FUELS FOR THE FUTURE

AUGUST 2023, TODD ALLEN, PROFESSOR & SENIOR FELLOW

FASTEST PATH TO ZERO
UNIVERSITY OF MICHIGAN

CONTEXT

WHAT DO WE WANT IN OUR FUTURE?

VS.

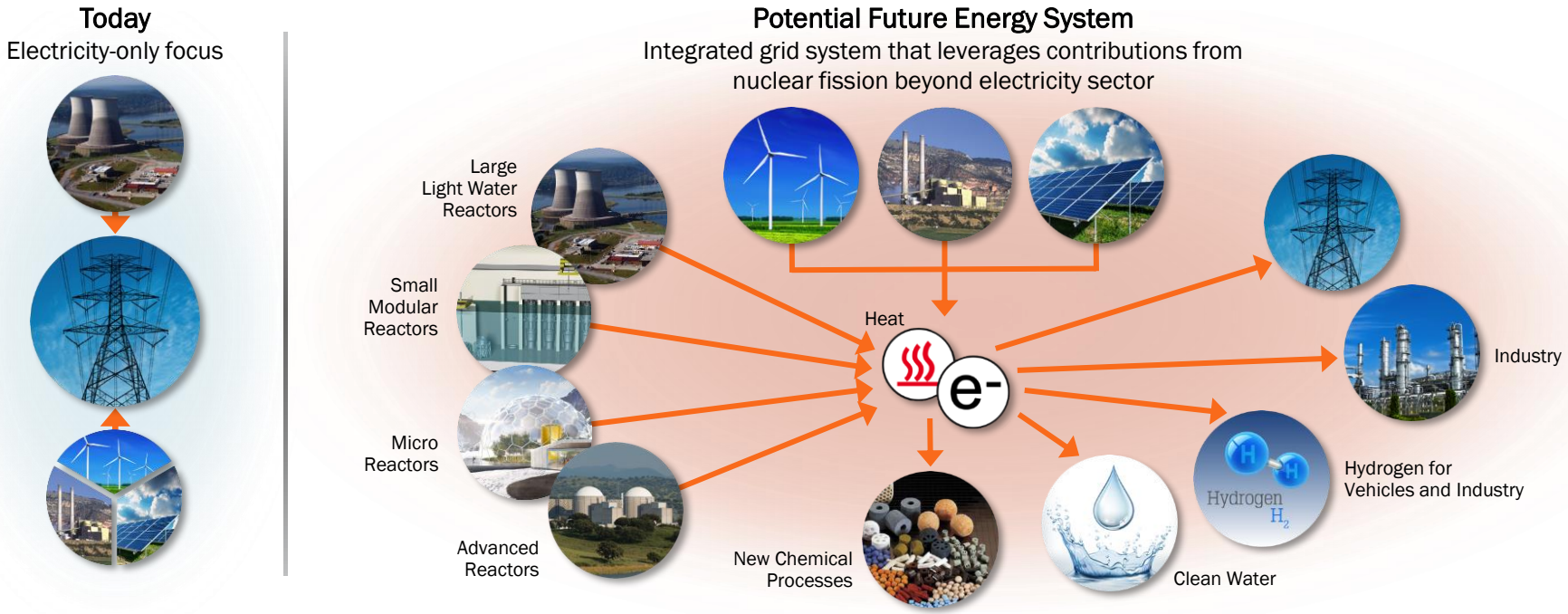
- Water purification
- Sanitation
- Irrigation
- Heating & air conditioning
- Vaccinations
- Pharmaceuticals
- Homes

- Clean
- Affordable
- Resilient
- Equitable

Innovation: Not Limitation

ENERGY REIMAGINED

Maximizing energy utilization, generator profitability, and grid reliability and resilience through novel systems integration and process design



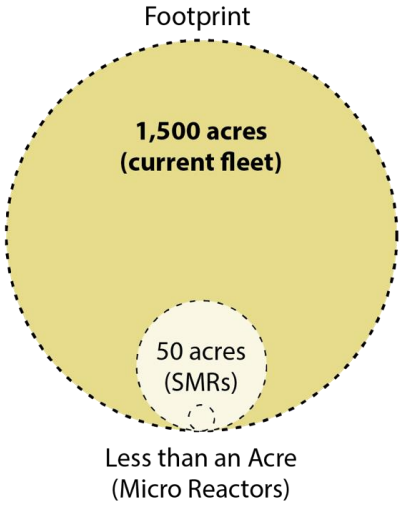
Flexible Generators ❖ Advanced Processes ❖ Revolutionary Design

Courtesy Shannon Bragg-Sitton, Ph.D., Idaho National Laboratory

EXISTING COMMERCIAL NUCLEAR REACTORS

Number in operation:	**98 in U.S.**
Timeframe:	**Built in the 1950s-1980s**
Products:	**Electricity**
Megawatts:	**1,000+ megawatts**
Customers:	**Large utilities**
Emergency zone:	**10 miles**
Construction:	**Custom built on site**
Scalability:	**Difficult due to size and cost**

