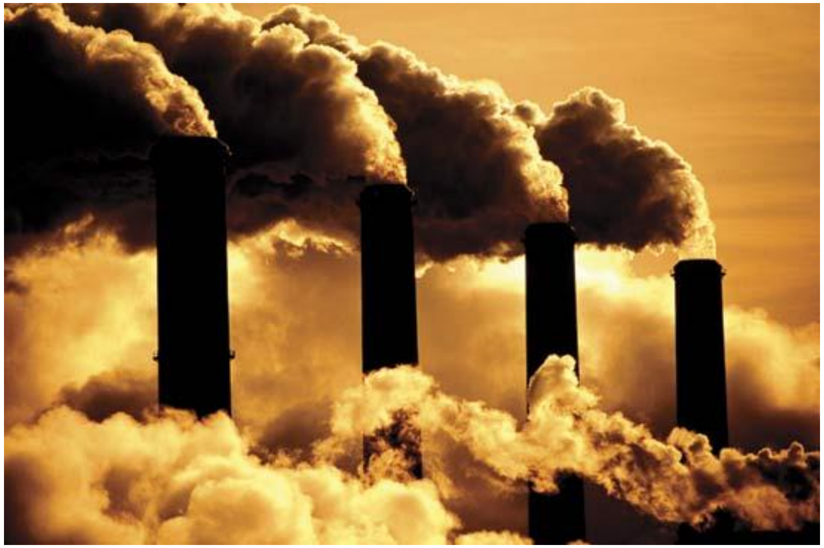
Aim High!

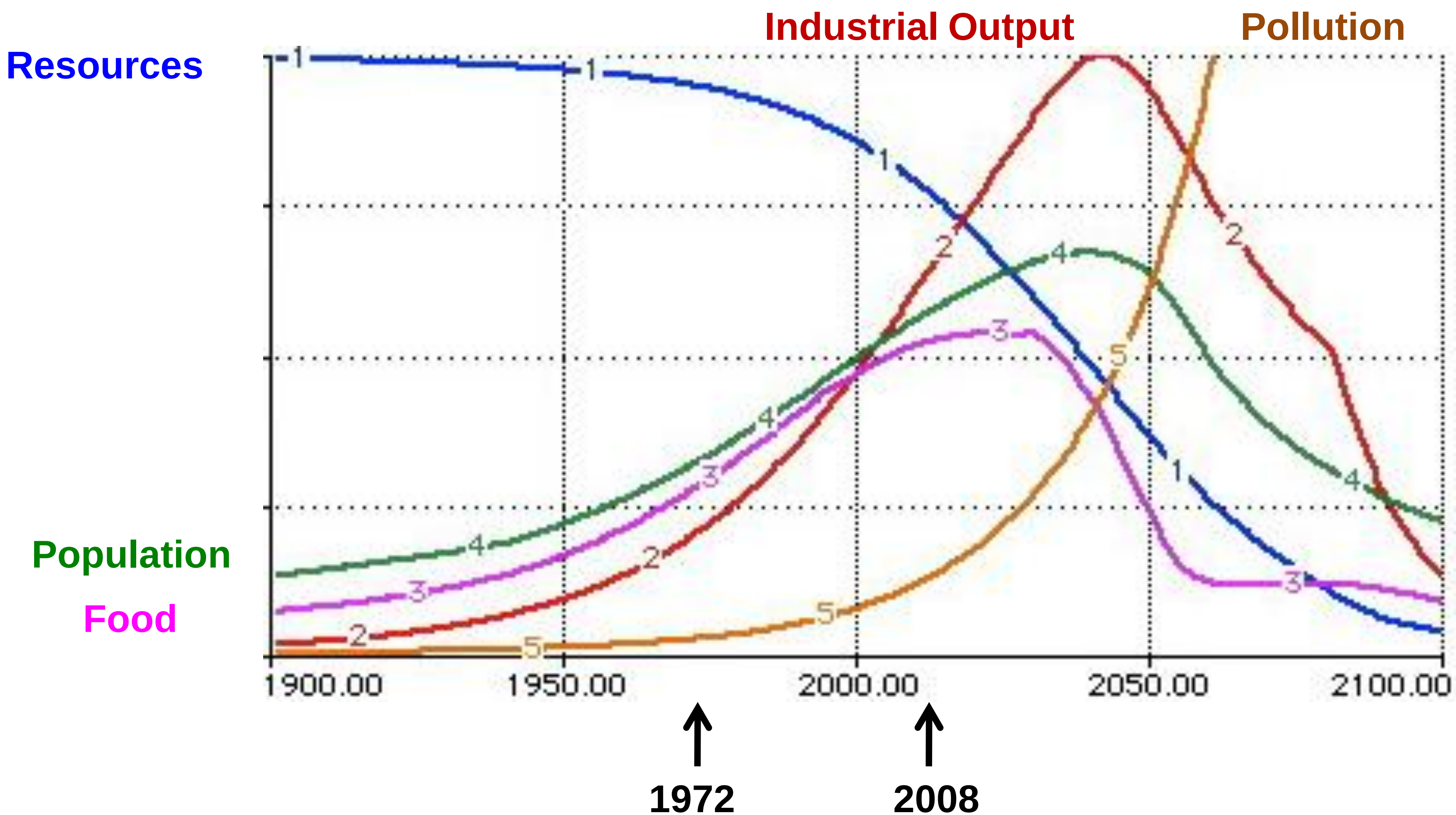
1. Limits to growth
2. Aim High
3. Thorium power
4. Project
5. Questions

Robert Hargraves, Hanover NH

Global environmental problems mount.

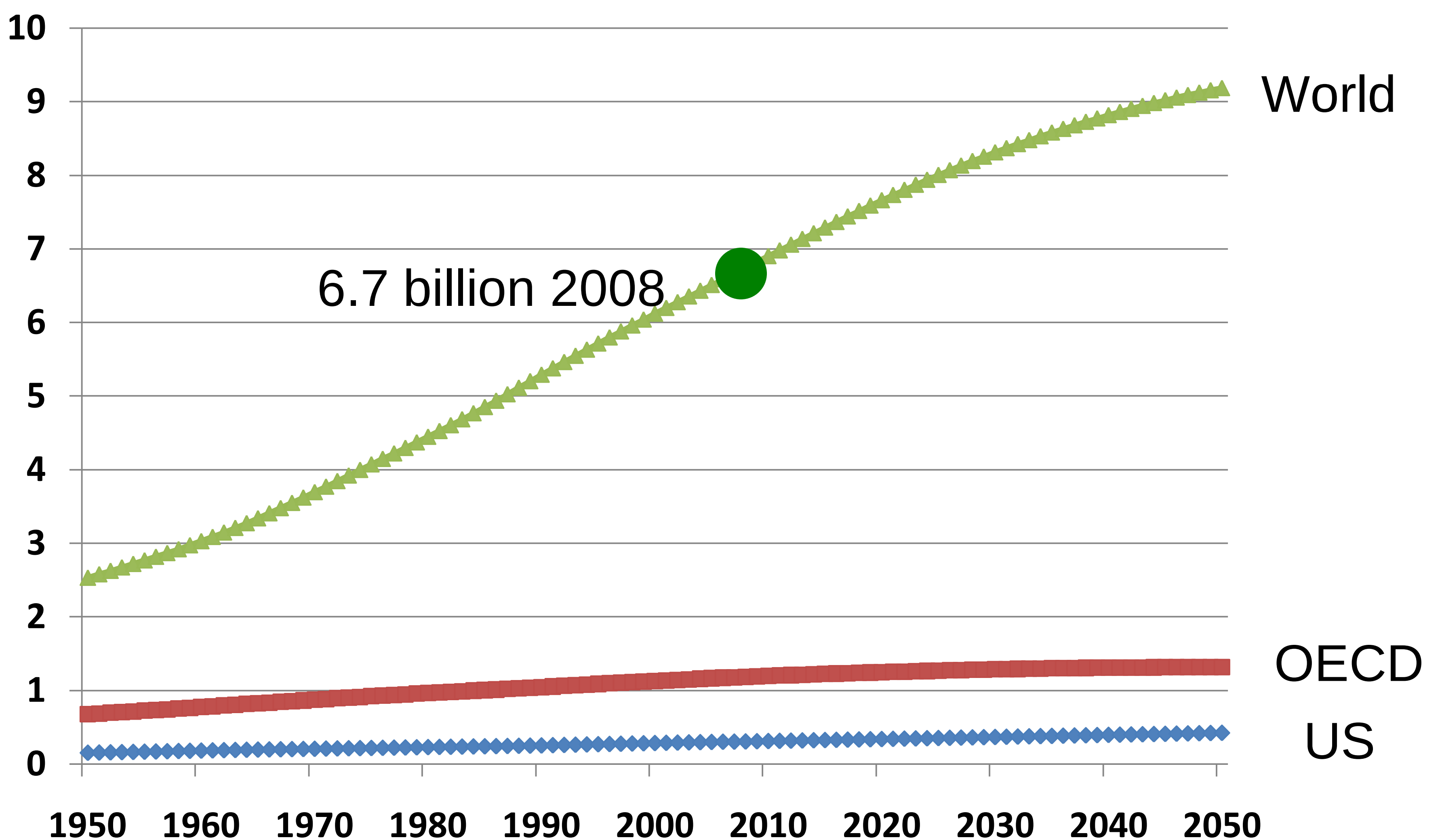


Dennis Meadows' *Limits to Growth* showed effects of finite resources.



http://www.aspoitalia.net/images/stories/aspo5presentations/Meadows_ASPO5.pdf

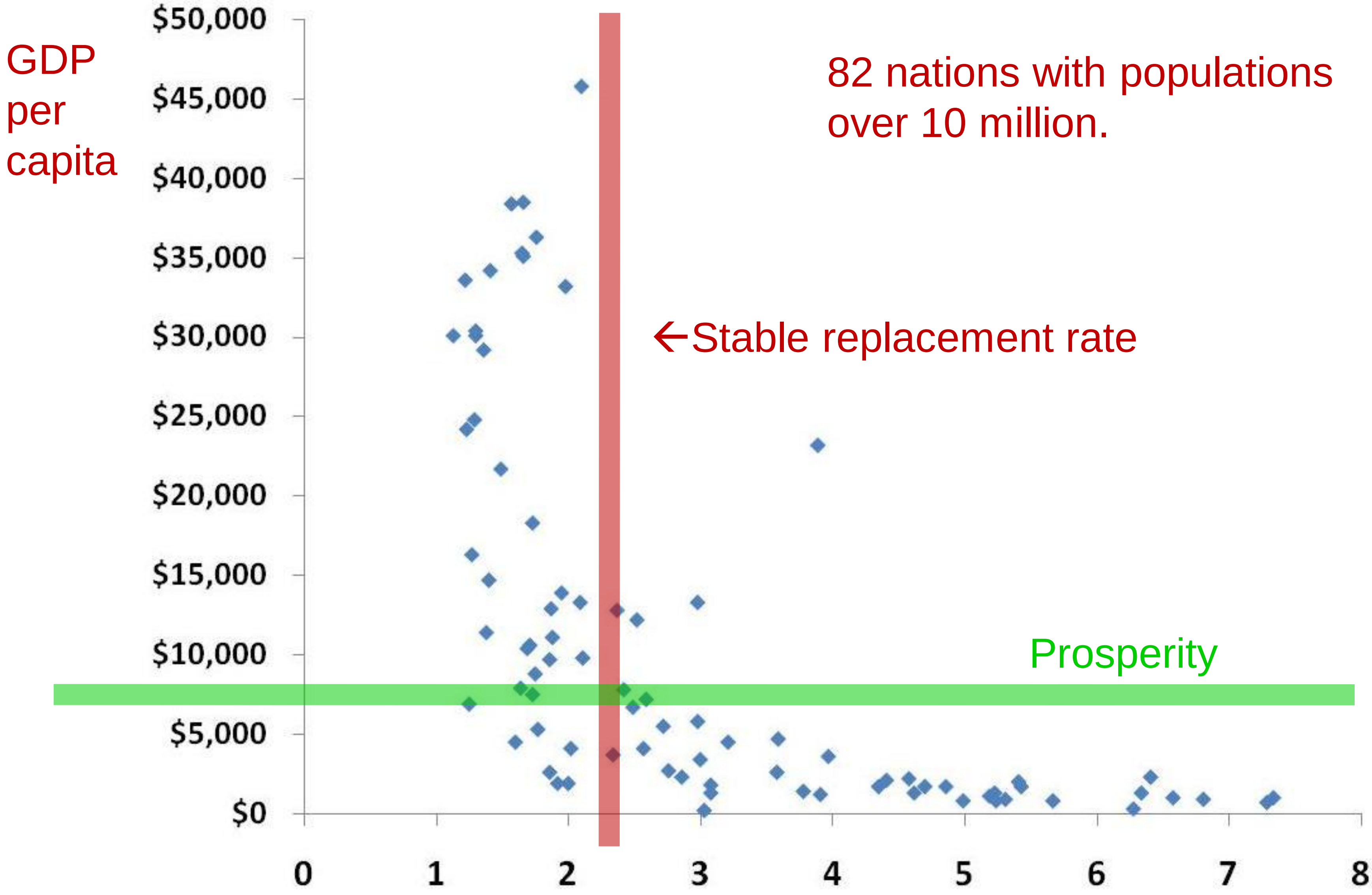
Population is stable in developed nations.



http://caliban.sourceoecd.org/vl=1260748/cl=17/nw=1/rpsv/factbook/010101.htm

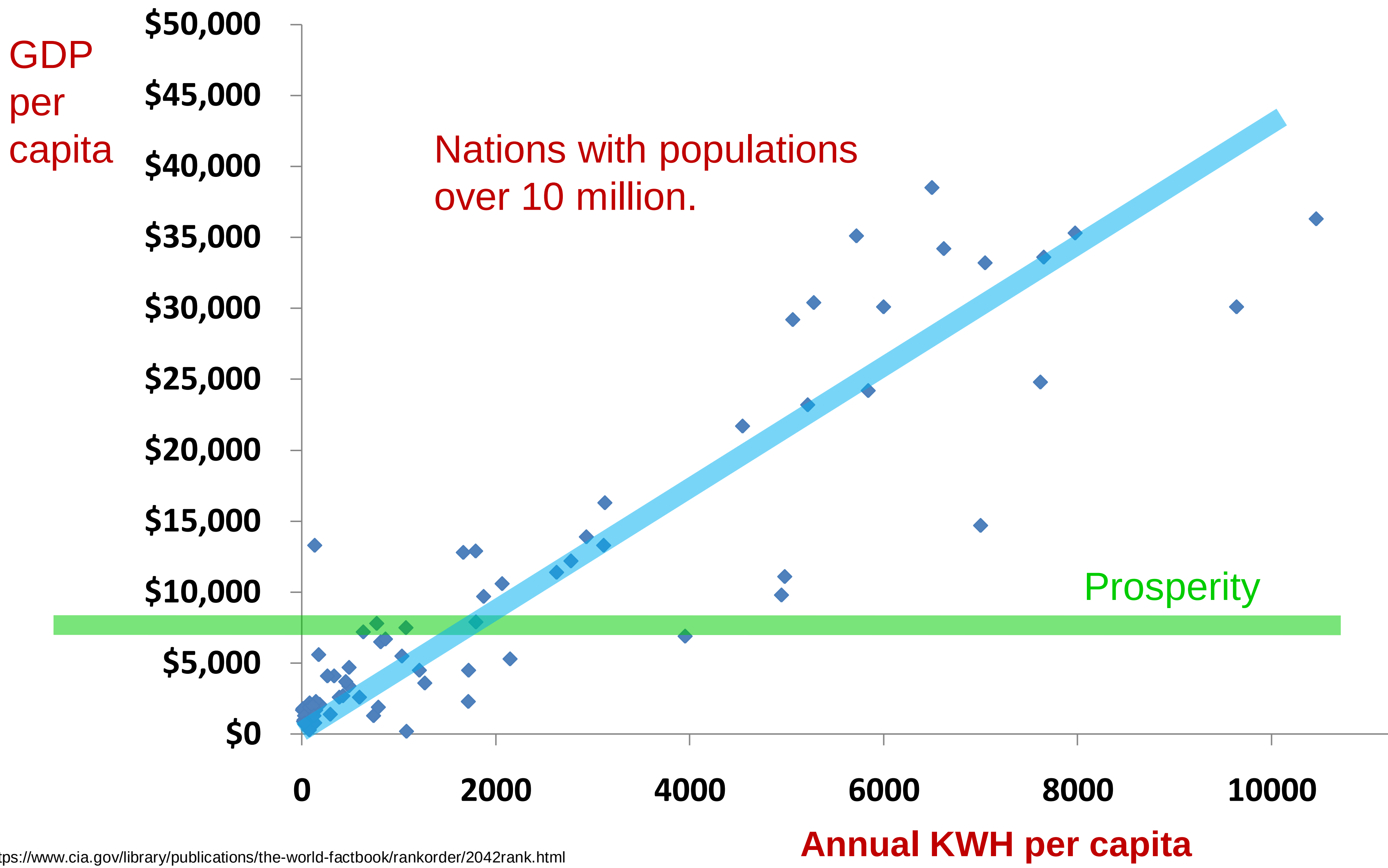
http://www.oecd.org/dataoecd/13/38/16587241.pdf

Prosperity stabilizes population.



https://www.cia.gov/library/publications/the-world-factbook/docs/rankorderguide.html

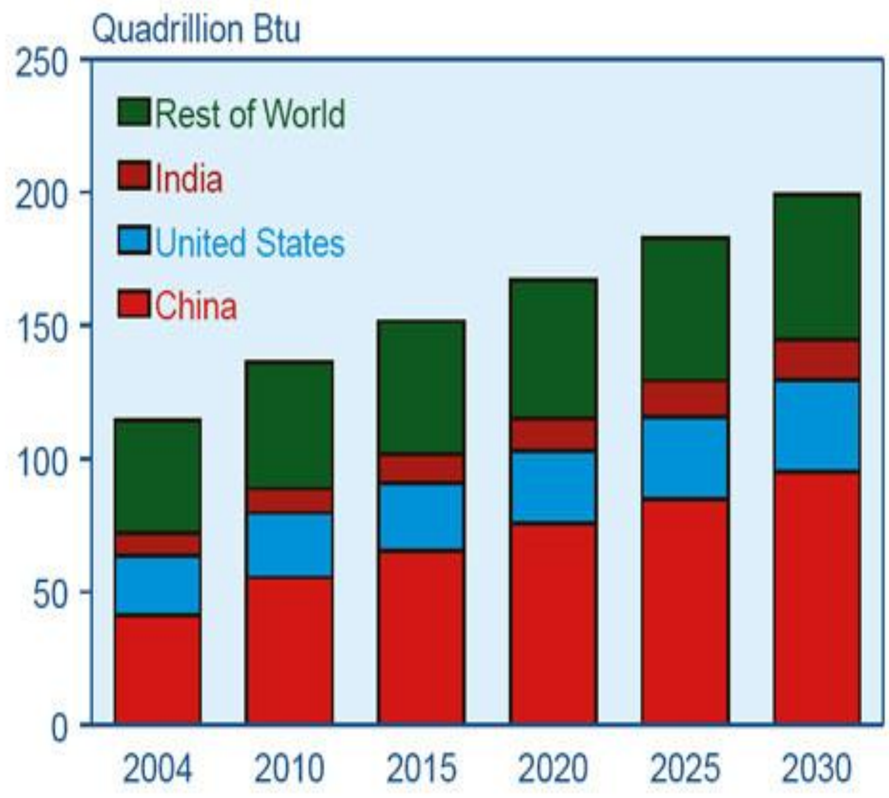
Prosperity depends on energy.



https://www.cia.gov/library/publications/the-world-factbook/rankorder/2042rank.html

Energy and coal use is growing rapidly in developing nations.

Non-OECD energy use



World coal use

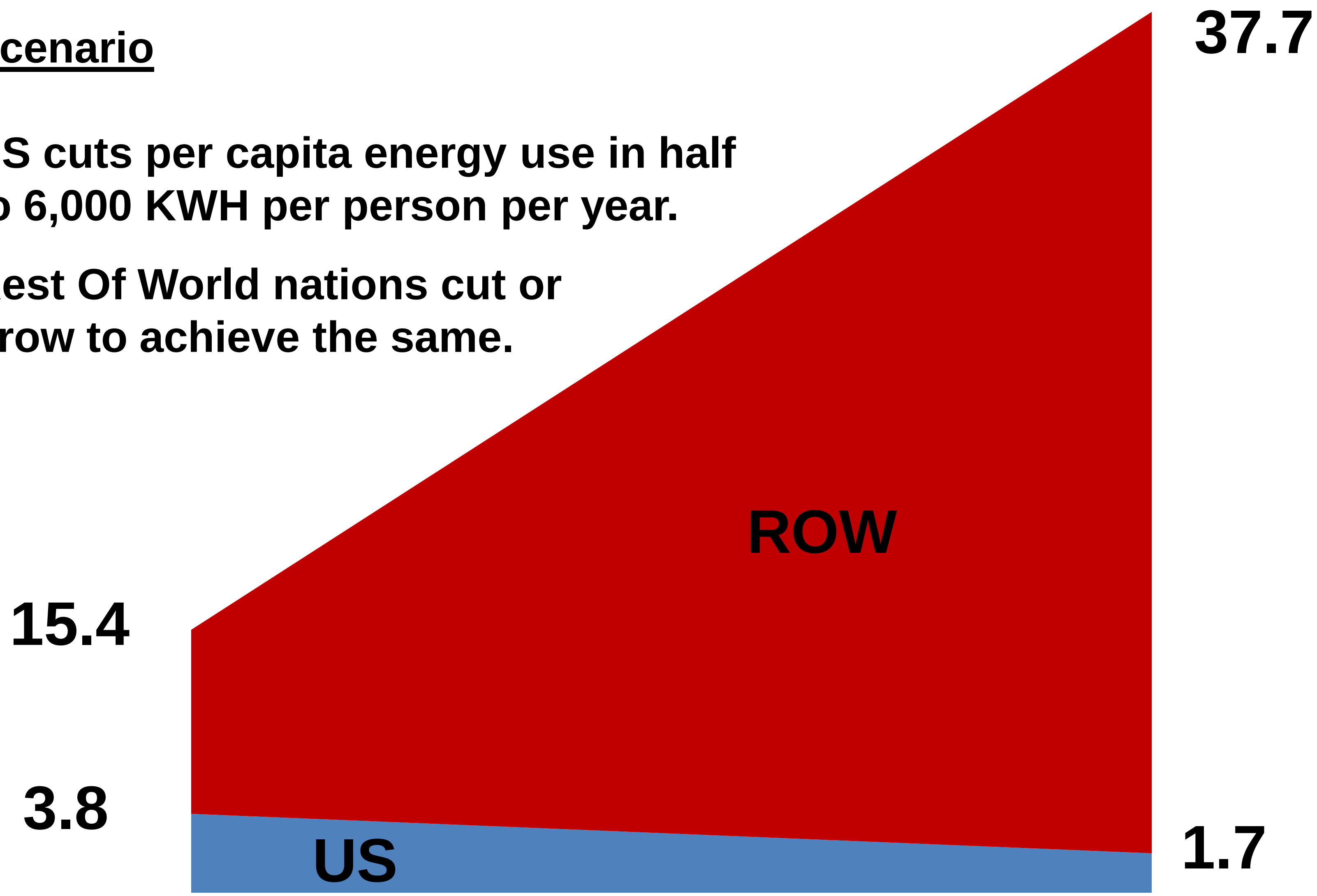
http://www.eia.doe.gov/oiaf/ieo/world.html

Conservation won’t stop the growth.

