Applying Systems Engineering in a Renewable Energy Research & Development Environment

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OVERVIEW

- Introduction
- Apply Classical SE Tools
- Apply Enhanced Modeling & Simulation
- Apply Complex Systems Thinking
- View Renewable Energy as a Complex System
- View Renewable Energy as part of a System of Systems
- Apply Roadmapping Techniques to Renewable Energy Systems
- Conclusions

INTRODUCTION

- Systems Engineering has largely developed around a few specific industries (aerospace, defense, IT)
  - Well-understood process in these industries and others
  - Generally starts with conceptual development of a physical system that will be produced and deployed
- Renewable Energy R&D environment has largely developed without SE
  - SE not generally accepted or well-understood
  - R&D activities oriented toward technology development and refinement
- Classic SE concepts must be significantly tailored in this environment
  - Approaches to the application of systems engineering in the DOE environment are evolving

INTRODUCTION

- DOE's Office of Energy Efficiency and Renewable Energy (EERE) is our customer
  - NREL formed Systems Engineering and Program Integration Office (SEPIO) in 2003 to support EERE R&D programs
    - Hydrogen & Fuel Cells
    - Biomass
    - Vehicle Technologies
    - Geothermal Programs
- EERE's mission states in part that it "works to strengthen the United States' energy security, environmental quality, and economic vitality in public-private partnerships"
  - Program goals and mission are always subject to change not only with technology but with geo-political and economic forces

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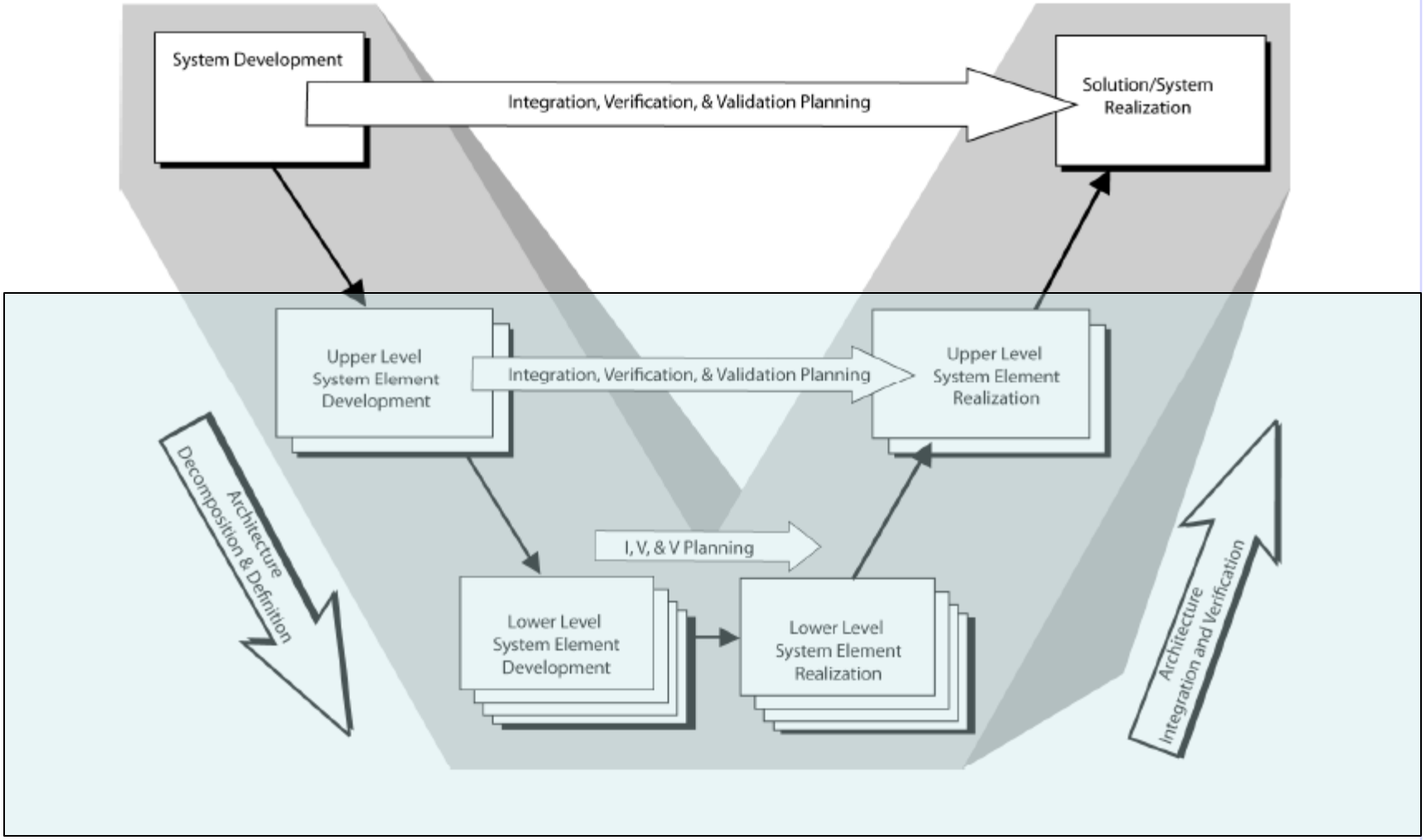
APPLY CLASSICAL SE TOOLS

