Where Will We Get Our Energy?

Van Snyder

van.snyder@sbcglobal.net

vandyke.mynetgear.com/Nuclear.html

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What's The Problem?

- **Wind:** Cannot provide more than 15% of today's total energy use.
- **Hydro:** Provides 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.

What's The Problem?

No one knows how to make a 100%-renewable electricity system work

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.

The paper reviewed 24 schemes published in peer-reviewed professional journals that claimed to be viable designs for 100%-renewable electricity systems.

The schemes were scored on seven criteria.

No scheme satisfied more than four criteria.

What's The Problem?

Storage is not economically feasible

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): 36 years North America geophysical data. **400-800 watt hours per average watt.**

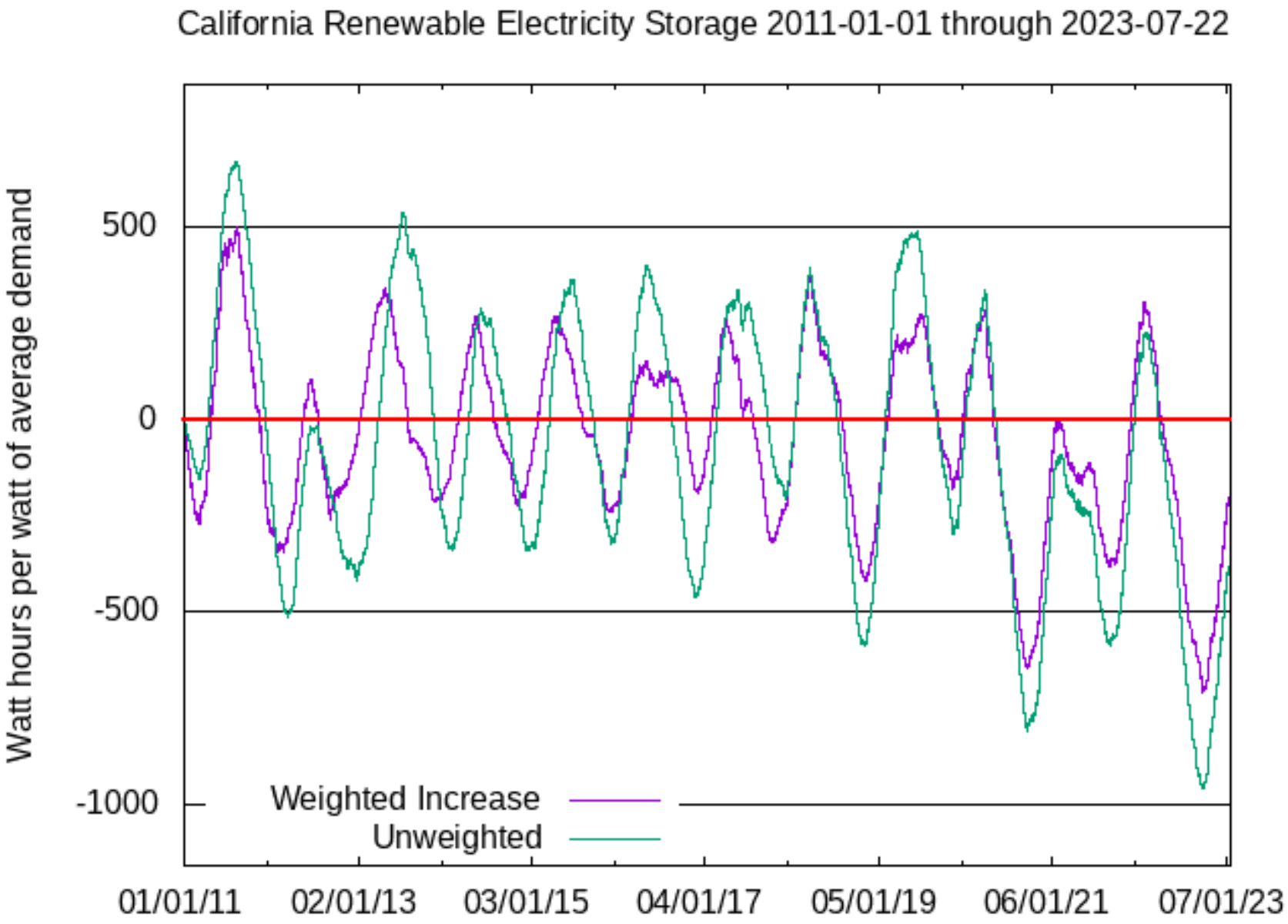
Euan Mearns, **Energy Matters**: 2016 England & Scotland renewable output. **390 watt hours per average watt**.

Norman Rogers, **Is 100 Percent Renewable Energy Possible?** Same for Texas. **400 watt hours per average watt.**

James Hansen and Michael Shellenberger:
ClimateMatters.TV with host Stuart Scott
Nuclear Power? Are Renewables Enough?
Bonn 2017

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

What's The Problem?



What's The Problem?

Why not back up using batteries?

All-electric US economy would have 1,700 GWe average demand.

Tesla PowerWall 2 price is \$0.578/Wh before installation, \$0.778/Wh installed.

Most optimistic estimate

1,700 GWe $\times$ 390 Wh/W $\times$ \$0.578/Wh = **\$383 trillion.**

Five year battery life = \$76 trillion per year =

FOUR TIMES TOTAL US GDP EVERY YEAR!

What's The Problem?

Capacity Factors

$$\text{Capacity Factor} = \frac{\text{Actual Output (kWy)}}{\text{Label Capacity (kW)} \times \text{One Year}}$$

Solar and wind capacity factors are 25-30%.

Three to four times label capacity is needed to match demand.

Backup using batteries means doubling that to **seven times label capacity** to keep the lights on AND charge batteries.

What's The Problem?

Dispersed, Variable, Unreliable Sources need 100% Backup 100% of the time

Solar and wind backed up with coal, gas or nuclear displace only the fuel cost.

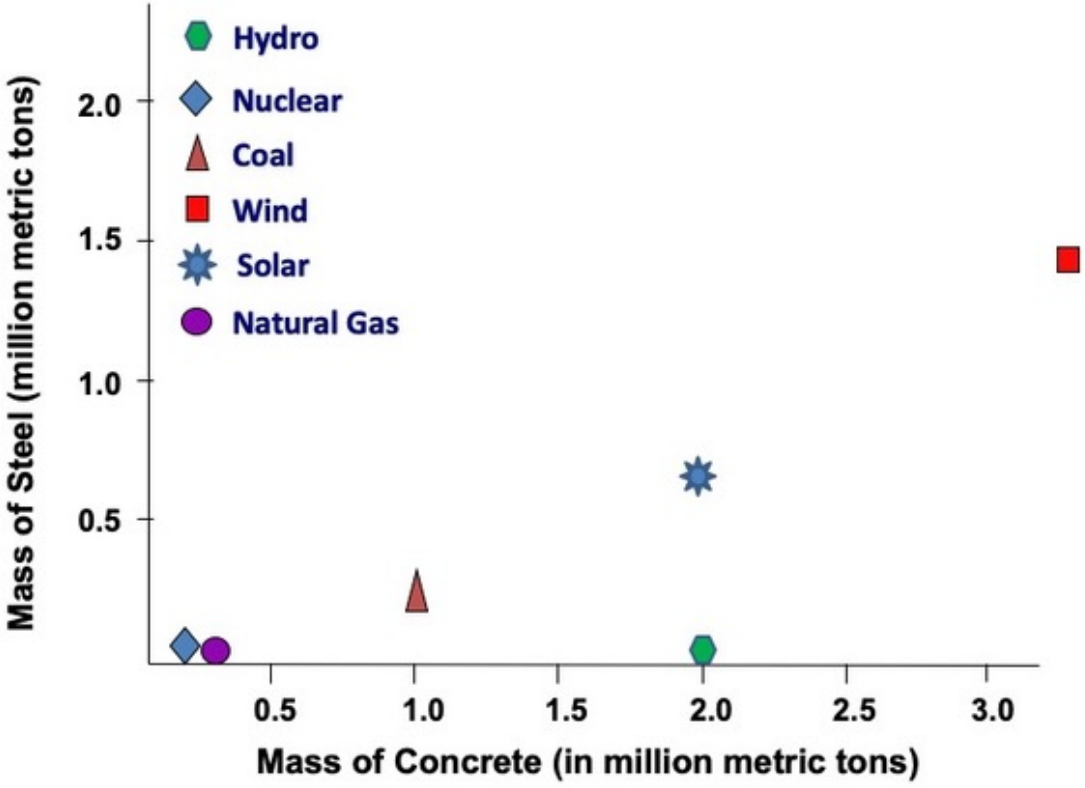
Backup must be online, ready to go, 100% of the time, idling, while operators play video games.

Solar and wind do not displace labor costs, capital costs, or interest on loans for backup systems.

IF YOU NEED THE BACKUP 100% OF THE TIME, WHY BUILD THE PRIMARY?

What's The Problem?

Serious Materials Problems



The amount of concrete and steel needed for various energy systems to produce 656,000,000 MWh

United States cannot make enough steel and concrete

What's The Problem?

