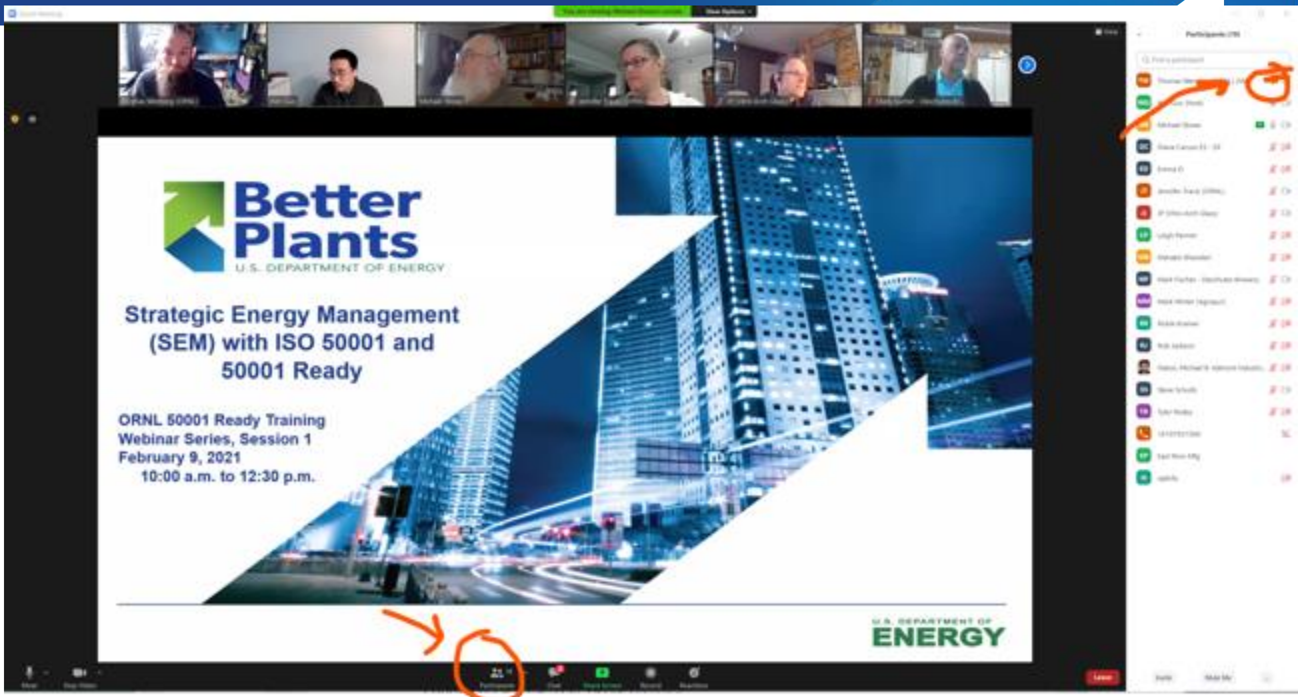
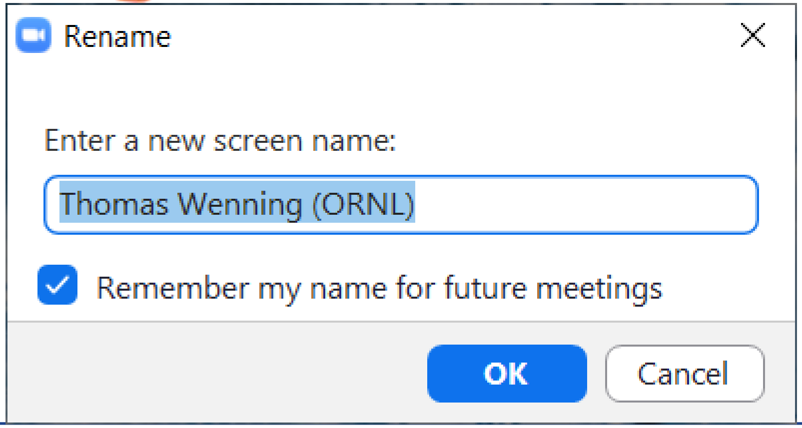
Rename Yourself to be your Real Name (Company Name)

1. Click on Participant list
2. Go to the right and hover over your name
3. Select “More” & “Rename”
4. Enter your company name in brackets
5. Turn on your camera ☺





Virtual Training: Onsite Energy Generation and Storage

Overview of Combined Heat and Power, Onsite Biomass, and Small Modular Reactors

Session #5
July 1, 2025
10:00am – 12:00pm EST

General Information

- Schedule: Every Tuesday (June 3rd – July 8th) morning @ 10am ET
- Sessions will be recorded
- We want these VT to be interactive!
- We're hoping you finish the VT with some big progress
- There will be homework – just try your best!
  - "You'll get out what you put in!"

Links:
https://bptraining.ornl.gov/
http://betterbuildingssolutioncenter.energy.gov/better-plants
https://measur.ornl.gov

Training Overview

1. 06/03: Introduction to Onsite Energy Generation
2. 06/10: Exploring Onsite Energy For Your Facility
3. 06/17: Evaluating an Onsite Energy System
4. 06/24: Onsite Energy Success Stories and Overview Of Geothermal Systems
5. **07/01: Overview of Combined Heat and Power, Onsite Biomass, and Small Modular Reactors**
6. 07/08: Considerations for Onsite Energy and Renewable Energy Supply Options

Agenda

1. Homework Discussion
2. Overview of Combined Heat and Power Systems
   - *Gearoid Foley, Advisor, Mid-Atlantic TAP*
3. Onsite Biomass Energy and RNG
   - *Dr. Dipti Kamath, ORNL*
4. Introduction to Small Modular Reactors
   - *Indraneel Bhandari, ORNL*
5. Q&A
6. Homework Assignment

Today’s Speakers

Gearoid Foley

Senior Technical Advisor,
DOE Mid-Atlantic Onsite Energy TAP

CHP: A Key Part of Our Energy Future

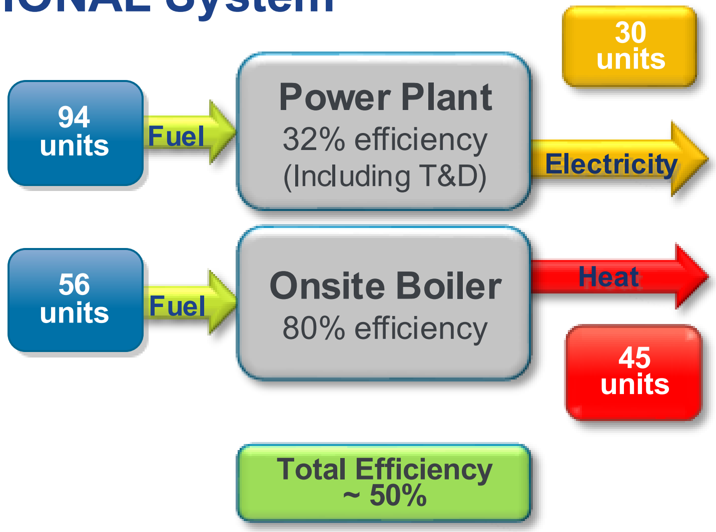
- Form a Distributed Generation (DG)
- An integrated system
- Located at or near a building/facility
- Provides at least a portion of the electrical load
- Uses thermal energy for:
  - Heating / Cooling / Refrigeration / Dehumidification

CHP provides efficient, clean, reliable, affordable energy – today and for the future.

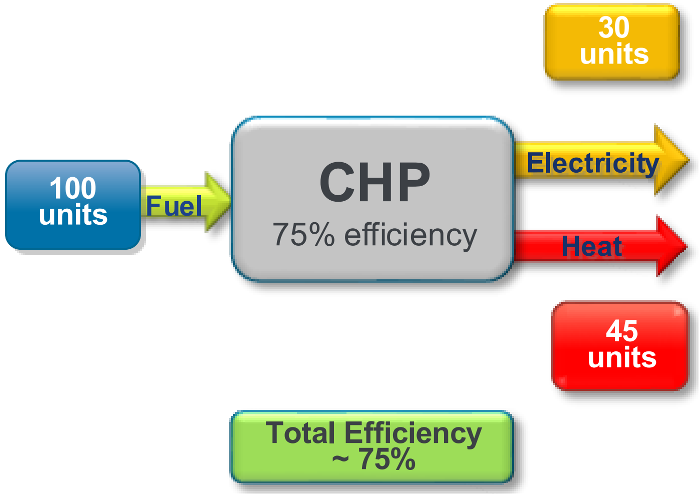
Source: www.energy.gov/chp

30% to 55% reduction in Scope 1&2 Greenhouse Gas Emissions

CONVENTIONAL System

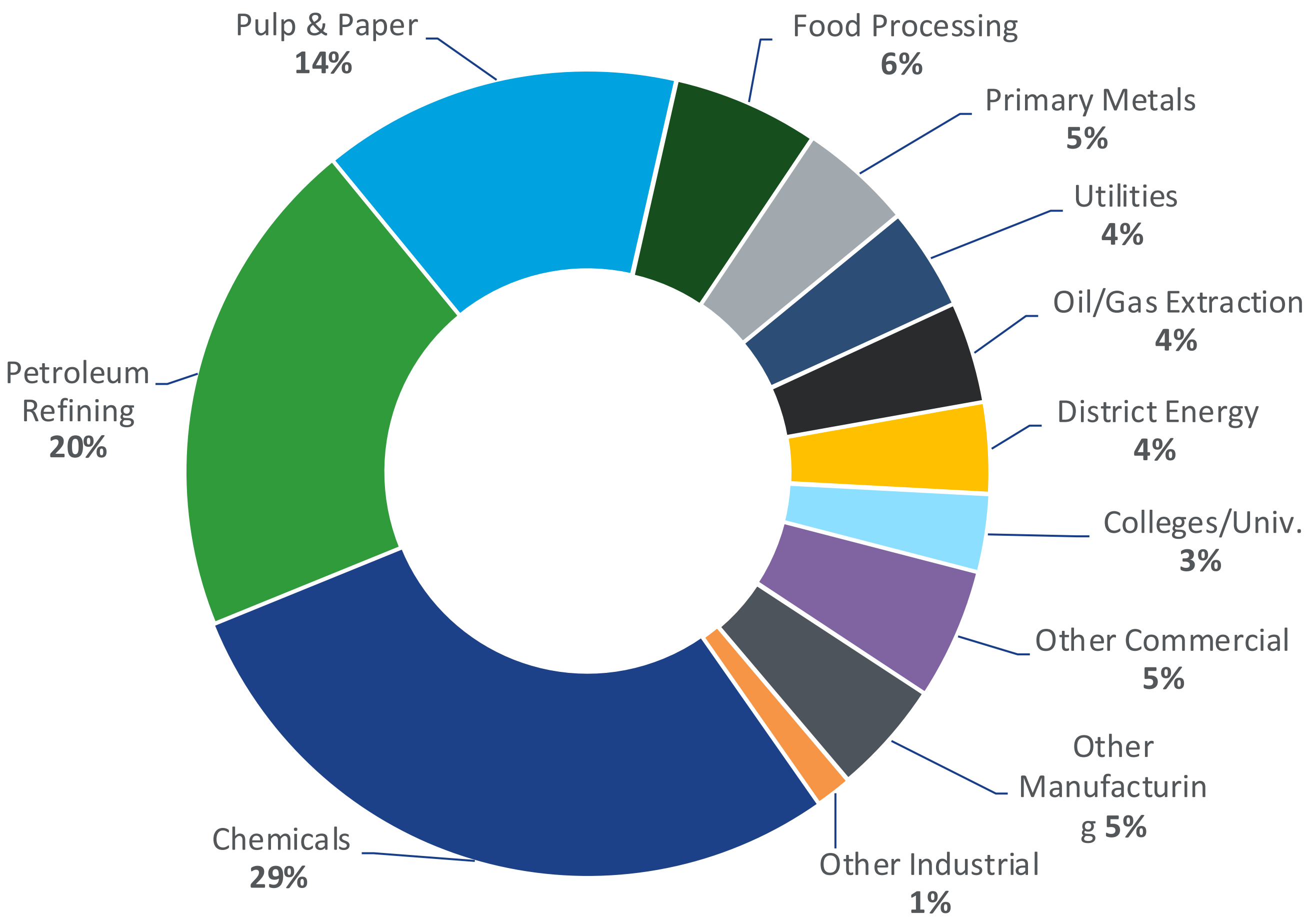


CHP System



CHP Today in the United States

Existing CHP Capacity (79.2 GW)



Source: DOE CHP Installation Database (U.S. installations through December 31, 2023, as of August 2024)

Avoids **1.2 Quadrillion Btus** of fuel consumption annually.

Avoids **200 million tons of CO²** compared to separate production.

79.2 GW of installed CHP at more than **4,700** industrial and commercial facilities.

6% of U.S. electric generating capacity; 13% of generation.

Food Processing

Taylor Foods

One 2.0 MW CHP System

LOCATION: Gonzales, CA

FACILITY SIZE: 250,000 sq. ft. Processing Plant

PEAK LOAD: 6 MW

EQUIPMENT: One 2 MW recip engine generator with heat recovery driving a 240-ton ammonia absorption chiller.

FUEL: Natural gas

Flooring Production

Mohawk

Five 1 MW CHP Systems

LOCATION: Dickson, Tennessee

EQUIPMENT: Five Capstone C1000s

USE OF THERMAL ENERGY: Supplement the burner in their spray dryer

FUEL: Natural Gas

Carpet Fiber Production

Shaw Industries

One 14.1 MW CHP System

LOCATION: Columbia, South Carolina

EQUIPMENT: Solar Turbines Titan 130

USE OF THERMAL ENERGY: Process steam, hot water, cooling

FUEL: Natural Gas

What are the Benefits of CHP?

- More efficient than separate generation of electricity and heating/cooling
  - Lower carbon and other pollutant emissions
  - Lower operating costs (but requires capital investment)
- Works with any fuel, including carbon neutral fuels
  - Efficiency becomes more important as fuels become scarce
- Increases energy reliability and resiliency
- Reduces grid congestion and avoid distribution costs
  - Complements intermittent renewable resources

Prime Mover Technology Comparisons

- Five Prime Movers
  - Reciprocating engines
  - Combustion turbines
  - Fuel cells
  - Steam turbines
  - Organic Rankine Cycles

Reciprocating engine CHP installation at an industrial facility.
Photo courtesy of Caterpillar.

Gas turbine CHP installation at a university.
Photo courtesy of Solar Turbines

Microturbine CHP installation at a commercial facility.
Photo courtesy of Capstone Turbine Corporation

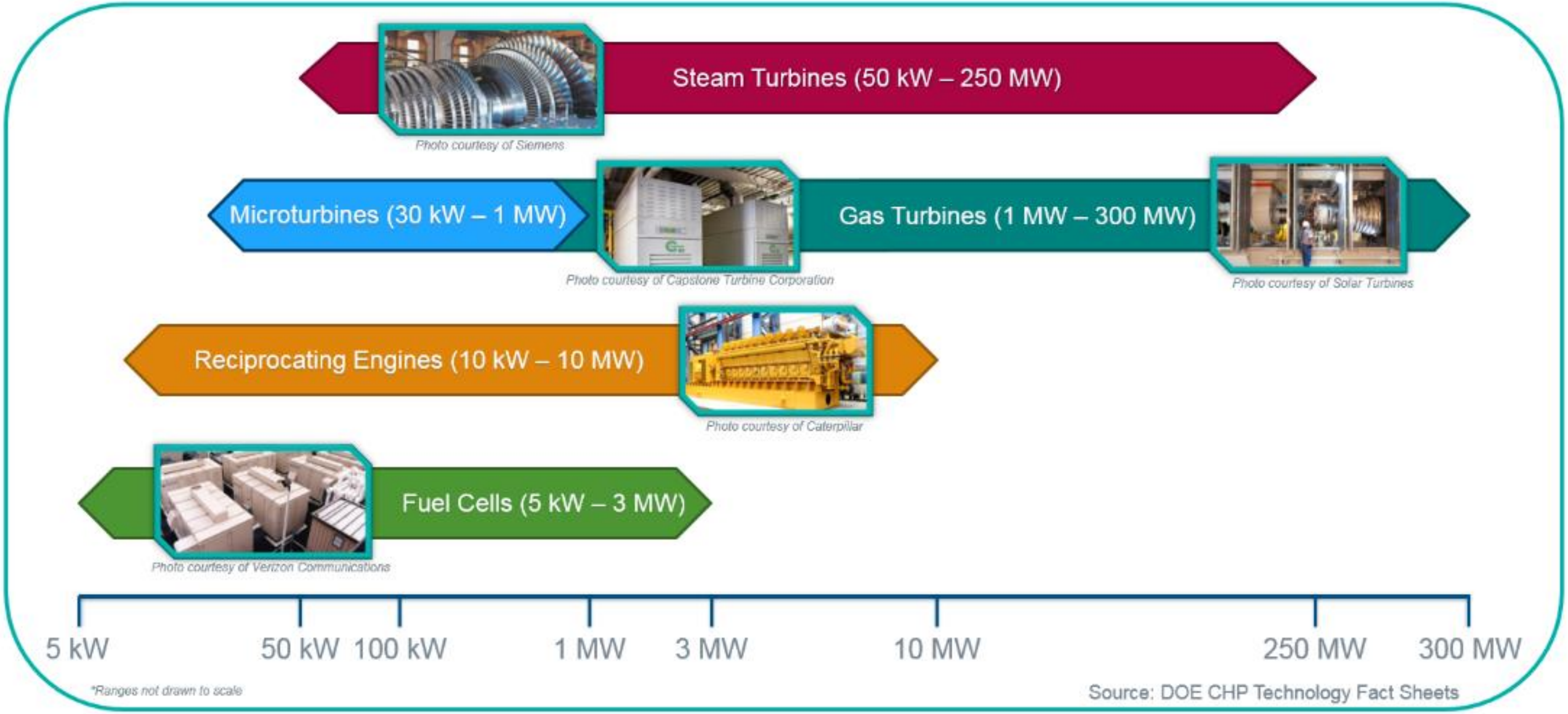
CHP fuel cell installation at Verizon data center.[1]
Photo courtesy of Verizon Communications.

Comparison of CHP Characteristics

Characteristic	Technology				
	Reciprocating Engine	Gas Turbine	Microturbine	Fuel Cell	Steam Turbine
Size Range	10 kW – 10 MW	1 – 300 MW	30 kW – 330 kW (larger modular units available)	5 kW – 1.4 MW (larger modular units available)	100 kW – 250 MW
Electric Efficiency (HHV)	30% – 42%	24% – 36%	25% – 29%	38% – 42%	5% – 7%
Overall CHP Efficiency (HHV)	77% – 83%	65% – 71%	64% – 72%	62% – 75%	80%
Total Installed Cost ($/kW) [3]	$1,400 – $2,900	$1,300 – $3,300	$2,500 – $3,200	$4,600 –$10,000	$670 – $1,100 [4]
O&M Cost (¢/kWh)	0.9-2.4	0.9-1.3	0.8-1.6	3.6-4.5	0.6-1.0
Power to Heat Ratio	0.6 – 1.2	0.6 – 1.0	0.5 – 0.8	1.3 – 1.6	0.07 – 0.10
Thermal Output (Btu/kWh)	2,900 – 6,100	3,400 – 6,000	4,400 – 6,400	2,200 – 2,600	30,000 – 50,000

Notes:
1) Unless noted otherwise, information based on U.S. Department of Energy, CHP Technology Fact Sheet Series, 2016, 2017.
2) All performance and cost characteristics are typical values and are not intended to represent a specific product.
3) Costs will vary depending on site specific conditions and regional variations.
4) Costs shown are for a steam turbine only, and do not include costs for a boiler, fuel handling equipment, steam loop, and controls.

Common CHP Technologies and Capacity Ranges



Heat Recovery

- Heat Exchangers
  - Recover exhaust gas from prime mover
  - Transfers exhaust gas into useful heat (steam, hot water) for downstream applications
  - Heat Recovery Steam Generators (HRSG) the most common
- Heat-Driven Chillers
  - Absorption Chiller
    - Use heat to chill water
    - Chemical process (not mechanical)
  - Steam Turbine Centrifugal Chiller

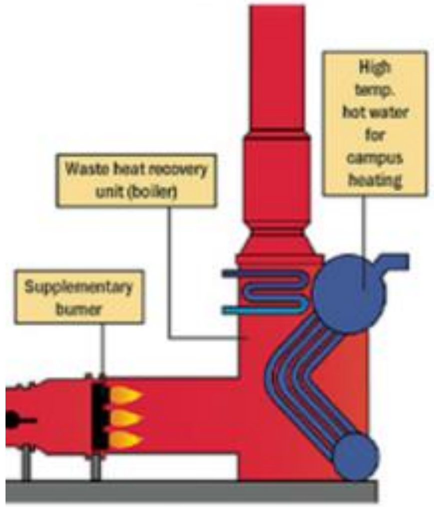


Image Source: University of Calgary

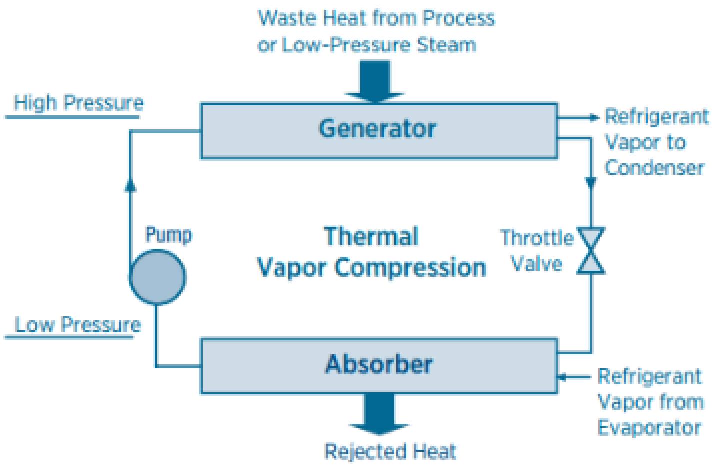


Image Source: DOE - EERE

Business Case – What Are the Benefits of CHP?

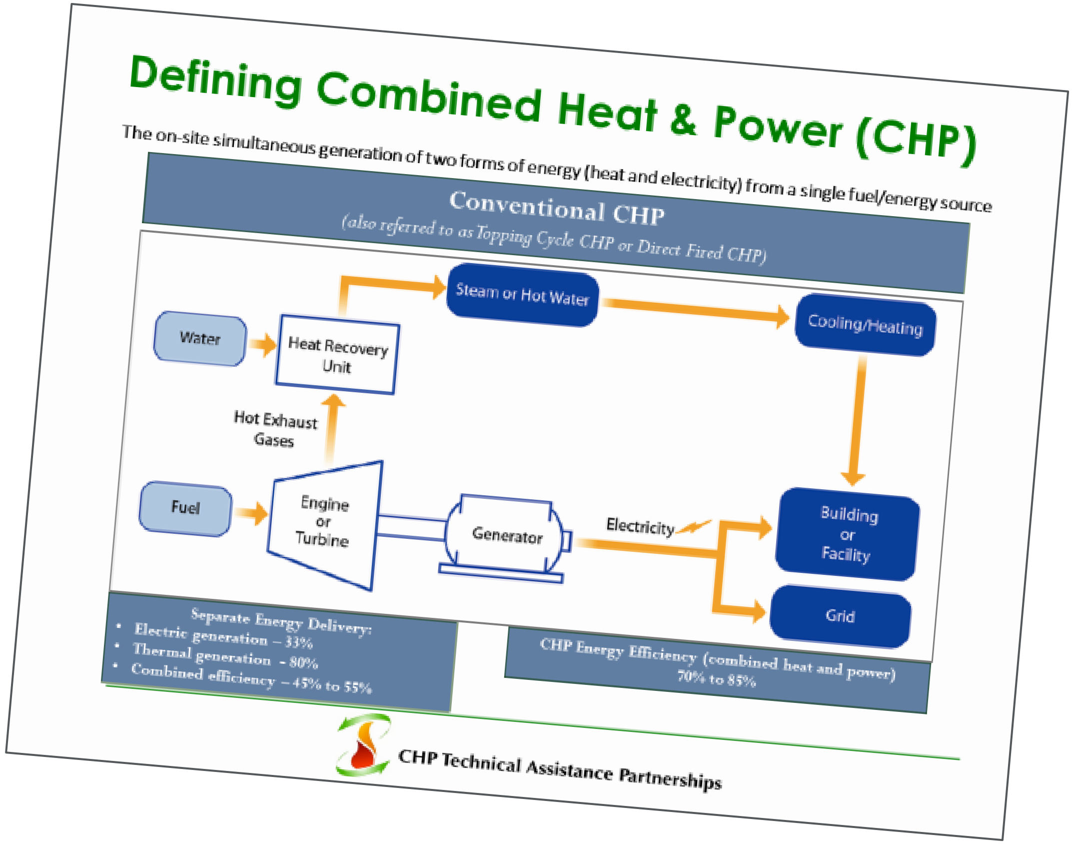
- CHP displaces both electric power and thermal energy and is more efficient than the separate generation of electricity and heating/cooling saving primary energy
- Reduced primary energy demand translates to lower operating costs and lower emissions
- On-site electric generation can reduce grid congestion and avoid distribution costs. Behind the meter CHP is an effective load reduction technique.
- CHP can increase energy reliability and enhance power quality resulting in offset of shutdown costs. CHP can provide backup power when the utility grid is out

- Institutional

- Industrial

Business Case – Thermal is a Prerequisite

- CHP is defined by the beneficial utilization of the heat output from the electric or mechanical power generation process.
- CHP heat can be converted to hot air, hot water, steam, chilled water, refrigeration or dehumidification.
- In all scenarios a thermal load must be present that is uniform with the CHP plant thermal output.

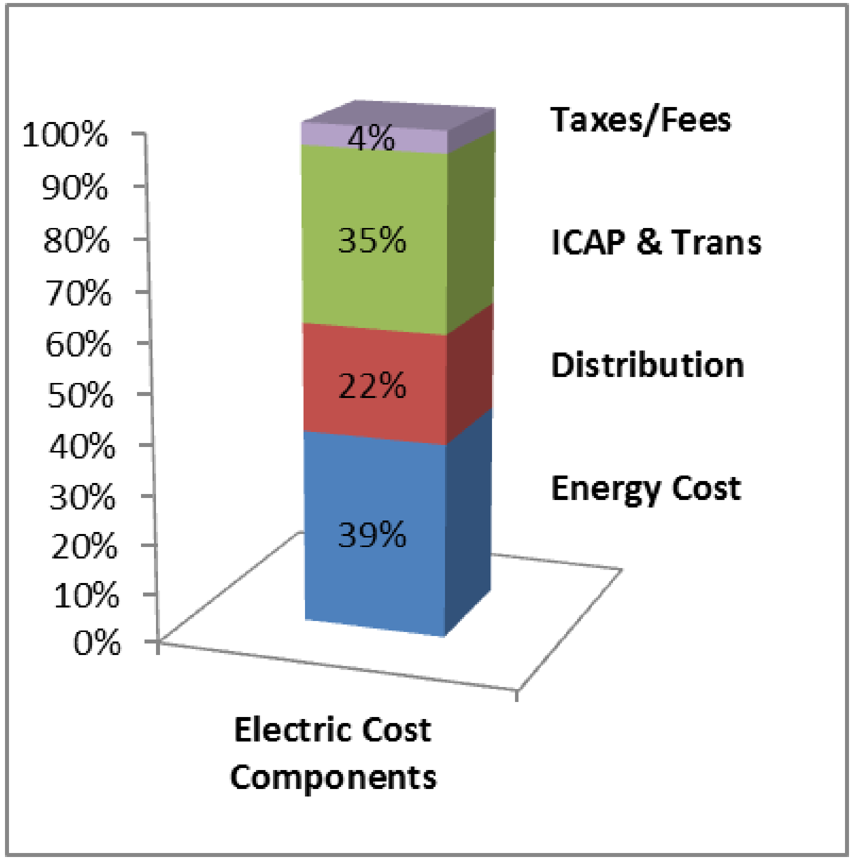


Business Case – Spark Spread

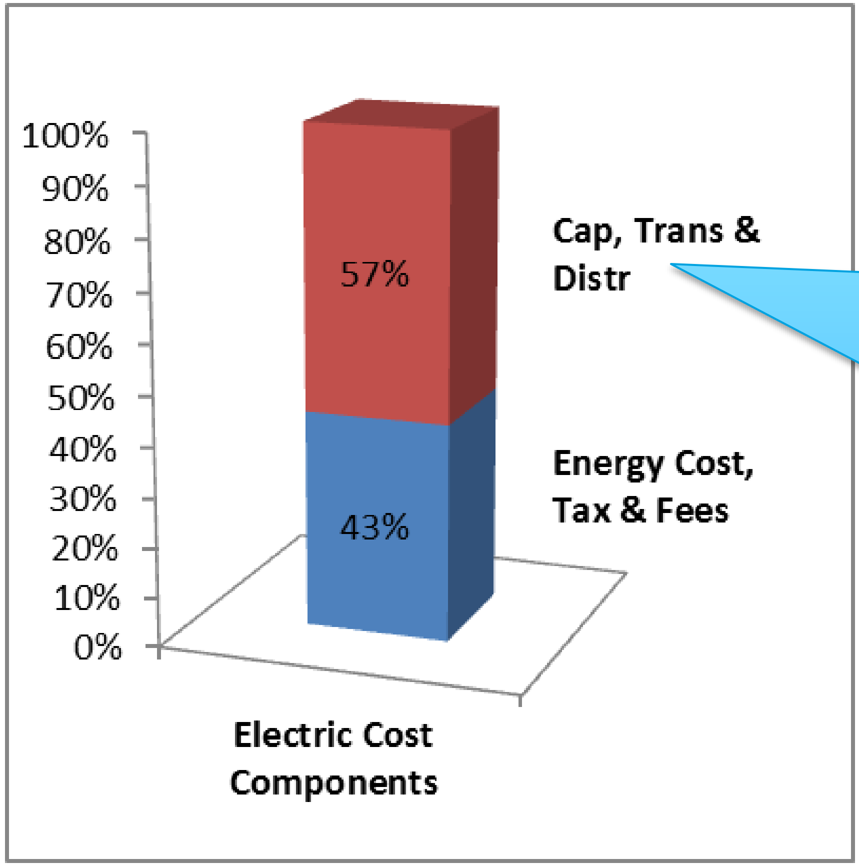
- The cost to generate electricity locally through CHP is offset by reduced load on the boiler plant resulting in a lower net cost to generate power.
- Spark spread is difference between the utility price for power and the cost to generate power locally.
- Typically, CHP costs less to generate the same energy output using natural gas than separate power and heating devices. CHP’s lower fuel requirement means that CHP is always more efficient no matter what fuel is being used when a thermal load is present.

