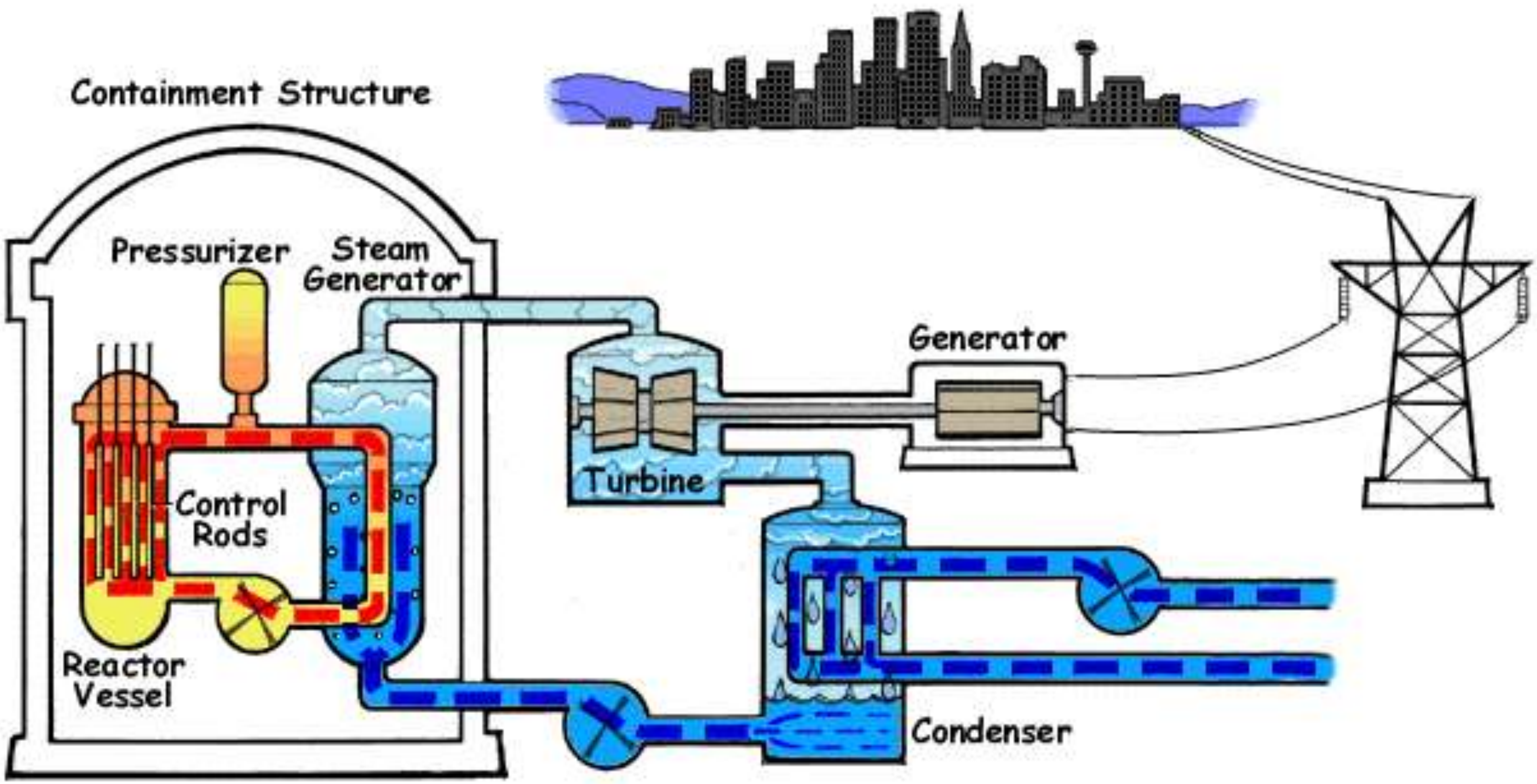
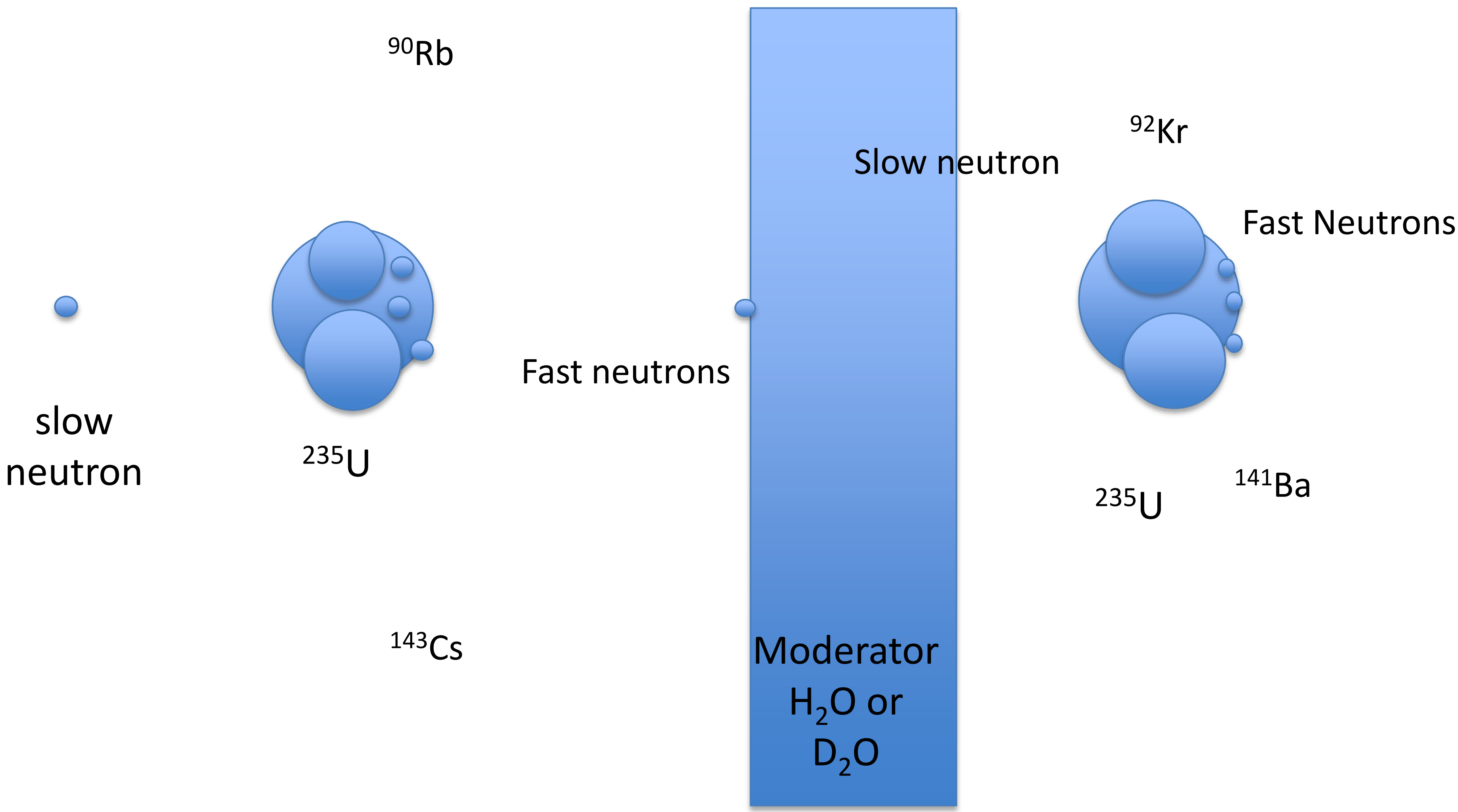
Global Warming &
The Case for



Nuclear Power

Thermal Fission



Sunbathing on radioactive beaches

Guarapari, Brazil

The city of Pripyat in the Chernobyl zone

Chernobyl eco-system

Chernobyl

- 50 deaths
  - 31 radiation poisoning
  - 9 thyroid cancer
  - Rest from physical accidents (helicopter crash)
- 4000 deaths from cancer based on LNT model
  - Will be undetectable against background cancer rate (i.e., statistically equivalent to zero). Most doses are comparable to background doses.
- Greatest medical problems to survivors has been psychological not radiological.
- The eco-system is healthy and intact, although radioactive.

عربي 中文 English Français Русский Español

World Health Organization

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Chernobyl: the true scale of the accident

20 Years Later a UN Report Provides Definitive Answers and Ways to Repair Lives

As of mid-2005, however, fewer than 50 deaths had been directly attributed to radiation from the disaster, almost all being highly exposed rescue workers, many who died within months of the accident but others who died as late as 2004.

The estimated 4000 casualties may occur during the lifetime of about 600 000 people under consideration. As about quarter of them will eventually die from spontaneous cancer not caused by Chernobyl radiation, the radiation-induced increase of about 3% will be difficult to observe.

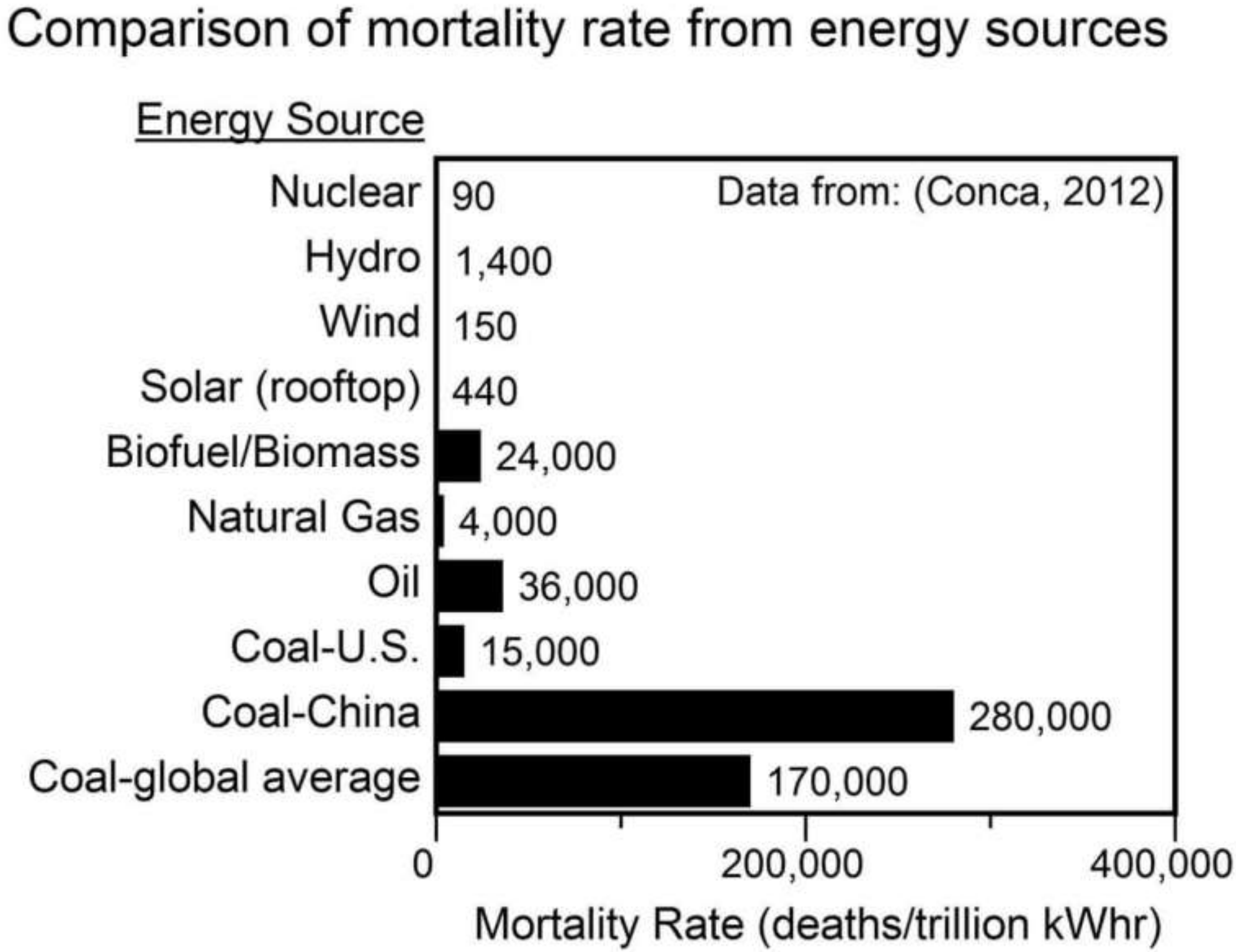
Alongside radiation-induced deaths and diseases, the report labels the mental health impact of Chernobyl as “the largest public health problem created by the accident” and partially attributes this damaging psychological impact to a lack of accurate information. These problems manifest as negative self-assessments of health, belief in a shortened life expectancy, lack of initiative, and dependency on assistance from the state.

http://www.who.int/mediacentre/news/releases/2005/pr38/en/index.html

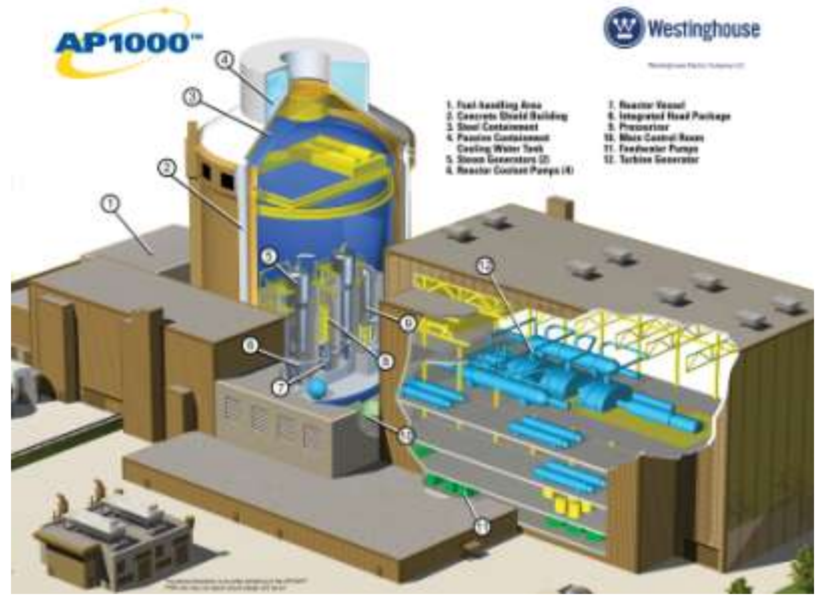
Fukushima

- No deaths
- No projected deaths. WHO did not release such numbers. Increased cancer rates will be not detectable against the background cancer rate.
- Greatest medical problem for evacuees again is psychological not radiological
- Radiation released by Fukushima 1/5th of Chernobyl. Presumably the eco-system is intact.

So Nuclear Power Is it safe?

