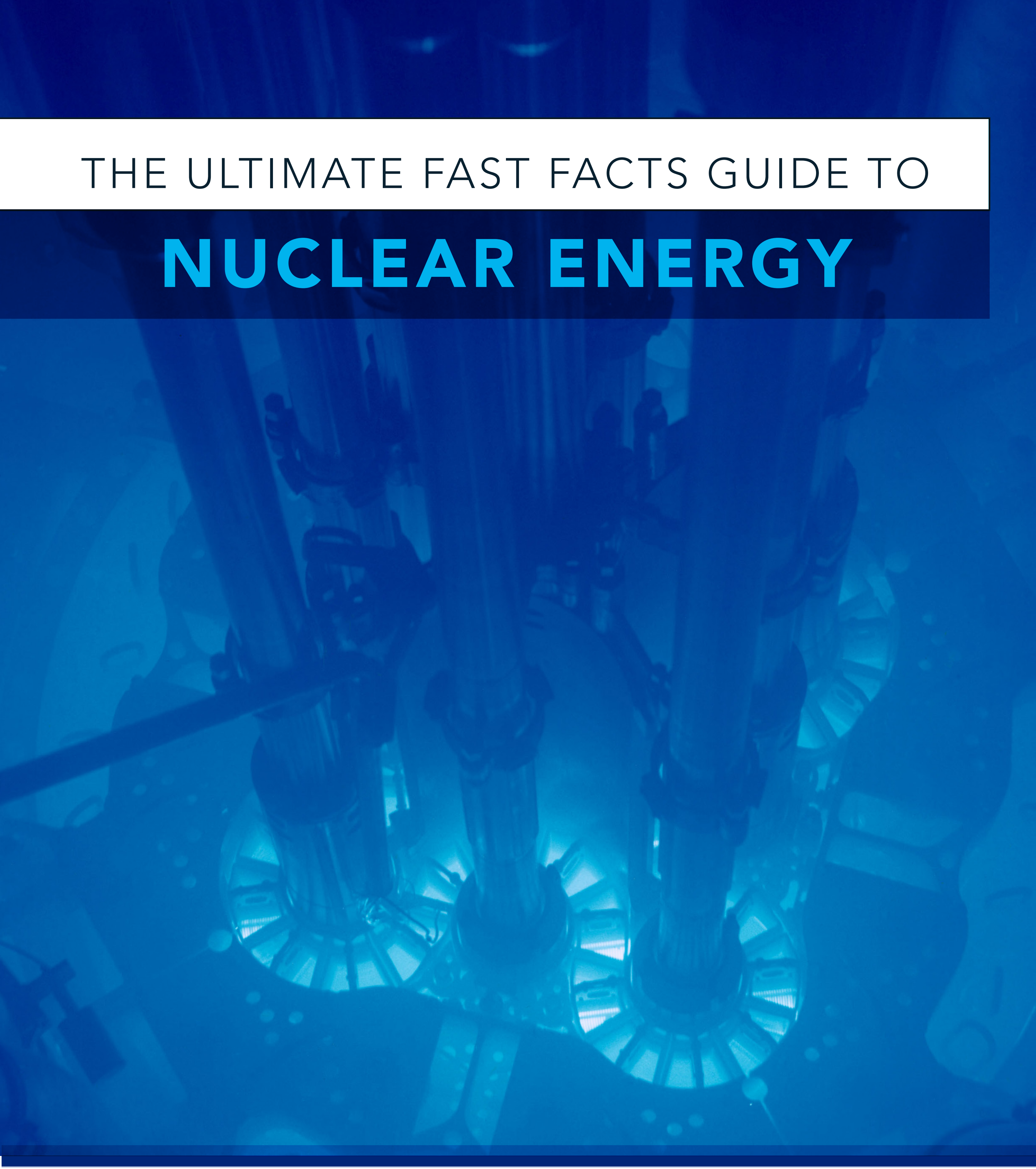

THE ULTIMATE FAST FACTS GUIDE TO

NUCLEAR ENERGY

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

Clean. **Reliable. Nuclear.**

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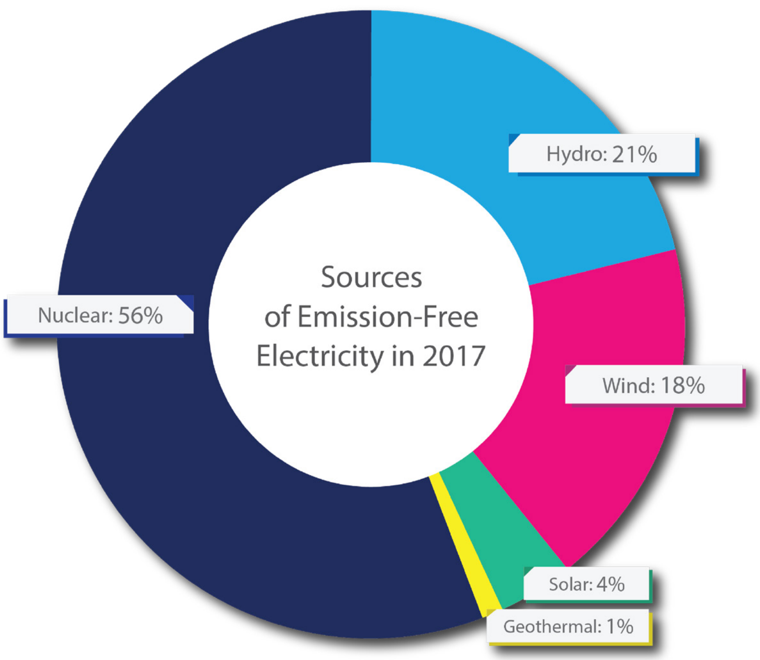
5 FAST FACTS ABOUT NUCLEAR ENERGY

Nuclear energy has been quietly powering America with clean, carbon-free electricity for the last 60 years. It may not be the first thing you think of when you heat or cool your home, but maybe that's the point. It's been so reliable that we sometimes take it for granted. Did you know about a fifth of the country's electricity comes from nuclear power each year? If not, then it's about time you get to know nuclear. Here are five fast facts to get you up to speed:

1. NUCLEAR POWER PLANTS PRODUCED 805 BILLION KILOWATT HOURS OF ELECTRICITY IN 2017

The United States is the world's largest producer of nuclear power. It generated just under 805 billion kilowatt hours of electricity in 2017—enough to power 73 million homes. Commercial nuclear power plants have supplied around 20% of the nation's electricity each year since 1990.