Spark Spread – Electric Price versus Offset Value

Identify and understand energy cost, not usage



PJM RFC-East Cost Breakout



PJM RFC-East Cost Breakout

At low natural gas costs prevalent in the recent past, non-energy costs represented more than half of the wholesale charge

Business Case – Capital Cost Recovery

- Spark spread taking into account O&M should be in the order of 2 ₵ per kWh for reasonable rate of return on the capital investment not including interest or profit. Interest and profit can add from 50% to 100% of the borrowed amount over the term of the loan depending on terms and rates requiring a spark spread of 4 ₵ per kWh in order to consider the project.
  - $2,500/kW at 8,760 hrs x 95% available = $0.30/kWh in first year or $0.02/kWh in 15 years

Operating Costs to Generate	**$/kWh**
Fuel Costs, $/kWh	0.0545
Thermal Credit, $/kWh	(0.0175)
Incremental O&M, $/kWh	0.0190
Total Operating Costs to Generate, $/kWh	**$0.056**

- Capital Cost recovery is based on net investment after credits and offsets

Business Case – Energy Cost Component

- Industries that have a large energy component in their process such as metals processing, distillation, food processing, pulp and paper, etc. are more sensitive to energy costs and more likely to implement energy cost saving measures.

- Food processing typically may have 30% of its cost base be energy and in a highly competitive market, a 10% reduction in energy cost could have significant impact on the bottom line.

High energy component
High volume/Low margin

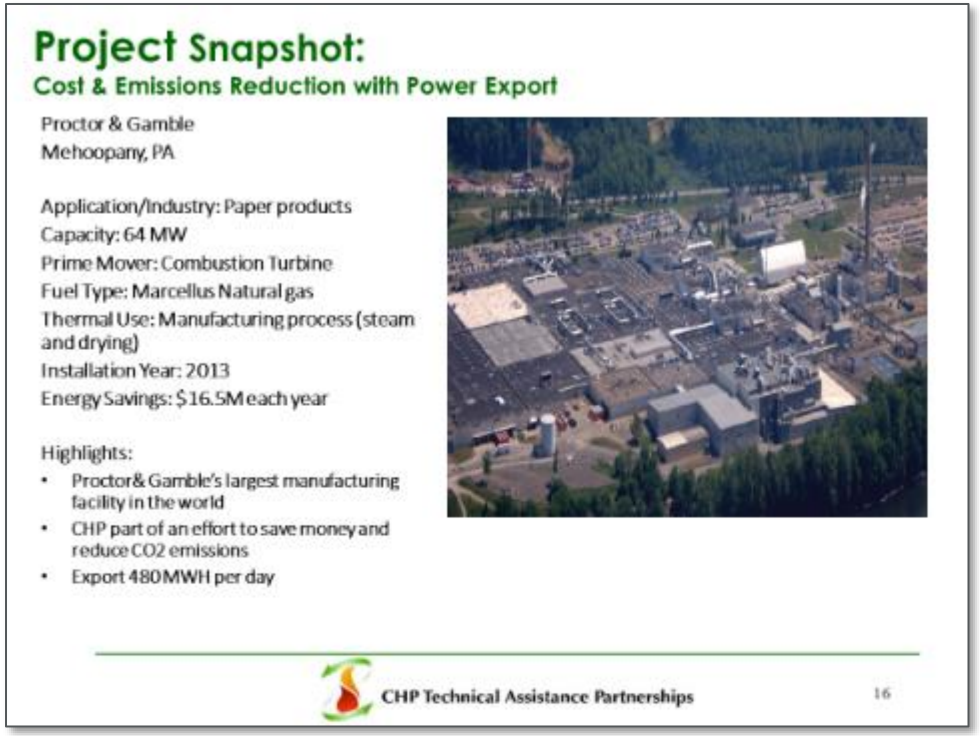
Business Case – Energy Resilience

- For end users:
  - Provides continuous supply of electricity and thermal energy for critical loads
  - Can be configured to operate in “island mode” during a utility outage
  - Ability to withstand long, multiday power outages
- For utilities:
  - Enhances grid stability and relieves grid congestion
  - Enables microgrid deployment for balancing renewable power and providing a diverse generation mix
- For communities:
  - Keeps critical facilities like hospitals and emergency services operating and responsive to community needs

Business Case – Power Quality/Reliability/Availability

- CHP is not only a way to generate power efficiently, but also a way to obtain additional electric power or improve power quality and reliability when the utility cannot provide the service required.

- Very large loads such as Data Centers can use CHP as a cost effective way to provide additional reliable power and thermal management.



CHP – Project Highlights

Carolina Poultry Power

Quick Facts

LOCATION: Farmville, North Carolina
MARKET SECTOR: Agriculture, Food Processing
GENERATING CAPACITY: 1.74 MW electricity
THERMAL CAPACITY: 77,000 lb/hr steam
EQUIPMENT: (3) Hurst Biomass Boilers, (2) 800 kW and (1) 175 kW Skinner steam turbines
FUEL: Poultry Waste
USE OF THERMAL ENERGY: Hot water for processing and sterilization.
USE OF ELECTRICAL ENERGY: Plant service, sold offsite under a PPA with Pitt-Greene EMC
CHP TOTAL EFFICIENCY: 74%
TOTAL PROJECT COST: $32 million
CHP IN OPERATION SINCE: 2019

Milliken Textiles

Quick Facts

LOCATION: Blacksburg, SC
MARKET SECTOR: Textiles
CHP IN OPERATION SINCE: 2021
GENERATING CAPACITY: 14 MW
THERMAL OUTPUT: 200,000 lb/hr steam
EQUIPMENT:
14 MW Titan 130 Solar Turbine
Rentech Heat Recovery Steam Generator
FUEL: Natural Gas
USE OF THERMAL ENERGY: Process heating
CHP TOTAL EFFICIENCY: 70%
ENVIRONMENTAL BENEFITS:
Eliminates coal for steam generation
20% overall efficiency improvement
TOTAL PROJECT COST: $25 million
ESTIMATED ANNUAL SAVINGS: $4 million
SIMPLE PAYBACK: ~6 years

Bell's Brewery

Quick Facts

LOCATION: Galesburg, Michigan
MARKET SECTOR: Brewery
FACILITY SIZE: 130,000 sq. ft.
FACILITY PEAK LOAD: 1.2 MW
GENERATING CAPACITY: 150 kW
SYSTEM EFFICIENCY: 80-85%
EQUIPMENT: (3) anaerobic digesters, (1) CAT G3406 generator set, (1) Unison Solutions Gas Treatment System
FUEL: Biogas from onsite treatment of process water
THERMAL APPLICATION: Heating water for cleaning barrels, maintaining digester temperature
BEGAN OPERATION: 2014
SIMPLE PAYBACK: Less than 8 years

Identifying the Right Candidate

- There is a large constant thermal load
- Spark spread is favorable (higher energy costs are better)
- Multi-shift operation or long run hours
- Tax credits or performance payments are available
- State and/or Corporate goals include GHG reduction
- Regulatory mandates for GHG reduction
- Resilience improvements are valued
- Utilities are supportive
- Grid policy supports distributed resources

Facility Location

Codes & Regs

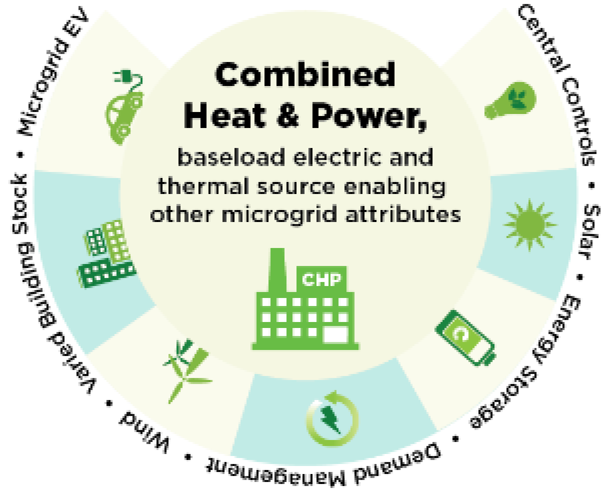
Policy

CHP Microgrids with DERs

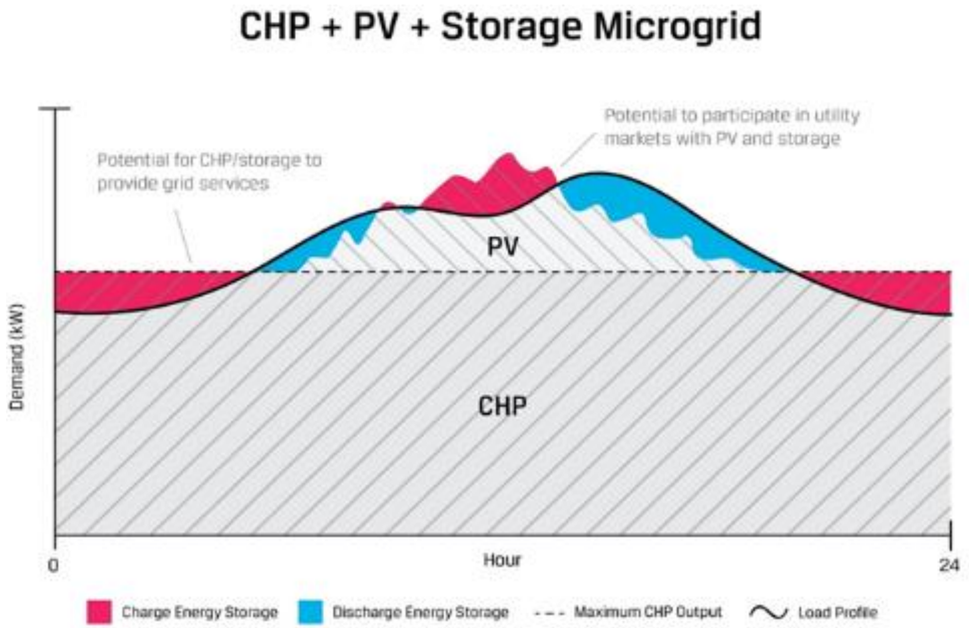
A microgrid is a **group of interconnected loads and distributed energy resources** within clearly defined electrical boundaries that acts as a **single controllable entity** with respect to the grid.

A microgrid can **connect and disconnect** from the larger utility grid to enable it to operate in both **grid-connected** or **island-mode**.

Source: U.S. Department of Energy Microgrid Exchange Group



- With a CHP system providing reliable baseload electric and thermal energy, microgrids can support renewable generation and energy storage.
- Increased focus on resilience for critical infrastructure: Universities, Hospitals, Military bases, Communities

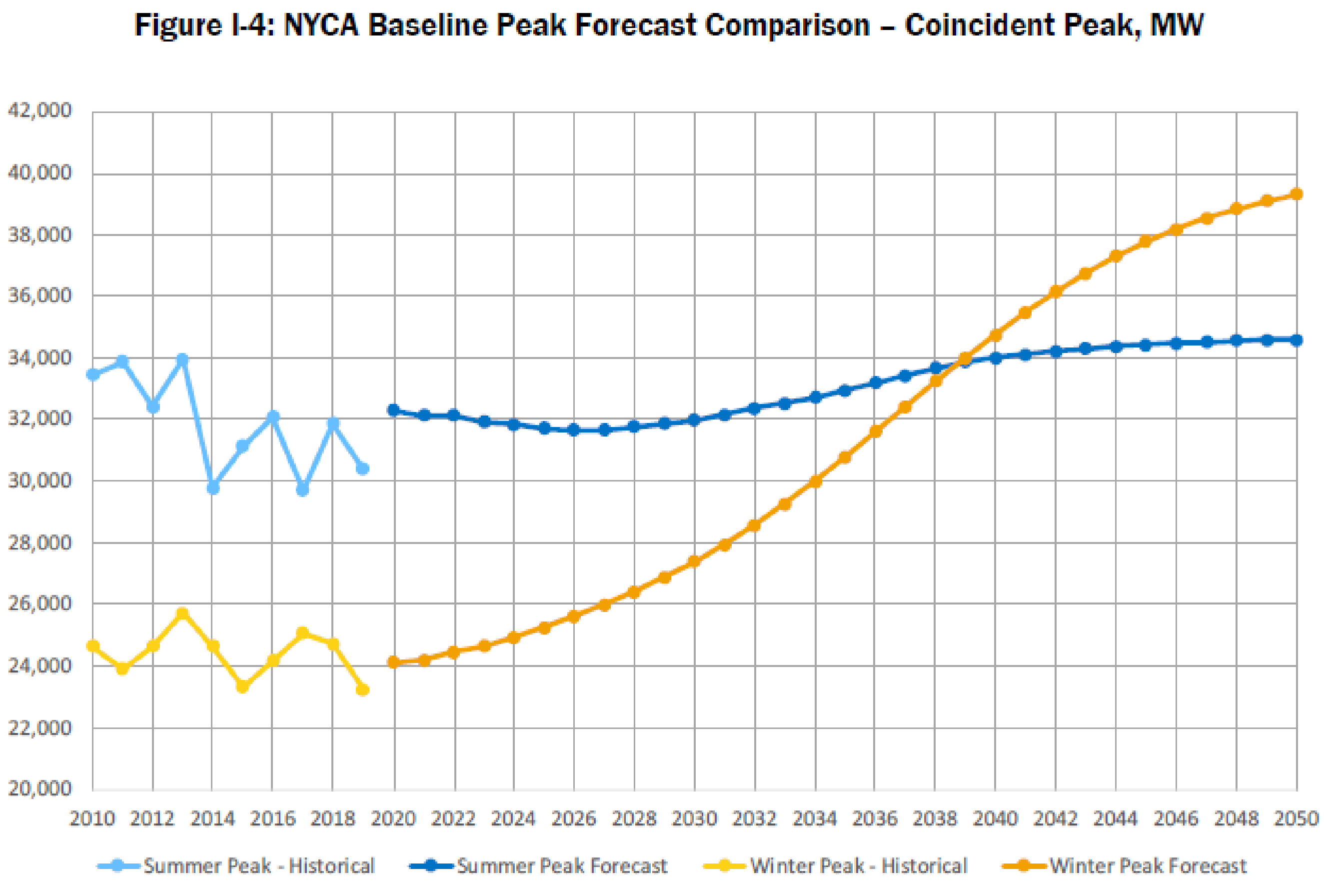


CHP Versus traditional Backup Generation

- CHP provides continuous benefits to host facilities rather than just during emergencies
- Includes thermal as well as power
- CHP can result in daily operating cost savings
- CHP offsets capital costs associated with investments in traditional backup power

CHP Assist Heat Pumps

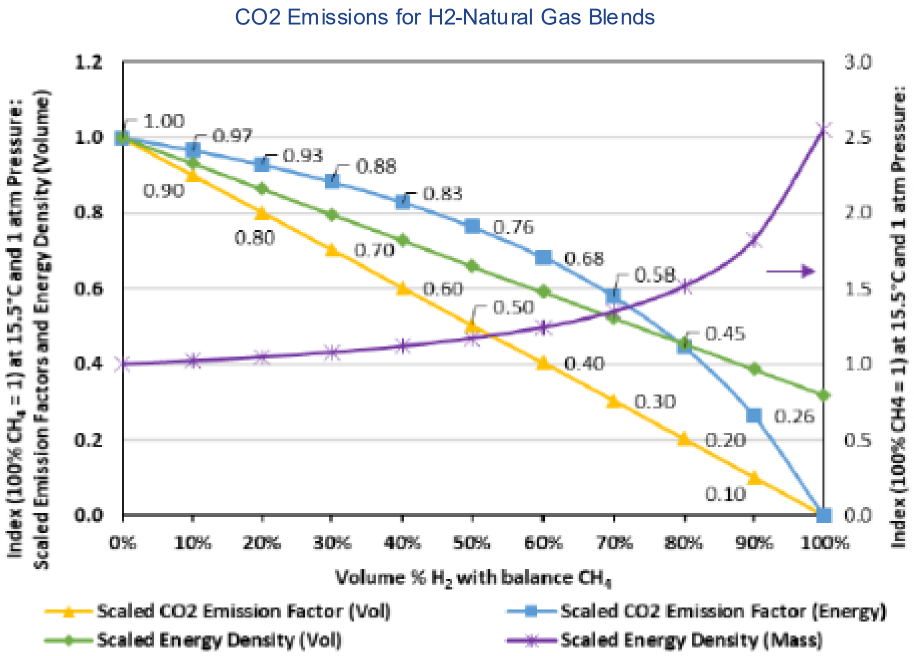
- By providing both heat and power in mid winter when solar insolence in the northern hemisphere is at its lowest, CHP can provide a resilience component as well as offset oversizing of heat pumps and PV capacity to meet low duration cold weather events.



The 2020 NYISO forecast for summer and winter peak demands for the New York Control Area (NYCA) through 2050

Hydrogen Blending

- Benefits of hydrogen blending: reduced carbon emissions and utilization of expansive, existing natural gas pipeline network.
- Hydrogen use considerations include safety for transport and the control of nitrogen oxide emissions released during combustion.
  - **Up to 15% hydrogen-by-volume blends are safe to inject into existing pipelines without major infrastructure modifications.**
  - The use of selective catalytic reduction (SCR) technology has proven to mitigate the release of NOX emissions.
- NREL developed the Pipeline Preparation Cost Tool (PPCT) to help determine which pipeline modifications are needed and the associated costs.
- Hawai’i Gas has been blending up to 15% hydrogen-natural gas blends for years.
- **CHP equipment can use hydrogen blends of 20-30% with minimal modifications required.**

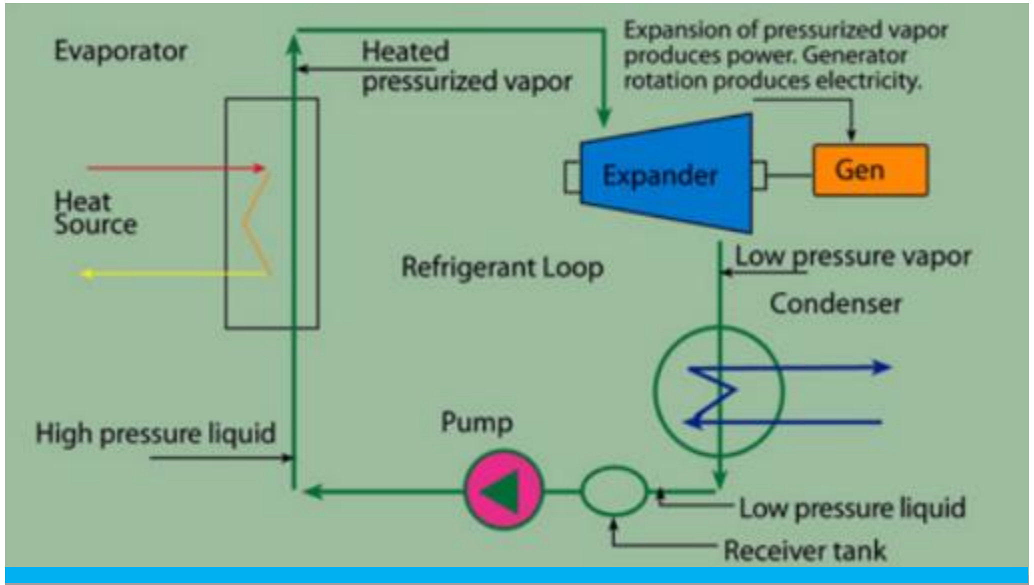


[Energies | Free Full-Text | Impact of Hydrogen/Natural Gas Blends on Partially Premixed Combustion Equipment: NOx Emission and Operational Performance (mdpi.com)]

Basic Information about NO2 | US EPA
EPRI Home
Hydrogen for Power Generation Whitepaper
Siemens Energy · Technical document · DIN A4 portrait – Template (siemens-energy.com)
HyBlend: Pipline CRADA Cost and Emissions Analysis (energy.gov)
Decarbonization | Hawaii Gas
https://crsreports.congress.gov/product/pdf/R/R46700

Organic Rankine Cycle

- For low-temperature waste heat recovery applications typically between 170-600°F
- Commercially available size ranges from 100 kW to 8 MW
- Uses working fluid other than water/steam such as a hydrocarbon or ammonia, allowing for lower working temperatures, potentially eliminating need for 24/7 boiler operators
- Pros: Variety of temperature and size range applications across numerous market sectors, no emissions
- Cons: High installation costs (~1.5 X Steam Turbine costs), complex engineering



Organic Rankine Cycle Thermodynamic Cycle
Photo courtesy of gulfcoastgreenenergy.com

Pairing CHP with Renewables and Storage for Resilience

- CHP can be a resilient base load anchor for multi-technology microgrids, particularly those incorporating renewable generation sources like solar PV or wind.
- CHP paired with renewable DERs optimizes overall emissions reductions and resilience.
- Net-zero fueled CHP can decarbonize critical facilities that need dispatchable on-site power for long duration resilience and operational reliability

critical infrastructure, cities, and communities

United States Marine Corps Recruit Depot (MCRD) Parris Island, SC, installed a hybrid microgrid including a 3.5 MW natural gas-fired CHP system plus 5.5 MW solar photovoltaic arrays to provide secure and resilient energy. The site also incorporated an 8 MWh battery-based energy storage system, all of which are controlled by a microgrid control system capable of fast load shedding.

Public Safety Headquarters, Gaithersburg, Maryland

Project Snapshot: CHP Microgrid

Application	Government Buildings
Capacity	865 kW
Prime Mover	Reciprocating Engine
Fuel Type	Natural Gas
Thermal Use	Heating and hot water
Installation Year	2018

The CHP system is accompanied with 2 MW of solar capacity. The combined solar and CHP capacity allows the facility to maintain an infinite backup capacity. *Photo courtesy of Montgomery County.*

Project Highlights:
Following a 2012 derecho which left buildings across Montgomery County without power for days, the county decided to invest in a CHP + solar microgrid to replace existing standby generators.

Project Testimonial
"On a typical operating day at the PSHQ advanced microgrid, the combined heat and power system can provide up to 70% of the site's energy from CHP with the remainder from on-site solar with very little utility power."
- Eric Coffman, Chief – Office of Energy and Sustainability, Montgomery County

U.S. DOE CHP Resources

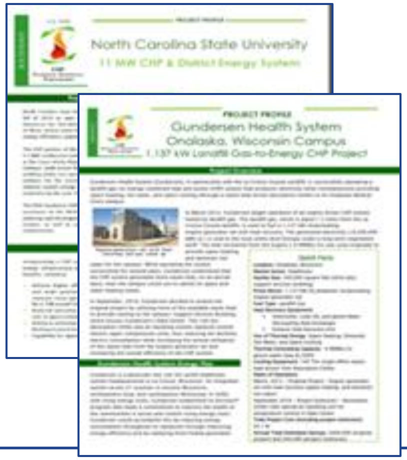
CHP and Microgrid Installation Databases

Packaged CHP eCatalog

CHP Technologies Fact Sheet Series

CHP Market Sector Fact Sheet Series

Project Profile Database



Policy/ Program Profiles

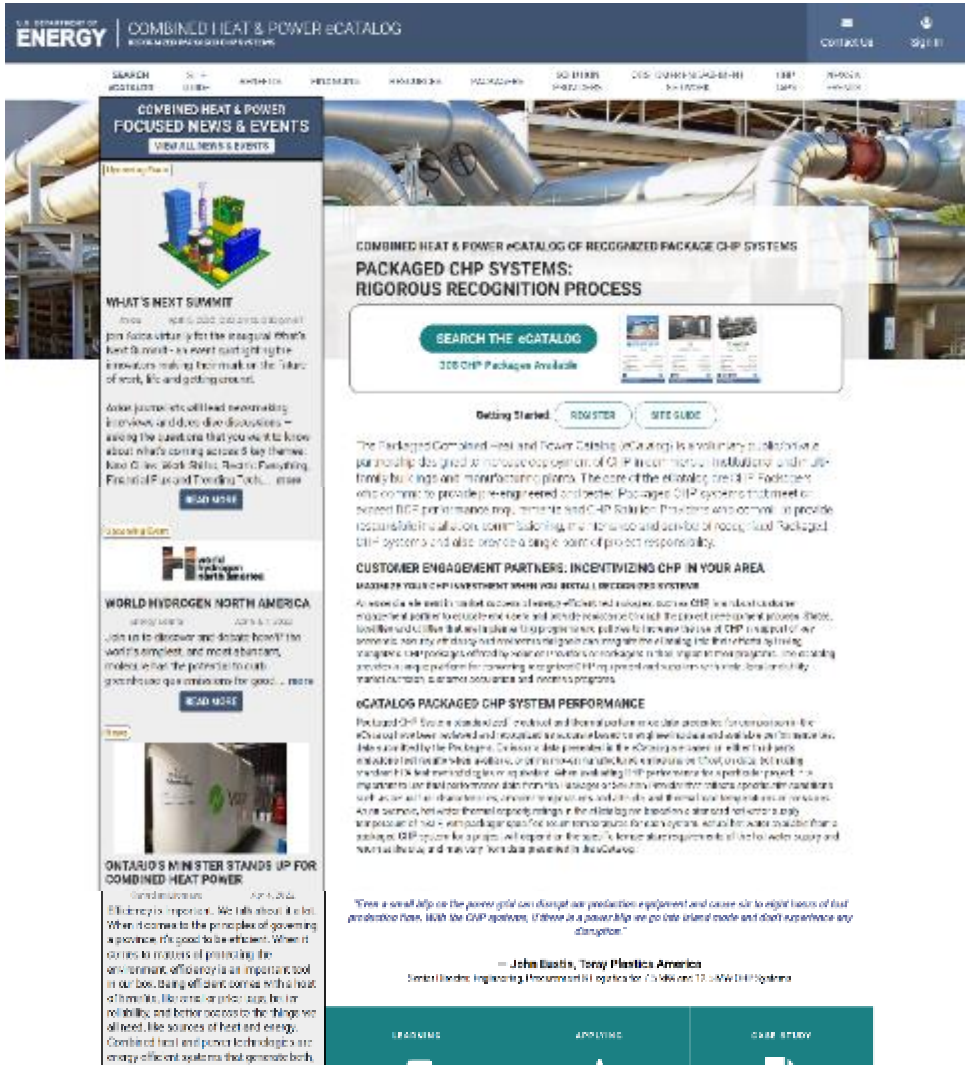
DG for Resilience Planning Guide

and more:

- CHP Issue Brief Series
- Model Guidance
- CHP Tech Potential Report
- CHP Financing Primer
- CHP Issue Briefs
- CHP For Resiliency Accelerator
- Webinars and Presentations
- Technical Reports

DOE Packaged CHP eCatalog

- A national web-based searchable catalog of DOE-recognized packaged CHP systems and suppliers with the goal to reduce risks for end-users and vendors through partnerships with:
  - *CHP Packagers that assemble and support recognized packaged CHP Systems*
  - *Solution Providers that install, commission and service packaged CHP systems*
  - *CHP Engagement partners that provide CHP market deployment programs at the state, local and utility level*
- Pre-engineered and tested packaged CHP systems that meet DOE performance requirements.
- eCatalog audience: end-users with engineering staff, consulting engineers, utilities, state energy offices, regulators, federal agencies, and project developers.
- Users search for applicable CHP system characteristics, and get connected to packagers, installers and CHP engagement programs
- Allows users to compare technology options on a common basis.



