Energy (and) Security

The End (and beginning) of Cheap Petroleum

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Long-Term Sustainability of Nuclear Fission Energy - Part II
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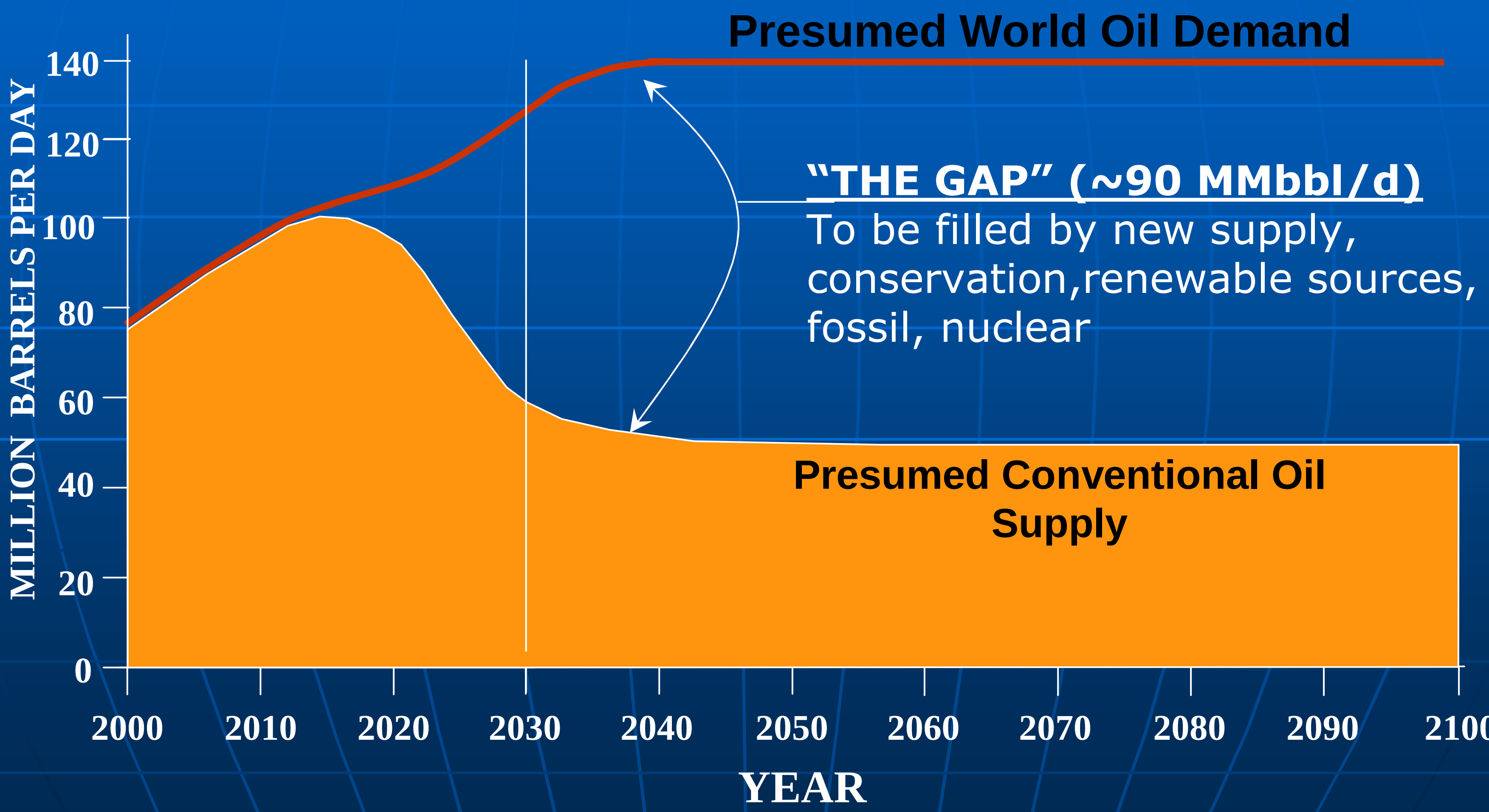
Long Term Oil Supply -Nobody Knows

Source: International Energy Agency, Matthew Simmons (up to 2030)

Wild Guess from 2030 to 2100



Where do we Stand?

