Stantec

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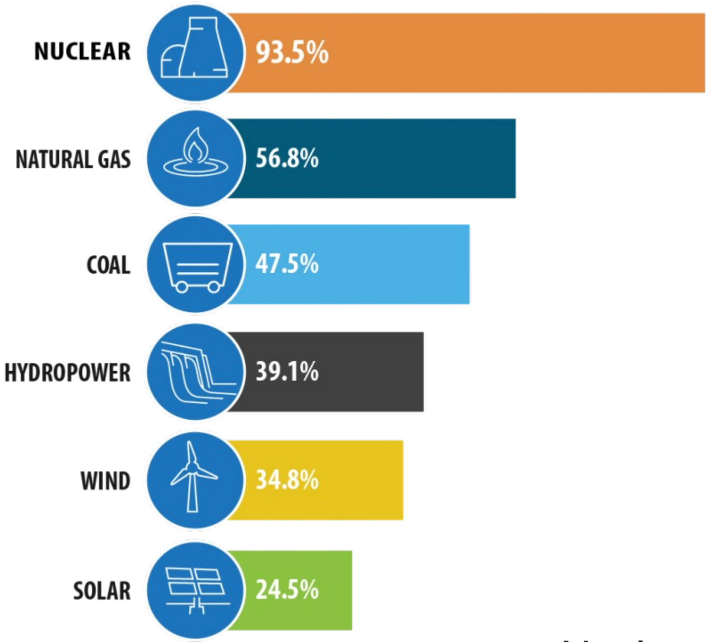
SaferTogether™

Safety Moment

Safety and security are the heart of the Nuclear industry…the constant self- reminding of the high industry standards ensure that key principles are implemented in everyday practice by all stakeholders resulting in safe plants throughout all lifecycle stages

Safety Moment

Capacity Factor by Energy Source – 2019



Source - Capacity Factor by Energy Source - 2019 | U.S Department of Energy

Table 6
Mortality rates for each energy source in deaths per billion kWh produced.
Source: Updated (corrected) data from: World Health Organization; CDC; Seth Godin; John Konrad.

Energy source	Mortality rate (deaths per billion kWh)
Coal – global average	100 (50% of global electricity)
Coal – China	160 (75% of China's electricity)
Coal – U.S.	15 (44% of U.S. electricity)
Oil	36 (36% of global energy, 8% of global electricity, none in U.S.)
Natural gas	4 (20% of global electricity)
Biofuel/biomass	24 (21% of global energy)
Solar (rooftop)	0.44 (<1% of global electricity)
Wind	0.15 (~ 1% of global electricity)
Hydro – global average	1.4 (15% of global electricity, 171,000 Banqiao dead)
Nuclear – global average	0.04 (17% of global electricity, with Chernobyl & Fukushima – none in US)

Source: https://www.researchgate.net/publication/272406182_Why_nuclear_energy_is_sustainable_and_has_to_be_part_of_the_energy_mix#pf5

Nuclear is the safest energy sector by far. Even with Three Mile Island, Chernobyl and Fukushima, the combined loss of lives from the three major nuclear accidents is 32 people. In fact, estimates on the number of deaths caused by the nuclear energy sector overall is 90 per 1000TWh —the least of any energy sector! We will talk about how and why nuclear plants are so safe using defense in depth later.

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AGENDA ITEM

Safety and security moment

Overview -Canadian Nuclear Industry/SMR roadmap

Conventional CANDU reactors vs Gen III vs Gen IV SMRs

Concerns– Safety, Waste, Cost

Stakeholder organizations - CNSC, IAEA, NWMO

Design considerations – Regdoc 2.5.2, radiological, shielding, dose, safeguards

Waste per MW/Energy Density/CO_2 emissions

Market sector figures – new build, operations and maintenance, decommissioning

Questions and Close

Overview -Canadian Nuclear Industry/SMR roadmap

Current Nuclear Market

About 15% of Canada's electricity comes from nuclear power, with 19 reactors mostly in Ontario providing 13.6 GWe of power capacity.

Reactor Name	Model	React or Type	Net Capacity (MWe)	Construction Start	First Grid Connection
Bruce 1	CANDU 791	PHWR	732	1971-06-01	1977-01-14
Bruce 2	CANDU 791	PHWR	732	1970-12-01	1976-09-04
Bruce 3	CANDU 750A	PHWR	750	1972-07-01	1977-12-12
Bruce 4	CANDU 750A	PHWR	750	1972-09-01	1978-12-21
Bruce 5	CANDU 750B	PHWR	822	1978-05-31	1984-12-02
Bruce 6	CANDU 750B	PHWR	822	1978-01-01	1984-06-26
Bruce 7	CANDU 750B	PHWR	822	1979-05-01	1986-02-22
Bruce 8	CANDU 750B	PHWR	795	1979-07-30	1987-03-09
Darlington 1	CANDU 850	PHWR	881	1982-04-01	1990-12-19
Darlington 2	CANDU 850	PHWR	881	1981-09-01	1990-01-15
Darlington 3	CANDU 850	PHWR	881	1984-09-01	1992-12-07
Darlington 4	CANDU 850	PHWR	881	1985-07-01	1993-04-17
Pickering 1	CANDU 500A	PHWR	508	1966-06-01	1971-04-04
Pickering 4	CANDU 500A	PHWR	508	1968-05-01	1973-05-21
Pickering 5	CANDU 500B	PHWR	516	1974-11-01	1982-12-19
Pickering 6	CANDU 500B	PHWR	516	1975-10-01	1983-11-08
Pickering 7	CANDU 500B	PHWR	516	1976-03-01	1984-11-17
Pickering 8	CANDU 500B	PHWR	516	1976-09-01	1986-01-21
Point Lepreau	CANDU 6	PHWR	660	1975-05-01	1982-09-11

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Upcoming Nuclear Market

Four provinces within Canada have committed to the deployment of SMRs. Ontario, New Brunswick, Saskatchewan and Alberta. Ontario are intending on deploying the Gen-III GEH reactor, NB are exploring the Gen-IV aSMRs from ARC and Moltex, Saskatchewan is in early planning for both Gen-III and IV and Alberta has just announced a 2 year feasibility exercise to determine what is the most appropriate SMR.

Along with this plan for SMRs, Bruce Power in Ontario has announced plans for the construction of another conventional reactor on site.

Utility	Site	Capacity (MWe)	Type
Bruce	Bruce C	6x800?	CANDU?
NB Power	Point Lepreau	1x100	ARC-100
OPG	Darlington	1x300	BWRX-300
OPG	Darlington	3x300	BWRX-300

The Roadmap team took a collaborative, pan-Canadian approach. Interested provinces, territories and power utilities from across Canada were invited to join in.

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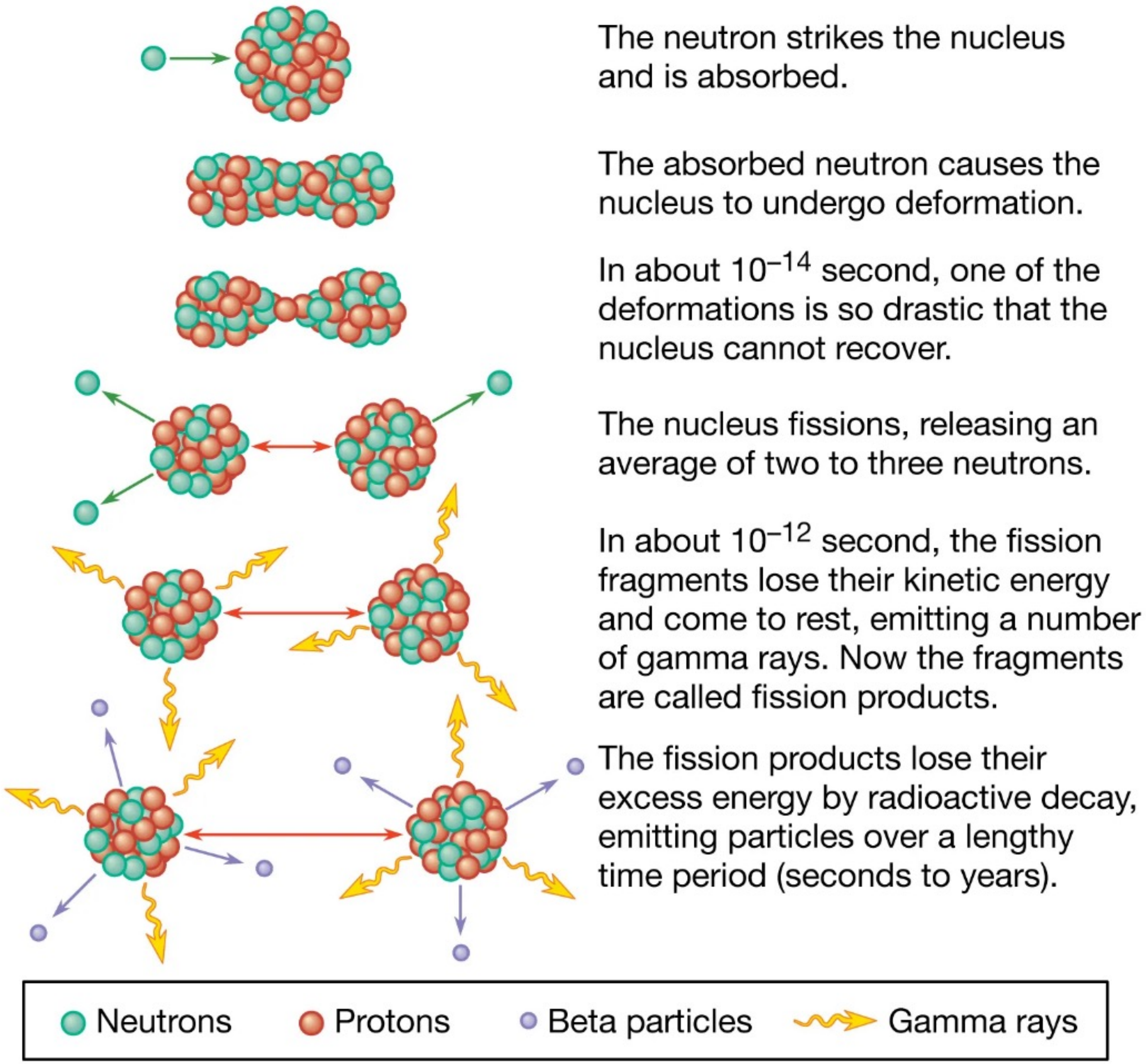
Conventional CANDU reactors vs Gen III vs Gen IV SMRs