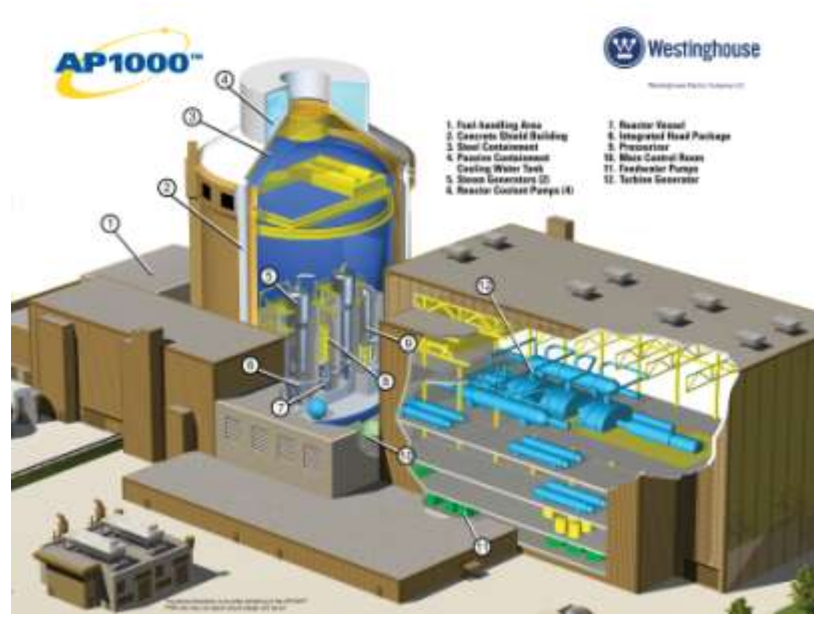


Future Fukushimas?



- Wheatley, Sovacool, & Sornette – 2015
- Probability of another Fukushima 50:50 in 50 years.
- They assumed GEN II reactors forever. If all reactors are replaced with GEN III+ (100 times safer), the probability of another Fukushima will be 50:50 in 5000 years.
- If Nuclear supplied all the world power (a factor of 20), then probability of another Fukushima is 50:50 in 5000÷20 = 250 years.

Future Fukushimas?



- In 40 years or less, more likely much less, GEN IV reactors will come on line. GEN IV reactors have no pressure vessels to blow up.
- The probability of a future Fukushima will then be zero

Open letter to policy makers

November 2013

- Hansen, Caldeira, Emanuel, and Wigley
- Asked all environmental policy makers to stop opposition to nuclear power
- Quantitative analyses show that the risks associated with the expanded use of nuclear energy are orders of magnitude smaller than the risks associated with fossil fuels.
- No energy system is without downsides. We ask only that energy system decisions be based on facts, and not on emotions and biases that do not apply to 21st century nuclear technology.

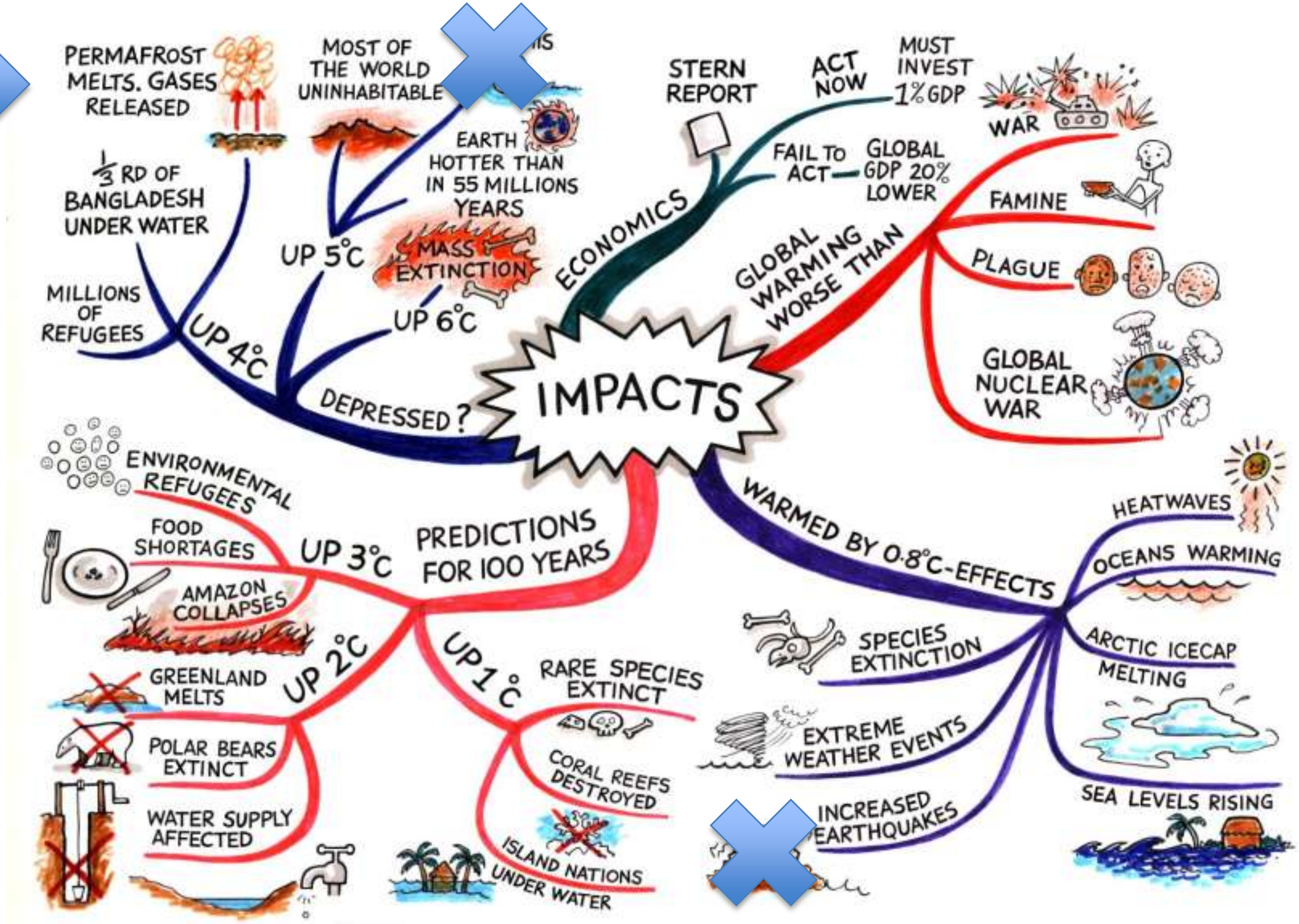
Open letter to policy makers

- While it may be theoretically possible to stabilize the climate without nuclear power, in the real world there is no credible path to climate stabilization that does not include a substantial role for nuclear power

So why did they say this?

- Bill McKibben "Global Warming's Terrifying New Math" *Rolling Stone* August 2, 2012
- For an 80% chance of **not** exceeding 2°C, global emissions must not exceed 565 Gt of CO_2
- (Gt = 10^9 tonnes) (tonne = 1000 kg)

Consequences



So why did they say this?

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- For an 80% chance of **not** exceeding 2°C, global emissions must not exceed 565 Gt of CO_2
- (Gt = 10^9 tonnes) (tonne = 1000 kg)
- In 2011 the world emitted 31.6 Gt of CO_2
- CO_2 emissions are climbing at about 3.2% per year.
- Do the math. That means we have 14 years emitting as we have been doing until our carbon budget is used up.
- That is by 2011 + 14 = 2025 !!!

GHG Free Power

Plant Type	Capacity factor (%)	Levelized Cost \$/MWh	GHG emissions $g(CO_{2e})/kWh$
Advanced Nuclear	90	102.8	12
Geothermal	91	45.0	38
Advanced CCGT	87	57.2	490
Hydro	58	67.8	24
Wind	40	64.5	11
Wind - Offshore	45	158.1	12
Solar PV	25	84.7	48
Solar - Thermal	20	235.9	27

U.S. Energy Information Administration

GHG emissions from IPCC

First location, local



Local only
40% renewable
60% CCGT
\$67/MWh
298 $g(CO_{2e})/kWh$

renewable

Combined cycle gas
Turbine
CCGT

Two locations
64% renewable
36% CCGT
\$87/MWh
190 $g(CO_{2e})/kWh$

Transmission line

Second location



Three locations
78% renewables
22% CCGT
\$113/MWh
132 $g(CO_{2e})/kWh$

Summary of Smart Grid

No. of locations	% renewable	Cost $/MWh	GHG emissions $g(CO_{2e})/kWh$
1	40.0	67.4	298
2	64.0	86.7	190
3	78.4	112.5	132
4	87.0	143.3	102
5	92.2	178.3	89
Advanced Nuclear	100.0	102.8	12

So What about Energy Storage?



40% renewable
45% batteries
15% CCGT
\$176/MWh
107 g(CO_{2e})/kWh



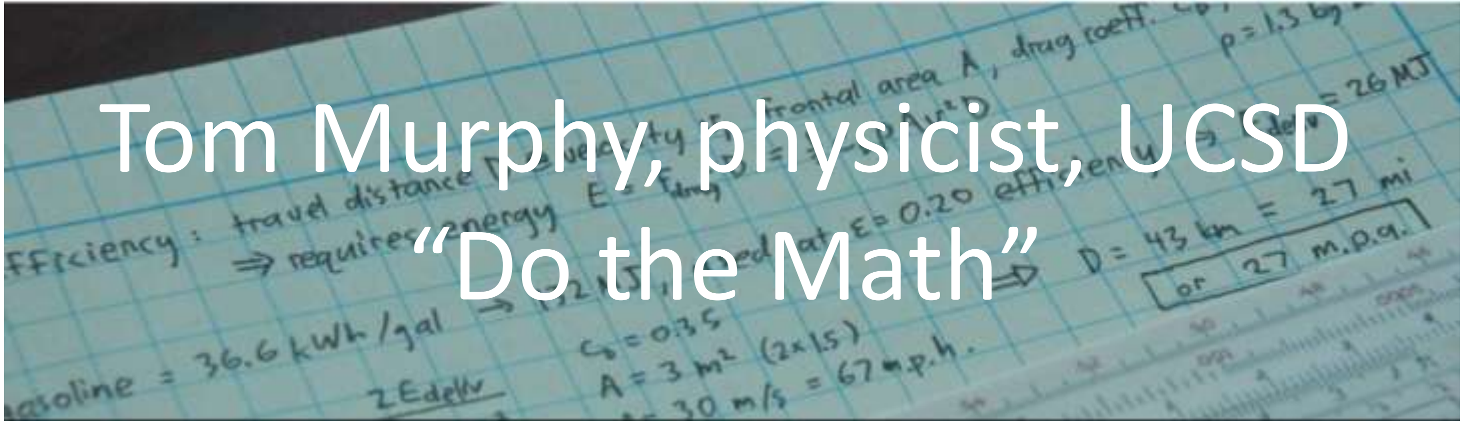
However
Batteries last only 8 years. Over 40 years of a Wind Farm must be replaced 5 Times.

40% renewable
45% batteries
15% CCGT
\$476/MWh
194 g(CO_{2e})/kWh

Summary of Renewables

type	% renewable	Cost \$/MWh	GHG emissions $g(CO_{2e})/kWh$
3 station smart grid	78.4	112.5	114
300% infrastructure with batteries	85.0	176.4	107
same with battery replacement	80.0	476.4	194
Advanced Nuclear	100.0	102.8	12

Tom Murphy, physicist, UCSD
“Do the Math”



- The current mineral reserves of the entire planet for crucial elements like Lead and Lithium, necessary for the construction of batteries, will only supply <10% of the U.S. requirement for energy storage.
- The geological capacity of the U.S. can only supply <10% of the necessary pumped storage for U.S. requirements. This result should be the same for the world as a whole.
- All schemes for energy storage prove to be woefully inadequate when putting in the numbers to scale them up to the capacity that will be required. It will require a miracle in energy storage technology and none is currently on the time horizon.

So

- Non-dispatchable renewables cannot supply 100% of the power 100% of the time.
- Need dispatchable GHG emissions free power to cover the down time
- What choices are there?

Hydro	Geographically limited
Geothermal	Geographically limited
Biomass	Competes with food and arable land and has air pollution
Advanced Nuclear	There are no other choices

Nuclear Checklist

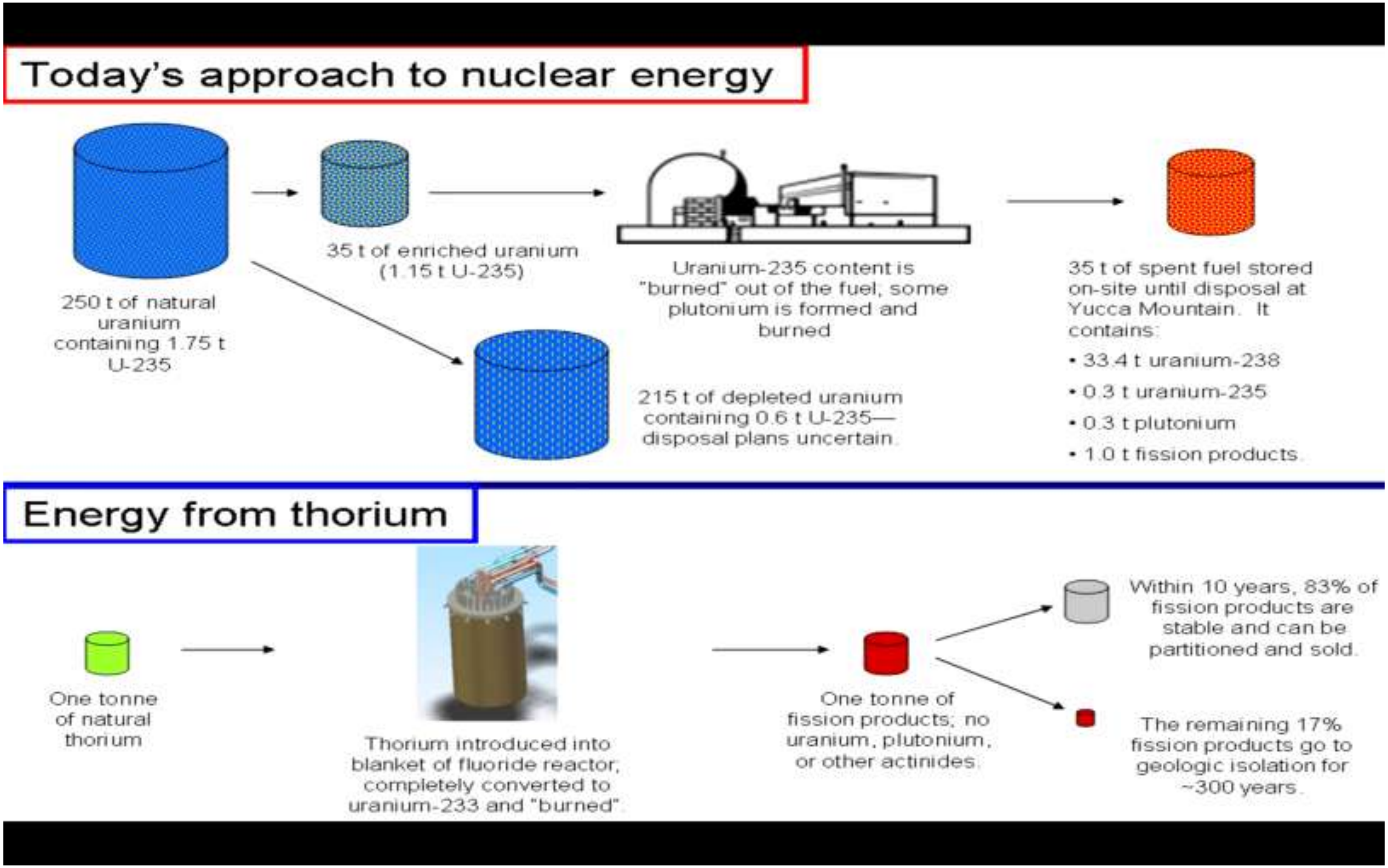
- Is it safe? ✓
- Is it economical? ✓
- Is it green? ✓
- What about nuclear waste? … Not yet

Nuclear Waste Problem?