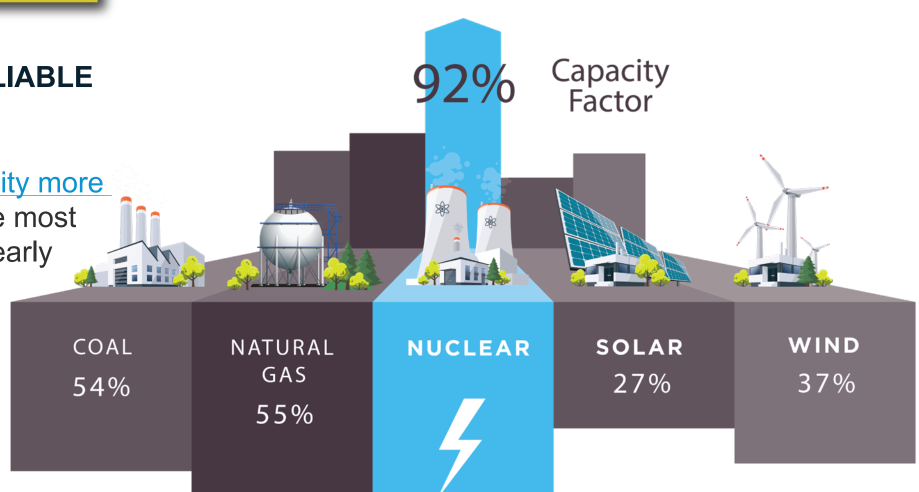


2. NUCLEAR POWER PROVIDES 56% OF AMERICA'S CLEAN ENERGY

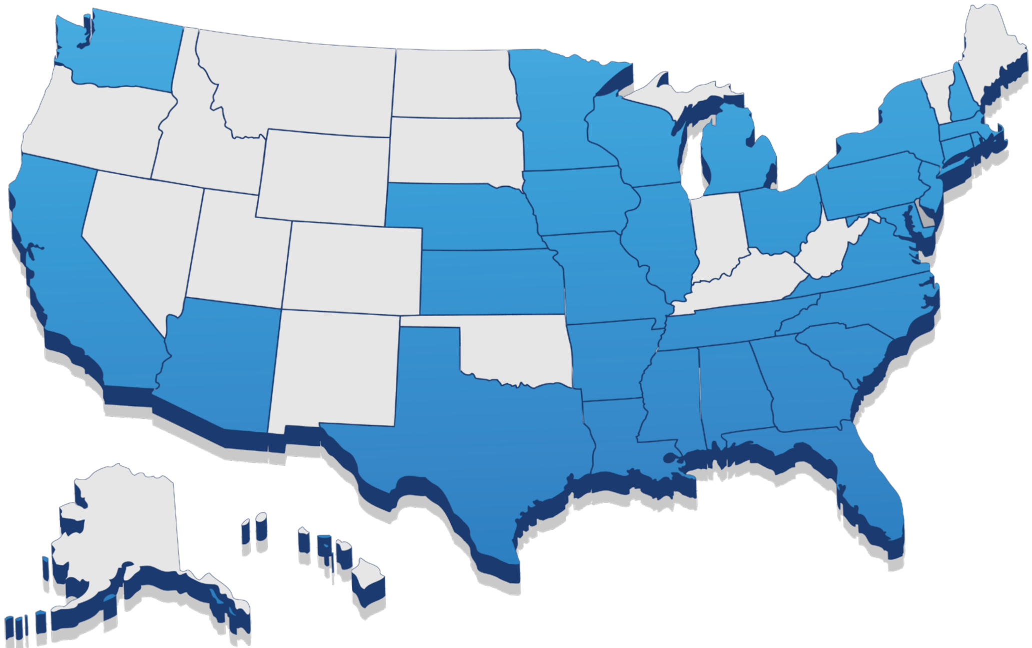
Nuclear energy provided 56% of America's carbon-free electricity in 2017, making it by far the largest domestic source of clean energy. Nuclear power plants do not emit greenhouse gases while generating electricity. They produce power by boiling water to create steam that spins a turbine. The water is heated by a process called fission, which makes heat by splitting apart uranium atoms inside a nuclear reactor core.

3. NUCLEAR ENERGY IS THE MOST RELIABLE ENERGY SOURCE IN AMERICA

Nuclear power plants operated at full capacity more than 92% of the time in 2017—making it the most reliable energy source in America. That's nearly twice as reliable as coal (54%) and natural gas (55%) plants, and 2 to 3 times more reliable than wind (37%) and solar (27%) plants. Nuclear power plants are designed to run 24 hours a day, 7 days a week because they require less maintenance and can operate for longer stretches before refueling (typically every 1.5 or 2 years).



Source: U.S. Energy Information Administration

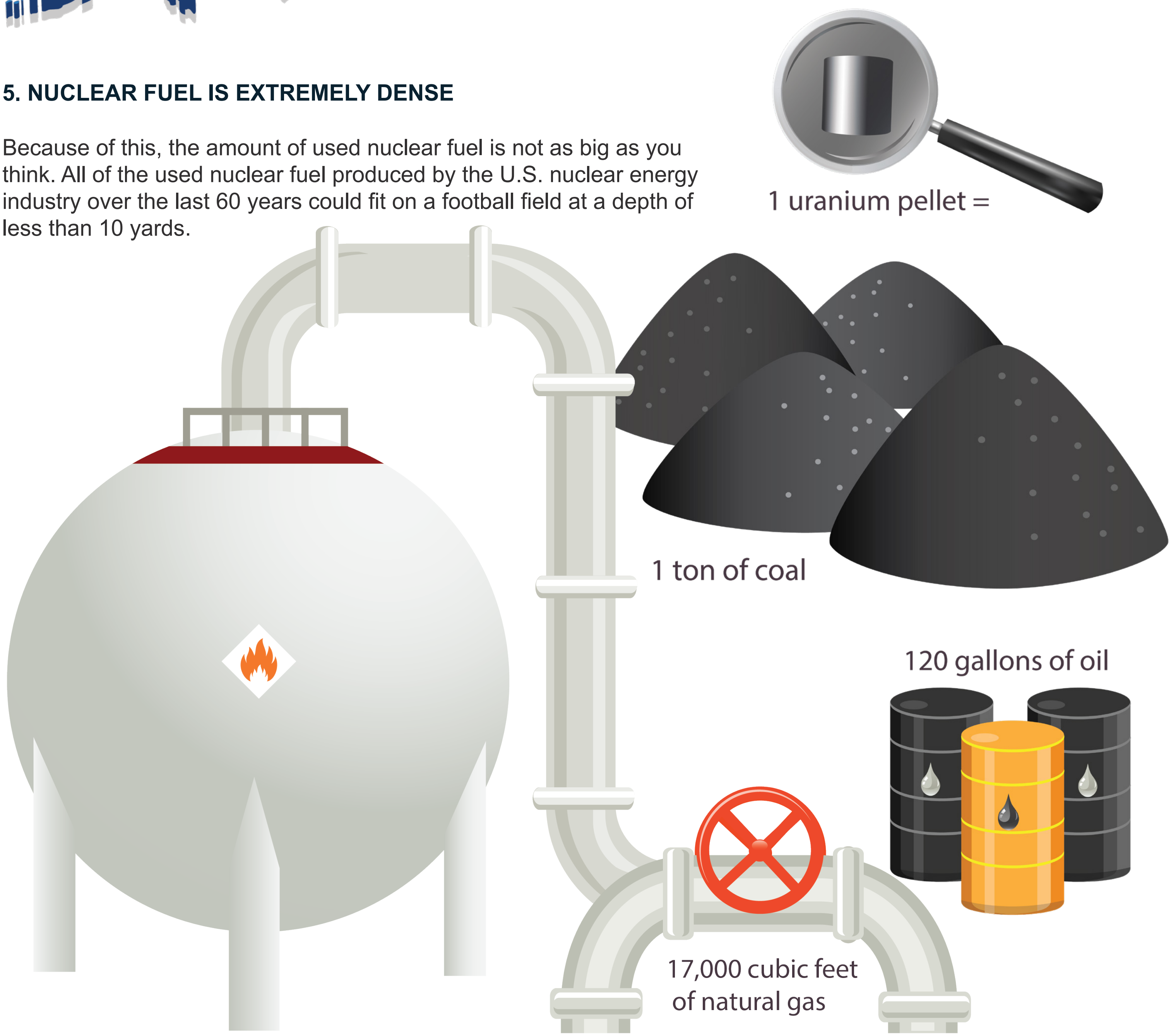


4. NUCLEAR HELPS POWER 30 U.S. STATES

As of September 2018, 98 commercial reactors help power homes and businesses in 30 U.S. states. Illinois has 11 reactors—the most of any state—and joins South Carolina and New Hampshire in receiving more than 50% of its power from nuclear.

5. NUCLEAR FUEL IS EXTREMELY DENSE

Because of this, the amount of used nuclear fuel is not as big as you think. All of the used nuclear fuel produced by the U.S. nuclear energy industry over the last 60 years could fit on a football field at a depth of less than 10 yards.



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HOW DOES A NUCLEAR REACTOR WORK?

NUCLEAR REACTORS ARE THE HEART OF A NUCLEAR POWER PLANT.

They contain and control nuclear chain reactions that produce heat through a physical process called fission. That heat is used to make steam that spins a turbine to create electricity.

With more than 450 commercial reactors worldwide, including 98 in the United States, nuclear power continues to be one of the largest sources of reliable carbon-free electricity available.

NUCLEAR FISSION CREATES HEAT

The main job of a reactor is to house and control nuclear fission—a process where atoms split and release energy.

Reactors use uranium for nuclear fuel. The uranium is processed into small ceramic pellets and stacked together into sealed metal tubes called fuel rods. Typically, more than 200 of these rods are bundled together to form a fuel assembly. A reactor core is usually made up of a couple hundred assemblies, depending on the power level.

