Five Myths about Nuclear Power

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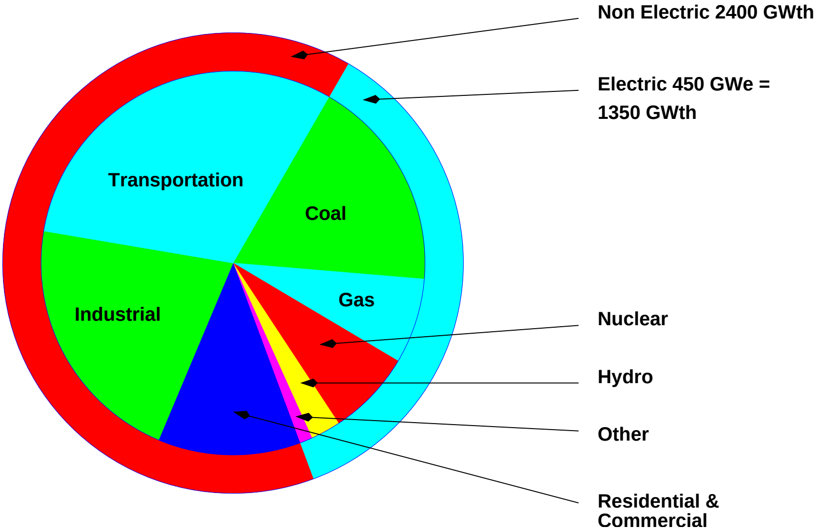
"The great enemy of the truth is very often not the lie – deliberate, contrived, and dishonest – but the myth – persistent, persuasive, and unrealistic."

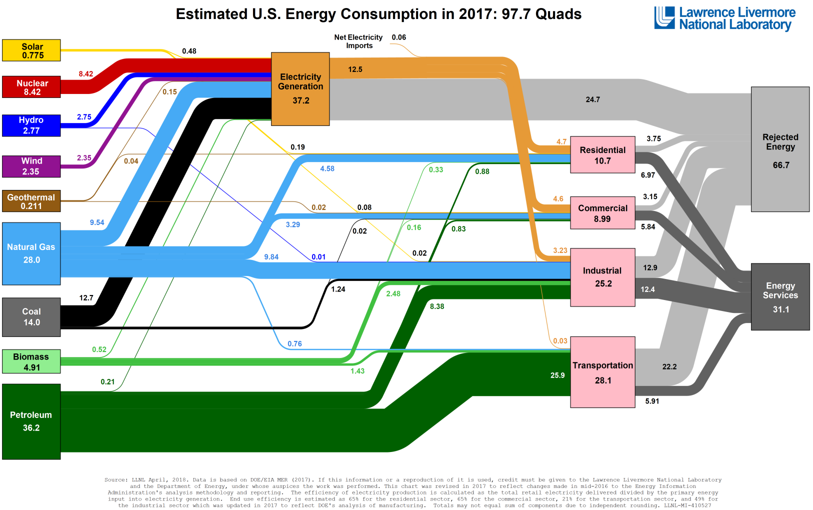
– John F. Kennedy, Yale University commencement speech, 1962

How Much Energy Do We Need?

Electricity Sources and Non-Electric Energy Uses



Details to follow. . . .



https://flowcharts.llnl.gov/

Total U.S. Power Demand in 2012

Total U.S. average demand: 3,269 GWth $\approx$ 3.27 TWth.

Non-electric demand = 1,986 GWth[1] $\approx$ 1.9 TWth.

If all non-electric demand must be satisfied as heat, and electricity is converted to heat with $\approx$100% efficiency, total electric demand would be 462 + 1,986 $\approx$ 2,449 GWe.

If all non-electric demand could be satisfied as electricity, total electric demand would be 462 + 1,986/3.412 $\approx$ 1,044 GWe. (3.412 is the average power plant's thermal-to-electric conversion efficiency).

The correct amount is between 1,044 GWe and 2,449 GWe.

[1] http://www.eia.gov/totalenergy/data/monthly/pdf/sec2_3.pdf

Replacing Non-Electric Demand with Electricity

Sector	Current Demand as Heat§		If Supplied as Electricity
Commercial / Residential	18.4%	364 GWth	79 GWe*
Industrial	35.7%	710 GWth	561 GWe†
Road, Rail, Pipeline	37.1%	736 GWth	295 GWe¶
Ships, Airplanes	8.8%	175 GWth	350 GWe‡
Total Non-Electric	100%	1,986 GWth	1,285 GWe
Electric	—	—	462 GWe
Total if all Electric	—	—	$\approx$ 1,700 GWe

§ `http://www.eia.doe.gov/energyexplained/index.cfm?page=us_energy_home`

* Assumes mostly space and water heating using heat pumps having 460% efficiency (E.g., Mitsubishi EcoDan/BRE).

† Assumes 500 GW as heat provided by electricity + 210/3.412 GW used directly as electricity. Co-located industries could get process heat directly from a reactor at temperatures up to 1000°F.

¶ Assumes increase in end-to-end efficiency from 15% to 73%.

‡ Assumes 50% efficient conversion of CO_2 + H_2O + energy to liquid hydrocarbon fuel.

Why Nuclear Power?

Why Nuclear Power?

Nuclear power is

> *. . . the energy source that can save our planet from another possible disaster: catastrophic climate change. . . . Nuclear energy is the* **only** *large-scale, cost-effective energy source that can reduce these emissions [of CO_2] while continuing to satisfy a growing demand for power. . . .*

– Patrick Moore, founder of Greenpeace Canada
cofounder of Greenpeace International, 2006

http://www.washingtonpost.com/wp-dyn/content/article/2006/04/14/AR2006041401209.html

Why Nuclear Power?

