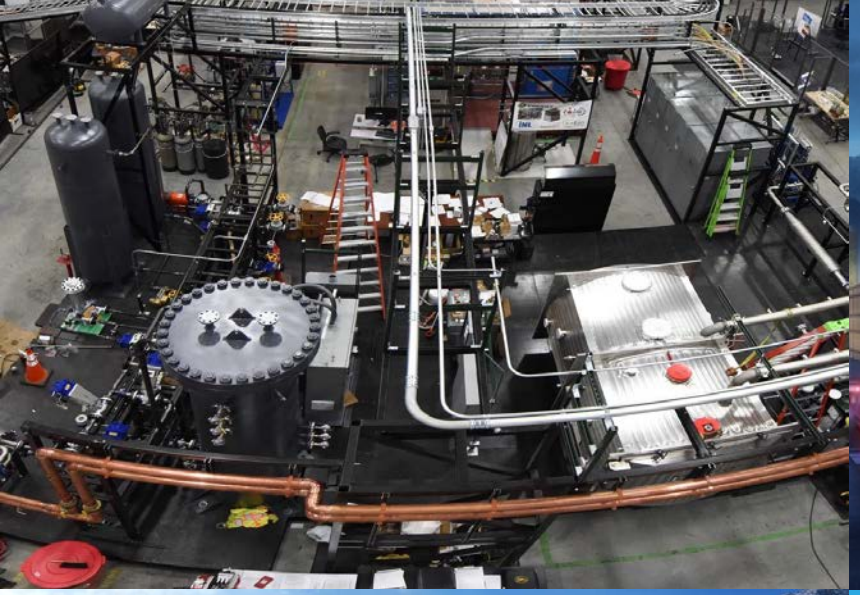

Shannon Bragg-Sitton, Ph.D.

Director, Integrated Energy & Storage Systems, INL

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Integrated Energy Systems: Advancing Economy-wide Net-Zero Solutions

Idaho National Laboratory

24 August 2023

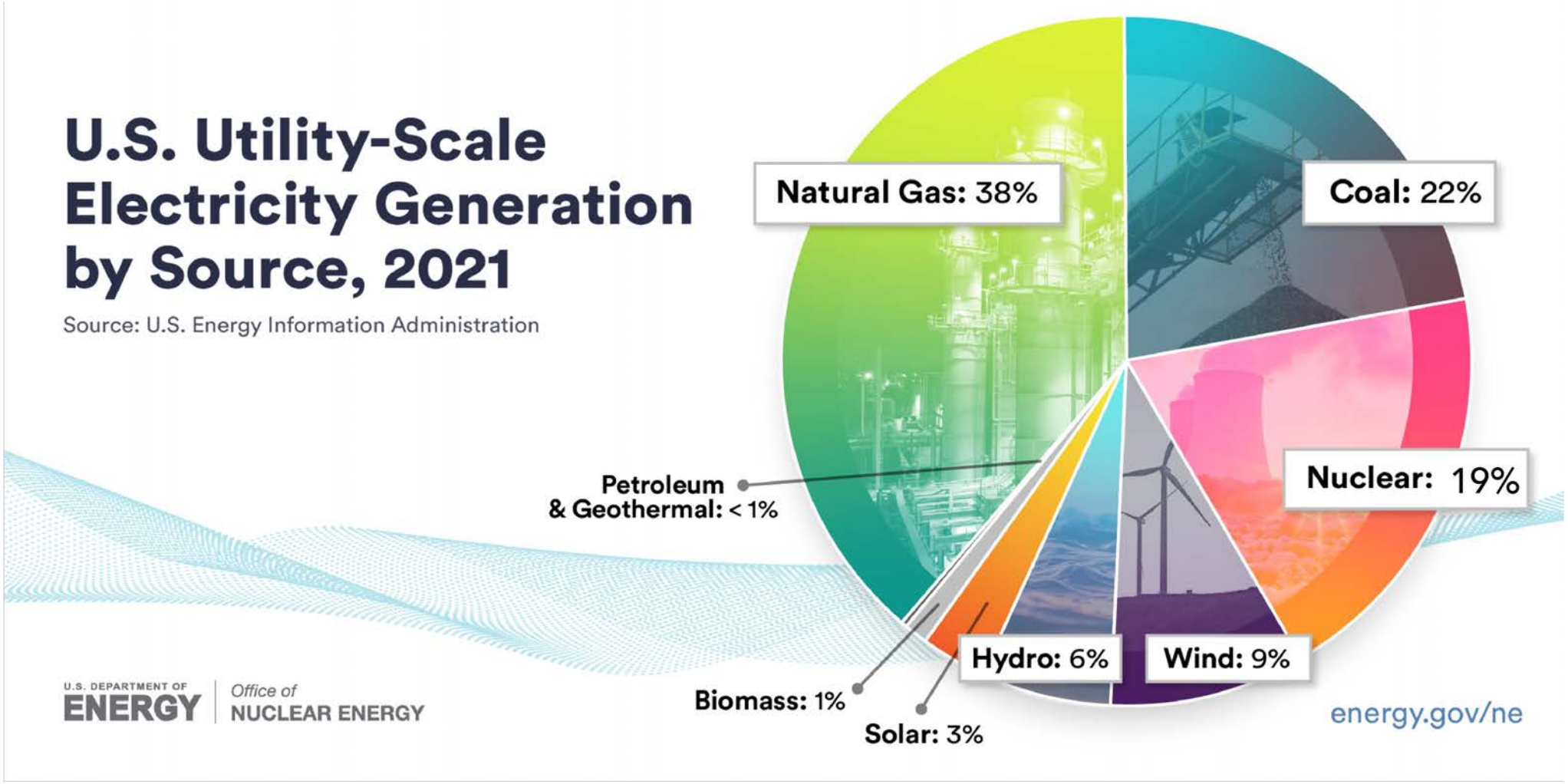
Ambitious goals to mitigate climate change: Achieving “net-zero”

- President Biden has set a goal of achieving net-zero greenhouse gas emissions by no later than 2050 and limiting global warming to 1.5 degrees Celsius
- Steps in reaching this goal require the U.S. to achieve
  - 100 percent carbon pollution-free electricity by 2035
  - Net-zero economy wide by 2050
- Must be achieved while…
  - Investing in infrastructure
  - Fueling an economic recovery – job creation
  - Advancing environmental justice
  - Bolstering domestic supply chains

What is “net-zero”?

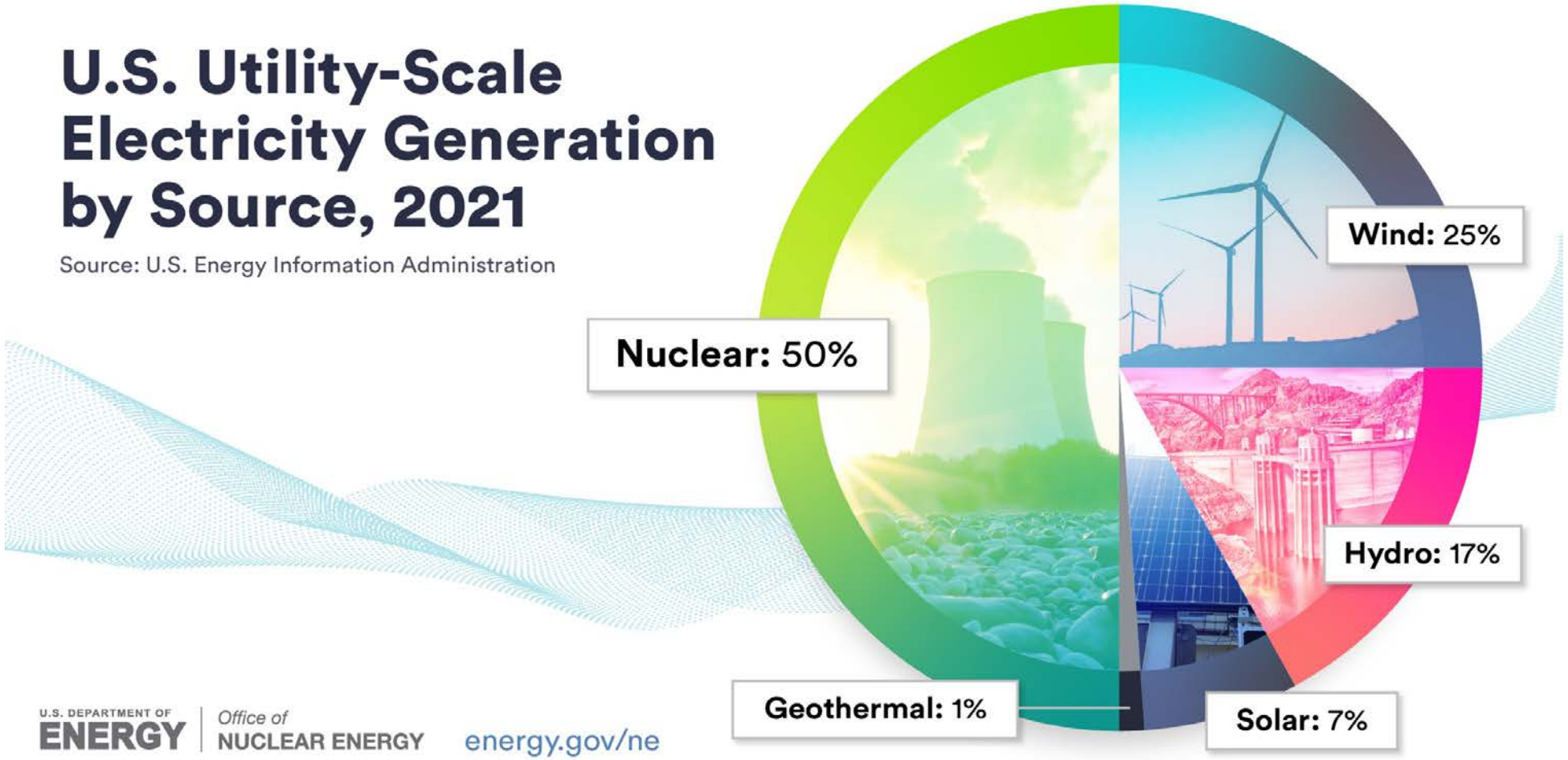
“Net-zero” refers to a target of completely negating the amount of greenhouse gases produced by human activity, to be achieved by reducing emissions and implementing methods of absorbing carbon dioxide from the atmosphere.

