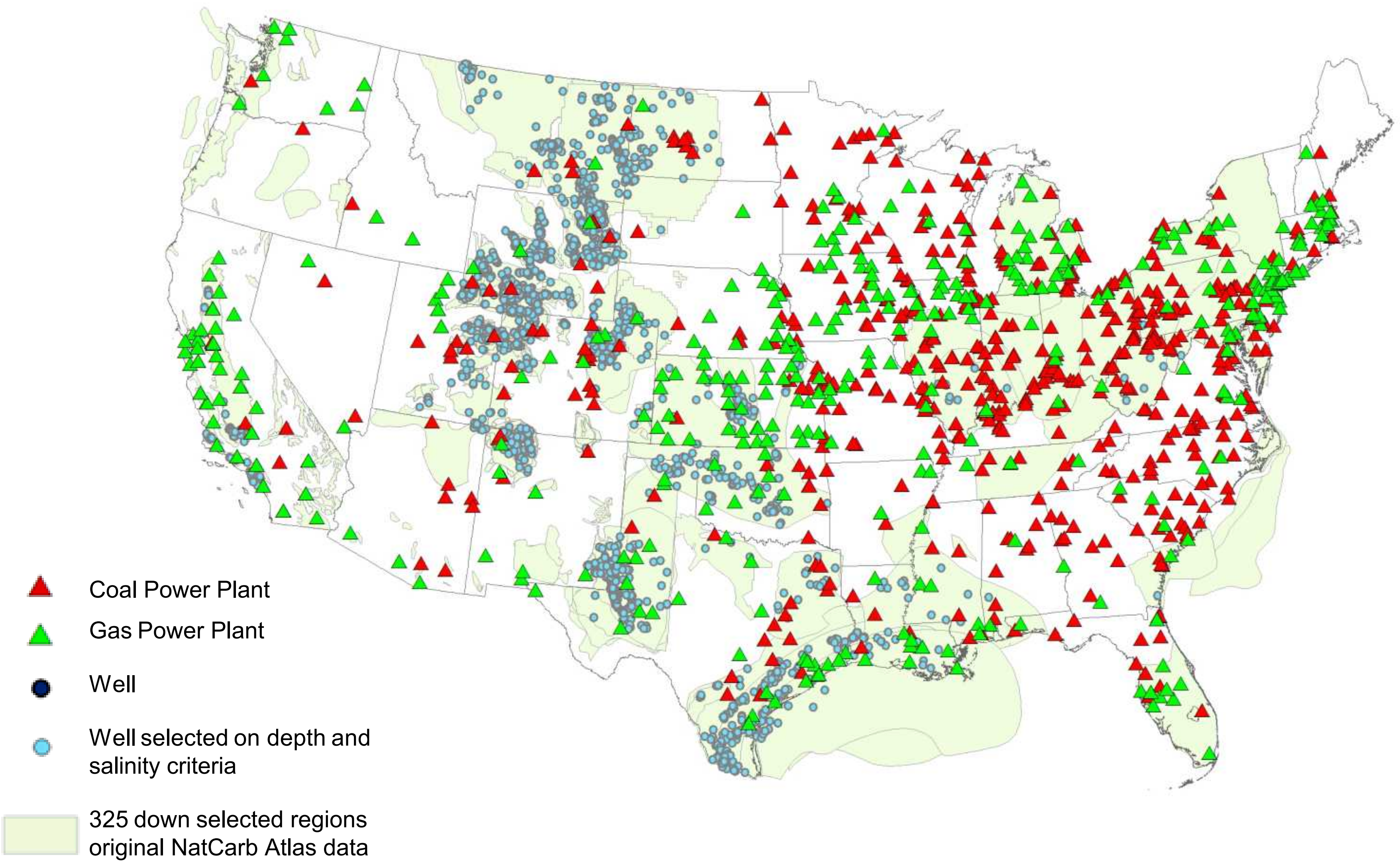
Developing a National, CO_2 Storage Supply Curve



