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Maximizing Clean Energy Integration: The Role of Nuclear and Renewable Technologies in Integrated Energy Systems

Summary / Objectives:

Many cities, states, utilities, and public commissions are setting energy standards that aim to reduce carbon emissions. In order to realize a clean and resilient energy future, new methods of energy production, distribution, and use will be required. The primary focus of the DOE Office of Nuclear Energy (DOE-NE) Program on Integrated Energy Systems, led by researchers at Idaho National Laboratory (INL), has been to assess the potential of **integrated energy systems to enhance the flexibility and utilization of nuclear reactors alongside renewable generators** and, thereby, to maximize the use of the clean energy provided by these systems. This work begins with the question: "What goals are we trying to achieve, and how will the produced energy be used?" These questions must be addressed within the context of a specific deployment location, which has implications relative to the electricity market structure, supply, and demand; available feedstock for industrial processes; and available product markets. Product streams, ranging from potable water to hydrogen, fertilizer, synthetic fuels, and various chemicals, have been considered. Each product stream has its own market and market drivers and its own geographic location that would maximize profitability. Some of these products would only require electricity to support production, while others require both thermal and electrical energy. This webinar highlights work led by INL, in collaboration with other national laboratories and industry partners, to evaluate integrated energy system options that utilize nuclear energy in new ways. By working with key collaborators in the nuclear industry, these analytical studies are now becoming a reality in demonstration projects.

Meet the Presenter:

Dr. Shannon Bragg-Sitton is the Lead for **Integrated Energy Systems (IES) in the Nuclear Science & Technology Directorate at Idaho National Laboratory** (INL). Within this role, Shannon serves as the co-Director for the INL Laboratory Initiative on IES, which includes focus areas for thermal energy generation, power systems, data systems, and chemical processes/industrial applications. Shannon is also the INL lead for the DOE Applied Energy Tri-Laboratory Consortium, which includes INL, the National Renewable Energy Lab, and the National Energy Technology Lab.

Assessment of integrated energy systems is
to check Resource -- Technology – Economic – Market potentials

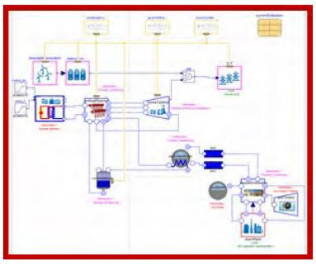
Technical & Economic Assessments (TEA)

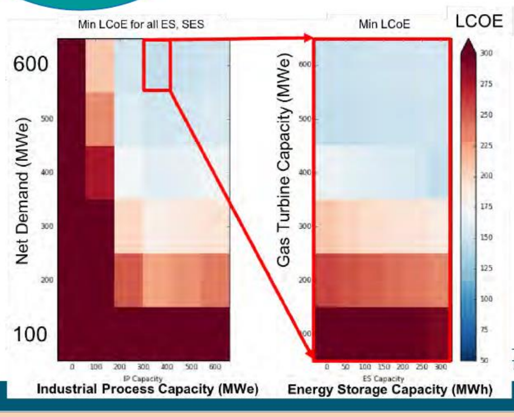
Resource Potential
- Market size
- Resource availability
- Resource attributes
- Infrastructure requirements

Technology Potential
- Thermodynamics
- Performance
- Systems integration and control

Economic Potential
- Pro forma
- ROI / IRR
- Cash Flow

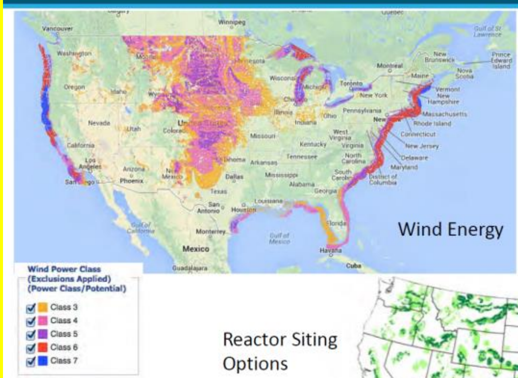
Market Potential
- Competition
- Policy, Regs





https://ies.inl.gov

What is the resource potential in a selected region?