Scenario

US cuts per capita energy use in half to 6,000 KWH per person per year.

Rest Of World nations cut or grow to achieve the same.



Units are 10^{15} watt hours per year

"Technology policy lies at the core of the climate change challenge."

Prof. Jeffrey Sachs
Economist, Columbia University
Director of The Earth Institute

"If we try to restrain emissions without a fundamentally new set of technologies, we will end up stifling economic growth, including the development prospects for billions of people."

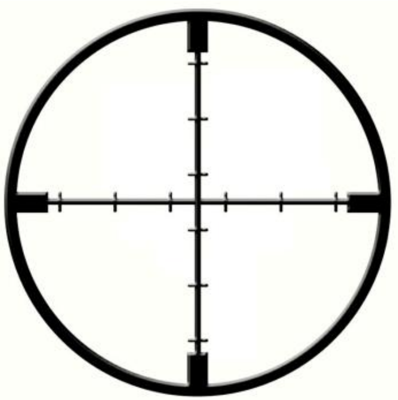
"We will need much more than a price on carbon."

"The US, Europe and Japan will need to start all this technological innovation soon if we are to have a chance to stabilize carbon emissions…"

"…low emissions technologies developed in the rich world will need to be adopted rapidly in poorer countries."

http://www.sciam.com/article.cfm?id=technological-keys-to-climate-protection-extended

Aim high!
Set aggressive goals.



Develop a **new energy source** that

1. produces **electricity** cheaper than from coal,

2. synthesizes vehicle **fuel** cheaper than from oil,

3. is **inexhaustible**,

4. reduces **waste**, and

5. is **affordable to populations** of developing nations.

Thorium is a plentiful fuel.

Thorium metal was discovered in Norway in 1828.

Thorium is named after Thor, the Norse god of thunder and lightning.

Lemhi Pass alone has enough thorium in 1,400 acres to power the US for a milleneum.

Thorium per se is not fissionable. How can thorium be a fuel?

http://en.wikipedia.org/wiki/Thorium

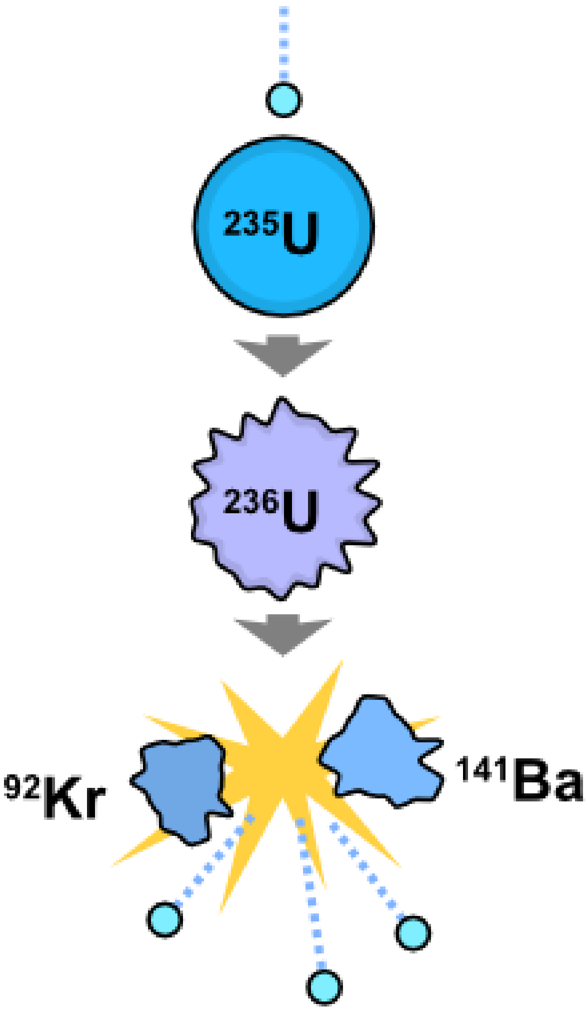
U-233, U-235, and Pu-239 are three possible reactor fission fuels.

nucleons	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95
241						
240						
239						
238						
237						
236						
235						
234						
233						
232						

Natural

fission

Uranium-235 fissioning into krypton and barium releases energy.



The total mass of the resulting

barium-141
krypton-92
neutrons (3)

is less than the mass of the U-235 + neutron,

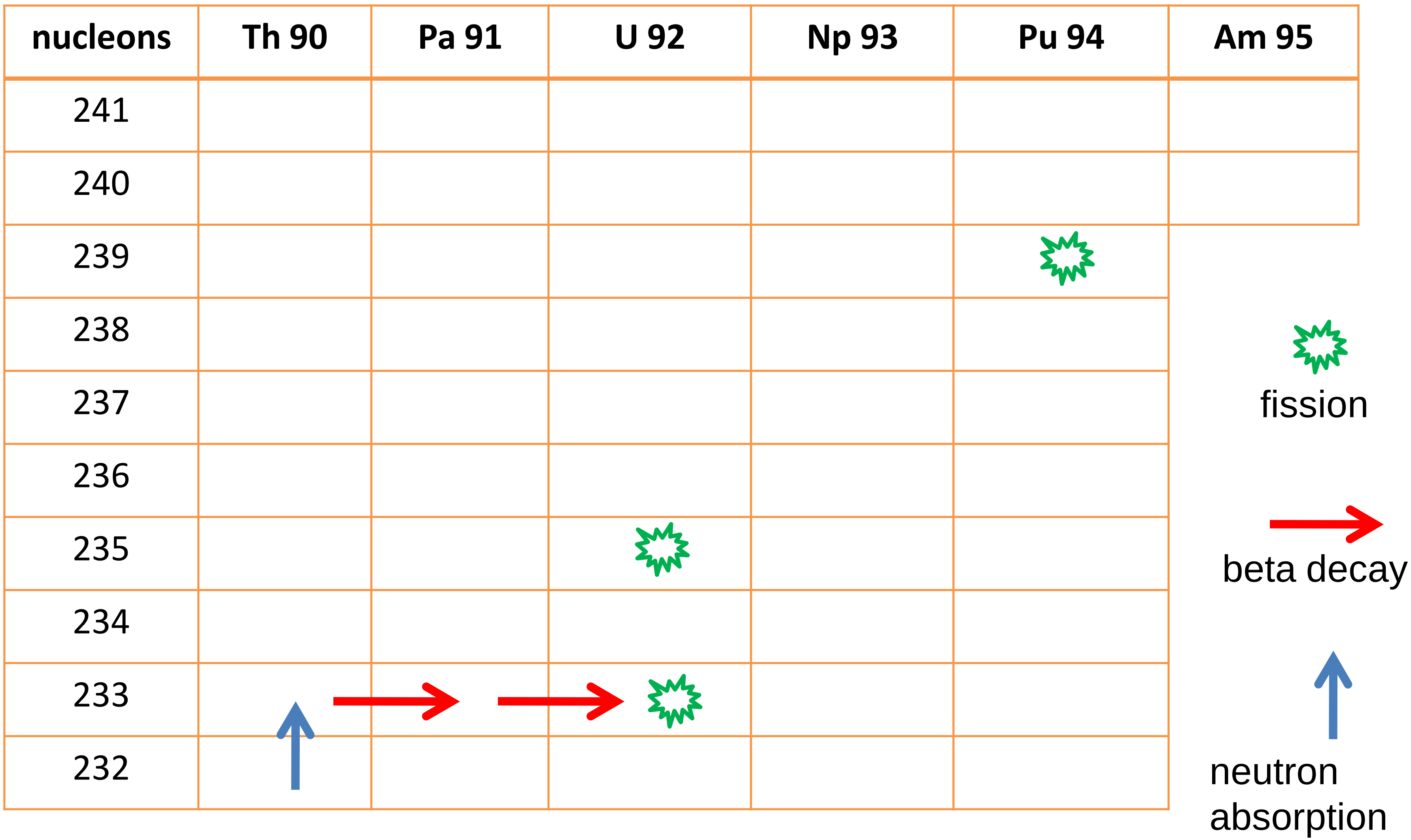
releasing 166 Mev of energy.

http://en.wikipedia.org/wiki/Nuclear_fission

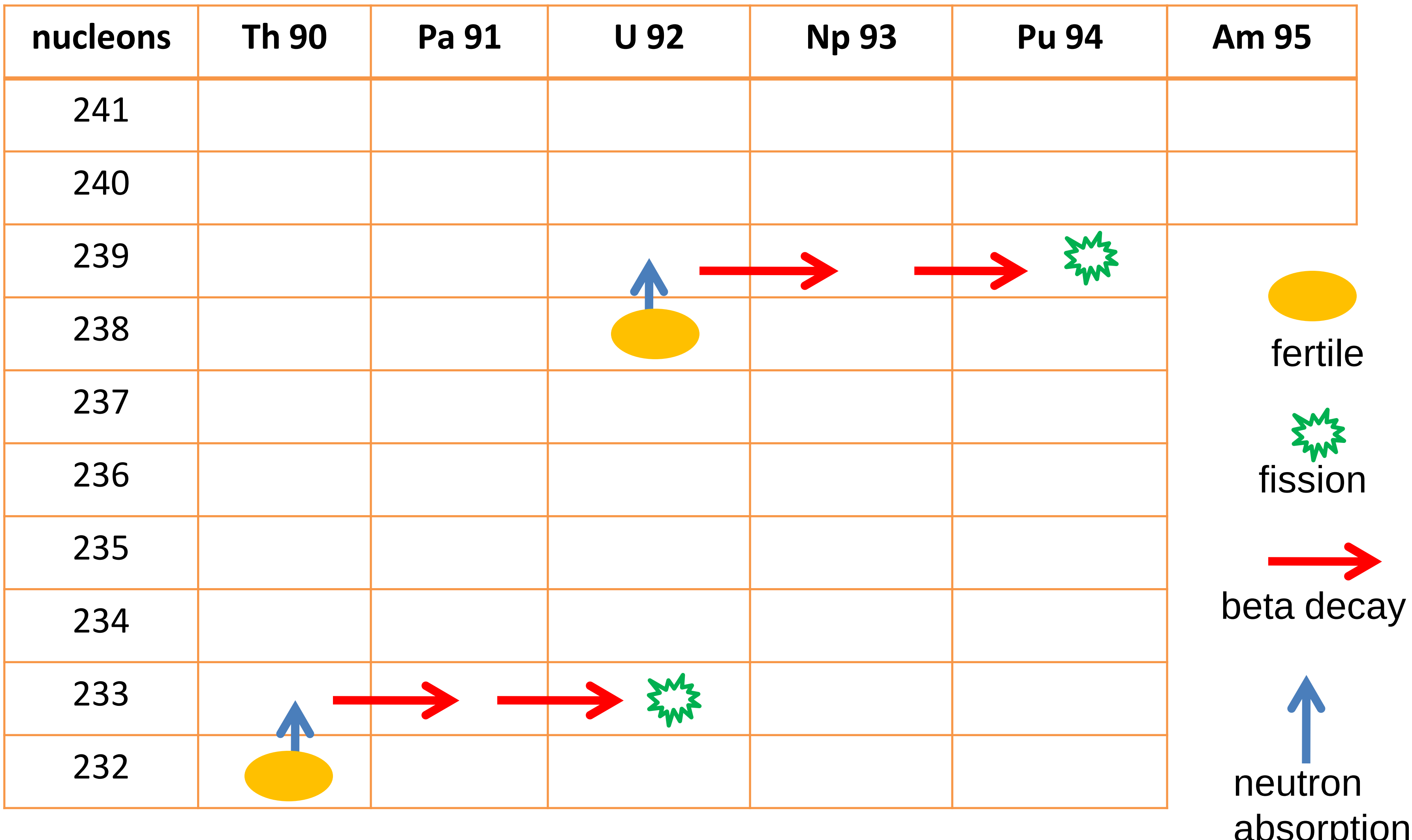
Uranium-238 neutron absorption makes fissionable plutonium-239.

nucleons	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95
241						
240						
239						
238						
237						
236						
235						
234						
233						
232						

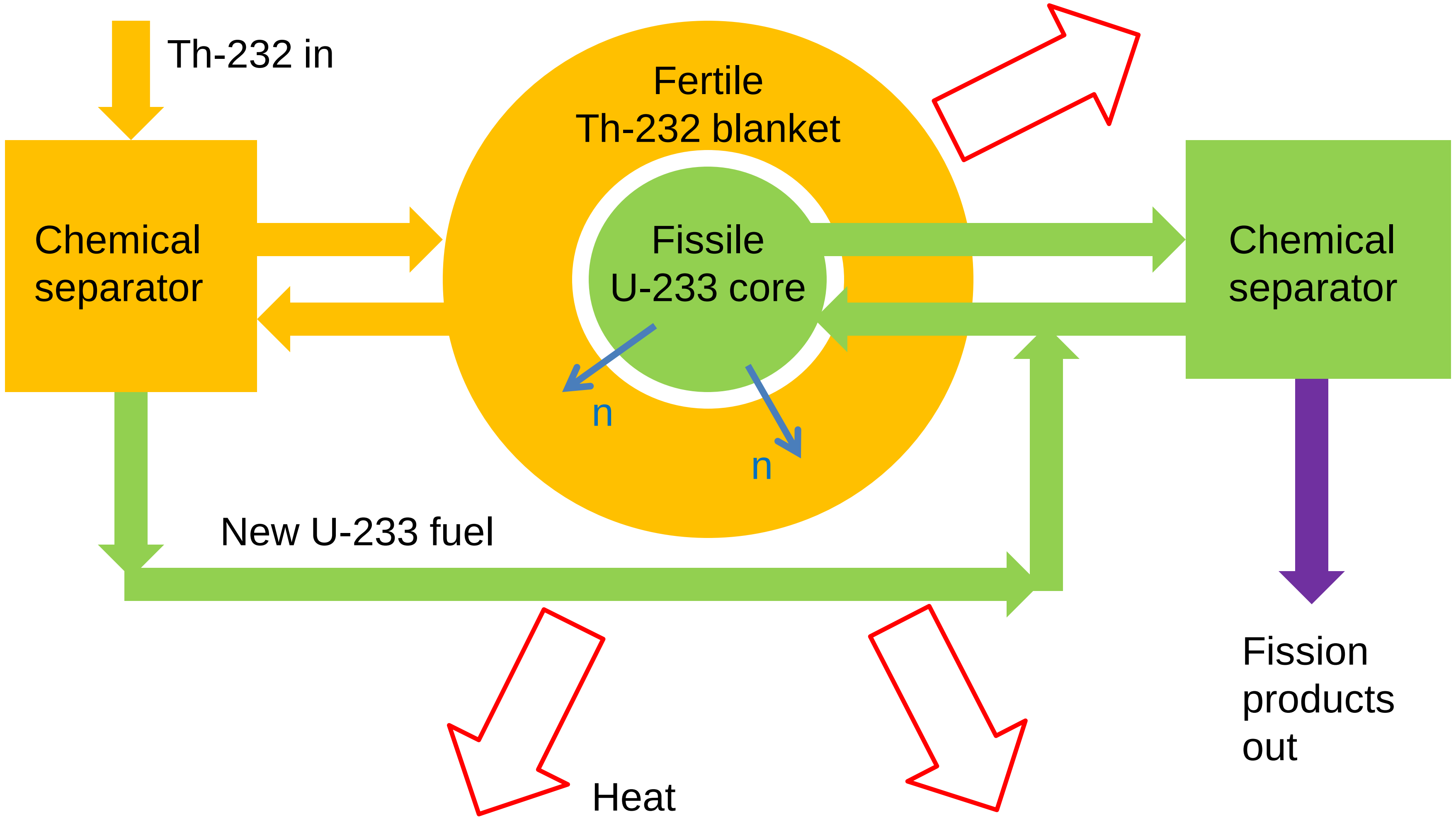
Thorium-232 makes fissionable uranium-233.



U-238 and Th-232 are called fertile because they can make fissionable fuel.



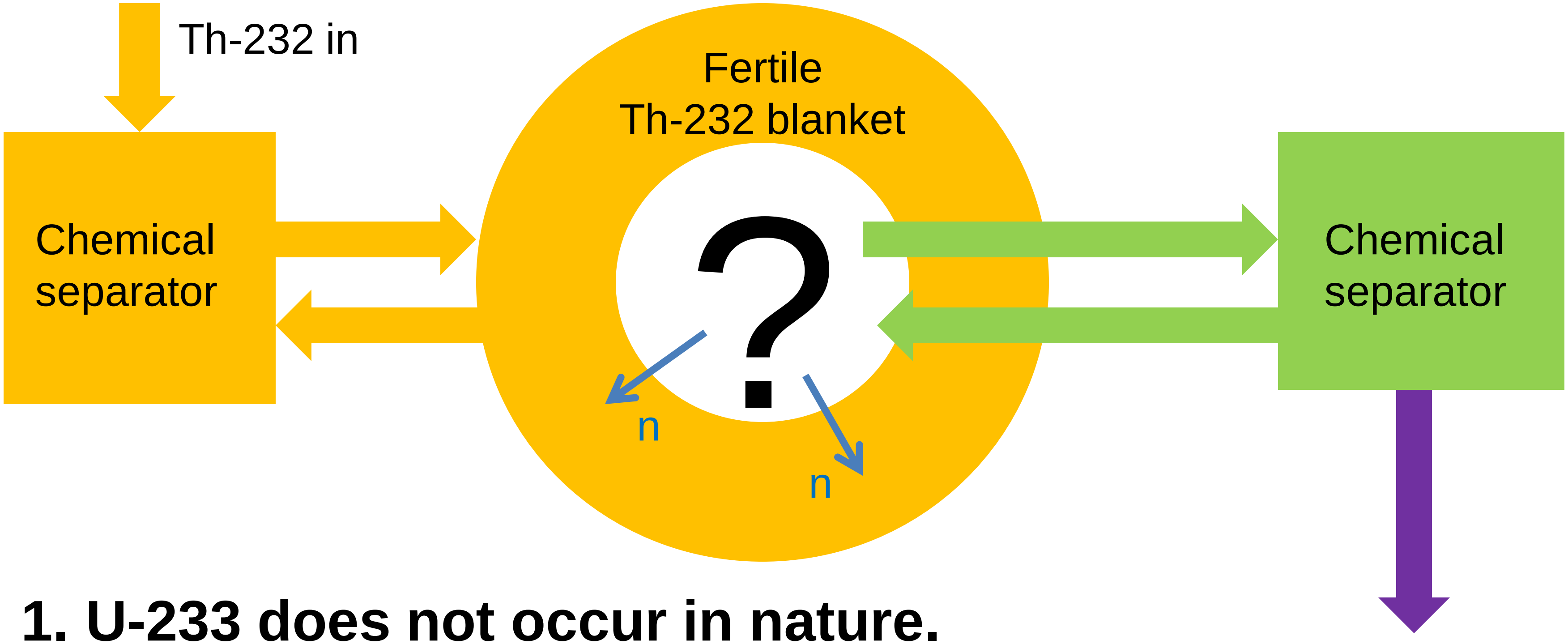
In a thorium reactor the Th-232 blanket becomes the U-233 core.



The Liquid Fluoride Thorium Reactor is innovative.

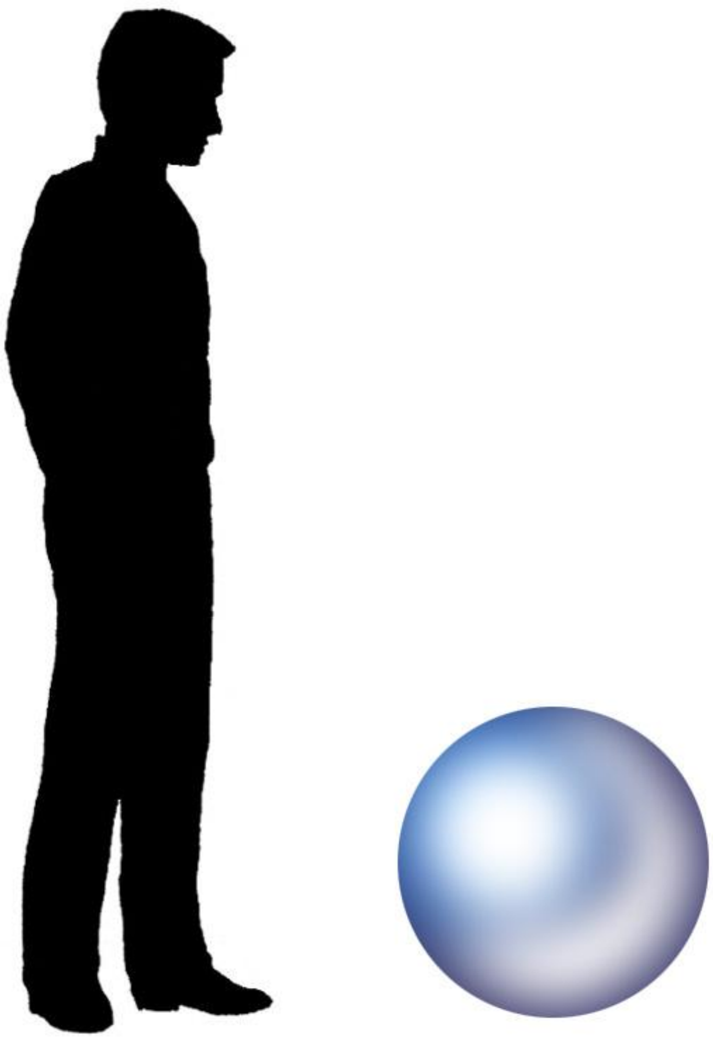
1. Fuel is dissolved in liquid for easy pumping and chemical processing. Liquid is molten fluoride salt!
2. Reactivity is inherently stable, because heat expands the salt past criticality.
3. High temperature (800^{O}C) enables 50% efficient Brayton power conversion turbine-generator.
4. High temperature enables electrolysis of hydrogen, a fuel feedstock.
5. Long term radioactive waste is < 1% that of typical plants.