Questions?

U.S. DEPARTMENT OF ENERGY

Thank you!

Today's Speakers

Dipti Kamath, PhD.

R&D Associate Staff Member,
Oak Ridge National Laboratory

Better Plants
U.S. DEPARTMENT OF ENERGY

Renewable Natural Gas and Biomass

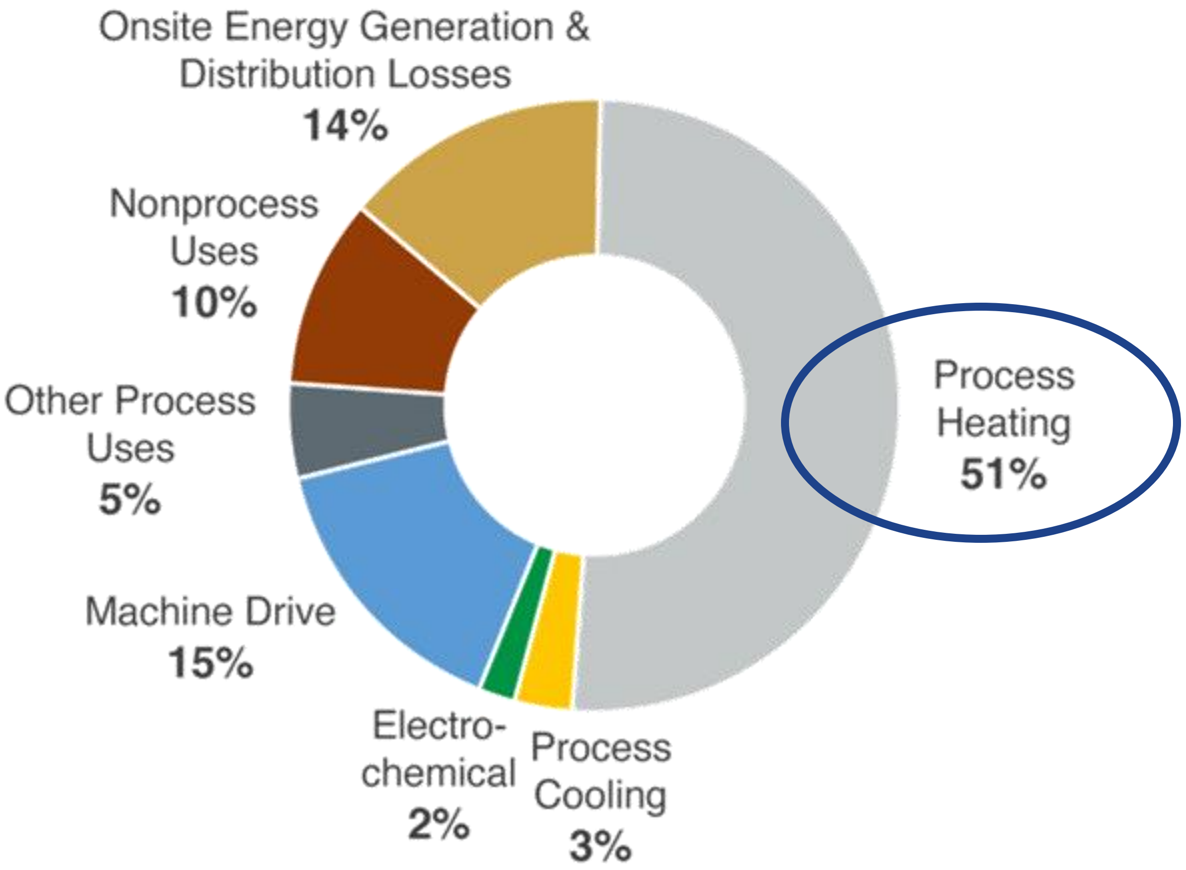
Dipti Kamath, Ph.D.
Oak Ridge National Laboratory

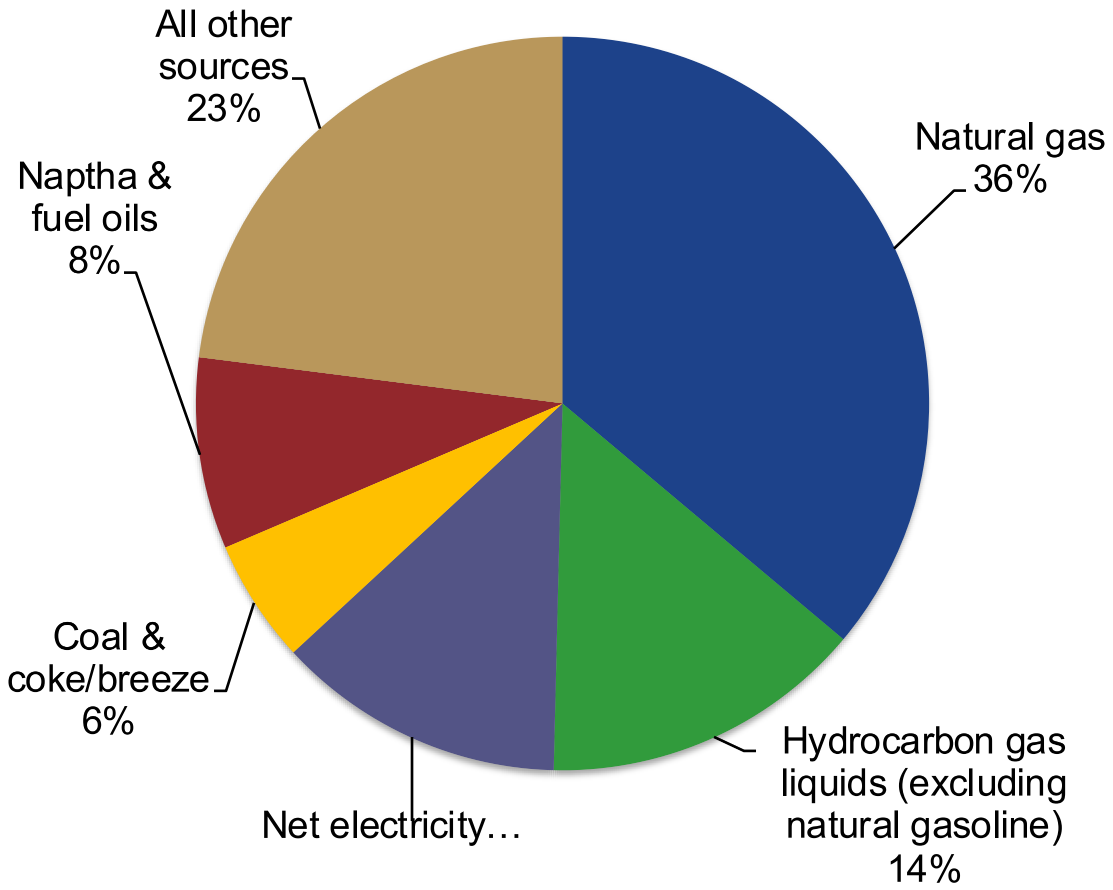
Agenda

- Opportunities for Industrial Use of Alternative Fuels
- Alternative Fuel Options for Industrial Use
- Biomass as an Industrial Fuel
- Renewable Natural Gas as an Industrial Fuel
- Relevant Resources
- Summary
- Q&A

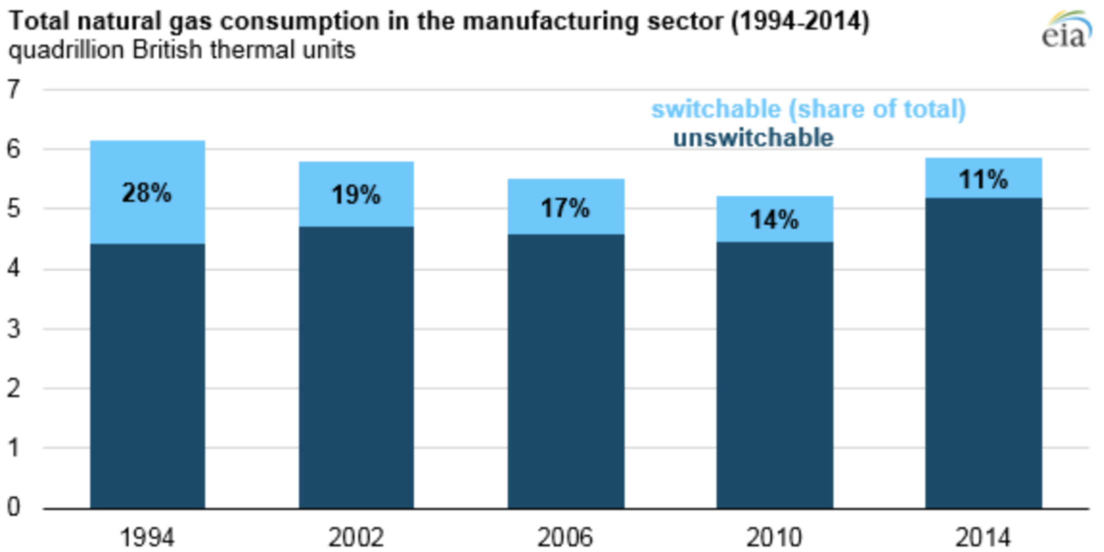
Opportunities for Industrial Use of Alternative Fuels

Breakdown of Energy Use Onsite at Manufacturing Facilities, 2018

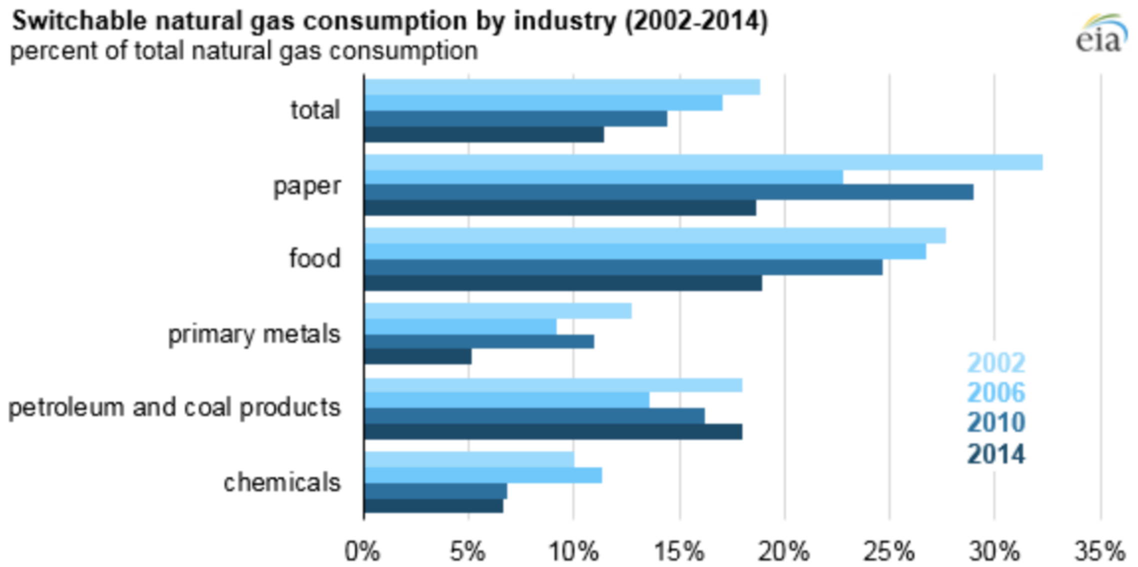




Opportunities for Industrial Use of Alternative Fuels



Source: U.S. Energy Information Administration, Manufacturing Energy Consumption Survey

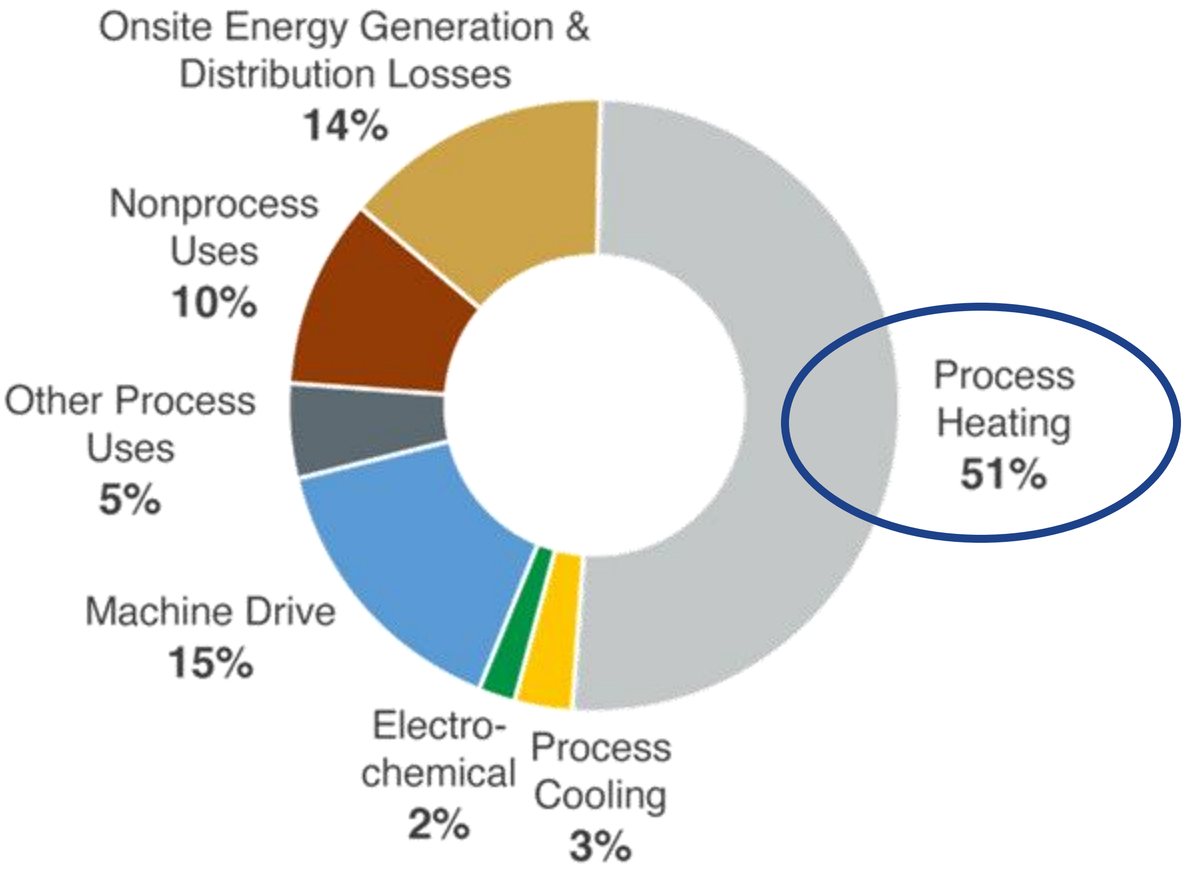


Source: U.S. Energy Information Administration, Manufacturing Energy Consumption Survey

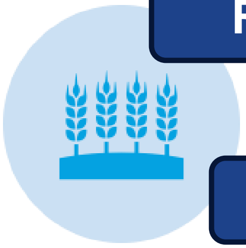
- In 2014, reason most cited by respondents for not being able to switch fuels was
  - **equipment onsite would not support it**
  - accounted for 78% of unswitchable natural gas consumption, 75% of unswitchable electricity receipts, and 62% of unswitchable coal consumption.
- Other reasons for being unable to switch fuels included
  - lack of **availability** of alternative fuels, **environmental restrictions** on alternative fuels, and restrictions of **long-term contract**s.

Opportunities for Industrial Use of Alternative Fuels

Breakdown of Energy Use Onsite at Manufacturing Facilities, 2018



Renewable Hydrogen



RNG

Biomass

Biofuel, Biomass, Bio-feedstock

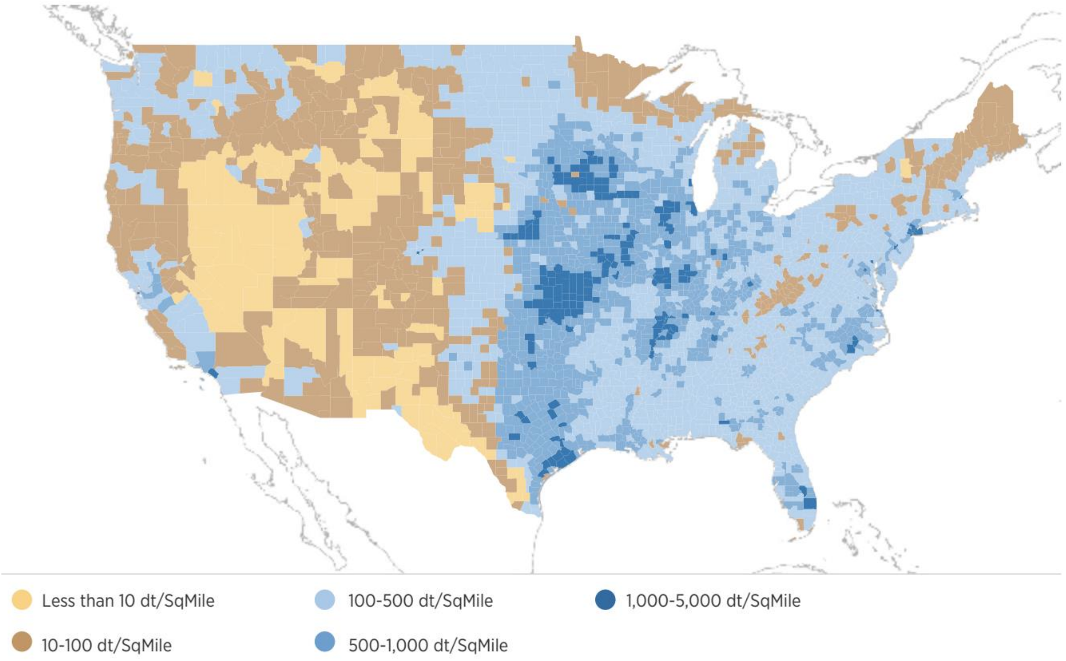
Solar thermal & Geothermal

Renewable Sources Of Heat

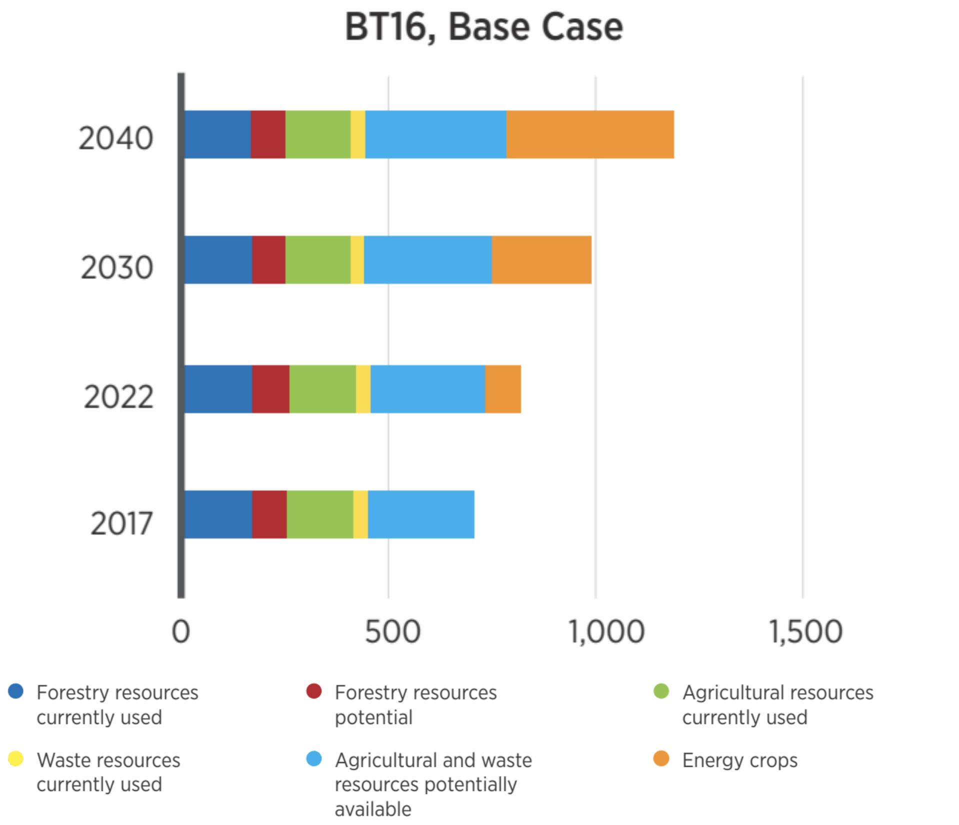
Biomass as an Industrial Fuel

U.S. DEPARTMENT OF
ENERGY

Sources of Biomass



Combined potential supplies from forestry, wastes, and agricultural resources, base case, 2040



Summary of currently used and potential resources at $60 per dry ton or less identified under base-case assumptions of BT16

Source: Billion Ton Report, 2016: Chapter 1

Biomass Combustion

Key properties of biomass combustion heating include:

- 1,950 ºC max. temp.
- High heat flux
- Heats all materials

These properties align with requirements for several process heating applications.

Industry Sector	Process Heating Applications						Relevant Equipment
Refineries	Distillation	Reactors					Boiler, process heater
Chemicals	Distillation	Drying	Reactors				Boiler, process heater, furnace, air heater
Iron & steel	Pelletization	Hot rolling	Basic oxygen furnace	Blast furnace			Boiler, furnace
Food	Drying	Pasteurizing	Boiling	Sterilizing	Washing	Cooking	Air heater, boiler, oven
Paper	Stock steaming	Drying	Wood processing	Evap. & chem. prep.	Lime calcination		Air heater, boiler, oven, furnace
Cement	Pre-heating & treating	Melting furnace	Forming	Annealing	Kiln combustion		Furnace

Not applicable	Potentially applicable	Currently deployed

Note: Since RNG has been blended into the existing natural gas distribution network, all potentially applicable process heating applications are denoted as "currently deployed"

The Renewable Thermal Vision Report

Challenges of Using Biomass, Biofuels, and Bio-feedstocks

- Pre-processing needed for heterogeneity of sources
  - Increases costs and complexity
- Transportation costs
  - Need to correlate with supply locations to minimize costs
  - Can constrain the applicability to certain locations
- Biomass combustion related GHG emissions => net carbon emission reduction?
  - GHG emissions may not be recaptured for decades
  - Sustainability of biomass source
- Non-GHG emissions
  - Volatile organic compounds, NOx, PM
- For low-quality biomass, validation with process needed

Case study: Nestlé rice husk and cocoa husk boilers

Rice husk boiler project

- Nestlé Karawang Plant, West Java
- Replace LNG with rice husk to produce steam
- Working closely with farmers, industry partners, government, etc.
- Utilize 8,880 tonnes of rice husk per year
  - Reduce emissions by 6,068 tons of CO_2e per year
  - Energy costs reduction by 14%
  - By-products (ash residue) to be used as organic fertilizer to be given to local rice farmers
- Also replicated at Nestlé Kejayan Plant, East Java

Source: Nestlé Supports Economic Development 2022

Cocoa husks as fuel and fertilizer

- Nestlé La Penilla de Cayón chocolate factory, Spain
  - Biomass boiler to use cocoa husk
  - 10% of required steam
  - Also, zero waste to landfill
  - Reduce emissions by 2000 tonnes of CO_2e per year
  - Also replicated in Konolfinger and Orbe in Switzerland => reducing 1000 tonnes of CO_2e per year
- Nestlé York confectionary site, UK
  - Cocoa shells to low-carbon fertilizer
  - 2-year trial to evaluate fertilizer performance on cross
  - Expected to produce up to 7,000 tonnes of low carbon fertilizer (25% of Nestlé UK's fertilizer use for wheat)

Source: Nestlé values cocoa husks.. 2022, Nestlé low carbon fertilizer pilot, 2023

Renewable Natural Gas as an Industrial Fuel

U.S. DEPARTMENT OF
ENERGY

Renewable Natural Gas (RNG)

Key properties of RNG combustion heating include:

- 1,950 ºC max. temp.
- High heat flux
- Heats all materials

These properties align with requirements for several process heating applications.