Inside the reactor vessel, the fuel rods are immersed in water which acts as both a coolant and moderator. The moderator helps slow down the neutrons produced by fission to sustain the chain reaction.

Control rods can then be inserted into the reactor core to reduce the reaction rate or withdrawn to increase it.

The heat created by fission turns the water into steam, which spins a turbine to produce carbon-free electricity.

TYPES OF LIGHT-WATER REACTORS IN THE UNITED STATES

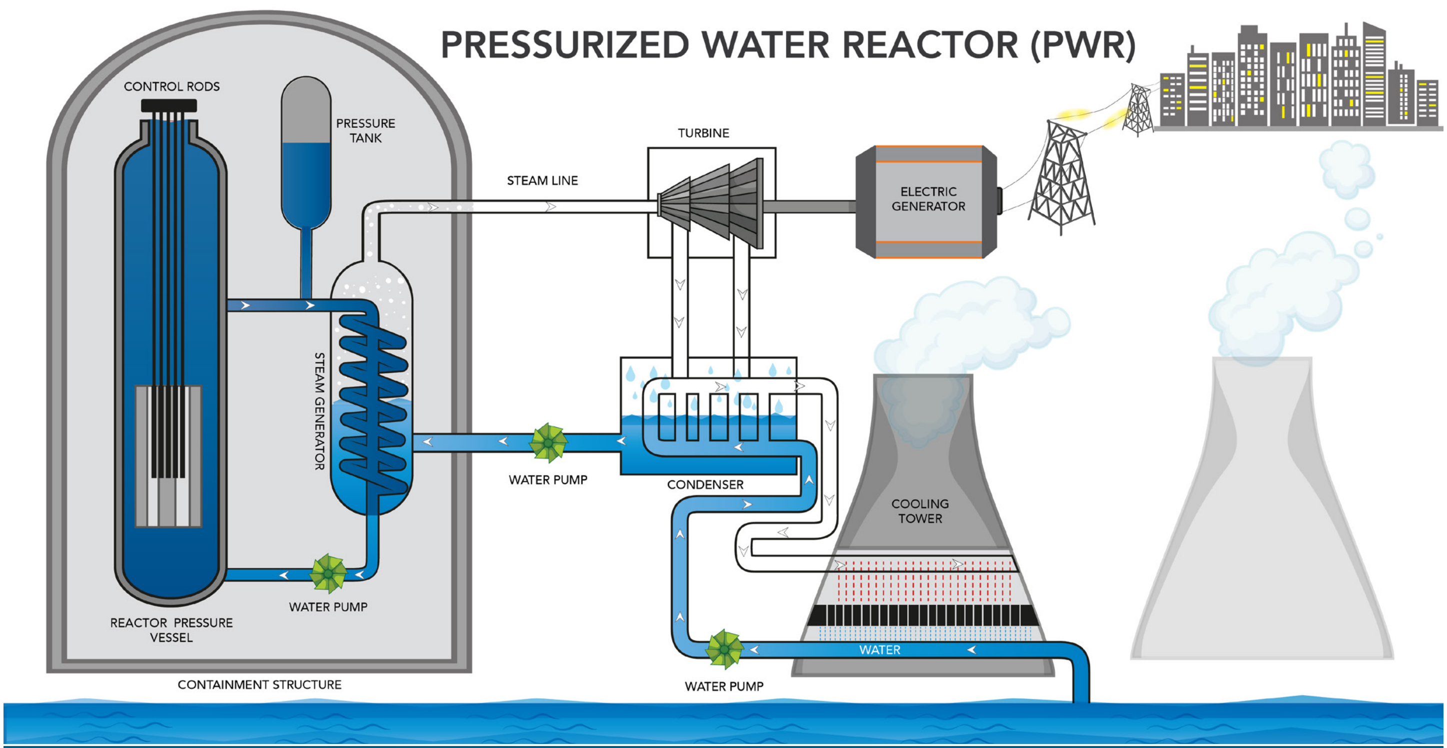
All commercial nuclear reactors in the United States are light-water reactors. This means they use normal water as both a coolant and neutron moderator.

There are two types of light-water reactors operating in America:

PRESSURIZED-WATER NUCLEAR REACTORS

More than 65% of the commercial reactors in the United States are pressurized-water reactors or PWRs. These reactors pump water into the reactor core under high pressure to prevent the water from boiling.

The water in the core is heated by nuclear fission and then pumped into tubes inside a heat



exchanger. Those tubes heat a separate water source to create steam. The steam then turns an electric generator to produce electricity.

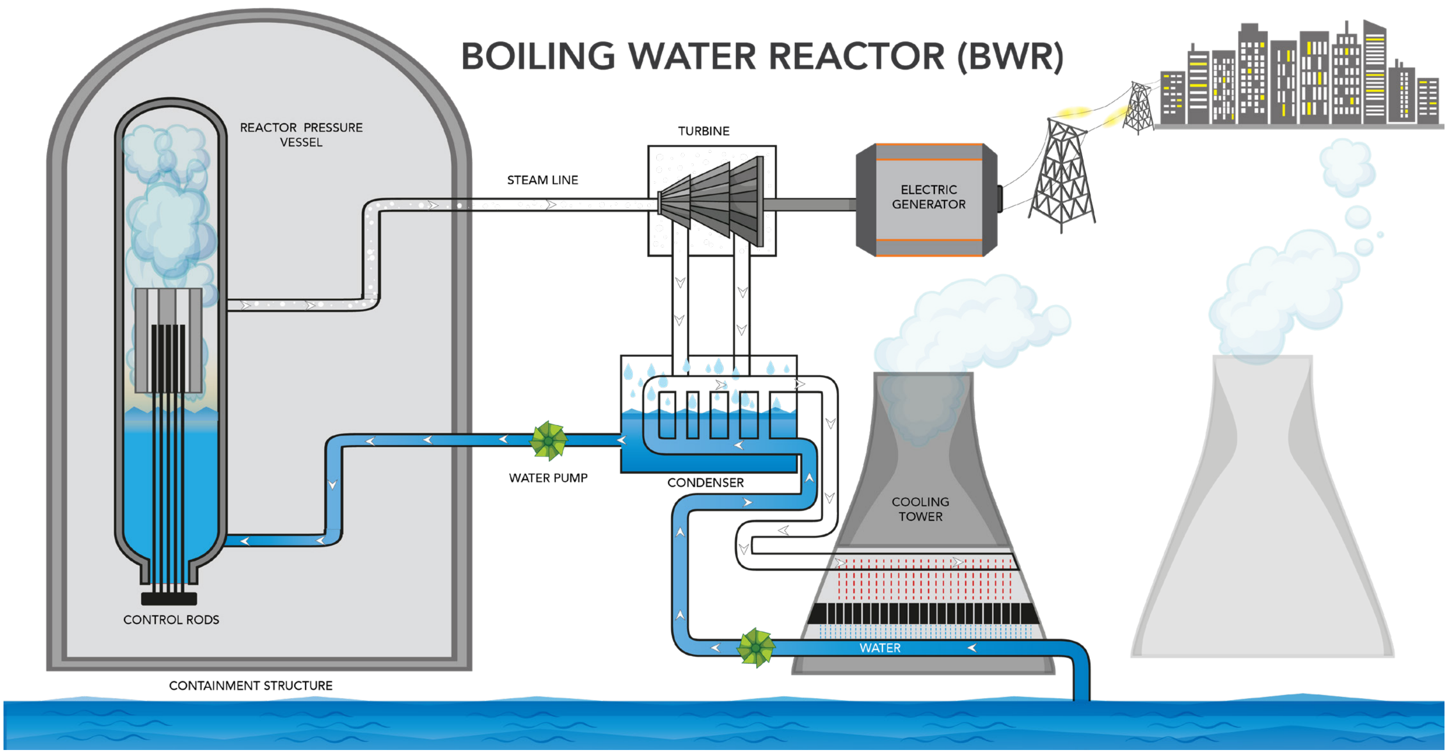
The core water cycles back to the reactor to be reheated and the process is repeated.

