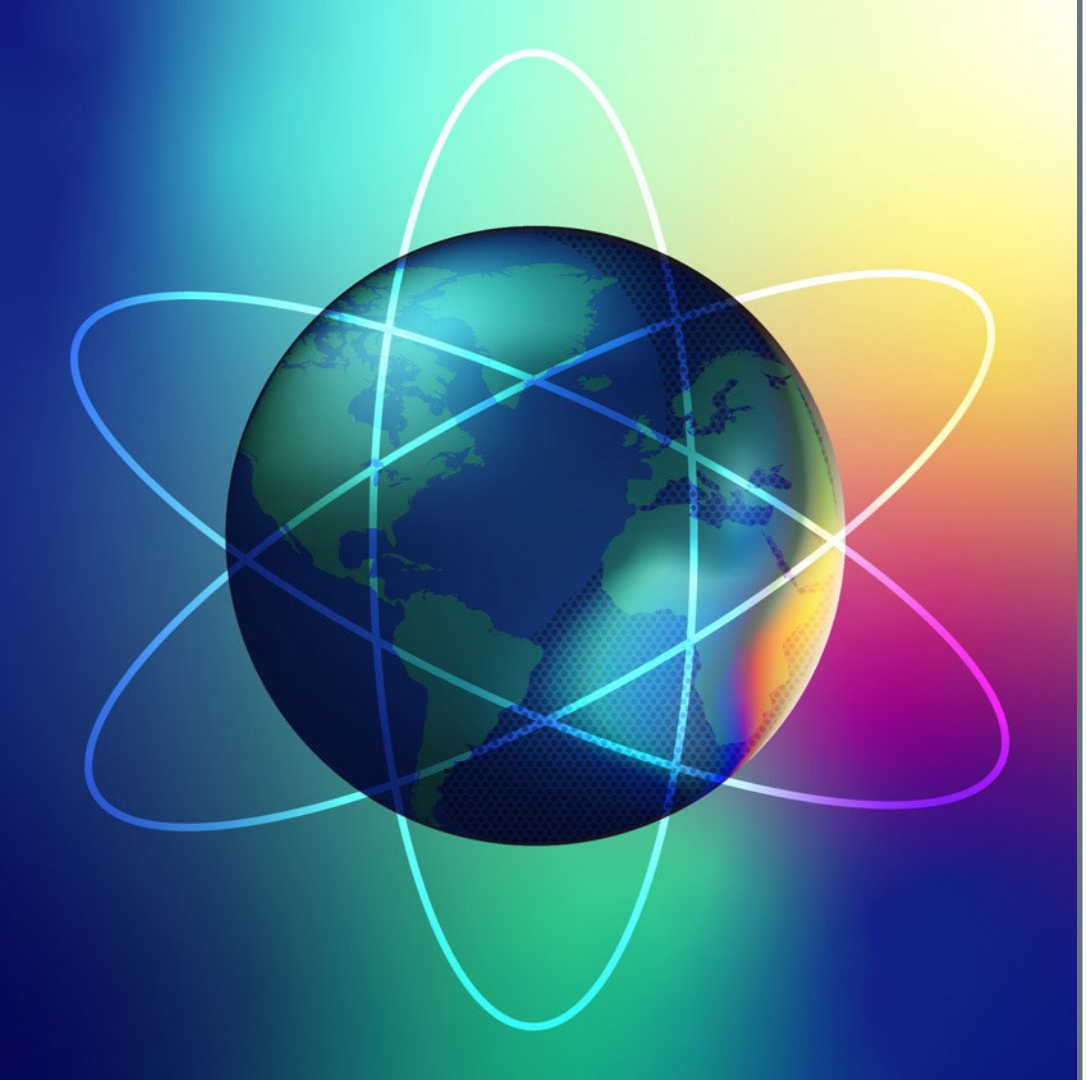


NEI NUCLEAR ENERGY INSTITUTE

Advancements in Nuclear: ANS Northeastern Section Discussion

Ben Holtzman
Director, New Nuclear

January 24th, 2024

300+ Members

Nuclear Utilities

EPCs & Suppliers

Fuel Cycle

Decommissioning

National Labs

Investment & Financial Firms

Advanced Reactors

Universities

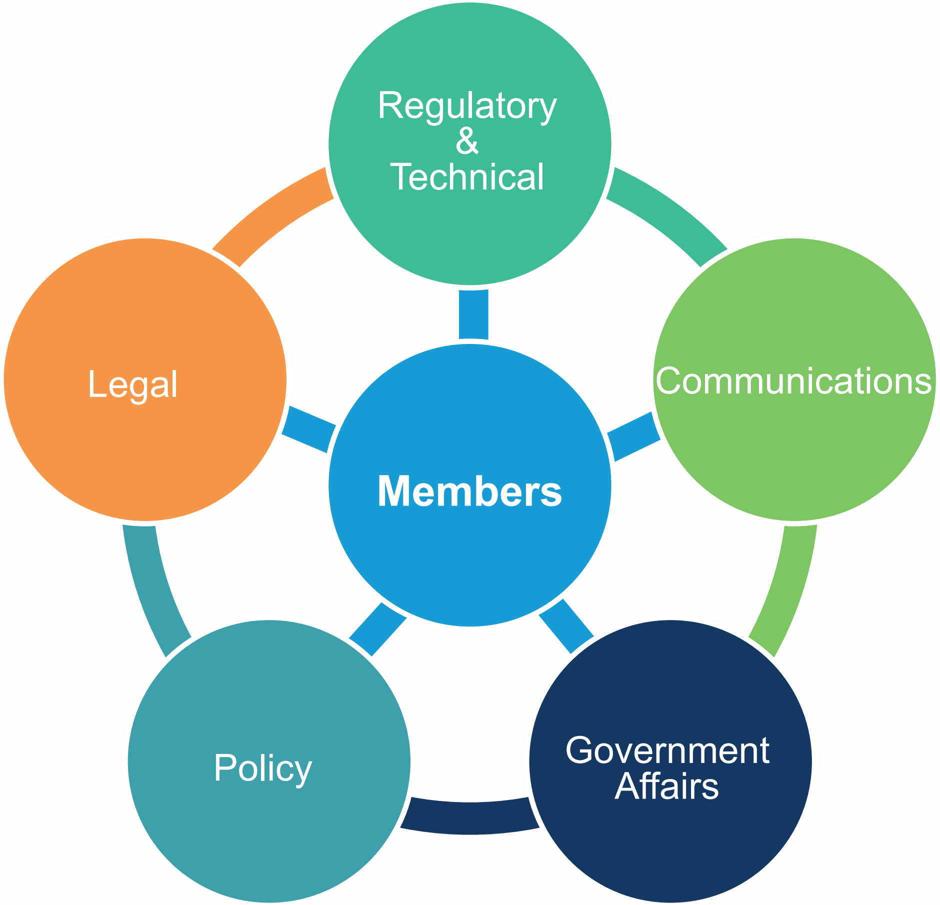
Law Firms

Consultants

Labor Unions

NGOs & Think Tanks

NEI Functions



- Member centric organization
- Diverse, broad membership
- Unique combination of technical, regulatory, and policy capabilities

Presentation Overview

- Nuclear Energy Today
  - Global Energy Challenge
  - Electricity Generation Today
- Advanced Nuclear Designs
  - New Nuclear Designs Overview
  - Fuel Supply
- New Nuclear
  - Future Electric Demand
  - Deployment Plans
  - Licensing Statuses
- Applications
  - Versatility of New Nuclear - Beyond Grid Scale Electricity

Nuclear Energy Today

TAKE YOUR MARKS, GO!

The Global Energy Challenge

Standard of Living

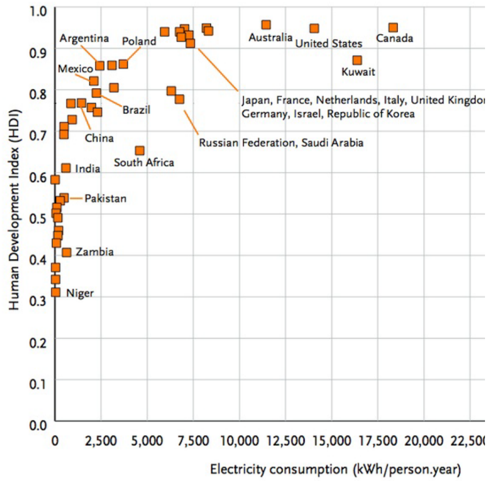
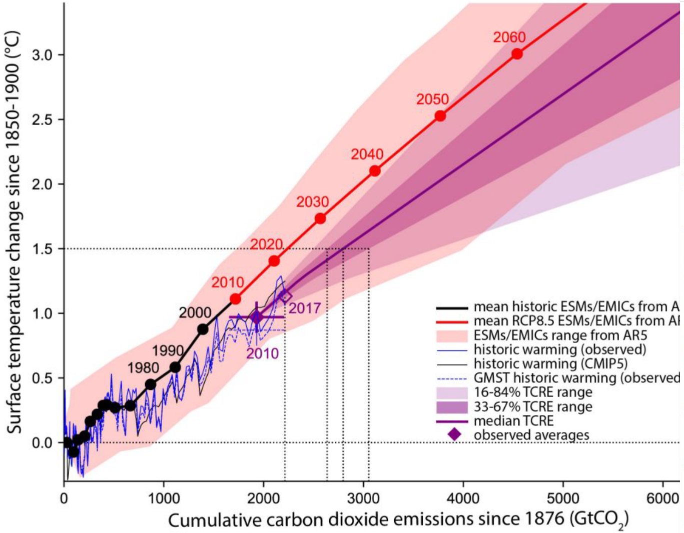


Figure 1.6 Relationship between human development index (HDI) and per capita consumption, 2003 – 2004

Note: World average HDI equals 0.741. World average per capita annual electricity at 2,490 kWh per person.year, translates to approximately 9 gigajoules (GJ)/perso kilowatts (kWh) = 36 GJ]

Source: UNDP, 2006.

