Expanding Nuclear Energy Beyond Base-load Electricity: Challenges and Opportunities

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February 6, 2014

Frontiers in Sustainable Fuels and Chemicals:

What's Beyond the Horizon?

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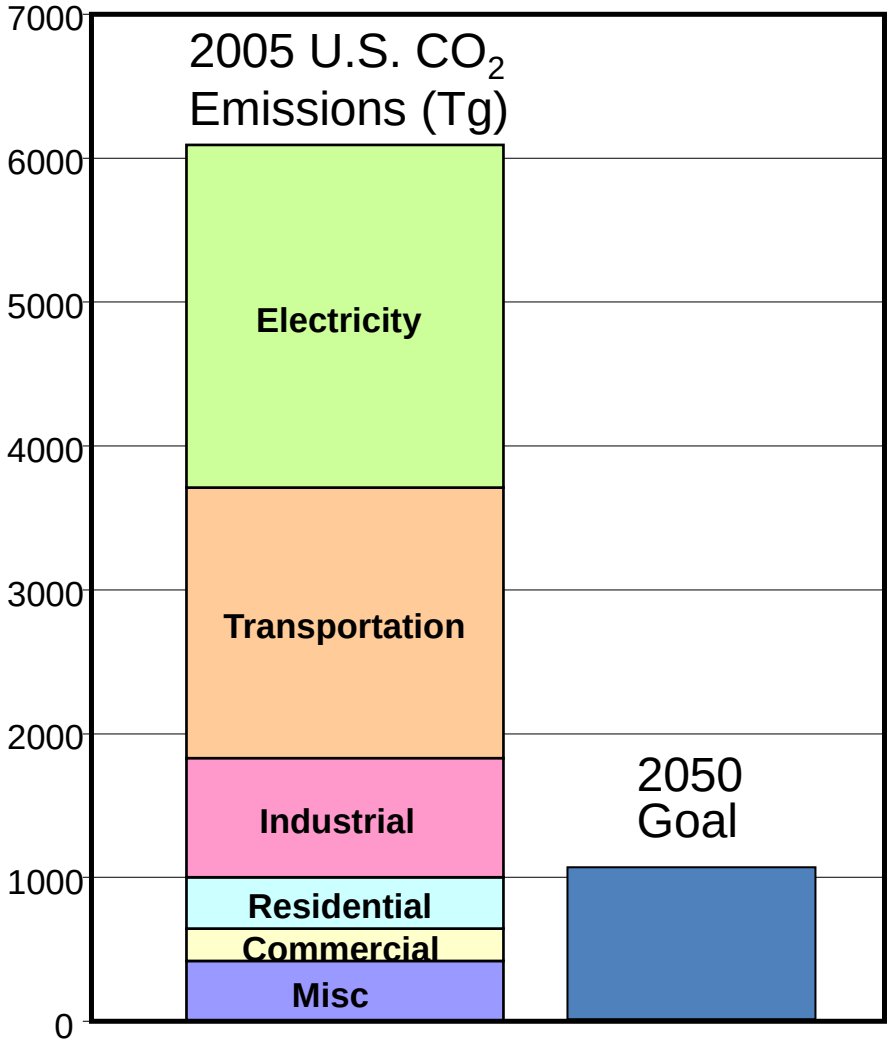
Why “all of the above”



For nuclear energy:

1. Reach more utility customers
2. Reach more non-electric energy consumers

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Nuclear Energy Development Timeline