BOILING WATER REACTORS

Roughly a third of the reactors operating in the United States are boiling water reactors (BWRs).

BWRs heat water and produce steam directly inside the reactor vessel. Water is pumped up through the reactor core and heated by fission. Pipes then feed the steam directly to a turbine to produce electricity.

The unused steam is then condensed back to water and reused in the heating process.

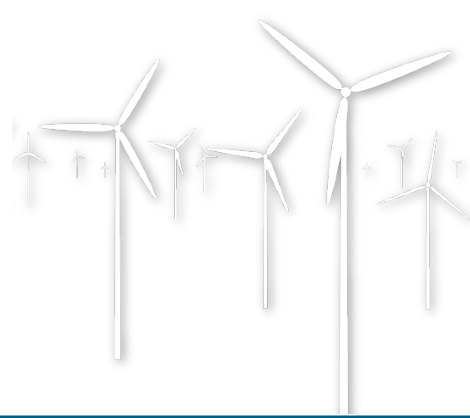


HOW MUCH POWER DOES A NUCLEAR REACTOR PRODUCE?

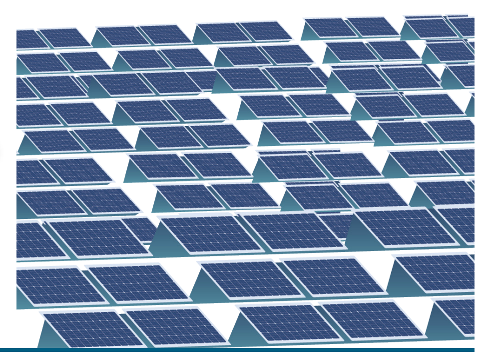
A typical reactor produces around 1 gigawatt of power or the same amount of power as:

100 million
LED bulbs

431 utility-scale
wind turbines



3.125 million
PV panels



NUCLEAR IS CLEAN AND SUSTAINABLE

When you hear the words "clean energy," what comes to mind?

Most people immediately think of solar panels or wind turbines, but how many of you thought of nuclear energy?

Nuclear is often left out of the "clean energy" conversation despite it being the second largest source of low-carbon electricity in the world behind hydropower.

So, just how clean and sustainable is nuclear?

Try these quick facts for starters.

NUCLEAR IS A ZERO-EMISSIONS CLEAN ENERGY SOURCE

It generates power through fission, which is the process of splitting uranium atoms to produce energy. The heat released by fission is used to create steam that spins a turbine to generate electricity without the harmful byproducts emitted by fossil fuels.

According to the Nuclear Energy Institute (NEI), the United States avoided more than 14,000 million metric tons of carbon dioxide emissions between 1995 and 2016. That's the equivalent of removing 3 billion cars from the road.

It also keeps the air clean by removing thousands of tons of harmful air pollutants each year that contribute to acid rain, smog, lung cancer and cardiovascular disease.

NUCLEAR ENERGY'S LAND FOOTPRINT IS SMALL

Despite producing massive amounts of carbon-free power, nuclear energy produces more electricity on less land than any other clean-air source.

A typical 1,000-megawatt nuclear facility in the United States needs a little more than 1 square mile to operate. NEI says wind farms require 360 times more land area to produce the same amount of electricity and solar photovoltaic plants require 75 times more space.

To put that in perspective, you would need more than 3 million solar panels to produce the same amount of power as a typical commercial reactor or more than 430 wind turbines (capacity factor not included).

NUCLEAR ENERGY PRODUCES MINIMAL WASTE

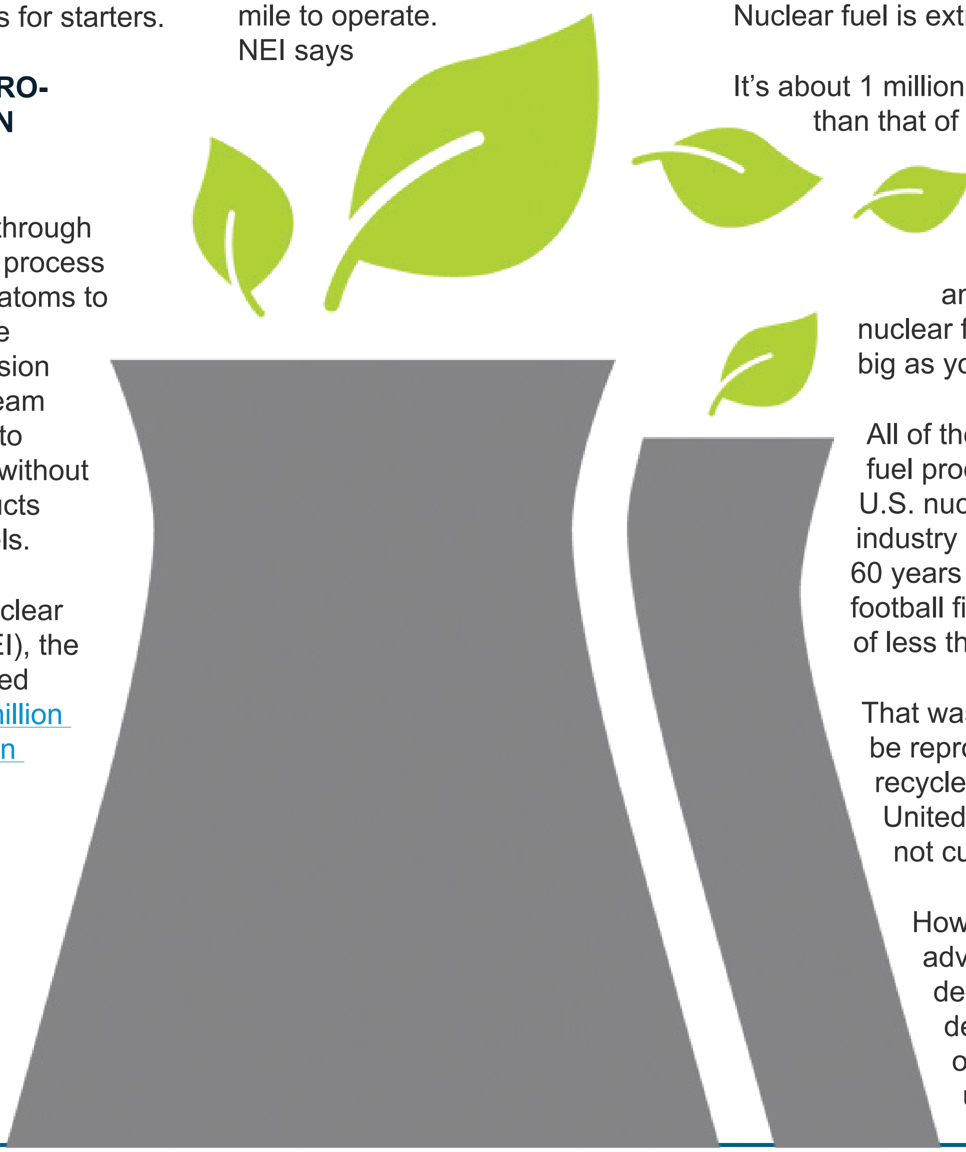
Nuclear fuel is extremely dense.

It's about 1 million times greater than that of other traditional energy sources and because of this, the amount of used nuclear fuel is not as big as you might think.

All of the used nuclear fuel produced by the U.S. nuclear energy industry over the last 60 years could fit on a football field at a depth of less than 10 yards!

