Integration Challenges for Nuclear Cogeneration coupled to Renewable Energy Systems

Planning and Economic Systems Section

OECD HQ Paris, France - 4-5 April 2013

David Shropshire
Agenda

- Impetus for Study
- Hybrid HTGR System
- System Behavior
- Integration Challenge and Lessons
- Economic Tradeoffs
Impetus behind the Case Study

Renewable energy, a critical component of EU roadmap for a low-C economy by 2050, is driving demands for:

1. Significantly increased shares of variable renewable energy for electricity and related need for balancing energy;
2. Demand for low-C transportation fuels;
3. Other low-C energy technologies, such as nuclear, energy storage, and smart grids.
Hybrid Energy System Composition

- HTGR – supporting cogeneration
  - Balancing electricity to offset variable energy (nearby wind farms)
  - Process heat to support Biomass processing, where *Biomass collected within 80 km radius*
  - $\text{H}_2$ production (low-temp. electrolysis) for synfuel processing, using “Surplus Electricity”
- Dynamic Energy Switching (DES) – used to achieve highest capital utilization
**“Optimal” Configuration of HES**

Max Output of 1061 MWe to the power GRID ►►

Composite Wind Farms

Variable Electricity ►

1018 MWe

Dynamic Energy Switching

Nuclear reactor 347 MWe (755 MWth)

Regional Biomass (80 Km radius or ~2 million hectares)

Drying and Torrefaction Processes

1.000.000 t/DM/yr

104 GWh heat at 200°C

1169 GWh heat at 500°C

Torrified Product

Pyrolyzed oil + char + offgas

753 m³/day bio-diesel

597 m³/day bio-gasoline

Hydrogen Electrolysis

42,000 t H₂/yr

Offsetting SMR ▲ Electricity

Reactor Heat

Electricity

Synfuel Production

753 m³/day bio-diesel

597 m³/day bio-gasoline
Illustrative Flow Chart - Rankine Cycle

- Primary coolant (helium) from reactor
- Secondary coolant (HP steam)
- HP steam \( T = 500^\circ C \) pyrolysis
- LP steam \( T = 200^\circ C \) drying & torrefaction
- Power to grid and to electrolysis

Steam Generator

Feedwater pump

Feedwater heater

Condenser

Generator

IAEA
Variability increases with wind capacity

Best Result: Wind to nuclear 2:1
HES Compensates for Wind Variability

The graph illustrates the power output from different sources over a period of January, with the x-axis representing time in hours. The y-axis denotes power output in MWe. The lines represent:

- Wind farm
- Power to grid from HES
- Reactor
- Electrical for H2 production
- Demand

The graph shows how the HES system compensates for wind variability, ensuring a consistent and reliable power supply to the grid.
Integration Challenge

• The challenge was finding the optimal ratio of the wind farm capacity to nuclear capacity, while providing adequate heat to support biomass processing while matching power demands
Integration Lessons

• Nuclear and wind capacities need to generate adequate heat and electricity for local biomass heat needs while supporting local demands for electricity

• Variability of power to grid relative to instantaneous demand should be minimized

• If nuclear is sized too large, variability of power production may be reduced, however process heat and electricity are wasted.
Integration Lessons

• Biomass availability is a key constraint
  • Key to setting the heat demand
• Biomass/Bioenergy production
  • Drying and torrefaction “only” required a small reactor (<10 MWe) not considered economic.
  • Drying, torrefaction, and pyrolysis, best solution is 480MWe wind farm and 240MWe Nuclear.
  • With Synfuel production, excess energy goes to \( \text{H}_2 \) production acting as a storage buffer.
## Economic Trade-offs

<table>
<thead>
<tr>
<th>Hybrid System w/ RES</th>
<th>Conventional System w/ RES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compensates variable RES</td>
<td>Highly variable RES</td>
</tr>
<tr>
<td>Electricity price in balancing/peaking markets</td>
<td>Electricity price in base-load electricity market</td>
</tr>
<tr>
<td>Value from Synfuels</td>
<td>Cost to remove waste heat</td>
</tr>
<tr>
<td>Additional capital and operating costs, some loss of thermal efficiency</td>
<td>Addition of grid upgrades and energy storage for balancing, subject to fuel price volatility</td>
</tr>
<tr>
<td>Little or no backup capacity needed, no C emitted</td>
<td>100% backup for RES, using natural gas, subject to C-tax</td>
</tr>
</tbody>
</table>
In Conclusion

• Move toward low-C economy is creating new opportunities for nuclear power,
• Integration challenges for nuclear and RES are not simple, but “no solution that allows substantial increases to renewable energy penetration in the grid will be simple”,
• Economic studies are needed to confirm this opportunity.
Back-up Slides
Strong Wind Variability (Jan., July)
Case 1: Too small sized

Case 1: Drying and torrefaction
Case 2: Best match 2:1 wind:nuclear

![Graph showing power demand, installed power, and ratio standard deviation.](image)

- **Installed wind farm capacity**
- **Reactor capacity**
- **Ratio standard deviation: HES/wind**

**Case 2:** Drying, torrefaction, pyrolysis