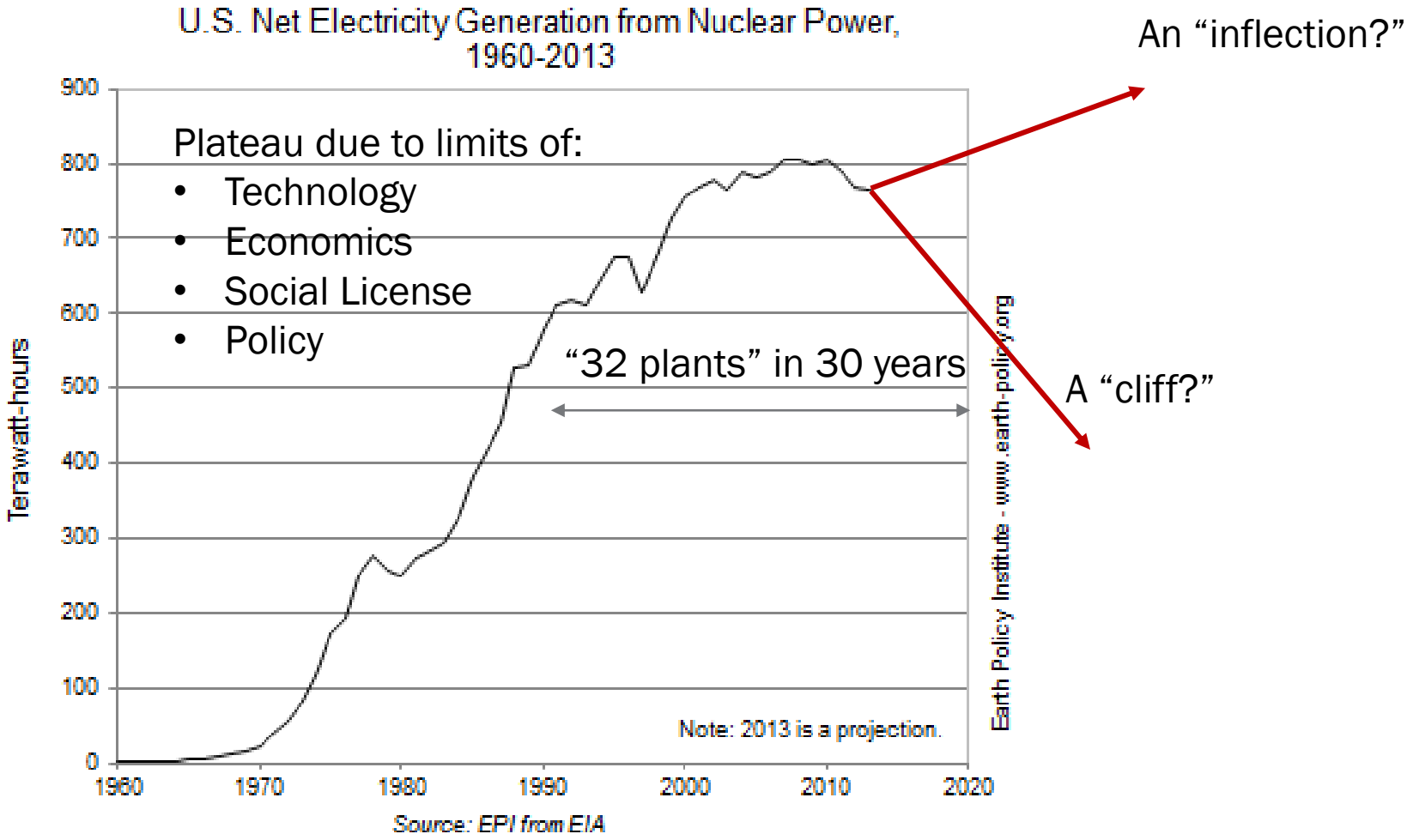
Applications:
Baseload electricity; 24/7



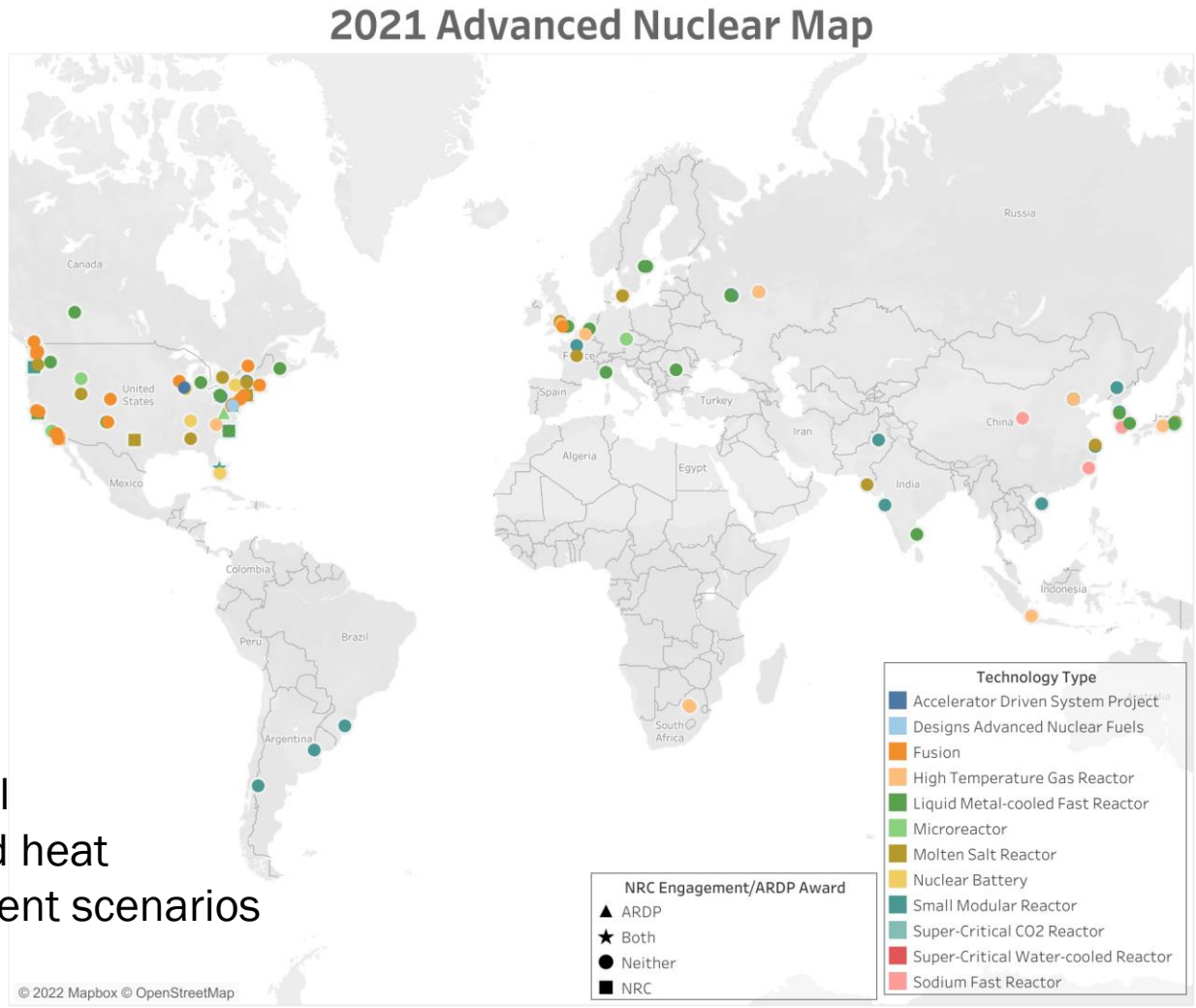
Did you know? In November 2018, the Union of Concerned Scientists recommended federal and state governments adopt policies to preserve the low-carbon electricity the current fleet of nuclear reactors provides.

