Peak Oil

Putting Teeth into Sustainability
or
Mother Nature Bats Last

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(original talk, November 2004
most recent update, September 2007)


WRONG
WAY

Where Oil Comes From

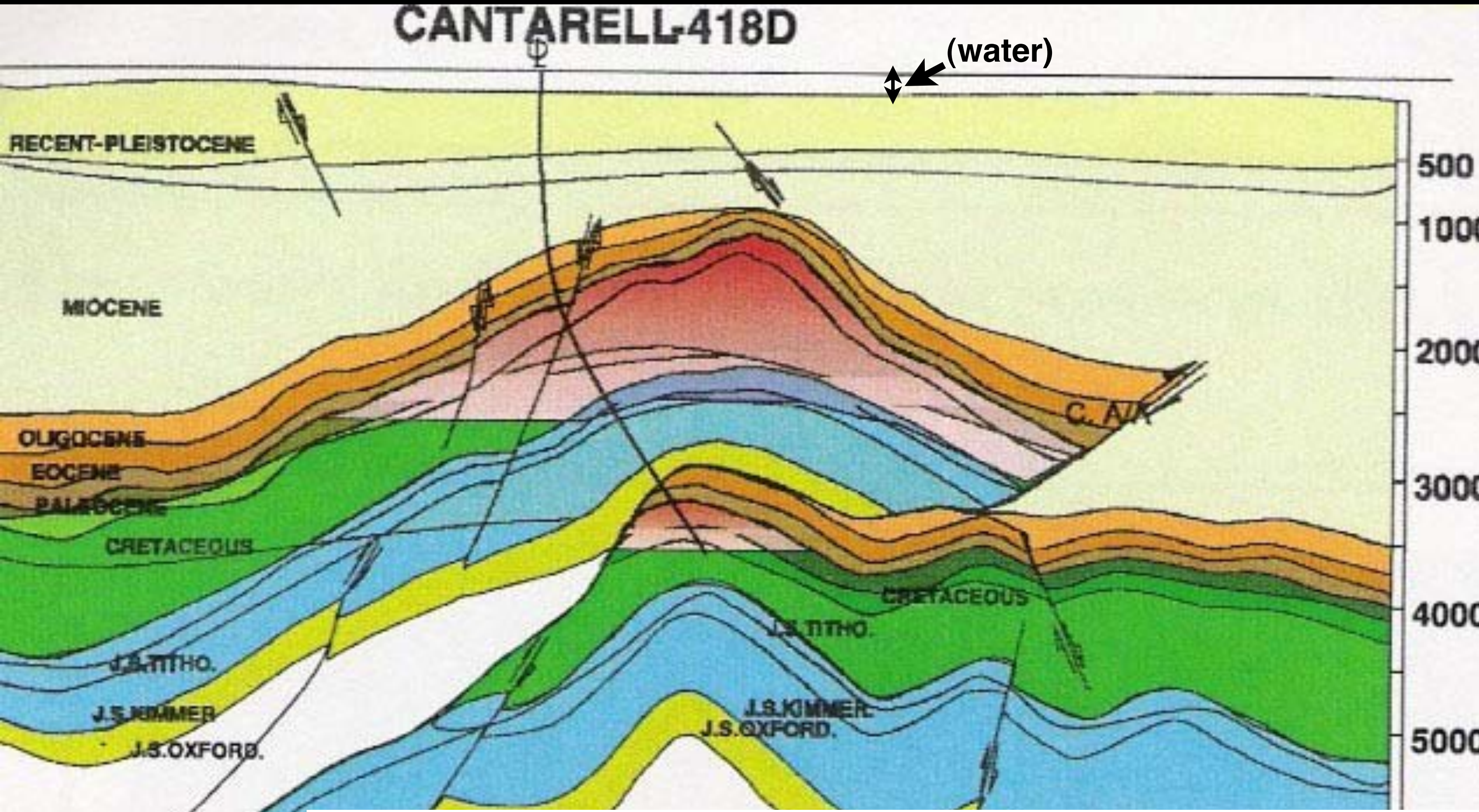
- raw organic material for oil (e.g., from plankton) is present in low concentrations in ‘all’ sedimentary rocks, but esp. from two warm periods 90 million and 140 million years ago
- temperature rises with depth (radioactivity, Kelvin’s mistake)
- oil is generated in rocks heated to 60-120 deg Celsius
- rocks at this temp. occur at different depths in different places
- oil is ‘cracked’ to natural gas at higher temperatures (deeper)
- abiotic oil from “crystalline basement” is negligible, if it exists
- exhausted oil fields do not refill

Recoverable Oil

- oil must collect in a “trap” to be practically recoverable
- a trap is a permeable layer capped by an impermeable one
- obvious traps: anticlines, domes (AKA “oil in those hills”)
- less obvious traps found by seismic imaging: turned up edges of salt domes, buried meteorite craters (Mexico)
- harder-to-get-at traps: shallow continental shelf (GOM)
- really-hard-to-get-at traps: deep continental shelf
- essentially no oil in basaltic ocean floor or granitic basement

Second Largest Oilfield (by current production)

Cantarell currently supplies 2% of world oil



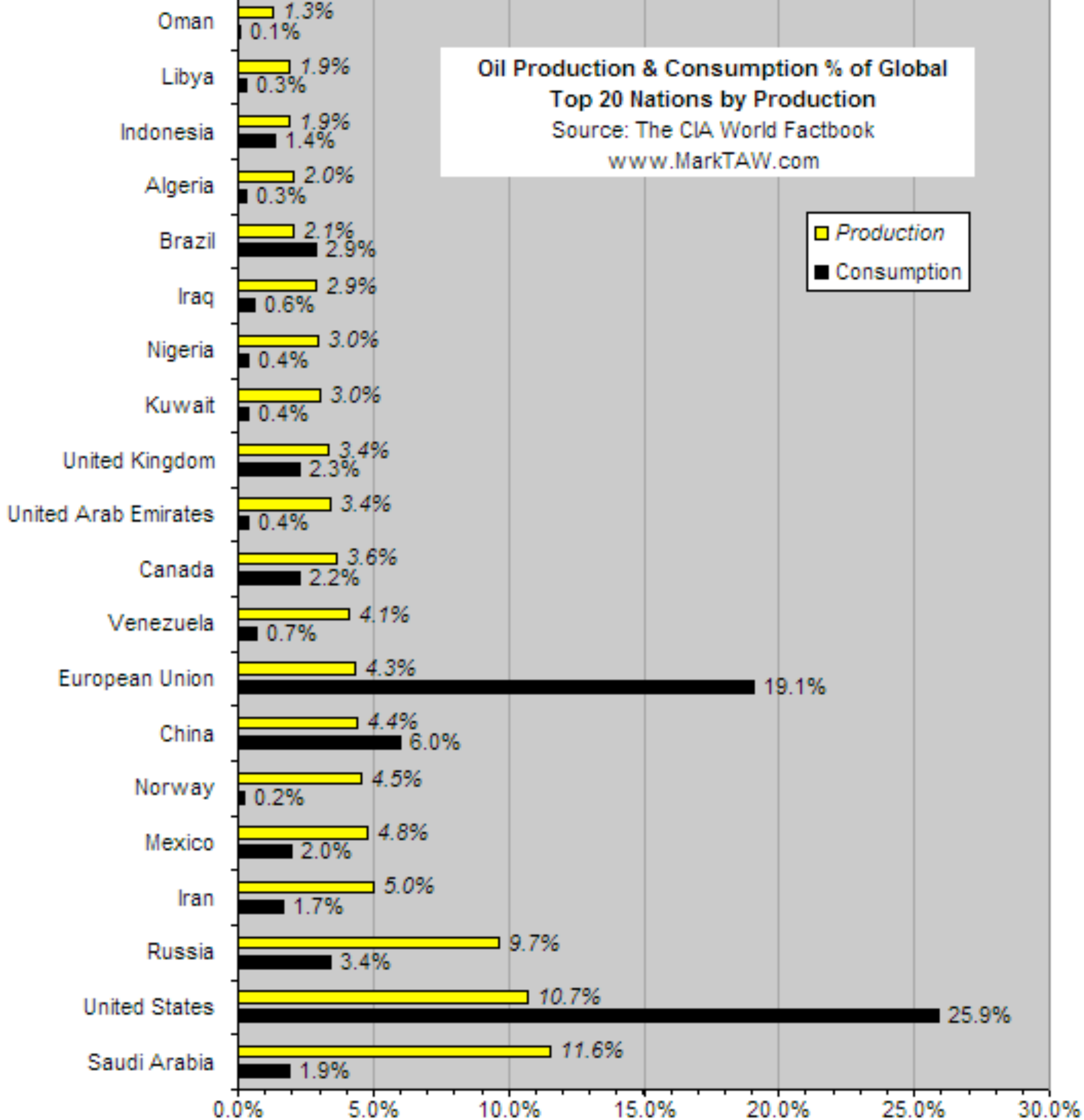
Guzman, A.E. and B. Marquez-Dominguez (2001) The Gulf of Mexico basin south of the border: *The* petroleum province of the twenty-first century. In M.W. Downey, J.C. Threet, and W.A. Morgan, eds., *Petroleum Provinces of the Twenty-First Century*. Tulsa: AAPG, p. 346.

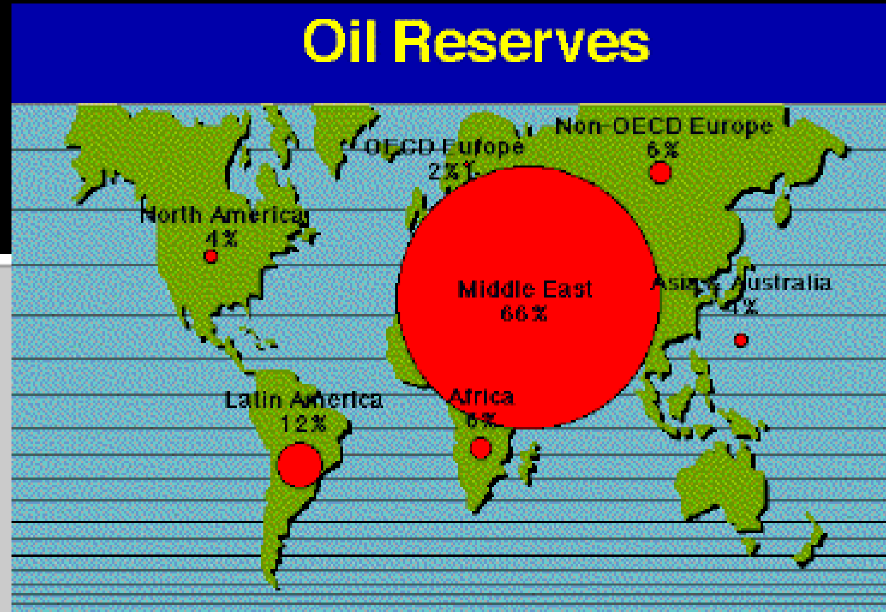
Recoverable Oil is Highly Localized in Space

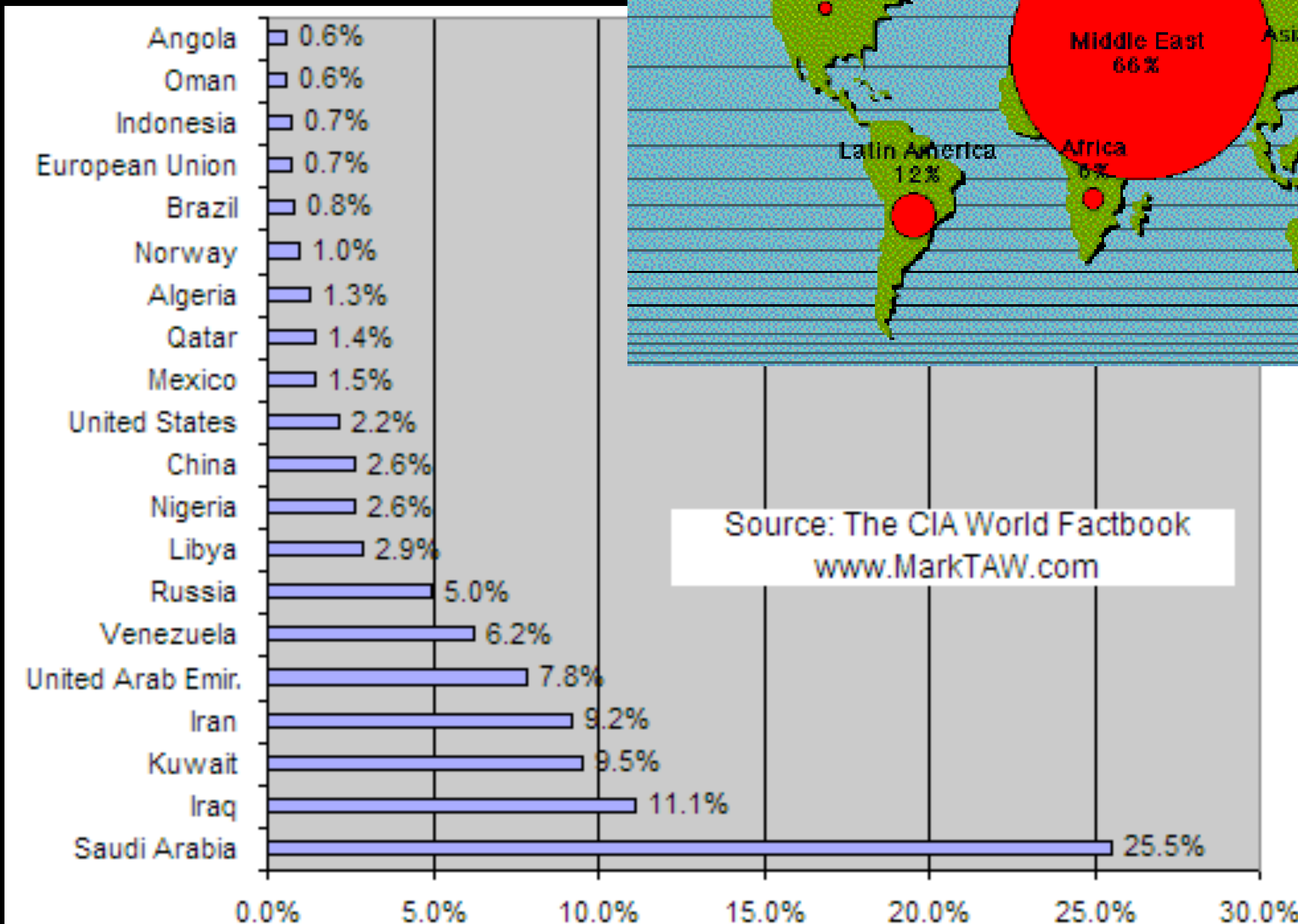
Country	Reserves	Production
Saudi Arabia	261.8 Gb	8.8 Mb/day
Iraq	112.5	2.4
UAE	97.8	2.4
Kuwait	96.5	2.1
Iran	89.7	3.7
Venezuela	77.7	3.4
Russia	48.6	7.1
US	30.4	7.7
Libya	29.5	1.4
Mexico	26.9	3.6

Crude oil: beginning of 2002

Major oil trade movements
Trade flows worldwide (million tonnes)


Oil Production & Consumption % of Global
Top 20 Nations by Production
Source: The CIA World Factbook
www.MarkTAW.com
Production
Consumption
Oman 1.3% 0.1%
Libya 1.9% 0.3%
Indonesia 1.9% 1.4%
Algeria 2.0% 0.3%
Brazil 2.1% 2.9%
Iraq 2.9% 0.6%
Nigeria 3.0% 0.4%
Kuwait 3.0% 0.4%
United Kingdom 3.4% 2.3%
United Arab Emirates 3.4% 0.4%
Canada 3.6% 2.2%
Venezuela 4.1% 0.7%
European Union 4.3% 19.1%
China 4.4% 6.0%
Norway 4.5% 0.2%
Mexico 4.8% 2.0%
Iran 5.0% 1.7%
Russia 9.7% 3.4%
United States 10.7% 25.9%
Saudi Arabia 11.6% 1.9%
0.0% 5.0% 10.0% 15.0% 20.0% 25.0% 30.0%


Oil Reserves
Non-OECD Europe 6%
OECD Europe 2%
North America 4%
Middle East 66%
Asia & Australia 4%
Latin America 12%
Africa 6%


Angola 0.6%
Oman 0.6%
Indonesia 0.7%
European Union 0.7%
Brazil 0.8%
Norway 1.0%
Algeria 1.3%
Qatar 1.4%
Mexico 1.5%
United States 2.2%
China 2.6%
Nigeria 2.6%
Libya 2.9%
Russia 5.0%
Venezuela 6.2%
United Arab Emir. 7.8%
Iran 9.2%
Kuwait 9.5%
Iraq 11.1%
Saudi Arabia 25.5%
0.0% 5.0% 10.0% 15.0% 20.0% 25.0% 30.0%
Source: The CIA World Factbook
www.MarkTAW.com

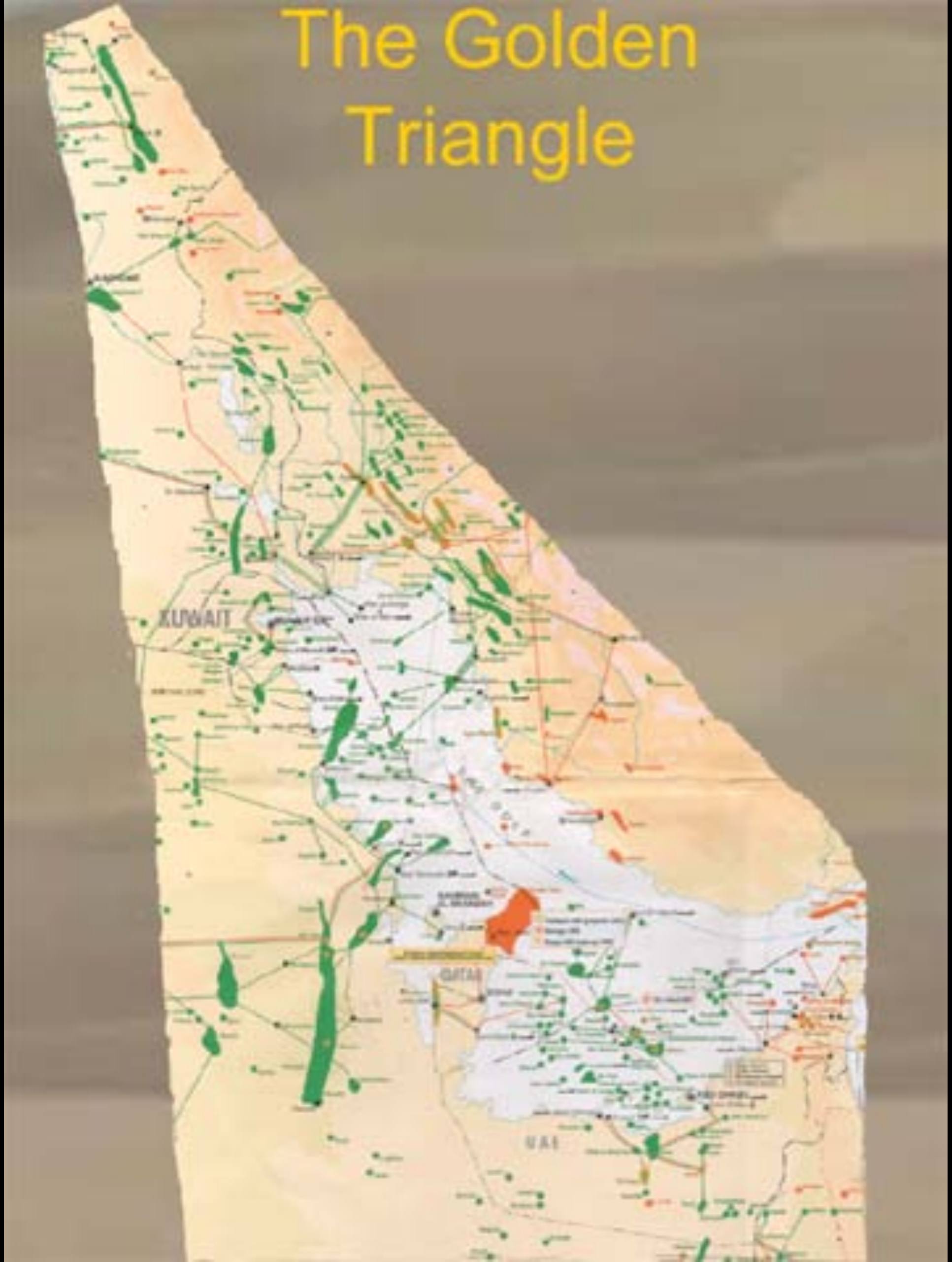
Significant traps are extremely localized in space

oil = red

largest: Ghawar

from Matt Simmons

Persian Gulf Close-up



from Matt Simmons

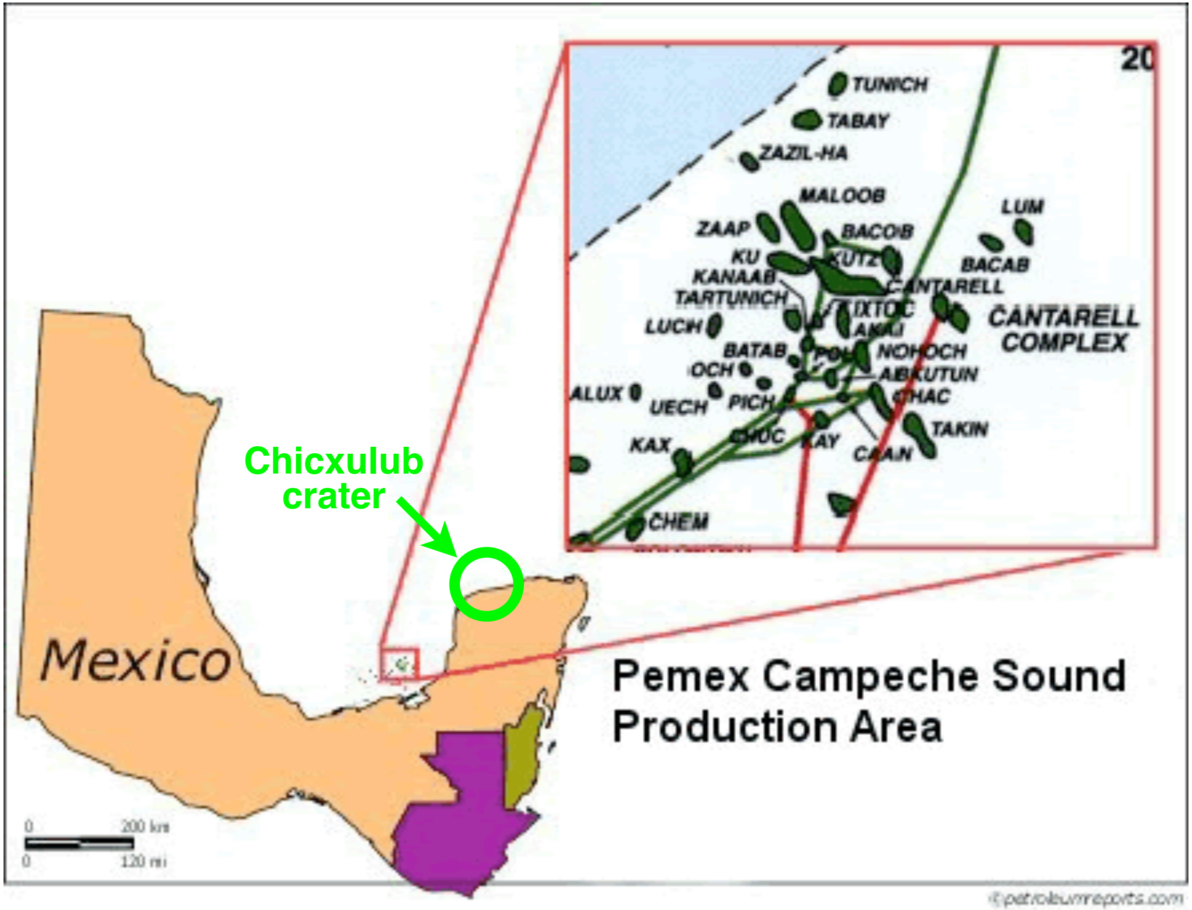
Big Oil

Several of the world's largest oil fields show signs of fading, according to several studies, raising questions about the reliability of global energy supplies. An internal Pemex study suggests Mexico could see steep declines.

OIL FIELD	COUNTRY	OIL OUTPUT IN MILLIONS OF BARRELS PER DAY	PERCENTAGE OF NATIONAL OIL OUTPUT	STATE OF FIELD
Ghawar	Saudi Arabia	4.5	40%	Possibly declining
Cantarell	Mexico	2	60	Declining
Burgan	Kuwait	1.7	68	Possibly declining
DaQing	China	1	40	Possibly declining

Sources: Deutsche Bank; Reuters; Oil and Gas Journal

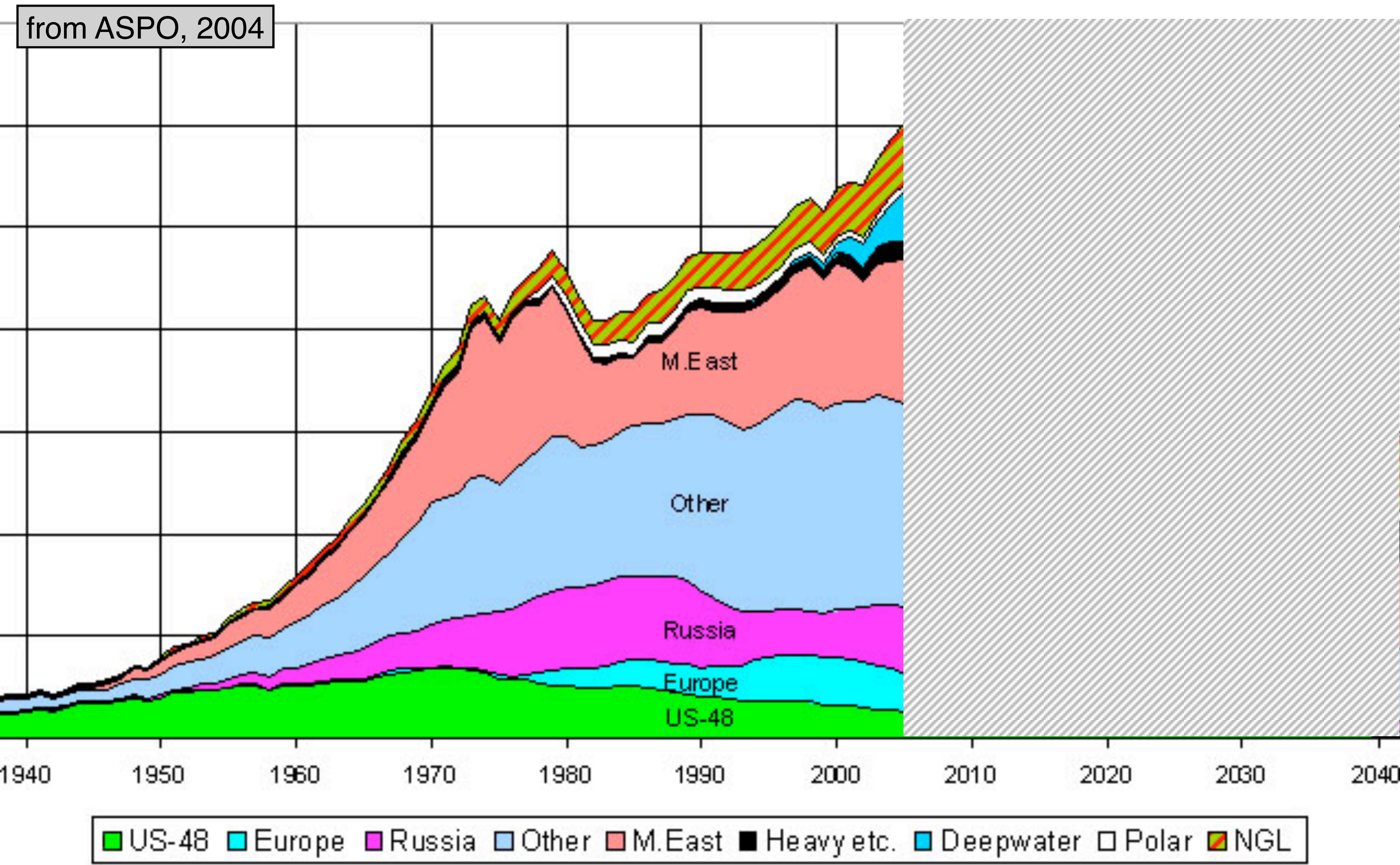
from WSJ, Feb 9, 2006



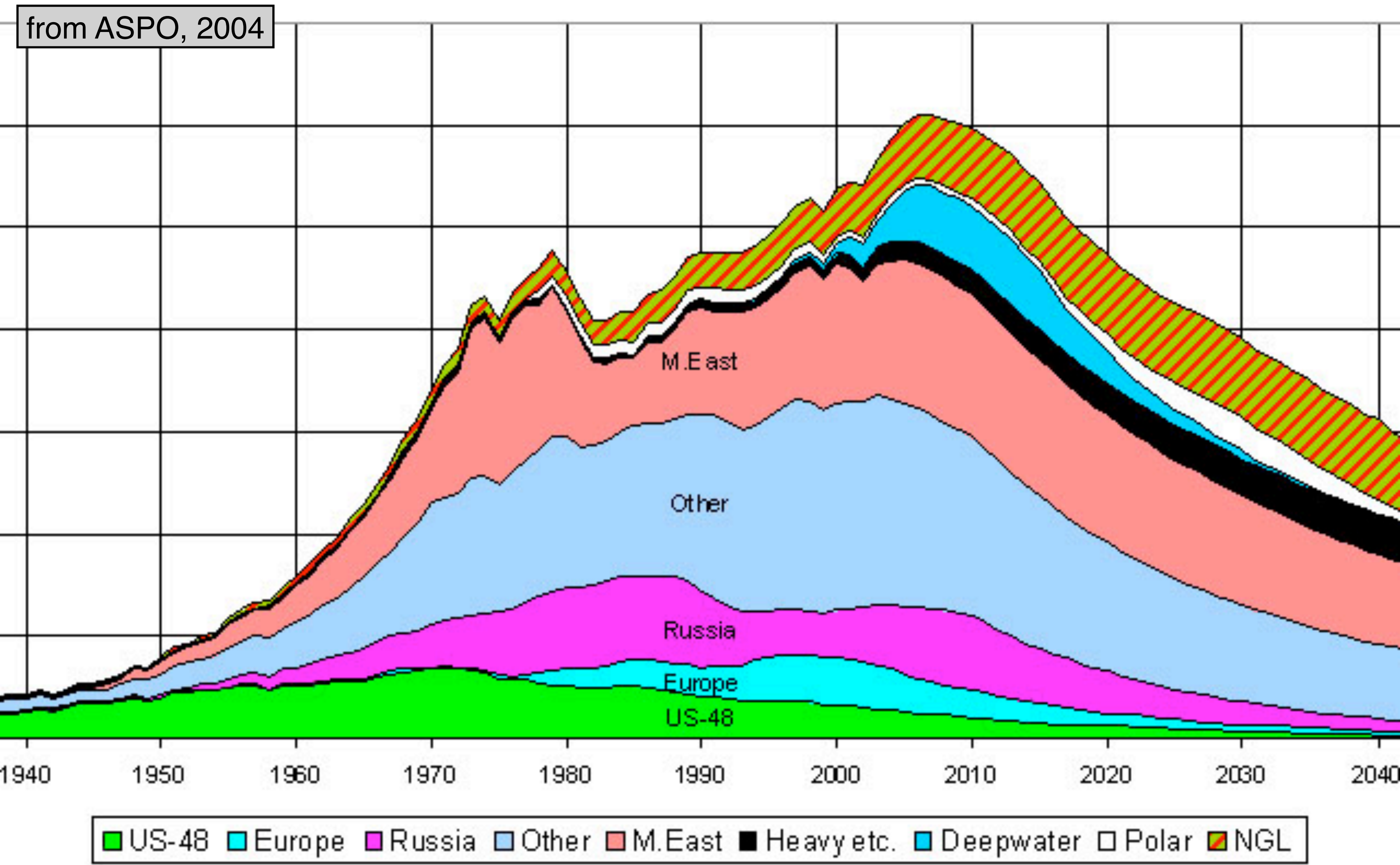
http://www.eia.doe.gov/emeu/cabs/Mexico/Oil.html