WECSsim Modular Structure

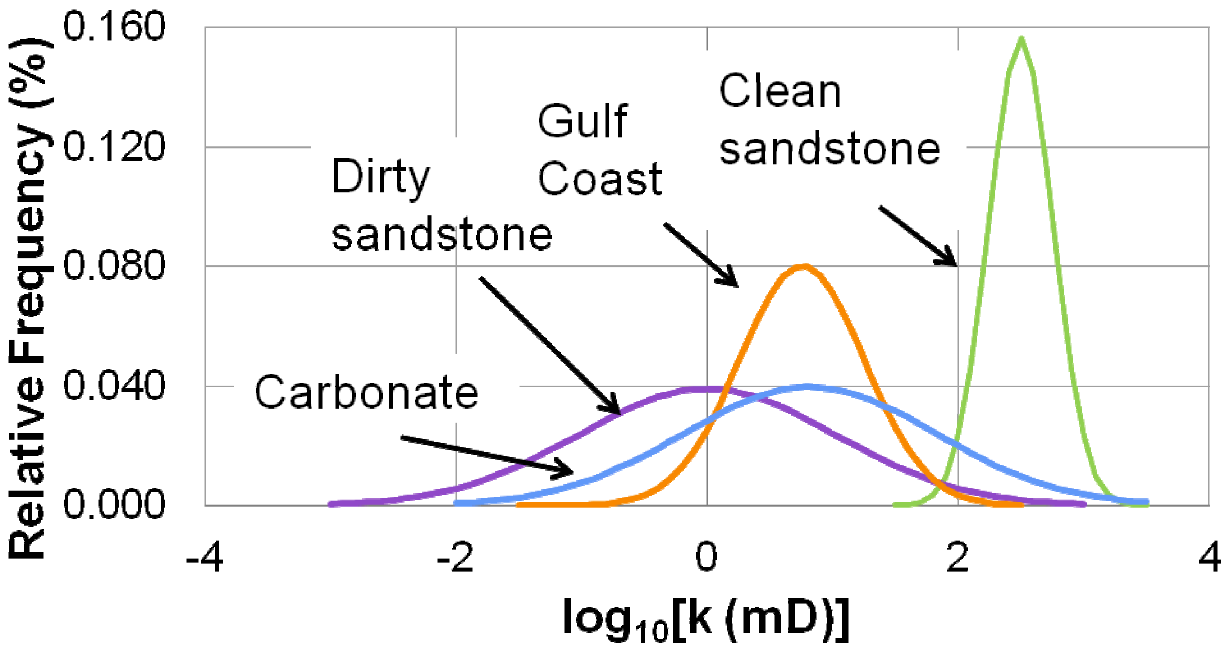


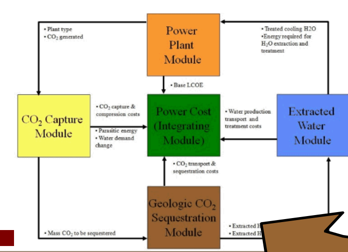
Geological CO_2 Storage Database Challenges



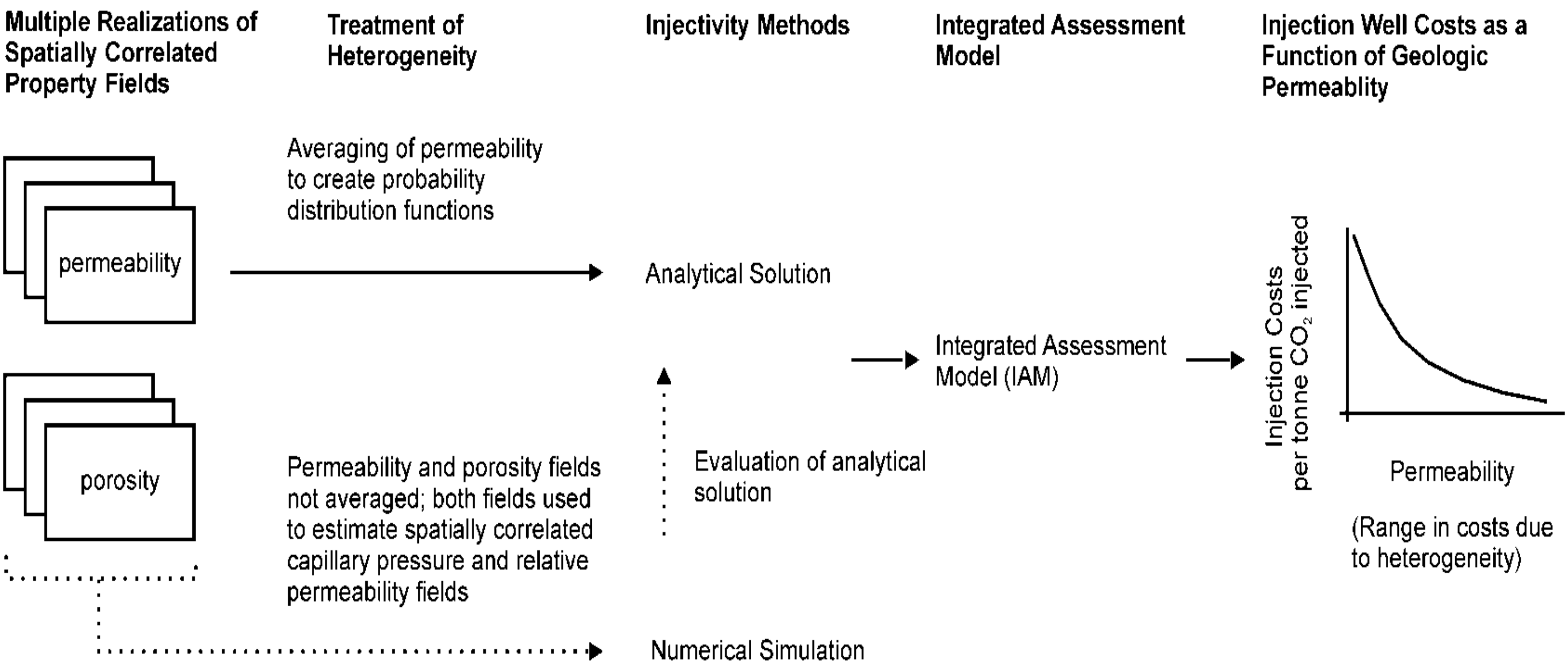
Expanding the 'Geology Controlled' (Permeability) factor to Cost Relationship across all Sinks