Carbon Reduction



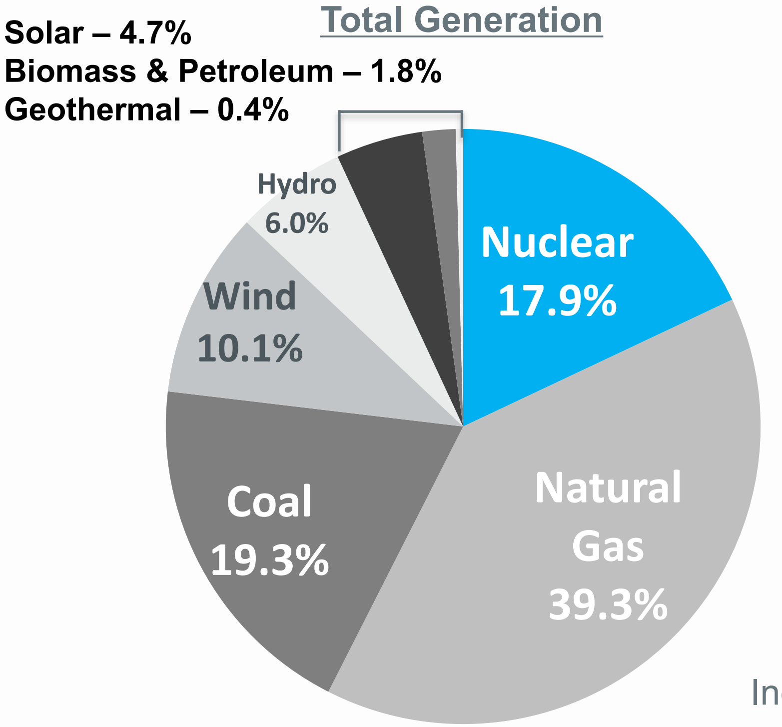
Energy Security

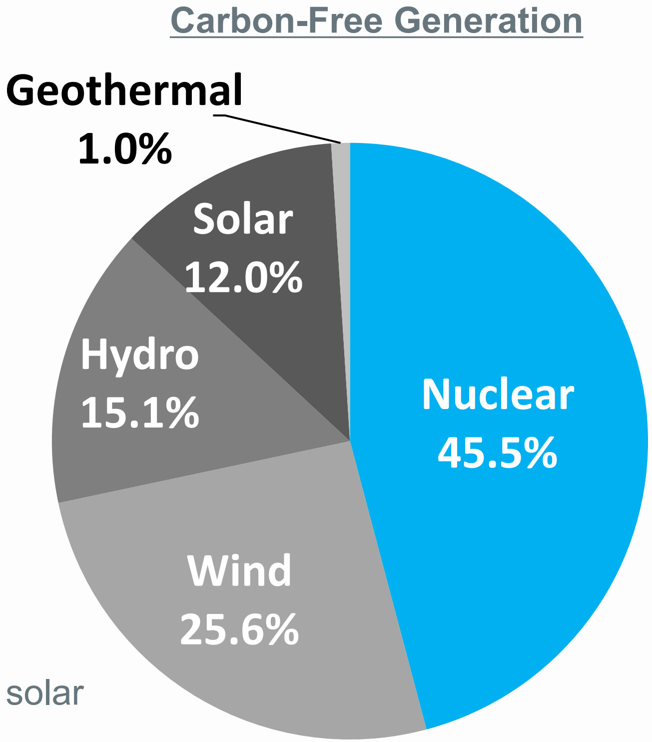
The New York Times

The European Union seeks independence from Russian oil and gas.

Europe had long trusted in what many thought was a mutually beneficial business relationship. That has changed.

Electricity Generation Today

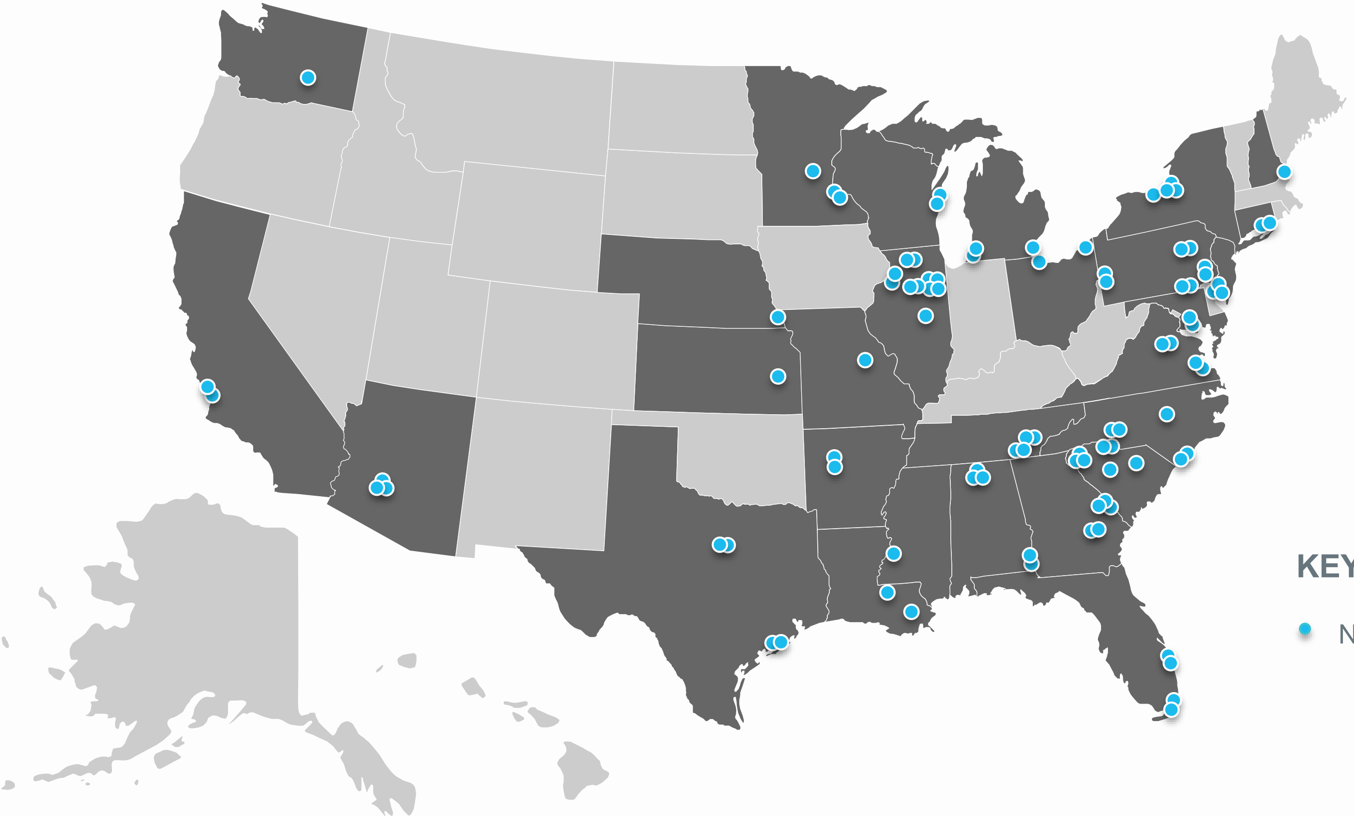




Including rooftop solar

Source: U.S. Energy Information Administration
Updated: March 2023

US Commercial Reactors



KEY

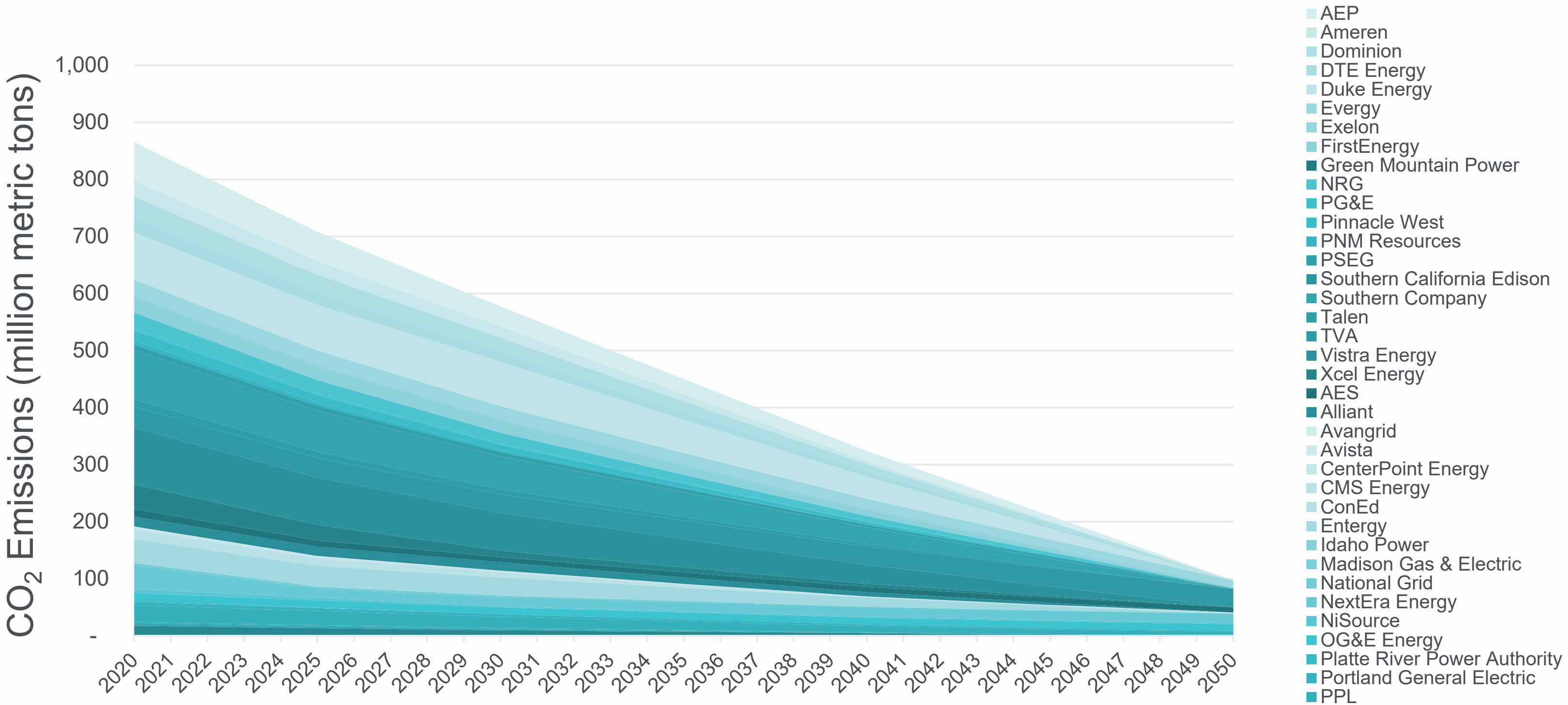
Nuclear power reactor

Updated: May 2023

New Nuclear

THE ENGINE OF TOMORROW

Utility Carbon Emission Projections Based on Pledges



Source: ABB Velocity Suite, U.S. Environmental Protection Agency, utility press releases.

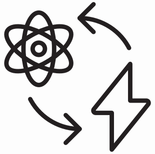
Survey of NEI's U.S. Utilities

Nuclear power's potential role in meeting their company's decarbonization goals:

SLR

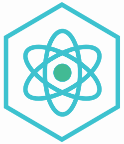
>90% of fleet expects to operate to at least **80 years**

GW



100 GW of new nuclear opportunity by **2050s**

SMRs



Translates to roughly **300 SMR-scale plants**

NEI utility member companies produce nearly half of all US electricity.