The U.S. Electricity Mix (2021)

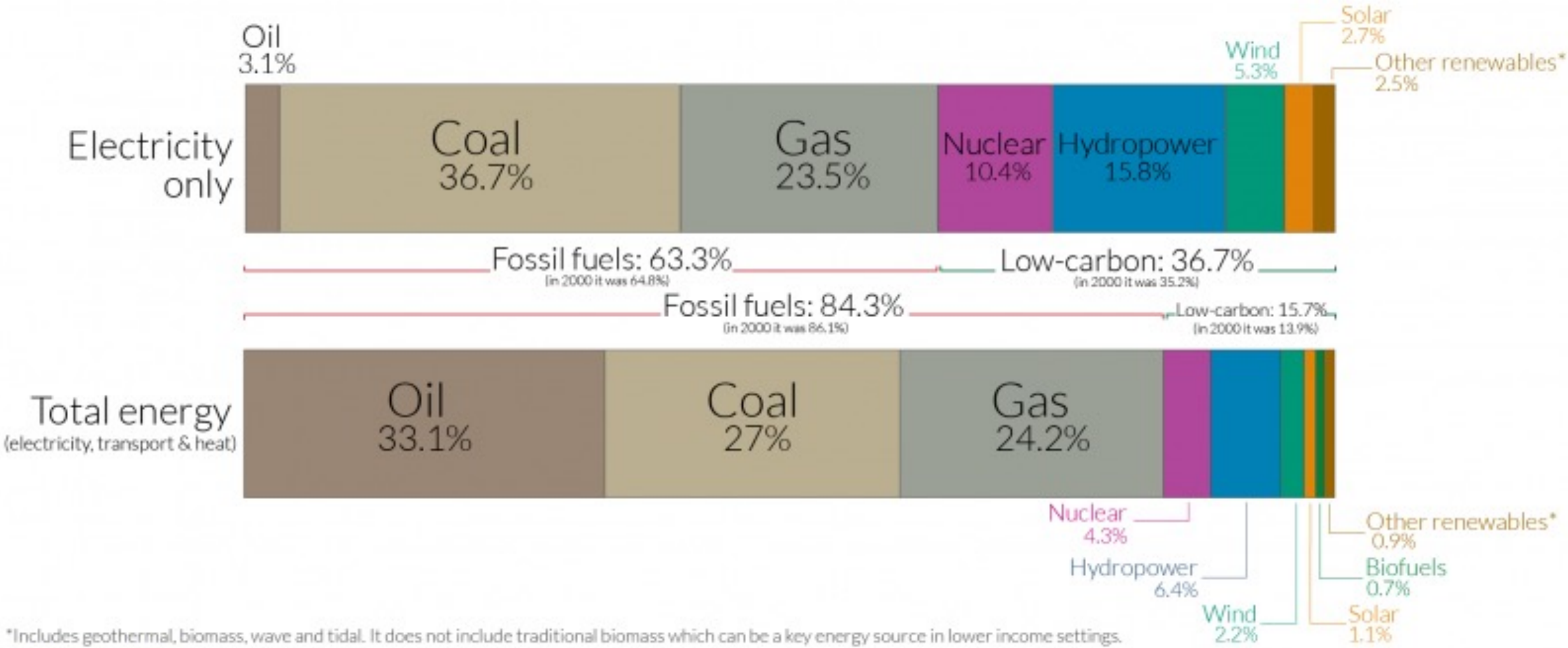


60% of U.S. electricity in 2021 was derived from fossil-based generation sources

The U.S. Clean Electricity Mix (2021)



The global challenge: Decarbonizing electricity and total energy sources (2019)



*Includes geothermal, biomass, wave and tidal. It does not include traditional biomass which can be a key energy source in lower income settings.

OurWorldinData.org – Research and data to make progress against the world's largest problems.

Source: Our World in Data based on BP Statistical Review of World Energy (2020). Based on the primary energy and electricity mix in 2019.

The U.S. Department of Energy is doubling down on the commitment to clean energy

- *Energy Earthshots™ will accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade. They will drive the major innovation breakthroughs that we know we must achieve to solve the climate crisis, reach our 2050 net-zero carbon goals, and create the jobs of the new clean energy economy.* *(https://www.energy.gov/policy/energy-earthshots-initiative)*

Hydrogen Shot

Long Duration Storage Shot

Carbon Negative Shot

Enhanced Geothermal Shot

Floating Offshore Wind Shot

Industrial Heat Shot

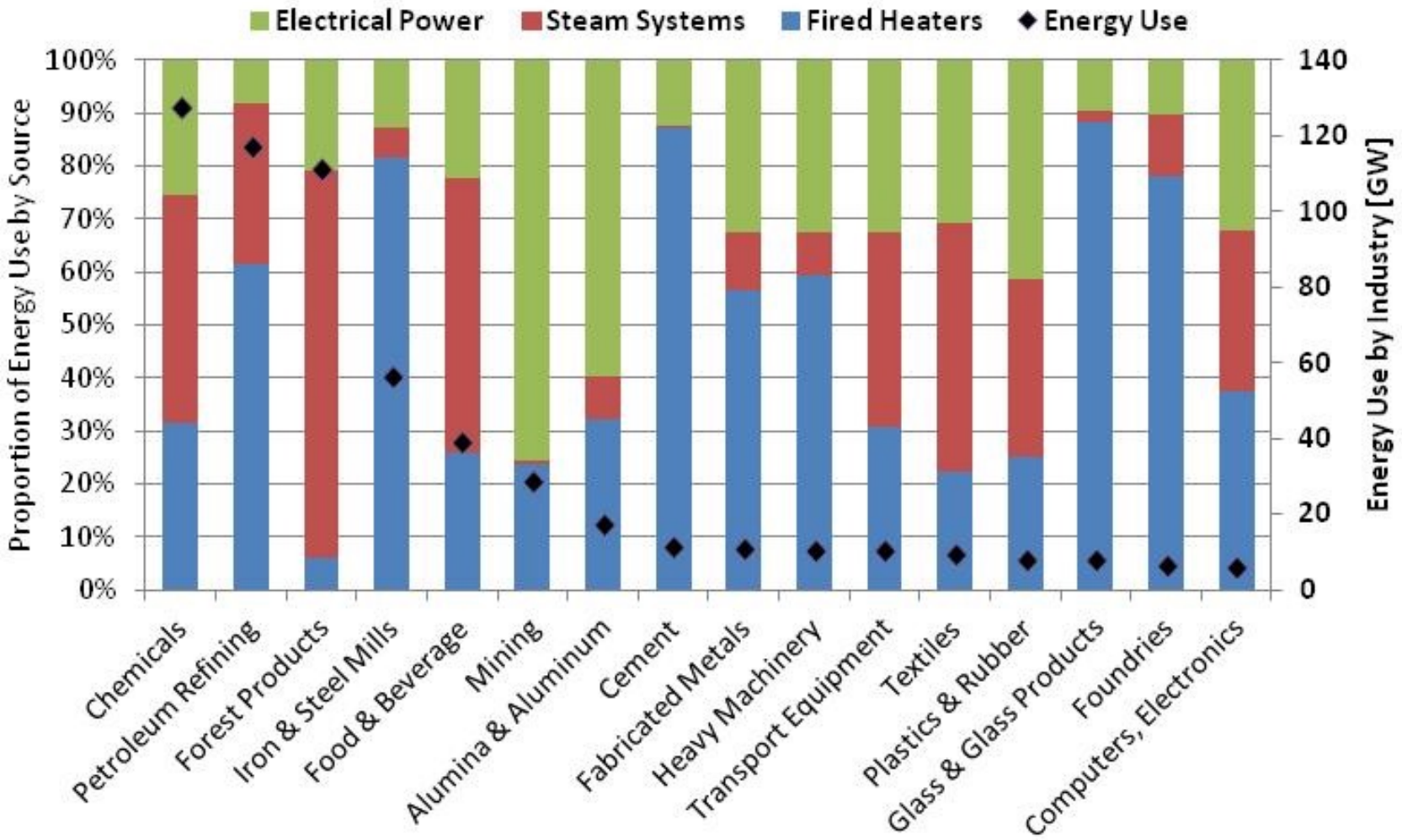
Clean Fuels & Products Shot

ENERGY earthshots
U.S. DEPARTMENT OF ENERGY

Considerations in selecting a clean energy option

- **Type of energy required —** Electricity? Heat? Steam?
- **Flexibility —** Is the energy demand constant, or does it vary over time?
- **Availability —** Is the energy available “on demand”?
- **Land use —** How much space is needed to support the selected energy source?
- **Resource utilization —**
  - What materials are needed to construct the generation asset? Are those resources readily available?
  - How are materials disposed of at the end of life?
- **Lifetime —** How long will the generation system operate?
- **Cost —** Capital costs to build, operation/maintenance costs

Energy use by U.S. manufacturing and mining industries
(2004 data)

