

Operating Experience and Opportunities with Flexible Nuclear Plant Operations

ESIG 2020 Spring Technical Workshop

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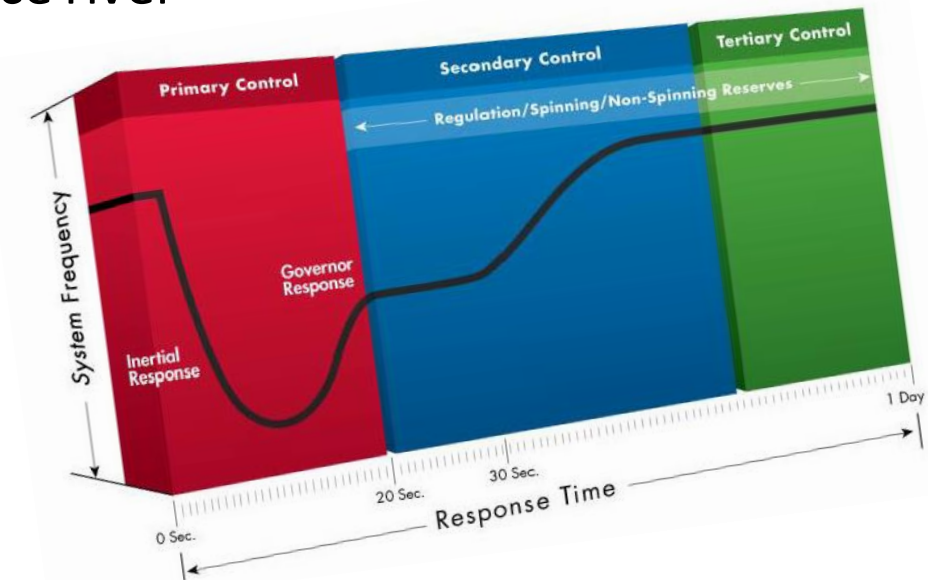
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Tucson, AZ



Nuclear Power Plant Flexible Operations is Not New

- Past Operating Experience (OE) in the United States
 - Until mid-1980's nuclear plants were used for frequency control
 - Nuclear Regulatory Commission changed their rules for reactor power control
 - Columbia NPP has decades of flexible operations to balance river flowage
- France
 - 58 reactors with over 30 years of flexible OE
 - Output can vary between 20% and 100% power within 30 minutes, twice a day for load following
 - Provide primary and secondary frequency control
 - Use grey control rods to vary reactor power



Nuclear power plants were designed for flexible operations

Recognizing the Need to be Flexible in Today's Market

- EPRI research program started in 2013

- Support transitioning from base load, to flexible operations
- Assess long-term impacts on the nuclear fuel and plant
- Develop proactive management strategies
- Employing a phased approach

- Recent Operating Experience

- Xcel – Day Ahead Market
- Exelon – Advance Nuclear Dispatch
- Columbia – Load Shaping Agreement
- Bruce Power – Surplus Base Generation
 - CANDU reactor design allows steam bypass mode
- Europe
 - Belgium and Spain
- United States
 - Several utilities are actively evaluating options

Phase 1 - Pre-Planned FPO 100 - 70 -100% Power

- On a daily basis – sometimes with frequent ramping
- Ramp rate 0.5-1% per minute

Phase 2 – Extended Low-Power ~ 50% Power

- 2-8 week duration
- Seasonal

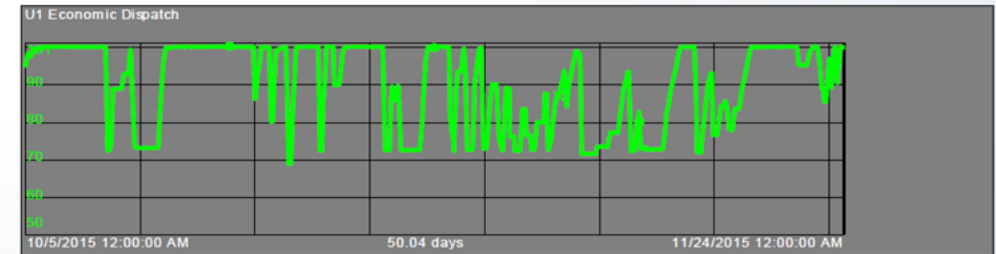
Phase 3 – Expanded FPO 100-30-100%

- Ramp rate 2-5% per minute
- Response to Grid - short notice, no defined duration