Injectivity equation: permeability sampled from 4 Rock Types





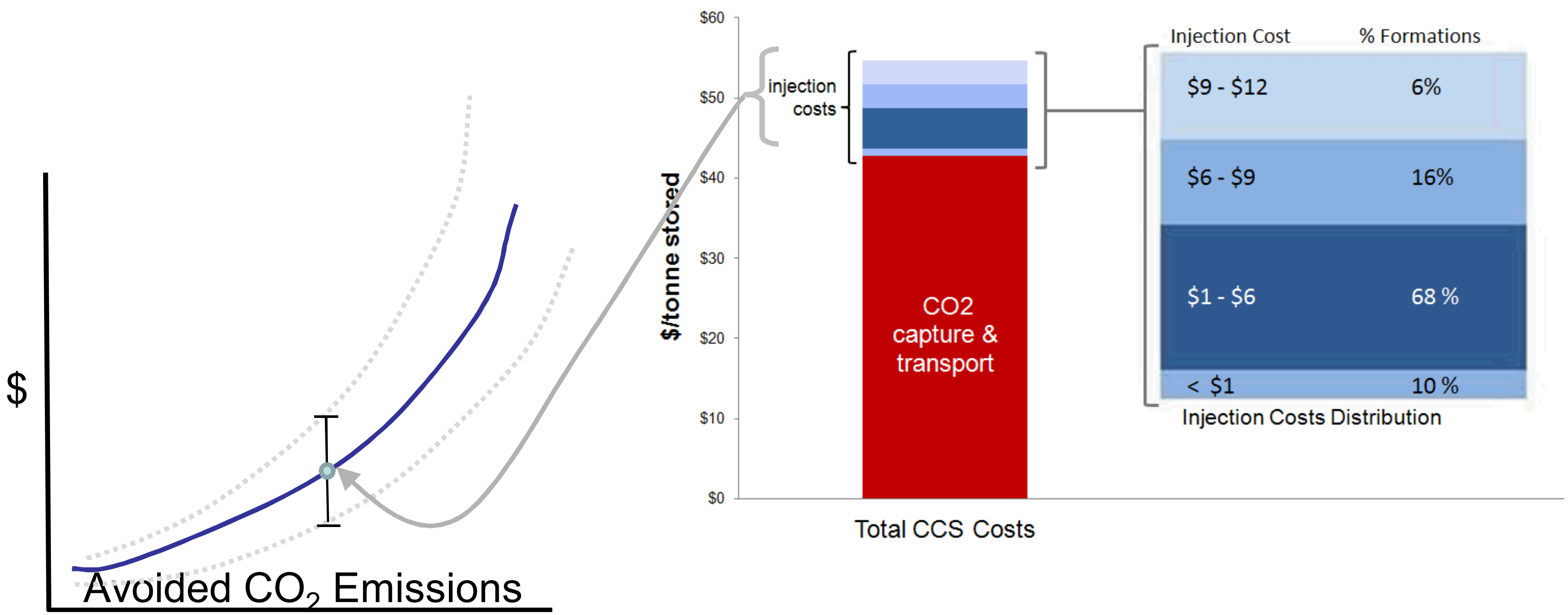
Methods behind the Permeability-to-Cost Analysis