Serious Materials Problems

Requirements to build new "technology units" of the IEA spectrum for a non-fossil-fuel economy:[1]

Metal	Required MT	2019 KT	Years to Produce	Reserves MT	Fraction Possible	Rock / Metal [2]
Copper	4 575.5	24 200	189	880	19%	513
Nickel	940.6	2 350	400	95	10%	250
Lithium	944.1	95	9921	22	2.3%	1630
Cobalt	218.4	126	1733	7	3.5%	895
Graphite	8 973.6	1 156	3288	320	3.6%	
Vanadium	681.8	96	7101	24	3.5%	1340
Neodymium	0.97	24	40	8	829%	

Copper requirement alone is about six times the total amount mined in all of human history.

Old units are only about 30% recyclable, and need replacement every twenty years.

[1] Prof. Simon Michaux, Geologian Tutkimuskeskus – Geological Survey – Finland.

[2] Rock-to-metal ratio from Nedal T. Nassar et al, US Geological Survey.

Serious Materials Problems

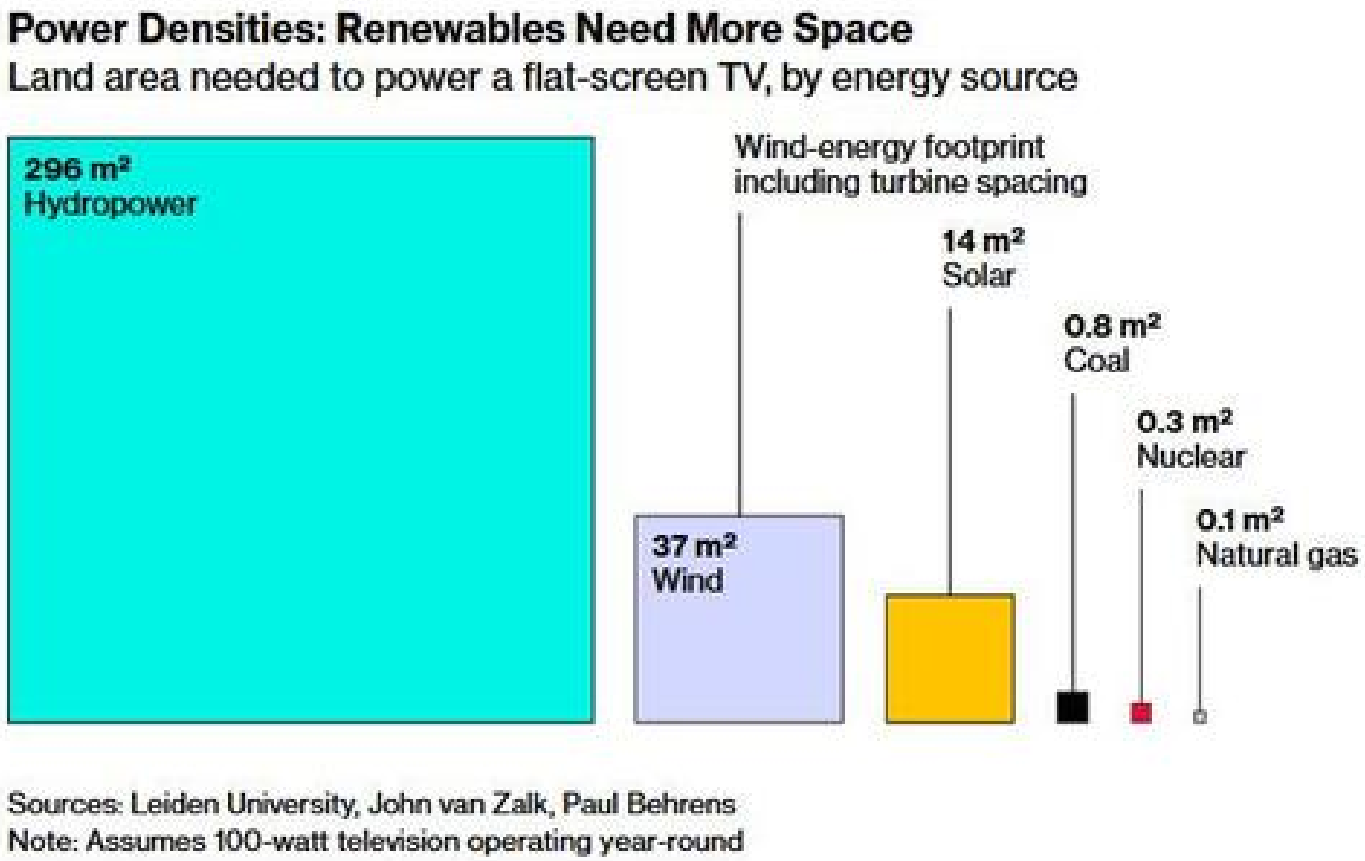
Lithium ion batteries are made from lithium, cobalt, nickel, graphite, aluminum, steel, plastic. . . .

- Essentially all the lithium comes from Tibet, and the Argentina-Chile-Peru triangle.
- Essentially all the cobalt comes from Chinese-owned mines in Congo, where four-year old children work for $2 per day.
- More than half the nickel comes from Russia.
- 70% of graphite comes from China.
- Every kilogram of lithium batteries requires mining and processing 500 kg of ores.
- More than 95% of all solar panels are made in China.

What's The Problem?

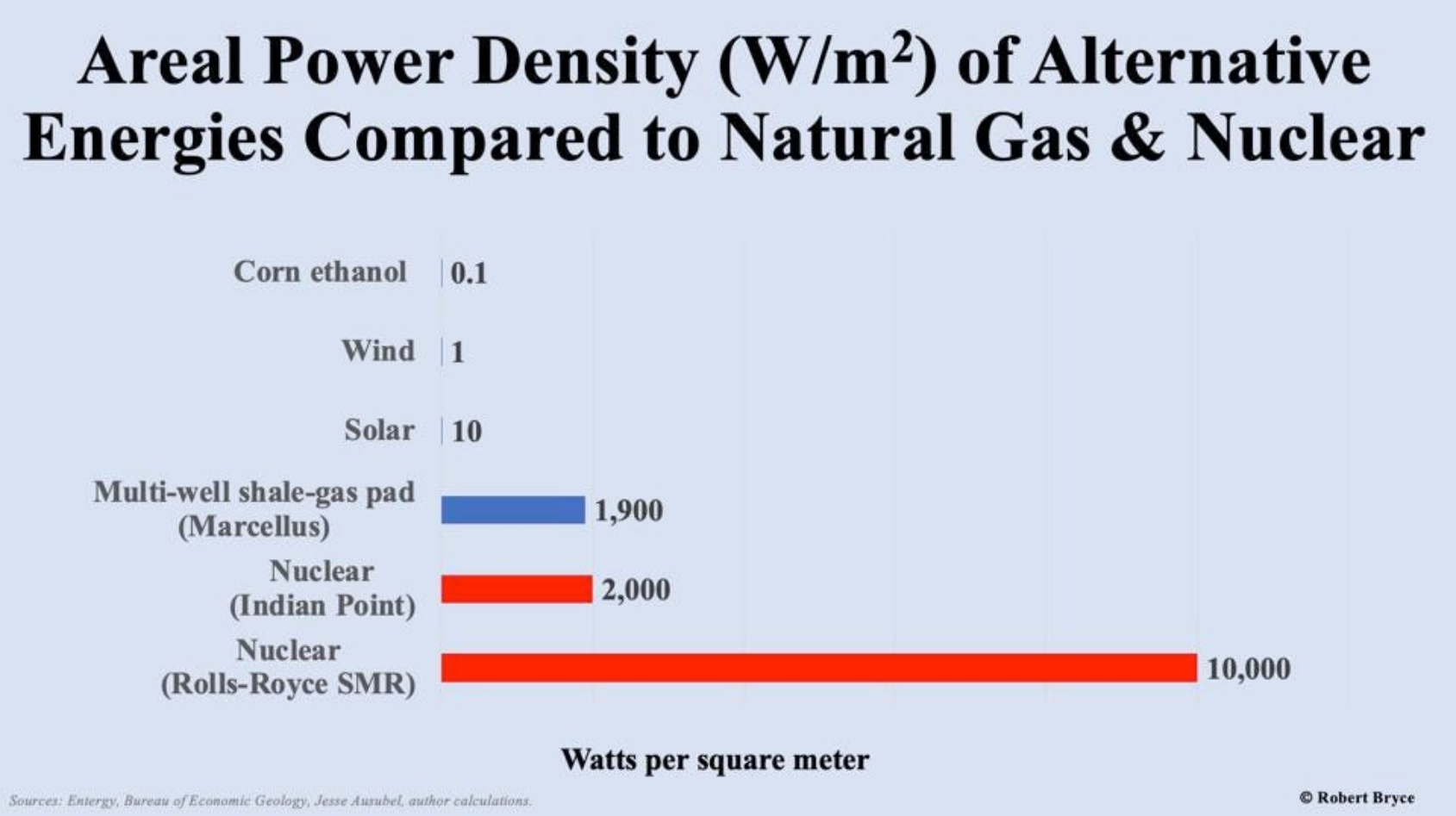
Land Requirements

Gas	Nuclear	Coal	Solar	Wind	Hydro
0.33	1.0	2.7	47	123	987



What's The Problem?