Principles of Nuclear Fission Energy



Nuclear reactors operate on the principle of nuclear fission, the process in which a heavy atomic nucleus splits into two smaller fragments (fission products or daughter products - waste). The nuclear fragments are in very excited states and emit neutrons, other subatomic particles, and photons. The emitted neutrons may then cause new fissions, which in turn yield more neutrons, and so forth. Such a continuous self-sustaining series of fissions constitutes a fission chain reaction. A large amount of energy is released in this process, and this energy is the basis of nuclear power systems.

The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

Source: ***https://www.britannica.com/technology/nuclear-reactor***

Fast Spectrum vs Thermal Spectrum

Fast spectrum and thermal spectrum reactors differ in their neutron energy spectrum and have their own advantages and disadvantages.

Fast Spectrum Reactors use fast neutrons with energies greater than 1 MeV. Thermal Spectrum Reactors slow down the neutrons to less than the 1MeV energy range using a moderator.

Thermal Spectrum Reactors:

Pros:
They are less expensive to build than fast spectrum reactors.
They have a lower risk of nuclear proliferation.
They have a lower risk of nuclear accidents.
They have a lower risk of corrosion.

Cons:
They cannot burn nuclear waste.
They cannot breed fuel.
They require enriched uranium as fuel.
They have a lower fuel efficiency than fast reactors.

Fast Spectrum Reactors:

Pros:
They can burn nuclear waste and breed fuel.
They have a higher fuel efficiency than thermal reactors.
They can operate without a moderator.
They can use natural uranium as fuel.
They can produce more neutrons than thermal reactors.

Cons:
They are more expensive to build than thermal reactors.
They have a higher risk of nuclear proliferation.
They have a higher risk of nuclear accidents.
They have a higher risk of corrosion.

Nuclear Fuel

Different Nuclear reactor technologies use different fuels, similar to different transportation vehicles using different fuels:

- A car can use gasoline,
- A truck may use diesel,
- A plane may use kerosene
- A rocket ship may use hydrogen.

All reactors will have Uranium as the base fuel. Most will be solid metallic pellets and some new aSMRs are using a liquid fuels.

CANDU (PHWR) uses Natural uranium which contains 0.7% of the U-235 isotope. The remaining 99.3% is mostly the U-238 isotope which does not contribute directly to the fission process (though it does so indirectly by the formation of fissile isotopes of plutonium).

Light water reactors (of two types – PWR and BWR) use uranium enriched between 0.7% to 3-5% U-235. This is normal low-enriched uranium (LEU) and most reactors use this.

Many of the new aSMRs are designed around higher enriched levels about 7%-20% as high-assay LEU (HALEU).

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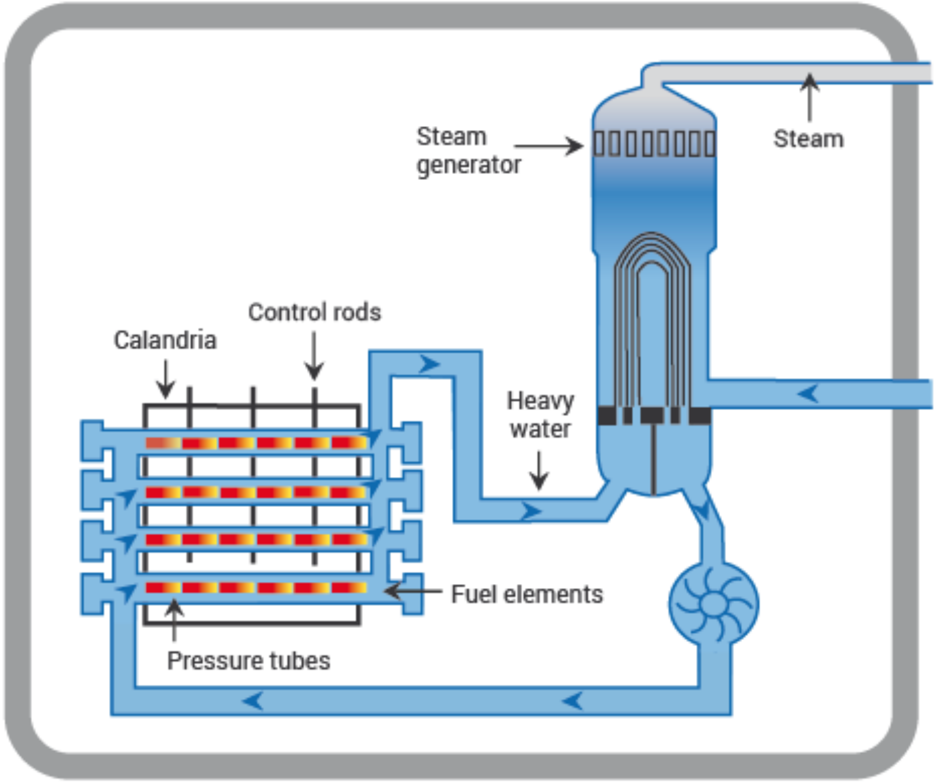
Conventional CANDU Reactors (Pressurized Heavy Water Reactor, PWHR)

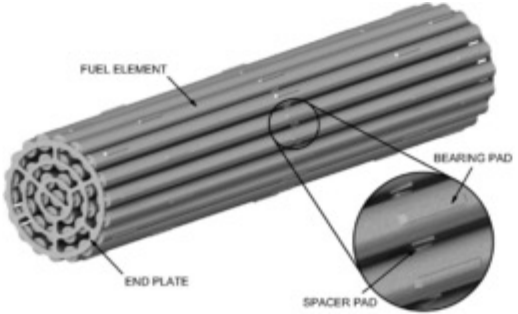


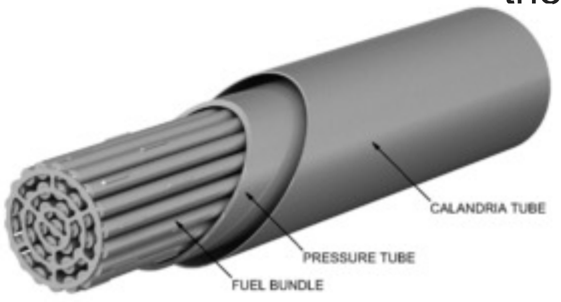
The PHWR reactor has been developed since the 1950s in Canada as the CANDU.

PHWRs generally use natural uranium (0.7% U-235) oxide as fuel, hence needs a more efficient moderator, in this case heavy water (D2O).

The PHWR produces more energy per kilogram of mined uranium than other designs, but also produces a much larger amount of used fuel per unit output.

The moderator is in a large tank called a calandria, penetrated by several hundred horizontal pressure tubes which form channels for the fuel, cooled by a flow of heavy water under high pressure (about 100 times atmospheric pressure) in the primary cooling circuit, typically reaching 290°C. As in the PWR, the primary coolant generates steam in a secondary circuit to drive the turbines.