Lowest System Cost Achieved by Enabling Large Scale New Nuclear Deployment

NEI

Lowest Cost System

Nuclear is 43% of generation (>300 GW of new nuclear)

Wind and solar are 50%

Energy System with Nuclear Constrained

Wind and Solar are 77% of generation

Nuclear is 13% (>60 GW of new nuclear)

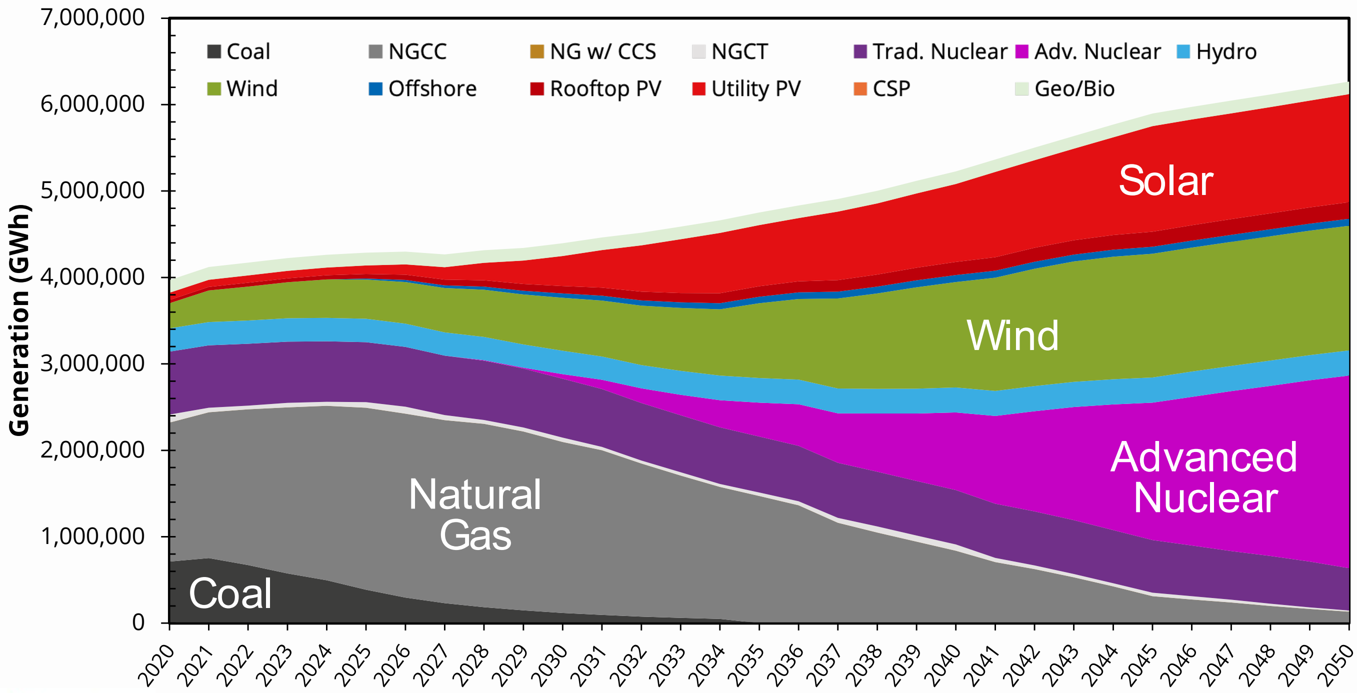
Increased cost to customers of $449 Billion

Both scenarios are successful in reducing electricity grid GHG emissions by over 95% by 2050 and reducing the economy-wide GHG emissions by over 60%

VCE VIBRANT CLEAN ENERGY

Source: Vibrant Clean Energy: https://www.vibrantcleanenergy.com/media/reports/

Modeling Forecast – Nominal Case



Generation: 2,718 TWh
Legacy: 491 TWh
New: 2,227 TWh

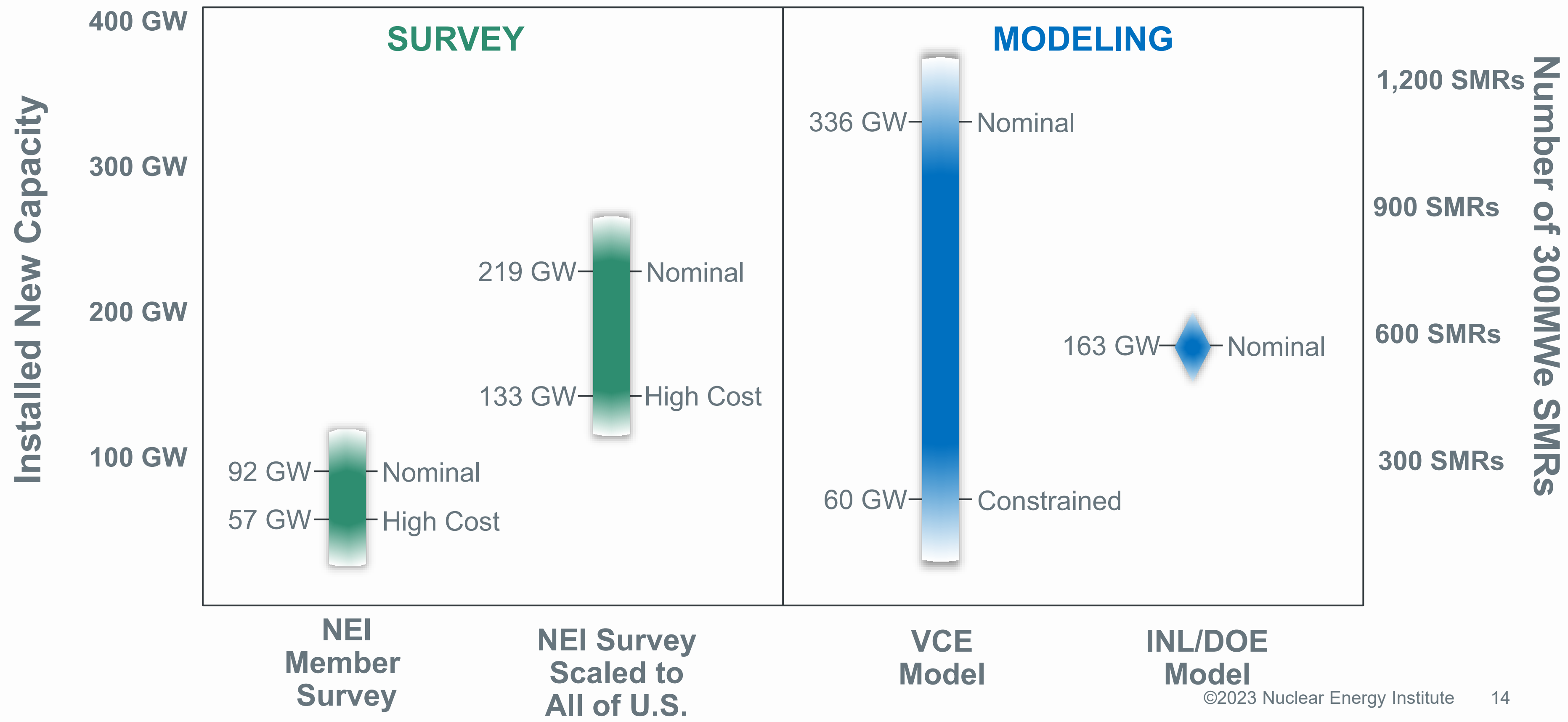
Capacity: 404 GW
Legacy: 67 GW
New: 336 GW

Share: 43%

Converted Fossil: 271

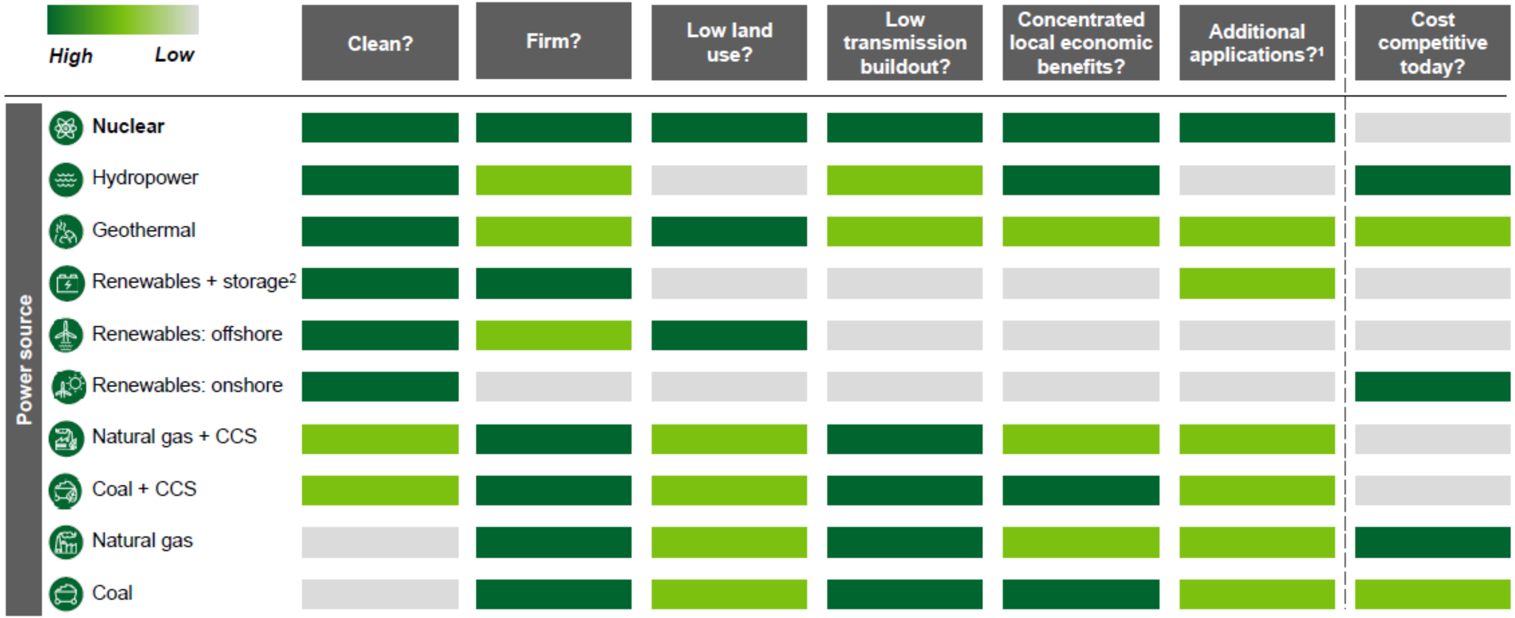
Scan to view the complete study.

Triangulating New Nuclear Demand – Grid Only



DOE Liftoff Report

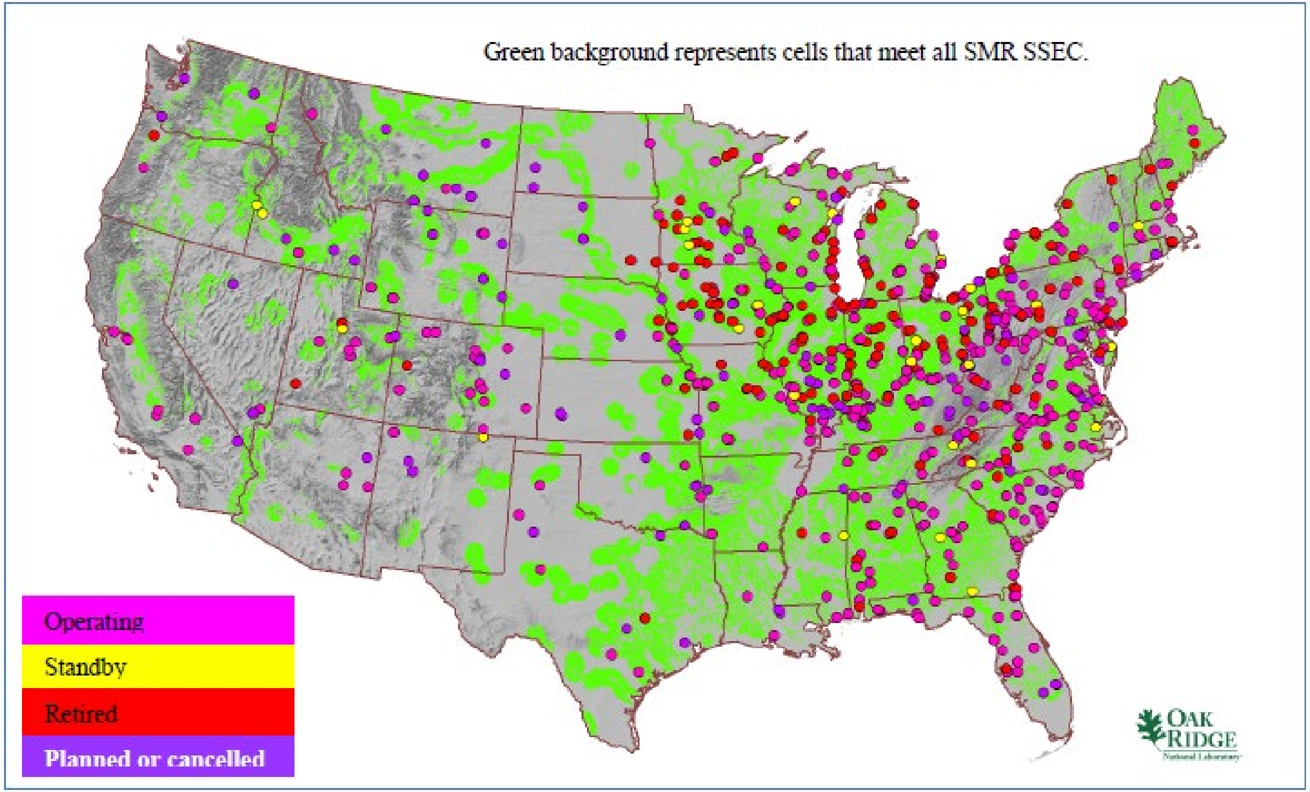
Nuclear has a unique value proposition for the net-zero grid



