Integrated Nuclear – Renewable Hybrid Energy: Arizona Regional Case Study

Presented to Arizona Collaboratory for Advanced Energy Solutions

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In operation since 1949, INL is a science-based, applied engineering national laboratory dedicated to supporting the U.S. Department of Energy's missions in nuclear and energy research, science, and national defense.

Mission: Proving the principle of national energy and security solutions using world-class capabilities.

Vision: To sustain core technical capabilities and develop innovative solutions that secure and advance nuclear and other clean energy choices for our future.
INL Timeline

- 1940: Naval Proving Ground was used to test artillery
- 1949: National Reactor Testing Facility
- 1951: The first usable amounts of electricity were generated by nuclear power from EBR-1
- 1953-1994: Training ground for Nuclear Navy
- 1997: DOE assigns Idaho as lead lab for nuclear reactor development
INL Research and Development

• **Nuclear Science and Technology**
  • Domestic Programs
  • International Programs
  • Nuclear Systems Design and Analysis

• **Energy and Environment Science and Technology**
  • Energy Systems & Technologies
  • Environmental Resource Management
  • Process Science & Technology

• **National & Homeland Security Science and Technology**
  • Critical Infrastructure Protection
  • Defense Systems
  • Homeland Security
  • Mission Support Center
  • Nuclear Nonproliferation
  • Wireless National User Facility
Problem Statement

1. Increasing global concerns regarding climate change have resulted in requirements to significantly reduce greenhouse gas (GHG) emissions in the coming decades. [Goal: 80% of electrical power from “clean” energy sources by 2035.] http://www.whitehouse.gov/the-press-office/2011/01/25/remarks-president-state-union-address

2. Non-emitting renewable resources are being added to the grid in increasing numbers to meet the state and federal policy goals – leading to an increased need for grid flexibility.

3. Increased role of intermittent renewables in many regions can lead to more frequent occurrences of low or negative electricity prices at times of high wind or solar output, reduced baseload generator market size and associated baseload generator power reductions (e.g. load-following operation). Can lead to decreased capital deployment efficiencies and declining business cases for baseload and renewable technologies.

4. The carbon footprint of all energy segments must be significantly reduced if long-term climate goals are to be met.
Energy Security: A Balance of Priorities

Clean
- Low greenhouse gas emissions
- Reduced water withdrawals
- Reduced land impacts

Safe
- Domestic source
- Physical & cyber protection

Affordable
- Reasonable TOTAL costs
- Predictable, stable price
- Marketable in free-economy

Secure
- Available on demand
- Continuous quality
- Easily maintainable

Resilient
- Adapts to resource characteristics
- Adjusts to market demands
- Capable of meeting new regulations
# Energy Currency

## Primary Energy Resources

- **Fossil**
- **Nuclear**
- **Water**
- **Biomass**
- **Hydro & Geothermal**
- **Wind & Solar**

## Energy Services

- **Consumer Products**
- **Comfort & Illumination**
- **Communication**
- **Sustenance**
- **Materials & Structures**
- **Transportation**

## Energy Storage

- **Crude Refining**
- **Hydrocarbon Conversion**
- **Hydrogen**
- **Syngas**
- **Methanol**
- **Ammonia**
- **Synfuels**

## Energy Currency

- **Electricity**
- **Steam & Heat**
- **Power**
- **HEAT**
**Key take-away:**
Thermal energy re-purposing and storage helps smooth large-scale variability in the system while operating the reactor at steady state.

Integrated systems require the design and operation of nuclear reactors, energy storage / recovery buffers, and **dynamically responsive interfaces** with the electrical grid.