Courtesy Shannon Bragg-Sitton, Ph.D., Idaho National Laboratory

TRAJECTORY OF ATOMS FOR PEACE GENERATION



http://www.earth-policy.org/plan_b_updates/2013/update116



Large to small
Electricity and heat
New deployment scenarios

Map from Third Way

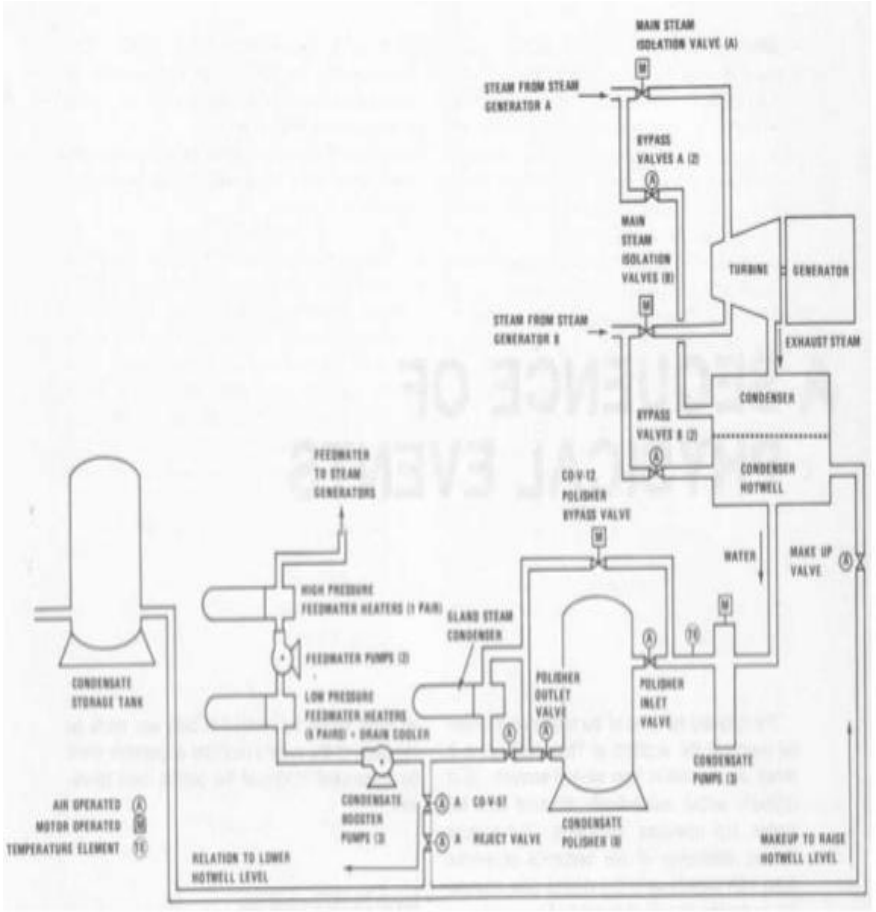
ENERGY TECHNOLOGY COMPLEXITY

THREE MILE ISLAND ACCIDENT

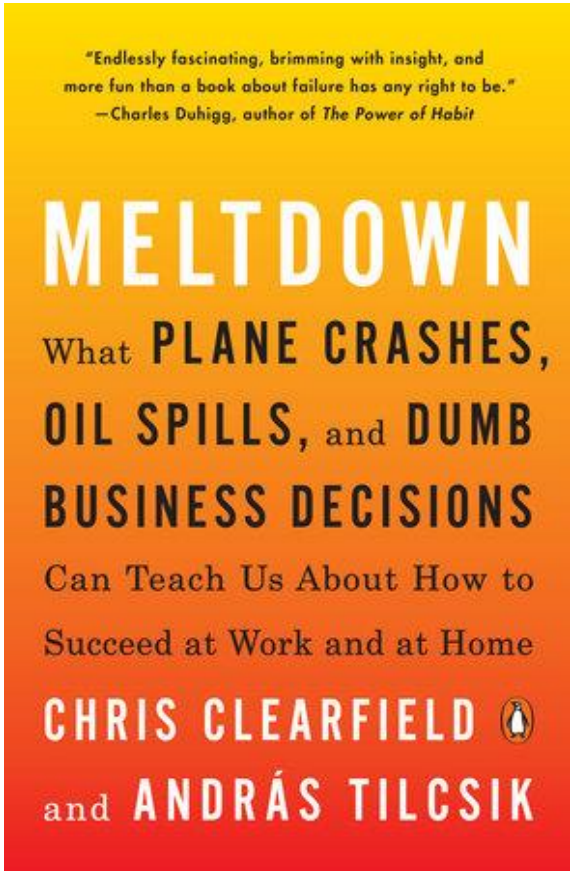
TMI-I shutdown at the time.