Generation I

Early Prototype Reactors

- Shippingport
- Dresden, Fermi I
- Magnox

Generation II

Commercial Power Reactors

- LWR-PWR, BWR
- CANDU
- VVER/RBMK

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- EPR

Generation III+

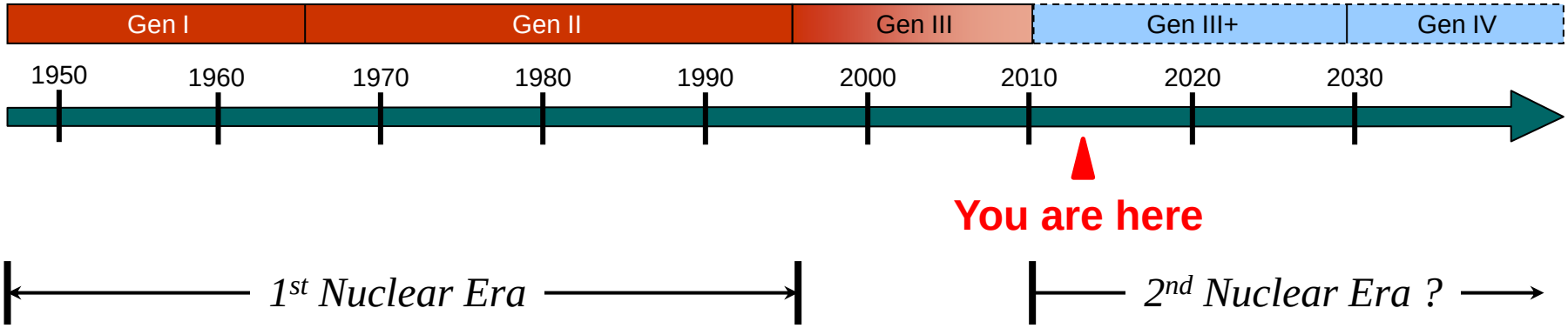
Evolutionary Designs Offering Improved Economics

-AP1000

-ESBWR

Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant



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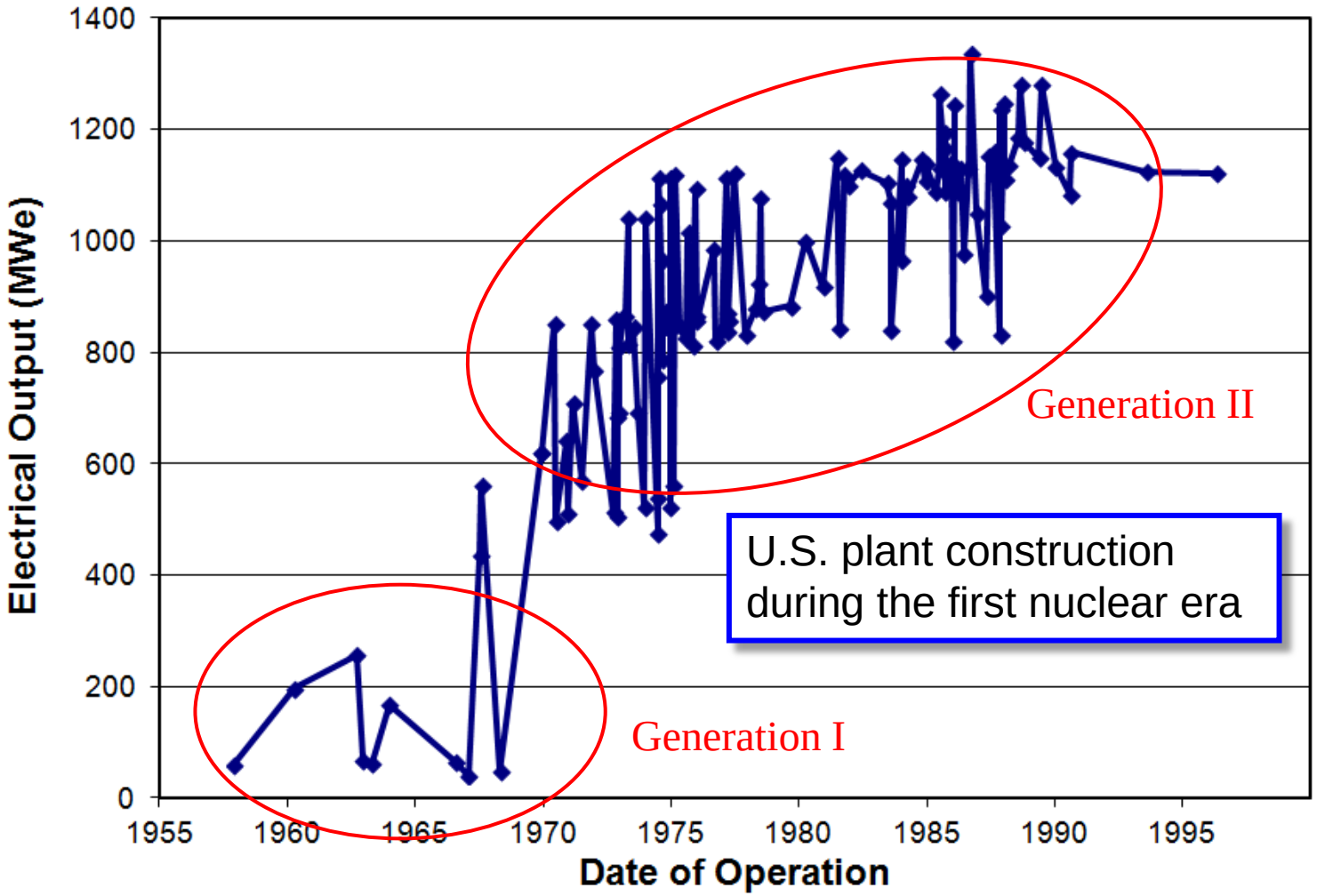
1st Nuclear Era: large base-load electricity