Industry Sector	Process Heating Applications						Relevant Equipment
Refineries	Distillation	Reactors					Boiler, process heater
Chemicals	Distillation	Drying	Reactors				Boiler, process heater, furnace, air heater
Iron & steel	Pelletization	Hot rolling	Basic oxygen furnace	Blast furnace			Boiler, furnace
Food	Drying	Pasteurizing	Boiling	Sterilizing	Washing	Cooking	Air heater, boiler, oven
Paper	Stock steaming	Drying	Wood processing	Evap. & chem. prep.	Lime calcination		Air heater, boiler, oven, furnace
Cement	Pre-heating & treating	Melting furnace	Forming	Annealing	Kiln combustion		Furnace

Not applicable	Potentially applicable	Currently deployed

Note: Since RNG has been blended into the existing natural gas distribution network, all potentially applicable process heating applications are denoted as "currently deployed"

The Renewable Thermal Vision Report

Sources of Renewable Natural Gas

Sources:

- Municipal Solid Waste (MSW) Landfills
- Municipal WWTP (using AD)
- Livestock farms (using AD)
- Stand-alone organic waste management operations (using AD)

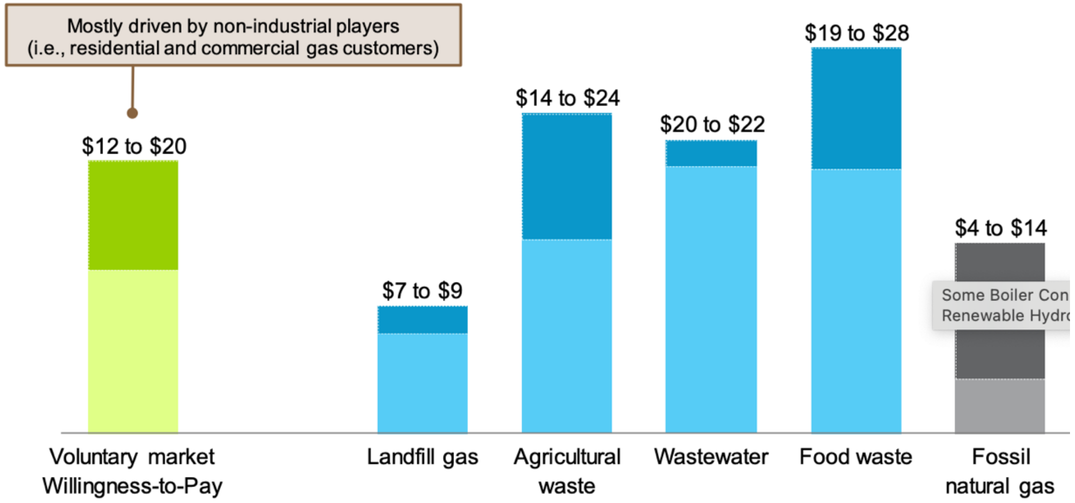
RNG Delivery mechanisms to end users:

- Injection into a pipeline
- On-site/ local applications

WWTP: wastewater treatment plant; AD: anaerobic digestion

Barriers for RNG Use

- Economic:
  - Higher cost of RNG compared to fossil NG systems
  - Competitive supply environment (i.e., transportation, power generation)



Interconnection costs for RNG production and pipeline injection exhibit strong economies of scale; Can favor large projects over small ones

- Technical:
  - Gas quality
  - Gas infrastructure may require reconfiguration to account for RNG supply locations
  - Limited total supply due to feedstock constraints

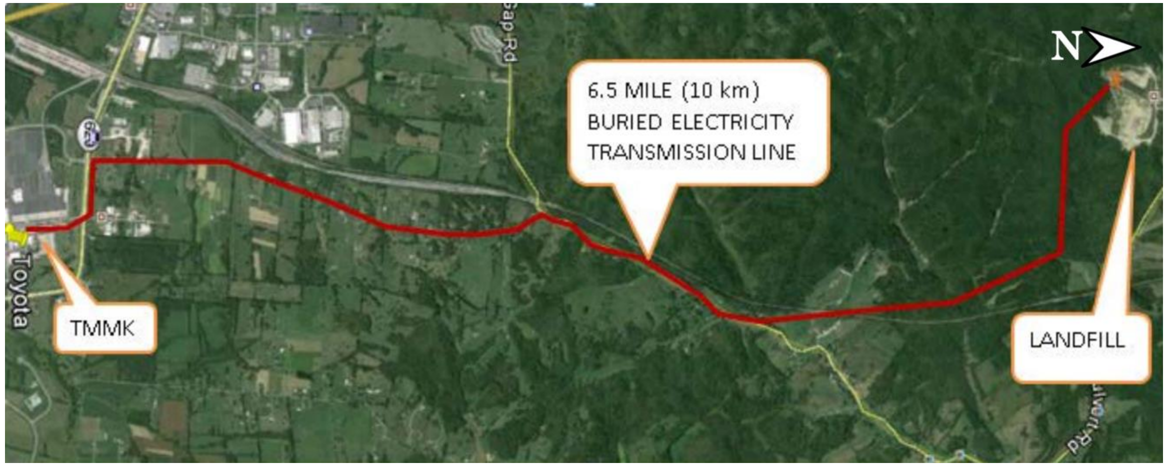
RNG Database of Argonne National Lab

Credit: Ahmad Abbas, ORNL

The Renewable Thermal Vision Report

Case study: Landfill Gas to Energy, Toyota (2014-15)

- Toyota manufacturing facility, Kentucky
- Landfill gas to electricity, but lessons to be learnt
  - Low CO2 and reduces CO2 release from landfill
  - Fixed cost, long term contract
  - Landfill has enough gas for 1MW of electricity generation, expected to grow
- EPA's Landfill Gas Emissions Model (Land-GEM) study used
  - Revealed sufficient gas flow for 1MW of electricity production
- Public/Private partnership
  - Partnering with local landfill
  - Toyota to generate electricity at landfill and transmit to site
    - Contracted with landfill to operate and maintain equipment
  - Equipment at remote site, but meets KY electricity generation rules
    - Compared to landfill selling electricity to Toyota site or piping landfill gas to Toyota site



Path from Landfill to Toyota's site

- Learnings:
  - Project took longer to complete than anticipated
  - Initial project estimates were higher than anticipated
  - Gaining approval from private/ public sector was very relationship driven
  - Understand local govt. ordinances, local environmental issues for construction
  - Working with a partner vs. a supplier

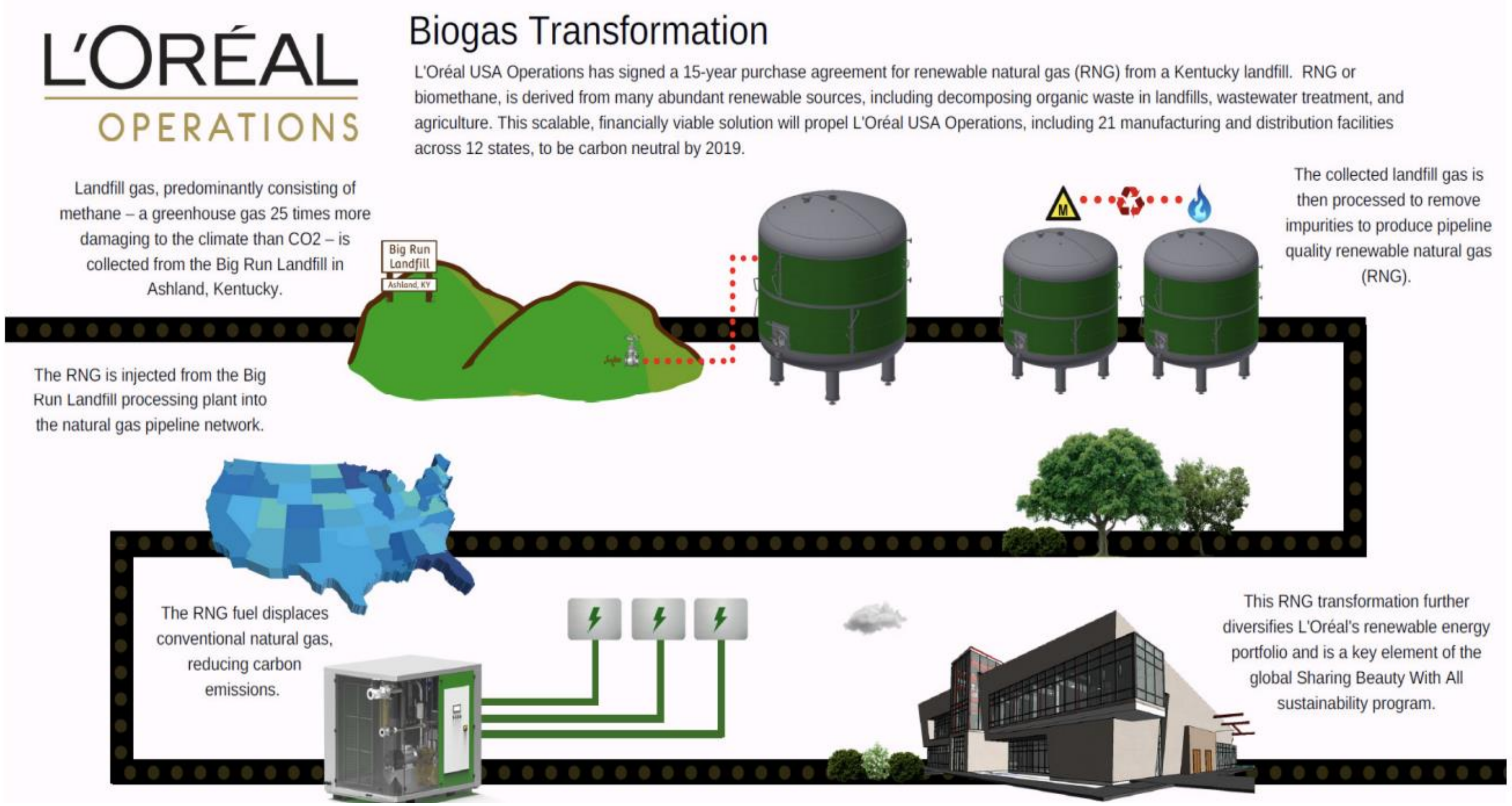
Source: [Toyota Motor Manufacturing, Kentucky: Landfill Gas to Energy Project. WECC Presentation]

Case study: City of Fort Wayne City Utilities Grease Cooperative

- Innovative Collaboration for Sustainable Restaurants
  - Use a waste product as a sustainable energy source.
  - Ensure high quality grease interceptor cleaning service.
  - Protect the public and the environment from sewage backup and overflow
  - Waste FOG will be used to power our Water Pollution Control Plant
  - Energy efficiency and reduced need for sewer line maintenance => lower rates

Source: https://utilities.cityoffortwayne.org/greasecooperative

Case study: L'Oréal USA + Big Run Landfill RNG project



- Reduction in 16% of Scope 1 emissions
- Scope 2: with 100% renewable energy; Scope 1 strategy was more difficult
- Needed to find financial structure to make this project financially sustainable due to NG costs

Source: Sustainable Options for Reducing Emissions from Thermal Energy, 2018

Steam Generation Alternatives in the Food Industry*

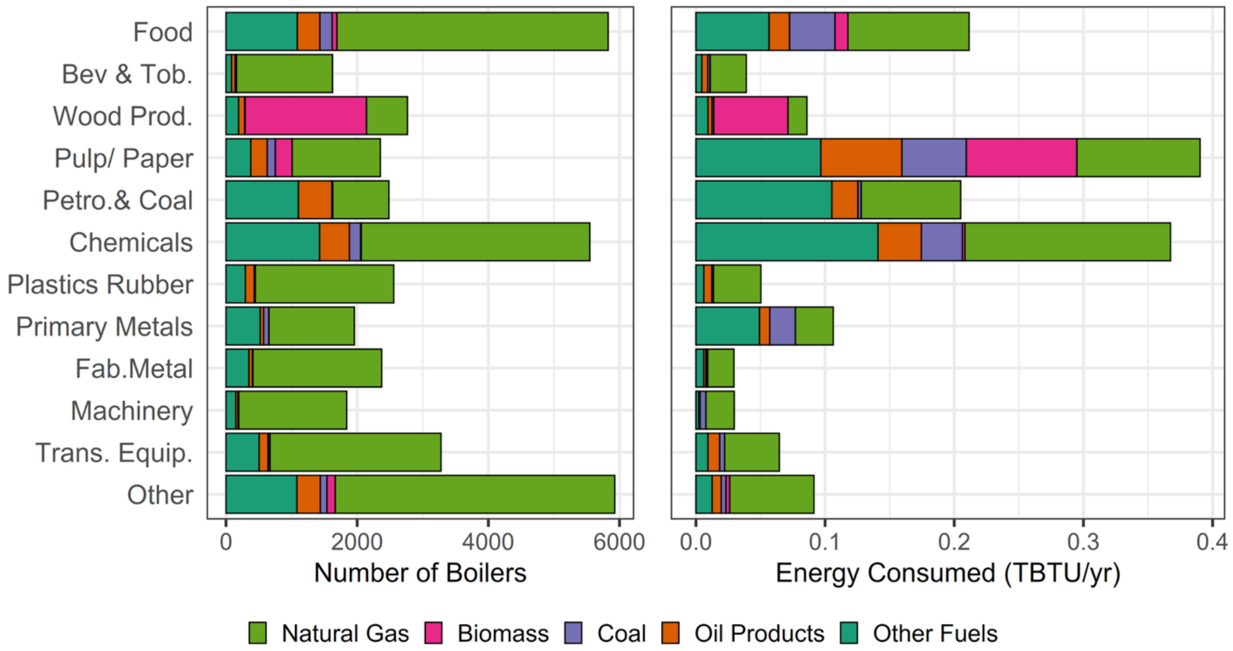
*Banboukian, A., Armstrong, K., Nimbalkar, S.U., Cresko, J., 2025

<under review>

U.S. DEPARTMENT OF
ENERGY

Introduction

- The food industry has among the **highest number of boilers** installed and the **highest installed capacity**
- The food industry overwhelmingly uses boilers fueled by fossil fuels
- Food boilers cover the full range of industrial-scale capacities
  - Most are <120 MMBtu/hr
- Decarbonizing boilers is a key step to decarbonizing the industry



Amended dataset – source https://doi.org/10.1016/j.adapen.2022.100089

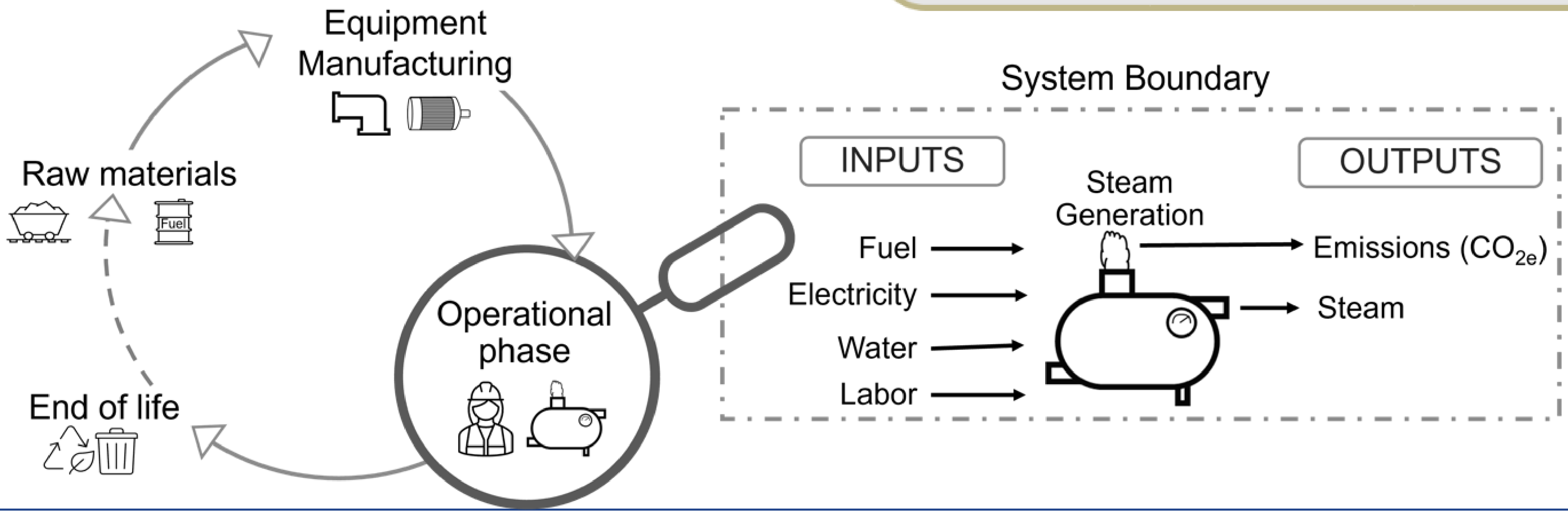
*Banboukian, A., Armstrong, K., Nimbalkar, S.U., Cresko, J., 2025 <under review>

Methodology

- Cradle to gate attributional LCA
- Functional unit 1klb of steam generated
- System boundary – Operational Phase of boiler

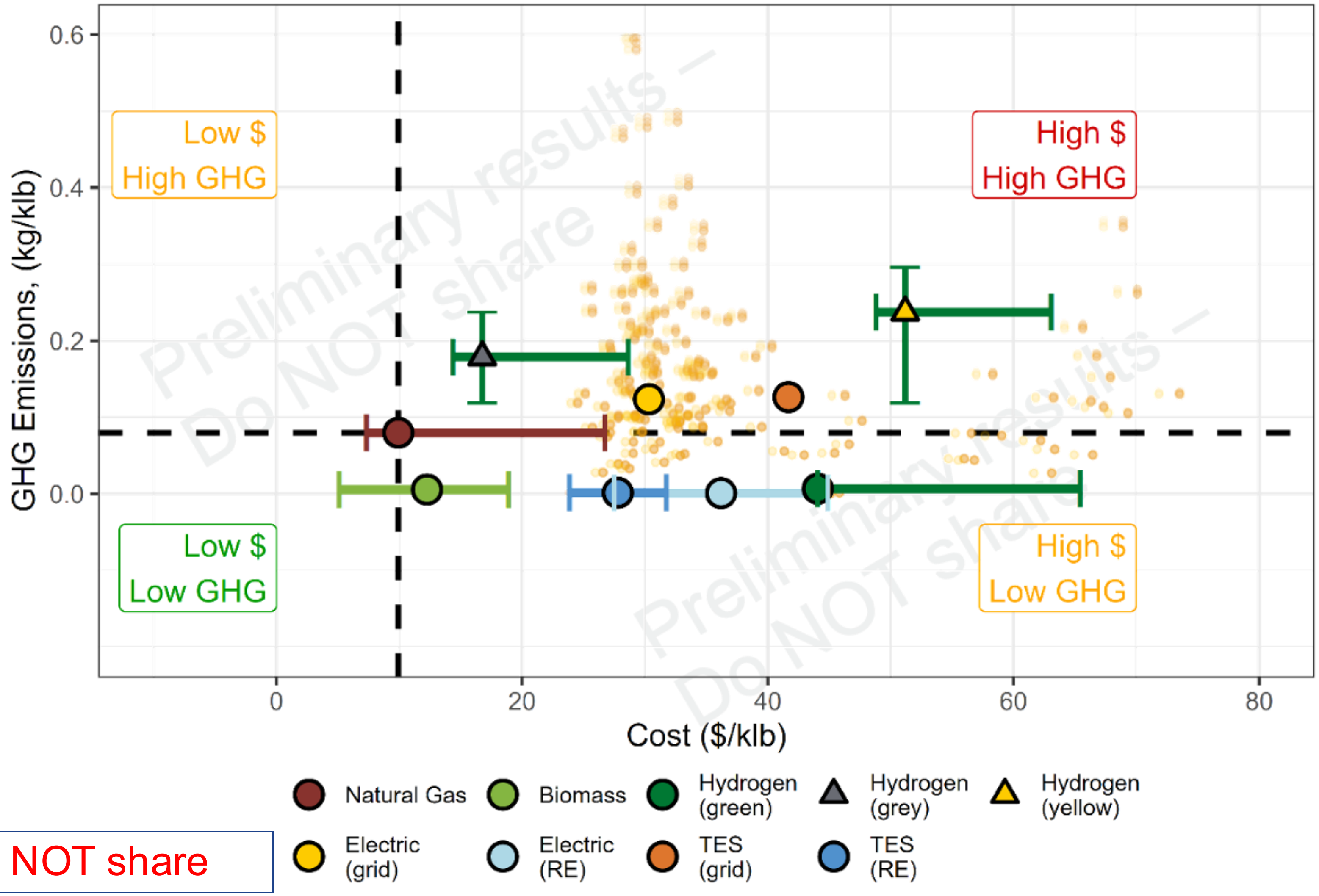
Steam generating technologies:

1. Natural gas boiler
2. Biomass boiler
3. Hydrogen boiler
4. Electric boiler (grid & RE)
5. Thermal energy storage (grid & RE)



Results

- All energy sources have a *wide range of costs*
- Many have a *wide range of emissions*
- ***"Which is better?"*** depends on: location, contract negotiation (policy), primary source



Preliminary results – Do NOT share

*Banboukian, A., Armstrong, K., Nimbalkar, S.U., Cresko, J., 2025 <under review>

Relevant Resources

U.S. DEPARTMENT OF ENERGY

Relevant Resources

- Bioenergy Knowledge Discovery Framework (https://bioenergykdf.net/)

  BETO research and development (R&D) efforts, including state of technology (SOT) reports, technology design pathways analyses, life cycle assessments (LCAs), techno-economic analyses (TEAs), and a supply chain analysis

- Waste Energy Content Calculator Tool (https://betterbuildingssolutioncenter.energy.gov/resources/waste-stream-energy-content-calculator)

  To quickly estimate the energy recovery potential of waste streams based on the values of waste generated annually. The calculator only considers two main pathways for energy recovery, direct combustion and anaerobic digestion.

- EIA U.S. Energy Atlas (EIA U.S. Energy Atlas)

  These dataset provide the latest detailed information on locations of biodiesel, ethanol, natural gas storage and other energy sources in the U.S.

Relevant Resources

- REopt: Renewable Energy Integration & Optimization Tool (https://reopt.nrel.gov/)

  The REopt® techno-economic decision support platform is used by NREL researchers to optimize energy systems for buildings, campuses, communities, microgrids, and more.

- Reports and Assessments
  - Bioenergy: A Pathway to Decarbonization Fact Sheet | Department of Energy
    - https://www.energy.gov/eere/bioenergy/bioenergy-pathway-decarbonization-fact-sheet
  - Role-of-biomass-in-industrial-heat.pdf (ieabioenergy.com)
    - https://www.ieabioenergy.com/wp-content/uploads/2022/02/Role-of-biomass-in-industrial-heat.pdf
  - Hydrogen's Decarbonization Impact for Industry (RMI)
    - https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf
  - decarbonization-of-industrial-sectors-the-next-frontier.pdf (mckinsey.com)
    - https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20industry%20can%20move%20toward%20a%20low%20carbon%20future/decarbonization-of-industrial-sectors-the-next-frontier.pdf

Summary

- Alternatives to fossil fuel use are available for industrial applications at varying degrees of readiness.
- Important considerations when choosing include availability (now and future) and ability to be resilient to such changes.
- Multiple DOE resources developed for navigating the alternatives and considerations.

Applicability of LCFFES

Sector	Renewable Heat and Its Sources			
	Biomass Combustion (and Biofuels Feedstock)	Other RE (Geotherm. and Conc. Solar)	Green H_2 (Electroly-sis/Gasification)	Biomethane (Anaerobic Digestion)
Steel	X	XXX	XXX	XXX
Chemicals	XXX	XX	XXX	XX (**)
Fertilisers	XXX	XX	XXX	XX (**)
Cement	XXX	XX	X	XX (**)
Lime	XXX	XX	X	XXX
Refining	XXX	XX	XXX	XXX (**)
Ceramics	X	XXX	XX	XXX
Paper	XXX	XX	O	XXX (**)
Glass	XXX	XXX	X	XXX
Non-Fe metals	XXX	XX	XX	XXX
Alloys	XXX	XX	XX	XXX
Notes	O: Limited or no significant application foreseen X: Possible application but no main route or wide-scale applications XX: Medium potential XXX: High potential		**: already used as feedstock for value-added products	

Source: Carmona-Martínez, A.A. et al. 2023. https://doi.org/10.3390/pr11010018

Questions/Comments?

Dipti Kamath, ORNL
kamathdd@ornl.gov

5 Minute Break

Today’s Speakers

Indraneel Bhandari

R&D Associate Staff Member
Oak Ridge National Laboratory

bhandarii1@ornl.gov
(865) 341-4259

Introduction to Small Modular Reactors (SMR)

Indraneel Bhandari
Oak Ridge National Laboratory

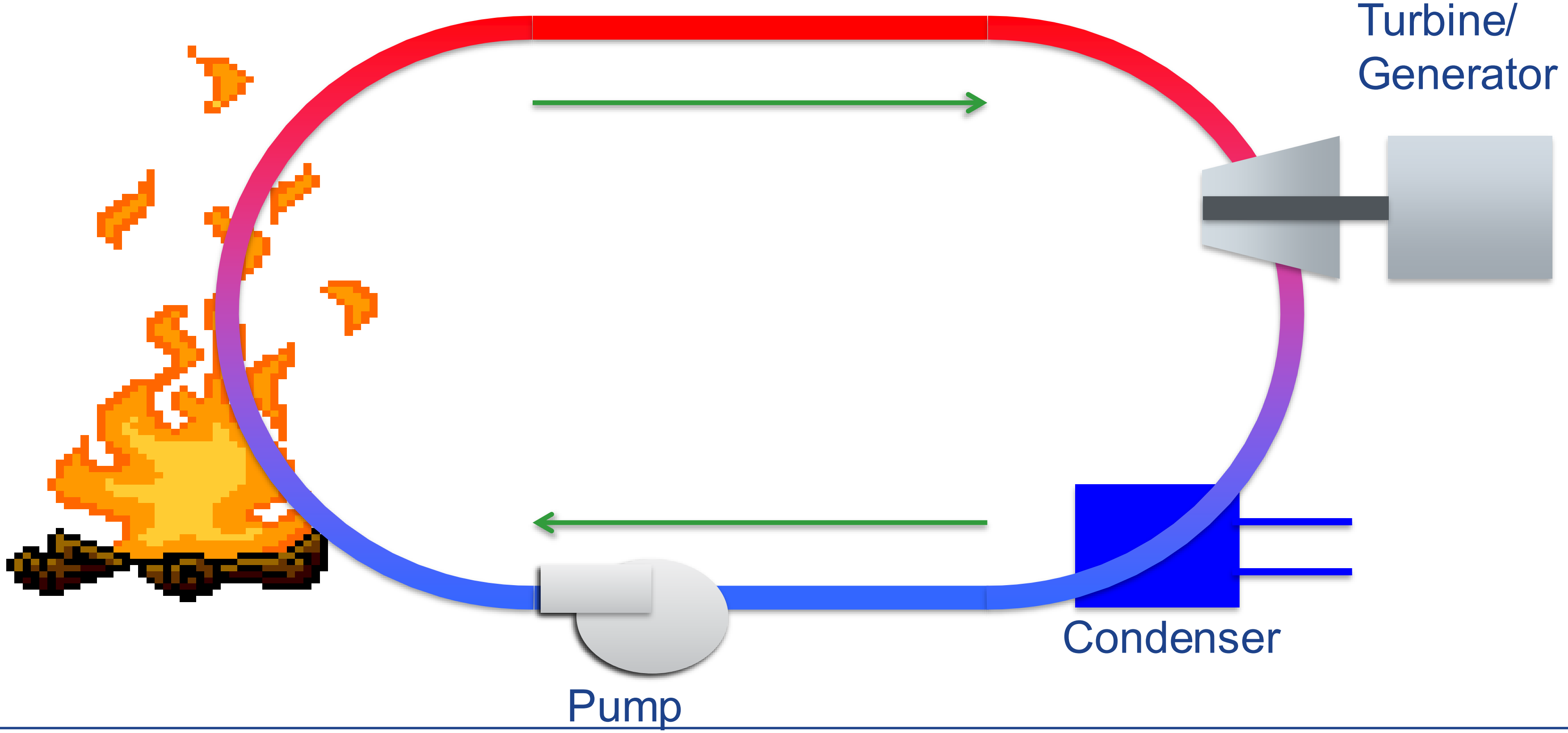
Acknowledgements

- U.S. Department of Energy, Industrial Technologies Office (ITO)
- Dave Pointer, Nuclear Energy and Fuel Cycle Division, ORNL
- Thomas Wenning, ORNL
- Idaho National Laboratory

- Information used in the presentation is derived from several sources including equipment manufacturers' websites, media articles, published literature, and handbooks.

- Most of us have some notional idea of how a power plants work

Fuel Sources ⟶ Heat ⟶ Steam ⟶ Electricity



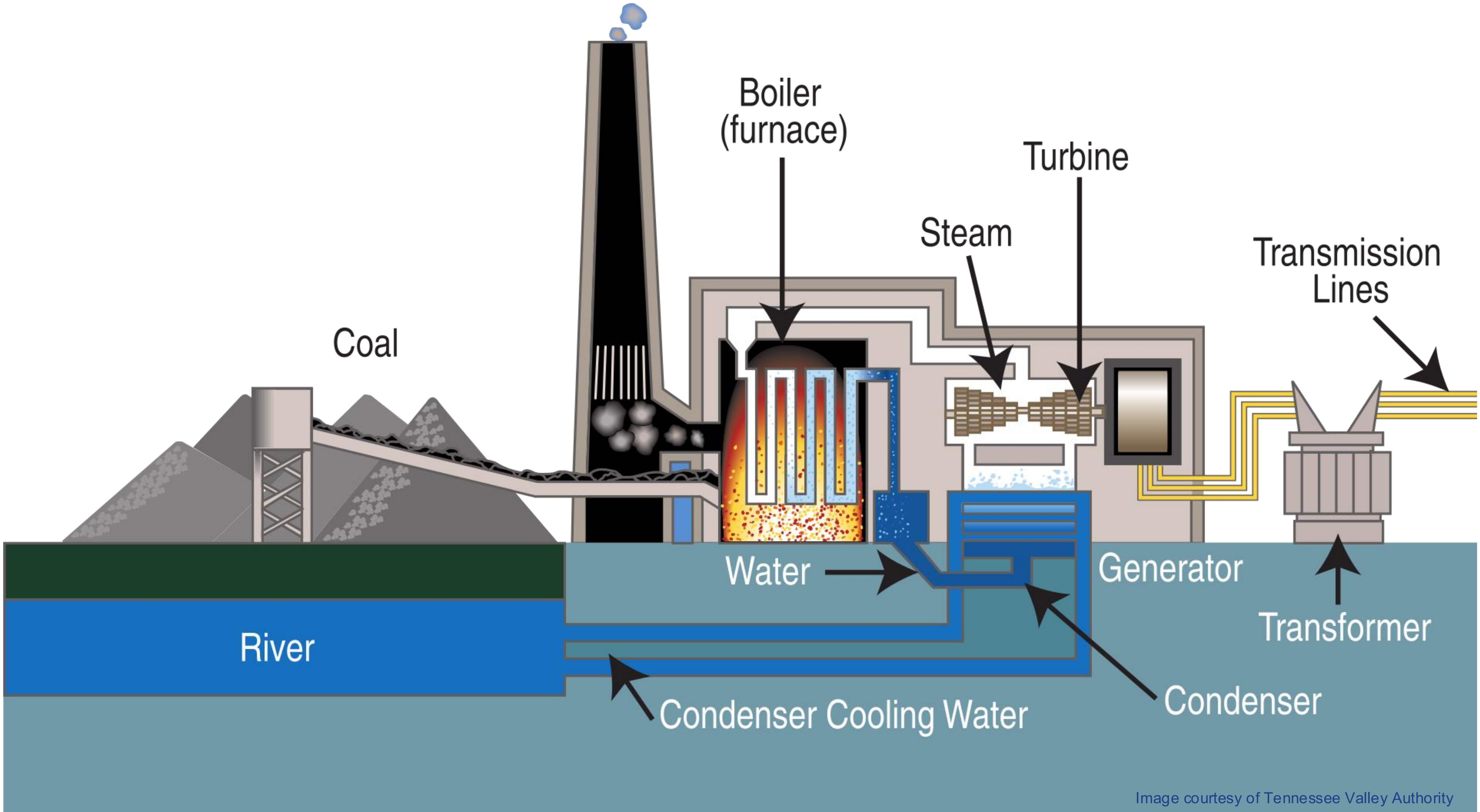


Image courtesy of Tennessee Valley Authority

What makes a nuclear power plant different?