- Non-routine maintenance practice
- Violation of an NRC rule
- Design Flaw

The accident progressed faster than the humans responded



ENERGY TECHNOLOGY COMPLEXITY



Tightly coupled systems can fail fast and in unanticipated ways

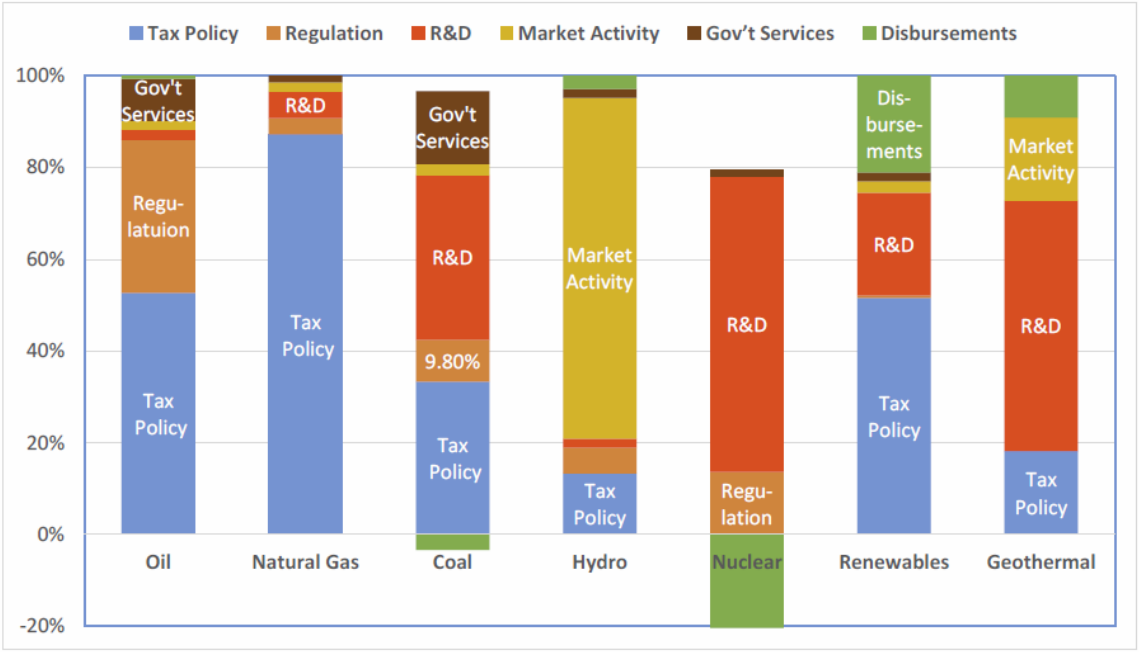
COMMUNITY APPROPRIATENESS

A first entertainment use of radiation-induced mutant creatures

Repository Community, Safeguards Community, ...

SYSTEM-INFORMED DECISION-MAKING

Exhibit 4 – Mix of Federal Expenditures for Each Energy Source



Expenditures for nuclear need better balance between R&D and tax policy

2015/2016 PIVOT

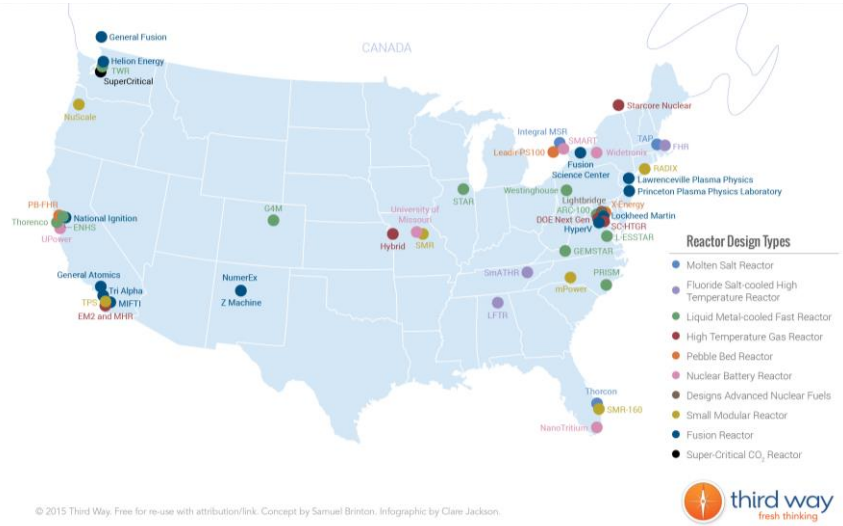
The 2015/2016 Pivot:

- Research
  - GAIN
  - NRIC
  - ARPA-E
- Legislation & Policy
  - NEIMA/NEICA
  - ARDP
  - NGOs (Third Way, CATF, BTI, Good Energy Collective, NIA, Global Nexus Initiative, Energy for Humanity)
- Education & Advocacy
  - Nuclear Reimagined
  - Nuclear Energy Bootcamp
  - Fastest Path to Zero

Figure 3: Nuclear Plants Closing in Restructured States

Source: Chris Wood, President and CNO, First Energy. Testimony to Nuclear Energy Caucus (4/17/18)