- Deep underground repositories in geological secure sites is an adequate solution.
- Yucca Mountain repository in Nevada for the U.S. waste was closed for political reasons not for technical reasons
- The world's waste can be stored in areas the the size of a couple of football fields.

Nuclear Waste Problem?

- Burn it!



Is It Abundant?

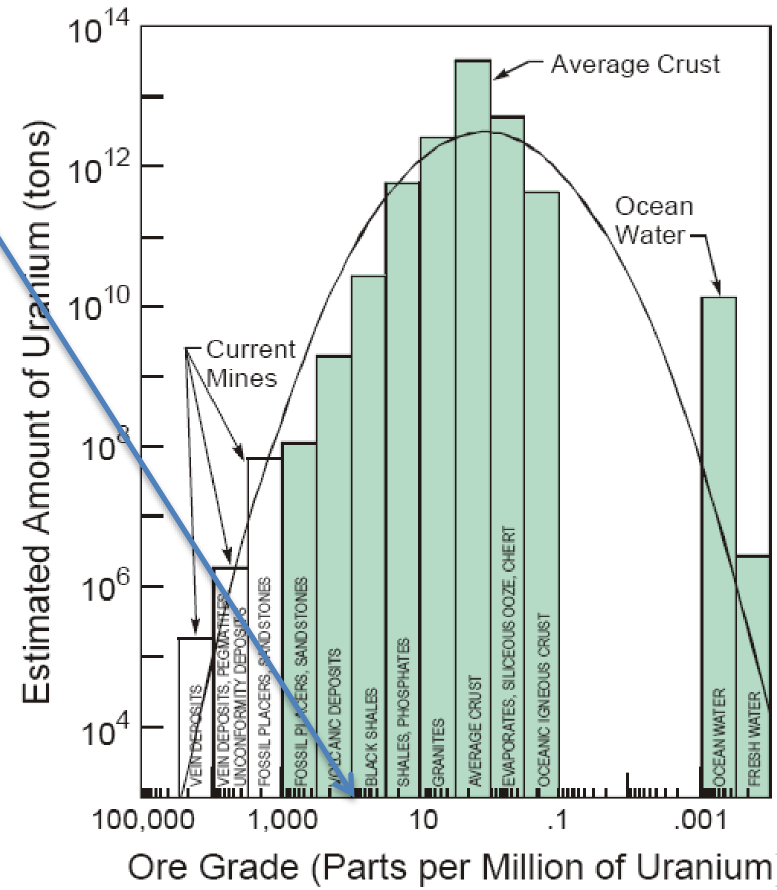
FCCG Presentation

Distribution of Uranium in the Earth's Crust

Namibia 100 ppm

The ratio between amount
Of high grade ore and low
Grade ore is ~100:1

Cost of nuclear fuel mostly
In the enrichment process



Reno Presentation RS038-00 2001 ANS Winter Meeting Reno, NV November 13, 2001 9

When critics say there is not enough uranium for expansion

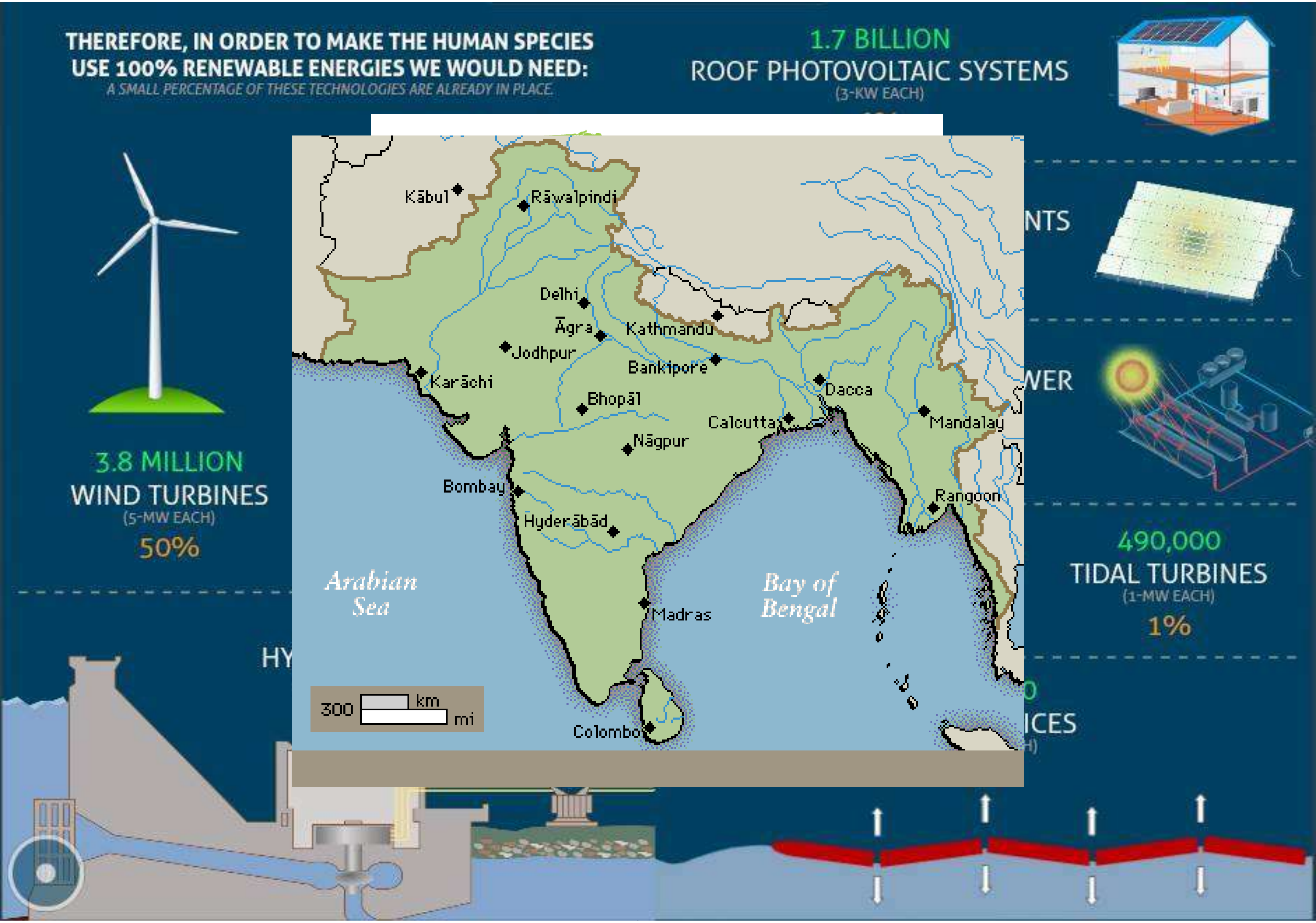
Is It Abundant?

They are referring to this figure

- Assume that nuclear instantaneously produced all the energy now produced by fossil fuels and nuclear
- There is enough high quality ore to last 5.2 years
- There is enough low quality ore to last 520 years
- If breeder reactors come on line there is enough fuel to last 300,000 years.

Nuclear Checklist

- Is it safe? ✓
- Is it economical? ✓
- Is it green? ✓
- What about nuclear waste? … ✓
- Is it plentiful? ✓



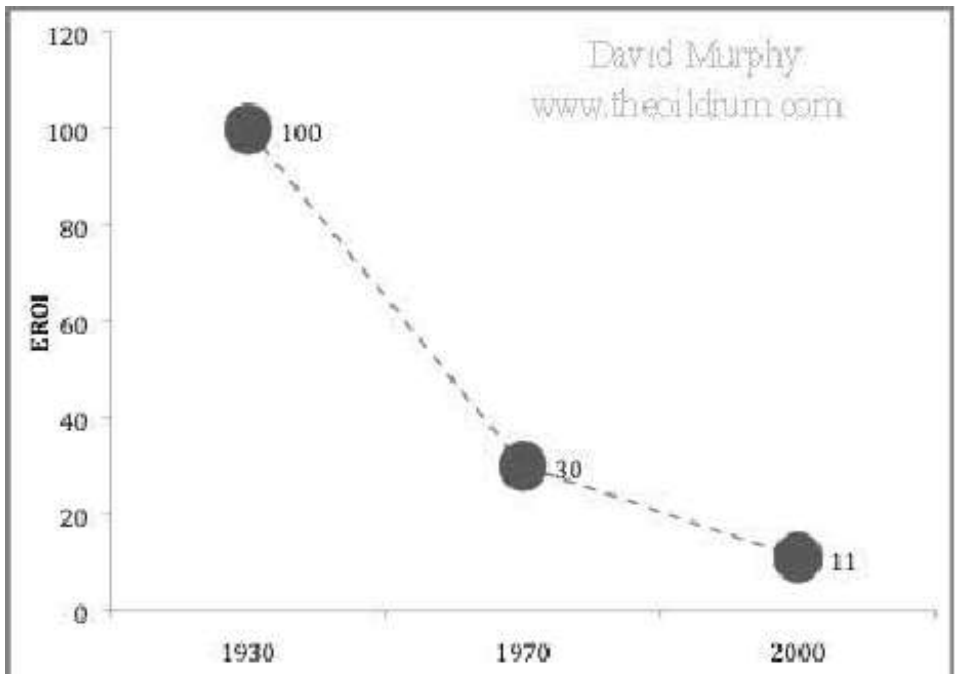
THEREFORE, IN ORDER TO MAKE THE HUMAN SPECIES USE 100% RENEWABLE ENERGIES WE WOULD NEED:
A SMALL PERCENTAGE OF THESE TECHNOLOGIES ARE ALREADY IN PLACE.
1.7 BILLION
ROOF PHOTOVOLTAIC SYSTEMS
(3-KW EACH)
3.8 MILLION
WIND TURBINES
(5-MW EACH)
50%
NTS
WER
490,000
TIDAL TURBINES
(1-MW EACH)
1%
HY
ICES
Kābul
Rāwalpindi
Delhi
Āgra
Kathmandu
Jodhpur
Bankipore
Karāchi
Bhopāl
Dacca
Calcutta
Mandalay
Nāgpur
Bombay
Rangoon
Hyderābād
Arabian Sea
Bay of Bengal
Madras
300 km
mi
Colombo

