Nuclear fission energy an answer to limited fossil fuels and their extraction peaks?

Università di Pisa 22 January 2009

Dr. Michael Dittmar ETH

- **How unsustainable is todays energy system?**
- **What is the real potential of nuclear energy?**
  - **Energy from nuclear fission, status, perspectives**
  - **Fast Breeders and Generation IV power plants**
    A better use of uranium?
  - **Uranium requirements, resources and mining.**
- **Summary: Our Energy Future**
  Wishful thinking and real possibilities?

Energy news headlines (early 2009):

- **“Russian gas flow disappoints EU” and “Why Europe needs Russian gas” (BBC news 13.1.09)**
  “The EU gets a quarter of its gas supplies from Russia - 80% of which passes through Ukraine - and more than 15 countries across central Europe have been hit by the shutdown of Russian supplies.”

- **Nuclear the ’only solution’ to Italy’s energy imports (World Nuclear Association (WNA) 9 January 2009)**
  ”Italy has the most advanced and efficient energy system of the world, based on combined cycle power plants. The only problem is that these plants need gas to work.” (Giuliano Zuccoli president of Edison, made the statement in an interview with Corriere della Sera).

- **Slovak nuclear plant to restart in days? (WNA 12 January 2009)**
  “The EU called for Slovakia to close the Bohunice V1 units (the first was shut down at the end of 2006) on safety grounds as a condition of its accession to the EU.”

How we use energy (a comparison)

M.D.: roughly 40000 kWh/year (+ working at CERN: 240000 kWh),

an average person in Western-Europe: 50000 kWh/year
(including work and consumption)

an average human being (6.5 billions today): 17000 kWh/year.

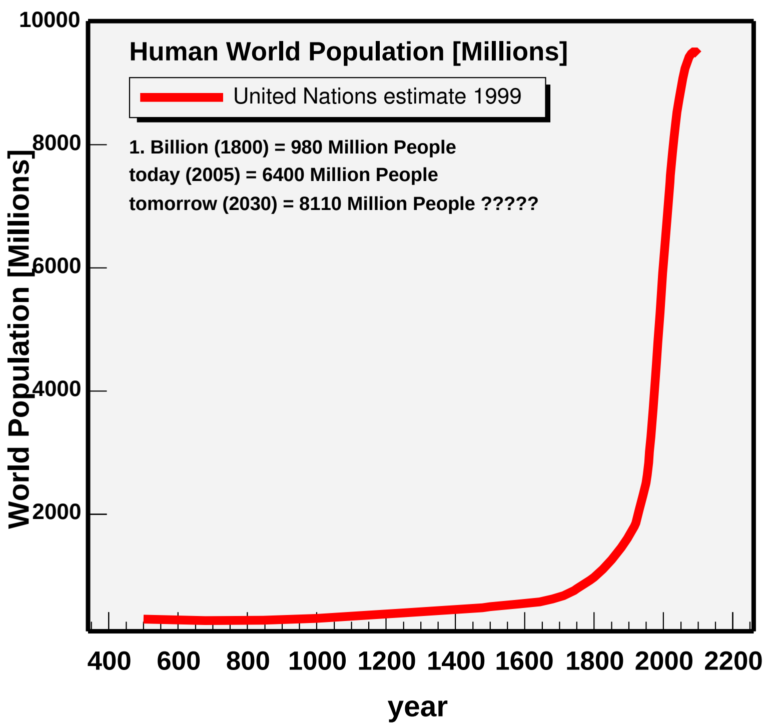
an average person in China (1.3 billions today): 9400 kWh/year.

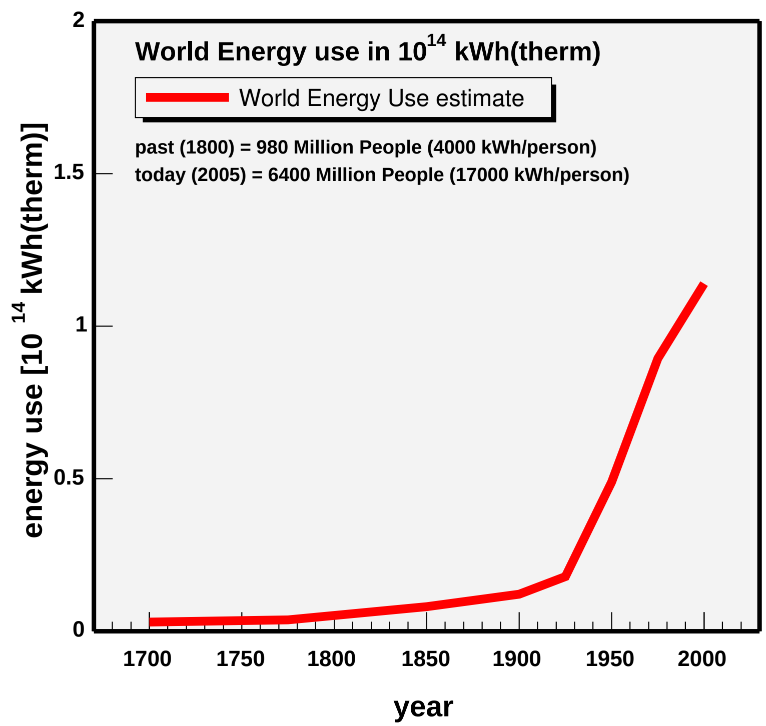
an average person in India (1.1 billions today): 3700 kWh/year.

6.5 Billion humans need energy for XYZ

≈ 129 Million children born/year and ≈ 56.5 Million humans die/year (10 Million from hunger and hunger related problems).

The energy use per person varies by orders of magnitude
≈ 2 Billion people live without electricity!

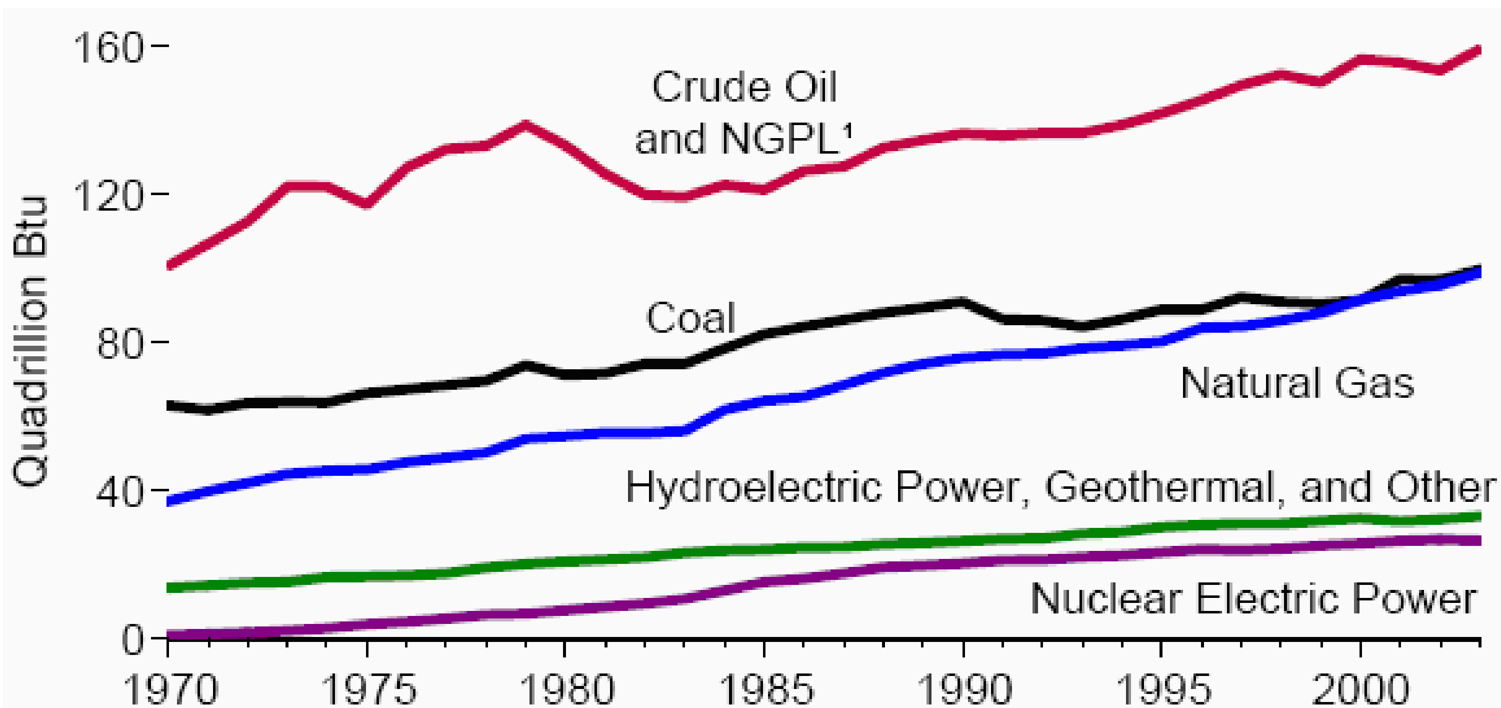




Energy use (world 2005) ≈ 133000 TWh(therm)
(world 1970 ≈ 62000 TWh(therm))