Advanced Reactor Companies

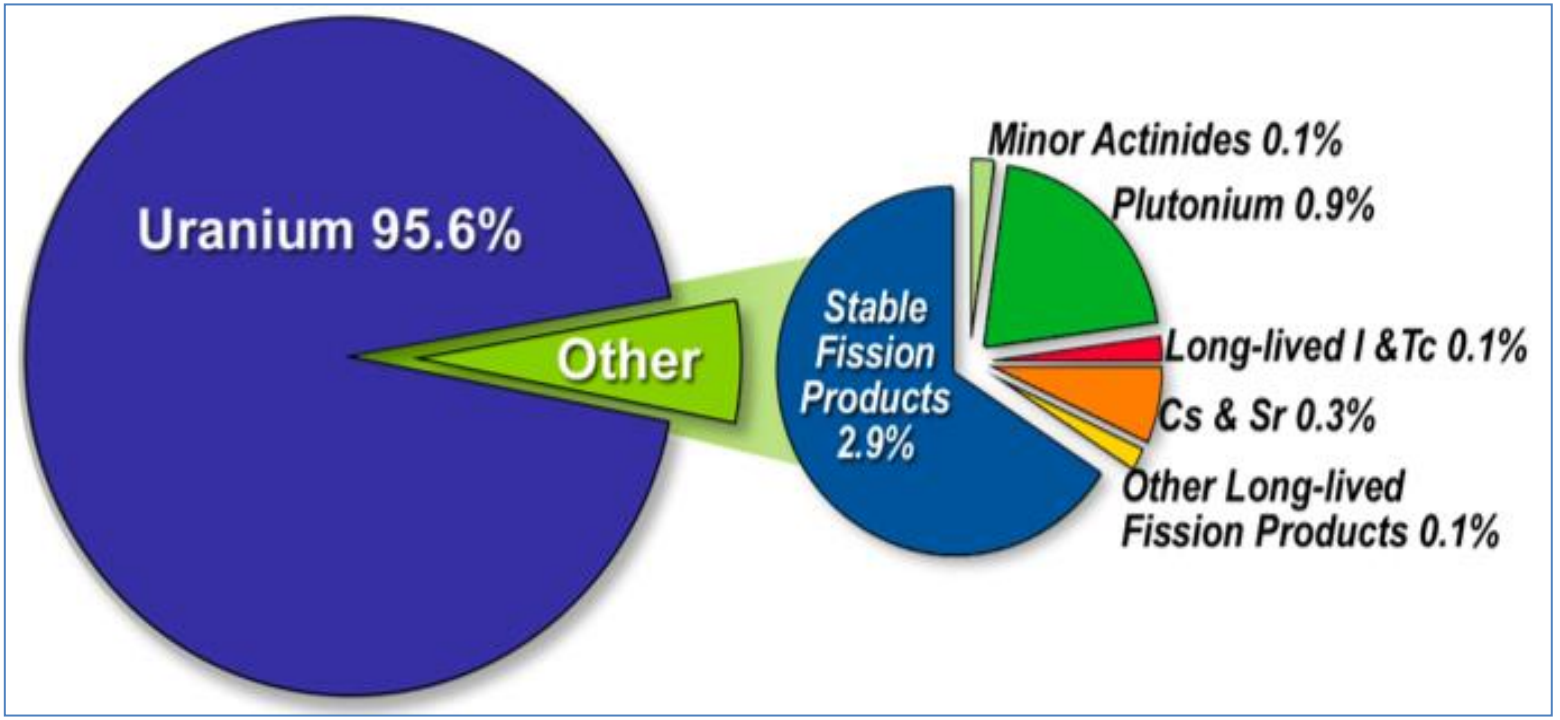


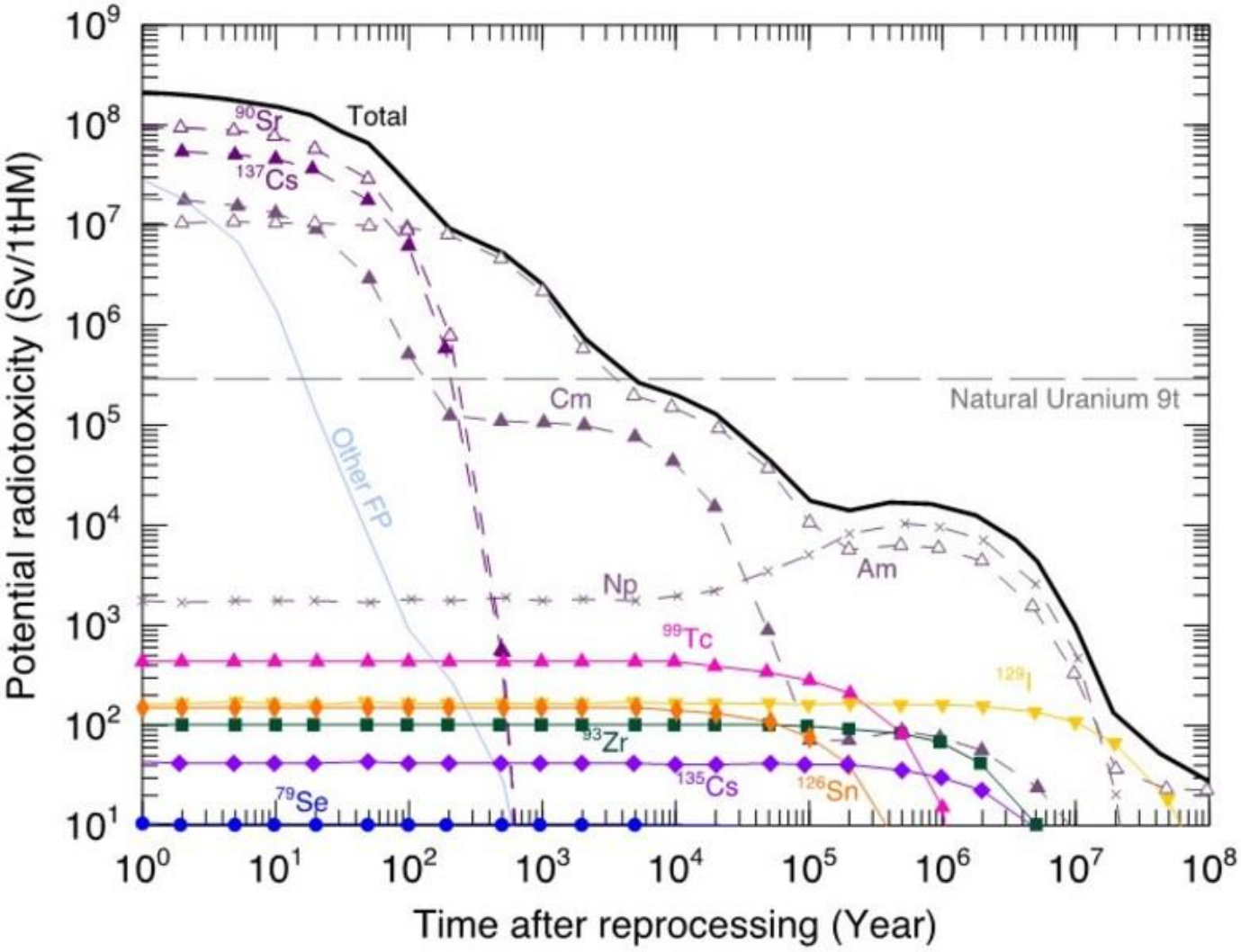
“There are decades where nothing happens; and there are weeks where decades happen.”

