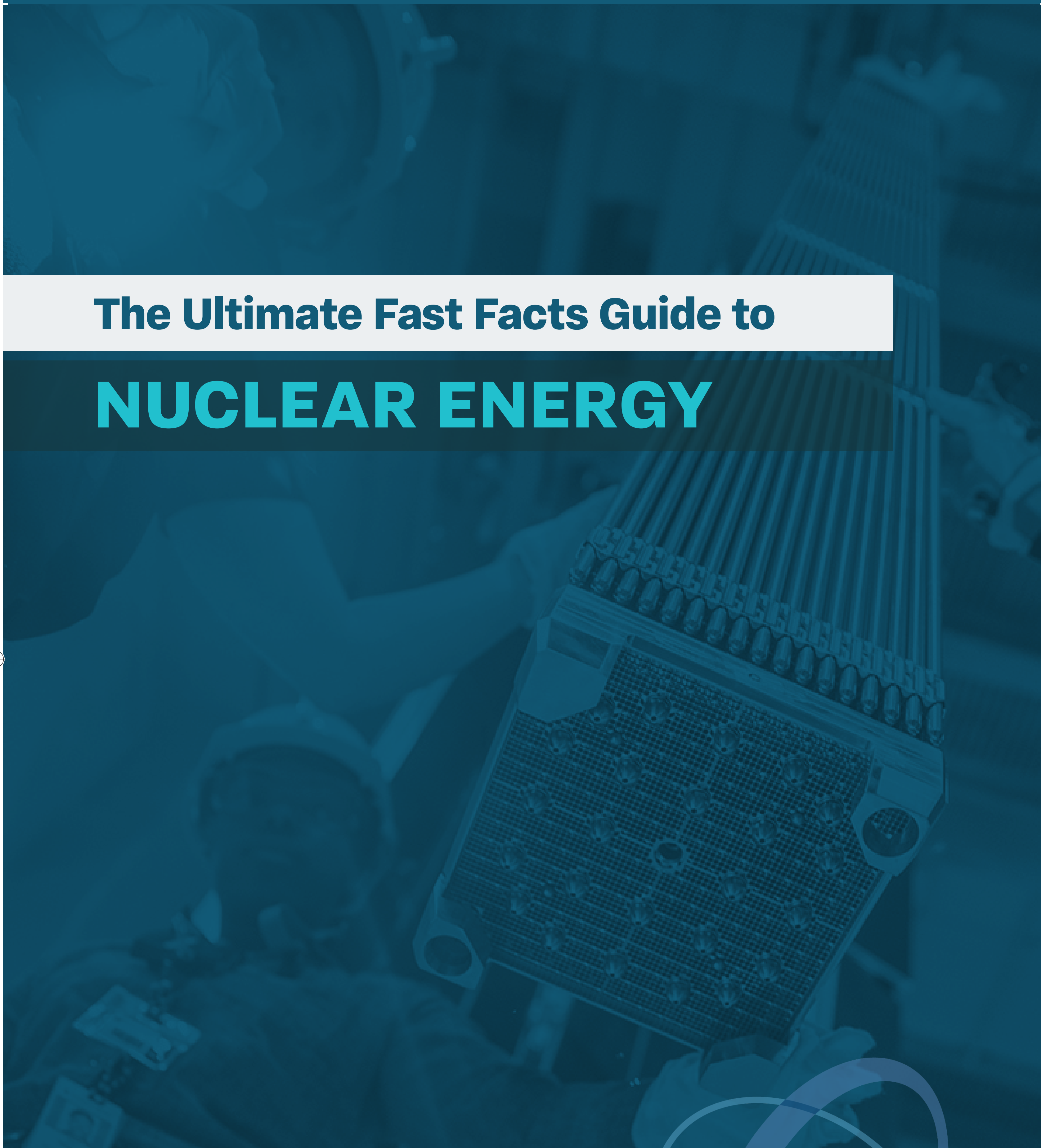


The Ultimate Fast Facts Guide to NUCLEAR ENERGY

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

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.

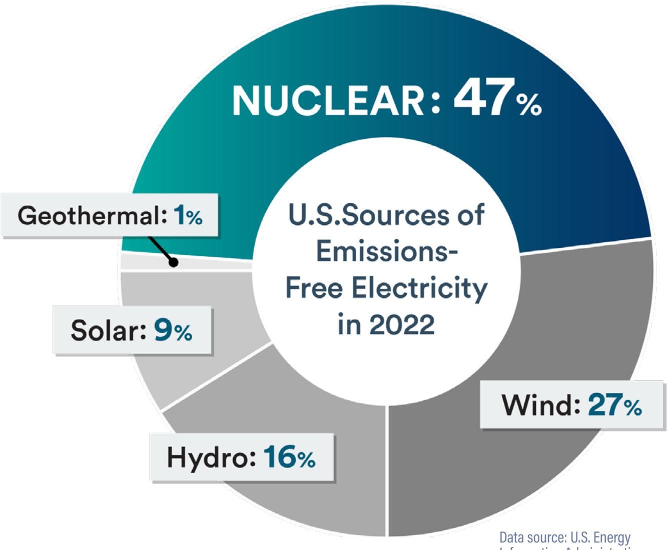
Did you know nearly a fifth of the country's electricity comes from nuclear power each year? If not, then it's about time you get to know nuclear. Here are five fast facts to get you up to speed:

1: Nuclear power plants produced 772 billion kilowatt hours of electricity in 2022.