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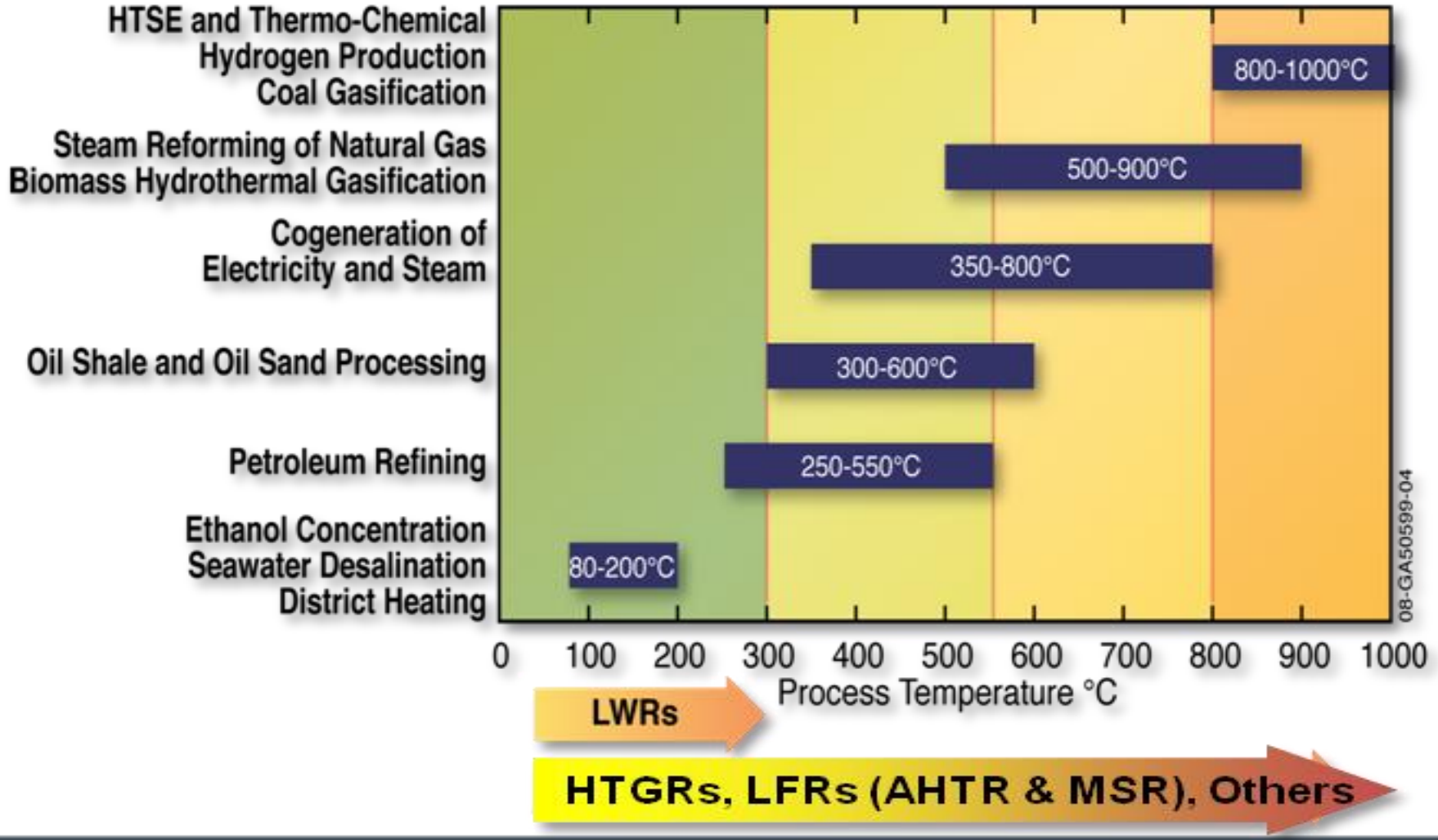
Moving beyond Gen II