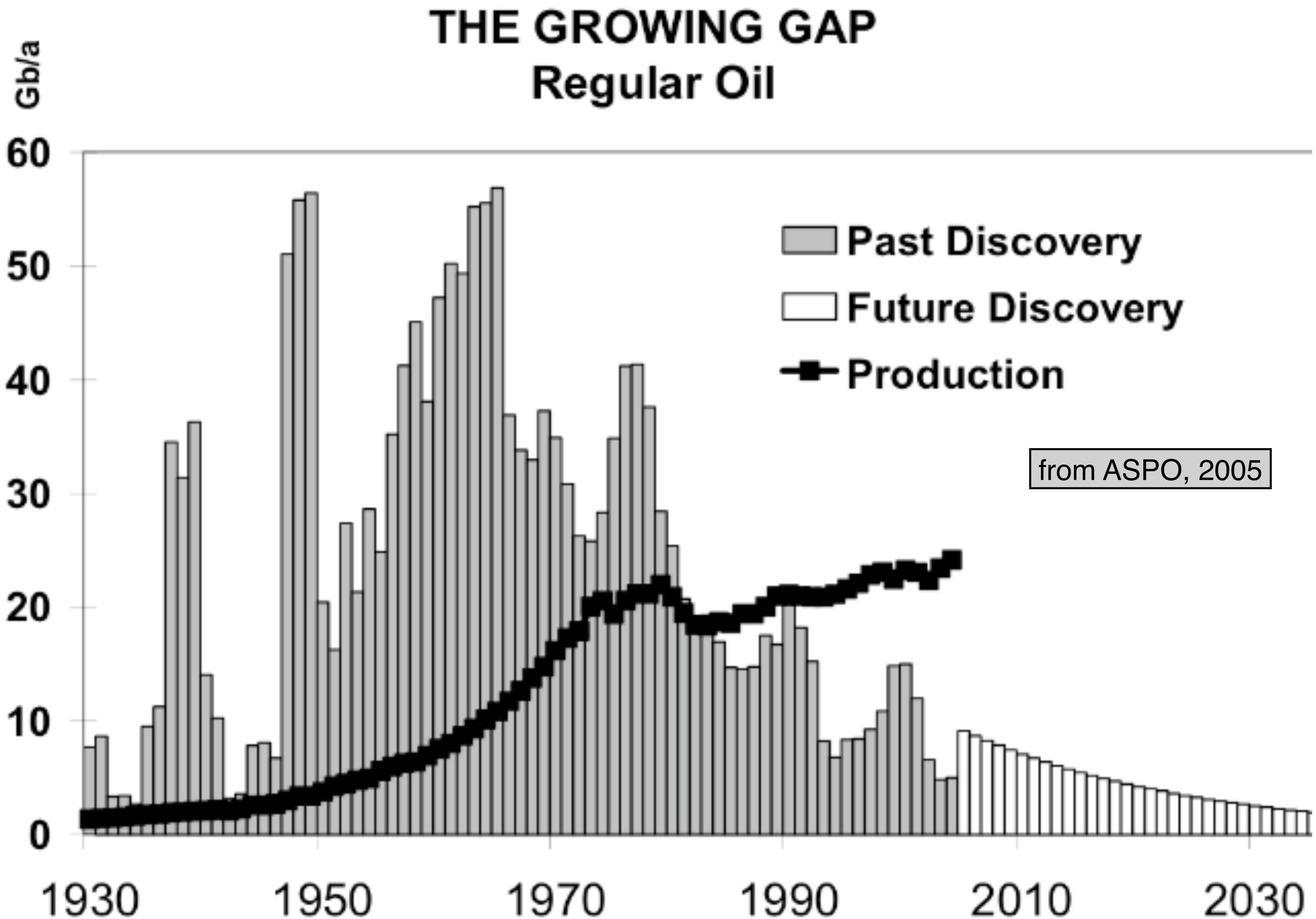
[named after Yucatan fisherman Rudecindo Cantarell, who discovered oil seep!]

OIL AND GAS LIQUIDS
2004 Scenario

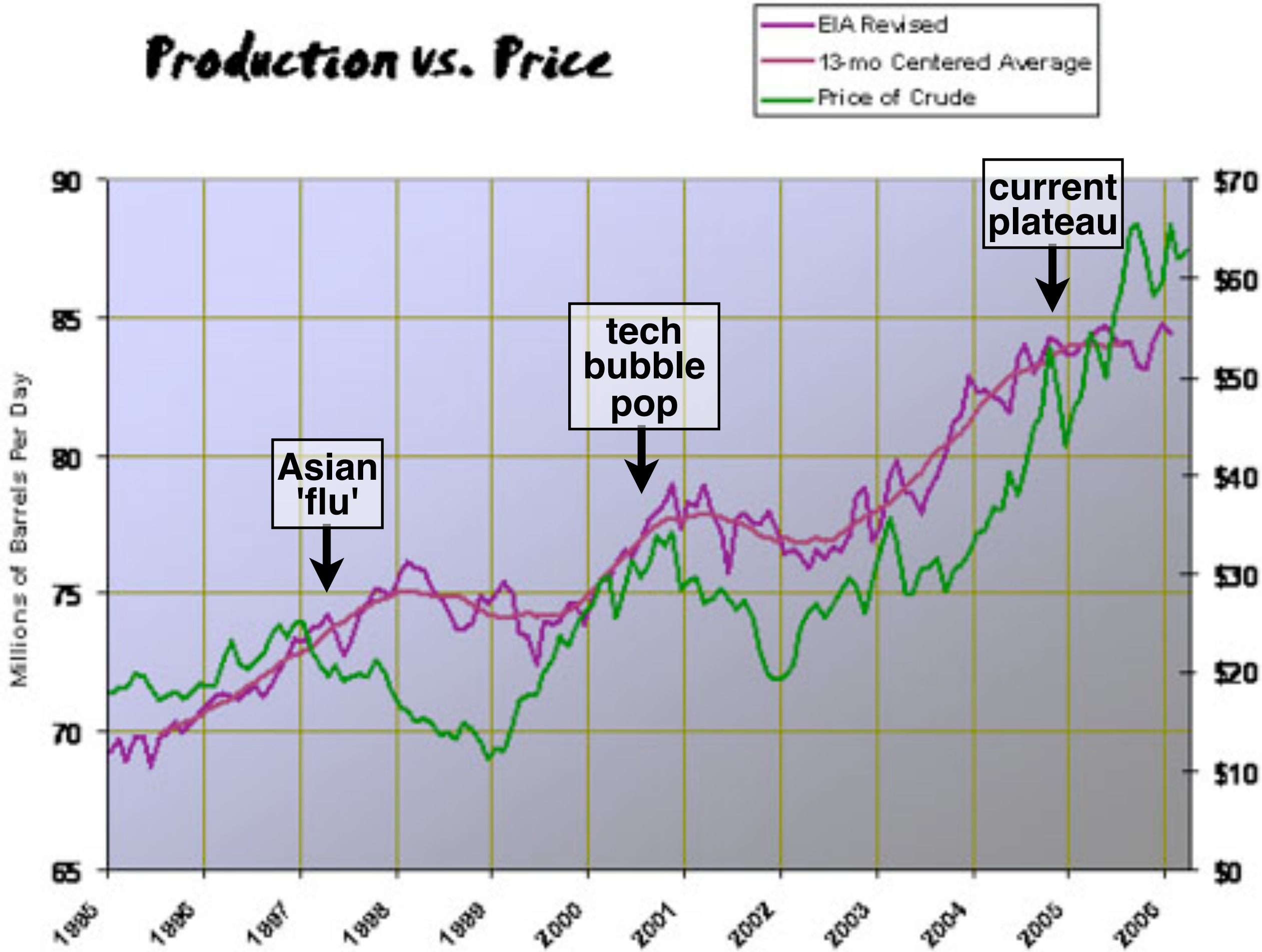


OIL AND GAS LIQUIDS
2004 Scenario



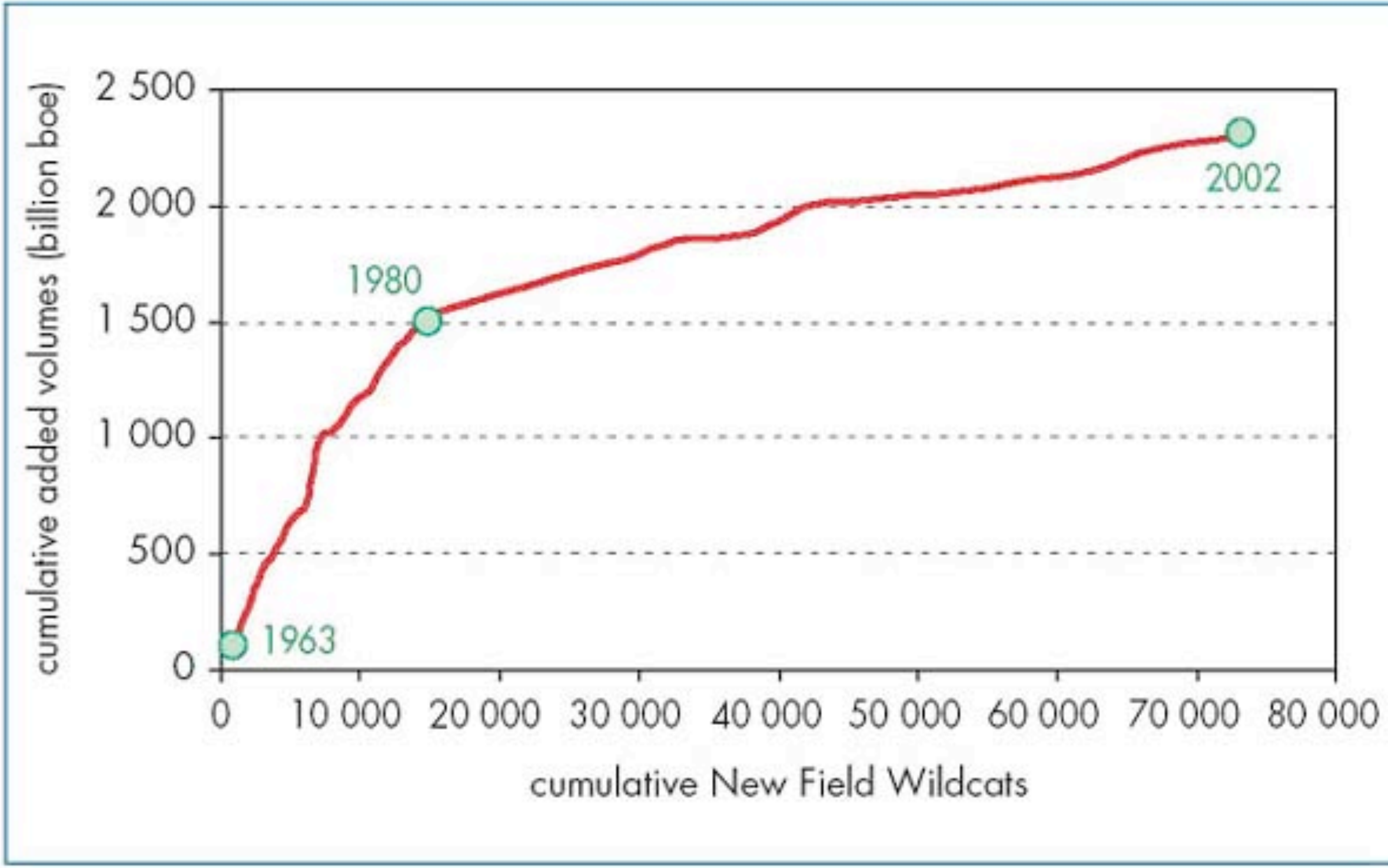

THE GROWING GAP
Regular Oil
Gb/a
60
50
40
30
20
10
0
Past Discovery
Future Discovery
Production
from ASPO, 2005
1930
1950
1970
1990
2010
2030

Previous production plateaus preceded by price drop (demand-driven) vs. current



http://www.theoildrum.com/story/2006/4/12/204811/033#117

World Creaming Curve

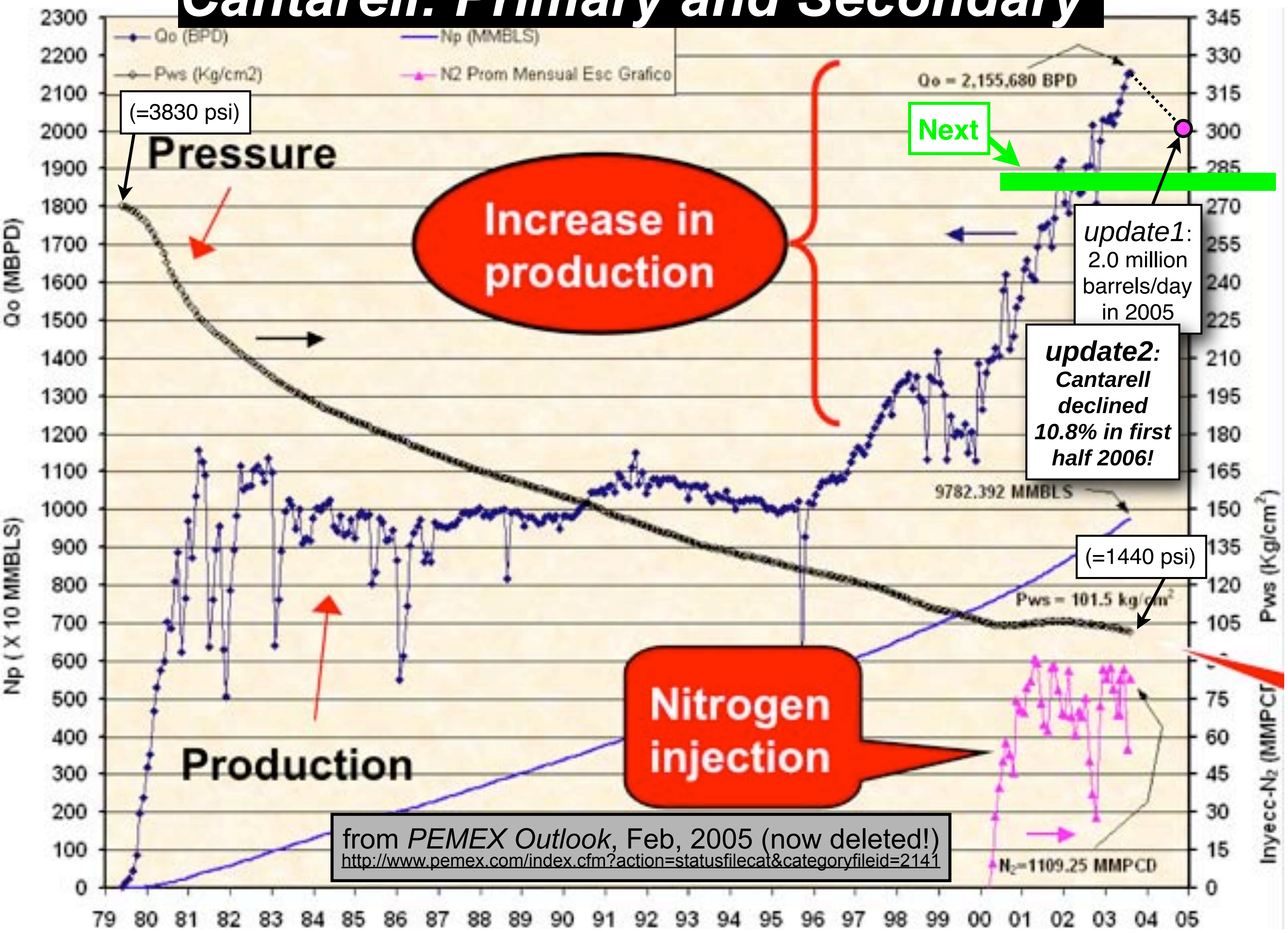


Source: IEA analysis based on IHS Energy database.

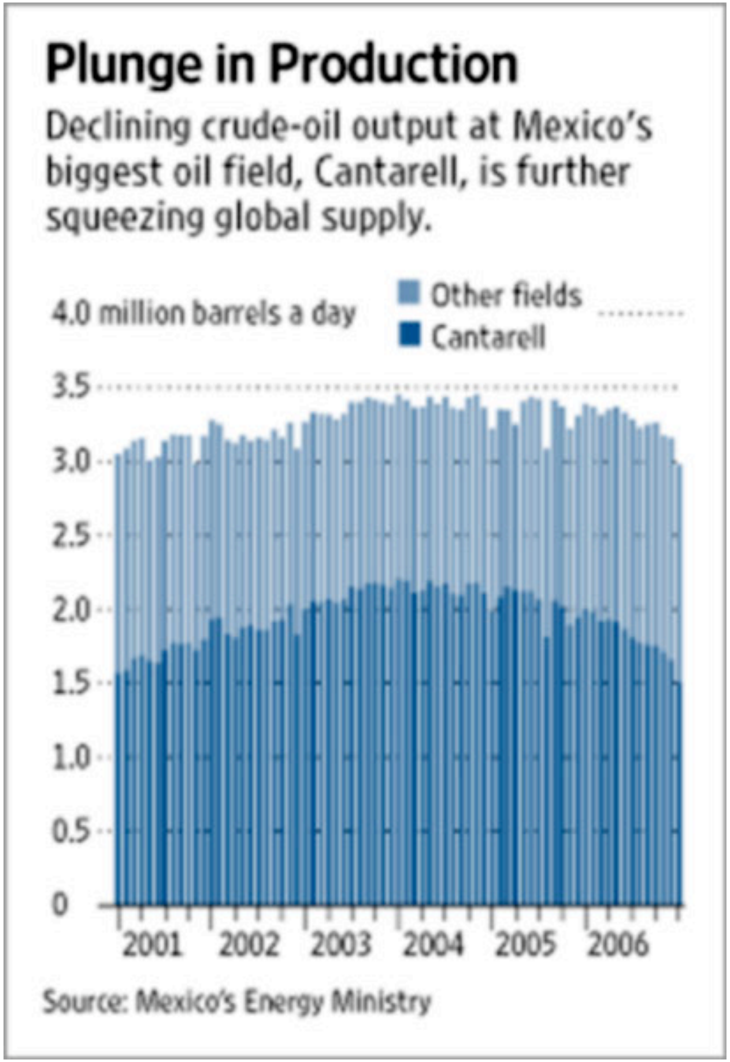
Stages of production

- ***Primary production*** (just produce)
  - initially, oil sprays out under own pressure (e.g.,3500 psi)
  - main productive run as pressure slowly drops (2000 psi)
  - as pressure drops, dissolved gas comes out of solution
- ***Secondary production*** (reinstate pore pressure by injection)
  - pump water down underneath oil (Ghawar, Saudi Arabia)
  - pump nitrogen down above oil (Cantarell, Mexico)
  - pump natural gas (or CO_2) down above oil (US)
- ***Tertiary production*** (extreme measures)
  - underground pumps, detergents, explosions
  - inject oil-eating bacteria (repressurize with bacterial gas)
- ***EROEI*** (energy return on energy investment)
  - EROEI decreases with each successive stage until < 1.0

Cantarell: Primary and Secondary



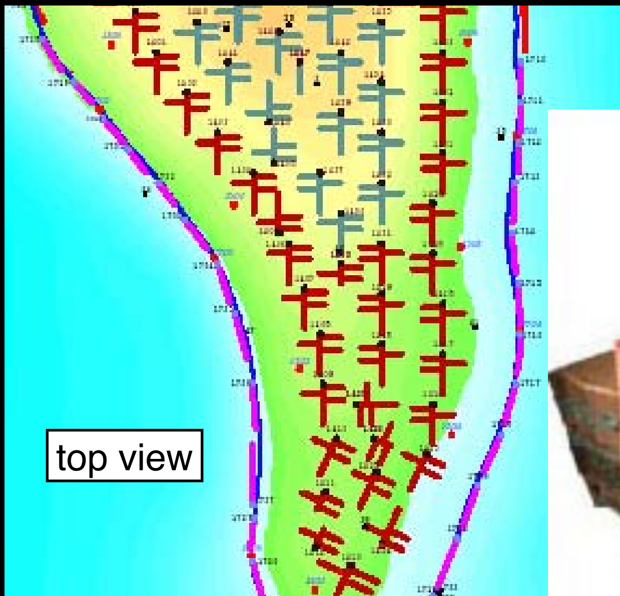
from *PEMEX Outlook*, Feb, 2005 (now deleted!)
http://www.pemex.com/index.cfm?action=statusfilecat&categoryfileid=2141

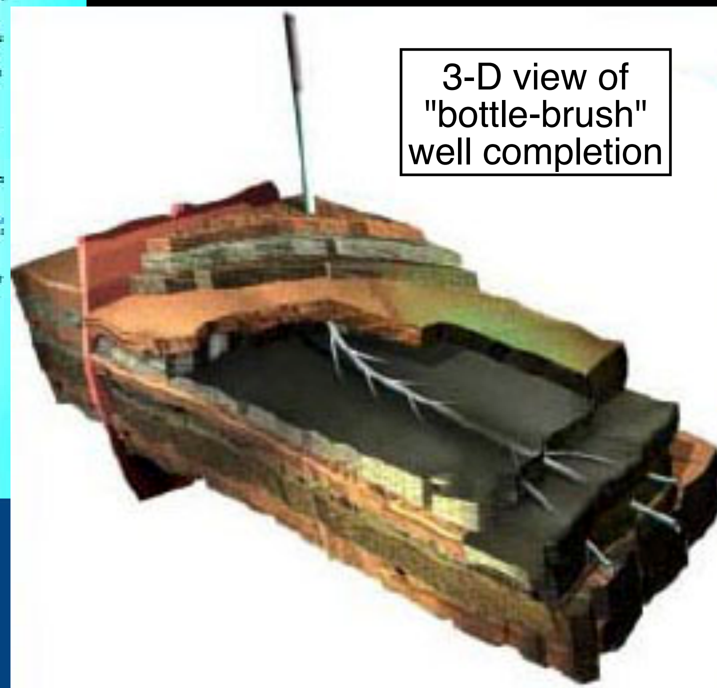


http://www.rigzone.com/news/article.asp?a_id=40538

Sideways Drilling – e.g., Ghawar

(increases flow by exposing longer length of borehole to oil floating on injected water)

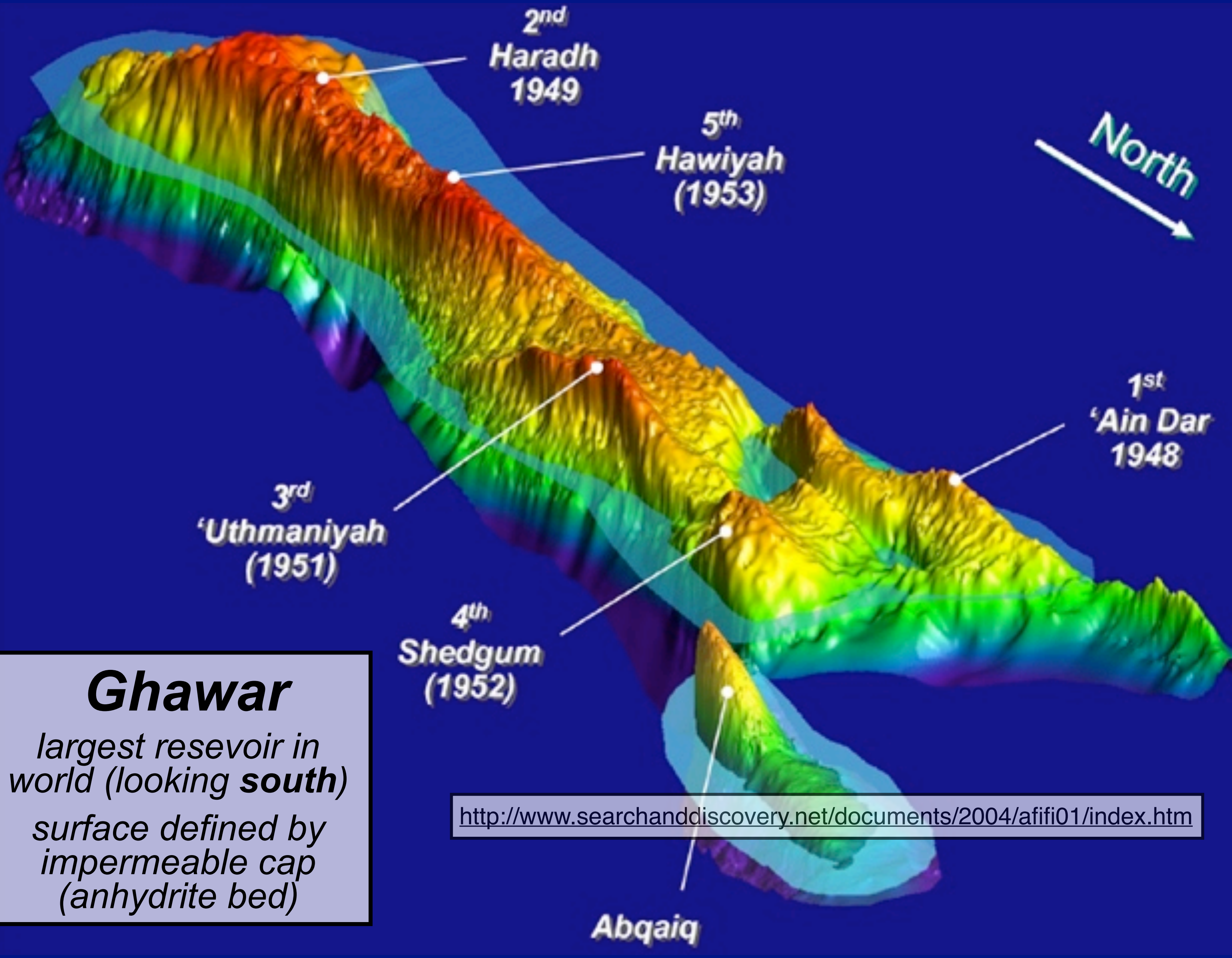




Greatly increases flow rate from single wells

(e.g., 10,000 barrels/day vs. 300 barrels/day)

from Matt Simmons



Ghawar

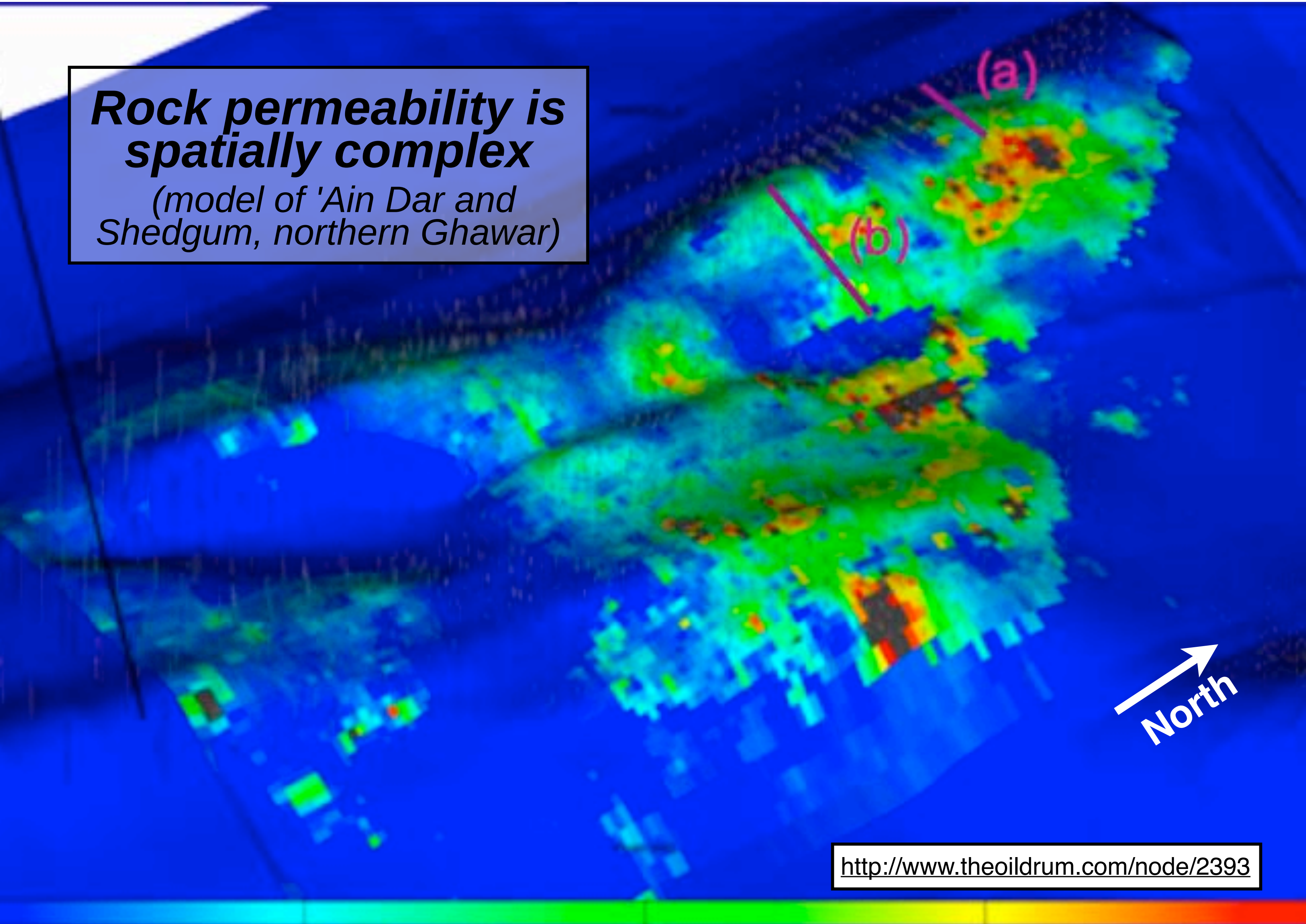
*largest resevoir in world (looking **south**)*

surface defined by impermeable cap (anhydrite bed)

http://www.searchanddiscovery.net/documents/2004/afifi01/index.htm

Rock permeability is spatially complex

(model of 'Ain Dar and Shedgum, northern Ghawar)



http://www.theoildrum.com/node/2393

http://www.spe.org/elibinfo/eLibrary_Papers/iptc/2005/05IPTC/IPTC-10395-MS/IPTC-10395-MS.htm