Start the LFTR by priming it with another fissile fuel.



1. U-233 does not occur in nature.
2. The US government has 500 kg of U-233.
3. Prime with U-235, or Pu, or spent nuclear reactor fuel.
4. U or Pu will be replaced with U-233 in ~ 1 year.

Thorium fuel is plentiful, compact, and inexpensive.



1 t will fuel a 1 GW power plant for one year.

500 GW would power the entire US.

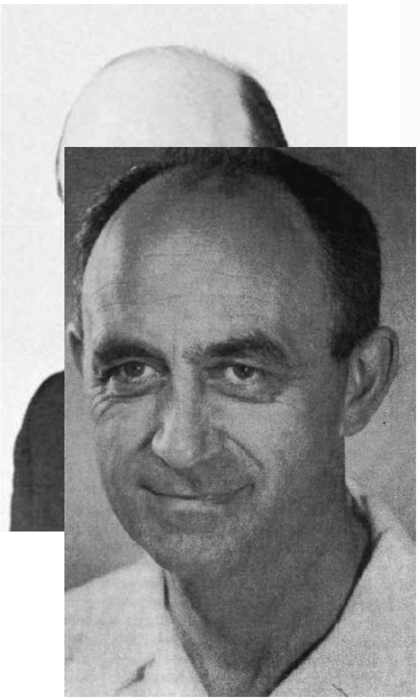
$107,000 per tonne

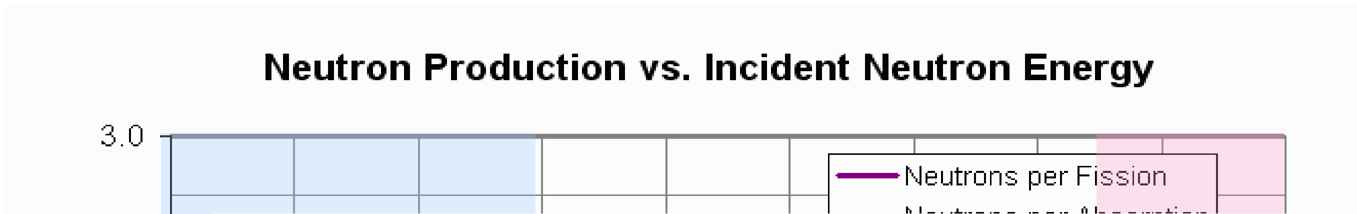
US has 3,752 t in storage, 400,000 t of reserves.

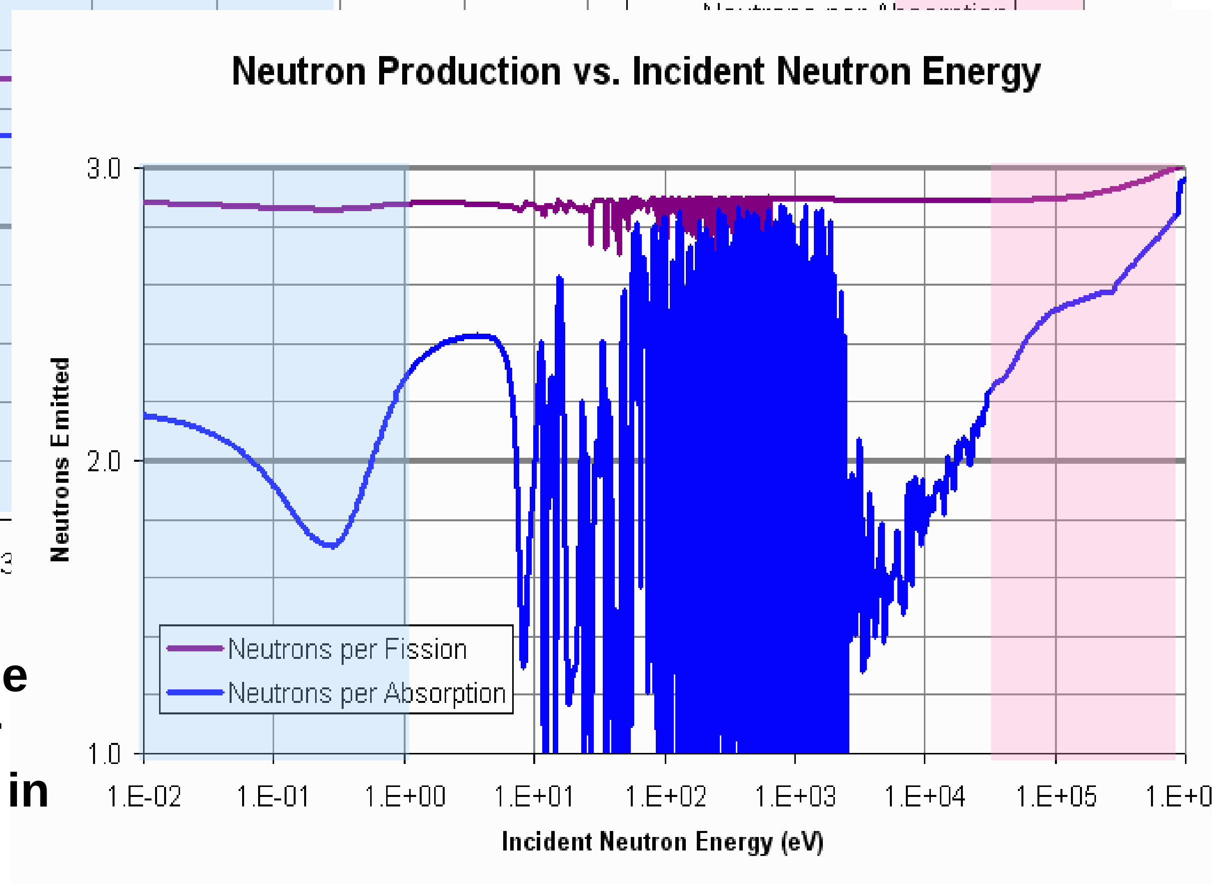
← dense, silvery, ½ m,
1 tonne thorium sphere

http://minerals.usgs.gov/minerals/pubs/commodity/thorium/690798.pdf

Nobel laureate Eugene Wigner conceived the thorium-uranium breeder reactor.







Enrico Fermi argued that the uranium-plutonium breeder made more weapons faster in the Manhattan Project.

Concepts proven in 1960s still are valid.

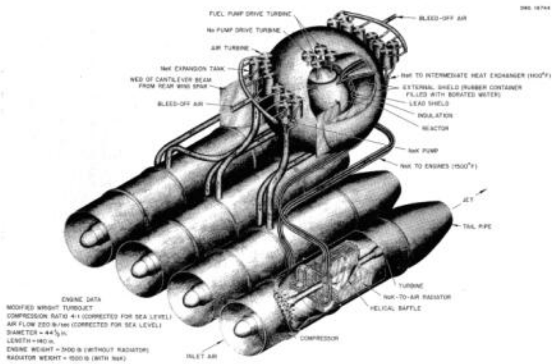


Fig. 4.33. Aircraft Power Plant (200 Megawatt).

1954: Aircraft Reactor Experiment used uranium fluoride dissolved in molten salt at 860^{o}C.

1965: Molten Salt Reactor Experiment tested U-233 molten salt fuel at 650^{o}C, over 4 years. A thorium breeder blanket was never installed.

2008: No molten salt reactors are in test. Theoretical research continues in:

Germany built the THTR-300 Thorium High Temperature Reactor in 1983.

300 MW electric power output.

Fueled with U-235 and Th-232.

67,000 6-cm graphite pebbles.

Pressure vessel of reinforced concrete.

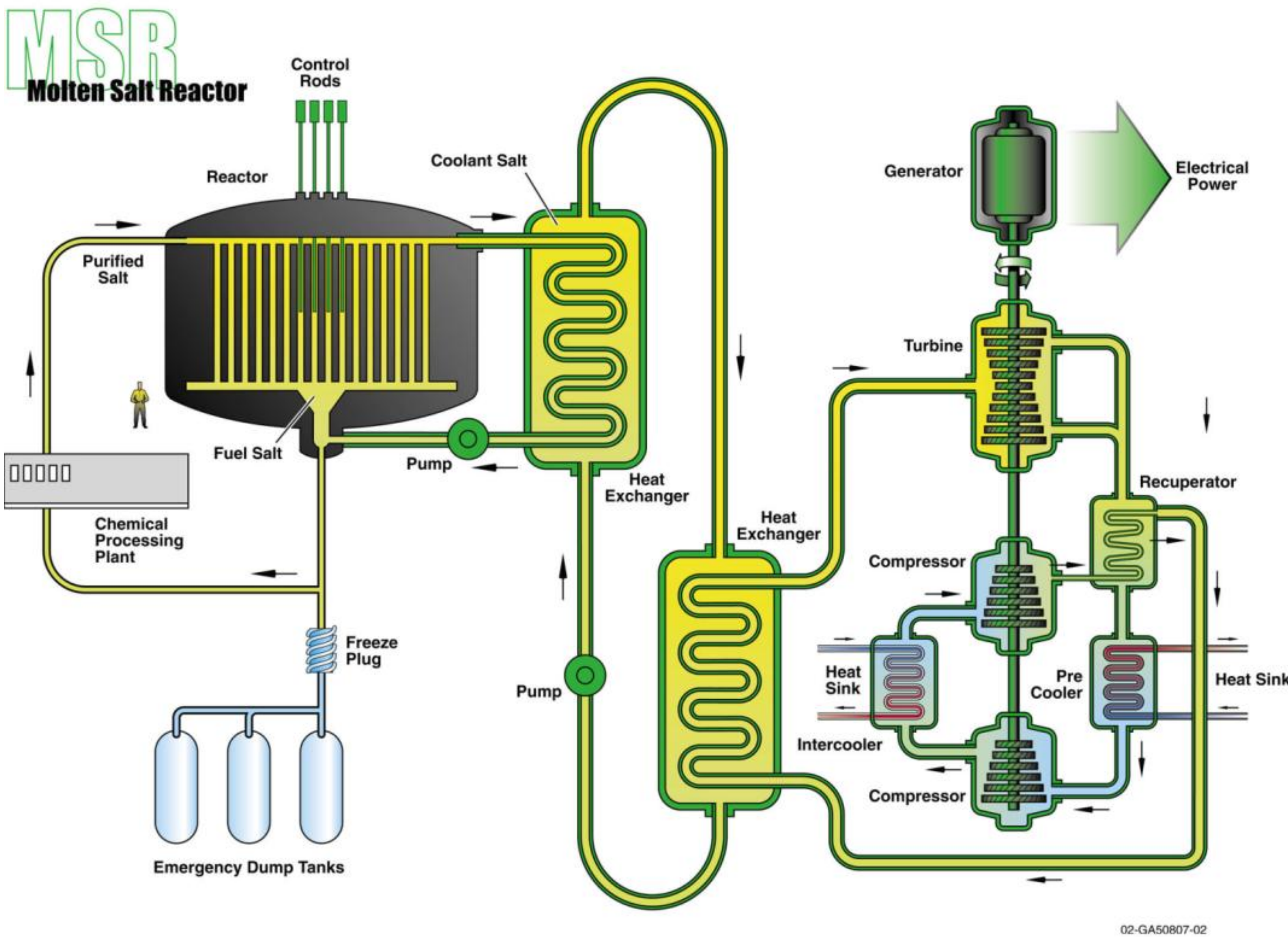
180 m high dry cooling tower.

1985, fuel pellet lodged in feed pipe.

1989, shut down after Chernobyl.

http://en.wikipedia.org/wiki/THTR-300

The molten salt reactor is one of six international Generation IV designs.



U or Pu fluoride, in molten Be & Li fluoride salt.

Converts U238 or Th232.

Actinide burning.

1 GW.

450-800^{o}C.
Salt @ ~1 atm.

Graphite moderated.

$990M R&D estimate.

http://nuclear.inl.gov/gen4/msr.shtml

Atomic physicist Edward Teller promoted the LFTR to the last month of his life.

THORIUM-FUELED UNDERGROUND POWER PLANT BASED ON MOLTEN SALT TECHNOLOGY

FISSION REACTORS

TECHNICAL NOTE

RALPH W. MOIR* and EDWARD TELLER†
Lawrence Livermore National Laboratory, P.O. Box 808, L-637
Livermore, California 94551

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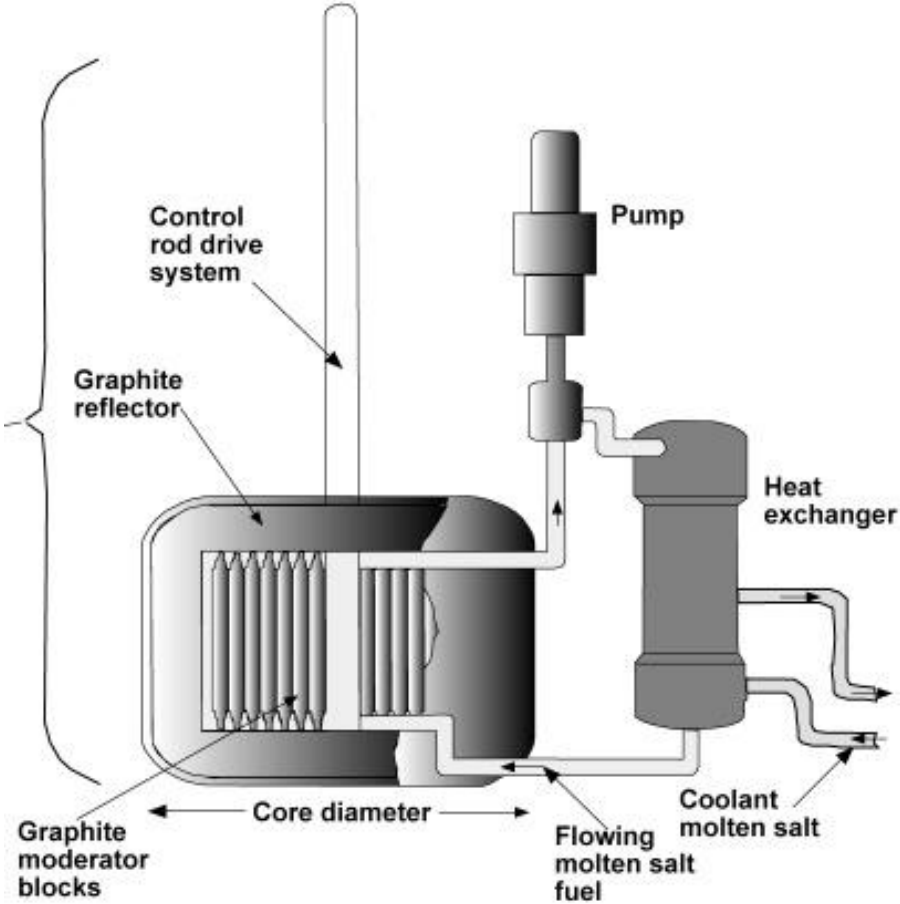
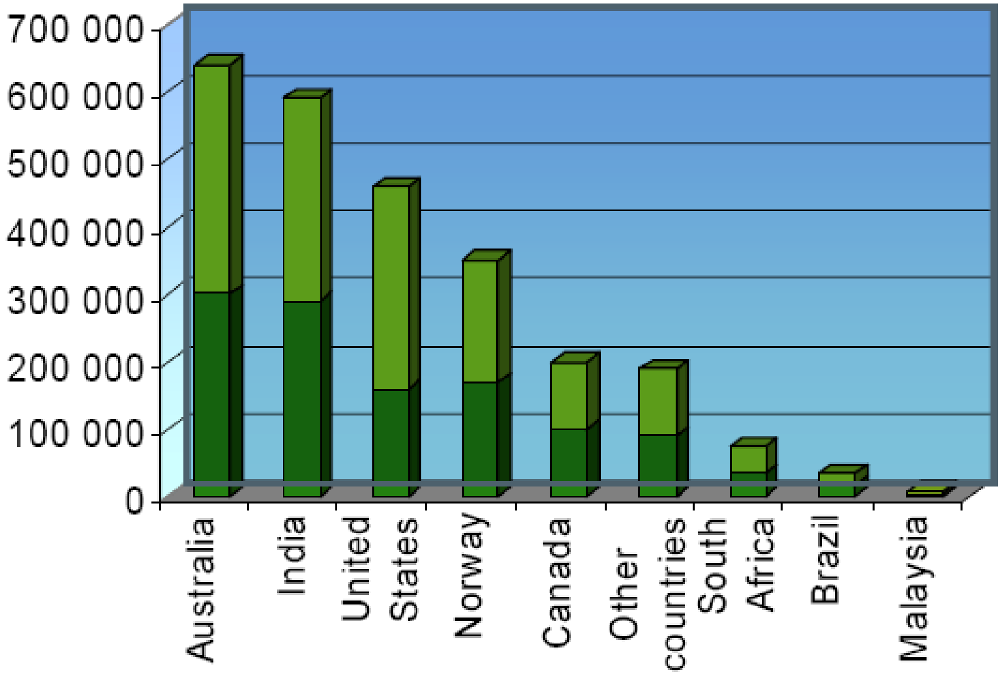


http://www.geocities.com/rmoir2003/moir_teller.pdf

India's thorium reserves stimulate its thorium power development.



India's nuclear strategy

1. Heavy water reactors for unenriched, limited uranium reserves.
2. Fast breeder reactor for plutonium from spent fuel uranium
3. Thorium fast breeder reactor.

http://www.regjeringen.no/upload/OED/Rapporter/ThoriumReport2008.pdf

India has 13 heavy water reactors plus 4 under construction.

The CANDU-like technology allows breeding U-238 to Pu-239 and Th-232 to U-233.

India already has reprocessing facilities and a developmental breeder reactor.

Kamini reactor tests U-233 from Kalpakkam experimental breeder.

0.5 GW fast breeder reactor is under construction, due 2010.

20 GW of U and Th power by 2020. 30% of electricity from Th by 2050.

http://thoriumenergy.blogspot.com/2008/04/thorium-fuel-cycle-development-in-india.html

Over 100 professionals cooperate in the Energy From Thorium forum.

Energy From Thorium Discussion Forum • Index page - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.energyfromthorium.com/forum/

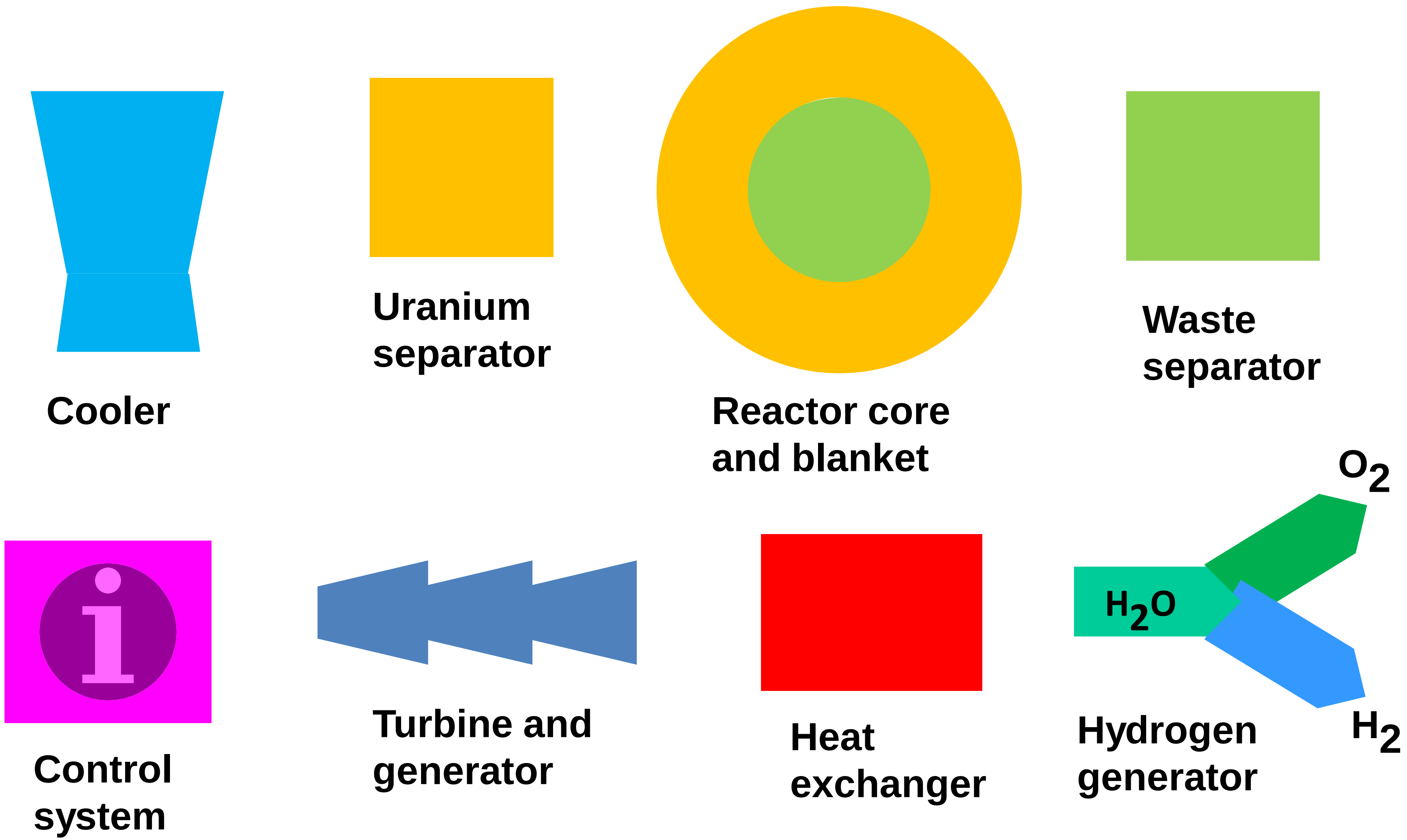
acres us farmland

acres us farmland - Google Search | Energy From Thorium Discussion ...