- Demanding more stringent performance goals
  - Safety
  - Economics
  - Sustainability
  - Proliferation Risk

- Expanding nuclear energy to new applications
  - High-temperature reactors for process heat
  - Fast spectrum reactors for resource extension and waste management
  - Small reactors for diverse and distributed customers

Why high-temperature reactors?



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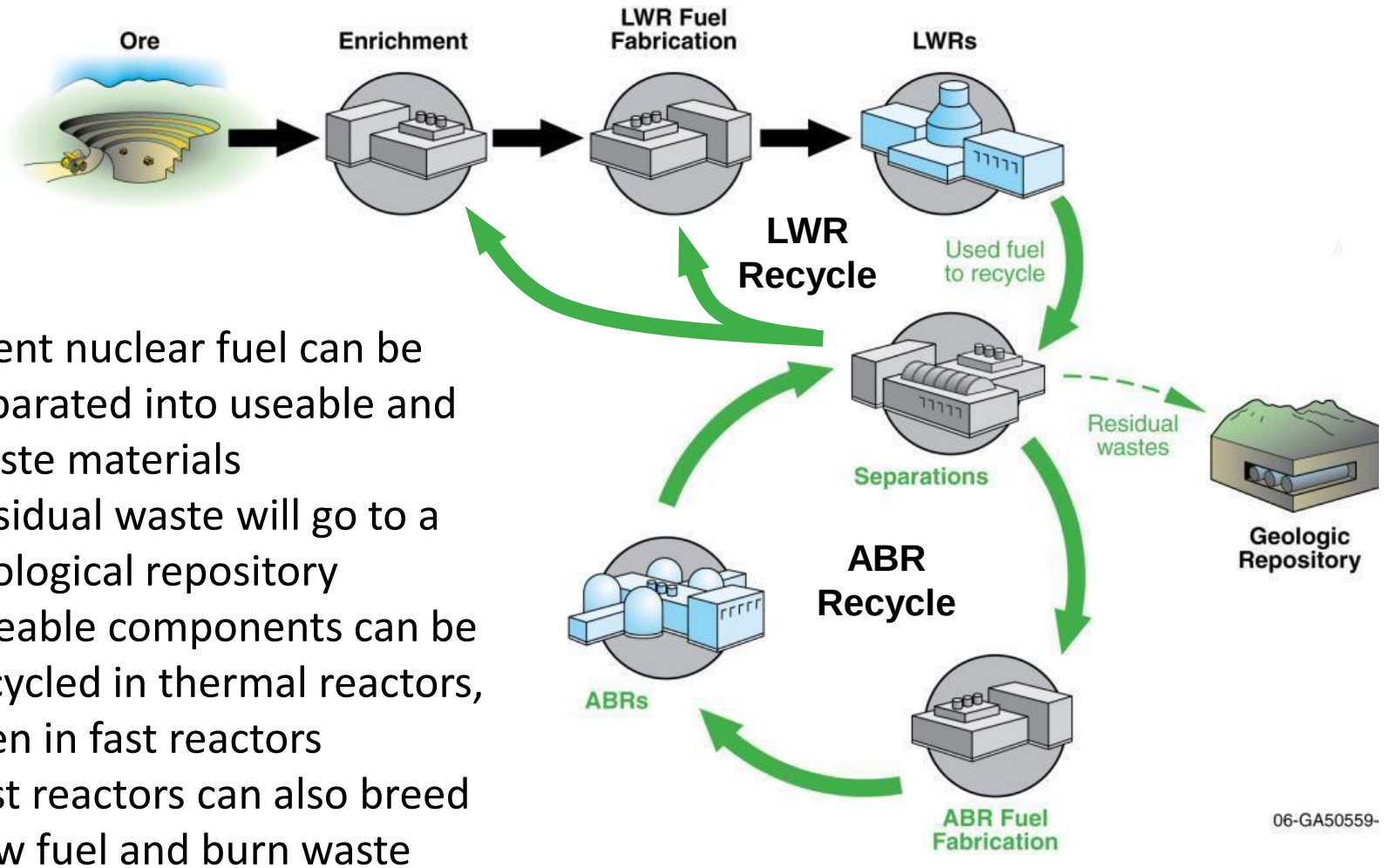
Why fast reactors?