It’s the Fuel!

Nuclear power plants use the energy stored in the nucleus of large atoms rather than the energy stored in weaker chemical bonds.

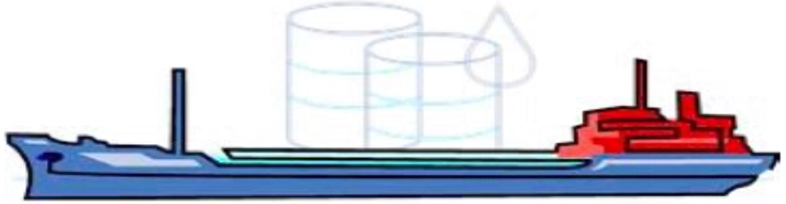
Image courtesy of NRC

Nuclear fuel is highly energy dense

TO POWER 1000 HOMES

150 Tons of Uranium

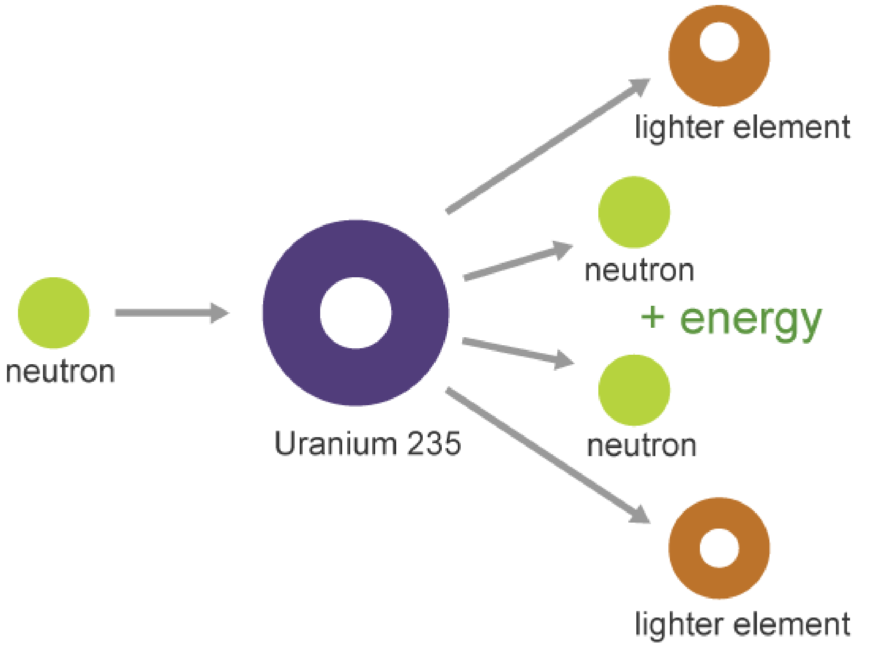
2,100,000 Tons of Coal



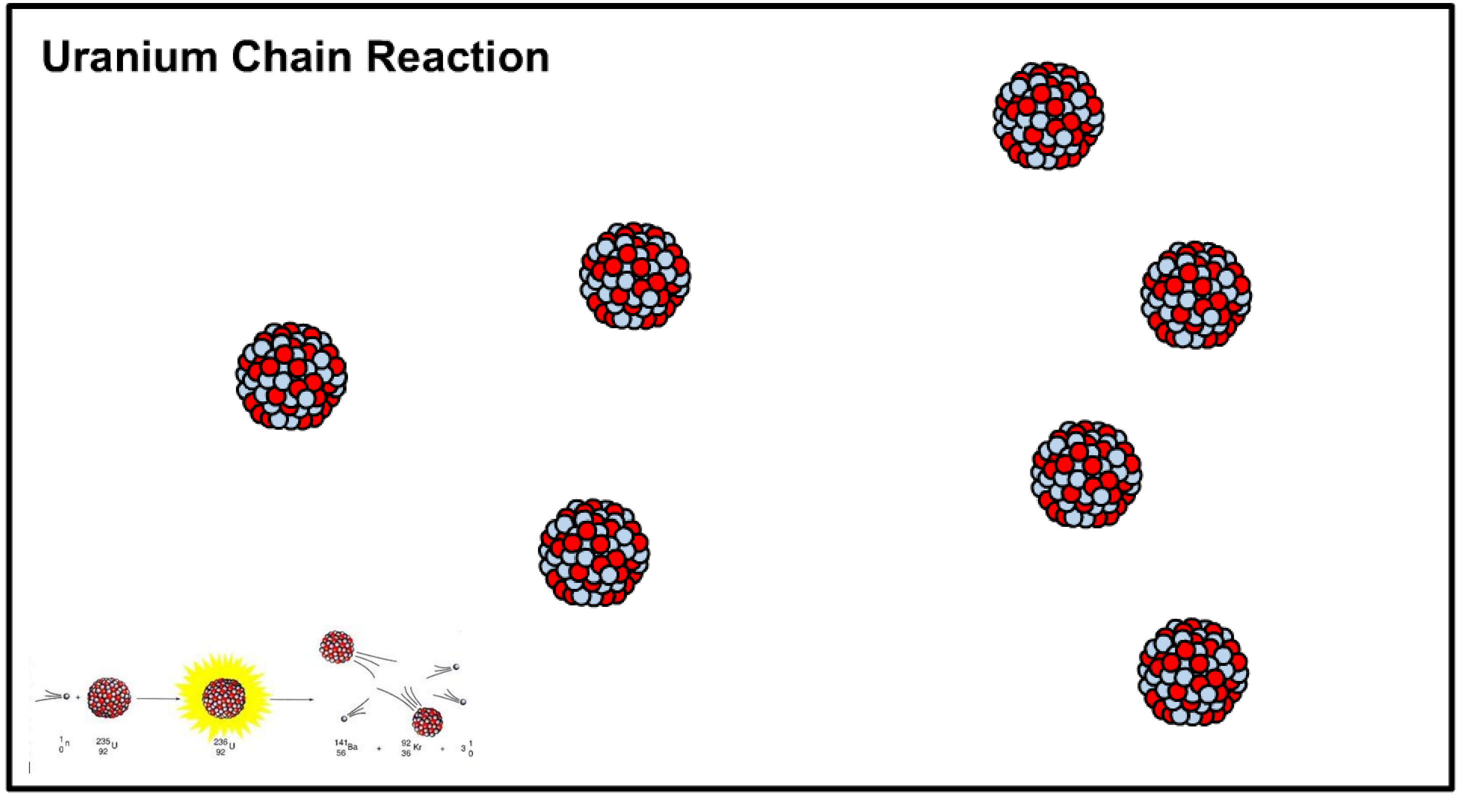
10,000,000 Barrels of Oil

Nuclear energy is energy in the core of an atom

How fission splits the uranium atom



Source: Adapted from National Energy Education Development Project (public domain)

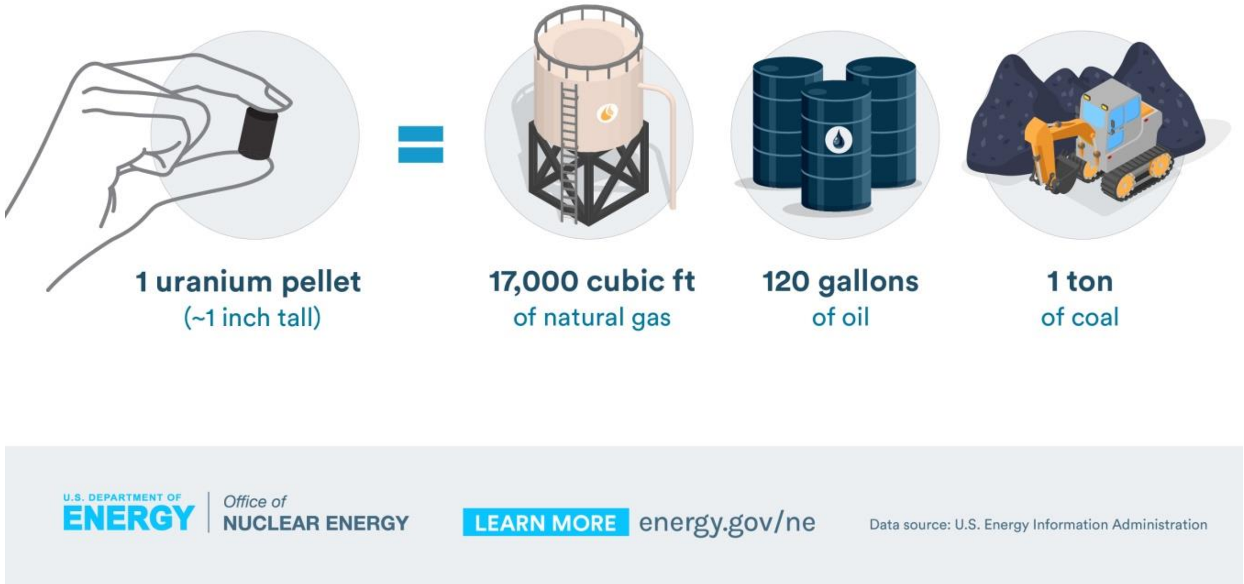


Source: Bramble Chemistry

Nuclear fuel is highly energy dense

- U-235 is the fissile material
  - U-235 is the only naturally occurring
- Enrichment – Separative work calculation
  - Natural Uranium (0.7% U-235) to 3-5% U-235

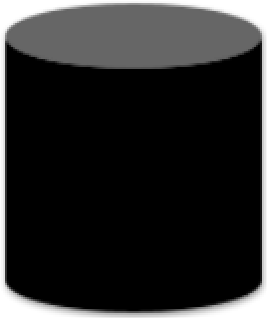
U-235 will fission with slow velocity neutrons



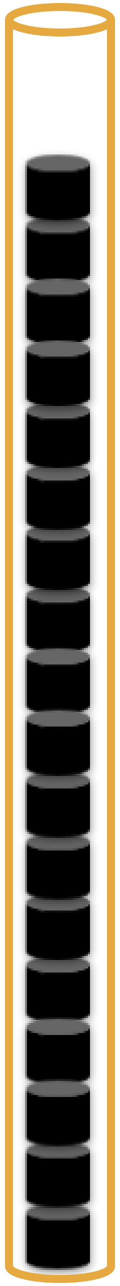
Nuclear fuel is very energy dense

The nuclear fuel used to generate the energy used in one American's entire lifetime could fit in here.

Image courtesy: https://www.pixelsquid.com/png/generic-blue-can-355ml-1273408776299961 08?image=G13

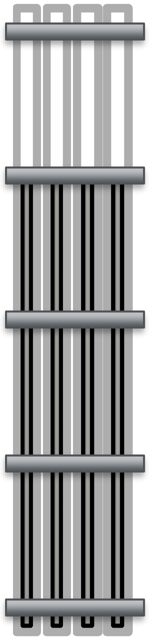


First, ceramic **fuel pellets** are manufactured from **uranium** ore

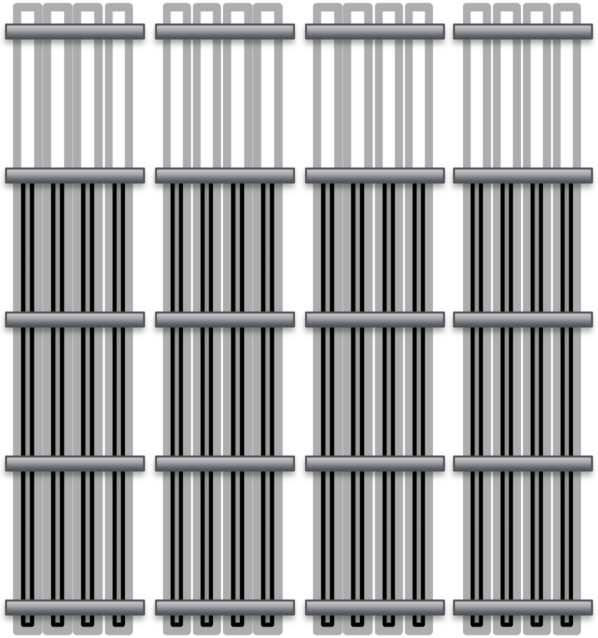


The ceramic **fuel pellets** are stacked in a column

And sealed inside a metallic alloy case, called the **cladding**, to form a **fuel rod**

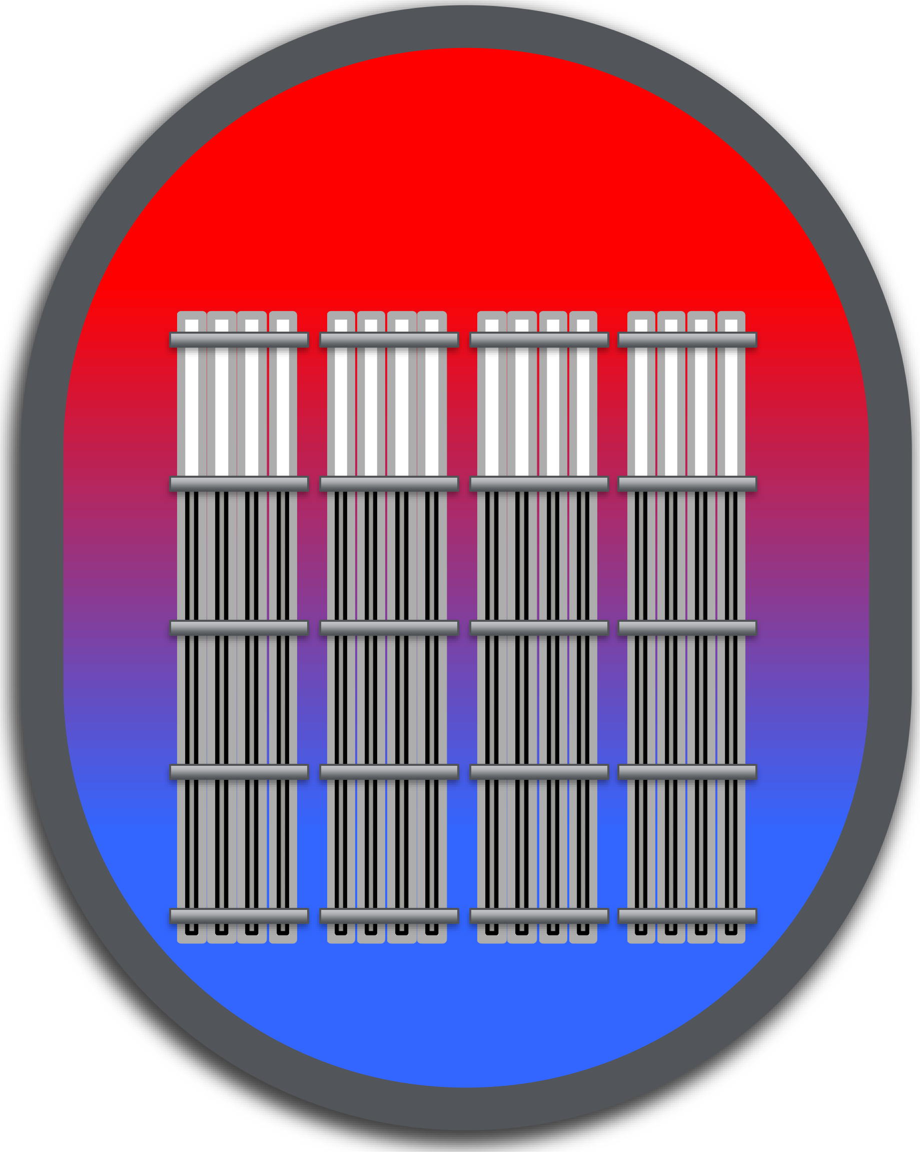


The **fuel rods** are grouped together in a regular array or **fuel assembly**



The **fuel rods** are grouped together in a regular array or **fuel assembly**

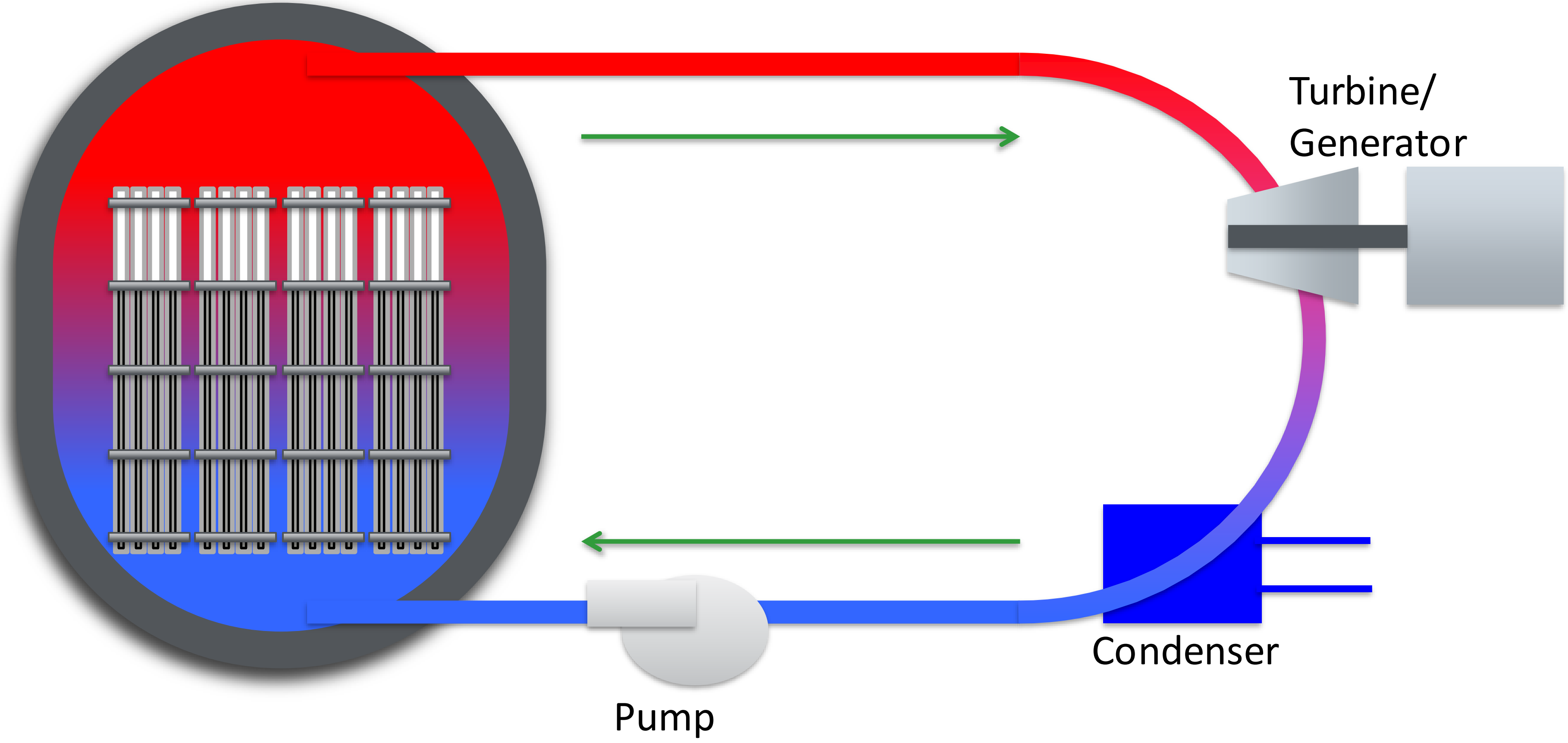
The **fuel assemblies** are arranged in a larger regular array or **reactor core**



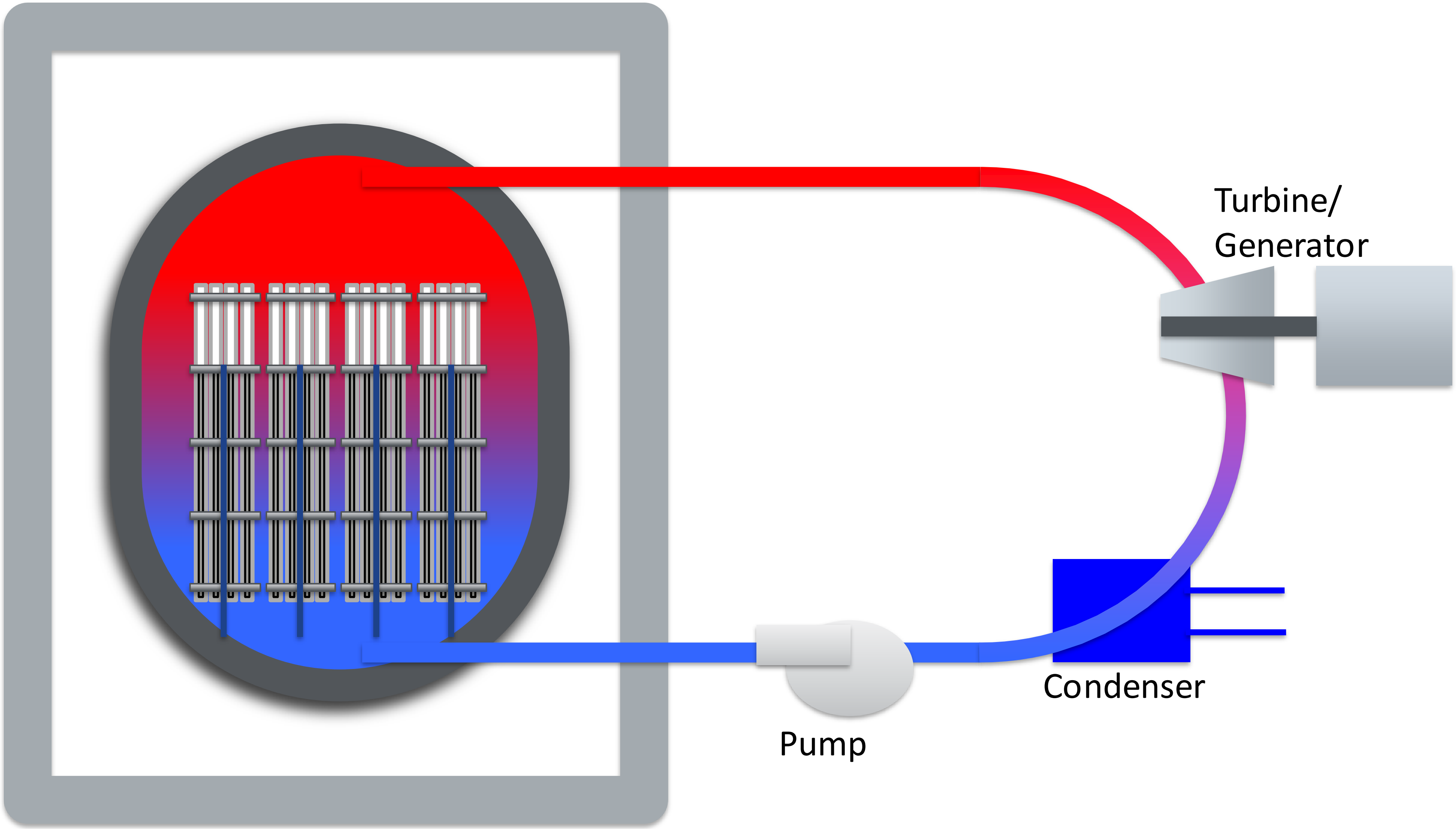
The **fuel rods** are grouped together in a regular array or **fuel assembly**

The **fuel assemblies** are arranged in a larger regular array or reactor **core**

The reactor **core** is contained inside a heavy steel **reactor pressure vessel (RPV)**

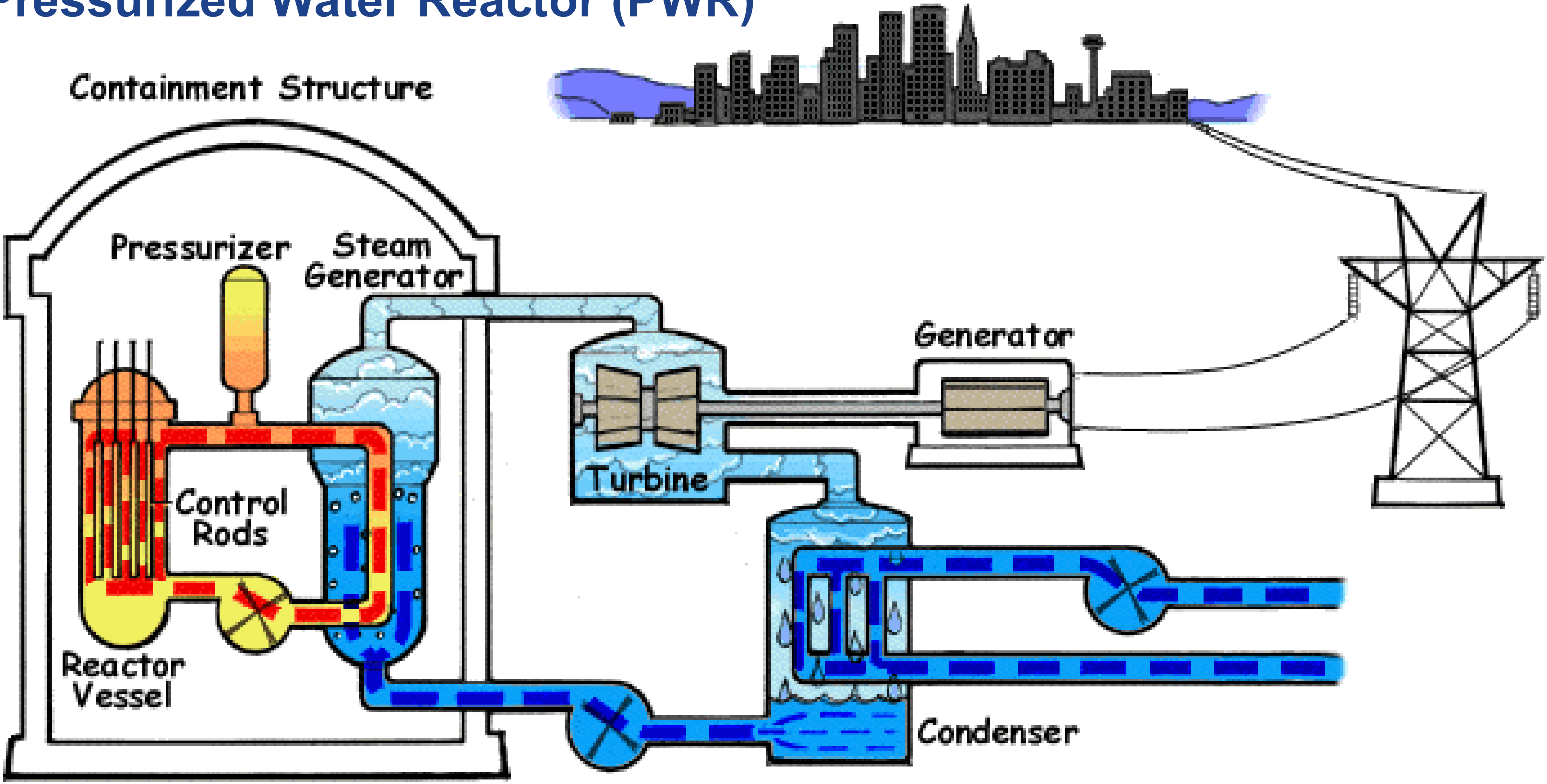


In a nuclear power plant, the **reactor core** is the energy source



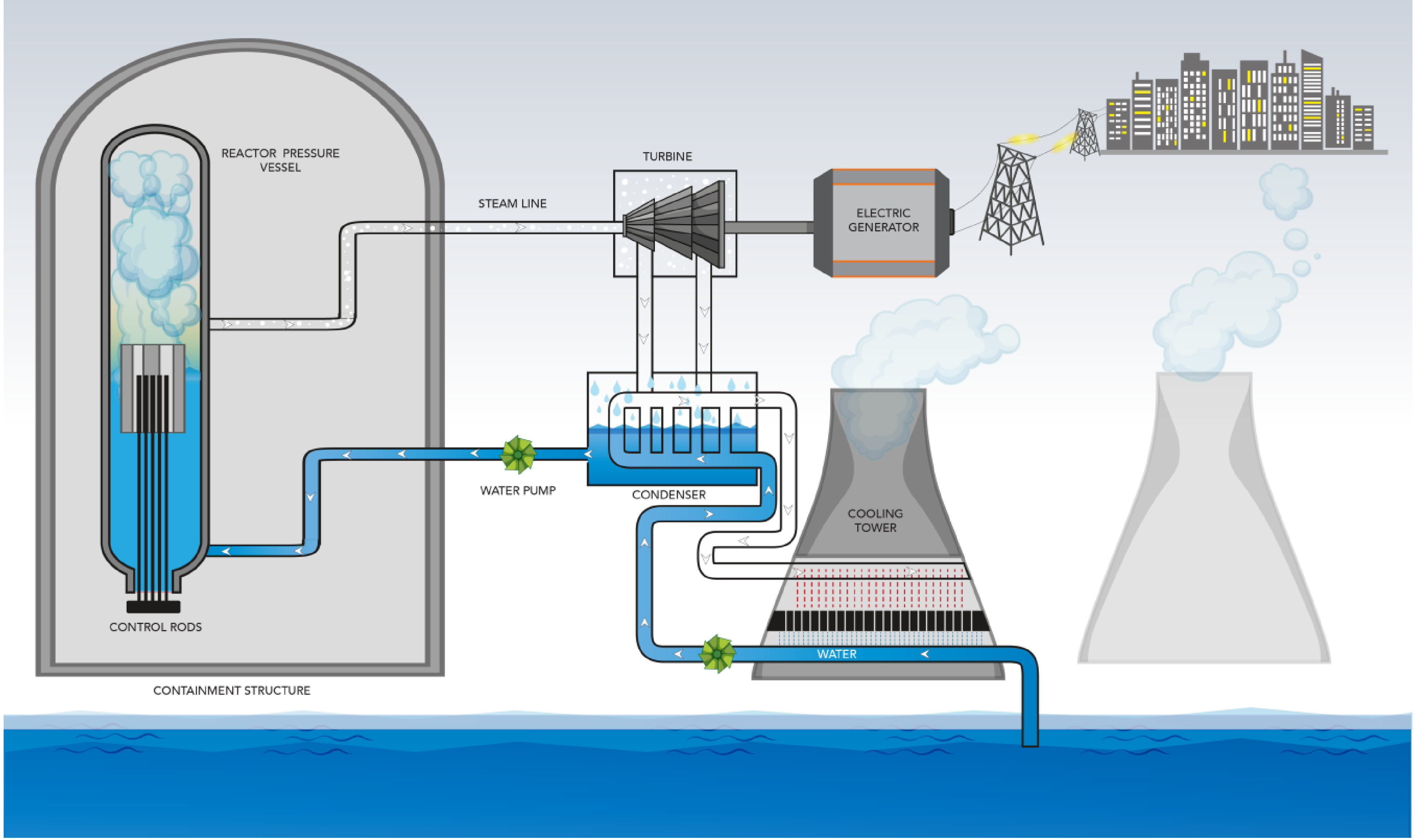
The entire reactor sits inside a large concrete and steel **containment building**

