Flexible Nuclear-Based Integrated Energy System

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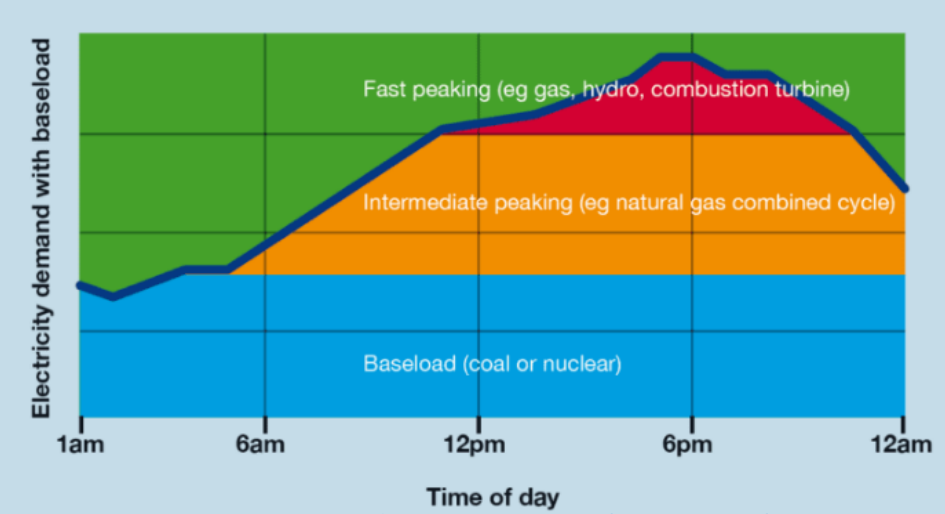
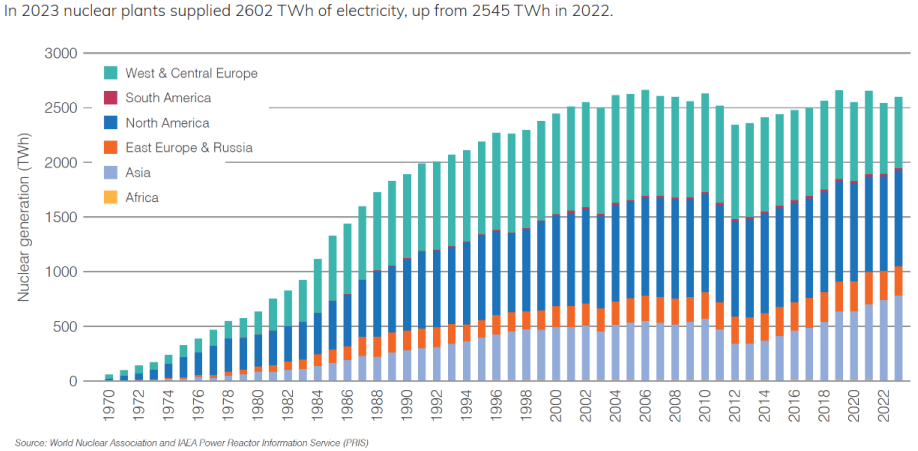
Motivation