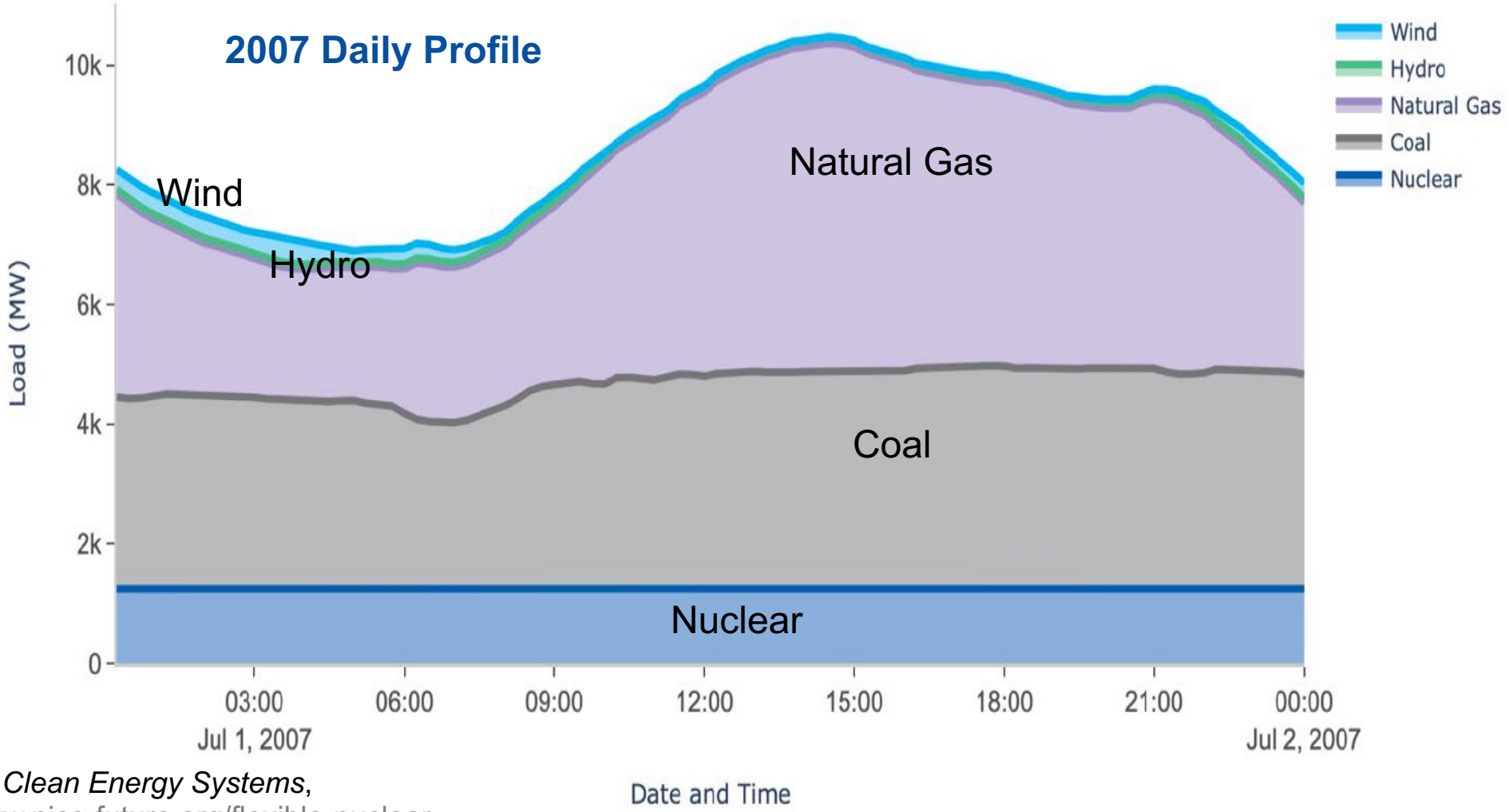


Data from Pelligrino et al., 2004, DOE IPT Report.

Plotted by Ruth et al., 2014, Energy Conversion and Management.

The electrical power sector is shifting away from traditional baseload

ERCOT (Texas) generation by fuel source for July 1, 2007
(ERCOT 2020)

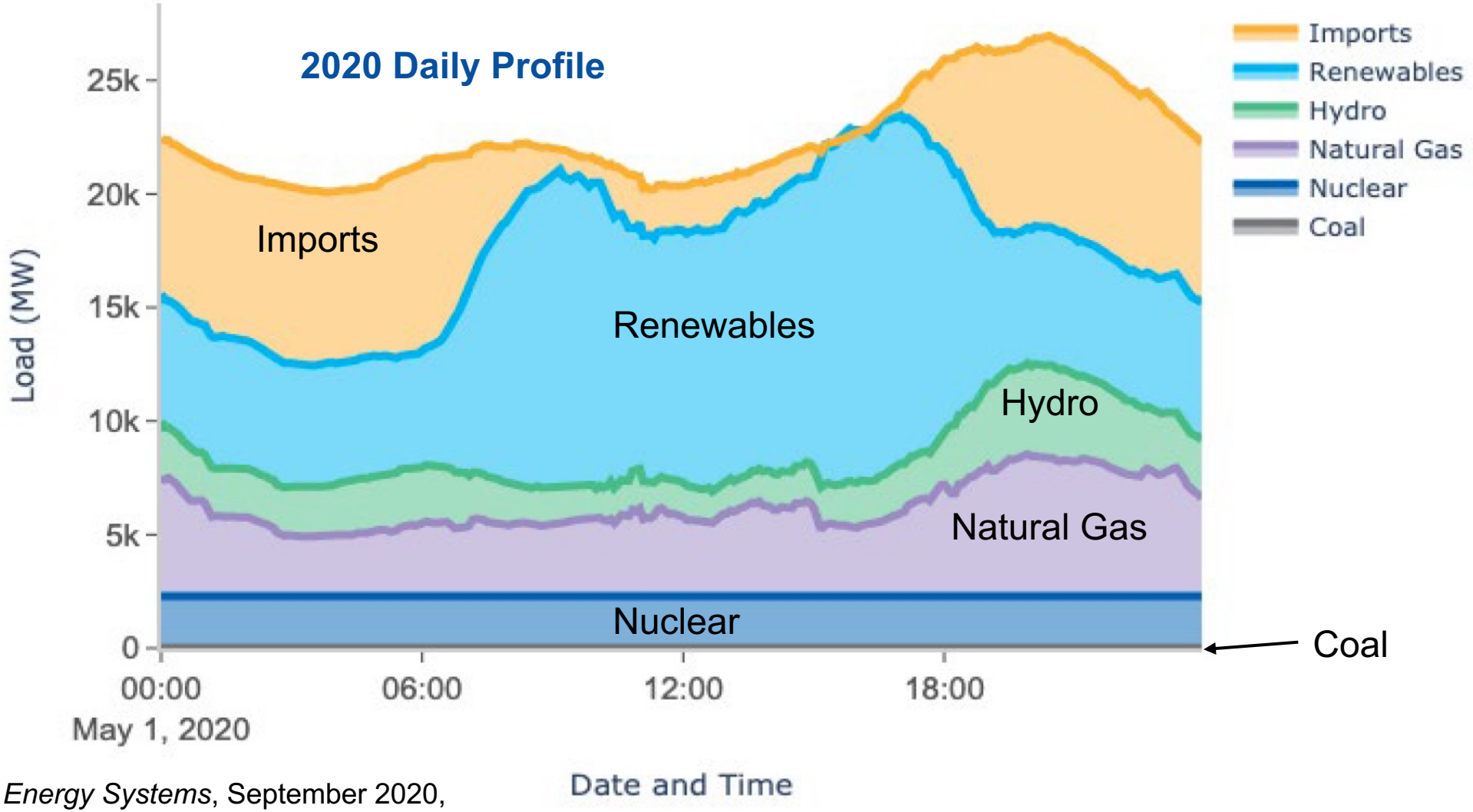


Flexible Nuclear Energy for Clean Energy Systems, September 2020, https://www.nice-future.org/flexible-nuclear-energy-clean-energy-systems.

The electrical power sector is shifting away from traditional baseload

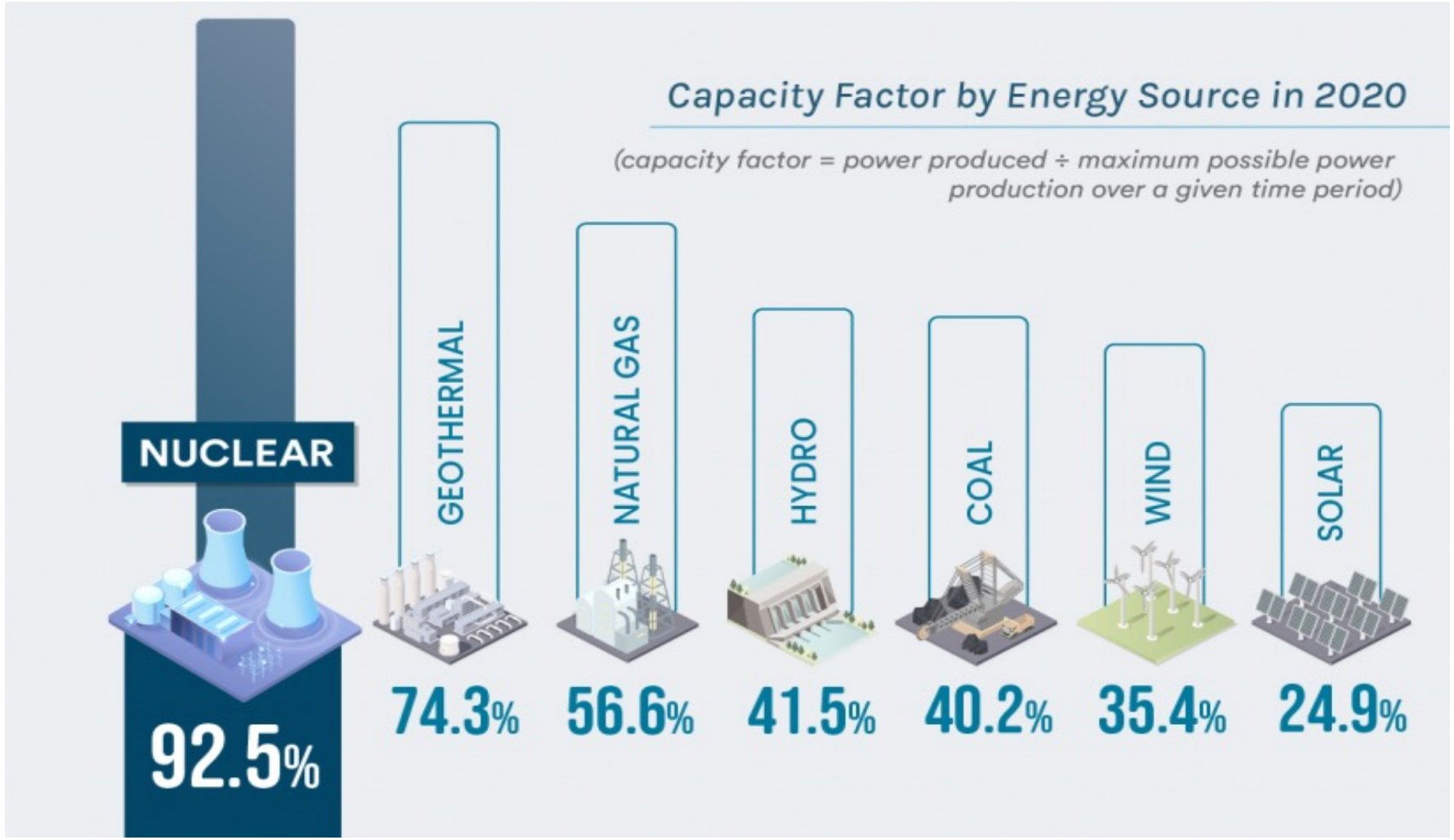
California Independent System Operator (CAISO) generation by fuel source for May 1, 2020

Source: "FERC: Documents & Filing – Forms – Form 714 – Annual Electric Balancing Authority Area and Planning Area Report – Data Downloads", n.d.