May require hydrocarbon and input of other natural resources.
Process Heat Applications

- Heat
- Steam
- Electricity

Energy Dispatch

- Energy Cascade
- District Heating
- Food & Beverage Processing
- Biomass & Paper Drying
- Desalination
- Ethanol
- Geothermal Heating
- Synfuels & Biofuels
- Hydrogen Production
- Methanol & Fertilizer
- Chemicals: Methanol & Fertilizer
- Oil Refining
- Paper Drying
Regional Case Studies

- For initial discussion, the U.S. was divided into 8 regions based on resources, traditional industrial processes, energy delivery infrastructure, and markets.
Progression of Integrated Energy Systems Analysis

- Integrated Systems -Complexity-

- Gas Turbines
- Thermal Users
- Energy Storage
- Smart Grids
- SMRs
- Solar/Wind
- Coal/Conventional Nuclear

Scaled Experimental Representation
Real Time Integration
Numerical Representation
Understanding, Designing, Optimization
Computational and simulation tools to model complex energy systems

1) Systems assessment based on defined requirements (region specific)

2) Strategic energy systems analysis and optimization

3) Technical / economic / environmental analyses that involve detailed plant design, optimized mass and energy integration, capital and operating cost estimates, discounted cash flow / net present value economic calculations, and life-cycle environmental sustainability assessments

4) Dynamic energy system integration tools are key to optimal system design, performance evaluation, development and application of optimized monitoring & controls, and information management for tightly coupled systems

A library of Modelica models has been developed for most common U.S. chemical and fuels synthesis plants and power generation facilities.
Current Modeling and Simulation (M&S) Approach

• Scoping analyses: Aspen
  – Steady state analysis (does not include renewable)
  – Mass and energy balances
  – Calculation of stream flows and conditions
  – Basic economic analysis
  – Provide initial conditions to ensure well-posed problem for dynamic analyses

• Current Dynamic analysis tools: Modelica/Dymola, Matlab, Fortran, RELAP
  – Matlab model supports modeling, controls synthesis, design and operational optimization, and economic analyses
  – Modelica model for dynamic and transient analysis of components and integrated energy systems; many aspects and system components already available, with other parts of the toolset still under development
  – RELAP for detailed nuclear system analysis – identifying ways to couple to Modelica
  – Evaluation of MOOSE-based tools for system analysis
  – Evaluation of external modeling and simulation tools (NREL, EPRI, ANL, ORNL, etc.)

• Currently developing
  – Advanced M&S approach that could support future licensing
  – Enhanced economic assessment tool with exergy analysis
Regional Case Evaluation – RTDS

- Model and simulate a simple mix of conventional and renewable energy sources (RES) to demonstrate the effect and value of using RES with conventional generation in dynamic operation in AZ.
  - RES will consist of 20% wind farm and 30% solar (10% PV & 20% thermal) generation while conventional plant is modeled as a multi-mass machine model for a thermal power plant.
  - Actual transmission system modeled in RSCAD for portion of AZ Public Service.
  - Real-world demand curve.

- RTDS Simulations
  - Dynamic load following for load demand, solar, and wind variations.
  - Dynamic response tests, step load variations (2%, 5%, 10%, ... to determine system response.

Figure: APS HV transmission system to be modeled in RTDS-RSCAD.
Energy Systems Laboratory: Integrated Energy System Development and Demonstration

Control room simulator addresses human factors and dynamic process control
Selected Case: Southwest (Arizona)

Additional options / considerations:
- Solar photovoltaics
- Land-based wind
- Desalination / water purification

Alternative desalination process, requires thermal and electrical input:
Desalination

- Uses waste heat from power conversion unit or electrical power

- Main parameters
  - Capacity: Production of water
  - Quality: Amount of dissolved solids
  - Gain Output Ratio: steam needed to produce 1 kg of water (MSF, MED)
  - Top Brine Temperature (MSF, MED)
  - Pressure (RO)

Korea’s 330 MWt SMART reactor can produce either 40,000 tons/day of water with 90 MWe power or 77,000 tons/day of water and 83 MWe Power using MED
AZ case study facts and assumptions

• Population of greater Phoenix as of 2009: 4.36 million. Expected to double in 2 decades (Greater Phoenix Economic Council)

• Population of 980,263 as of 2010. Grew 20% in population from 1990 to 2000, but only grew 7% from 2000 to 2010.

• Average water usage is 100 gallons per person per day

• 10 MW of electrical power to the Reverse Osmosis desalination of brackish water can provide enough daily potable water for 958,000 people

• Small Modular Nuclear Reactor generating 530 MWt heat, producing 184 MWe power.

• Integration of photo-voltaic (PV) power from 15 to 45 MWe onto grid.

• To allow integration of PV, would need to make enough water for ~ 1.5 million to 4.5 million people per day (does not account for industrial water usage)
Questions?
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