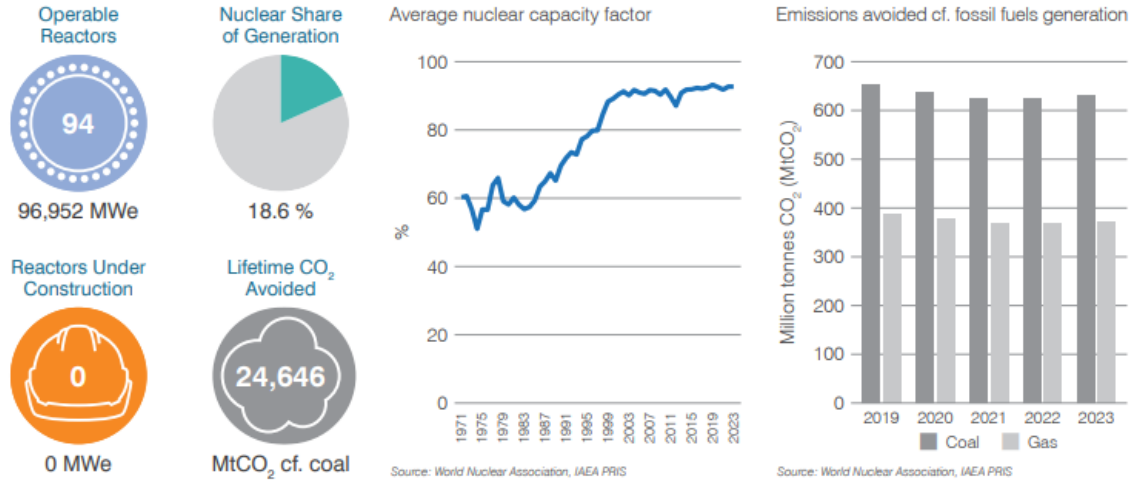
Nuclear Energy Remains an Important Source of Electricity

- Capable of reliably **producing base-load** electricity
- **Low emissions**
- **High power density** and capacity factor
- **Ad hoc ramping** of power output is a challenge



Source: How Renewables Can Provide "Baseload" Power (2-Year Process)



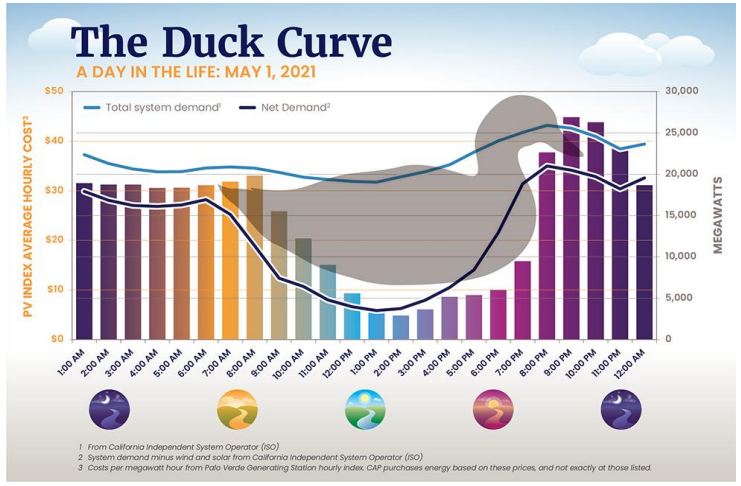


Source: Nuclear Power in the World Today - World Nuclear Association

Motivation

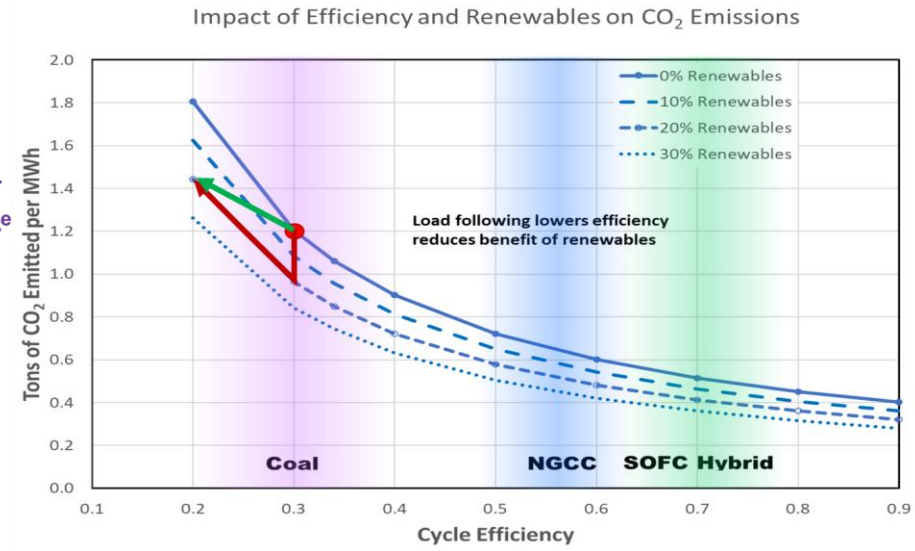
The Need for High Efficiency, Flexible, and Reliable Energy Systems

