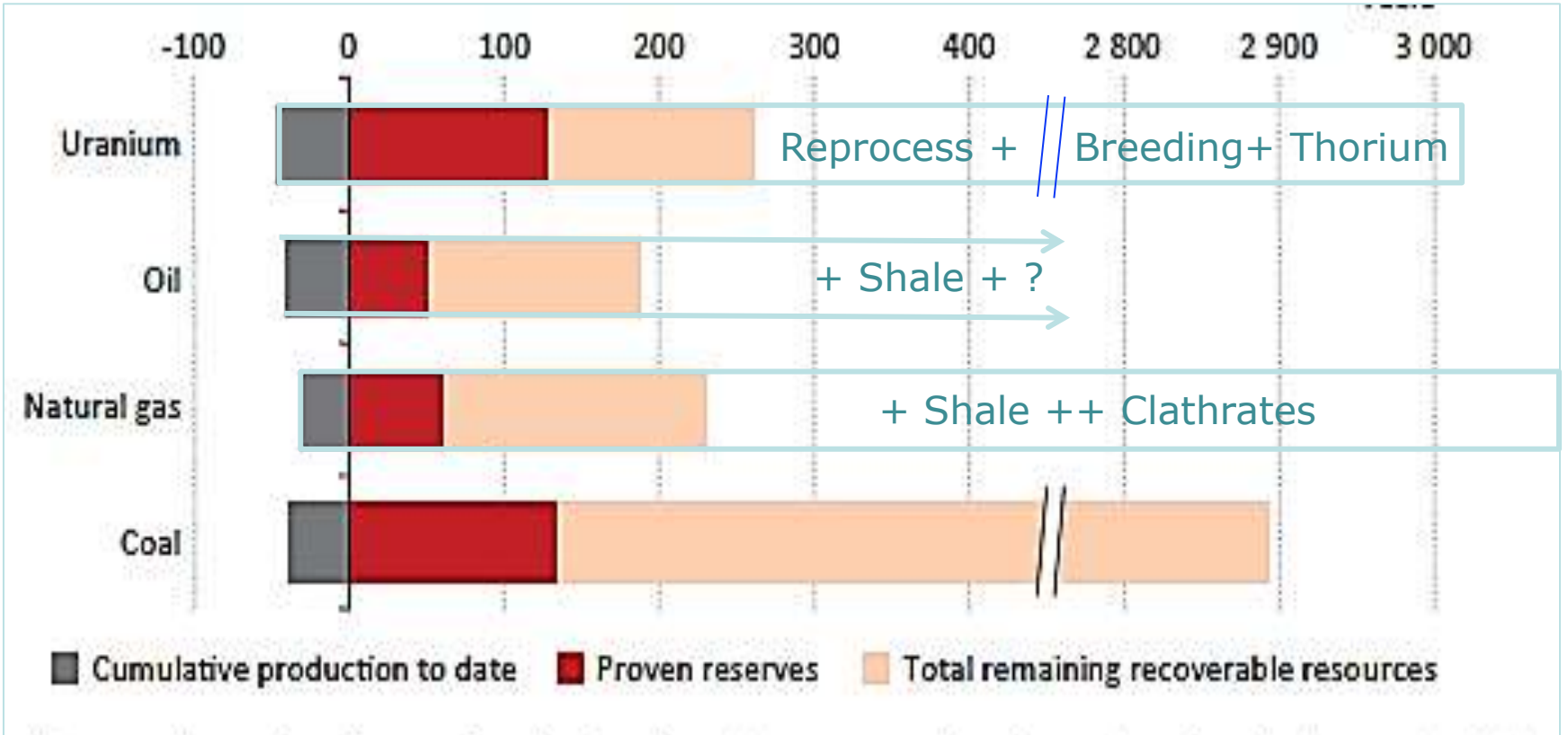
Nuclear Fuels Resources

Calvert Cliffs Station/UK

World Primary Energy Resources

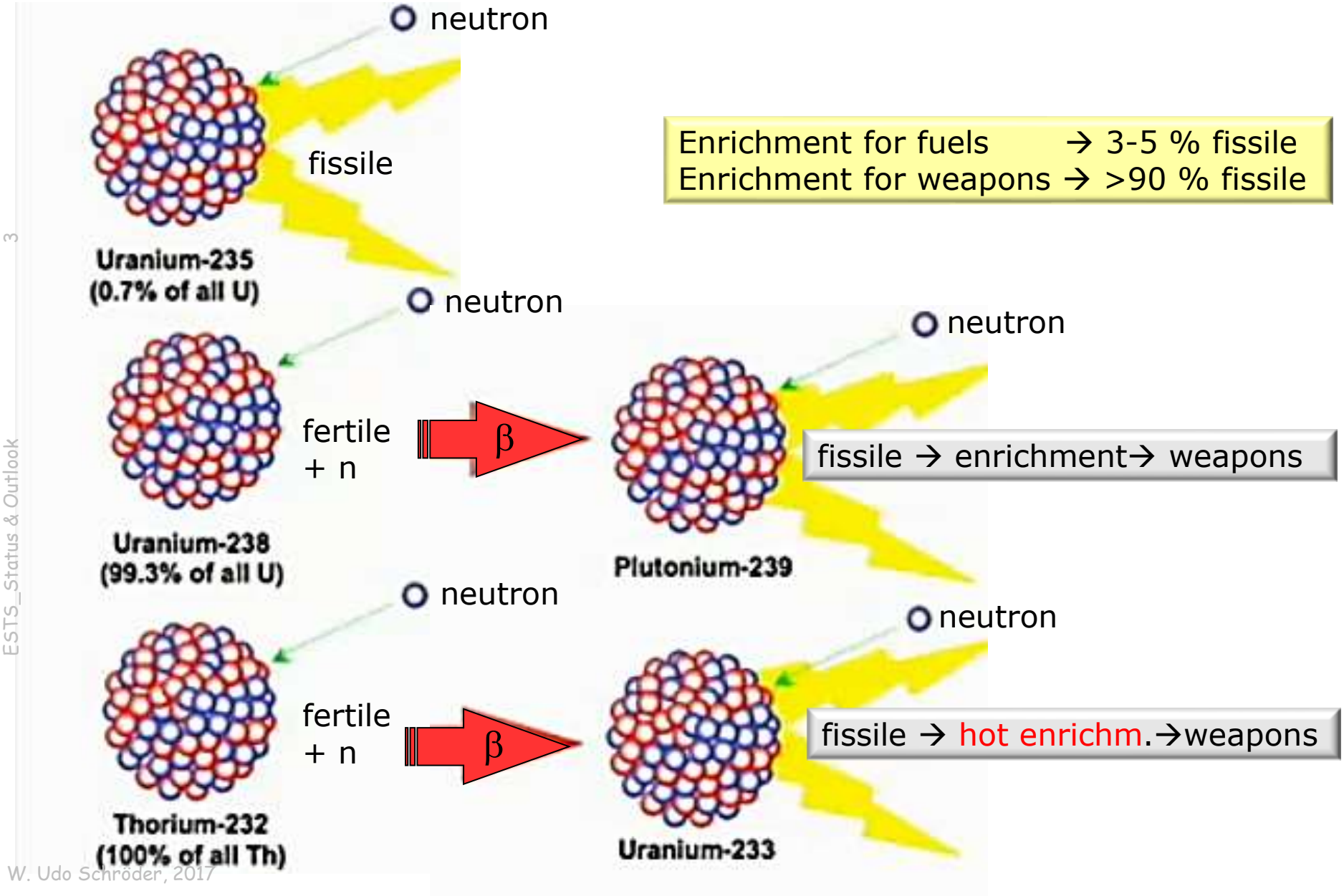


Modified after IEA World Outlook 2014, in light lettering: use reprocessing + U-238 breeding, Th 232 fertile fuel,

unconventional gas (fracking) + clathrates in frozen environments.

Neglect losses in reprocessing and breeding. Assumed present rate of consumption in future.