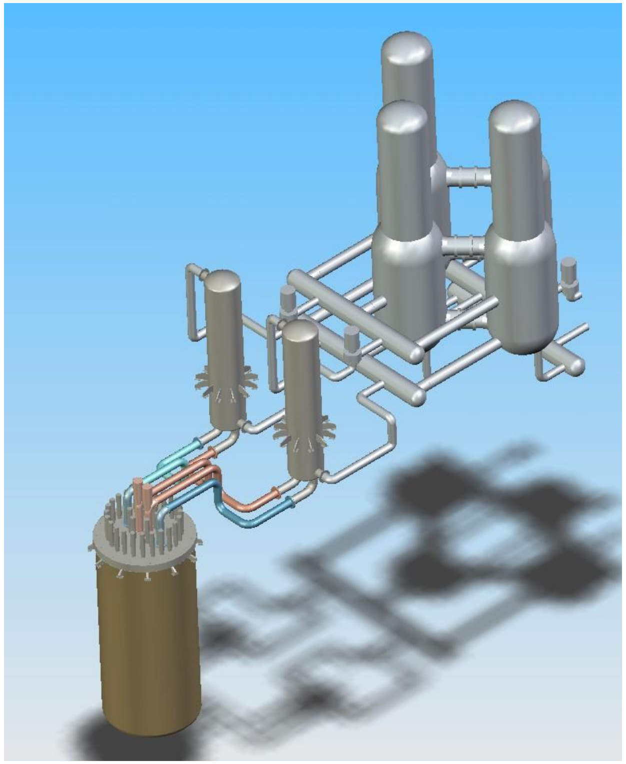
Energy Issues and Technologies Discussion of coal, oil, gas, solar, wind, ethanol, energy policy, and global warming.	70	804	Sep 23, 2008 6:11 pm Klaus Allmendinger
Liquid-Fluoride Reactors			
Reactor Design Threads relating to the design of liquid-fluoride reactors.	104	1426	Sep 22, 2008 3:52 pm David
Reprocessing Reprocessing the liquid fuel/blanket of a fluoride reactor.	37	493	Sep 17, 2008 11:48 pm ondrejch
Power Conversion Systems Discussion about gas-turbine and other power conversion systems for fluoride reactors.	25	275	Aug 06, 2008 5:56 pm dezakin
Applications Terrestrial power, space power, naval power, hydrogen production.	34	391	Sep 19, 2008 5:21 pm rgvandewalker
Mobile/Submersible Reactors	12	211	Sep 19, 2008 2:06 pm Kirk Sorensen
National Thorium Programs/Interests			
United States Home of the liquid-fluoride reactor...and 3200 MT of buried thorium nitrate.	10	119	Jul 25, 2008 8:51 pm Charles Barton
Canada Home to both thorium and CANDU reactors--feel free to post in French!	21	215	Sep 22, 2008 4:04 pm rgvandewalker
Europe	35	137	Sep 15, 2008 4:34 pm honzik
India Sandy beaches of thorium stretch for miles...and it has an active thorium program!	29	160	Sep 22, 2008 7:29 pm Lars

Done

Recommendation: Develop the Liquid Fluoride Thorium Reactor.



Aim High! Cost-engineer to < $2/watt capital and < 3¢ / KWH electricity cost.



Fluoride-cooled reactor with helium gas turbine power conversion system

Low cost potential

Low pressure reactor vessel.
Negative temperature reactivity.
Simple inherent safety, freeze plug.
No pressurized steam containment.
Factory production.
Truck transport to site
Cheap thorium fuel in liquid.

Low cost drivers

Stop global warming.
Produce electricity cheaper than from coal.
Bring prosperity and low birth rates to developing nations.

Aim High! Develop a 100 MW size unit.

A small LFTR unit can be transported by trucks.

Many LFTR units will be installed where there are no rails or rivers.

Objective: 100 MW, < $200 million

affordable to developing nations.

power sources near points of use

low transmission line losses

less vulnerable to terrorism or storms

multiple units for large power stations

Aim High! Make electricity cheaper than from coal.

100 MW Liquid Fluoride Thorium Reactor Cost Model

Item	$ Cost	$ per month, 40 years, 8% financing, levelized	$ per KWH @ 90%
Construction	200,000,000	1,390,600	0.0214

http://www.nti.org/e_research/cnwm/reducing/heudeal.asp

Aim High! Make electricity cheaper than from coal.

100 MW Liquid Fluoride Thorium Reactor Cost Model

Item	$ Cost	$ per month, 40 years, 8% financing, levelized	$ per KWH @ 90%
Construction	200,000,000	1,390,600	0.0214
Start-up U/Pu 100 kg	1,000,000	6,953	0.000108
Thorium fuel	10,700/yr	892	0.00000138

http://www.nti.org/e_research/cnwm/reducing/heudeal.asp

Aim High! Make electricity cheaper than from coal.

100 MW Liquid Fluoride Thorium Reactor Cost Model

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Construction	200,000,000	1,390,600	0.0214
Start-up U/Pu 100 kg	1,000,000	6,953	0.000108
Thorium fuel	10,700/yr	892	0.00000138
Decomm @ ½ const	100,000,000	960	0.00000148
Operations	1,000,000/yr	83,333	0.00128
TOTAL			0.0228

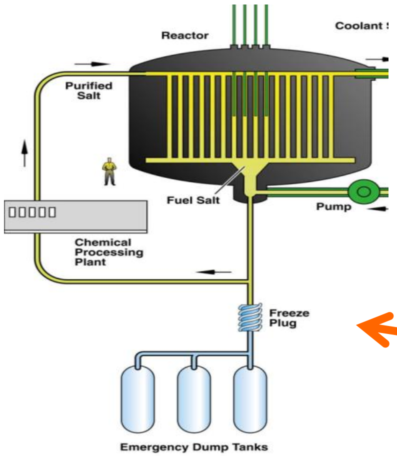
2008 electric power costs $/KWH (delivered)

Guangdong	0.0720
Shanghai	0.0790

http://www.nti.org/e_research/cnwm/reducing/heudeal.asp

http://www.bloomberg.com/apps/news?pid=20601080&refer=asia&sid=aV_2FPlVxISE

Aim High! Use automated controls, backed by inherent passive safety.



- Implement high reliability systems for automated, unattended plant operations.
- Use aeronautical quality computer systems, and technology from unmanned space explorers.
- High temperature expands salt past criticality and ending nuclear reaction.
- In event of a leak or loss of power molten salt flows into containment, cools, solidifies. Freeze plug.

Operate with no on-site workers.

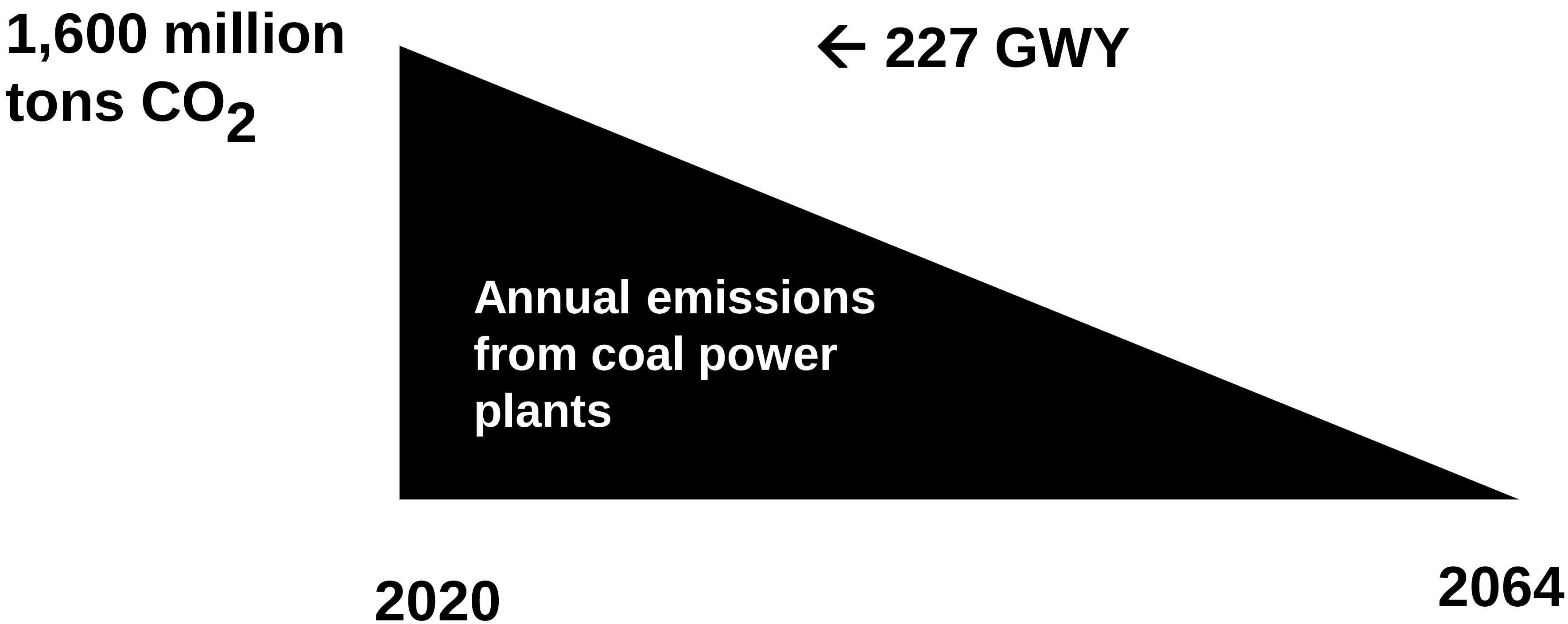
- Low operational costs.
- No risk of safety over-rides or experimentation.
- No risk of U-233 theft.

Aim High!
Emulate Boeing mass production.

- Production line.
- One per day.
- Standardized units.
- Computer-aided design, engineering, manufacturing.
- $200 million per unit.
- Life safety paramount.

Aim High! Check US global warming.

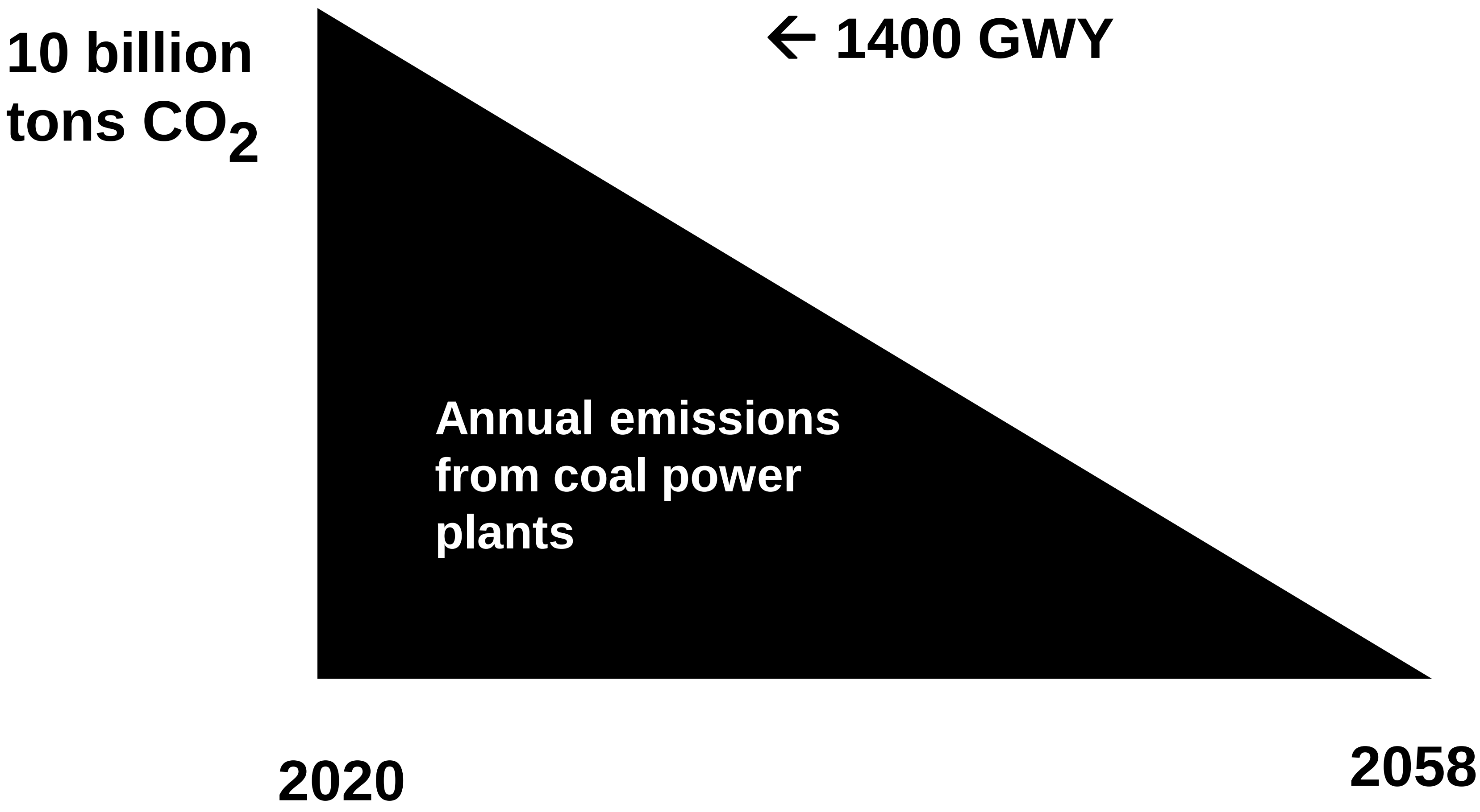
Install one 100 MW LFTR each week to replace US coal power.



http://wwf

Aim High! Zero emissions worldwide.

Install one 100 MW LFTR each day, worldwide, to replace all coal power.

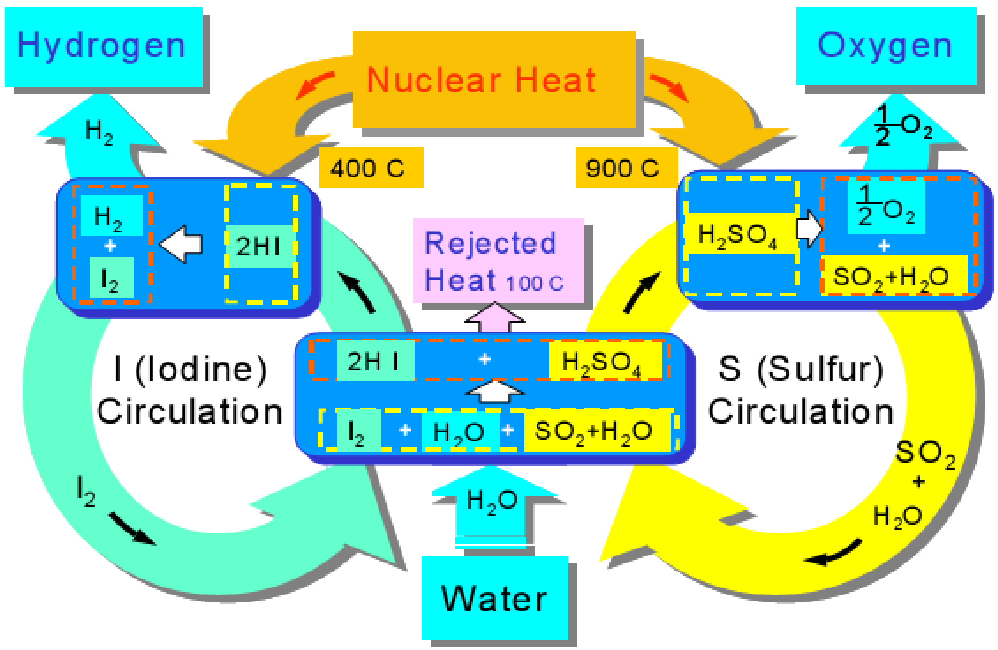


http://www.eia.doe.gov/pub/international/iealf/table63.xls

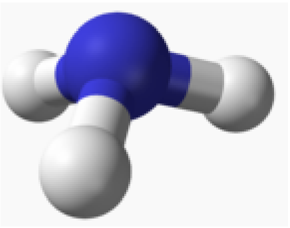
Aim High!

Make motor fuel cheaper than from oil.

Dissociate water at 900ºC to make hydrogen, with sulfur-iodine process.

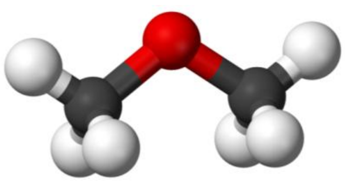


Alternatively start at 700ºC with a less efficient process.

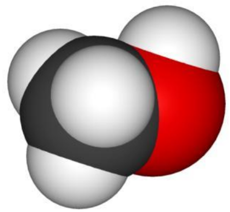


Ammonia

$CO_2 + 3 H_2 \rightarrow CH_3OH + H_2O$



Dimethyl ether for diesel



Methanol for gasoline

$0.03 / KWH x 114,100 BTU / gal / 3,419 BTU / KWH / efficiency

= $2.00 per gallon [if 50% efficient]

http://wwwtest.iri.tudelft.nl/~klooster/reports/hydro_slides_2003.pdf

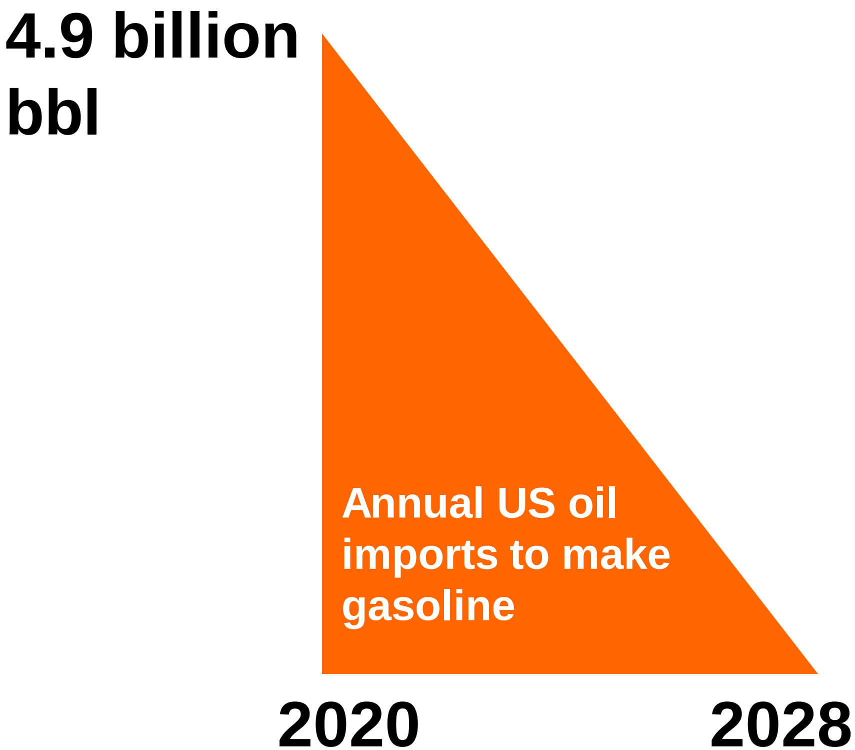
Aim High! Cut US oil imports. Hard to do!

Configure for H_2 production (50% eff) and fuel conversion (50%).
100 MW LFTR makes 250,000 bbl/year.
Install one LFTR each week.

http://www.eia.doe.gov/pub/international/iealf/table63.xls

Electric cars cut oil imports drastically.

Chevy Volt recharges with 8 KWH for 40 miles.
100 MW LFTR can power 300,000 cars per day.
Install one LFTR each week.



Best use of petroleum fuel is for airplanes.

http://farm4.static.flickr.com/3112/2654553896_fe93088b30_o.jpg

http://www.boeing.com/commercial/gallery/787/index1.html

Aim High! Use air cooling.

Power plant are typically cooled by flowing water or evaporative cooling towers.

A typical 1 GW coal or nuclear plant heats 600,000 gal/min of river water, or evaporates 20,000 gal/min.

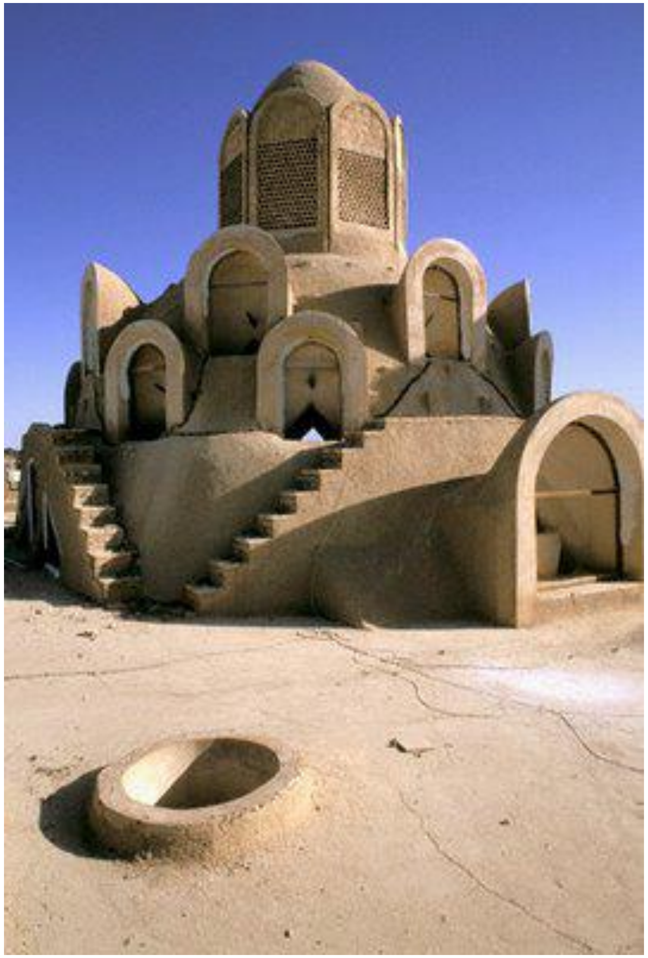
50% efficiency of LFTR lowers heat loss.

Air cooling is needed in arid lands, or any place water is in short supply.

Cogeneration can make good use of waste heat in host cities, or for industrial processes.

http://wwf

Aim High! Design aesthetic structures.