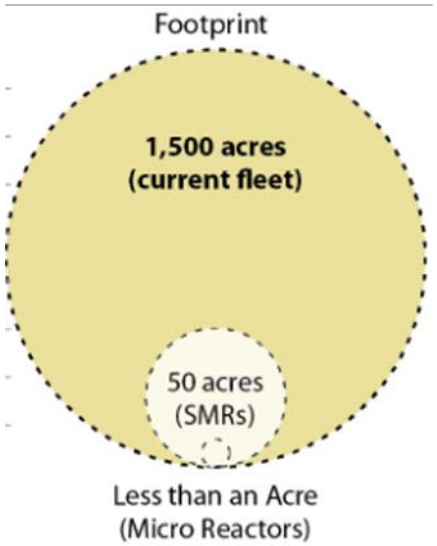
Flexible Nuclear Energy for Clean Energy Systems, September 2020, https://www.nice-future.org/flexible-nuclear-energy-clean-energy-systems.

Net-zero needs reliable, dispatchable energy



Source: NEI

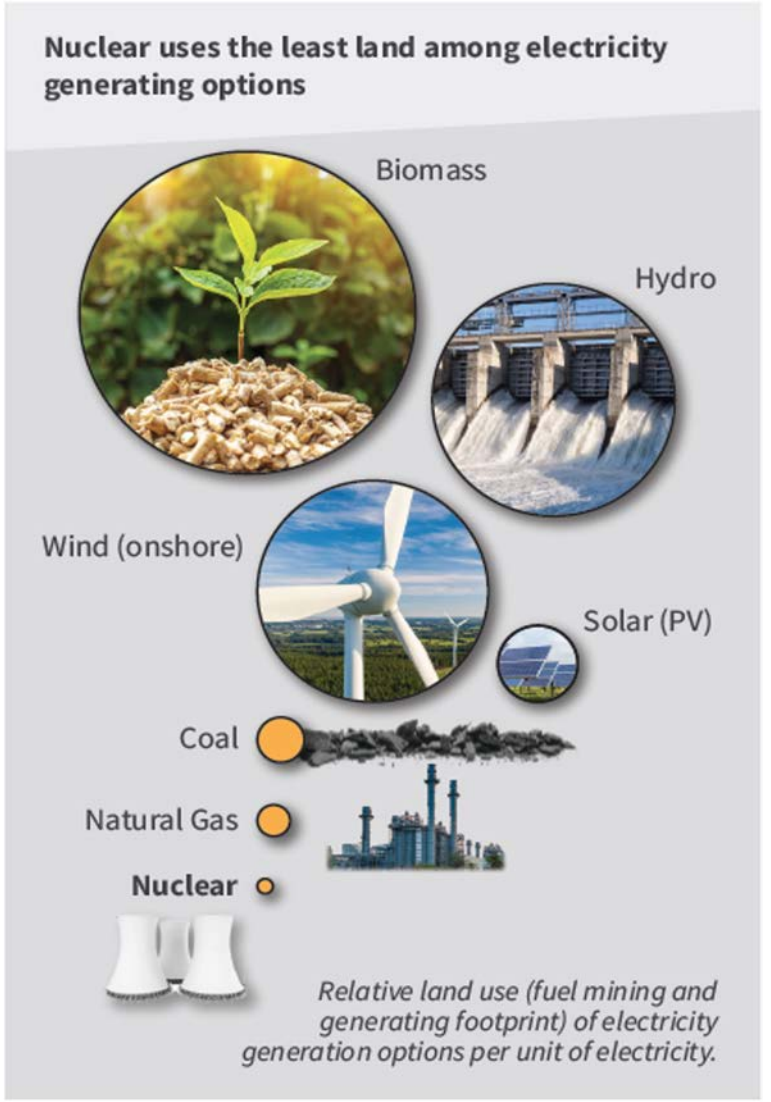
Nuclear energy and deployment flexibility



Artist renditions courtesy of GAIN and Third Way, inspired by the *Nuclear Energy Reimagined* concept led by INL. Learn more about these and other energy park concepts at thirdway.org/blog/nuclear-reimagined

Microreactors and small modular reactors can be deployed to provide reliable energy where it is needed with a small footprint that allows for siting very near to the intended use.

IES
Integrated Energy Systems



Source: https://world-nuclear.org/information-library/energy-and-the-environment/nuclear-energy-and-sustainable-development.aspx

Thinking outside the box to meet clean energy demands

Today's energy systems

- Individual generators contribute to meeting grid demand, managed by an independent grid operator
- Individual thermal energy resources typically support industrial demand
- Transportation mostly relies on fossil fuels (with growing, yet limited, electrification)

Achieving net-zero emissions will require us to consider the role(s) of <u>all</u> clean energy generation options— and we must look to non-emitting sources of <u>heat</u> in addition to electricity.

Future clean energy systems – transforming the energy paradigm

Nuclear Energy Generation

(Light water reactors, high temperature advanced reactors, small modular reactors, etc.)

Other Energy Generation

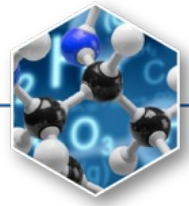
(Variable renewables, municipal waste, fossil with carbon capture, etc)

Integrated energy systems (IES) leverage the contributions from nuclear fission beyond electricity