Nuclear Fuels



Enrichment for fuels → 3-5 % fissile
Enrichment for weapons → >90 % fissile

Nuclear Fuel Resources

World (US)
443 (103) reactors + >50 (+2 in USA)
365 (100) GW
– Germany, Italy, Sweden
+ China, India, E-Europe

U use: 66 kt/a
World reserves: 5.9 Mt known (>15Mt est)
Primitive, once-through cycle: > 90 years

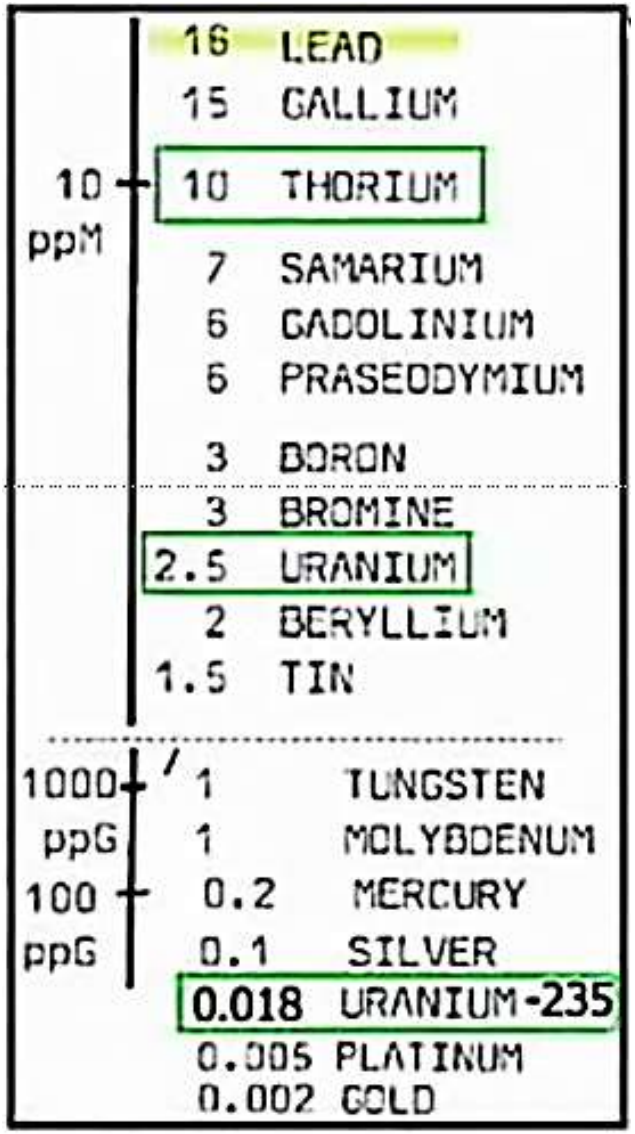
Reprocessing: ~10^3 years
US:174 t weapons grade (>90%) ^{235}U
+20t/a Pu for fuel mix (→ 0.2 Mt fuel)

Th use: little yet (India ramping up fleet)
World reserves >15 Mt known ~ 10^3 a
with reprocessing. Likely much higher.