— Vladimir Ilyich Lenin

No implied support for Lenin or anything he did except the quote

FUEL USAGE

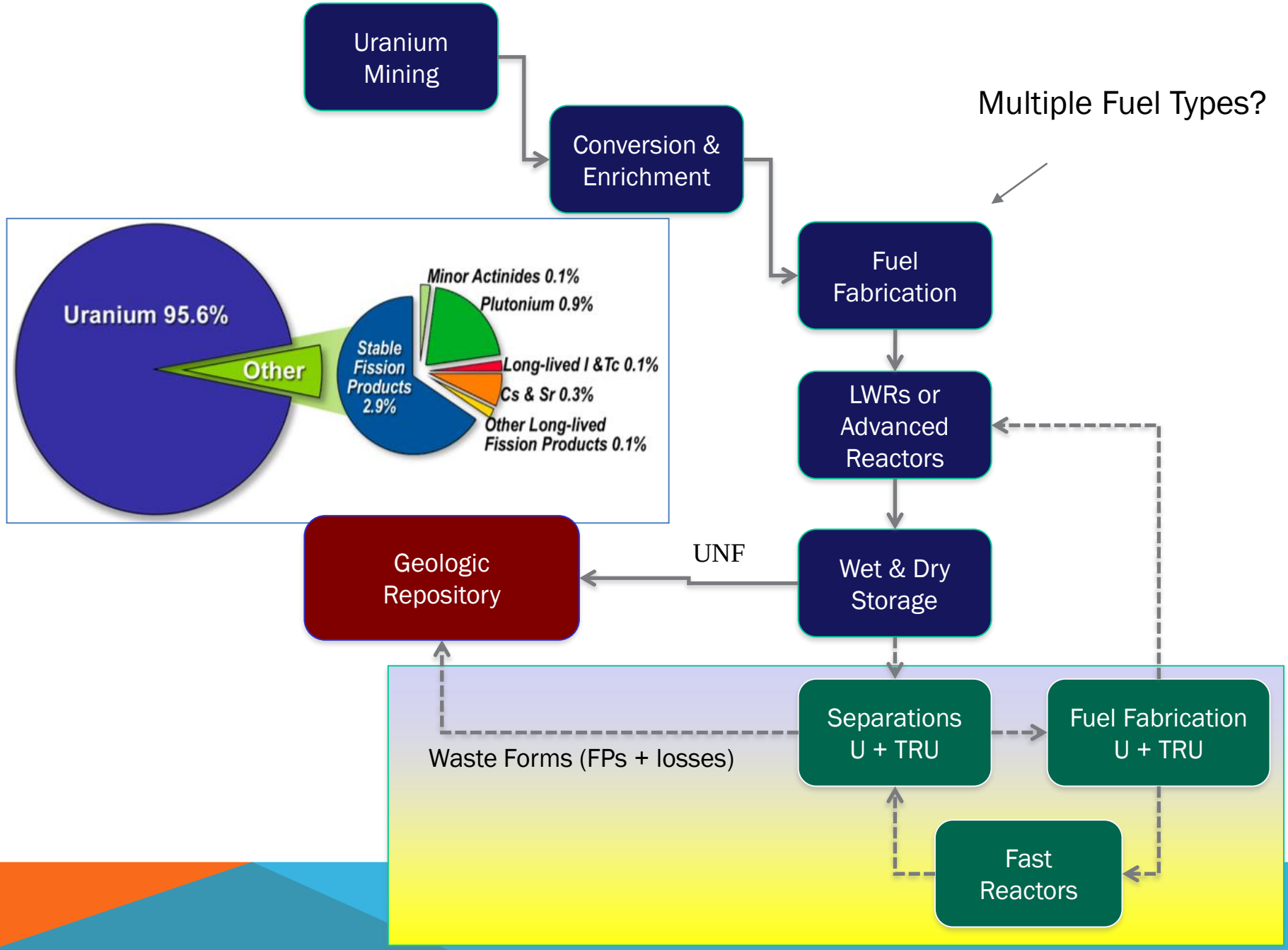

Uranium 95.6%
Other
Stable Fission Products 2.9%
Minor Actinides 0.1%
Plutonium 0.9%
Long-lived I &Tc 0.1%
Cs & Sr 0.3%
Other Long-lived Fission Products 0.1%



Transmutation: Use neutron probabilities to create shorter – lived isotopes

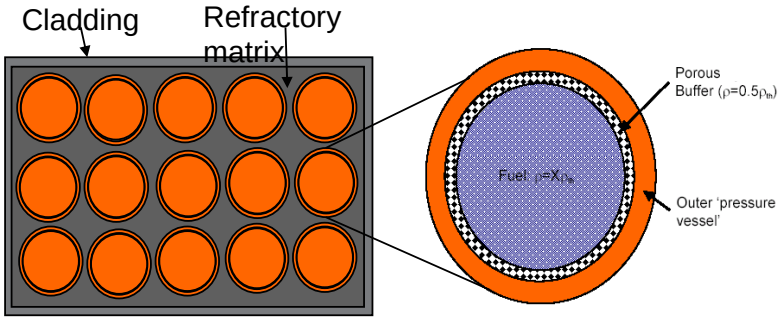
Tokyo Institute of Technology

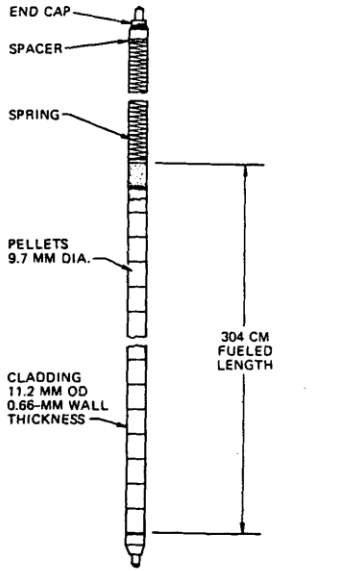
(https://nuclearstreet.com/nuclear_power_industry_news/b/nuclear_power_news/archive/2017/11/14/researchers-in-japan-propose-nuclear-waste-reduction-technique-111401)


Uranium Mining
Conversion & Enrichment
Multiple Fuel Types?
Fuel Fabrication
Uranium 95.6%
Other
Stable Fission Products 2.9%
Minor Actinides 0.1%
Plutonium 0.9%
Long-lived I &Tc 0.1%
Cs & Sr 0.3%
Other Long-lived Fission Products 0.1%
LWRs or Advanced Reactors
Geologic Repository
UNF
Wet & Dry Storage
Separations U + TRU
Fuel Fabrication U + TRU
Waste Forms (FPs + losses)
Fast Reactors

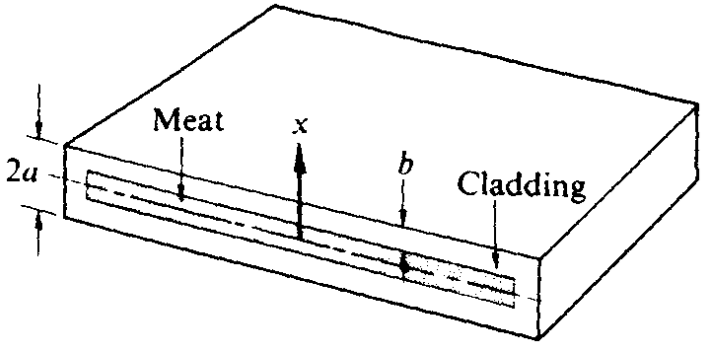
FUEL

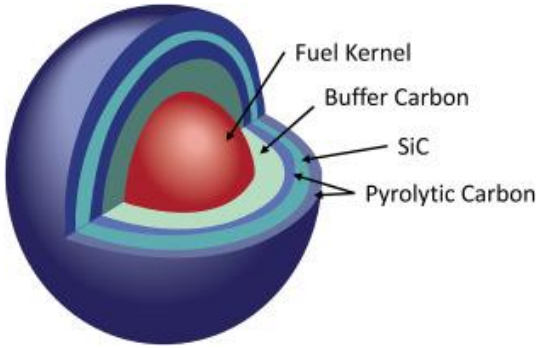
FUEL TYPES





Fuel rod of a pressurized-water reactor.