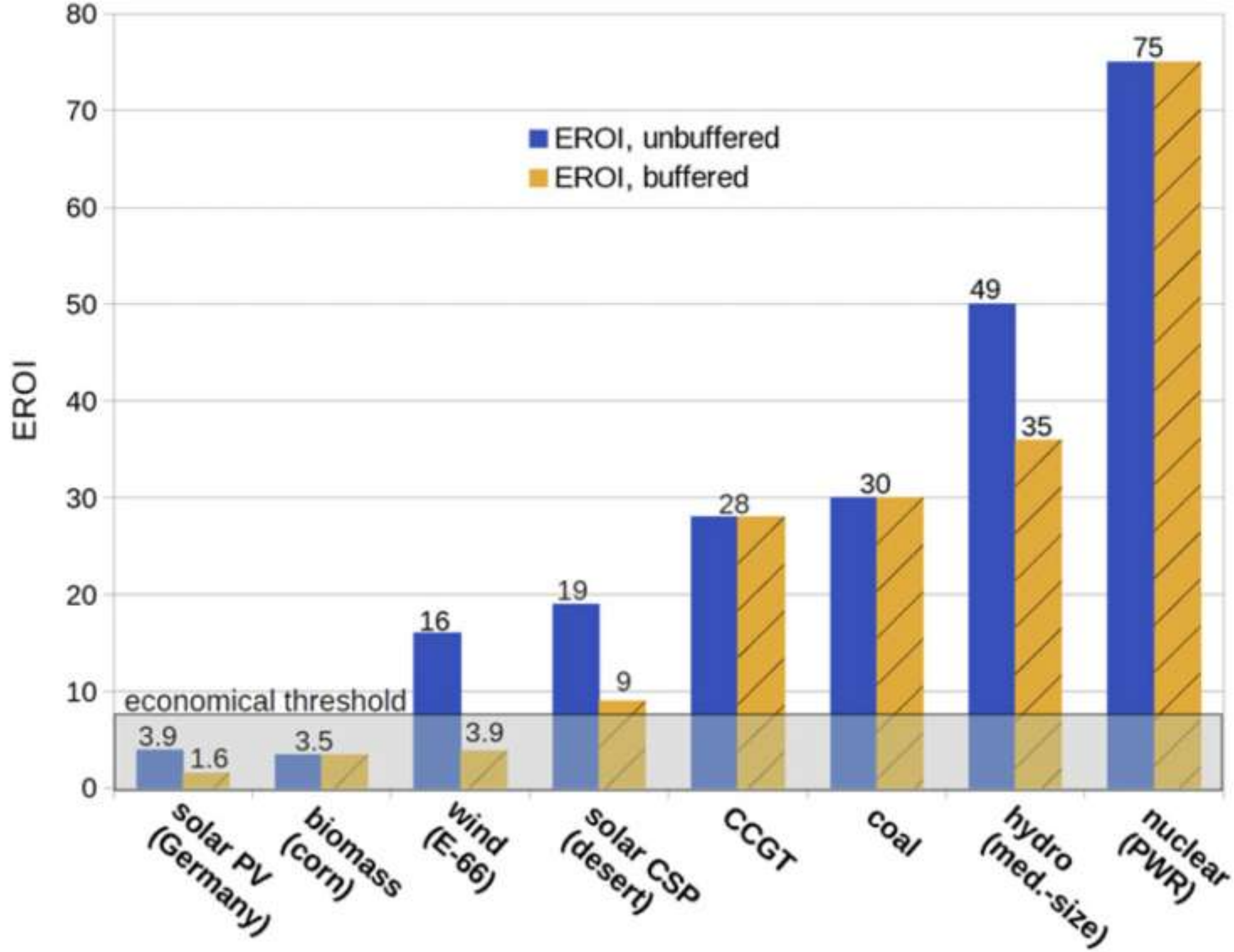
EROI

- Energy Return on Investment

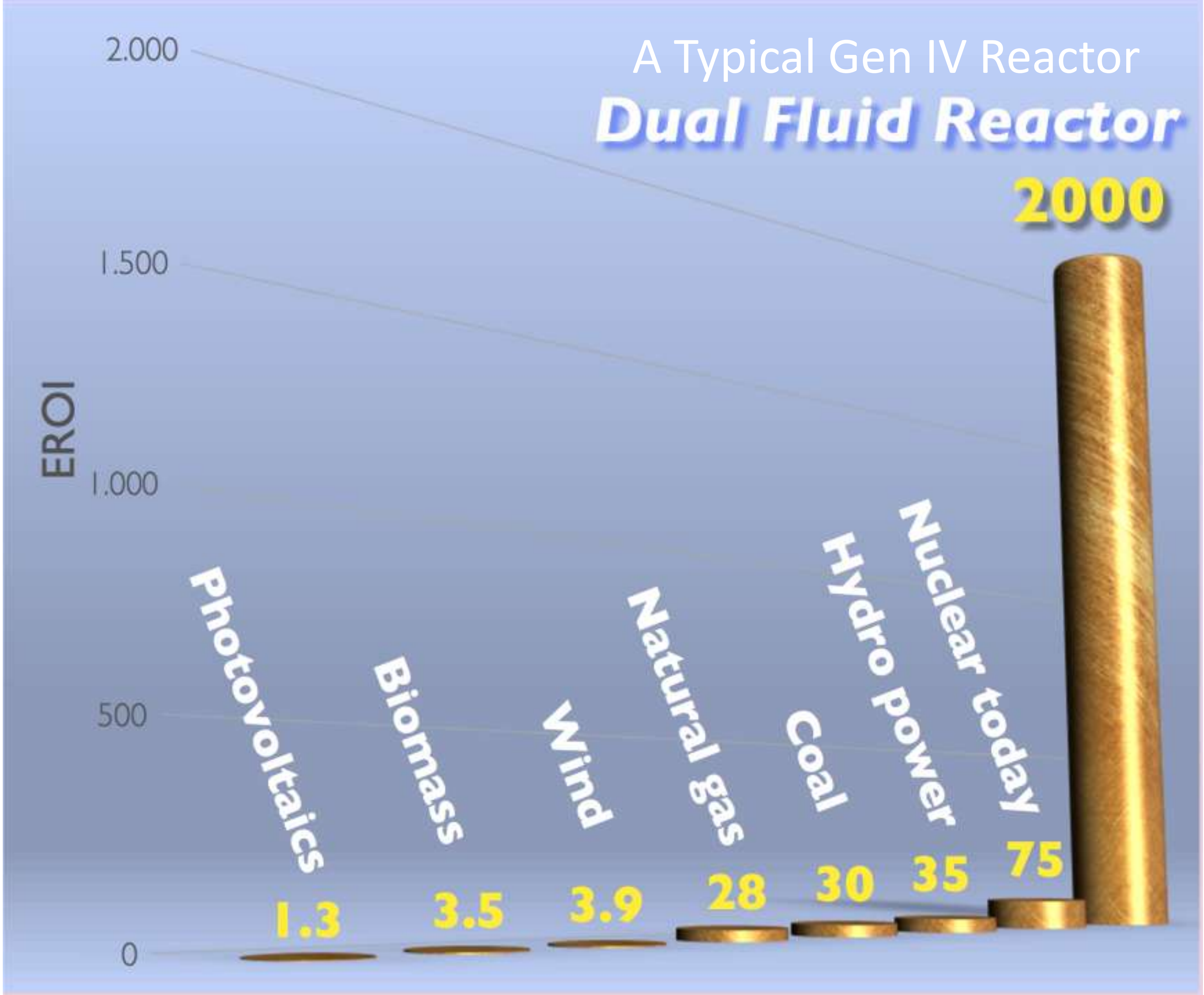
$$EROI = \frac{E_{out}}{E_{in}}$$

EROI for U.S. Oil
data from
Hall et al.

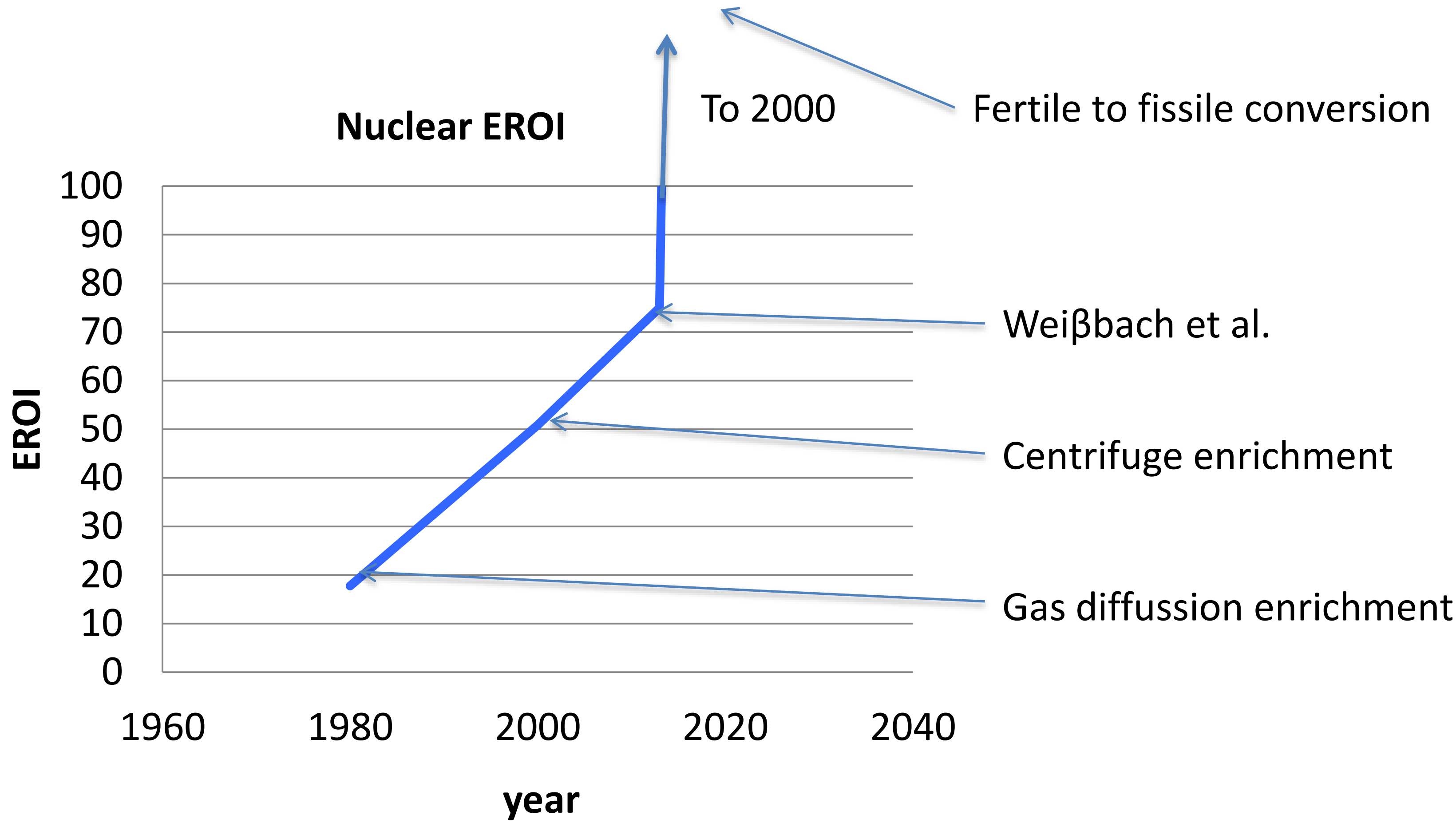


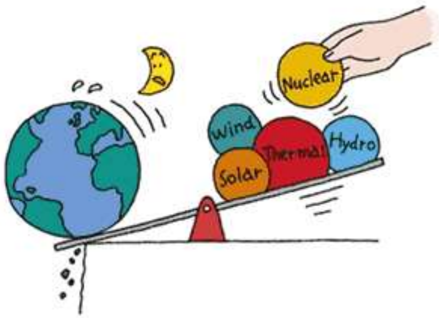


Weiβbach et al. Energy **52**(2013)210


A Typical Gen IV Reactor
Dual Fluid Reactor
2000
EROI
2.000
1.500
1.000
500
0
Photovoltaics
Biomass
Wind
Natural gas
Coal
Hydro power
Nuclear today
1.3
3.5
3.9
28
30
35
75

Nuclear energy is the only energy system where the EROI is increasing!





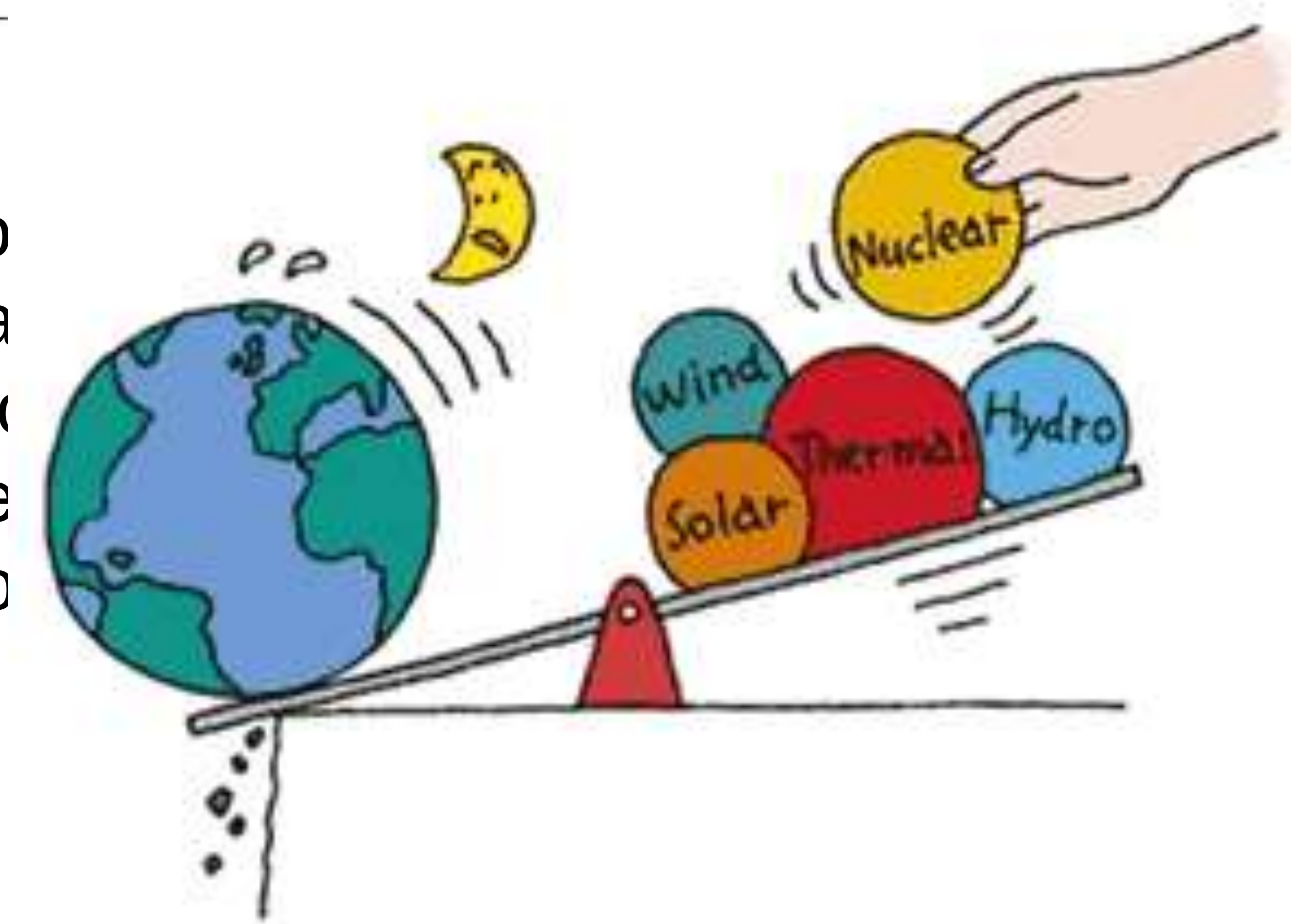
Conclusions

- We must transition from a fossil fuel economy to a green house gas (GHG) emissions free economy as soon as possible.
- Modern nuclear technology exists and is ready to be implemented now.
- There is no credible path to climate stabilization that does not include a substantial role for nuclear power.
- Nuclear power is one of the safest, most economical, plentiful, and greenest sources of energy available.

