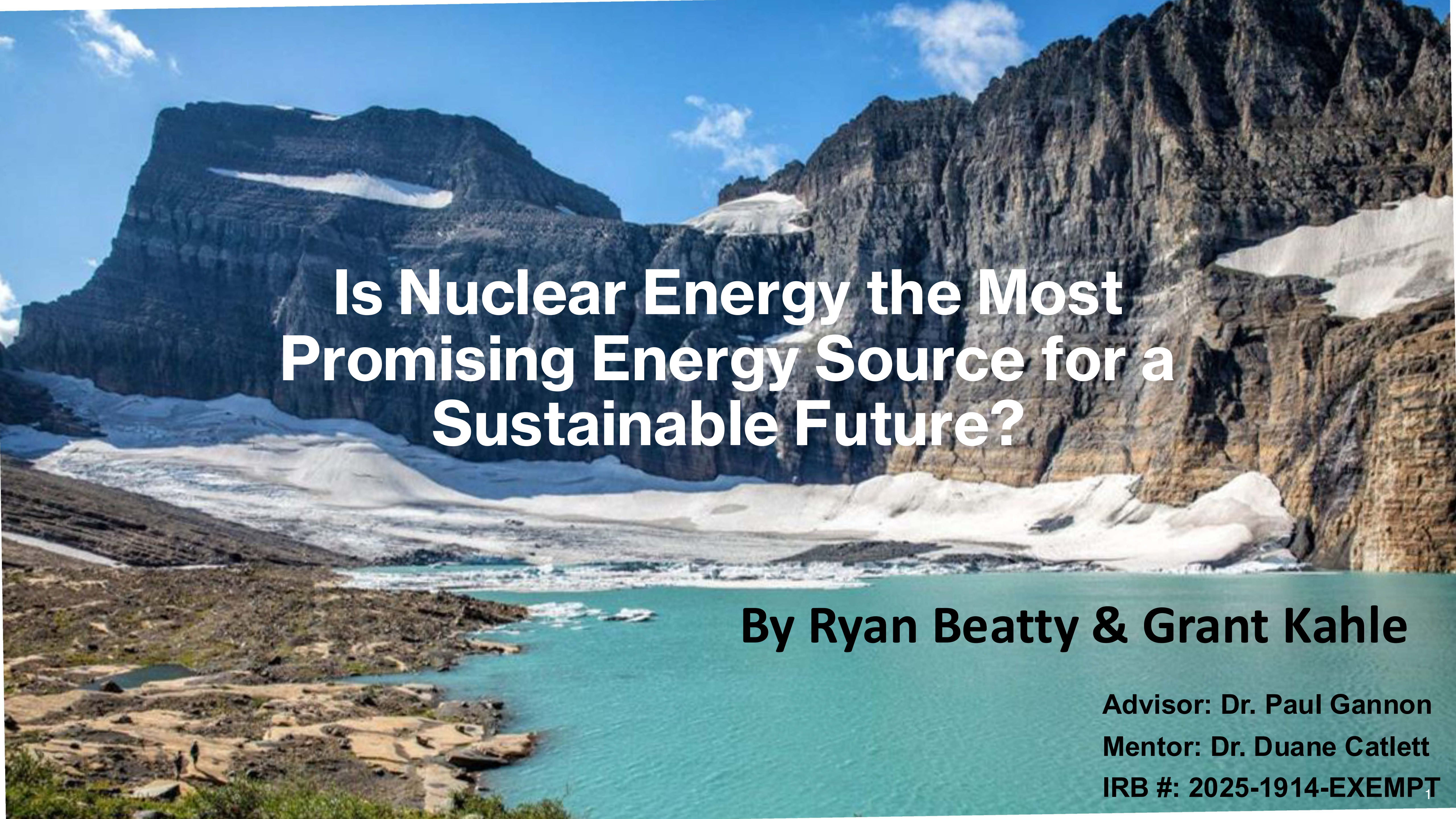
Is Nuclear Energy the Most Promising Energy Source for a Sustainable Future?

Ryan Beatty & Grant Kahle



Is Nuclear Energy the Most Promising Energy Source for a Sustainable Future?

By Ryan Beatty & Grant Kahle

Advisor: Dr. Paul Gannon

Mentor: Dr. Duane Catlett

IRB #: 2025-1914-EXEMPT

INL
Idaho National Laboratory
70 YEARS OF SCIENCE & INNOVATION

MONTANA STATE LEGISLATURE

MONTANA CHAMBER OF COMMERCE

MEIC

GAIN Gateway for Accelerated Innovation in Nuclear

NorthWestern Energy

arc CLEAN TECHNOLOGY

Mark Pérès
NUCLEAR ENGINEER
"Clean energy for the world"

Stanford | Department of Economics
SCHOOL OF HUMANITIES AND SCIENCES

What Are We Talking About?