85% from fossil fuels: 40% oil, 22% natural gas, 23% coal
8% so called renewables (mainly hydropower) and 7% nuclear

in reality 16% of the world energy mix is electric energy and 14% of this (2007) come from nuclear energy!
→ nuclear fission contribute marginal ≈ 2.3%:



Source: www.eia.doe.gov/aer/pdf/perspectives.pdf

Today's (demand based) "energy" predictions:

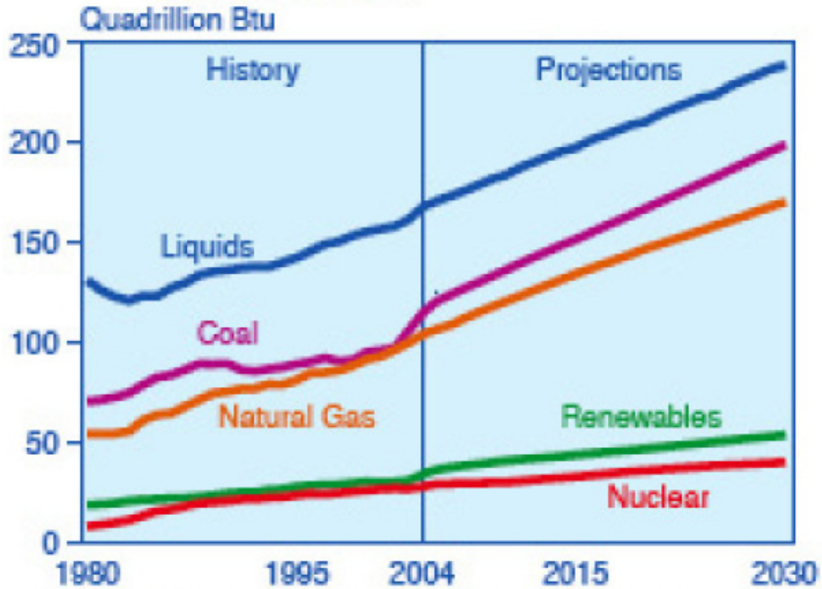
Fossil fuels remain dominant, 1-2% growth/year

nuclear fission and renewables remain marginal

the global warming/CO_2 problem will be ignored

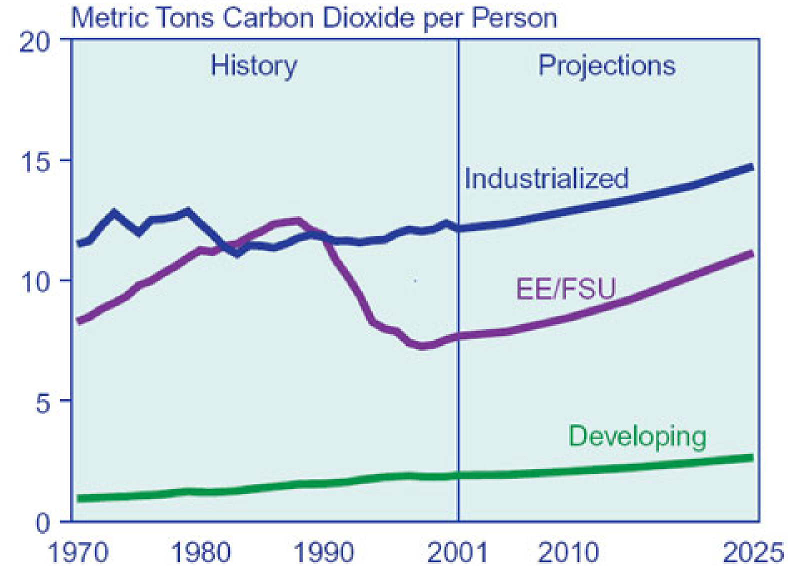
and the poor remain poor!

Figure 4. World Marketed Energy Use by Fuel Type, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

Figure 19. Energy-Related Carbon Dioxide Emissions per Capita by Region, 1970-2025

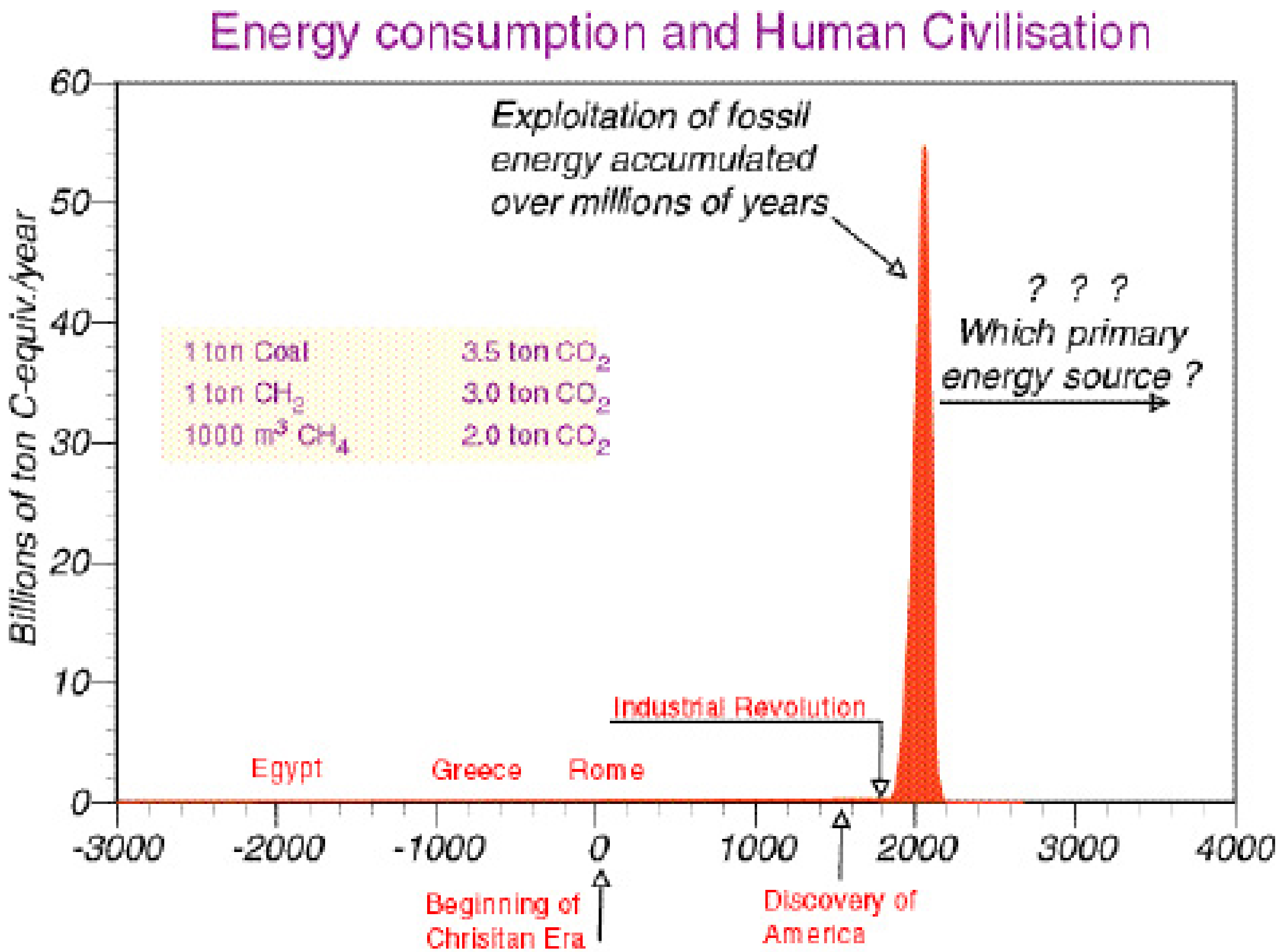


Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2001*, DOE/EIA-0219(2001) (Washington, DC, February 2003), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2004).