That's enough to power more than 72 million homes! U.S. reactors have supplied around 20% of the nation's power since the 1990s and are also the largest producer of nuclear energy in world.

2. Nuclear power provides nearly half of America's clean energy.

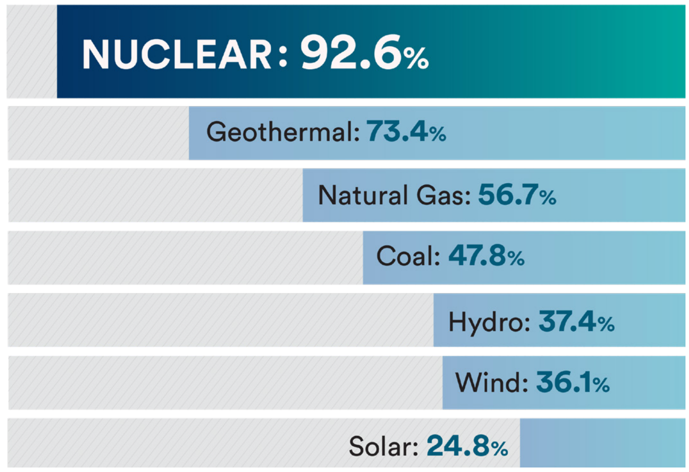
Nuclear energy provided 47% of America's carbon-free electricity in 2022, making it the largest domestic source of clean energy. Nuclear power plants do not emit greenhouse gases while generating electricity. They produce power by boiling water to create steam that spins a turbine. The water is heated by a process called fission, which makes heat by splitting apart uranium atoms inside a nuclear reactor core.



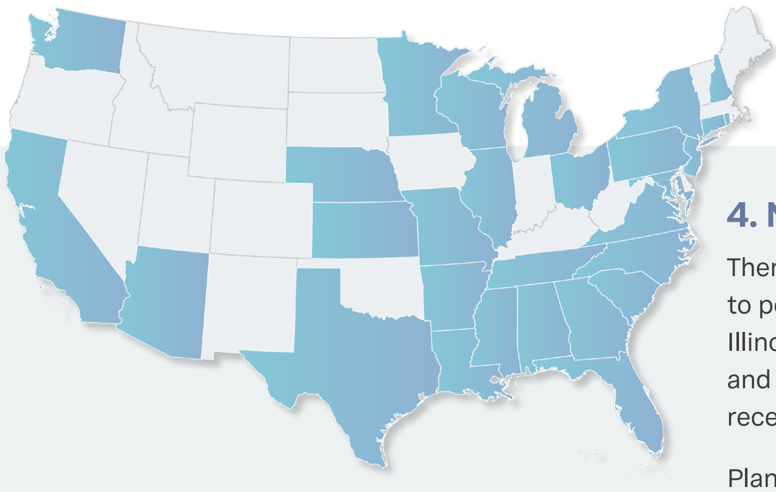
Data source: U.S. Energy Information Administration

3. Nuclear energy is one of the most reliable energy sources.

Nuclear power plants operated at full capacity more than 92% of the time in 2022 — making it one of the most reliable energy sources in America. 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).



Data source: U.S. Energy Information Administration



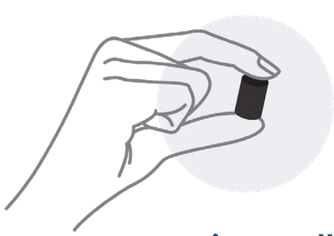
4. Nuclear helps power 28 U.S. states.

There are currently 93 commercial reactors helping to power homes and businesses in 28 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.

Plant Vogtle Unit 3 in Waynesboro, GA became the nation's newest reactor when it entered into commercial service in the summer of 2023.

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.



1 uranium pellet
(~1 inch tall)

=

17,000 cubic ft
of natural gas

=

149 gallons
of oil

=

1 ton
of coal

Nuclear Power: How it Works

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 typically made up of a couple hundred assemblies, depending on 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.

