

NUCLEAR ENERGY

Now & Onward

By

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For

Nuclear Outreach Program



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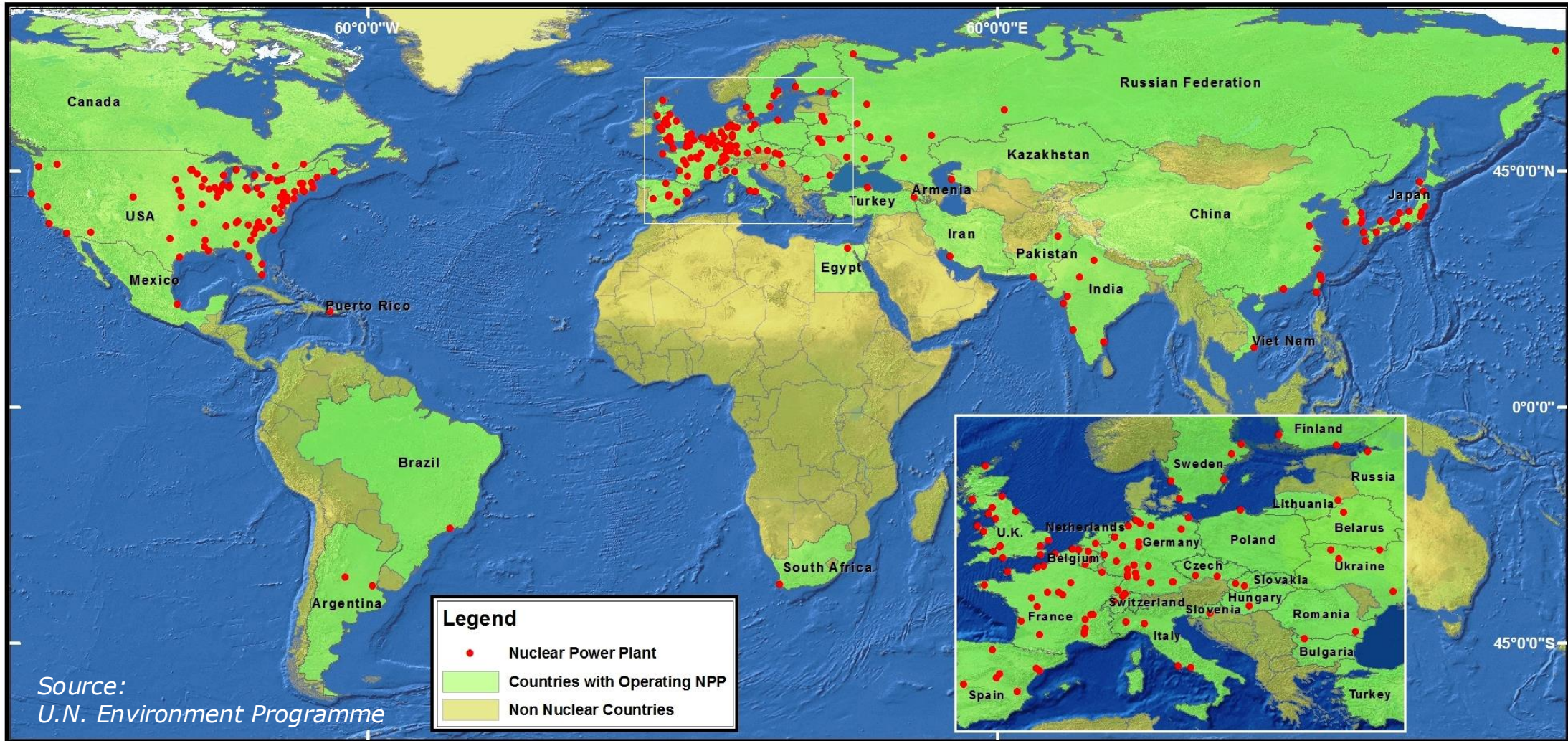
CONTENTS

- **Introduction:** State of Nuclear Energy & Facts.
- **Nuclear Power Reactor System:** How it Works.
- **Evolution of Nuclear Power Technology:** Legacy
LWR, SMR, MR

STATE OF NUCLEAR ENERGY

Global Nuclear Power Generation

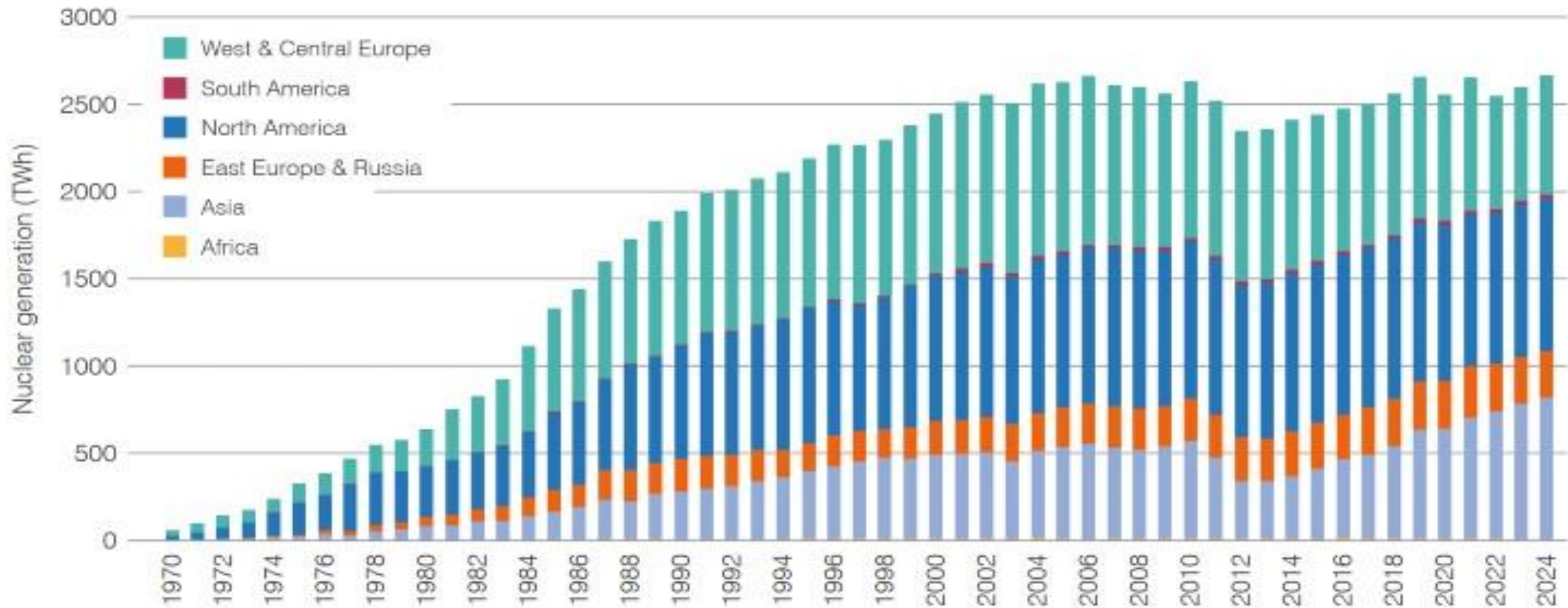
As of 2024, there are **31 countries** operating **417 nuclear reactors**, with **62 under construction**.



STATE OF NUCLEAR ENERGY

Global Nuclear Power Generation

As of 2024, nuclear power generated approximately **2,667 TWh** which accounts for approximately **9%** of total global electricity demand (~**25%** of carbon-free energy generation)