The Case For

Conclusions

- To ... ot ha ... of the mo ... gy be ... ich do



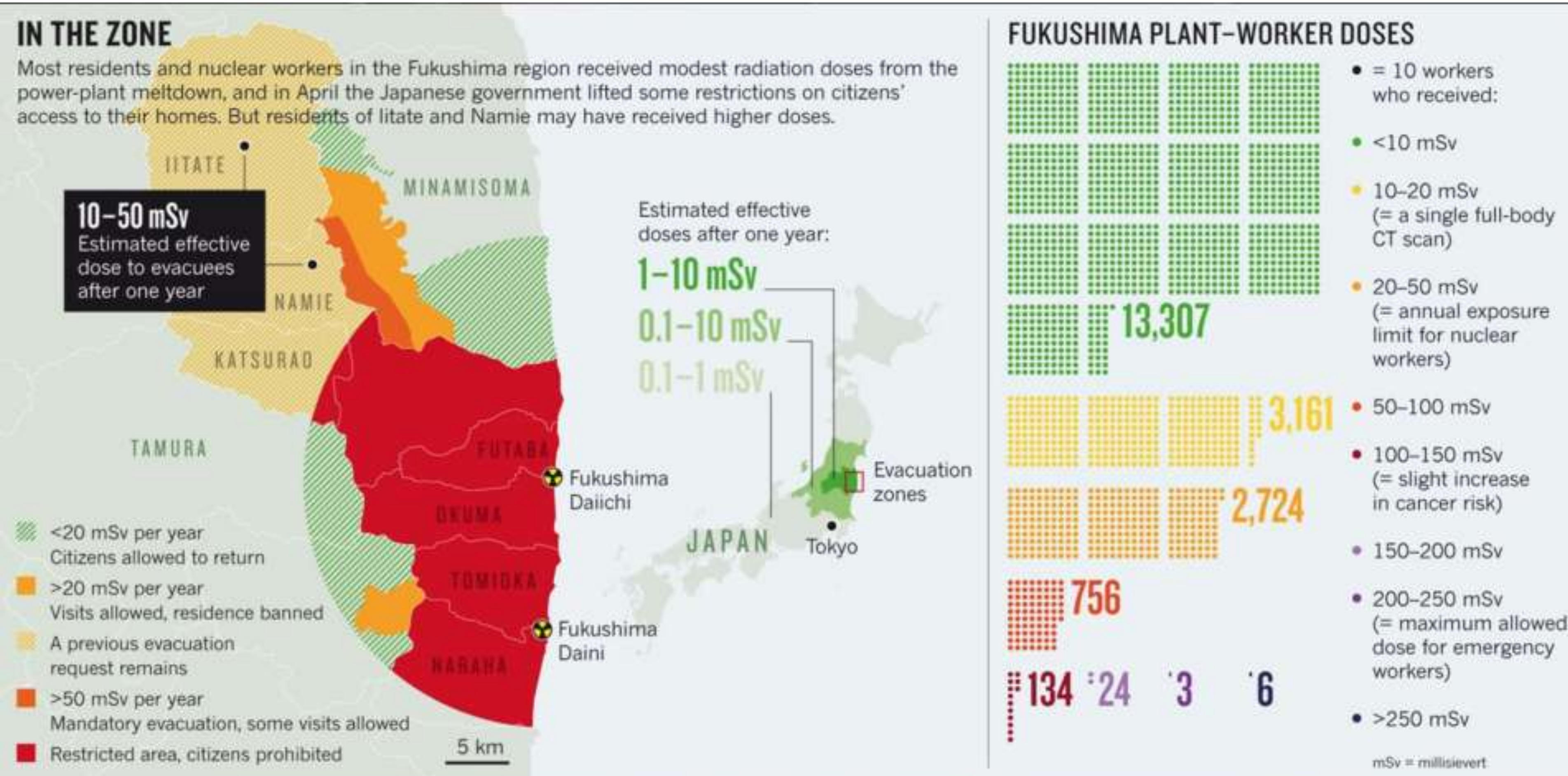
Nuclear Power

If you want to know more

Google Canada

pwalden

Fukushima Doses



Radiation Risks

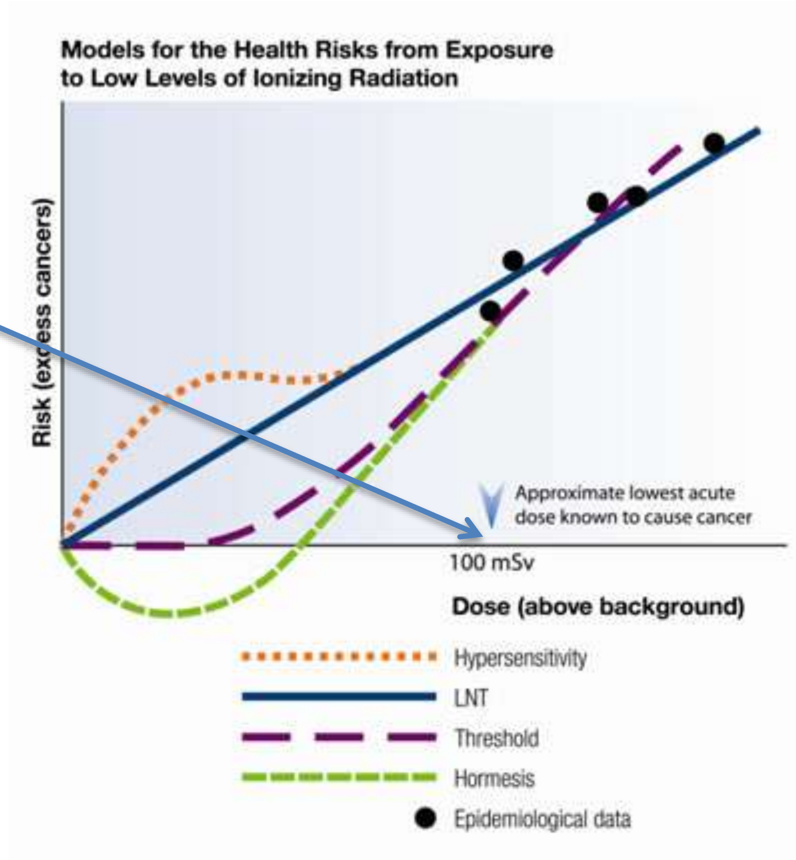
Limits

TRIUMF continuous occupation
1 μSv/hr

TRIUMF yearly dose
10 mSv/y => 1.14 μSv/hr

Radiation Worker yearly dose
20 or 50 mSv/y

Cancer risk
~0.5%



Dental Xray 0.15 mSv

Background ~4 mSv/y

CT scan 10 mSv

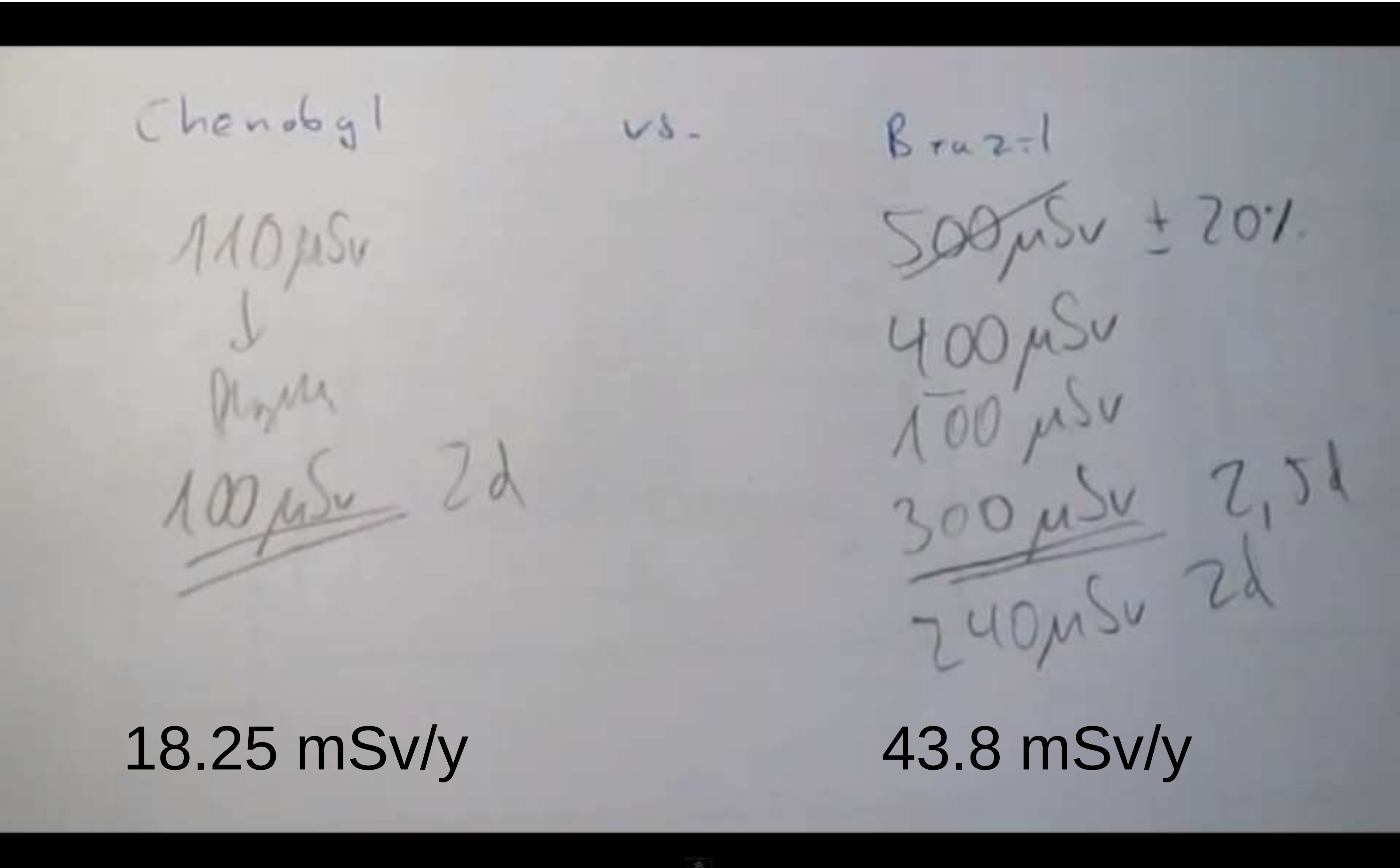
Radiation poisoning
First symptoms 400 mSv