Cooling tower of Iranian museum

Can the tower be a graceful part of the building?

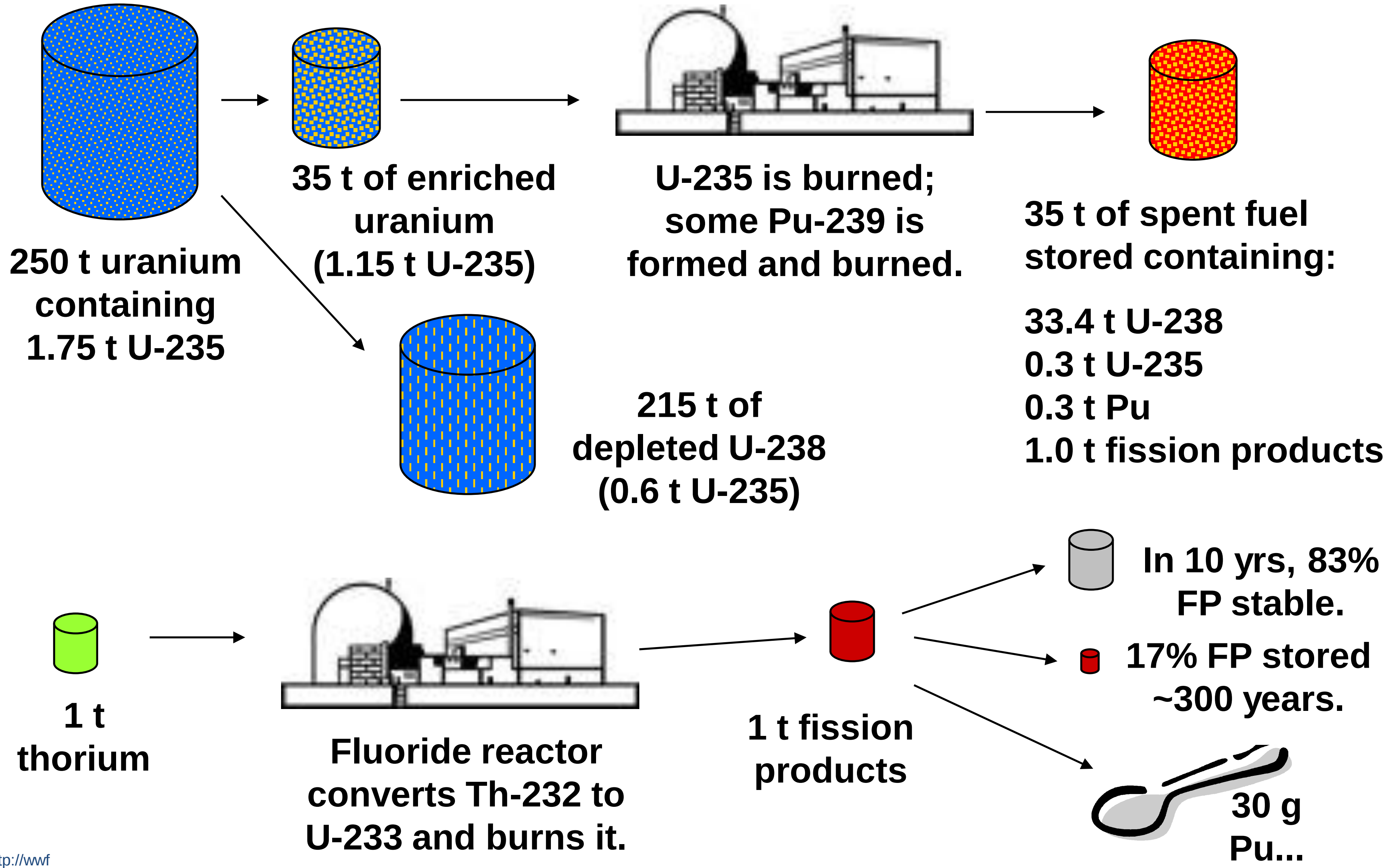
http://wwf

...or hire an artist.

Cora Kent painted the Rainbow Gas Tank in Boston.

Folk art may instill local pride.

In one year, a 1 GW thorium reactor produces < 1% of the hazardous waste.



http://wwf

NASA's strategic plan focuses on space.

1. Fly the Shuttle until 2010 retirement.
2. Complete the International Space Station.
3. Develop overall program of human spaceflight focusing on exploration.
4. Bring a new Crew Exploration Vehicle ASAP after shuttle retirement.
5. Encourage partnerships with commercial space sector.
6. Establish a lunar return program with utility for Mars.

http://www.nasa.gov/pdf/142302main_2006_NASA_Strategic_Plan.pdf

NASA's 2010 budget is $18 billion.

Theme	$ millions
Earth science	1,351
Planetary science	1,410
Astrophysics	1,122
Heliophysics	599
Aeronautics	447
Exploration	3,738
Space shuttle	2,984
International space station	2,277
Space and flight support	612
Education	126
Cross agency support	3,324
Inspector general	36
TOTAL	18,026

Developing the Liquid Fluoride Thorium Reactor should cost less than $1 billion over 5 years.

http://www.nasa.gov/pdf/210020main_NASA_FY09_Budget_Estimates_Summary.pdf

Much NASA expertise is applicable to the Liquid Fluoride Thorium Reactor.

Materials
Corrosion
High temperature
Low temperature
Composite materials
Exotic metals
Radiation damage

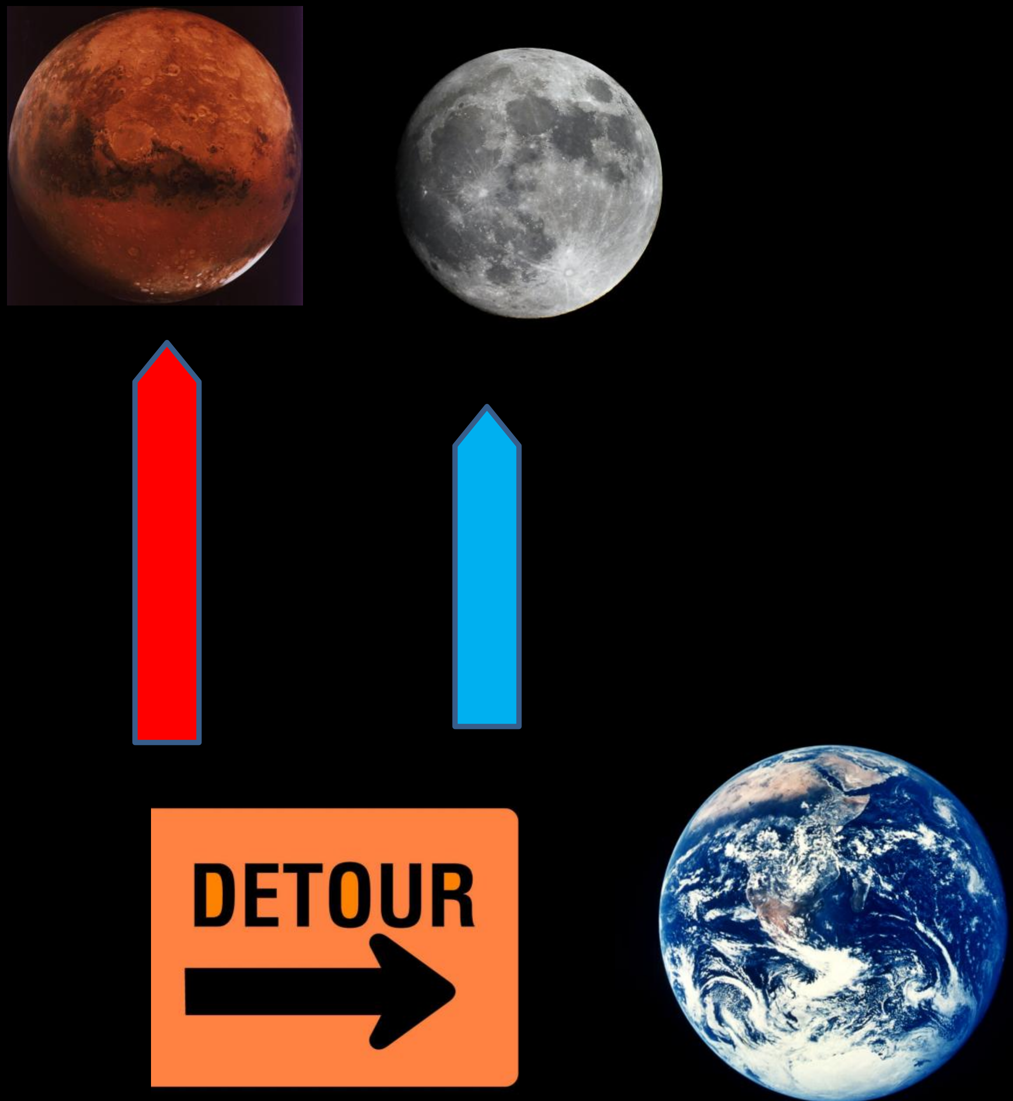
Projects
Project management and control
Financial management
Quality management
Procurement of technical services
Fabrication of large devices

Safety
Probabilistic risk assessment
Root cause analysis
Statistical quality control
Radiation

Energy
Nuclear powered space craft
Hydrogen fuel
Thermodynamics
Radiative cooling

Information technology
Electronic control systems
Redundant computer systems
High reliability software

Aim High! Redirect NASA expertise and funding to national energy project.



Establish national energy program.

Delay or curtail some NASA strategic programs.

What's more important?

Select best leadership from
- **INL**
- **NASA**
- **Oak Ridge**
- **Argonne**
- **Lawrence Livermore**
- **…?**

Re-use the skills of scientists, engineers, contractors and suppliers.

Project plan and budget scenario.

$ 1 B — **Develop** — **2010**

$ 5 B — **Scale up** — **2015**

Commercialize

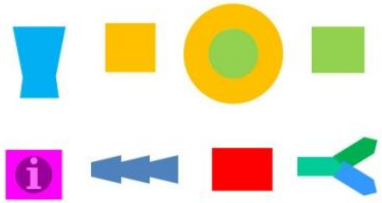
$ 10 B per year — **Produce** / **Export** — **2020**

One 100 MW US LFTR per week

Export or license one LFTR per day

$70 B per year industry

Action recommendations.



1. Establish national energy project based on the liquid fluoride thorium reactor.

2. Commandeer resources from NASA and national laboratories.

3. Share R&D stage technologies freely; commercialize thereafter.

Aim high! Enjoy the benefits.

Use a new energy source that

1. **produces electricity cheaper than from coal,**

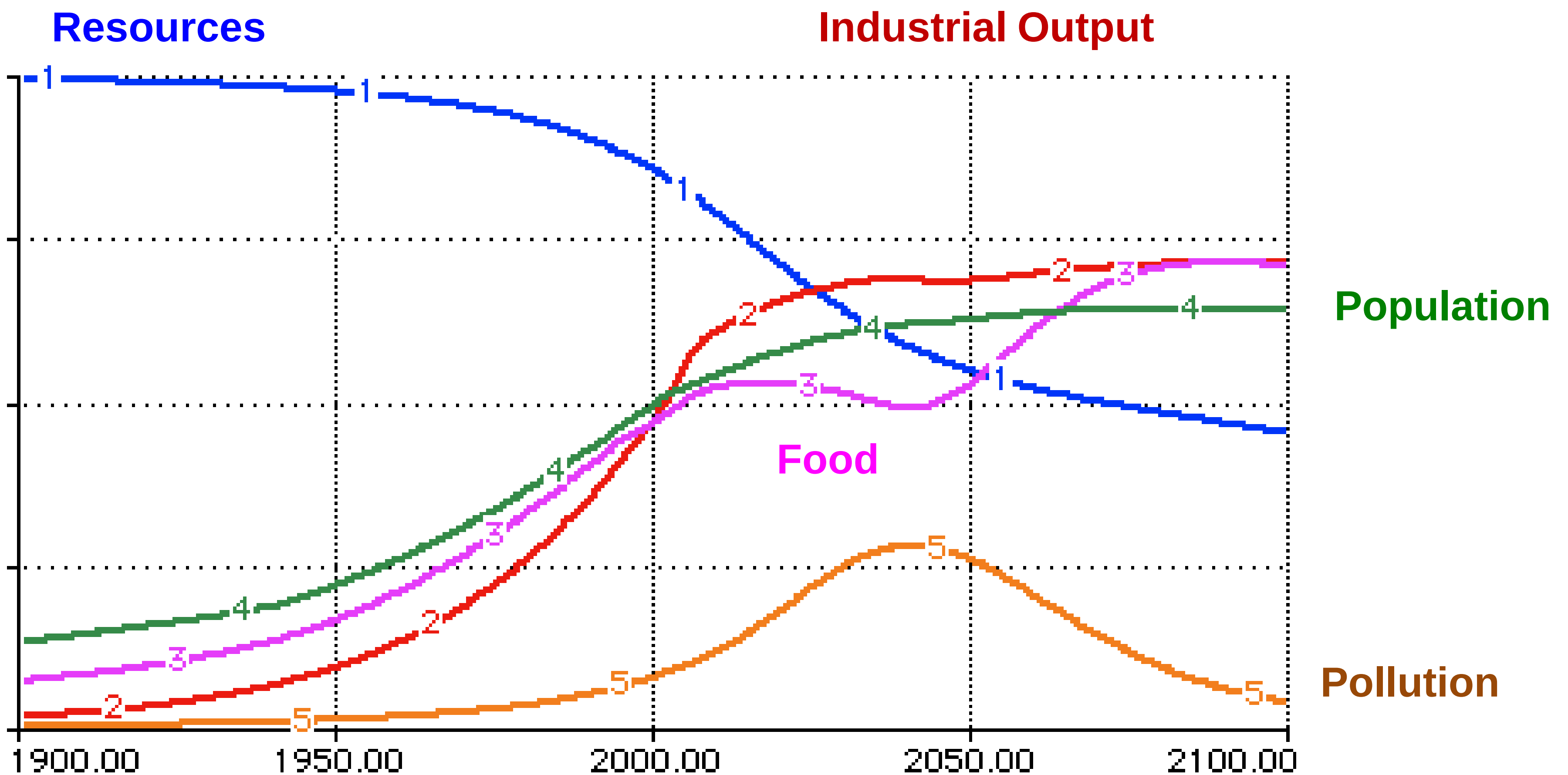
2. **synthesizes vehicle fuel cheaper than from oil,**

3. **is inexhaustible,**

4. **reduces waste, and**

5. **is affordable to populations of developing nations.**

Aim high! Help stabilize pollution, resources, and population.



Thank you.

Questions.

Can we achieve the same goals with the **pebble bed reactor**

Can we achieve the same goals with the **integral fast reactor**

How does the LFTR compare to today's **typical nuclear reactor**

How plentiful is **thorium**

What about **carbon capture and sequestration**

What about **biofuels**

Isn't **solar** better

Where can we get **more U-233**

What about nuclear **weapons proliferation**

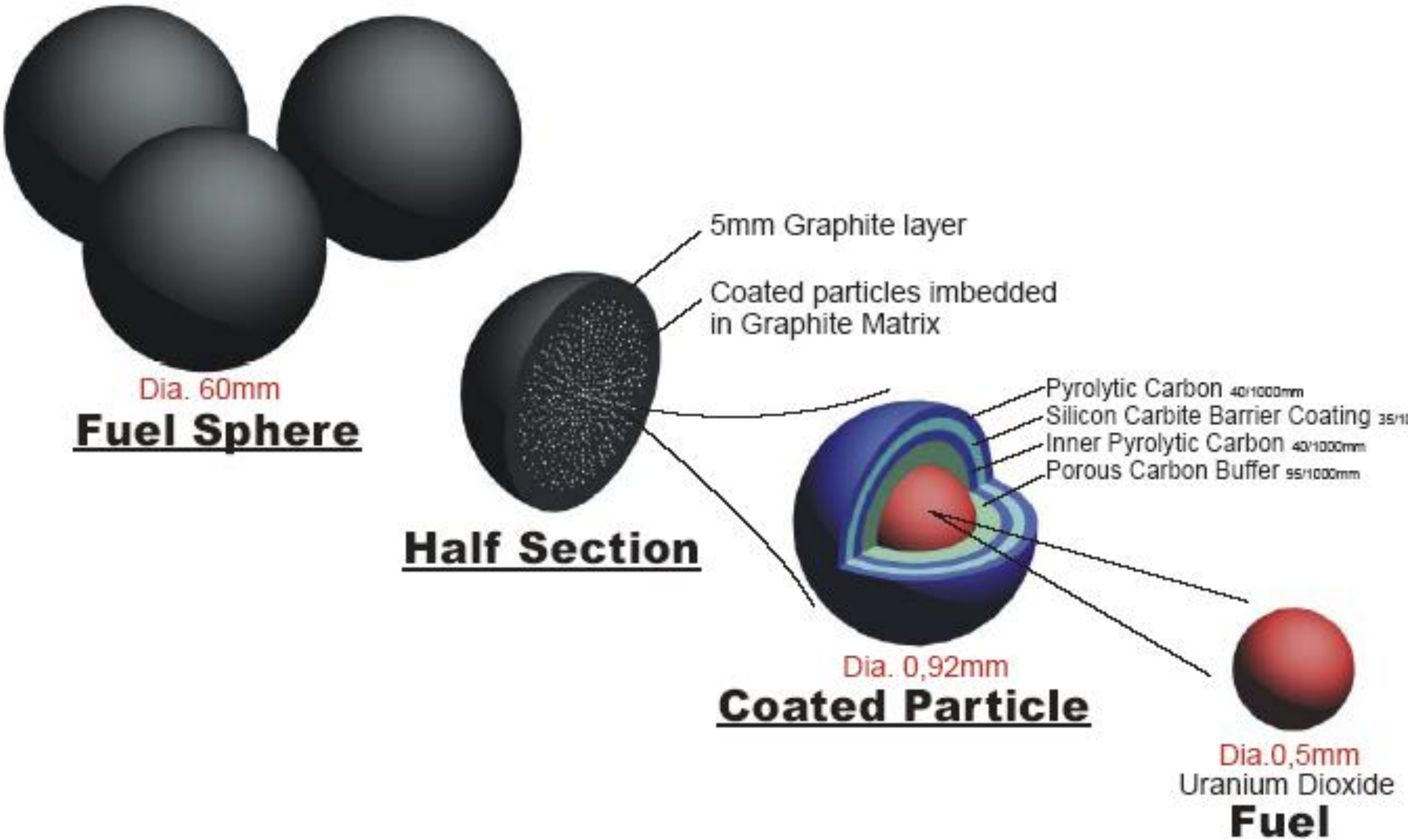
How will **environmentalists** react to energy cheaper than from coal

What about **wind** and the Pickens Plan?

Why is the **waste** so much less?

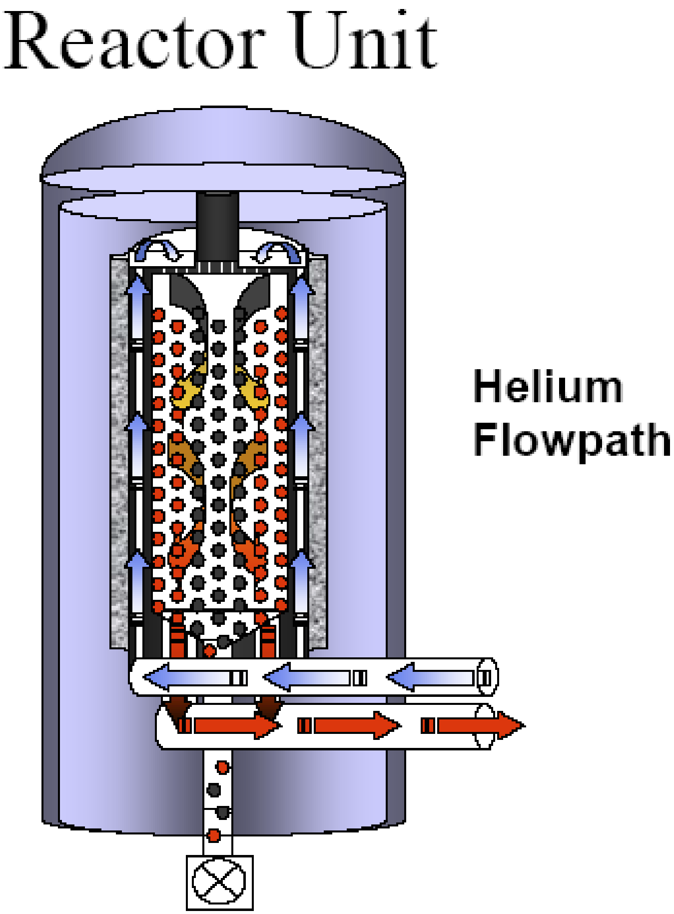
Why is the **politics** so difficult?

Can the pebble bed reactor achieve the same goals?



http://web.mit.edu/pebble-bed/papers.html

The PBR uses uranium fuel.



PBR technology is much **more fully developed** and operating today.

PBR uses the standard once-through fuel cycle, with spent pebbles destined **for long term waste** storage.

PBR is more **proliferation resistant**, because the fuel pebbles are difficult to reprocess.

Known world **uranium reserves** of 64,000 tons will only fuel existing and planned reactors 43 years. Adding a PBR fleet requires more uranium.

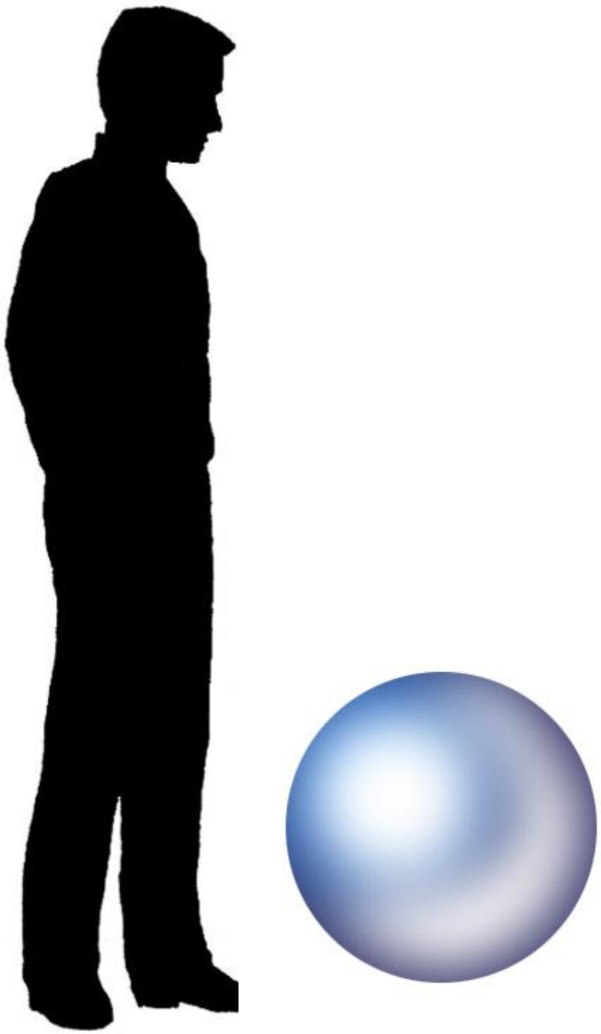
Cosing under $100/pound, uranium contributes <$0.0041 per KWH to electricity costs.