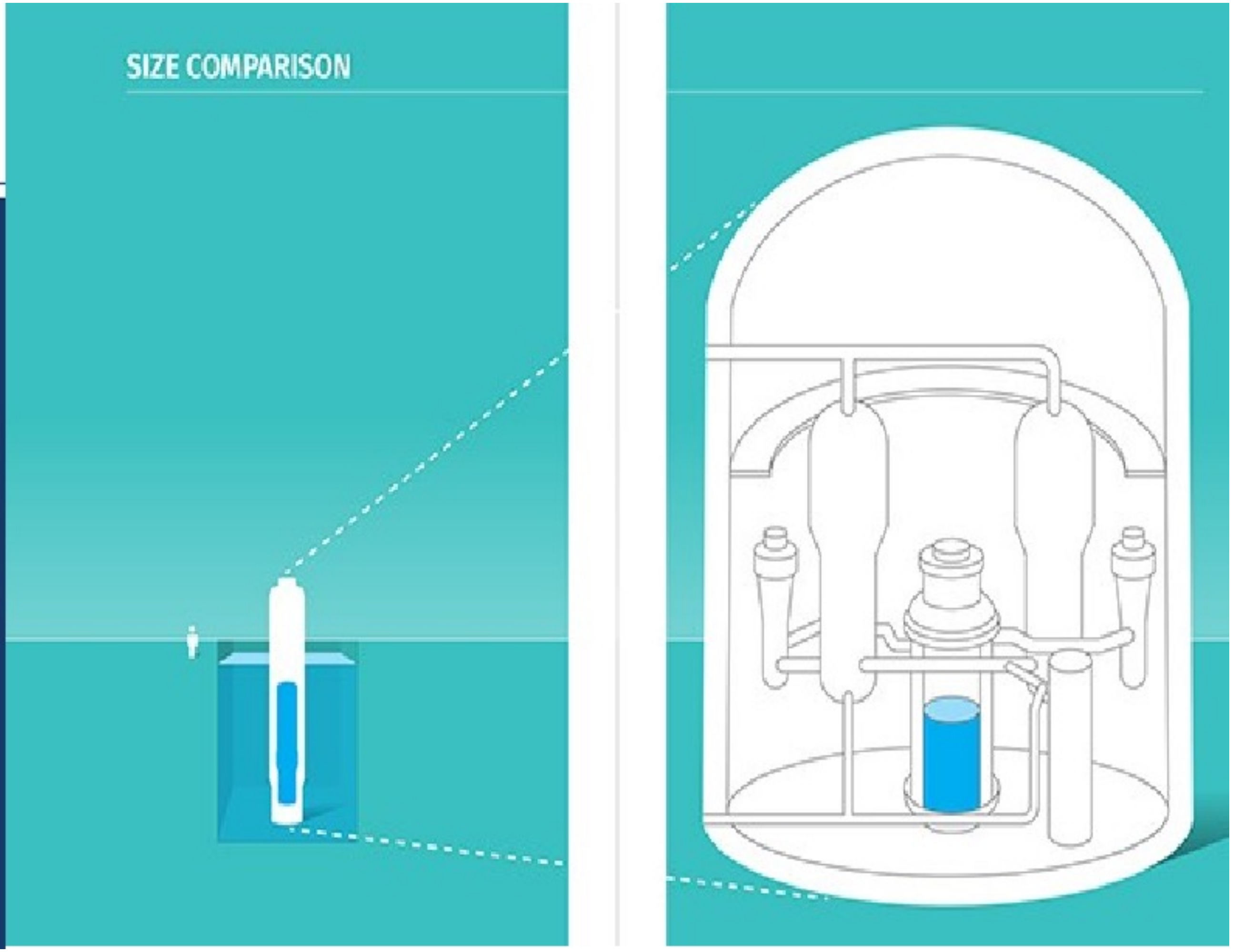




SMRs - Small Modular Reactors

The World Nuclear Association defines small modular reactors (SMRs) as nuclear reactors generally 300 MWe equivalent or less, designed with modular technology using module factory fabrication, pursuing economies of series production and short construction times.

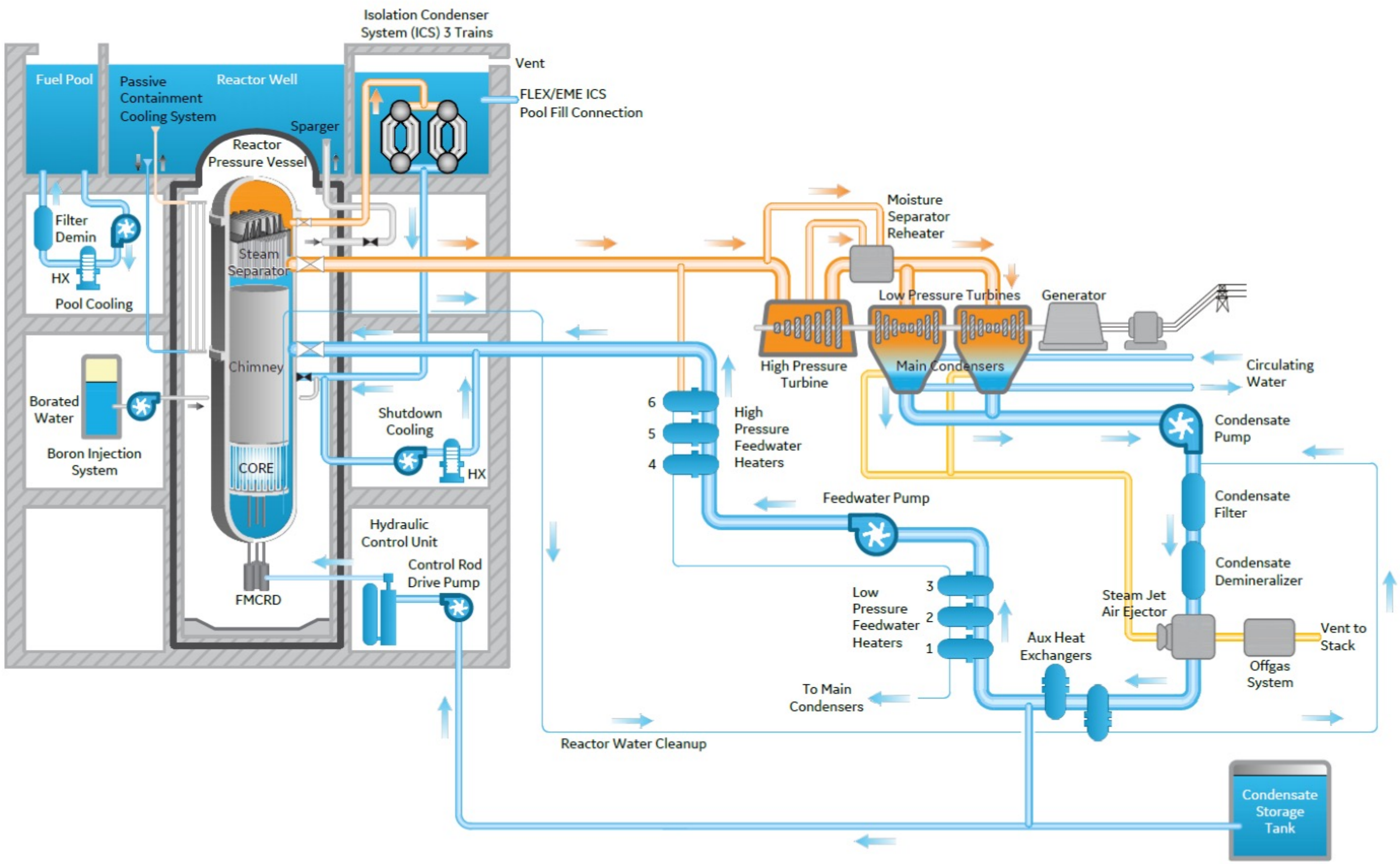
Small Modular Reactor (SMR)	Typical Pressurised Water Reactor
Zero carbon emissions from power production	**Zero carbon emissions** from power production
90 per cent energy capacity	**90 per cent** energy capacity
Compact design (partly underground)	**Large** above ground plant
Fabricated **in factory**	Built **at site**
Construction **3-5 years**	Construction **6-12 years**
Emergency planning zone **2km radius**	Emergency planning zone **16km radius**
WalkAway safe passive safety features	**Automatic safety** operator intervention
~$1-3 billion US	**~$6-12 billion US**
Reduced waste	Waste in the form of **spent fuel bundles**
Reduced fuel requirements with next generation technologies	**Standard fuel requirements**



SMR – Gen III GE-Hitachi BWRX300, Thermal neutron spectrum

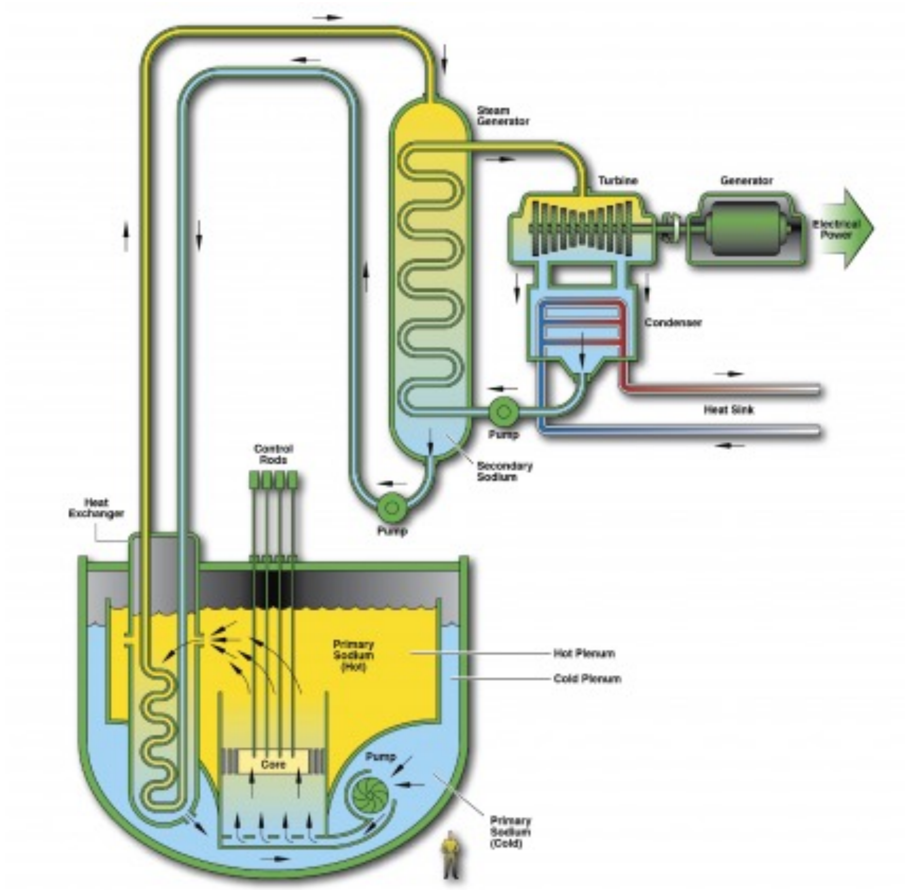
The BWRX-300 is a water-cooled, natural circulation reactor that uses boiling water reactor (BWR) technology. It is designed to be cost-competitive with gas and can be deployed for electricity generation and industrial applications, including hydrogen production, desalination, and district heating. The reactor has a net electrical capacity of 300 MW(e) and a refueling cycle of 12-24 months. The fuel is the GNF-2 bundle with Low Enriched Uranium (LEU) pellets. The approach to safety systems is fully passive and the design life is 60 years.