100%-renewable electricity systems can't work

"While many modelled scenarios have been published claiming to show that a 100% renewable electricity system [that excludes nuclear power] is achievable, there is **no empirical or historical evidence that demonstrates that such systems are in fact [physically] feasible***."*
[my emphasis]

B.P. Heard, B.W. Brook, T.M.L. Wigley, C.J.A. Bradshaw, *Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems*, **Renewable and Sustainable Energy Reviews 76**, Elsevier (2017), pp 1122-1133.

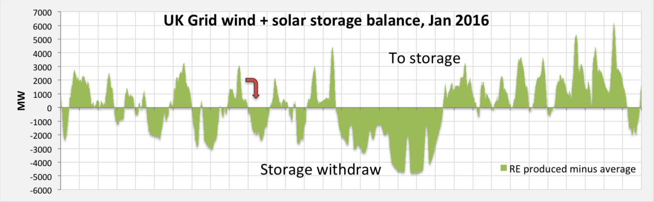
Why Nuclear Power?

From the abstract of *Burden of Proof*:

> *Our review of 24 studies of 100% renewable electricity systems finds that* **none individually, nor the literature in aggregate, provide compelling evidence for even the basic [physical] feasibility**. . . .
>
> *Our review gave no assessment whatsoever of important [economic] viability aspects such as financial cost, planning constraints, technology assumptions, governance and policy requirements and land use conflicts.*
>
> *The true costs of 100% renewable electricity systems cannot be determined on the basis of systems that are not even technically feasible, yet at this time that is all the literature offers.*

How much storage is needed for firm power?

- Euan Mearns, **Energy Matters**. Data for grid-connected wind and solar for all of England and Scotland, with 30-minute resolution, for all of 2016: **390 watt-hours** of storage are needed per average watt of capacity (Wh/W), to provide firm power.



http://euanmearns.com/grid-scale-storage-of-renewable-energy-the-impossible-dream

How much storage is needed for firm power?

- Matthew R. Shaner, Steven J. Davis, Nathan S. Lewis, Ken Caldeira, *Geophysical constraints on the reliability of solar and wind power in the United States*, **Energy and Environmental Science**, Royal Society of Chemistry (February 2018). Geophysical data for 36 years for all of North America, with one hour resolution: **400–800 Wh/W**.
- Norman Rogers, **Is 100 Percent Renewable Energy Possible?** Wind and solar data for Texas: **400 Wh/W**.
- James Hansen and Michael Shellenberger *Nuclear Power? Are Renewables enough?* **Climate Matters**: Similar conclusion. `https://www.youtube.com/watch?v=v1f4BKsFrCA`

Big South Australian Battery

How much would storage cost?

- The Big South Australian Battery cost \$0.517/Wh. Tesla recently raised the price of PowerWall 2 to \$0.578/Wh.
- An all-electric United States energy economy would need about 1,700 GWe average capacity.
- Using the least pessimistic projection:
  1,700 GWe $\times$ 390 Wh/W $\times$ \$0.578/Wh $=$ **\$383 trillion.**
  Five year battery life means \$76 trillion per year $=$
  3.95 times US 2017 GDP **EVERY YEAR!**.
- Using all the rechargeable batteries in the state, including in every laptop, telephone, car, truck, flashlight, and smoke detector, **California has 23 minutes of storage!**

Will human civilization survive an all-renewable energy economy when Mount Tambora erupts again, giving us another 1816, the "year without a summer?"

Why Nuclear Power?

Power systems were severely damaged by an electromagnetic pulse (EMP) when the Sun belched out several trillion cubic miles of super-hot plasma in 1969. Aurora were seen as far south as Cuba.

The Sun does this every sixty years or so.

Solar panels and windmills are inherently vulnerable to EMP. The enormous amount of wiring necessary to collect dispersed sources would be a giant EMP antenna. **An all-renewable energy system would be catastrophically damaged. Recovery would take decades.**

Nuclear power plants, inside four-foot-thick concrete domes, laced with steel rebar, **are inherently invulnerable to EMP**.

Why Nuclear Power?

- **No one knows how to make an all-renewable electrical grid work.**
- **Storage is not economically viable.**
- **Human civilization cannot build enough storage to survive a major volcanic eruption or meteorite strike.**
- **Solar, wind, and enormous wiring are inherently vulnerable to electromagnetic pulse (EMP).**

100% renewable is too dangerous to consider seriously!

Why NOT Nuclear Power?

“If you tell a lie big enough and keep repeating it, people will eventually come to believe it.”
– Nazi Propaganda Minister Joseph Goebbels

(Frequently mis-attributed to Vladimir Ilyich Lenin)

“If a lie is only printed often enough, it becomes a quasi-truth, and if such a truth is repeated often enough, it becomes an article of belief, a dogma, and men will die for it.”
– Isa Blagden, *The Crown of a Life* (1869)

The Five Myths

Everything you've been told about nuclear power:

- It's too dangerous
- No one knows what to do about waste
- It's too expensive
- It leads to weapons proliferation
- There isn't enough uranium

Is False!

It's Too Dangerous

- Three Mile Island.
- Fukushima.
- Chernobyl.

It's Too Dangerous

Three Mile Island

- **No one** was injured (except financially) or killed by Three Mile Island and **no significant amounts of radioactive materials were released.**
- The core didn't melt through the floor of the reactor and fall to China.
- Actually, Madagascar is opposite from Pennsylvania, but **Madagascar Syndrome!** wouldn't have been a catchy movie title.
- Three Mile Island didn't prove nuclear power is unsafe. It proved the safety systems – even in reactors of antique design – work.