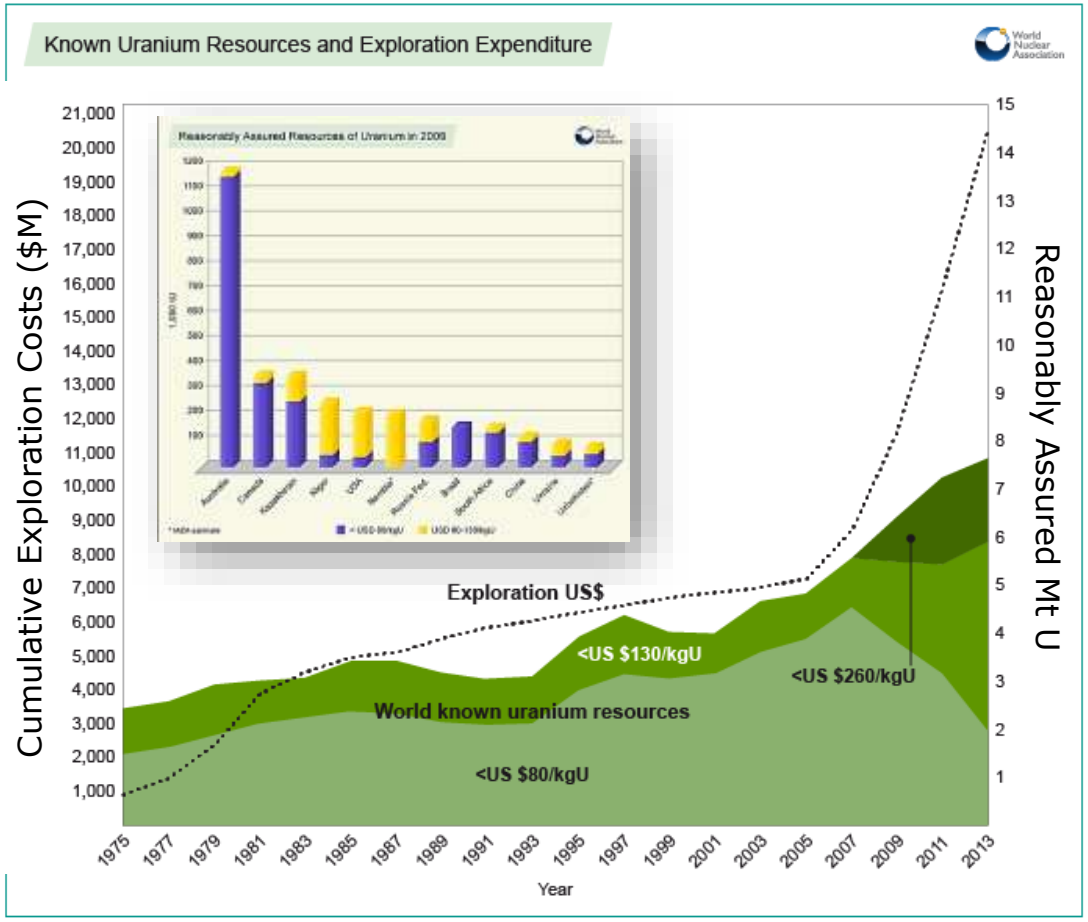
Gen IV breeder (^{238}U, ^{232}Th) reactors,
modular S-4, molten salt reactors

Large uranium contents in oceans →
sustainable but not economic energy source

Reserves in Earth crust



Uranium Exploration/Recovery



Current usage: 66 ktU/yr. World U resources = 5.9 Mt = 90 years.

All conventional resources (U = main or major by-product): + (7.3 - 8.4) Mt > 200 years.

Unconventional resources (U = minor by-product), e.g., in coal, phosphate/ phosphorite deposits → + 22 Mt U, black shales (schists – + 5.2 Mt U), lignite (+0.7 Mt U).