1. Additional applications include clean hydrogen generation, industrial process heat, desalination of water, district heating, off-grid power, and craft propulsion and power
2. Renewables + storage includes renewables coupled with long duration energy storage or renewables coupled with hydrogen storage

U.S. DEPARTMENT OF ENERGY 4

Coal Plants and SMR Suitability



Source: ORNL, *Evaluation of Suitability of Selected Set of Coal Plant Sites for Repowering with Small Modular Reactors*, March 2013

Similar Jobs and Limited Retraining

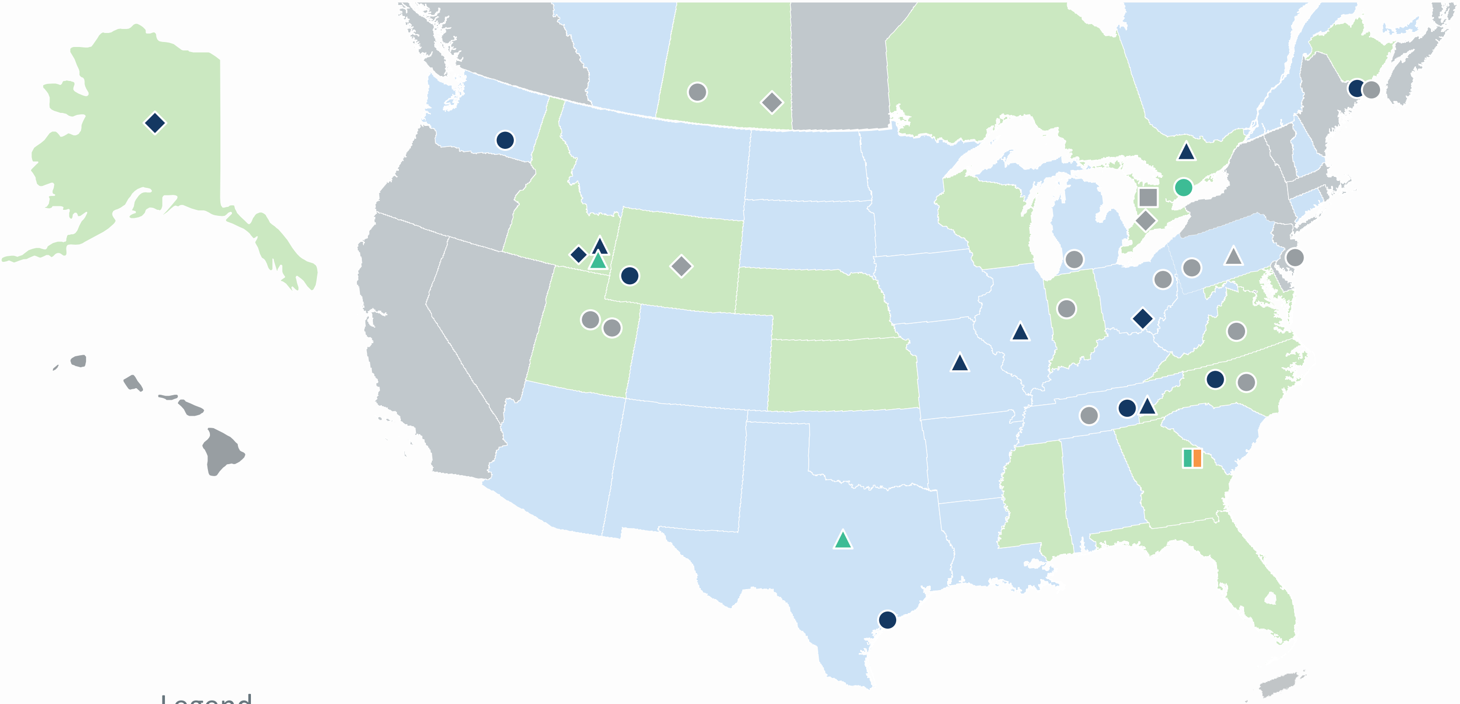
Coal Plant Position	# Dedicated Coal Positions	SMR Position	# Dedicated SMR Positions	Position Type	Degree of Retraining Required
Operations Supervisor	5	Senior Reactor Operator	5	Supervisor	High
Control Room Operator	10	Reactor Operator	15	Operator	High
Field Operator	15	Non-Licensed Operator	25	Operator	Low
Lab Operator/Chemistry/Scrubber	4	Chem Tech	14	Craft	Medium
Maintenance Supervisor	2	Maintenance Supervisor	3	Supervisor	Medium
Mechanical Craft	12	Mechanical Craft	21	Craft	Low
I&C Craft	9	I&C Craft	10	Craft	Medium
Electrician Craft	5	Electrician Craft	11	Craft	Low
Technician	11	Technician	13	Laborer	Low
Security Officer	20	Security Officer	48	Laborer	Low
Sub-Total	**93**		**165**		
All Other Positions	14		72	42 are O&M Support (Planners, Outage, etc.)	Medium
Total On-Site Positions	**107**		**237**		
Possible Centralized Positions			33		
Total Positions			**270**		

Source: NuScale and Scott Madden, *Gone with the Steam*

Advanced Nuclear Deployment Plans

State support and projects that may be in operation by early 2030s

Updated 12/19/2023



Legend

State Actions – Substantive Incentives

State Actions – Supportive and Exploring

Considered project

Planned project

Under construction

Operating

Large (1,000 MWe)

Small (<300 MWe)

Micro-reactor (<50 MWe)

University / Research / Test

Advanced Reactor Deployment Plans (1/4)

Grid-scale reactors (1/2)

Updated 11/16/2023

NEI

Developer	Utility / User	Location	Size	Target Online
NuScale	Standard Power	PA and OH, USA	12 @ 77 MWe (2 plants)	2029
	KGHM Polska Miedz	Poland	6 @ 77 MWe	2029
	Nuclearelectrica	Romania	6 @ 77 MWe	2028
GEH BWR X-300	OPG	ON, Canada	4 @ 300 MWe	2028
	TVA	TN, USA	4 @ 300 MWe	2032
	Synthos & Orlen	Poland	300 MWe (>10 plants)	Early 2030s
	SaskPower	Sask., Canada	~300 MWe (4 plants)	2032 to 2042
Holtec SMR-160	TBD	NJ, USA	160 MWe	2030
	TBD	MI, USA	2 x 160 MWe	2032
	Entergy	Gulf Coast, USA	160 MWe	Early 2030s

Advanced Reactor Deployment Plans (2/4)

Grid-scale reactors (2/2)

Updated 11/16/2023

Developer	Utility / User	Location	Size	Target Online
X-energy	Dow	Texas, USA	4 @ 80MWe	2030
	Energy Northwest	Washington, USA	80 MWe (up to 12)	2030
TerraPower	Pacific Corp.	Wyoming, USA	345 – 500 MWe	2030
ARC	NB Power	NB, Canada	100 MWe	2030
Moltex	NB Power	NB, Canada	300 MWe	2032
TBD	Duke Energy	NC, USA	TBD	2034
TBD	Purdue/Duke Energy	Indiana, USA	TBD	TBD

Advanced Reactor Deployment Plans (3/4)

Micro-reactors and low scale test reactors (1/2)

Updated 11/16/2023

Developer	Utility / User	Location	Size	Target Online
Oklo	Oklo	Idaho, USA	15 MWe	2026
	Oklo	Ohio, USA	2 @ 15 MWe	2028
	Compass Mining	TBD	TBD (150 MWe total)	TBD
Ultra Safe Nuclear	Global First / OPG	CRL, Canada	5 MWe	2025
	University of Illinois	Illinois, USA	5 MWe	2027
Westinghouse	Sask Research Council	West Canada	5 MWe	2027
	Bruce Power	ON, Canada	5 MWe	2027
	Penn State University	USA	5 MWe	2027

Advanced Reactor Deployment Plans (4/4)

Micro-reactors and low scale test reactors (2/2)

Updated 11/16/2023

NEI

Developer	Utility / User	Location	Size	Target Online
Radiant	TBA	Idaho, USA	1.2 MWe	2026
BWXT	DoD SCO	Idaho, USA	1.5 MWe	2024
	Tata Mining	Wyoming, USA	TBD	TBD
Kairos Power	Kairos	TN, USA	3 @ 35 MWth	2026
Natura	Abilene Christian University	TX, USA	1 MWth	2025
TBD	Univ. of Missouri	MO, USA	TBD	TBD
TBD	Eielson AFB	Alaska, USA	1 – 10 MWe	2027

North American Customer Interest (1/2)

Updated 11/02/2023

Utility/Customer	Recent Public Expressions of Interest in SMRs
Dominion	• 2023 Integrated Resource Plan identifies need for up to 4.8 GWe by 2050, first plant online in 2034
Dow	• Investment in X-energy and deployment of Xe-100 by 2030 for electricity and process heat
Duke	• Pursuing Early Site Permit in North Carolina, plans for 7.7 GWe between 2032 and 2048
Energy Northwest	• Considering deployment of advanced reactors
Entergy	• Plans for SMR-160 by early 2030's
NB Power	• Plans for ARC-100 and Moltex MSR by early 2030's
NPPD	• SMR feasibility and potential site study
NuCor Steel	• Investment in NuScale and interest in deployment for electricity
OPG	• Submitted Construction Permit application for BWRX-300 at Darlington for operation by 2029
PacifiCorp	• Deployment of Natrium by 2029, and IRP includes 2 more plants

North American Customer Interest (2/2)