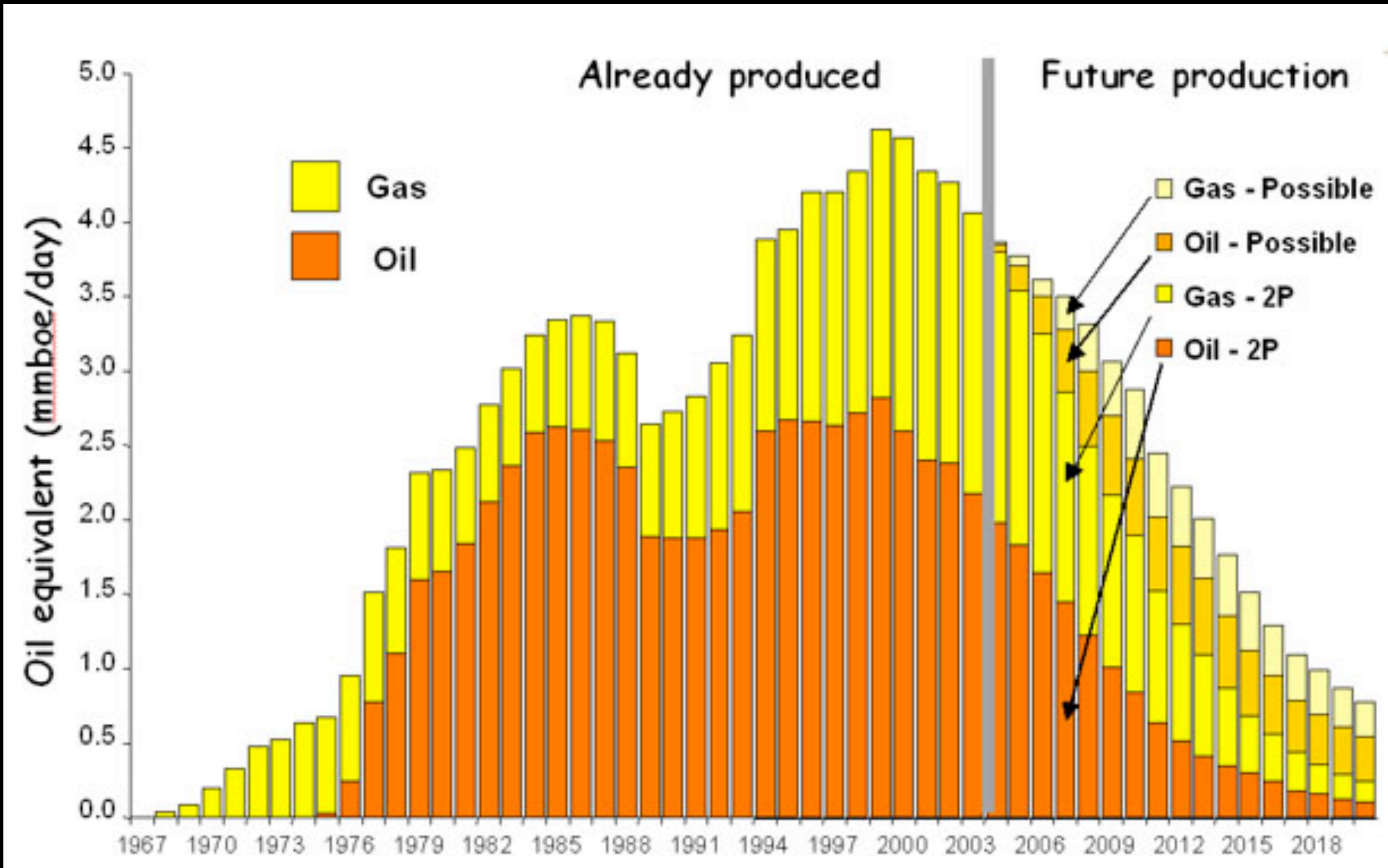
Most of the World has Already Peaked

- Only producers that have *not* peaked are OPEC and FSU
- This is called "depletion"
- Depletion is occurring despite widespread use of secondary methods in mature fields
- Since world demand is growing, depletion means that the non-peaked countries will have to increment production both to offset depletion *and* to meet new demand
- Recent price increases may make companies return to previously unprofitable/abandoned fields
- Higher prices cannot make fields re-fill with easy-to-get oil, or make remaining oil with EROEI<1.0 an energy ***source***

Natural Gas Liquids (NGL's)

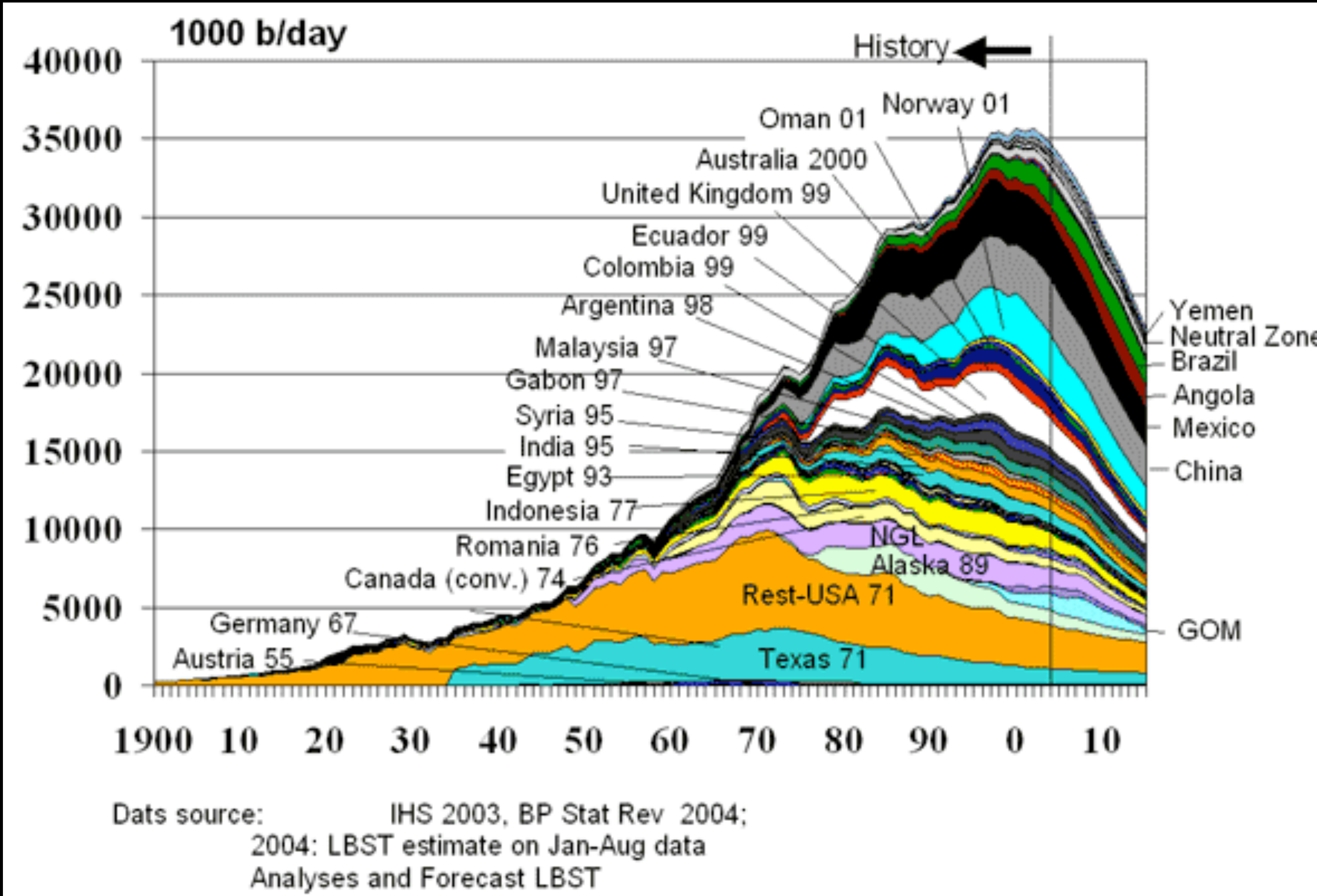
- Don't confuse these with "liquified natural gas" (LNG), which is cooled, compressed methane
- "Natural gas liquids" (NGL's) are short chain hydrocarbons (e.g., pentane) extracted from deep, hot (e.g., 180 deg C) natural gas wells with (75% the energy density of crude)
- NGL's are gases *in situ* but some condense to liquids when brought to the surface and cooled
- NGL's and "condensates" are divided into immediately separated "lease condensates" (e.g., pentane) and later stage "natural gas plant liquids" (e.g., propane, butane)
- 75% of US 'oil' production is now "natural gas liquids"!
- finally, "all liquids" adds together crude oil, NGL's, and "other liquids" (mainly ethanol, and a little biodiesel)

Past/Predicted Production, North Sea
(already discovered sites)



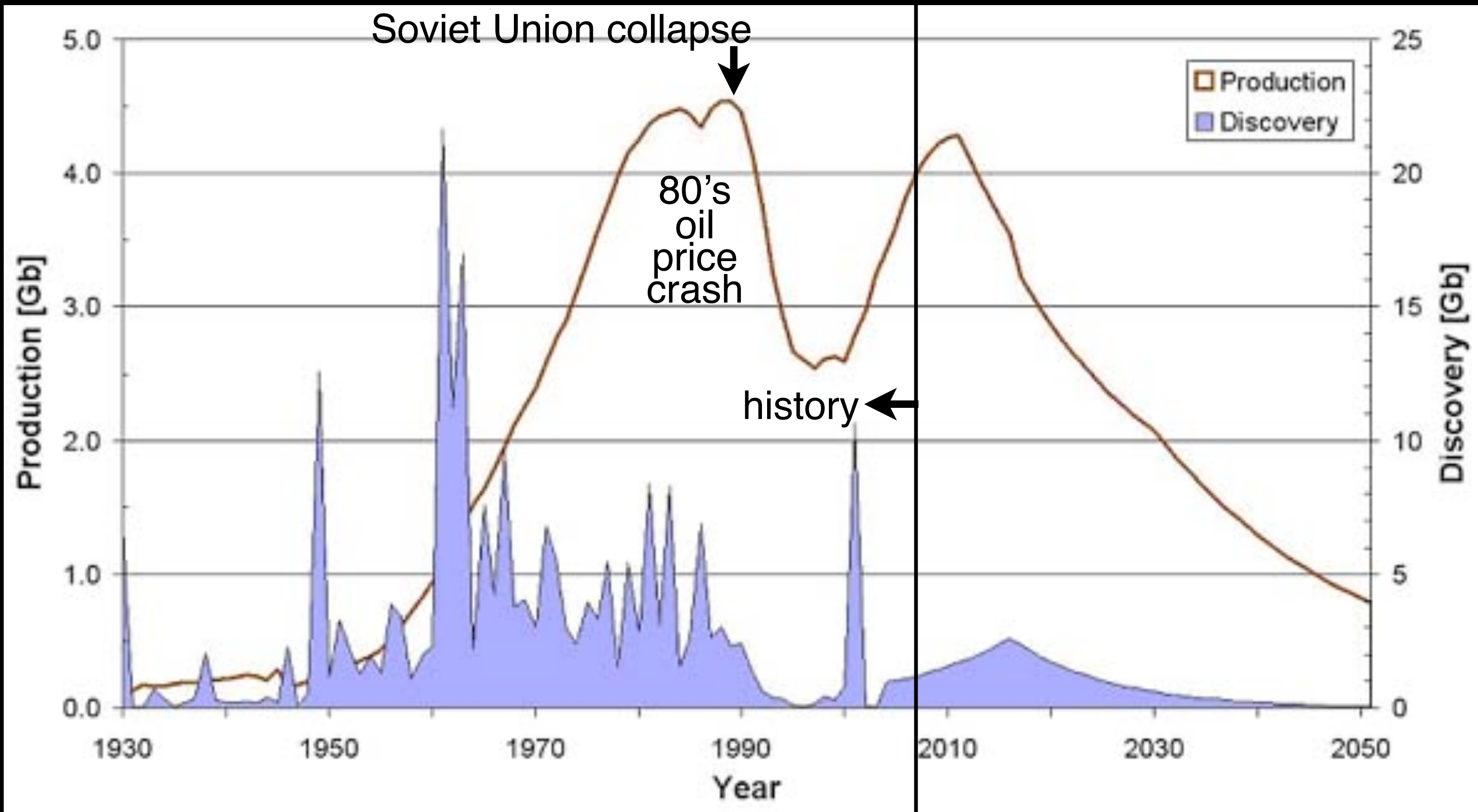
Peter Haile, UK Dept Trade & Industry

World Production Excluding OPEC, FSU



http://www.odac-info.org/links/documents/LBST_Countdown_2004-10-12.pdf

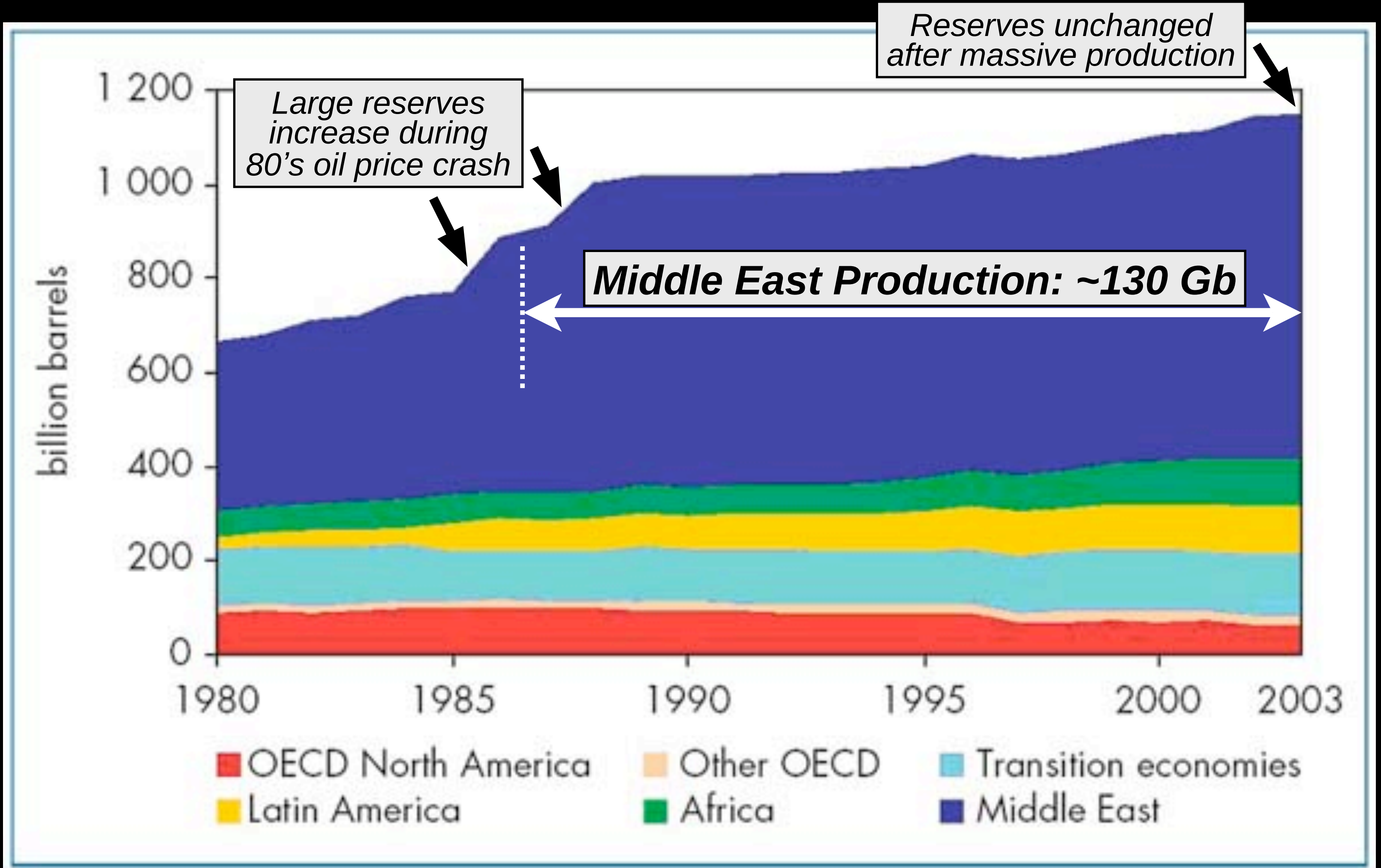
Past/Predicted Discovery and Production FSU (former Soviet Union)



Reserve Estimates Unreliable, Semi-Secret

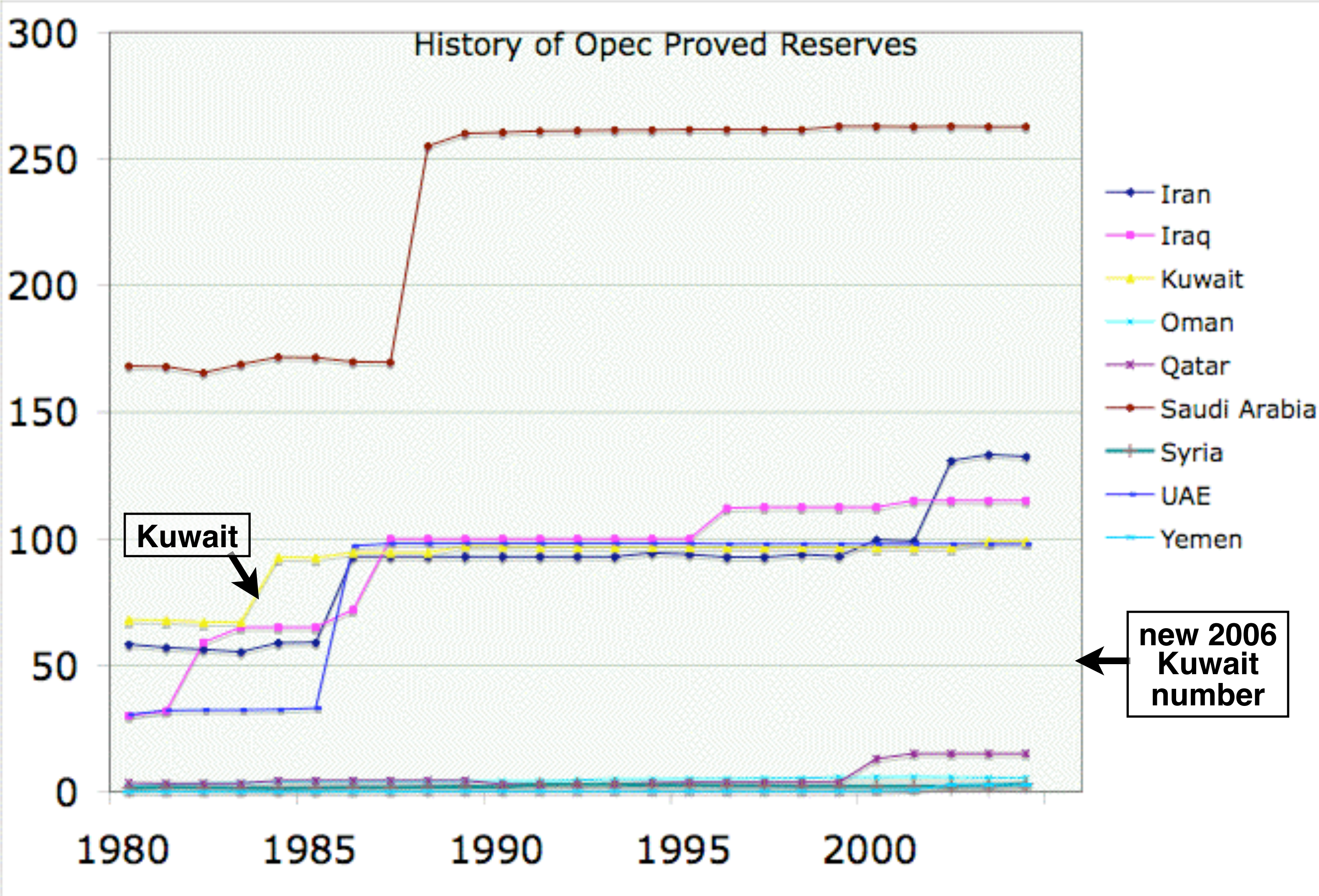
- Several major oil companies recently downgraded reserves
- OPEC countries all doubled reserves estimates in mid 80's
- OPEC reserves have remained unchanged after strong 90's production despite absence of new discoveries
- Secondary production can end with sharp drops (sharp late 1990's North Sea peak *versus* shallower US peak) when water reaches borehole, or sidesteps left-behind oil
- In newer fields, primary and secondary production are being done sooner (e.g., Cantarell), or from beginning
- Kuwait halved stated reserves in 2006 (~100 Gb to ~50 Gb)

World Reserves Estimates Through Time



Source: BP (2004).

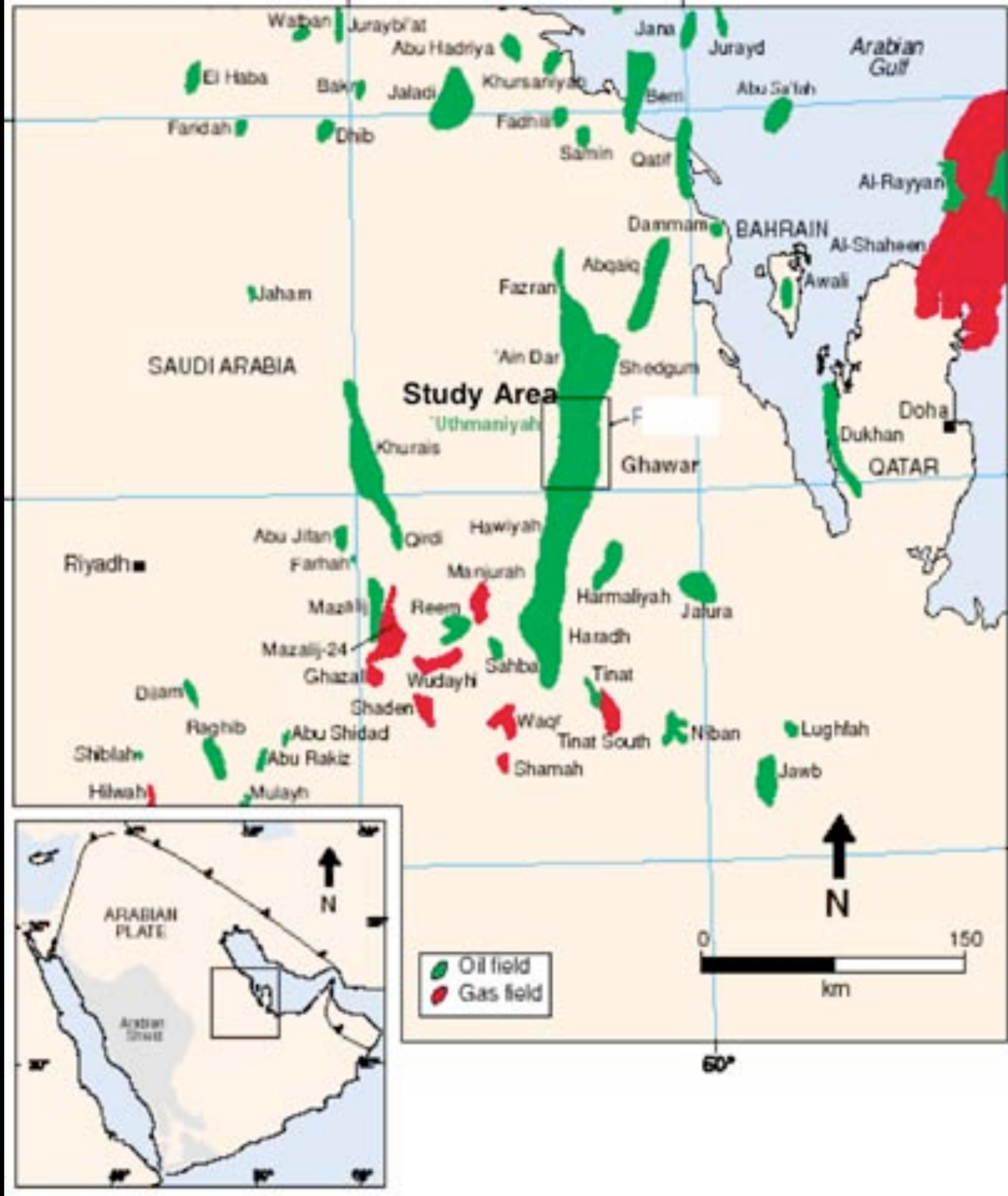
OPEC proved reserves – details



http://www.bp.com/genericsection.do?categoryId=92&contentId=7005893

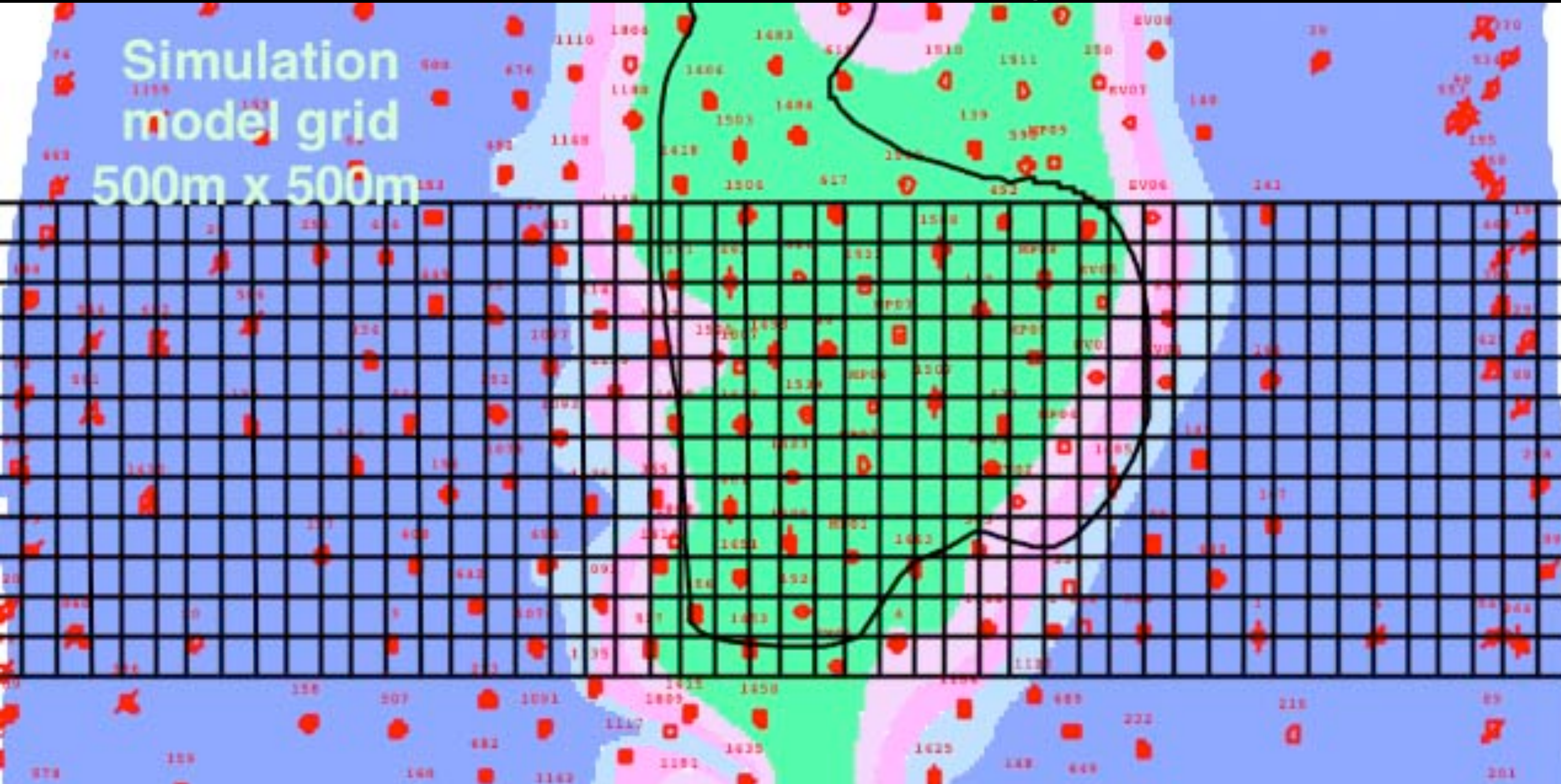
Ghawar

Largest Oilfield (~5% world production)