The 300MWe reactor literally boils water to generate the steam and uses LEU fuel. It is still big with a 26m RPV height!



SMR – Gen IV ARC reactor, fast spectrum molten metal

Liquid metal fast reactors use liquid metal as the reactor coolant in place of the water that is typically used in commercial nuclear power plants. The ARC-100 reactor is a 100MWe reactor.
Fast reactors employ a fast neutron spectrum, meaning that neutrons can cause fission without having to be slowed down first, as is required for water-cooled reactors. The fast neutron spectrum allows fast reactors to use both fissile materials and reprocessed spent nuclear fuel to produce heat.



The fuel for the reactor is currently metallic HALEU pellets. The refuelling cycle is currently expected around 20 years!

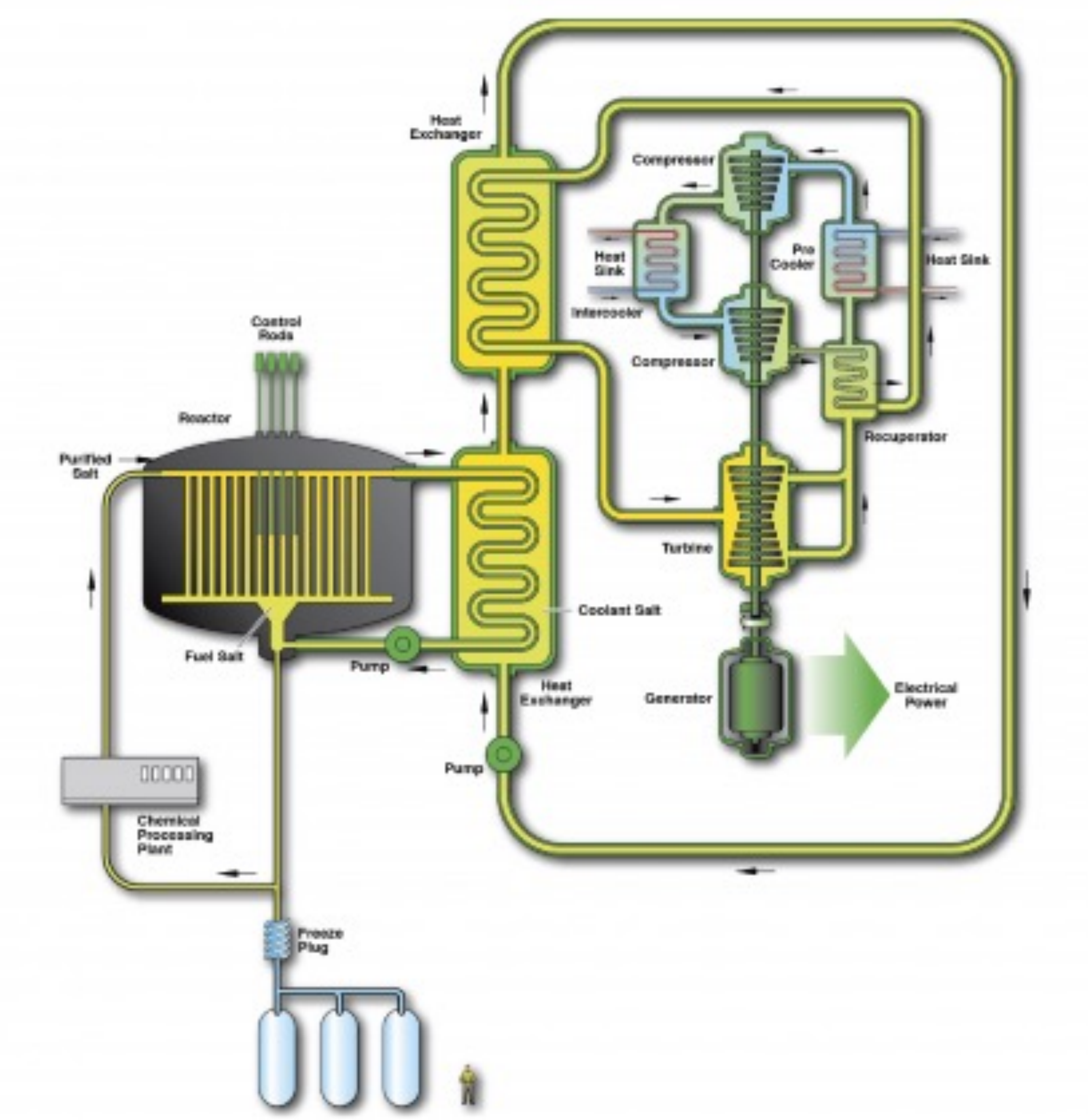
Liquid sodium metal has been chosen as the coolant for the ARC-100 reactor due to its high boiling point of 883°C
which allows for a core outlet coolant temperature of 510°C, and a 373°C margin of safety to boiling. Liquid sodium
metal allows the ARC-100 to operate at higher temperatures and lower pressures than current reactors while
improving both the thermal efficiency of the reactor for electricity generation and maintaining a large safety margin during accident transients.

SMR – Gen IV Moltex Reactor, Fast Spectrum Molten Salt

The fast spectrum “Wasteburner” SSR-W Molten Salt 300MWe is fueled by higher actinides from recycled conventional oxide fuel. Unlike other technologies molten salt reactors (MSR) use molten fluoride or chloride salts as a coolant that provides greater thermal properties than water allowing higher temperature operation.

The Moltex reactor has the TRUs dissolved in the salt forming liquid fuel in assemblies.
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.



SMR – Gen IV Terrestrial Reactor, Thermal Spectrum Molten Salt

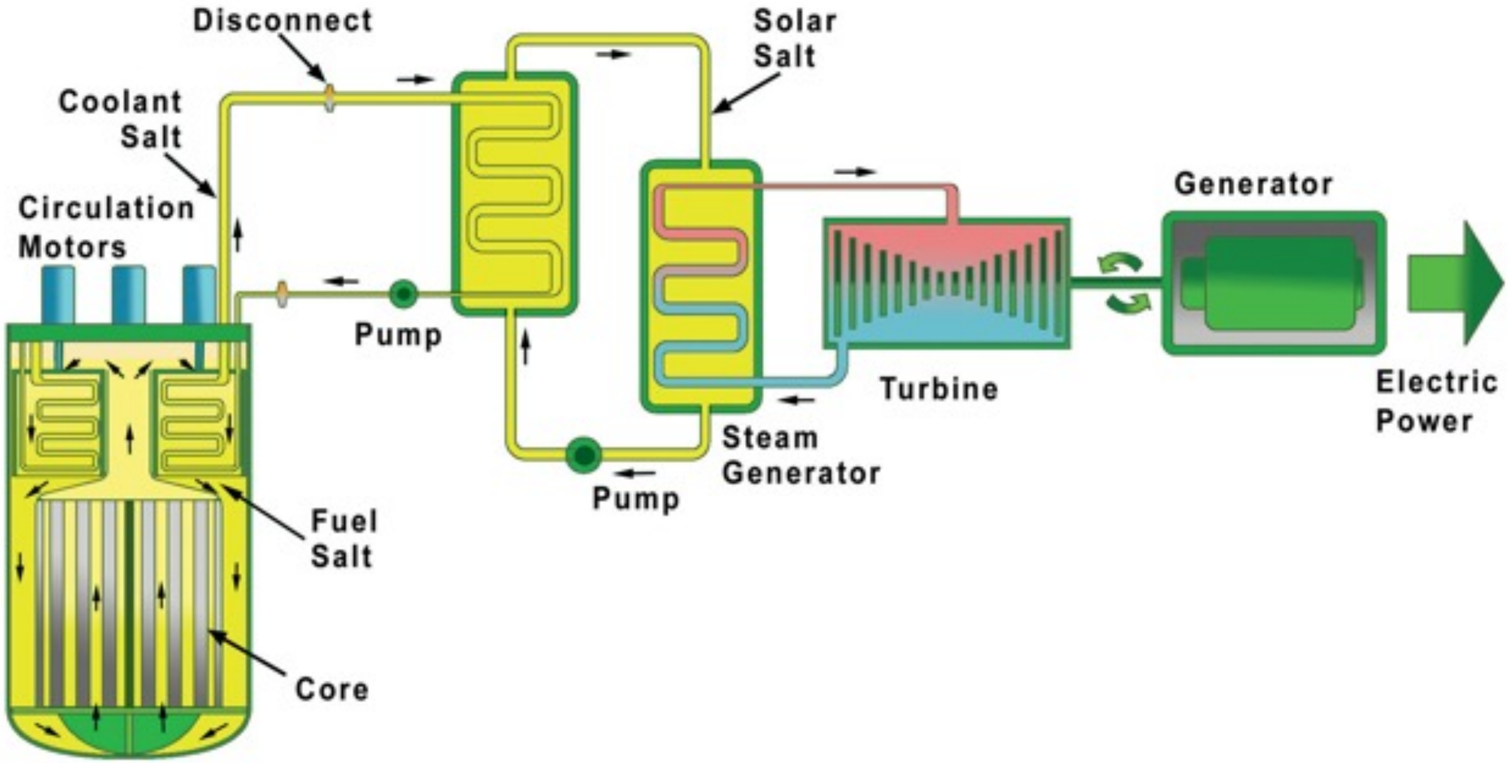
This simplified MSR, based closely on the Oak Ridge MSRE, integrates the primary reactor components, including primary heat exchangers to secondary clean salt circuit, in a sealed and replaceable core vessel that has a projected life of seven years. The IMSR will operate at 600-700°C, which can support many industrial process heat applications. The current concept is 440 MWt/195 MWe.