Dynamic flexibility and high part-load efficiency are essential to lower the overall CO_2 emitted/MWh of power generation.

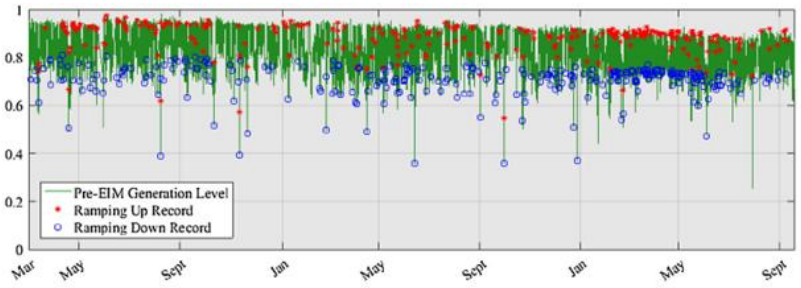


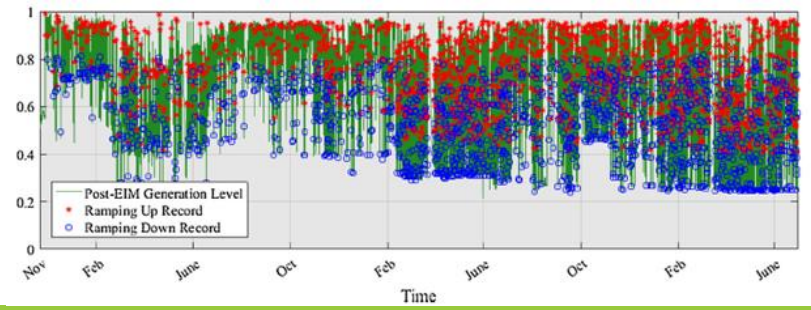
Increasing grid complexity:

- Increasing demand
- Intermittency
- Reduced dispatchability



More Frequent Ramping Events





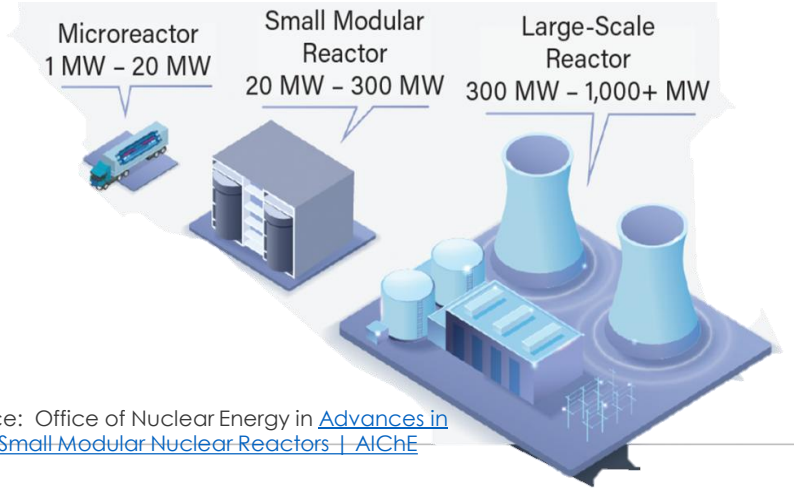
More frequent load cycling due to daily fluctuations in intermittent power resources: Shorter plant life - lower reliability - increased emissions