Source: Heath et al., 2012, "Geologic Heterogeneity and Economic Uncertainty of Subsurface Carbon Dioxide Storage," *SPE Economics & Management Journal*, January 32-41.

WECSsim Results:

Similar Full Economic Analysis Underway



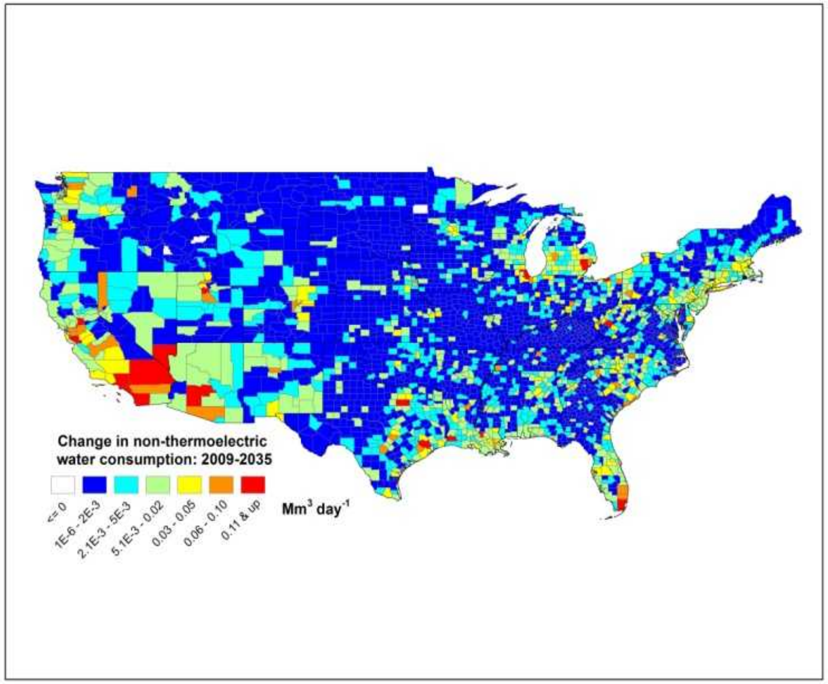
Note: Illustrative Example at this time

Energy, Power and Water Model (EPWSim): Assessing Surface and Groundwater Use to meet Demand from Power Plants and the Economy

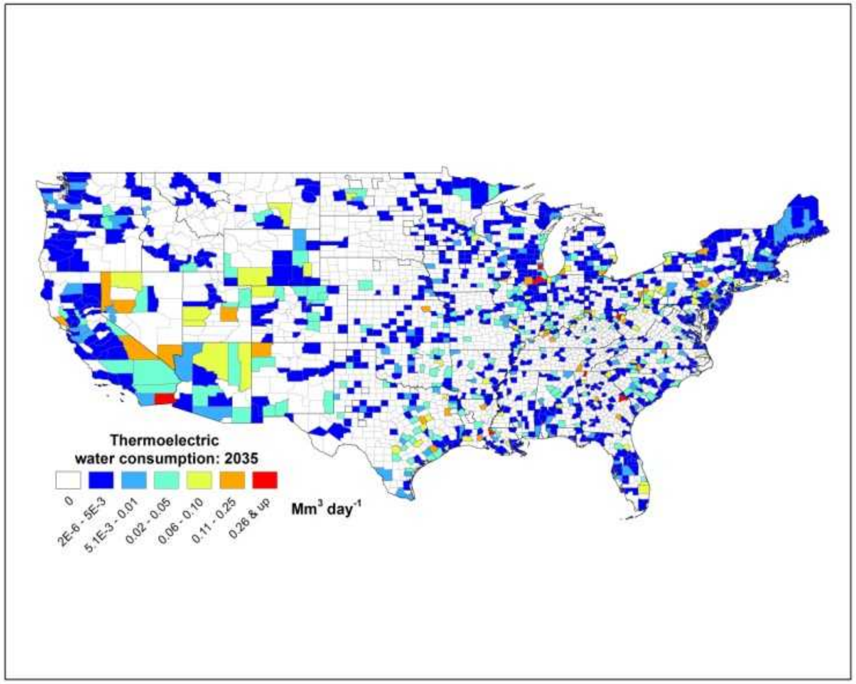
Sandia National Laboratories

Change in Water consumption between 2005 and 2035 in the continental U.S.