- World oil production is at or near its historical peak
- Most production capacity is controlled by national oil companies -- and is not part of a market economy
- China and India oil demands are increasing rapidly -- they expect to import mainly from OPEC, but the supply is limited
- Demand increases must be satisfied by new discoveries -- tar sands and oil shale might help satisfy the increasing demand

Matthew Simmons: "**We are In a Deep Hole**"

What Can be Done?

- To fill “The Gap” we need to build > 6000 large nuclear units
- It is necessary to consider whether or not nuclear energy production can be increased in time to take over a large fraction of the load now carried by oil and gas
- Nuclear expansion? How about manufacturing capacity, safety, plant sites, <u>fuel supply</u>?
- World “demand” will certainly decrease, unless <u>something</u> fills it
- We can fill part of the oil gap, at least.

Basics

- Manufacturing capacity
  - This can be dealt with -- the scale is not exceptionally large
- Safety
  - Individual plant damage frequency must be very low
  - Reliable plant life must be maximized
- Plant Siting
  - Large, multi-unit sites will become the norm
  - Land availability will be a problem
  - Distribution of products from these sites will be difficult
  - Island sites may be the answer
- Fuel Supply
  - The outstanding question -- we now use >100 te/year of uranium per 1000 MWe unit

Uranium -- A Small Part of Electricity Cost*

Thermal reactors	Electricity/kWh
$70/kg	$0.0015
$7,000/kg	$0.15
North America price range	$0.05 – 0.15
U at $7,000/kg	$0.20 – 0.30
Fast reactors	
U at $14,000/kg	$0.003

Price of U	Reserves
$80/kg	3,192,000 t
$130/kg	15,400,000 t
$14,000/kg	?

* D.Lightfoot et al, “Nuclear Fission Energy is Inexhaustible”, Proc. Climate Change Technology Conference, EIC, Ottawa, May 2006

Quantities of Nuclear Fuel and Potential Energy Yield*

Sources of U and Th	Uranium Resources te x10^{-3}	Thermal Reactors EJ x10^{-3}	Fast Reactors EJ x10^{-3}
1: U–USGS 2179-A (reserves)	3,192	1.6	253.6
2: IPCC CC2M (total conventional)	15,400	7.7	1,223
3: Used fuel	2,000	Very small	160
4: Surplus military U & Pu	Small	Small	Small
5: Phosphate deposits	20,000	10.0	1,600
6: U in seawater	4,400,000	2,200	317,760
7: Th – USGS 2004 (reserves)	1,200	0.6	95.3