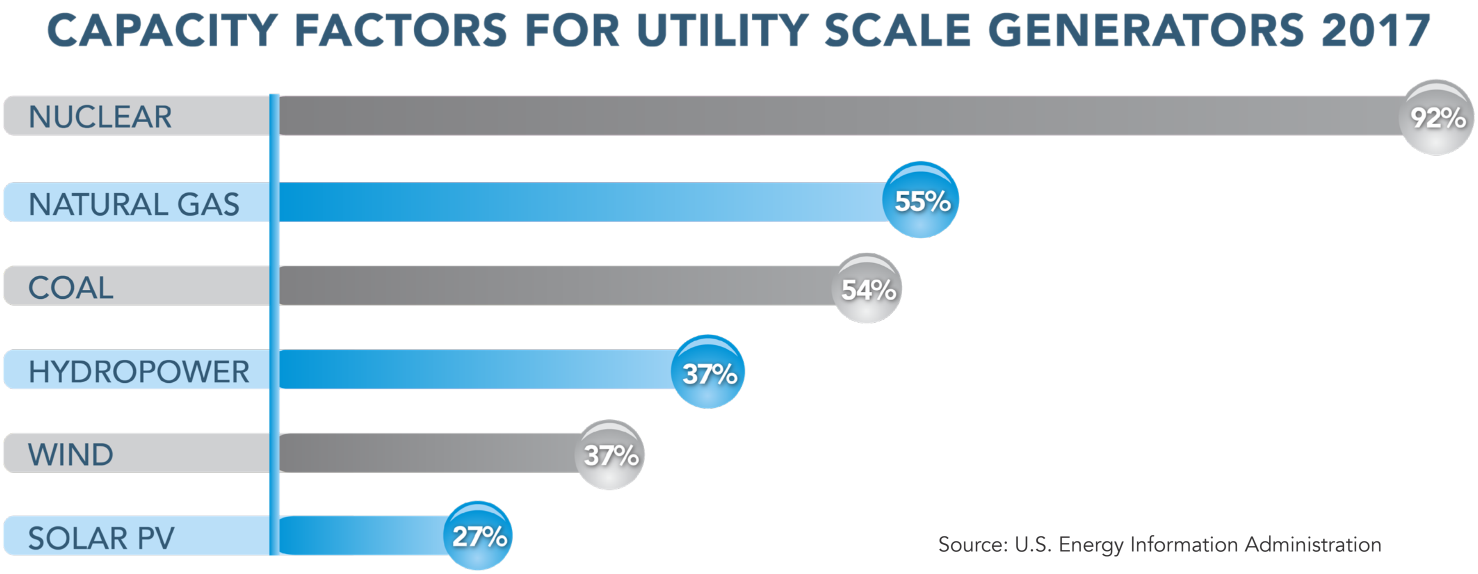
That waste can also be reprocessed and recycled, although the United States does not currently do this.

However, some advanced reactor designs being developed could operate on used fuel.



NUCLEAR POWER IS THE MOST RELIABLE ENERGY SOURCE AND IT'S NOT EVEN CLOSE

To better understand what makes nuclear so reliable, take a look at the graph below.



As you can see, nuclear energy has, by far, the highest capacity factor of any other energy source. This basically means nuclear power plants are producing maximum power more than 92% of the time during the year.

That's almost twice as reliable as coal or natural gas units, and 2 to 3 times more reliable than wind and solar plants.

WHY ARE NUCLEAR POWER PLANTS MORE RELIABLE?

Nuclear power plants are typically used more often because they require less maintenance and are designed to operate for longer stretches before refueling (typically every 1.5 or 2 years).

Natural gas and coal capacity factors are generally lower due to routine maintenance and/or refueling at these facilities.

Renewable plants are considered intermittent or variable sources and are mostly limited by a lack of fuel (i.e. wind, sun, or water). As a result, these plants need a backup power source such as large-scale storage (not currently available at grid-scale)—or they can be paired with a reliable baseload power like nuclear energy.

WHY DOES THIS MATTER?

A typical nuclear reactor produces 1 gigawatt (GW) of electricity. That doesn't mean you can simply replace it with a 1 gigawatt coal or renewable plant.

Based on the capacity factors above, you would need almost two coal or nearly three renewable plants (each of 1 GW size) to generate the same amount of electricity onto the grid.

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4 Things The Simpsons Got Wrong About Nuclear

"The Simpsons."

It's a show we all know and grew to love—unless you actually work with nuclear technology.

America's longest-running animated series on FOX has been making nuclear workers cringe on their couches for almost 3 decades now.

And while this show has produced a number of catch phrases that are immortalized in today's pop culture, its comedic depiction of the fictitious Springfield nuclear power plant—and its negligent safety operator Homer Simpson—is far from "excellent."

Here are four things "The Simpsons" didn't get quite so right about nuclear energy.

1. CONTROL ROOM OPERATORS DO NOT WORK BY THEMSELVES

In several episodes, Homer Simpson is by himself in a control room working on a remote safety console to help manage the reactor.

According to the Nuclear Regulatory Commission (NRC), a supervisor, along with a second supervisor or reactor operator must be present at all times during reactor operation. All individuals, either operating or supervising the operation of a U.S. commercial reactor, must also be licensed by the NRC.

2. COMMERCIAL NUCLEAR SPENT FUEL IS NOT A LIQUID

The show routinely depicts radioactive waste as a green, oozy liquid that is seeping out of huge drum containers and pipes throughout the facility.

In current reactors, nuclear fuel is made up of metal fuel rods that contain small ceramic pellets of enriched uranium oxide. The fuel rods are combined into tall assemblies that are then placed into the reactor.

After use, the fuel rods are first moved into steel-lined temporary storage pools that are about 40 feet deep. After at least 3 years of wet storage, they are then sealed inside welded steel-reinforced concrete containers.

3. NUCLEAR WASTE IS SAFELY STORED

Radioactive waste is commonly seen around the town of Springfield carelessly dumped into seas, stuffed into trees and put on playgrounds.

The process is a little different in real life.

Spent fuel is safely and securely stored at more than 100 reactor and storage sites across the country. The fuel is either enclosed in storage pools or dry casks as mentioned above.

On-site storage at nuclear power plants is not intended to be permanent. The U.S. Department of Energy is requesting funds to restart its application process for a permanent repository site and to initiate a robust interim storage program.

4. NUCLEAR POWER PLANTS DO NOT CAUSE MUTATIONS

Who can forget Blinky—the three-eyed fish or that scary mutated spider?

You won't see these characters because nuclear power plants do not release any pollution into the environment—just water vapor. In fact, your granite counter tops give off more radiation than living next door to a nuclear power plant over the course of a year.

3 ADVANCED REACTOR SYSTEMS TO WATCH OUT FOR BY 2030

Move over millennials, there's a new generation looking to debut by 2030.

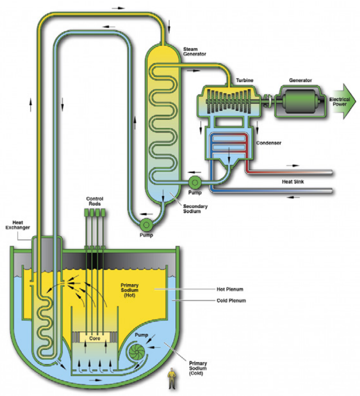
Generation IV nuclear reactors are being developed through an international cooperation of 14 countries—including the United States.

The U.S. Department of Energy and its national labs are supporting research and development on a wide range of new advanced reactor technologies that could be a game-changer for the nuclear industry. These innovative systems are expected to be cleaner, safer and more efficient than previous generations.

Intrigued?

Here are three designs we are currently working on with industry partners to help meet our future energy needs in a cost-competitive way.

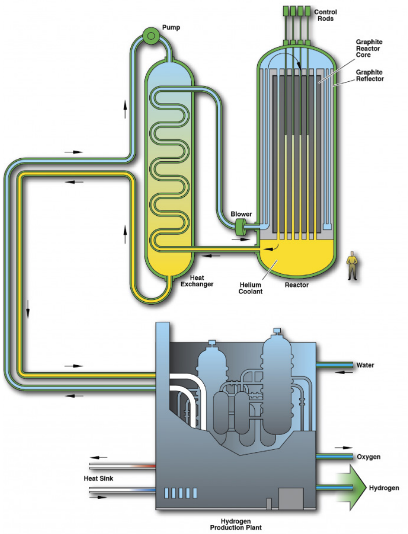
SODIUM-COOLED FAST REACTOR



The sodium-cooled fast reactor (SFR) uses liquid metal (sodium) as a coolant instead of water that is typically used in U.S. commercial power plants. This allows for the coolant to operate at higher temperatures and lower pressures than current reactors—improving the efficiency and safety of the system.