What is the Energy Problem? I

Fossil fuels are very very limited and dirty!

As shown by C. Rubbia, IAEA Fusion Energy Conf. Oct. 2000
Original plot probably made around 1971 by Dr. M. King Hubbert (1903-89) (geophysicist)



What is the Energy Problem? II
How limited are oil, gas and coal?

Standard Question: “How many years of oil, gas and coal remain?”
(assuming no further growth: “with todays use”)

- **Oil ≈ 42 years (fraction of world energy mix 40%)**
  EU resources ≈ 8 years (without import 1.3!) years ;

- **Gas ≈ 60 years (fraction of world energy mix 22%)**
  EU ≈ 15 years (without import 6!) years;

- **Coal ≈ 133 years (fraction of world energy mix 23%)**
  EU ≈ 50 years(without import 28!) years.

(source BP World Energy Review 2008)

- **Are these resource numbers correct?**

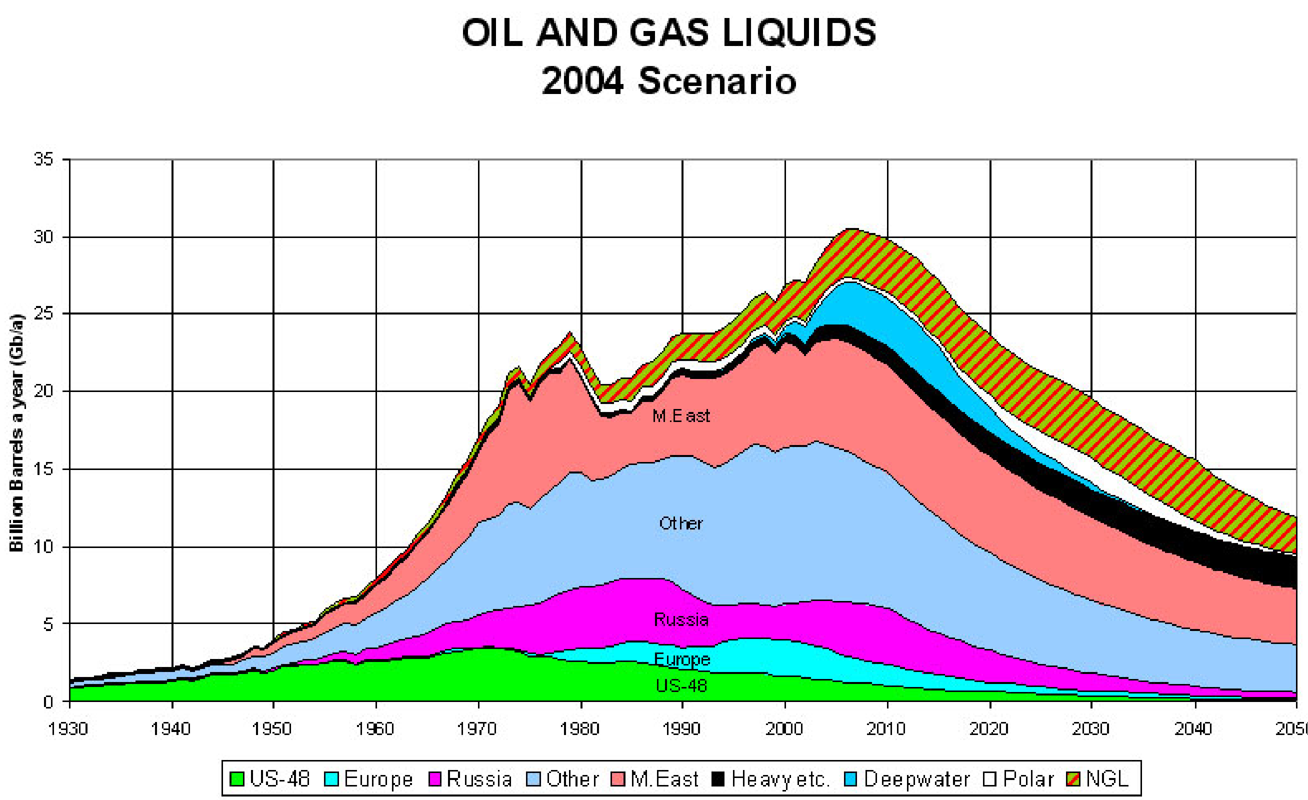
- **What do these numbers mean in “energy growth” scenarios?**

- **Are there other fundamental limits?**
  (like Hubbert’s oil peak and the law of dimishing return)

World's Oil extraction limits as seen by geologist's (peak oil)

Oil extraction: Past and Future for different countries

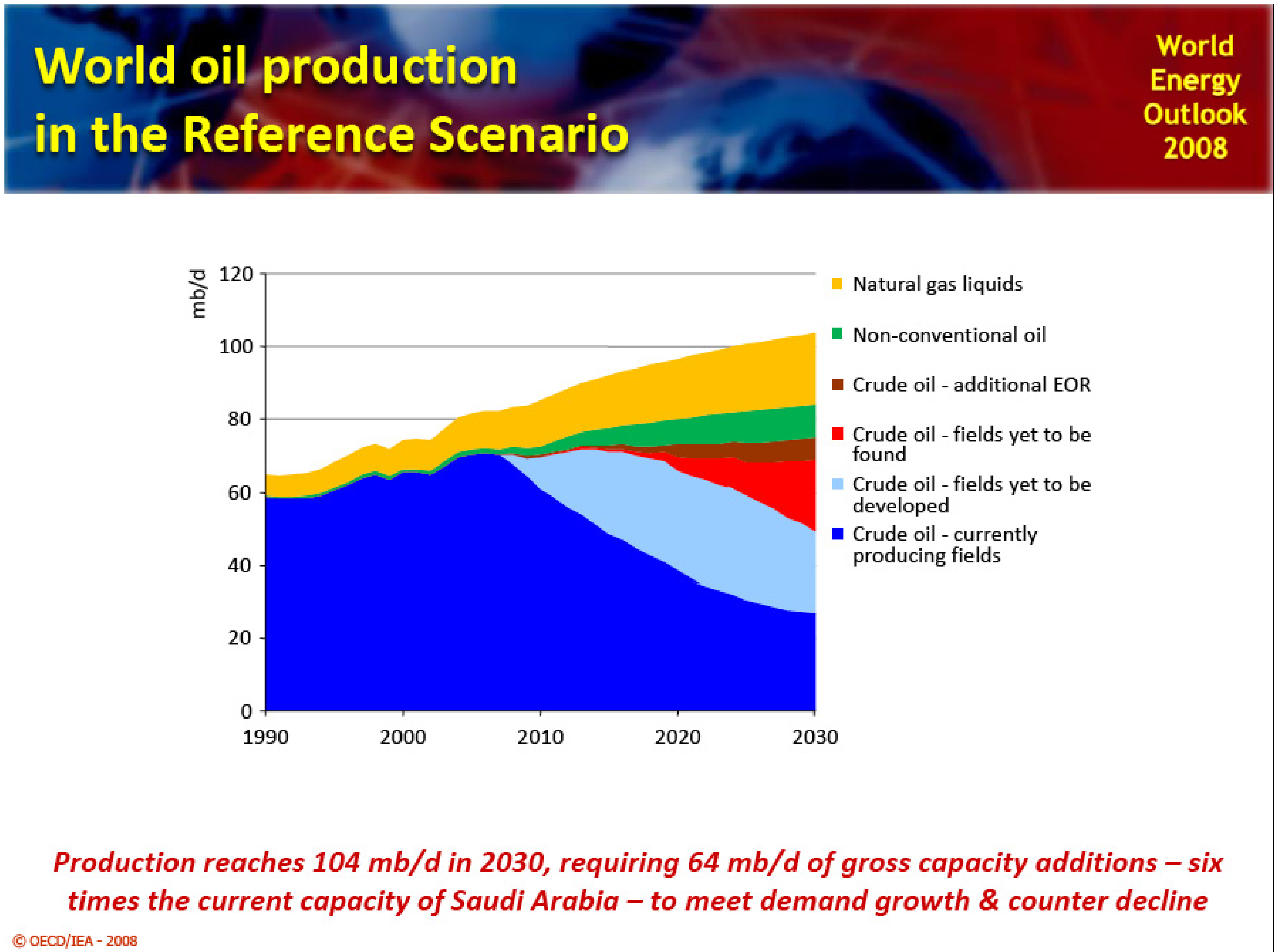
The 2004 ASPO scenario (Colin J. Campbell et al., 2004-05-15 www.peakoil.net/uhdsg/Default.htm)



World's Oil extraction limits (International Energy Agency)

IEA November 2008 (similarity to "Peak Oil" is only accidentally!)