Nuclear Energy

- **How is it made?**
- **Why do we need it?**

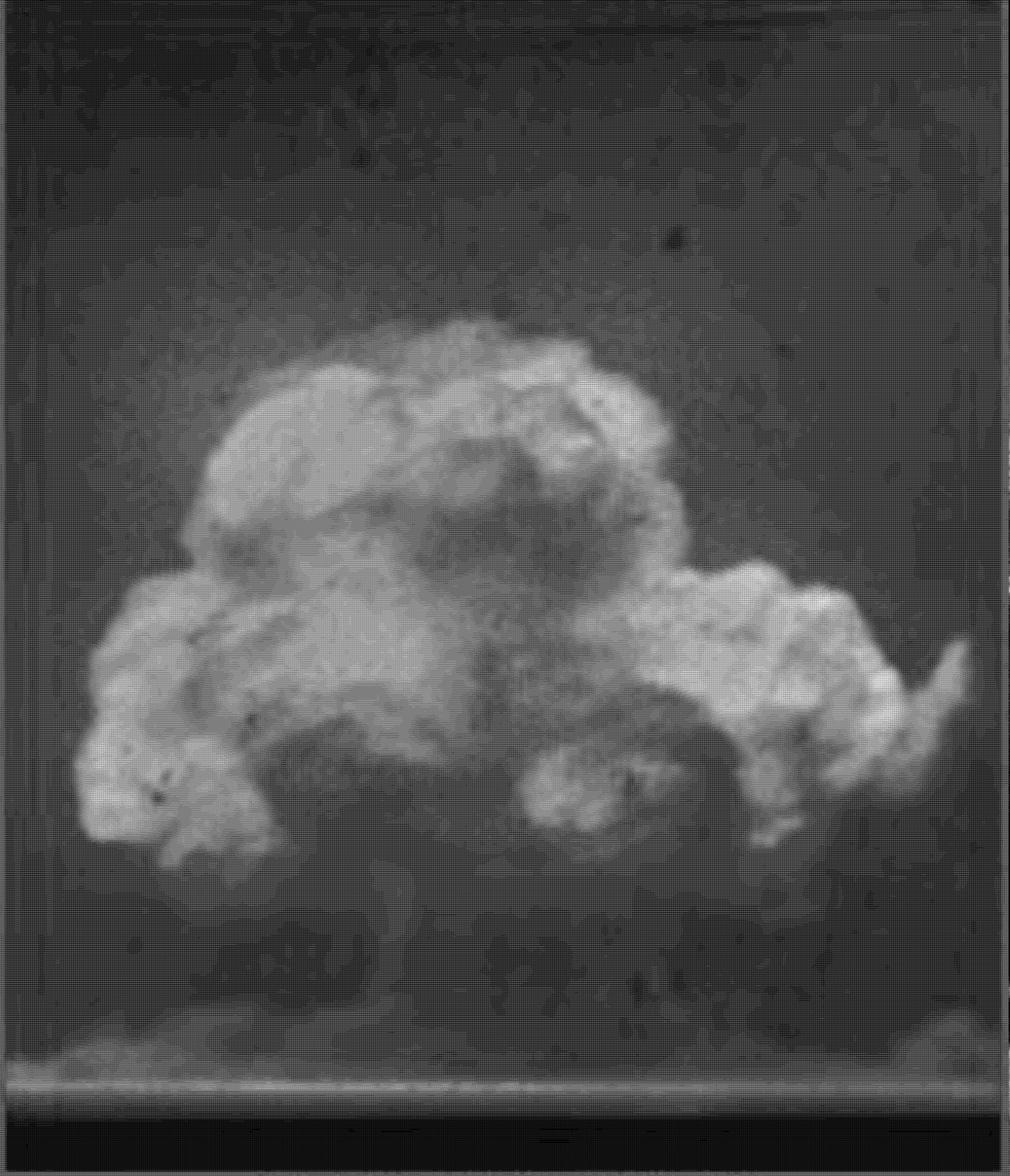
Survey Results

- **Data Analysis**
- **Findings**

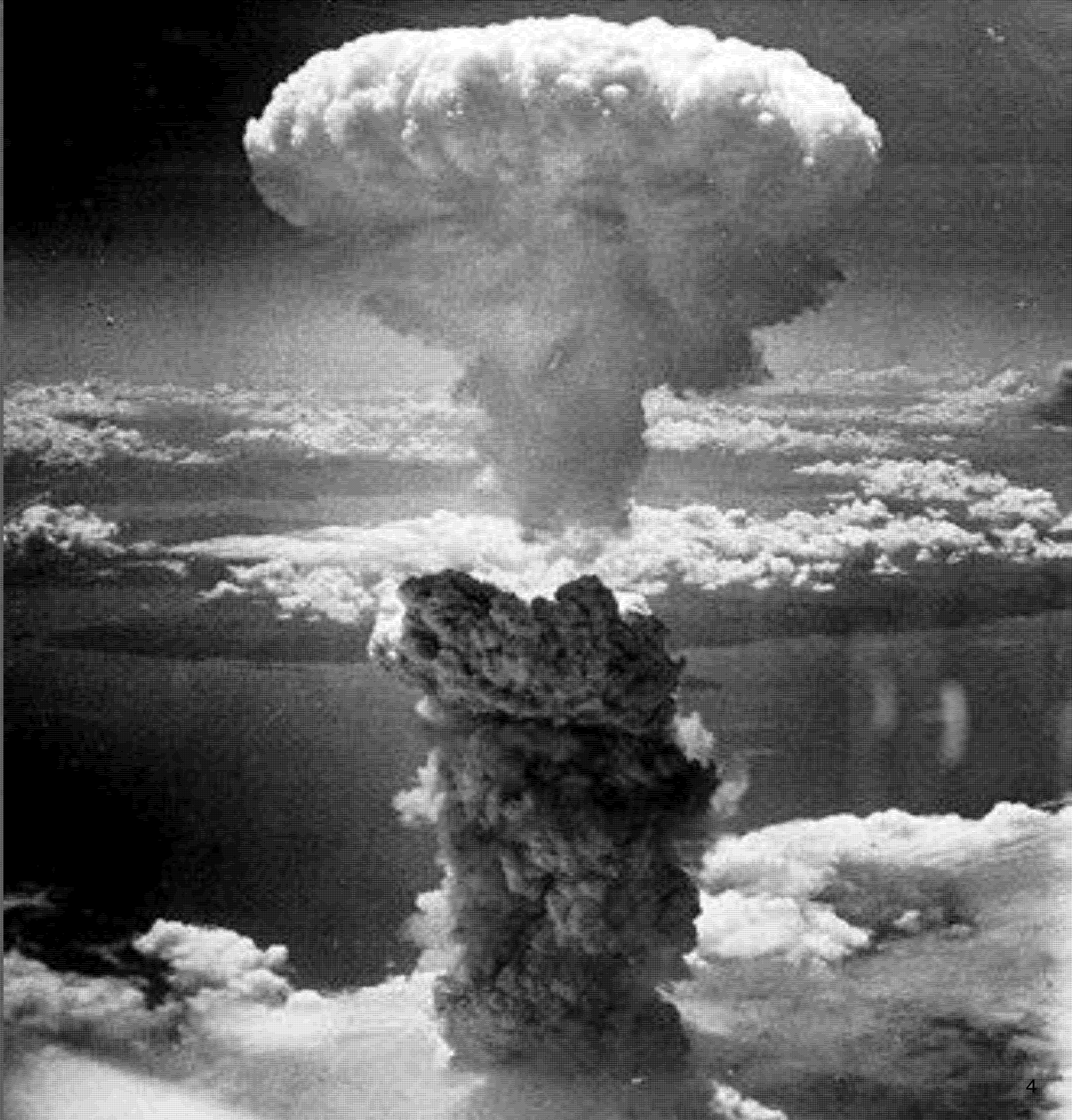
The Future of Nuclear Energy

- **Challenges and Solutions**
- **Nuclear vision for Montana**

Question Form



Trinity test, July 16, 1945

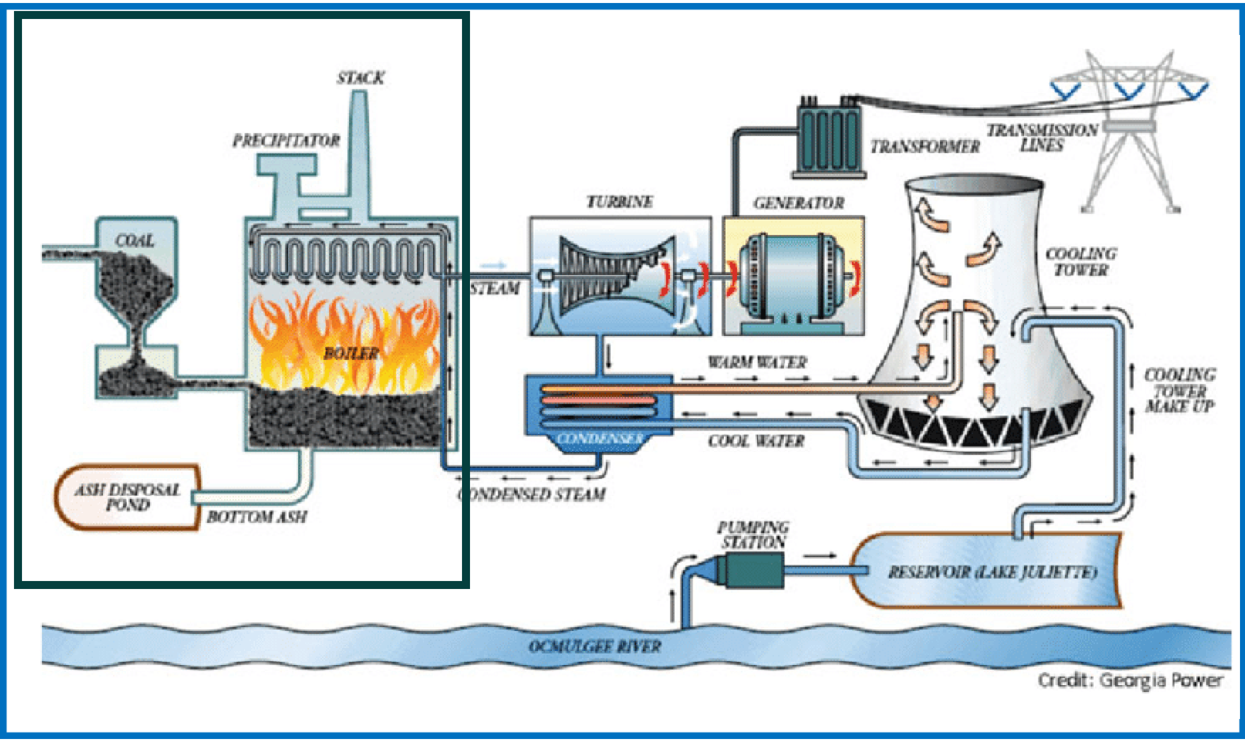


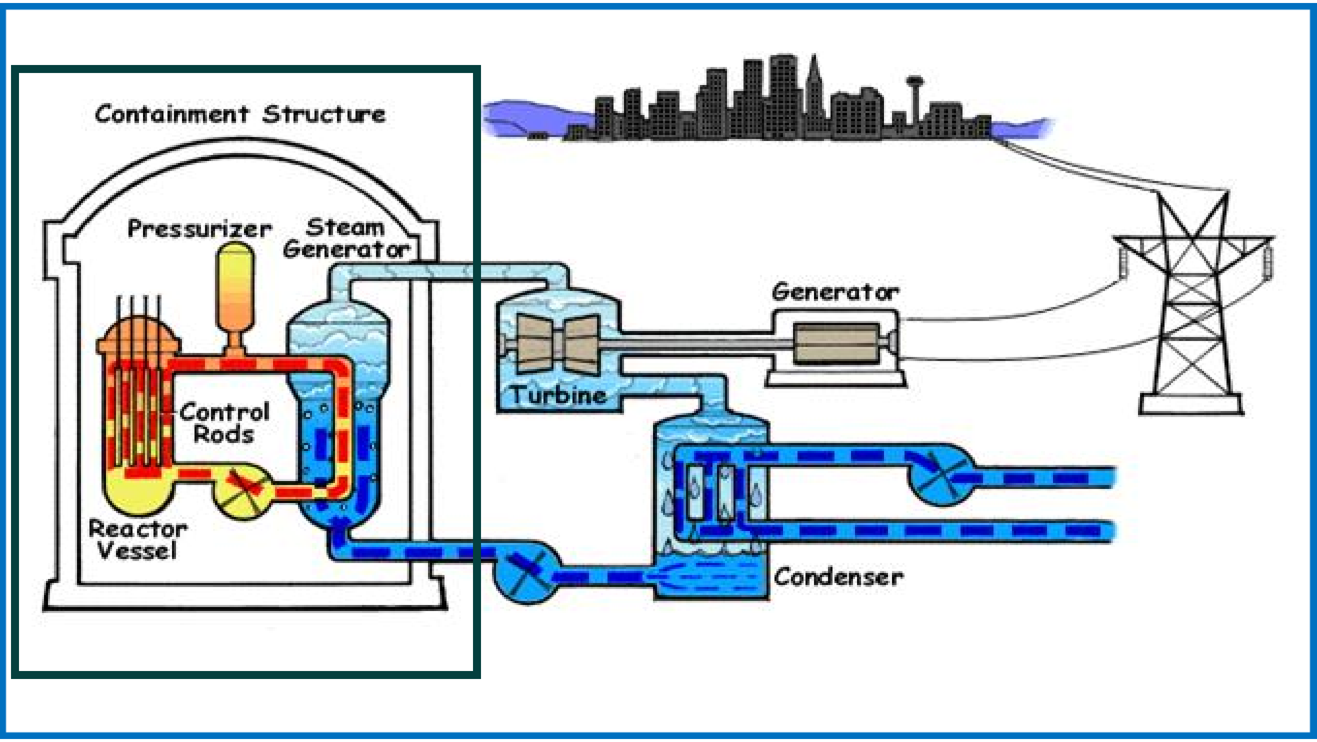
Cooper Nuclear Station

Location:	**Brownville**
Capacity:	**810 MW**
Units:	**1**
Fuel:	**Uranium**
Employs:	690
In-service:	**July 1, 1974**
License:	**Licensed with the Nuclear Regulatory Commission until 2034**
	CNS Emergency Planning Information

- Type: General Electric BWR
- Plant footprint: 12 acres on 1.2 sq miles land.
- Powers 324,000 homes, 1 million people.

Coal Boiler → Nuclear Reactor





Coal-Fired Power Plant

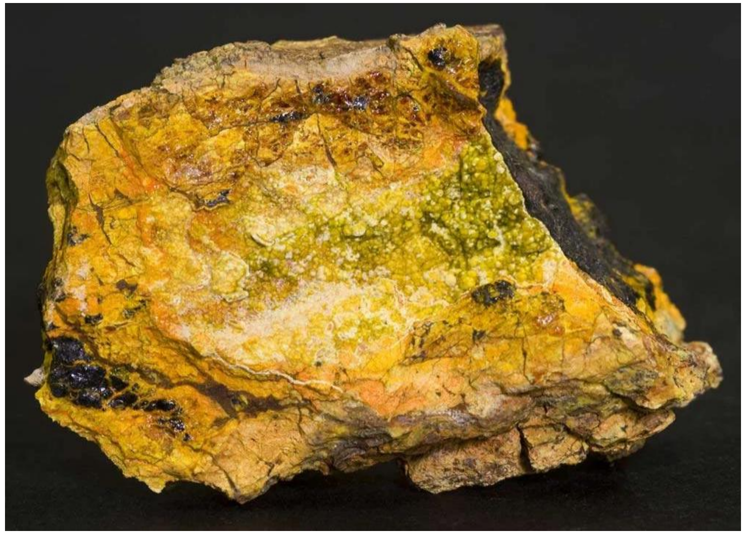
Chemical Energy –
24 KJ per gram of Coal

Nuclear-Fired Power Plant

Nuclear Fission –
200,000,000 KJ per gram of Uranium

How is useable Energy made?