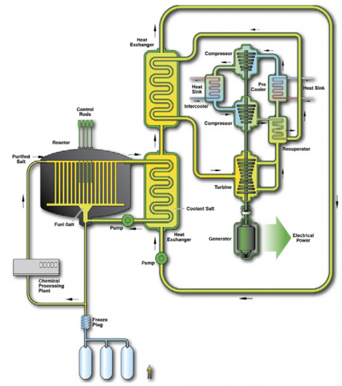
The SFR also uses a fast neutron spectrum, meaning that neutrons can cause fission without having to be slowed down first as they are in current reactors. This could allow SFRs to use both fissile material and spent fuel from current reactors to produce electricity.

VERY HIGH TEMPERATURE REACTOR



The very high temperature reactor is cooled by flowing gas and is designed to operate at high temperatures that can produce electricity extremely efficiently. The high temperature gas could also be used in energy-intensive processes that currently rely on fossil fuels, such as hydrogen production, desalination, district heating, petroleum refining, and ammonia production. Very high temperature reactors offer impressive safety features and can be easy to construct and affordable to maintain.

MOLTEN SALT REACTOR



Molten salt reactors (MSR) use molten fluoride or chloride salts as a coolant. The coolant can flow over solid fuel like other reactors or fissile materials can be dissolved directly into the primary coolant so that the fission directly heats the salt.
MSRs are designed to use less fuel and produce shorter-lived radioactive waste than other reactor types. They have the potential to significantly change the safety posture and economics of nuclear energy production by processing fuel online, removing waste products and adding fresh fuel without lengthy refueling outages.

Their operation can be tailored for the efficient burn up of plutonium and minor actinides, which could allow MSRs to consume waste from other reactors.

The system can also be used for electricity or hydrogen production.

COMING SOON: ADVANCED SMALL MODULAR REACTORS

Welcome to the future of nuclear energy. Within the next decade, advanced small modular reactors (SMRs) could change the way we think about reliable, clean and affordable nuclear power. Instead of going big, scientists and engineers went small developing mini reactors that are roughly a third of the size of a typical nuclear power plant.That means America's largest clean energy source could be coming to a market near you—making nuclear more scalable and flexible than ever before.

Here's how they work.

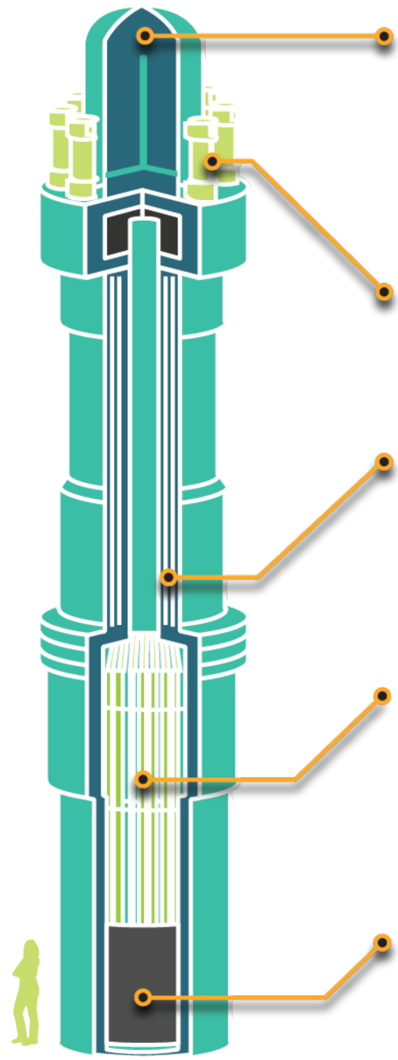
1. Nuclear power plants generate heat through nuclear fission. The process begins in the reactor core. Atoms are split apart -- releasing energy and producing heat as they separate into smaller atoms. The process repeats again and again through a fully controlled chain reaction.

2. Control rods made of neutron-absorbing material are inserted into the core to regulate the amount of heat generated by the chain reaction.

3. Reactor coolant water picks up heat from the reactor core. Reactor coolant pumps circulate this hot water through a steam generator, which converts water in a secondary loop into steam.

4. The steam is used to drive a turbine, which generates electricity.

5. Throughout the process, the pressurizer keeps the reactor coolant water under high pressure to prevent it from boiling.



FOUR KEY BENEFITS TO SMRS

LESS PREP

SMR modules require limited on-site preparation -- which could significantly reduce up-front capital costs and construction times compared to large scale reactors.

MORE OPTIONS

SMRs could increase nuclear technology options -- their smaller size makes them ideal for locations that cannot support large reactors.

FLEXIBILITY

As energy demand increases, additional SMRs can be added to provide more power at a site.

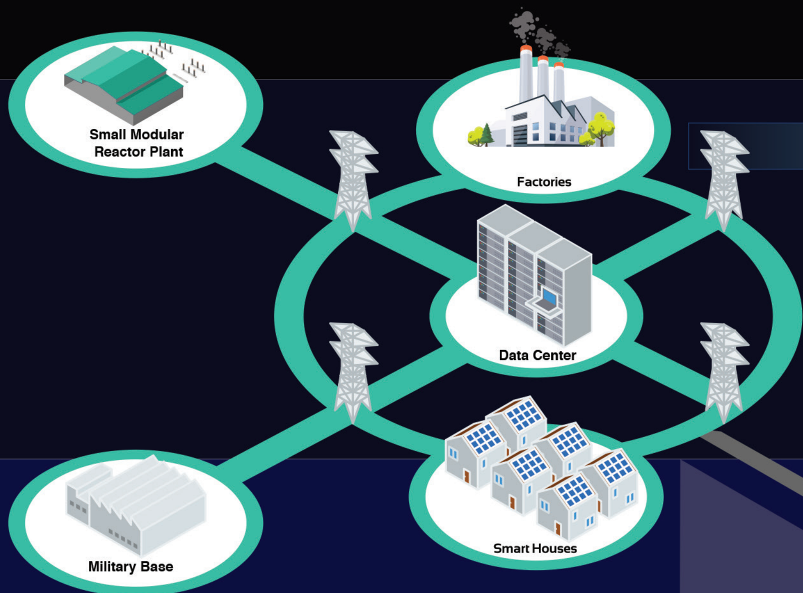
NEW BUSINESS

SMRs could strengthen U.S. leadership in nuclear energy worldwide -- creating new domestic jobs and businesses, and global export opportunities.

RESILIENCY FEATURES OF SMRs

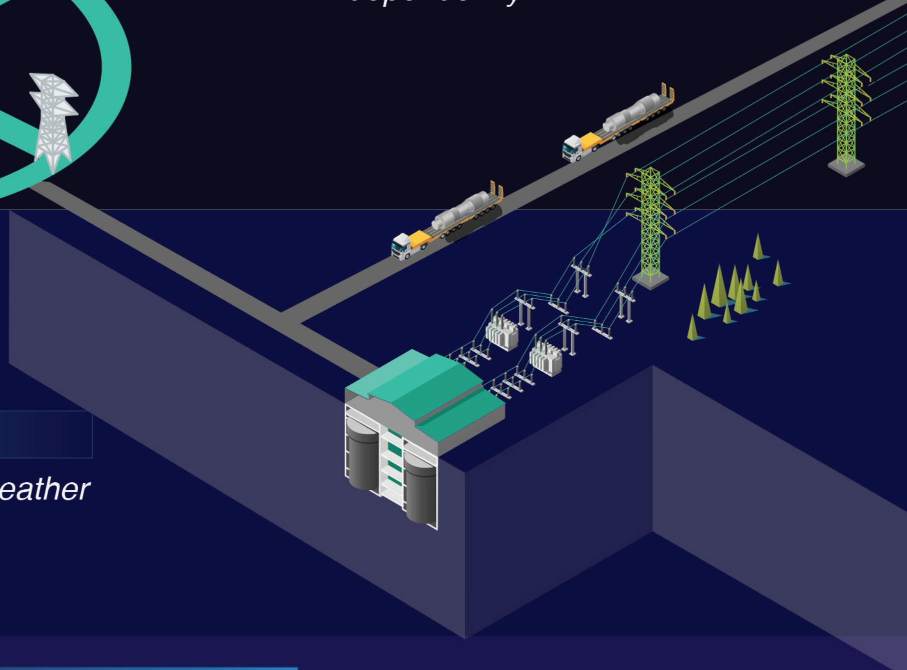
BLACK START

Can start up from a completely de-energized state without receiving power from the grid.