"We should leave oil before it leaves us"
F. Birol IEA chief economist (spring 2008)

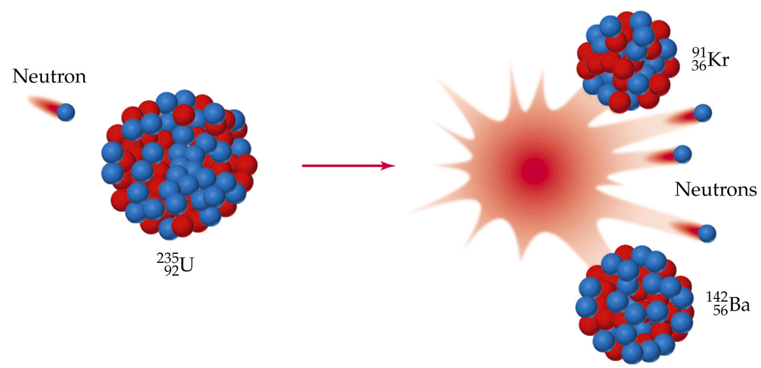


What is the real potential of nuclear energy?

Energy from nuclear fission

neutron (slow)+$U^{235} \rightarrow X + Y + 2.5$ fast neutrons + 200 MeV energy

1 neutron needed for the chain reaction and ≈ 1.5 free for other reactions
A 1 GW(e) fission power plant needs $\approx 10^{20}$ fission processes/sec.



Energy from deuterium tritium fusion

$H^2 + H^3 \rightarrow He^4 + n$ + 17.59 MeV energy
A hypothetical 1 GW(e) fusion power plant needs $\approx 10^{21}$ fusion reactions/sec

“Nuclear Fusion Optimists”: If ITER works .. Commercial reactor perhaps in 50 years!

Some additional never discussed problems about controlled fusion:

- **Commercial energy production requires a “steady state” 1 GW(e) power plant operation, running for years not for minutes!**
  The ITER timeline: a 0.5 GW(thermal) 400 second pulse in 2022!

- **High temperature and high neutron flux resistant material unknown! Such neutron resistant material can not be developed/tested with ITER!**

- **Tritium handling: Running a hypothetical 1 GW(e) reactor “burns” about 200 Kg of tritium/year. (ITER needs a few kg only)**
  External tritium sources can provide only a few kg per year, world tritium inventory by 2027 at best 30 kg!

- **A self-sustained tritium breeding chain looks impossible!**

In short: Commercial fusion reactors will always be 50 years away!

Nuclear Fission Energy today (I)

Some numbers from the International Atomic Energy Agency, IAEA (website: www.iaea.org PRIS):

- **2009: 438 nuclear power plants with 371.6 GW(e) in operation; only 1 "existing" russian fast breeder reactor!**
  44 reactors (2 fast breeders) under construction

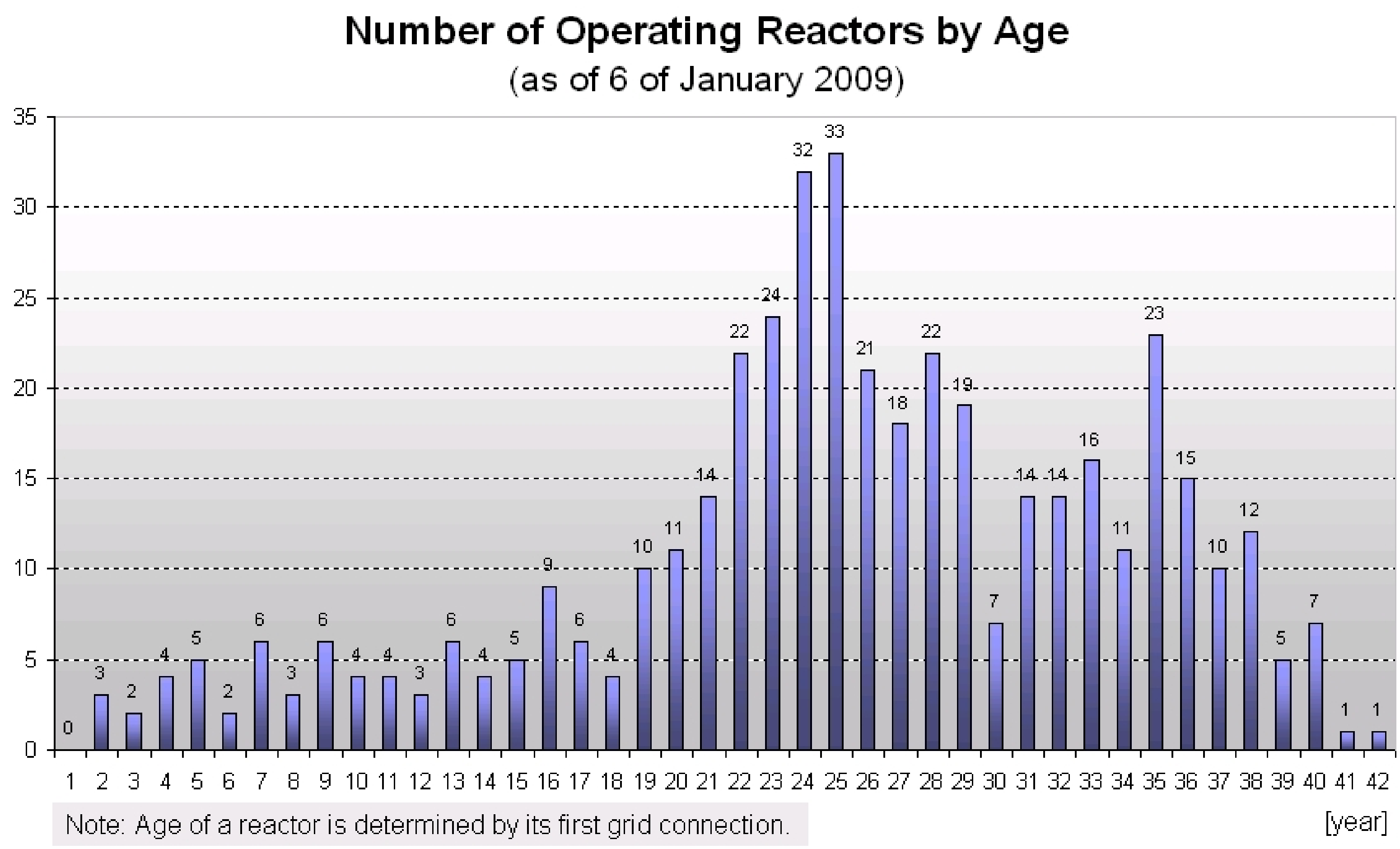
- **World nuclear electric energy production 2007 = 2608 TWh**
  $\approx$ **5% lower than 2005 = 2768 TWh (2008 will be even lower!)**

- **Only 14% of the world's electric energy from nuclear!**
  Maxium fraction in 1993: 18%!

- **Todays constructions: 3-4 new reactors with about 4 GW(e)/year during next 5-10 years. Similar numbers to be shutdown!**
  $\rightarrow$ **limited "growth" rate of** $\approx$ **0.3% per year.**
  Decisions today can not have any effect before 2015/20!