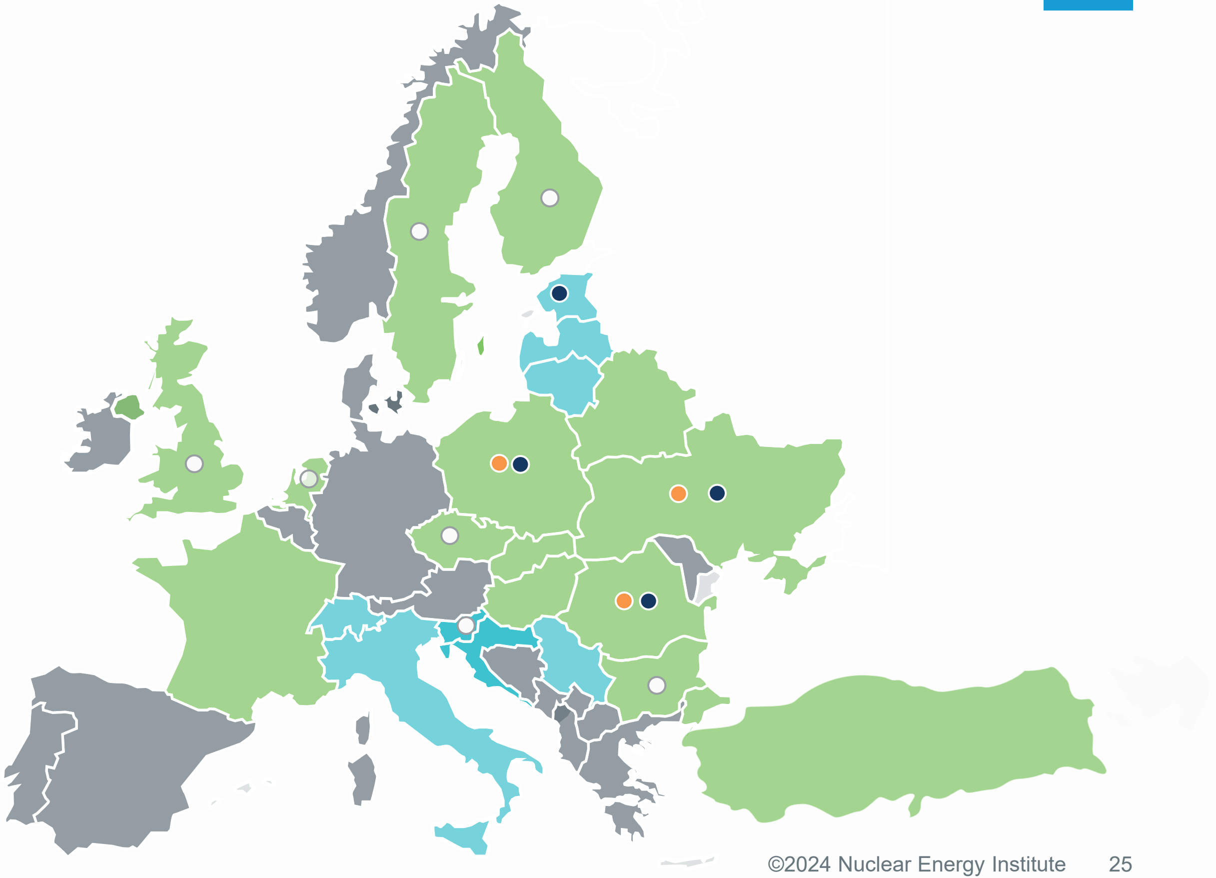
Updated 11/02/2023

Utility/Customer	Recent Public Expressions of Interest in SMRs
SaskPower	• Selected BWRX-300 for future deployment
Standard Power	• Selected NuScale for 2 plants of 12-pack in OH and PA by 2029
TATA Mining	• Working with BWXT for feasibility study for use in Wyoming mining operation
TVA	• Construction Permit application for BWRX-300 at Clinch River in late 2023
Universities	• Univ. of Illinois, Penn State, Purdue, Abilene Christian University, Univ. of Missouri – Columbia
US Government	• Air Force pursuing micro-reactor in Alaska
Others	• Dairyland Power, Grant County PUD, Copper Valley, Compass Mining, Sask Research Council,

U.S. Advanced Nuclear Deployment – Europe

KEY

- National policies to support new nuclear in place
- National policies to support new nuclear under consideration
- U.S. supplier selected for one or more SMR projects
- U.S. supplier selected for one or more large reactor projects
- Near-term commercial opportunity for large and/or SMR projects



Advanced Reactor Licensing Progress

NEI

Approved

- NUSCALE™ – Power for all humankind

Under Review

- Kairos Power
- NUSCALE™ – Power for all humankind
- Natura Resources – SUSTAINABLE ENERGY

Pre-Application

- Kairos Power
- TerraPower
- GE HITACHI
- TERRESTRIAL ENERGY
- GENERAL ATOMICS
- USNC – ULTRA•SAFE•NUCLEAR
- HOLTEC INTERNATIONAL
- X energy®
- OKLO
- Westinghouse

Advanced Reactor Deployments

2024

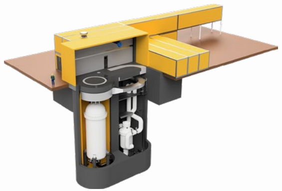
INL MARVEL

2025

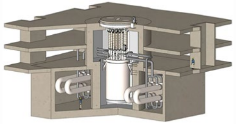
DoD Pele/BWXT

Oklo Aurora

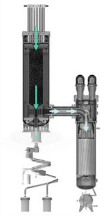
2026



USNC MMR®

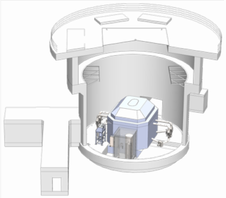


Kairos Hermes

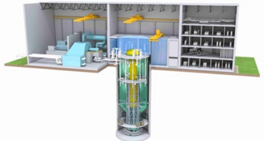


X-energy Xe-100

Southern Co./ TerraPower MCRE



2030



GEH BWRX-300

TerraPower Natrium™

Advanced Nuclear Designs

LET'S TALK ABOUT TECH

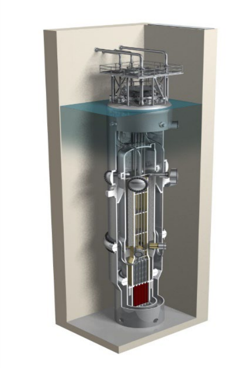
Types of Advanced Reactors

Range of sizes and features to meet diverse market needs

Micro Reactors
< 20MWe

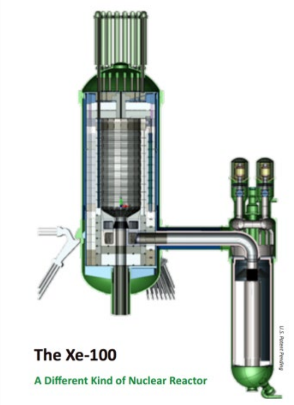
Oklo (shown)
Approximately a dozen in development

LWR SMRs
<300MWe



NuScale (shown)
GEH BWRX-300
Holtec SMR-160
Westinghouse AP300

High Temp Gas Reactors

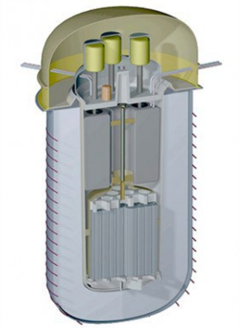


X-energy (shown)
Several in development

Liquid Metal Reactors

TerraPower Natrium™ (shown)
Several in development

Molten Salt Reactors



Terrestrial (shown)
Several in development

Non-Water Cooled
Most <300MWe, some as large as 1,000 MWe

Learn more about innovative technologies with the Nuclear Innovation Alliance.

Technology Developers – NEI Members

ADNA Corporation
Accelerator Driven Neutron Applications

ALPHA NUR

GE HITACHI

Muons, Inc.
Innovation in Research

TerraPower

Alpha Tech Research Corp

GENERAL ATOMICS

newcleo
Futurable Energy

TERRESTRIAL ENERGY

USNC
ULTRA•SAFE•NUCLEAR

arc
CLEAN TECHNOLOGY

HOLTEC INTERNATIONAL

NuGen

NUSCALE™
Power for all humankind

Westinghouse

BWXT
BWX Technologies, Inc.

Kairos Power

OKLO

X energy®

EXODYS ENERGY

LAST ENERGY

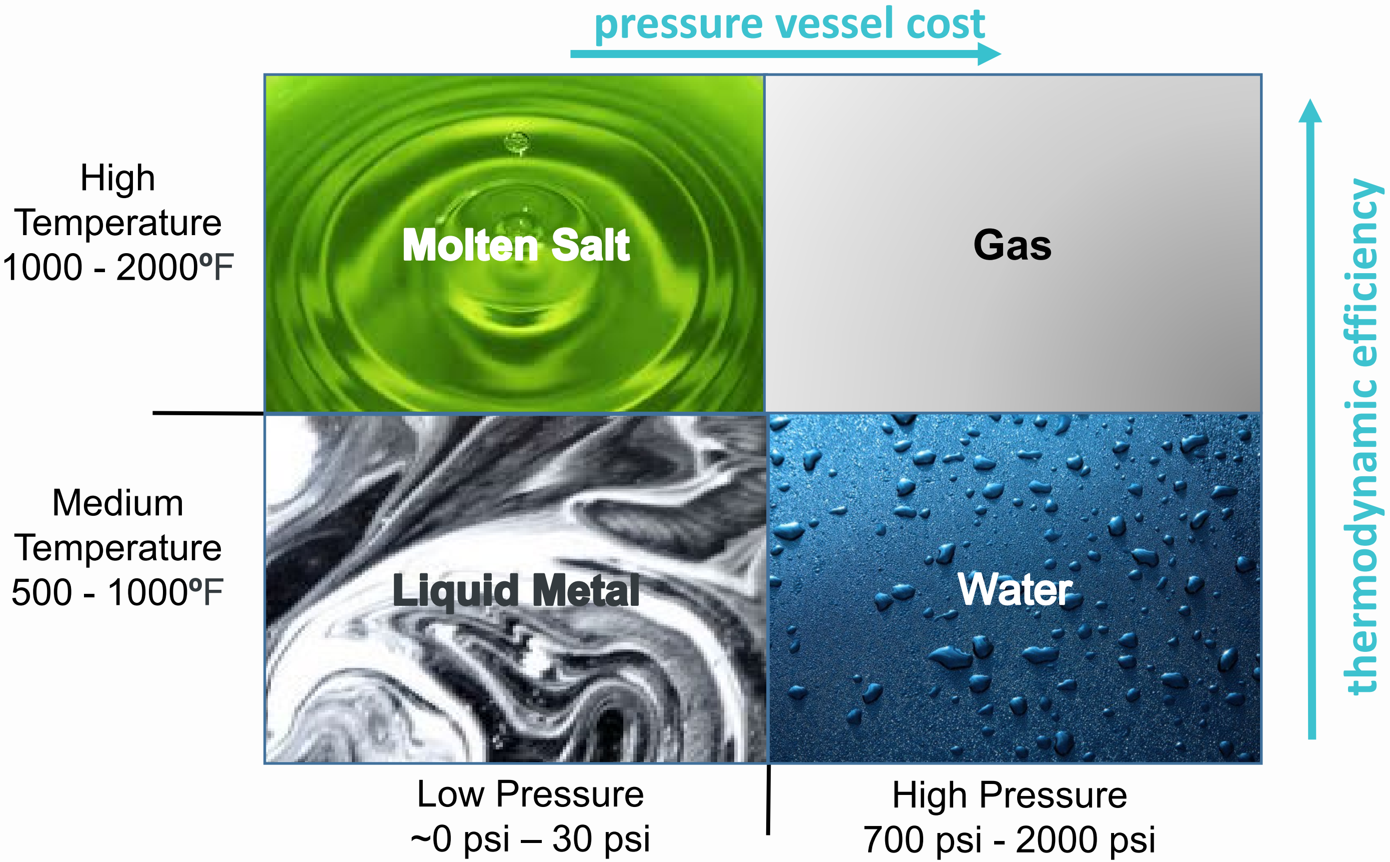
framatome

moltex
clean energy

RADIANT

ZENO
POWER SYSTEMS

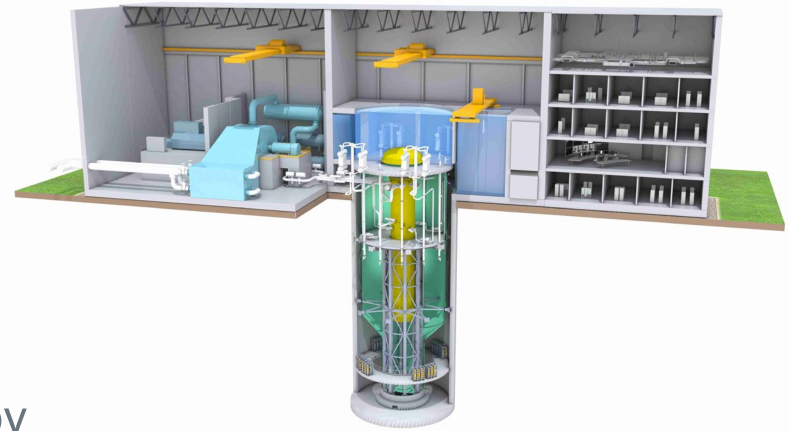
Technology - Coolant Choice



GEH BWRX-300

Light-Water SMR

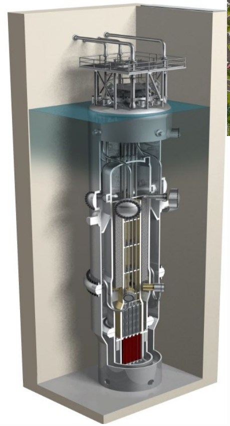
- 350 MWe
- Leverages NRC approved ESBWR
- 7 days of cooling without power or operator actions
- Novel construction techniques
- Designed to be cost competitive with combined cycle natural gas
- Existing fuel design
- Ontario Power Generation plans to deploy around 2028