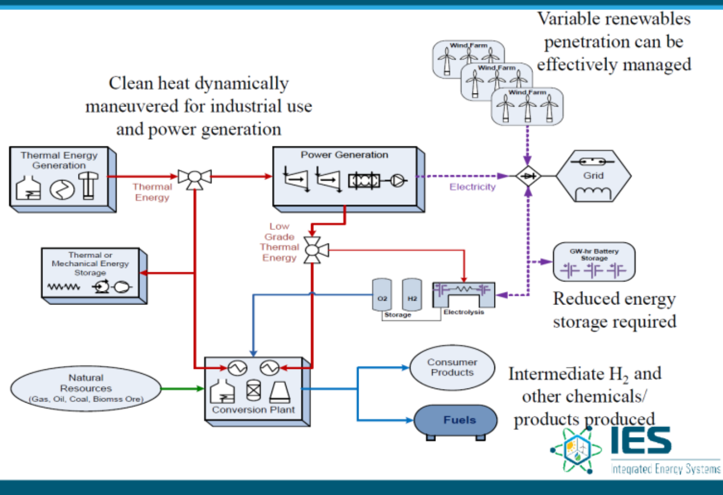
Reactor Siting Options

Figure excerpts from the

https://ies.inl.gov

Evaluation of Candidate IES

- **Technical Feasibility:** Tightly coupled systems involve dynamic exchange of energy streams, process conditions data, and diagnostics/ prognostics control commands.
- **Economic Feasibility Requires Efficient Capital Utilization:** The impact of improved capital utilization, increased reliability, and enhanced maintainability on overall plant revenue must be characterized and understood.



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Graded approach to identify design.

Process model code (process engineering + economics)

Dynamics model code (plant dynamics + control)

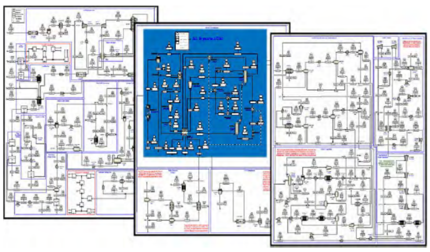
System optimization (system configuration + physics + economics)

+AI (used to develop surrogate models for complex physical models)

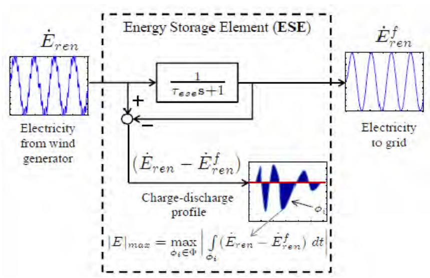
Energy System Modeling, Analysis, and Evaluation for Energy System Optimization

Graded approach to identify design, and evaluate hybrid system architectures

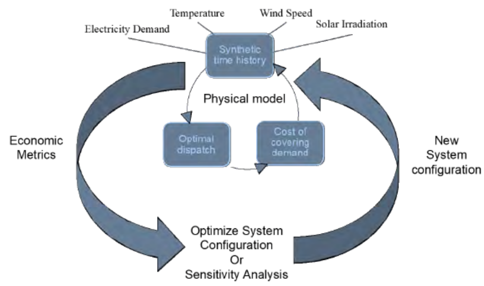
Aspen Plus® and HYSYS® Process Models



Modelica®, Aspen Dynamics®



RAVEN (INL System Optimization)



Process modeling addresses technical and economic value proposition

Dynamic modeling addresses technical and control feasibility

System modeling addresses whole-system coordination

Consideration of Resource—Technology—Economic—Market Potential

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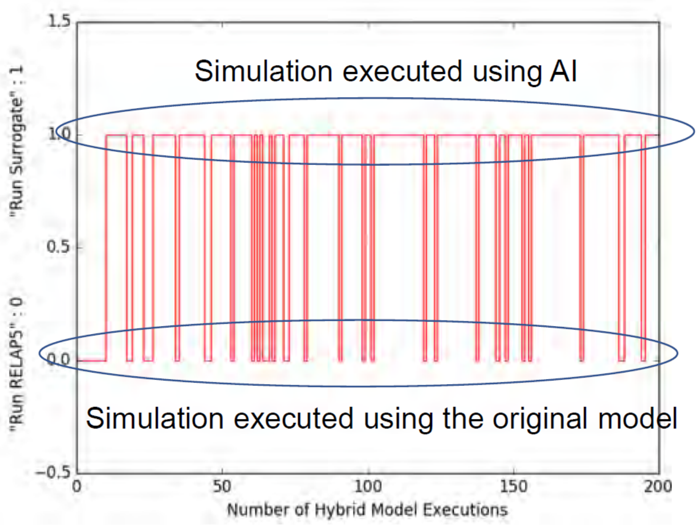
IES: Artificial Intelligence (AI, Supervised Learning) Generation and Validation