Power Density

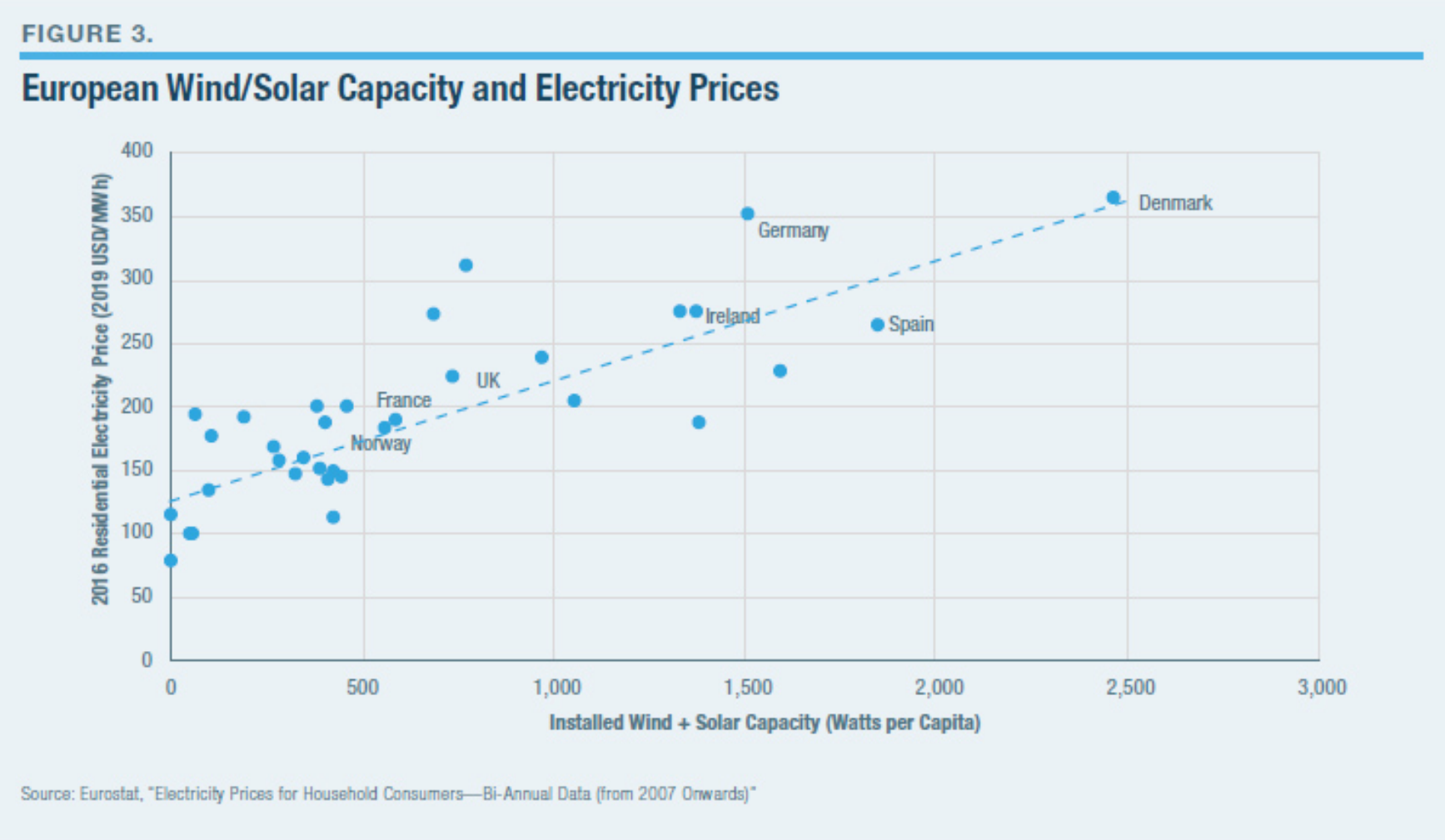


Environmental Problems

- Wind turbines generate harmful infrasound.
- Wind turbines cause light flicker.
- Wind turbines have aircraft warning lights blinking all night.
- Wind turbines kill birds – especially endangered raptors – and bats and beneficial insects.
- Offshore wind turbines ruin fishing.
- Magnetic fields from undersea cables cause birth defects in crabs and lobsters.
- Wind turbine blades are not recyclable.
- Mountain tops are being leveled.
- Forests are being cleared.

What's The Problem?

Solar and Wind increased costs in Europe



There is no place in the world where renewables increased and prices decreased.

Electromagnetic Pulse Vulnerability

- In 1969, the Sun belched out several trillion cubic miles of exceedingly hot plasma.
- When it hit the Earth, it caused an enormous electromagnetic pulse (EMP) that caused significant damage to electrical and electronic systems.
- The Sun does this about every eleven years.
- It hits the Earth about every sixty years.
- Millions of miles of additional wiring, millions of solar panels, thousands of windmills, and millions of electronic devices necessary to connect a grid of dispersed, variable, and unreliable sources, would be a giant EMP antenna.
- Damage would be immense. Recovery would take decades and cost trillions.

Nothing but nuclear power will work

(and not emit CO_2)

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, early member of Greenpeace, 2006

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

Greenpeace kicked Moore out for saying this.

Why NOT Nuclear Power?

The Five Myths

Alarmists say

- 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

But These Claims Are All False!

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

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

Why Are We Afraid?

Fossil fuel interests see nuclear power as a competitor.

- Rockefeller Foundation paid for fraudulent research to promote the false Linear No Threshold theory of risk.
- ARCO paid David Brower to start Friends of the Earth.
- Bloomberg pays Sierra Club to scare us.
- Low levels of radiation are helpful. Hiroshima and Nagasaki survivors in zones A and B had LOWER leukaemia incidence.
- Lower incidence of cancer in nuclear power plant workers.

Solar and wind need 100% backup, 100% of the time so fossil fuel interests support them

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

- **Three Mile Island**
  - **No one** was injured (except financially), made ill, or killed.
  - **no significant amounts of radioactive materials were released.**
- **Fukushima** (UNSCEAR 2013[3])
  - TEPCO was warned of tsunami hazard eight years earlier.
  - **No one** was made ill or killed.
  - Japan over-cleaned. The dirt in Fukushima is half as radioactive as the dirt in Denver.
  - Residents could return to their homes without risk.
  - 15,000 Japanese live as refugees in their own country.

In the entire civilized world, more people have been killed by Teddy Kennedy's car!

[3] 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) 321 pp.

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

Chernobyl, the irrelevant Hindenburg of nuclear power

(UNSCEAR 2008[4])

- Inherently unsafe. Unlicensed. Incompetently operated. Nothing like it built elsewhere, nor ever again.
- 28 deaths from acute radiation syndrome.
- "There is no scientific means to determine whether a particular cancer in a particular individual was or was not caused by radiation."[4]
- But it caused 15 fatal juvenile thyroid cancers?
- "Residents need not live in fear of adverse health effects."[4]

[4] 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) 179 pp.

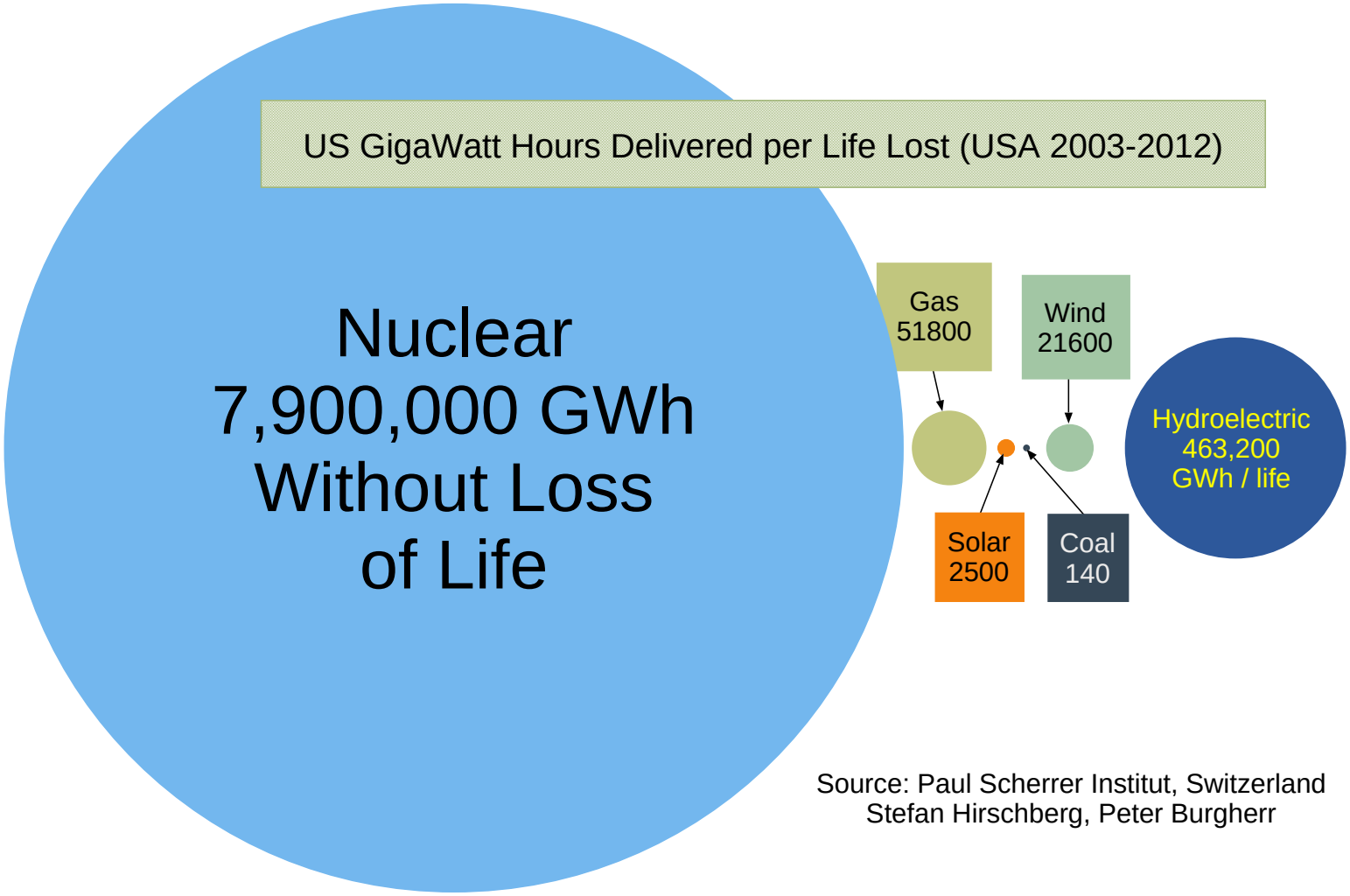
It's Too Dangerous (no it's not)