If uranium reserves are exhausted, uranium can be **adsorbed from seawater at $400/pound**.

http://web.mit.edu/pebble-bed/papers.html

http://npc.sarov.ru/english/digest/132004/appendix8.html

The LFTR uses thorium fuel.



The LFTR thorium fuel supply is less expensive and readily available.

The innovative liquid salt fuel medium has none of the radiation-induced structural issues of solid fuel in the PBR.

The liquid salt facilitates online addition of new fuel, reprocessing, and removal of waste.

The molten form of the LFTR core might enable rogue nations to chemically extract the U-233 for weapons, so anti-proliferation safeguards include

- U-238 dilution preventing U-233 removal
- U-232 contamination, sourcing gamma rays hazardous to weapons builder.

Can we achieve the same goals with the Integral Fast Reactor?.

Same onsite reprocessing.

Plentiful, U-238 fuel.

More well developed than LFTR.

Solid fuel operations expected to be more expensive than liquid.

Both can consume existing actinide wastes.

How does the LFTR compare to today's typical nuclear reactor?.

Spent fuel contains fission products, fissile fuel, and fertile uranium.

In: 3.5% fissile fuel

Out: 2.2% fissile fuel

Enriched uranium fuel

96.5% U-238
3.5% U-235

Power reactor

3% fission products

WASTE

1% plutonium

0.50% Pu-239 FUEL
0.25% Pu-240 future FUEL
0.15% Pu-241 FUEL

96% uranium

0.83% U-235 FUEL
0.40% U-236 future FUEL
94.77% U-238 future FUEL

trace % minor actinides

Np, Am, Cm, …

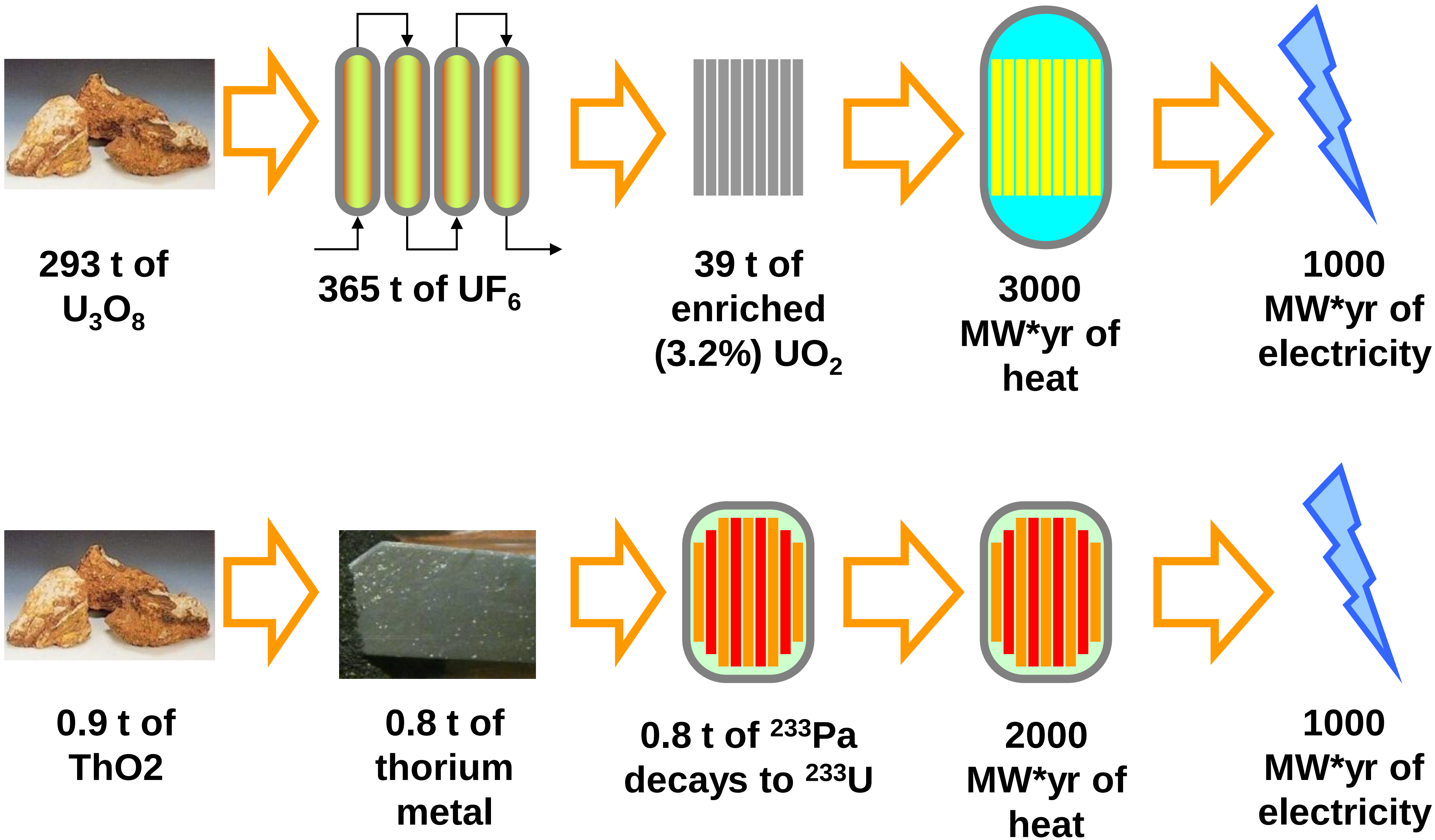
Fuel becomes spent as

(1) solid fuel is stressed by fission

(2) poisons like Xe absorb neutrons

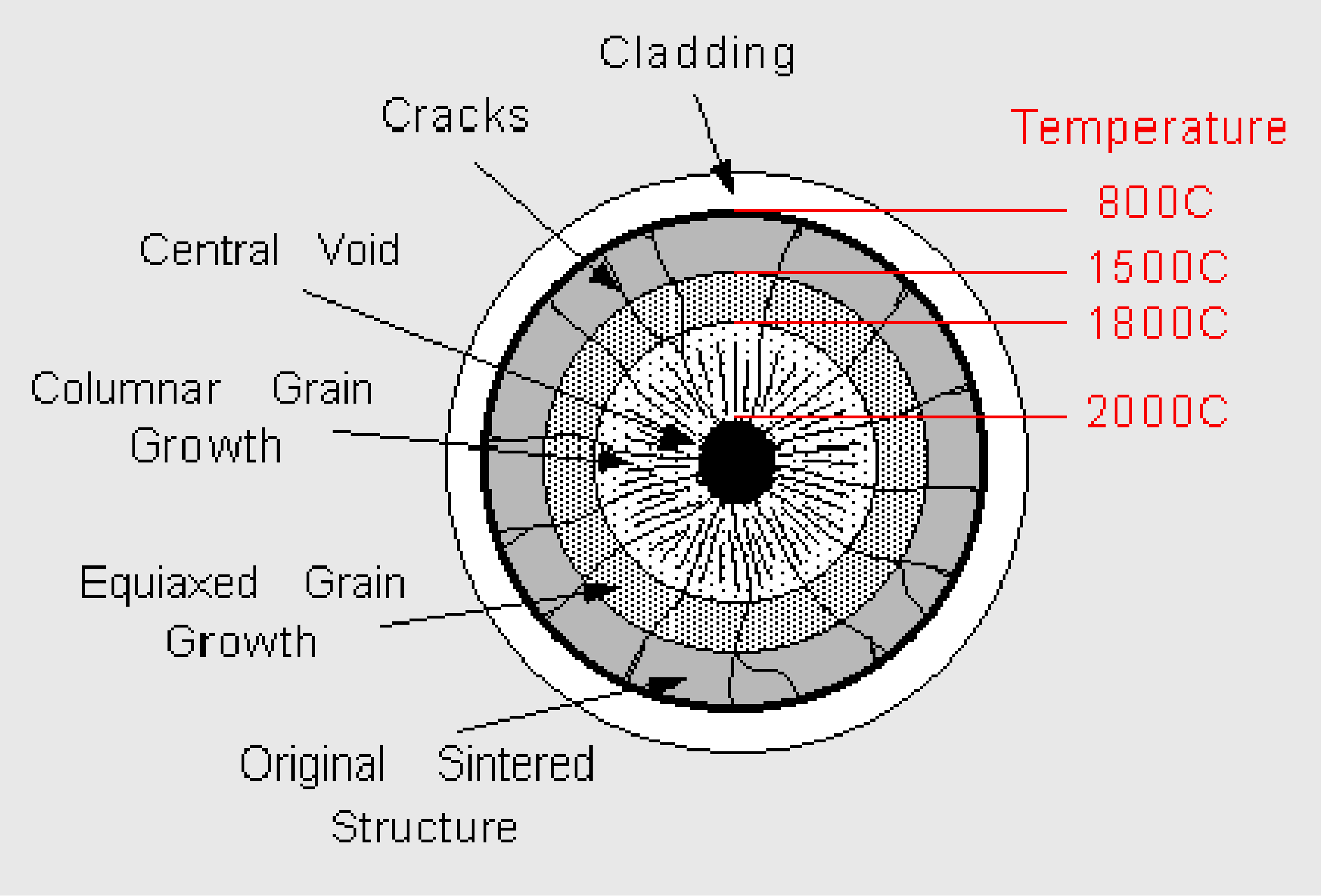
http://en.wikipedia.org/wiki/Spent_nuclear_fuel

All thorium can be burned, but only 0.7% of uranium is fissile U-235.



WISE nuclear fuel material calculator: http://www.wise-uranium.org/nfcm.html

Radiation damage to fuel further limits burn-up in a typical nuclear reactor.



Krypton, xenon gases build up.

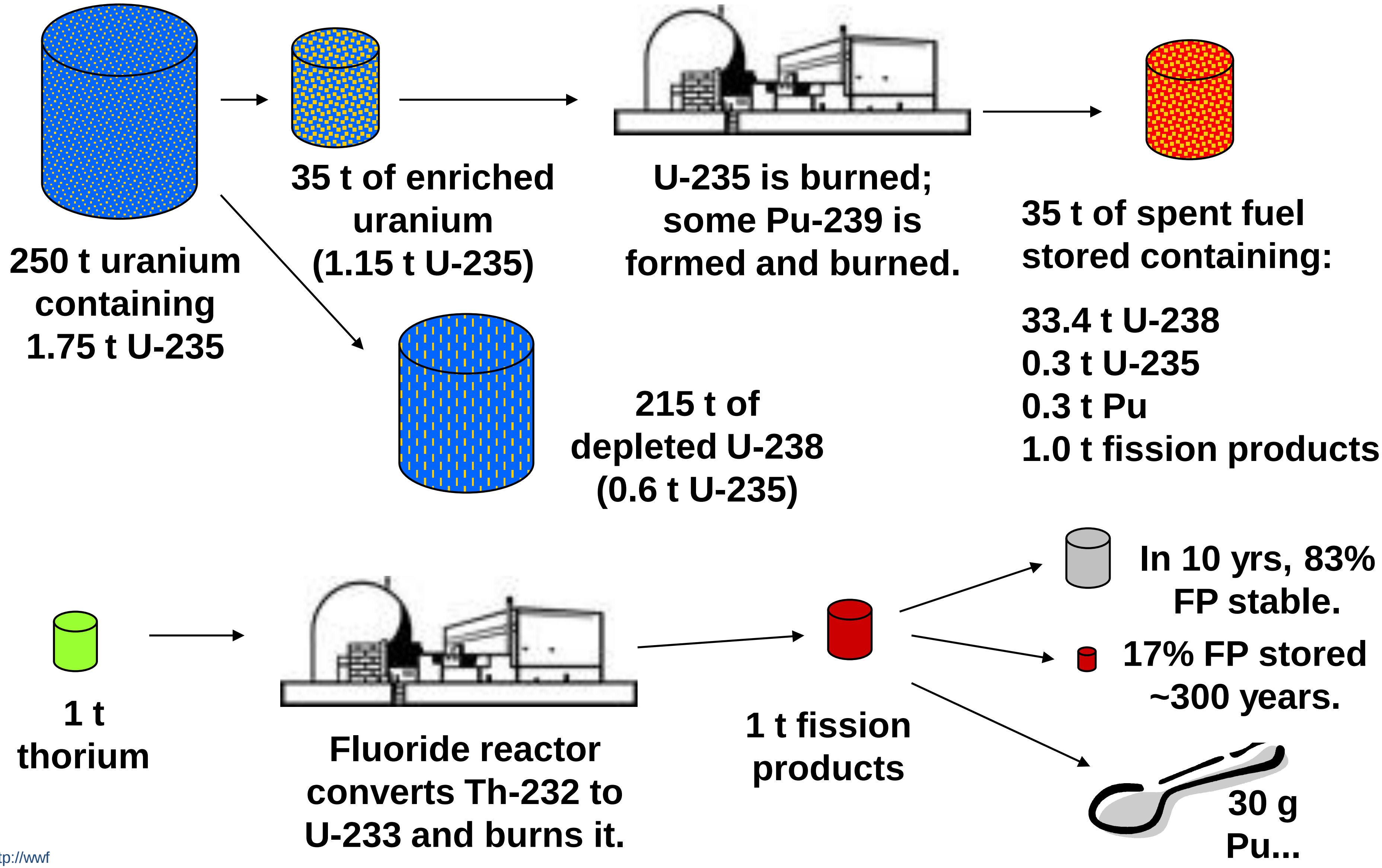
Fission fragments and neutrons disturb the fuel lattice.

Metal cladding contains fission products from the coolant.

Cross section of fuel rod of water cooled reactor.

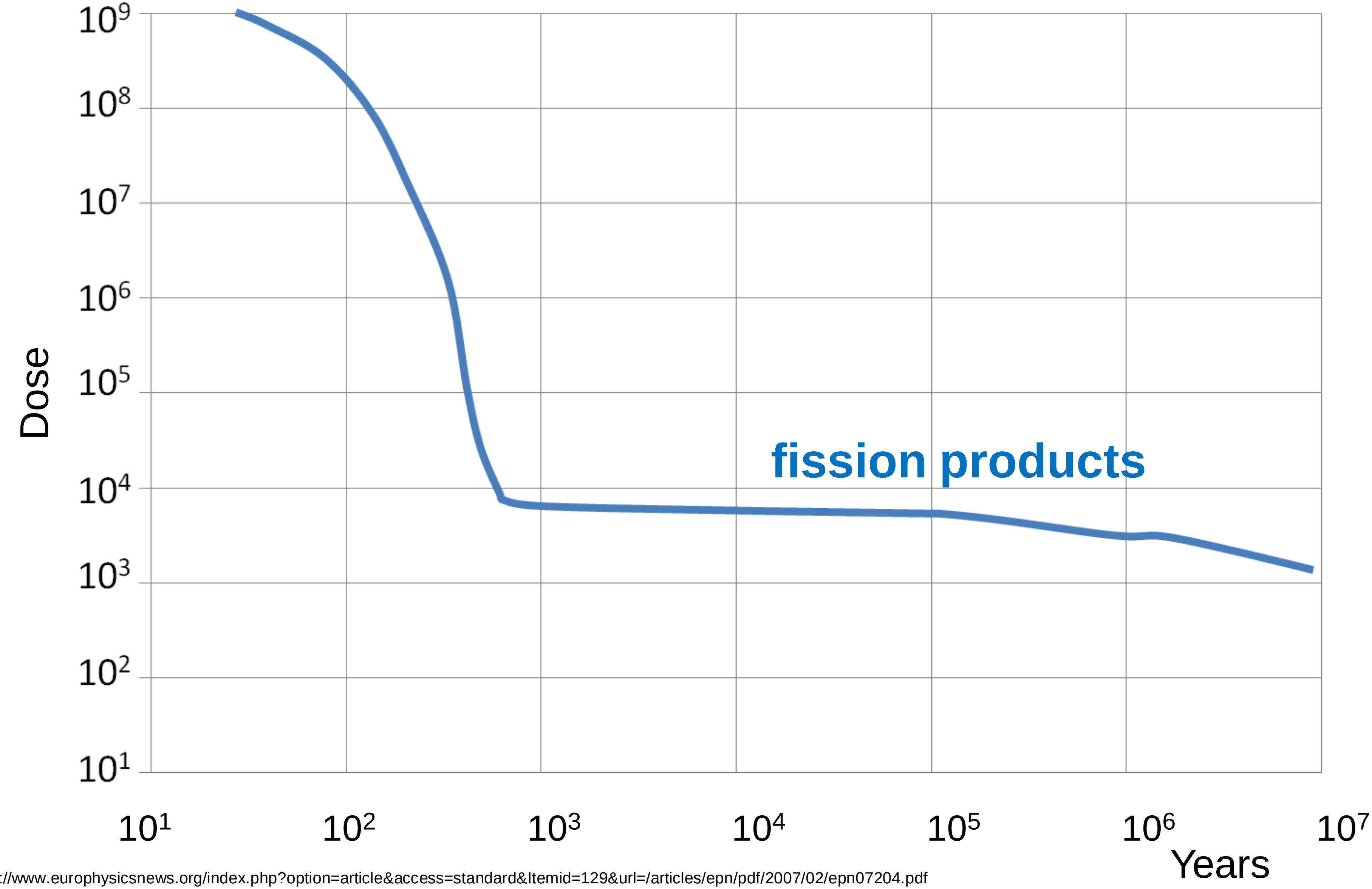
http://wwf

In one year, a 1 GW thorium reactor produces < 1% of the hazardous waste.



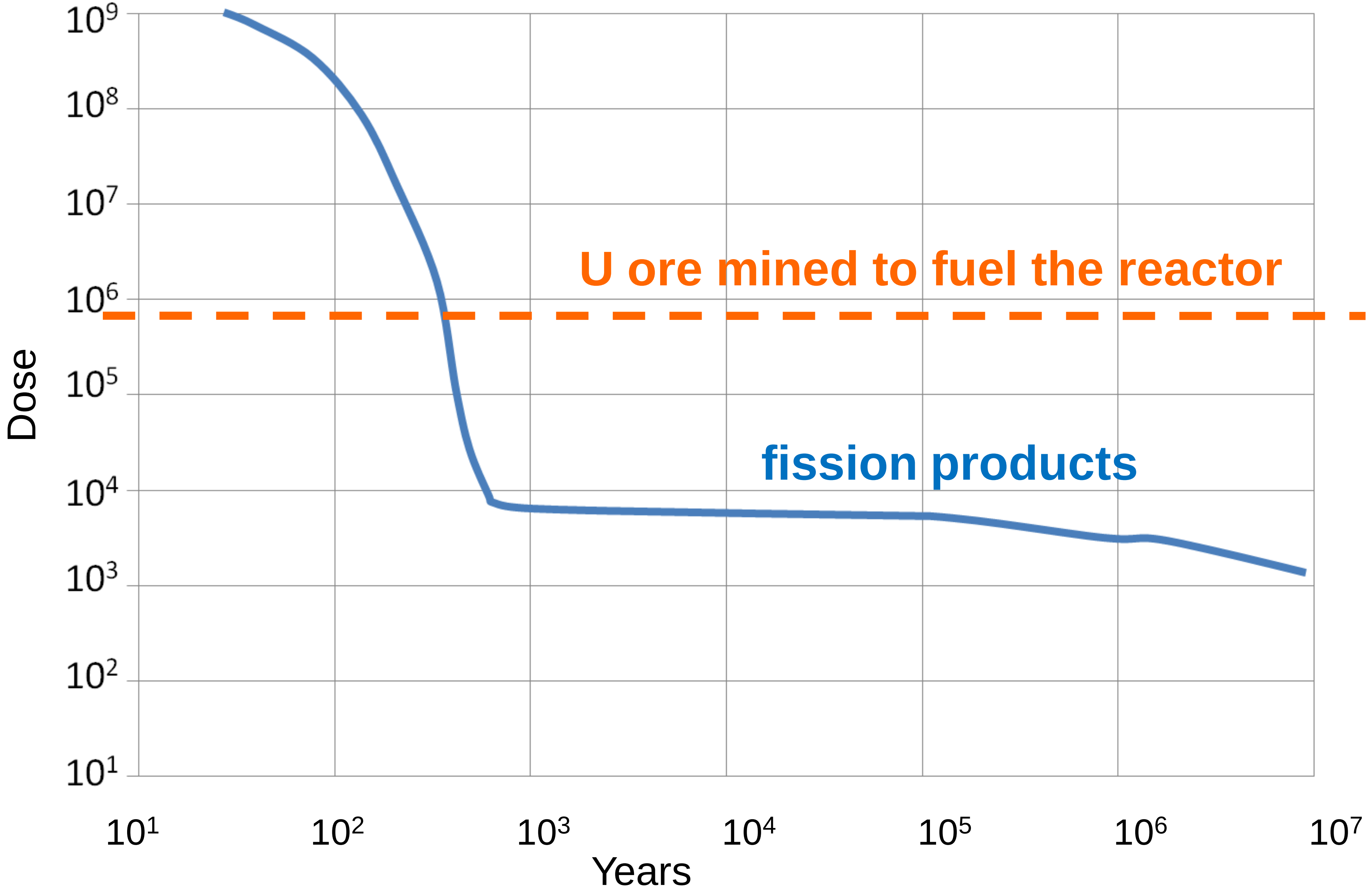
http://wwf

Radiotoxicity of fission products decays in a few hundred years.