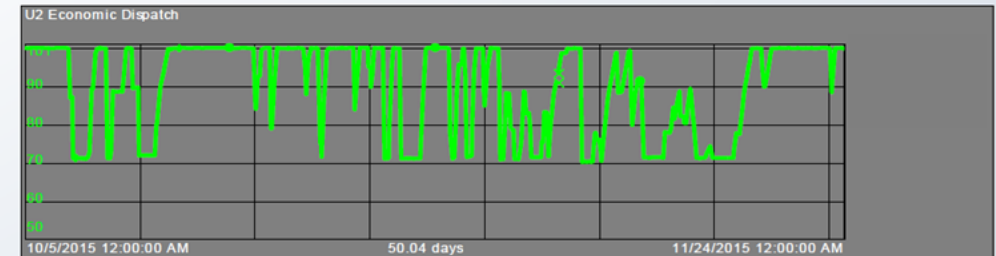
Key Lessons Learned

- The plant operator is responsible for maintaining a safe operating window
- Training is critical
- Chemistry can be challenging – more frequent monitoring may be warranted
- Water usage may increase for PWRs
- Inspection frequencies need to be adjusted for critical components
- Flow accelerated wear rates change
- Maintenance practices need to be robust
- Most plant impacts are latent and additional monitoring for unexpected changes is needed

Unit 1 Economic Dispatch over past 7 weeks



Unit 2 Economic Dispatch over past 7 weeks



Data provided by Exelon for a PWR

Flexible Operations is being successfully implemented with manageable impacts

An Operating Protocol Is Needed

- Only a licensed plant operator can change reactor power levels
- The rate, depth, duration, frequency and time in reactor core life are tied to core physics
 - Need to be well defined up front
 - Ensure the plant stays within a safe operating envelope at all times
- Plant Management can decide to opt out of flexible operations based on other plant activities
 - Require the full attention of the control room operators, or
 - Require stable core power to complete



Nuclear flexible operations requires close coordination

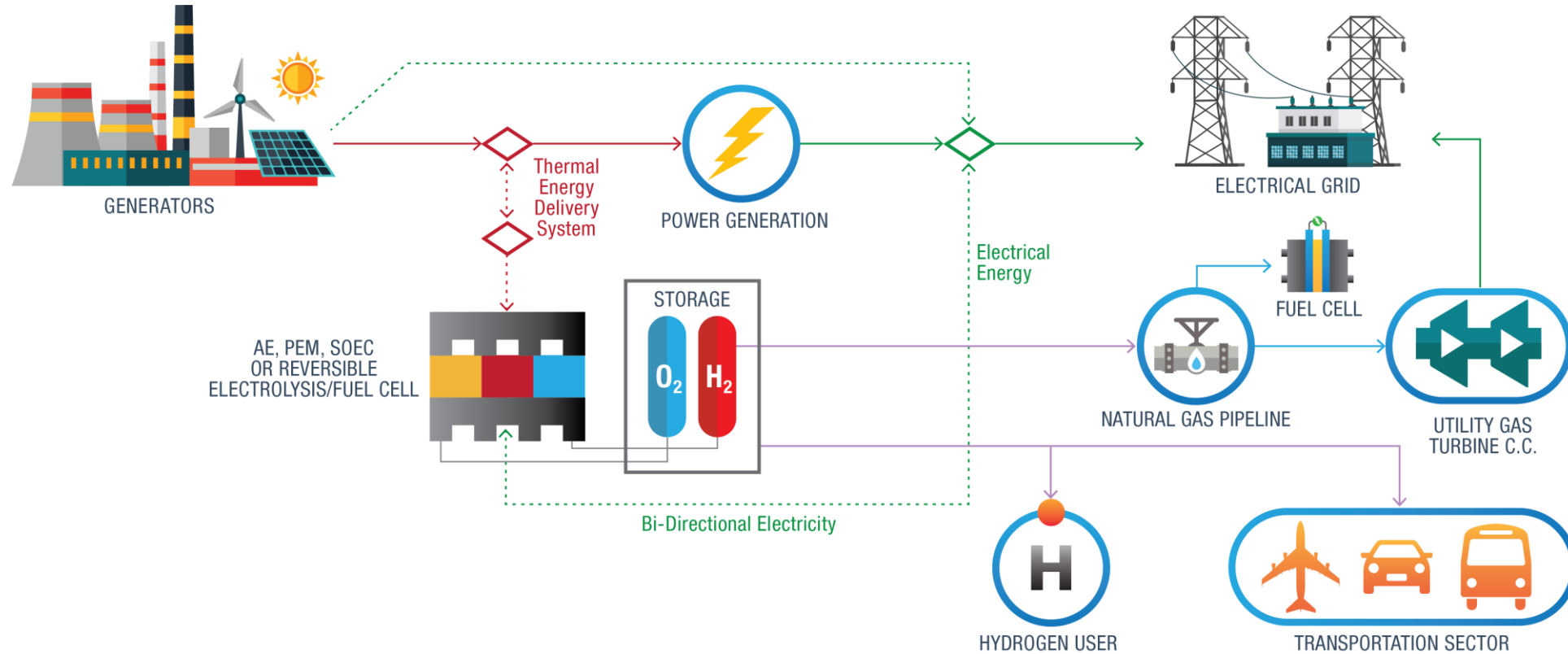
Optimizing Nuclear Flexible Operations

- Pilot study to quantify the cost of NPP flexible operations
- Expand The Range of Flexibility, i.e. 100-30-100%
 - White Paper published in 2019 on possible ‘pinch points’
 - Research started in 2020 to address options
- Frequency Control and Other Grid Services
 - Study on NPP frequency control considerations is in progress
 - Working with DOE on an Economic Drivers for Nuclear Flexible Operations study
- Nuclear Beyond Electricity
 - Thermal storage
 - Water de-salinization
 - Hydrogen generation