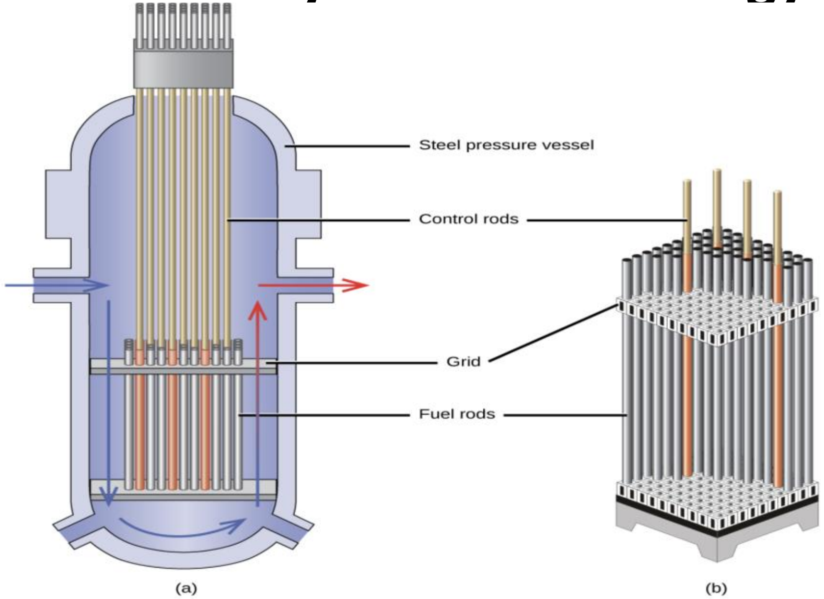
Uranium is Stored Unusable Energy



Uranium Fuel Pellets in Rods

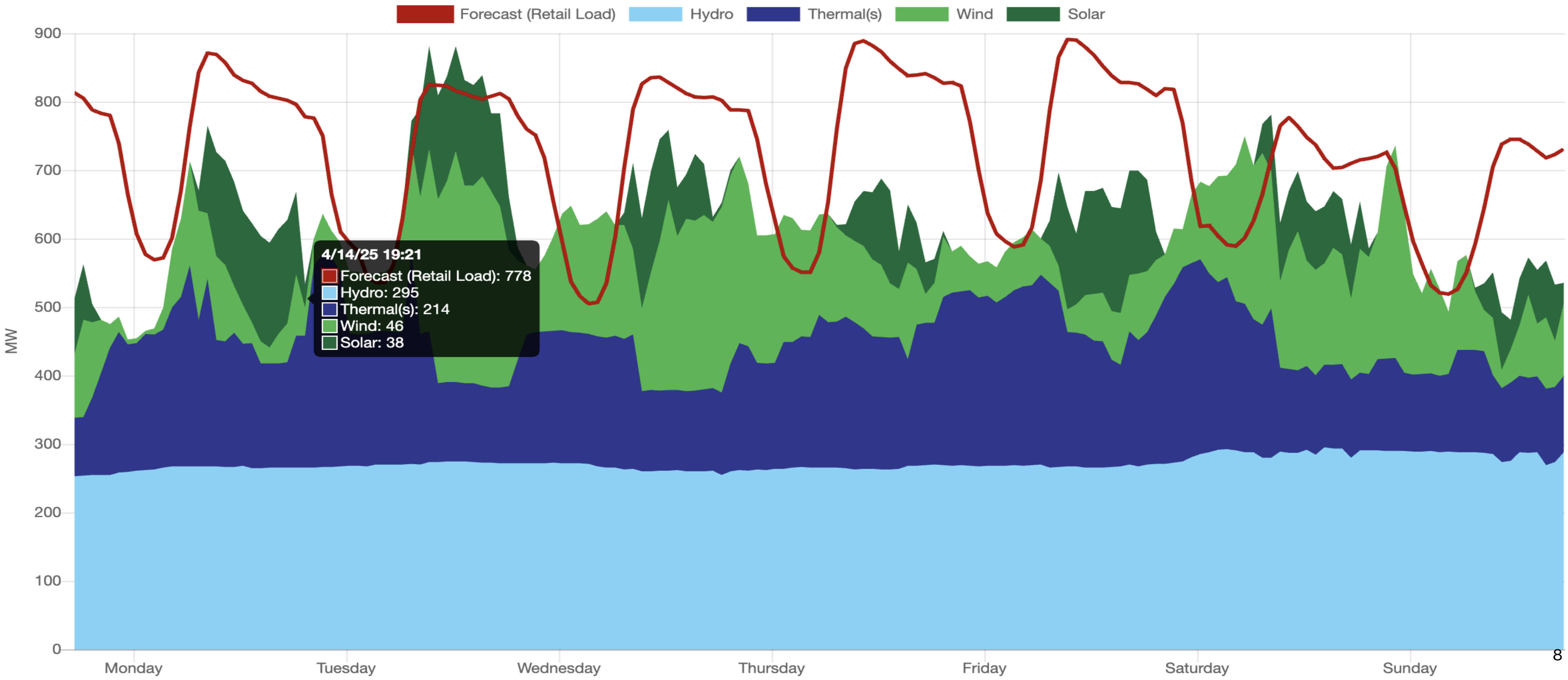
Energy Distributed to Customers

Electricity is Useable Energy



Energy Demand

NorthWestern Energy's weekly retail load forecast



Future Energy Demand

Threat of an energy deficit

- **Growing population**
- **Manufacturing**

AI/data centers will place enormous energy demand in the future

- **energy demand by 2030 of just data centers alone would require as much energy consumption as the whole of Japan**

Large Energy Users Pledge

Why do we need Nuclear Energy?

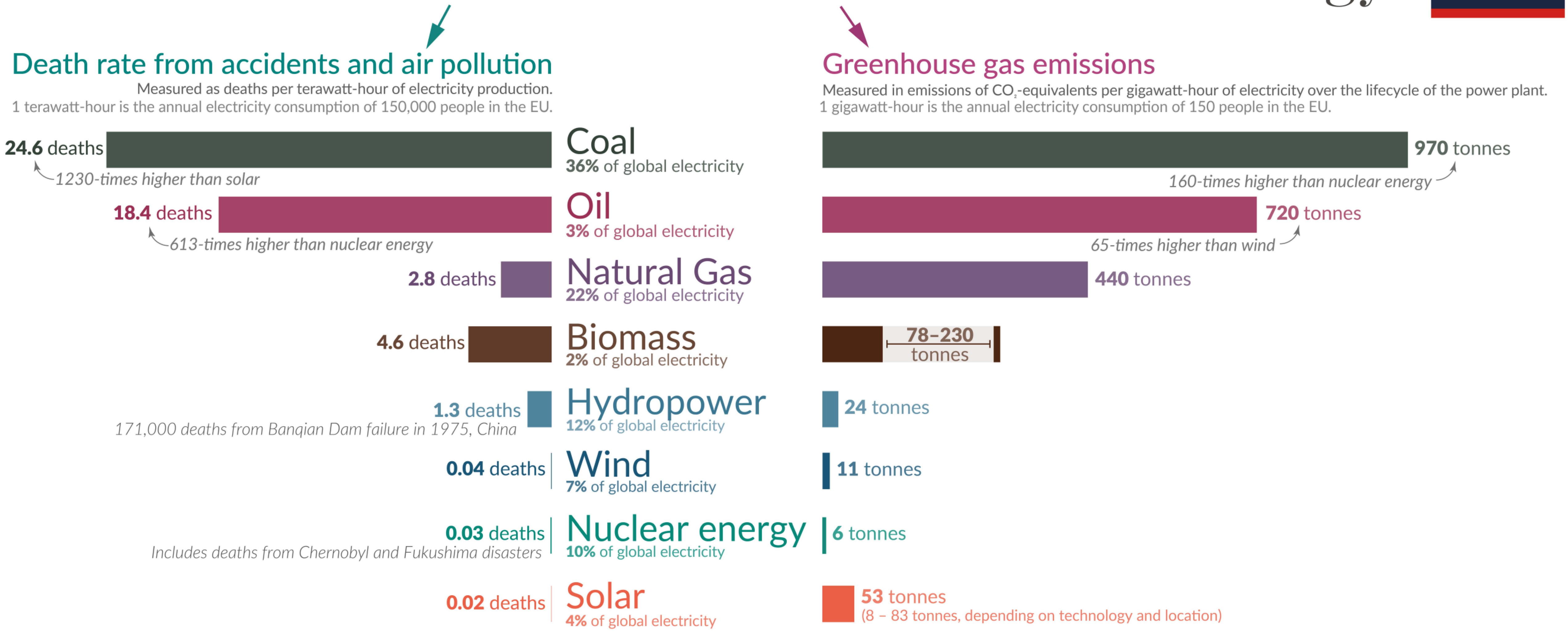
Unparalleled 70+ yr Record of Successful Operations in Energy Industry:

- Safety
- Zero CO2 Emissions in operation
- Reliability (capacity factor)
- Small compact land usage
- High fuel energy density
- Long Reactor Life Spans

Question Form

What are the safest and cleanest sources of energy?

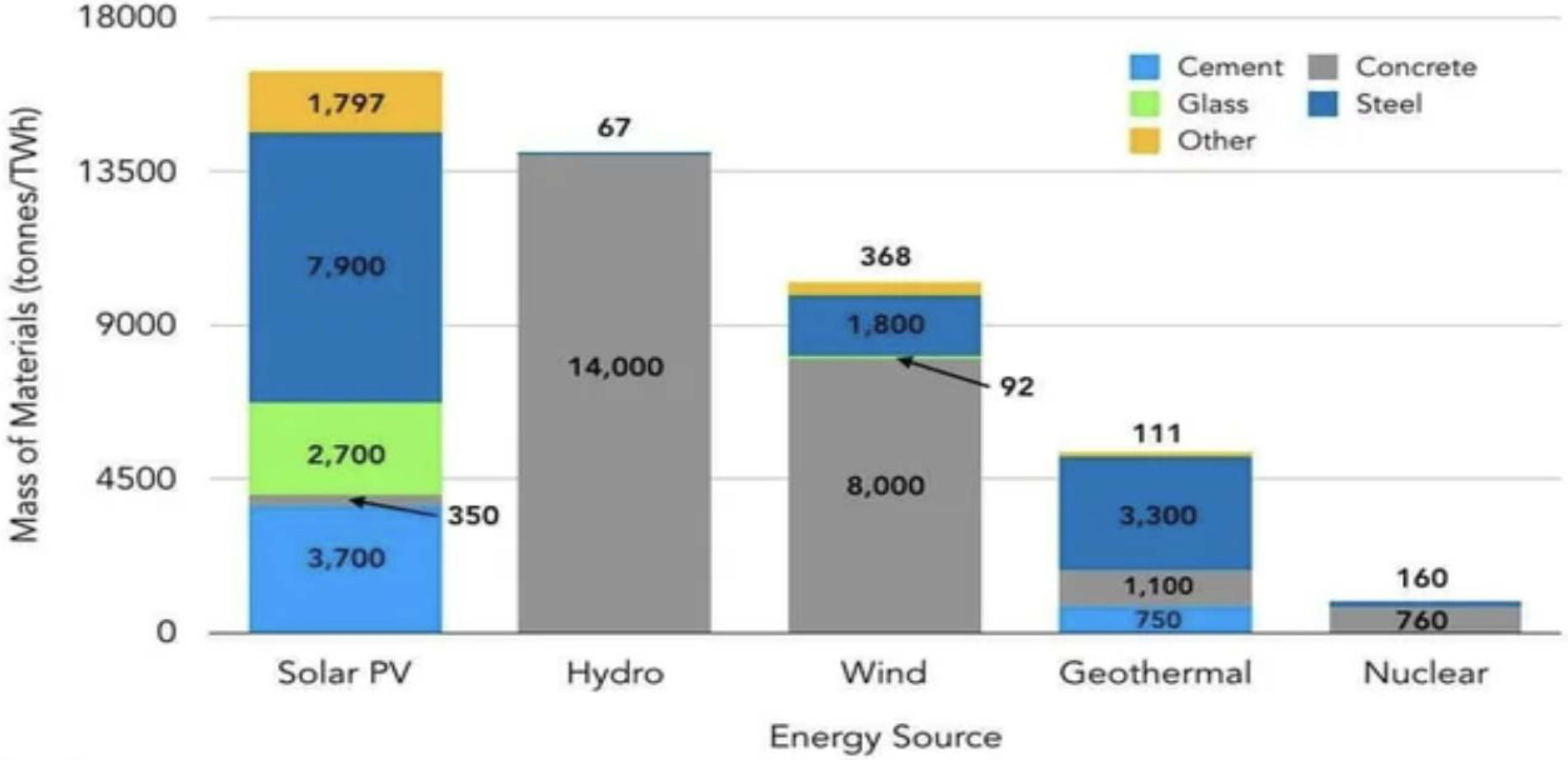
Our World in Data



Death rates from fossil fuels and biomass are based on state-of-the art plants with pollution controls in Europe, and are based on older models of the impacts of air pollution on health. This means these death rates are likely to be very conservative. For further discussion, see our article: OurWorldinData.org/safest-sources-of-energy. Electricity shares are given for 2021.

Data sources: Markandya & Wilkinson (2007); UNSCEAR (2008; 2018); Sovacool et al. (2016); IPCC AR5 (2014); UNECE (2022); Ember Energy (2021).