Fukushima

- Tsunami killed 15,000 in Fukushima prefecture and 5,000 elsewhere.
- No deaths or illnesses caused by radiation exposure.
- Incompetent evacuation of 150,000 – which should have been "shelter in place" – killed 1,500.
- TEPCO employees were prosecuted for removing people from life support in hospitals to save them from a one-in-a-billion chance of a significant radiation dose.
- Japan over-cleaned. Dirt in Fukushima is half as radioactive as dirt near Denver.
- Residents could have returned to their homes in 3-6 months, after ^{131}I decayed. Instead, seven years later, thousands are living as refugees.
- Fukushima didn't prove nuclear power is unsafe.

UNSCEAR 2013 General Assembly report

- "Japanese people receive an effective dose of radiation from **normally occurring sources** of, on average, about 2.1 mSv annually and a total of about 170 mSv over their lifetimes."
- "For adults in Fukushima Prefecture, the Committee estimates [the increase in] average lifetime effective dose to be of the order of 10 mSv or less."
- "**Discernible increase in cancer incidence** in this population that could be attributed to radiation exposure from the accident **is not expected.**"

Average dose

Fukushima pre-2012 Fukushima post-2012	2.1 mSv/yr 2.24 mSv/yr
Tibetan plateau	13-20 mSv/yr
Guarapari Beach, Brazil	1148 mSv/yr
One abdominal and pelvic CT scan, with and without contrast	30 mSv

Chernobyl

- 28 workers and emergency responders died from Acute Radiation Syndrome.
- Fifteen cases of fatal juvenile thyroid cancer during the next fifteen years, mostly in rural areas with poor medical care.
- Normal fifteen year incidence of thyroid cancer in Eastern Europe is 6,000 cases (400 per year).
- Two workers killed by falling debris; one died from a heart attack.
- Three killed in a helicopter crash.

I don't count the last six as "radiation related deaths."

Total worldwide fifty-plus year death toll: **43** – doesn't prove nuclear power is unsafe.

Chernobyl

The Hindenburg of nuclear reactors

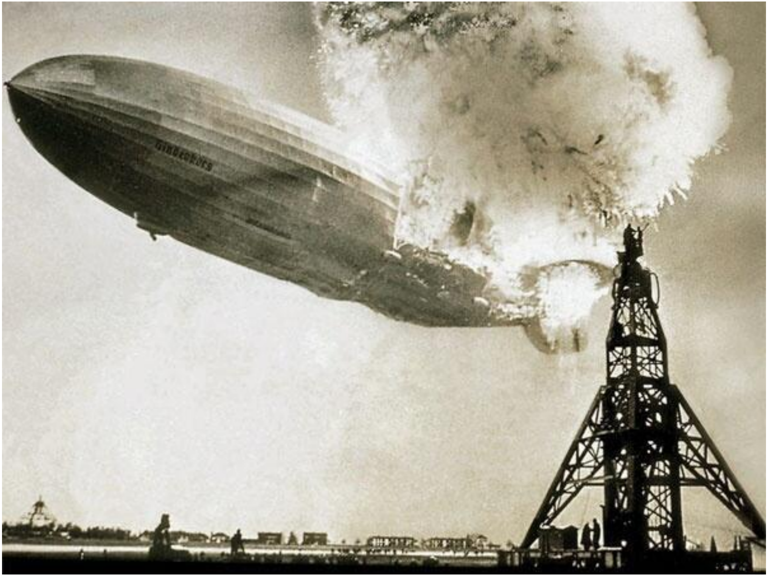
- Soviet Union had no safety culture.
- Soviet Union had no licensing criteria.
- Chernobyl reactor was not licensed.
- Chernobyl reactor would not have been licensed or built anywhere else.
- Inherently unstable.
- Operators lost control when they bypassed the inadequate shutdown mechanisms, ironically in a rush to finish a safety test.
- Had a tin-foil containment shed, not a real containment dome.
- Steam explosion and graphite fire, not a nuclear explosion.
- Licensed power reactor **cannot cause a nuclear explosion.**

UNSCEAR 2008 General Assembly report

- Average additional dose to general public in Eastern Europe 1986-2005: 9 millisieverts (mSv) – 0.45 mSv per year.
- "There **no scientific means** to determine whether a particular cancer in a particular individual was or was not caused by radiation" (but they blamed fifteen thyroid cancer deaths on radiation from Chernobyl anyway).
- "There is **no scientific evidence** of increases in overall cancer incidence or mortality rates or in rates of non-malignant disorders that could be related to radiation exposure."
- "Residents need not live in fear of serious health consequences."

It's Too Dangerous (no it's not)

Does this prove. . .



When the Hindenburg exploded May 6, 1937

It's Too Dangerous (no it's not)

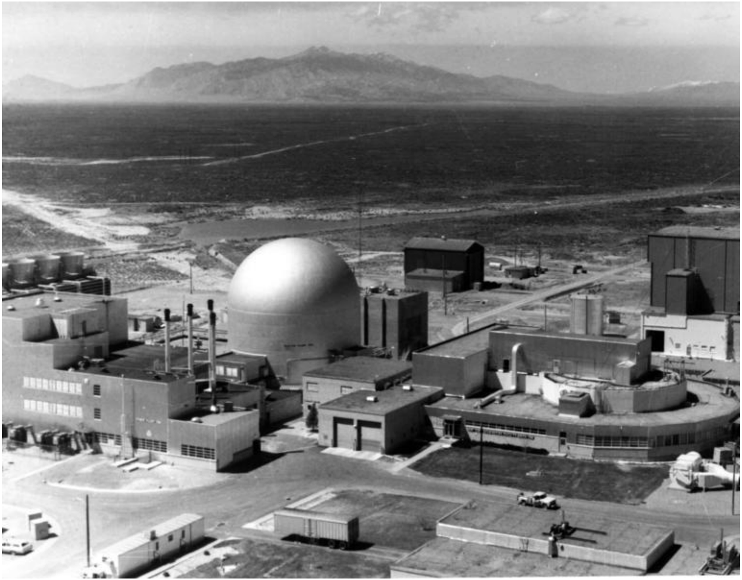
This isn't safe?