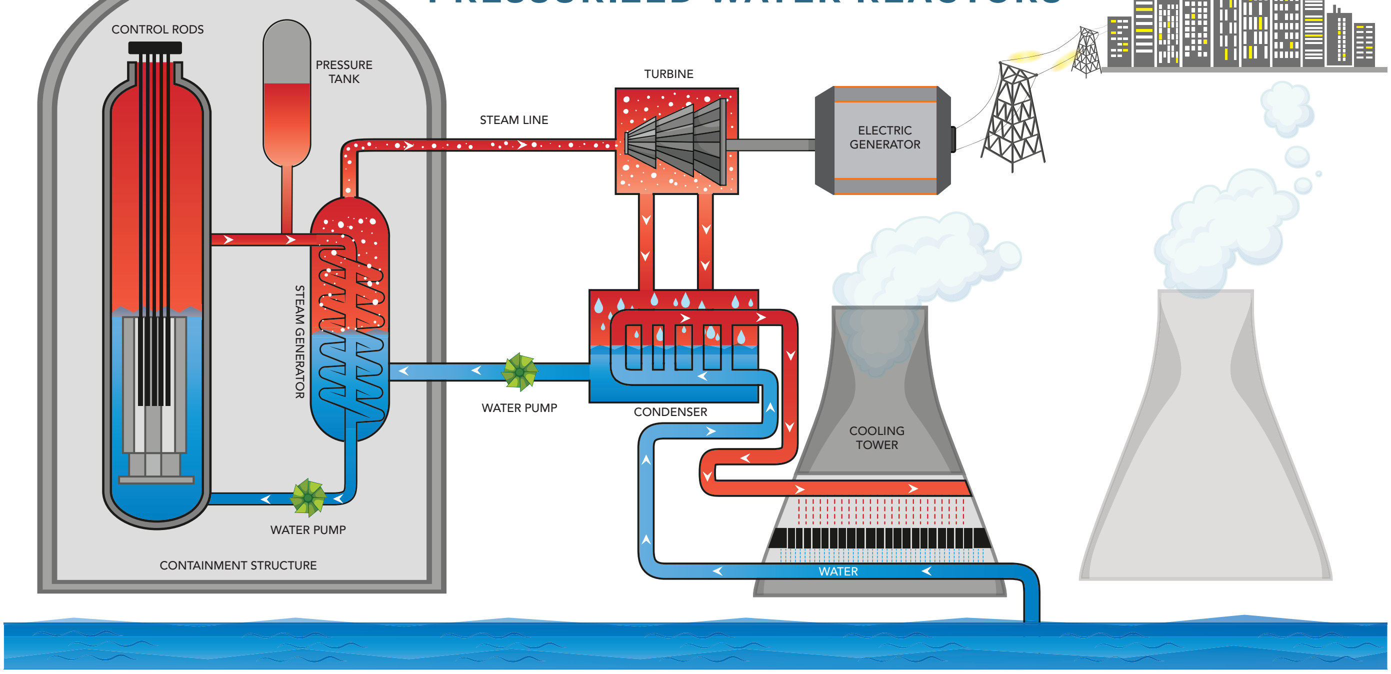
The heat created by fission turns the water into steam, which spins a turbine to produce carbon-free electricity.

Types of Reactors in the U.S.

All commercial nuclear reactors in the United States are **light-water reactors**, meaning they use normal water as a coolant and neutron moderator. There are two types of light-water reactors operating in America — pressurized water reactors and boiling water reactors.

1

PRESSURIZED WATER REACTORS



1 PRESSURIZED WATER 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.

2 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?

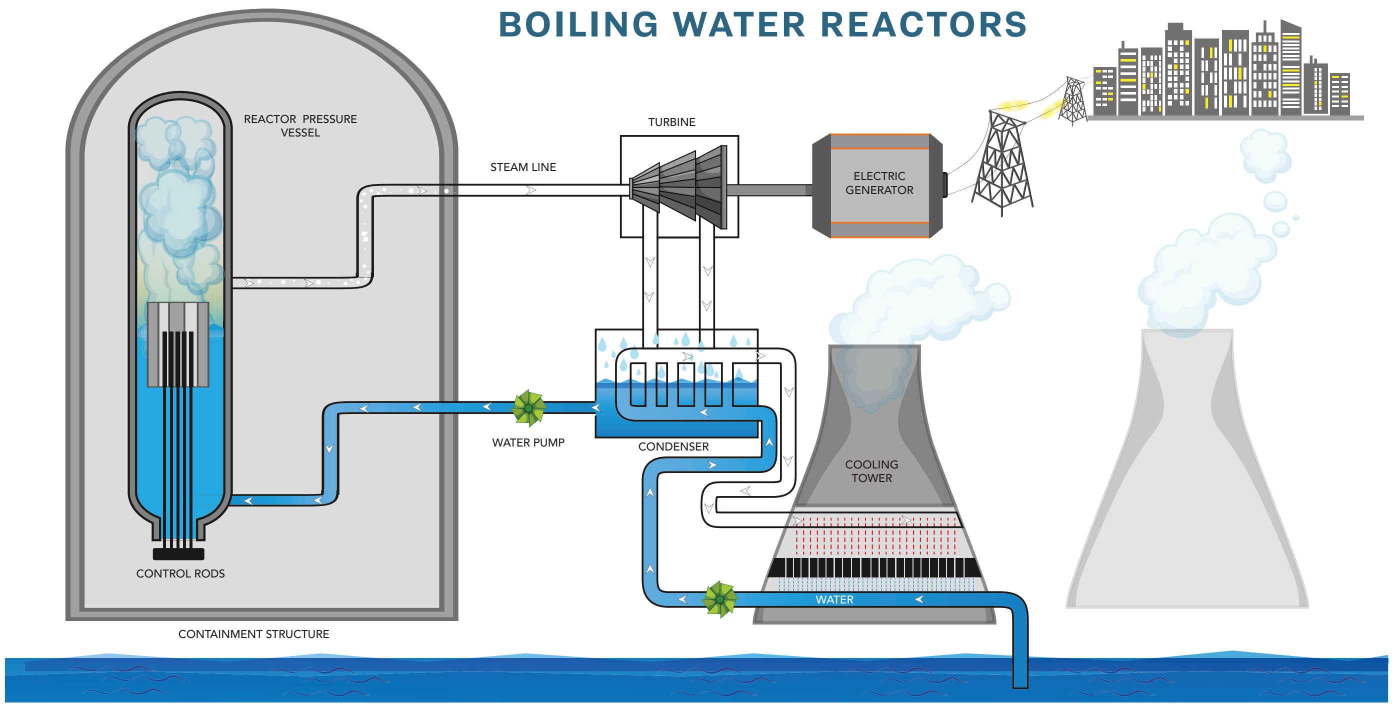
A typical reactor produces **1 gigawatt** of power, or the same amount of power as:

100 million
LED bulbs

3.125 million
PV panels

431
utility-scale wind turbines

2 BOILING WATER REACTORS



Other Uses for Nuclear

Commercial reactors offer various applications beyond providing electricity for homes and businesses. They can also be used to drive energy-intensive processes typically powered by fossil fuels.

Here are three surprising ways industries could leverage nuclear energy to help decarbonize our society.

1. Nuclear Desalination

Advancements in sewage systems, desalination, and wastewater treatment plants significantly improve public health. Still, one-fifth of world's population experiences water scarcity. The demand for freshwater continues to grow due to increases in population and impacts of climate change on arid and semi-arid regions.

In the U.S., drinking water and wastewater plants account for roughly 2 percent of energy use, and it's estimated that by 2040, desalination projects will account for 20% of water-related energy demand.

Desalination plants around the world produce freshwater from seawater through distillation. These processes require energy in the form of heat to remove salt from saline water, which in turns make it drinkable. However, desalination plants are often powered by carbon-emitting heat sources like fossil fuels.

Dozens of U.S. nuclear energy companies are currently working on advanced reactor systems that are carbon-free, can be sited virtually anywhere in the world, and can concurrently produce water and electricity when paired with desalination plants.

2. Clean Hydrogen Production

Hydrogen is a key component of future energy systems and can be generated with little to no emissions with technologies like nuclear energy.

Right now, roughly 95% of the hydrogen produced in the U.S. comes from natural gas. It's produced through a process called steam methane reforming and emits roughly 830 million tonnes of carbon dioxide per year.

Nuclear power plants could be used to generate clean hydrogen to create ammonia and nitrogen for fertilizers. The hydrogen could also be used for steel refining or to develop synthetic fuels for cargo ships to drastically reduce its carbon footprint.

To help scale up the production of clean hydrogen, the U.S. Department of Energy is supporting three hydrogen demonstration projects at U.S. nuclear power plants. The projects are part of DOE's Hydrogen Shot goal to reduce the cost of hydrogen to $1 per 1 kilogram in one decade and could also open up new markets for the nuclear industry.

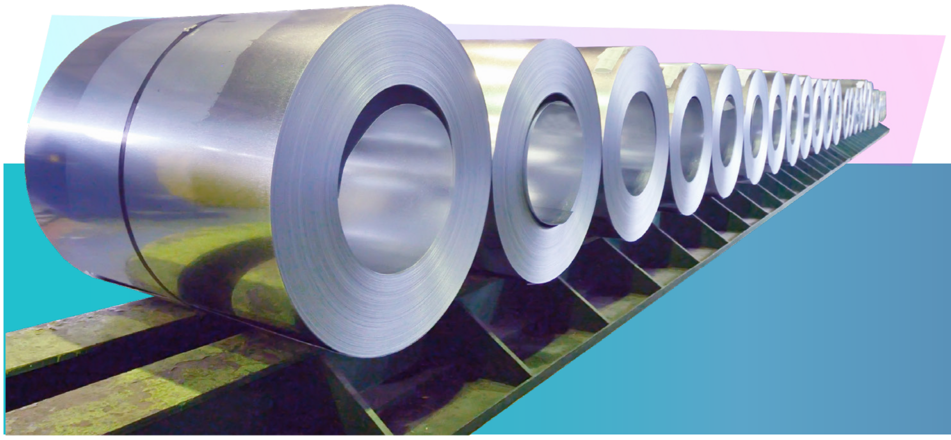
3. Process Heating for Industry

Process heat is energy in the form of heat used mainly by the industrial sector for processes such as drying, manufacturing, refining, warming, and cooling.

It's estimated that industrial process heat applications account for roughly one-third of the nation's energy consumption and most of the direct industrial CO2 emission each year. Currently, most of the process heat for the industrial sector comes from fossil fuel combustion.

Heat drives many industrial processes ranging from steam electrolysis to melting iron and other scrap materials to make steel. Nuclear energy is as a carbon-free alternative that can power industrial facilities and provide high-temperature heat that is clean, reliable, and constant.

Nuclear power plants produce heat through a process called fission, which is used to make steam that spins a turbine to create electricity. Nuclear reactors convert one third of heat produced into electricity. The remaining heat is released to the environment, which could be harnessed to meet process heat demands.



What About the Waste?

U.S. reactors generate nearly a fifth of the nation's electricity and almost half of its clean power.

During this process, it creates spent or used fuel (sometimes incorrectly referred to as nuclear waste) but it's not the green oozy liquid you might be thinking of when watching "The Simpsons."

In fact, some in the industry actually consider it a valuable resource.

Here are five things you should know about commercial spent nuclear fuel.