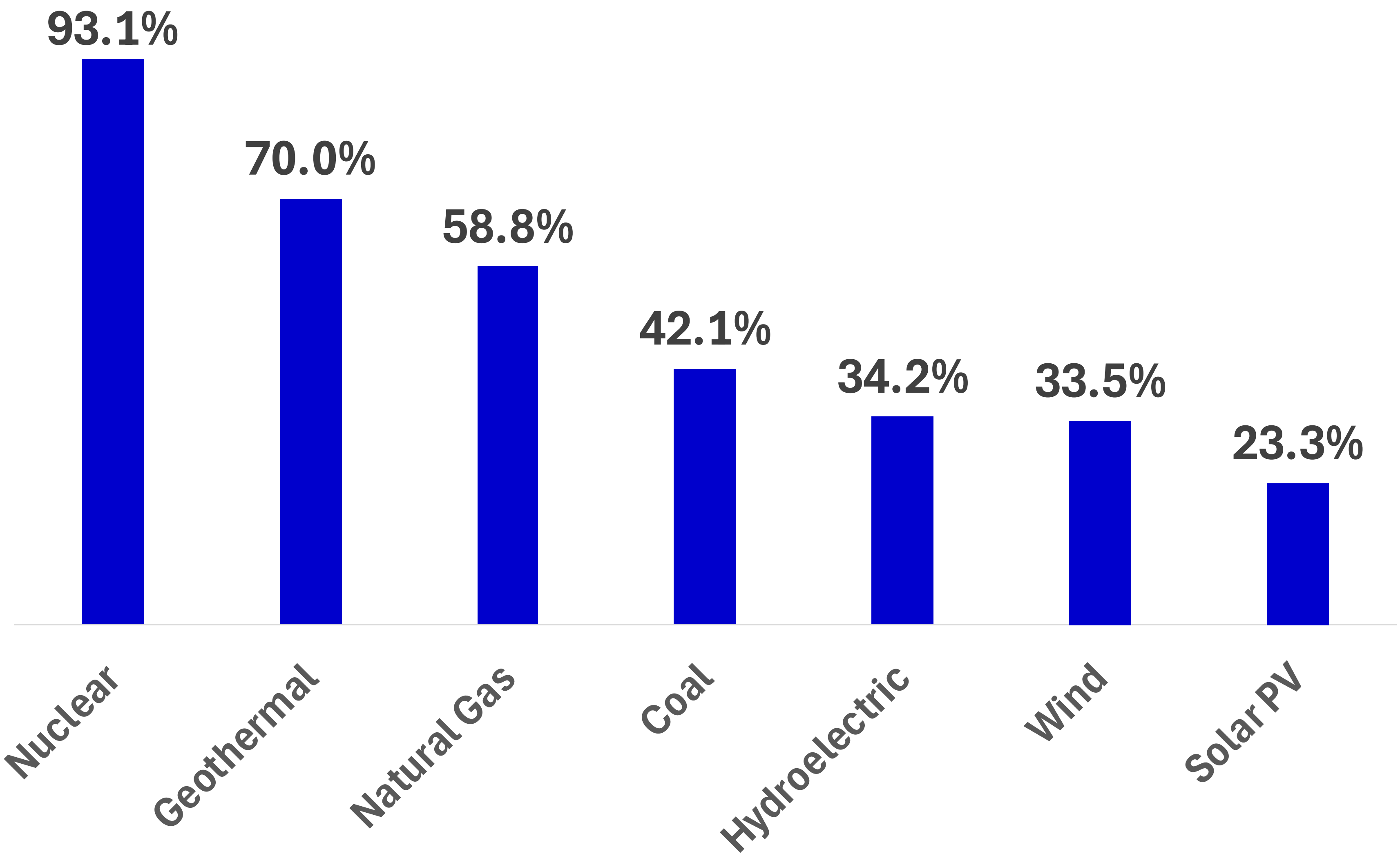
Materials throughput by type of energy source



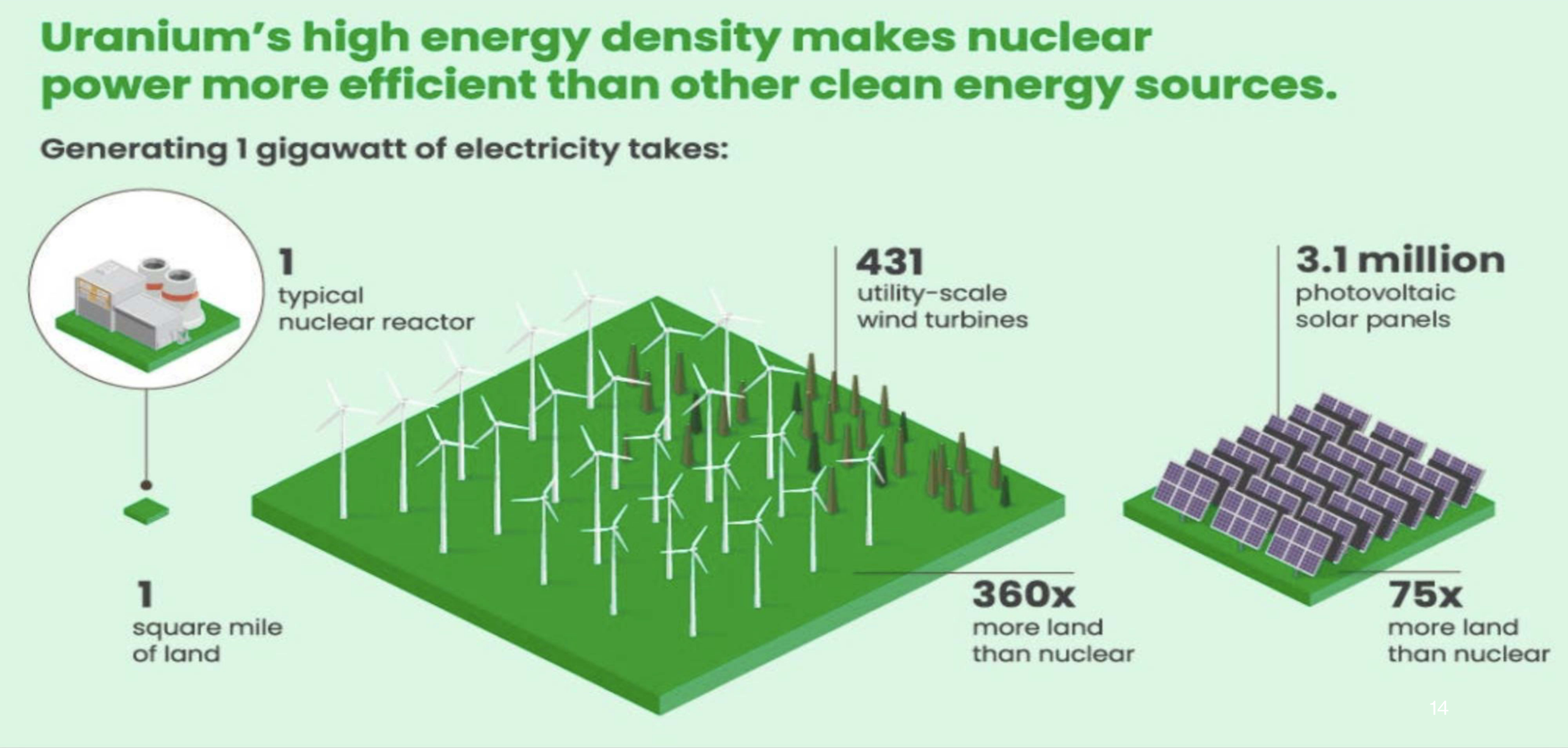
ENVIRONMENTAL PROGRESS

"Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities," Table 10. September 2015. United States Department of Energy. Nuclear and hydro require 10 tonnes/TWh and 1 tonne/TWh of other materials, respectively, but are unable to be labeled on the graph.

Capacity Factor

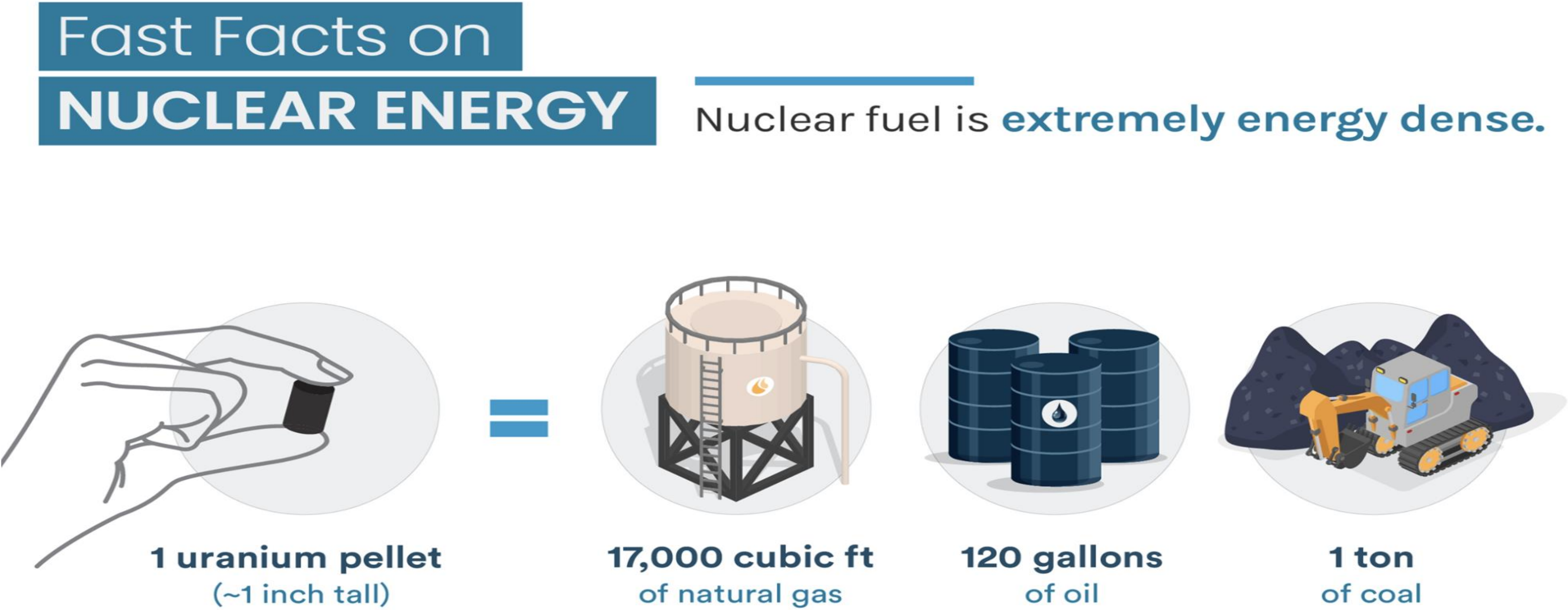


Land Use



Uranium's high energy density makes nuclear power more efficient than other clean energy sources.
Generating 1 gigawatt of electricity takes:
1
typical nuclear reactor
1
square mile of land
431
utility-scale wind turbines
360x
more land than nuclear
3.1 million
photovoltaic solar panels
75x
more land than nuclear