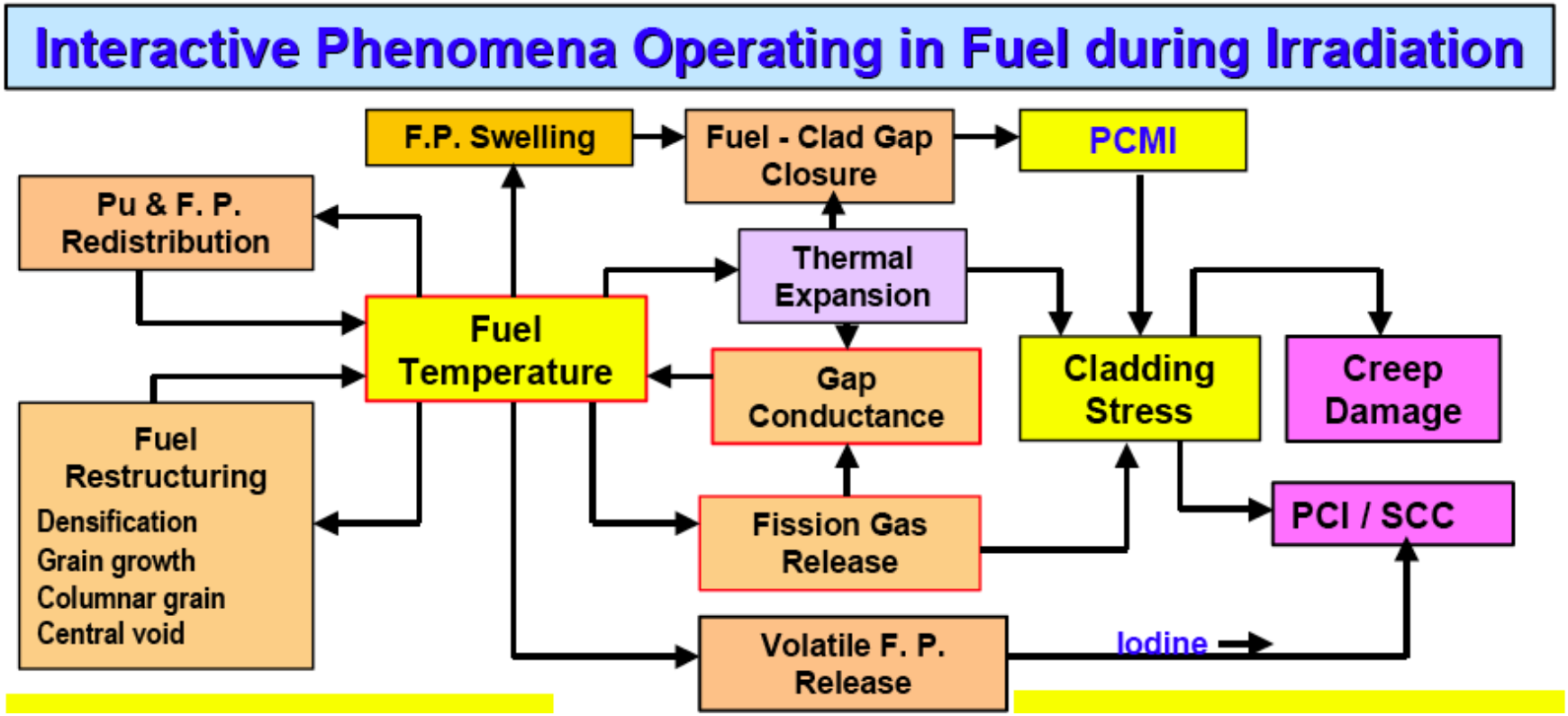




Fuel-clad system is designed to

- Produce and transfer heat to the coolant while
- Preventing fission products from reaching the coolant

FUEL ENVIRONMENT



Graphic from S. Banerjee, Bhaba Atomic Research Center

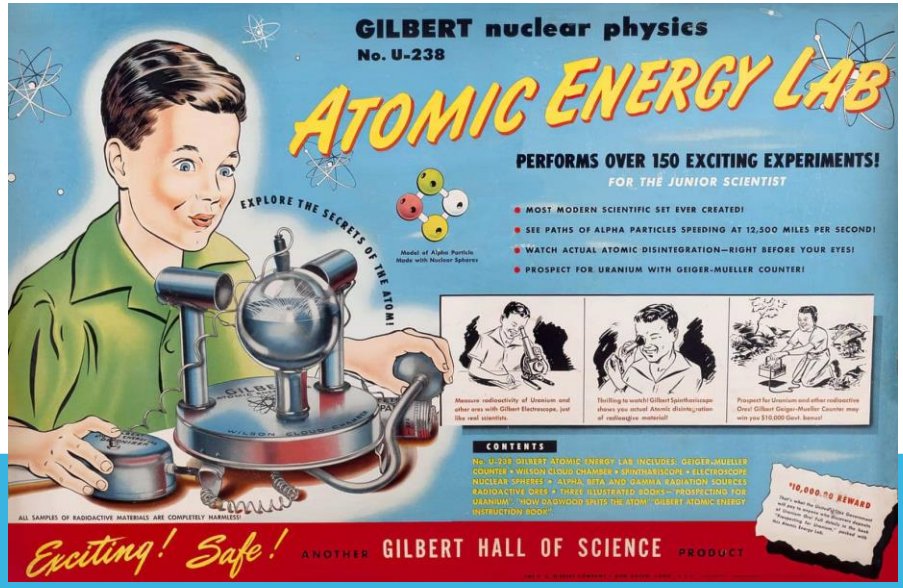
FUTURE

MOTIVATION

Build nuclear fuels to:

- Optimize resource utilization
- Minimize product lifecycle waste
- Minimize cost
- Simplify manufacturability
- Maximize operational lifetime while minimizing failures/eliminate failure mechanisms
- Maximize social acceptance