Biofuel, transportation fuels

Hydrogen for transportation

New chemical processes



Polymers, chemicals

Industrial heat & fuels

Fertilizer, ammonia

Iron, steel, metals

Wood products, cardboard, paper

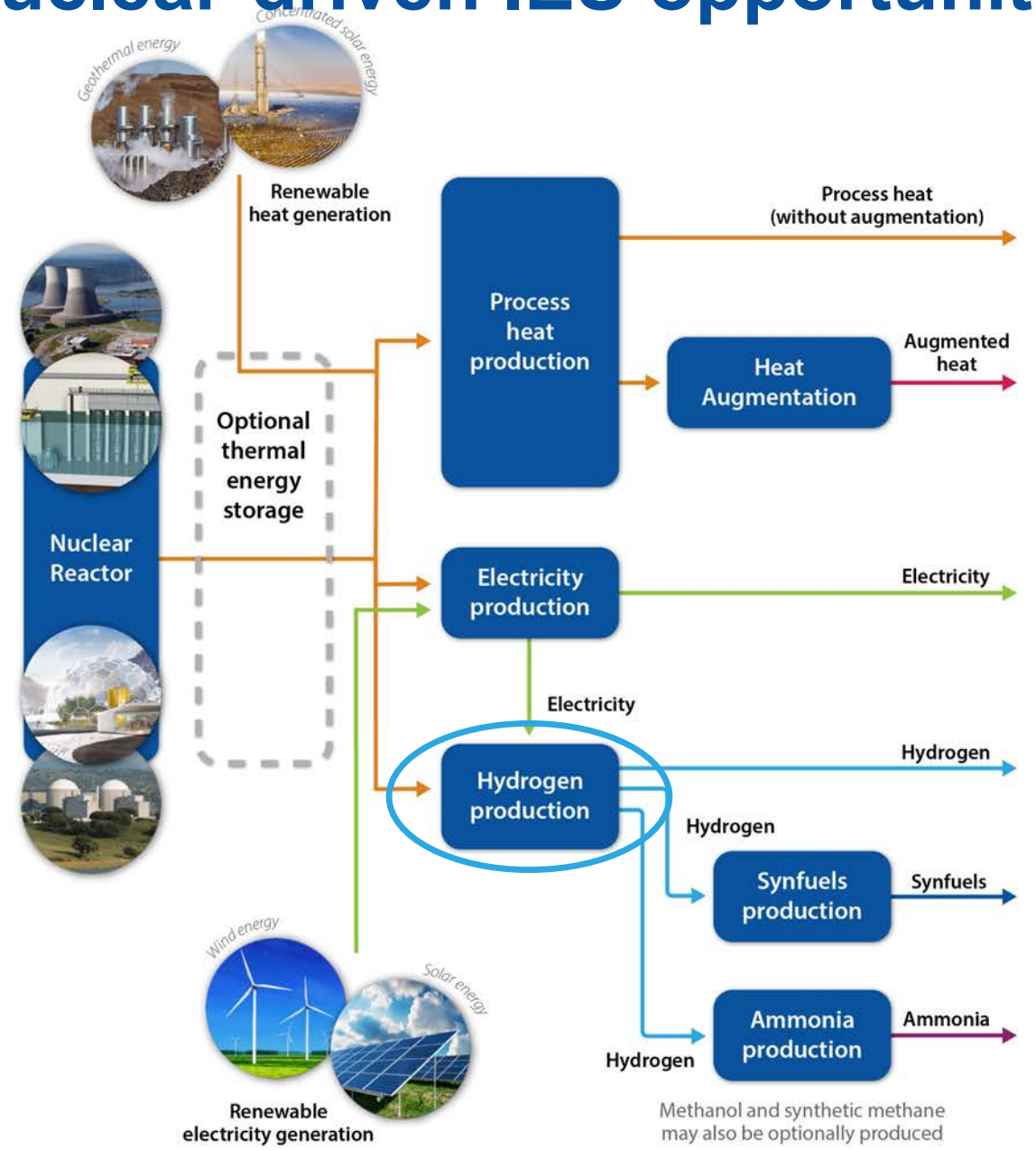
Clean Water

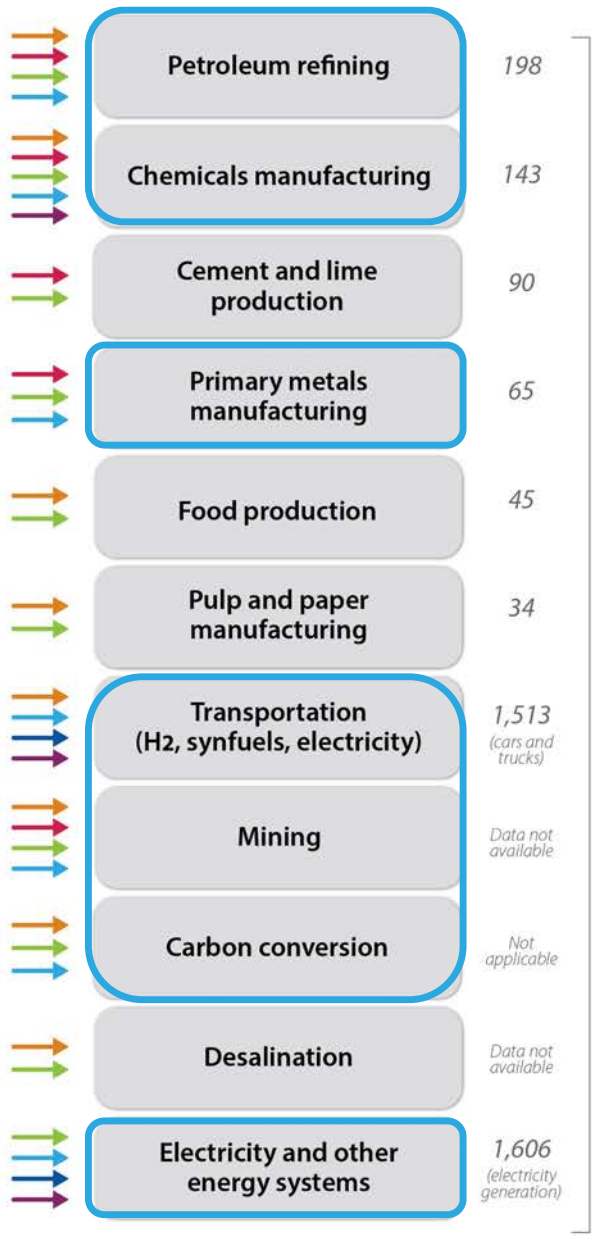
District heating

Flexible electricity

Potential nuclear-driven IES opportunities

Reactor sizes align with the needs of each application; heat augmentation can be applied if needed to match process temperature demands.





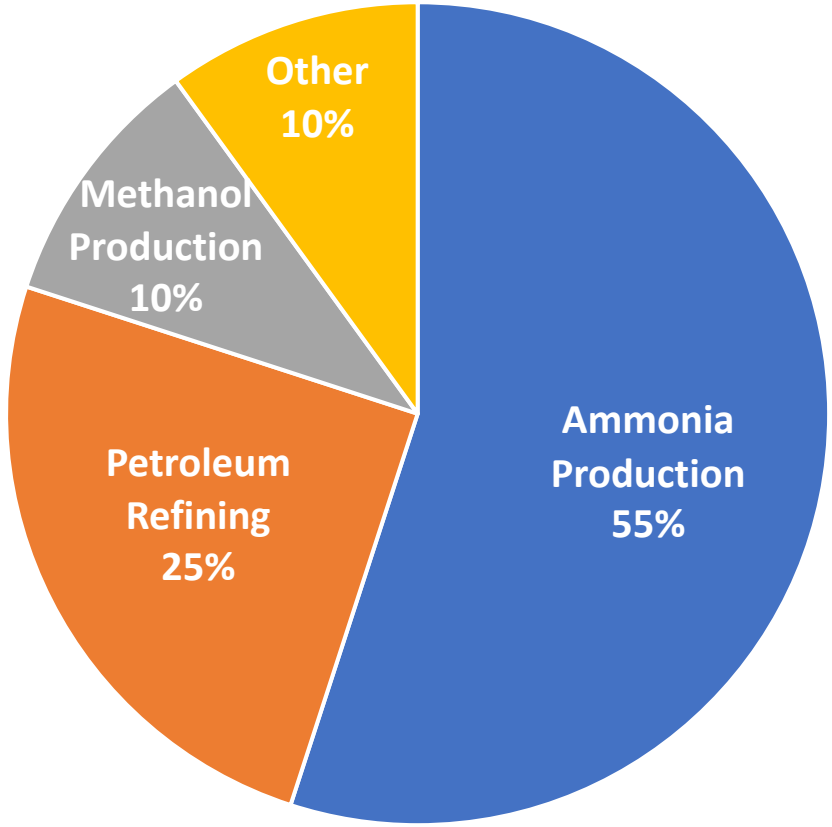
Source: Adapted from INL, *National Reactor Innovation Center (NRIC) Integrated Energy Systems Demonstration Pre-Conceptual Designs*, April 2021

Why all the hype about hydrogen?

Hydrogen applications in industry

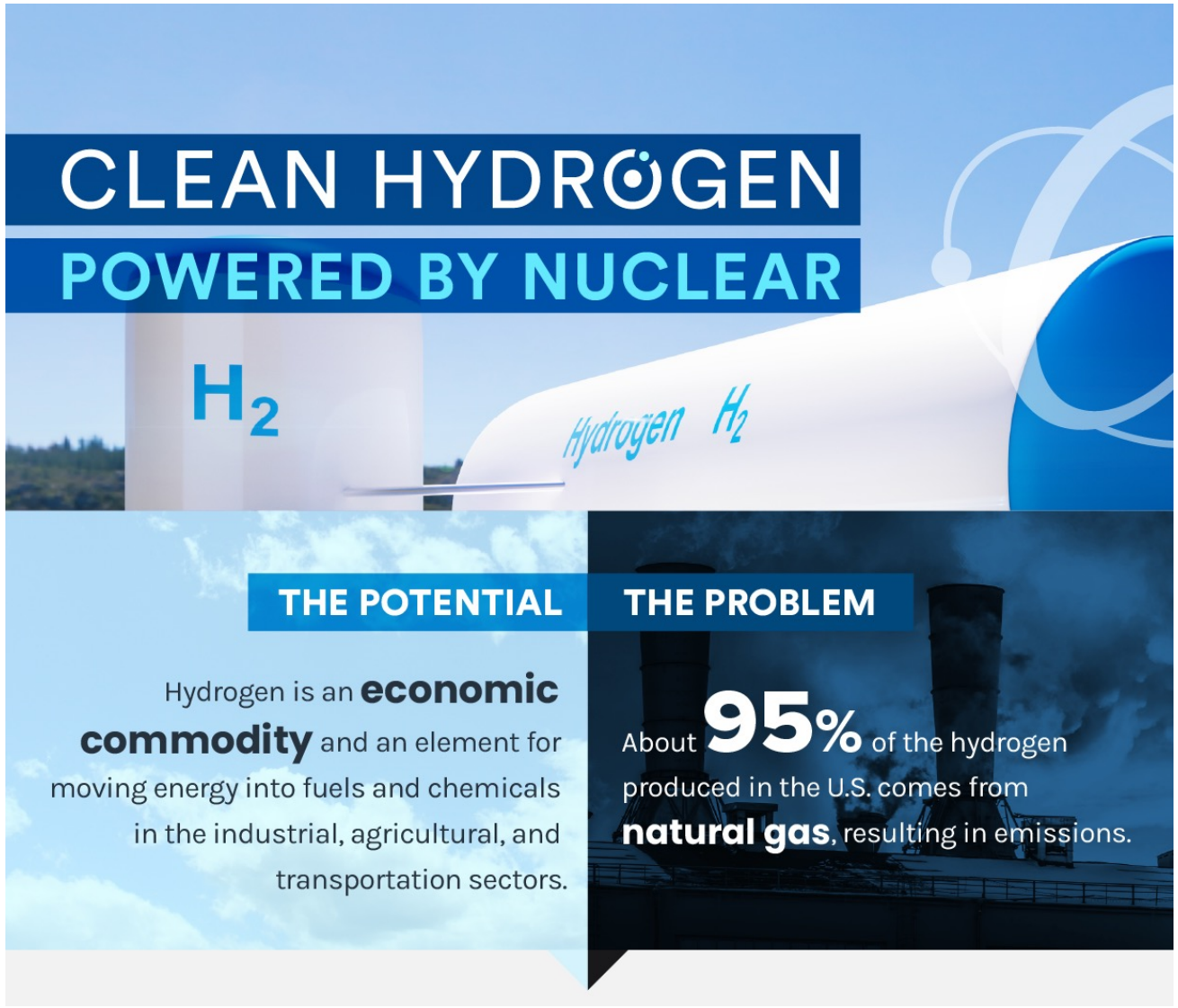
- Agriculture/chemical industry: ammonia, ammonia-based fertilizers
- Petroleum refining: hydrocracking to produce gasoline, diesel
- Methanol production
- Other:
  - Food (e.g., hydrogenated oils)
  - Metalworking
  - Welding
  - Flat glass production
  - Electronics manufacturing
  - Medical applications

Fraction of Global Hydrogen Use by Industry



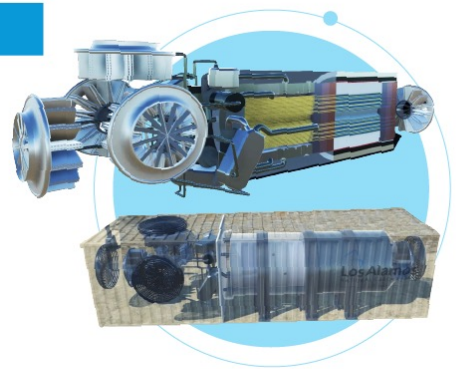
Data source: Hydrogen Europe
hydrogeneurope.eu/hydrogen-applications

Research and development will enable a clean hydrogen future



BUT HOW?

Current and advanced reactors can utilize the constant heat and electricity they generate to split water into pure hydrogen and oxygen through **low- and high-temperature electrolysis**.