Pressurized Water Reactor (PWR)



Source: U.S. Nuclear Regulatory Commission (NRC)

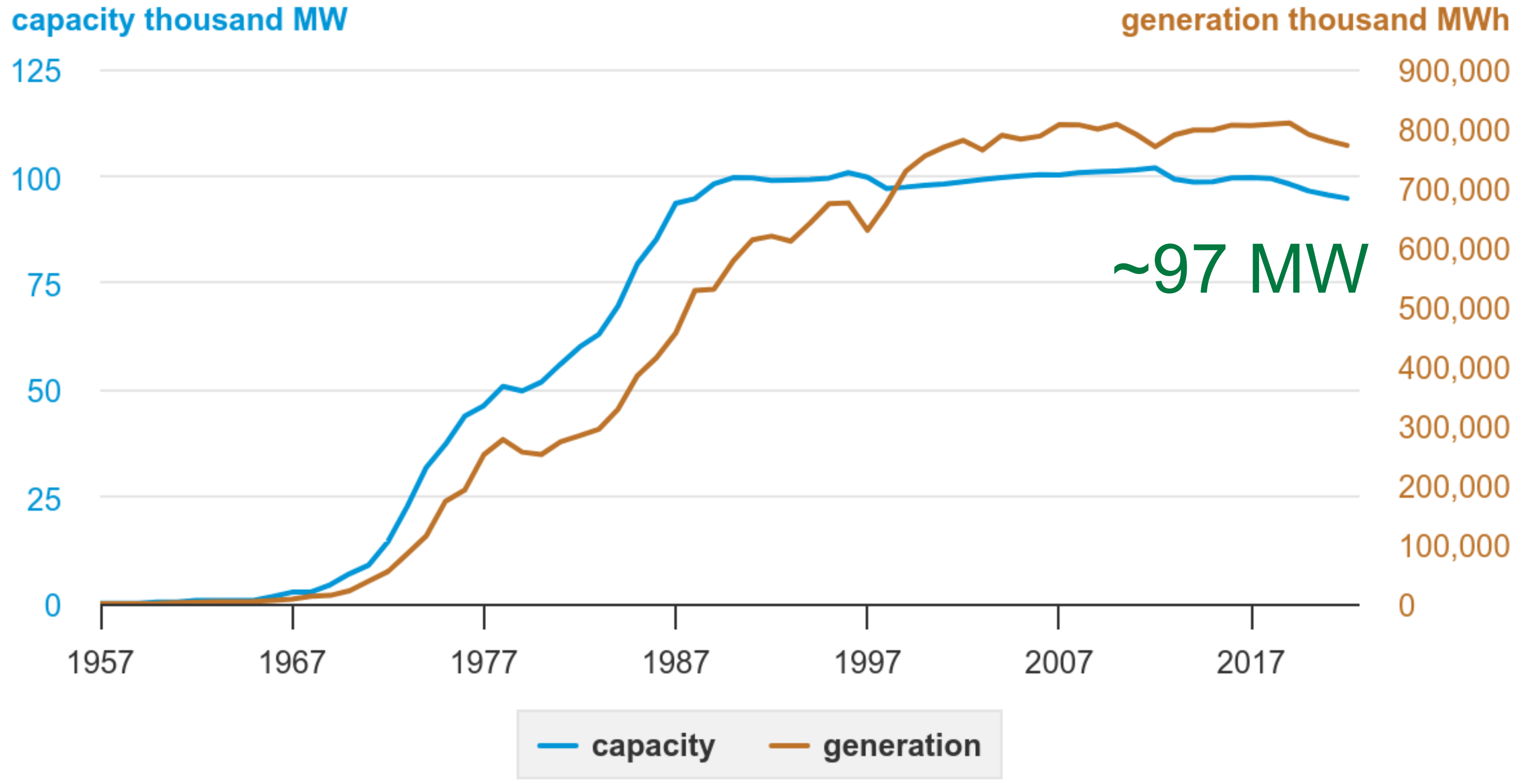
BOILING WATER REACTOR (BWR)



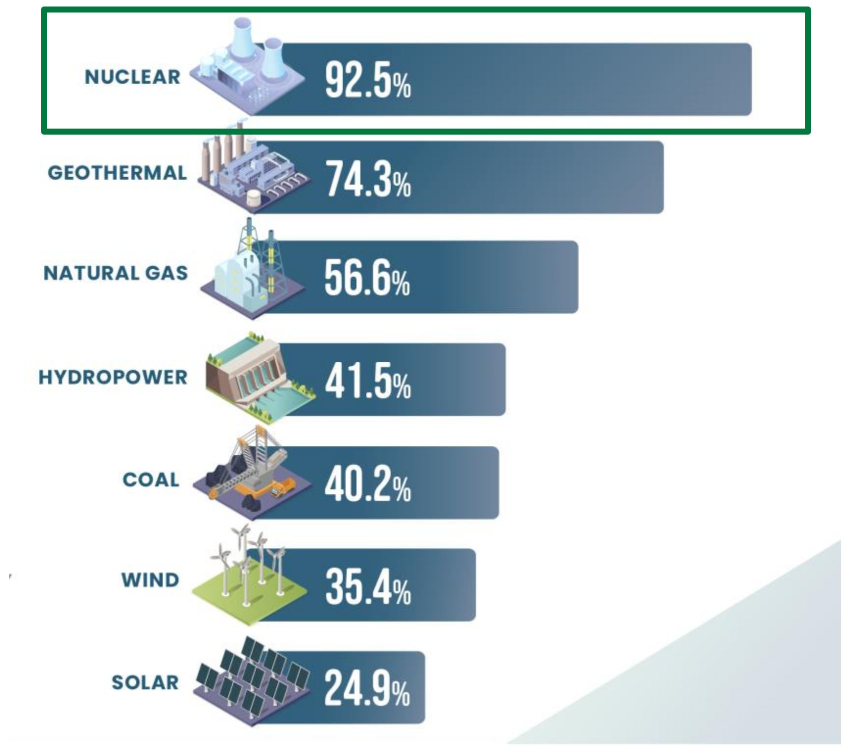
Source: U.S. Department Of Energy (DOE)

U.S. Nuclear Power

U.S. nuclear electricity generation capacity and generation, 1957-2022



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 8.1, July 2023, preliminary data for 2022
Note: Capacity is net summer; MW is megawatts; MWh is megawatthours.



Capacity factor by energy source

U.S. Nuclear Power

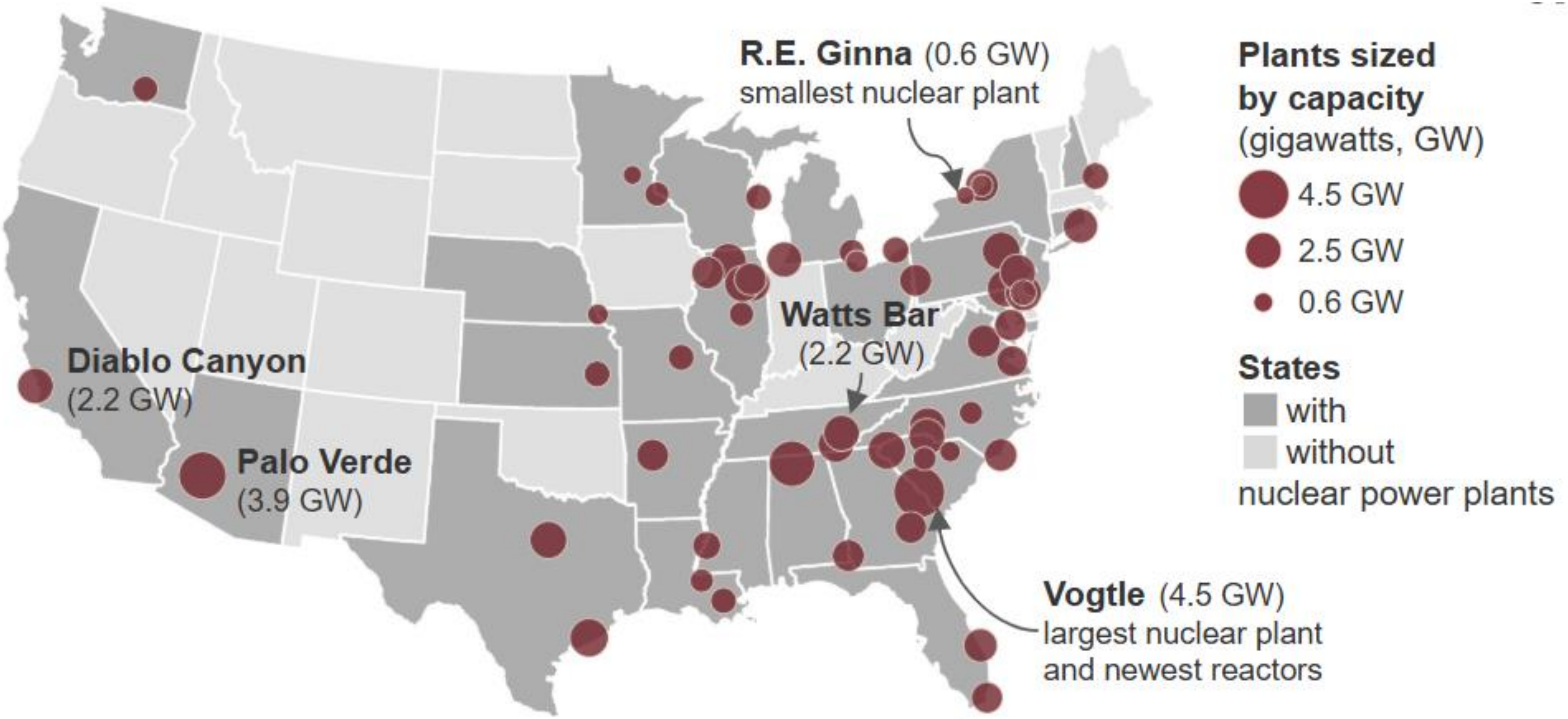
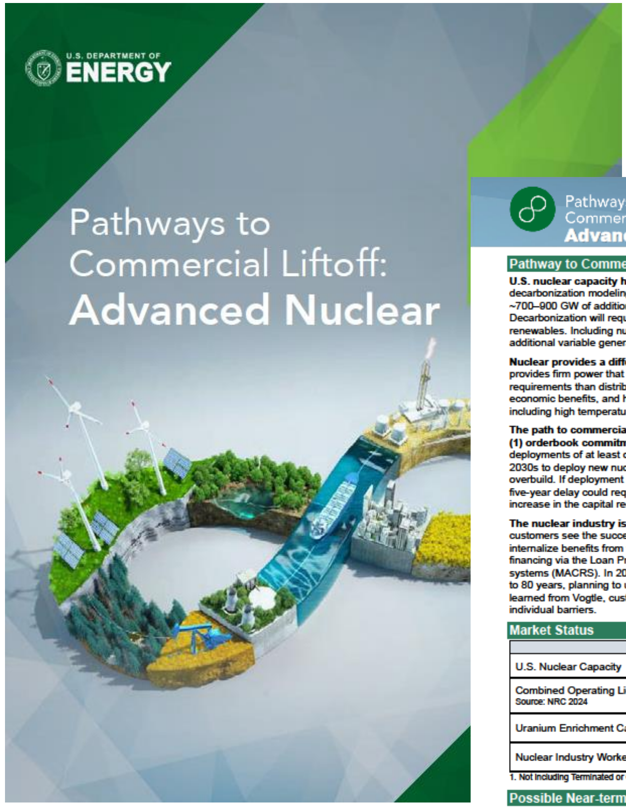
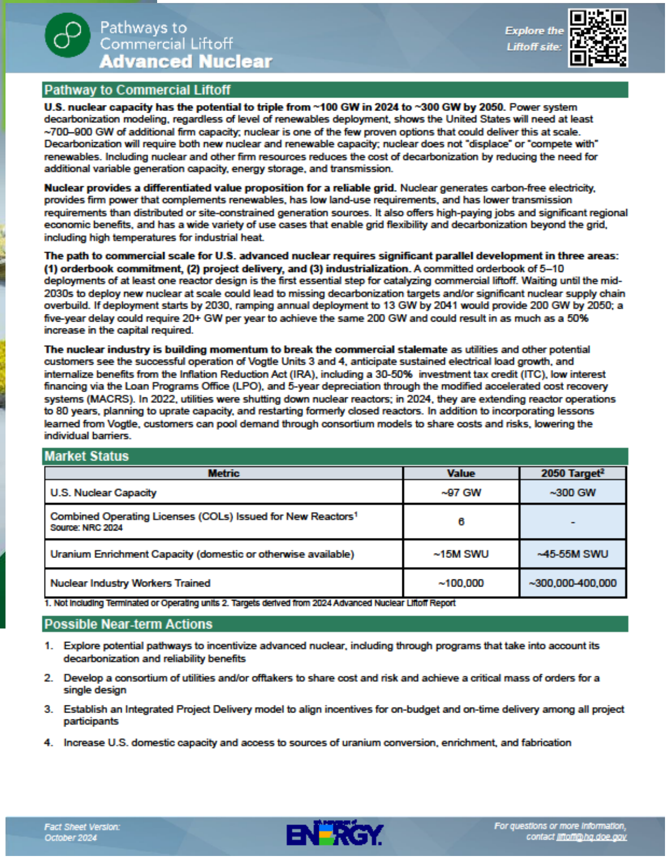


Image courtesy: EIA

U.S. Nuclear Power

- **Triple** nuclear energy capacity by 2050
- 6 Combined Operating Licenses (COLs) Issued for New Reactors
- Substantially increase the Uranium enrichment capacity
- Triple industry workforce





Pathways to Commercial Liftoff
Advanced Nuclear

Explore the Liftoff site:

Pathway to Commercial Liftoff

U.S. nuclear capacity has the potential to triple from ~100 GW in 2024 to ~300 GW by 2050. Power system decarbonization modeling, regardless of level of renewables deployment, shows the United States will need at least ~700–900 GW of additional firm capacity; nuclear is one of the few proven options that could deliver this at scale. Decarbonization will require both new nuclear and renewable capacity; nuclear does not "displace" or "compete with" renewables. Including nuclear and other firm resources reduces the cost of decarbonization by reducing the need for additional variable generation capacity, energy storage, and transmission.

Nuclear provides a differentiated value proposition for a reliable grid. Nuclear generates carbon-free electricity, provides firm power that complements renewables, has low land-use requirements, and has lower transmission requirements than distributed or site-constrained generation sources. It also offers high-paying jobs and significant regional economic benefits, and has a wide variety of use cases that enable grid flexibility and decarbonization beyond the grid, including high temperatures for industrial heat.

The path to commercial scale for U.S. advanced nuclear requires significant parallel development in three areas: (1) orderbook commitment, (2) project delivery, and (3) industrialization. A committed orderbook of 5–10 deployments of at least one reactor design is the first essential step for catalyzing commercial liftoff. Waiting until the mid-2030s to deploy new nuclear at scale could lead to missing decarbonization targets and/or significant nuclear supply chain overbuild. If deployment starts by 2030, ramping annual deployment to 13 GW by 2041 would provide 200 GW by 2050; a five-year delay could require 20+ GW per year to achieve the same 200 GW and could result in as much as a 50% increase in the capital required.

The nuclear industry is building momentum to break the commercial stalemate as utilities and other potential customers see the successful operation of Vogtle Units 3 and 4, anticipate sustained electrical load growth, and internalize benefits from the Inflation Reduction Act (IRA), including a 30-50% investment tax credit (ITC), low interest financing via the Loan Programs Office (LPO), and 5-year depreciation through the modified accelerated cost recovery systems (MACRS). In 2022, utilities were shutting down nuclear reactors; in 2024, they are extending reactor operations to 80 years, planning to uprate capacity, and restarting formerly closed reactors. In addition to incorporating lessons learned from Vogtle, customers can pool demand through consortium models to share costs and risks, lowering the individual barriers.

Market Status

Metric	Value	2050 Target[2]
U.S. Nuclear Capacity	~97 GW	~300 GW
Combined Operating Licenses (COLs) Issued for New Reactors[1] Source: NRC 2024	6	-
Uranium Enrichment Capacity (domestic or otherwise available)	~15M SWU	~45-55M SWU
Nuclear Industry Workers Trained	~100,000	~300,000-400,000

1. Not including Terminated or Operating units 2. Targets derived from 2024 Advanced Nuclear Liftoff Report

Possible Near-term Actions

1. Explore potential pathways to incentivize advanced nuclear, including through programs that take into account its decarbonization and reliability benefits
2. Develop a consortium of utilities and/or offtakers to share cost and risk and achieve a critical mass of orders for a single design
3. Establish an Integrated Project Delivery model to align incentives for on-budget and on-time delivery among all project participants
4. Increase U.S. domestic capacity and access to sources of uranium conversion, enrichment, and fabrication

Fact Sheet Version: October 2024

ENERGY

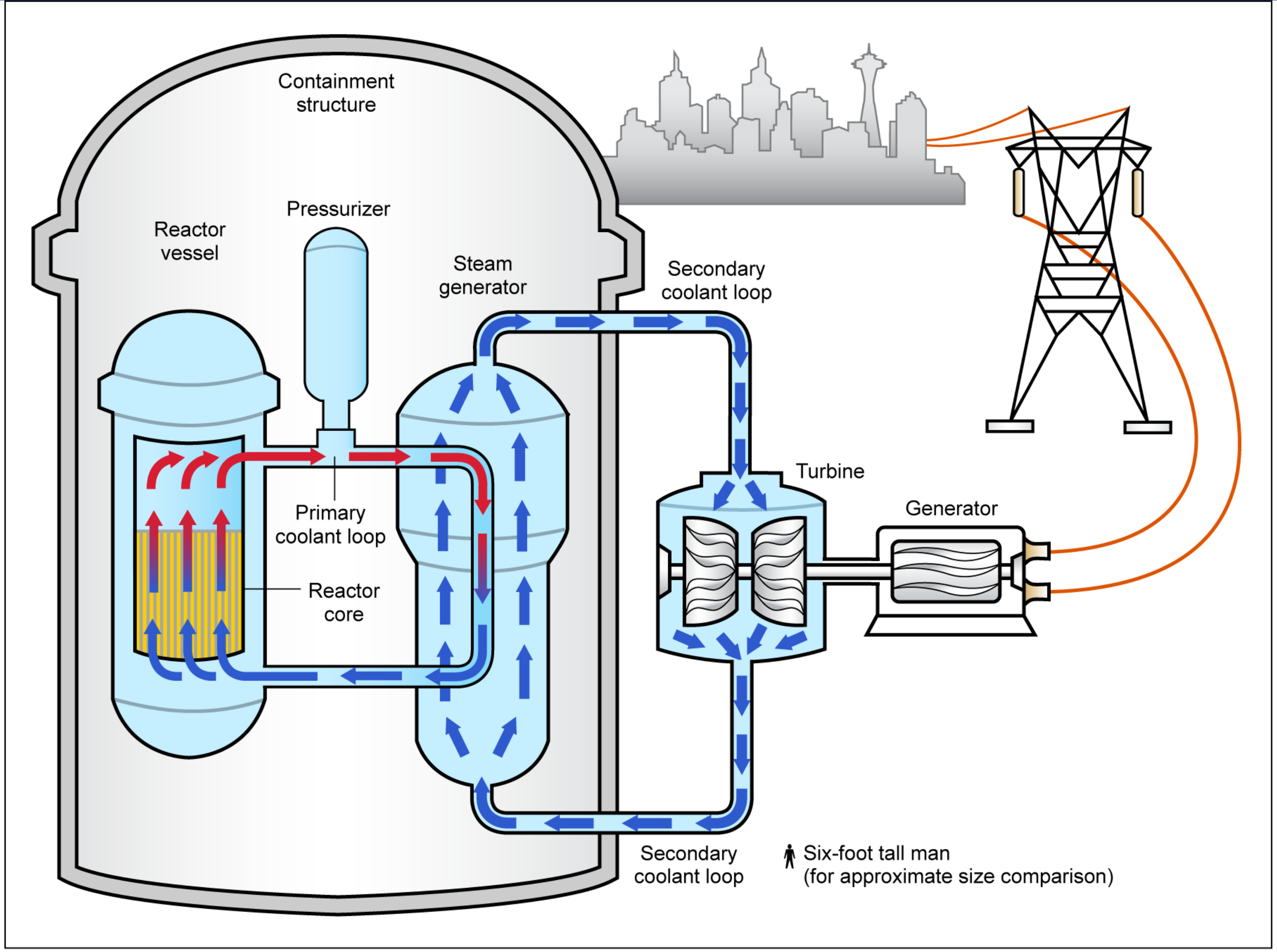
For questions or more information, contact liftoff@hq.doe.gov

Image courtesy: Energy.gov/ne

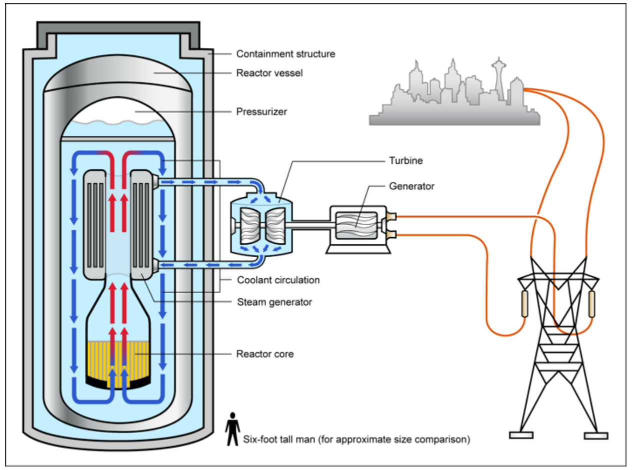
SIZE

Nuclear has the **right-sized reactors** to meet the energy needs of any community.

What are Small Modular Reactors?