1. Commercial spent nuclear fuel is a solid.

Spent fuel refers to the nuclear fuel that has been used in a reactor.

The fuel used in today's commercial reactors is made up of small ceramic pellets of low-enriched uranium oxide. The fuel pellets are stacked vertically and encased in a metallic cladding to form a fuel rod. These fuel rods are bundled together into tall fuel assemblies that are then placed into the reactor.

The fuel is a solid when it goes into the reactor and a solid when it comes out. Sorry "Simpsons!"

Pictured at right: Dry storage casks at Dresden Generating Station.

2. The U.S. generates about 2,000 metric tons of spent fuel each year.

That may sound like a lot, but the volume of the spent fuel assemblies is actually quite small considering the amount of energy they produce. The amount is roughly equivalent to less than half the volume of an Olympic-sized swimming pool. The clean energy generated from this fuel would be enough to power more than 70 million homes — avoiding more than 400 million metrics tons of carbon dioxide emissions. All told, U.S. commercial reactors have generated about 90,000 metric tons of spent fuel since the 1950s. If all of it could be stacked together, it'd fit on a single football field at a depth of less than 10 yards.

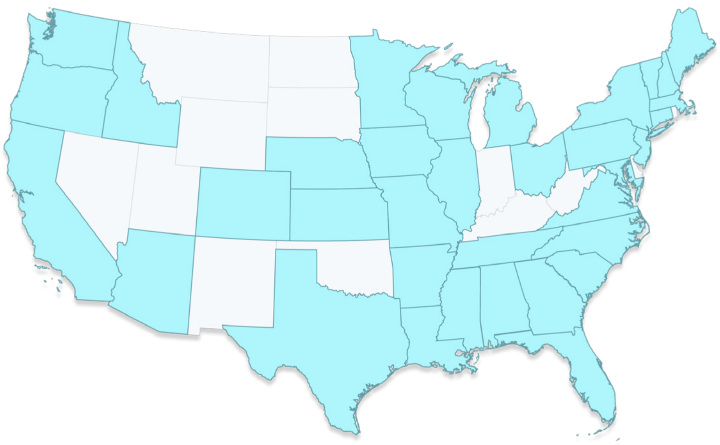
The nation's spent nuclear fuel is initially stored in steel-lined concrete pools surrounded by water. It's later removed from the pools and placed into dry storage casks that are made of steel and concrete or other materials used for protective shielding.

Above: Spent fuel assembly diagram.

Photo courtesy of U.S. Nuclear Regulatory Commission

3. Spent fuel from U.S. commercial nuclear power reactors is stored at more than 70 sites in 35 states.

Most of the nation's spent fuel is safely and securely stored at more than 70 reactor sites across the country. Roughly a quarter of these sites no longer have a reactor in operation.



The U.S. Department of Energy is now exploring the possibility of consolidating this spent nuclear fuel at one or more federal interim storage facilities using a consent-based siting process.

For the foreseeable future, the spent fuel can safely stay at the reactor sites or a future consolidated interim storage facility until a permanent disposal solution is determined by the federal government.

4. Spent fuel is safely transported across the United States.

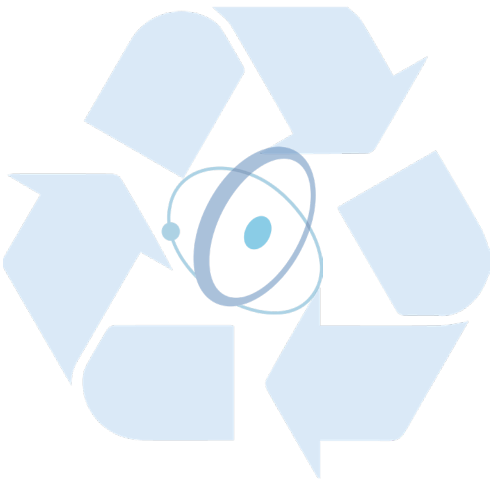
Over the last 55 years, more than 2,500 cask shipments of spent fuel have been transported across the United States without any radiological releases to the environment or harm to the public.

The fuel is shipped in transportation casks that are designed to withstand more than 99 percent of vehicle accidents, including water immersion, impact, punctures and fires.

5. Spent fuel can be recycled.

That's right! Spent nuclear fuel can be recycled to make new fuel and byproducts. More than 90% of its potential energy still remains in the fuel, even after five years of operation in a reactor. The United States does not currently recycle spent nuclear fuel but foreign countries, such as France, do.

There are also some advanced reactor designs in development that could consume or run on spent nuclear fuel in the future.



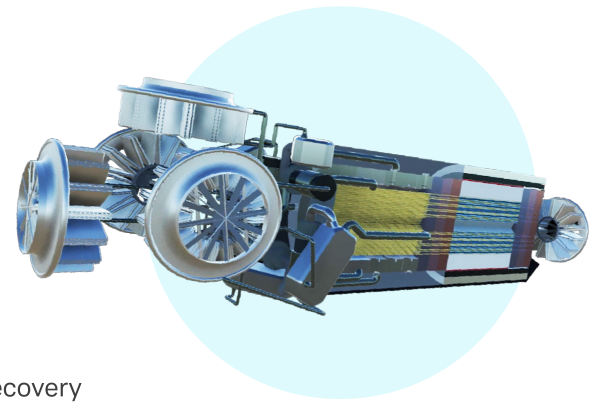
New Technology on the Horizon

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.