43 radiation-related deaths in the entire six-decade worldwide history of nuclear power!

Nothing else that humanity does is this safe!

Meanwhile: 7 million deaths per year, worldwide, from air pollution, from coal-fired power plants and using wood and dung for indoor cooking.

It's Not Safe (yes it is)



Source: Paul Scherrer Institut, Switzerland
Stefan Hirschberg, Peter Burgherr

(Bigger means safer)

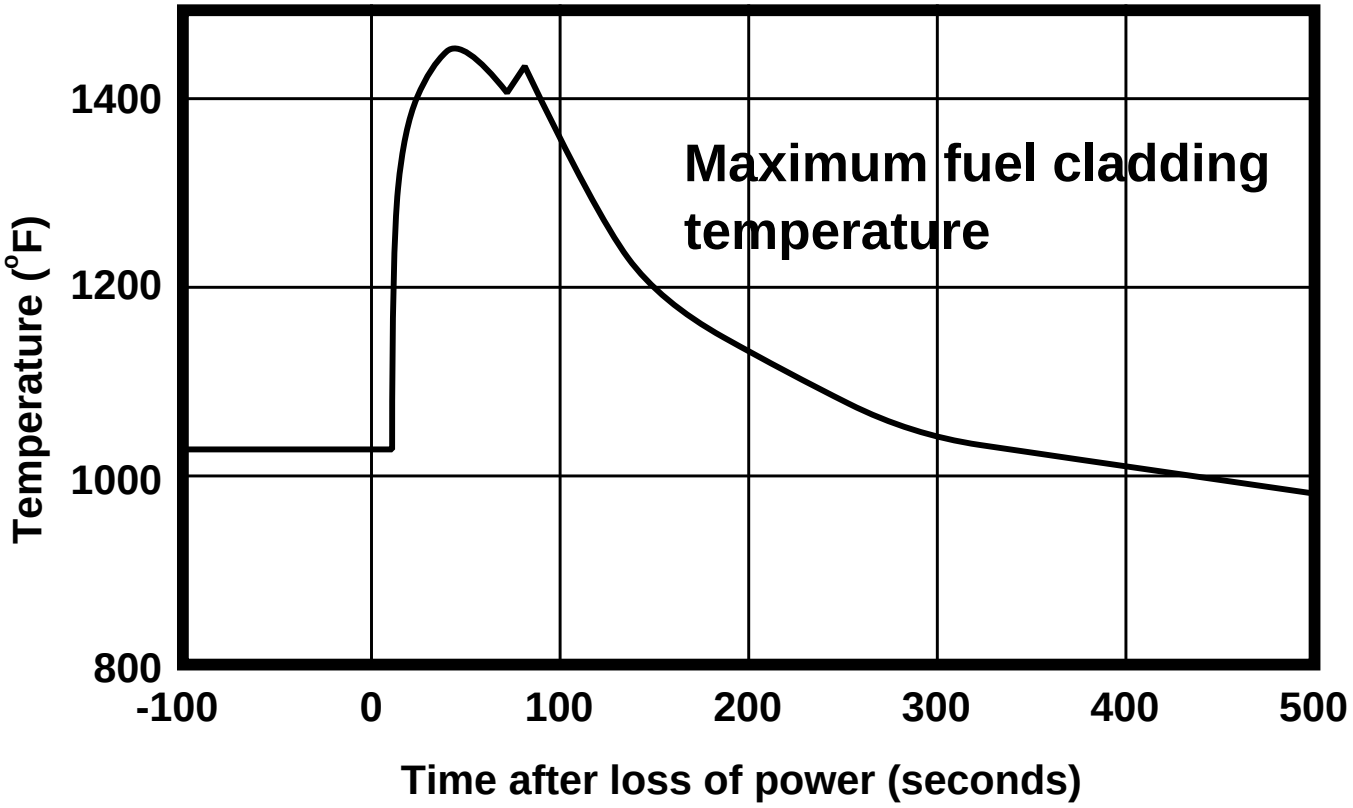
It's Too Dangerous (no it's not)

Notwithstanding the **perfect safety record** of American reactors, Argonne 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 research program in 1994, when it was an inch from completion, at more cost than finishing it and destroyed the reactor! Clinton pandered "I know; it's a symbol."

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



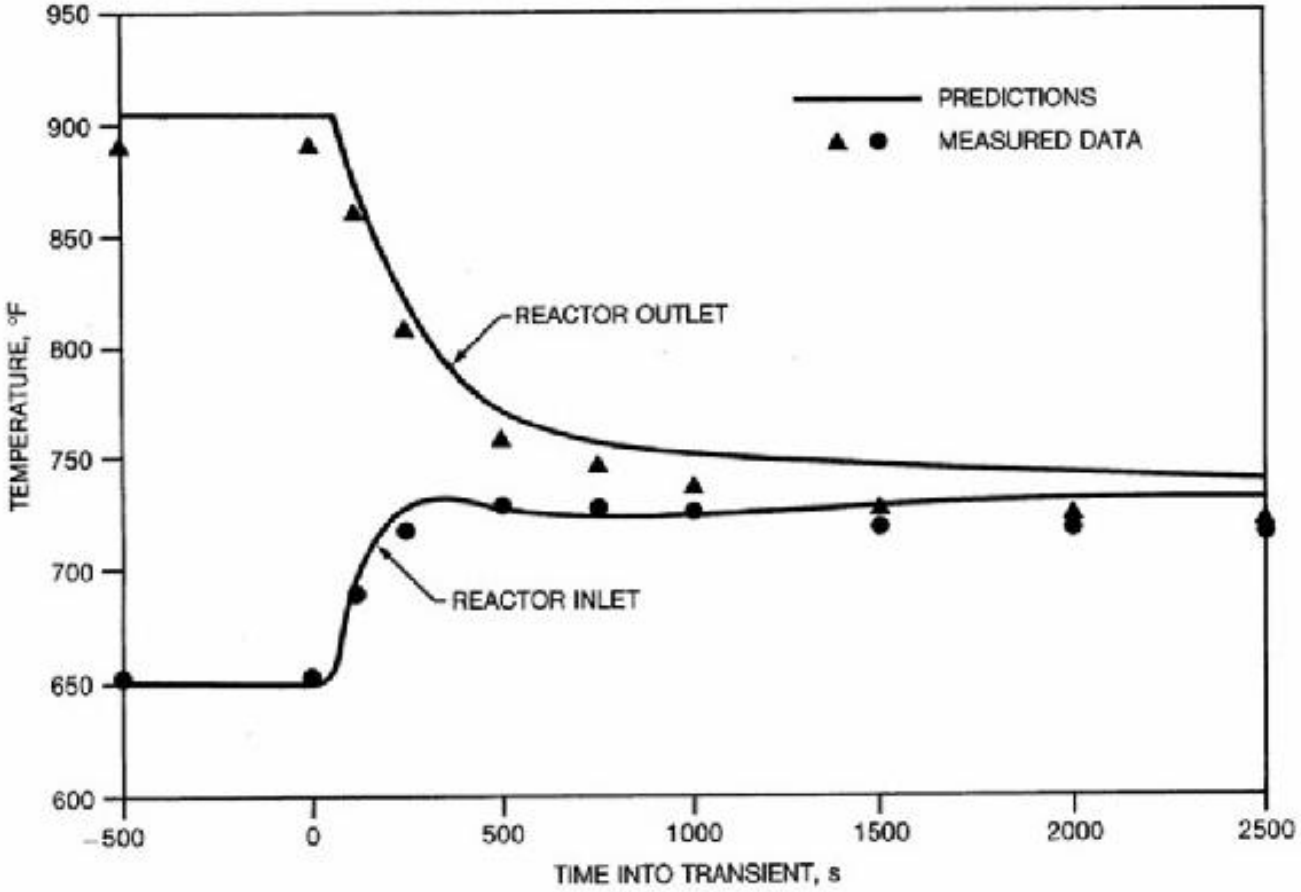
Result of 1986 safety test at EBR-II

Loss of Coolant Flow

Coolant boils at 1620°F. Fuel 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)