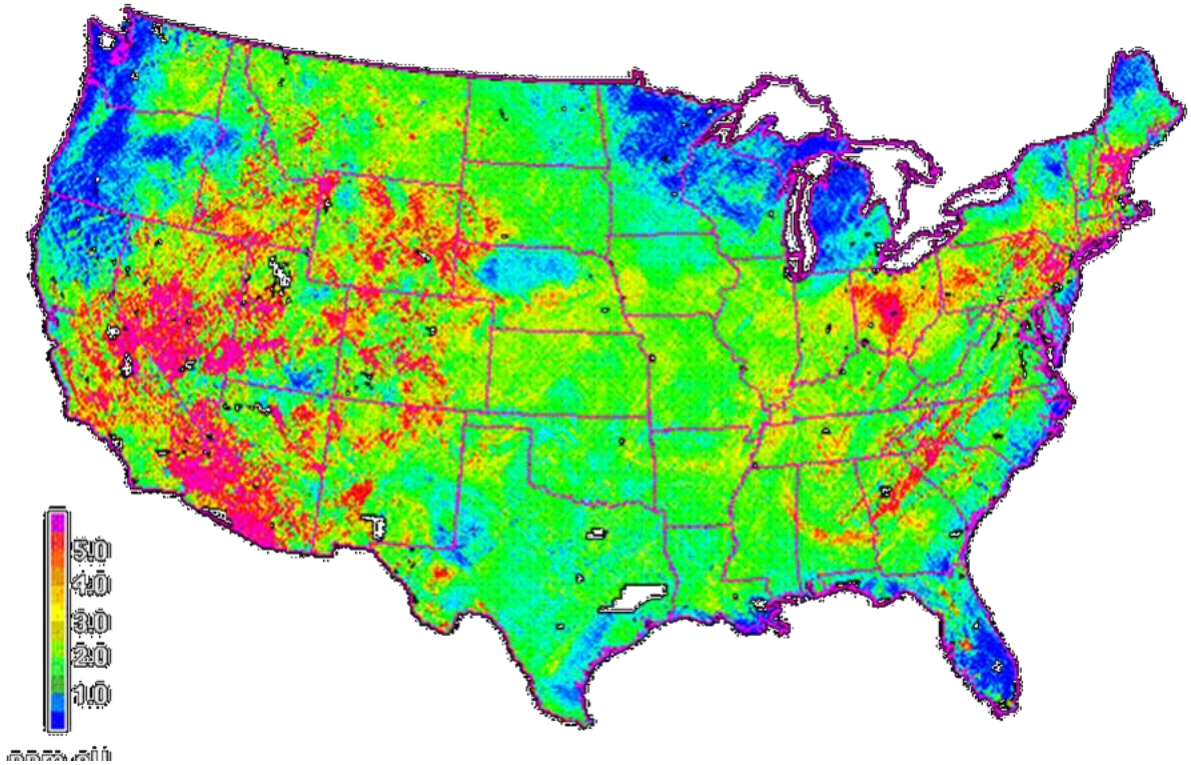
Seawater (+ 4,000 Mt), presently uneconomic to extract.

But:
General trends to mine ocean floor.

Exploration has increased known resources (matter of $/kg)

Coal ash: easily-accessible uranium resource. USA (1960s - 1970s): recover 1,100 tU from coal ash; 210 ppm U (0.021%U) > cut-off level for uranium mines.
China (central Yunan province): U content in coal = (65 - 315 ppm).

U.S. Uranium Deposits



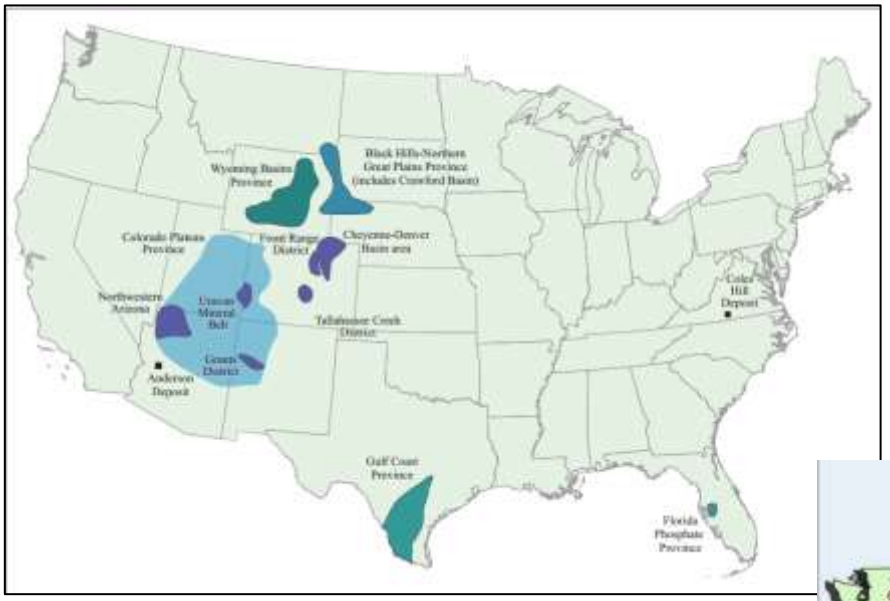
Increasing fractions of the world's uranium now comes from in situ leach (ISL) mining: oxygenated groundwater is circulated through porous ore, dissolving U_3O_8 and bringing it to the surface.