Nuclear Fission Energy today (II)

- From 1980-1985 about 20 to 30 reactors were completed per year. During 1995-2007 3-4 reactors were completed per year. Not a single reactor in 2008!
- about 100 reactors are 30 to 40 years old. They will reach "retirement" age during the next 10-15 years!



source www.iaea.org

Nuclear Fission Energy today (III)
Status of "Fast breeder" reactors

A fast reactor operates with prompt fission neutrons ("fast")
needs higher enrichment of U235 or PU239 and sodium cooling

theoretical ideas/hopes/claims from 30-40 years ago:

optimal use of the "unused" 1.5 fission neutrons to
increase fissile resources by a factor of $\approx$ 60(!)
by "breeding" fissile material faster than fissioning it

U238 + neutron $\rightarrow$ Pu239 and Th232+ neutron $\rightarrow$ U233

30 years of fast reactors are not really a success story!

Few countries tried to construct (larger) expensive prototypes:
Only one operating 0.56 GW(e) reactor remains today in Russia

Other 12 larger fast reactors never functioned well, are now closed or not operating.

Little is known (openly?) about fast reactor running experience.

Nuclear Fission Energy today (IV)
Fast breeder Reactors status and perspectives

2 prototype fast reactors are currently under construction:
India 470 MW(e) and Russia 750 MW(e),
expected start 2010 and 2012.

No commercially functioning fast breeder exists today!

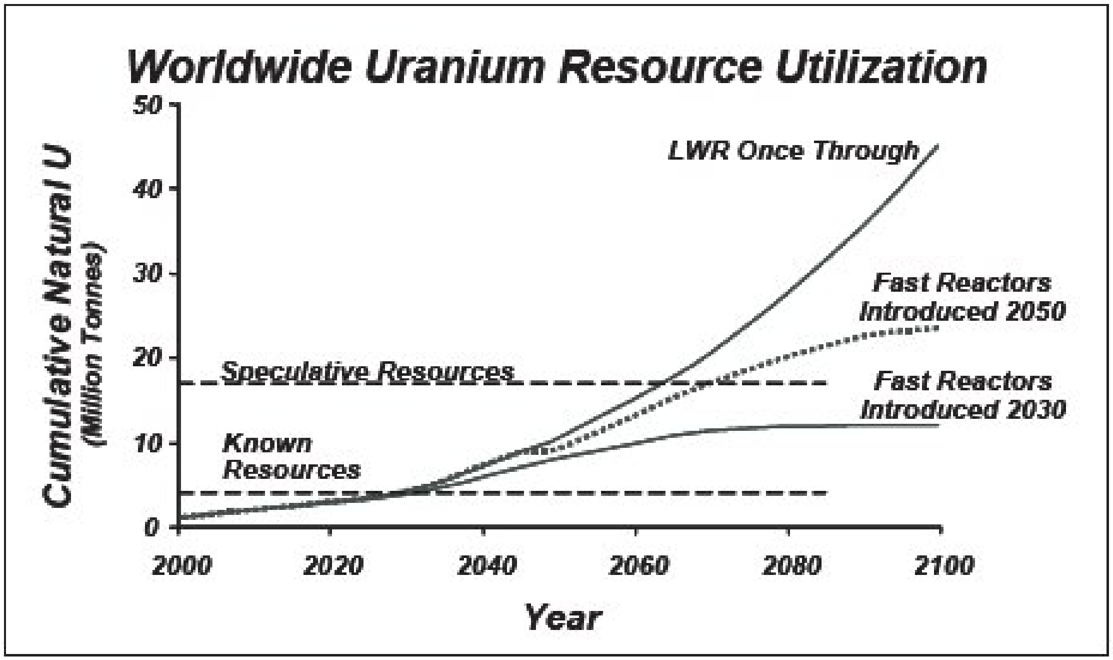
No public scientific document seems to exist which quantifies the achieved longer term useful Pu(239) breeding factor!

Were all fast reactors operated without achieving efficient breeding?

Nuclear Fission Energy today (V)
Generation IV (fast reactor) perspectives

around 2000, a world wide initiative for a nuclear revival started to develop new safe and very efficient reactors

Document claims: known uranium resources will be gone within 30 years!



source: 2002 roadmap, http://gif.inel.gov/roadmap/

A first look at uranium requirements (I)

- A 1 GW(e) reactor needs $\approx$ 180 tons of natural uranium per year. First reactor load requires about a factor of three more!
- Todays 371 GW(e) with 438 reactors need $\approx$ 65000 tons/year!
- Uranium requirements in 2030 (breeder reactors not ready!)? How much nuclear energy does the “world” want/need in 2030?
- Nuclear Energy Association (OECD) estimated (2006): “Uranium resources, plenty to sustain growth of nuclear power” (assuming a 1-2% per year for the next 20 years)
- World Nuclear Association WNA (2007 Market report) assumes:
  reference growth scenario (installed power by 2030): 529 GW(e)
  WNA high and low growth scenarios: 720 GW(e) and 282 GW(e)

  yearly requirement (2030): between 51000 to 130000 tons uranium
  (pro nuclear “realists” hope only for doubling by 2030!)

A first look at uranium requirements (II)

- World uranium production 2007 = 41 279 tons
  only 64% of the uranium requirements!
  (source: http://www.world-nuclear.org/info/inf23.html)

- assumed uranium resources (IAEA Red Book 2007):
  3 338 300 Tonnen (reasonable assured) + 2 130600 (inferred)

- If numbers are accurate: “known” resources last for
  50 (83) years (todays use with 14% of the world electric energy)!

- With a hypothetical growth of 10%/year (doubling time 7 years)
  “known” resources last only 18 (22) years.

Does it make sense (for whom) to become active for a new “EPR” reactor which might be ready by 2020(?) without discussing uranium supplies?

A first look at uranium requirements (III)

Natural uranium needs for the 150 nuclear reactors within the EU-27:

Euratom expects a 30% reduction up to 2027!

- **2008: 21810 tons of natural uranium**
- **2017: 17529 tons of natural uranium**
- **2027: 14492 tons of natural uranium**

looks like: Europe has already decided!
((Germany's decision explains a reduction of only 3000 tons!)

source: Euratom Supply Agency Website (annual report 2007 page 30) http://ec.europa.eu/euratom/

Nuclear Fission Energy tomorrow?
Generation IV reactor perspectives

Generation IV: goals and plans from the 2002 roadmap:

- Be ready for commercial construction around the year 2030.
- Develop high efficiency fast reactor with a closed fuel cycle using Pu239 and or U233 breeding/burning ≈ 1.
- Make detailed studies about "six" new reactor prototypes
  requested research budget (for next 10-15 years):
  $\approx$ 1 billion dollar for each reactor type!

The initiative six years later

It seems that not much funding has been found so far and no(?) experimental results published during the last 5 years!