NuScale VOYGR™ Reactor

Light-Water SMR

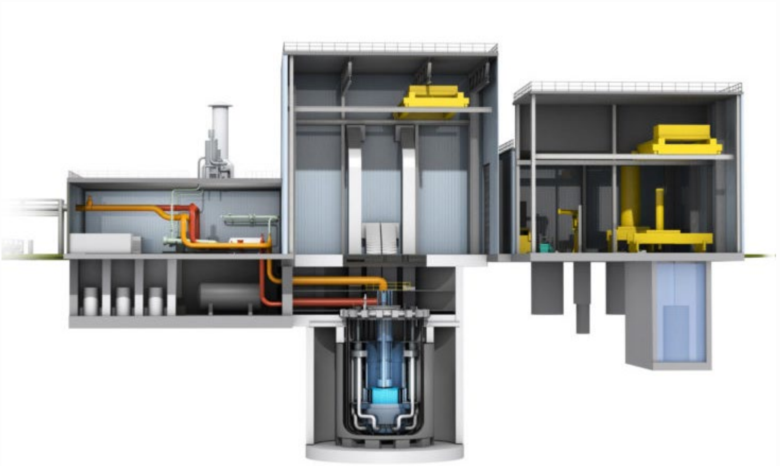
- 308 MWe to 924 MWe gross
  - Four to 12 modules - 77 MWe each
- Rapidly adjusts power output with individual modules
- NRC completed review of Design Certification – 2020
- Ability to safely shut down and self-cool, indefinitely
- Air cooling for condensers is an option
- Existing fuel design

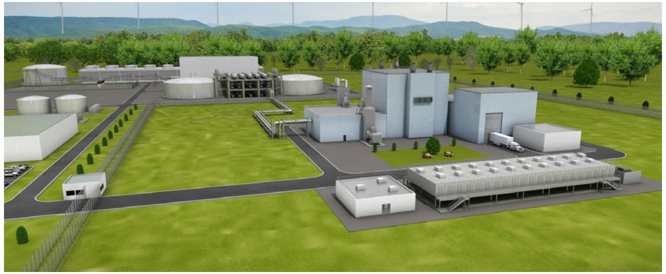


TerraPower/GEH - Natrium™ Reactor

Liquid Sodium Fast Reactor (SFR)

- 345 MWe
  - Molten salt thermal storage for peaking to 500 MWe
- Requires HALEU – metallic fuel
- Possible higher temperature, non-electricity applications
- Innovative construction methods
- PacifiCorp plans to deploy around 2028 at Kemmerer, WY – retiring coal facility

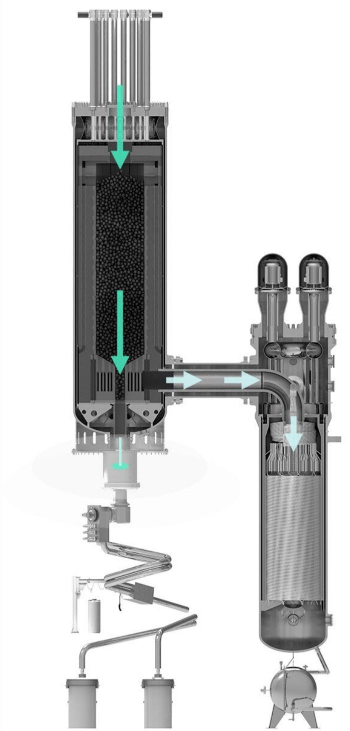




X-energy Xe-100

[High Temperature Gas Cooled SMR]

- 320 MWe
  - 4 modules @ 80 MWe each
- Requires HALEU for TRISO fuel
  - Online Refueling
- Possible high temperature, non-electricity applications
- Dow plans to deploy Dow's industrial Seadrift, TX site for cogeneration around 2027

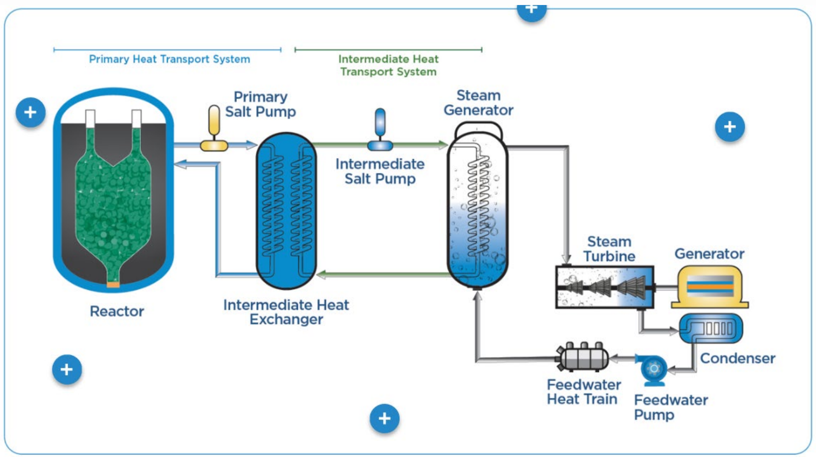


Kairos Power – Hermes Test Reactor

NEI

Molten Salt Cooled SMR

- 35 MWth – will not produce electricity
  - Commercial reactor will be 140 MWe
- Molten salt coolant with TRISO fuel pebbles (requires HALEU)
- Possible high temperature, non-electricity applications
- NRC Part 50 construction permit application accepted for review in November 2021
  - Complete review September 2023
- Location: Oak Ridge, Tennessee
  - Operational: 2026

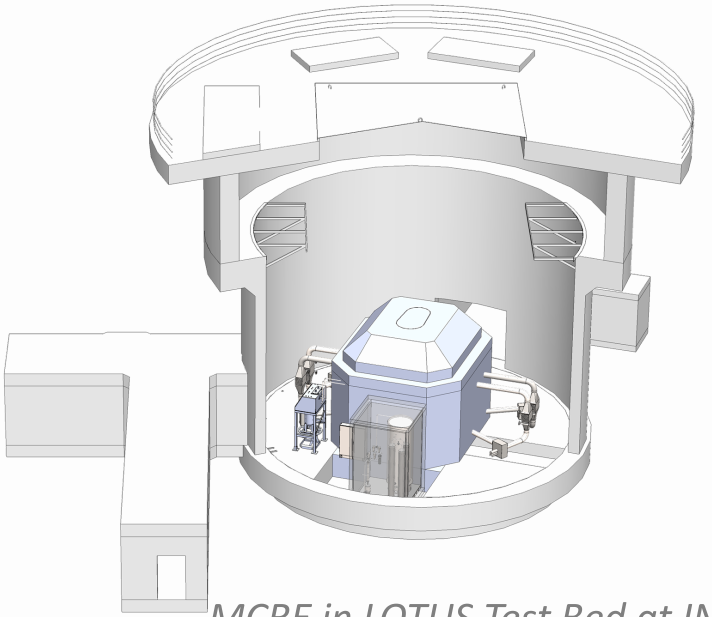


Molten Chloride Reactor Experiment

Southern Company TerraPower CORE-POWER orano 3M EPRI

Molten Salt Cooled SMR

- Will lay the foundation for Molten Chloride Fast Reactor (MCFR) liquid fueled demonstration reactor
- Confirm key physics phenomena
- INL sited & DOE authorized
- Multi-year cost share partnership with DOE
- Year 5 critical operations



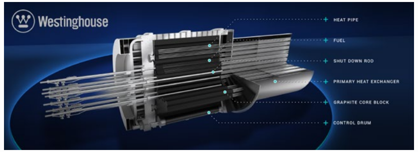
MCRE in LOTUS Test Bed at INL

Micro Reactor Technology

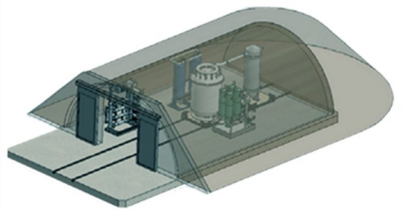
Designed to replace Diesel Generators

Oklo Aurora
15 MWe

Ultra Safe Nuclear Corporation
5 MWe



Westinghouse eVinci™
5 MWe



BWXT BANR
17 MWe

- Very small size
  - Site as small as 0.1 acres, building ~size of a house
  - Reactor is road shippable, minimal site work
- Resilience – withstand, mitigate or quickly recover from
  - Extreme natural events
  - Man-made physical and cyber threats
- Operations
  - Automatic operations, island mode and black-start
  - Flexible – hybrid energy and renewables integration

<u>Other Designs (not all inclusive)</u>

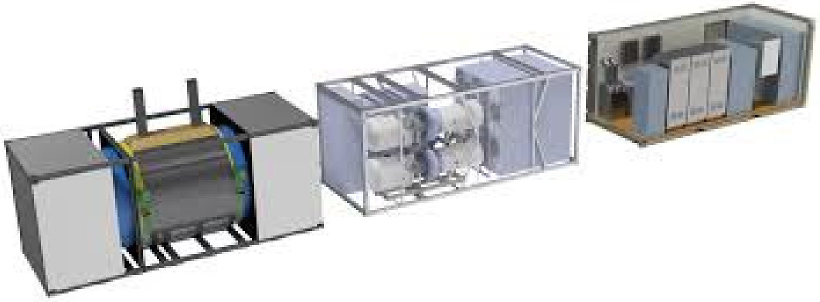
- General Atomics
- HolosGen
- Hydromine
- NuGen
- NuScale
- Radiant
- X-energy