- When SEPIO was first formed, its primary functions were defined as:
  - Establish and maintain the baseline
    - Mission analysis
    - Functional analysis
    - Identification of alternatives
  - Analyze the system and program
    - Utilize modeling & simulation, trade studies, risk analysis, and decision analysis
  - Verify technical performance
    - Utilize analysis, evaluation, test and demonstration

APPLY CLASSICAL SE TOOLS



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APPLY ENHANCED MODELING & SIMULATION

- Classical use of modeling & simulation is to avoid the risk of failing to meet mission and performance requirements on complex systems projects
- Renewable energy modeling & simulation has a heavy emphasis on socio-economic-political forecasting
  - In addition to technical modeling
- Examples developed by SEPIO
  - Hydrogen Program: Macro-System Model
  - Biomass Program: Biomass Scenario Model

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APPLY COMPLEX SYSTEMS THINKING

- Need to project the state of energy production and use several decades into the future
  - Enhanced modeling & simulation allows projections out into the 10 – 15 year timeframe
  - Driven by rapidly increasing global demands for energy and concerns about climate change, what about 20 – 40 years?
- Need to consider social, political, and economic circumstances as well as the state of energy technology
  - Just beginning to apply complex systems theory to developing an energy strategy for this time frame

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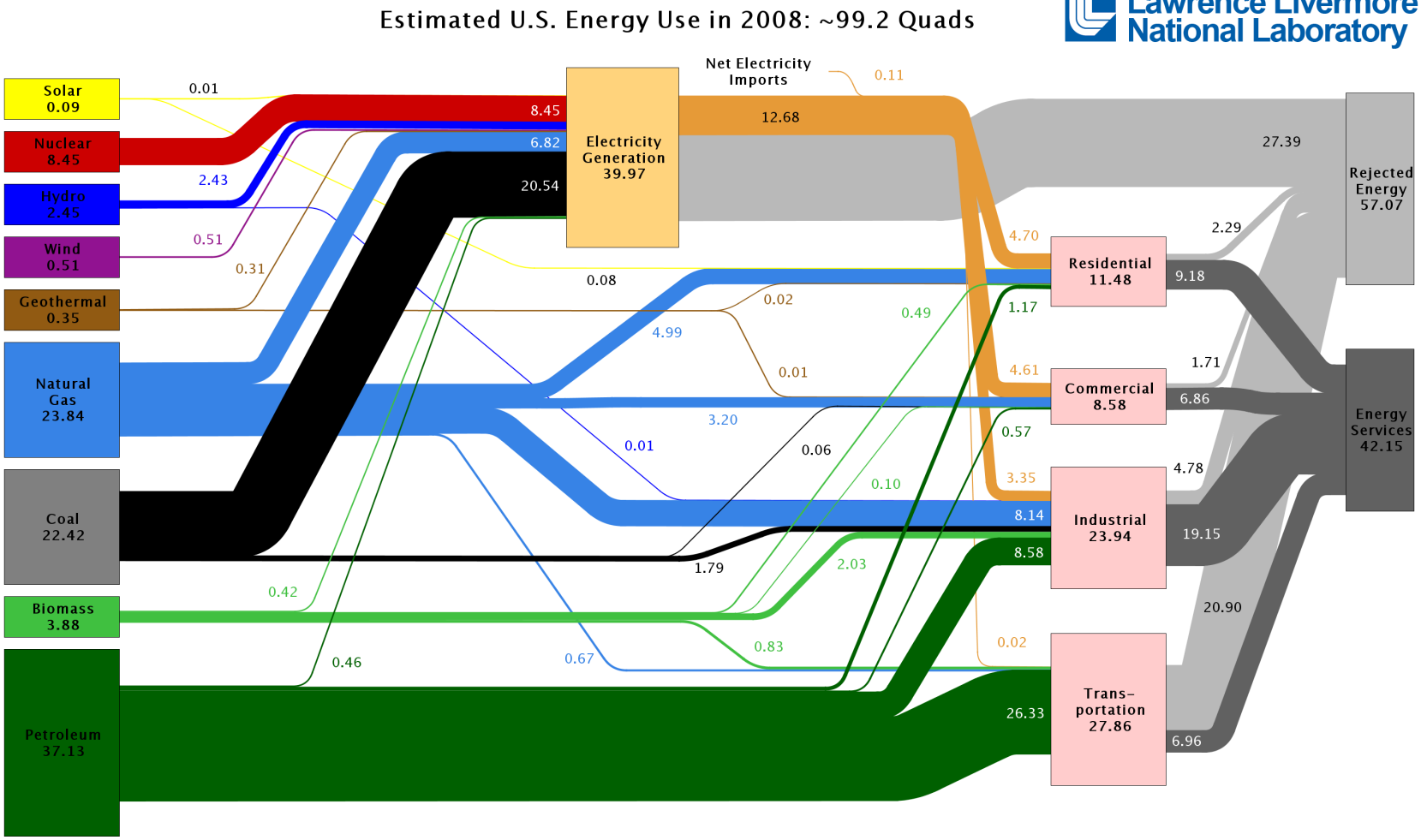
VIEW RENEWABLE ENERGY AS A COMPLEX SYSTEM

- Renewable energy consists of a diverse suite of technologies that must be integrated with existing electrical and transportation infrastructures
- Complexity of the overall energy system may force changes to be evolutionary rather than revolutionary
- New, high-level energy architectures need to be developed; at a minimum:
  - Transmission
  - Vehicles and fuels
  - Direct heating
- From a practical standpoint, need to design incremental changes to the high-level architectures, and where possible design for integration with legacy systems
- Utilize flexible designs to account for uncertainties and emergent properties of the systems