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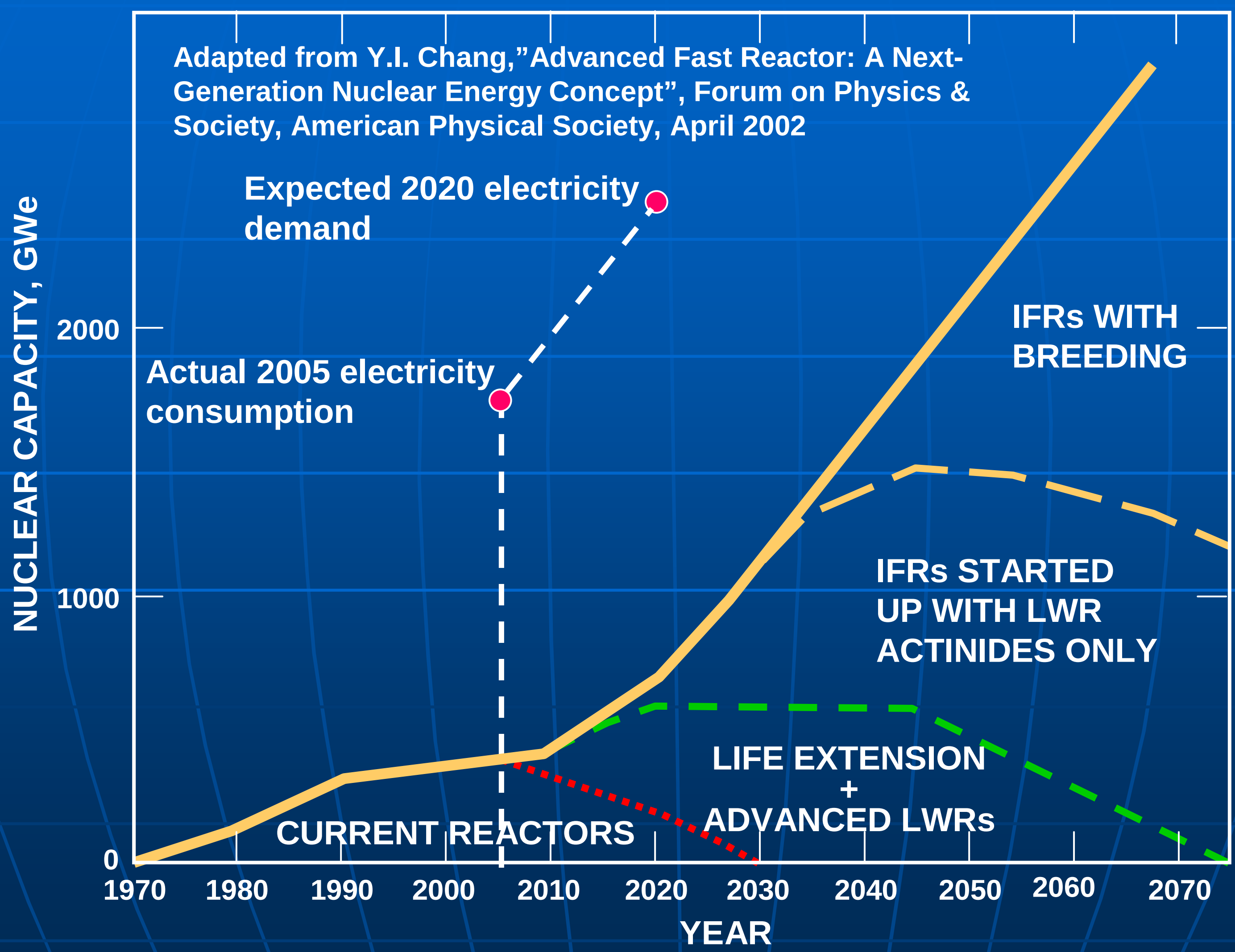