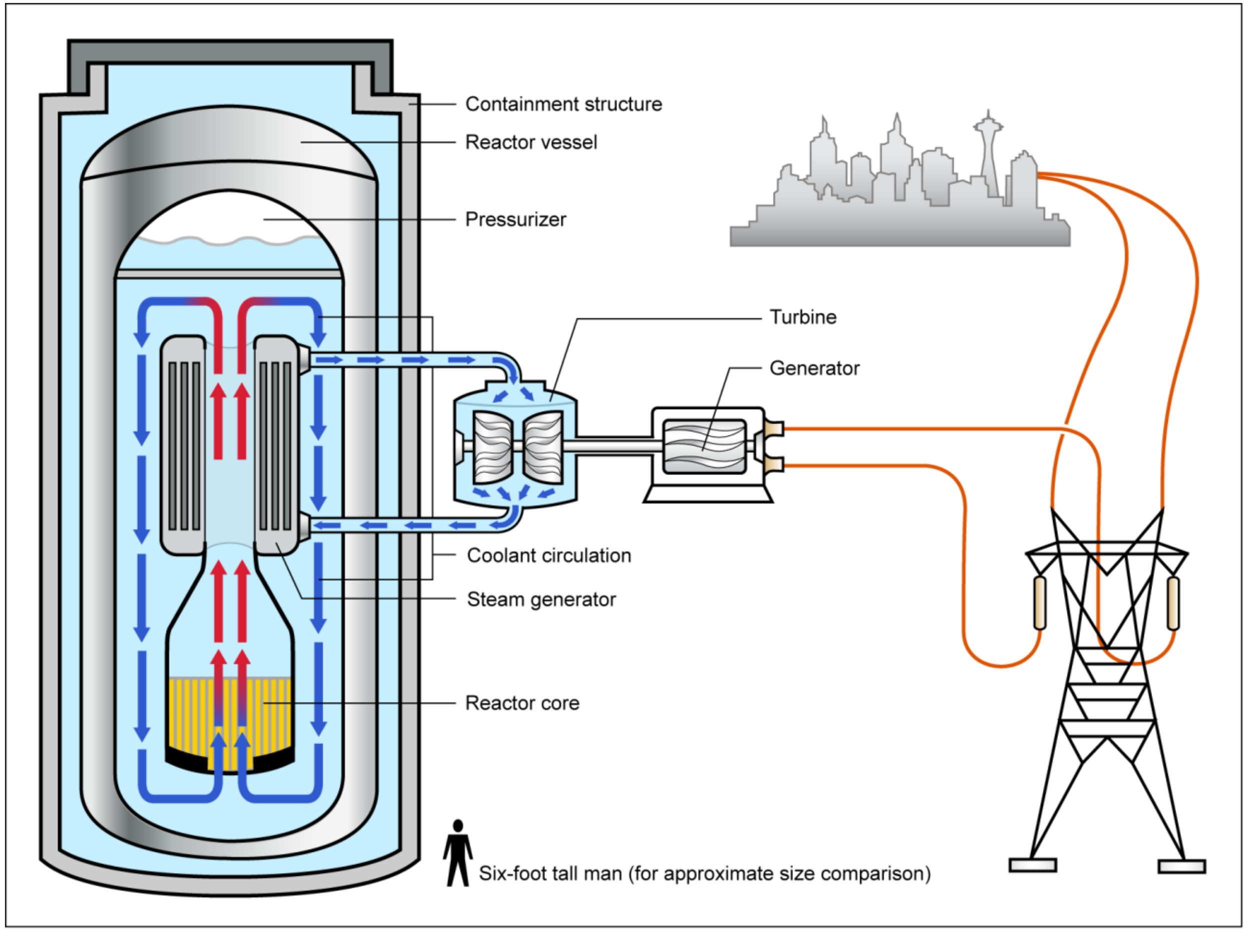
- Shrunken version of larger reactors
- Difference in size and construction



Source: GAO, based on Nuclear Regulatory Commission documentation. | GAO-15-652

Small Modular Reactors

- Up to 300 MW*
- Compact
- Incremental expansion strategies
- Simplified design and standardization
- Passive safety mechanisms
- Longer fuel intervals



Closely match the increasing energy demand

Small Modular Reactors

- Modular Construction modeled after large scale aircraft manufacture
  - Built in controlled factory setting
  - Standardization of design
  - Range of capacities
  - Spreading fixed and variable costs over a larger production quantity
  - Economies of series production = Reduced capital cost

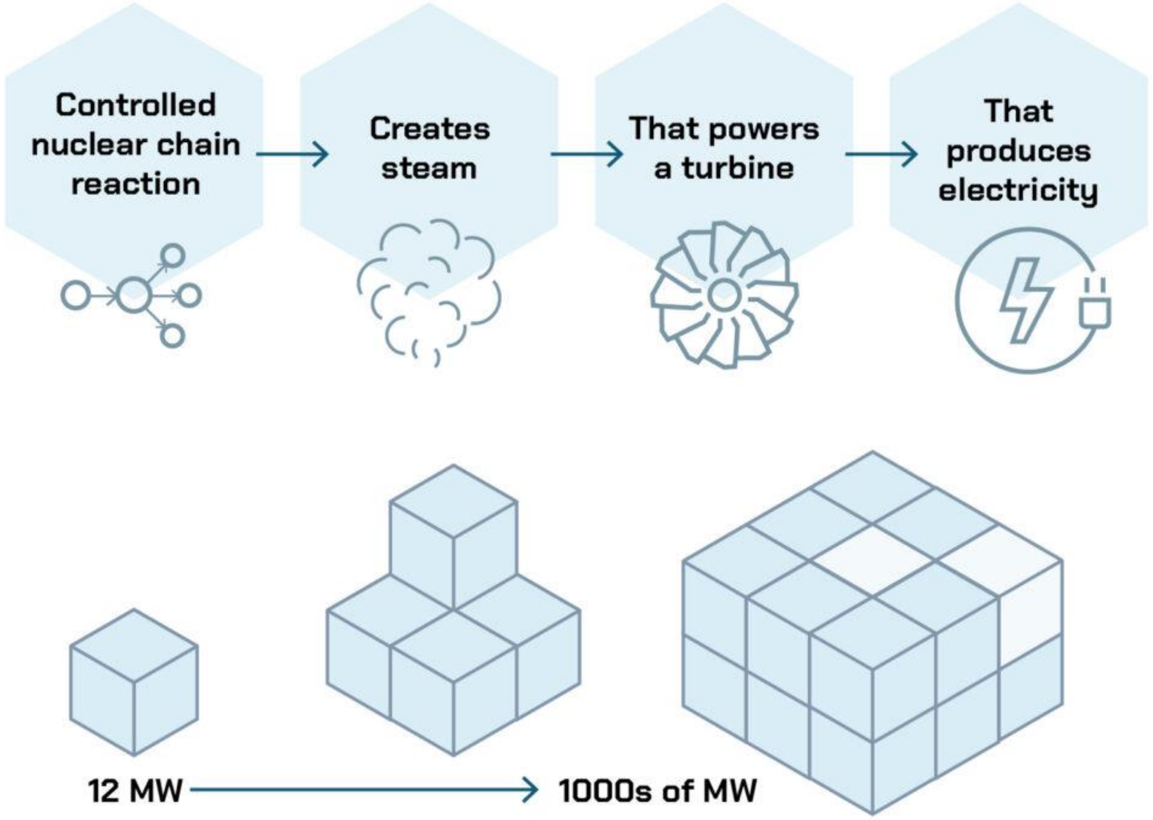
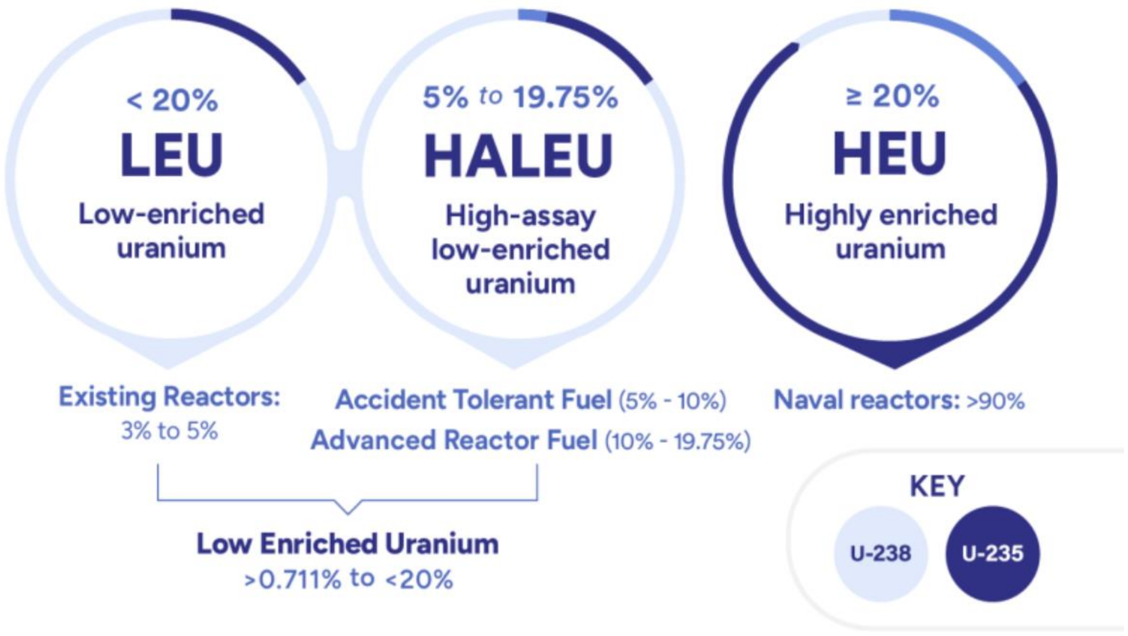


Image source: Idaho National Laboratory

Fuel Enhancements

- HALUE
  - High-Assay Low-Enriched Uranium
  - 5% U-235 to 19.75% U-235
- Enables smaller designs
- Longer refueling intervals
  - Longer operating cycles
  - Increased fuel efficiency
  - Reduced waste



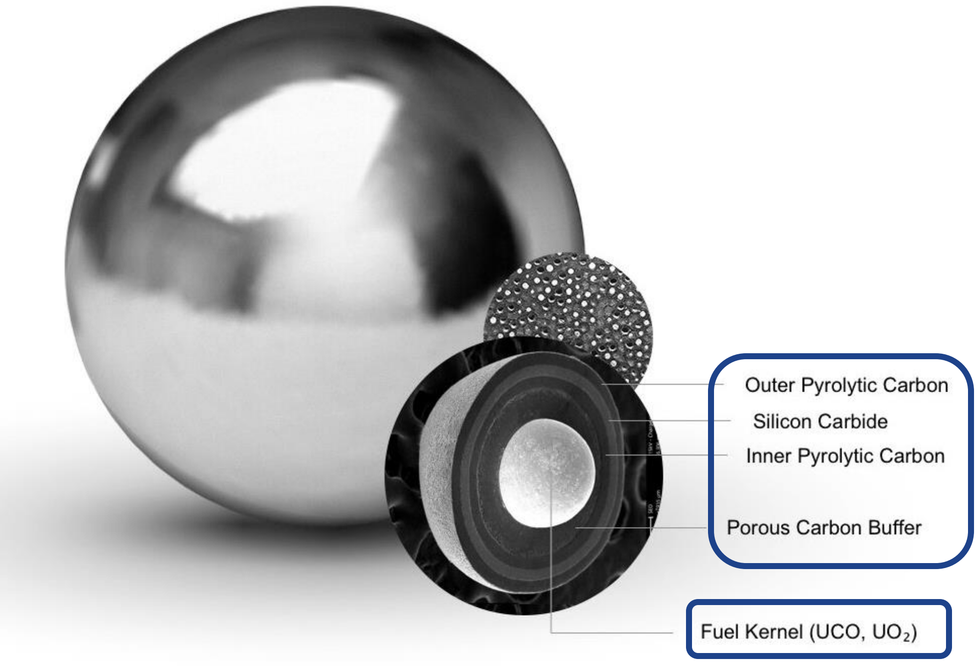
HALUE is the fuel that powers the SMR

Assay is the measure of the concentration of the fissile isotope U-235 in uranium

Image source: Energy.gov/ne

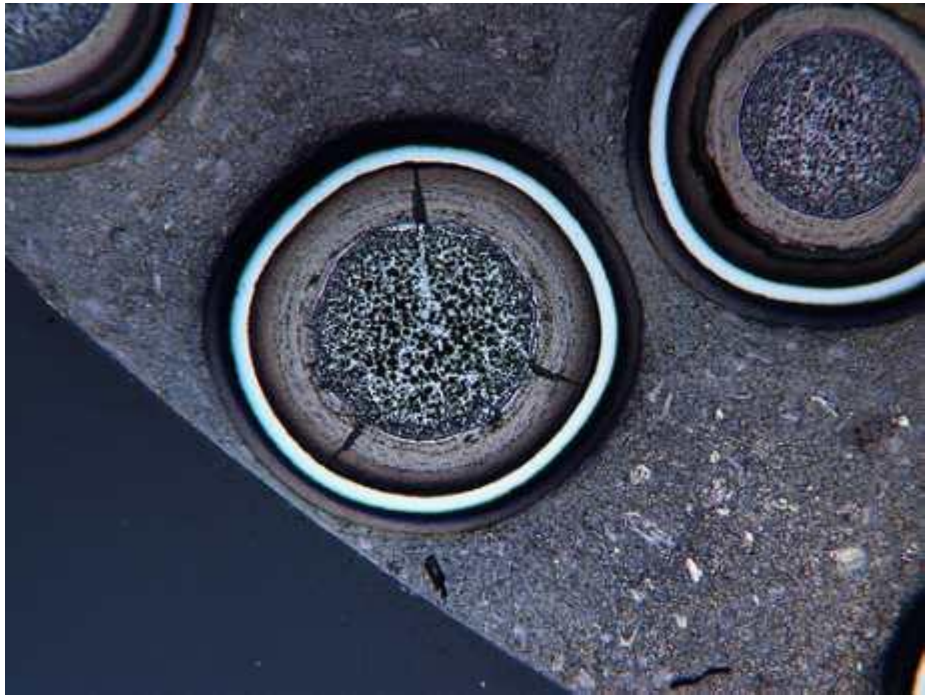
Fuel Enhancements

- TRISO Fuel
  - **TRI**-Structural I**SO**tropic fuel particles
  - Advanced nuclear fuel
  - Contains fission products around each fuel element
- High temperature reactors applications ~ cogeneration options
- Limit impacts to site boundary through novel fuel designs
  - Keep fuel cool without power supply using passive safety approaches
- Pebble bed design leads to 94% Capacity Factor



Fuel Enhancements

- TRISO Fuel
  - Resistant to extreme temperatures and heat
  - Design prevents corrosion and oxidation
- TRISO-HALEU fuel is used in high temperature gas cooled reactors



TRISO Particles

Advanced Approaches

- "Passive/inherent safety"
  - High thermal mass: no added coolant required
  - Natural circulation: no pumping power required
  - Fail-safe valves: no backup power required
  - "Walk-away-safe": plant shuts down on its own in emergency scenarios, driven by laws of physics
  - Molten salt fuel – contains fission products in liquid or removes and stores continuously; online refueling
- Faster construction timeline
  - Installed module by module
- Long fuel cycles
- Reduced waste

Source: Idaho National Laboratory
Image source: Illustration Kaspar Manz / NZZ

Considerations for SMRs

- Factors affecting site selection for SMRs
  - Proximity to the load (consumer)
  - Costs
  - Setbacks and Buffers
    - Population density
    - Wetland and Critical habitat
    - Safety
    - Security
    - Environment
    - Socio-economic impacts

Technical and Economic

- Timeline and Offtakers
- Geographical data
- Geological data
- Insurance
- Transportation and logistical data
- Waste Management

Considerations for SMRs

- Waste Management
  - Nuclear fissions creates spent fuel byproducts
  - Similar waste from advanced LWRs
- Dry Storage Casks
  - On-site
  - Concrete storage bunkers

Similar principle as larger nuclear plants

Image source: Illustration Kaspar Manz / NZZ

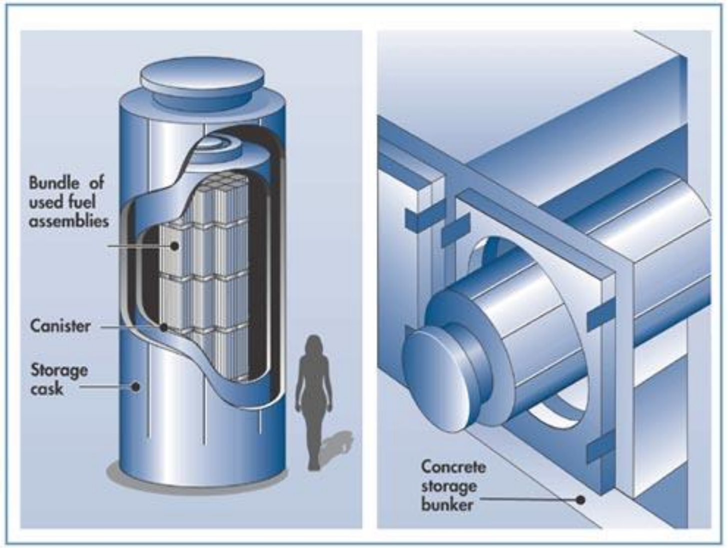
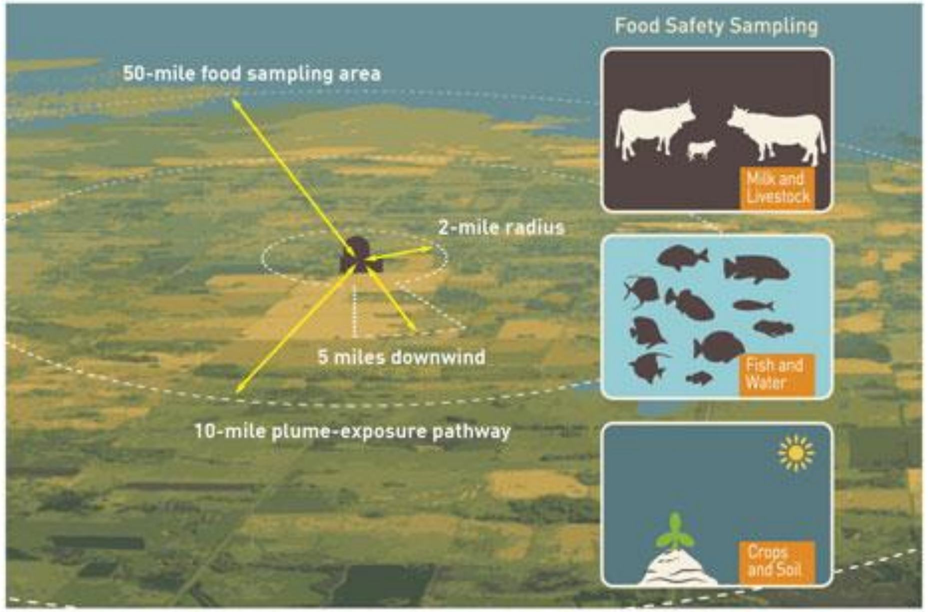


Image source: NRC, U.S. DOE

Siting Considerations

- EPZ – Emergency Planning Zones
  - Plume Exposure Pathway EPZ (10-mile radius)
  - Ingestion Exposure Pathway EPZ (50-mile radius)

Emergency Planning Zones



Note: A 2-mile ring around the plant is identified for evacuation, along with a 5-mile zone downwind of the projected release path.

Image source: U.S. National Regulatory Commission (NRC)

Siting Considerations

- SMRs approaches
  - Wide range of designs
  - Improved containment functions
- EPZ – Emergency Planning Zones
  - Depends on capacity ~ ~ Fuel
  - Performance based EPZ Sizing - exclusions and buffer determined case by case basis*
  - Onsite-only EPZ option

Rule of thumb:

Zone	Traditional Reactor	SMRs
Exclusion Area (EA)	~0.5–1 mile radius	~600 meters (site-specific)**
Emergency Planning Zone	~10 miles (plume)	~Can be **onsite only**

* As per 73 FR 60612, *"the size of plume exposure pathway EPZs and IPZs for gas-cooled nuclear reactors and for reactors with an authorized power level less than 250 MWt may be determined on a case-by-case basis"*

** for Source: IAEA Emergency Facilities, Locations and Zones

Advanced Reactors

- SMR designs may employ light water as a coolant or other non-light water coolants such as a gas, liquid metal, or molten salt

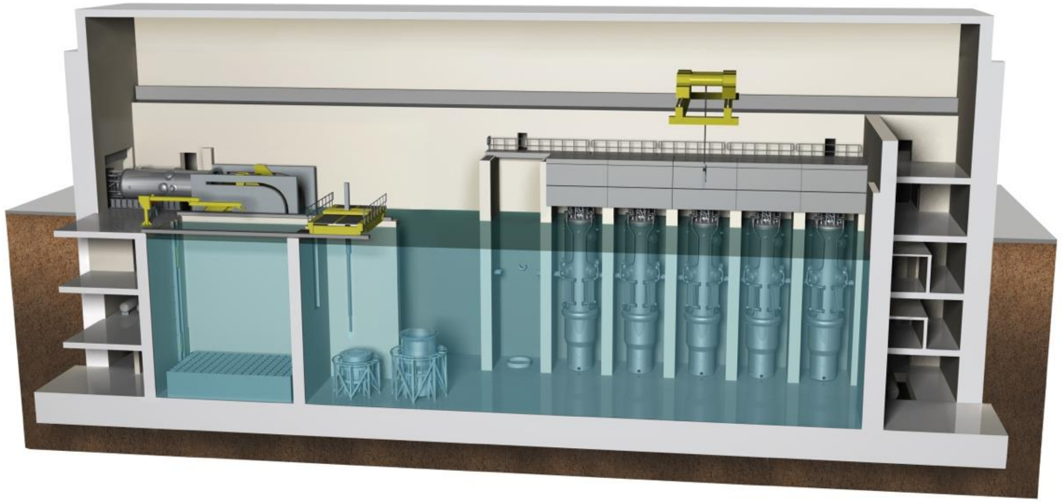
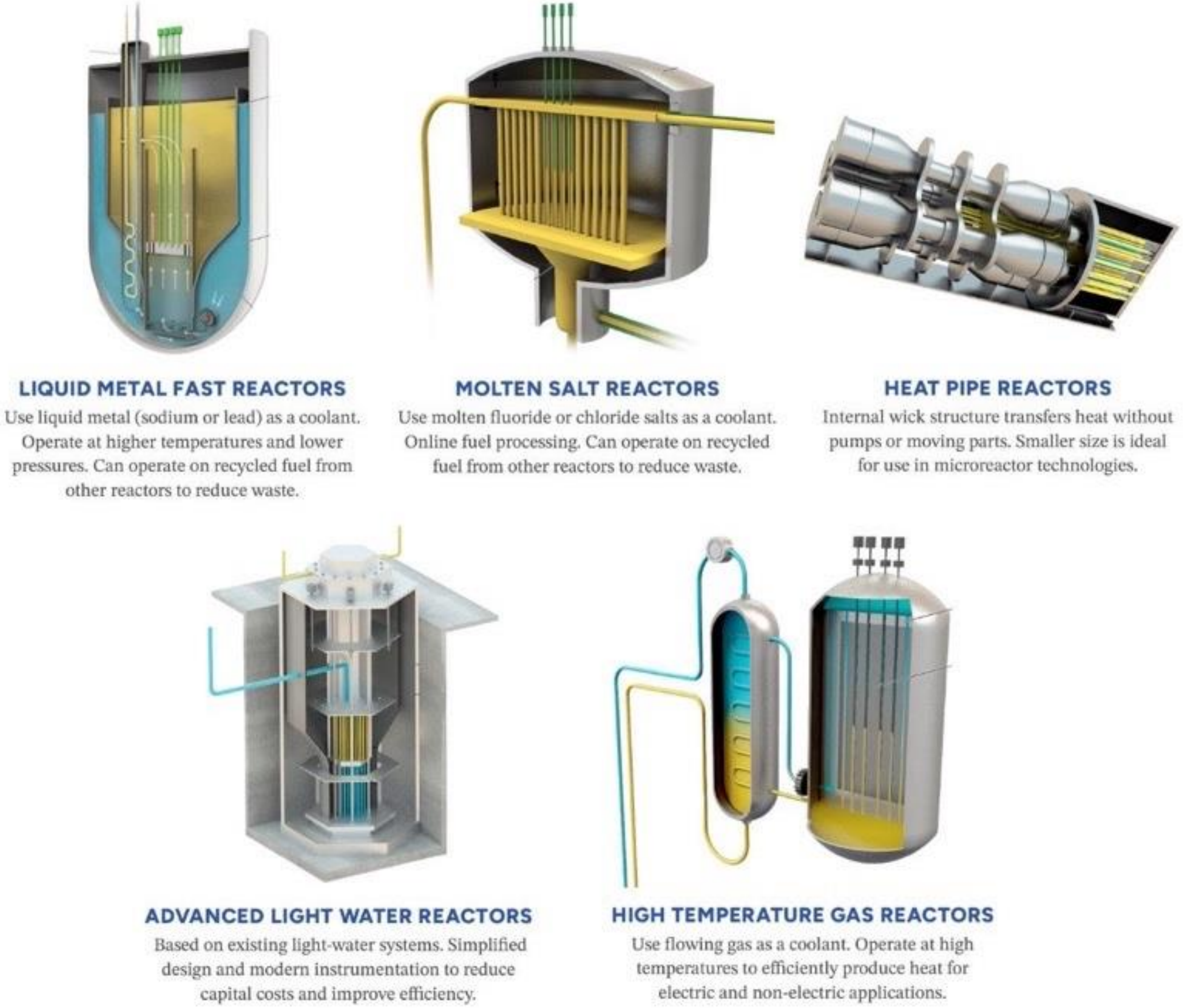


Image Courtesy: NuScale Power Reactor Building
NuScale Power Reactors. ©NuScale Power, LLC, All Rights Reserved



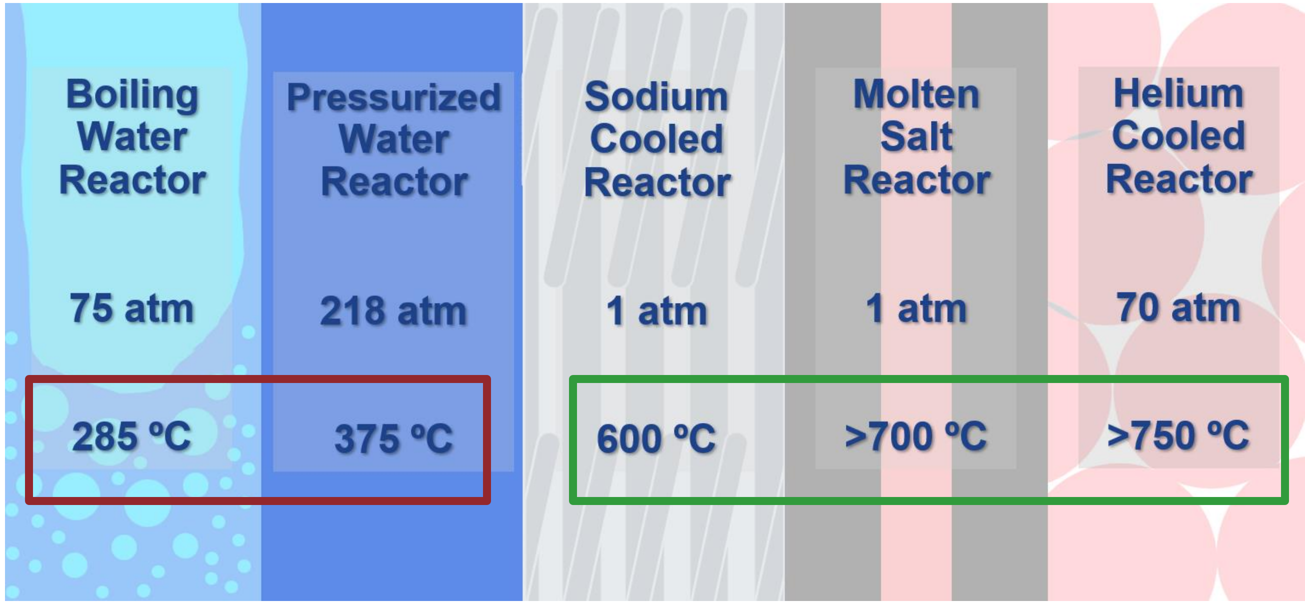
Source: Energy.gov/ne

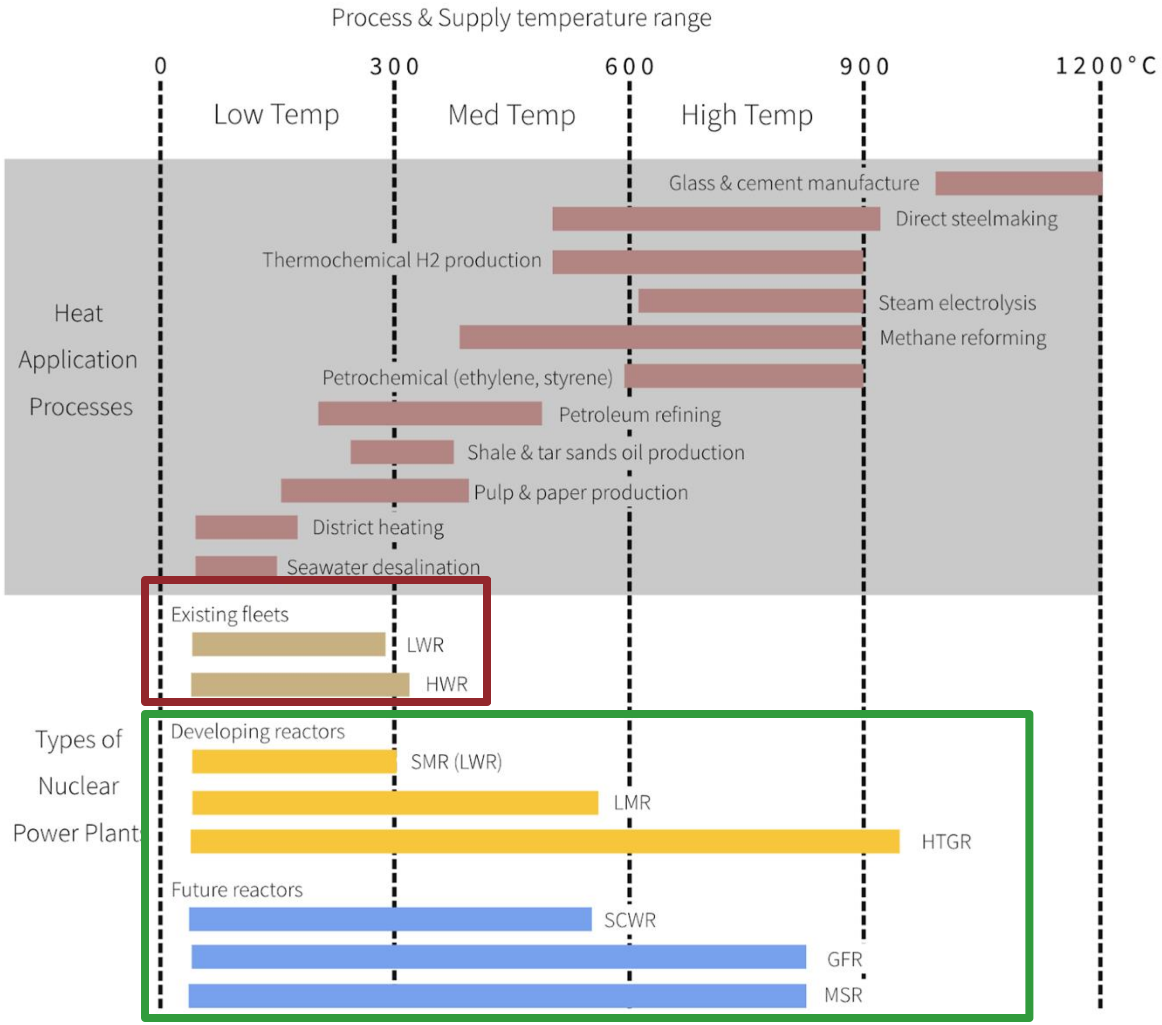
Reactor Core Temperatures

Boiling Water Reactor	Pressurized Water Reactor	Sodium Cooled Reactor	Molten Salt Reactor	Helium Cooled Reactor
75 atm	218 atm	1 atm	1 atm	70 atm
285 ºC	375 ºC	600 ºC	>700 ºC	>750 ºC