It operates in the thermal neutron spectrum with a hexagonal arrangement of graphite elements forming the moderator.

The fuel-salt is a eutectic of low-enriched (2-4%) uranium-235 fuel (as UF4) and a fluoride carrier salt – likely sodium rubidium fluoride.

Unlike the other reactors, the fuel is not in assemblies and is actually circulated around the core while the static graphite pillars moderate to allow the neutrons to enter the thermal spectrum!

The sealed core can be removed and replaced in one without having to remove individual fuel assemblies.



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SMR – Summary of SMRs in their Stages

Contrary to popular belief and detractors from the viability or feasibility of SMRs, there are some in operation many under construction and many more in design development stages.

SMRs in operation

Name	Capacity	Type	Developer
CNP-300	300 MWe	PWR	SNERDI/CNNC, Pakistan & China
PHWR-220	220 MWe	PHWR	NPCIL, India
EGP-6	11 MWe	LWGR	at Bilibino, Siberia (cogen, soon to retire)
KLT-40S	35 MWe	PWR	OKBM, Russia
RITM-200	50 MWe	Integral PWR, civil marine	OKBM, Russia

SMRs under construction

Name	Capacity	Type	Developer
CAREM25	27 MWe	Integral PWR	CNEA & INVAP, Argentina
HTR-PM	210 MWe	Twin HTR	INET, CNEC & Huaneng, China
ACP100/Linglong One	125 MWe	Integral PWR	CNNC, China
BREST	300 MWe	Lead FNR	RDIPE, Russia

Source: https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

SMRs near term deployment – well advanced

Name	Capacity	Type	Developer
VBER-300	300 MWe	PWR	OKBM, Russia
NuScale Power Module	77 MWe	Integral PWR	NuScale Power + Fluor, USA
SMR-160	160 MWe	PWR	Holtec, USA + SNC-Lavalin, Canada
SMART	100 MWe	Integral PWR	KAERI, South Korea
BWRX-300	300 MWe	BWR	GE Hitachi, USA
PRISM	311 MWe	Sodium FNR	GE Hitachi, USA
Natrium	345 MWe	Sodium FNR	TerraPower + GE Hitachi, USA
ARC-100	100 MWe	Sodium FNR	ARC with GE Hitachi, USA
Integral MSR	192 MWe	MSR	Terrestrial Energy, Canada
Seaborg CMSR	100 MWe	MSR	Seaborg, Denmark
Hermes prototype	35 MWt	MSR-Triso	Kairos, USA
RITM-200M	50 MWe	Integral PWR	OKBM, Russia
RITM-200N	55 MWe	Integral PWR	OKBM, Russia
BANDI-60S	60 MWe	PWR	Kepco, South Korea
Xe-100	80 MWe	HTR	X-energy, USA
ACPR50S	60 MWe	PWR	CGN, China
Moltex SSR-W	300 MWe	MSR	Moltex, UK

Concerns– Safety, Waste, Cost

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Challenges

There are three main sentiments of concern with respect to Nuclear in general. These tend to be:

- What do we do with the waste?
- Aren't they expensive?
- Are they not safe?

Nuclear Waste

Primary waste in the terms of Nuclear generation is the spent/used fuel released out of the core. Of the fuel pellet approx. 10% of it is fissioned into daughter products – the split atoms. Every radionuclide has a half-life – the time taken for half of its atoms to decay, and thus for it to lose half of its radioactivity. Radionuclides with long half-lives tend to be alpha and beta emitters – making their handling easier – while those with short half-lives tend to emit the more penetrating gamma rays which decay much more quickly.

Currently, in Canada, waste is stored in ponds for around 7 years to let them "cool". This allows the highly radioactive components to decay away. The more radioactive the component the quicker the decay.

Eventually all radioactive waste decays into non-radioactive elements. The more radioactive an isotope is, the faster it decays. Radioactive waste is typically classified as either **low-level (LLW), intermediate-level (ILW), or high-level (HLW), dependent, primarily, on its level of radioactivity**.

HLW and ILW are often packaged and sentenced to a geological repository but companies, such as Moltex, are creating technologies to actually recycle this stored waste to extract the desirable trans-Uranics, separating the fission products (HLW waste) while cleaning up the Uranium (80% unused) as products.

LLW is deemed safe enough to be stored at a near surface repository and is safe to handle without shielding.

Nuclear power is the only large-scale energy-producing technology that takes full responsibility for all its waste and fully costs this into the product.

The amount of waste generated by nuclear power is very small relative to other thermal electricity generation technologies.

Used nuclear fuel may be treated as a resource or simply as waste.

Safe methods for the final disposal of high-level radioactive waste are technically proven; the international consensus is that geological disposal is the best option.

Nuclear Waste Comparison

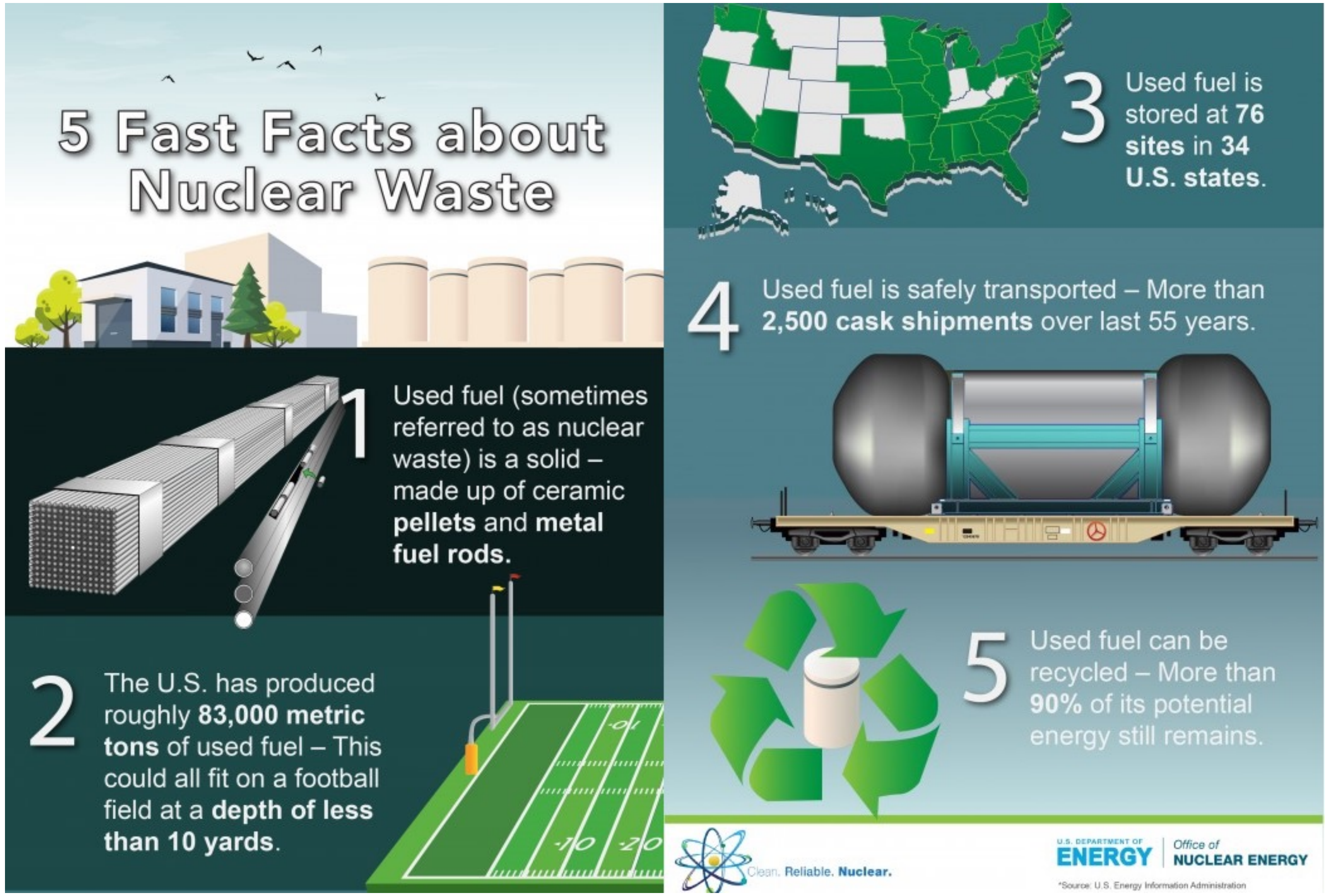
The amount of waste produced by the nuclear power industry is small relative to both other forms of electricity generation and general industrial activity.