THE IMPACT

- Oil Refining
- Fertilizer Production
- Steel Production
- Synthetic Fuels
- Grid Storage
- Transport Fuels

THE RESULT

- ✓ Reduces air emissions
- ✓ Deploys hydrogen at scale
- ✓ Expands the use of carbon-free nuclear energy into the transportation and industrial sectors
- ✓ Supports the Hydrogen Shot goal of reducing the cost of clean hydrogen by **80%** *to $1 per kilogram within a decade*

LEARN MORE: energy.gov/ne

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Nuclear-based hydrogen production is a reality!

Press release:
https://www.constellationenergy.com/newsroom/2023/Constellation-Starts-Production-at-Nations-First-One-Megawatt-Demonstration-Scale-Nuclear-Powered-Clean-Hydrogen-Facility.html

Constellation Starts Production at Nation's First One Megawatt Demonstration Scale Nuclear-Powered Clean Hydrogen Facility

State-of-the-art facility will demonstrate the value of producing hydrogen with carbon-free nuclear energy to help address the climate crisis

OSWEGO, NY (Mar. 7, 2023) — Hydrogen production has commenced at the nation's first 1 MW demonstration scale, nuclear-powered clean hydrogen production facility at Constellation's Nine Mile Point Nuclear Plant in Oswego, New York, an advancement that will help demonstrate the potential for hydrogen to power a clean economy.

Photos courtesy Constellation, https://www.ans.org/news/article-4810/constellation-starts-hydrogen-production-at-nine-mile-point/

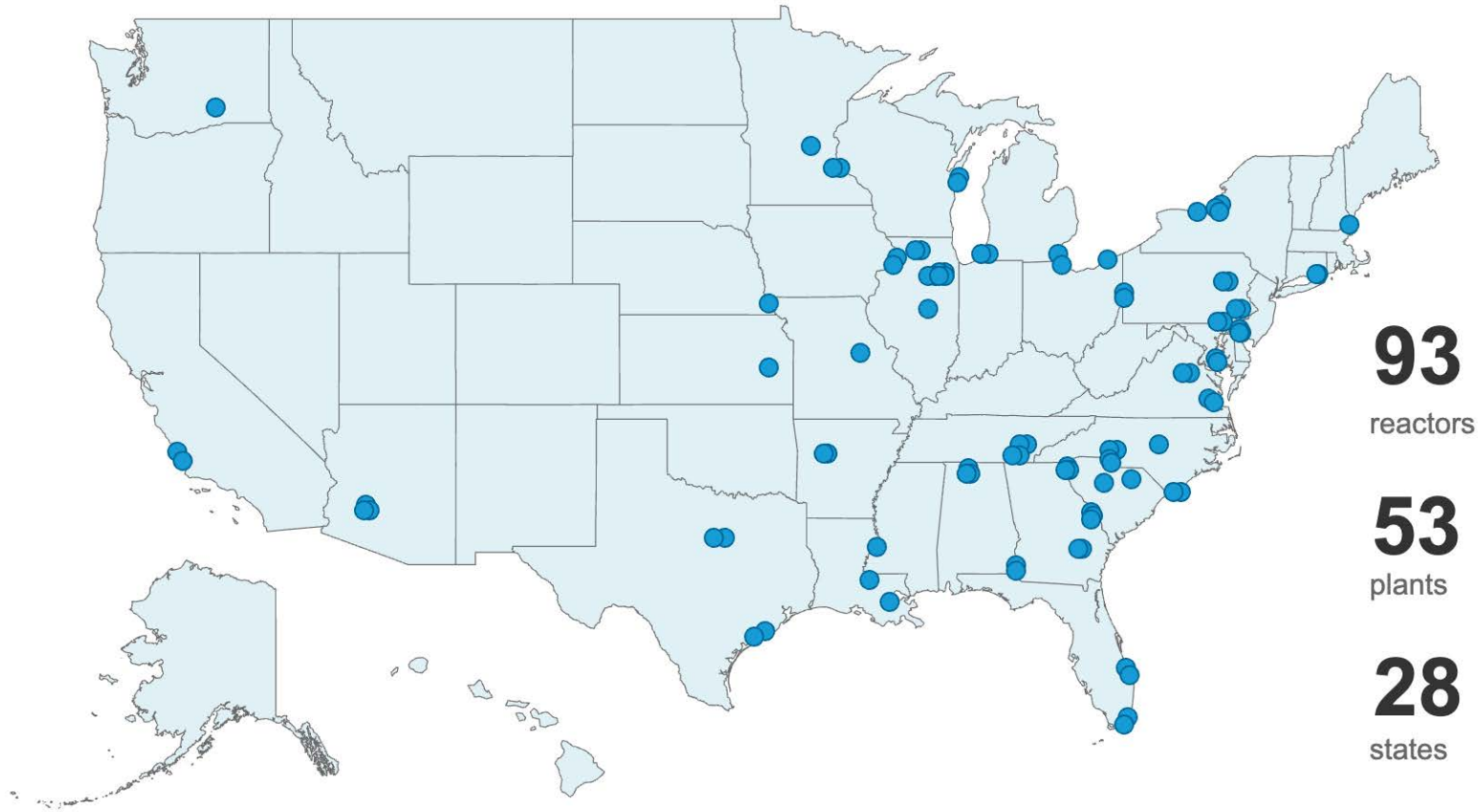
Nuclear Energy Opportunities

NUCLEAR ENERGY INSTITUTE

NUCLEAR ENERGY
FACT SHEET 2023

United States

NUCLEAR POWER ACROSS THE U.S.



93
reactors

53
plants

28
states

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

470M
metric tons of carbon emissions avoided in 2022

475,000
well-paying, sustainable direct and indirect jobs in the nuclear industry

92.6%
capacity factor of U.S. nuclear plants in 2022 as a reliable electricity source

Nuclear plants operating in the US today are “light water reactors.”

Each of these reactors provides electricity to support regional grid demands. Most are large-scale, generating ~1000 MW of electricity.

These plants can operate reliably for 40-80 years of electricity, without emissions.

Why Advanced Nuclear?

Key Benefits

- Inherent/passive safety
- Deployment flexibility
- Versatile applications
- Long fuel cycles
- Reduced waste
- Advanced manufacturing to reduce cost

70+ private sector projects under development

SIZES

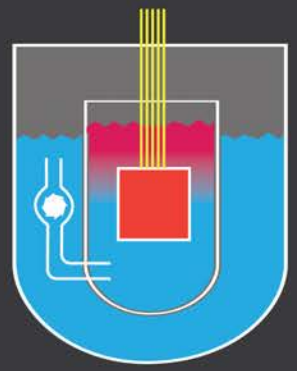
SMALL
1 MW to 20 MW
Micro-reactors
Can fit on a flatbed truck. Mobile. Deployable.

MEDIUM
20 MW to 300 MW
Small Modular Reactors
Factory-built. Can be scaled up by adding more units.

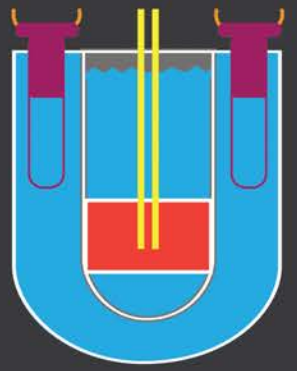
LARGE
300 MW to 1,000 + MW
Full-size Reactors
Can provide reliable, emissions-free baseload power

Advanced Reactors Supported by the U.S. Department of Energy

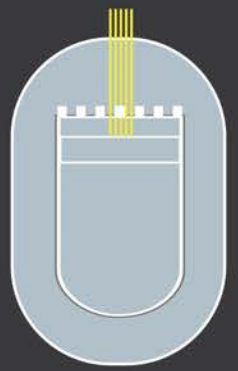
TYPES



MOLTEN SALT REACTORS – Use molten fluoride or chloride salts as a coolant. Online fuel processing. Can re-use and consume spent fuel from other reactors.

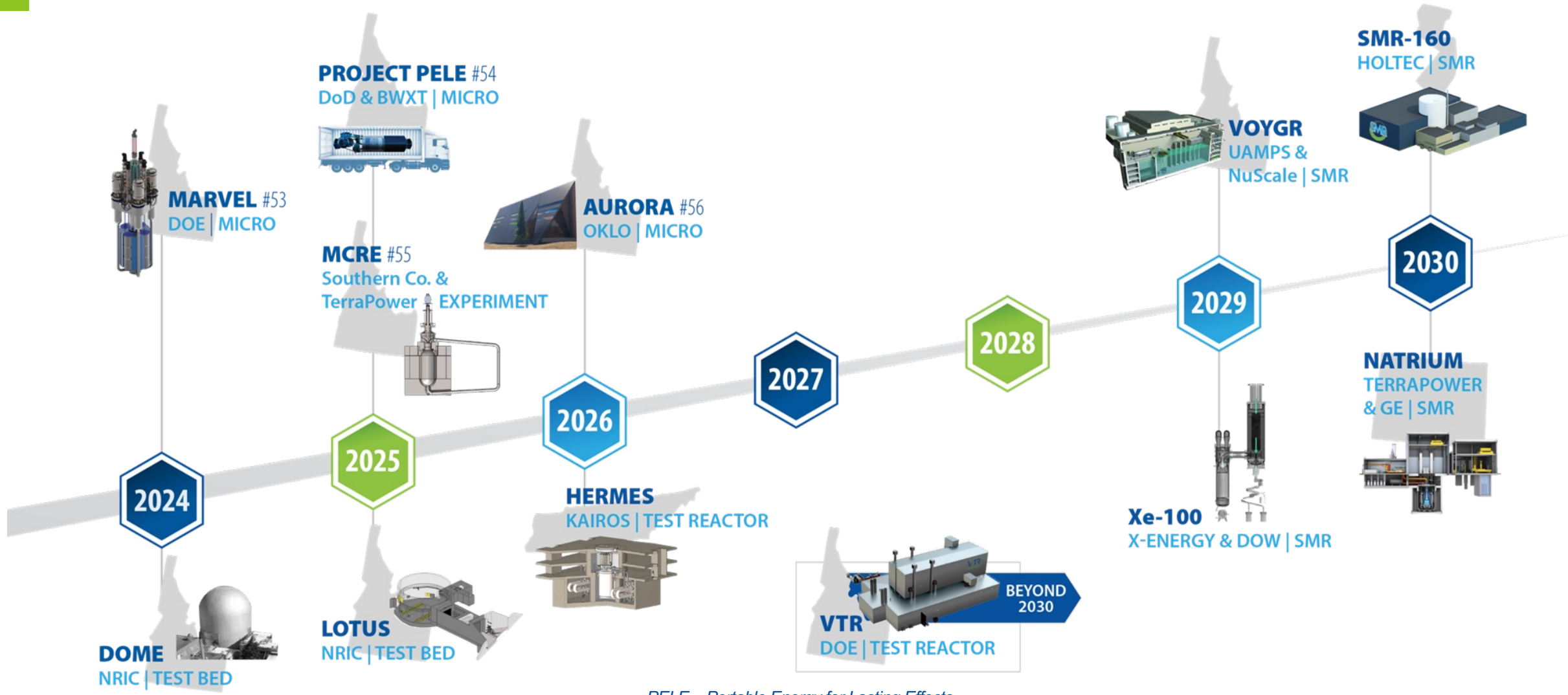


LIQUID METAL FAST REACTORS - Use liquid metal (sodium or lead) as a coolant. Operate at higher temperatures and lower pressures. Can re-use and consume spent fuel from other reactors.