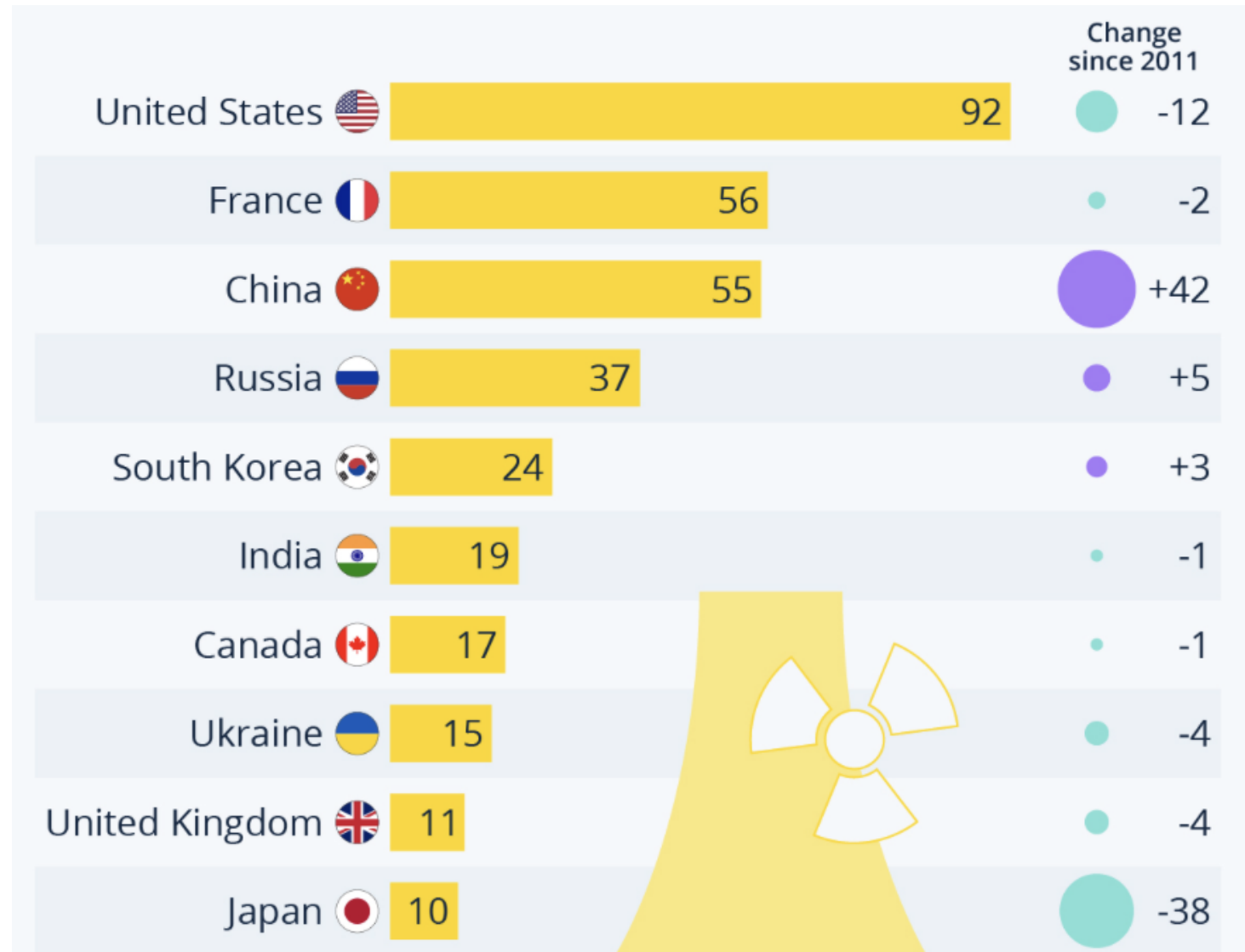


Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

STATE OF NUCLEAR ENERGY

Nuclear Power Plants (NPPs) Per Country

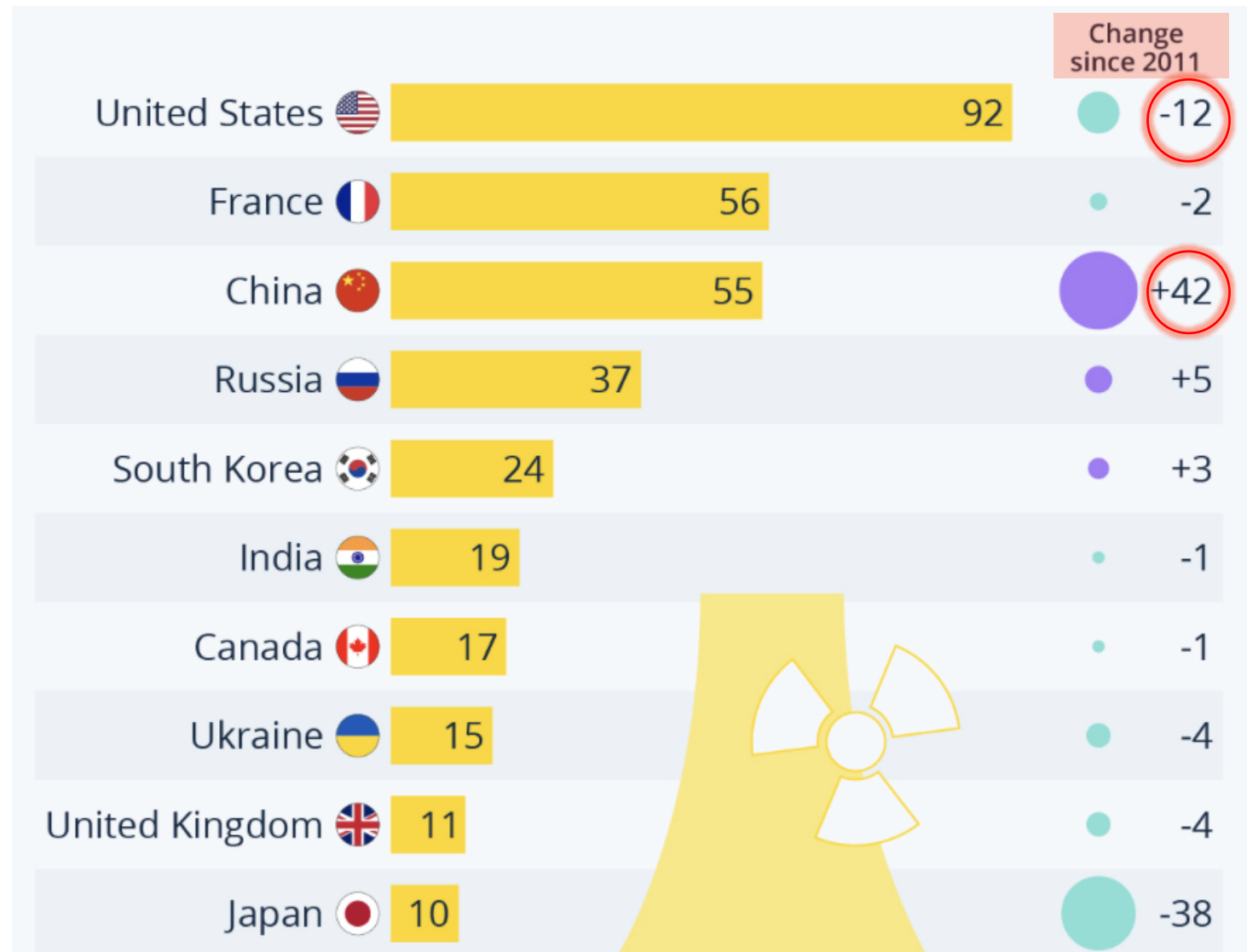
- Top 10 countries with most nuclear power plants as of 2022.
- U.S. ranked #1



STATE OF NUCLEAR ENERGY

Nuclear Power Plants (NPPs) Per Country

- Top 10 countries with most nuclear power plants as of 2022.
- Most of US nuclear reactors were **built in 1970's** and are operating under a **renewed license** (extended from 40 to 60 years).
- A growing subset is currently under review for a **second renewal** (extended from 60 to 80 years).



Source: World Nuclear Industry Status Report 2022

Image from

statista

STATE OF NUCLEAR ENERGY

Domestic

- **94** commercial nuclear reactors currently in operation in the U.S. (63 PWR; 31 BWR) as of 2024.
- As of 2024, the net capacity by nuclear energy is **~98 GW**, which accounts for **~18%** of US electricity.
- Accounts for **nearly half** of carbon-free energy generation.
- Provides baseload power.



STATE OF NUCLEAR ENERGY

Domestic Projections

- U.S.'s 5-year load growth rate forecast increased by **nearly 500% (2.6GW to 15GW)***
- **Workforce Needs**
 - ✓ Nuclear industry directly employs approximately **100,000 people (95GW) today (475,000** when including secondary jobs)[#]
 - ✓ Each NPP employs approximately **500 to 800** workers (permanent jobs)
 - ✓ Need to increase workforce to **375,000 (or 300 GW) by 2050***
 - ✓ Building a nuclear power reactor employs **thousands of** workers at peak construction (e.g., Vogtle 3 & 4 supported **9,000** workers at peak construction and **800** permanent jobs)⁺

NUCLEAR ENERGY FACTS

Reliability

Capacity Factor per Energy Source



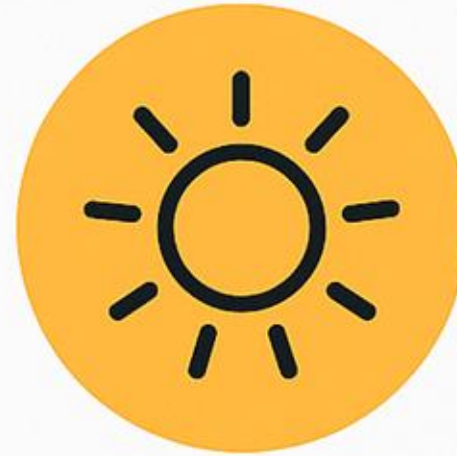
NUCLEAR

92%



WIND

~35%



SOLAR

~25%



**COAL /
NATURAL GAS**

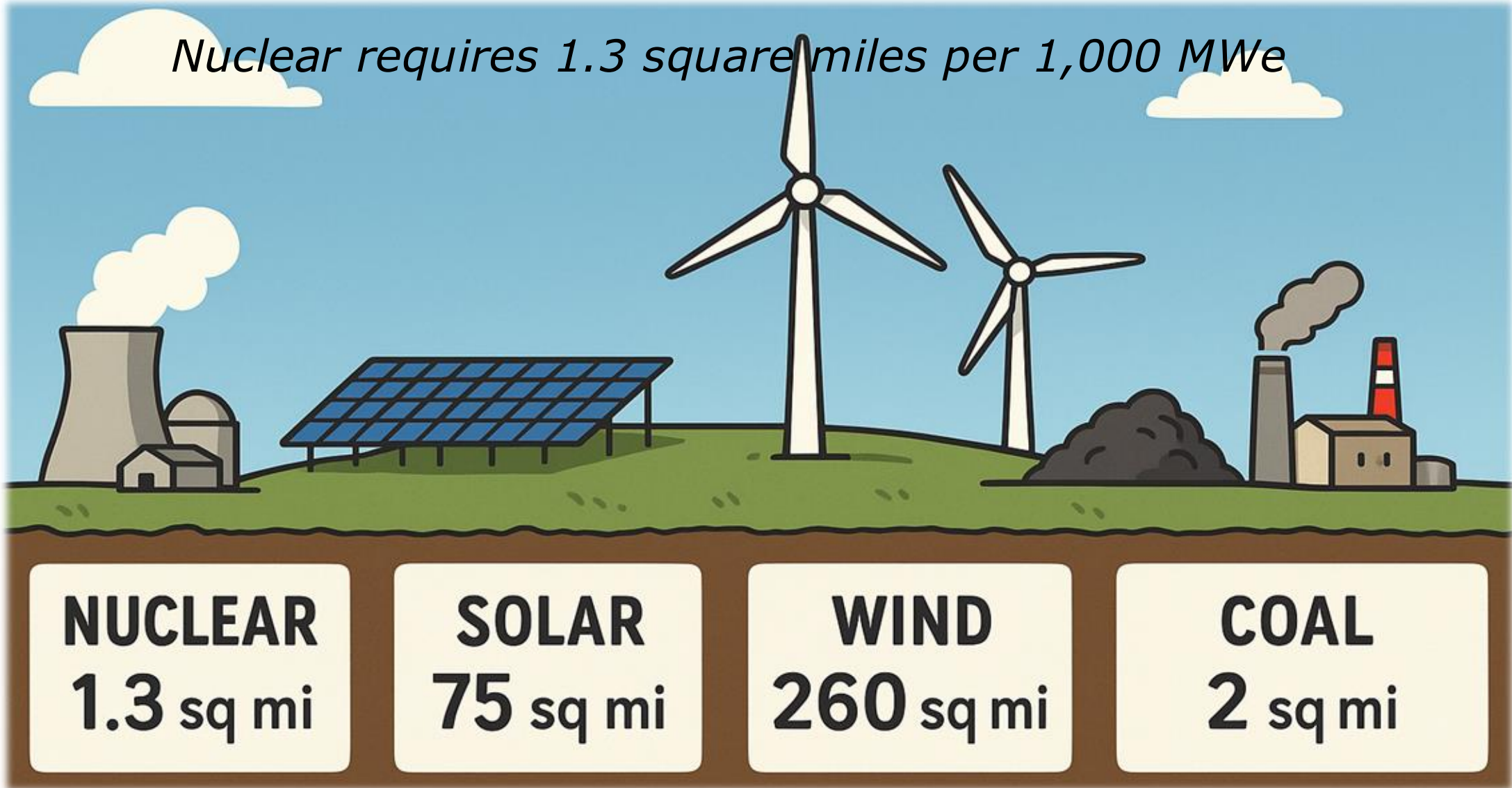
~55%

The numbers shown here are estimated based on publicly available data and are subject to change as technology evolves