It's Too Dangerous (no it's not)

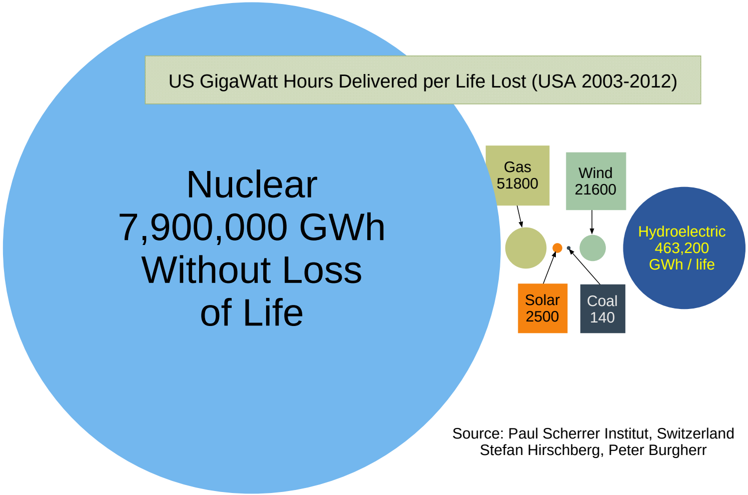
Does this prove. . .

It's Too Dangerous (no it's not)

This isn't safe?



It's Too Dangerous (no it's not)



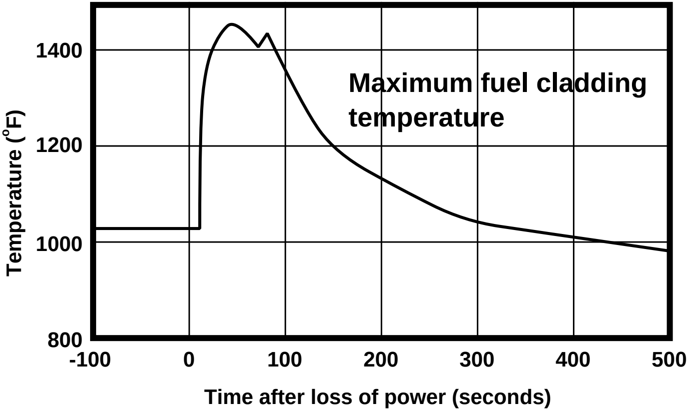
It's Too Dangerous (no it's not)

Despite the perfect safety record of licensed nuclear reactors, scientists, engineers, chemists, and metallurgists at Argonne National Laboratory and Idaho National Laboratory set out to **solve all the world's energy problems** with one system that

- Is inherently safe,
- Consumes existing nuclear waste, effectively destroying it,
- Is economical to build and operate,
- Is extremely resistant to diversion for nefarious purposes, and
- Creates more fuel than it consumes.

And they did it! Then the Clinton administration canceled the project in 1993, when it was an inch from completion, at more cost than finishing it. Clinton pandered "I know; it's a symbol."

It's Too Dangerous (no it's not)



Result of 1986 safety test at EBR-II

Fuel pin cladding melts at 3360°F.

David Baurac, *Passively safe reactors rely on nature to keep them cool*, **Logos 20** (2002)
http://www.ne.anl.gov/About/hn/logos-winter02-psr.shtml

It's Too Dangerous (no it's not)

43 deaths in the entire fifty-year history of generating electricity using nuclear power.

All at a reactor that never should have been built.

There is nothing that humans do that is safer.

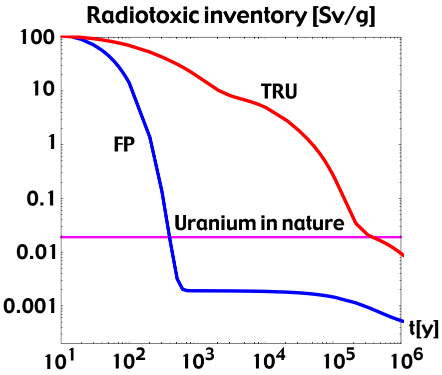
No One Knows What to Do about Nuclear Waste
(yes we do know)
(and we have known for seventy years)

No One Knows What to Do about Nuclear Waste

Spent fuel consists of **5% fission products** and **95% unused fuel**.

Unused fuel is dangerously radiotoxic for 300,000 years.

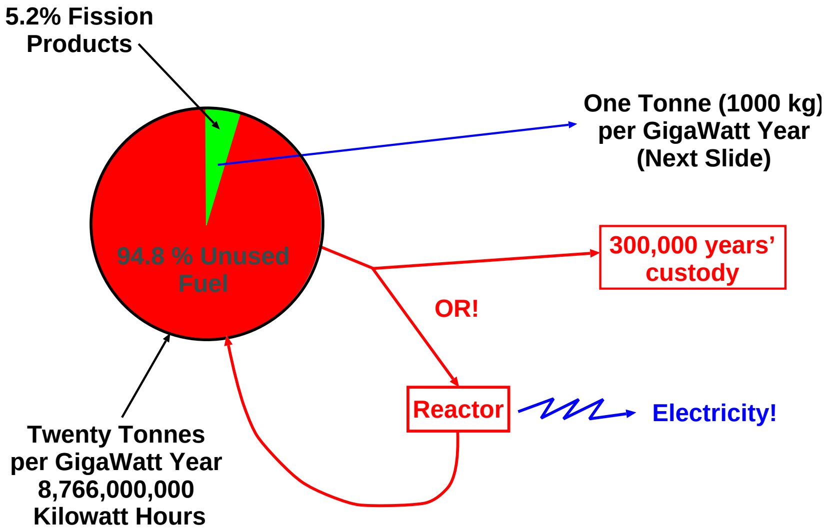
Fission products are dangerously radiotoxic for 300 years.