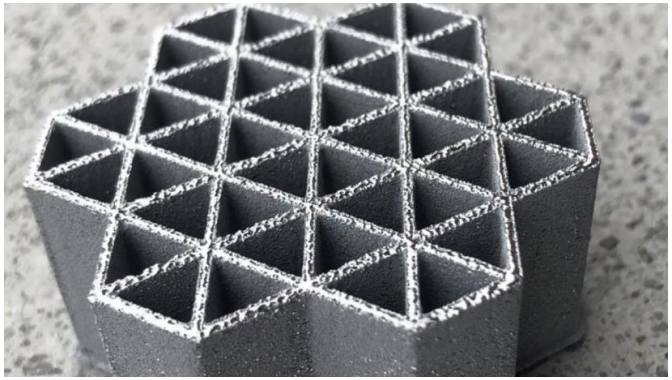
But these goals were the same 70 years ago so what is new

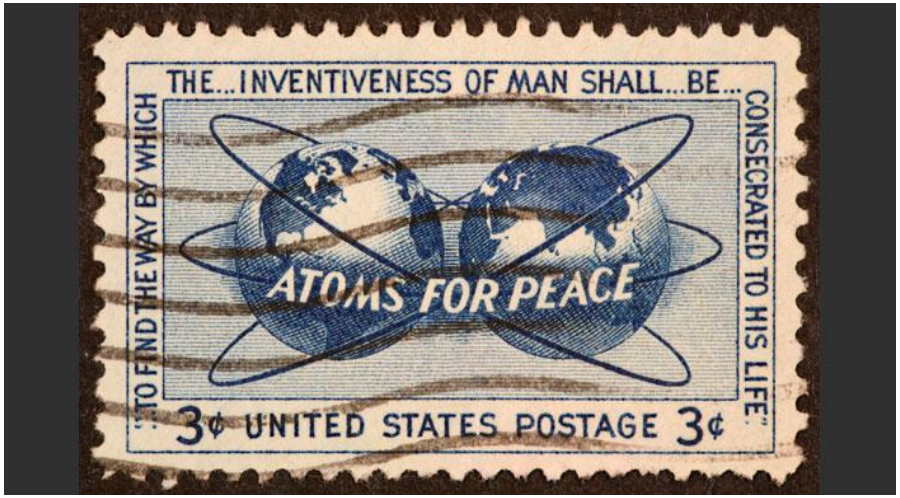


21ST CENTURY

We can now notionally:

- Build through additive manufacturing (fuel “chips” by design)
- Embed designer sensors
- Build digital twins
- Use artificial intelligence
- Design structures to simplify reprocessing
- Connect with community members during the design phase (TRISO versus pin)
- Craft the associated policy levers





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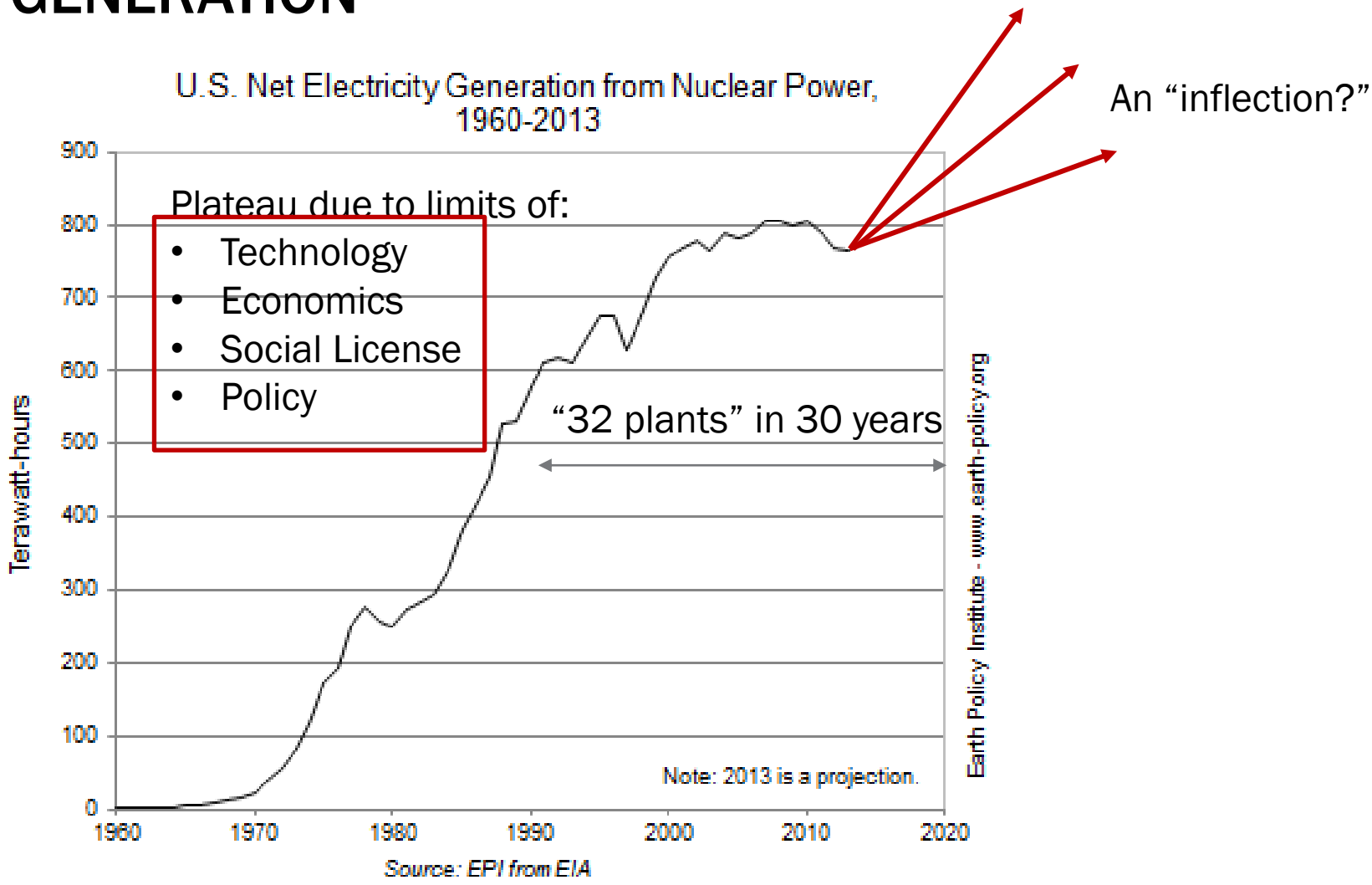

http://www.earth-policy.org/plan_b_updates/2013/update116

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