ISL may be done with slightly acidic or alkaline solutions to keep the uranium in solution.

U_3O_8 recovered from solution as in conventional mills.

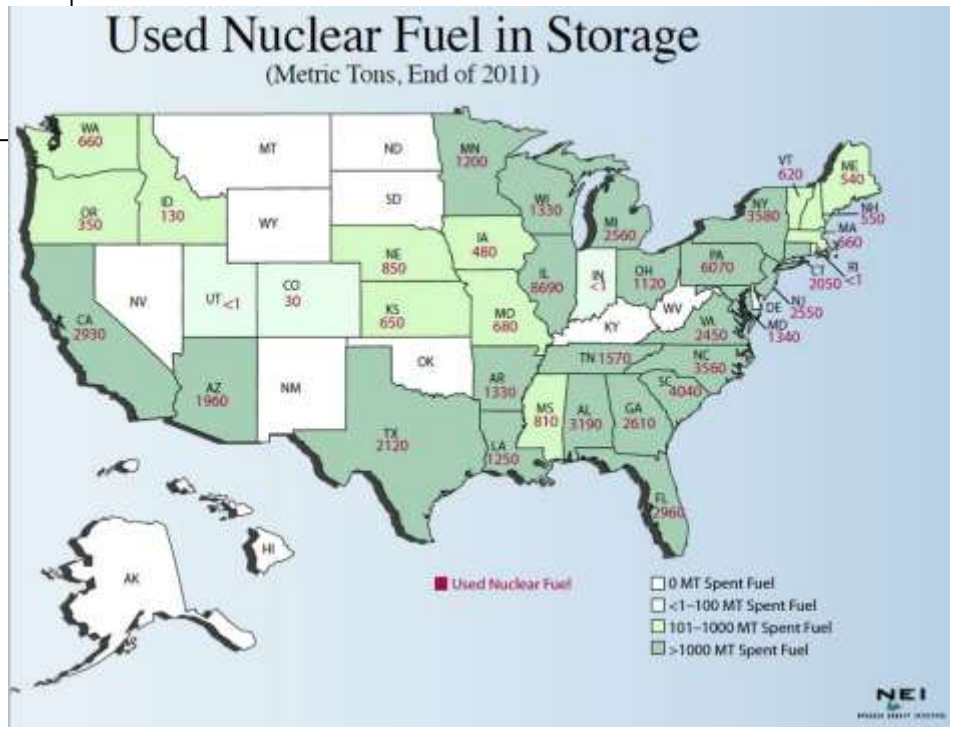
Open-pit U-ore mining in Australia,..., Africa(Namibia, Tanzania, S-Africa...)

U.S. Uranium Resources/Used Fuel Elements



NP stations use U enriched in U-235.

Once-used fuel elements contain:
< 3 % U-235, > 95% U-238
U-238 = fertile fuel for "breeding."



1GWe nuclear reactor requires
yearly core load of (17.5-20) t
low-enriched uranium U_3O_8
(3.5 - 5)% U-235, > 95% U-238

U.S. Nuclear Fuels (U) Production

Total production of uranium concentrate in the United States

pounds U_3O_8

Quarter/year	2014P	2013	2012	2011
1st Quarter	1,242,179	1,147,031	1,078,404	1,063,047
2nd Quarter	1,095,011	1,394,232	1,061,289	1,189,083
3rd Quarter	1,468,608	1,171,278	1,048,018	846,624
4th Quarter	1,100,111	946,301	957,936	892,013
Calendar year total	**4,905,909**	**4,658,842**	**4,145,647**	**3,990,767**