Energy Density

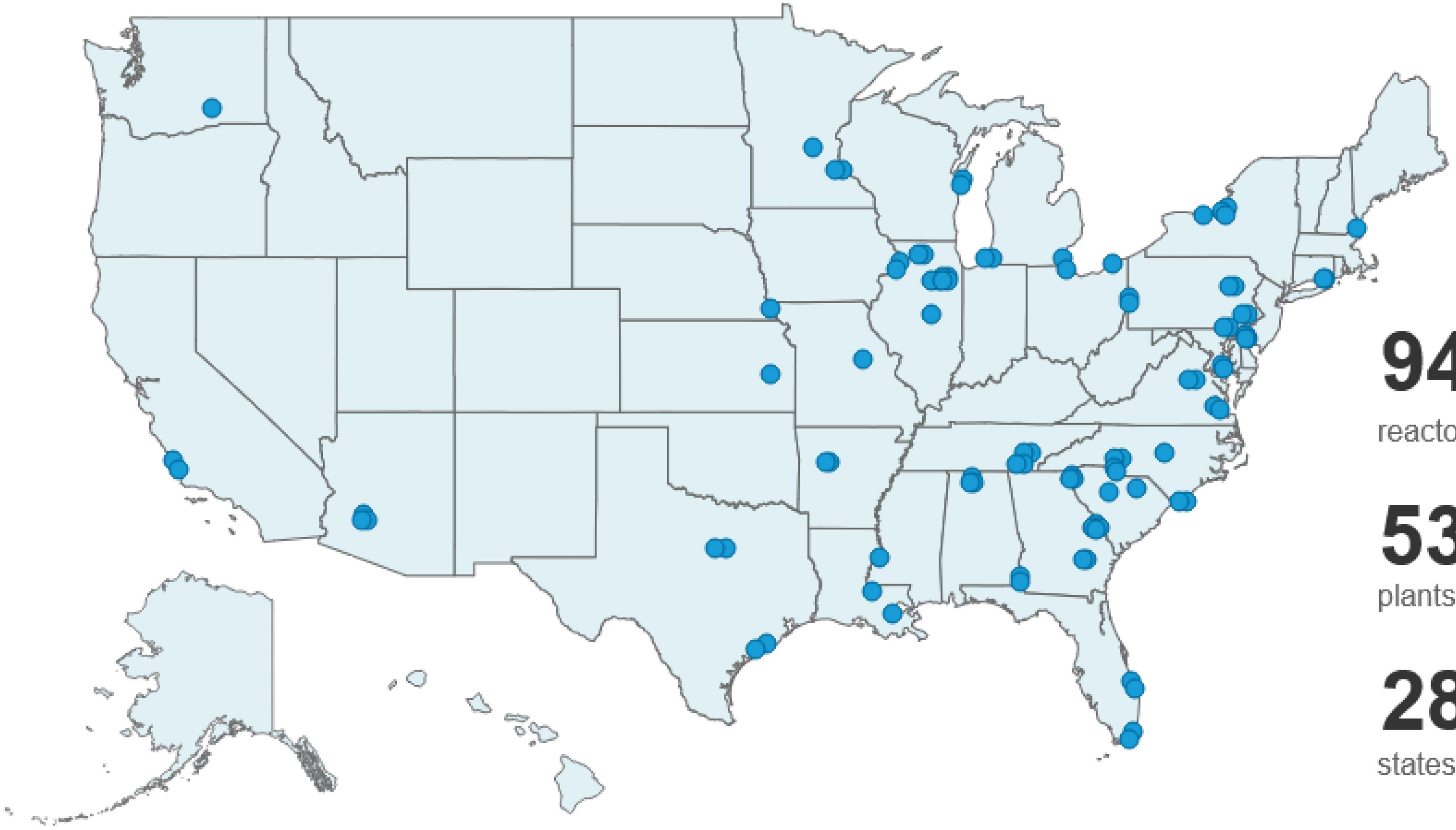


What is The Status of Nuclear Energy Today?

Palo Verde, Arizona (GEN-III)
PWR, 3,300 MWe

Vogtle, Georgia (GEN-III+)
PWR, 4,600 MWe

NUCLEAR POWER ACROSS THE U.S.



94
reactors

53
plants

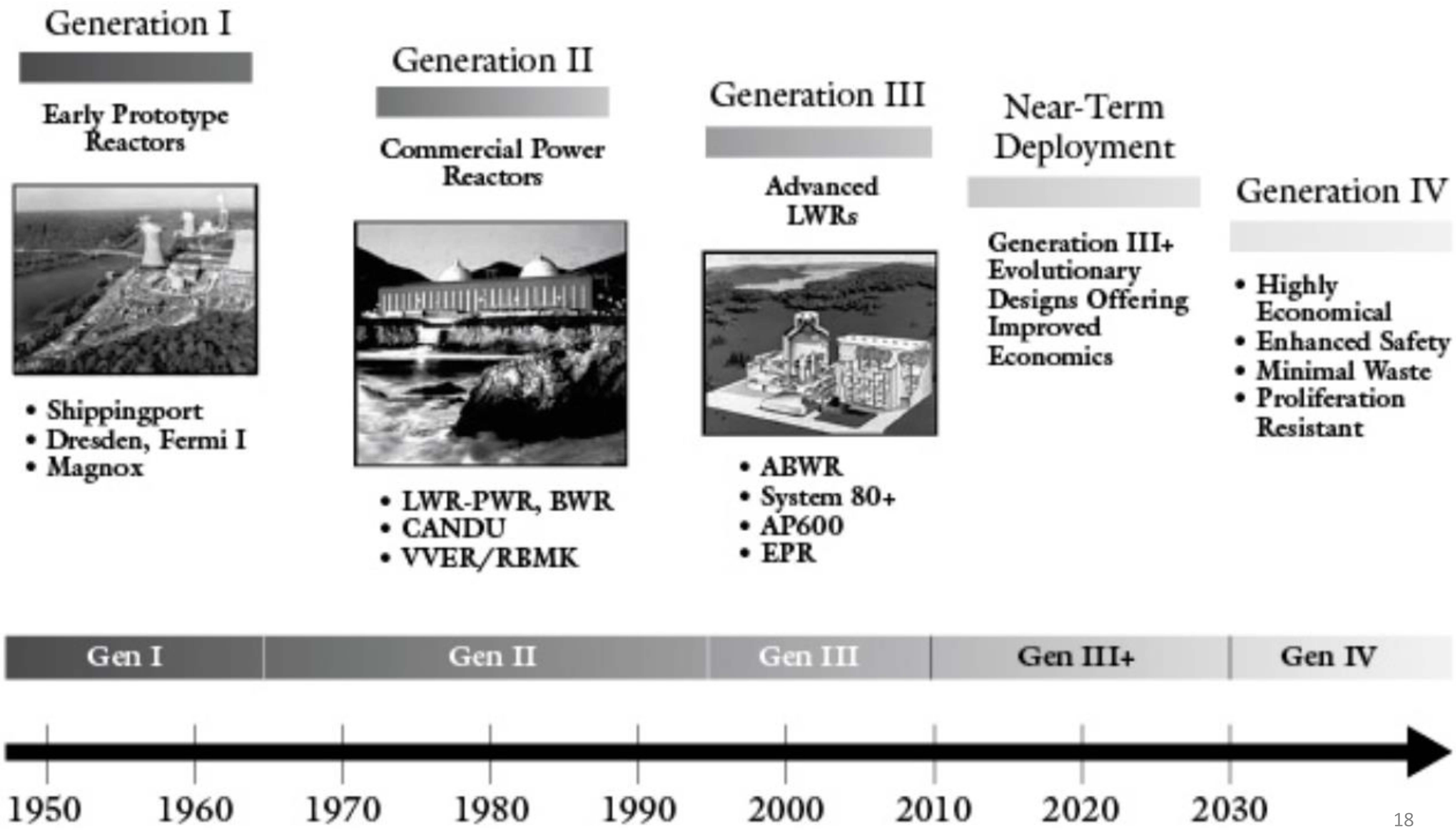
28
states

45.5%
share of carbon-free electricity generated by nuclear energy

437M
metric tons of carbon emissions avoided in 2023

250,000
well-paying, sustainable direct and indirect jobs in the nuclear industry

93.0%
capacity factor of U.S. nuclear plants in 2023 as a reliable electricity source


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
Near-Term Deployment
Generation III+ Evolutionary Designs Offering Improved Economics
Generation IV
• Highly Economical
• Enhanced Safety
• Minimal Waste
• Proliferation Resistant
Gen I
Gen II
Gen III
Gen III+
Gen IV
1950
1960
1970
1980
1990
2000
2010
2020
2030

Our Survey Results

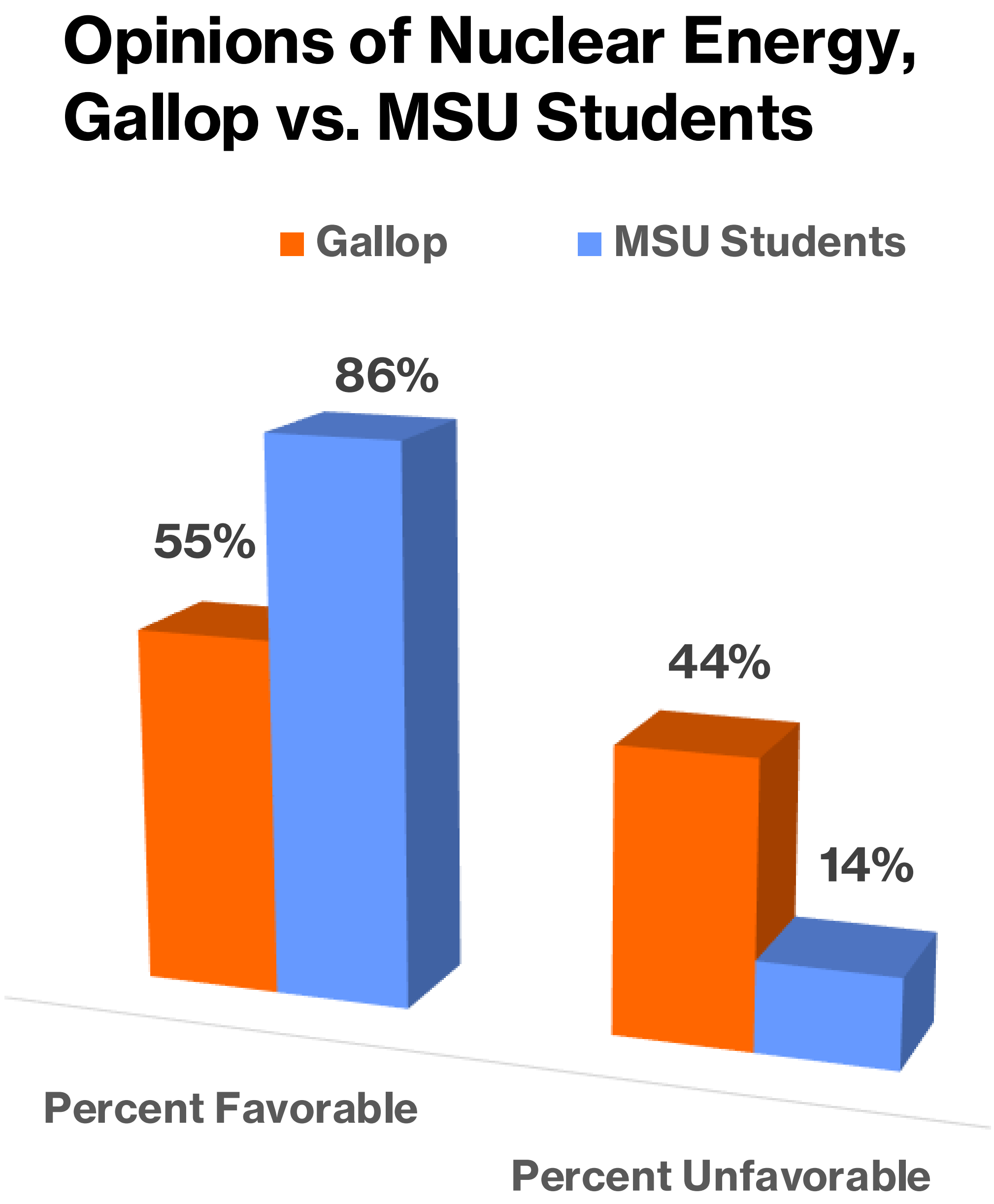
- The Survey Framework
- Our Data Analysis
- Our Findings