Source: Dave Pointer, ORNL

Industrial Process Heating Temp Graph

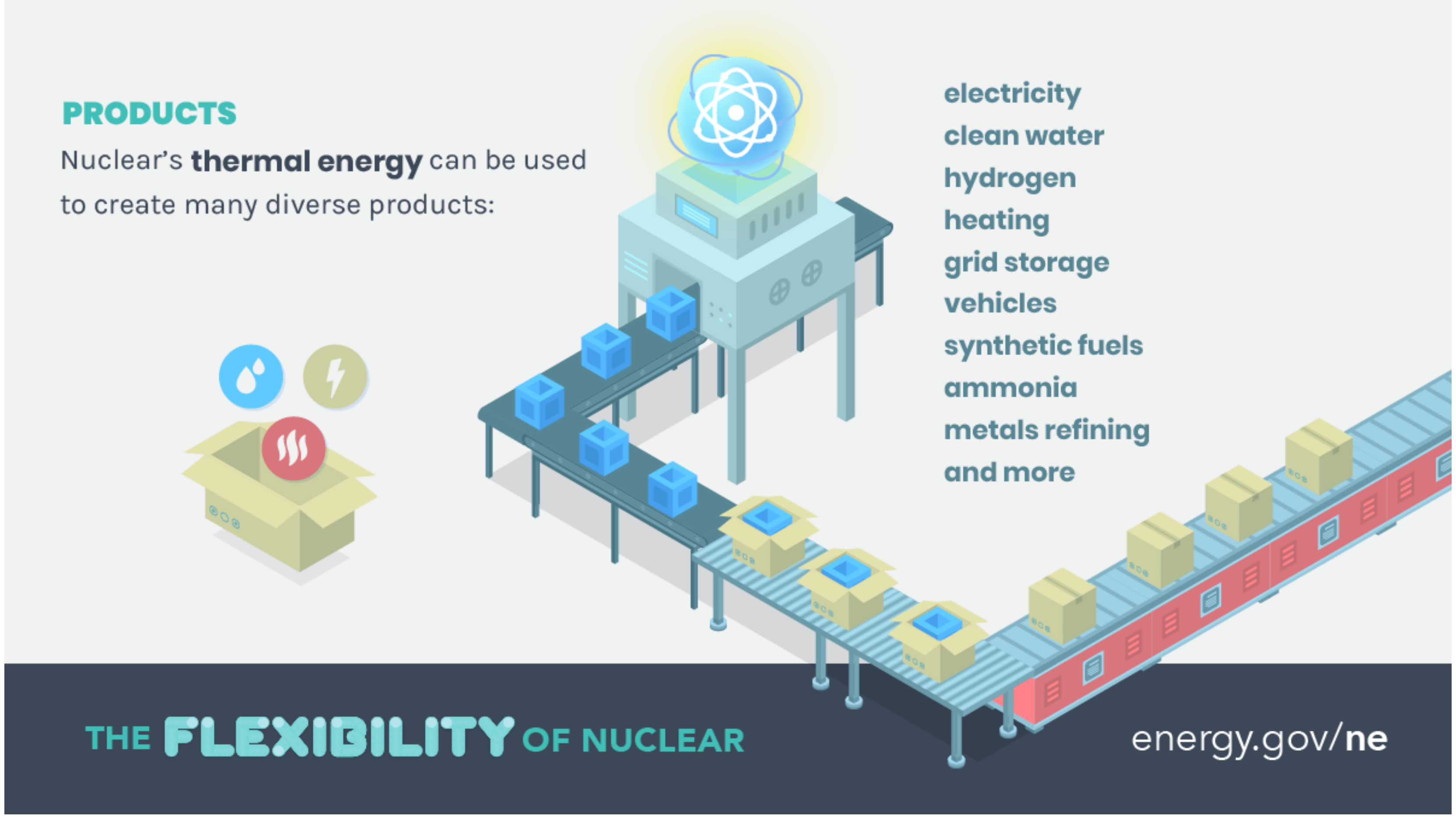




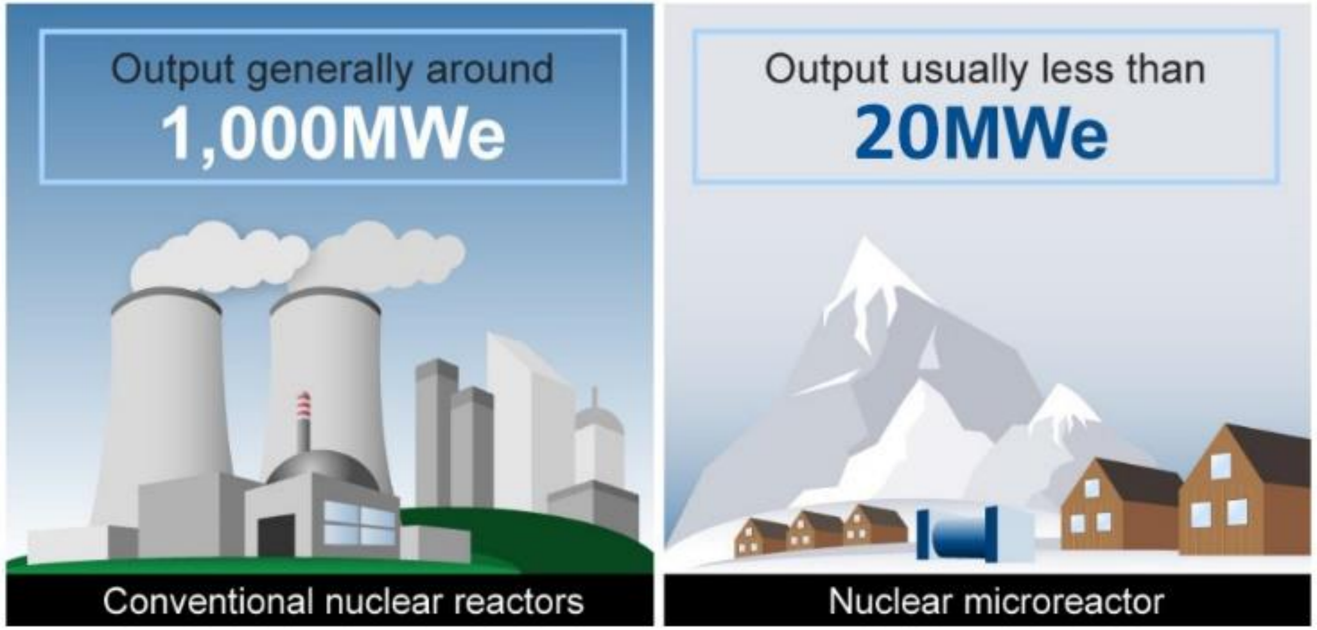
Source: https://www.steelatlas.vc/valar-atomics/

Applications of SMRs

- Flexible Output
- Clean Baseload Power
- Modularity and Scalability
- Siting Flexibility
- Fuel Diversification
- Efficiency



Microreactors



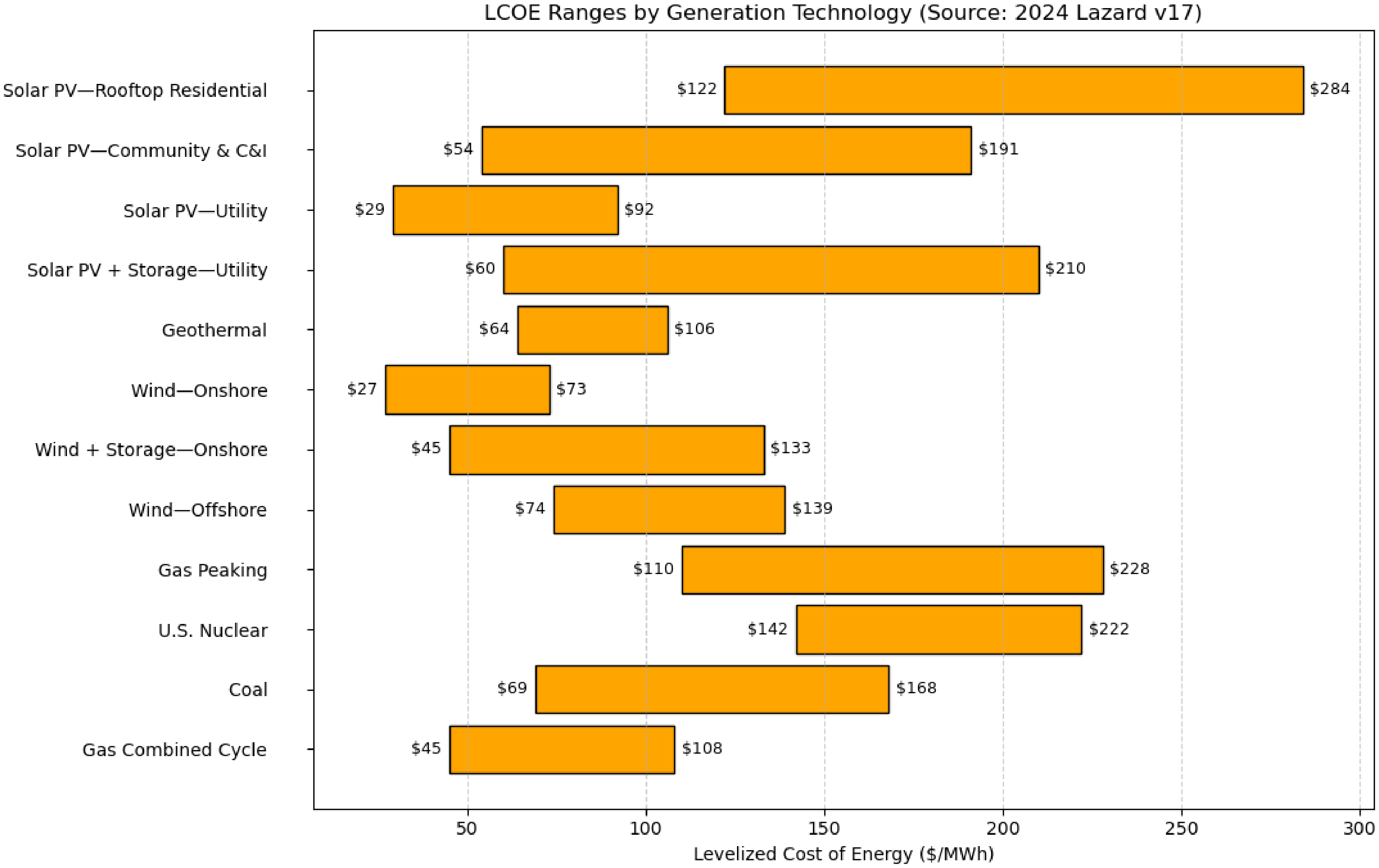
Source: GAO. | GAO-20-380SP

- Small footprint
- Reduced site preparation
- Flexible operation
- Reduced refueling or "nuclear battery" replacement
- Reduced safety and security risks

Levelized Cost of Electricity, LCOE

Assumptions:

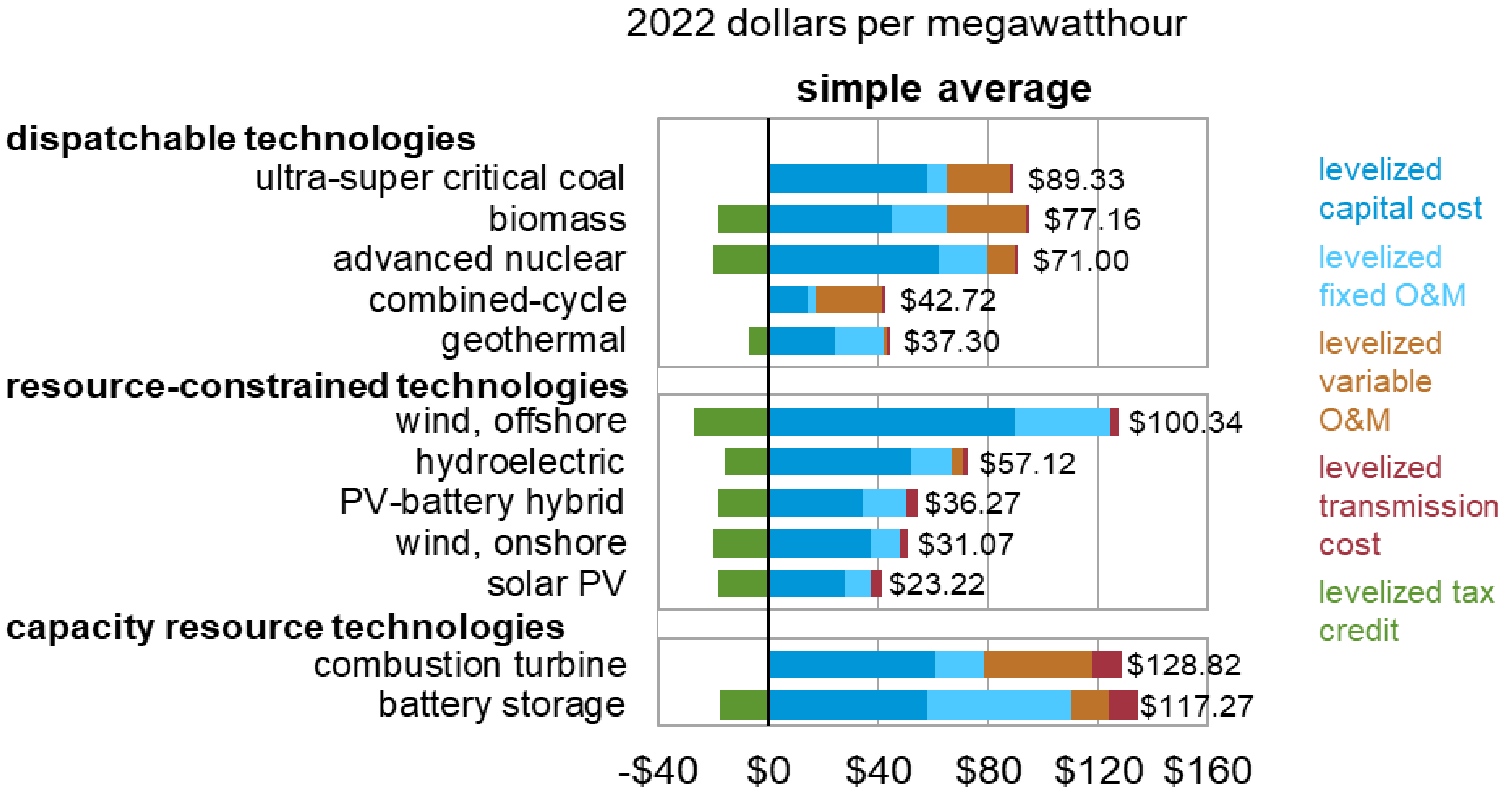
- Based on recent estimates
- Inclusive of decommissioning costs
- Capacity factor of 97%



Does not factor in ITC

Source: Lazard and Roland Berger estimates and publicly available information

Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2028

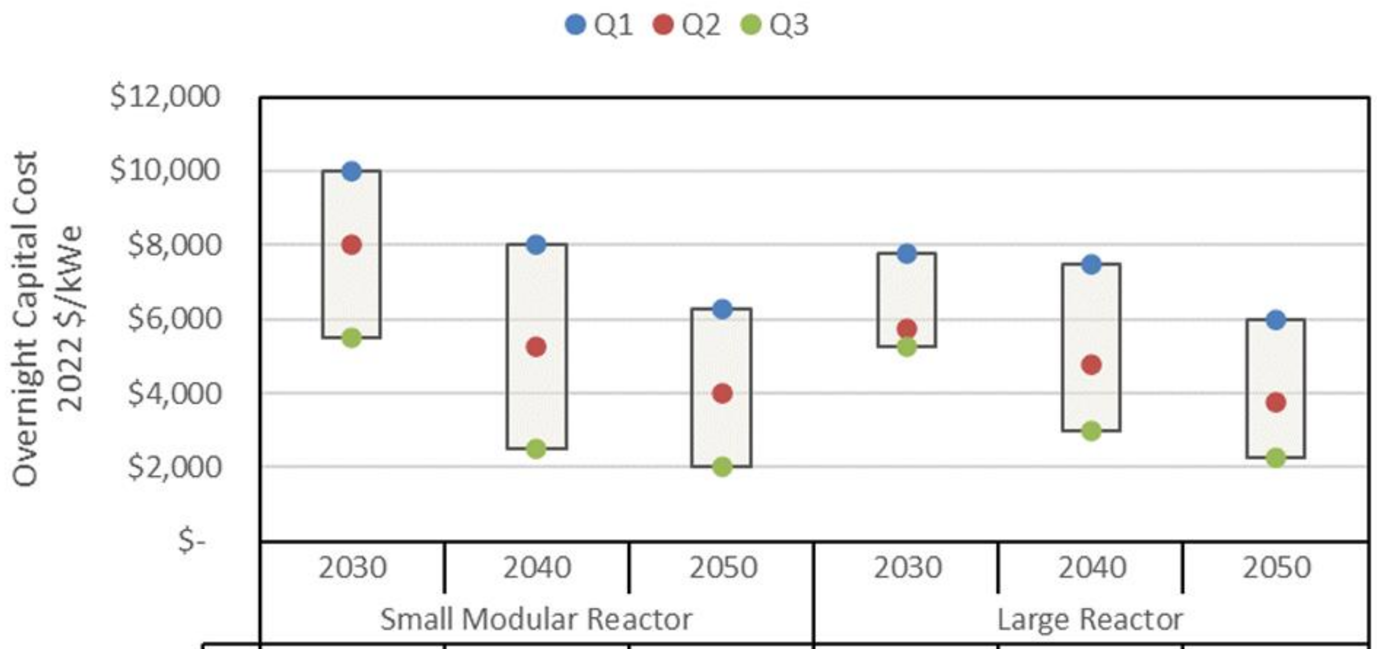


Data source: U.S. Energy Information Administration, Annual Energy Outlook 2023

Note: PV = photovoltaic, O&M = operations and maintenance; technologies in which capacity additions are not expected in 2028 do not have a capacity-weighted average. The stated LCOE values include the levelized tax credit component for eligible technologies.

Nuclear Cost Projections[1]

- Assumptions
  - SMR are 300 MWe
  - Large Reactors are assumed to be 1000 MWe
- US-based overnight capital costs (OCC)
  - *Next commercial offering* post demonstration



	Small Modular Reactor 2030	Small Modular Reactor 2040	Small Modular Reactor 2050	Large Reactor 2030	Large Reactor 2040	Large Reactor 2050
Q1	$10,000	$8,000	$6,250	$7,750	$7,500	$6,000
Q2	$8,000	$5,250	$4,000	$5,750	$4,750	$3,750
Q3	$5,500	$2,500	$2,000	$5,250	$3,000	$2,250

OCC range for large reactors and SMRs. Costs are in 2022 USD

FOAK: First of a kind
BOAK: Between First and N^{th} of a kind
NOAK: N^{th} of a kind

Source: Abou-Jaoude, Abdalla, et al. "Meta-Analysis of Advanced Nuclear Reactor Cost Estimations." , Jun. 2024. https://doi.org/10.2172/2371533

1) Numbers are estimates and averages with limitations and should be interpreted as an initial step to develop cost ranges for nuclear technology

Nuclear Cost Projections[1]

- Assumptions
  - SMR are 300 MWe
  - Large Reactors are assumed to be 1000 Mwe
- O&M costs were less-significant contributors to the levelized costs

		Advanced	Moderate	Conservative
Large Reactor	BOAK OCC ($/kWe)	5,250	5,750	7,750
	OCC 2050 ($/kWe)	2,250	3,750	6,000
	Fuel Costs ($/MWh)	9.1	10.3	11.3
	Fixed O&M ($/kW-yr)	126	175	204
	Variable O&M ($MWh)	1.9	2.8	3.4
	Power output (MWe)	1,000		
	Capacity Factor	0.93		
	Construction time (months)	60	82	125
	Ramp rate (%power/min)	5%		
	Learning Rate	8%		
SMR	BOAK OCC ($/kWe)	5,500	8,000	10,000
	OCC 2050 ($/kWe)	2,000	4,000	6,250
	Fuel Costs ($/MWh)	10.0	11.0	12.1
	Fixed O&M ($/kW-yr)	118	136	216
	Variable O&M ($MWh)	2.2	2.6	2.8
	Power output (MWe)	300		
	Capacity Factor	0.93		
	Construction time (months)	43	55	71
	Ramp rate (%power/min)	10%		
	Learning Rate	9.5%		

OCC range for large reactors and SMRs. Costs are in 2022 USD

Source: Abou-Jaoude, Abdalla, et al. "Meta-Analysis of Advanced Nuclear Reactor Cost Estimations." , Jun. 2024. https://doi.org/10.2172/2371533

1) Numbers are estimates and averages with limitations and should be interpreted as an initial step to develop cost ranges for nuclear technology

How does nuclear drive your clean energy future?

Images courtesy of US DOE Office of Nuclear Energy GAIN program and ThirdWay

What’s next?

GAIN Gateway for Accelerated Innovation in Nuclear

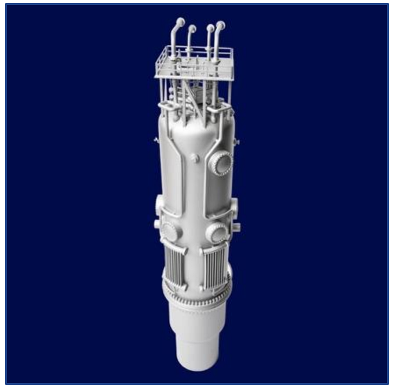
ARDP

ANPI
ADVANCED NUCLEAR POWER FOR INSTALLATIONS

HPC4 ENERGY INNOVATION

arpa-e

SBIR·STTR America’s Seed Fund



Google signs deal to use small nuclear reactors to power data centers

The tech giant is in search of a lot of 24/7 carbon-free electricity. It’s betting that a fleet of advanced reactors from Kairos can provide some of it — eventually.

Dow's Seadrift, Texas location selected for X-energy advanced SMR nuclear project to deliver safe, reliable, zero carbon emissions power and steam production

TVA, State and Industry Leaders Unite to Accelerate SMR Deployment

Jan 17, 2025

Contact: Scott Fiedler

Share this Story

Release Summary

- TVA is leading an application for an $800 million U.S. Department of Energy grant to accele construction of the nation's first Small Modular Reactor (BWRX-300).
- TVA has put together a strong coalition of co-applicants including leading utilities and deve who are exploring building SMRs, suppliers, construction partners and additional entities s workforce and lessons learned components as well as the State of Tennessee.
- In 2024, Congress created the grant program to strengthen America's domestic nuclear ind spur SMR development. This funding would support deployment of the nation's first SMR a establish the supply chain for advanced nuclear technology.
- Editor's Note: Click here for site b-roll, photos and quotes from Jeff Lyash, TVA President a

ADVANCED REACTORS

Amazon investing in SMRs to deploy 5 GW by 2039

Last Energy Secures PPAs for 34 SMR Nuclear Power Plants in Poland and the UK

Image courtesy: Nuscale Power, TVA, Canary Media, WNN, Power Magazine, American Nuclear Society, ESG News

What’s next?

Announced Deployment Timeline for Selected Advanced Reactors Projects in the United States

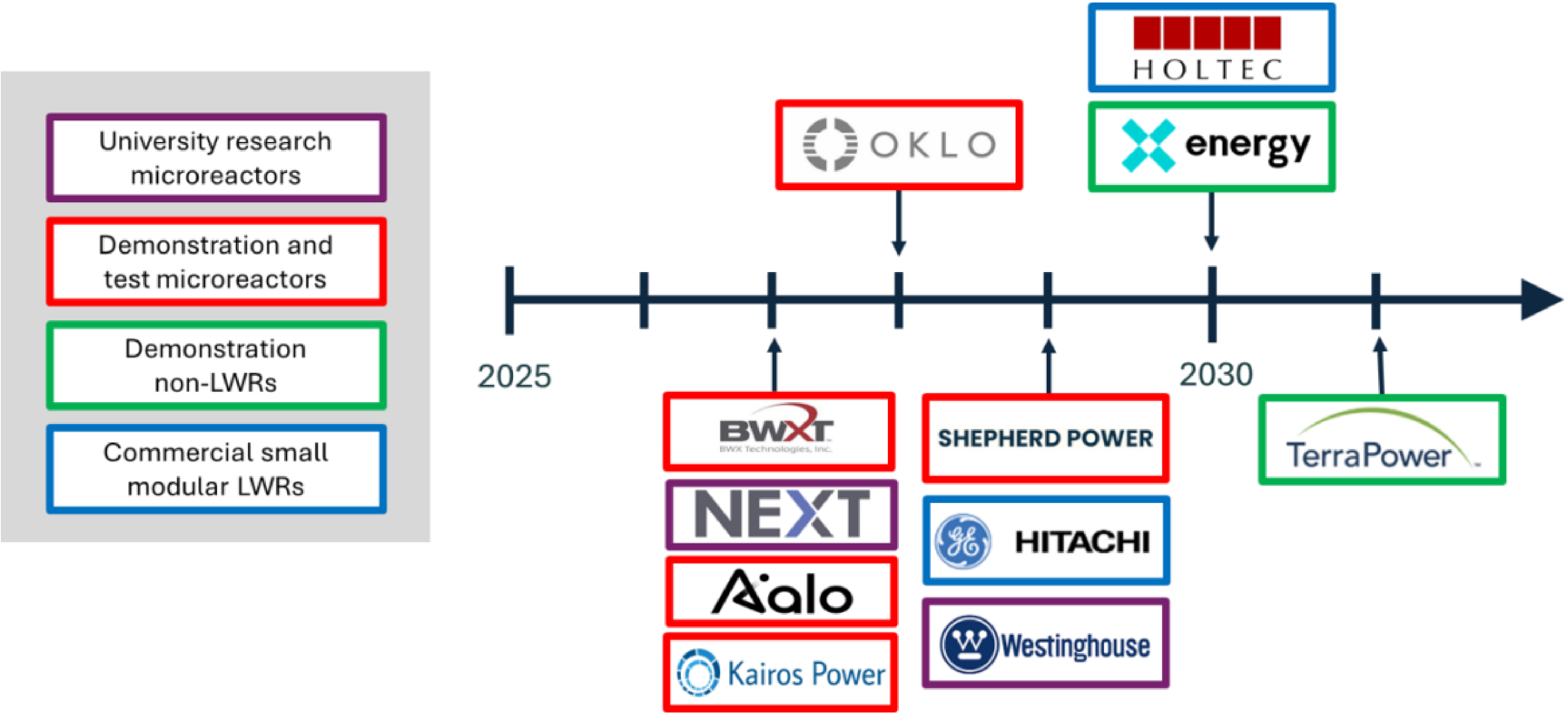


Image courtesy: Nuclear Innovation Alliance, “Advanced Reactor Deployment Timelines”

Resources

- Literature Review of Advanced Reactor Cost Estimates;
  DOI: https://doi.org/10.2172/1986466
- Meta-Analysis of Advanced Nuclear Reactor Cost Estimations;
  DOI: https://doi.org/10.2172/2371533
- Consolidated Innovative Nuclear Research (CINR)
- GAIN Nuclear Energy (NE) Vouchers
- Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR)
- Advanced Reactor Information System - https://aris.iaea.org/

INL/RPT-23-72972
Revision 3

Literature Review of Advanced Reactor Cost Estimates

Milestone M3CT-23IN1207065

October 2023

Abdalla Abou-Jaoude, Linyu Lin, Chandrakanth Bolisetti, Elizabeth Worsham, Levi M Larsen, Aaron Epiney
Nuclear Science & Technology Directorate, Idaho National Laboratory

IES
Integrated Energy Systems

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/RPT-24-77048
Revision 2

Meta-Analysis of Advanced Nuclear Reactor Cost Estimations

July 2024

Gateway for Accelerated Innovation in Nuclear (GAIN)

Abdalla Abou-Jaoude, Levi M Larsen, Nahuel Guaita, Ishita Trivedi, Frederick Joseck, and Christopher Lohse
Idaho National Laboratory

Edward Hoffman and Nicolas Stauff
Argonne National Laboratory

Koroush Shirvan
Massachusetts Institute of Technology

Adam Stein
Breakthrough Institute

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

Questions?

U.S. DEPARTMENT OF ENERGY

Thank you!

U.S. DEPARTMENT OF ENERGY

Week #5 Homework : Due COB Monday 7/1