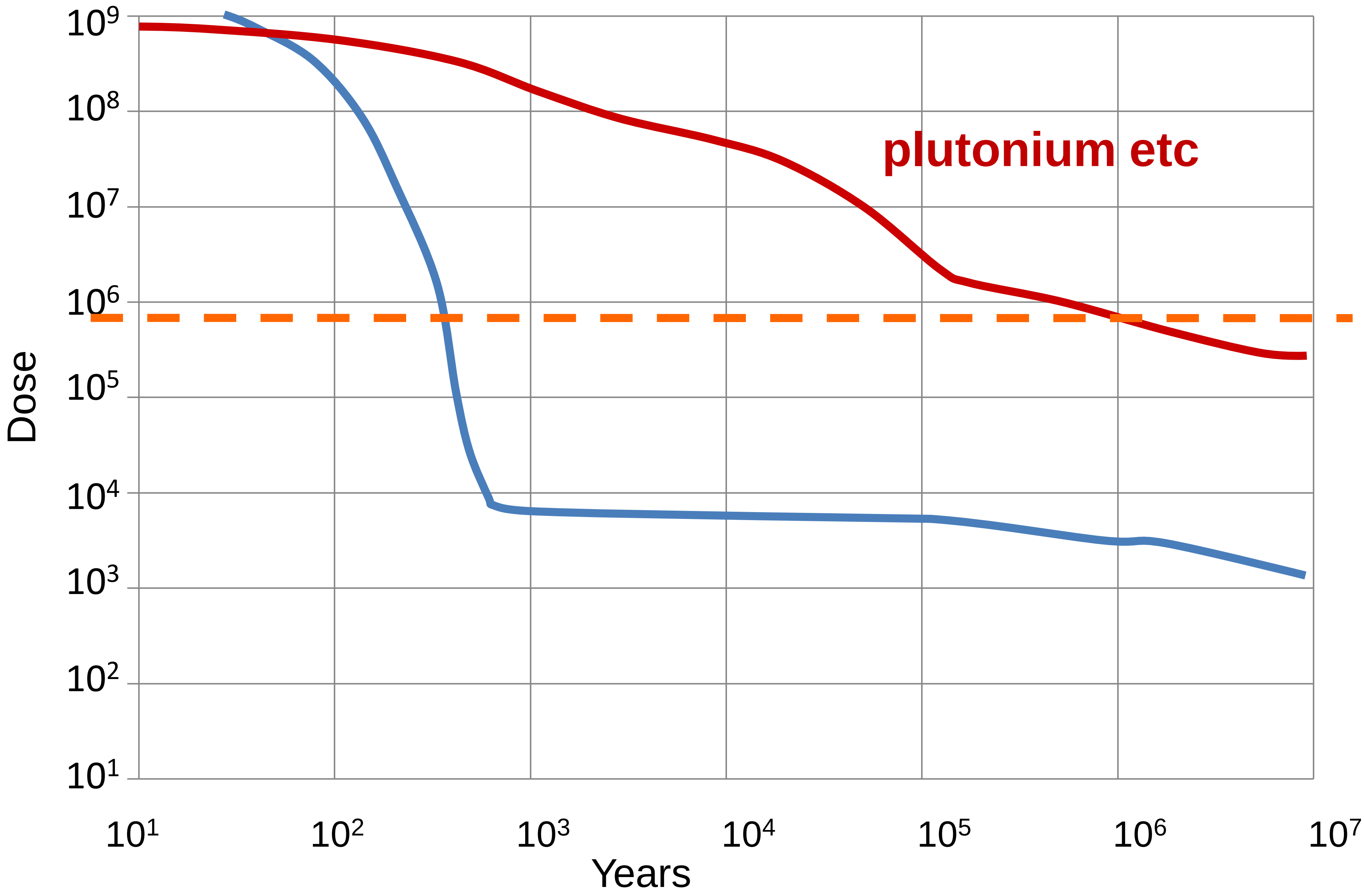


http://www.europhysicsnews.org/index.php?option=article&access=standard&Itemid=129&url=/articles/epn/pdf/2007/02/epn07204.pdf

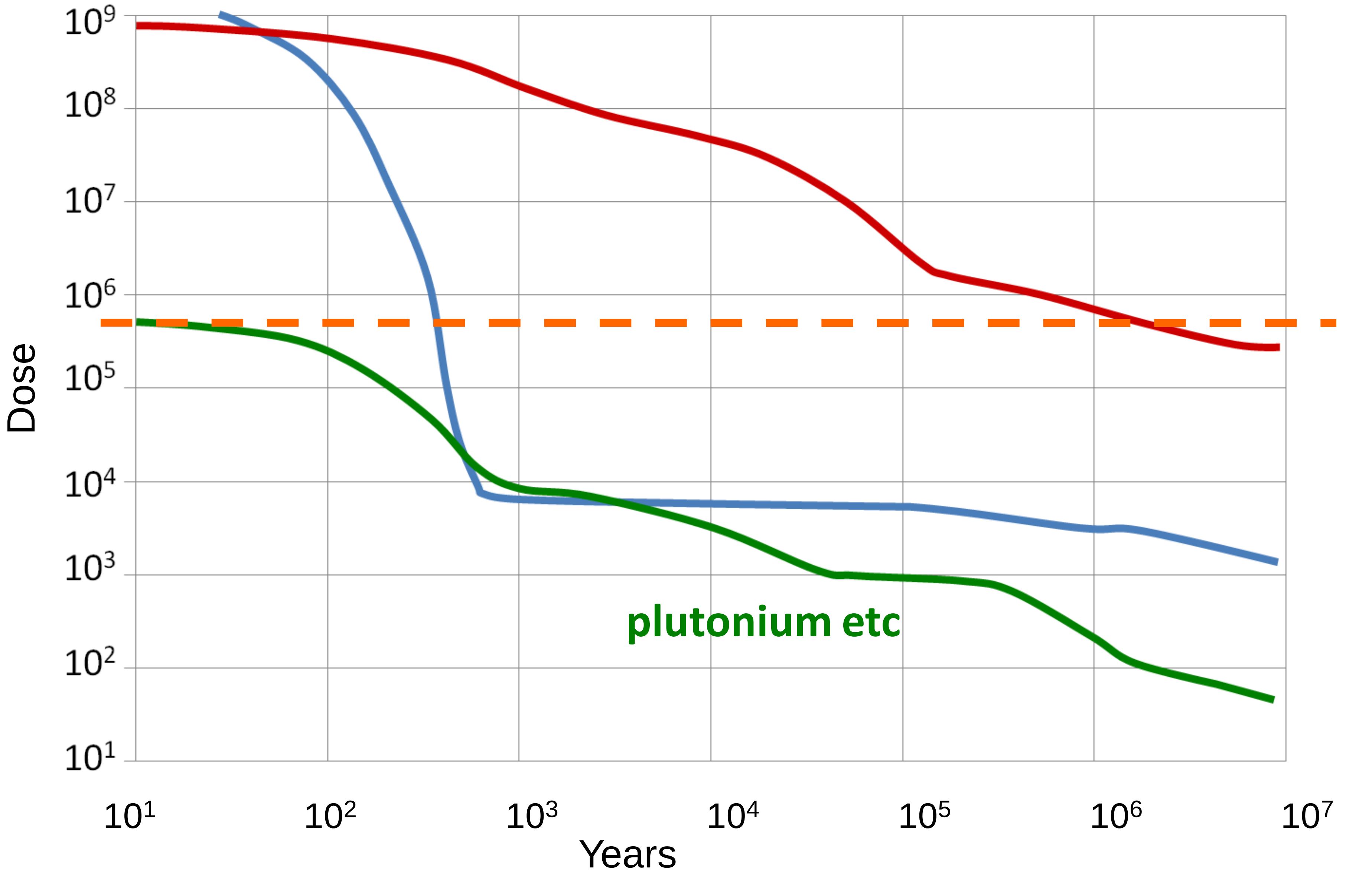
Radiotoxicity of fission products decays in a few hundred years, relative to natural U ore.



Radiotoxicity of unburned plutonium etc from uranium reactor decays more slowly.



Radiotoxicity of unburned plutonium etc from an LFTR is 10,000 x less.



Lemhi Pass alone has enough thorium to power the US for millennia.

500 tons will supply all US electricity needs for one year.

The US already has 3200 tons stored in the Nevada desert.

Thorium Energy, Inc. claims 1,800,000 tons of high-grade thorium ore on 1,400 acres.

http://www.thoriumenergy.com/index.php?option=com_content&task=view&id=17&Itemid=33

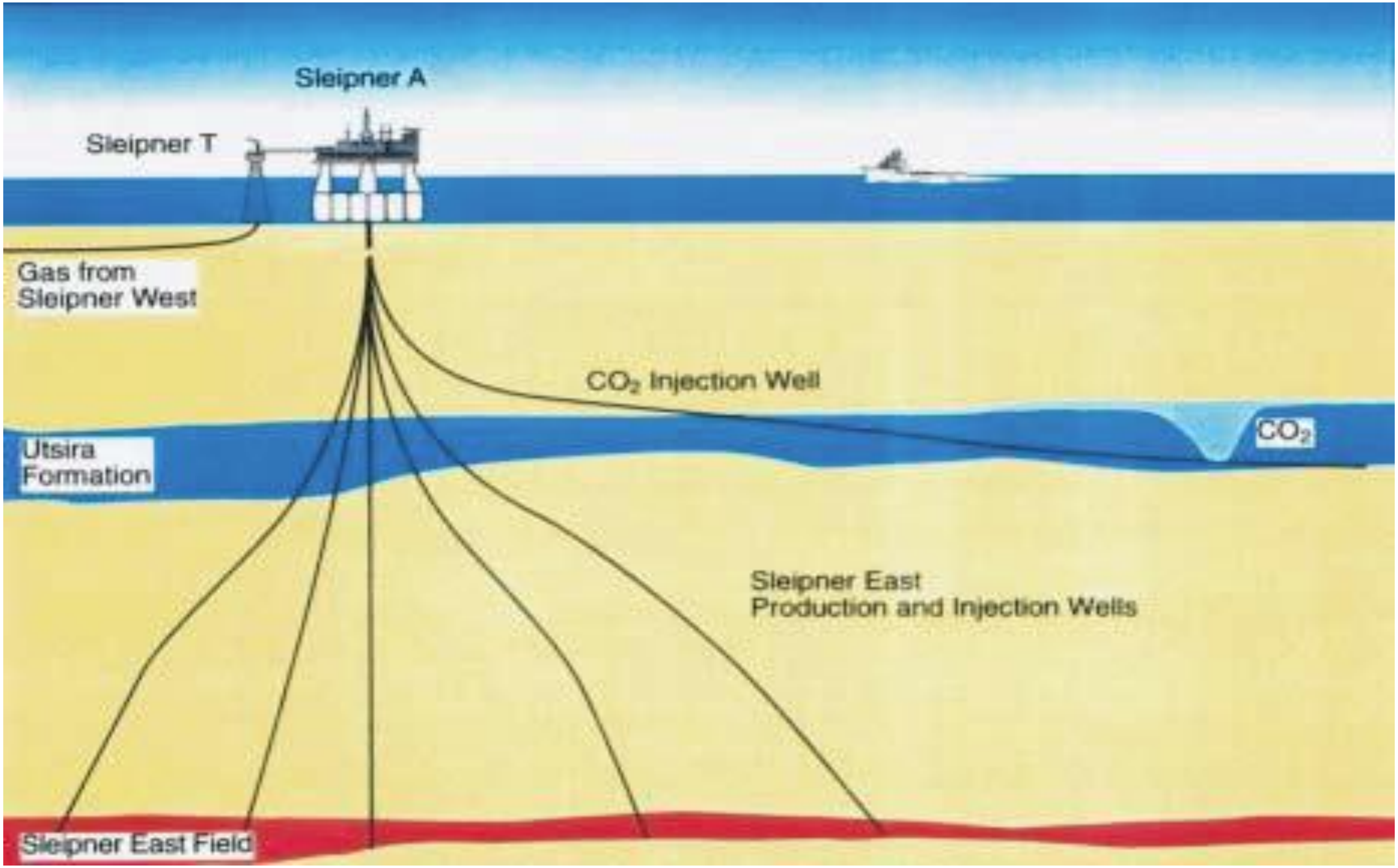
http://www.energyfromthorium.com/ppt/ThoriumBriefSep2008.ppt

1.6 million tons of CO_2 erupted from Lake Nyos in 1986, suffocating 1,700 people.

- **Each US 1 GW coal power plant generates 7 million tons of CO_2 per year.**
- **Sequestration of 227 GWY of coal power production of CO_2 means burying 1,500 Lake Nyos' worth a year.**

http://en.wikipedia.org/wiki/Lake_Nyos

CO2 is being stored beneath the North Sea at 2,700 t/day. **0.03% of US coal CO2!**



http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_Chapter5.pdf

Why not use biofuels instead?.

1. On the average, in one year one acre can grow 3 tons of dry biomass, whether corn, grass, or trees.

2. Burning one ton of dry biomass yields 16 million BTU.

3. The US consumes 500 quads annually.

4. 500 Quadrillion BTU
   x (1 ton/16 million BTU)
   x (1 acre/3 tons)
   = 10.4 billion acres required

5. US has 1 billion acres of farmland

http://wwf

Jean Ziegler, UN Special Rapporteur for Right for Food, condemns biofuels.

"This is an imminent massacre," Ziegler warned. He said that while families in the well-off West spent only about 10 percent to 20 percent of their budgets on food, those in the poorest countries laid out 60 percent to 90 percent. "It's a question of survival."

He blamed the crisis on "the indifference of the rulers of the world", and singled out the US support of bio-fuels for particularly harsh criticism.

"When a bio-fuel policy is launched in the United States, thanks to subsidies of 6 billion of bio-fuels that drains corn from the market, the foundation is laid for a crime against humanity to satisfy one's own thirst for fuel," Ziegler charged.

http://www.dispatch.co.za/article.aspx?id=192811

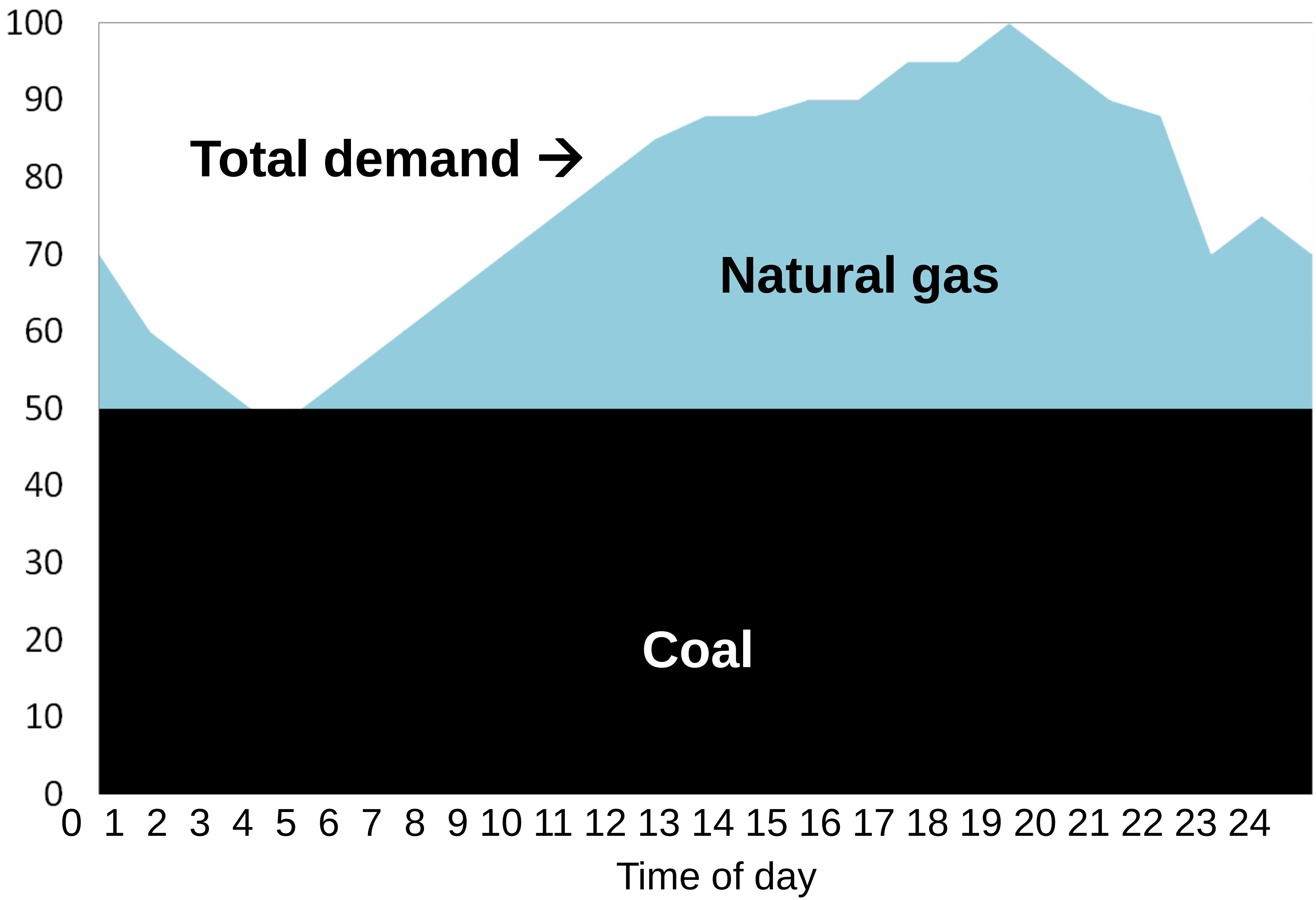
Why isn’t solar better?

What happens when or sun does not shine?

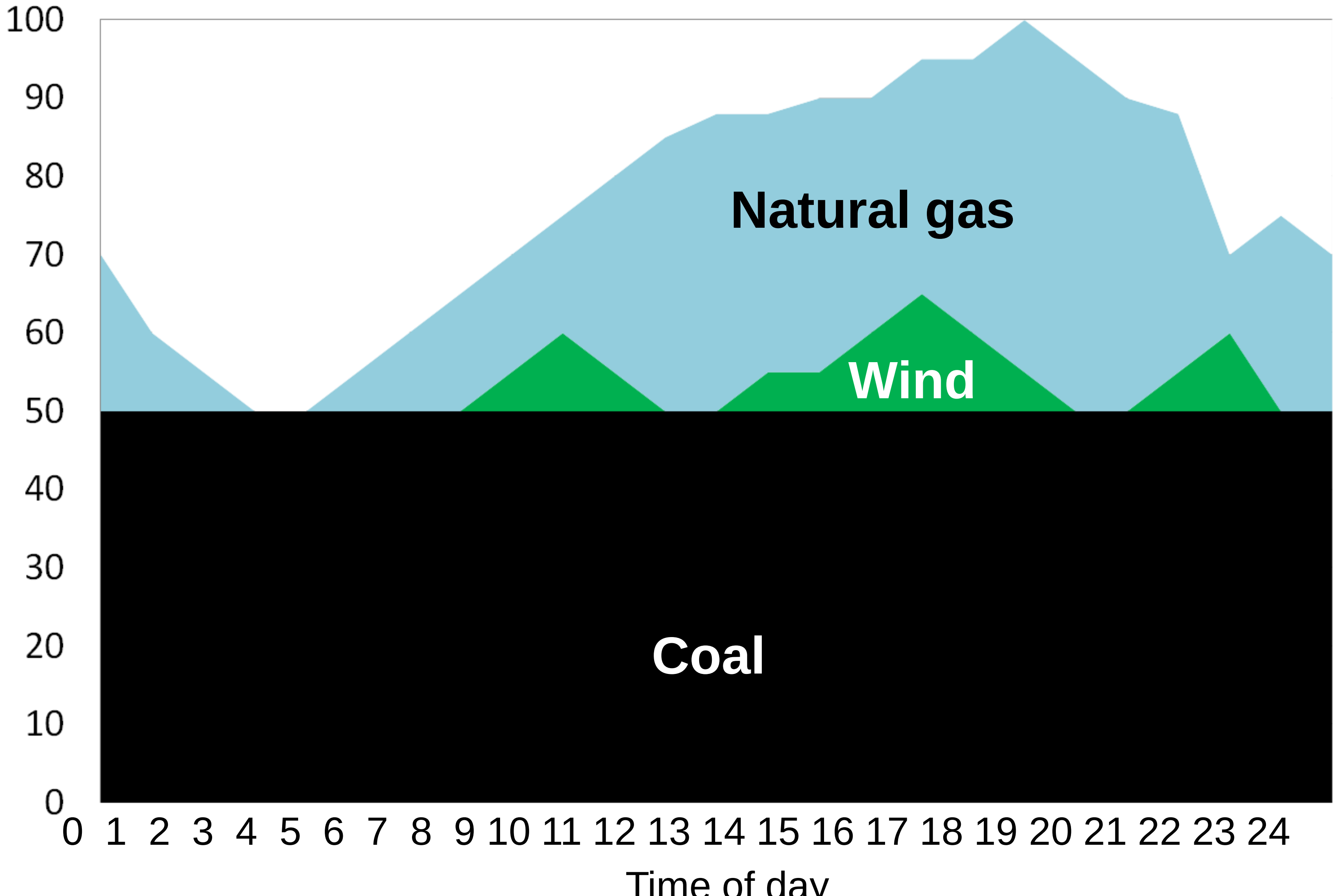
Energy storage is a big problem.

Compressed air?
Pumped hydro?
Molten salt?
Fuel synthesis?