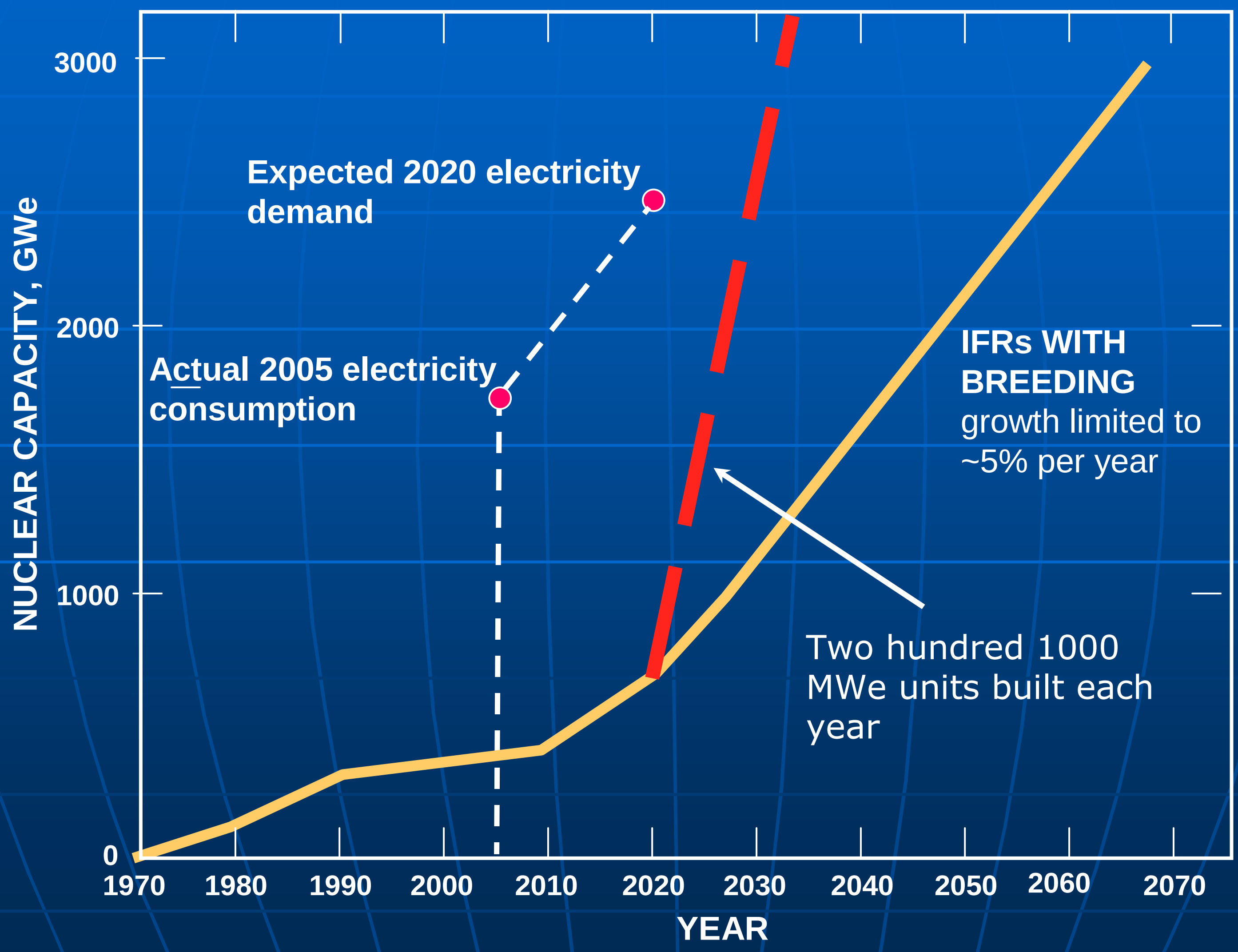
Can Fast Reactors be Built Fast Enough?