Small Modular Nuclear Reactor (SMR) Systems

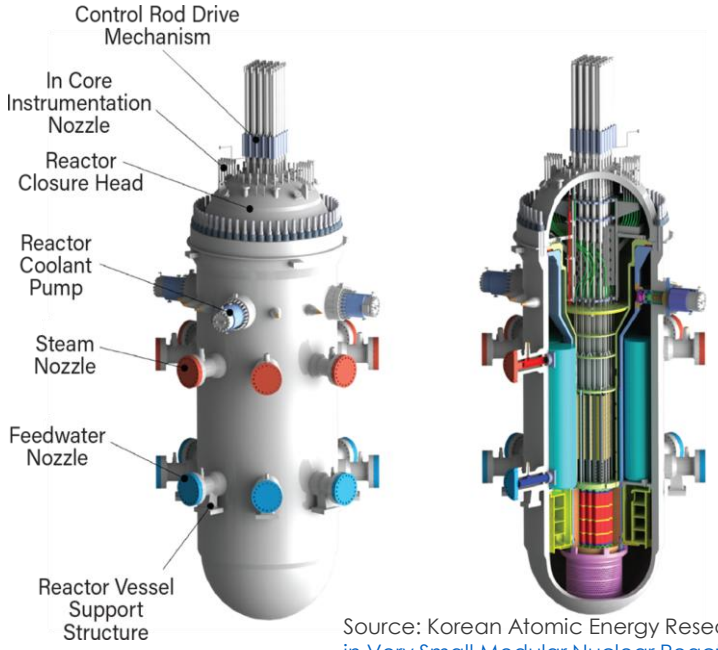
A Key Solution to Transforming Future Nuclear Energy

Spectrum of nuclear technologies:

1. Micro modular reactor (1 MW – 20 MW) – Remote, off-grid, and microgrid
2. Small modular reactor (20 MW – 300 MW) – Regional utilities, small to mid-size grid supply, coal power plant replacement, industrial heat/steam
3. Large-scale reactor >300 MW – National base-load grids



Source: Office of Nuclear Energy in Advances in Very Small Modular Nuclear Reactors | AIChE



Source: Korean Atomic Energy Research Institute in Advances in Very Small Modular Nuclear Reactors | AIChE

Benefits of small modular nuclear reactor system:

- Modularity design
- Shorter construction time and easier installation
- Transportable
- Scalability
- Design diversity for flexible deployment
- Safety management

Transitioning to Future Nuclear Energy

Potentials to Accommodate Variable Power Generation

Integrated SMR energy systems can enable load following capability:

- The most common integrated SMR systems are with a **steam Rankine cycle**
- The SMR can power a turbine for **electricity** generation
- Load following can be realized through coupling with molten salt tanks for **thermal energy storage**
- SMR thermal energy and electricity can support **cogeneration of H_2** from the proton exchange membrane (PEM) or solid oxide electrolysis cell (SOEC), as well as the **desalination** process
- Integration with batteries can help overcome the renewable intermittency on the power grid