Non-thermoelectric



Thermoelectric



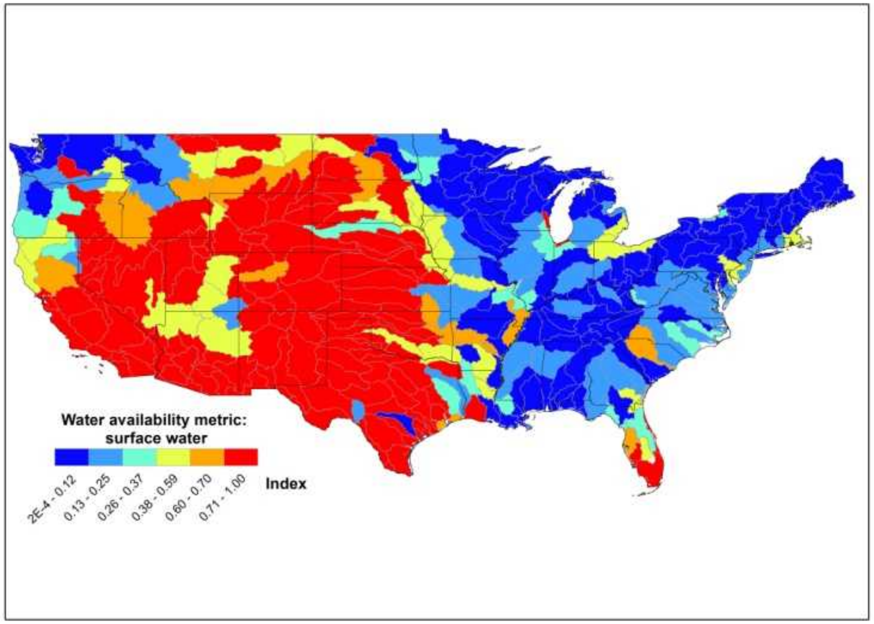
Data are displayed at the county level in units of million cubic meters per day (Mm^3/d).

Source: Adapted from Tidwell et al., 2012.

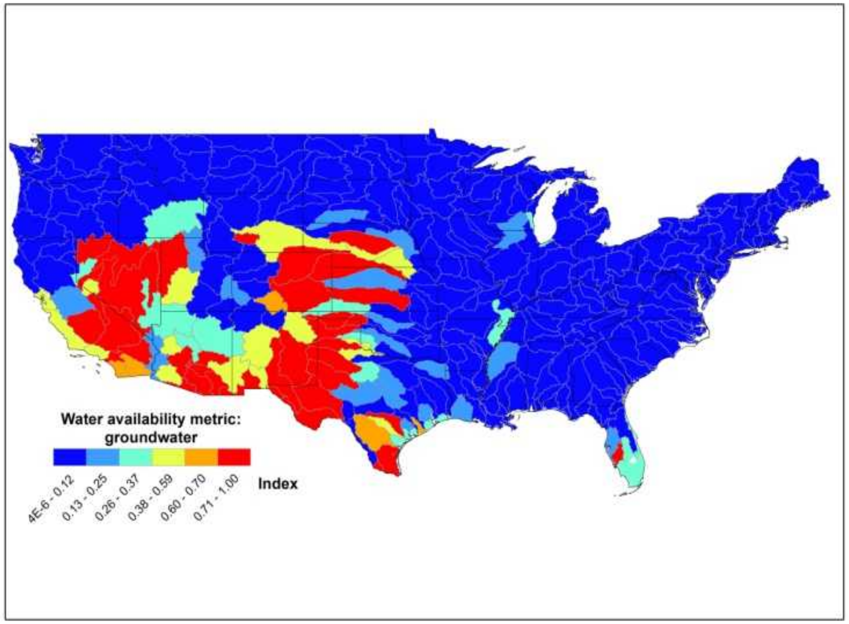
Energy, Power and Water Model (EPWSim): Up to 19% of new Demand by Power Plants may be in regions with substantial water stress