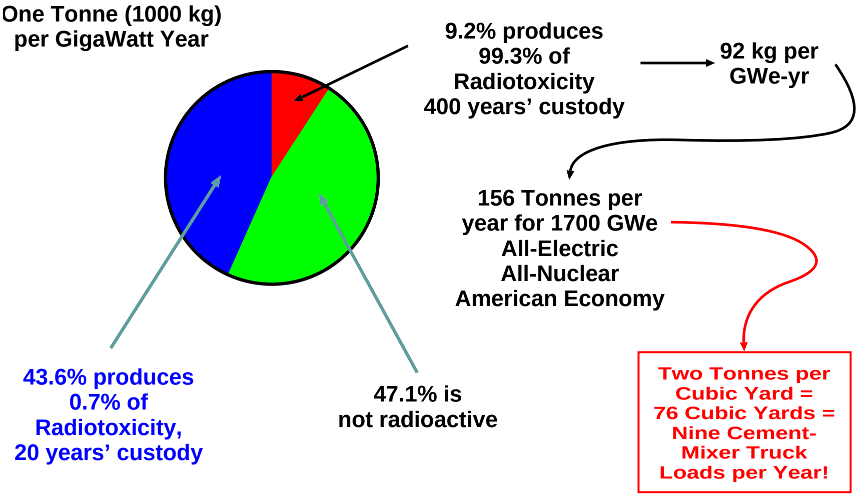
Janne Wallenius, *Återanvändning av långlivat kärnavfall och sluten bränslecykel möjlig i nya reaktortyper*, **Nucleus** (April 2007), page 15

Recycling of long-lived nuclear waste and a closed fuel cycle are possible in new reactor types

Closed Fuel Cycle
Recycling Long-Lived Waste



Fission Products



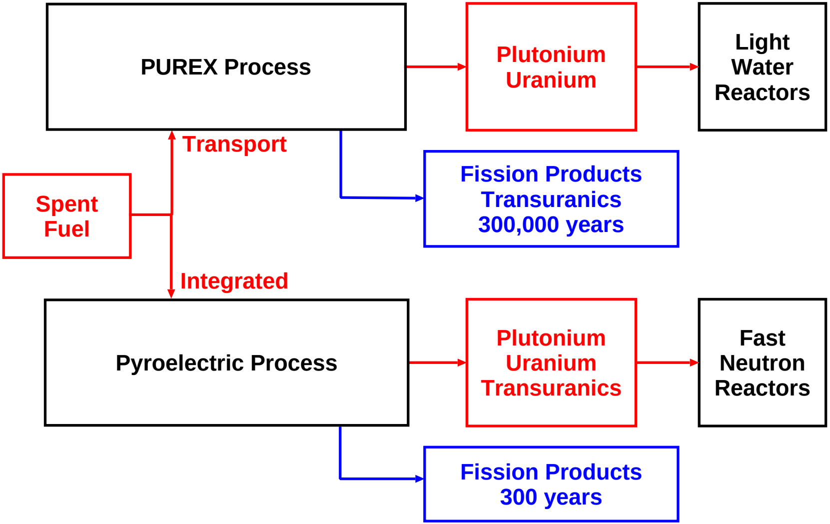
PUREX
Plutonium and **UR**anium **EX**traction

- Used in the United States until the late 1970's; still used in France, Britain, and Russia.
- Does not separate other transuranics from fission products.
- Solvent-refining process using immiscible solvents – water and tributyl phosphate – in counter-current flow.
- Very dilute, to avoid criticality (water is a good moderator).
- Plant occupies thousands of acres, has kilometers of pipes, thousands of reaction vessels, and hundreds of pumps.
- Very expensive to build, operate, and maintain.
- Leaks a lot.
- Spent fuel must be transported from reactors to a huge processing plant.

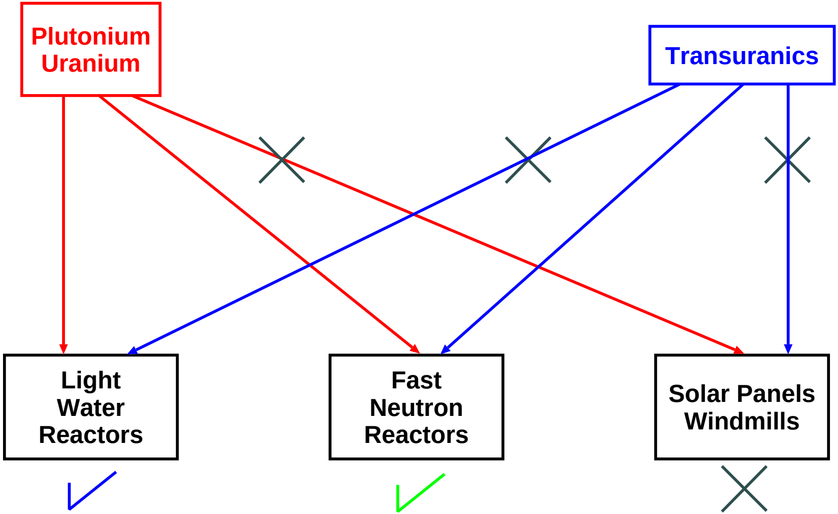
Pyroelectric refining
Similar to Electroplating

- Separates *all* transuranics from fission products.
- Molten salt process.
- Stand-alone 100 tonne per year plant, including fuel pin processing, laboratories, offices, parking, storage... would occupy forty acres.
- Estimated to cost about $500 million.
- Could process fuel from 5 GWe capacity plant(s).
- 100 tonne per year electrorefiner would be sixteen cubic yards – six feet $\times$ six feet $\times$ twelve feet.
- Integrated with reactor would be sized to match reactor capacity, share laboratories, offices, parking, storage... and be less expensive.
- No need to transport spent fuel if reactor and fuel reprocessing are integrated.