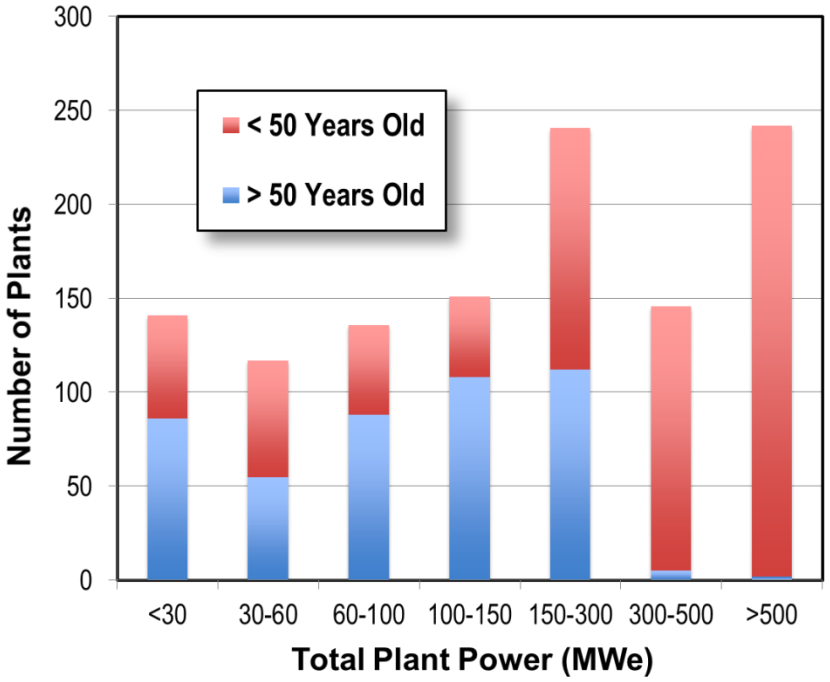
- Spent nuclear fuel can be separated into useable and waste materials
- Residual waste will go to a geological repository
- Useable components can be recycled in thermal reactors, then in fast reactors
- Fast reactors can also breed new fuel and burn waste

Why small modular reactors?

- Safety
  - Smaller decay heat
  - Easier to remove decay heat
  - Smaller radionuclide inventory
  - Lower overall risk
- Affordability
  - Smaller up-front cost
  - Lower debt profile & financing costs
  - Incremental capacity additions
- Flexibility
  - Better match to local power needs
  - Incremental capacity for regions with low growth rate
  - Adaptable to non-electric applications
  - Match to retiring coal plants
  - Stabilize wind/solar variability