For example, in the UK – the world's oldest nuclear industry:

- the total amount of radioactive waste produced to date, and forecast to 2125, is about 4.9 million tonnes. After all waste has been packaged, it is estimated that the final volume would occupy a space similar to that of a large, modern soccer stadium.
- Total annual generation of 200 million tonnes of conventional waste, of which 4.3 million tonnes is classified as hazardous.

Of the nuclear waste numbers above, only 0.03% is classified as HLW. In over 50 years of civil nuclear power experience, the management and disposal of civil nuclear waste has not caused any serious health or environmental problems, nor posed any real risk to the general public.

In context, it is important to consider the non-desirable by-products (carbon dioxide emissions) of other large-scale commercial electricity generating technologies.



In 2019, nuclear power plants supplied 2657 TWh of electricity, about **10%** of the world's total consumption. Fossil fuels supplied about **63%**, of which coal contributed the most (9914 TWh), followed by gas (6346TWh), and oil (747 TWh). If the about 10% of electricity supplied by nuclear power had been replaced by gas – by far the cleanest burning fossil fuel – an additional c. **1300 million tonnes of CO_2** would have been released into the atmosphere; the equivalent of putting an additional **250 million** cars on the road.

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SMR Economics

Nuclear power plants are expensive to build but relatively cheap to run.

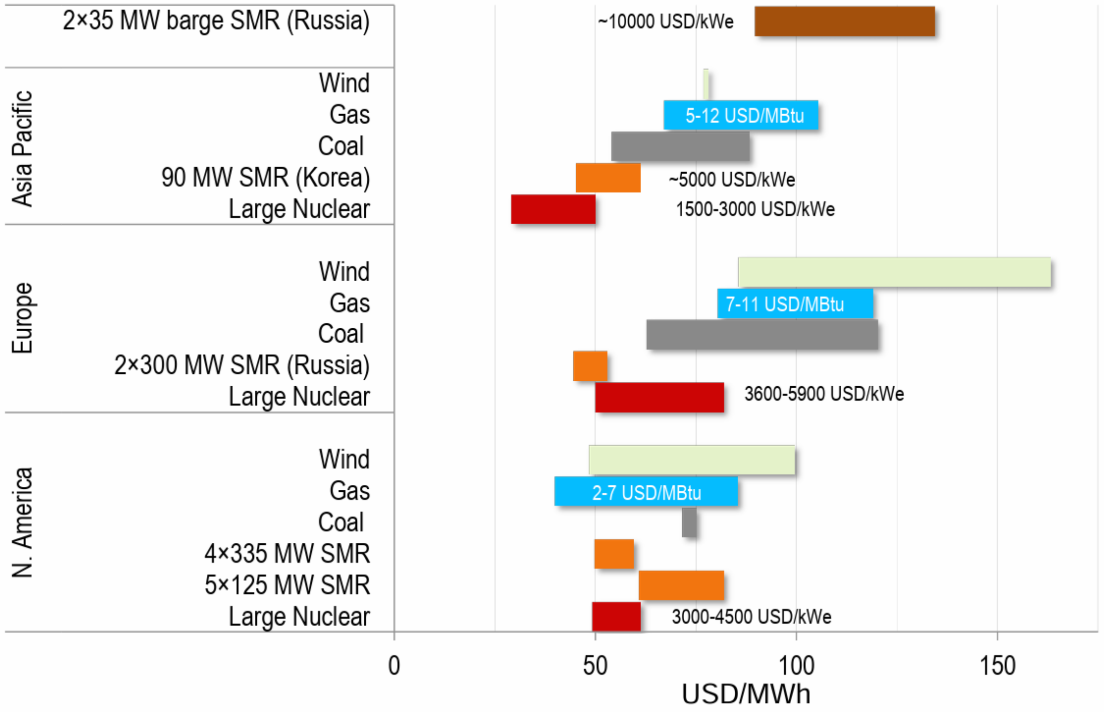
In many places, nuclear energy is competitive with fossil fuels as a means of electricity generation. Waste disposal and decommissioning costs are usually fully included in the operating costs.

The basic economics metric for any generating plant is the **levelized cost of electricity (LCOE)**. It is the total cost to build and operate a power plant over its lifetime divided by the total electricity output dispatched from the plant over that period, hence typically cost per megawatt hour. It takes into account the financing costs of the capital component (not just the 'overnight' cost).

These plants could present the lowest cost generation options available, making nuclear power "effectively competitive with any other option for power generation. At the same time, this could enable a significant expansion of the nuclear footprint to the parts of the world that need clean energy the most – and can least afford to pay high price premiums for it."

LCOE estimates for SMRs and alternative sources, at 5% real discount rate

The band represents the uncertainty on data and calculations



Source:https://nucleus.iaea.org/sites/INPRO/df6/Session%204/2.sozoniuk.pdf

The companies included in a study for LCOE *(https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf)* were Elysium Industries, GE Hitachi, Moltex Energy, NuScale Power, Terrestrial Energy, ThorCon Power, Transatomic Power, and X-energy. LCOE figures ranged from **\$36/MWh to \$90/MWh, with an average of \$60/MWh.**

Once the SMR industry becomes established with the n^{th} of a kind plant the economies of scale, manufacturing and supply chain robustness will provide even better economics.

Stakeholder organizations - CNSC, IAEA, NWMO, First Nations

Nuclear Regulatory Bodies

Nuclear is the most regulated industry in the world and for good reason. The risks are low due to all the robust underpinning and qualification required of design and build, however the consequences are severe if things go wrong. Regulators play an important role to ensure that the highest standards are met for safety and safeguards.

The International Atomic Eneregy Authority (IAEA)

- Peaceful uses: Promoting the peaceful uses of nuclear energy by its member states,
- Safeguards: Implementing safeguards to verify that nuclear energy is not used for military purposes, and
- Nuclear safety: Promoting high standards for nuclear safety

The Canadian Nuclear Safety Commission (CNSC)

- Regulating the use of nuclear energy and materials to protect health, safety, security and the environment;
- Implementing Canada's international commitments on the peaceful use of nuclear energy, and
- disseminating objective scientific, technical and regulatory information to the public.
- **READ REGDOC 2.5.2!!!** - REGDOC-2.5.2, Design of Reactor Facilities, Version 2.1 (cnsc-ccsn.gc.ca)

In Canada, the main steps to licensing a nuclear reactor are:

- VDR 1 and VDR 2 (optional paid assessment – but it should be done)
- LTPS – License to prepare site
- LTO – License to operate
- LTC – License to construct
- LTD – License to decommission

Other considerations - Federal Impact assessment, Provincial Environmental Impact Assessment

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Waste

The organization responsible for all Nuclear waste in Canada is the National Waste Management Organization (NWMO). NWMO is a federal agency responsible for designing and implementing Canada's plan to contain and isolate used nuclear fuel.

Currently generating sites store their wastes on site. Typically after the seven year cool off period of spent fuel in the ponds, the bundles are packaged and stored in silos.

The plan for HLW/ILW is for a Deep Geological Repository in Ontario for long term storage of waste as other countries around the world do the same.

The plan for LLW is a Near Surface Disposal Facility (NSDF) at Chalk River

First Nations Communities

First Nations communities are playing an active role in the nuclear industry in Canada, from investing in SMR developers to participating in the planning and implementation of nuclear waste facilities.

Design considerations – REGDOC 2.5.2

REGDOC 2.5.2 - Design of Reactor Facilities

REGDOC-2.5.2, *Design of Reactor Facilities*, sets out requirements and guidance for new licence applications for water-cooled reactor facilities but it is used as a general benchmark for other nuclear facilities as well.

It establishes a set of comprehensive design requirements and guidance that are risk informed and align with accepted international codes and practices (International Atomic Energy Agency (IAEA) document SSR-2/1, *Safety of Nuclear Power Plants: Design)*.

1. establishing the safety goals and objectives for the design
2. utilizing safety principles in the design
3. applying safety management principles
4. designing structures, systems and components (SSCs)
5. interfacing engineering aspects, plant features and facility layout
6. integrating safety assessments into the design process

General Nuclear Safety Objective: Facilities be designed and operated in a manner that will protect individuals, society and the environment from harm. This objective relies on the establishment and maintenance of effective defences against **radiological hazards**.

This is supported by 3 further complementary objectives, detailed on the following slide.

REGDOC 2.5.2 - Design of Reactor Facilities

Complementary Objectives:

Radiation protection objectives: The radiation protection objective is to ensure that during normal operation, or during anticipated operational occurrences, radiation exposures within the reactor facility or due to any planned release of radioactive material from the reactor facility are kept below prescribed limits and as **low as reasonably achievable (ALARA)**.
Provisions shall be made for the mitigation of the radiological consequences of any accidents considered in the design.

Technical safety objectives
The technical safety objectives are to provide all reasonably practicable measures to prevent accidents in the reactor facility, and to mitigate the consequences of accidents if they do occur. This takes into account **all possible accidents** considered in the design, including those of very low probability.
When these objectives are achieved, any radiological consequences will be below prescribed limits, and the likelihood of accidents with serious radiological consequences will be extremely low.

Environmental protection objective
The environmental protection objective is to provide all reasonably practical mitigation measures to protect the environment during the operation of a reactor facility and to mitigate the consequences of an accident.
The design shall include provisions to **control, treat and monitor releases to the environment and shall minimize the generation of radioactive and hazardous wastes.**

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REGDOC 2.5.2 – Defence in Depth

The concept of defence in depth shall be applied to all organizational, behavioural, and design-related safety and security activities. This concept shall be applied throughout the design process and operation of the plant to provide a series of levels of defence aimed at preventing accidents and ensuring appropriate protection in the event that prevention fails.