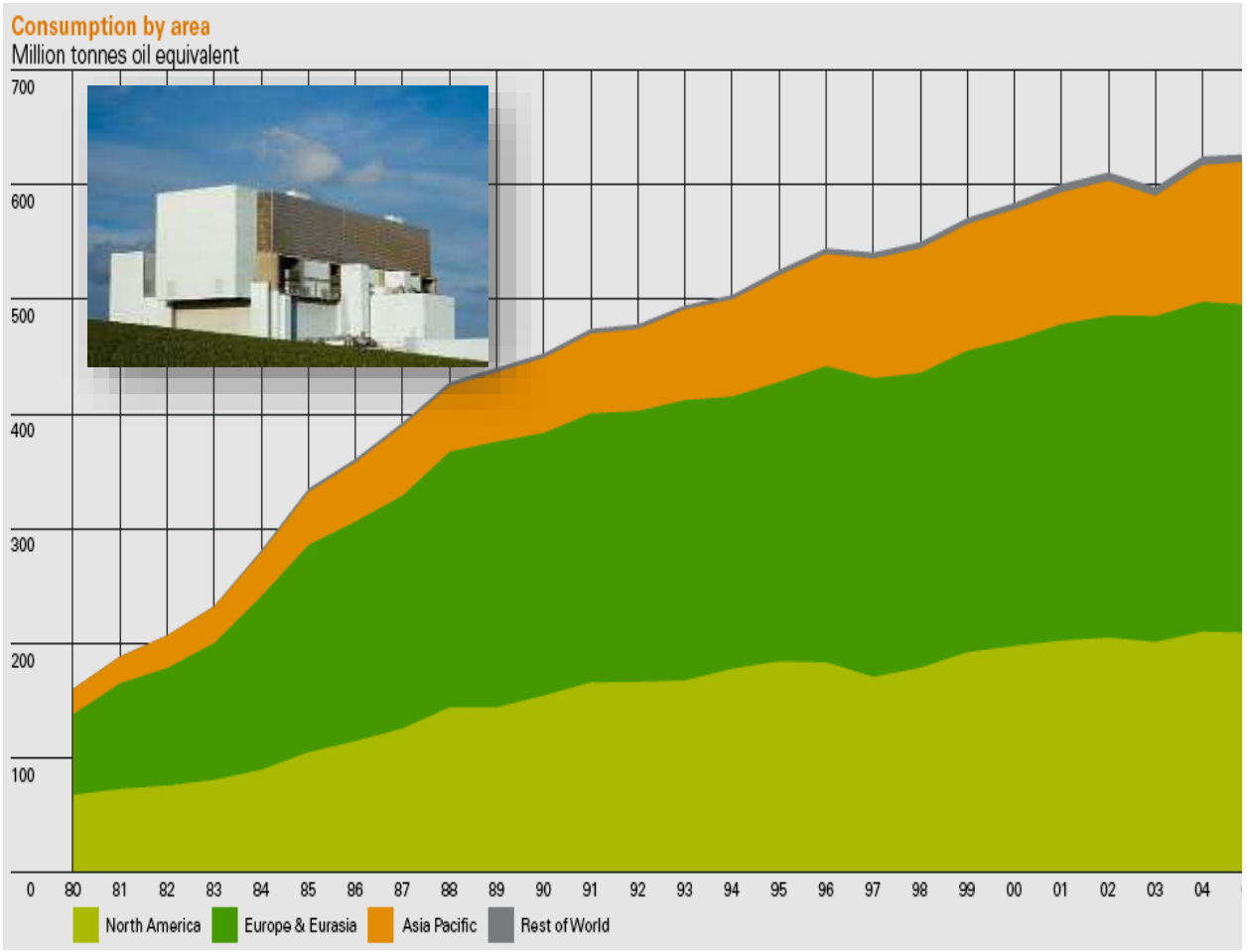
≈1 year's supply for US NPS

Source: U.S. Energy Information Administration, Domestic Uranium Production

Mixed fuels, diluting weapons' grade U purchased from Russia (< 2010, discontinued for now).