Estimated U.S. Energy Use in 2008



Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

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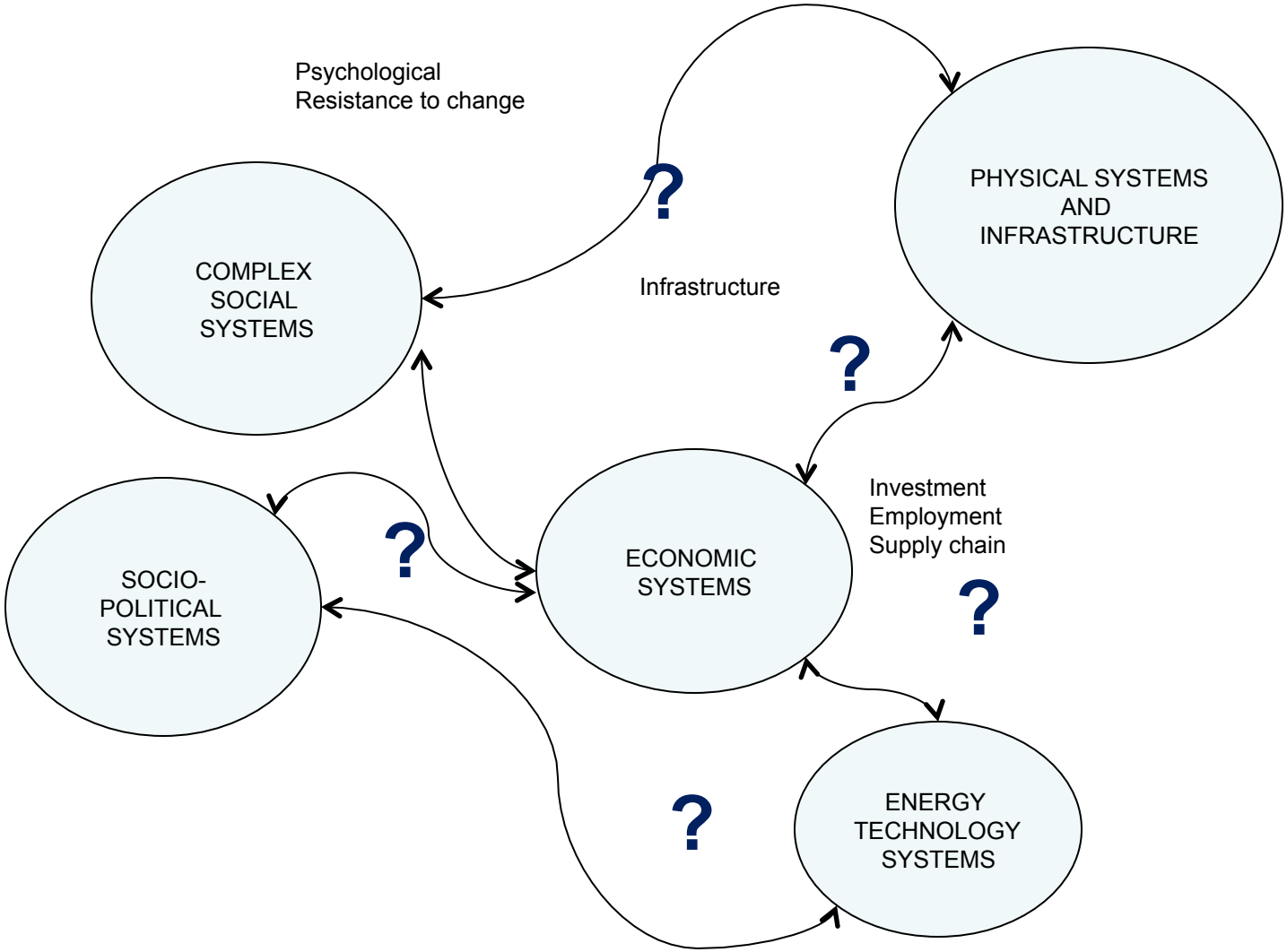
VIEW RENEWABLE ENERGY AS PART OF A SYSTEM OF SYSTEMS

- Energy systems are embedded within a larger system of systems that includes economic and psychological/social systems, along with related political behaviors
- Economic systems include the interests of various, diverse stakeholders
- Social systems can be driven by traditions and resistance to change
- Broadly-based research into this system of systems may provide a road map for widespread implementation of renewable energy technologies

