Opportunities and Challenges for Nuclear-Renewable Hybrid Energy Systems

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Mission: NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

Example Technology Areas:

- 1800 employees, plus 400 postdoctoral researchers, interns, visiting professionals, and subcontractors
- 327-acre campus in Golden & 305-acre National Wind Technology Center 13 miles north
- 61 R&D 100 awards. More than 1000 scientific and technical materials published annually

www.nrel.gov/about
Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.
NICE Future Initiative Began at CEM9 2018

Vision
NICE Future envisions nuclear power as an important energy option for clean, reliable, and resilient baseload electricity and non-electric applications and includes advanced and innovative designs and applications.

Areas of Work:
1. Evaluations of innovative systems, technology, storage, uses
2. Engagement
3. Economics
4. Communicating nuclear energy’s role in clean energy systems
Working Definition of an N-R HES

*Tightly-Coupled*

**Individual facilities** which take **two or more energy resources as inputs** and produce **two or more products**, with at least one being an energy commodity such as electricity or a transportation fuel.

Analysis Objective

• Financial (economic) analysis of N-R HES use cases
• Testing
  – Profitability
  – Profitability compared to natural gas alternatives
  – Competitiveness in grid resource adequacy markets
  – Potential for flexibility to improve profitability
Use Cases Analyzed

Liquid Transportation Fuels

Electrical interconnection
No purchase of grid electricity

Reverse Osmosis Desalination

Electrical interconnection
Possible purchase of grid electricity

Thermal Energy in an Industrial Park

Thermal interconnection
(primarily)
Possible purchase of grid electricity

Hydrogen Production

Thermal interconnection
for high temperature electrolysis.
Possible purchase of grid electricity

Analysis Methodology

Identify optimal configurations and internal dispatch under various product prices

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One Dispatch Option

Second Dispatch Option

Analysis Methodology

Analysis Methodology

Developed from Standard Scenarios:
Used the 2036 mix for the RPS80 scenario as the baseline

Based on historical costs and competition from natural gas combustion turbines: $50/kW-yr

Required to provide power during 50 highest load hours in the year

Hourly Electricity Price Estimates

Estimated as marginal operational costs using PLEXOS unit commitment modeling

Subsystem Sizing and Operational Optimization

Used REopt to identify optimal configurations and internal dispatch

Maximum sizes for all subsystems set to 50 MWe equivalent

Other Costs

Additional Financial Analysis

Capacity Payment

10% after tax IRR on 100% equity financing. 25 year analysis life. 35% tax rate. 3% inflation rate.
Electricity Prices

Developed and used generation mixes that cause volatile electricity prices

<table>
<thead>
<tr>
<th>Price Set</th>
<th>Primary</th>
<th>Arizona</th>
<th>Volatile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind generation percentage</td>
<td>21%</td>
<td>11%</td>
<td>8.6%</td>
</tr>
<tr>
<td>PV generation percentage</td>
<td>20%</td>
<td>22%</td>
<td>37%</td>
</tr>
<tr>
<td>Hours at $0/MWh annually</td>
<td>704</td>
<td>700</td>
<td>2,246</td>
</tr>
</tbody>
</table>

Energy Price Duration Curve for Texas Use Cases

Optimal Configurations Liquid Fuels Use Case

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Optimal Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low gasoline prices &amp; high electricity price multiplier</td>
<td>Both nuclear- &amp; wind-generated electricity</td>
</tr>
<tr>
<td>High gasoline prices &amp; lower electricity price multiplier</td>
<td>Nuclear heat and industrial process only</td>
</tr>
<tr>
<td>High gasoline prices &amp; high electricity price multiplier</td>
<td>Nuclear heat and industrial process with wind generation</td>
</tr>
</tbody>
</table>

Subsystems are Optimally Included if Independently Profitable

Conclusion #1:
Under our analytical method and most of our assumptions, the primary driver for whether a subsystem is included in the optimal configuration is whether it would be profitable independently.

Major Caveats:
- Negligible grid connection costs
- No value for inertia or resilience

Optimal Operation: Maximize Hours that Industrial Process Operates

Conclusion #2: Industrial processes usually maximize profitability by operating the maximum number of hours possible in a year

In other words: Our electricity price assumptions are insufficiently volatile for arbitrage (even with high renewables & capacity payments)

But Lower Cost Equipment Partially Overcomes Second Conclusion

Exception to #2:
Systems with lower hourly income required from the industrial process may optimally reduce the industrial product to receive a capacity payment (white & lighter blue regions in water production graph)

Conclusion #3:

- Lower capital cost industrial processes are more likely to utilize their flexibility to switch between electricity and the industrial product more often than their higher capital cost configurations.
- This flexibility increases the number of profitable situations.

Flexibility Benefits N-R HESs when Electricity Prices are High & Volatile

- N-R HES can produce electricity when price is high and industrial product when electricity price is low as shown in the yellow polygon.
- High and volatile energy prices necessary to realize the benefits of arbitrage.

Thermal Energy May Be an Opportunity for Nuclear Energy

Conclusion #4:
Nuclear reactors may be competitive selling thermal energy

Providing a thermal energy market exists and they can access that market

High Temperature Electrolysis N-R HES: Impact of Capacity Payments

Conclusion #5:
• Higher capacity payments lead to more optimal configurations that provide grid support
• But a sufficient industrial product price is still critical

Conclusions - Reiterated

1. Under our analytical method and most of our assumptions, the primary driver for whether a subsystem is included in the optimal configuration is whether it would be profitable independently

2. Industrial processes usually maximize profitability by operating the maximum number of hours possible in a year

3. Lower capital cost industrial processes are more likely to utilize their flexibility to switch between electricity and the industrial product more often than their higher capital cost configuration. This flexibility increases the number of profitable situations

4. Nuclear reactors may be competitive selling thermal energy providing a thermal energy market exists and they can access that market

5. Higher capacity payments lead to more optimal configurations that provide grid support but a sufficient industrial product price is still critical
Thank you!

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