Level 1
The aim of the first level of defence is to **prevent deviations from normal operation**, and to prevent failures of SSCs important to safety.

Level 2
The aim of the second level of defence is to **detect and intercept deviations** from normal operation in order to prevent AOOs from escalating to accident conditions and to return the plant to a state of normal operation.

Level 3
The aim of the third level of defence is to **minimize the consequences of accidents** by providing inherent safety features, fail-safe design, additional equipment and mitigating procedures.

Level 4
The aim of the fourth level of defence is to **ensure that radioactive releases** caused by severe accidents are kept **as low as practicable**.

Level 5
The aim of the fifth level of defence is to **mitigate the radiological consequences** of potential releases of radioactive materials that may result from accident conditions.

Energy Density/Waste Impact/CO2 emissions

Energy Density

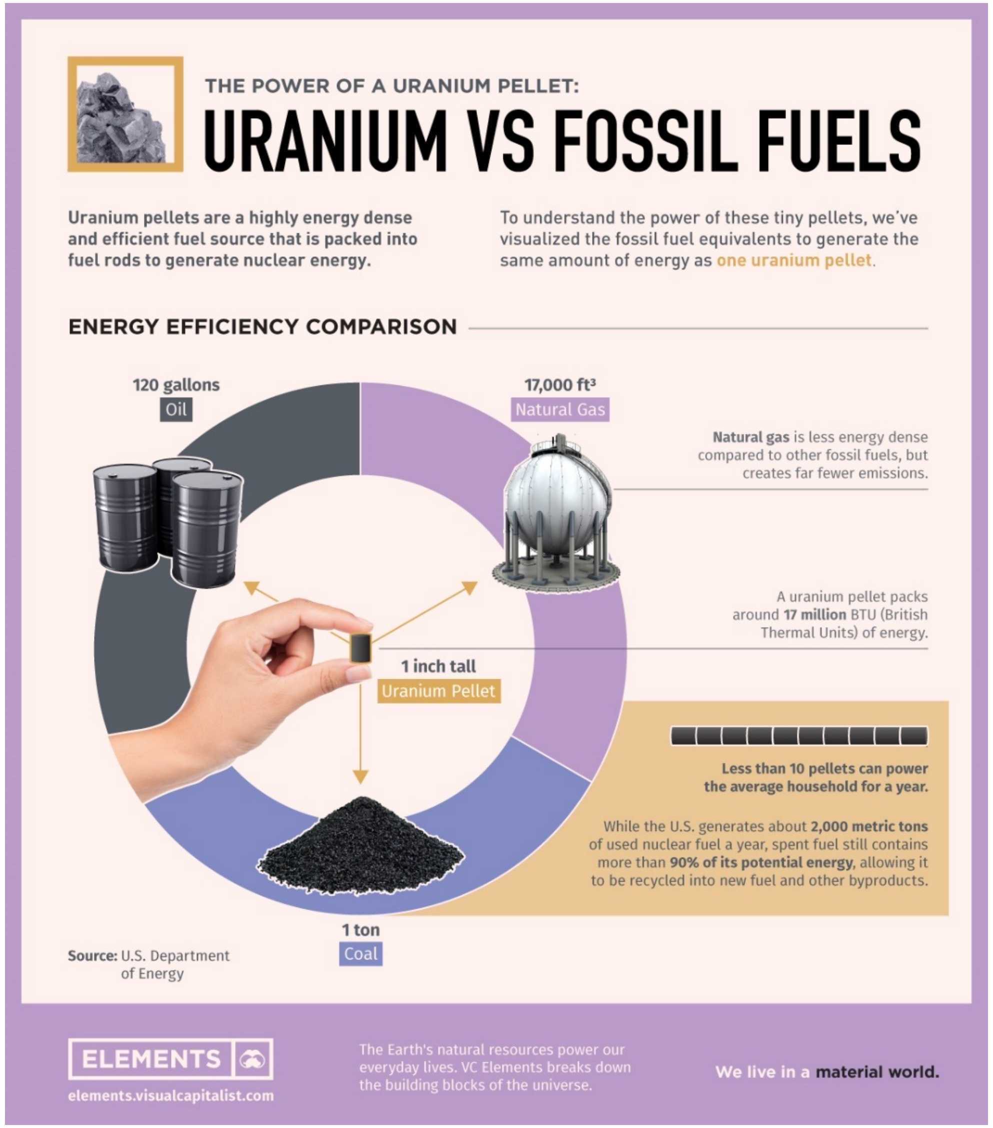
The heat value of a fuel is **the amount of heat released during its combustion**. Also referred to as energy or calorific value, heat value is a measure of a **fuel's energy density.**

Uranium figures are based on 45,000 MWd/t burn-up of 3.5% enriched U in LWR

MJ = 106 Joule, GJ = 109 J
MJ to kWh @ 33% efficiency: x 0.0926
One tonne of oil equivalent (toe) is equal to 41.868 GJ

	Heat value
Hydrogen (H_2)	120-142 MJ/kg
Methane (CH_4)	50-55 MJ/kg
Petrol/gasoline	44-46 MJ/kg
Diesel fuel	42-46 MJ/kg
Crude oil	42-47 MJ/kg
Liquefied petroleum gas (LPG)	46-51 MJ/kg
Natural gas	42-55 MJ/kg
Hard black coal (IEA definition)	>23.9 MJ/kg
Hard black coal (Australia & Canada)	c. 25 MJ/kg
Lignite/brown coal (IEA definition)	<17.4 MJ/kg
Firewood (dry)	16 MJ/kg
Natural uranium, in LWR (normal reactor)	**500 GJ/kg**
Natural uranium, in LWR with U & Pu recycle	**650 GJ/kg**
Natural uranium, in FNR	**28,000 GJ/kg**
Uranium enriched to 3.5%, in LWR	**3900 GJ/kg**

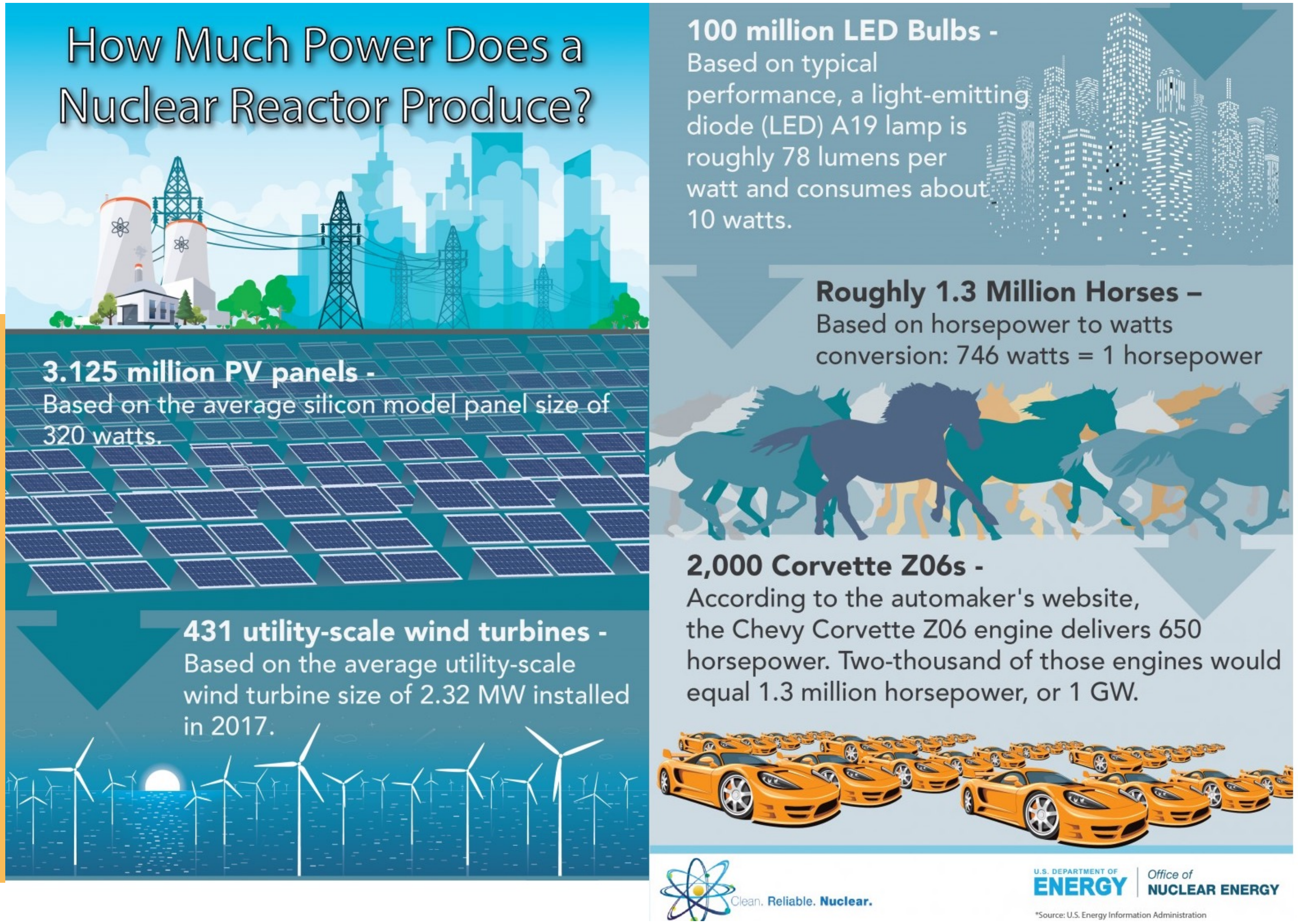
Source: https://world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx



Energy Density

Infographics describe this best!