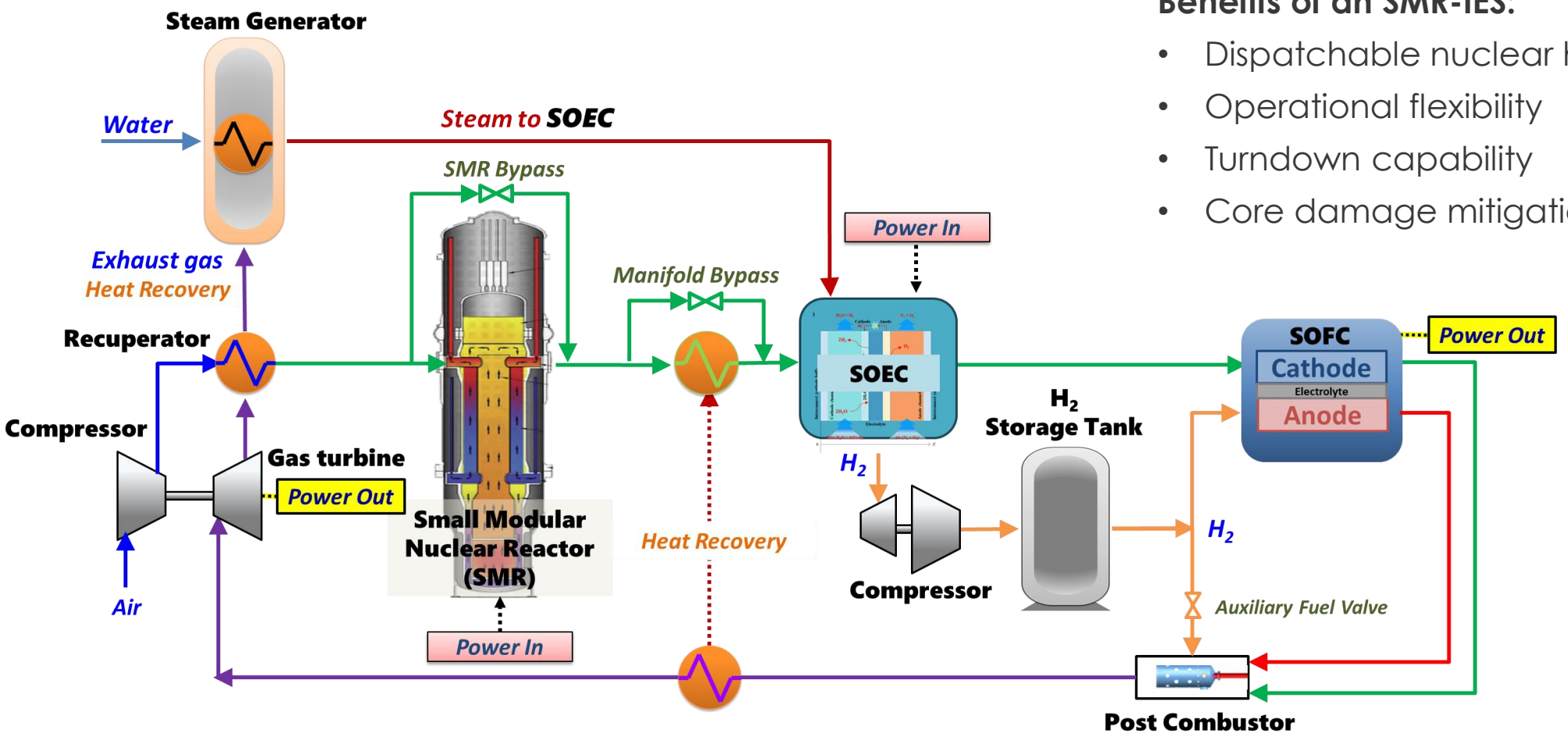
Other developing concepts of integrated nuclear systems also include integration with:

- Brayton **gas turbine** cycles
- Supercritical - **sCO_2 turbines**

SMRs can support load flowing and flexible hybrid operation but SMRs still serve as a "**steady-state**" **power generation asset** in the integrated energy systems.

Opportunities for SMR-Based Integrated Energy Systems (IES)

New Concept for Dynamic Efficiency and Flexibility



Benefits of an SMR-IES:

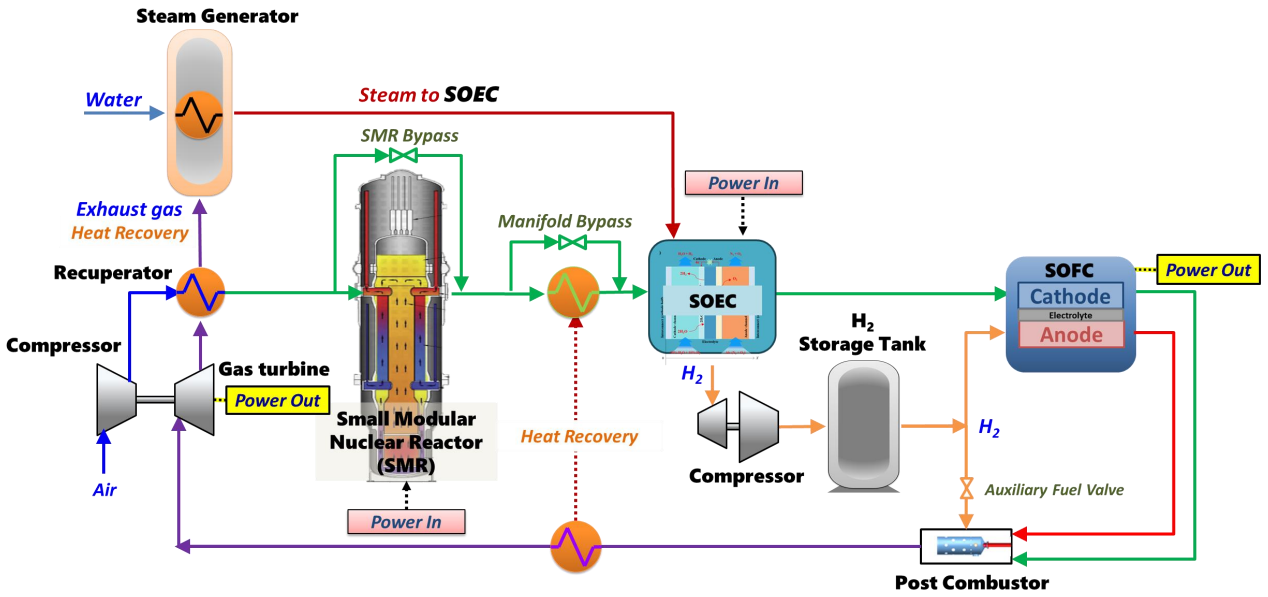
- Dispatchable nuclear hybrid system
- Operational flexibility
- Turndown capability
- Core damage mitigation

Opportunities for SMR-Based IES

Novel Concept Development for Dynamic Efficiency and Flexibility

This hybrid cycle presents great opportunities to:

- Achieve a greater efficiency than could be realized in a nuclear-steam Rankine cycle
- Produce hydrogen and power through the addition of SOEC and SOFC by using thermal energy from the SMR
- Minimize temperature gradients during transients through the constant heat rate of the SMR
- Enable rapid load following without damaging the components
- Improve stability and minimize degradation to the SMR