U.S. Coal Plants

Plants >50 yr old have capacities Less than 300 MWe



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SMR example: NuScale

Building on vast LWR experience

- *Innovations in design and engineering*

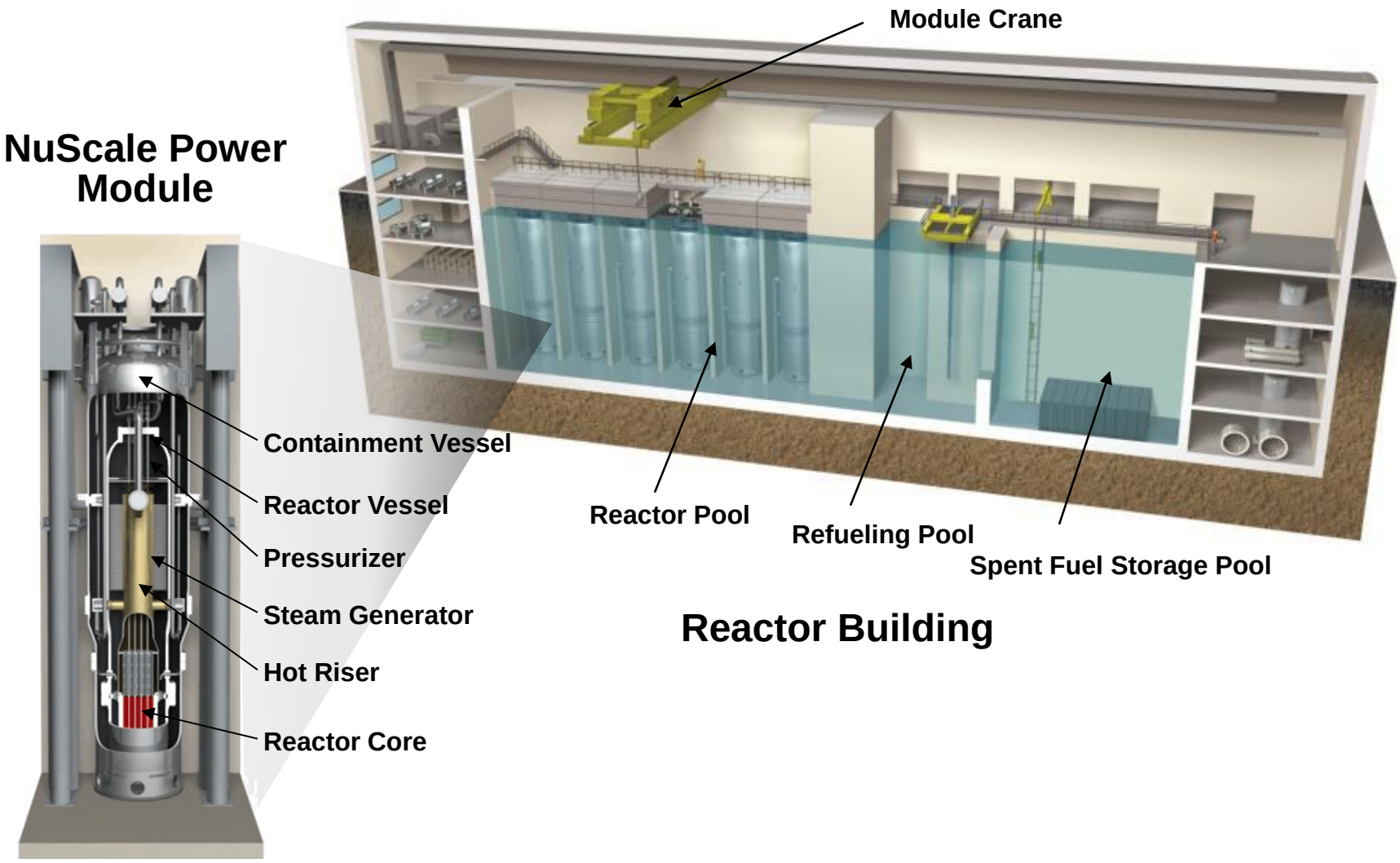
Incorporating integral system design with natural circulation cooling

- *Eliminates several major accident scenarios*
- *Design simplicity also simplifies emergency response*
- *Eliminates the need for post-accident power or operator response*