(from reference on next slide)

Ghawar 3D Seismic Survey Closeup



Oil column thickness *(orig:* ***1300 feet****)*

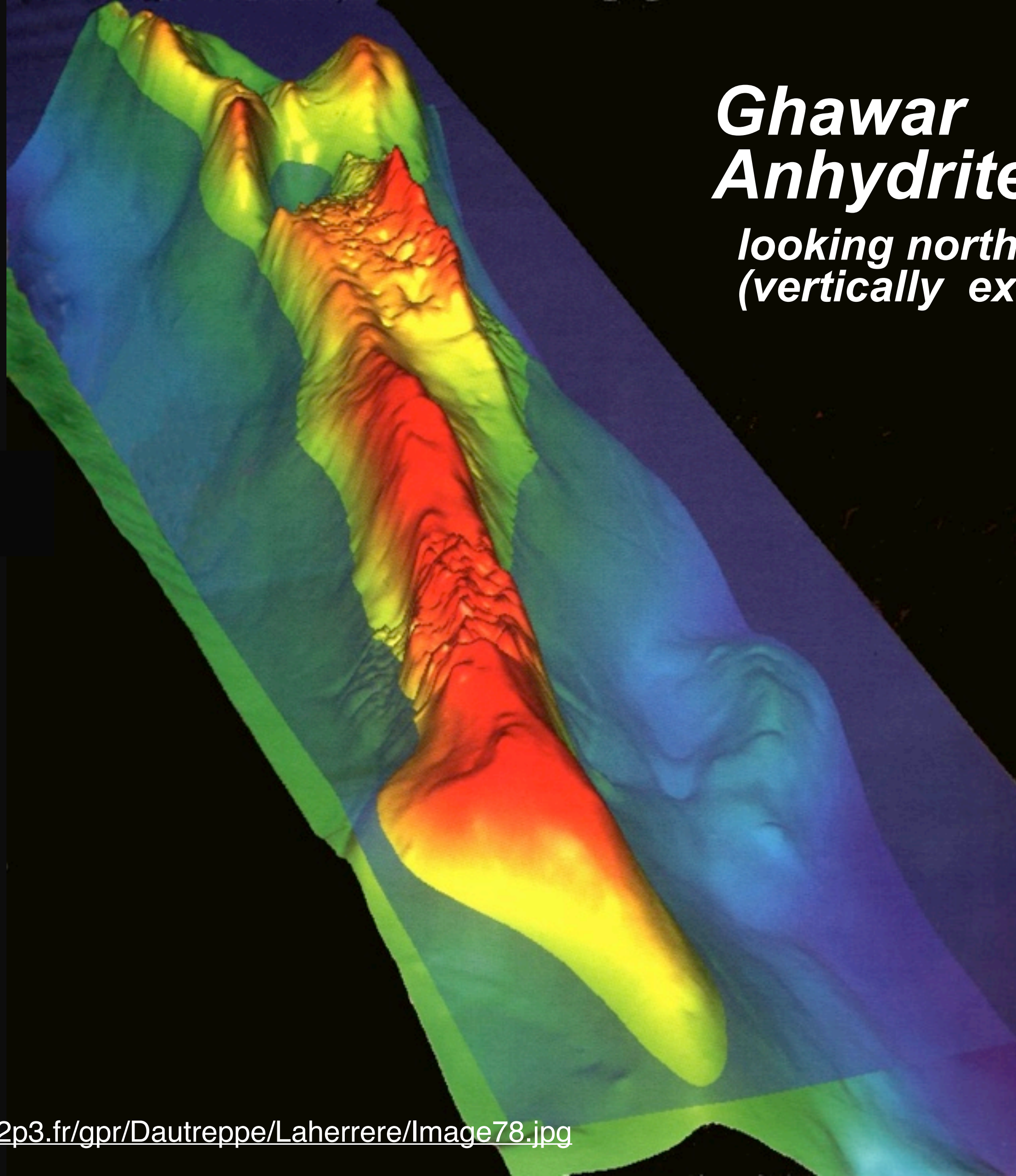
blue	**0-30 feet**
green	more than **120 feet**
red	boreholes (most now used for water injection)

Shiv Dasgupta, “Reservoir monitoring with permanent borehole sensors: Ghawar Arab D reservoir”, 74th SEG Conference, 2004

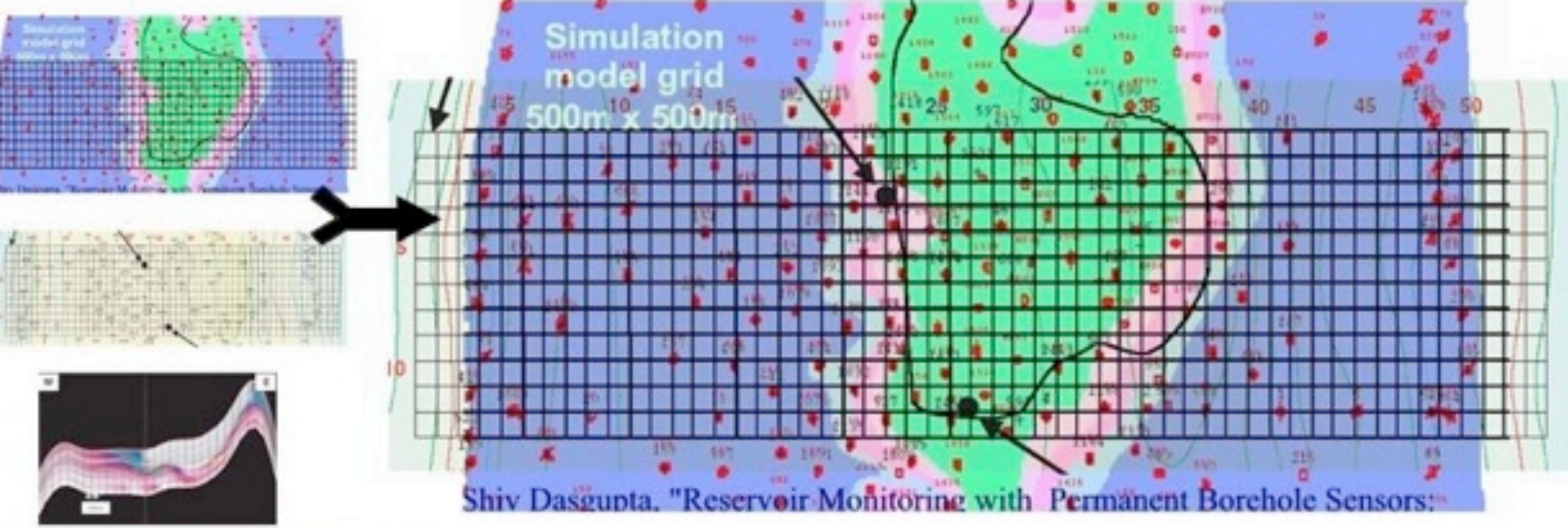
http://abstracts.seg.org/ease/techprog/downloadpaper?paper_id=817&assigned_num=762

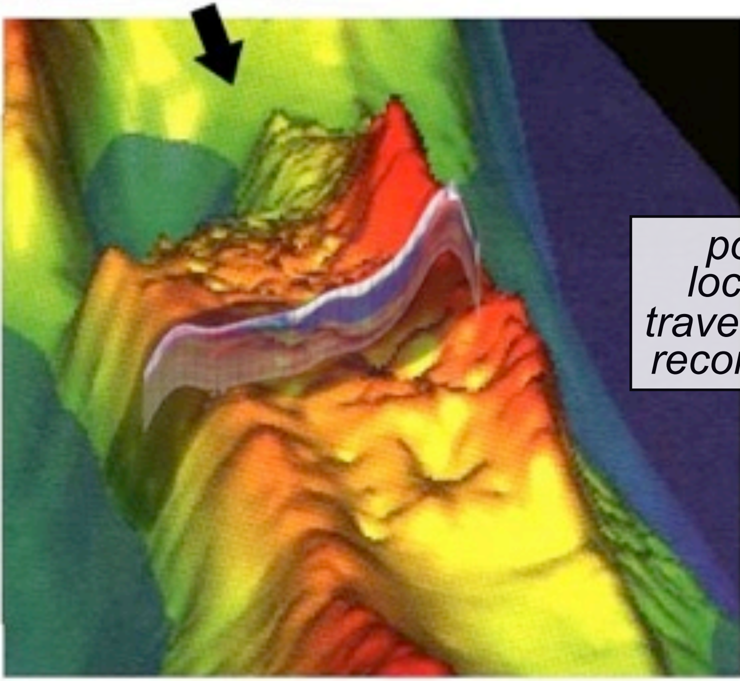
Ghawar Anhydrite Cap

looking north
(vertically exaggerated)

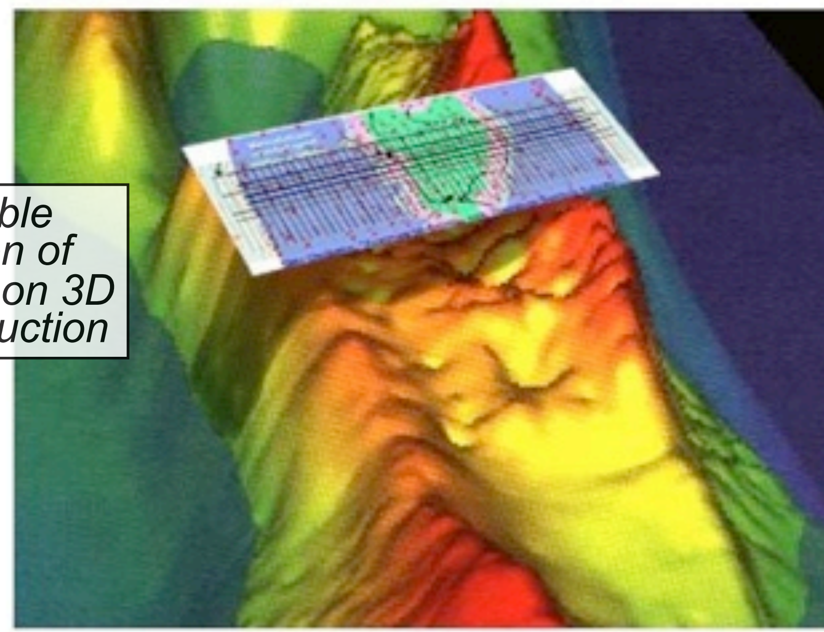


http://lpsc.in2p3.fr/gpr/Dautreppe/Laherrere/Image78.jpg



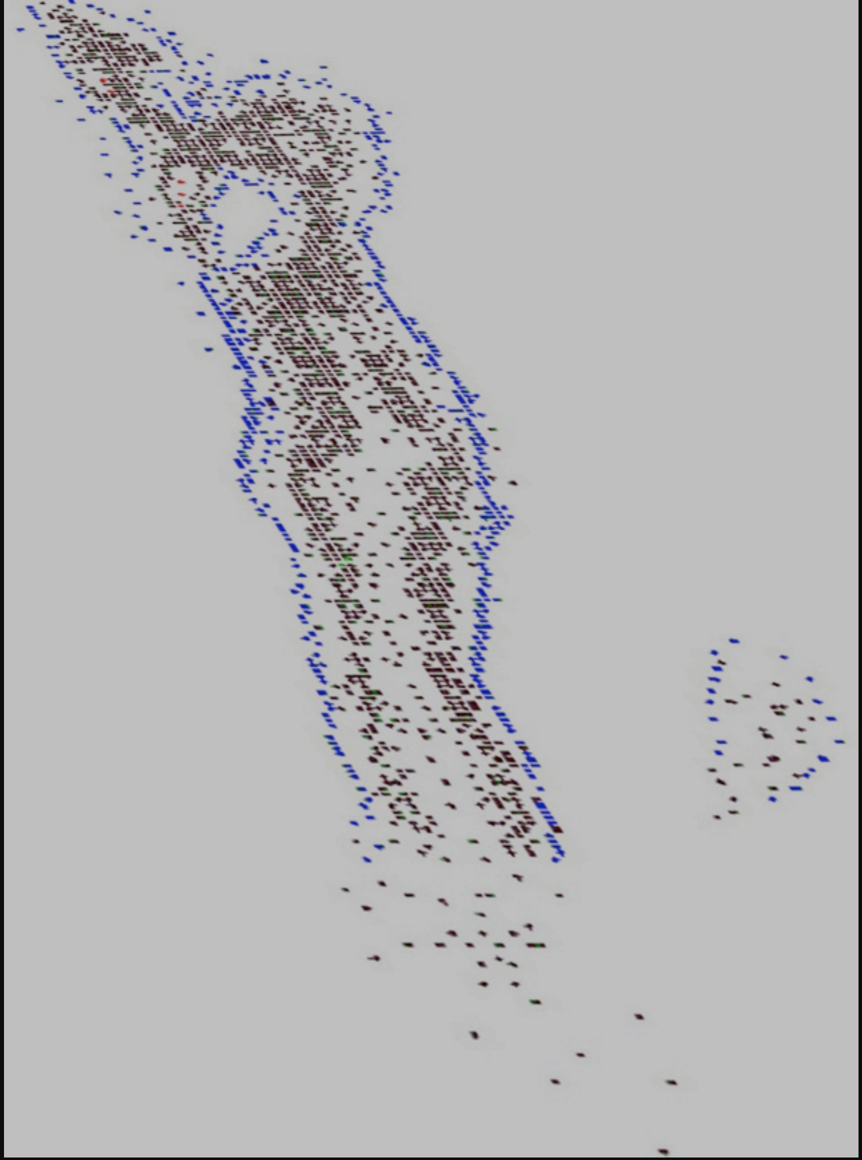


possible location of traverse on 3D reconstruction



from garyp

http://www.theoildrum.com/node/2441#comment-177244

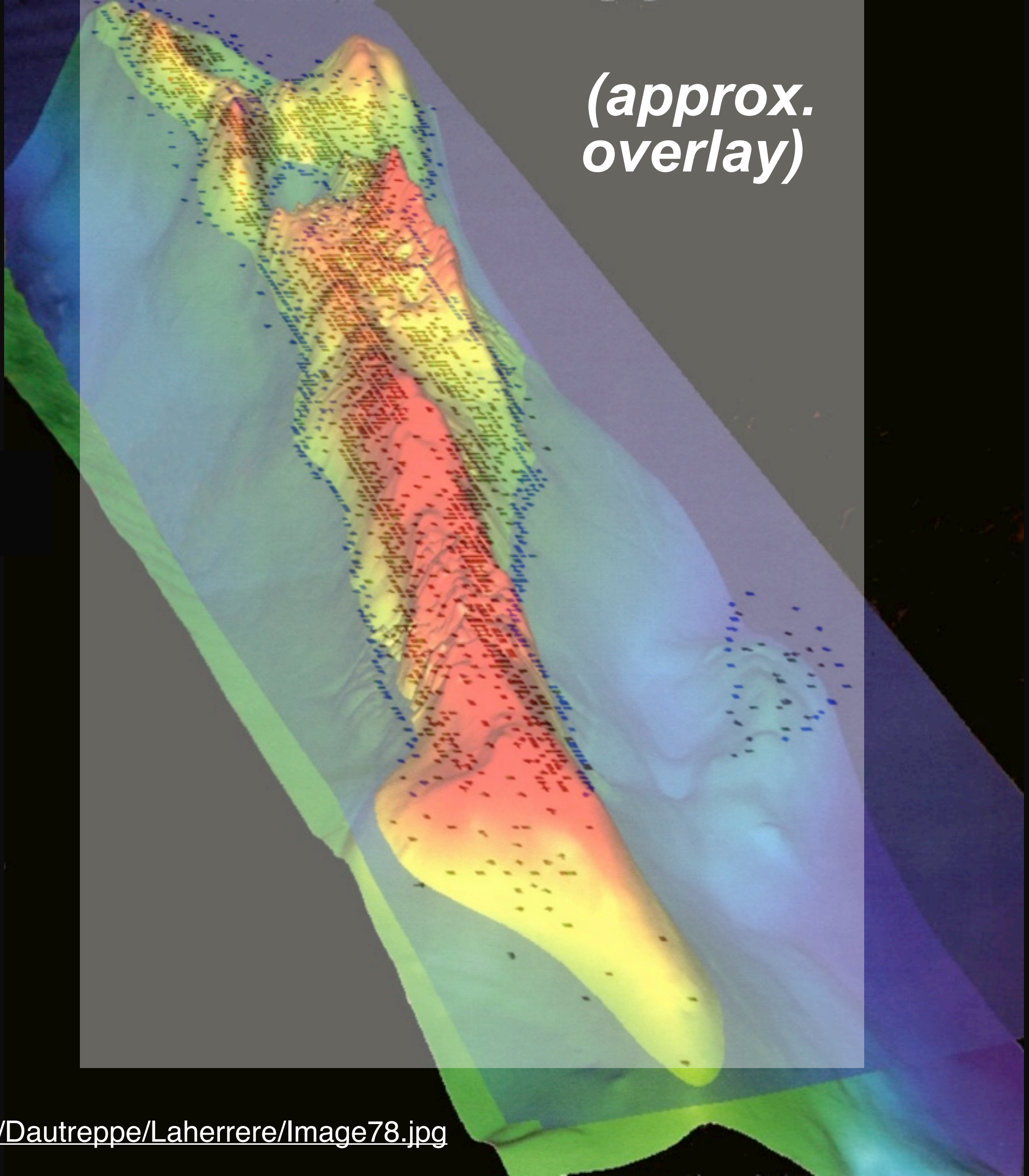


Ghawar Boreholes

blue: oil
brown: water inj

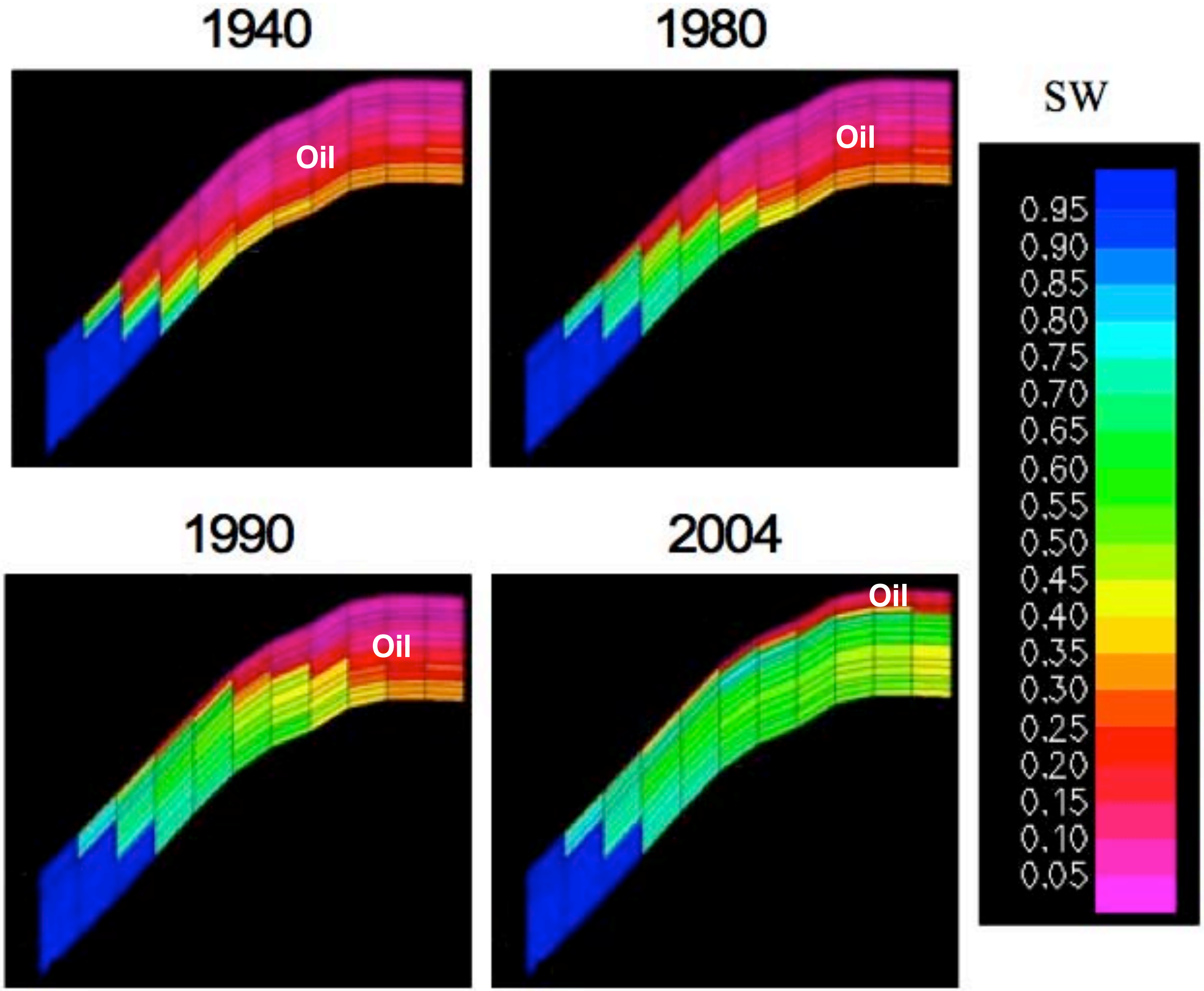
(approx. overlay)

http://pangea.stanford.edu/~jcaers/theses/thesisJoeVoelker.pdf



http://lpsc.in2p3.fr/gpr/Dautreppe/Laherrere/Image78.jpg

Depletion of North 'Ain Dar

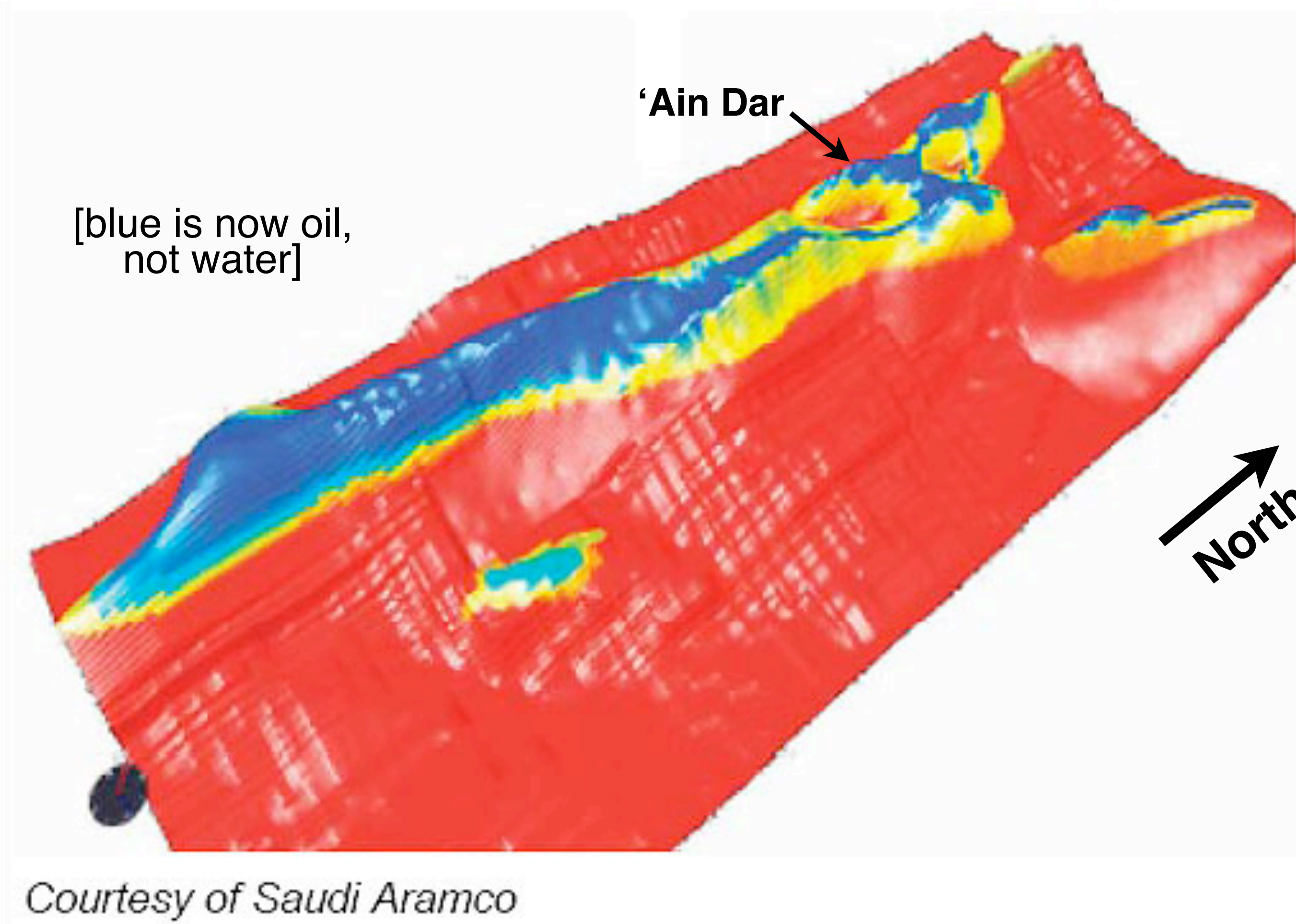


http://www.theoildrum.com/node/2441 **from Stuart Staniford**

http://www.spe.org/elibinfo/eLibrary_Papers/spe/2005/05MEOS/SPE-93439-MS/SPE-93439-MS.htm

Ghawar Field Oil Saturation Plot, 2002

(presumably just under anhydrite cap)



http://www.appro.com/company/0706_Appro_Eprint_A.pdf

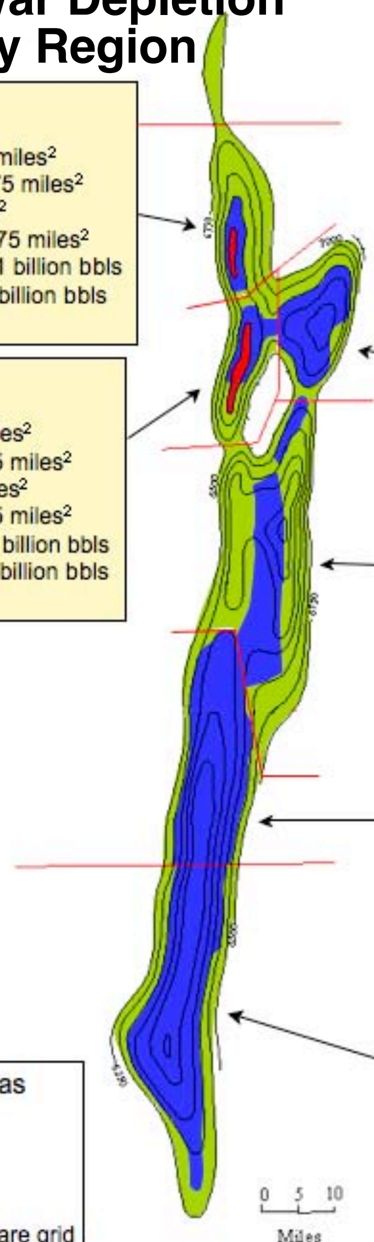
Ghawar Depletion by Region

N

Base Case Scenario
Base Case Scenario
2004 Whole Field Reserves:
34.3 billion bbls

North Ain Dar
Area: 149.5 miles^2
Swept Area: 120.75 miles^2
Un-swept Area: 28.75 miles^2
Area of Oil: 23 miles^2
Area of Gas Cap: 5.75 miles^2
Initial Reserves: 12.1 billion bbls
2004 Reserves: 1.5 billion bbls
% Depletion: 88

South Ain Dar
Area: 120 miles^2
Swept Area: 79.5 miles^2
Un-swept Area: 40.5 miles^2
Area of Oil: 25.5 miles^2
Area of Gas Cap: 15 miles^2
Initial Reserves: 9.7 billion bbls
2004 Reserves: 1.7 billion bbls
% Depletion: 83