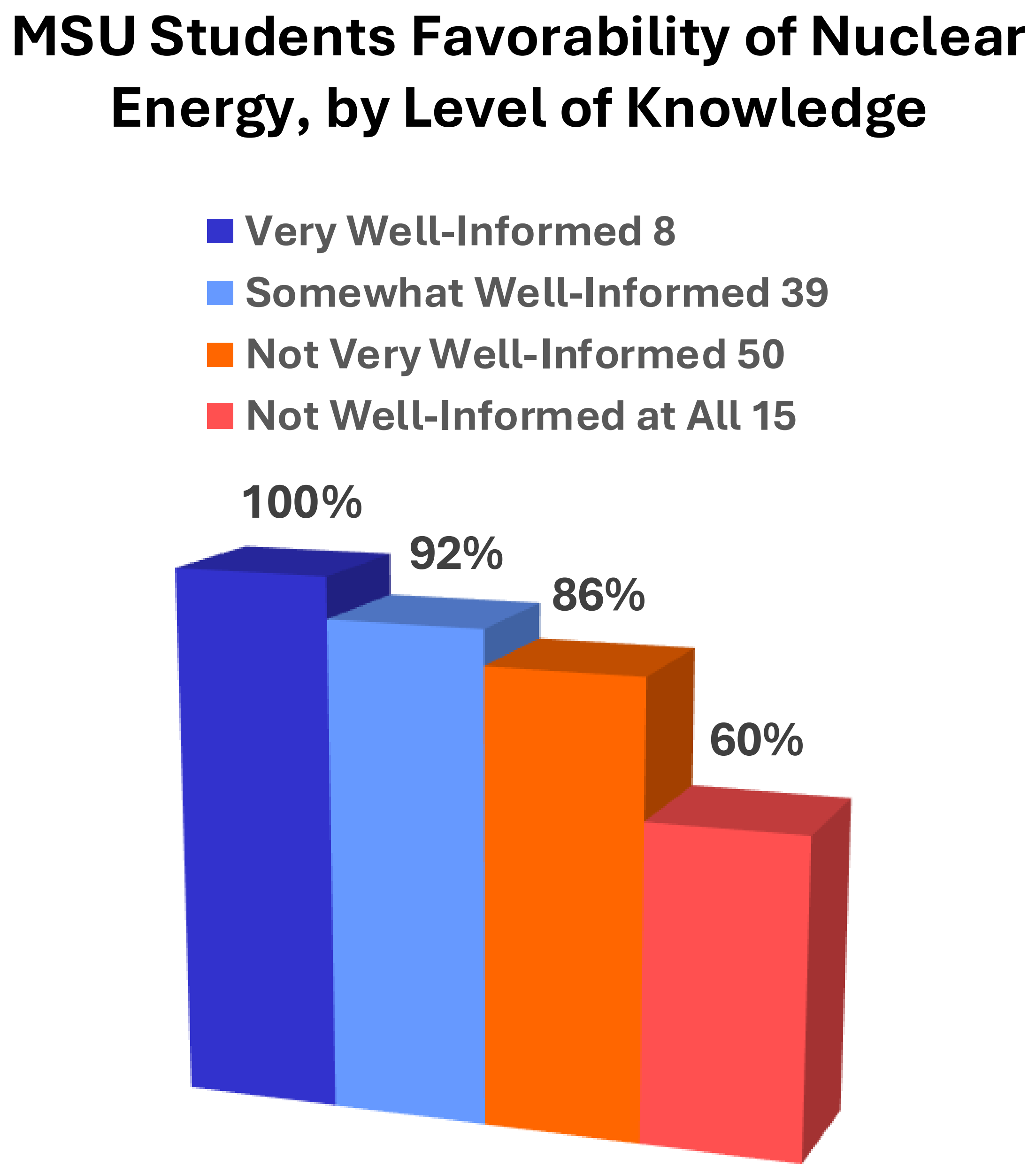
Question Form

Survey Questions

The key objective of the survey questions were to determine the favorability of nuclear energy implementation across the various stakeholder groups in Montana.

- **Concern for anthropogenic climate change**
- **Level of knowledge of nuclear energy**
- **Overall favorability of nuclear energy implementation**
- **Free response question to describe why participants felt this way?**

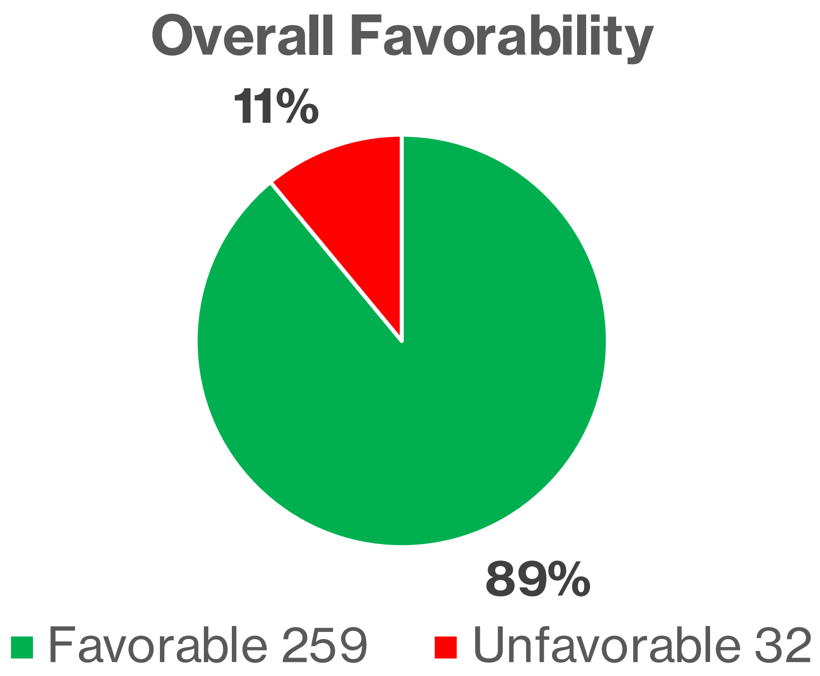

Opinions of Nuclear Energy, Gallop vs. MSU Students
Gallop
MSU Students
86%
55%
44%
14%
Percent Favorable
Percent Unfavorable

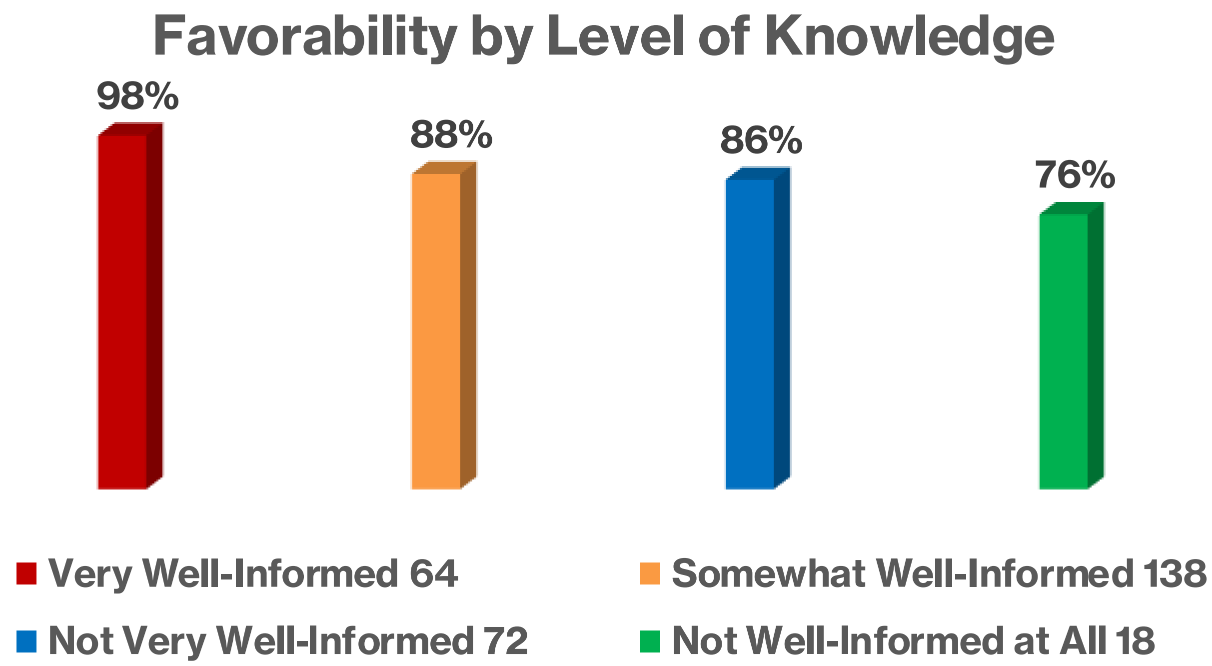

MSU Students Favorability of Nuclear Energy, by Level of Knowledge
Very Well-Informed 8
Somewhat Well-Informed 39
Not Very Well-Informed 50
Not Well-Informed at All 15
100%
92%
86%
60%

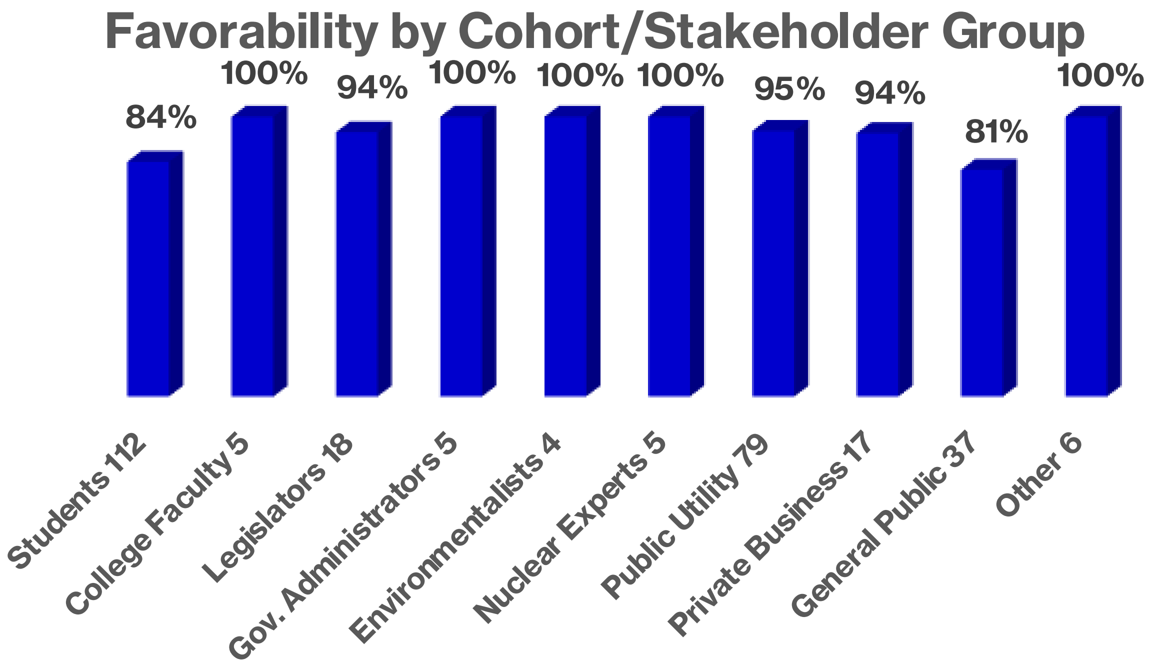
Survey Stakeholder Groups

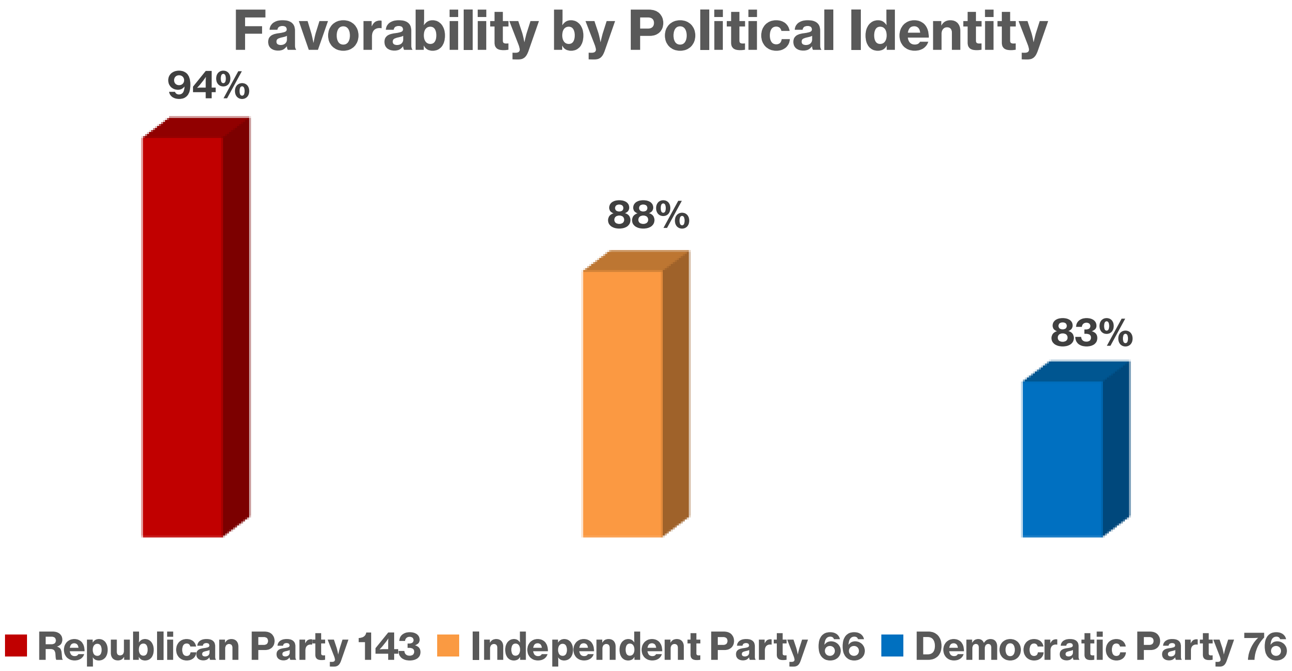
- **Decision makers, nuclear energy experts, environmentalists, general public, Montana businesses, MSU students and faculty, and public utility companies.**