NUCLEAR ENERGY FACTS

Physical Footprint

Nuclear requires 1.3 square miles per 1,000 MWe



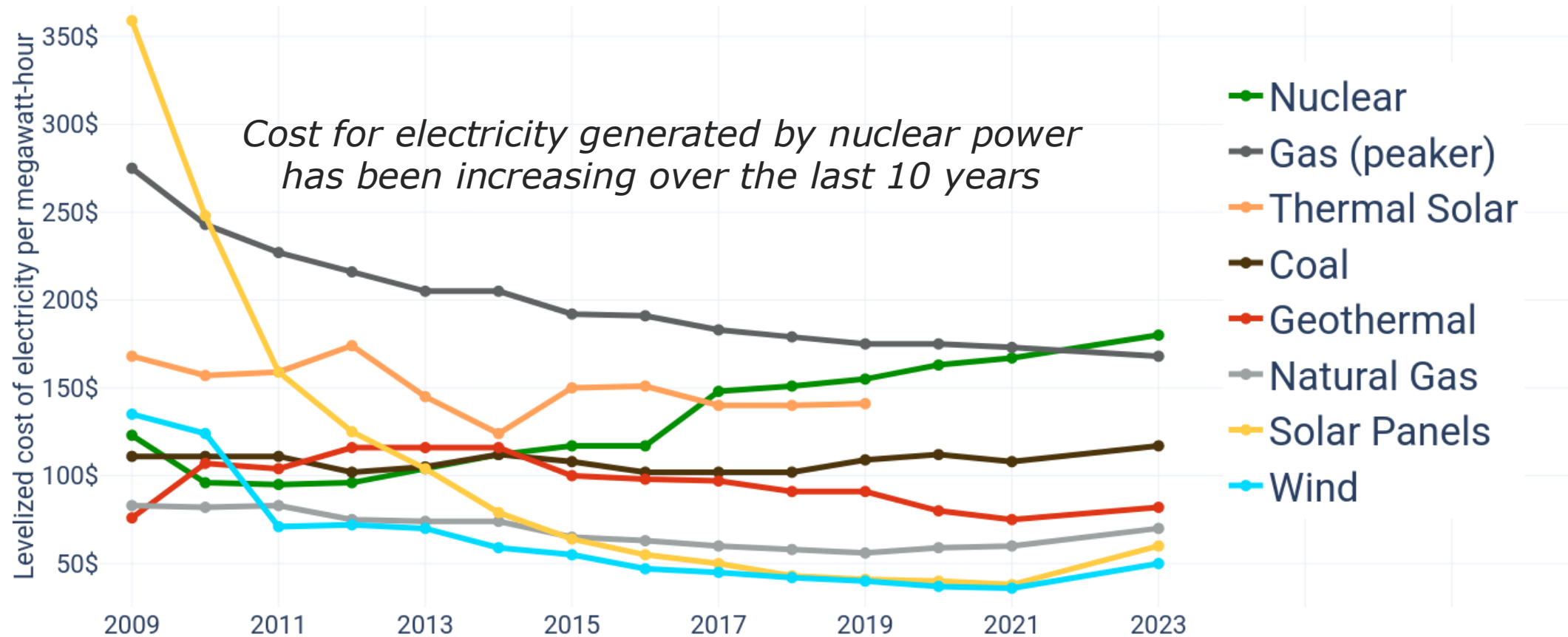
The numbers shown here are estimated based on publicly available data and are subject to change as technology evolves

NUCLEAR ENERGY FACTS

Cost

Electricity costs according to data from Lazard

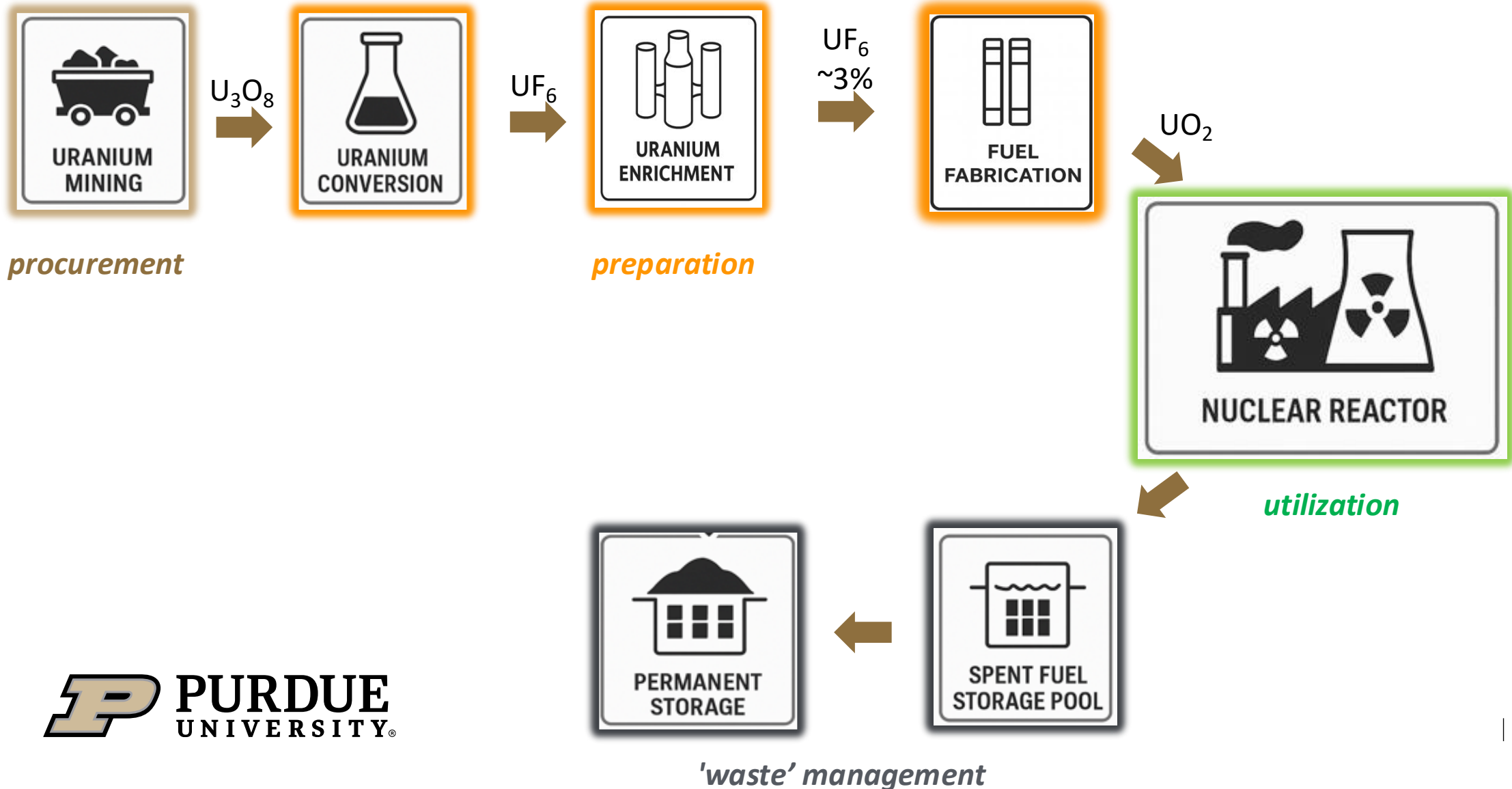
<https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/>



Levelized Cost of Electricity (LCOE): Measure of the average net cost of electricity generation over the lifetime.