Trends in Nuclear Energy Production

Steady increase of nuclear power output over past 20 years (ε>95%).
Now equivalent: 24 quads of oil



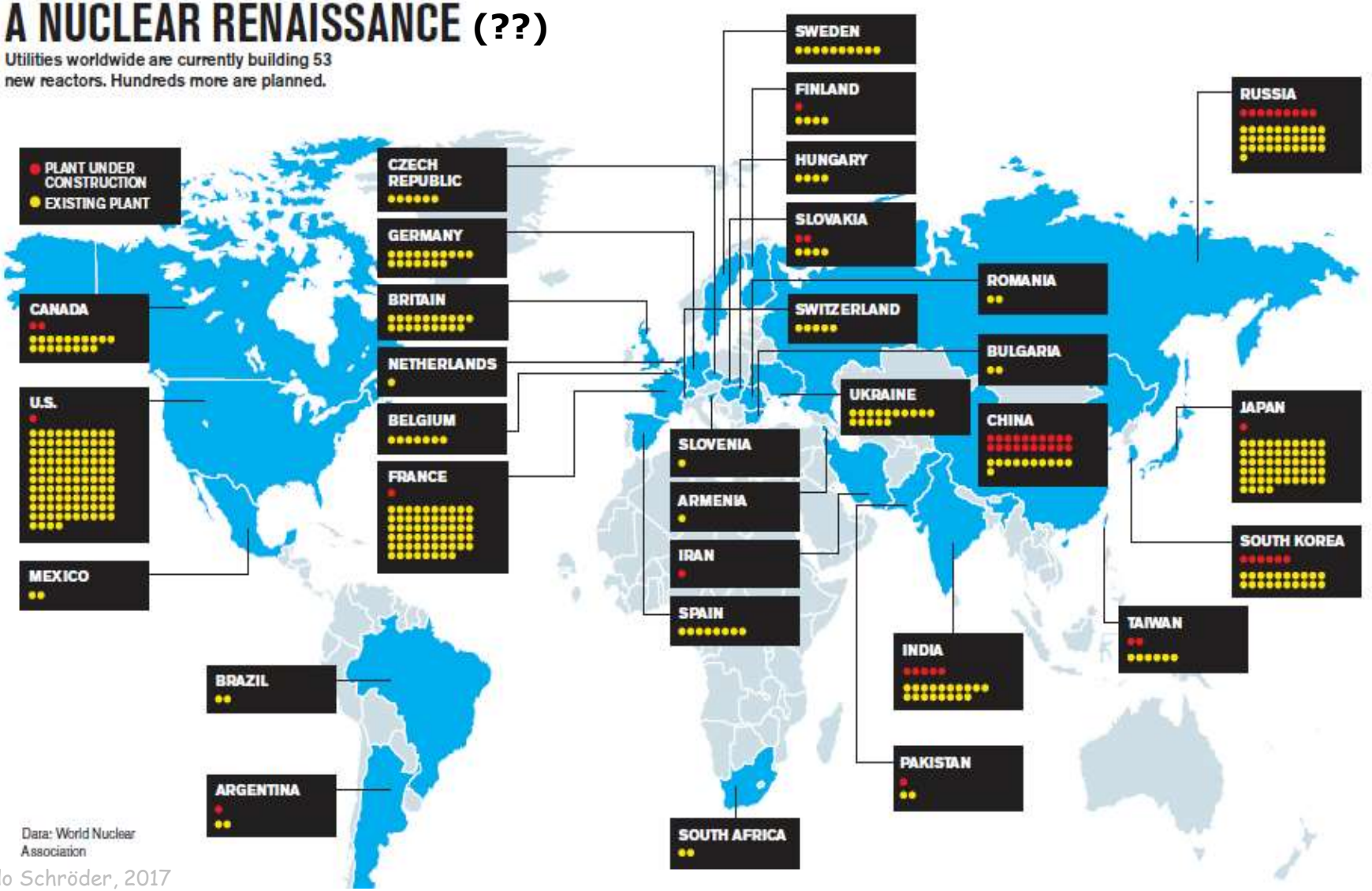
World (US)
443 (103) reactors
365 (100) GW

World
53 new reactors,
US:2 under construction
18- 20 planned (?) license apps
nat gas competes

US potential:
several new reactors/a
(@ $(6-8)B/GW$_e$,
→ (5-10)¢/kWh)

Nuclear Plants Existent & Under Construction

Bloomberg BusinessWeek (2010)



Fin Nuclear Fuel Resources