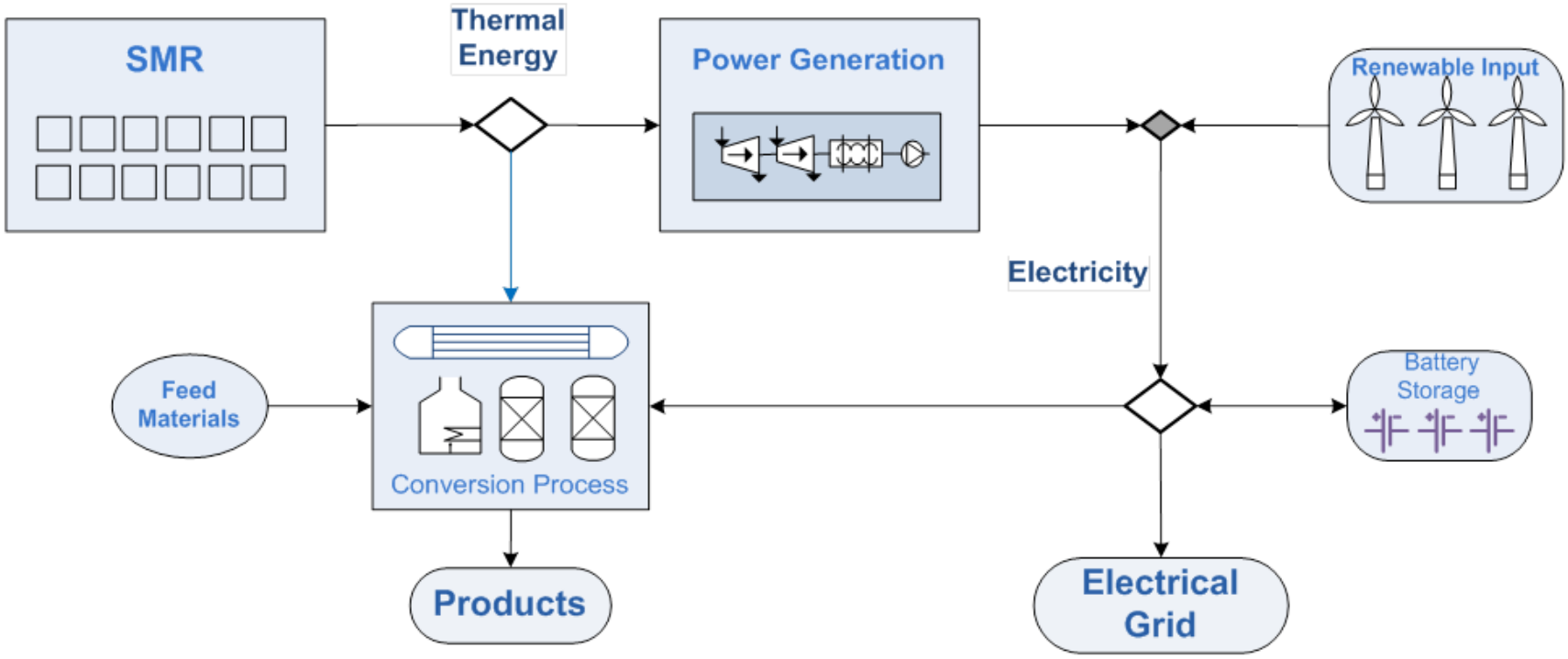
Operating under water and under ground

- *Assured access to ultimate heat sink for long term cooling*
- *Enhanced protection and security*

NuScale plant basics



“Load following” vs “load switching”

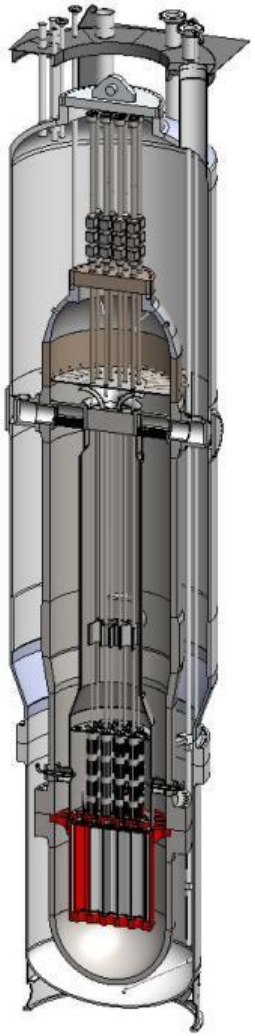


- ✓Integrate continuous (nuclear) with variable (wind/solar) generators
- ✓Couple to one or more non-electrical product streams
- ✓Optimize on capital investment, fuel costs, and product costs

Source: Idaho National Laboratory

Why NuScale for NHES?

- Scalable in small power increments
  - Low initial commitment and cost
  - Easily expandable as HES grows
  - High reliability and continuous power output
- Flexible for multi-product outputs
  - Co-generation of individual modules
  - Whole-module dedication to different products
- Strong basis for significantly reduced emergency planning zone (EPZ)
  - Low frequency of core damage
  - Additional features to reduce radionuclide release
  - Lower risk factors simplify co-location with industrial plant



New reactor challenges

- Technical challenges:
  - New materials and fuels (hi-temp and fast reactors)
  - Fuel reprocessing technologies (fast reactors)
  - New sensors, instrumentation and controls
  - Validating design and engineering innovations (SMRs)
- Institutional challenges:
  - Community mindset for large, centralized plants
  - Traditional focus of regulator on large LWR plants
  - Customer/investor fear of first-of-a-kind
  - Cheap natural gas and lack of national carbon policy

Expanding nuclear energy…

- We need to pursue all clean energy technologies to meet our national GHG goals
- Nuclear power should be a central part of our energy future
- Nuclear energy can integrate with other sources and applications
- New reactor technologies and designs are needed to meet the diverse energy needs of the country