GAS-COOLED REACTORS – Use flowing gas as a coolant. Operate at high temperatures to efficiently produce heat for electric and non-electric applications.

Accelerating advanced reactor demonstration & deployment



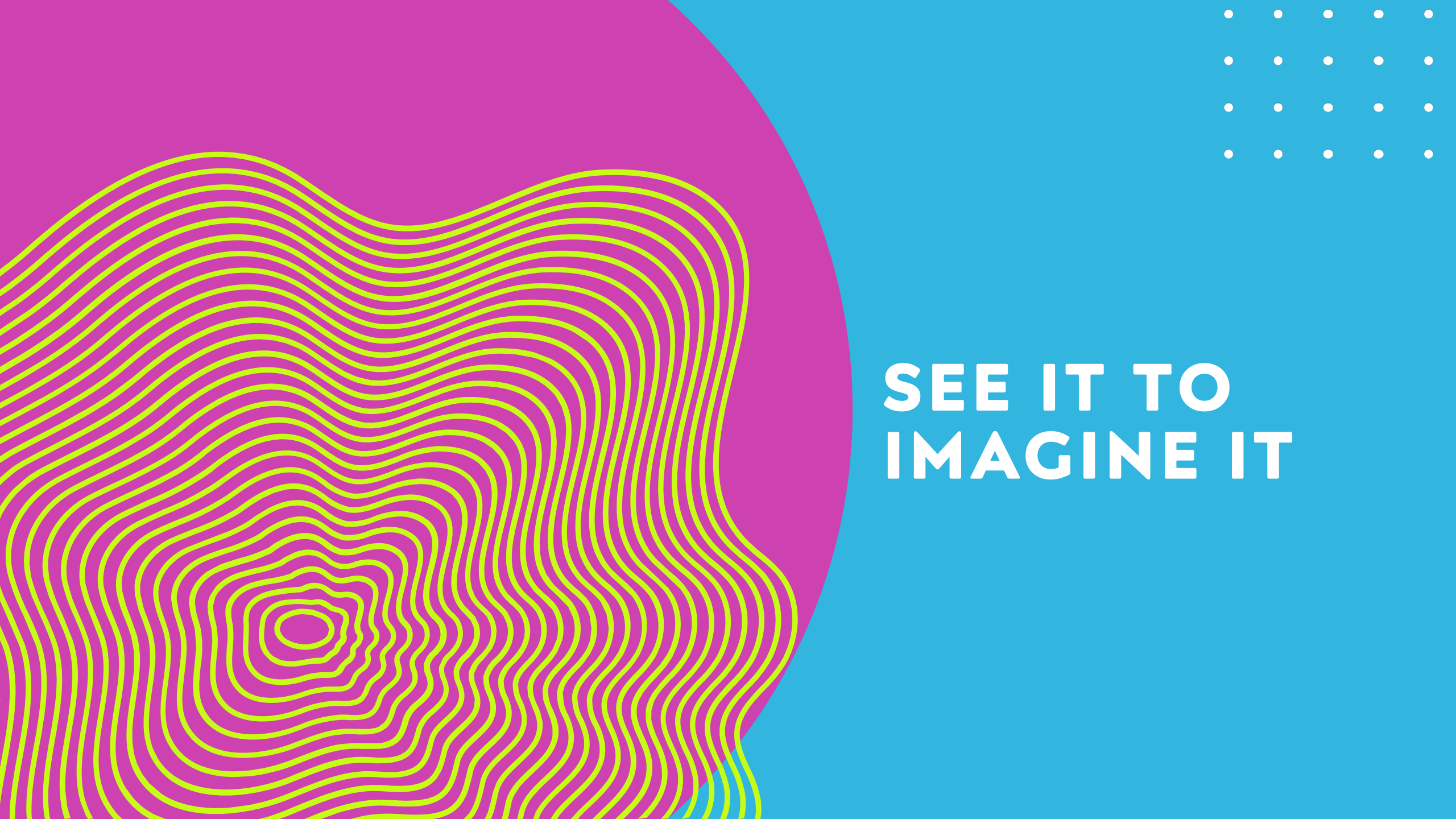
PELE – Portable Energy for Lasting Effects
DoD – Department of Defense
DOME – Demonstration of Microreactor Experiments
NRIC – National Reactor Innovation Center
LOTUS – Laboratory for Operating and Testing in the U.S.

Tools for Engaging of Next Generation Innovators

Example:

See It To Imagine It Toolkit

U.S. Women in Nuclear
Nuclear Executives of Tomorrow
2023 Cohort Capstone


SEE IT TO
IMAGINE IT

SEE IT TO IMAGINE IT

- A comprehensive toolkit for Nuclear Professionals, Industry Organizations, Parents, Teachers, Coaches, and Influencers to attract young women to the Nuclear Industry and STEM
  - Nuclear Fact Sheet
  - Inspirational Videos
  - Experiments and Activities
  - Choose your own adventure

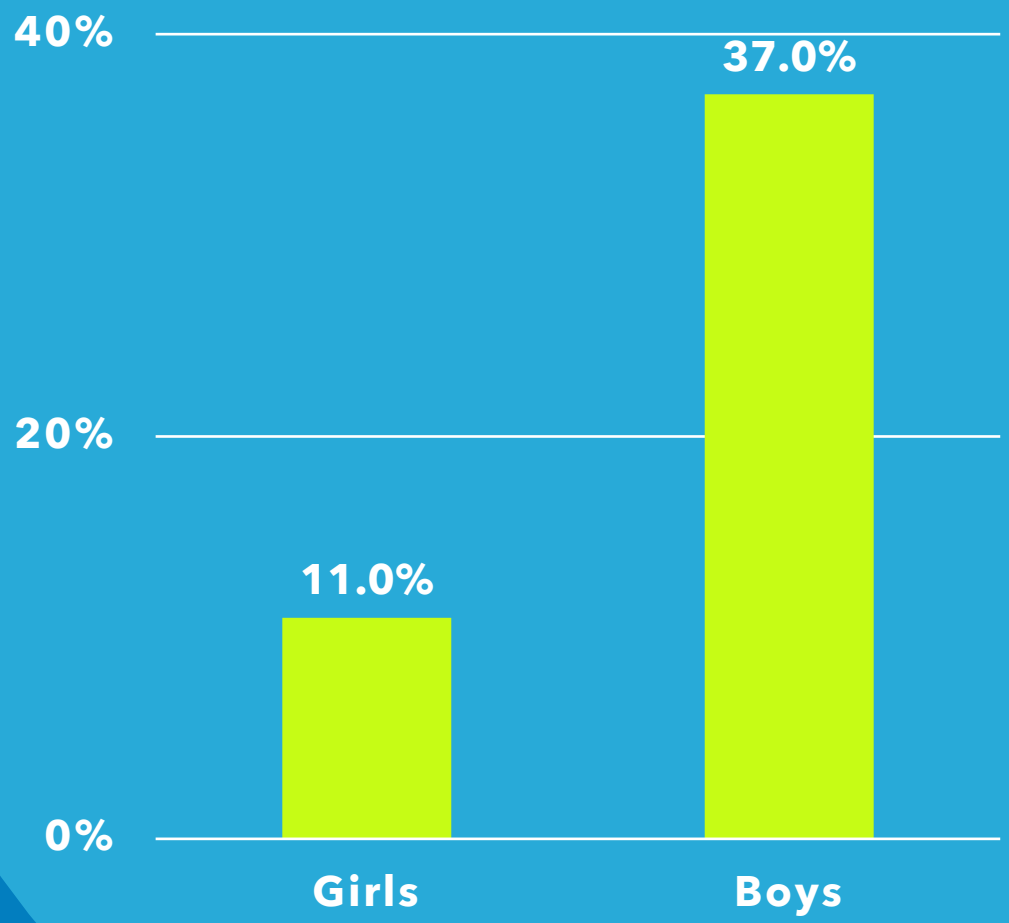
Download files here!