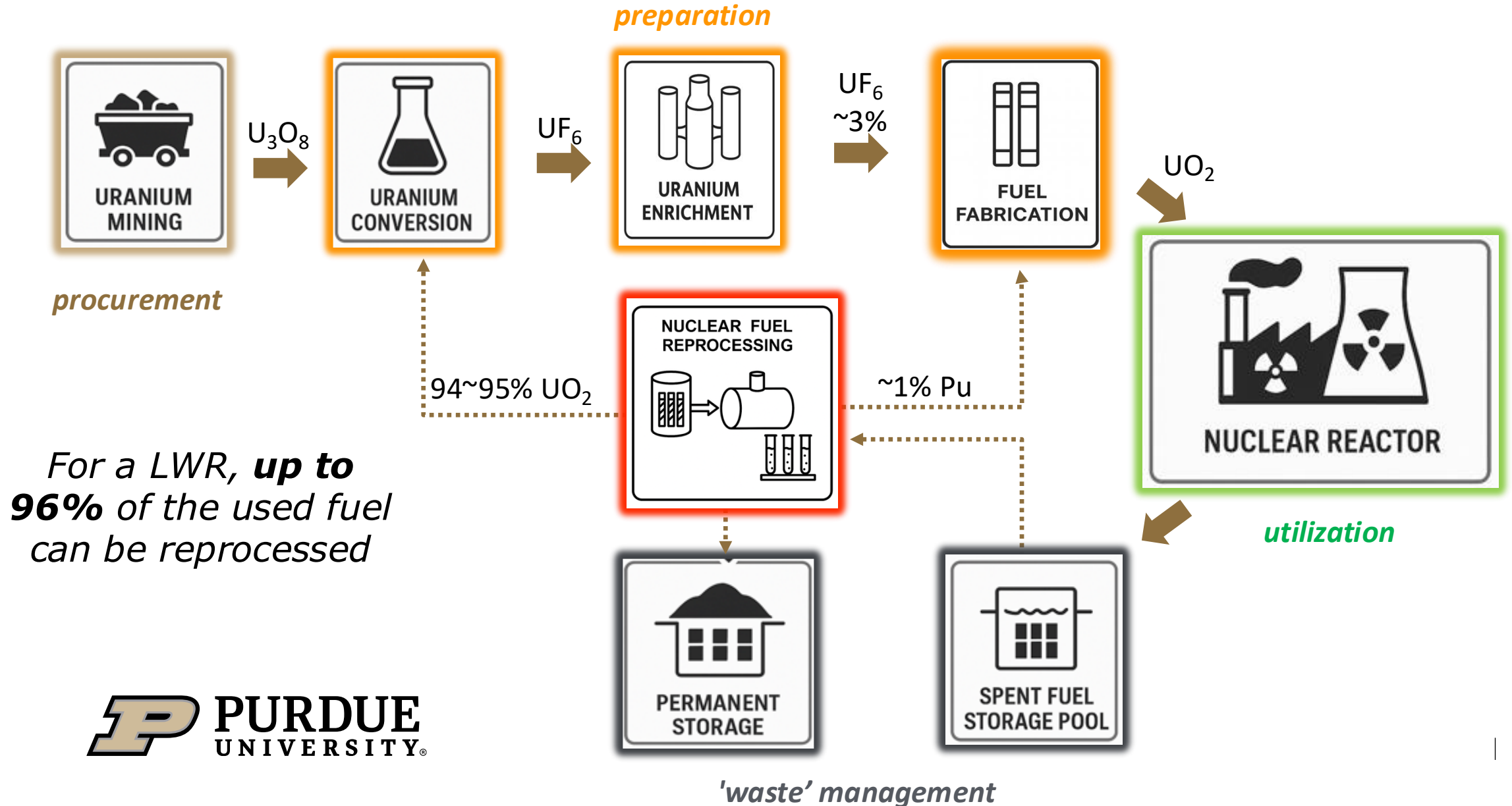
NUCLEAR ENERGY FACTS

Current Nuclear Fuel Cycle: Once –through Cycle



NUCLEAR ENERGY FACTS

Optional Nuclear Fuel Cycle: Reprocessing Cycle



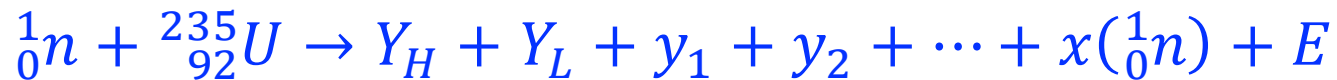
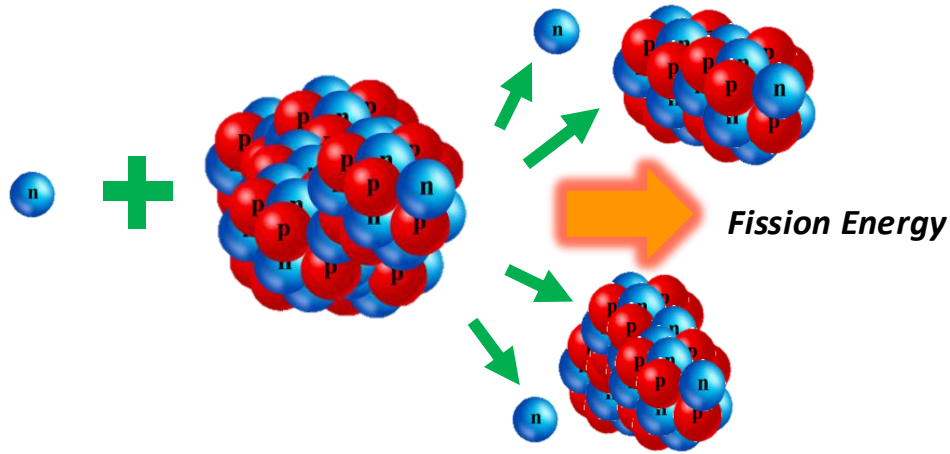
NUCLEAR ENERGY FACTS

Clean; Reliable; Safe; Affordable; Economical; Replenishable.

Energy Sources	Renewable	Sustainable	Scalable
Nuclear	POSSIBLE IF RECYCLED	YES	YES micro; small; large
Fossil Fuel (natural gas / coal)	NO	NO	med to large
Hydropower	YES	NO	small to med
Solar	YES	PARTIALLY	small to med
Wind	YES	PARTIALLY	small to med
Geothermal	YES	PARTIALLY	small

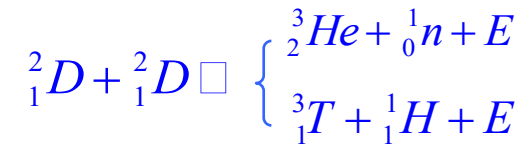
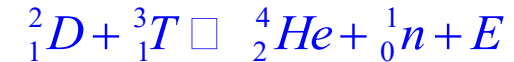
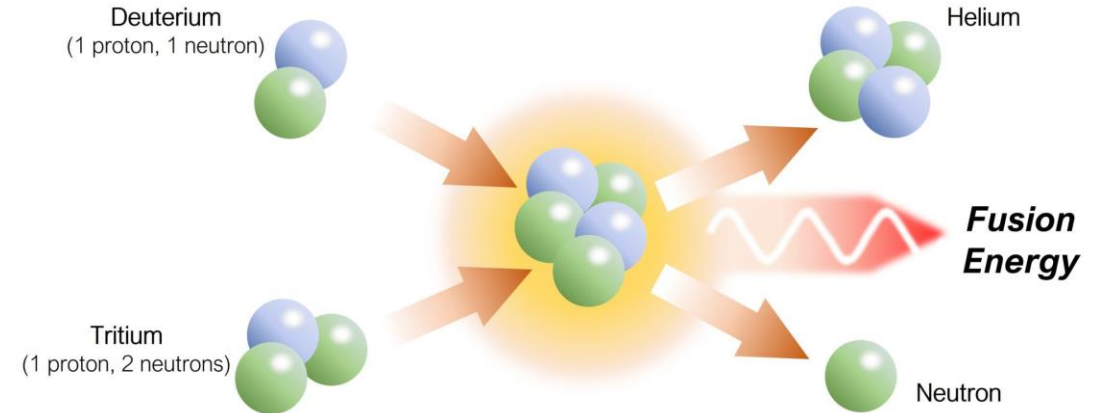
NUCLEAR FISSION vs. NUCLEAR FUSION

Fission Reaction



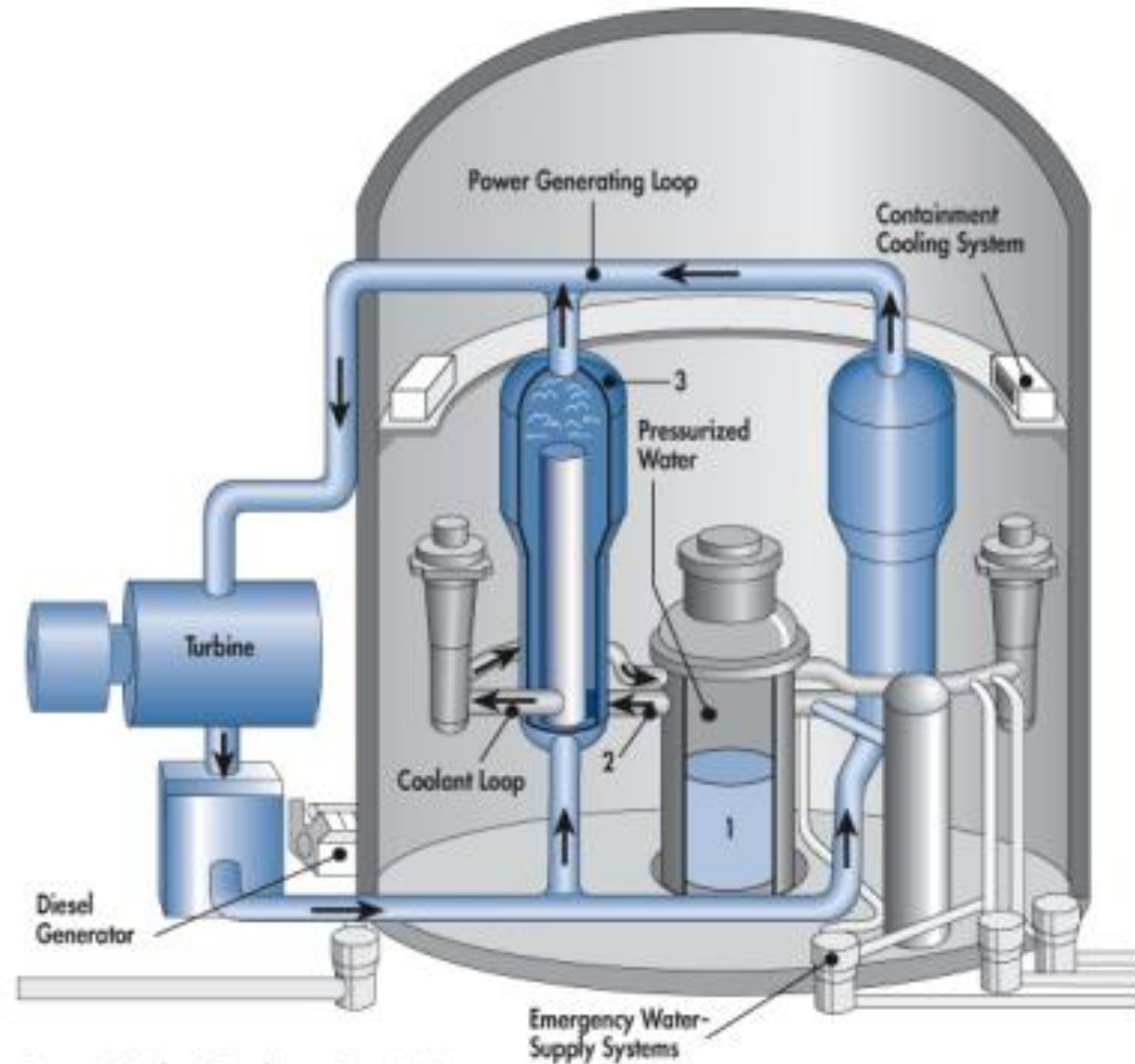
Split of a heavy nucleus into two nuclei (including multiple neutrons) via nuclear reaction