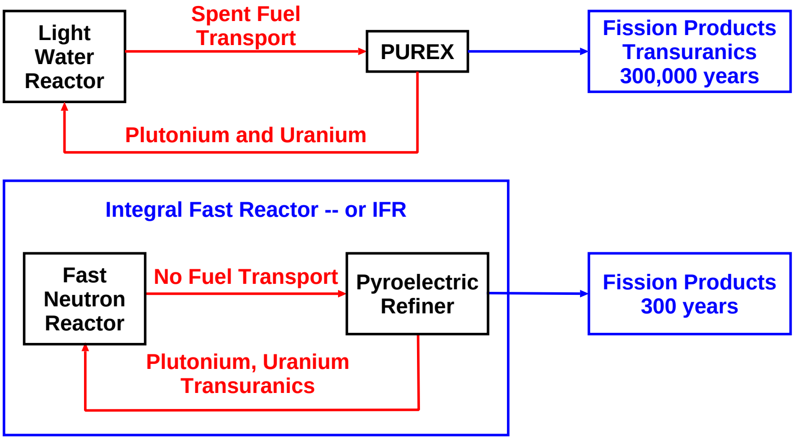
PUREX vs Pyroelectric



The 300,000 year problem



Integral Fast Reactor



Canceled by the Clinton administration in 1993 after 30 years' flawless operation, when it was an inch from completion, at more cost than completing it. **Clinton pandered "I know; it's a symbol."**

What I would do with fission products

1. Separate caesium and strontium – the 9.2% 300-year problem.
2. Convert to impervious insoluble ceramic.
3. Encase a cubic foot of it in a cubic yard of concrete.
4. Drop it into the Pacific Ocean halfway between Hawaii and Alaska.

   It would sink hundreds of feet into the mud at the bottom.

   Concrete dockworks poured by the Romans at Caesarea in Israel are still intact.
   By the time the concrete degrades so seawater can contact the impervious insoluble ceramic, there's less than 1% chance that one radioactive atom remains.

- Store the 43.6% 30-year problem until it's not dangerous.
- Sell what can be sold (rhodium is worth $500 per gram).
- Recycle the zirconium into new fuel-pin cladding (who cares that it's mildly radioactive?).

No One Knows What to Do about Solar Panel Waste
(Just for Comparison)

- Solar panels require 300 times more material per watt of capacity than nuclear power plants.
- Nuclear fuel is a tiny fraction of a nuclear power plant.
- When solar panels are taken out of service they enter the E-waste stream.
- E-waste is sent to Bangladesh or Africa for processing, where children disassemble and recycle them.
- Children are exposed to toxic heavy metals such as cadmium, chromium, and lead.
- Heavy metals are toxic forever. Fission products decay to elements that are not radioactive.

Nuclear Waste Disposal Fund

- Nuclear utilities paid 0.1 ¢/kWh for waste disposal.
- The Nuclear Waste Disposal Fund accumulated $25 billion.
- $8 billion was spent on Yucca Mountain. $43 billion to finish it.
- Eight Yucca Mountain-size repositories required.
- The Nuclear Waste Disposal Fund should be used to build pyroelectric reprocessing plants.

Nuclear power is the only industrial activity that fully includes all costs, including environmental costs, in the price of the product.

It's Too Expensive

Compared to What?

It's Too Expensive

Compared to What?

- **Wind:** Cannot provide more than 15% of today's total energy use.
- **Hydro:** 7% of today's US electricity, or 1.4% of total energy; cannot increase and will probably decrease.
- **Waves, tides, ocean currents, geothermal, biofuels, unicorns, pixie dust, vigorous hand waving:** Too small to be relevant.
- **Solar** is the only "renewable" source that can in principle provide all our energy (but what about storage?).

It's Too Expensive
Compared to What?

- Solar without storage: 11.7¢/kWh **unsubsidized cell capital cost alone**. Doesn't include
  - Fabrication into panels.
  - Transportation.
  - Installation.
  - Maintenance.
  - Recycling.
- Solar with storage: $4.10/kWh.
- Diablo Canyon: 5¢/kWh (Why does California legislature want to shut it down in 2024? Write to your legislators).
- Palo Verde: 4.3¢/kWh.
- Columbia Nuclear Generating Station: 4.7 – 5.2¢/kWh.
- Fully-amortized plants: 2¢/kWh (1.5¢ for operations, 0.5¢ for fuel).

It's Too Expensive

Compared to what?

- Nuclear power plants' capacity factors $> 90\%$.
- Nuclear power plants don't need energy storage.
- 2009 MIT study concluded nuclear power plants could be built for \$4/watt and produce electricity for 6¢/kWh, including capital amortization.
- First-of-a-kind 300 MWe fast neutron reactor might cost \$8/watt.
- GE says they can build 380 MWe modules for $<$ \$2/watt.

Nuclear power is artificially inexpensive because of subsidies (no, it's not)

2018 direct Federal subsidies for electricity generation
(latest year available from EIA)

	Coal	Gas	Hydro	Nuclear	Wind	Solar PV
¢/kWh	0.071	−0.066	0.0127	0.020	0.563	2.453
per nuclear $	2.158	−3.285	0.635	1.000	42.59	112.65

Yes, the government made a profit on gas

https://www.eia.gov/analysis/requests/subsidy/

Solar and wind subsidies, and mandates on utilities to buy solar and wind power at more than their generation cost, and distribute it, are driving utilities that own nuclear power plants into bankruptcy.