TARGET AUDIENCE

- Age 13: milestone development age
- Need role models to break gender stereotypes associated with STEM careers
- Care about the environment and climate change
- Looking for purpose

"Diverse teams make better decisions up to 87% of the time"

EXPRESSED INTEREST IN STEM



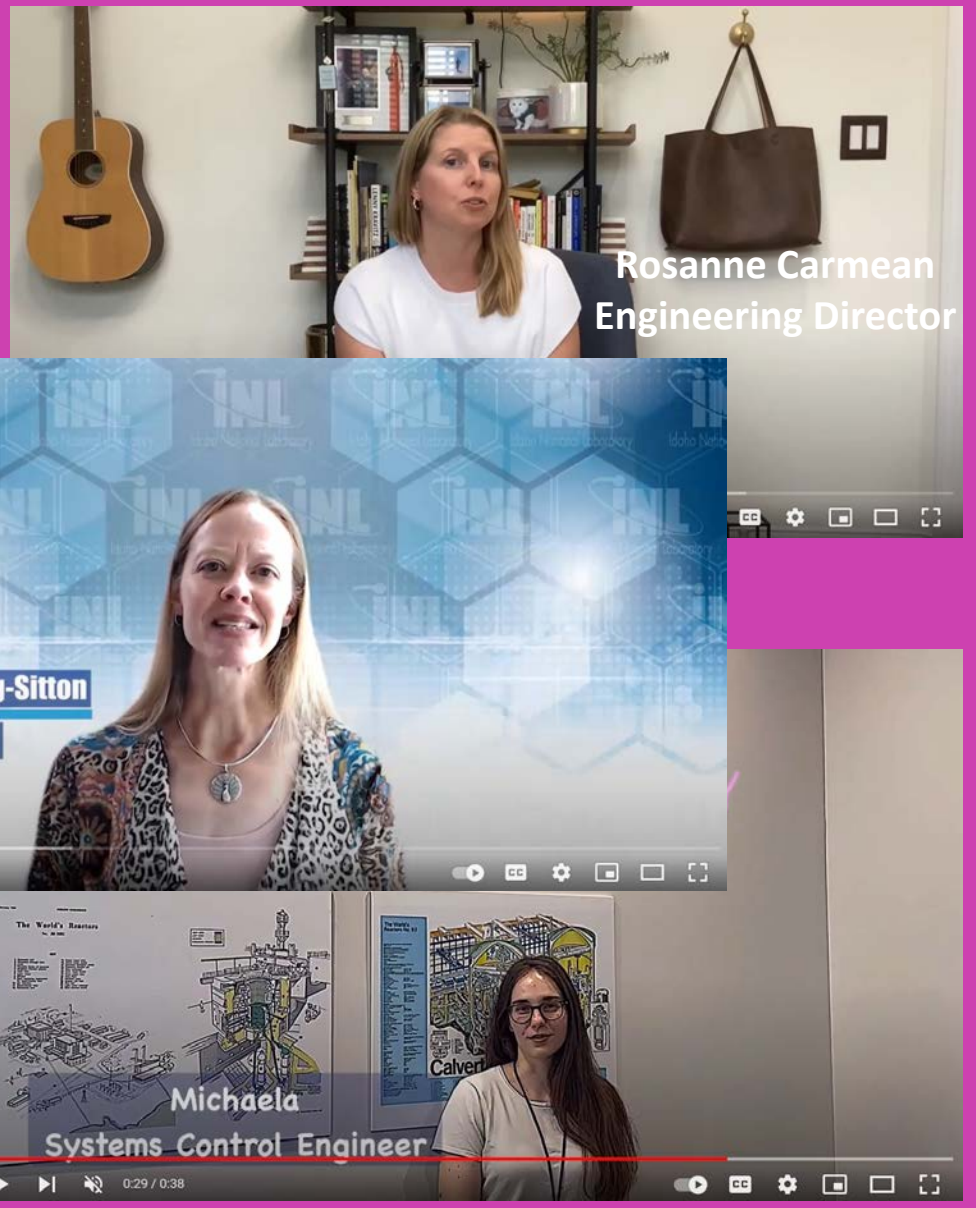
Source: https://heartofleadership.org/statistics/

NUCLEAR FACT SHEET

- 8th graders do not learn, talk or pay attention the same way adults do. To engage them, we have created an interactive Fact Sheet including:
  - *Fun facts about nuclear*
  - *Career exploration information*
  - *Virtual tours of nuclear facilities*
  - *Influencer nuclear videos*

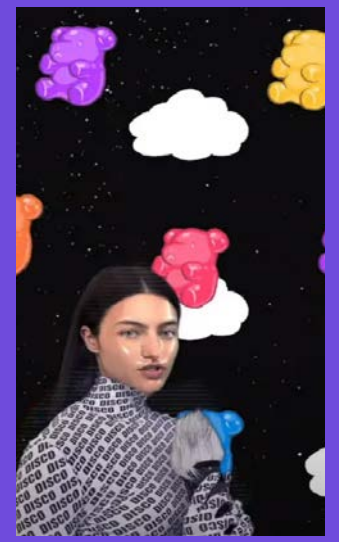
INSPIRATIONAL VIDEOS

- We have assembled a series of inspirational videos of real women in the nuclear industry
- Let's break stereotypes: girls and women can do anything they set their minds to
- Let them ***see*** us to ***imagine*** themselves!



Social Media Videos

- 13-year-olds learn and engage differently. We have curated a list of fun and educational videos that will resonate with them
- Include any of these in your collection for an interactive and appealing approach!



EXPERIMENTS AND ACTIVITIES

- There is no better way to engage 8th graders than with hands-on activities

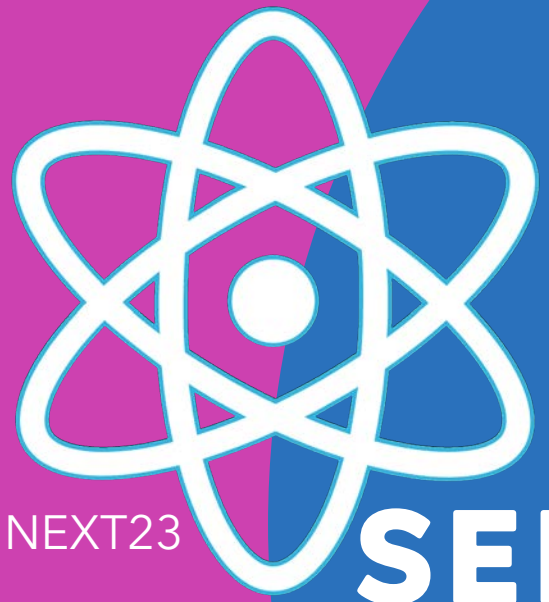
- We have compiled a variety of fun and educational experiments and activities to choose from

SHOPPING AND SOURCING LIST

- A curated list of products to consider as you prepare your own, customized toolkit
- Includes: consumables, experiments, educational items
- Direct link to Amazon shopping cart for convenience
- Preorder a kit by emailing win.next2023@gmail.com

CHOOSE YOUR OWN ADVENTURE

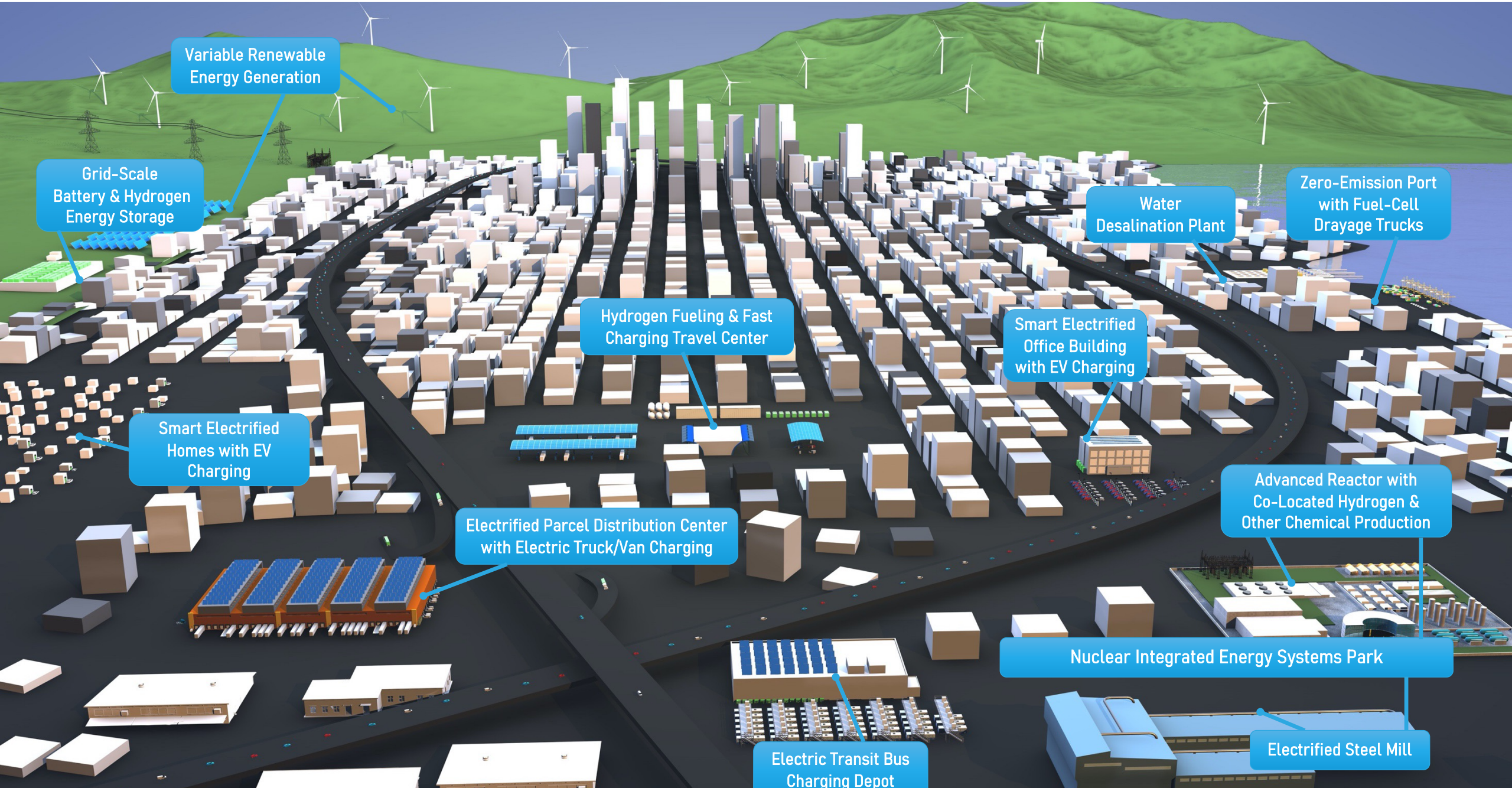
- While discovering who they are and what their **purpose** is, this interactive tool helps 8th graders start thinking about potential **career paths**
- Includes a variety of **alternatives**: from engineering and technicians to marketing and communications



WIN NEXT23

SEE IT TO IMAGINE IT

A vision for a net-zero future



Idaho National Laboratory