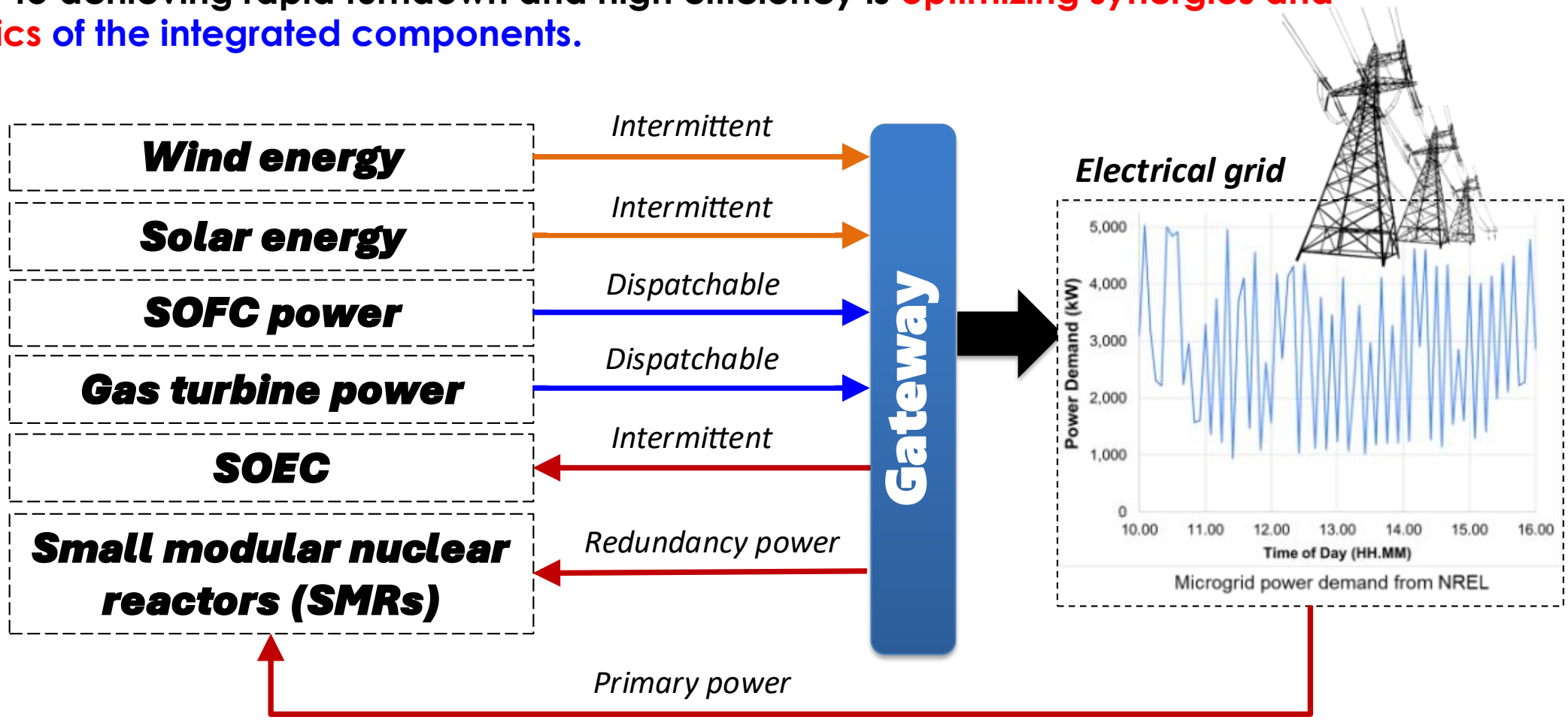


Other potentials:

- Exhaust recovery for a bottoming steam cycle
- Power production only with a nuclear-recuperated GT cycle - limited flexibility for transients
- Bypass valve deployment for load variation and thermal management in the system

Electrical Synergies in SMR-Based IES

The key to achieving rapid turndown and high efficiency is optimizing synergies and dynamics of the integrated components.



Conclusion

Challenges of integrated SMR deployment:

- System integration and controls
- Standard regulation and licensing

Source: U.S. Department of Energy, "Pathways to Commercial Liftoff: Advanced Nuclear," U.S. Department of Energy, March 2023.

Attractive — Less/Not attractive	Air emissions?	Stable?	Land use?	Transmission buildout?	Local economic benefits?	Cost competitive?	Additional applications?
Nuclear						$9000/kW	
Natural gas						$850/kW	
Renewable + storage						$3500/kw	