Fusion Reaction



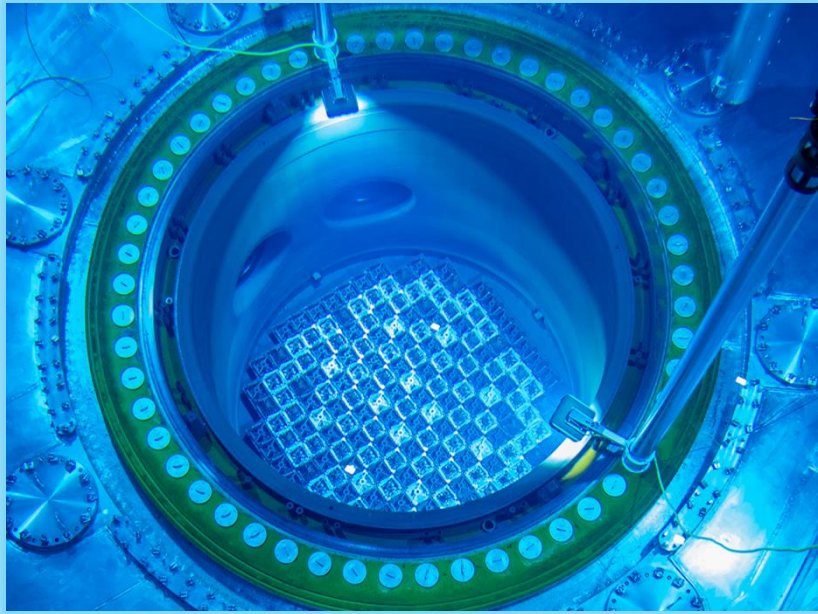
Fuse of two light nuclei to form one nucleus via nuclear reaction (~3 times more energy generated than fission)

HOW NUCLEAR POWER REACTOR WORKS



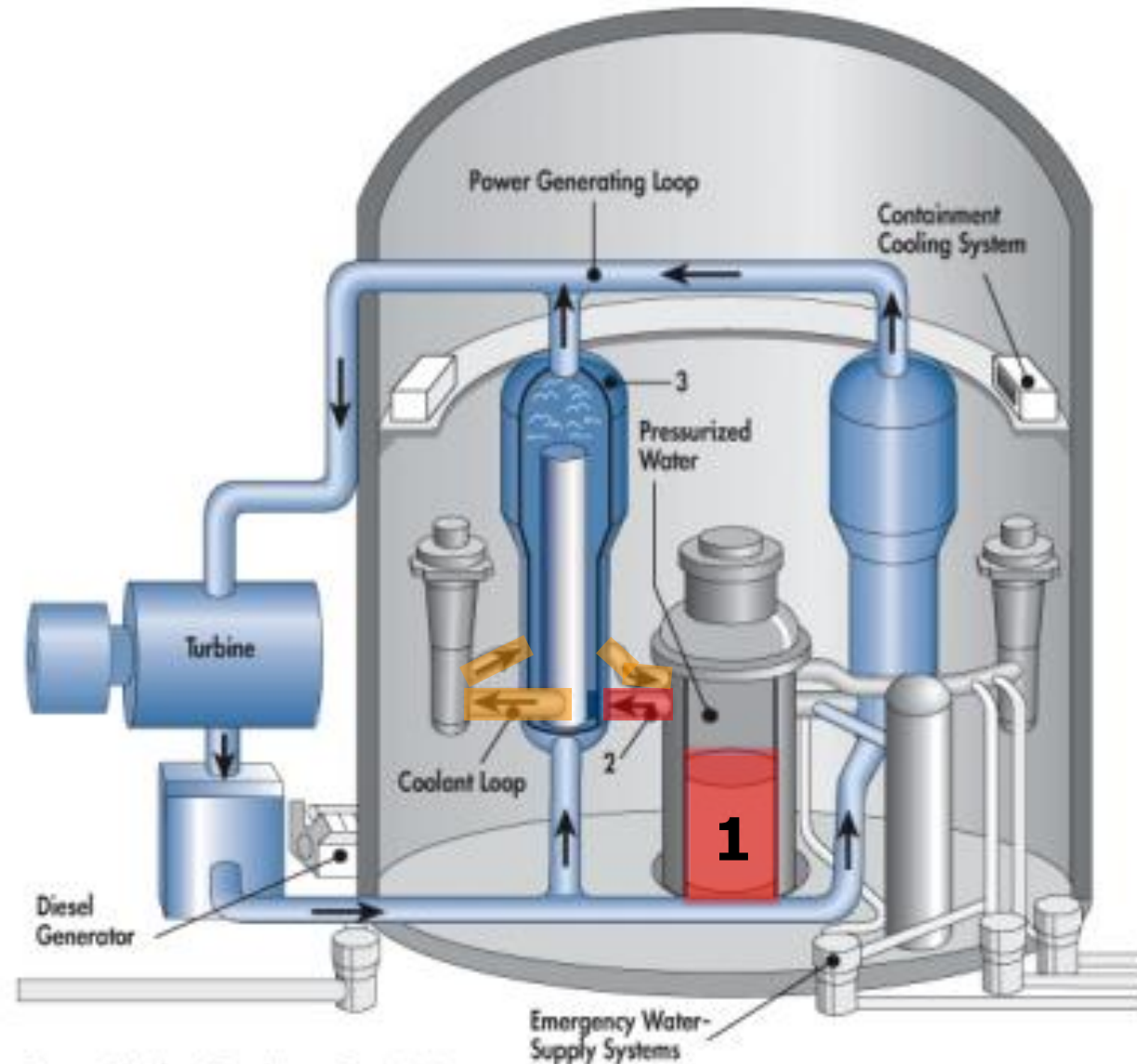
Source: Nuclear Regulatory Commission

HOW NUCLEAR POWER REACTOR WORKS



1. Reactor Pressure Vessel (RPV) & Reactor Core

Fission kinetic energy



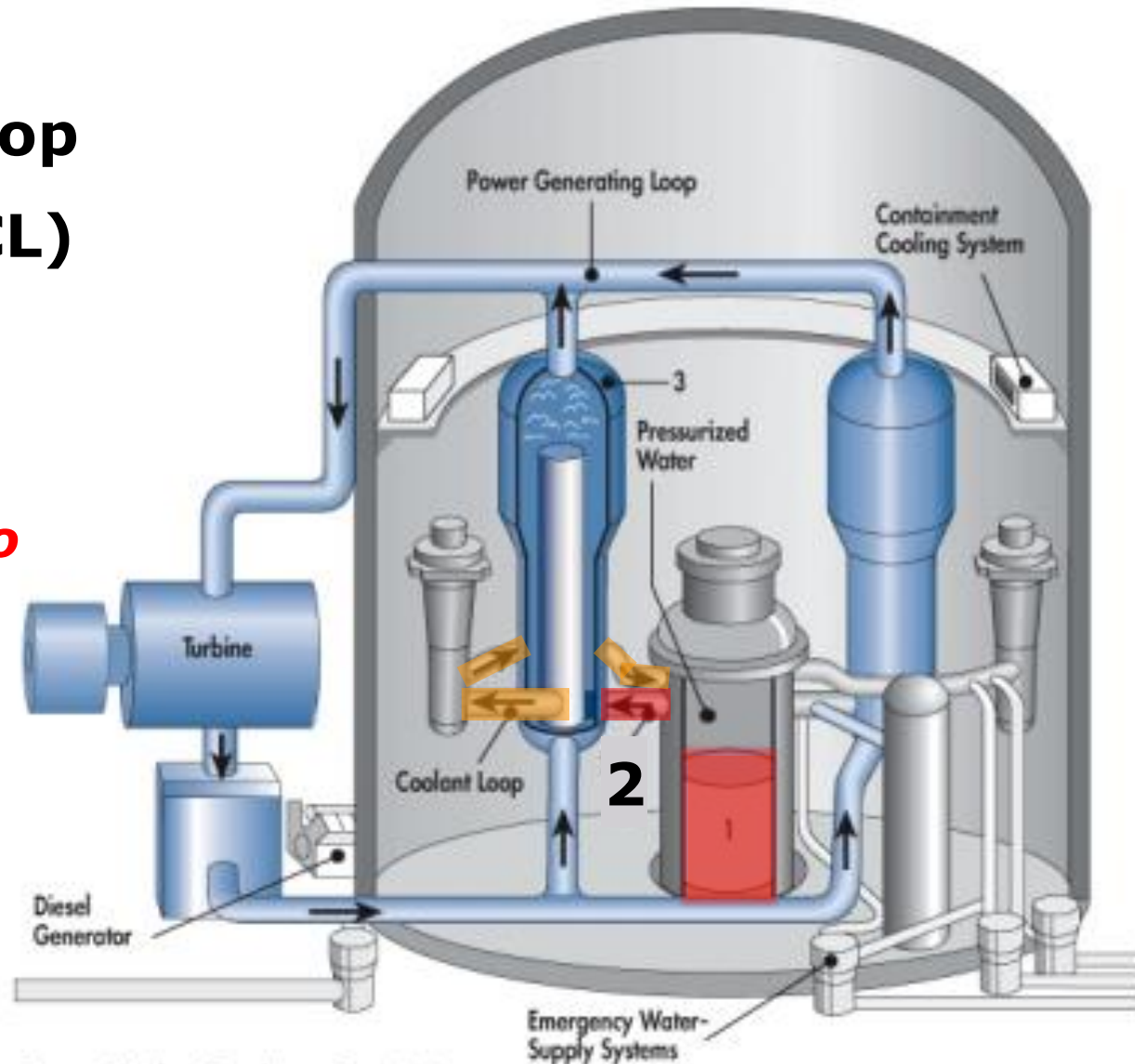
Source: Nuclear Regulatory Commission

HOW NUCLEAR POWER REACTOR WORKS

2. Primary Coolant Pipe Loop

Hot Leg (HL) / Cold Leg (CL)

- Heated coolant from reactor pressure vessel to the steam generator via coolant pipes
- Conversion of **kinetic energy to thermal energy**