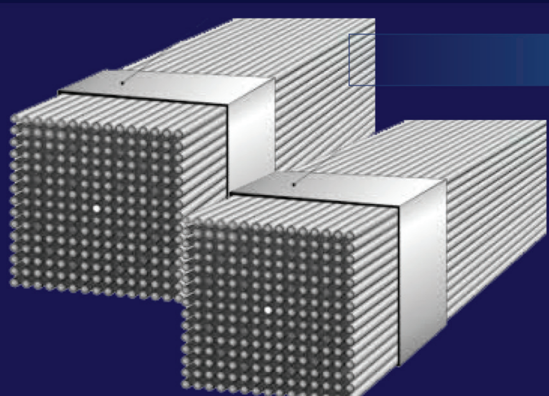
ISLANDING

Can operate connected to the grid or independently.



UNDERGROUND CONSTRUCTION

Makes reactors less vulnerable to extreme weather and physical attacks.

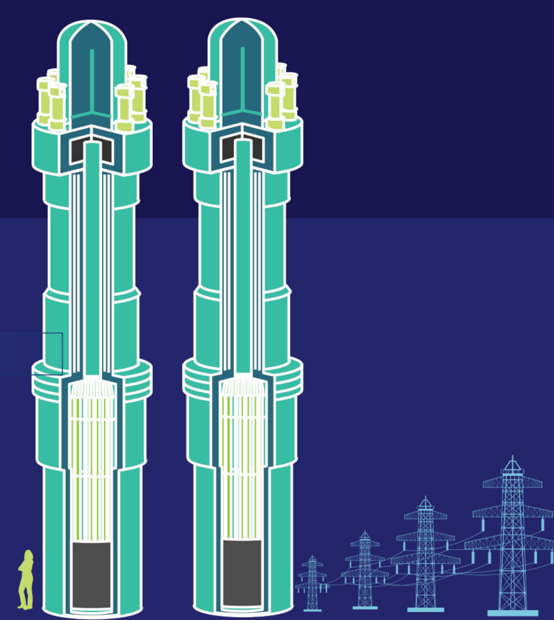


FUEL SECURITY

Can easily store fuel on-site for a decade or more without the need of an external fuel supply.

MODULARITY

Minimizes the use of electrical parts and uses passive cooling features to safely shutdown without pumps or operator intervention.



NUCLEAR MICROREACTORS

Nuclear is getting even smaller...and it's opening up some big opportunities for the industry. A handful of microreactor designs are under development in the United States and they could be ready to roll out within the next decade.These plug-and-play reactors will be small enough to transport by truck and could help solve energy challenges in a number of areas, ranging from remote commercial or residential locations to military bases.

FEATURES

Microreactors are not defined by their fuel form or coolant. Instead, they have three main features:

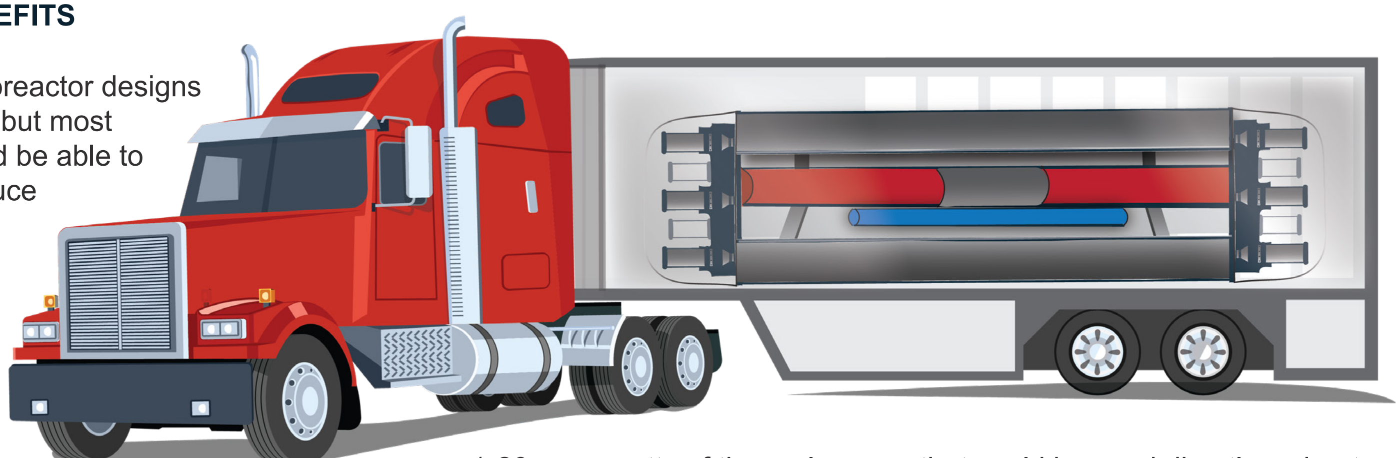
1. Factory fabricated: All components of a microreactor would be fully assembled in a factory and shipped out to location. This eliminates difficulties associated with large-scale construction, reduces capital costs and would help get the reactor up and running quickly.

2. Transportable: Smaller unit designs will make microreactors very transportable. This would make it easy for vendors to ship the entire reactor by truck, shipping vessel, airplane or railcar.

3. Self-regulating: Simple and responsive design concepts will allow microreactors to self-regulate. They won't require a large number of specialized operators and would utilize passive safety systems that prevent any potential for overheating or reactor meltdown.

BENEFITS

Microreactor designs vary, but most would be able to produce



1-20 megawatts of thermal energy that could be used directly as heat or converted to electric power. They can be used to generate clean and reliable electricity for commercial use or for non-electric applications such as district heating, water desalination and hydrogen fuel production.

Other benefits include:

- Seamless integration with renewables within microgrids
- Can be used for emergency response to help restore power to areas hit by natural disasters
- A longer core life, operating for up to 10 years without refueling
- Can be quickly removed from sites and exchanged for new ones.

Most designs will require fuel with a higher concentration of uranium-235 that's not currently used in today's reactors, although some may benefit from use of high temperature moderating materials that would reduce fuel enrichment requirements while maintaining the small system size.

The U.S. Department of Energy supports a variety of advanced reactor designs including gas, liquid metal, molten salt and heat pipe-cooled concepts. American microreactor developers are currently focused on gas and heat pipe-cooled designs that could debut as early as the mid-2020s.

ACCIDENT TOLERANT FUELS

The U.S. Department of Energy is working with industry to quickly develop new fuels with enhanced accident tolerance.These nuclear fuels will not only increase the safety of today's light-water reactors but also improve plant performance at a crucial time for the U.S. nuclear industry. A number of reactors are currently under economic stress and the benefits that these fuels bring to the table could make the case for utilities to extend plant operations. Here are 5 things you need to know about accident tolerant fuels.

1. ACCIDENT TOLERANT FUELS BEAT THE HEAT AND PERFORM BETTER

Nuclear fuel is exposed to harsh conditions inside the reactor core.

Accident tolerant fuels use new materials that reduce hydrogen buildup, improve fission product retention and are structurally more resistant to radiation, corrosion, and high temperatures.

In short, these fuel concepts will perform better and withstand extreme heat and steam for longer durations than the current fuel system of uranium dioxide fuel and zircaloy cladding.

2. ACCIDENT TOLERANT FUELS LAST LONGER

Accident tolerant fuels will be able to last longer and operate more efficiently in a reactor core. This could potentially extend the time between refueling from 1.5 years to 2 years or more and use roughly 30% less fuel. That would mean less waste and reduced fuel costs over the life of the reactor.