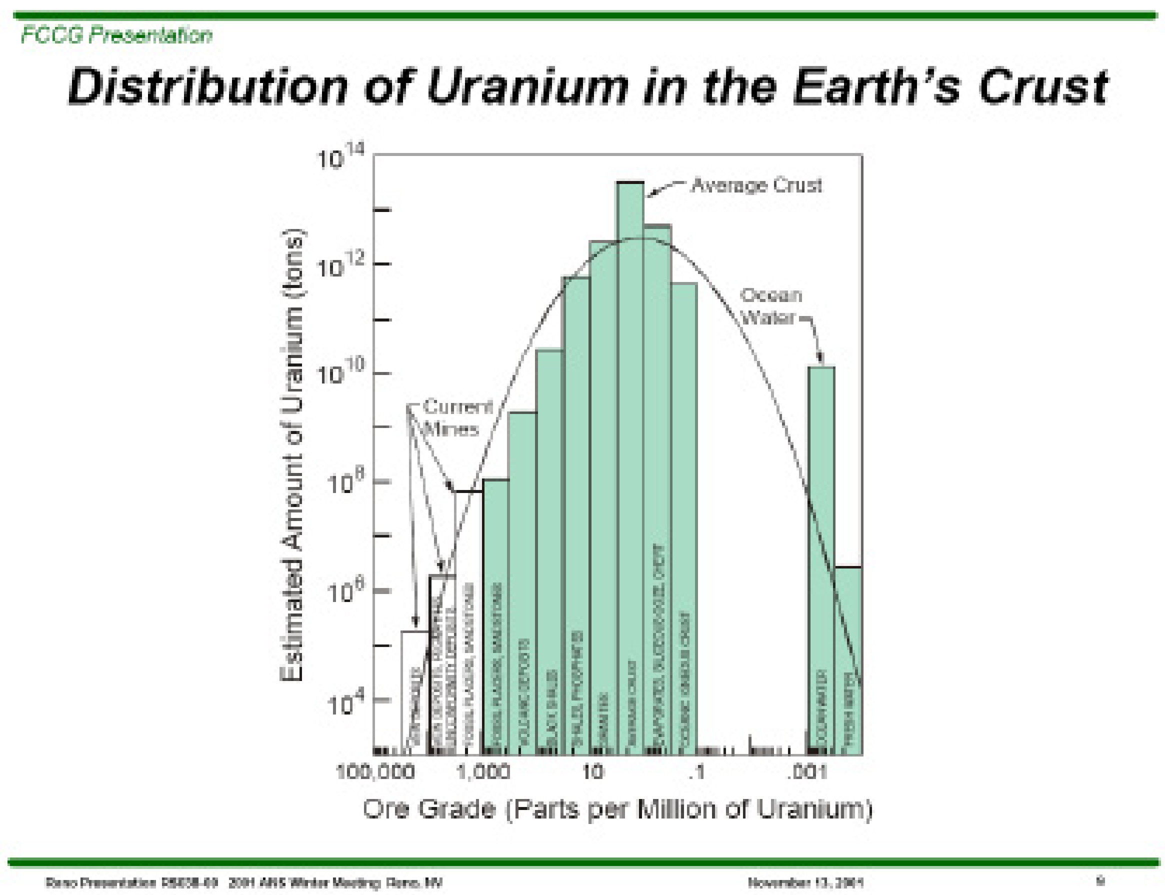
Little or no funding will give little or no results:

$\rightarrow$ impossible to have commercial "wonder" reactors within 20-30 years!

Uranium: not a rare element but ..

uranium in the crust: http://www.uic.com.au/nip75.htm (2006 version)

Uranium content of:	Concentration [ppm U]	kg/ ton
High-grade-or 2% U	20 000 ppm U	20 kg/ton
Low -grade-or 0.1% U	1 000 ppm U	1 kg/ton
Granite	4 ppm U	0.004 kg/ton
Sedimentary Rock	2 ppm U	0.002 kg/ton
Earth continental crust (average)	2.8 ppm U	0.003 kg/ton
Sea water	0.003 ppm U	3 mgram/ton



Enough uranium for todays fission plants? (I)

IAEA/NEA press declarations for the Red Book 2005(2007):

Declaration 2005 (www.nea.fr/html/general/press/2006/2006-02.html)

"By 2025, world nuclear energy capacity is expected to grow to between 450 GWe (+ 1%/year) and 530 GWe (+2%/year) from the present generating capacity of about 370 GWe. This will raise annual uranium requirements to between 80 000 tonnes and 100 000 tonnes. The currently identified resources are adequate to meet this expansion."

Declaration 2007 (www.nea.fr/html/general/press/2008/2008-02.html)

"World nuclear energy capacity is expected to grow from 372 GWe in 2007 to between 509 GWe (+38%) and 663 GWe (+80%) by 2030. To fuel this expansion, annual uranium requirements are anticipated to rise to between 94 000 tonnes and 122 000 tonnes, based on the type of reactors in use today. The currently identified resources are adequate to meet this expansion."

	Power [GWe] year 2007	Power [GWe] year 2010	Power [GWe] year 2015
2005 edit. (world)	373	382-399	409-445
2007 edit. (world)	370	377-392	410-456
WNA March 2008 (world)	372	379	424
2005 edit. (OECD)	309	303-308	304-315
2007 edit. (OECD)	309	304-309	310-326

Enough uranium for todays fission plants? (II)

OECD NEA(Nuclear Energy Agency) and IAEA report:
Uranium (Red Book) (definitions)

- "Known" recoverable uranium:
  Reasonable Assured Resources =RAR and
  Inferred Resources = IR
  classes: ($<$ 40 dollar/kg, 40-80 dollar/kg and $<$ 130 dollar/kg):

- Undiscovered Resources:
  Undiscovered and Prognosticated (UPR) and
  Undiscovered and Speculative (USR)

- Unconventional resources
  efficient (?) extraction technology does not exist today:
  phosphates = 22 million tons, sea water = 4000 million tons.

Enough uranium for todays fission plants? (III)

OECD NEA(Nuclear Energy Agency) and IAEA report: uranium 2005/2007 (red book) (estimates):

Red Book year	RAR less than 40 dollar / kg	RAR 40-80 dollar/kg	RAR 80-130 dollar/kg
2007	1766400	831600	740300
2005	1947383	695960	653346
2003	1730495	575197	661941
2001	1534000	708000	611000
Red Book year	IR less than 40 dollar / kg	IR 40-80 dollar/kg	IR 80-130 dollar/kg
2007	1203600	655480	272200
2005	798997	362041	285126
2003	792782	275170	320868
2001	552000	313000	215000
Red Book year	UPR less than 80 dollar / kg	UPR 80-130 dollar/kg	USR less than 130 dollar/kg
2007	1 946200	822800	4 797800
2005	1 700100	818700	4 557300
2003	1 474600	779900	4 437300

World "resource" numbers are totally inconsistent!
(even more when looking at different countries!)
inflation/energy costs are never calculated!
Country numbers indicate that "only" uranium from $<$ 40 dollar category is used!

Enough uranium for todays fission plants? (IV)

Fantasies about uranium from sea water (3 mg/m^3):
pro nuclear sources often claim (not the IAEA!):
(1) almost infinite amount of uranium in sea water
(2) extraction cost between 200 dollar/kg and a maximum of 1000 dollar/kg!

reference is a japanese (multi-million dollar??) experiment
claim: during several months and special membranes about 1 kg uranium was filtered (true?) from sea water

more at http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/mirai-en/2006/4_5.html

Numbers to estimate real cost:

standard 1 GW(e) reactor "burns" about 6 gr uranium per second
$\rightarrow$ uranium from 10000 m^3/sec water needs to be filtered (20% efficiency).
The Rhein discharges on average about 2000 m^3 per second

$\rightarrow$ for those who want to try for 1000 dollar/kg .. good luck!

Enough uranium for todays fission plants? (V)

Contradictions with "known" uranium resources

- Why did uranium mining stop in many mines and countries if energy independence is a goal?
- Like with oil reserves ... country numbers "never" seem to decrease!
- How are costs of uranium resources/ mining defined?
  Shouldn't the uranium resource/dollar numbers change because of inflation and higher oil price?

Real question for commercial nuclear energy production is:

"Do we know how to extract uranium fast enough?"

2006, a black year for uranium extraction and nuclear energy?

Hopes of additional uranium (about 7000 tons/year) from the Cigar Lake mine (Canada) ended with flooding in fall 2006! 2007 startup is now delayed to at least to 2012!

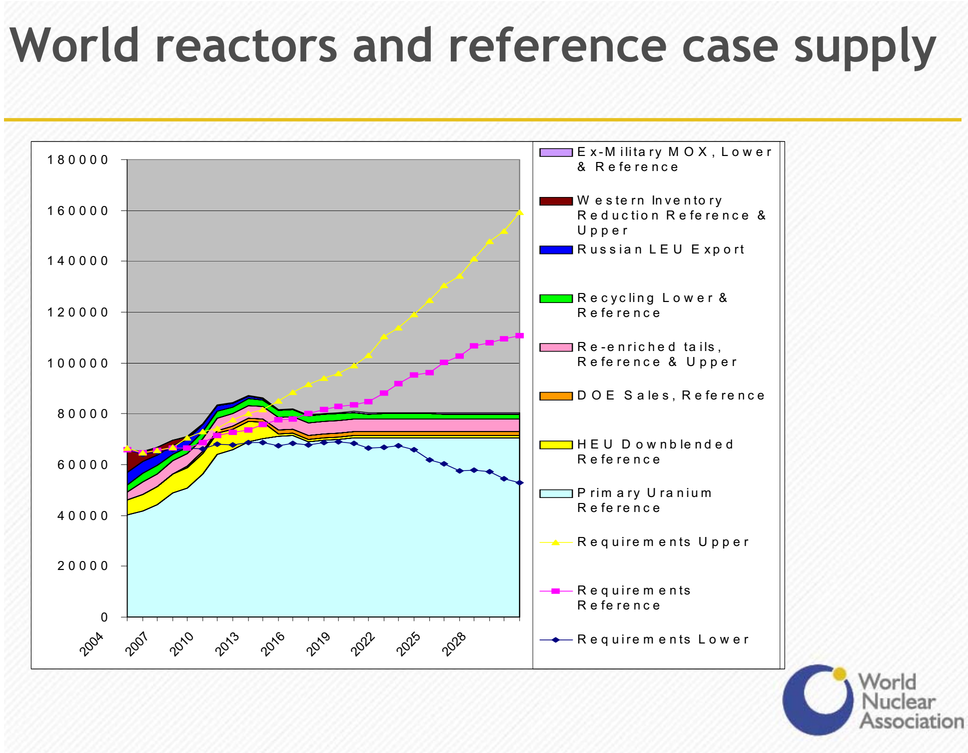
Incident looks like the nuclear equivalent of "loosing the oil from Saudi Arabia" for a few years!