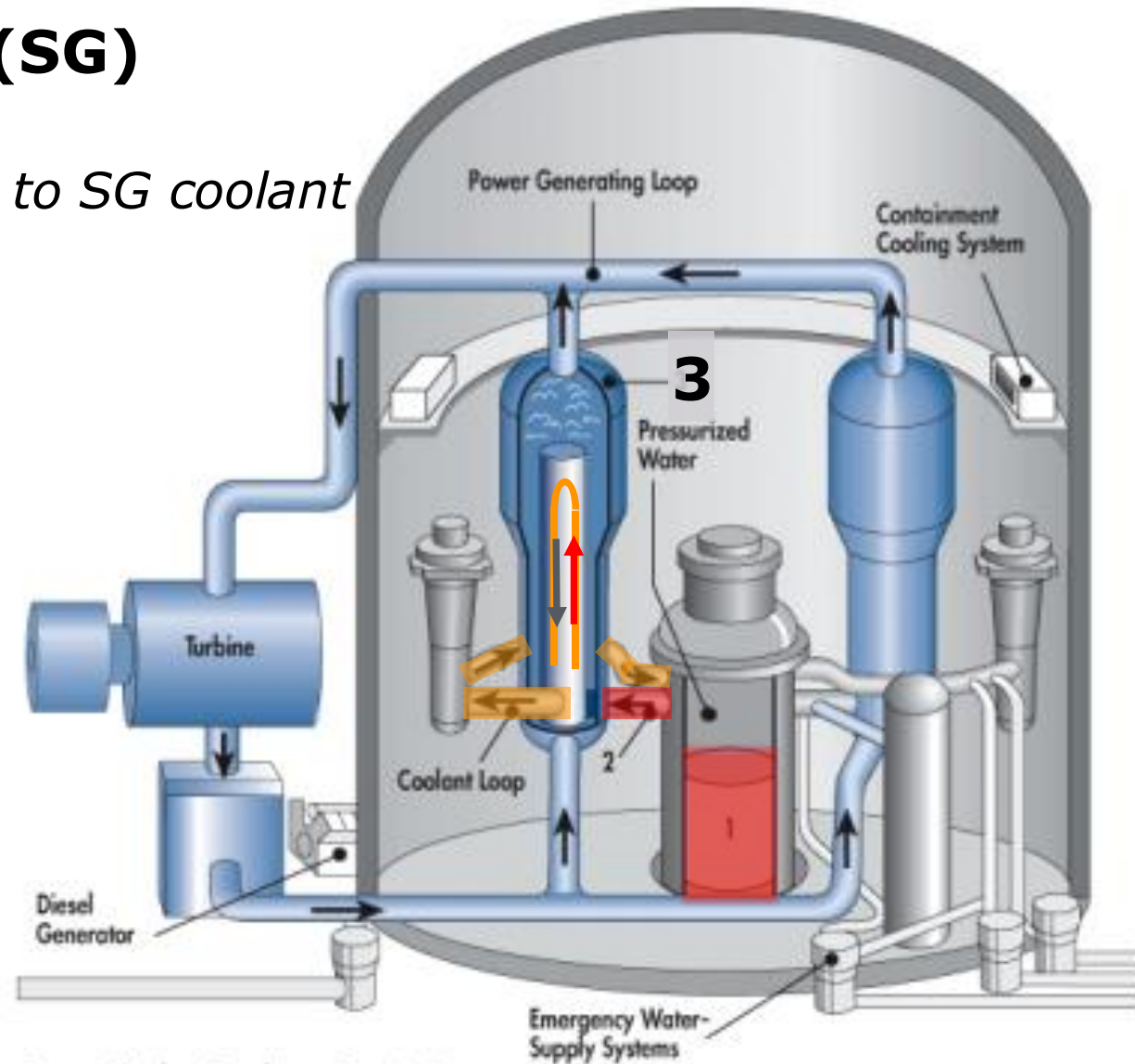
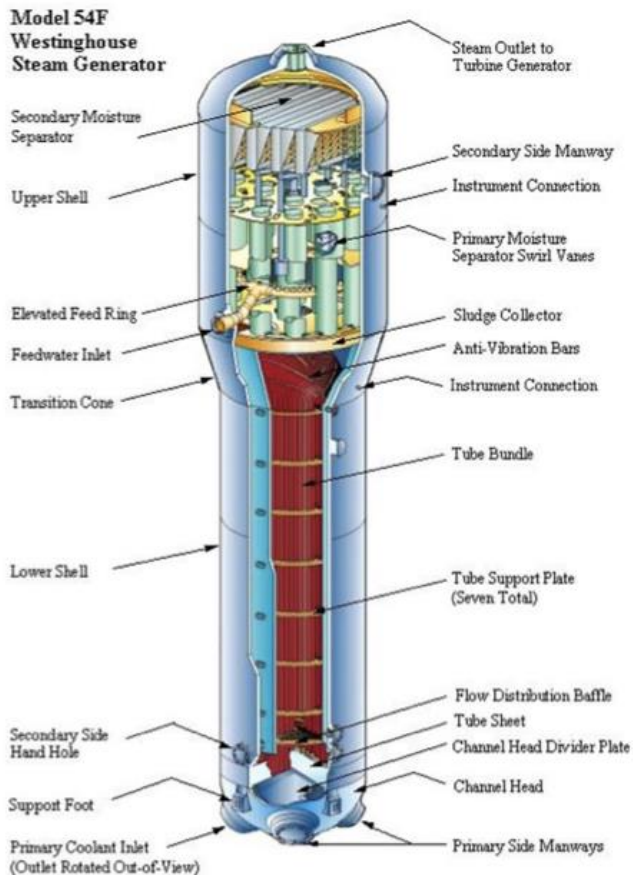


Source: Nuclear Regulatory Commission

HOW NUCLEAR POWER REACTOR WORKS

3. Steam Generator (SG)

- *Half the pressure of the RPV*
- *Heat transfer from primary coolant to SG coolant*
- *Water to steam: **Phase change***

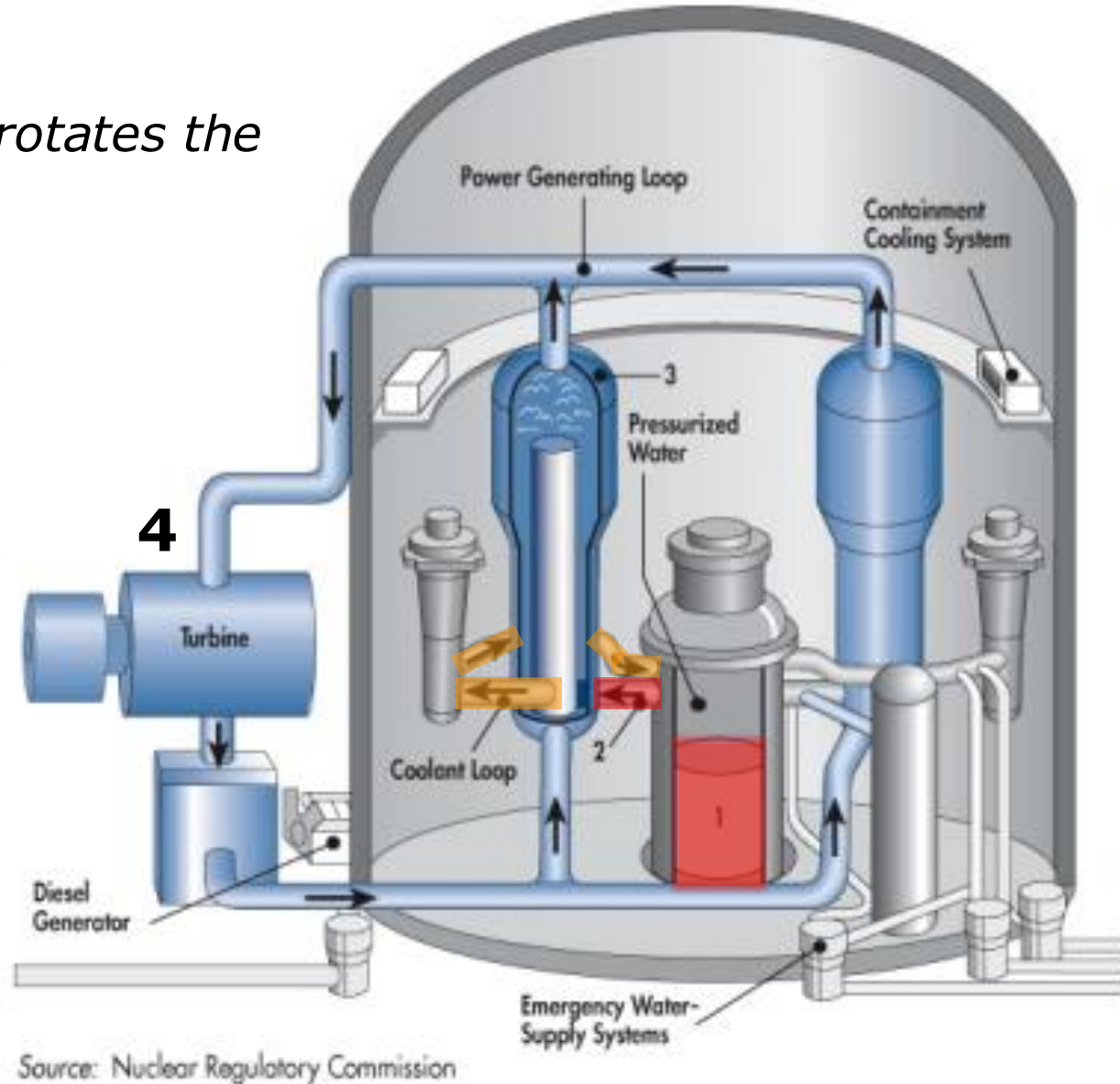
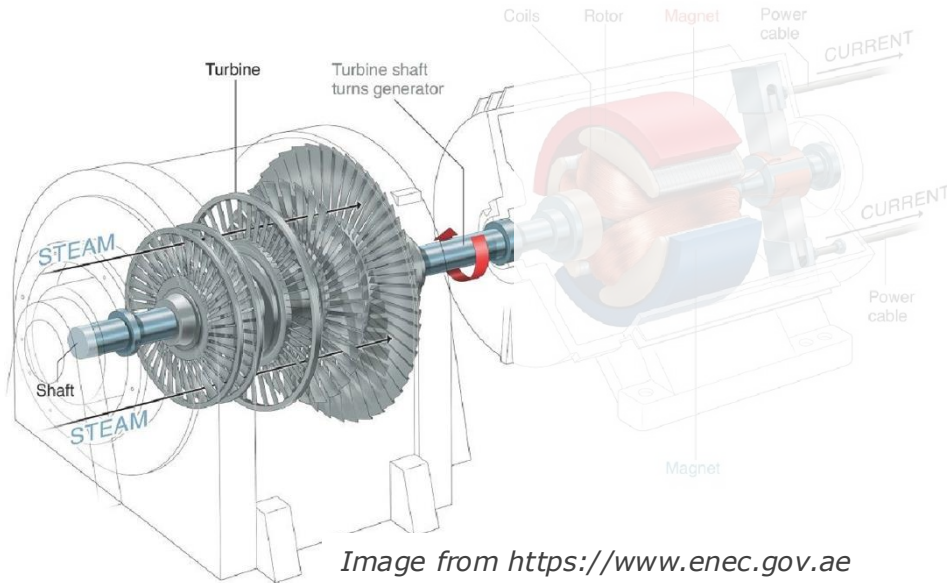