Severe radiation poisoning
2 Sv

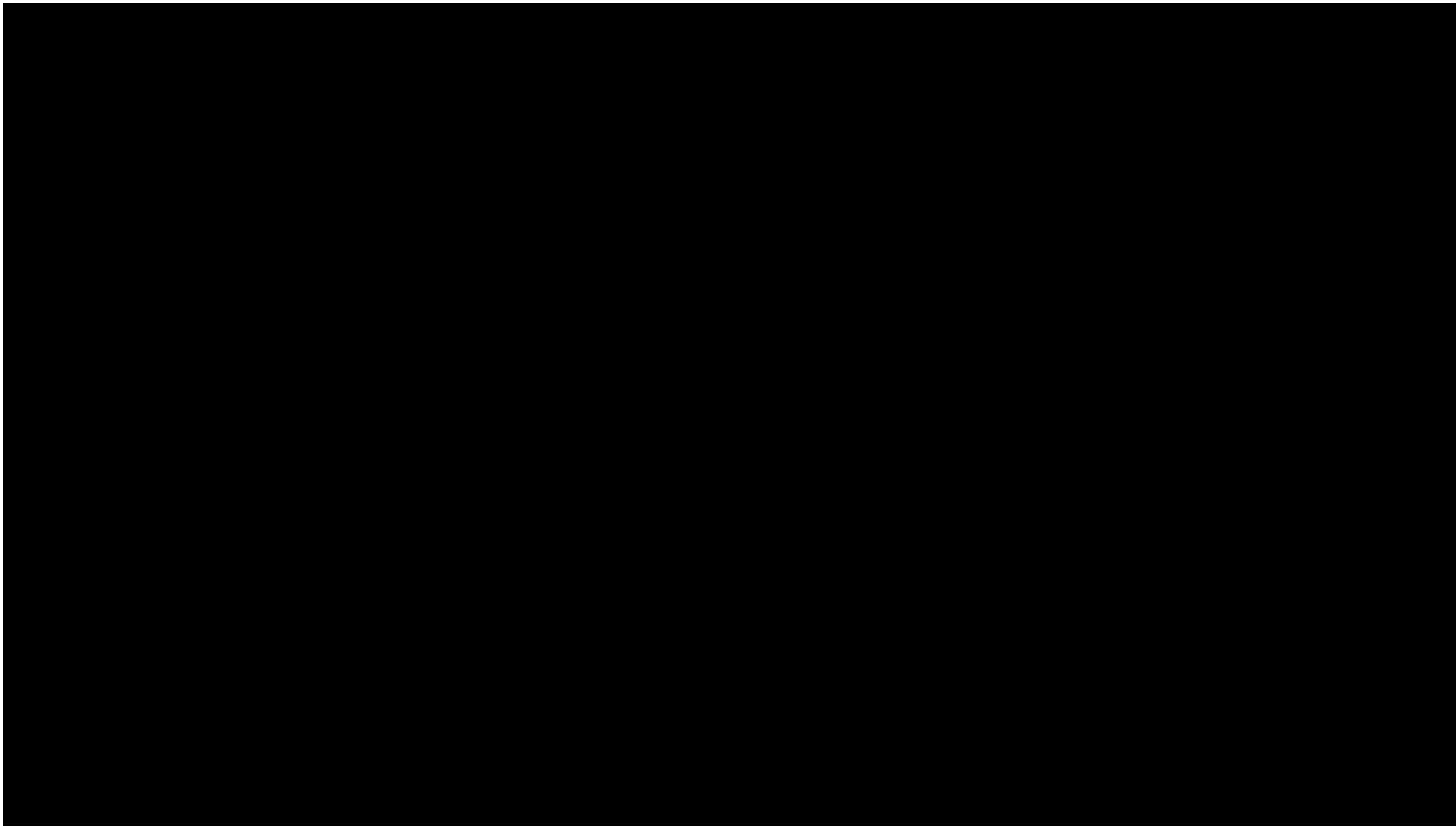
Death 4Sv or more

1 Sv = 1 Joule/kg

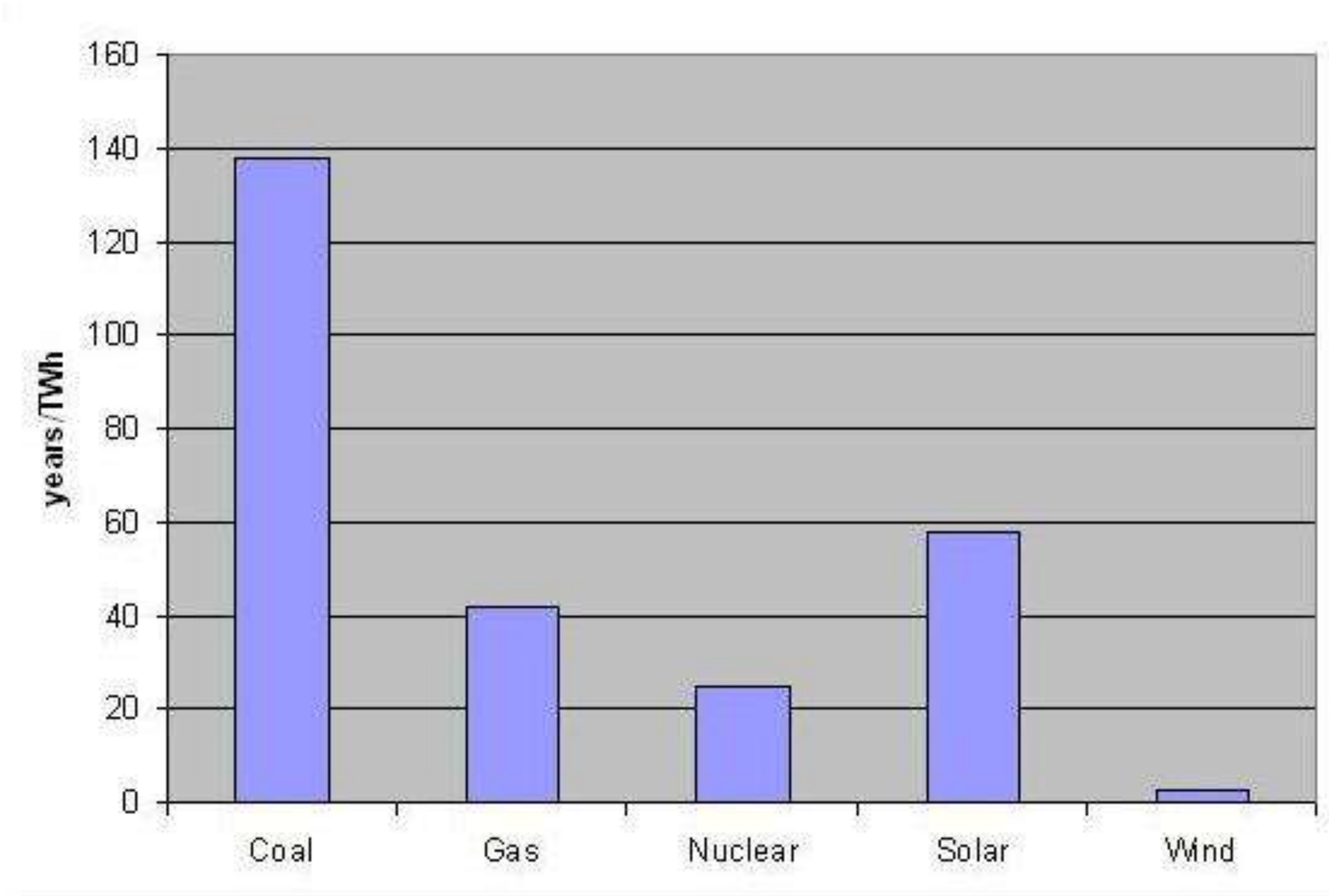
Brazil vs. Chernobyl



A dark lining in a silver cloud



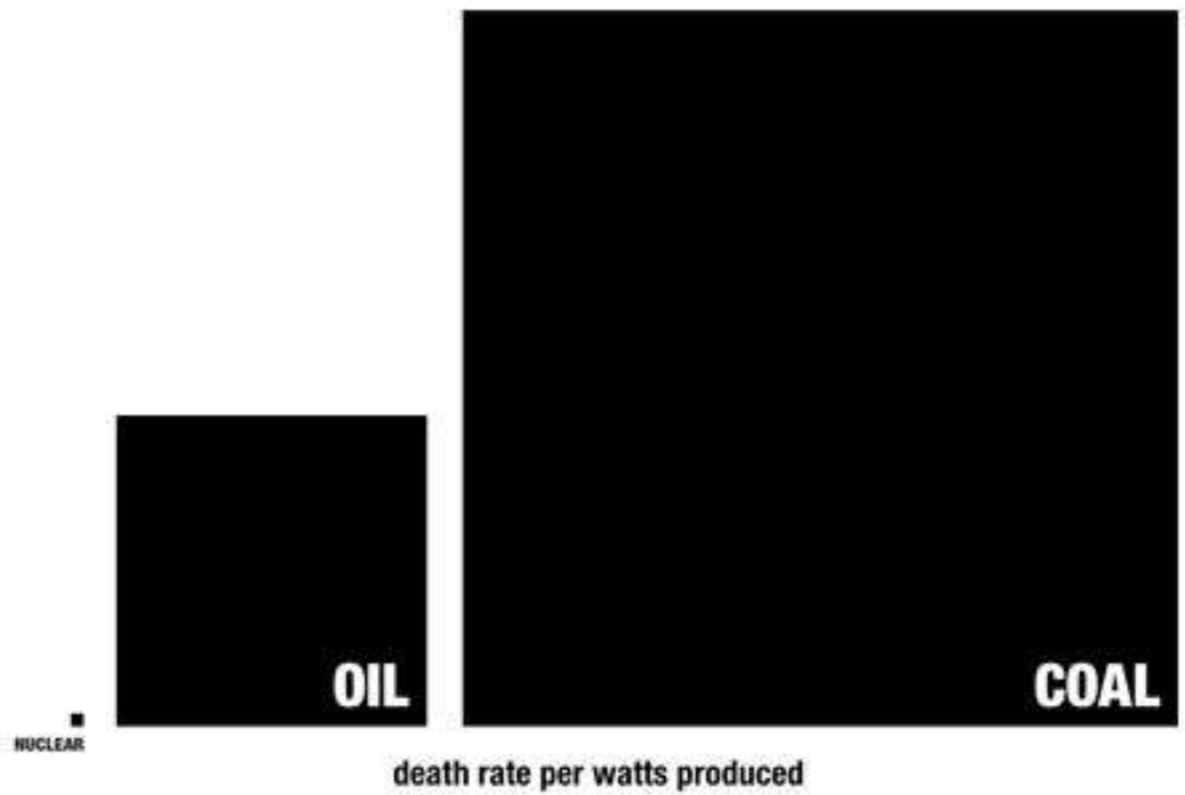
Is it safe?



16 years/TWh for nuclear due to estimates from LNT model

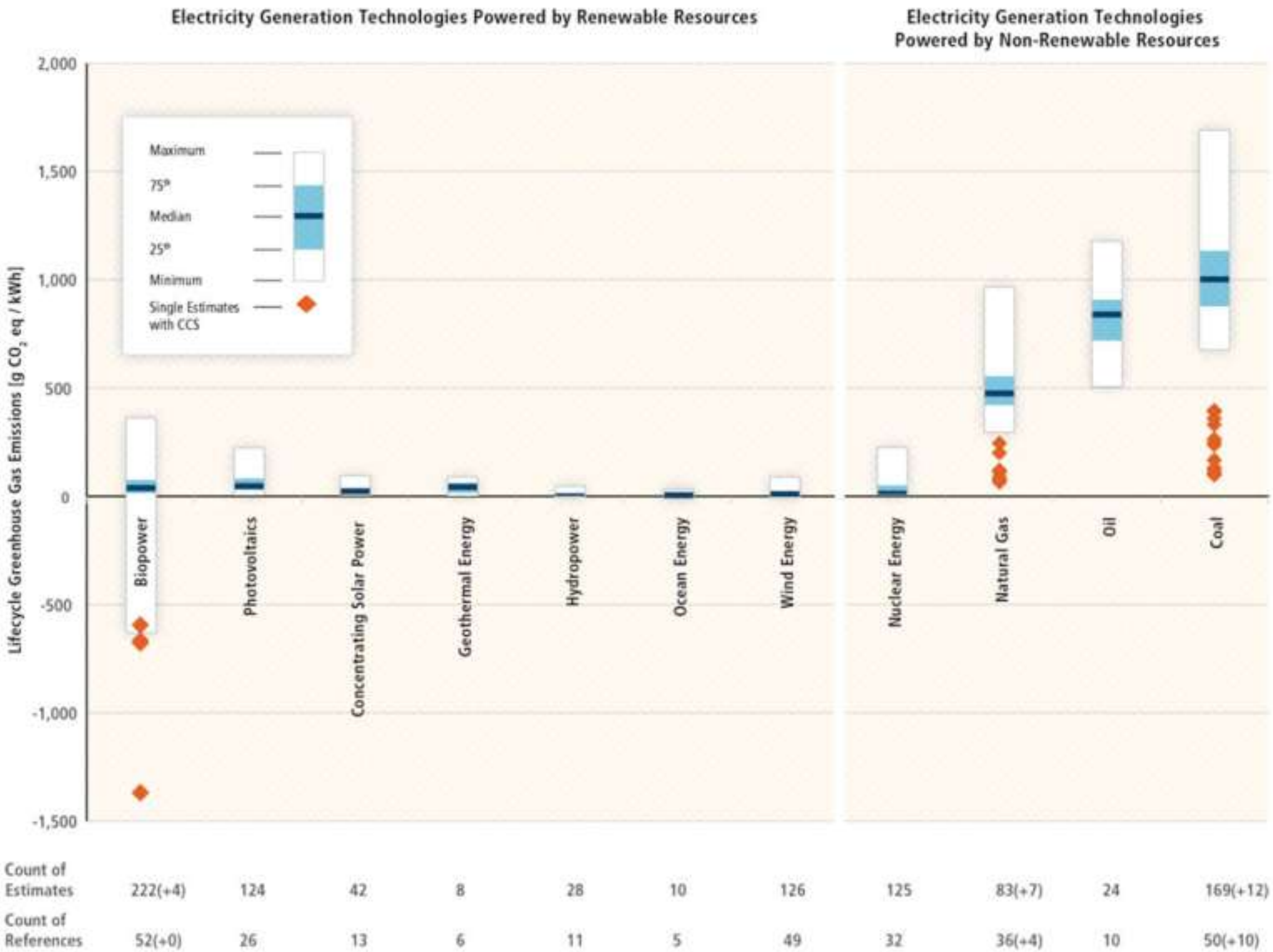
Krewitt et al. *Risk Analysis*, **18**, 377, 1998

Is it safe?



Presumably no LNT estimates in this projection

Is it Green?



Electricity Generation Technologies Powered by Renewable Resources
Electricity Generation Technologies Powered by Non-Renewable Resources
Lifecycle Greenhouse Gas Emissions [g CO2 eq / kWh]
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
Maximum
75th
Median
25th
Minimum
Single Estimates with CCS
Biopower
Photovoltaics
Concentrating Solar Power
Geothermal Energy
Hydropower
Ocean Energy
Wind Energy
Nuclear Energy
Natural Gas
Oil
Coal
Count of Estimates
222(+4)
124
42
8
28
10
126
125
83(+7)
24
169(+12)
Count of References
52(+0)
26
13
6
11
5
49
32
36(+4)
10
50(+10)

Is it Green?

Table A.II.4 | Aggregated results of literature review of LCAs of GHG emissions from electricity generation technologies as displayed in Figure 9.8 (g CO_2eq/kWh).

Values	Bio-power	Solar		Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Nuclear Energy	Natural Gas	Oil	Coal
		PV	CSP								
Minimum	-633	5	7	6	0	2	2	1	290	510	675
25th percentile	360	29	14	20	3	6	8	8	422	722	877
50th percentile	18	46	22	45	4	8	12	16	469	840	1001
75th percentile	37	80	32	57	7	9	20	45	548	907	1130
Maximum	75	217	89	79	43	23	81	220	930	1170	1689
CCS min	-1368								65		98
CCS max	-594								245		396

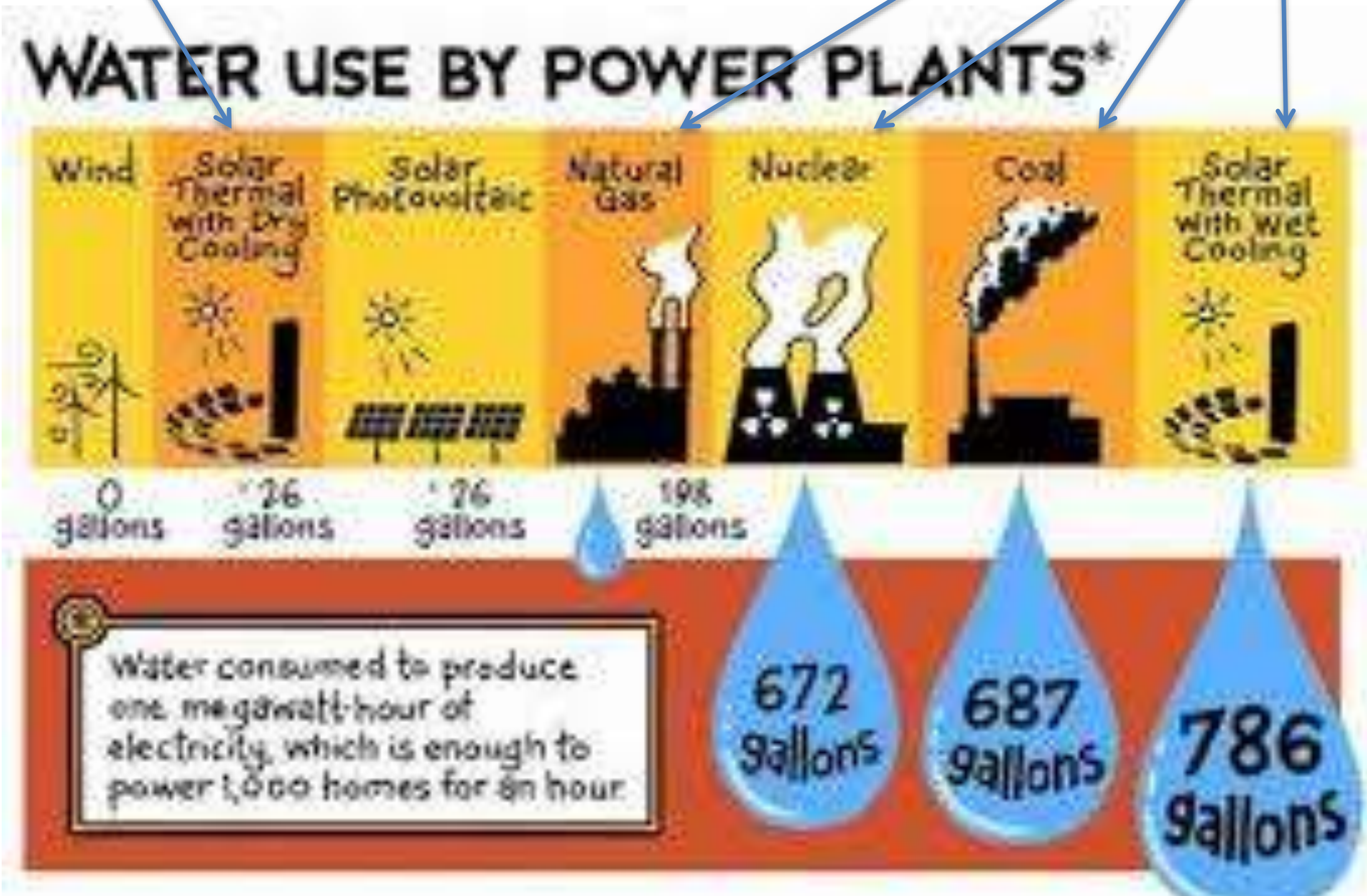
Note: CCS = Carbon capture and storage, PV = Photovoltaic, CSP = Concentrating solar power.

From the IPCC Special Report on Renewable Energy Sources

Water Problems?

Dry cooling
i.e., like a car radiator

Wet cooling
i.e., cooling towers

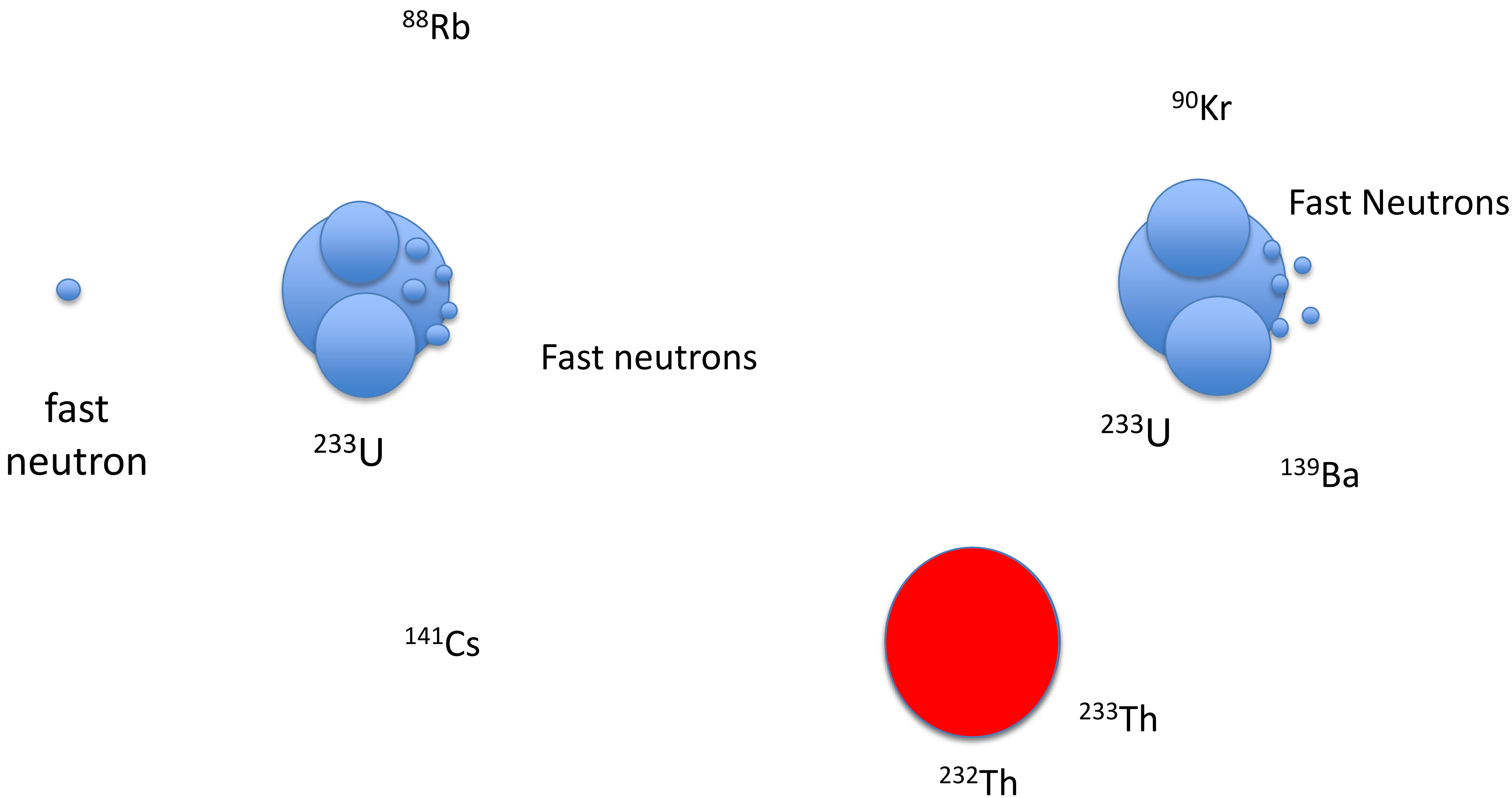


Water problems are not a show stopper. There are plenty of tricks.