Comparisons vs conventional fossil fuels and renewables.



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Waste impact

Nuclear fuel is extremely dense.

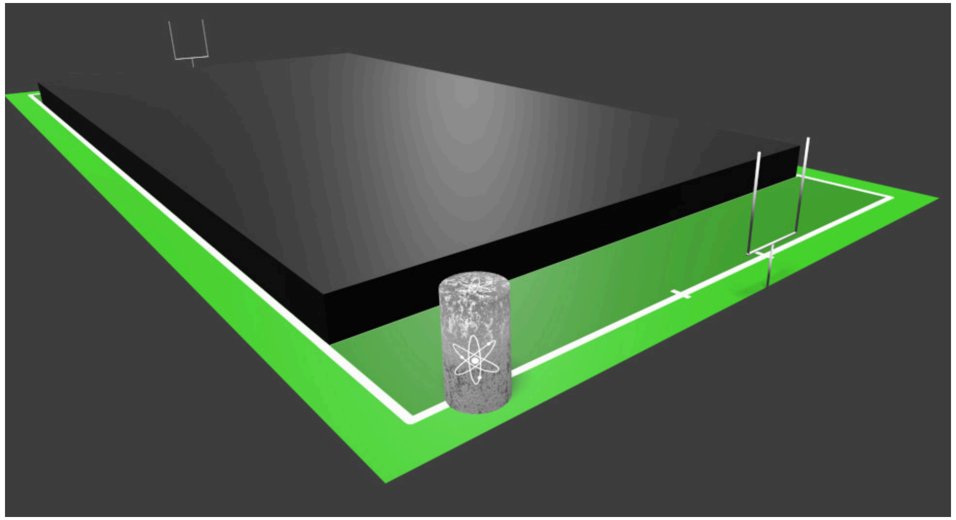
It's about 1 million times greater than that of other traditional energy sources and because of this, the amount of used nuclear fuel is not as big as you might think.

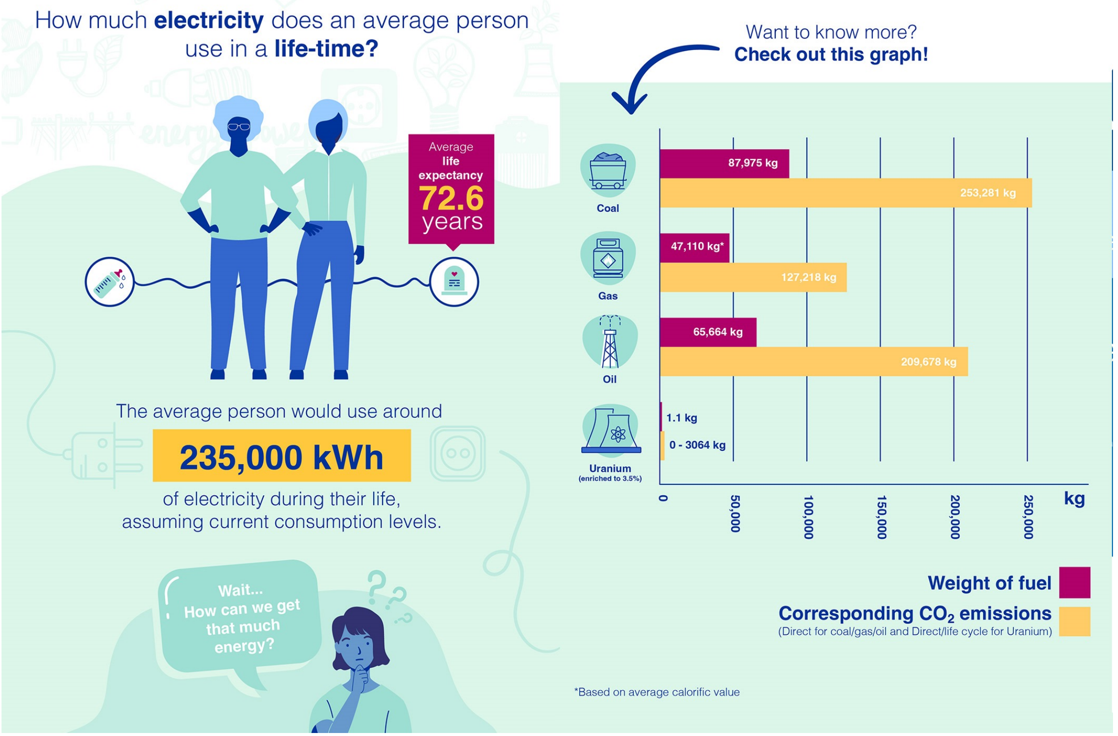
All of the used nuclear fuel produced by the U.S. nuclear energy industry over the last 60 years could fit on a football field at a depth of less than 10 yards!

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

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

Source: https://www.energy.gov/ne/articles/3-reasons-why-nuclear-clean-and-sustainable

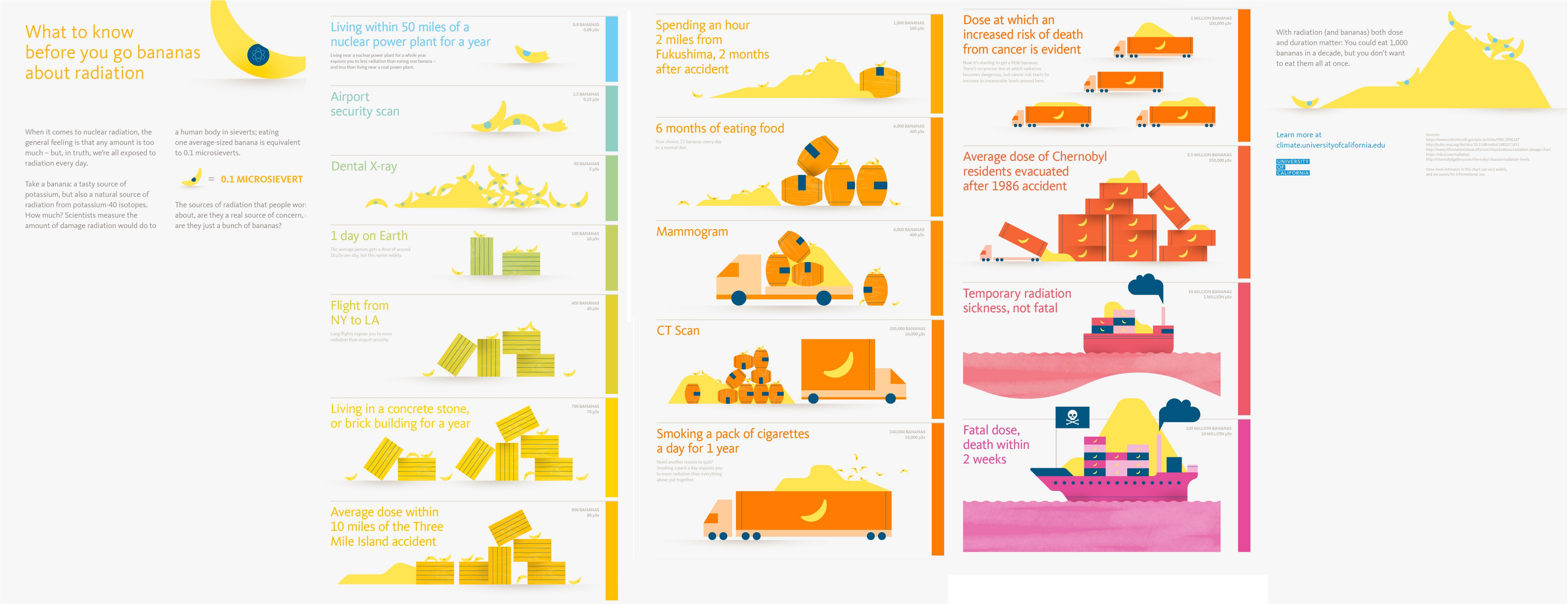




Source: https://ourfutureenergy.com/in-focus/nuclear-waste/

Radioactivity?

Radioactivity is a scary word for most but put into context, it looks a lot different..



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Market sector figures – new build, operations and maintenance, decommissioning

Market Economics

The global market for SMR technology is estimated at **$400 to $600 billion**. Early leadership in SMR technology could secure a significant share of that market. *(source: CNA factbook 2021)*

The capital cost of a new build of an SMR is estimated between **$300M and $1Bn for a FOAK SMR** and significantly less for a NOAK. This could mean a multi-$Bn market just for SMR new builds in Canada alone and much more in the whole of North America.

In the 2022 edition of the International Atomic Energy Agency's (IAEA's) Energy, Electricity and Nuclear Power, a range of estimates for various periods were presented. The high case projection has global nuclear energy capacity increasing from **390 GWe in 2021** to **479 GWe by 2030**, **676 GWe by 2040** and **873 GWe by 2050**.

During the World Climate Action Summit of the 28th Conference of the Parties to the U.N. Framework Convention on Climate Change today, more than 20 countries from four continents launched the Declaration to Triple Nuclear Energy. This results possibly a 100s of $Bn market (perhaps even a $Tn!)

When plant maintenance/operations and decommissioning are taken into account 100s of $M are injected into the supply chain and, with a robust socio-economic plan, nuclear based regions begin to flourish as local skills and businesses enjoy the benefits of strong, stable, long term projects.

Questions and Close

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Questions?

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