Source: Nuclear Regulatory Commission

HOW NUCLEAR POWER REACTOR WORKS

4. Turbine

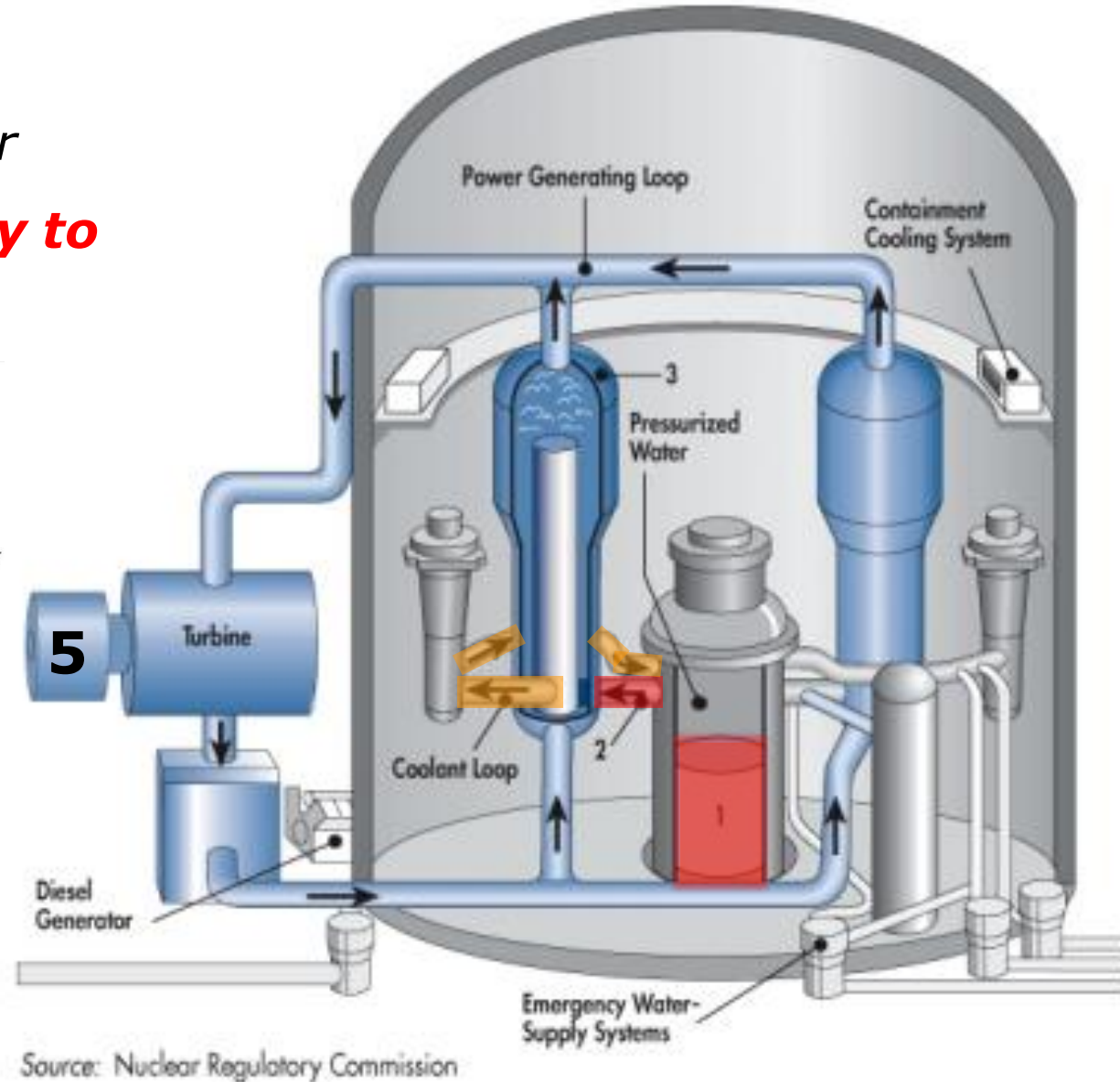
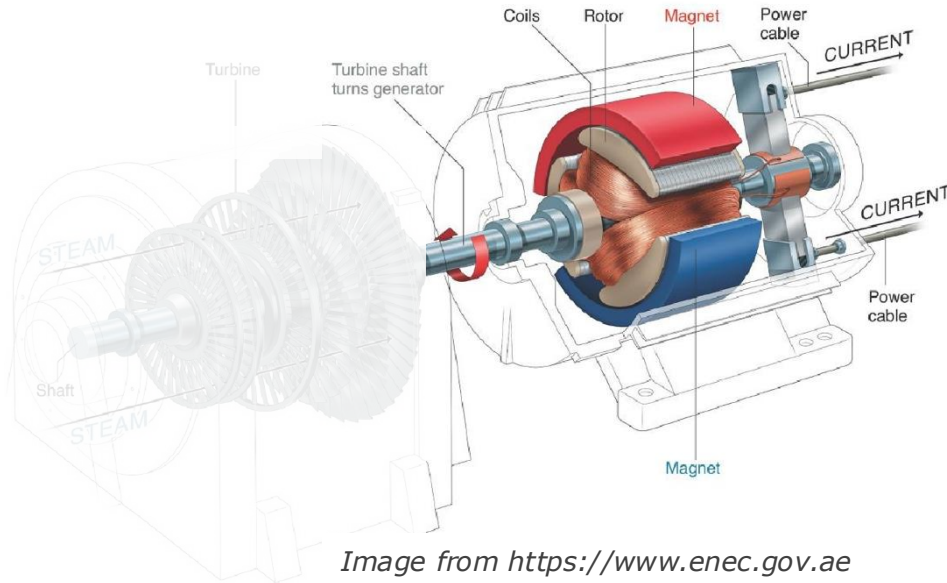
- High pressure steam from the SG rotates the Turbine blade
- Conversion of **thermal energy to mechanical energy**



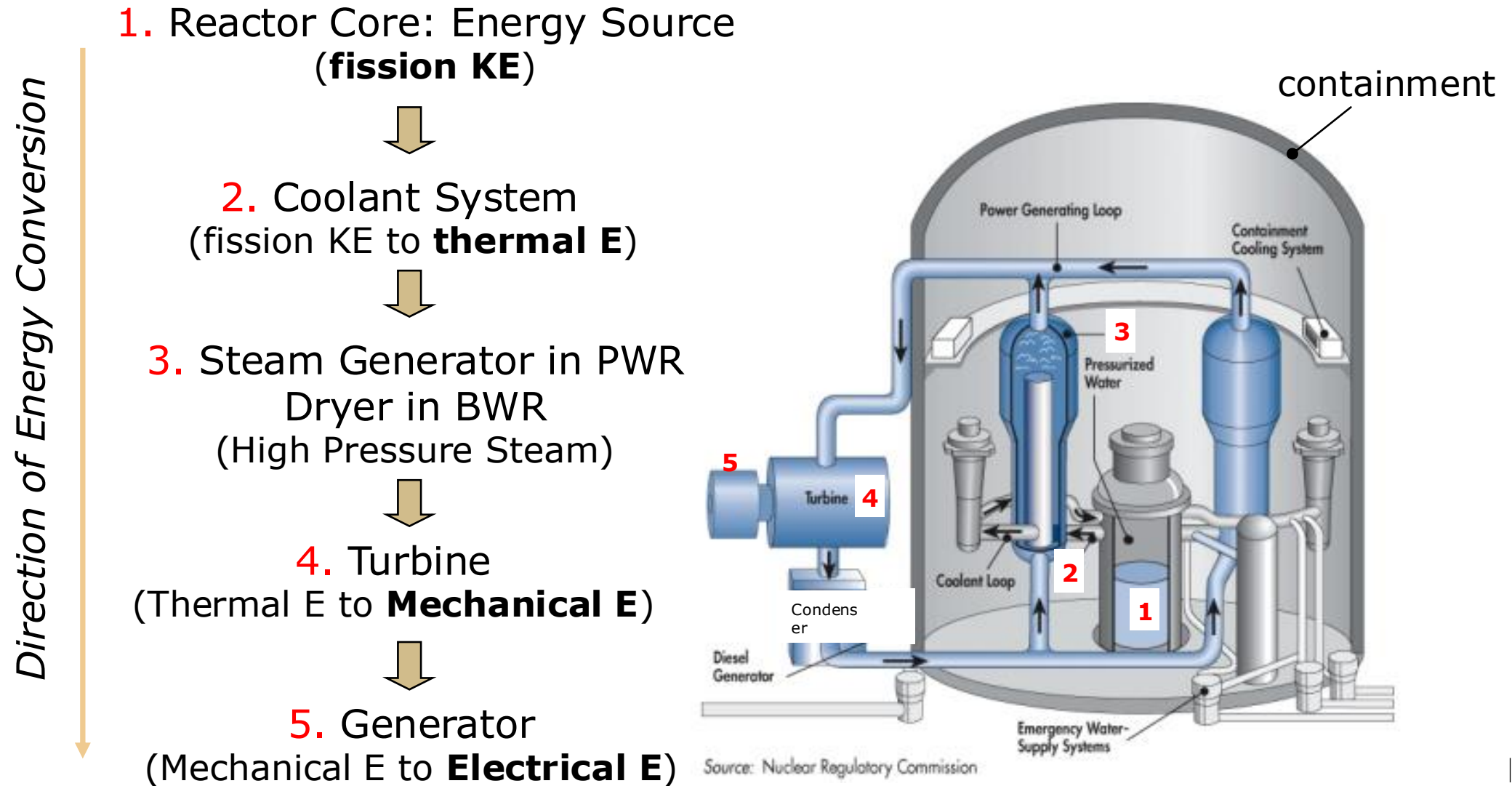
HOW NUCLEAR POWER REACTOR WORKS

5. Generator

- Turbine shaft turns generator rotor
- Conversion of **mechanical energy to electrical energy**