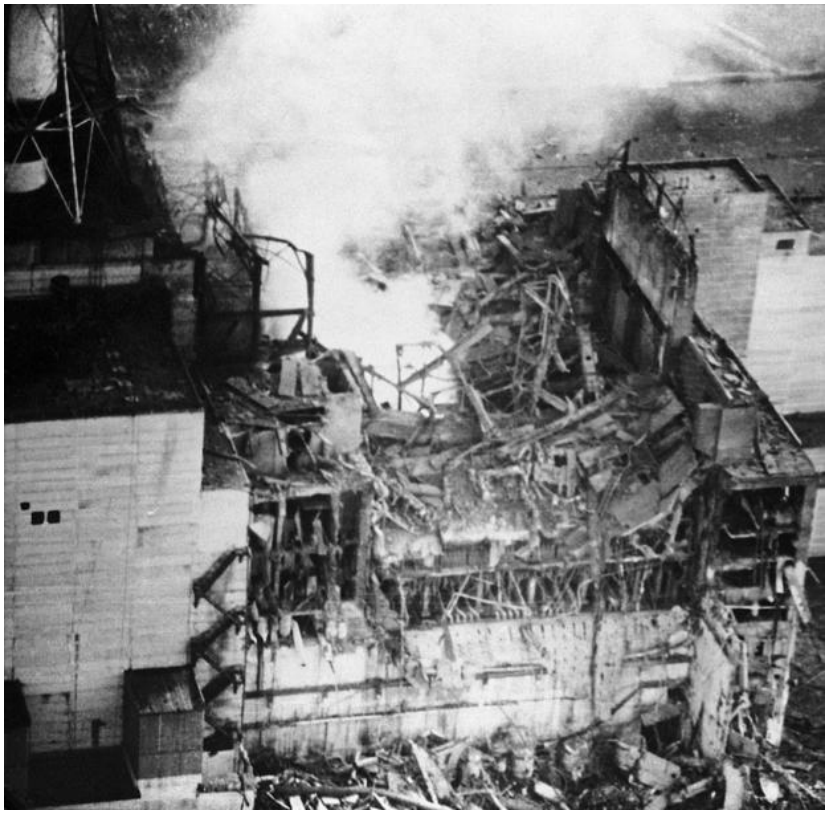
Result of 1986 safety test at EBR-II

Loss of Heat Sink

Yoon Il Chang, *Technical Rationale for Metal Fuel in Fast Reactors*, **Nuclear Engineering and Technology 39**, 3 (June 2007) http://koreascience.or.kr/article/JAKO200724737439335.pdf

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

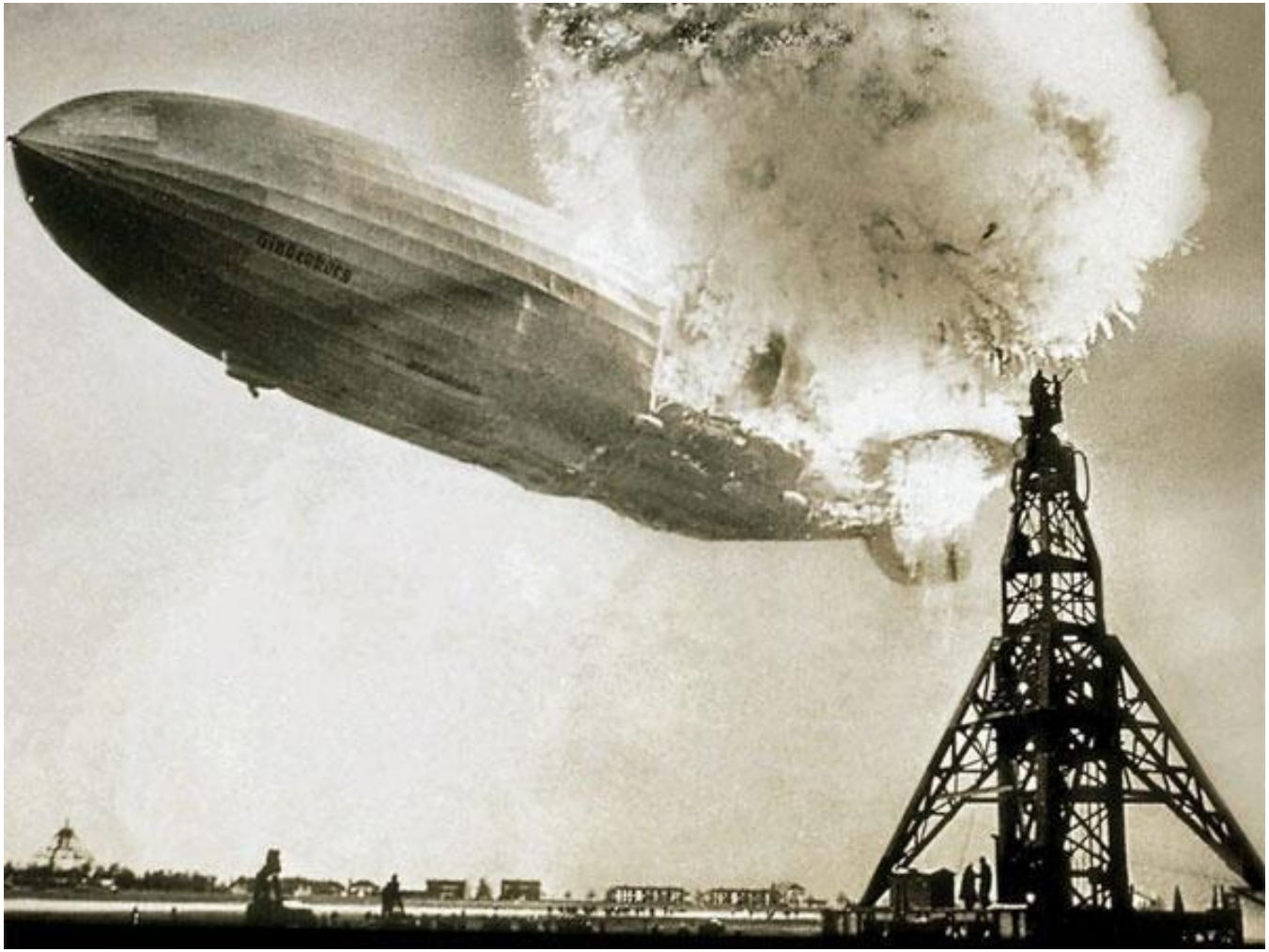
Six weeks later, operators at Chernobyl ran the second experiment



With rather different results.

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

So you see there is a difference between the Hindenburg



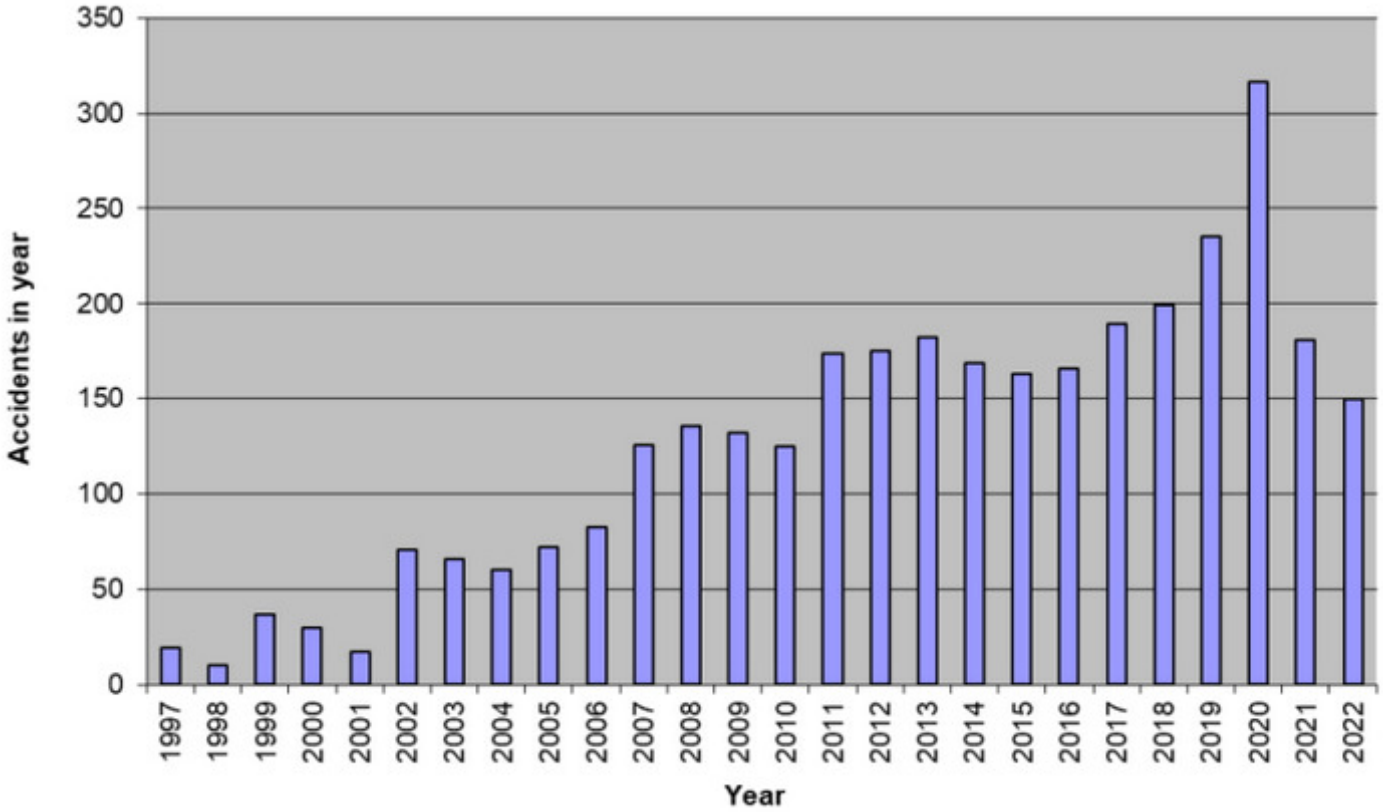
When the Hindenburg exploded May 6, 1937

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

And a Boeing 747

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

Meanwhile... Wind Accidents Continue[5]



229 Fatalities

Before 2000	2000 2005	2006 2010	2011 2019	2020	2021
24	16	37	73	9	3

[5] Caithness Wind Farms Forum.