It's Too Expensive

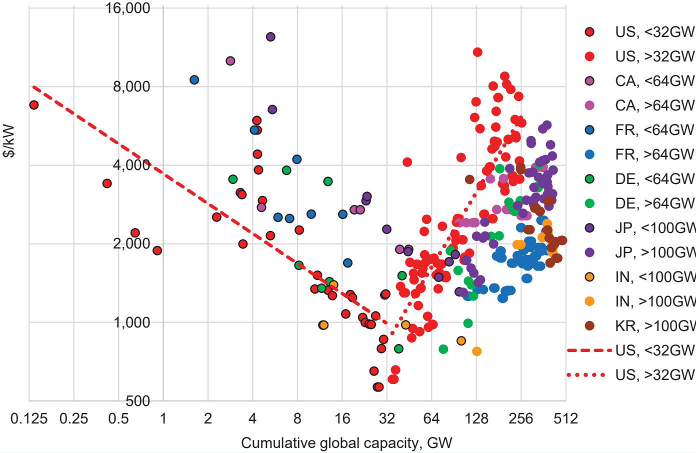


Figure 1: Overnight construction cost (in 2010 US$/kW) plotted against cumulative global capacity (GW), based on construction start dates, of nuclear power reactors for seven countries, including regression lines for US before and after 32 GW cumulative global capacity.

Peter Lang, *Nuclear Power Learning and Deployment Rates: Disruption and Global Benefits Forgone*, CAMA Working Paper No. 4/2017(January 15, 2017). Available at http://dx.doi.org/10.2139/ssrn.2899971

It Leads to Nuclear Weapons Proliferation

A Giant Stinking Red Herring

It Leads to Nuclear Weapons Proliferation

- Weapons grade plutonium is 93% fissionable ^{239}Pu.
- Plutonium in spent fuel is 55% ^{239}Pu.
- Plutonium in spent fuel is in a highly-radioactive and therefore easily monitored state.
- Yield of British experiment with 63% ^{239}Pu was much less than the Hiroshima uranium device.
- No one has ever deployed an operational weapon made from spent fuel. Heat and radiation would distort fine tolerances, require remote fabrication, damage chemical explosives, and might cause predetonation.
- LLNL report said **spent fuel cannot be used to make a nuclear weapon without significant further processing.**

Weapons-ready material from spent reactor fuel does not exist!

It Leads to Nuclear Weapons Proliferation

Even if “Weapons-ready material” existed “Proliferation” is still a red herring

- No country’s municipal reactors or reprocessing affect any other country’s ability or desire to make nuclear weapons. After USA naïevly stopped reprocessing fuel. . .
  - Pakistan developed nuclear weapons.
  - North Korea developed nuclear weapons.
  - Iran is developing nuclear weapons.
  - Iraq had an on-again off-again nuclear weapons program.
  - Libya had a very sophisticated and very advanced nuclear weapons program.
- On-site reprocessing implies very few opportunities for diversion or theft.
- Advanced industrial economies could make weapons much more effectively than from used municipal reactor fuel.

There Isn't Enough Uranium (fission is an inexhaustible energy source)

There Isn't Enough Uranium

- USA has 80,000 tonnes of used fuel and 700,000 (some say 900,000) tonnes of depleted uranium.
- Enough to power the entire American energy economy for 450 (or 575) years using fast-neutron reactors.
- Enough uranium could be recovered economically at current prices to power the entire world for 1,200 years using light-water reactors.
- Current reactors extract 0.6% of energy in mined uranium; IFR-type reactors extract more than 99%: **Currently-known reserves would last 200,000 years.**
- Uranium contribution to fuel cost would still be 0.001¢/kWh if it cost 167 times more.
- Economical to extract from lower-quality ores, and from seawater, where there's 1000 times more.
- Uranium is four times more common than tin and ten times more common than silver.
- Thorium is four times more common than uranium.

There Isn't Enough Uranium

Nuclear fission is an inexhaustible energy source!

Of What Use Are Windmills and Solar Panels?

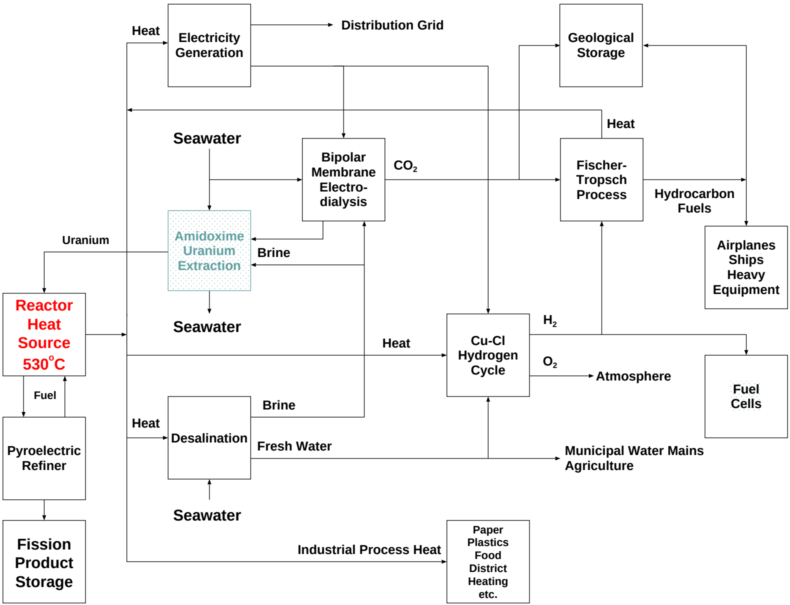
- Windmills and solar panels cannot follow demand.
  - If your hospital goes dark, you have a problem.
  - If your foundry freezes, you have a problem.
  - If the oven in your bakery goes cold, you have a problem. . . .
- Assuming you're willing to accept their risk, they could be used for problems that tolerate variable supply:
  - Desalination.
  - Charging batteries.
  - Extracting CO_2 from seawater using PARC Bipolar Membrane Electrodialysis.
  - Pumping water. . . .