Oklo Aurora

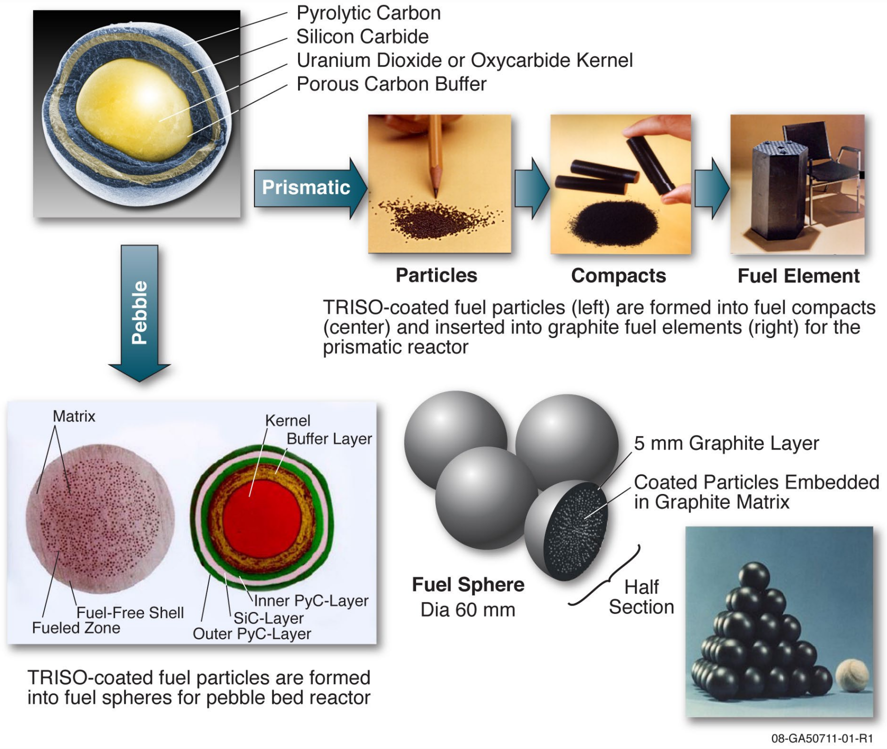
- Heat and electricity
- Sodium Fast Reactor
- Metallic HALEU fuel
- 15 MWe
- 10+ years before refueling
- Demonstration at Idaho National Lab around 2026

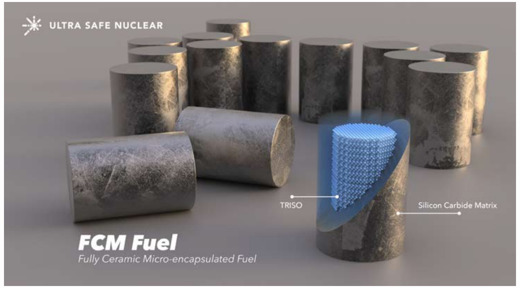
Westinghouse eVinci™

- Heat and electricity
- 1-5 MWe
- Heat pipe cooled
- 8+ years before refueling
- Fully factory built, fueled and assembled
- Target less than 30 days onsite installation
- TRISO Fuel
- Multi-year cost share partnership - DOE portion $7.4 million



Key Enabling Tech – TRISO Fuel

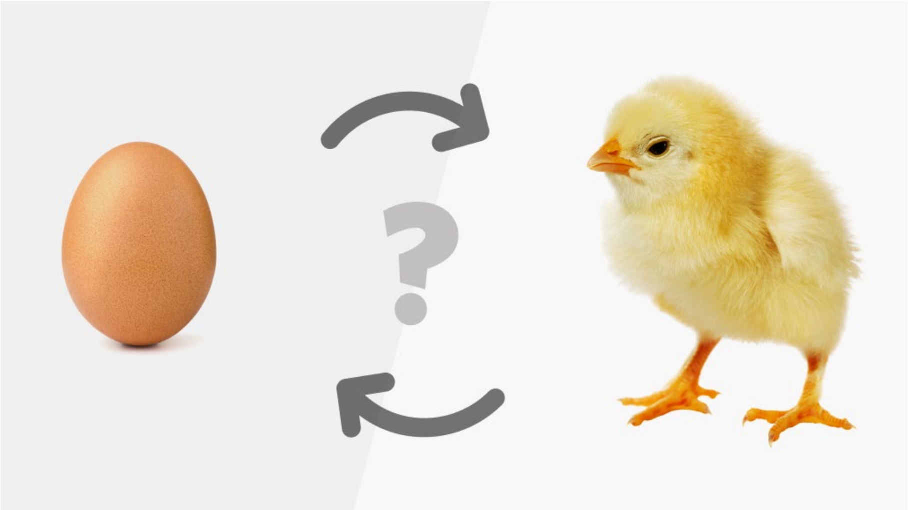




- Provides containment and can withstand temperatures well above accident conditions
- Higher operating temperatures – more efficient
- On-line refueling possible
- Passive decay heat removal

Challenges to Establishing Future Front End Fuel Cycle

- Technology is not the problem
- Market development and infrastructure investment (enrichment and transportation) is the challenge



HALEU for Industry – Two Uses

- Existing fleet
    - Between 5% and 10%
    - Extending burnup and time between outages
    - Confident in pathway for enrichment and transportation
- Advanced reactors
    - Between 10% and 20%
    - Needed by most but not all advanced non-LWR reactors and some advanced fuels for existing fleet
    - Enrichment, deconversion, and transportation challenges

Industry Needs Reported in 2021

- Letter to Secretary Granholm December 20, 2021
- Values in MTU
- Current fleet uses about 2000 MTU/year
- Data from ten companies
- Does not include enrichments below 10% for LWR fleet
- Not all ARs or advanced fuels need HALEU

Year	Annual	Cumulative
2023	7.7	9.5
2024	18.0	27.5
2025	25.8	53.3
2026	72.1	125.4
2027	78.7	204.1
2028	130.8	334.9
2029	151.7	486.6
2030	215.0	701.6
2031	252.3	954.0
2032	375.3	1329.2
2033	454.2	1783.4
2034	527.1	2310.5
2035	613.8	2924.3

Russian Reliance – A Dangerous Game

Third Way

Applications

A DEPLOYMENT STORY: GRID SCALE ELECTRICITY AND MORE

Advanced Nuclear Versatility

NEI

Spectrum of Sizes and Options

Micro

Small

Large

Variety of Outputs

Electricity

H_2 Hydrogen

Process Heat

Multitude of Uses

Homes

Vehicles

Businesses

Aviation

Rail

Shipping

Concrete

Steel

Factories

Water

Space

NEI

Learn more about new nuclear.

New Market Opportunities

DoD Pursuit of Micro-Reactors

Movable

Project Pele

RFP (2019) → Operate (2024) → Fleet (TBD)

https://www.cto.mil/pele_eis/

Fixed

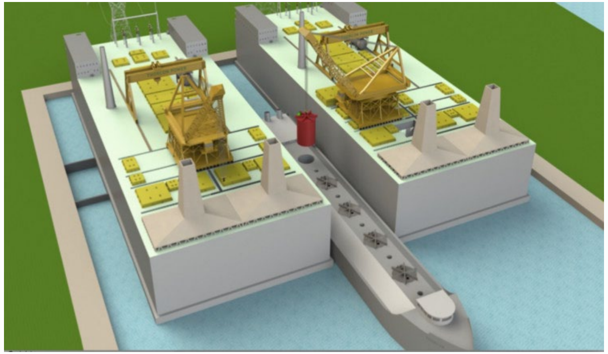
Eielson Air Force Base

RFP (2023) → Construct (2025) → Operate (2027)

https://www.eielson.af.mil/microreactor/

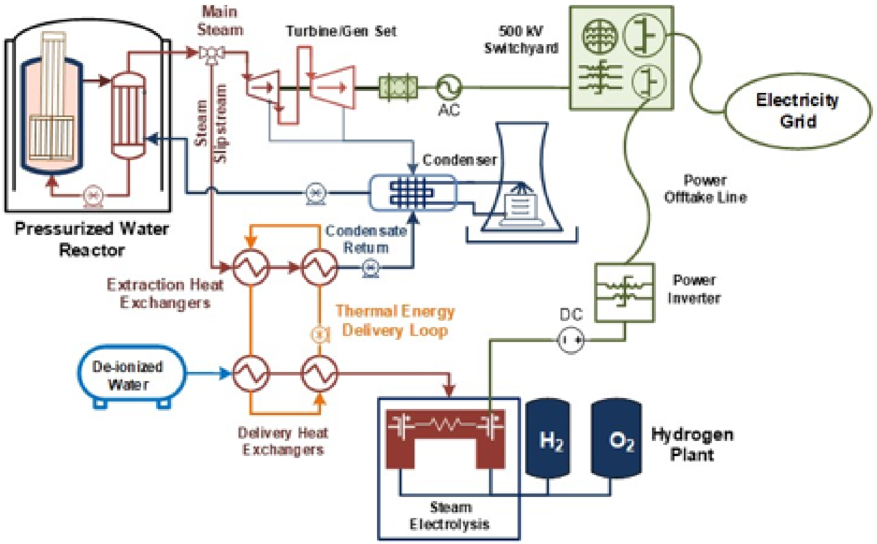
Shipboard Reactors

- Reactors are used by various navies but not used for commercial shipping
- Russia commissioned a barge with two pressurized water reactors 35 MWe each
- Other shipboard reactors designs
  - Seaborg – molten salt – 200-800 MWe
  - Core Power working with TerraPower and Southern Company – molten salt fast reactor
  - Prodigy Clean Energy working with NuScale – pressurized water reactor
  - Thorcon – molten salt thorium reactor – two 250 MWe reactors



Hydrogen Generation Using Existing Reactor Fleet

- Constellation, Energy Harbor, Xcel Energy, and Arizona Public Service have received DOE awards
- Will demonstrate hydrogen production from large light water reactors
- Hydrogen could be used for transportation, industrial processes, storage medium for electricity production

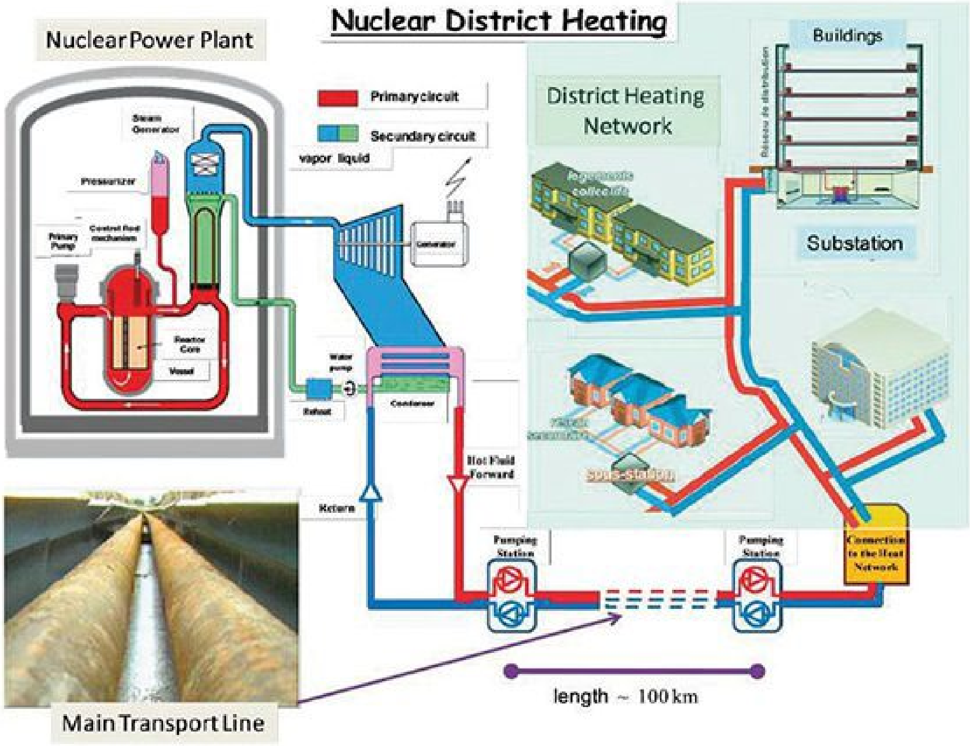


Where is District Energy Used?