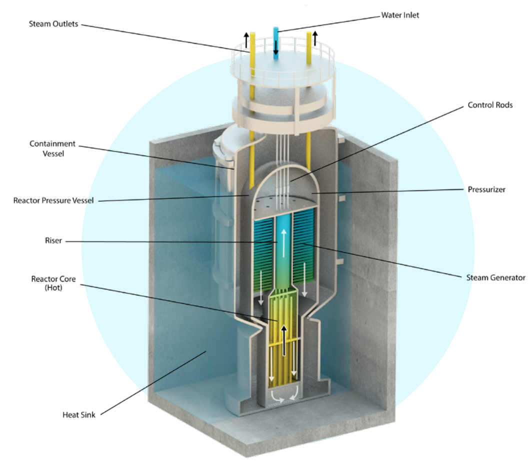
Here's a quick introduction.

Microreactors



Microreactors are factory-built, plug-and-play reactors. They can provide between 1-20 megawatts of thermal energy used directly as heat or converted to electric power. They fit on the back of a semi-truck and will not require a large number of people to operate them. Microreactors can integrate seamlessly into distributed grids to complement renewable power and are expected to run continuously for about 10 years without refueling. Once the core is spent, they can be exchanged for a new one. Microreactors can be used to power military bases, disaster recovery efforts or remote locations where traditional infrastructure doesn't exist.

Small Modular Reactors



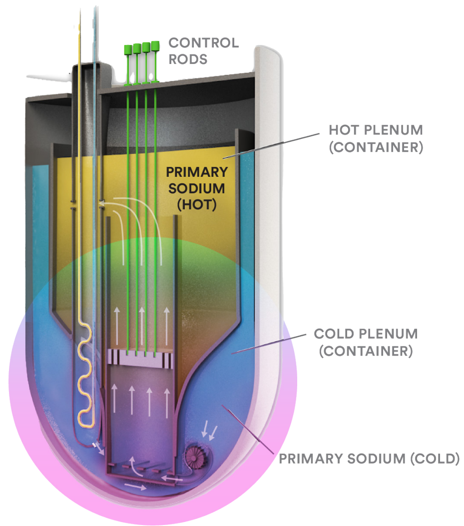
Small modular reactors are simply smaller, manufactured versions of large-scale reactors. They typically range from 20-300 megawatts of electric power and cost much less to build and operate. Some designs run alone, while others can be scaled up or down by adding or removing additional units. SMR designs rely on passive features that don't require operator intervention to remain safe in the event of an accident. They can start up from a completely de-energized state without receiving power from the grid and can supply resilient power in the face of natural disasters.

Large-Scale Advanced Reactors

The United States is building two AP-1000 reactors in Georgia. This light-water reactor technology is based on decades of proven technology with advanced passive safety features and more modern instrumentation and controls. They are built for the long-term and provide constant, reliable clean power to the grid. Future designs are also being pursued that use different types of coolants instead of water and operate at higher temperatures.

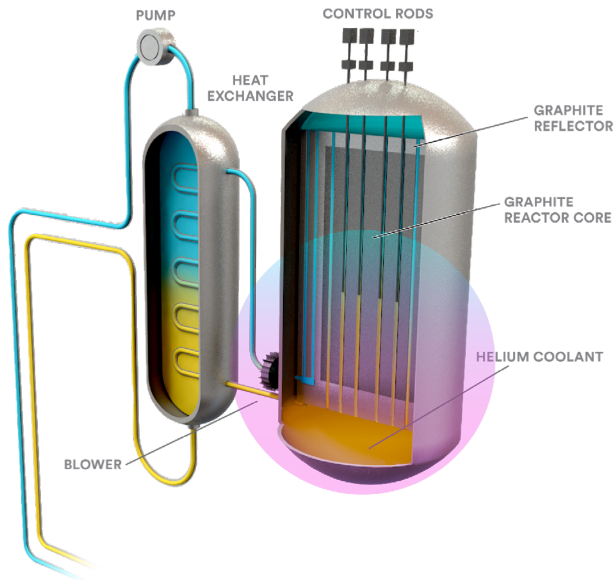
Liquid Metal Fast Reactors

Liquid metal fast reactors use sodium or lead as a coolant. They operate at high temperatures and low pressures with demonstrated passive safety features. Since they operate with a fast neutron spectrum, they can be set up to burn long-lived fission products like neptunium and americium. This would greatly reduce long-term disposal of nuclear waste.