No One Knows What to Do about Nuclear Waste

(yes we do know)

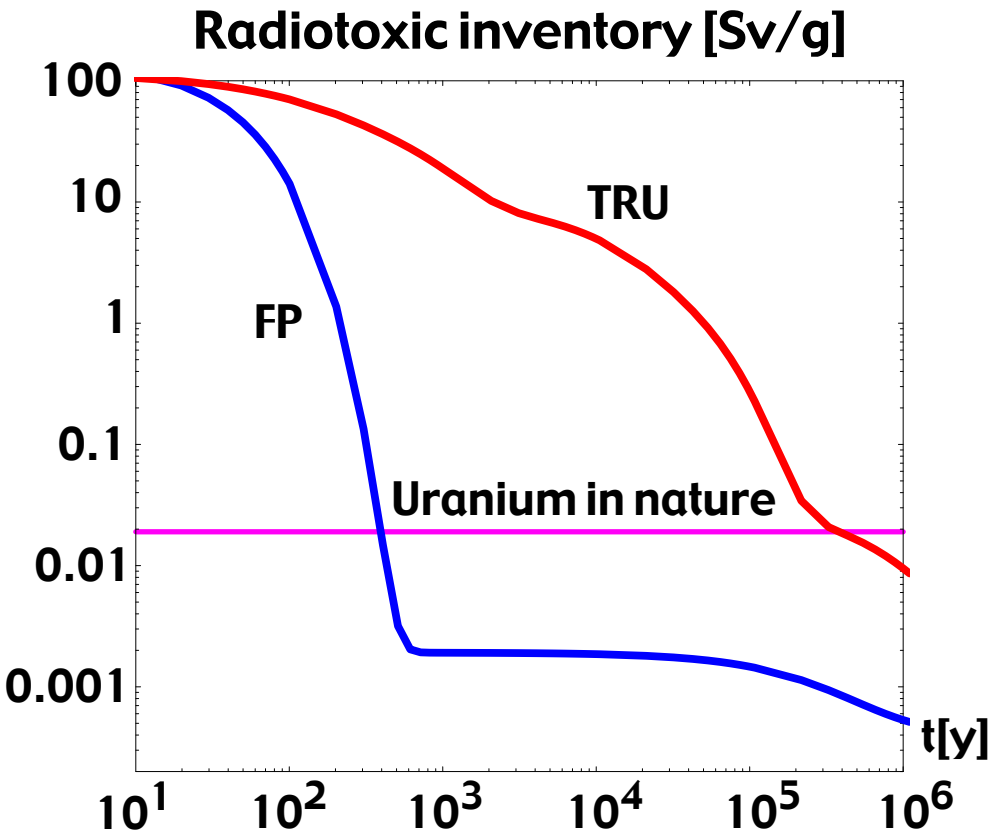
(and we have known for seventy years)

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 300-400 years.



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

No One Knows What to Do about Nuclear Waste

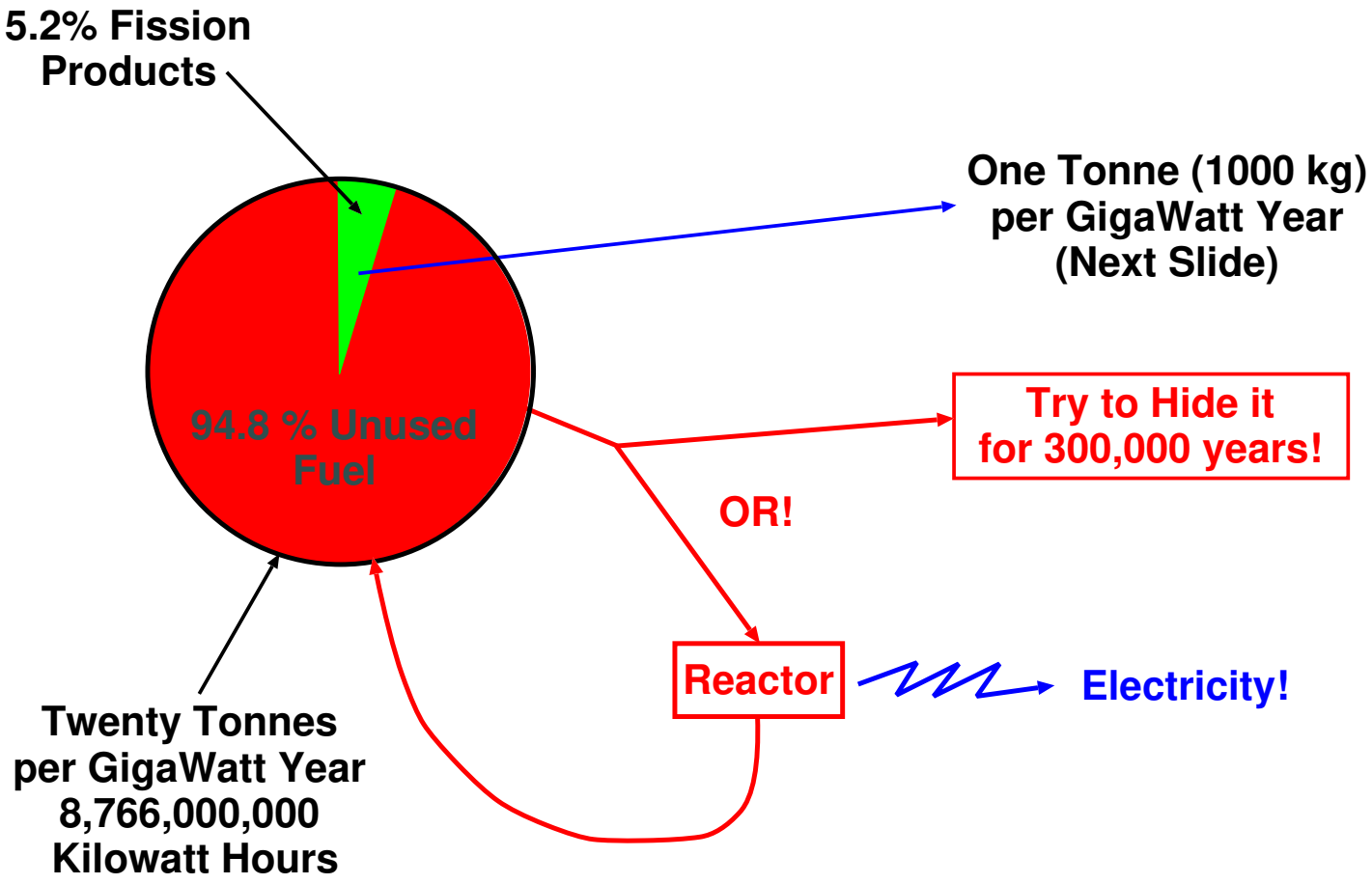
Unused fuel is dangerously radiotoxic for 300,000 years.

Fission products are dangerously radiotoxic for 300-400 years.