RENEWABLE ENERGY AS PART OF A SYSTEM OF SYSTEMS



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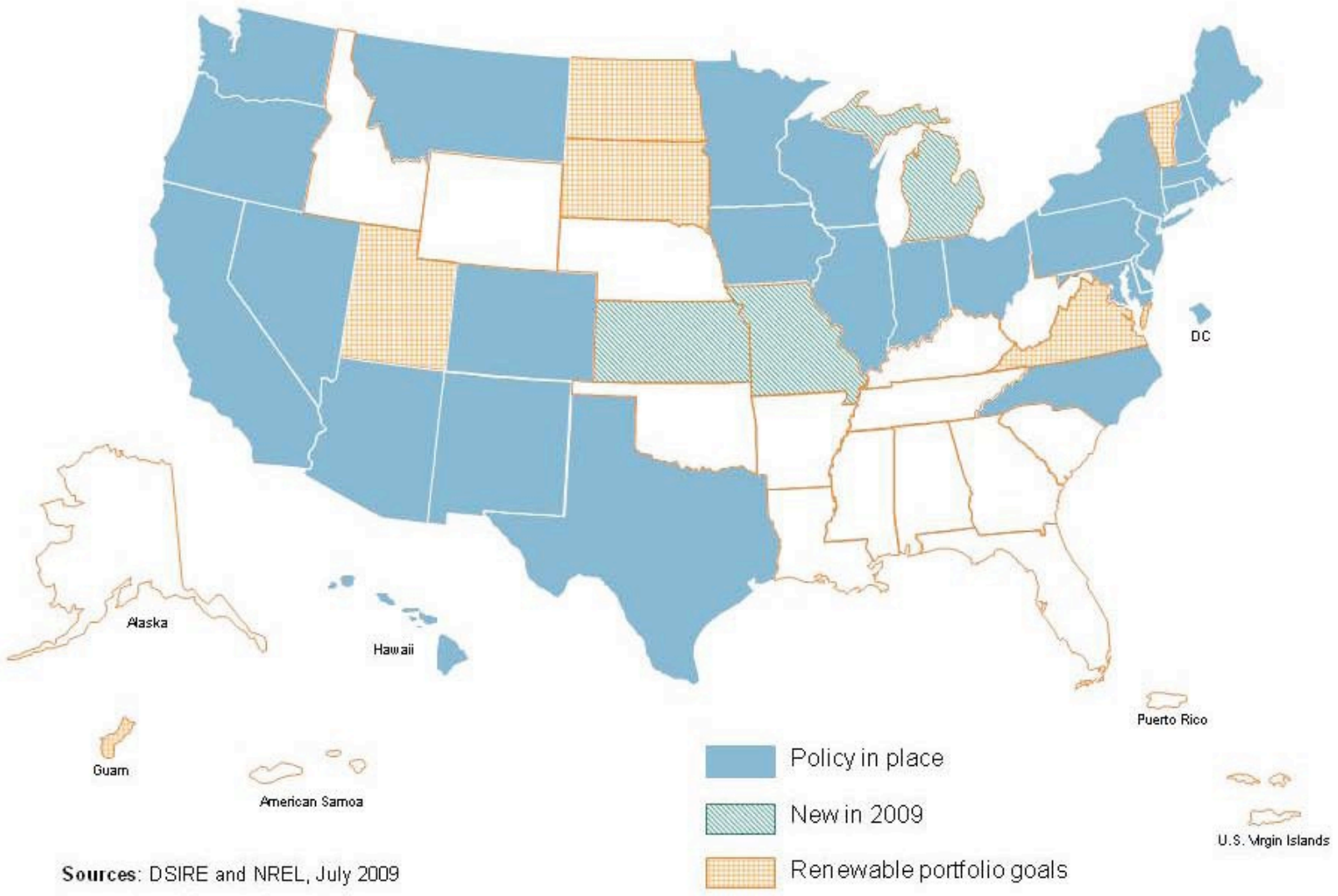
APPLY ROADMAPPING TECHNIQUES TO RENEWABLE ENERGY SYSTEMS

- Long-term U.S. national goals have been identified; these provide the starting point for roadmapping:
  - Electricity: 25% of generation from renewable sources by 2025; 80% reduction in greenhouse gas emissions by 2050; state-level renewable portfolio standards
  - Vehicles and Fuels: 80% reduction in greenhouse gas emissions by 2050; within 10 years save more oil than we currently import from the Middle East and Venezuela combined; put one million plug-in hybrid cars on the road by 2015
- Inputs from a large and diverse group of experts will be needed to develop potential pathways
- The DOE will need to sponsor these roadmapping activities to define an integrated path forward

States with Renewable Portfolio Standards and Goals



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CONCLUSIONS

- Adaptation of classical systems engineering to renewable energy R&D is challenging
- Enhanced use of modeling & simulation, along with emerging approaches to dealing with complex systems, are providing some solutions
- New approaches and tools are still needed to deal with the large-scale deployment of renewable energy