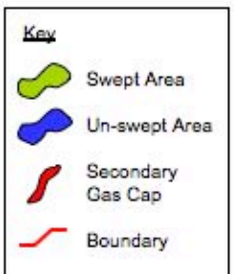


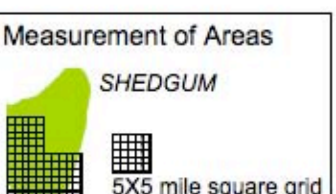
Shedgum
Area: 163.5 miles^2
Swept Area: 70.5 miles^2
Un-swept Area: 93 miles^2
Initial Reserves: 11.3 billion bbls
2004 Reserves: 5.4 billion bbls
% Depletion: 55

Uthmaniyah
Area: 461.75 miles^2
Swept Area: 327.5 miles^2
Un-swept Area: 134.25 miles^2
Initial Reserves: 29.3 billion bbls
2004 Reserves: 6.5 billion bbls
% Depletion: 78

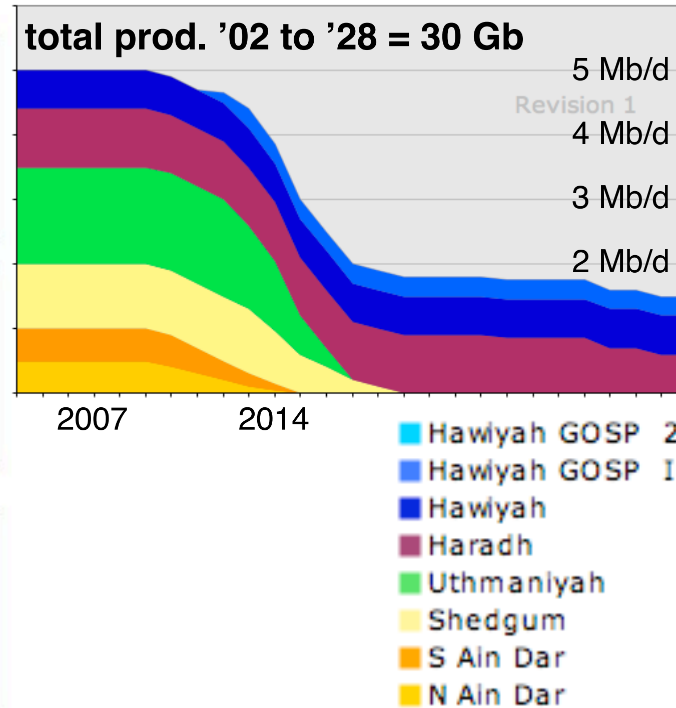
Hawiyah
Area: 293.75 miles^2
Swept Area: 56 miles^2
Un-swept Area: 237.75 miles^2
Initial Reserves: 13.8 billion bbls
2004 Reserves: 11.1 billion bbls
% Depletion: 19

Haradh
Area: 436 miles^2
Swept Area: 161.75 miles^2
Un-swept Area: 274.25 miles^2
Initial Reserves: 14.4 billion bbls
2004 Reserves: 8.4 billion bbls
% Depletion: 42





Ghawar Base Case Production Model



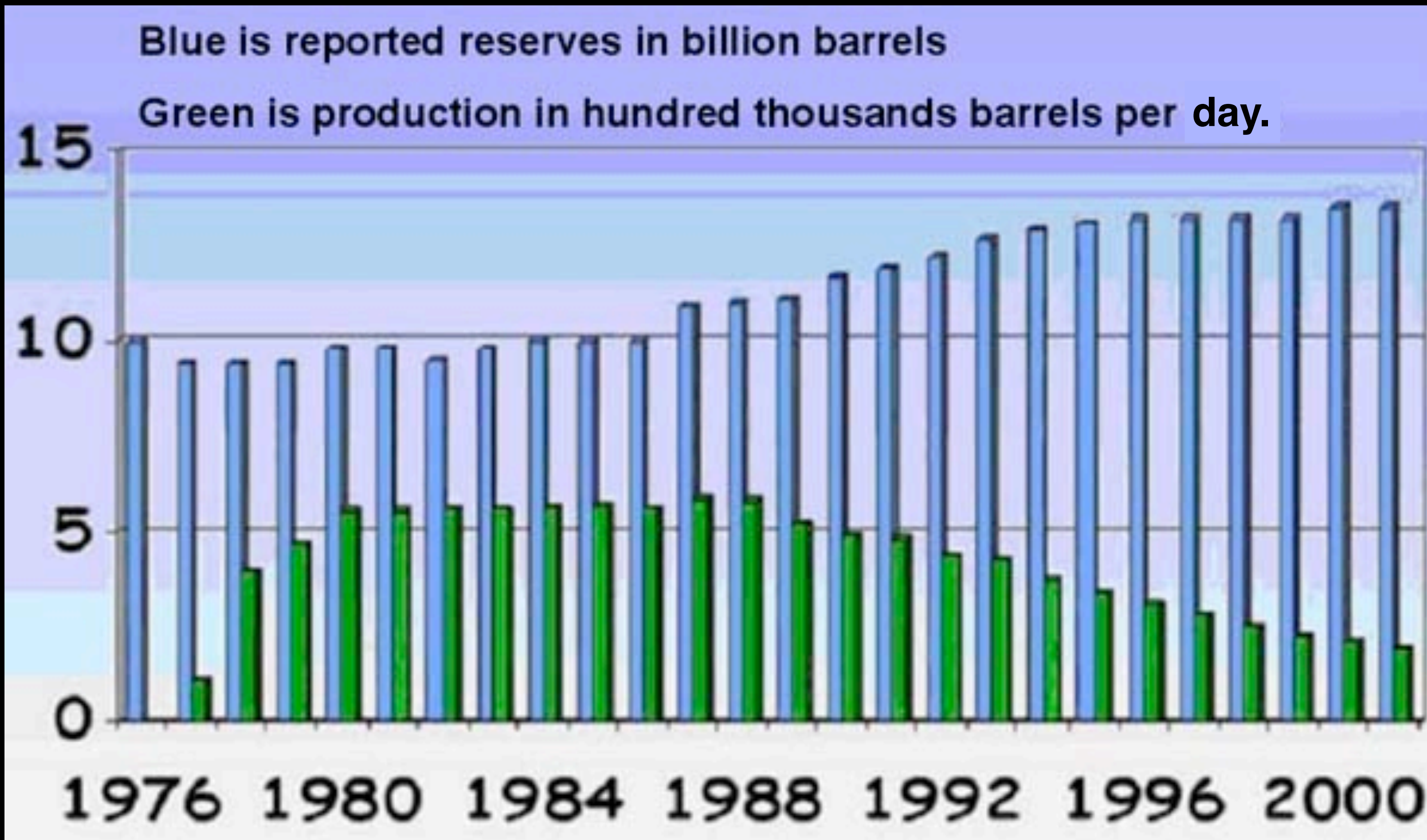
from Euan Mearns

http://europe.theoildrum.com/node/2507

http://europe.theoildrum.com/node/2494

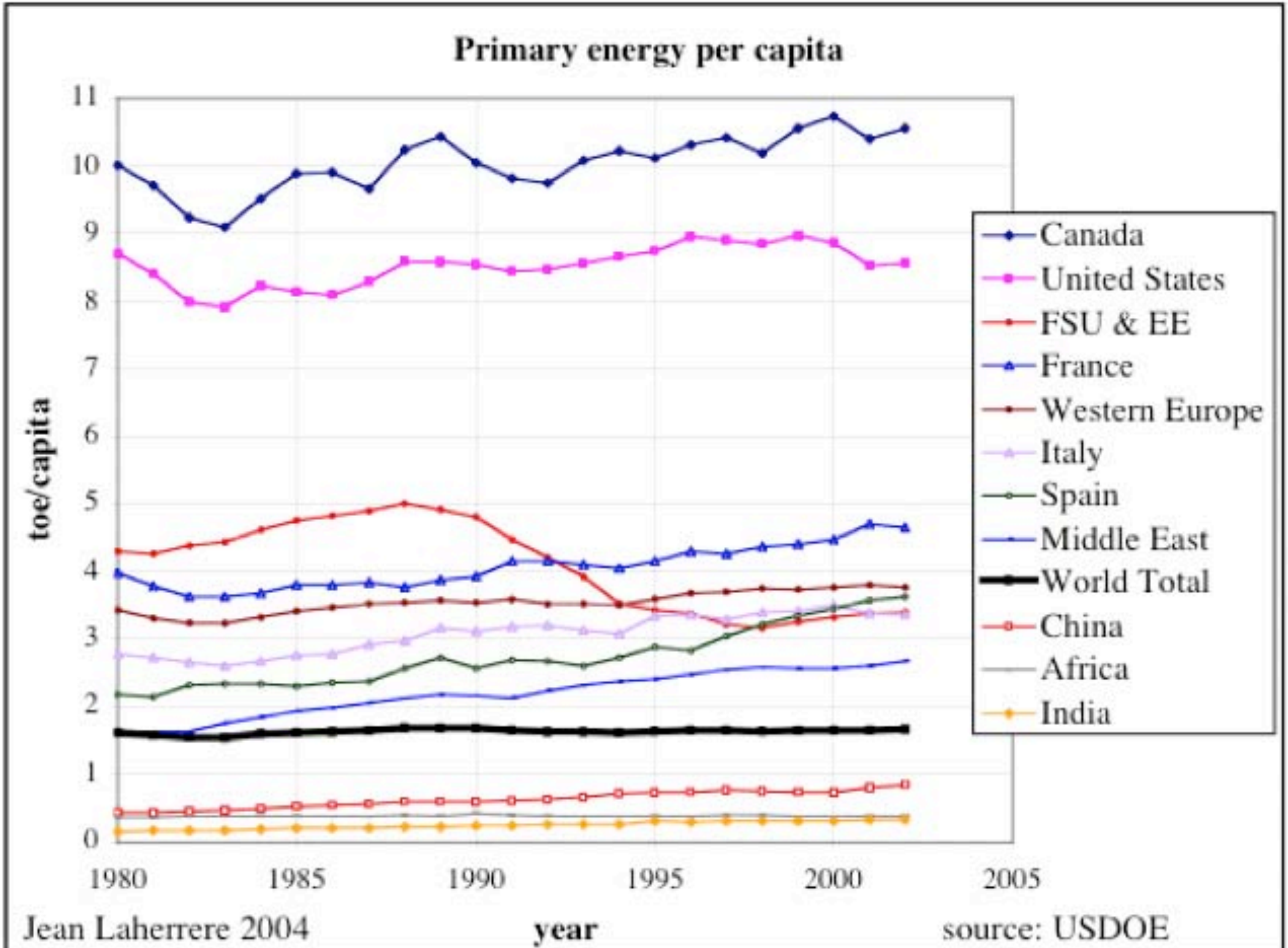
Prudoe Bay, Alaska – Production/Reserves

largest North American oil field (discovered 1968)
‘reserves’ increase but production continues to drop



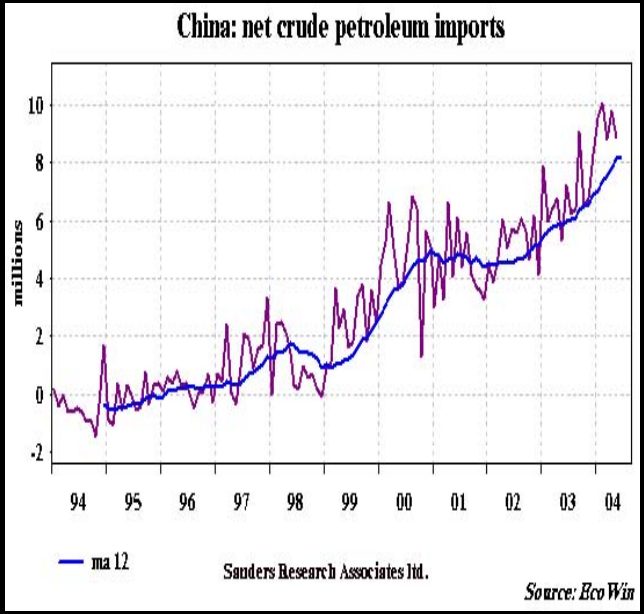
Demand is Growing

- for example: USA, China, India
- a bicycle is a 100-watt device
- a car is a 100,000-watt device


Primary energy per capita
toe/capita
11
10
9
8
7
6
5
4
3
2
1
0
1980
1985
1990
1995
2000
2005
year
Canada
United States
FSU & EE
France
Western Europe
Italy
Spain
Middle East
World Total
China
Africa
India
Jean Laherrere 2004
source: USDOE

China Imports Up (from 0) UK exports Down (to 0) since 1996

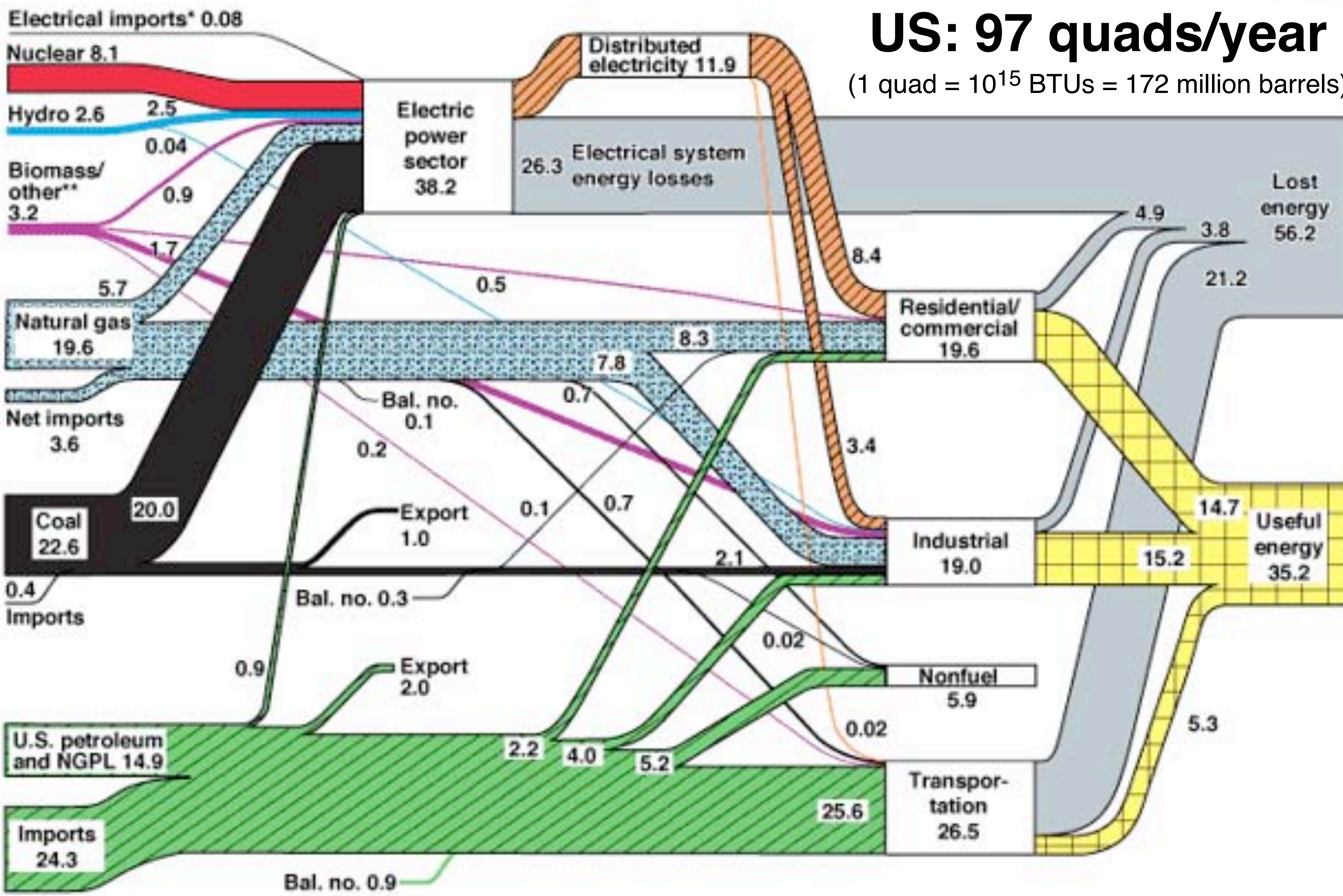
(same x and y scales)



Net Primary Resource Consumption ~97 Quads, 2002

US: 97 quads/year

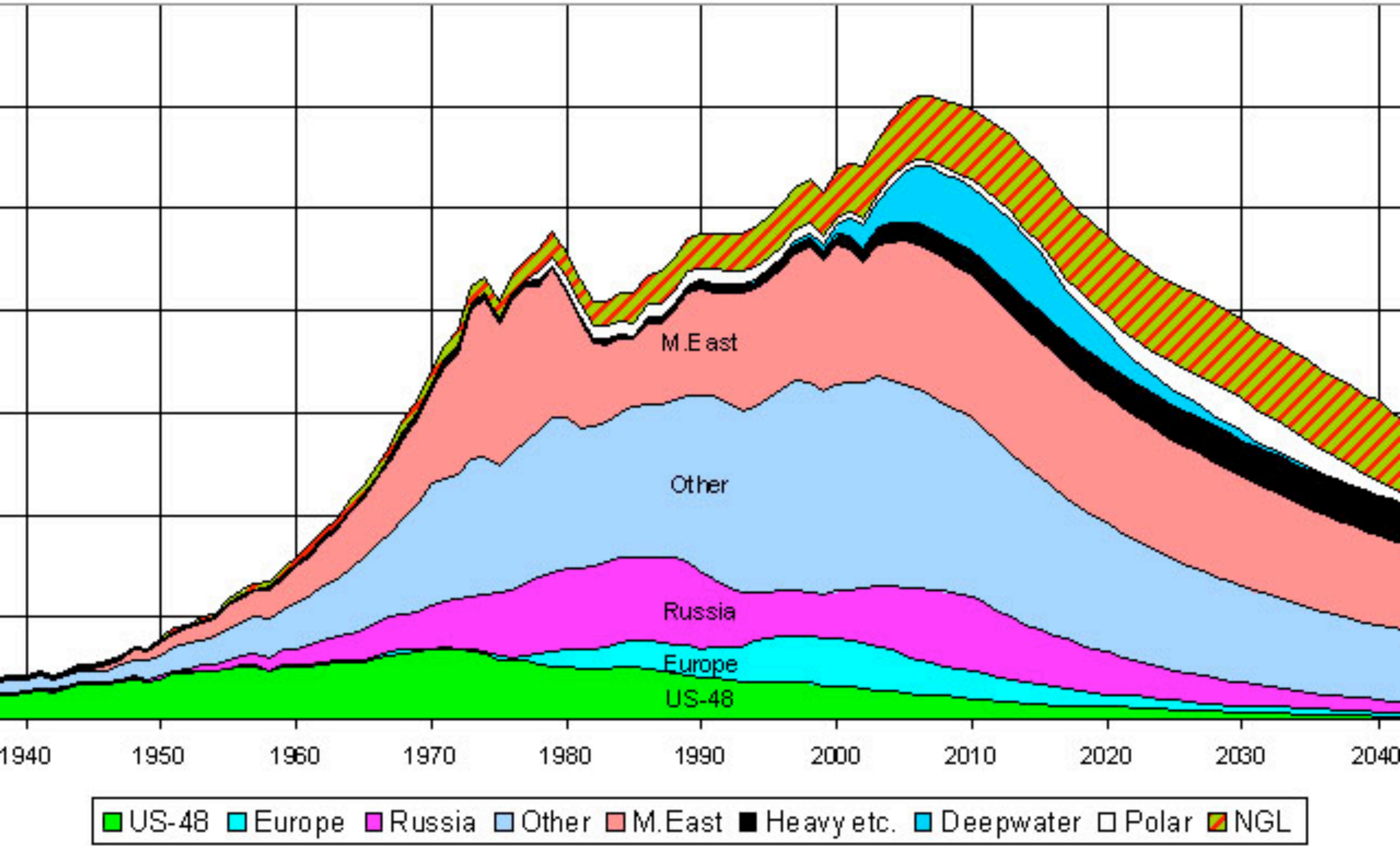
(1 quad = 10^{15} BTUs = 172 million barrels)



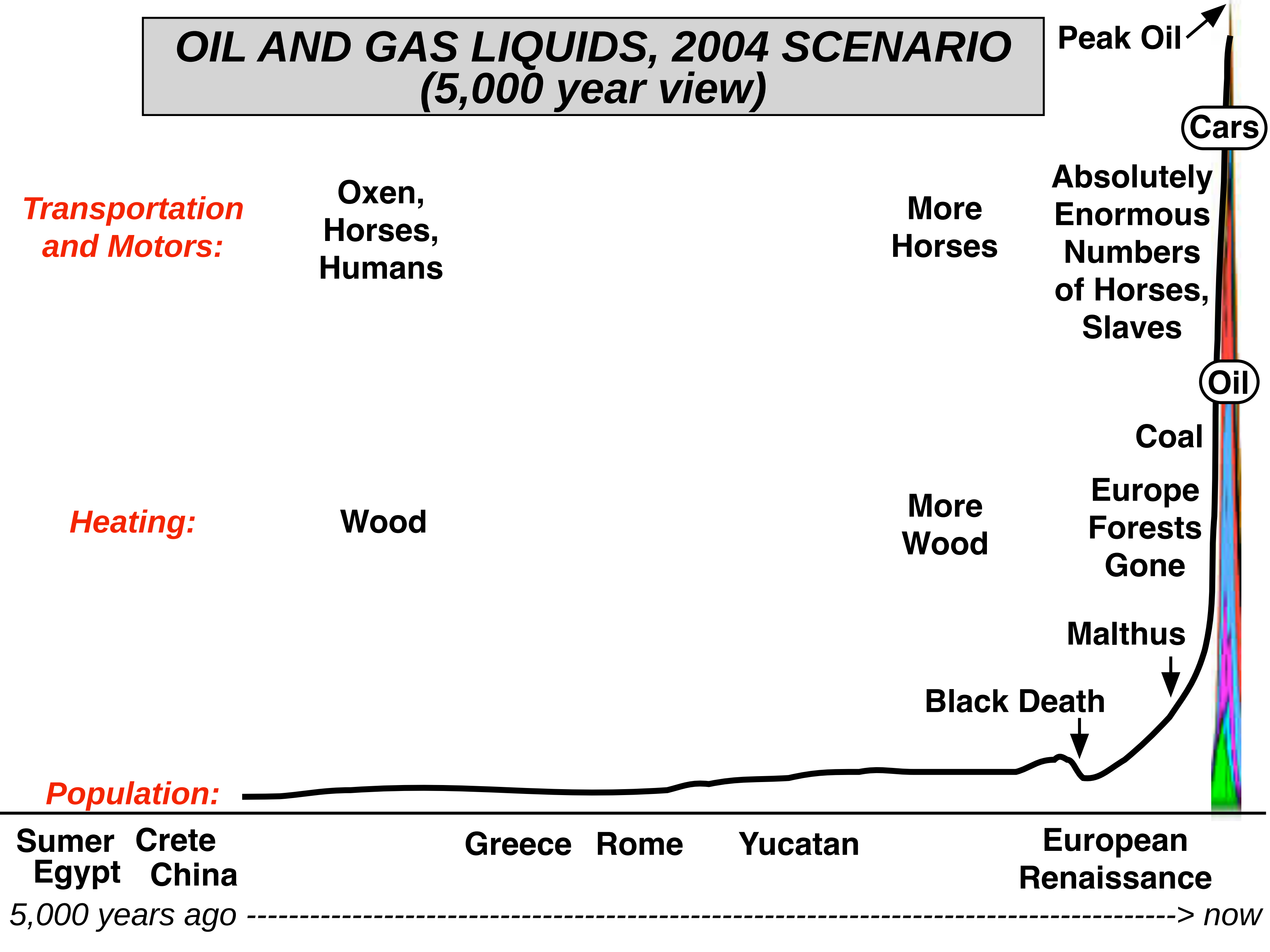
Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore National Laboratory
http://eed.llnl.gov/flow

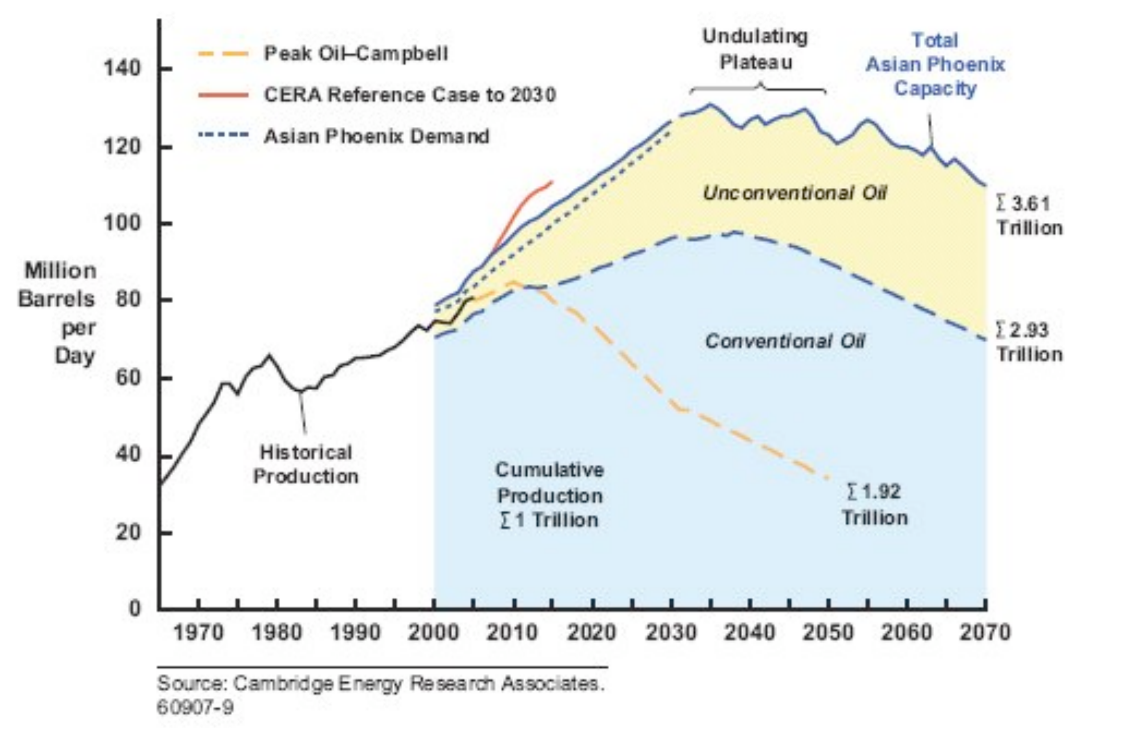
OIL AND GAS LIQUIDS, 2004 SCENARIO
(100 year view)

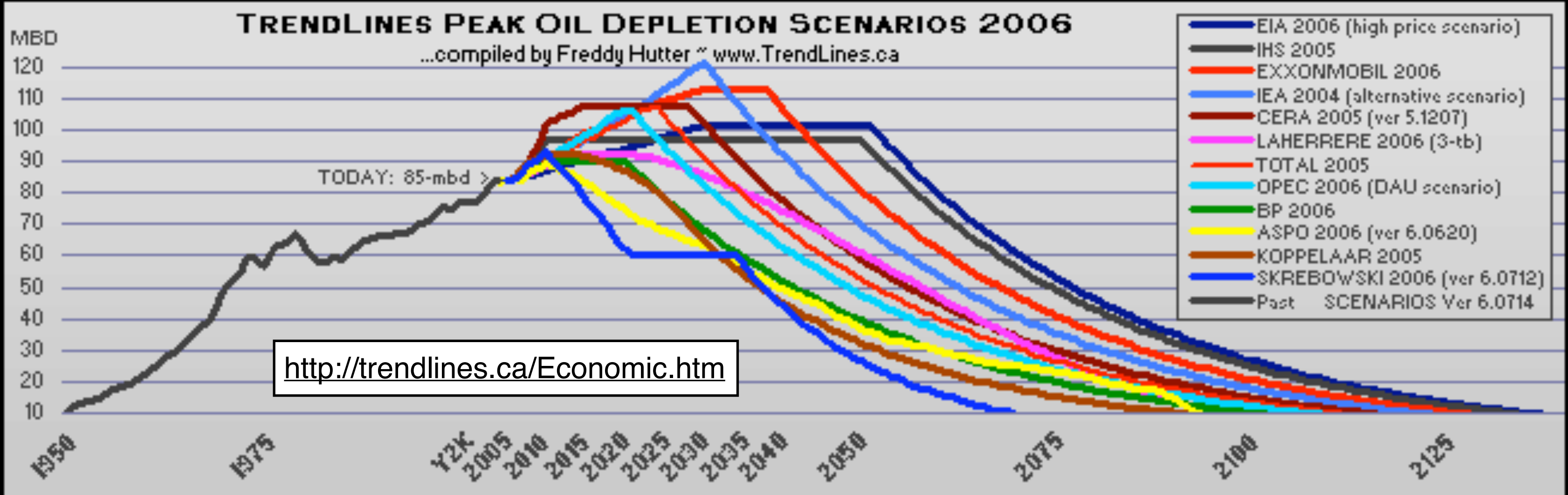


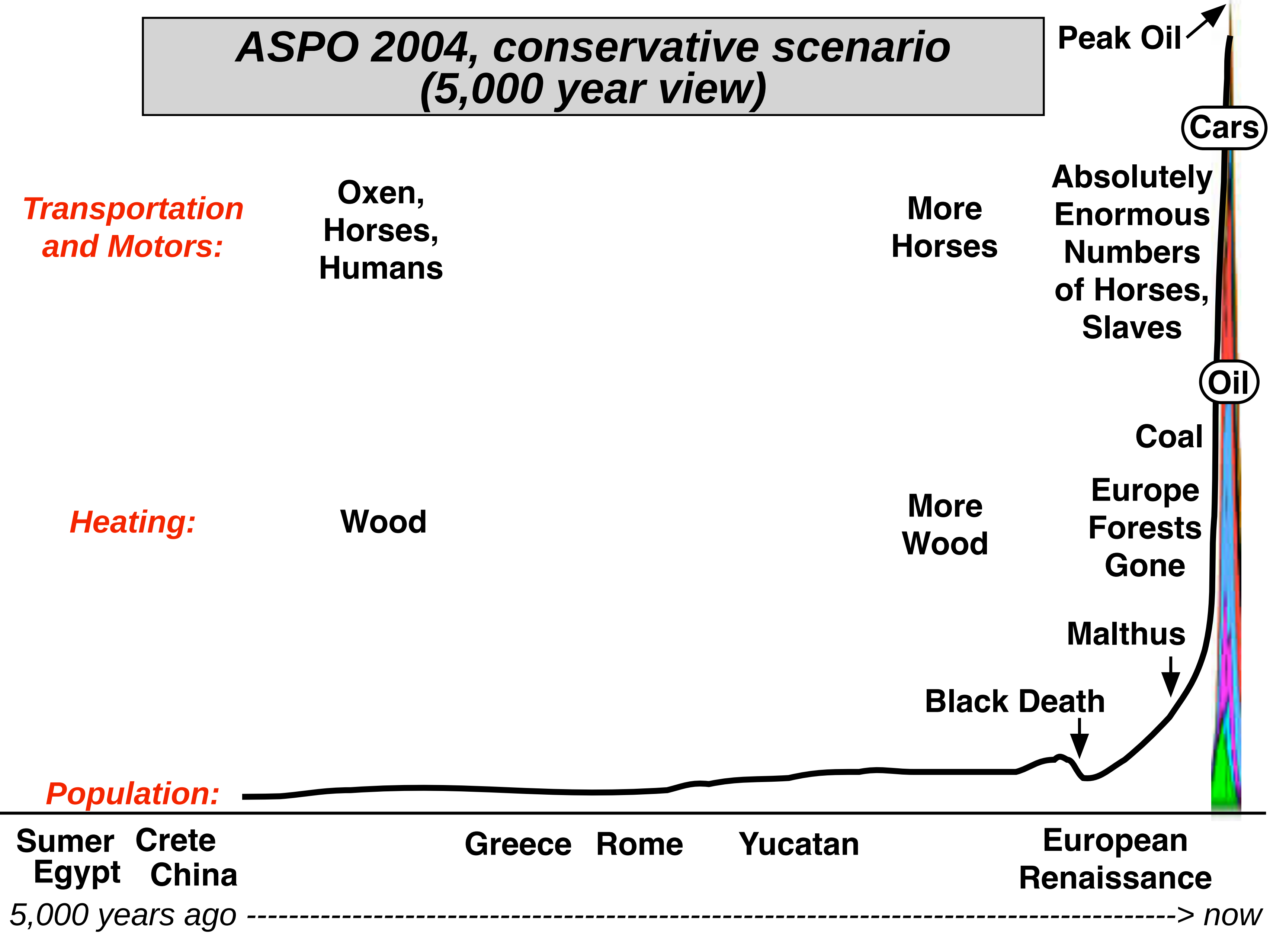
OIL AND GAS LIQUIDS, 2004 SCENARIO
(5,000 year view)