- Addresses computational cost of probabilistic analysis
  - AI is used to develop surrogate models for complex, computationally expensive, physical models
  - Concepts such as the hybrid model in RAVEN are currently being extended to time dependent AI (supervised learning)
  - AI validation is being tuned for these applications



- Needed 1000 simulations to generate a good statistic
- AI learned to replace the original simulation
- Only about 200 simulations were executed using the real model

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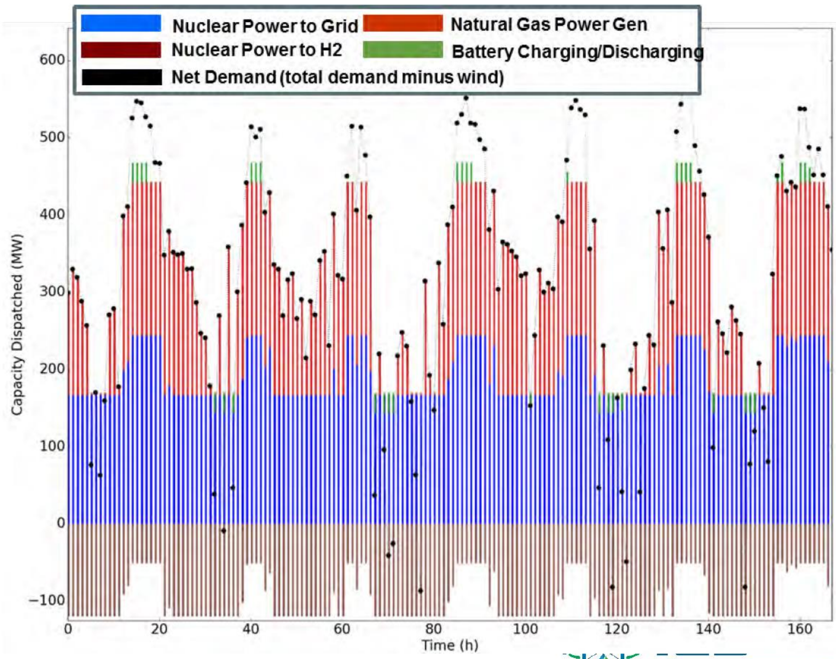
Examples Optimized Hybrid System Performances

+ System design optimization using time histories for one year (Nuclear, Hydrogen, Gas turbine, Battery, Wind)
+ Repurposing existing plant for H2 production via high temperature electrolysis; use of produced hydrogen for multiple off-take industries
+ LWRs with H2 production using low-temperature and high-temperature electrolysis

Example Optimized Hybrid System Performance Results INL-Developed Toolset

- **System design optimization using time histories for one year**
- **Results shown for a selected time history, one week period (hourly resolution)**
- **Optimized component capacities**
  - Nuclear Reactor 300 MW_e
  - Hydrogen Plant Capacity 120 MW_e
    (shown as negative – electricity input; 70% turndown limit; H_2 market price - \$1.75/kg-H_2)
  - Gas turbine 200 MW_e
  - Electric battery 100 MWh
  - Wind penetration 400 MW_e
    (100% of mean demand, installed capacity, 27% capacity factor)
  - Penalty function applied for over or under production of electricity.



Rabiti and Epiney, INL, 2018

Recent Hydrogen Production Analyses for Current Fleet LWRs

INL issued public-facing reports on in FY19 that provide the foundation for demonstration of using LWRs to produce non-electric products:

- ***Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest***
  Repurposing existing Exelon plant for H2 production via high temperature electrolysis; use of produced hydrogen for multiple off-take industries (ammonia and fertilizer production, steel manufacturing, and fuel cells) (INL/EXT-19-55395)

IES Integrated Energy Systems

- ***Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest***
  LWR market opportunities for LWRs with a focus on H2 production using low-temperature and high-temperature electrolysis; initial look at polymers, chemicals, and synfuels (INL/EXT-19-55090)

LWRS LIGHT WATER REACTOR SUSTAINABILITY

Example: Analysis results for H2 production, compression and delivery prices to meet ammonia plant demand.