- **We chose these groups because they have influence! And have a large role in nuclear energy's future in Montana.**


Overall Favorability
11%
89%
Favorable 259
Unfavorable 32


Favorability by Level of Knowledge
98%
88%
86%
76%
Very Well-Informed 64
Somewhat Well-Informed 138
Not Very Well-Informed 72
Not Well-Informed at All 18


Favorability by Cohort/Stakeholder Group
84%
100%
94%
100%
100%
100%
95%
94%
81%
100%
Students 112
College Faculty 5
Legislators 18
Gov. Administrators 5
Environmentalists 4
Nuclear Experts 5
Public Utility 79
Private Business 17
General Public 37
Other 6


Favorability by Political Identity
94%
88%
83%
Republican Party 143
Independent Party 66
Democratic Party 76

Free Response Themes

Favorable Response Themes

- Waste is Manageable & Low Risk
- Clean & Climate Benefitting
- Energy Dense
- Long-term National & Energy Security
- Passive and Inherent Safety Features

Unfavorable Response Themes

- Waste Management Concerns
- Costs
- Regulations
- Safety & Accidents
- Pursue Nuclear or Renewables?

Unfavorable Survey Responses

- "High level of waste and byproduct as opposed to solar or wind."
- "I don't want to live within a certain distance of it for a long period of time but not opposed to it being further away from cities."
- "3-mile island, Chernobyl, Fukushima. Problems are catastrophic and last forever."
- "It's expensive!"
- "It will take too long to bring up to speed to solve the climate crisis, there are issues of cost, waste, energy to extract and set up facility."
- "I don't know much information on the topic so that's why I lean towards unfavorable. But if I learn more about it, I might have a better opinion."

What about that Nuclear Waste?

- **Defense Waste (Legacy Waste Manhattan Project)**
- **Commercial Waste (Spent nuclear fuel rods)**

Did you picture this?

Reactor core before use

Reactor Core after use

"Nuclear waste is only waste if you waste it."
–Rep. Gary Parry

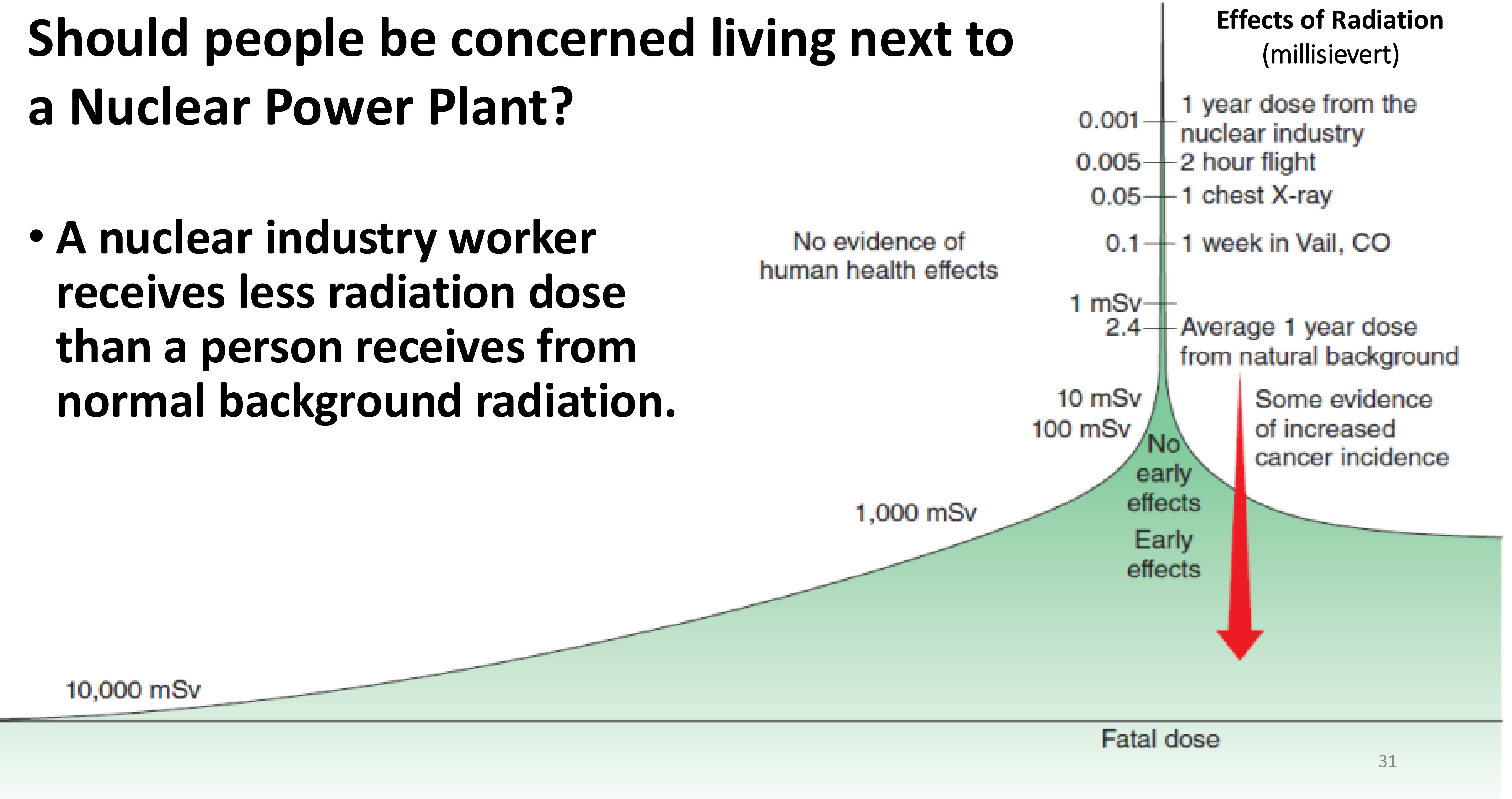
This is nuclear reactor waste!

The amount of waste a single person would produce over their entire lifetime using nuclear energy.

Size of a hockey puck.

Should people be concerned living next to a Nuclear Power Plant?

- A nuclear industry worker receives less radiation dose than a person receives from normal background radiation.



What about the Concern of Accidental Reactor Core Meltdowns?

Three-mile Island, Chernobyl, Fukushima.

- **Over the span of 70+ years of nuclear energy implementation/deployment, there have been a total of 3 nuclear accidents worldwide.**

- **Gen III+ and IV technology is designed with fail safes that prevent a nuclear meltdown**

What about the cost?

Cost: Huge startup capital requirements

Why is it so expensive?

- Past nuclear designs called for very large facilities
- Supply chain of both people and components
- Current costing methods do not accurately measure costs of nuclear (depreciation scale, infrastructure development).

How do we address cost?

- Building small to keep construction timelines and initial capital requirements.
- More accurate costing methods (GN-COA)
- Create effective ownership models

What about the construction risk?

Risk: Navigating a complex construction system

- **Why is it financially risky**
  - **Long periods of licensing and regulatory permitting approval**
  - **Who will buy the electricity?**
  - **Timelines of construction**

- **Mitigating risk factors**
  - **Effective interaction with regulators (streamline process)**
  - **AI/data center integration**
  - **Shared ownership model**
  - **PPA's (Power Purchasing Agreements)**

What About Future Development?

GEN – IV Technology

Question Form

GEN – IV Reactor Design Objectives

- **Walk-away Safety (needs no human intervention)**
- **Increase time between refueling & Maintenance**
- **Increase reactors' life cycles to 80+ years**
- **Decrease Cost and time of Construction**
- **Close the fuel cycle**

GEN – IV Reactor Design Approaches

- Design small reactor sizes, with potential to scale up
- Passive and inherent safety features
- Build reactors in certified factory (the Henry Ford model), deliver to prepared site by rail or transport for "Lego style" assembly.
- X-Energy, NuScale, Last Energy

Westinghouse AP1000

4,600 MWe, PWR

GEN III+ Technology

Westinghouse AP300 SMR
300 MWe, PWR
GEN III+ Technology
80-year design life

Advanced Small Modular Reactors For Near-Term Deployment

Reactor Name	Capacity	Type	Developer
• NuScale Power Module	300 MWe	PWR	NuScale Power + Fluor
• SMR-160	160 MWe	PWR	Holtec
• BWRX-300	300 MWe	BWR	GE-Hitachi
• PRISM	311 MWe	Sodium-FNR	GE-Hitachi
• Natrium	345 MWe	Sodium-FNR	TerraPower + GE-Hitachi
• ARC-100	100 MWe	Sodium-FNR	ARC with GE-Hitachi
• Hermes Prototype	35 MWe	MSR-Triso	Kairos
• Xe-100	80 MWe	HTR	X-energy
• Moltex SSR-W	300 MWe	MSR	Moltex, UK