White Paper December 2020: Technical, regulatory and financial aspects of using NPPs for primary frequency control

Example: Hydrogen Production via Steam Electrolysis

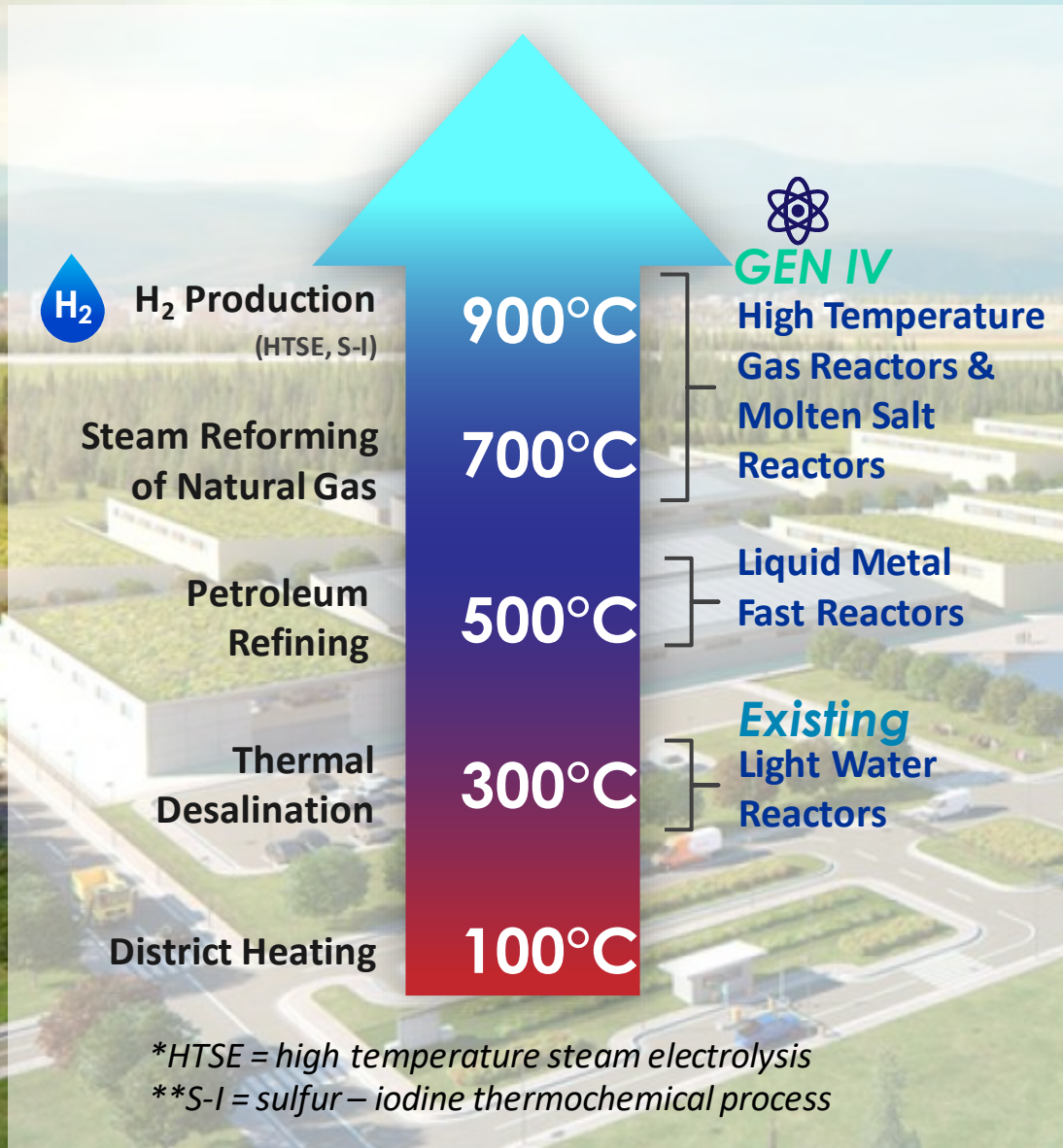


- 1) Provides second source of revenue
- 2) Provides energy storage, for electricity production or hydrogen user
- 3) Provides opportunity for grid services; reserves and grid regulation

US Department of Energy is funding demonstration projects for H₂ production at existing NPPs

Source: Idaho National Laboratory

Small Modular and Advanced Reactors Provide Increased Flexibility



Source: Nuclear Reimagined, Third Way, Oct. 2017

Together...Shaping the Future of Electricity