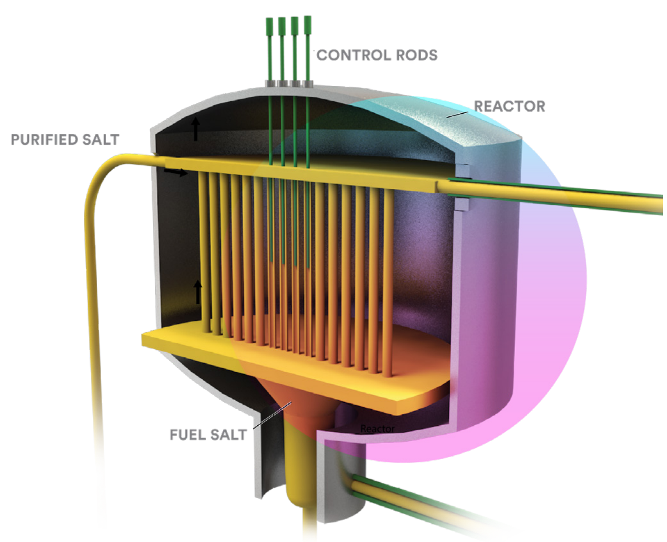
Gas-Cooled Reactors

Gas-cooled reactors operate at very high temperatures (750° Celsius) that can be used to provide electricity or support non-electric applications such as water desalination, hydrogen production, and chemical processing. The high temperature output improves efficiency and online refueling allows for high availability. These reactors can be scaled to be modular and small with 75 megawatt electric output, or as large as current light-water reactors.



Molten Salt Reactors

Molten salt reactors 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. These reactors are designed to use less fuel and produce shorter-lived radioactive waste than other reactor types. Online refueling offers high availability. The reactor can also use spent fuel from other reactors to greatly reduce the amount of waste disposal.



Advanced Fuels

Three of the largest nuclear suppliers in the United States are working with the U.S. Department of Energy (DOE) to develop new accident tolerant fuels for the nation's fleet of reactors.

These new approaches could help improve the overall economics and performance of today's reactors — and allow for longer response times at high temperatures in severe, beyond design basis, accident situations.

Testing is currently underway at DOE's national labs and in commercial reactors, with a goal to have them commercially available before the end of the decade.

Westinghouse

Westinghouse is testing uranium silicide fuel pellets for the first time in a commercial reactor. They use a mixture of uranium and silicon instead of uranium and oxygen to achieve a higher density of uranium atoms per pellet. This leads to longer operation times, increase power outputs and high burnups.

The company is also partnering with General Atomics to develop an advanced silicon carbide-based cladding concept for possible future implementation.

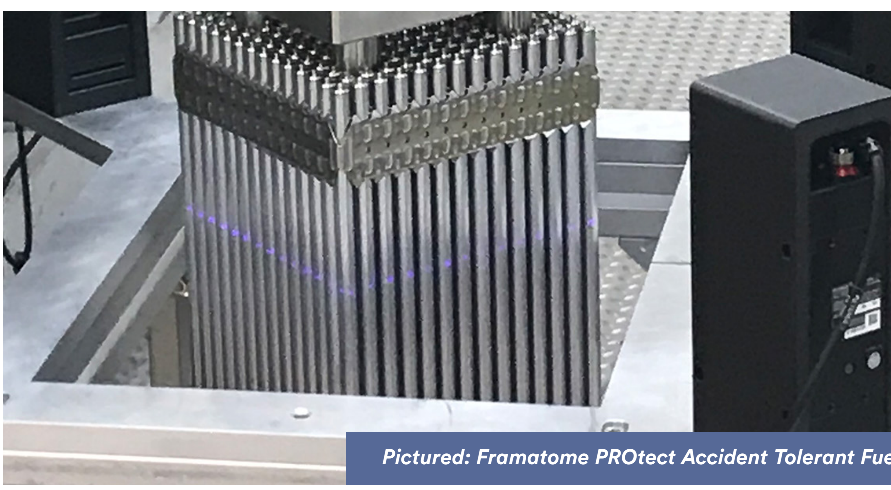
General Electric

GE's Global Nuclear Fuel developed IronClad fuel with support from Oak Ridge National Laboratory. It uses a combination of iron, chromium and aluminum for its fuel cladding to improve the fuel's behavior under extremely high temperatures. The steel material has a much lower oxidation rate when exposed to high temperature steam — improving the safety margins over traditional zirconium cladding used today.

The company is also testing a second fuel and cladding concept known as ARMOR. This coated zirconium cladding was developed outside of the DOE program but is now an integral part of the program.

Framatome

Framatome is testing chromium-coated cladding and chromia-doped fuel pellets. The special coating is designed to protect the fuel cladding from damage and oxidation at higher temperatures. The new fuel pellet mixture of chromium oxide and uranium oxide powders is expected to help the pellet last longer and perform better at high temperatures.



Pictured: Framatome PROtect Accident Tolerant Fuel assembly.

TRISO FUELS

Some of the newer reactor designs will require a new fuel that's tough enough to handle the higher operating temperatures of these advanced reactors.

Enter TRISO fuel — the most robust nuclear fuel on earth.

What is TRISO Fuel?

TRISO stands for TRi-structural ISOtropic particle fuel. Each TRISO particle is made up of a uranium, carbon and oxygen fuel kernel. The kernel is encapsulated by three layers of carbon- and ceramic-based materials that prevent the release of radioactive fission products.

The particles are incredibly small (about the size of a poppy seed) and very robust.

They can be fabricated into cylindrical pellets or billiard ball-sized spheres called "pebbles" for use in either high temperature gas or molten salt-cooled reactors.

TRISO fuels are structurally more resistant to neutron irradiation, corrosion, oxidation and high temperatures (the factors that most impact fuel performance) than traditional reactor fuels.

Each particle acts as its own containment system thanks to its triple-coated layers. This allows them to retain fission products under all reactor conditions.