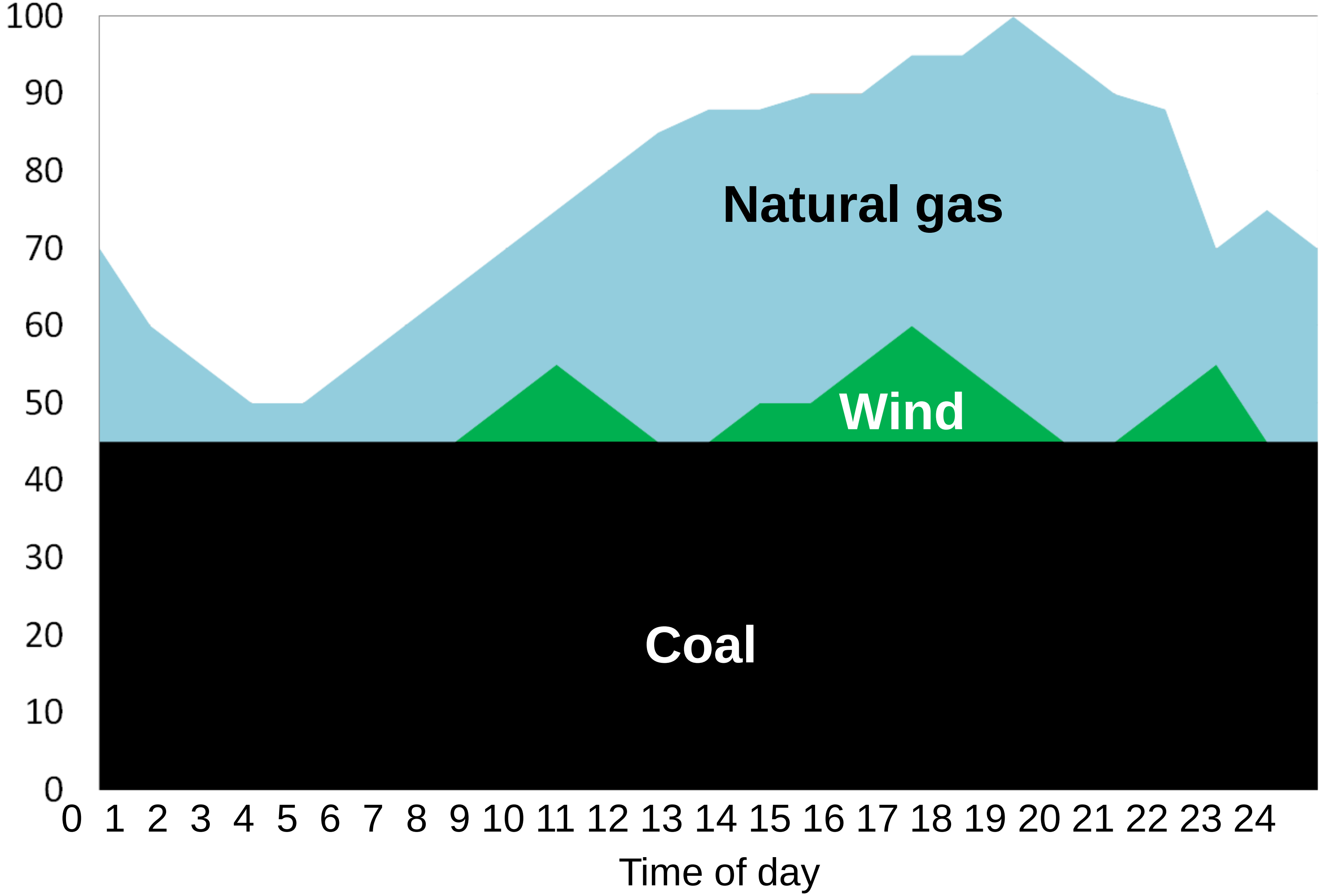
Natural gas adds to baseload coal power to meet varying demand.



Wind power can replace some clean natural gas power.



Using wind to replace dirty coal increases gas consumption.



Renewable energy wrecks the environment, says one scientist.

Jesse E. Ausubel

- Director, Program for the Human Environment, Rockefeller University.
- Program Director, Alfred P Sloan Foundation.
- Former Director of Studies, Carnegie Commission on Science, Technology, and Government.

Flooding the entire province of Ontario behind a 60 m dam would provide 80% of the power of Canada's existing nuclear electric plants.

Displacing a single nuclear power plant with biomass would require 1,000 square miles of prime Iowa farm land.

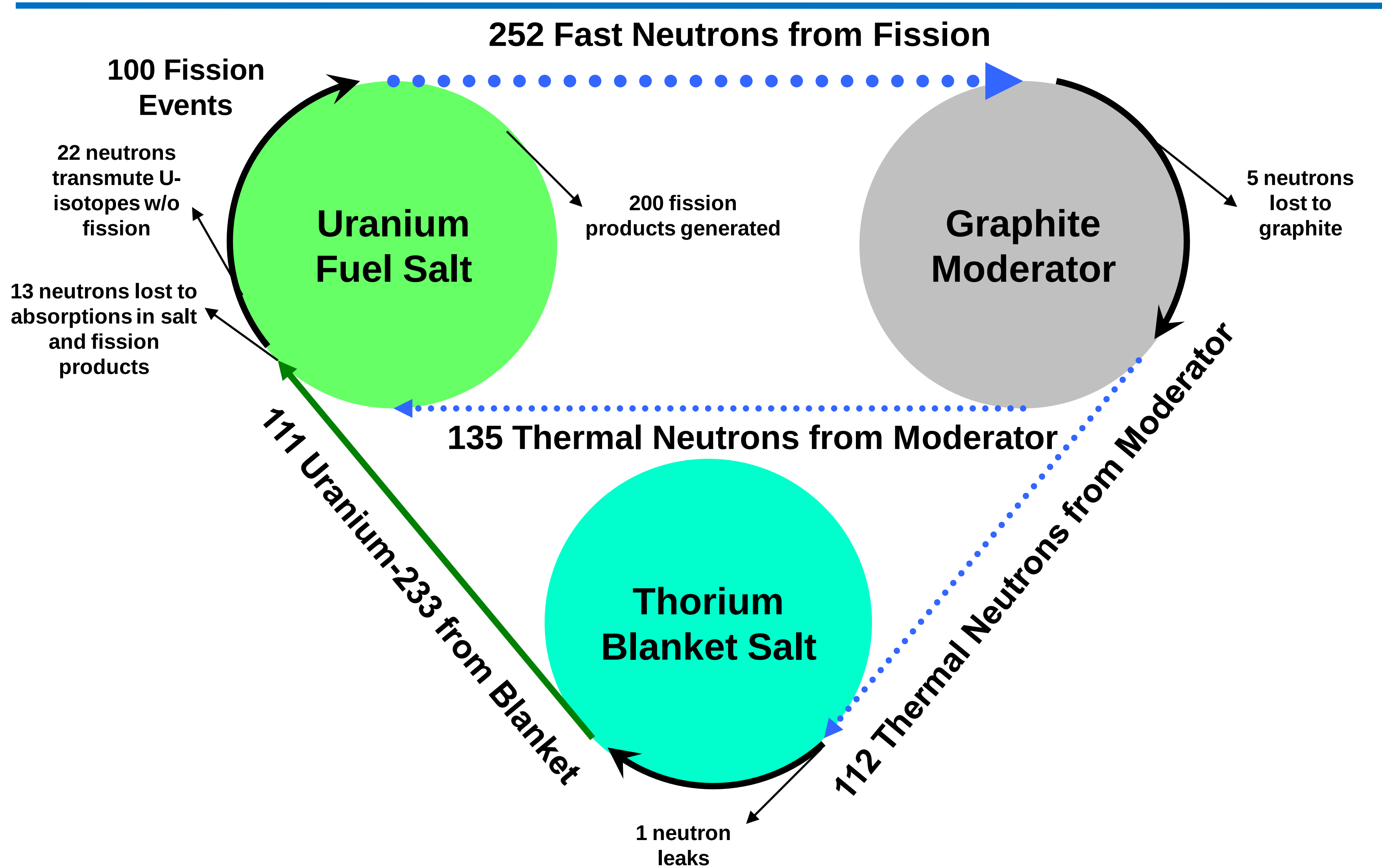
Wind farms on 300 square miles of land could displace a 1 GW nuclear plant.

60 square miles of photovoltaic cells could generate 1 GW.

Powering New York City would require a wind farm the size of Connecticut.

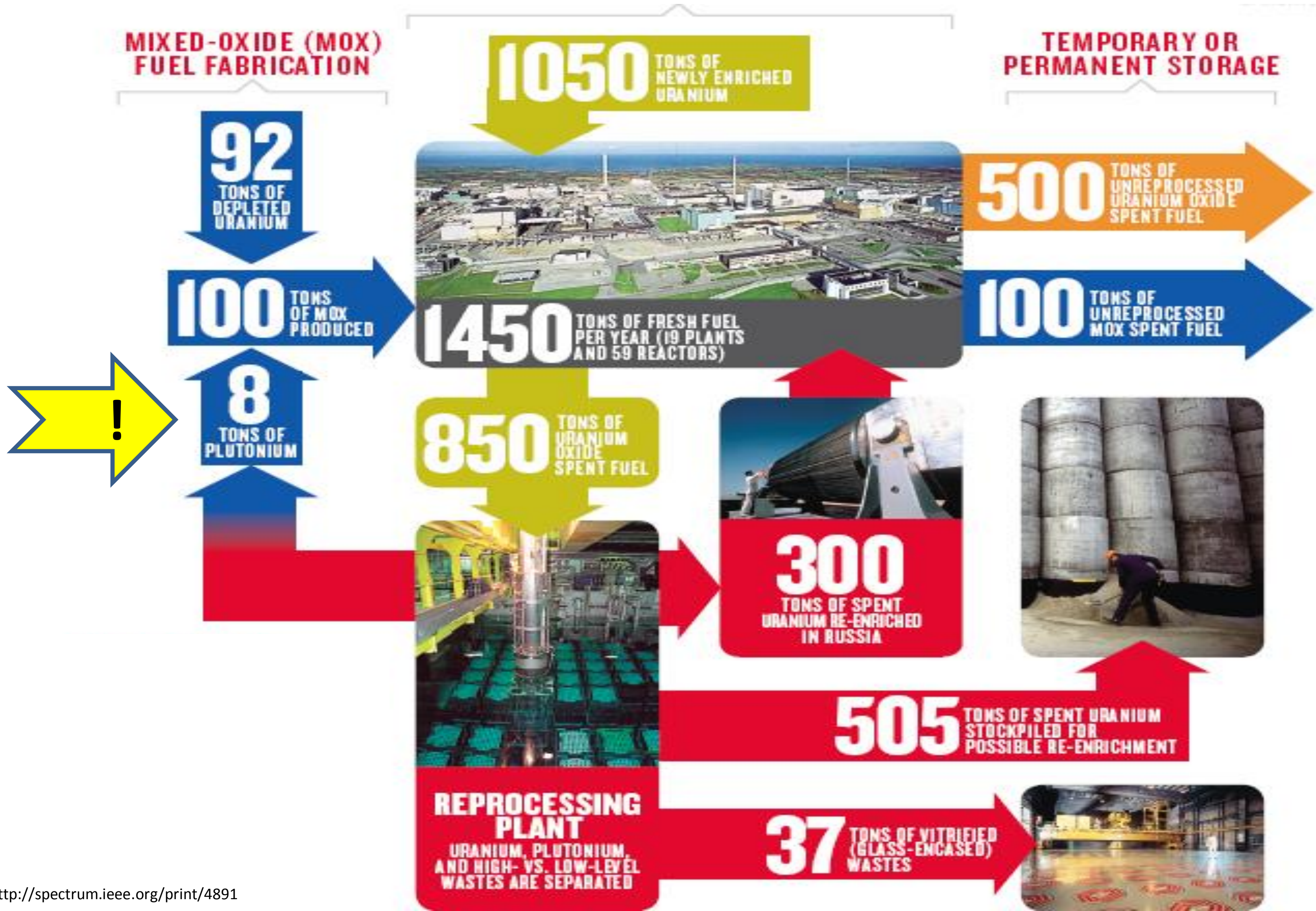
http://phe.rockefeller.edu/jesse/index.html

The LFTR can generate more U-233 than it consumes.



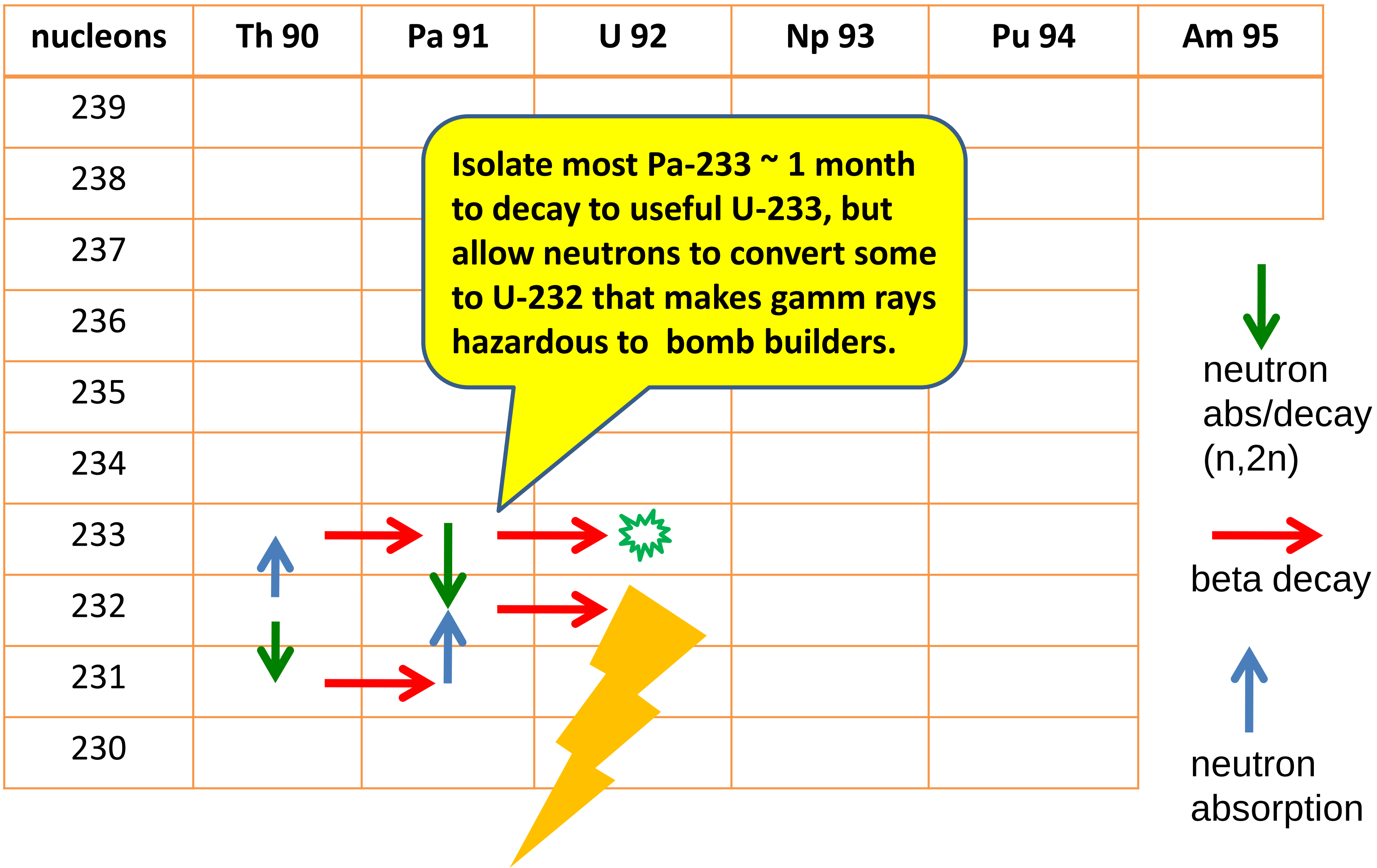
http://wwf

France's 850 T spent fuel → 37 T waste, but France separates 8 T of plutonium.



http://spectrum.ieee.org/print/4891

By-product U-232's decay chain emits gamma rays hazardous to bomb builders.



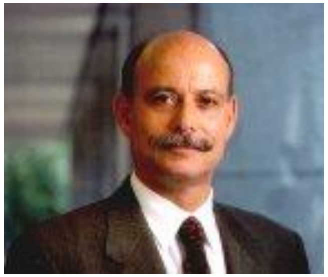
Some environmentalists will oppose energy cheaper than from coal.

Giving society cheap, abundant energy would be the equivalent of giving an idiot child a machine gun.

Prof Paul Ehrlich, Stanford University.

It would be little short of disastrous for us to discover the source of clean, cheap, abundant energy, because of what we might do with it.

Amory Lovins, Rocky Mountain Institute



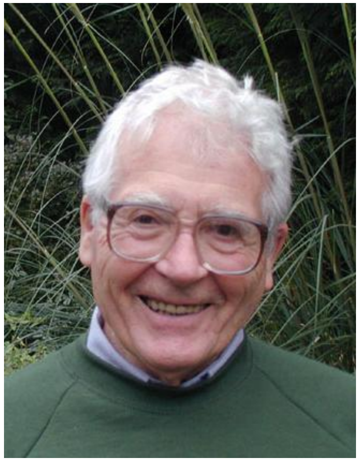
The prospect of cheap fusion energy is the worst thing that could happen to the planet.

Jeremy Rifkin, Greenhouse Crisis Foundation

http://green-agenda.com

http://www.motherearthnews.com/Renewable-Energy/1977-11-01/Amory-Lovins.aspx?page=14

Many environmentalists are becoming nuclear power supporters.



James Lovelock, Gaia

I find it sad but all too human that there are vast bureaucracies concerned about nuclear waste, huge organisations devoted to decommissioning nuclear power stations, but nothing comparable to deal with that truly malign waste, carbon dioxide.

Patrick Moore, Green Spirit

Nuclear energy is the only non-greenhouse gas-emitting power source that can effectively replace fossil fuels and satisfy global demand.

http://www.ecolo.org/lovelock/

http://www.greenspirit.com/index.cfm

Nuclear power was kindest to the human environment in 1969-1996.

Energy Chain	Accidents with > 4 fatalities	Fatalities	Fatalities per GW-year
Coal	185	8,100	0.35
Oil	330	14,000	0.38
Natural Gas	85	1,500	0.08
LPG	75	2,500	2.9
Hydro	10	5,100	0.9
Nuclear	1	28	0.0085

htpp://gabe.web.psi.ch/pdfs/PSI_**Report**/ENSAD98.pdf

Paul Scherrer Institut, November 1998, Severe Accidents in the Energy Sector

Senator Bingaman lists symptoms.

Starts and Stops in Energy Technology Policy

VEHICLE TECHNOLOGY

- Virtually pollution-free car (Nixon 1970)
- Reinventing the Car (Carter 1977-1980)
- Partnership for a New Generation of Vehicles (Clinton 1993-2000)
- FreedomCar (Bush 2003)

NUCLEAR TECHNOLOGY

- Clinch River Breeder Reactor (1970-1983)
- Advanced Liquid Metal Reactor Program (1989-1994)
- Global Nuclear Energy Partnership (2006)

COAL UTILIZATION

- Synthetic Fuels Corporation (1979-1985)
- Clean Coal Technology Program (1987)
- Clean Coal Power Initiative (2001)
- Future Gen (2003)

BIOFUELS

- Alcohol fuels (Energy Security Act 1980)
- Oxygenated fuels (Clean Air Act Amendments 1990)
- Biofuels (EPAct 2005; EISA 2007)

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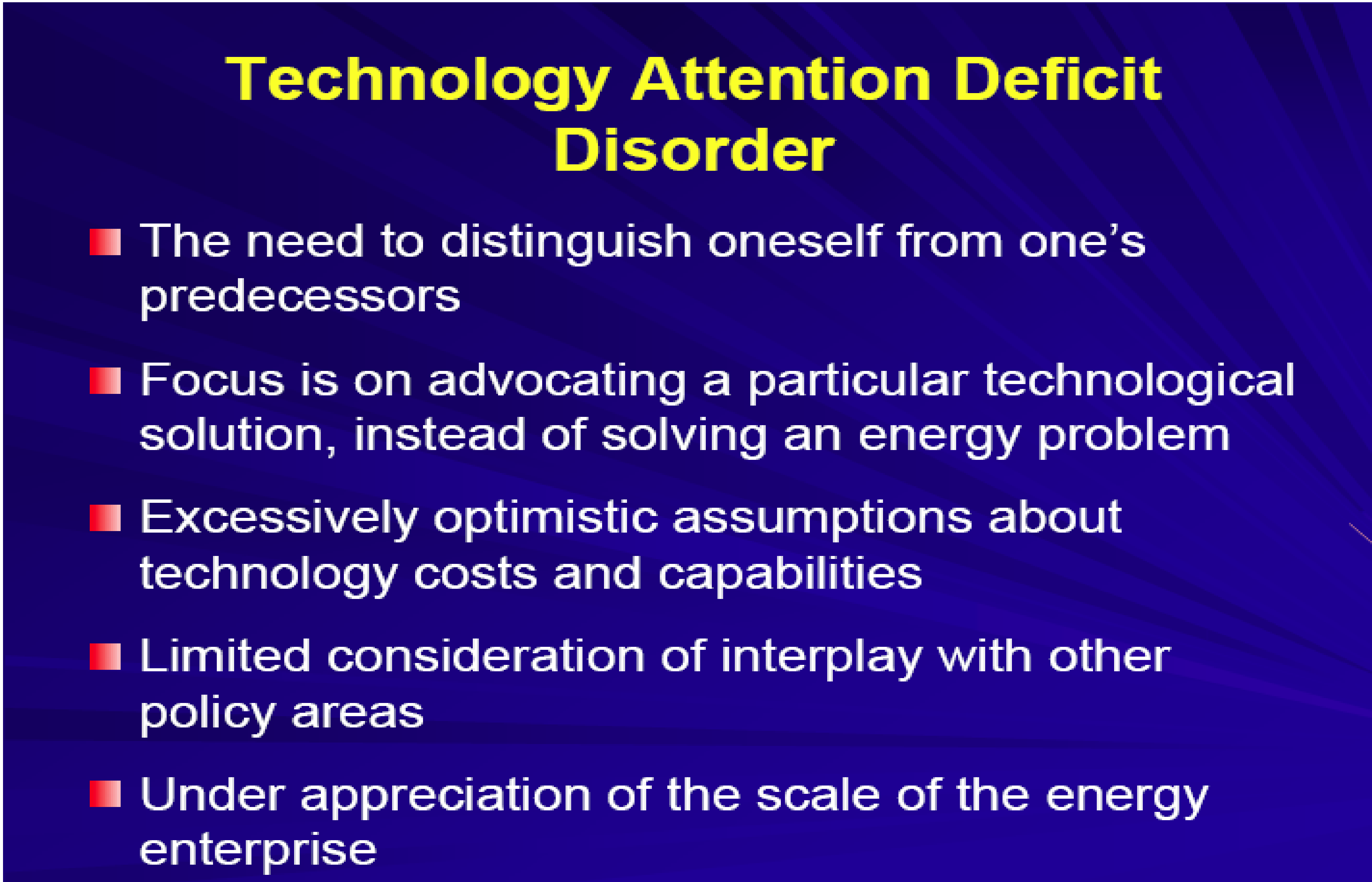
Senator Bingaman outlines reasons.



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