- Lifecycle emissions
- Bulk power generation/coal replacement

- All season supply
- Reliability and stability
- Reserve margin

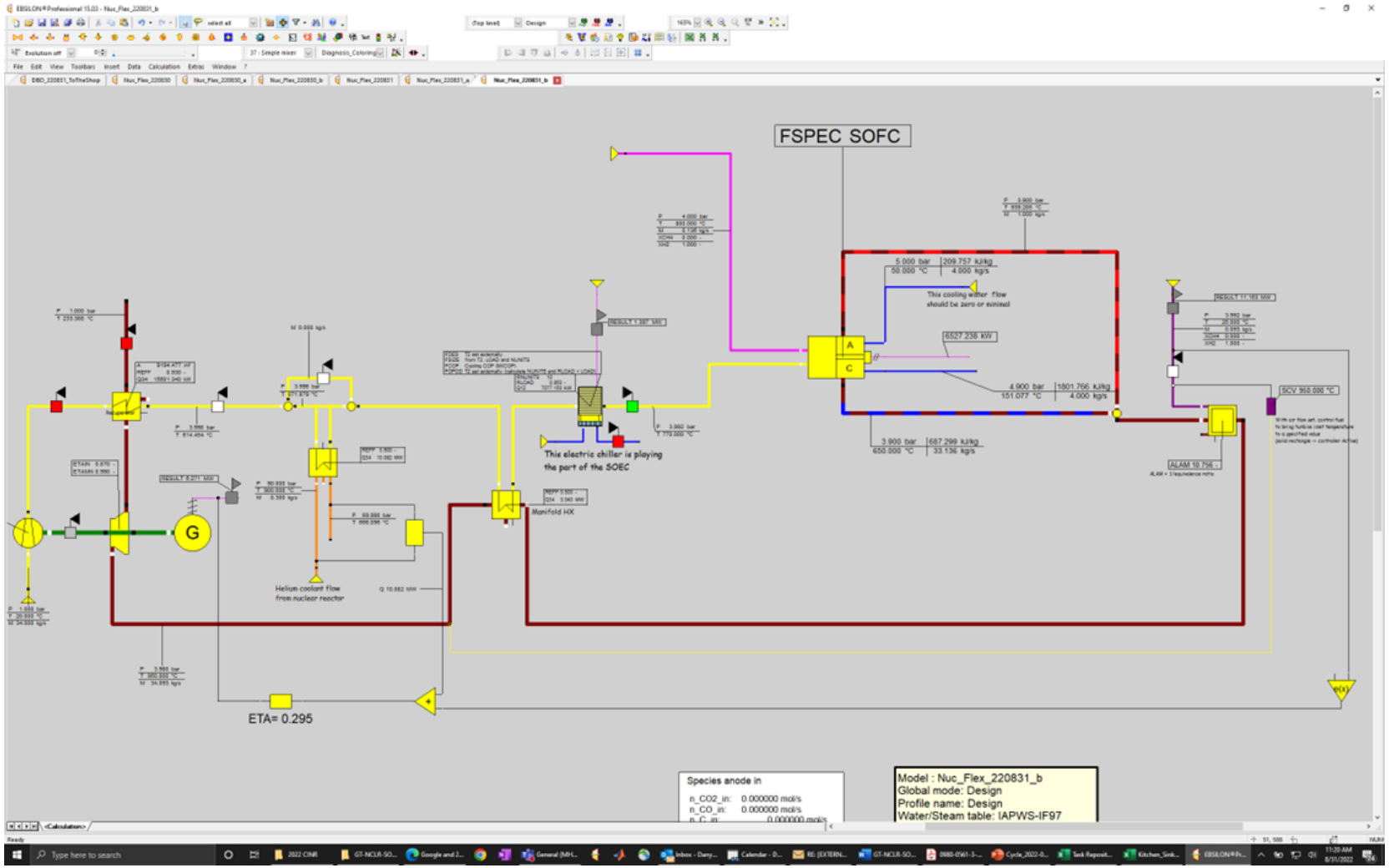
- Electricity per acre
- Footprint
- Lad acquisition

- Sitting closer to demand
- Power density
- Capacity factor

- High-paying jobs
- Economic impact on power generation

Added value proposition:
Dynamic Flexibility & Part Load Efficiency with IES

Next Step


FSPEC SOFC
This electric chiller is playing the part of the SOEC
Helium coolant flow from nuclear reactor
Manifold HX
ETA= 0.295
This cooling water flow should be zero or minimal
Species anode in
Model : Nuc_Flex_220831_b
Global mode: Design
Profile name: Design
Water/Steam table: IAPWS-IF97

Acknowledgments

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