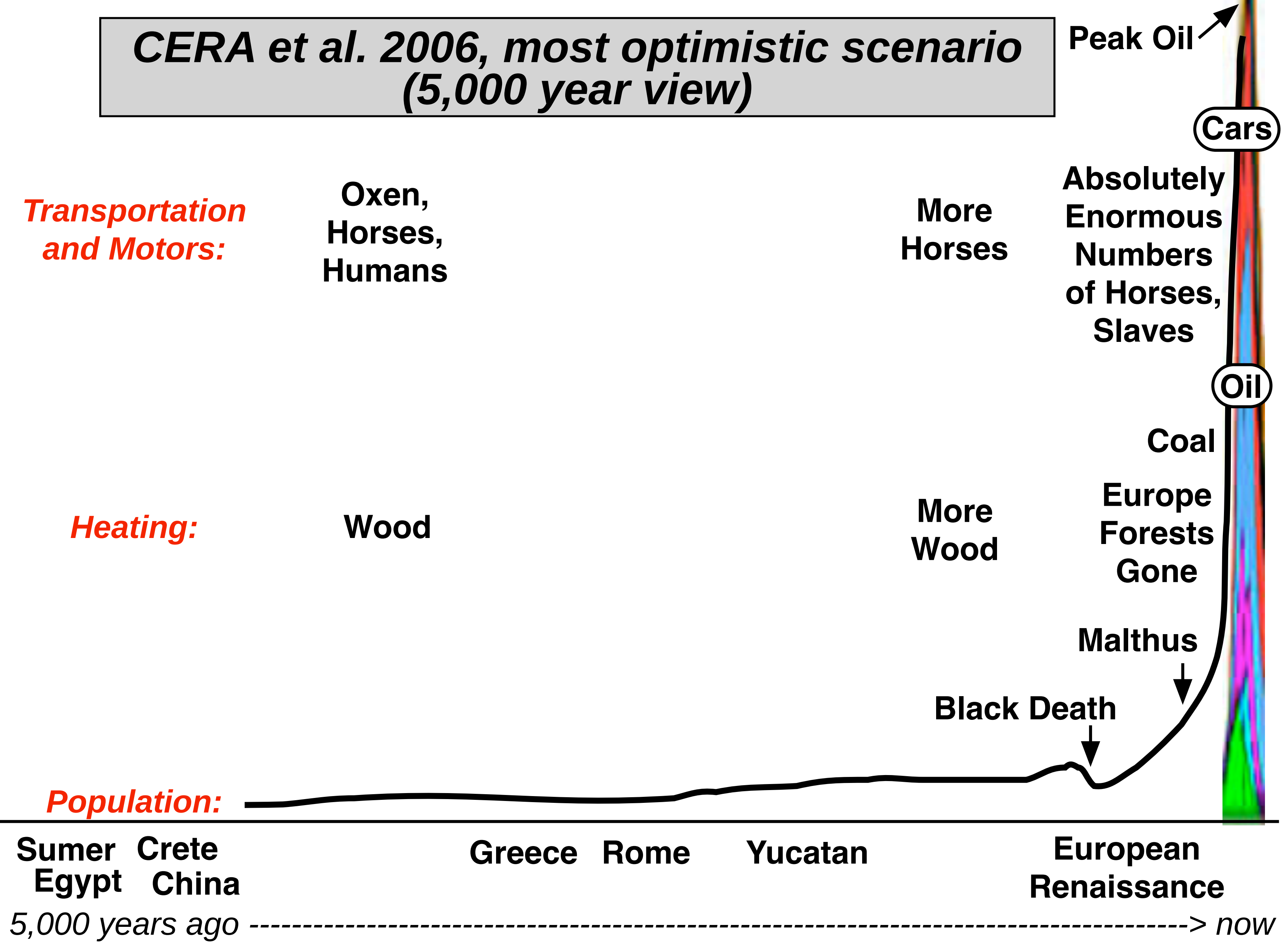
Other More Optimistic Scenarios 2006

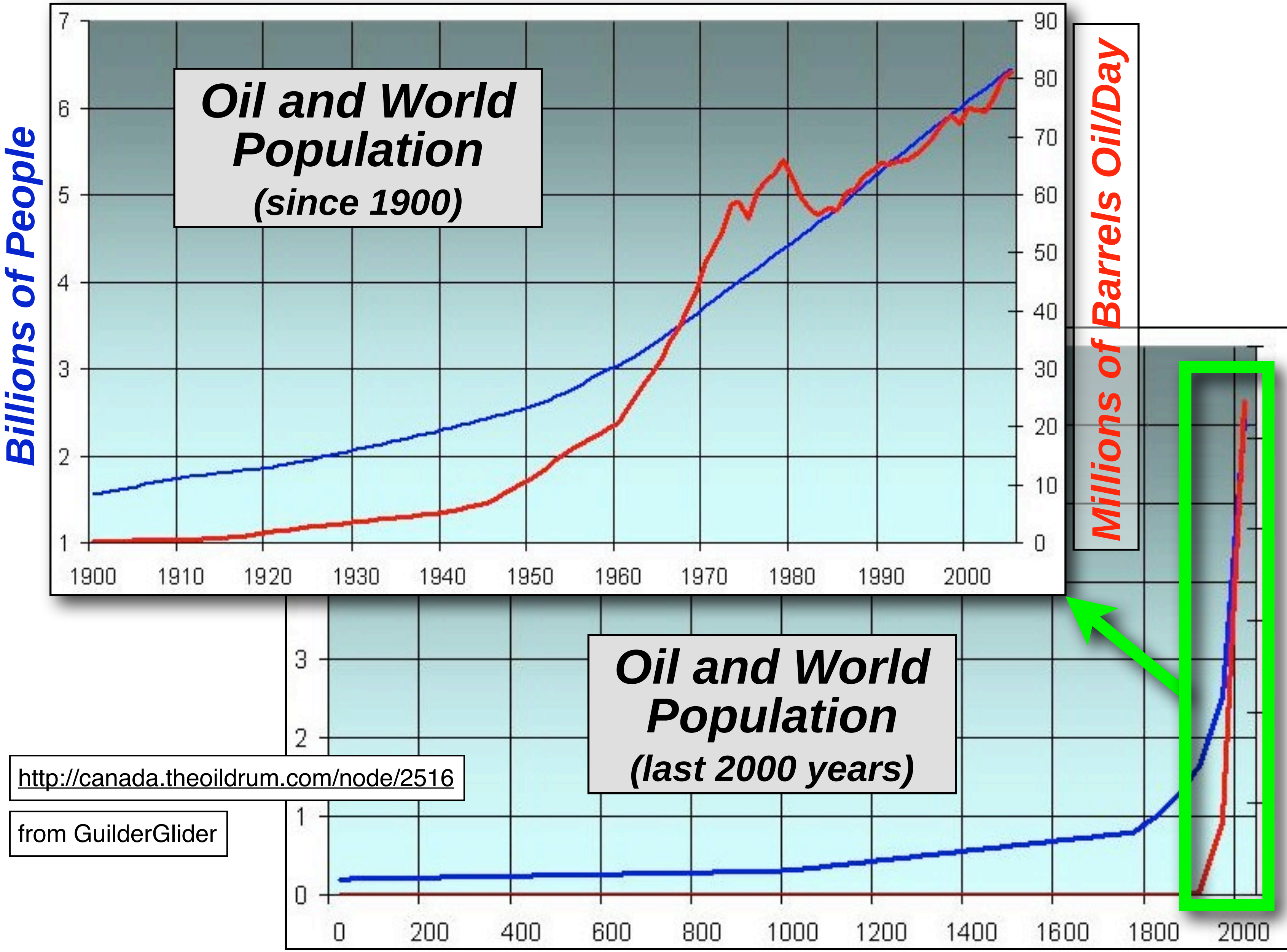





ASPO 2004, conservative scenario
(5,000 year view)
Peak Oil
Cars
Transportation and Motors:
Oxen, Horses, Humans
More Horses
Absolutely Enormous Numbers of Horses, Slaves
Oil
Coal
Heating:
Wood
More Wood
Europe Forests Gone
Malthus
Black Death
Population:
Sumer Egypt
Crete China
Greece
Rome
Yucatan
European Renaissance
5,000 years ago --> now

CERA et al. 2006, most optimistic scenario (5,000 year view)

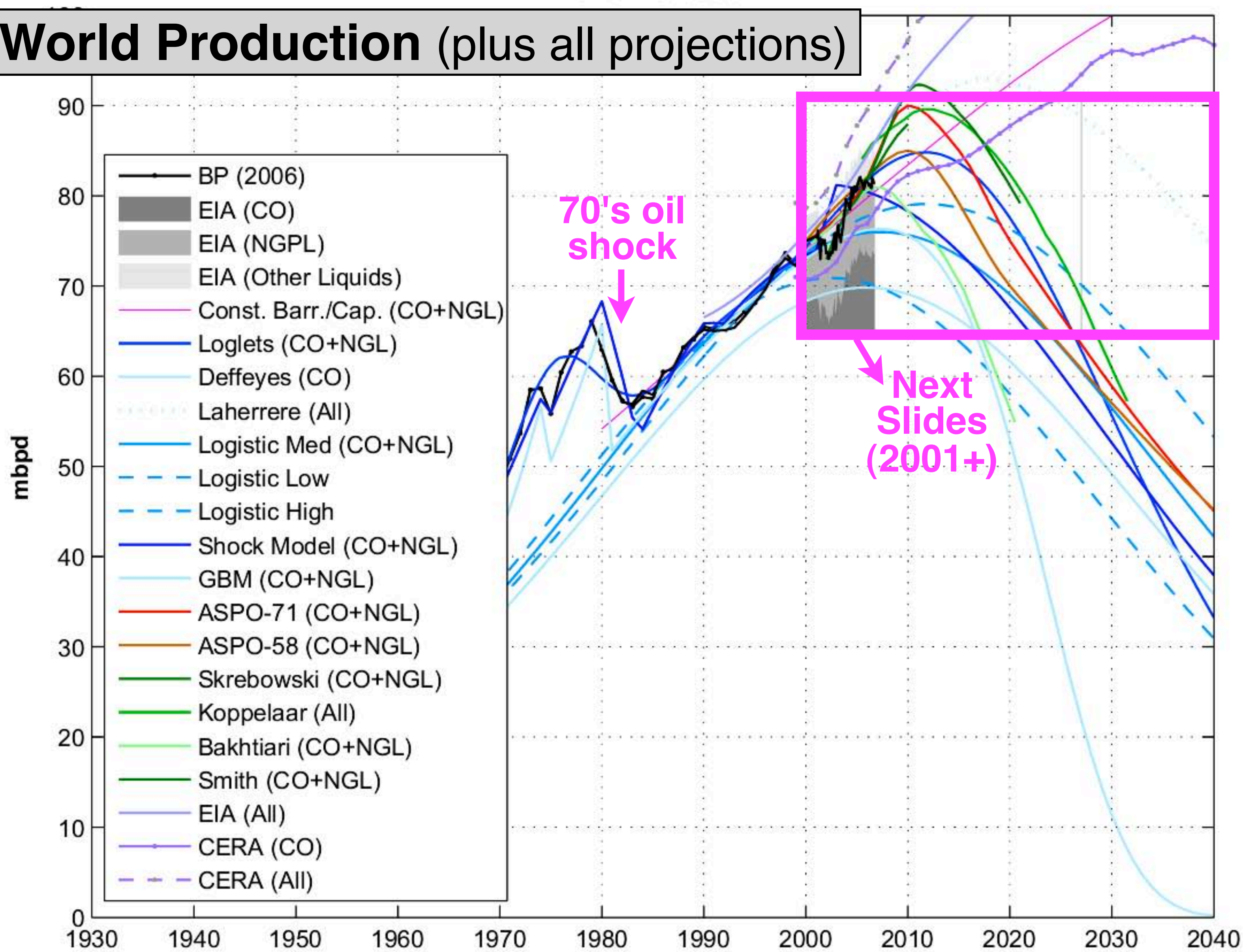



Oil and World Population
(since 1900)
Billions of People
Millions of Barrels Oil/Day
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Oil and World Population
(last 2000 years)
0
1
2
3
0
200
400
600
800
1000
1200
1400
1600
1800
2000
http://canada.theoildrum.com/node/2516
from GuilderGlider

More details about production, prediction

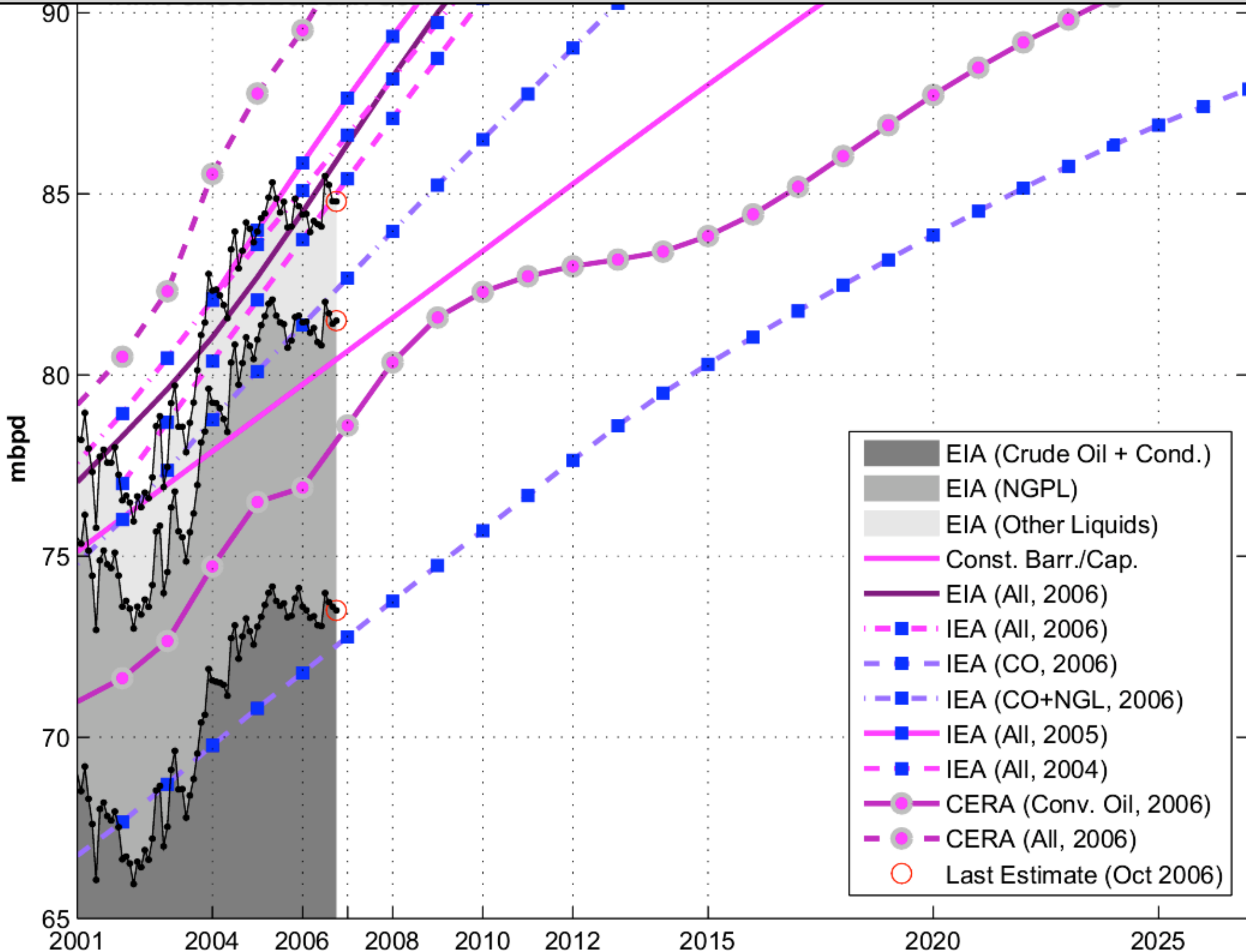
- business as usual (EIA, IEA, CERA)
- bottom-up (add producing, not-yet-in-production fields)
- curve-fitting (Hubbert, Deffeyes, Campbell, LaHerrere)
- country-by-country stacked graphs
- potential effect of tar sands

World Production (plus all projections)



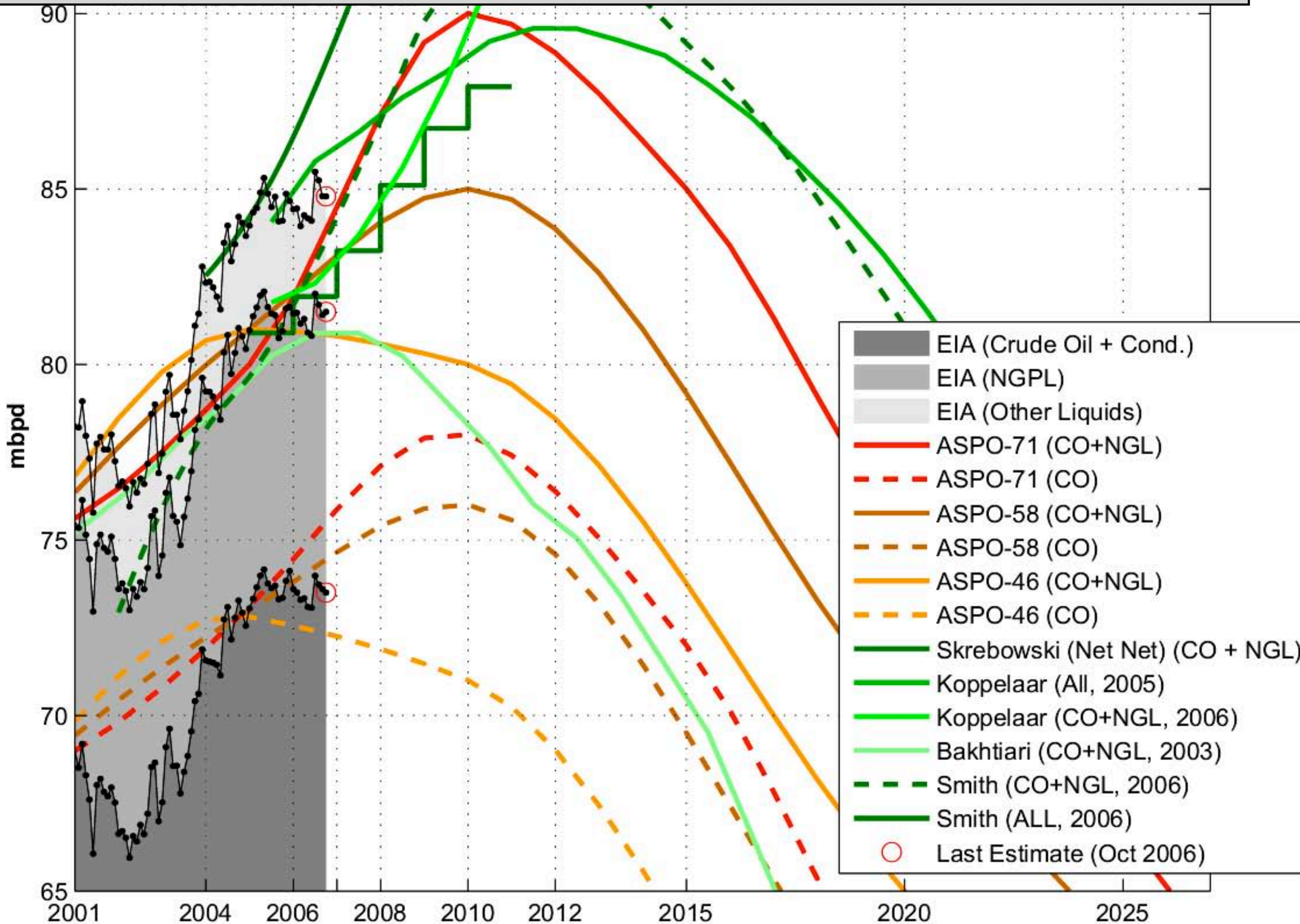
http://www.theoildrum.com/node/2143 (Jan 15, 2007)

Recent World Production (business as usual, CERA etc.)



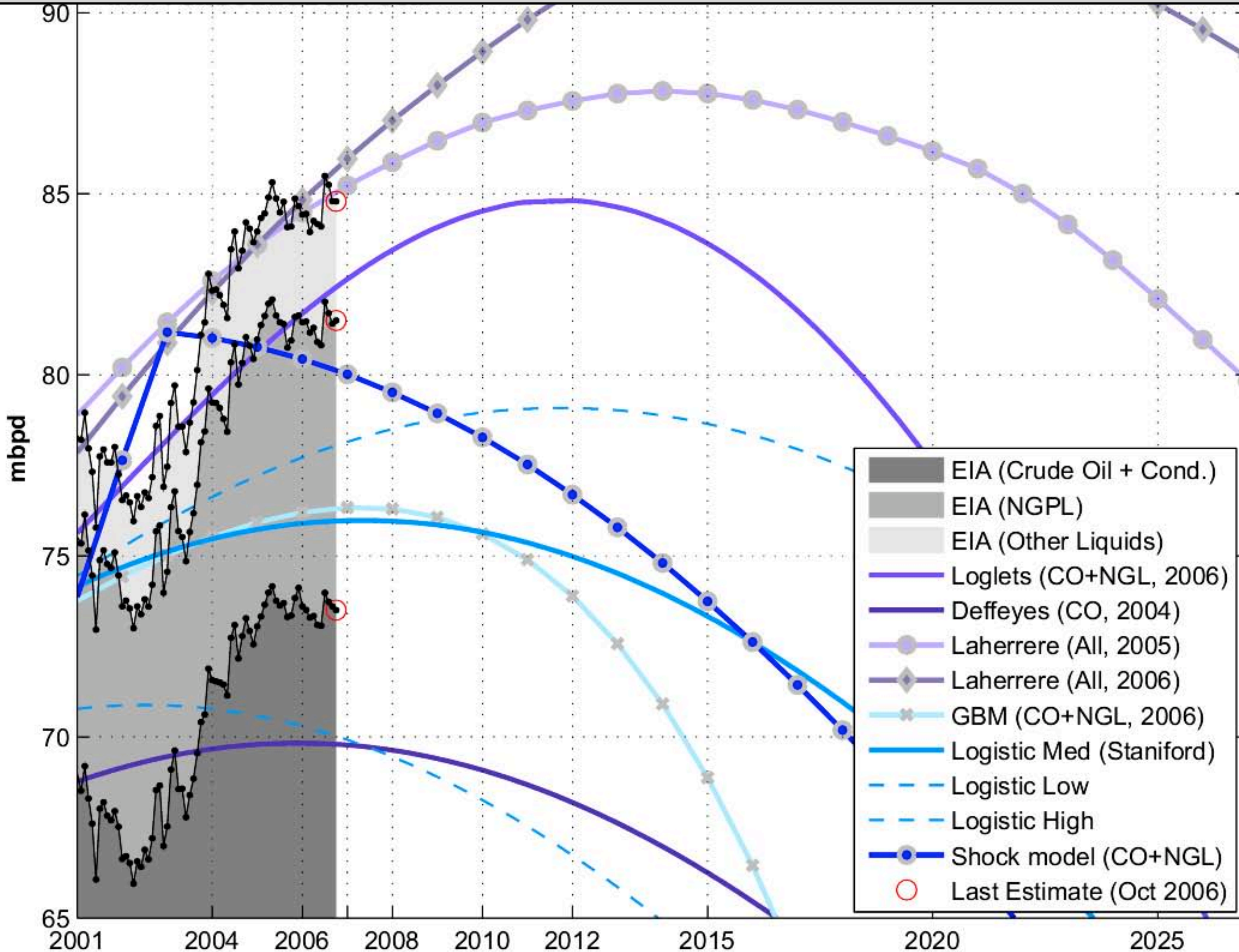
http://www.theoildrum.com/node/2143 (Jan 15, 2007)

Recent World Production (bottom-up peak-oilers)



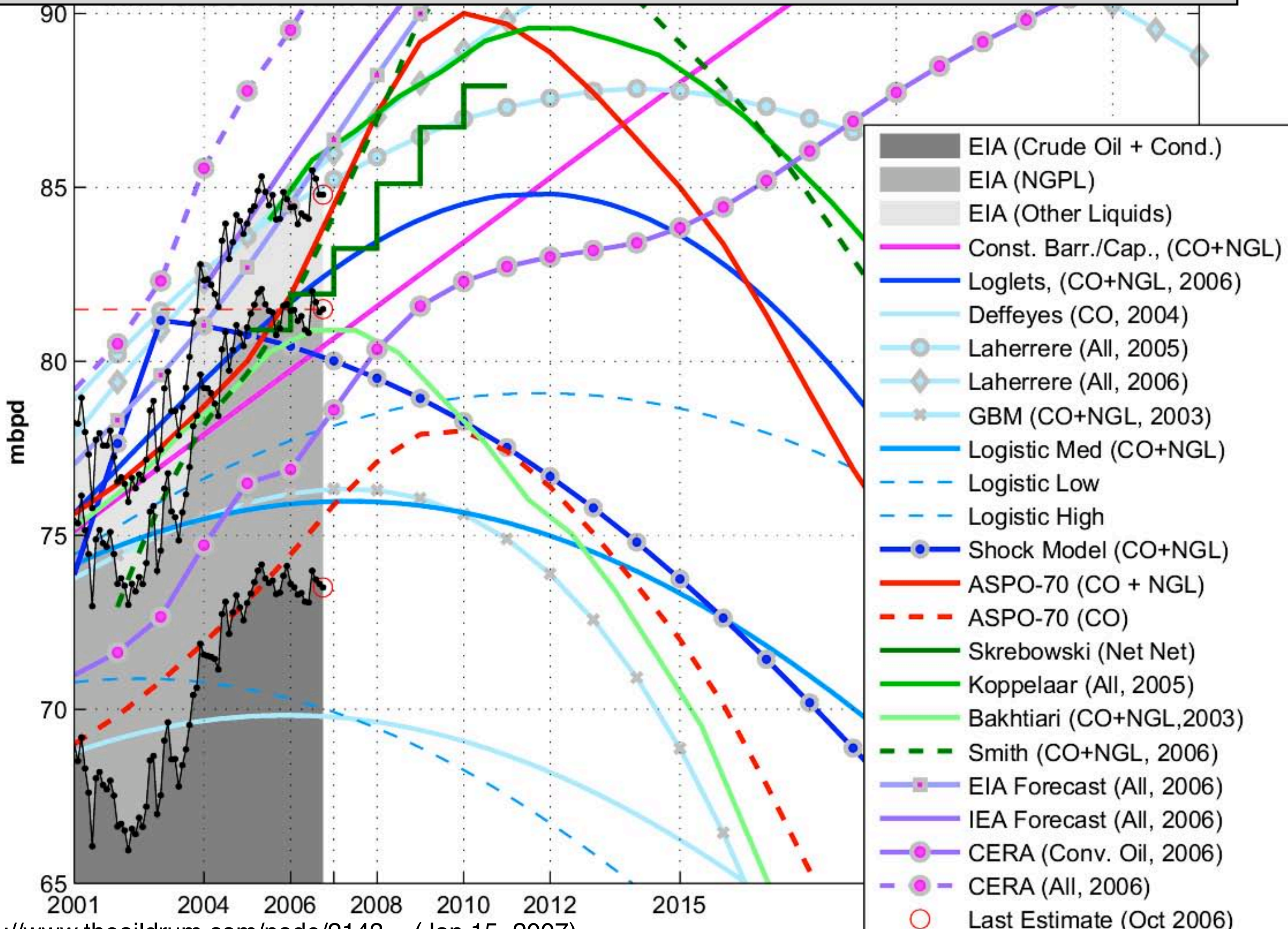
http://www.theoildrum.com/node/2143 (Jan 15, 2007)