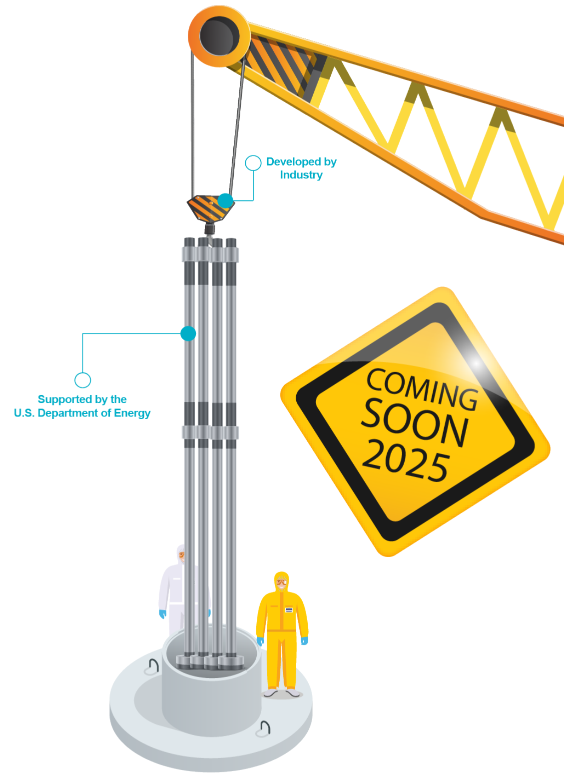
3. ACCIDENT TOLERANT FUELS IMPROVE PLANT PERFORMANCE

In addition to lasting longer, accident tolerant fuels are also designed to have higher burnup. This means plants would run for longer periods of time, possibly at higher power, with less downtime—leading to higher profit margins for the plants.

4. ACCIDENT TOLERANT FUELS ARE INDUSTRY-LED

Framatome, General Electric (GE) and Westinghouse are leading the charge to aggressively develop new reactor fuels in an accelerated timeframe.

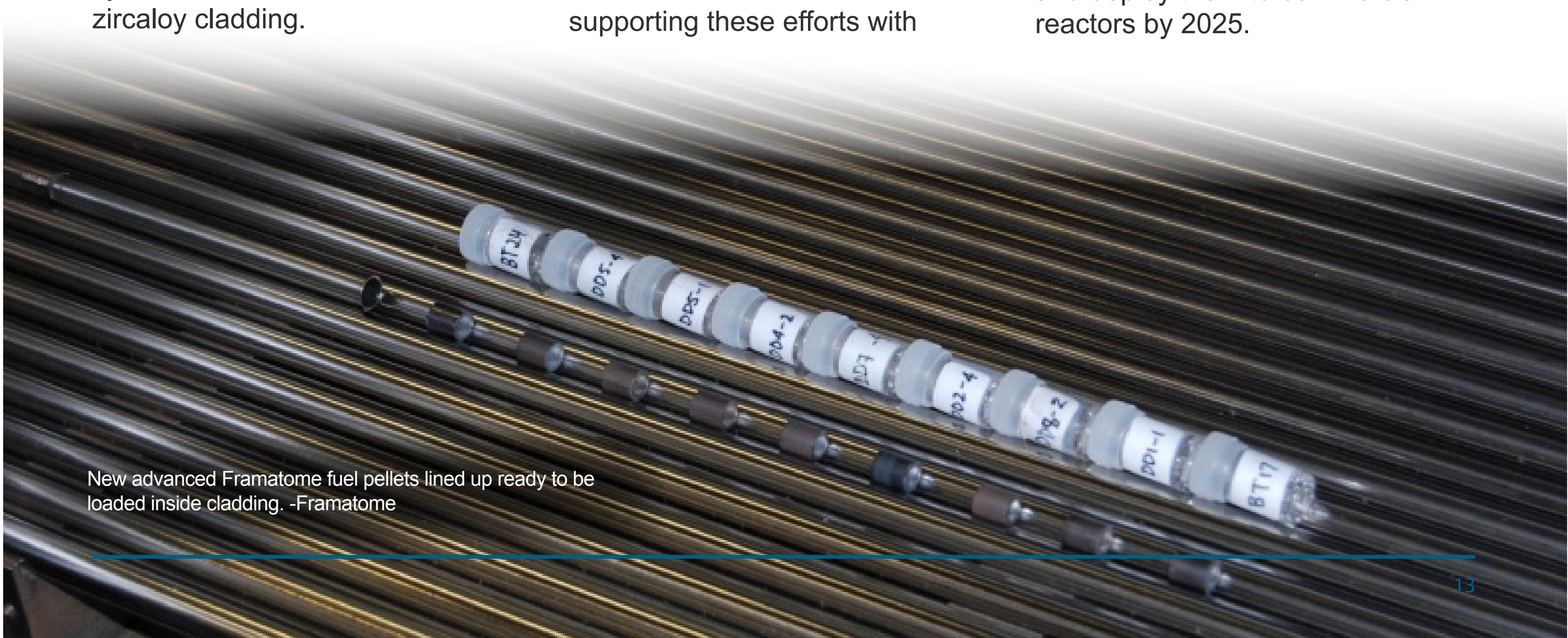
DOE and the national labs are supporting these efforts with



irradiation and safety testing, along with advanced modeling and simulation to help qualify their fuels with the U.S. Nuclear Regulatory Commission.

5. ACCIDENT TOLERANT FUELS COULD DEBUT BY 2025

Framatome, GE's Global Nuclear Fuel and Westinghouse are currently testing their accident tolerant fuels. With support from the government and national labs, the three companies hope to commercialize their fuels and deploy them to commercial reactors by 2025.



New advanced Framatome fuel pellets lined up ready to be loaded inside cladding. -Framatome

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NUCLEAR: ENERGY AND BEYOND...

Did you know nuclear does more than just produce massive amounts of clean energy?

It's used in a variety of applications, ranging from cancer treatments to fighting crime thanks to a little thing we call radioisotopes. These are simply atoms that emit radiation and since their discovery more than a century ago, they have transformed the medical industry and other fields to help benefit society.

Here are 5 ways nuclear powers our lives.

1. SPACE EXPLORATION

A great deal of what we know about deep space has been made possible by radioisotope power systems (RPSs). These small nuclear power sources are used to power spaceships in the extreme environments of deep space.

RPSs are proven to be safe, reliable, and maintenance-free for decades of space exploration, including missions to study Jupiter, Saturn, Mars, and Pluto.

2. NUCLEAR ENERGY

Nuclear provides nearly 20% of our electricity in the United States. It's also the nation's largest source of clean energy—making up more than half of our emissions-free electricity. That's more than all of the renewables combined.

The nation's fleet of reactors also operates more than 92% of the time, making it the most reliable energy source on the grid by far—and it's not even close.

3. MEDICAL DIAGNOSIS AND TREATMENT

Approximately one-third of all patients admitted to U.S. hospitals are diagnosed or treated using radiation or radioactive materials.

Nuclear medical imaging, which combines the safe administration of radioisotopes with camera imaging, helps physicians locate tumors, size anomalies, or other problems.

Doctors also use radioisotopes therapeutically to kill cancerous tissue, reduce the size of tumors, and alleviate pain.

4. CRIMINAL INVESTIGATION

Criminal investigators frequently rely on radioisotopes to obtain physical evidence linking a suspect to a specific crime. They can be used to identify trace chemicals in materials such as paint, glass, tape, gunpowder, lead, and poisons.

5. AGRICULTURE

Finally, farmers can use radioisotopes to control insects that destroy crops as an alternative to chemical pesticides. In this procedure, male insect pests are rendered infertile. Pest populations are then drastically reduced and, in some cases, eliminated.

Nuclear energy is also harnessed to preserve our food.

When food is irradiated, harmful organisms are destroyed without cooking or altering the nutritional properties of the food. It also makes chemical additives and refrigeration unnecessary, and requires less energy than other food preservation methods.

WHY I DECIDED TO BECOME A NUCLEAR ENERGINEER

Anna Biela is on the verge of graduating from Purdue University with a degree in nuclear engineering. She has plans to go to grad school to further her research on reactor core physics.

Her goal is to develop advanced reactors—an area and a career path she is very passionate about.

“I see a lot of potential in nuclear energy,” said Biela. “It’s good for the environment, and it can help stabilize the grid with affordable and reliable energy. I saw there was a space for me to contribute and I felt that what I could contribute would be of significance.”

Get more STEM info here:

STEM RISING

U.S. DEPARTMENT OF ENERGY

Clean. Reliable. **Nuclear.**

For more information, please visit energy.gov/ne

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