Let That Sink In

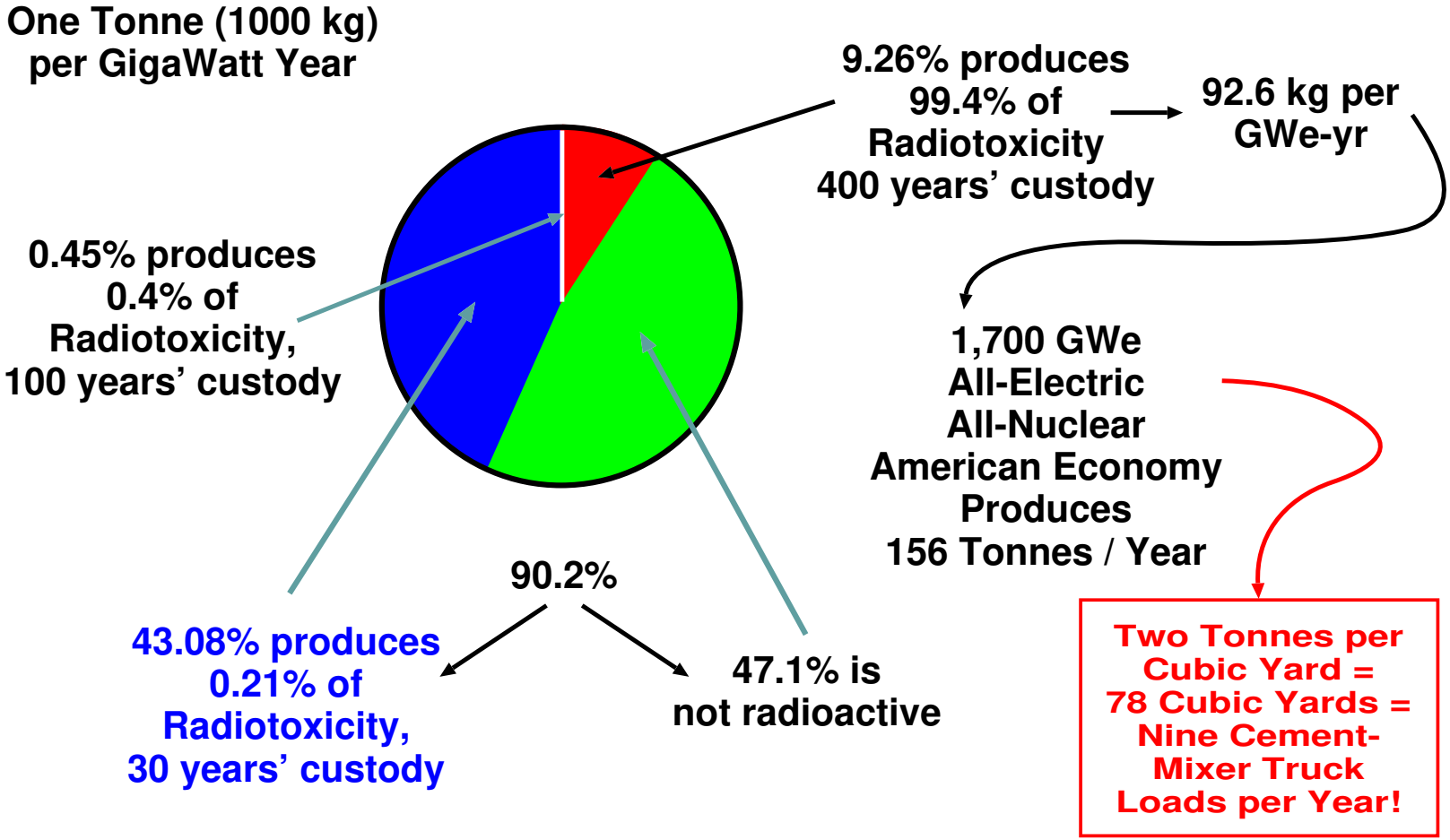
No One Knows What to Do about Nuclear Waste