Recent World Production (curve-fitting peak-oilers)



http://www.theoildrum.com/node/2143 (Jan 15, 2007)

Recent World Production (all projections)



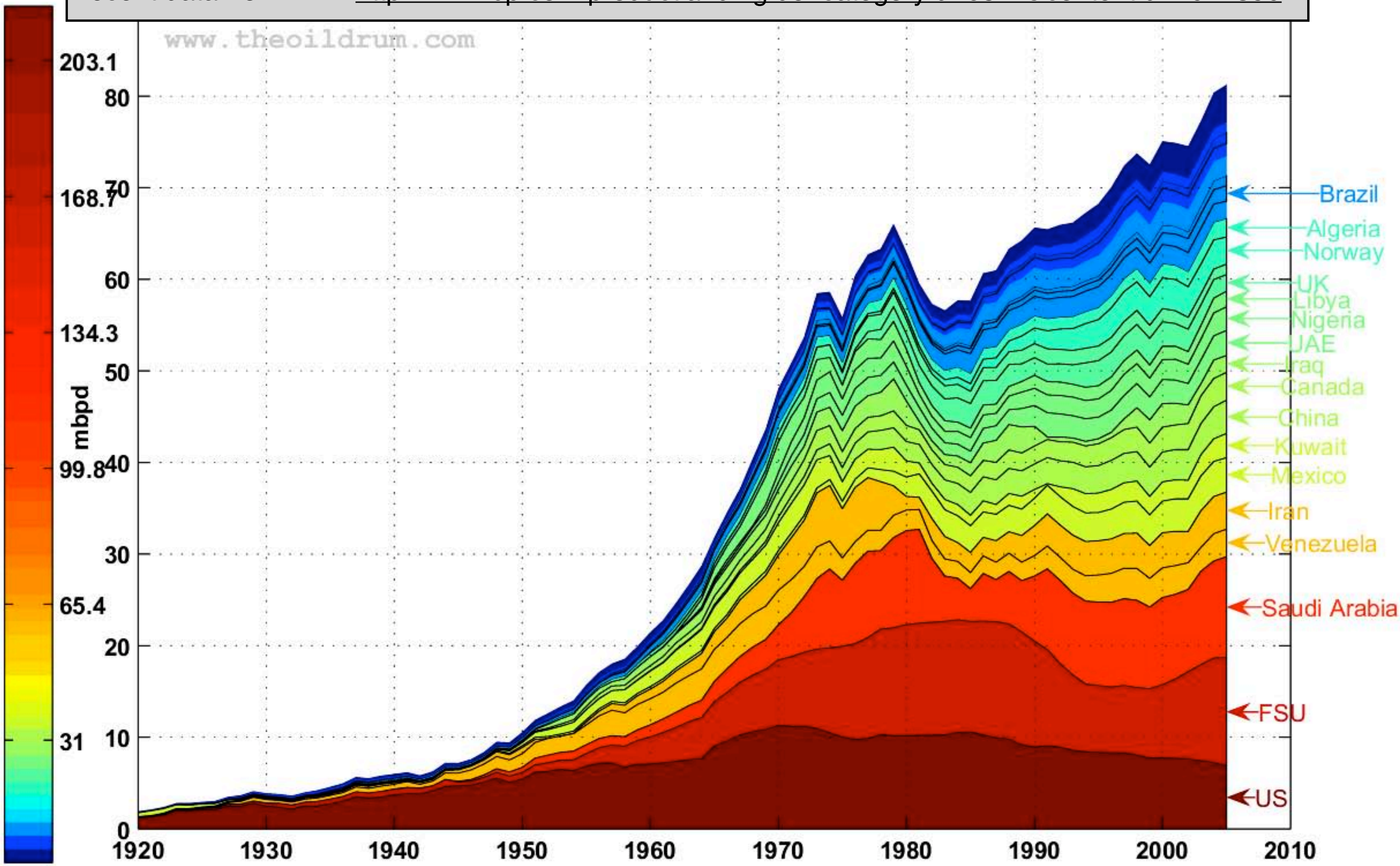
http://www.theoildrum.com/node/2143 (Jan 15, 2007)

World production crude oil + natural gas liquids

color coding -> cumulative production

graph by Khebab: http://www.theoildrum.com/story/2006/11/2/204936/516)

recent data from BP: http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390

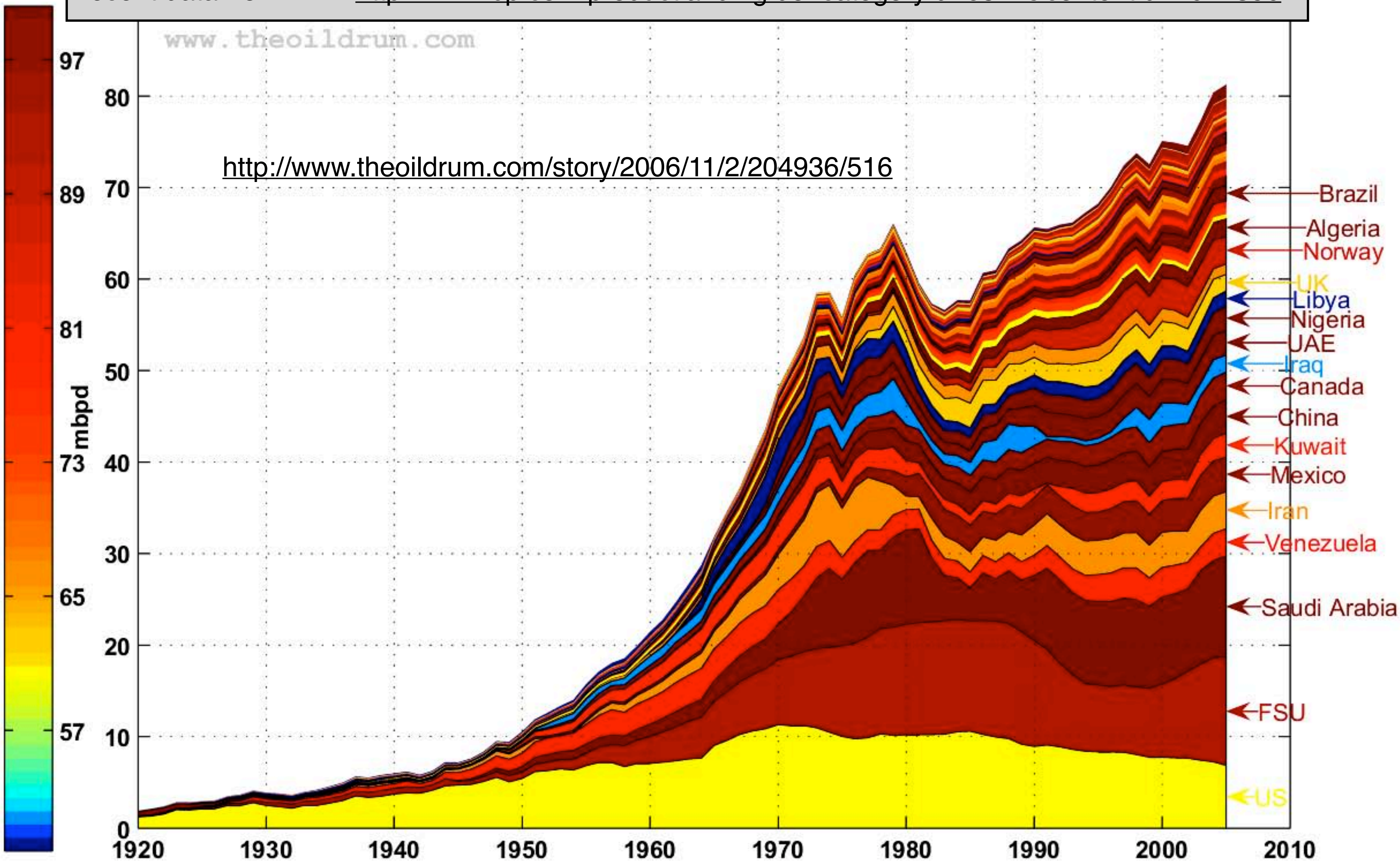


World production crude oil + natural gas liquids

color coding -> current production percent of maximum production

graph by Khebab: http://www.theoildrum.com/story/2006/11/2/204936/516)

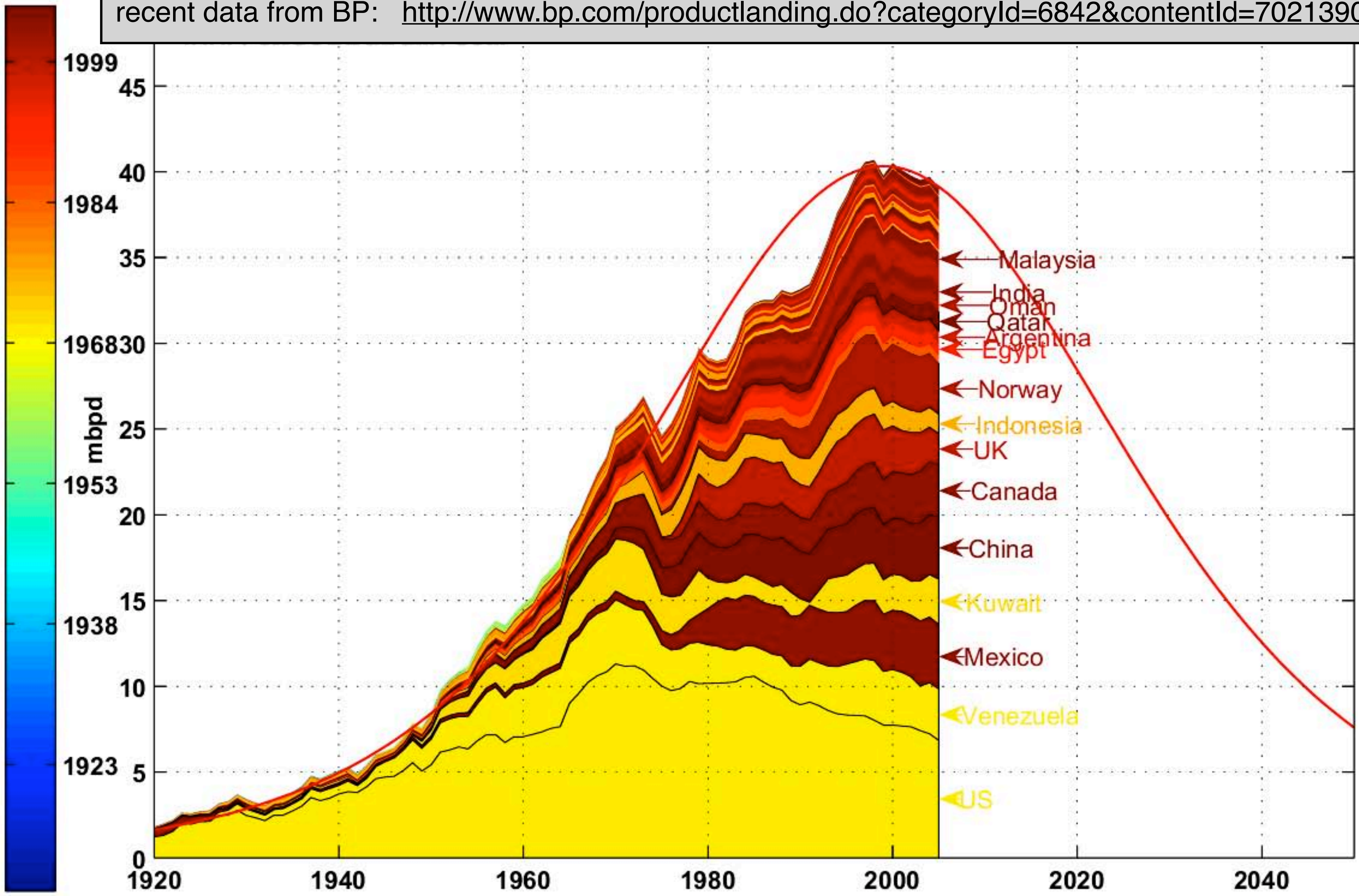
recent data from BP: http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390



Production of countries that have peaked

color coding -> year of peak production

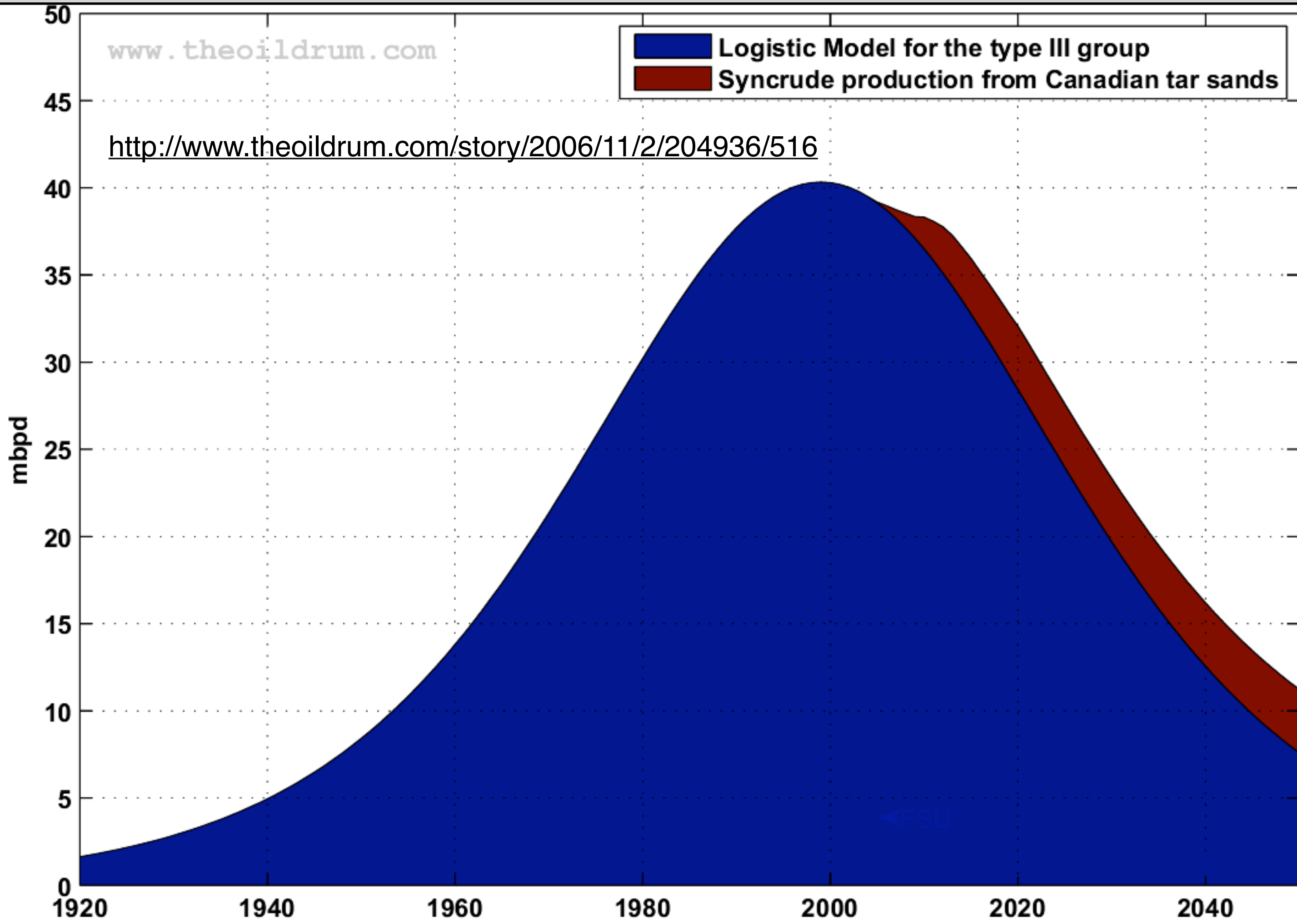
graph by Khebab: http://www.theoildrum.com/story/2006/11/2/204936/516)
recent data from BP: http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390



Color coding: peak year

Potential Impact of Canadian Tar Sands (high case)

graph by Khebab: http://www.theoildrum.com/story/2006/11/2/204936/516)
recent data from BP: http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390



Basic Energy Facts Everybody Should Know

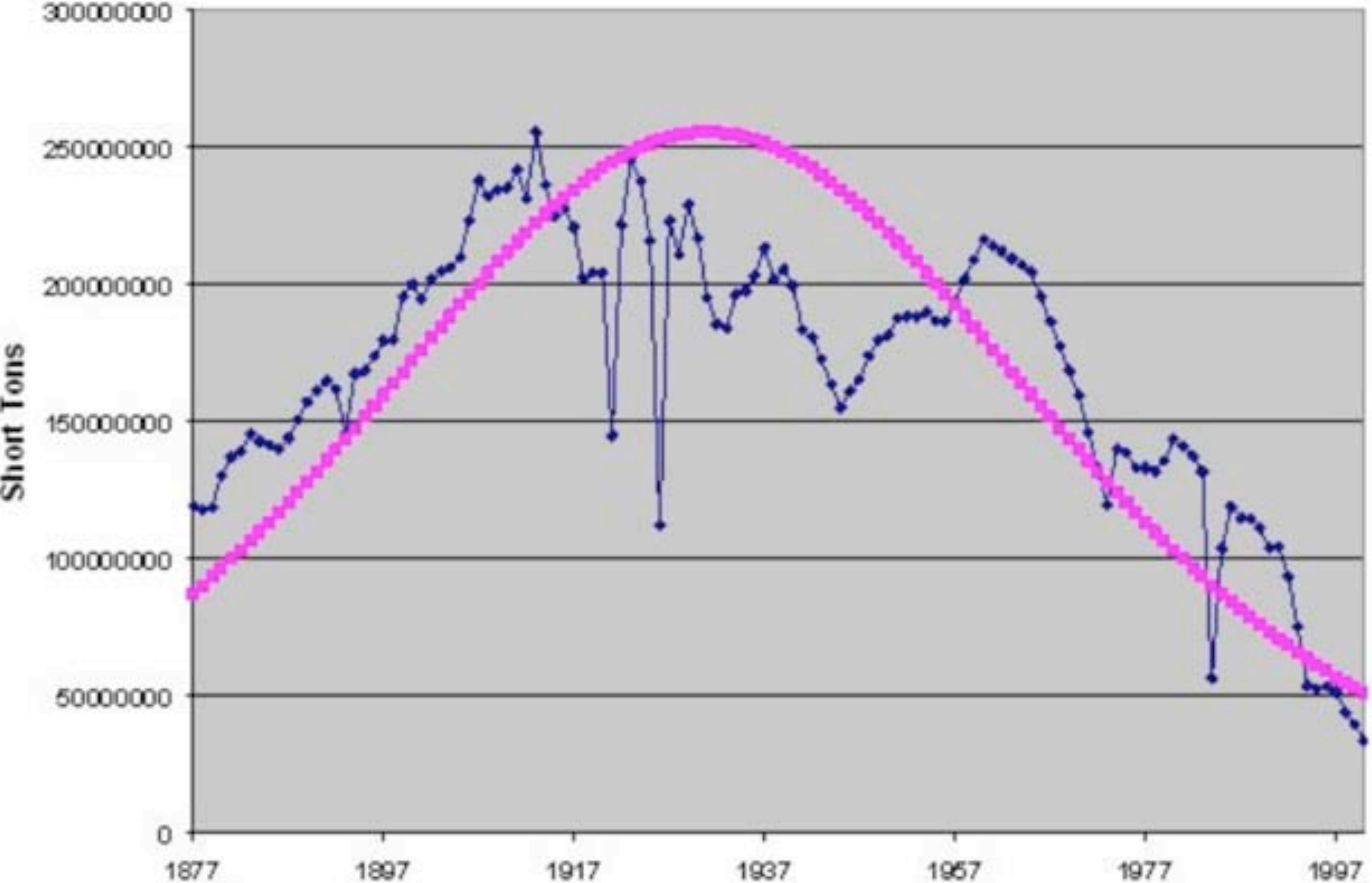
- oil and gasoline are extremely energy-dense & convenient
- a car is a ***100,000 watt device*** (accelerating a 130 hp car is like turning on 1,000 one hundred watt light bulbs)
- manufacturing a car uses ***substantial fraction of the oil*** car uses in its entire lifetime (also: 100,000 gallons of water)
- one gallon of gas (2.84 kg) contains ***36 kW-hours*** of energy (before losses), enough to power a small house for 1 week
- ***one barrel*** of oil = ***one year*** hard physical labor by a human (25%-efficiency gas *vs.* 6 hours 128 watts continuous/day)
- batteries have low energy-density (Prius NiMH battery is 0.07 kW-hours/kg – ***1/45*** that of 25%-efficiency-gasoline)
- solar radiation is ubiquitous but has ***very*** low energy density
- a “one kilowatt” photocell covers 100 sq feet and generates ***3-4 kW-hours*** of usable power per day (=about 1/10 gal. gasoline); must be used as generated or stored with loss
- the deployed military is 70% fossil fuel by weight
- current per capita US energy use: ***250 kWh/day***

Possible Replacements – Fossil Fuel Sources

- ***oil*** *(currently: 40% US energy)*
- ***coal*** *(currently: 22% US energy)*
  - may peak 2030, then reach EROEI=1.0 before all gone
  - mercury in fish from burning coal; 2x CO_2 of oil/gas
  - coal bed methane production growing but water intensive
- ***natural gas*** *(currently: 23% US energy)*
  - world peak later than oil, but NorthAmerican peak passed
  - requires energy-intensive cooling/liquification to transport
- ***oil/tar sands*** *(currently: small portion of oil imports)*
  - two tons *best* sand make 1 barrel oil (14:1 weight ratio)
  - sands must be dug, heated, washed (EROEI 1.0-3.0)
- ***oil shale*** *(currently: 0%)*
  - EROEI worse than oil/tar sands, maybe below 1.0
- ***methane hydrates*** *(currently: 0%)*
  - reserves unknown, extraction methods unknown
  - may outgas on their own with arctic melting

UK Coal Production

(why Newcastle has to have coal carried to it)

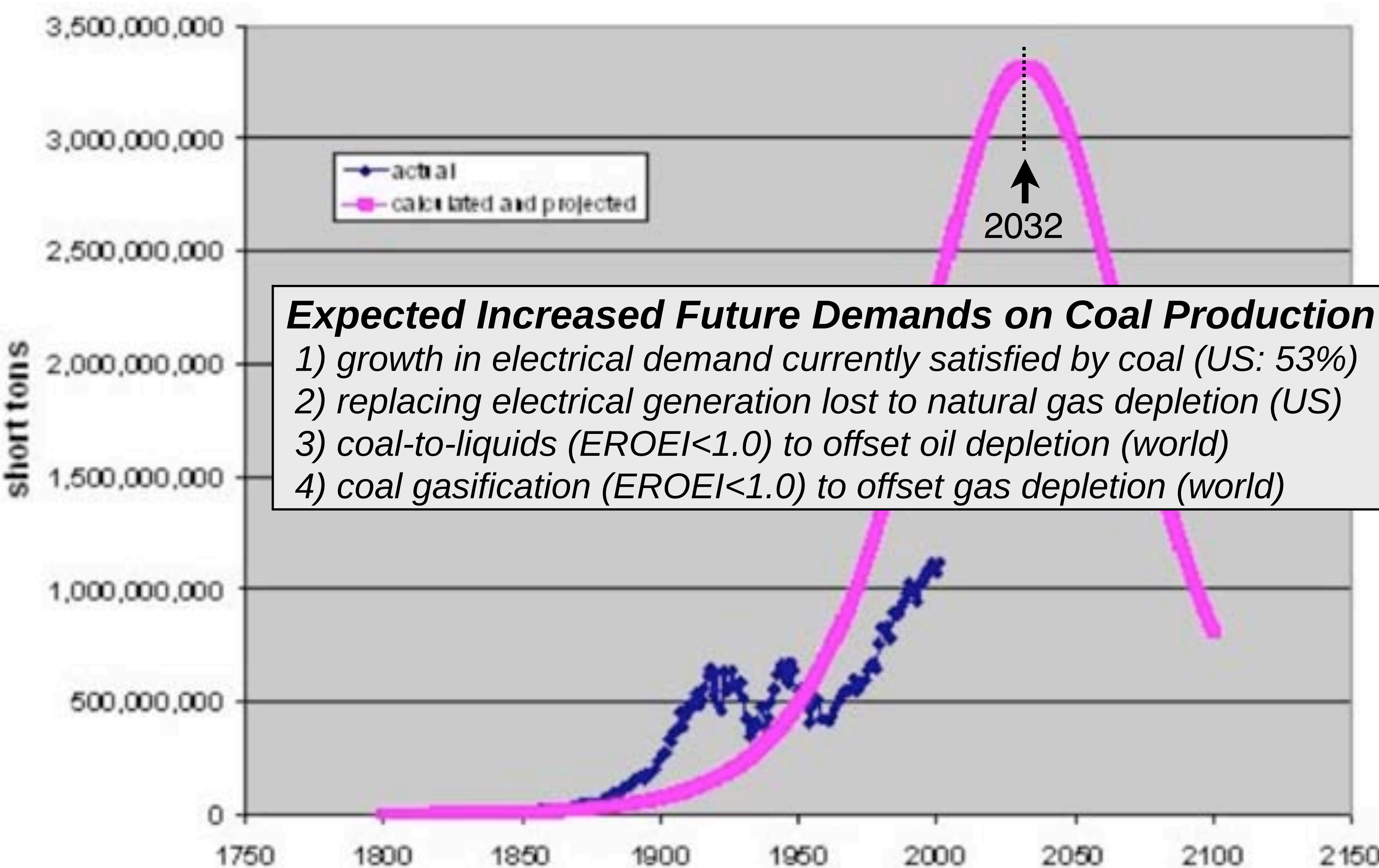


From Gregson Vaux

http://www.fromthewilderness.com/free/ww3/052504_coal_peak.html

World Coal Production

Hubbert curve using (generous) EIA reserves estimates



Expected Increased Future Demands on Coal Production

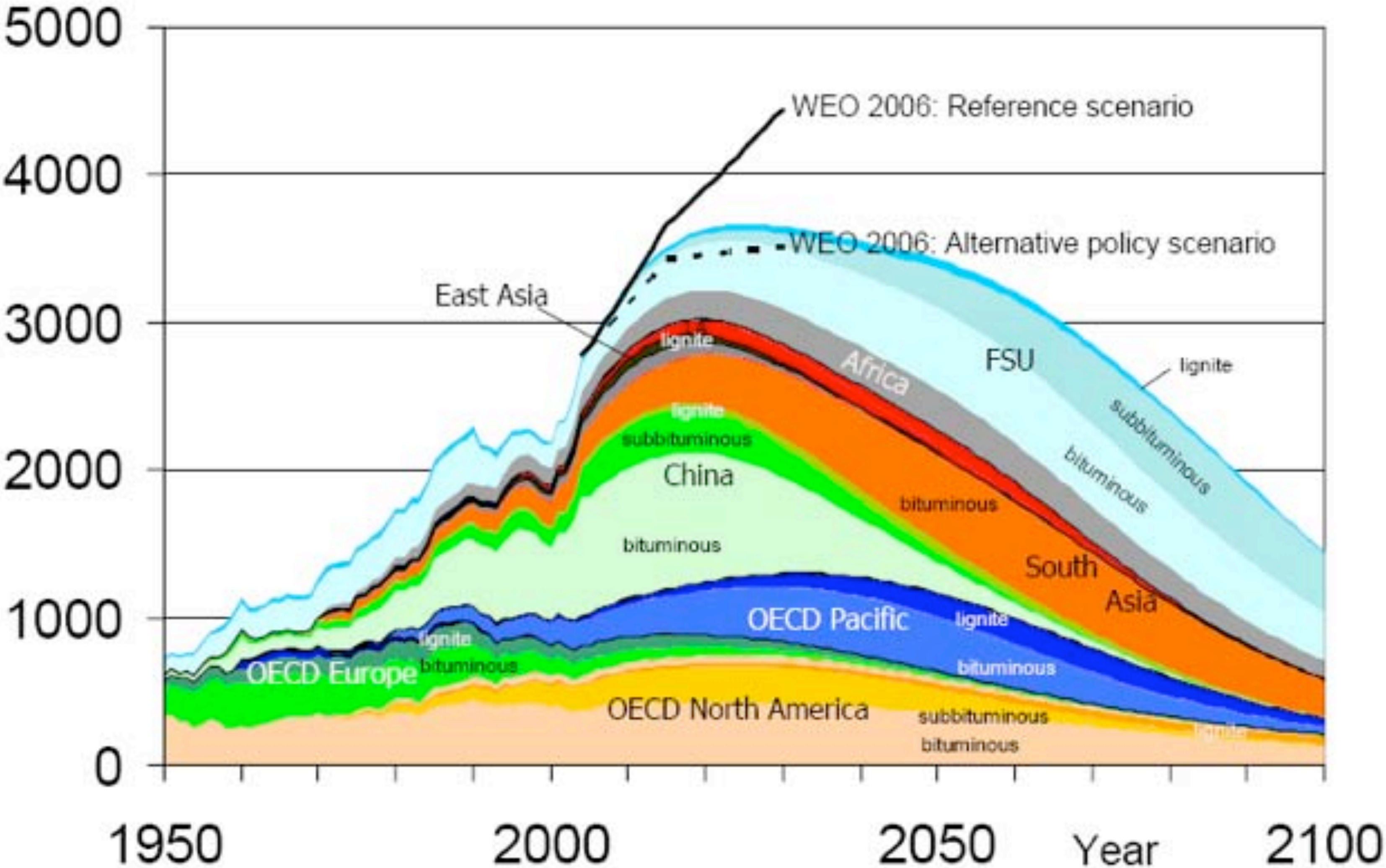
1) growth in electrical demand currently satisfied by coal (US: 53%)
2) replacing electrical generation lost to natural gas depletion (US)
3) coal-to-liquids (EROEI<1.0) to offset oil depletion (world)
4) coal gasification (EROEI<1.0) to offset gas depletion (world)