PRINCIPLES OF NUCLEAR POWER GENERATION



EVOLUTION OF NUCLEAR POWER REACTOR

Technological Roadmap at a Glance

GENERATION I

Experimental reactors (Fermi, Magnox)
Shippingport, PA (PWR, '57)
Dresden, IL (BWR, '60)



1st prototype nuclear power reactors

GENERATION II

Commercial Power Reactors
LWR: PWR, BWR
HWR: CANDU
HTGR / AGR
VVER / RBMK



most of the currently running commercial nuclear reactors

GENERATION III & III⁺

Evolutionary Advanced Reactors
Passive Safety Features
SBWR, APWR, EPR
ESBWR, ACR



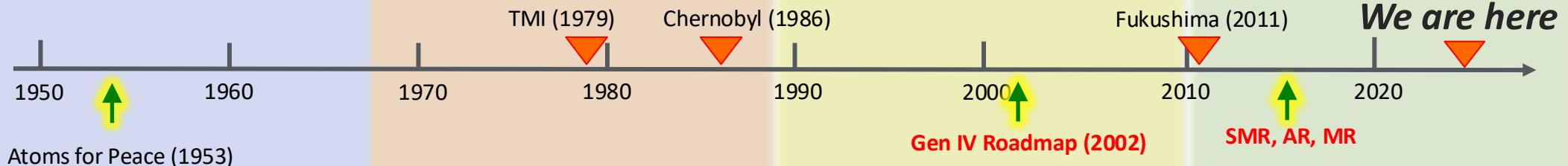
In operation/being built worldwide
U.S.: Vogtle Unit 3 & 4 started in 2009;
Powered 2023 and 2024

GENERATION IV

Next Generation Power Reactors by 2030
Economical; Safe; Sustainable;
Proliferation Resistant
Six Reactor Types



to be deployed by 2030



SMALL MODULAR REACTOR (SMR)

Design Features

- **“Small”** in Power and Size
 - ✓ SMR is designed to produce typically 300~500 MWe
 - ✓ Smaller core inventory
 - ✓ Smaller footprint

} Flexible & resilient in siting
- **“Modular”** in Design & Deployment
 - ✓ Factory assembled; transportable; deploy on site (plug-and-play concept) ➡ Improve manufacturing / construction efficiency
 - ✓ Ability to combine multiple modules ➡ Scalable

SMALL MODULAR REACTOR (SMR)

Design Features

▪ **Safer by Design**

- ✓ Single-vessel integrated design
 - Substantially increase heat capacity and thermal inertia, providing indefinite 'coping' time.
 - Less failure modes
 - Less reliance on active safety systems including pumps and AC power
- ✓ Passive safety system
- ✓ Below-grade Installation ➡ Enhanced protection from natural and external hazards

SMALL MODULAR REACTOR (SMR)

Design Features

- **Economical**

Smaller foot-print; Less capital cost; Longer plant lifetime; Cheaper electricity cost; Lower O&M cost

- **Co-generation Capability**

District heating; Hydrogen generation; Processed heat; Desalination

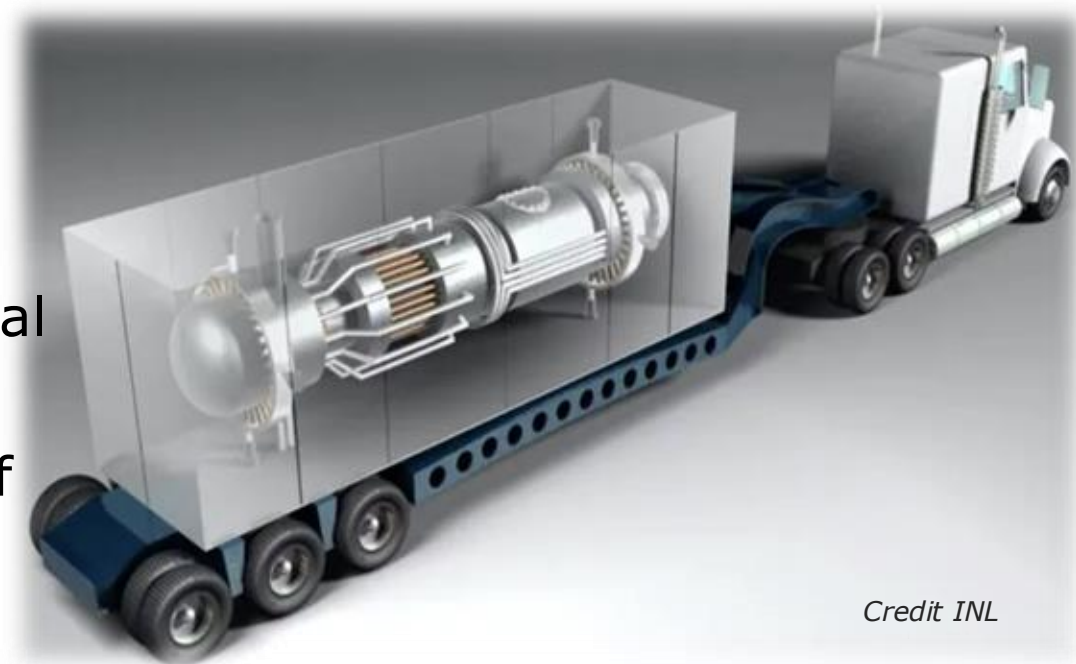
- **Dispatchability and Hybrid** Capability with Energy Storage System

- **Coal-to-Nuclear** (C2N)

MICRO REACTOR (MR)

Design Features

- **Small in Power** 1 MWe ~ 20 MWe
- **Transportable** by Truck, Rail, or Plane
- Factory Fabricated, Assembled & Installed On-site ➡ **Plug & Play**
- **“Nuclear Battery”** Concept: Operable for 5-10 yrs Without Refueling
- Applications
 - ✓ Remote & isolated communities, replacing diesel generators
 - ✓ Secured and independent energy for critical infrastructure
 - ✓ Rapid power deployment for disaster relief



NET ZERO BY 2050

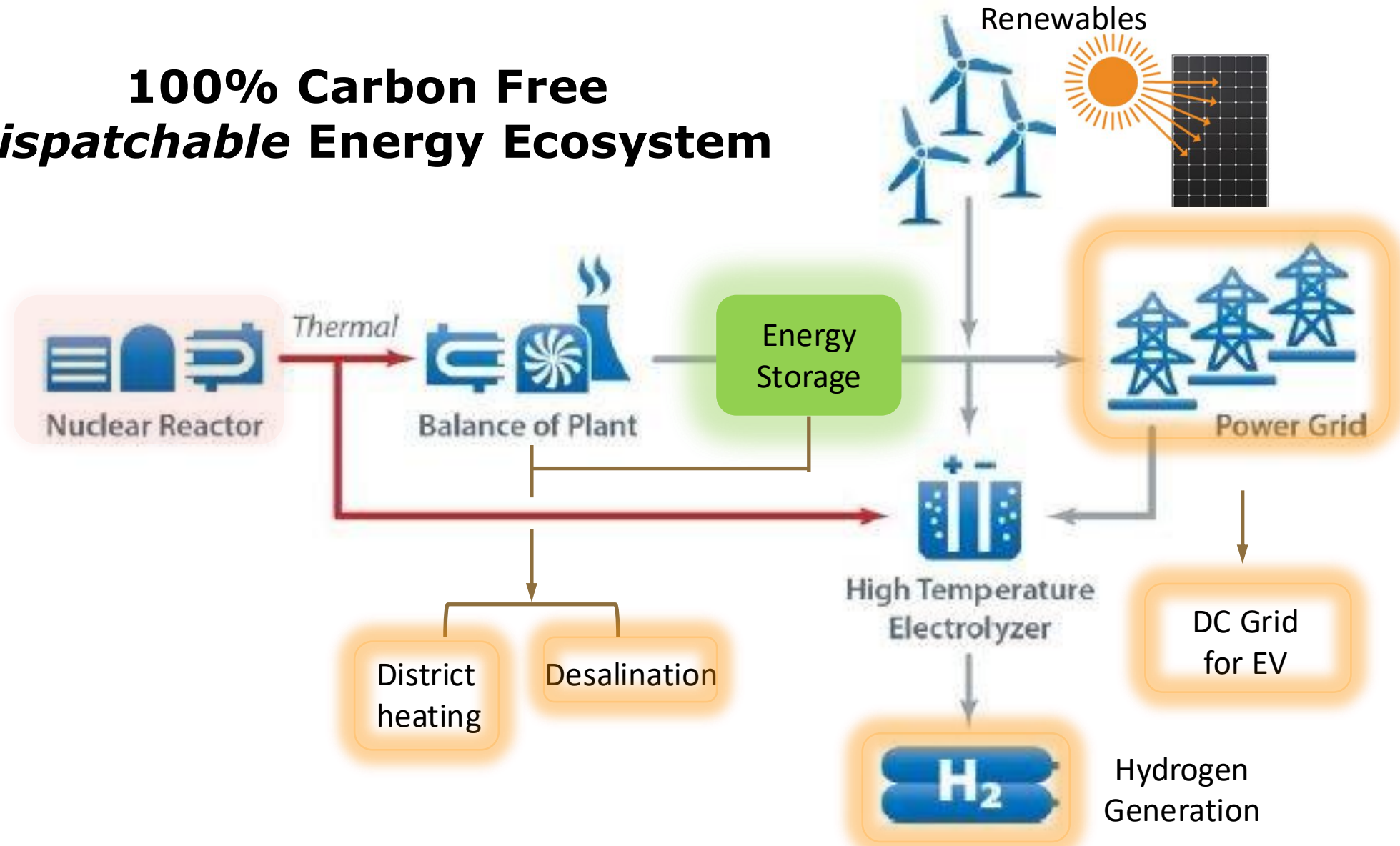
Challenges

- Net Electricity Capacity Need to Increase from **95GW** Today to **300 GW** by 2050.
- **Manufacturing** Capacity for Nuclear Parts/Components Needs to be Tripled.
- **Supply Chain** for Advanced Fuel Needs to be Established.
- **Regulatory Process** Needs to be Modernized.
- **Workforce:**

Nuclear industry directly employs around **100,000** people (~15% nuclear engineers). Need **375,000** by 2050.

NUCLEAR ENERGY

100% Carbon Free Dispatchable Energy Ecosystem



Thank You!