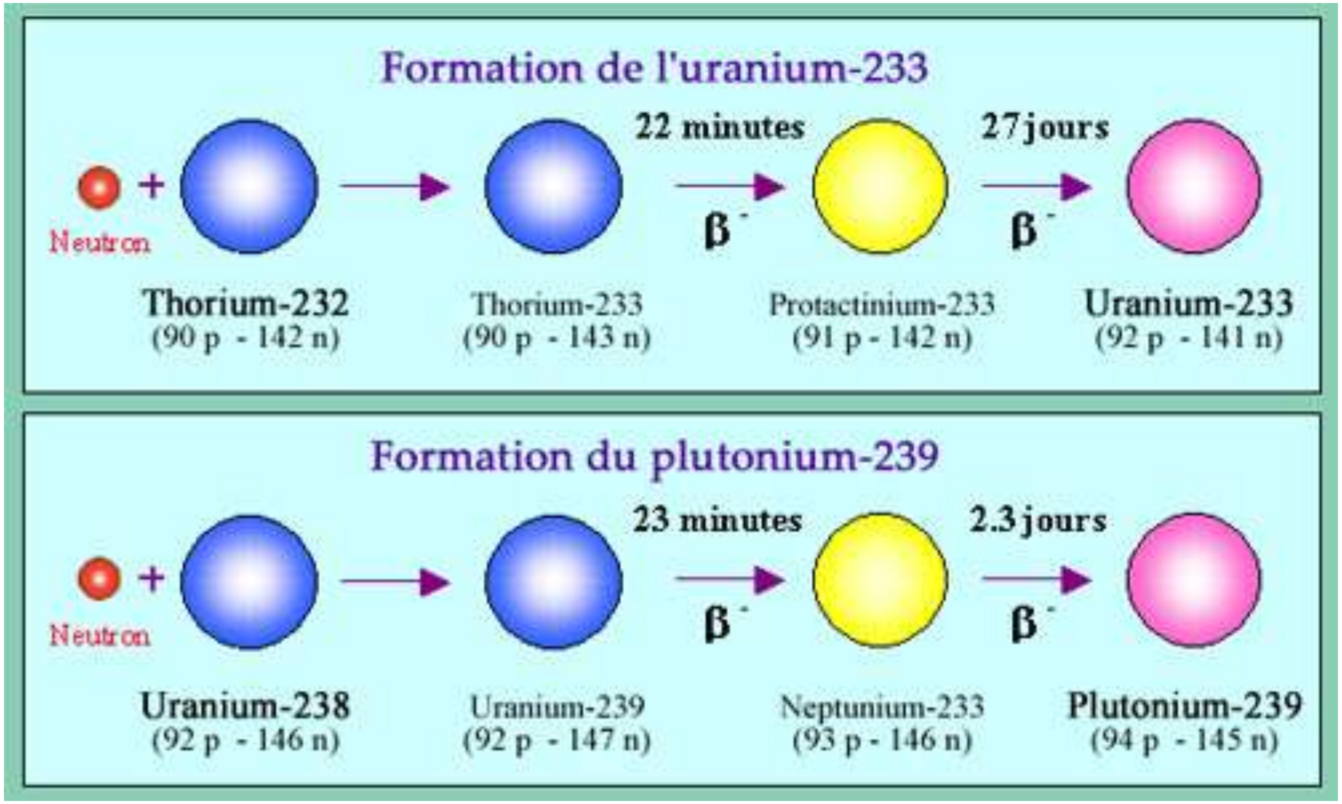
Water Problems?

- Once through cooling.
  - Uses a tremendous amount of water
  - Ocean water: Diablo Canyon 2.2 GW, California
- Evaporative cooling.
  - Sewage water: Palo Verde 3.3 GW, Arizona (desert)
  - Largest nuclear station in U.S.
- Closed cooling like a car radiator
  - None yet.
- Liquid sodium cooling, molten salt cooling
  - Higher temperature, more efficient less cooling
  - Air turbines like a jet engine.