Ships and Airplanes

- We will need liquid hydrocarbon fuels forever for airplanes.
- We will probably need liquid hydrocarbon fuels forever for ships.
- We might need liquid hydrocarbon fuels forever for heavy construction equipment and heavy agricultural equipment.
- We might even need liquid hydrocarbon fuels forever for automobiles.
- Hydrocarbon fuels should be made from CO_2 and hydrogen extracted from seawater, using the Fischer-Tropsch process, developed in 1925.

  This would likely be a net negative transfer of CO_2 to the atmosphere and oceans, not a net zero process, because some of the CO_2 that results from burning the fuels would be incorporated into plants and soils.

My Idea for a Combined Energy Center



More Food for Thought

- Breeder reactors make 5% more plutonium than they consume, from non-fissionable but plentiful ^{238}U, or 1% more ^{233}U from even more plentiful ^{232}Th.
- In 14 years, they make enough fuel to start a new reactor of the same size (70 years with thorium).
- Breeder reactors can be fueled with natural uranium plus reactor-bred fissionables.
  It will never again be necessary to enrich uranium. Any one who claims to need to enrich uranium for municipal electricity service would be exposed as a liar who has a weapons program.
- Plutonium is **not** the most toxic substance known. It is less chemotoxic than lead, and far far far less chemotoxic than ricin, but it is dangerously radiotoxic if inhaled or ingested.
  Yttrium-90 is 94,490 times more radiotoxic.
  Praseodymium-144 is 242,960 times more radiotoxic.

More Food for Thought

Current US inventory of fissionable material is 1125 tonnes.

- **No one has any idea what to do with it, other than to make electricity from it** – or store it for 300,000 years.
- **Solar panels and windmills cannot make electricity from it.**
- 1125 tonnes could immediately start 110-140 GWe capacity.
- At 5% breeding rate, 1,700 GWe capacity could be reached in 50-60 years without mining, milling, refining, or enriching any new uranium.

More Food for Thought

- "Developed nations should spend 1% of GDP to reduce CO_2 emissions by 25-70%, and another 1% to cope with climate change."

  Sir Nicholas Stern, vice chairman and chief economist of the World Bank.
- Spending 2% of U.S. GDP during the 50-60 years required to deploy an all-IFR energy economy would cost $18-20 trillion.
- Improvements to the electrical grid necessary to use dispersed and variable sources would add $4-5 trillion.
- Storage to mitigate variability would cost **$76 trillion per year – four times US GDP** – too expensive to contemplate seriously.
- Deploying 1,700 GWe of IFR capacity would cost $2.1-3.7 trillion, and would reduce net CO_2 emissions by well over 95% (not just 25-70%).

More Food for Thought

- Russia and France have had sodium-cooled fast-neutron reactors since 1973.
- China has contracted to buy BN-800 from Russia.
- Russia is developing BN-1200.
- India is building a 500 MWe prototype fast-neutron reactor to exploit its huge thorium reserves.
- A South Korean company plans to begin selling a 500 MWe fast-neutron reactor in 2020.
- American nuclear engineers and scientists are retiring and dying faster than new ones are being prepared. America will soon be a third-world country in energy technology.

Conclusion

An all-renewable energy system cannot work.

The five oft-cited objections to nuclear power are all baseless falsehoods.

Renewable sources cannot mitigate the "nuclear waste" problem.

It is clearly obvious that nuclear power in the form of clean safe fast-neutron breeder reactors with on-site pyroelectric refining must be a necessary (and economical) part of the American energy economy.

Should the United States develop the technology we invented, or buy it from Russia, China, South Korea, and India?

The sooner we start, the better off we will be.

Additional Reading

William Hannum, Gerald Marsh, and George Stanford, *Smarter Use of Nuclear Waste*, **Scientific American** (December 2005 and online).

Charles E. Till and Yoon Il Chang **Plentiful Energy**, Amazon (2011) ISBN 978-1466384606.

Tom Blees, **Prescription for the Planet** (2008) ISBN 1-4196-5582-5, ISBN-13 9781419655821.

UNSCEAR, *Scientific Annex D: Health effects due to radiation from the Chernobyl accident*, in **Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report to the General Assembly, Volume II**, ISBN-13 978-92-1-142280-1 (2011).

UNSCEAR, *Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami*, in **Sources and Effects of Ionizing Radiation, UNSCEAR 2013 Report, Volume I**, ISBN 978-92-1-142291-7 (2014).

Watch these videos!

Climate Matters

James Hansen and Michael Shellenberger: *Nuclear Power? Are Renewables Enough?*

`https://www.youtube.com/watch?v=v1f4BKsFrCA`

The New York Times Conferences ClimateTECH

Simon Irish, Michael Shellenberger, Lisa Friedman: *Untying the Nuclear Knot*

`https://www.youtube.com/watch?v=PHrBI1Iz_7c`

How Fear of Nuclear Ends

Michael Shellenberger
TEDx CalPoly

`https://www.youtube.com/watch?v=mI6IzPCmIW8`

Why I changed my mind about nuclear power

Michael Shellenberger
TEDx Berlin

`https://www.youtube.com/watch?v=ciStnd9Y2ak`

Five Myths about Nuclear Power

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http://vandyke.mynetgear.com/Nuclear.html

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