Water availability metric based on the ratio of water demand to water supply

Surface Water



Ground Water



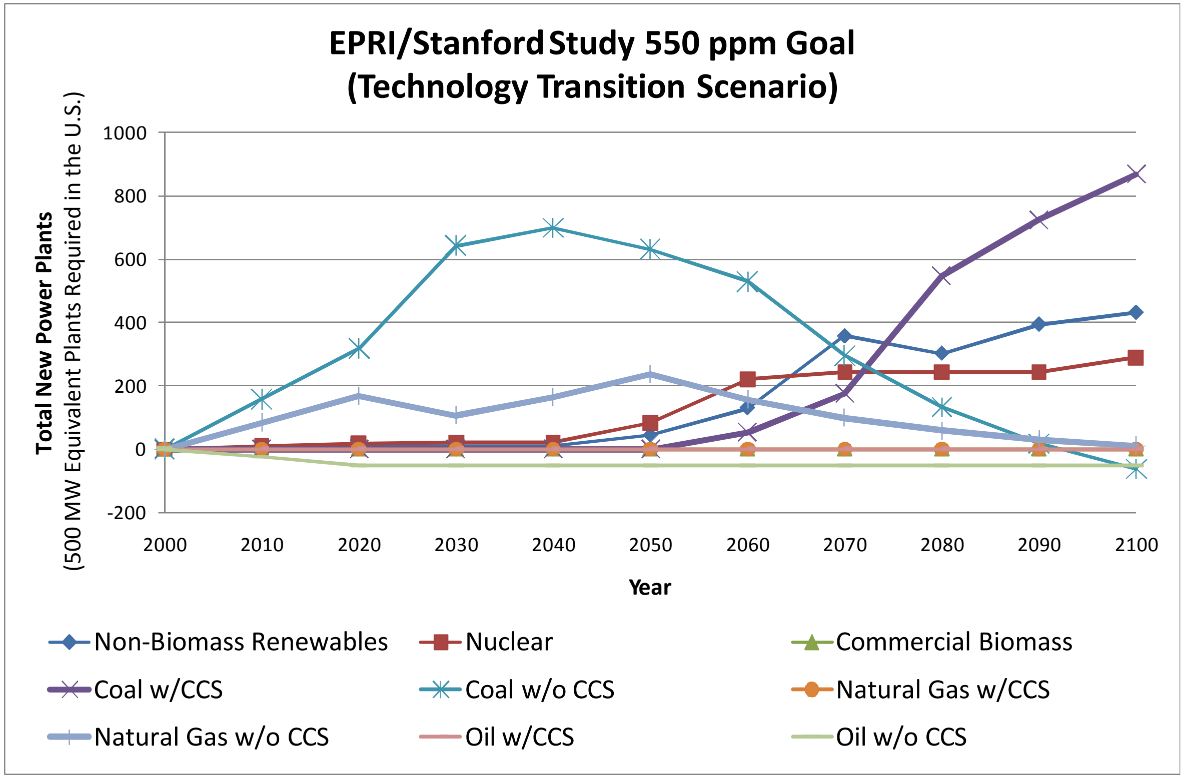
Higher index values indicate regions with limited water availability for new development.
Data are displayed at the county level in units of million cubic meters per day (Mm^3/d).

Source: Adapted from Tidwell et al., 2012.

Technology Transitions:

Engineering and Institutional Factors Affect Installations

Meeting policy goals → Requires numerous installations & supporting policies



- *Do we have the industrial base to build these technologies in time?*
- *Do we have the supportive governmental policies / business case justification?*

Source: Adapted from USCCSP, 2007.

Energy Economics and Modeling

- Energy Economics generally focuses on the energy supply, demand, price and income issues
- Employs various Modeling Techniques often based on the questions to be addressed and/or data limitations
  - Top-Down
  - Bottom-Up
  - Hybrid / Integrated Assessment
- Sandia applying Economic Tools (Mathematics & Multidisciplinary)
  - System Dynamics Models
  - Life Cycle Models
  - Input-Output Models, etc.
- Opportunities for Energy Economics & Modeling at SNL
  - Energy Technology Modeling
  - Energy Security
  - Forecasting and Impact Analyses

THANK YOU!