Closed Fuel Cycle

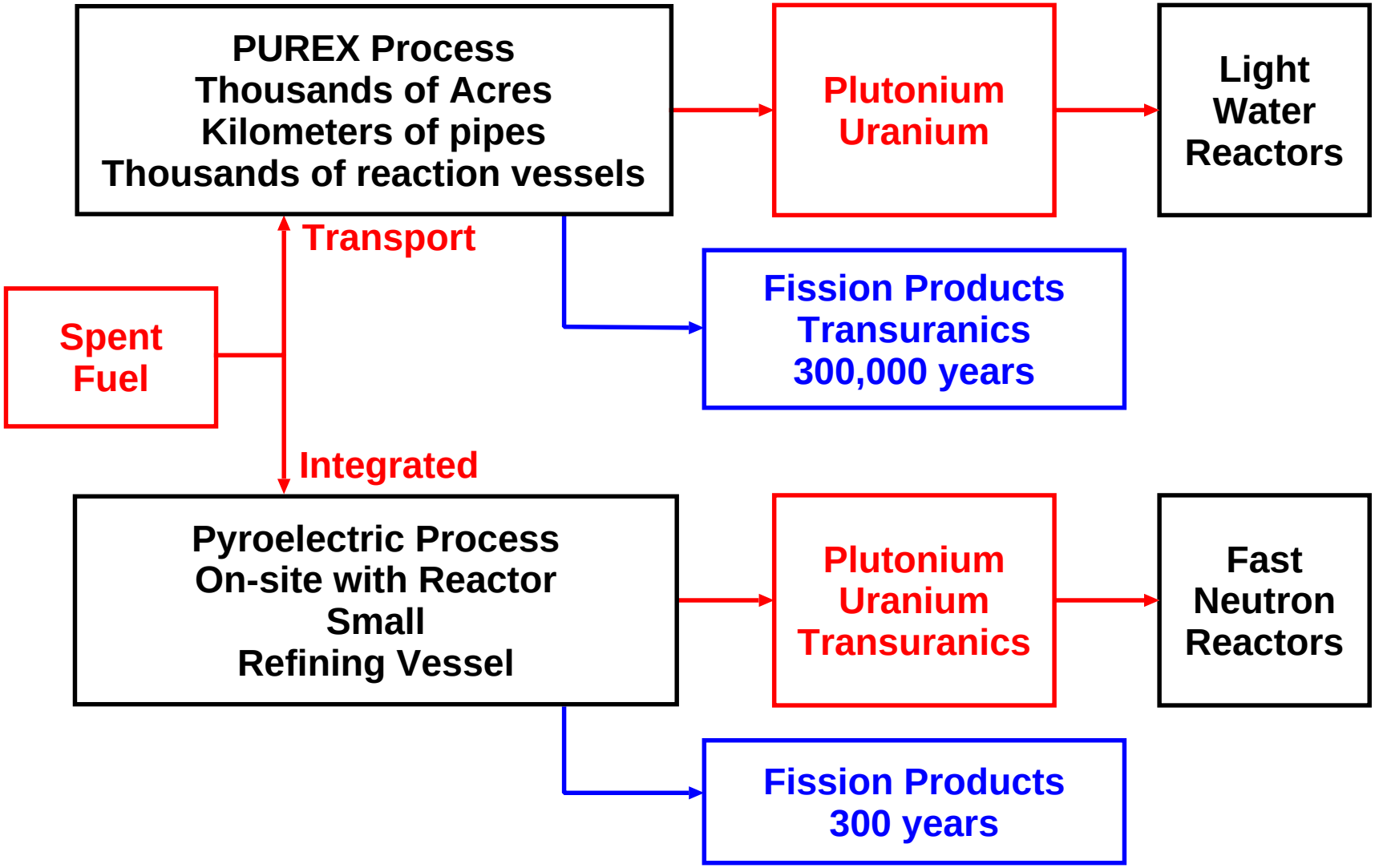


No One Knows What to Do about Nuclear Waste

Fission Products



PUREX vs Pyroelectric



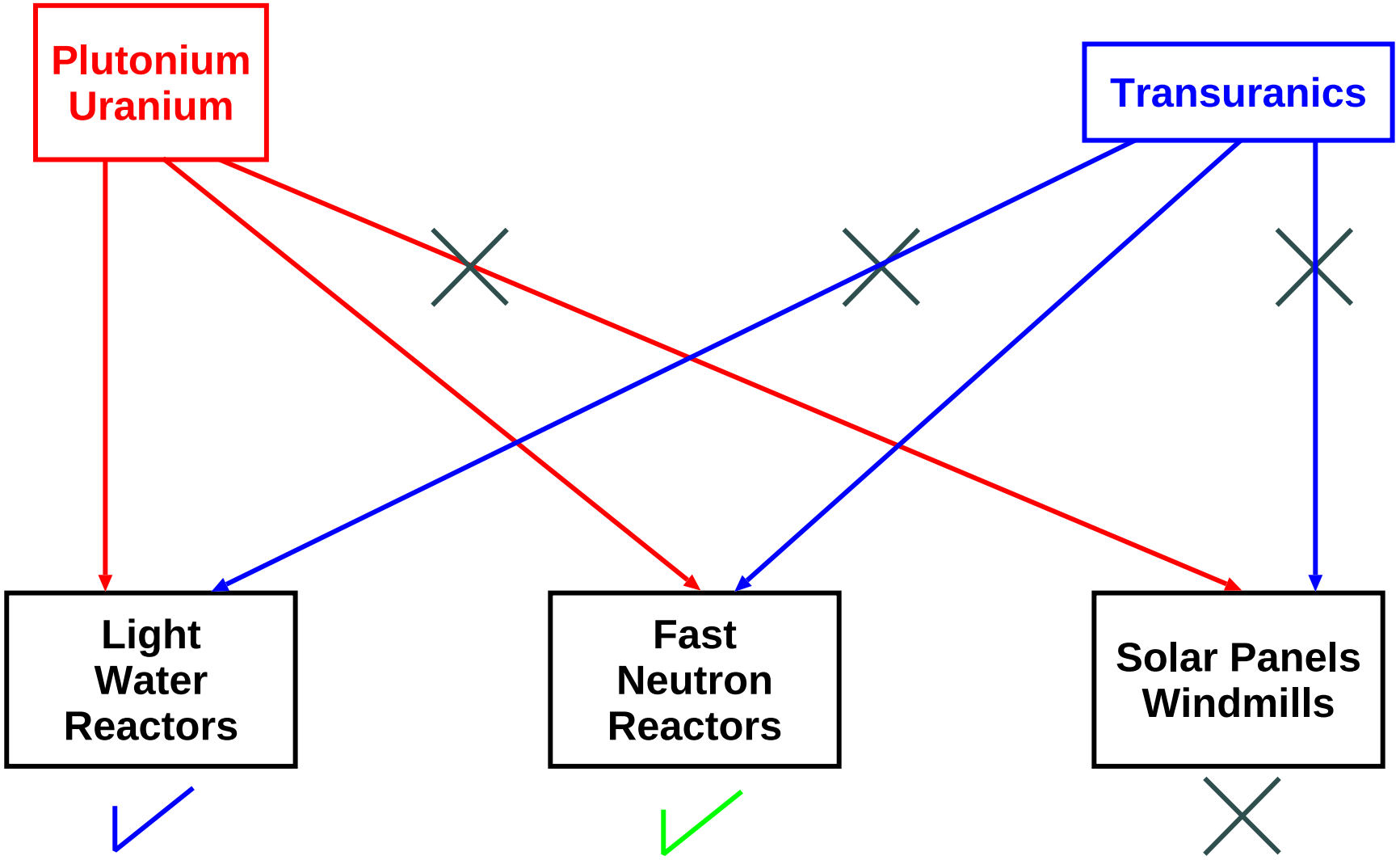
PUREX vs Pyroelectric

Costs for reprocessing

Plant	Area Hectares	Maximum Capacity T/yr	Capital Cost $US	Operating Cost ¢/kWh
Rokkasho	380	800	21 billion	0.52
THORP	285	900	6.3 billion	0.16
La Hague	300	1,700	18 billion	0.15
Barnwell	113	1,500	1.2 billion	0.081
Pyroelectric	17	400	900 million	0.05

No One Knows What to Do about Nuclear Waste

The 300,000 year problem



It's Too Expensive

Compared to What?

- Solar without storage: 11.7¢/kWh **cell capital cost alone**.
- Solar with storage: $57.92/kWh (5792¢/kWh).
- Diablo Canyon: 5¢/kWh.
- Palo Verde: 4.3¢/kWh.
- Washington Nuclear Generating Station: 3¢/kWh.
- Fully-amortized nuclear plants: 2¢/kWh (1.5¢ for operations, 0.5¢ for fuel).
- 2016 California average utility price: 15.34¢/kWh.

It's Too Expensive

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
¢/kWh*	0.071	−0.066	0.0127	0.020	2.063	3.753
per nuclear ¢/kWh	3.55	−3.3	0.635	1.000	**103.15**	**187.65**

Yes, the government made a profit on gas
*Includes 1.5¢/kWh Production Tax Credit for wind, and 1.3¢/kWh for solar
https://www.eia.gov/analysis/requests/subsidy/
Doesn't include investment tax credit, state and local support, or the effect of mandates.

It's Too Expensive

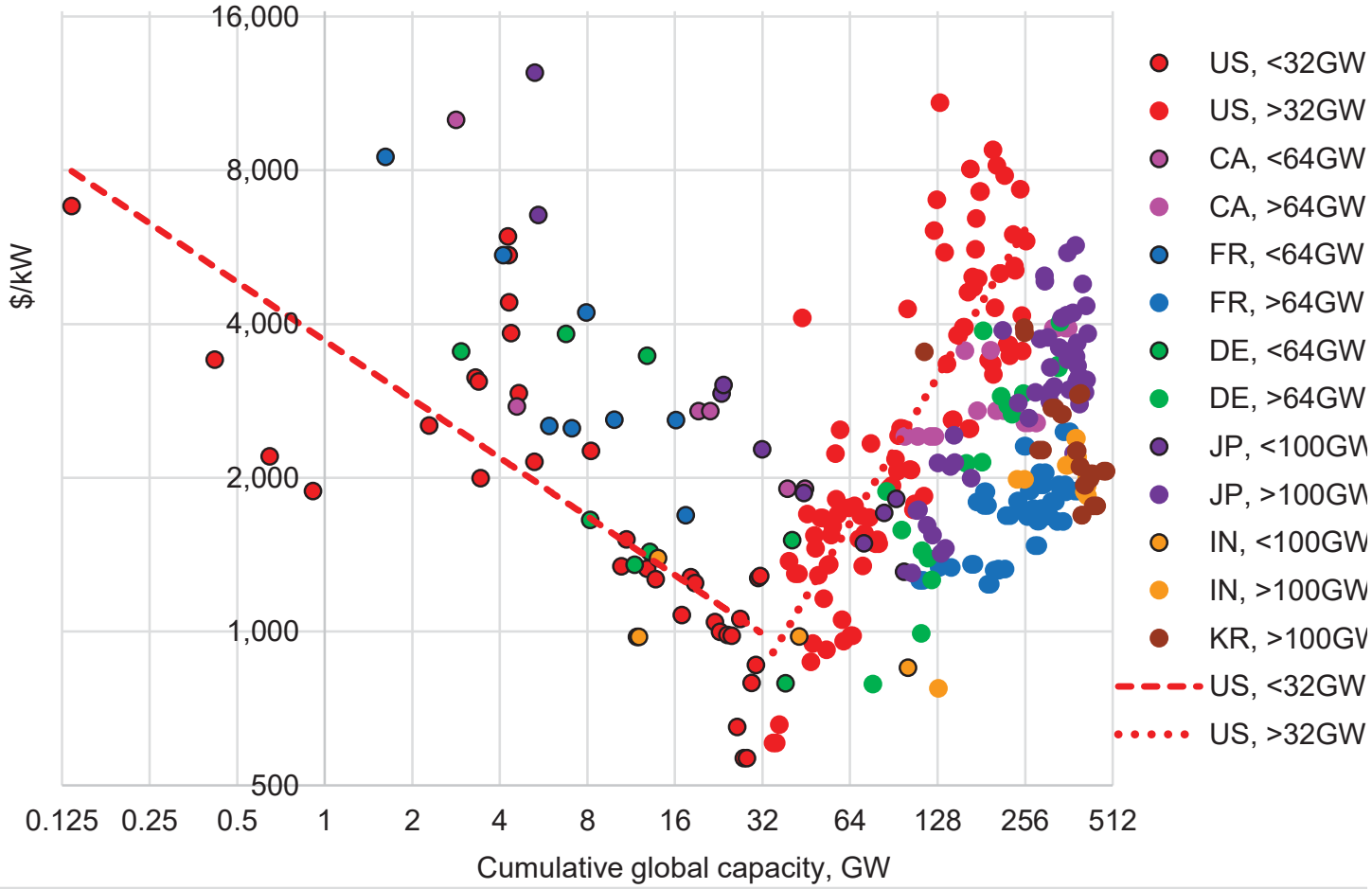


Figure 1: Overnight construction cost (in 2010 US$/kW) plotted against cumulative global capacity (GW), based on construction start dates, of nuclear power reactors for seven countries, including regression lines for US before and after 32 GW cumulative global capacity.

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.
- Yield of British experiment with 63% ^{239}Pu was much less than the Hiroshima device. "We will not bother to try that again."
- Plutonium in spent fuel is in a highly-radioactive and therefore easily monitored state.
- 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 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.
- On-site reprocessing in IFR-type reactors implies very few opportunities for diversion or theft.
- Advanced industrial economies already have nuclear weapons, or have the means to make them much more effectively than from used municipal reactor fuel.

There Isn't Enough Uranium

(it's an inexhaustible energy source)

There Isn't Enough Uranium

- USA has 90,000 tonnes of used fuel and 700,000 tonnes of depleted uranium (some say 900,000).
- Enough to power an all-electric 1,700 GWe 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 contemporary 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, but were used 167 times more efficiently.
- Economical to extract uranium from lower-quality ores, and from seawater, where there's 1000 times more.

There Isn't Enough Uranium

Nuclear fission is an inexhaustible energy source!

There Isn't Enough Uranium

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.**
- **Solar panels and windmills cannot make electricity from it.**

Unlimited Fuel

- 1125 tonnes could immediately start 110-140 GWe capacity.
- At 5% per year breeding rate, 1,700 GWe capacity could be reached in 50-60 years without importing, mining, milling, refining, or enriching any new uranium.

Proliferation

With breeder reactors, it will never again be necessary to enrich uranium.

Any one who claims to need to enrich uranium for municipal electricity service is a liar who has a weapons program.

Plutonium

Plutonium is not the most toxic substance known.

- It is less chemotoxic than lead.
- It is far far far less chemotoxic than ricin or botulinus toxin.
- 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

- 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 had hoped 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 that **we invented!**
- Solar, wind, hydro, and minor renewable players such as tides, waves, geothermal, ocean currents, and biofuels – and conservation – **cannot do anything to mitigate the existing "nuclear waste" problem.**

Conclusions

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

It is clearly obvious that nuclear power in the form of inherently 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, 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: The IFR Story**, Amazon (2011) ISBN 978-1466384606.

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) 179 pp.

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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

Untying the Nuclear Knot
https://www.youtube.com/watch?v=PHrBI1Iz_7c

How Fear of Nuclear Ends

Michael Shellenberger
TEDxCalPoly
https://www.youtube.com/watch?v=mI6IzPCmIW8

Why I changed my mind about nuclear power

Michael Shellenberger
TEDxBerlin
https://www.youtube.com/watch?v=ciStnd9Y2ak

Where Will We Get Our Energy?

Van Snyder

van.snyder@sbcglobal.net

vandyke.mynetgear.com/Nuclear.html

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