In addition uranium extraction/mining not really going up, despite the high uranium price:

2005 = 41702 tons, 2006 = 39429 tons,
2007 = 41 279 tons

Uranium for the nuclear renaissance”?

“For one reason or another, most future mining is likely to encounter delays, stalls or stops. Too much water, too little water, politics, greenies, economics, indigenous tribes, desalination plants, NGOs, camel trails, regulators and rebels are but a few of the land mines analysts face when hoping to forecast long-term uranium price peaks.”..
from James Fitch, Forecasted Uranium Production Not Always a ‘Sure Thing’
www.bestwaytoinvest.com/james-finch-july-18



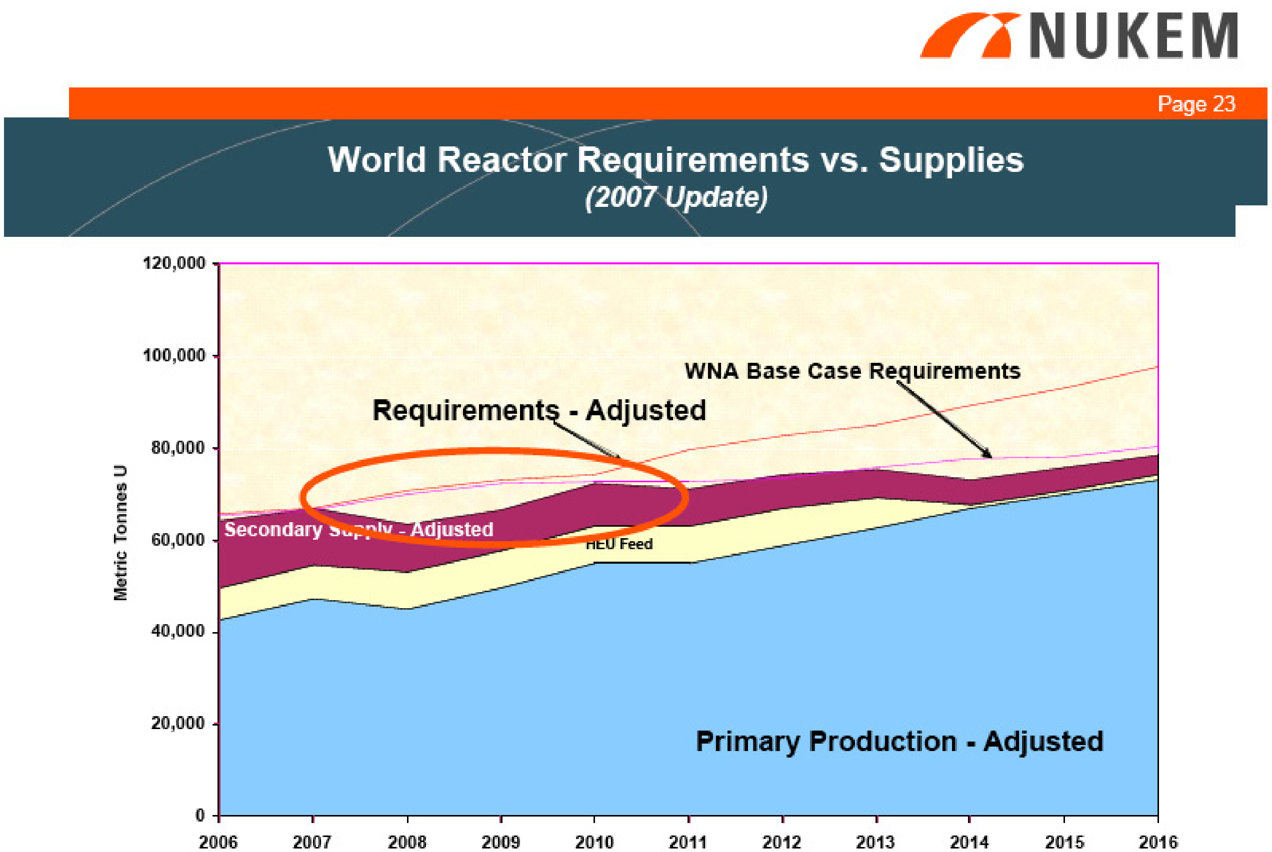
source: S. Kidd, the global uranium market 4th Uranium newsletter 17-19 Jan. 2007

Will the "nuclear renaissance" be ended by missing uranium supply?

Where to find the missing ≈ 5000 tons uranium/year for the next few years?

→ either 5-10% of world reactors (20-40 GW(e)) will be without uranium!
or a "divine intervention" (like converting all nuclear weapons!) is needed!

Will nuclear fission power ever recover from this uranium shortage?



Source: J. Cornell (Nukem CEO Feb. 2007) www.nukeminc.com/pdfs/Sprott_NY_022007.pdf

What is the Energy Problem? III

Todays “modern”, “civilized” and “industrialized” way of life depends on huge amounts of oil, gas and coal ($\approx$ 85% of the energy mix)!

oil required for the transport of almost “everything”

and almost nothing works today without electricity!

Imagine your life with regular shortages of oil and electricity.

In addition:

1. If one wants our (“reasonable(?)”) living standard for “all”
   $\rightarrow$ increase the energy use by at least a factor of 3!
   World population still grows by about 1% per year (70 Million people!)

2. World’s CO_2 production from fossil fuel burning is already too large!

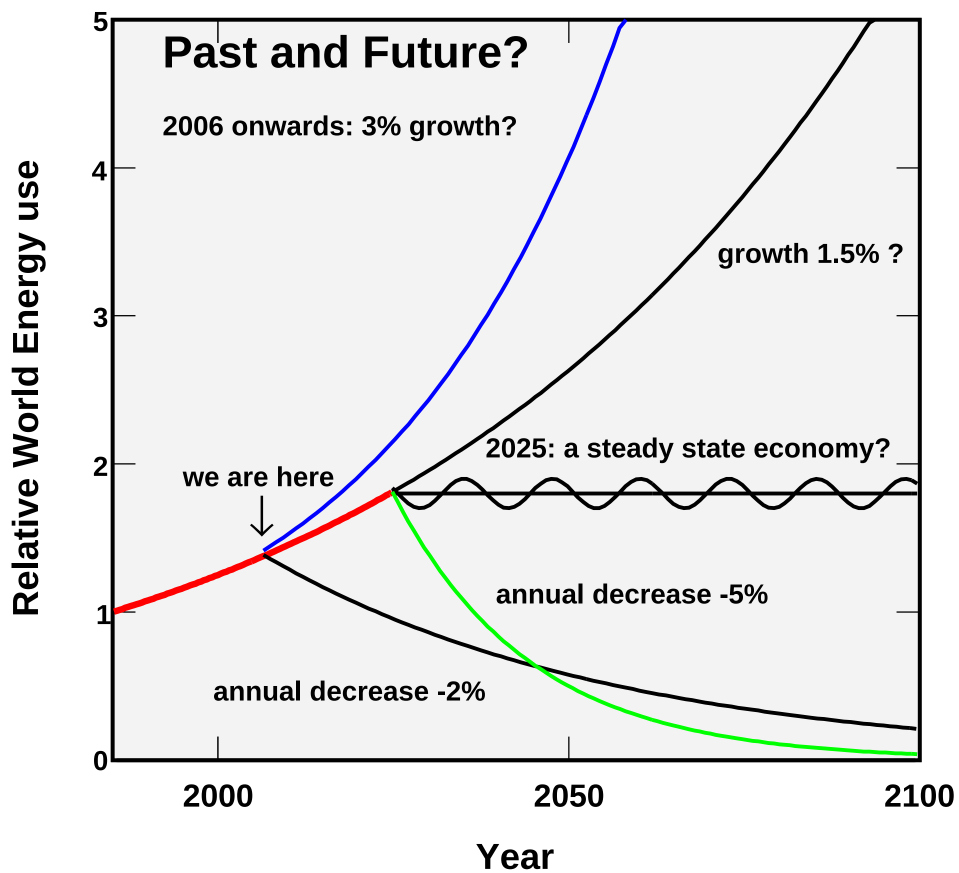
3. Earth is finite! $\rightarrow$ limited resources (not only for oil, gas, and coal).