QUESTION & ANSWER SESSION

Peter H. Kobos

phkobos@sandia.gov

(505) 845-7086

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
- Oak Ridge National Laboratory (ORNL)
  - Strategic Petroleum Reserve (SPR) support
- The University of Texas at Austin (UT Austin)
  - Center for Energy Economics (CESS)
- 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 . . .

A Few Energy & Economics Works from Sandia Teams

Sandia National Laboratories

- **System Dynamics & Forecasting**
  - Tidwell, V.C., Kobos, P.H., Malczynski, L.A., Klise, G. and C.R. Castillo, 2012, “Exploring the Water-Thermoelectric Power Nexus,” Journal of Water Resources Planning and Management, in press.
  - Heath, J.E., Kobos, P.H., Roach, J.D., Dewers, T.A. and S.A. McKenna, 2012, “Geologic Heterogeneity and Economic Uncertainty of Subsurface Carbon Dioxide Storage,” SPE Economics & Management Journal, January, 32 – 41.
  - Kobos, P.H., Cappelle, M.A., Krumhansl, J.L, Dewers, T.A., McNeamar, A. and D.J. Borns, 2011 “Combining power plant water needs and carbon dioxide storage using saline formations: Implications for carbon dioxide and water management policies,” International Journal of Greenhouse Gas Control, Volume 5, Issue 4, July, 899 – 910.
  - Malczynski, L.A., 2011, Best practices for system dynamics model design and construction with Powersim Studio, SAND2011-4108.
  - Pickard, P.S., Malczynski, L.A., et al., 2009, Models for Evaluation of Energy Technology and Policy Options to Maximize Low Carbon Source Penetration in the United States Energy Supply, 2009-8205.
  - Tidwell, V., Sun, A.C-t and L. Malczynski, “Biofuel Impacts on Water,” SAND2011-0168.
  - Kobos, P.H., Erickson, J.D. and T.E. Drennen, “Technological Learning and Renewable Energy Costs: Implications for U.S. Renewable Energy Policy,” Energy Policy, Vol. 34/13 pp. 1645-1658, 2006.
  - Kobos, P.H., Erickson, J.D. and T.E. Drennen, “Scenario Analysis of Chinese Passenger Vehicle Growth,” Contemporary Economic Policy, Vol. 21, No. 2, April 2003, 200-217.
  - *and many more …*

A Few Energy & Economics Works from Sandia Teams

- **Life Cycle Analysis**
  - T. E. Drennen and J. Rosthal, “Pathways to a Hydrogen Future”, Elsevier Press, 2007.
  - T. Drennen and J. Andruski, “Power Systems Life Cycle Analysis Tool (Power LCAT): Technical Description”, Sandia National Laboratories, January 2012 (forthcoming).
  - T. Drennen, R. Williams, and A. Baker, “Alternative Liquid Fuels Simulation Model (AltSim): Technical Documentation”, DOE/NETL-2010/1404, National Energy Technology Laboratories, March 2010.
  - Ehlen, M.A., Loose, V.W., and Griffin, T., A Preliminary Benefit-Cost Analysis of a Sandia Wind Farm, Sandia National Laboratories SAND Report 2011-1572, Sandia National Laboratories, March 22, 2011.
- **Input-Output Methods**
  - Backus et al., 2010, “Assessing the Near-Term Risk of Climate Uncertainty: Interdependencies among the U.S. States, SAND2010-2052.
  - Warren, D.E., Ehlen, M.A., Loose, V.W., Vargas, V.N., Estimates of Long-Term U.S. Economic Impacts of Global Climate Change-Induced Drought, Sandia National Laboratories SAND Report 2010-0692, Sandia National Laboratories, January 2010.
  - Loose, Verne W. with M. A. Ehlen, Vanessa N. Vargas, L.C. Ellebracht, and Shirley J. Starks. Regional Economic Accounting (REAcct): A Software Tool for Rapidly Approximating Economic Impacts, SAND2009-6552.
- **Other**
  - Loose, V.W. Quantifying the Value of Hydropower in the Electric Grid: Role of Hydropower in Existing Markets. Sandia National Laboratory Report Number SAND2011-1009, January 2011.
  - Loose, V.W., 1998, Clean Coal Technology Diffusion: The Impact of Electric Power Industry Restructuring, The Electricity Journal, 11 (10), pp. 51-58.
  - Burness, H.S., Cummings, R.G. and V. W. Loose, 1985, Scale Economies and Reliability in the Electric Power Industry, The Energy Journal, 6 (1), pp. 157-168.