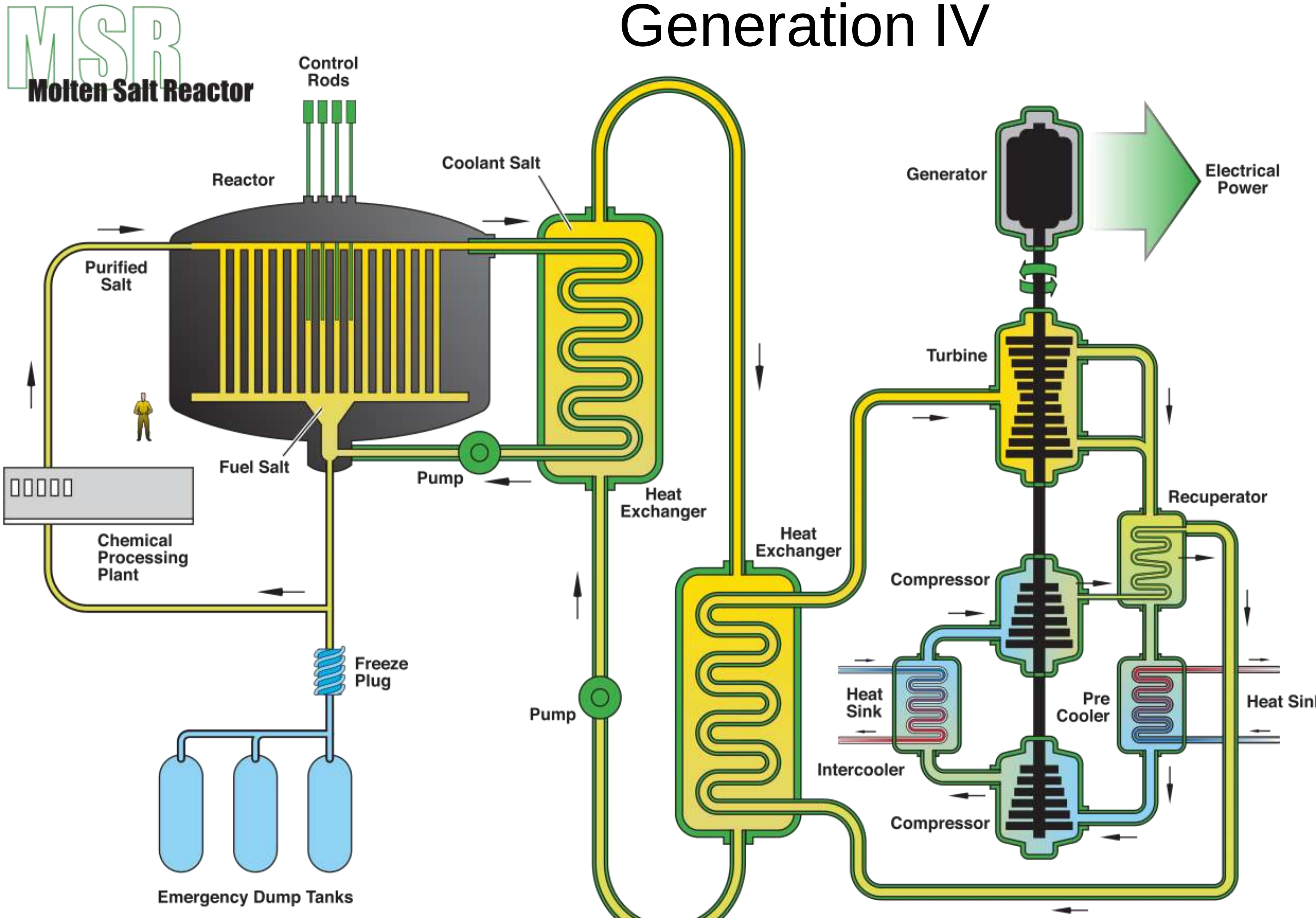
Fast Fission

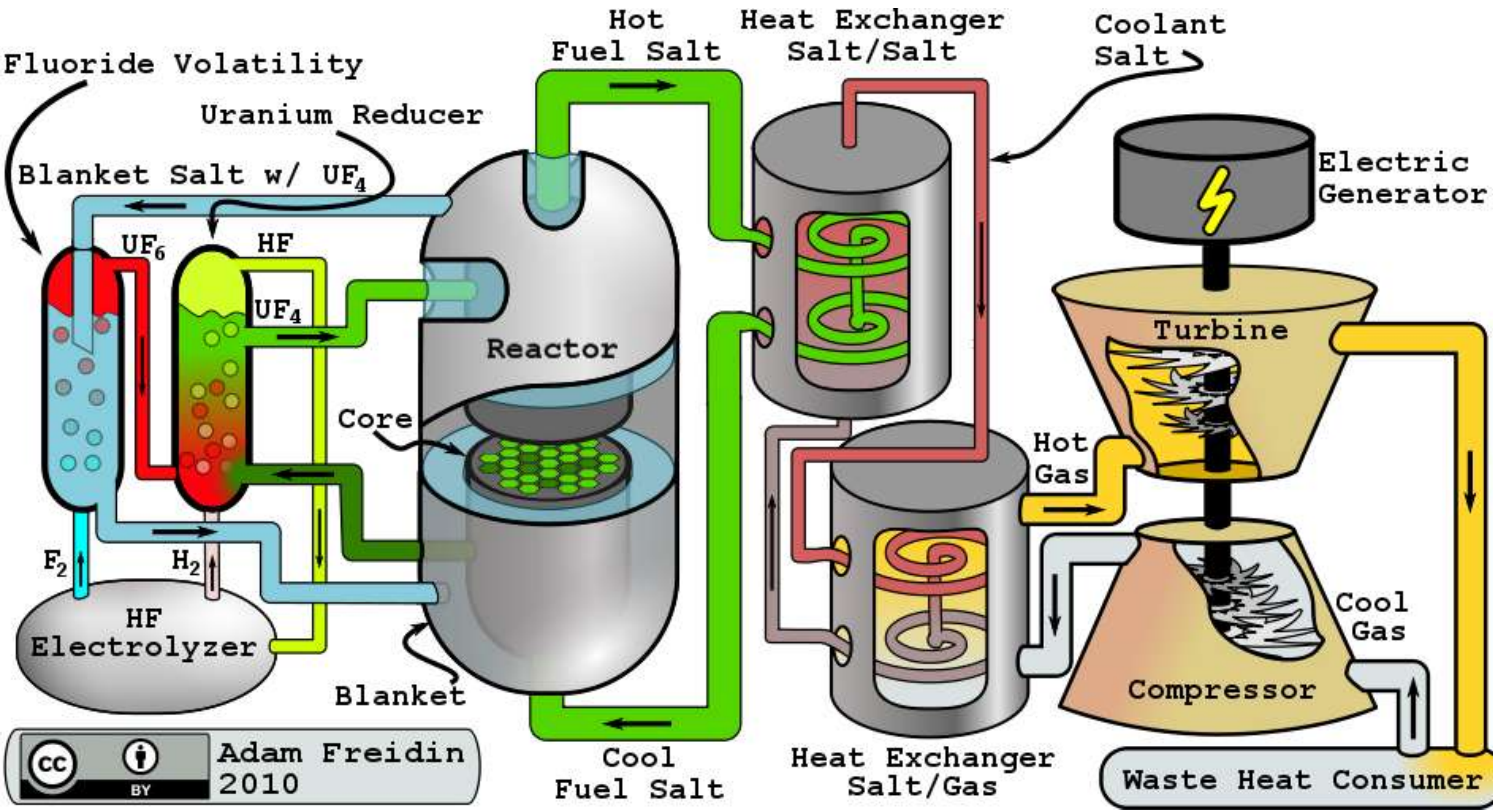


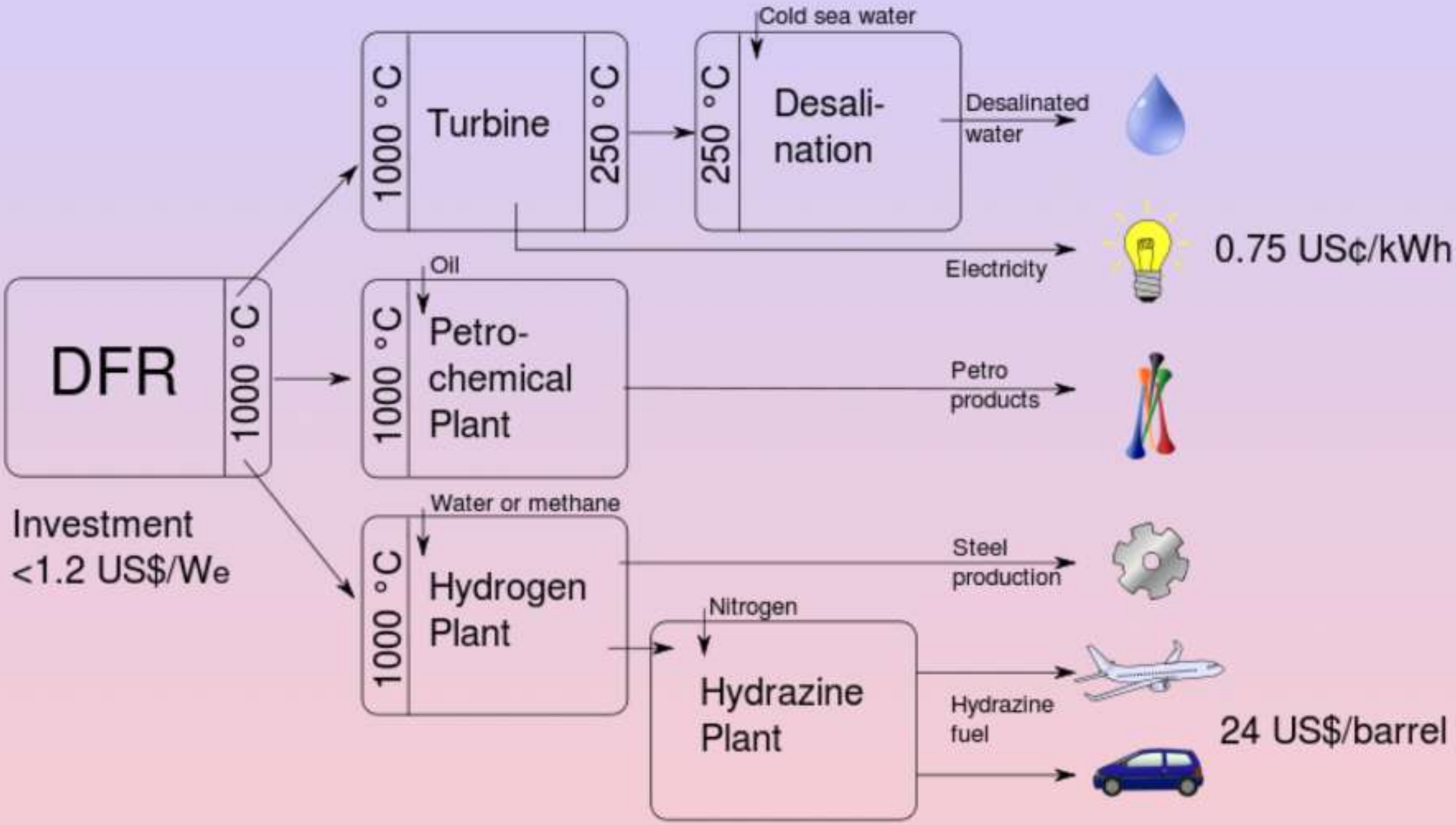
Fertile to Fissile



Generation IV



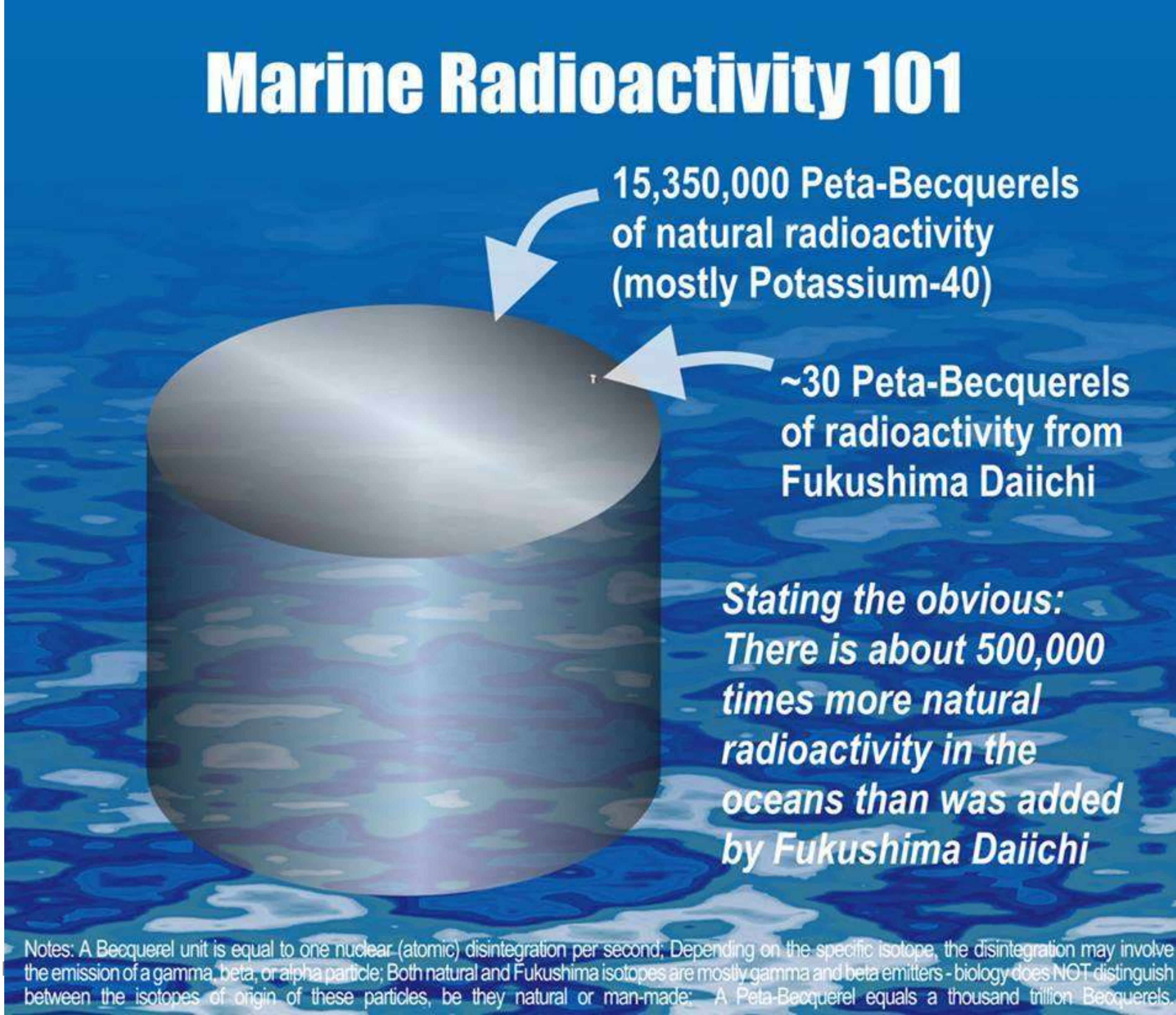

Fluoride Volatility
Uranium Reducer
Blanket Salt w/ UF4
UF6
HF
UF4
F2
H2
HF Electrolyzer
Hot Fuel Salt
Heat Exchanger Salt/Salt
Coolant Salt
Electric Generator
Reactor
Core
Blanket
Turbine
Hot Gas
Cool Gas
Compressor
Cool Fuel Salt
Heat Exchanger Salt/Gas
Waste Heat Consumer
Adam Freidin 2010


Cold sea water
1000 °C
Turbine
250 °C
250 °C
Desali-
nation
Desalinated
water
0.75 US¢/kWh
Electricity
Oil
DFR
1000 °C
1000 °C
Petro-
chemical
Plant
Petro
products
Water or methane
Investment
<1.2 US$/We
1000 °C
Hydrogen
Plant
Steel
production
Nitrogen
Hydrazine
Plant
Hydrazine
fuel
24 US$/barrel

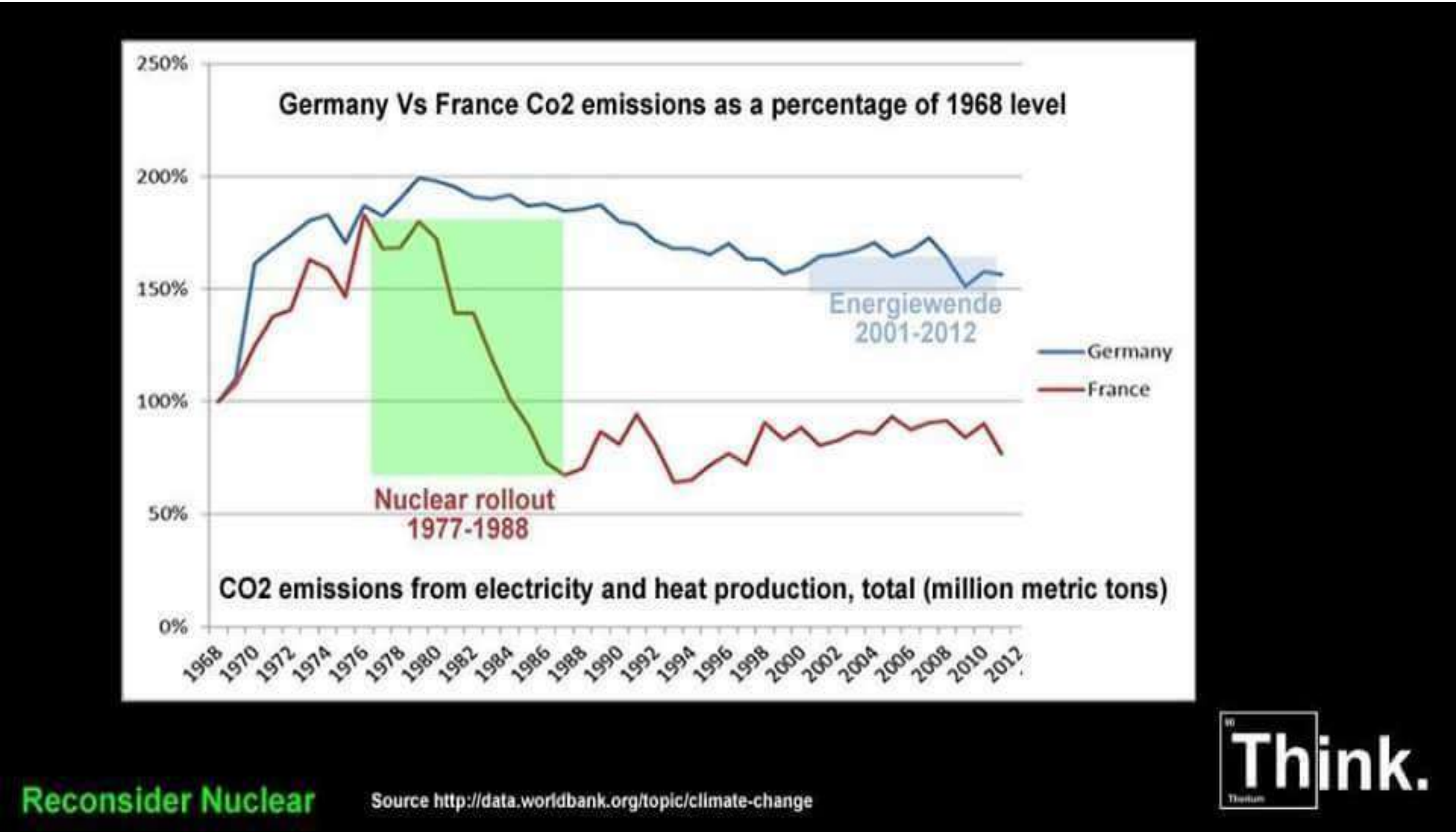
Cashton Green Wind Farm
North Wind Turbine Installation

Installing Re-Bar and Anchor Bolts Before Cement Pour
(45 Tons of Re-Bar)

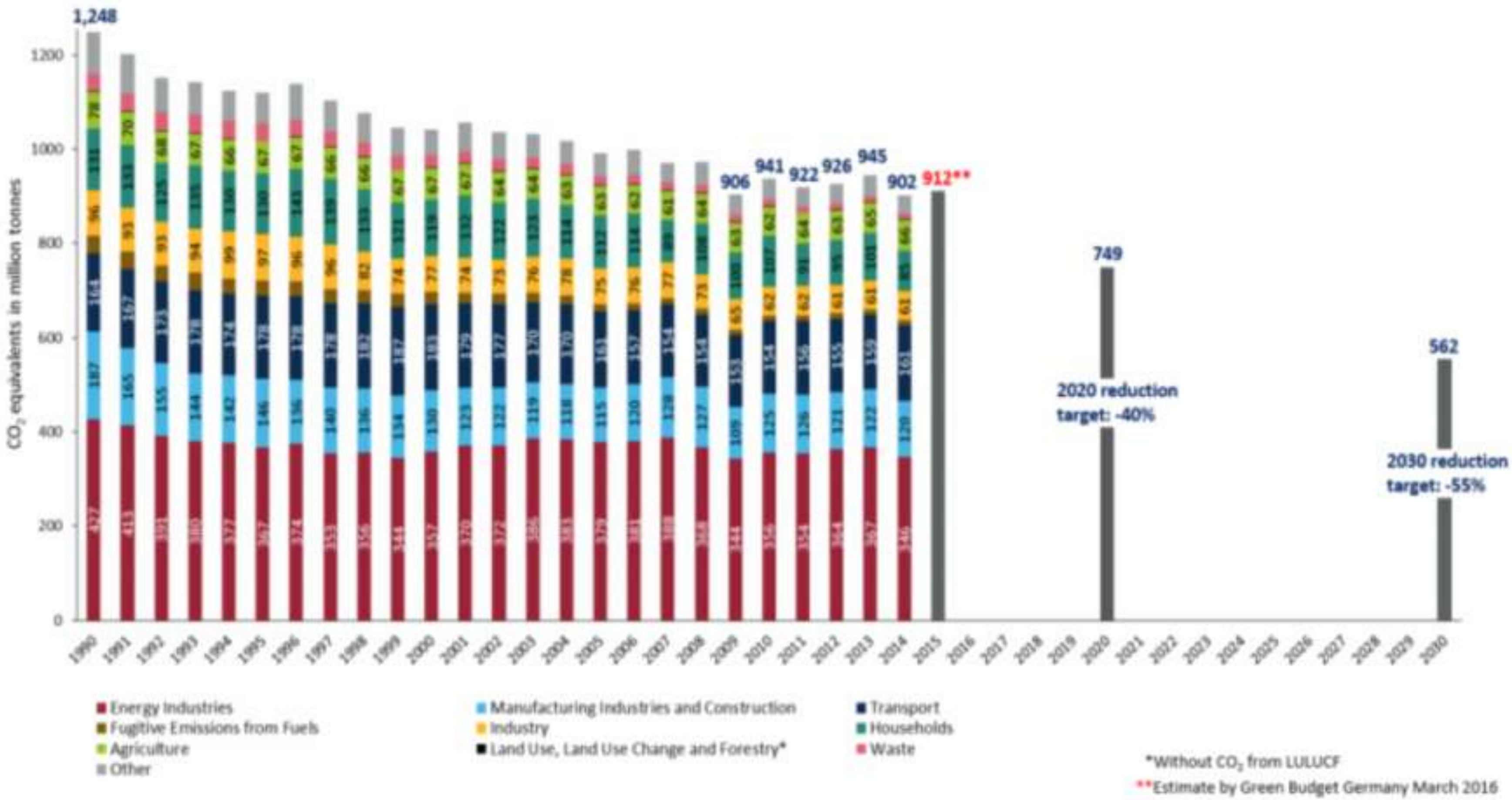
http://www.cashton.com/North_Wind_Turbine_Const-DM-CS-SB-2-reduced-in-size.pdf


Marine Radioactivity 101
15,350,000 Peta-Becquerels of natural radioactivity (mostly Potassium-40)
~30 Peta-Becquerels of radioactivity from Fukushima Daiichi
Stating the obvious: There is about 500,000 times more natural radioactivity in the oceans than was added by Fukushima Daiichi
Notes: A Becquerel unit is equal to one nuclear (atomic) disintegration per second; Depending on the specific isotope, the disintegration may involve the emission of a gamma, beta, or alpha particle; Both natural and Fukushima isotopes are mostly gamma and beta emitters - biology does NOT distinguish between the isotopes of origin of these particles, be they natural or man-made; A Peta-Becquerel equals a thousand trillion Becquerels.

The Effect of Energiewende I



The Effect of Energiewende II



Graph by Clean Energy Wire, data from German Environment Agency (UBA) and Green Budget Germany

The Effect of San Onofre

closed 2013