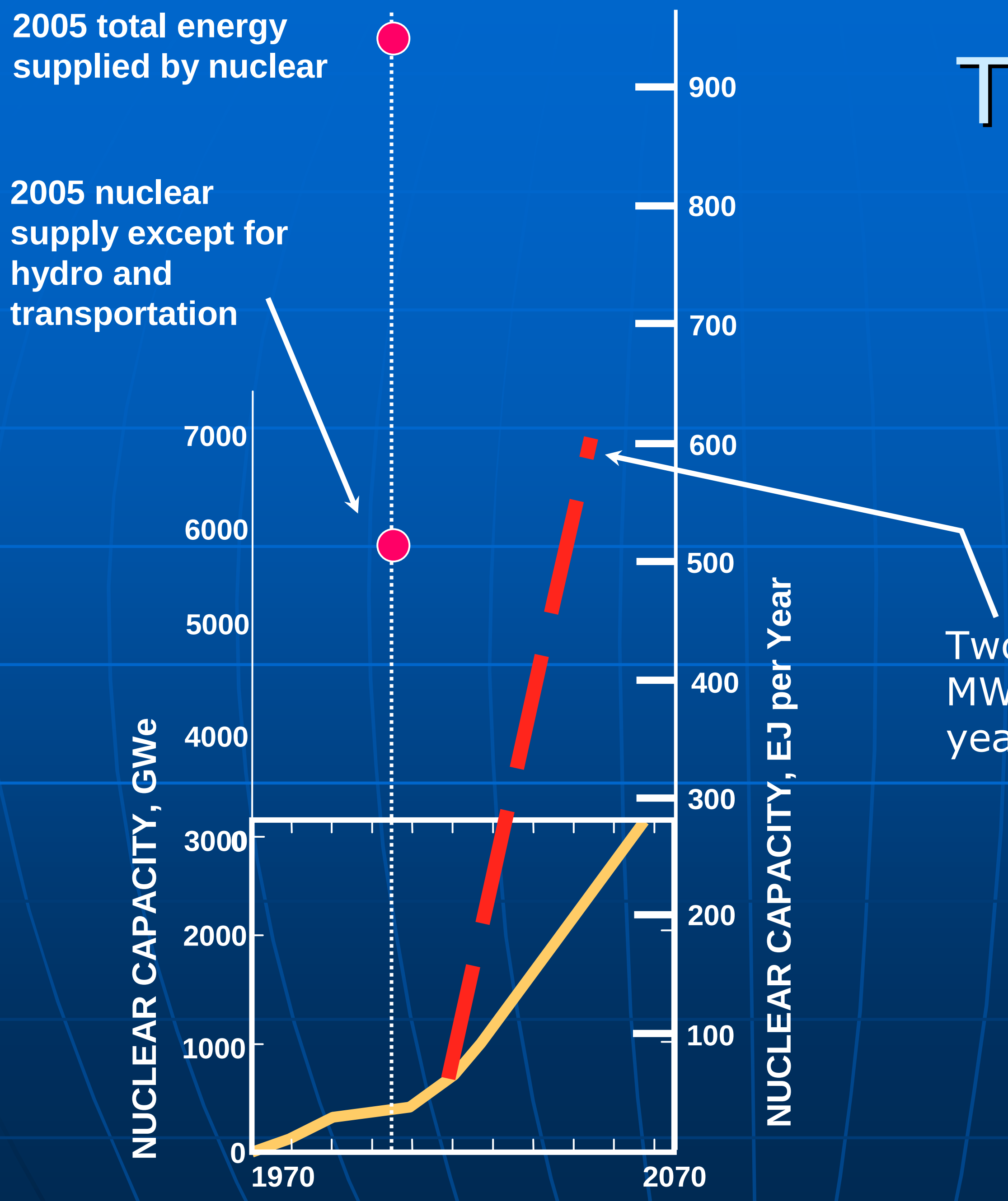
IFR = Integral Fast Reactor

LWR = Light Water Reactor

How about Thermal Reactors?



The Bigger Picture



Two hundred 1000 MWe units built each year for 30 years

Which Thermal Reactors Should We Build?

	Megawatt-years per Tonne	Years of Uranium Availibility for 6000 1000 MWe Units*
Enriched U in PWR, BWR	4.61	30
Pu Recycle in PWR, BWR	5.41	36
DUPIC (PWR-CANDU)	6.37	42
Natural U in CANDU	6.37	42
1.2% Enriched U in CANDU	8.77	58
Fast reactor	1000	6700
Fast reactor using seawater	1000	>100000

*Total conventional resources plus phosphate ores

Integrated Fuel Cycles - Equilibrium Mix

(Equal Energy Output from Each Unit)

Reactor Type	Thermal/Fast Ratio**
PWR, BWR	.83
PHWR	2.5
PHWR (Th)*	10.

* Seed-blanket fuelling with Pu-U driver fuel and Thorium blanket fuel

** Breeding and Conversion Ratios: FBR=1.5, PWR, BWR=0.6, PHWR=0.8, PHWR(Th)=0.95

Equilibrium: No. of thermal reactors/No. of fast reactors ≈ $(BR_f - 1)/(1 - CR_t)$

Some Observations

- This is not the end of oil - just the end of cheap oil
- Power plants using thermal reactors must be built for several more years, even though uranium price is likely to rise
- Power plants using fast reactors can improve long-term economics, ease waste disposal, and simplify safeguards
- Fast reactors have one major weakness -- they need a very large fissile inventory for their first fuel loading
- Integrated systems of thermal and fast reactors can supply the world's energy needs for many thousands of years
- The later we start, the harder it will be to make the transition

Finale

- CANDU is on the right track with its high conversion ratio. An integrated fuel cycle <u>on each site</u> can be balanced much more easily -- as fast reactors are finally introduced
- Fast reactors **PUT AN END** to the notion that nuclear energy is a short-term option. Fission fuel is <u>inexhaustible</u>
- Reprocessing will be needed - electro-refining?
- Rapid buildup of world capacity will lead to a temporary shortage of fissile isotopes -- uranium enrichment, electro-breeding, or fission-fusion hybrids?
- Oil will be cheap again only when we do not need it so badly