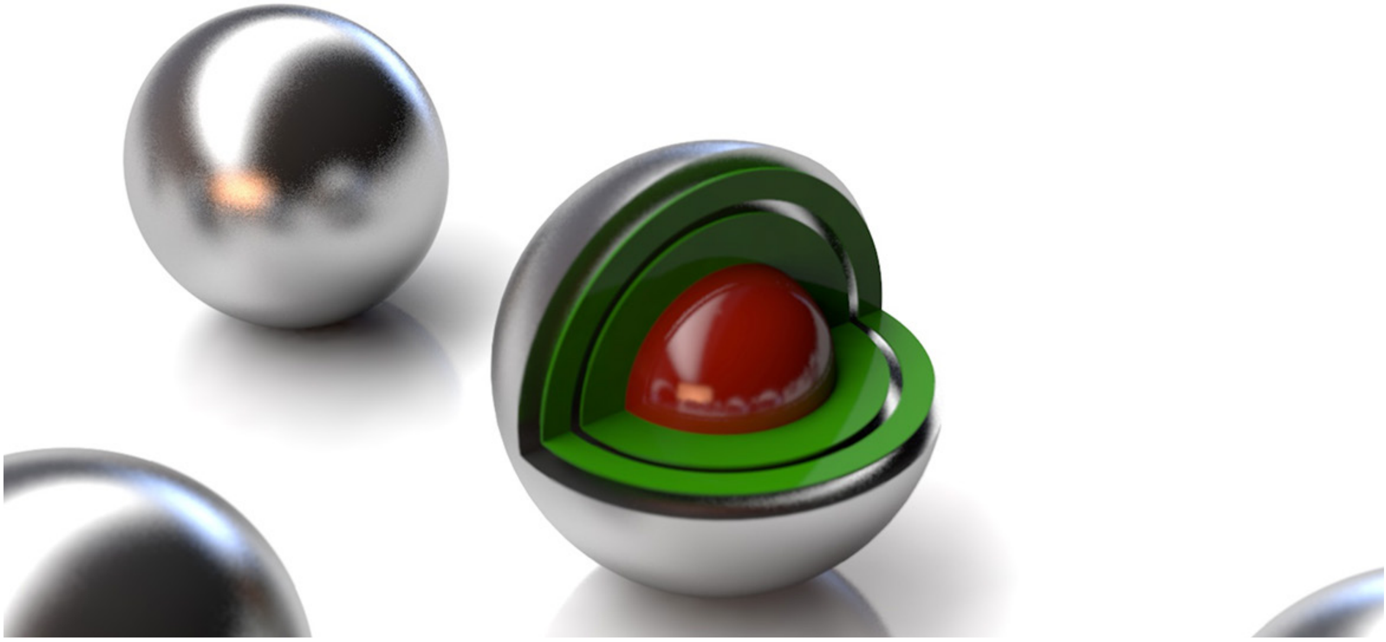
Simply put, **TRISO particles cannot melt in a commercial high-temperature reactor** and can withstand extreme temperatures that are well beyond the threshold of current nuclear fuels.

TRISO fuel testing is gaining a lot of interest from the advanced reactor community. Some reactor vendors such as X-energy and Kairos Power, along with the Department of Defense, are planning to use TRISO fuel for their small modular reactor and microreactor designs.

DOE also supported X-energy's efforts to design and submit a NRC license application for a new fabrication facility. The project would ultimately use high assay low enriched uranium to produce the TRISO fuel pellets and pebbles for future high-temperature gas and molten salt reactors.

Below: Rendering of a TRISO particle.

Photo courtesy Idaho National Laboratory



Electricity and Beyond

Nuclear energy is 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.

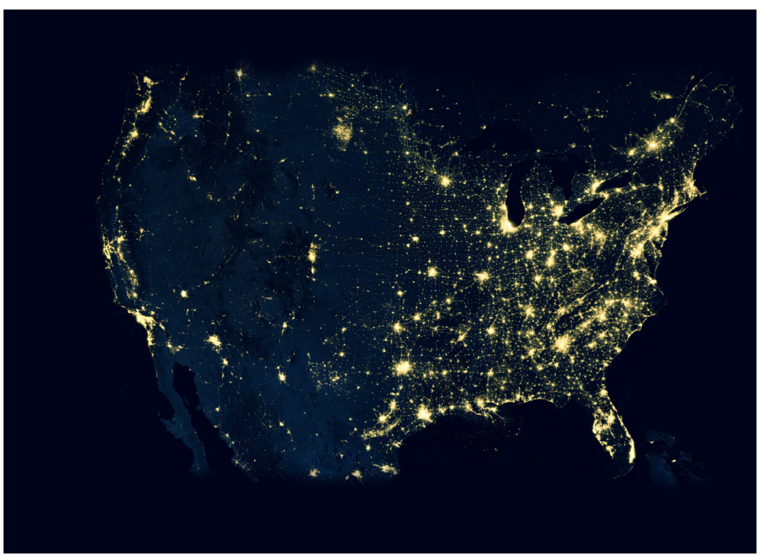
Here are 5 ways nuclear powers our lives.

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.

At right: NASA's Interplanetary space probe New Horizons.



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 nearly 60% 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.

LEARN MORE:

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