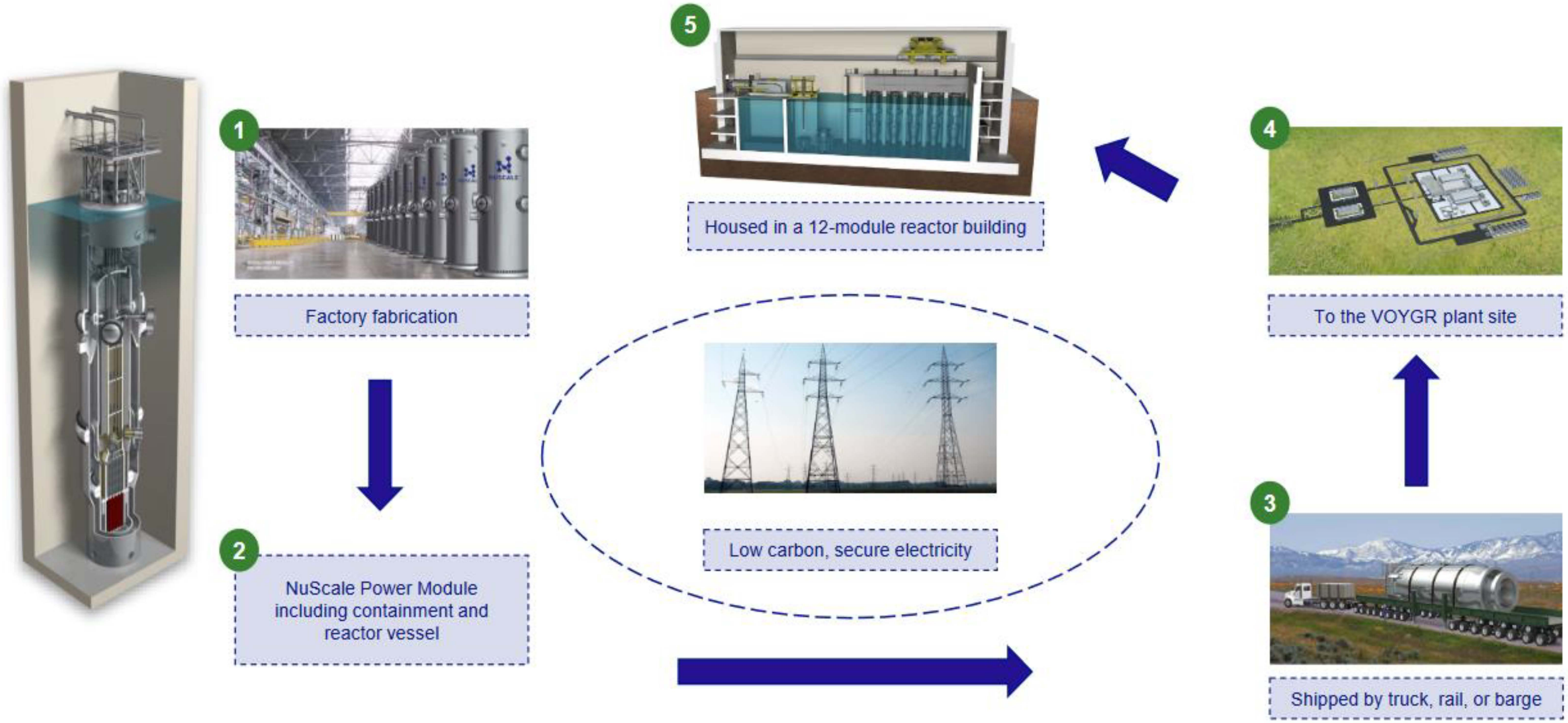
NuScale VOYGR Module 77 MWe, PWR

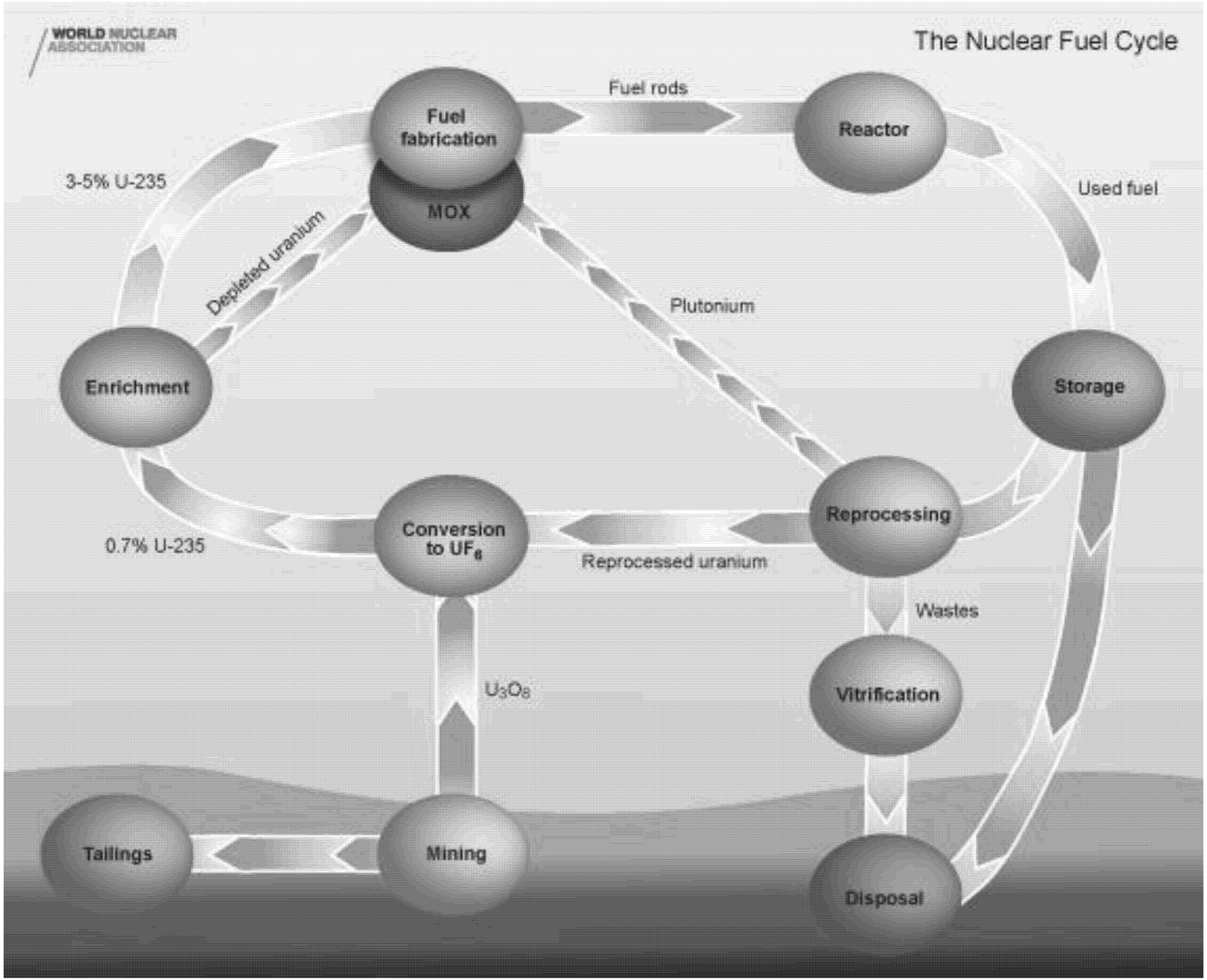
VOYGR-4, 308 MWe, PWR

VOYGR-12, 924 MWe, PWR

A New Approach to Construction and Operation

NuScale has revolutionized the nuclear supply chain with modular manufacturing of NPM units in-house that are shipped to sites




WORLD NUCLEAR ASSOCIATION
The Nuclear Fuel Cycle
Fuel fabrication
MOX
Fuel rods
Reactor
Used fuel
3-5% U-235
Depleted uranium
Plutonium
Enrichment
Storage
Conversion to UF_6
Reprocessing
0.7% U-235
Reprocessed uranium
Wastes
U_3O_8
Vitrification
Tailings
Mining
Disposal

What are the Future Development Challenges?

Licensing and Regulations

Construction Management

Costs

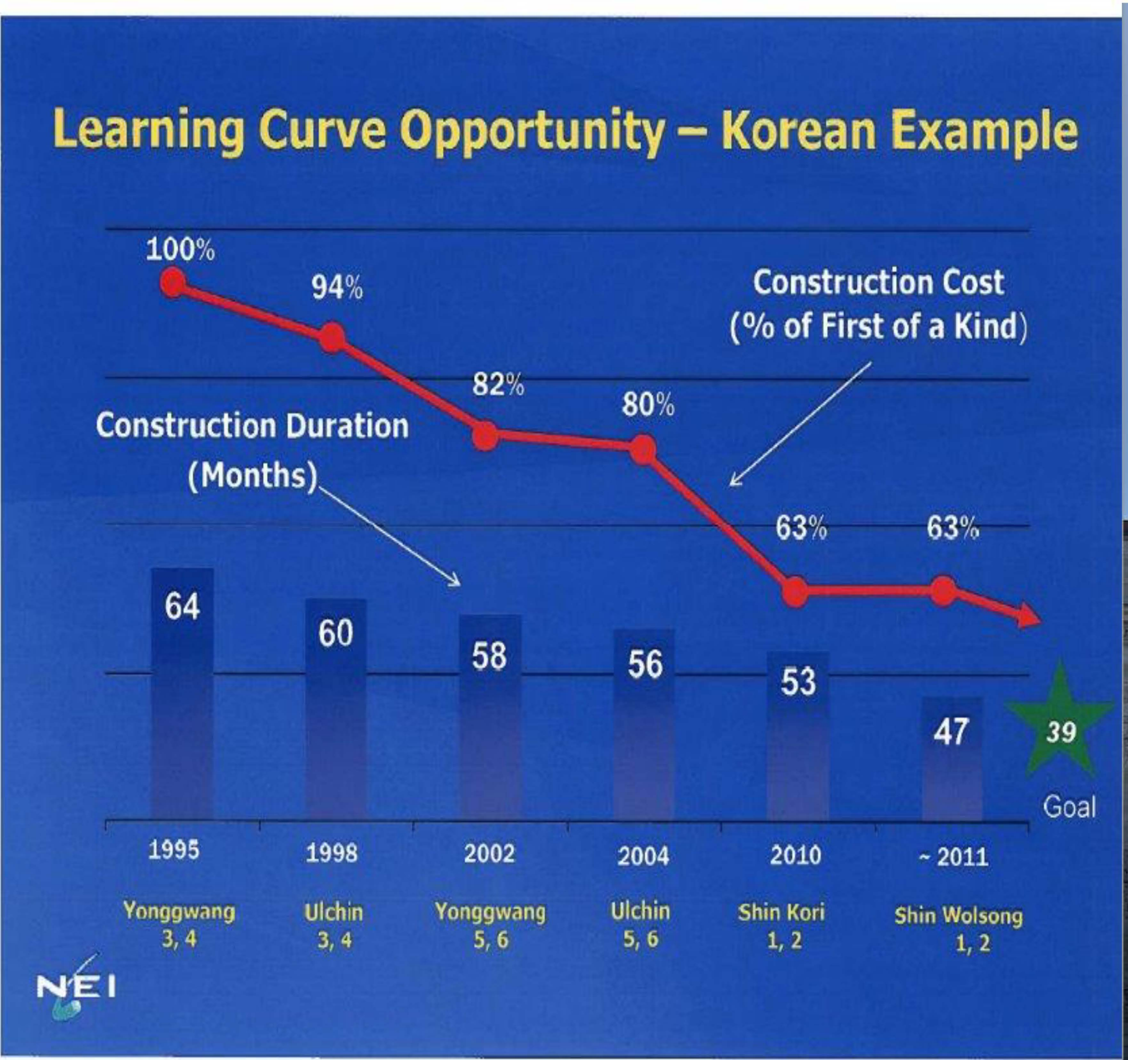
So How Do We Achieve Efficient and Effective Development of Nuclear Energy?

"Much to learn, you still have" -Master Yoda

Getting on time and on budget: ⌛ $

- Standardization of reactor technology
- Commitment to volume and series construction
- Effective interaction with regulators
- Shared ownership models
- (Re)build supply chain and workforce
- Willingness to take on learning costs.

NEA
NUCLEAR ENERGY AGENCY


Learning Curve Opportunity – Korean Example
100%
94%
82%
80%
63%
63%
Construction Cost
(% of First of a Kind)
Construction Duration
(Months)
64
60
58
56
53
47
39
Goal
1995
1998
2002
2004
2010
~ 2011
Yonggwang
3, 4
Ulchin
3, 4
Yonggwang
5, 6
Ulchin
5, 6
Shin Kori
1, 2
Shin Wolsong
1, 2
NEI


1889
1899
MONTANA

What is Our Future Vision?

"If you don’t know where you're going, you’ll end up somewhere else!“ - Yogi Berra

A Future Nuclear Vision for Montana

Nuclear hub in Montana

- **Workforce development (K-12, Trades, Colleges)**
- **Material and fuel supply chain strengthening**
  - **More secure Fuel sourcing (Canada)**
  - **Fuel recycling, repurposing, reusing infrastructure**
- **Other applications (Hydrogen, Water Desalination, Medical Isotopes, Manufacturing heat, etc.)**
- **Transmission Grid Strengthening**

Energy Revolution...

- **WE NEED MORE ENERGY, REGARDLESS OF THE SOURCE!**
- **Now is the time to invest in earth changing technology and energy sources; we need a long-term solution to a long-term issue.**
- **Energy demand will increase drastically with AI innovation.**
- **The US needs to find the right energy portfolio for its vast requirements, starting with low carbon emissions.**

Questions from the crowd?

Discussion / Q&A.

Members of crowd free to help answer.

Question Form

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