- Airports
- Higher Education
- Cities
- Government Facilities
- Healthcare Facilities
- Military Facilities
- Manufacturing Facilities

District Energy Has Been Used for Nearly 150 Years Globally

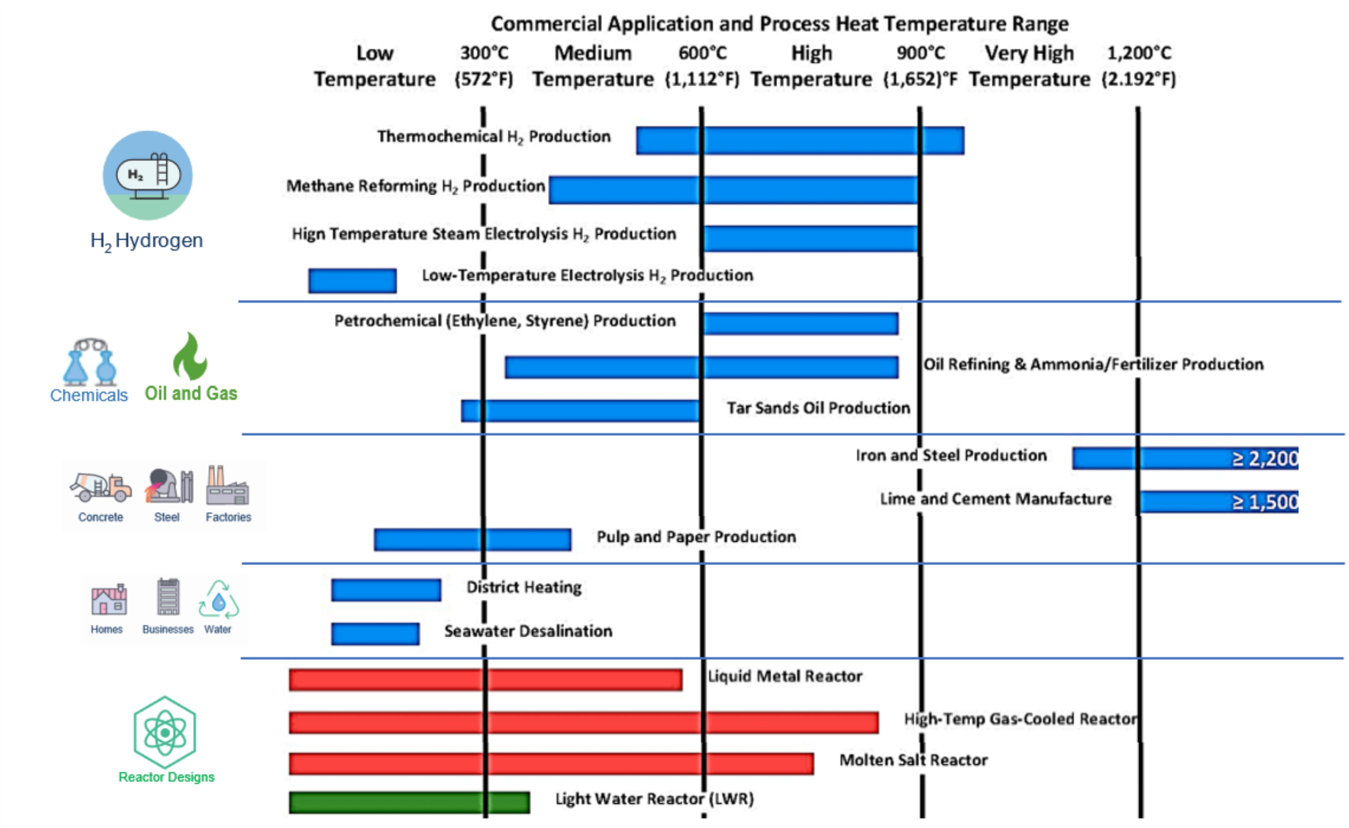
Current use of Nuclear for District Heating



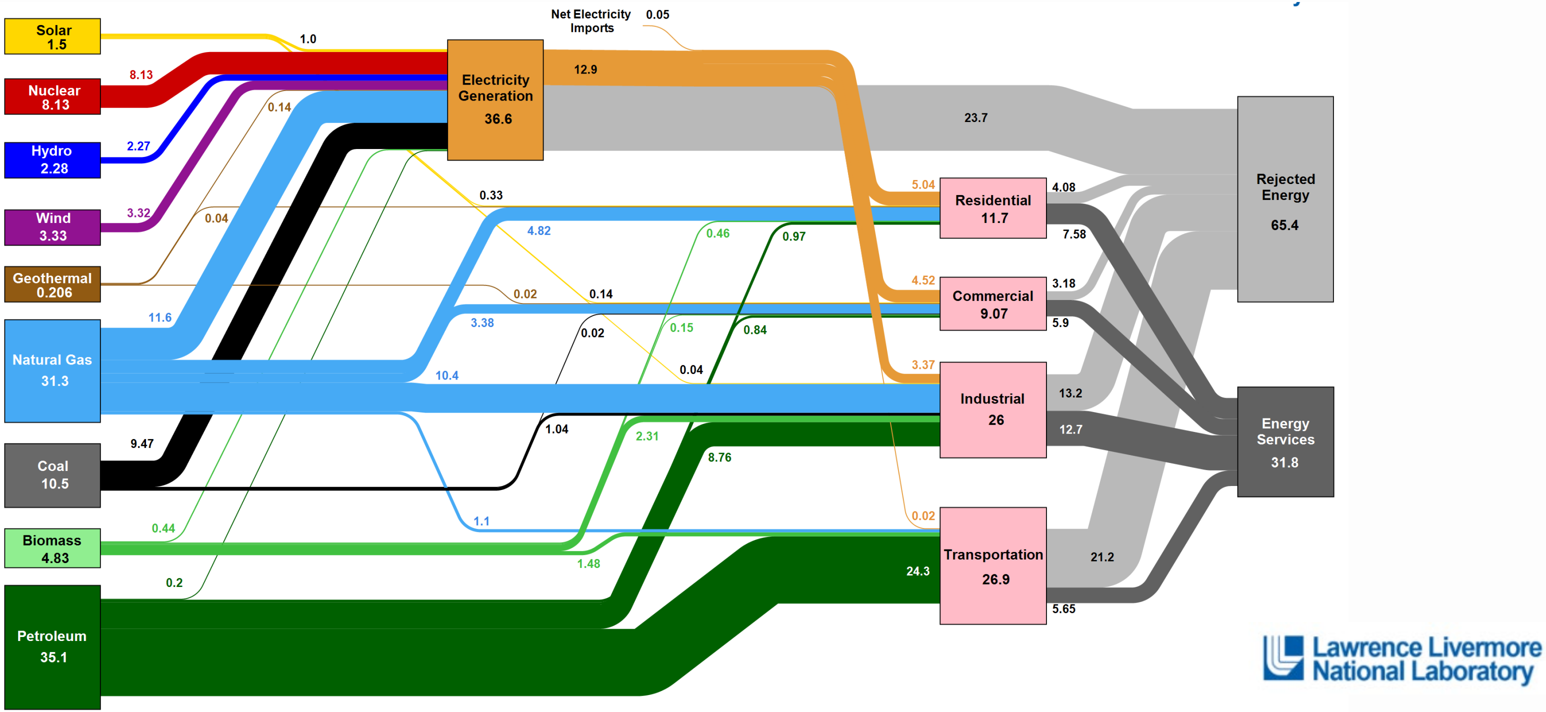
Source: Joseph Technology Corp.

- ~ 43 nuclear reactors provide combined heat and power for district energy
- 10% of nuclear power reactors in operation worldwide
- Hot water can be economically delivered up to 100 km away

Process Heat Temperature Applications

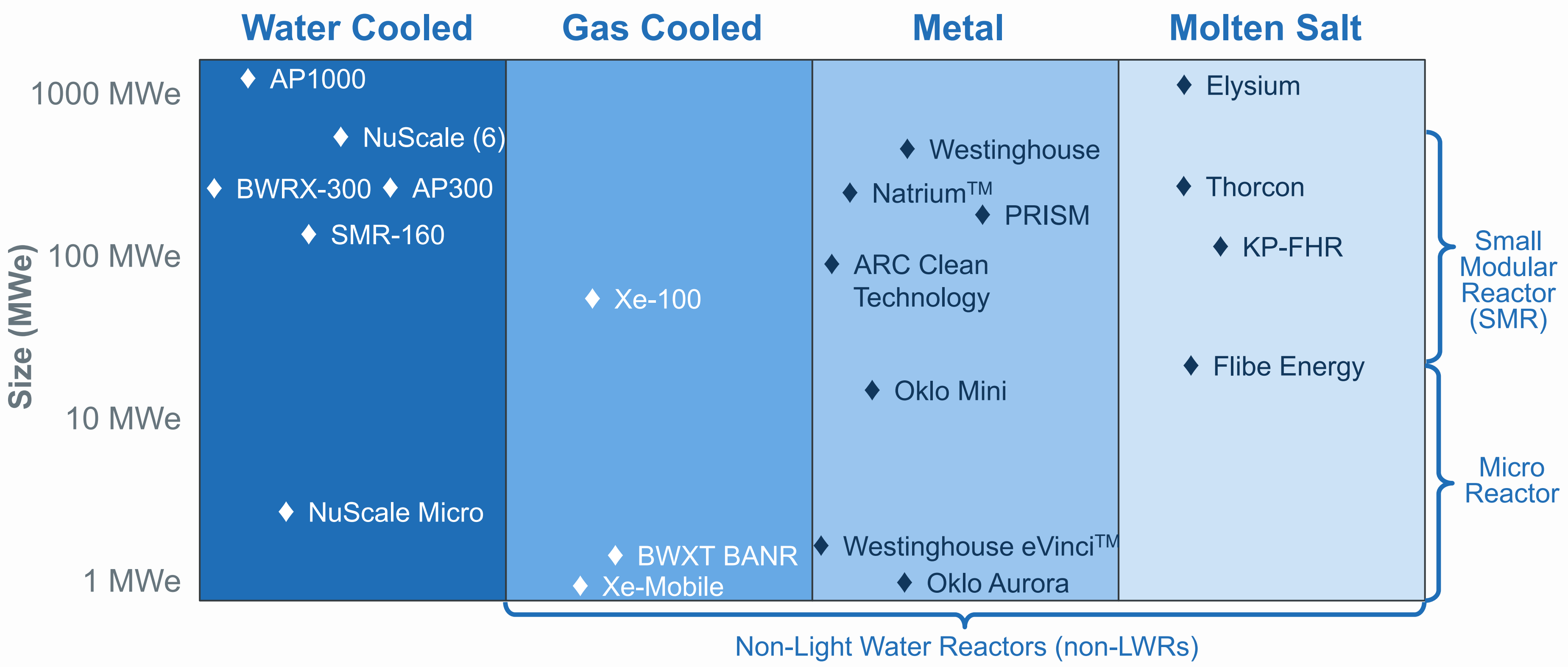


US Energy Flow (2021): 97.3 Quads



Source: LLNL March, 2022. Data is based on DOE/EIA MER (2021). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Advanced Nuclear Technologies*



* - partial list of technologies

Thank You for Your Time and Attention