Some hypothetical visions for our future

"Anyone who believes exponential growth can go on forever in a finite world, is either a madman or an economist." *Kenneth Boulding, Prof of Economics*

"Our ignorance is not so vast as our failure to use what we know."

K. M. Hubbert, Geophysicist



More numbers about uranium extraction (I)

country (peak Jahr)	Peak uranium [t]	production (2007) [t]	up to 2006 [t]
world (80/81)	69692	41264	2234083
USA (80/81)	16811	1773	360401
France (87/88)	3394	0	75978
Canada (01/02)	12522	9462	408194
Australia (04/05)	9512	8577	139392
Germany (65/66)	7090	45	219476
Russia/FSU (87/88)	16000	3385	132801
Kazakhstan (07?)	6654	6654	111755
South-Africa+Namibia (80/81)	10188	3423	143194
Niger (81/82)	4363	3154	104087
world 2001-2003	36366 36063 35783	10 top mines:27000	
world 2004-2006	40219 41595 39429	3 top countries:25000	

yearly uranium needs: 19000 tons (USA), 10500 tons (France), 7600 tons (Japan), 3400 tons Russia, 3300 tons (Germany) Source: World Nuclear Association

More numbers about uranium extraction (II)

Secondary Resources and expectations up to 2015 (IAEA Red Book 2007 numbers):

- Since 20 years about 25000 tons come from "secondary resources" (civilian and military Stockpiles, MOX..).
  civil secondary reserves will be finished within next 5-10 years.

- 2015 needs: 54 500-79 800 tons per year.

- Production capacity 2007 was 54000-57000 tons but
  real production was about 41000 tons (75% of the capacity)

- new mines by 2010 at most 17000-19000 tons;
  plus another 21000 tons up to 2015 (Red Book) $\rightarrow$ maximum production 2015 $\approx$ 80000 tons!

- Past Red Book predictions were always about 20-30% too high!
  UXC (uranium consulting company www.uxc.com) writes:
  "All existing and planned mines for 2015 can extract at most 58590 tons of uranium."
  Not even enough for todays 372 GWe!

Where is the RAR uranium?

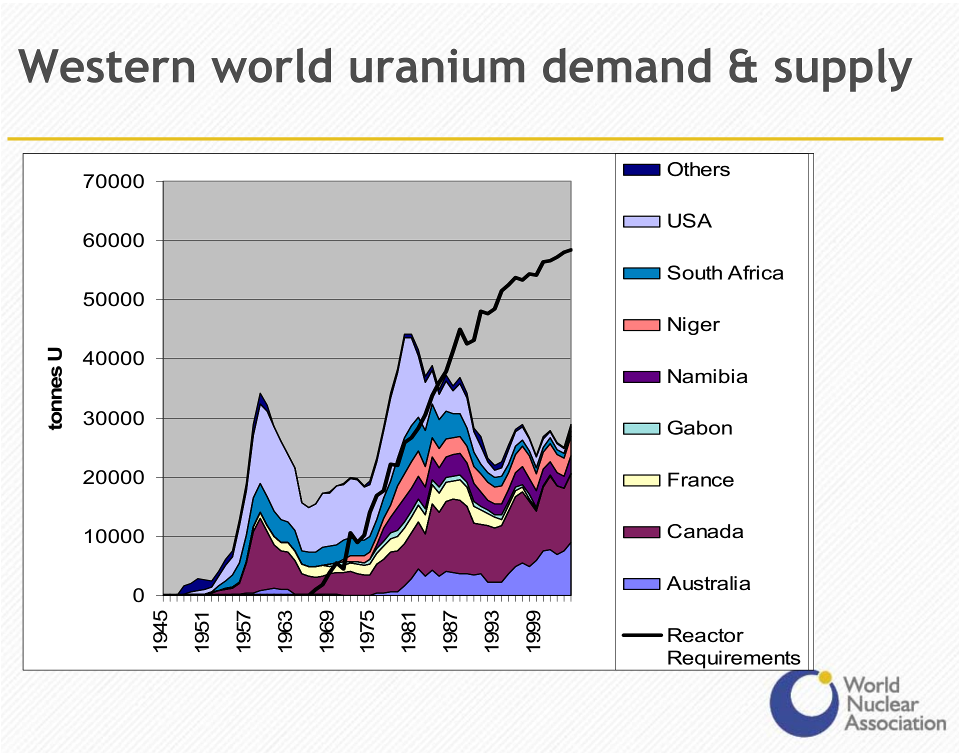
remaining "resources" (IAEA Red Book 2007 numbers)

country	tons U (cost < 40 $ /kg)	cost 40-130$ /kg
Australia	709000	16000
Brazil	139600	17800
Canada	270100	59100
Kazakhstan	235500	142600
Namibia	56000	120000
Niger	21300	222180
Russia	47500	124900
South Africa	114900	169500
Ukraine	27400	107600
USA* (<80 $/kg)	99000	339000
Summe	1 621000	1318700
Welt	1 766400	1 572900

- Uranium production (world) up to 1.1.2008 (total): 2 275 000 tons!
- Uranium use (world) up to 2007 (total): $\approx$ 1 500 000 tons!
- civilian uranium stocks (world) 2007: $\approx$ 60 000 tons!
  about 41000 tons in the USA (needs for 2 years)
- military stocks (world) 2007: $\approx$ 700 000 tons!
- production 2007 = 41000 tons
  with a capacity of about 55000 tons.

About half of the uranium needs come from excess production between 1960-1980!

Quote von Uranium Information Centre (www.uic.com.au/index.htm)
"No nuclear materials such as uranium from the civil nuclear fuel cycle have ever been diverted to make weapons. In fact today the whole picture is reversed in that a lot of military uranium is being brought into the civil nuclear fuel cycle to make electricity, which is widely seen as a positive development, unimaginable 40 years ago. One tenth of US electricity is made from Russian military warheads.



How we use energy I

Energy use of the (four person) Dittmar family in 2008

- Electricity and heating: with (French) nuclear power 14000 kWh and wood ≈ 5000 kWh(therm): 19000 kWh/year;
- Cooking with natural gas (bottles) 50 kg/year: $\rightarrow 50 \times 5 \times 10^4$ kJoule = 2.5 GJoule = 700 kWh;
- Car driving: 14000 km (9.5 l/100 km) + 12000 km (5.5 l/100 km) total ≈ 2000 liter petrol = 24000 kWh; (car driving needs ≈ 0.3-0.86 kWh/person/km)
- Train: 20000 km (0.25-0.78 kWh/person/km) = 8000-10000 kWh Flying: 0 km (0.42-0.70 kWh/person/km) = 0 kWh
- Food (in "rich" countries): 1 Calorie "contains" ≈ 10 Calories from fossil fuels (production and transport). (We are working on that ..) 2500 Calorie $\times 10 \times 365$ ≈ 37 GJoule/year/person ≈ 10000 kWh
- Energy for production and transport of consumer goods and services: unknown(?) making a car needs ≈ 25000 kWh (or ≈ kWh/Euro?)
- Working at CERN (together with roughly 3000 other people) ≈ 600 GWh → 200 MWh/person = 200000 kWh! (hm.. so much! Should one divide by 6.5×10^9 people?)