From Gregson Vaux (2005)

http://www.fromthewilderness.com/free/ww3/052504_coal_peak.html

World Coal Production

a 2020 peak from the Energy Watch Group (2007)



http://www.energywatchgroup.org/files/Coalreport.pdf

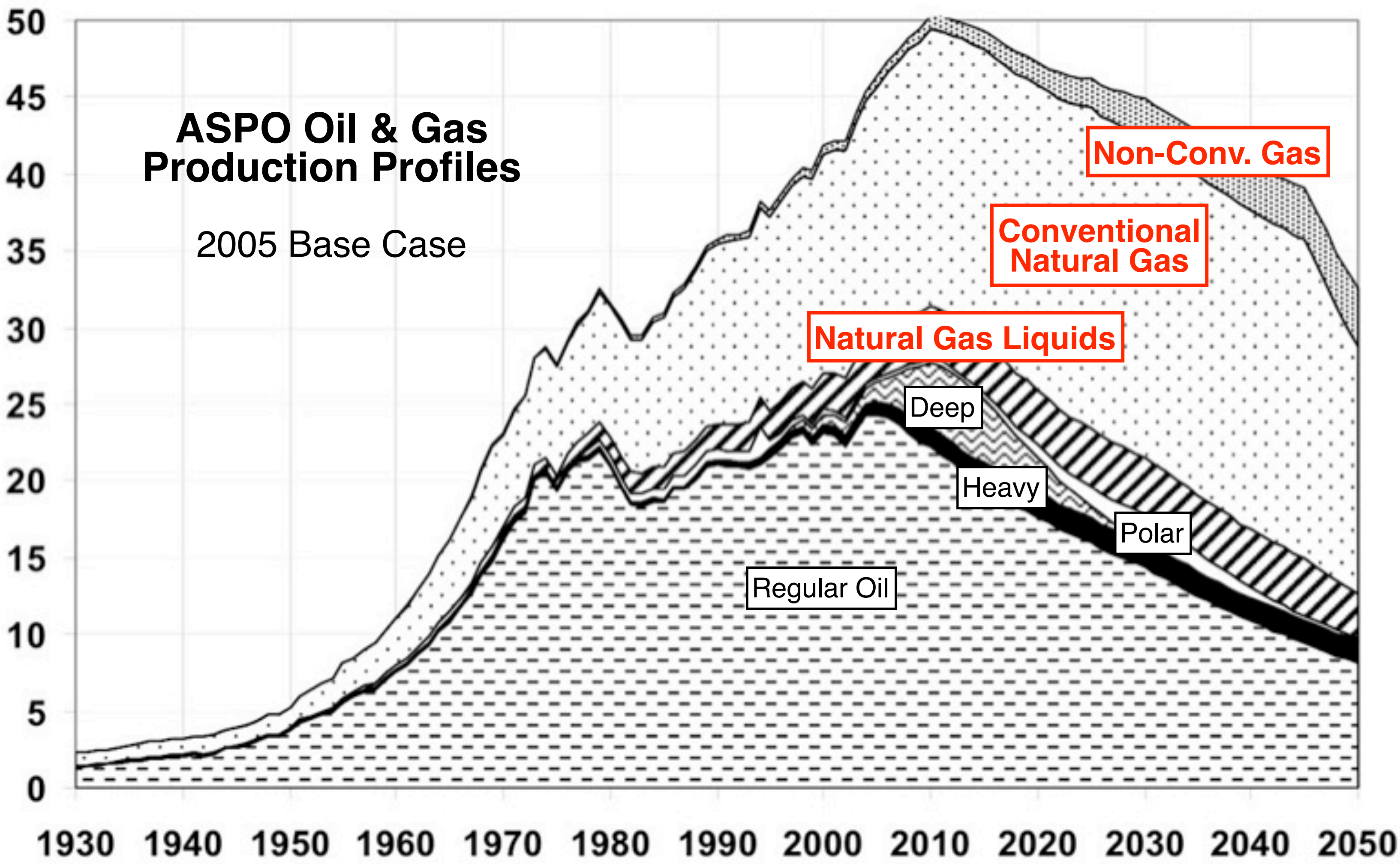
Coal Mining & Burning *(curr: 22% total US energy)*

- burning coal (without carbon sequestration) generates 2X as much CO_2 per unit energy as burning oil or natural gas
- coal-to-liquids and coal gasification generate more CO_2 than burning the coal directly (EROEI<1.0 for both)
- carbon and mercury sequestration requires additional energy and will speed approach to EROEI=1.0
- a large number of new coal electric and coal-to-liquids plants are currently being commissioned and planned, most without sequestration

45,000 ton Krupp earth-mover crossing a highway
in Germany en route to an open-pit coal mine

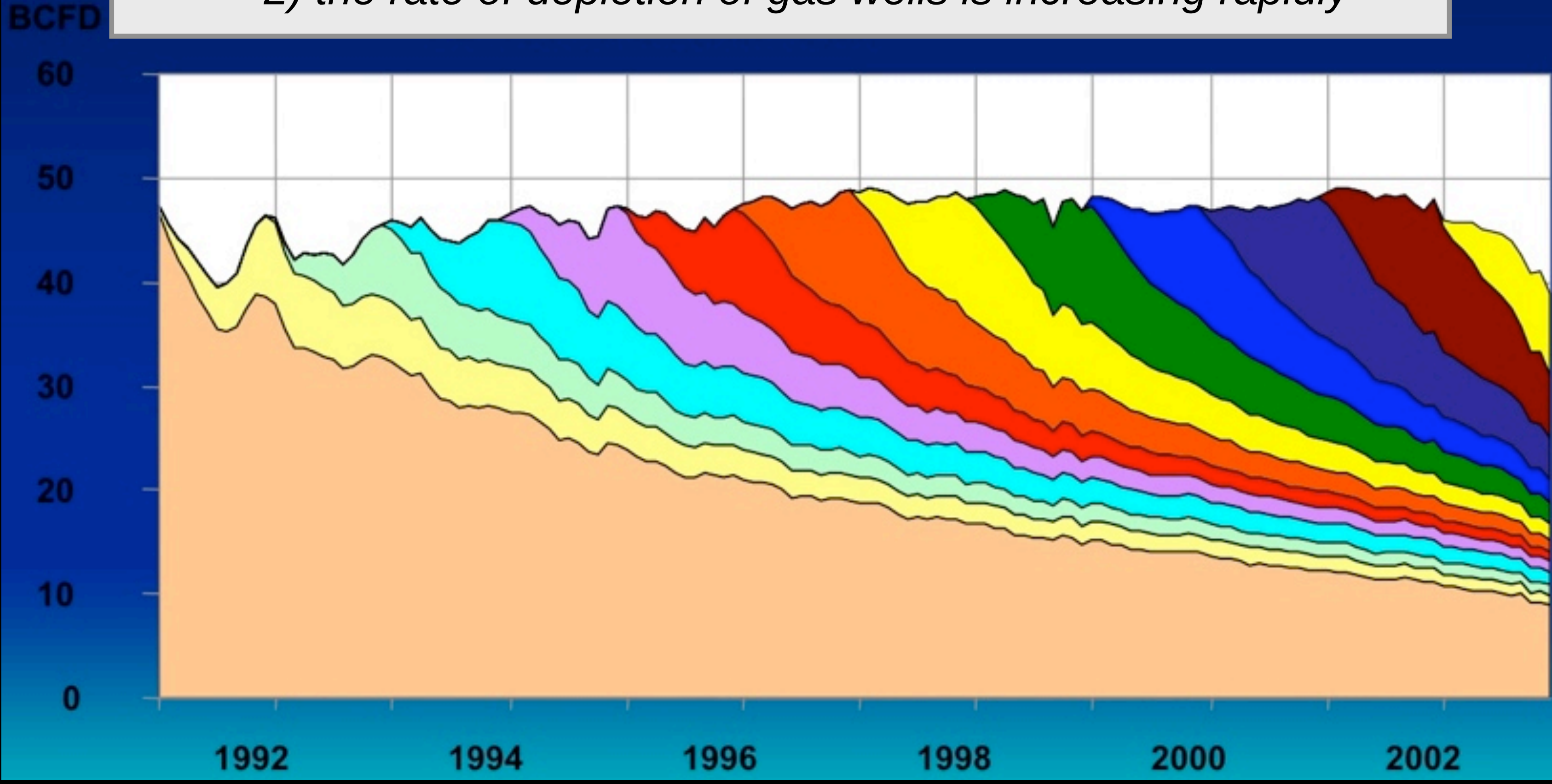
World Gas Production

Total gas peak is later than oil (~2035)
*but **combined** gas+oil peak **soon** (~2010)*



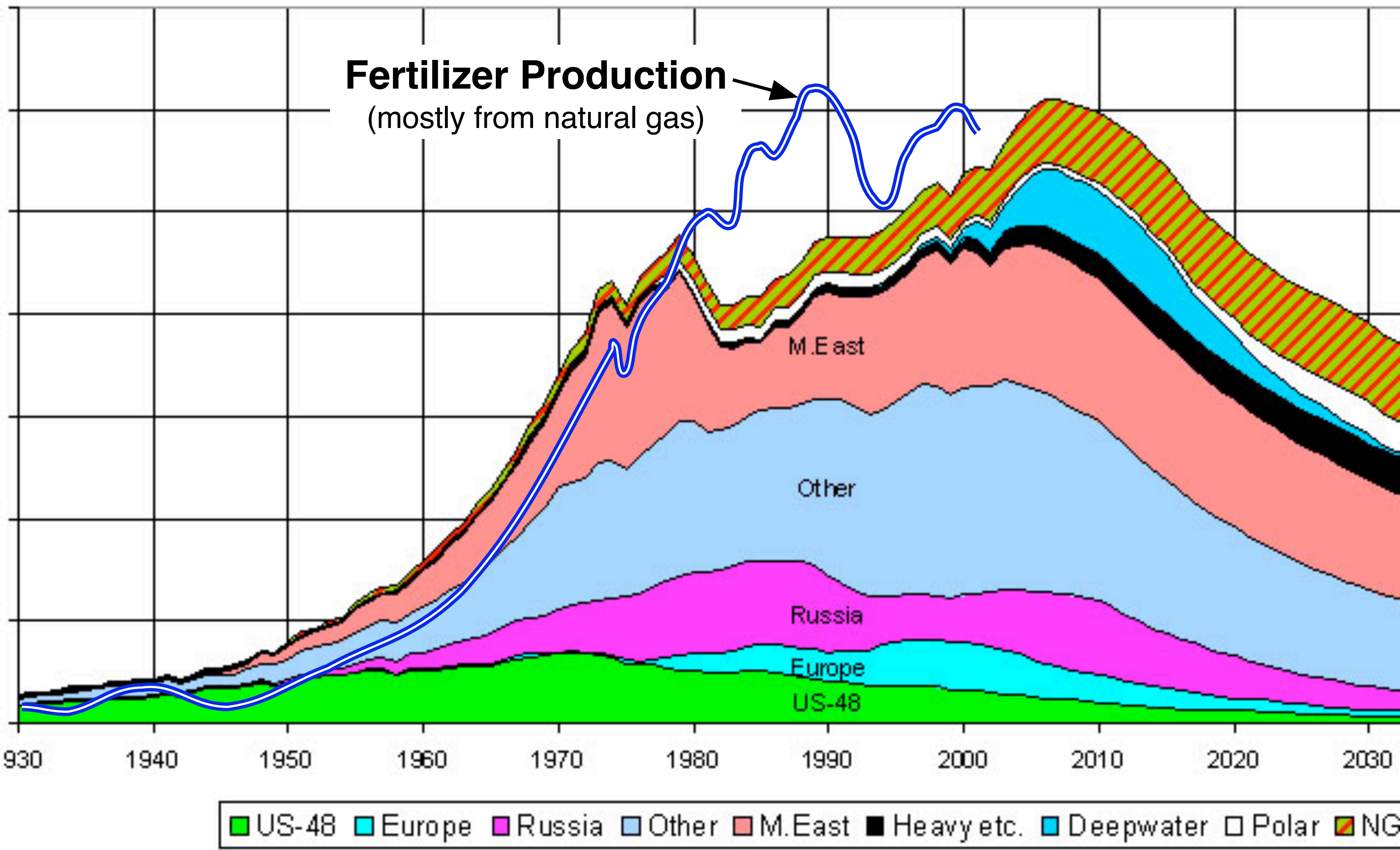
Depletion of US Gas Wells in the Lower 48 States (wet gas by year of start)

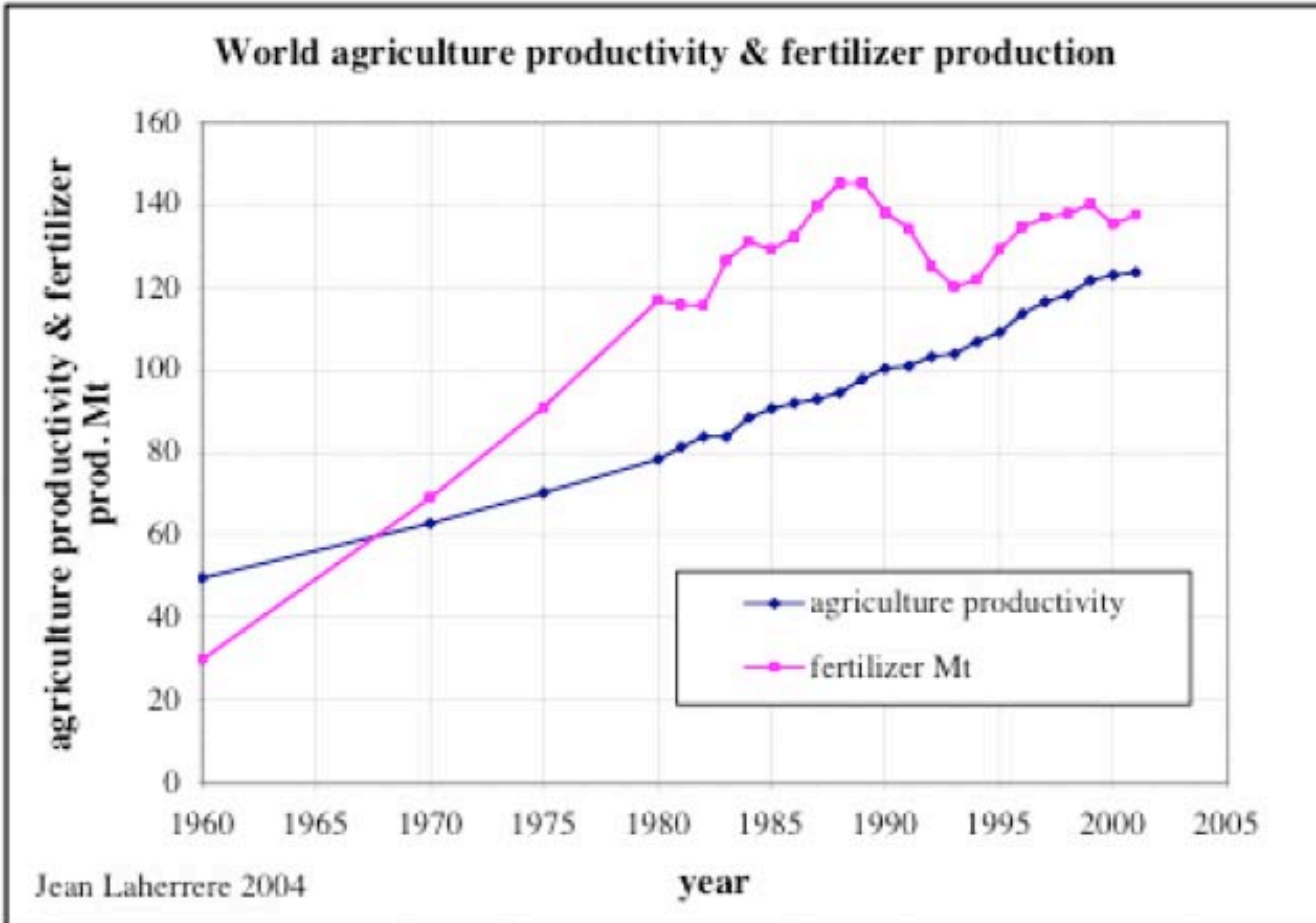
1) gas wells deplete more rapidly than oil wells
2) the rate of depletion of gas wells is increasing rapidly

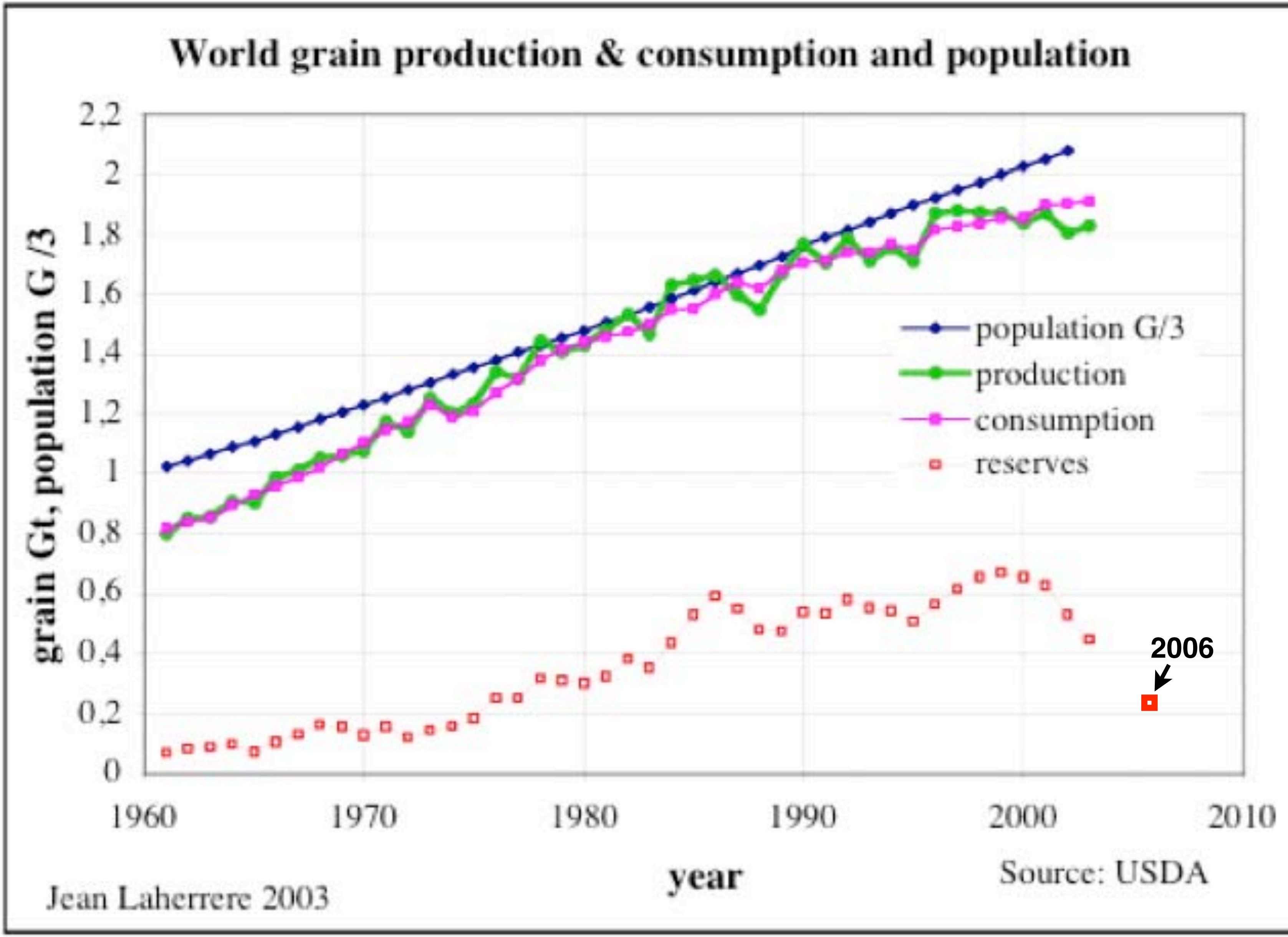


from David Maul http://www.energy.ca.gov/papers/2004-10-27_MAUL_GASOUTLOOK.PDF

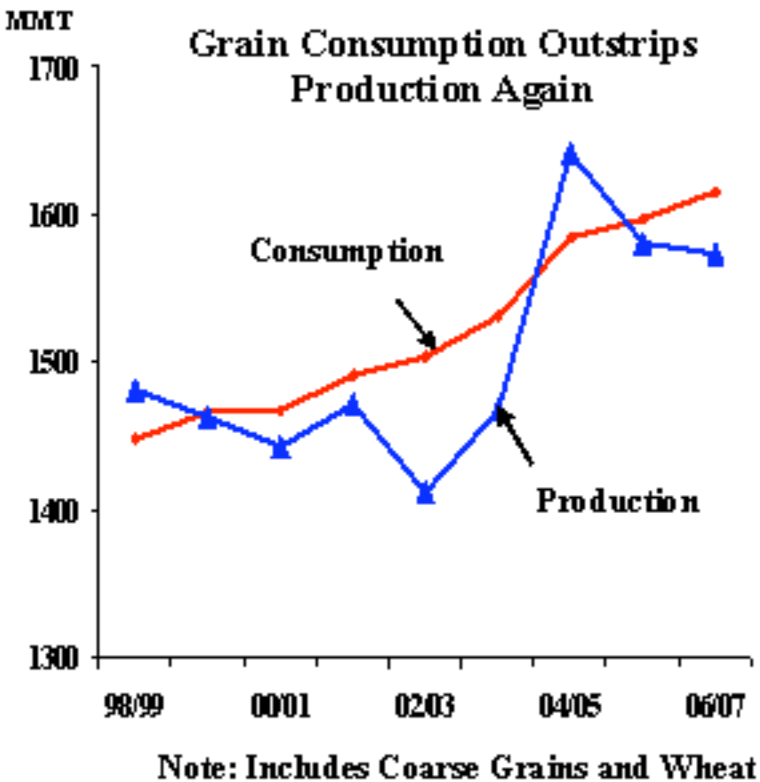
Oil and Natural Gas are Critical to Current World Food Production

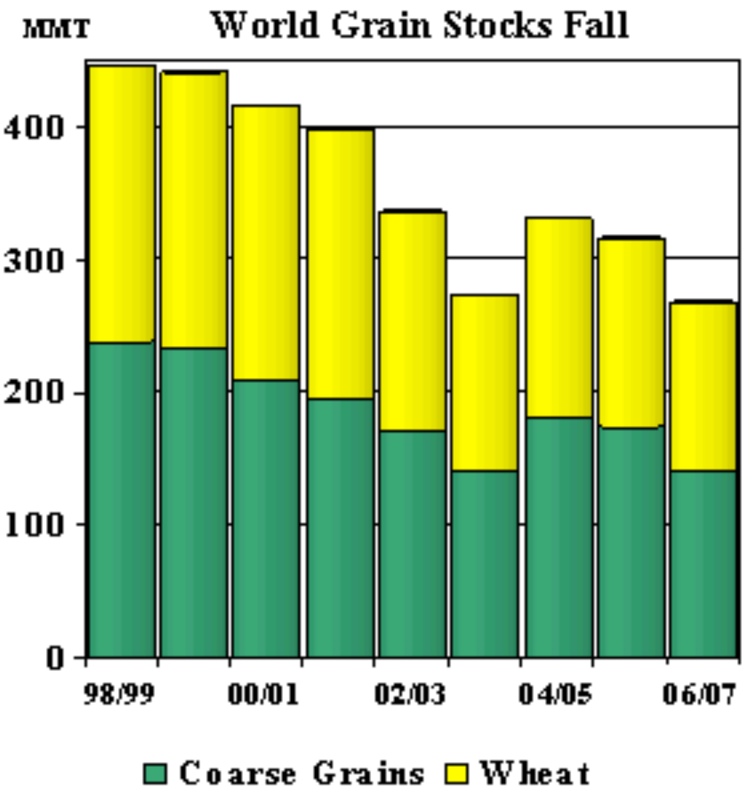



World agriculture productivity & fertilizer production
agriculture productivity & fertilizer prod. Mt
160
140
120
100
80
60
40
20
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
agriculture productivity
fertilizer Mt
Jean Laherrere 2004
year


World grain production & consumption and population
grain Gt, population G /3
2,2
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1960
1970
1980
1990
2000
2010
year
population G/3
production
consumption
reserves
2006
Source: USDA
Jean Laherrere 2003

Grain Consumption is Outstripping Production





http://www.fas.usda.gov/grain/circular/2006/05-06/graintoc.htm

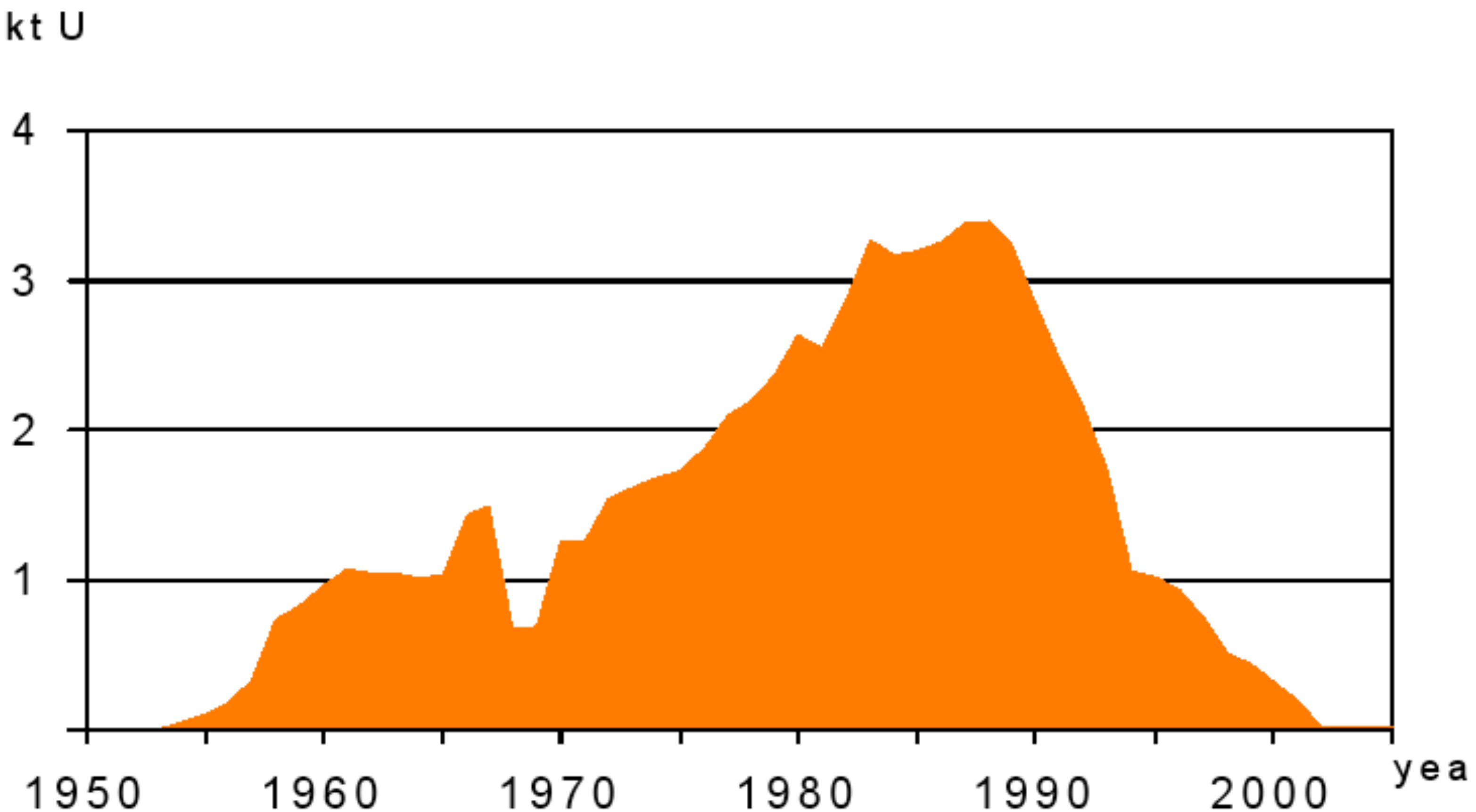
Hydrogen is Not an Energy Source

- more energy used in making hydrogen than you get out of it
- currently made from natural gas (50% loss chemical energy)
- can be made from oil (>50% loss)
- can be made (along with CO) from coal (65% loss)
- compression to 12,000 psi uses additional energy (15% loss)
- energy density still 1/3 that of gasoline (remember Avogadro)
- tanks leak (H is tiny); unburnt hydrogen is a greenhouse gas
- 4x as much energy needed to pump hydrogen vs. natural gas
- can be stored as metal hydride, but with 70% loss of energy
- fuel cells use expensive metals and have reliability problems
- **Concl.: hydrogen is a bad choice, even as energy carrier**

Possible Replacements – Nuclear Sources

- ***nuclear fission*** *(currently: 7.5% total US energy)*
  - making fuel is energy-intensive
  - 1960's EROEI for fissionable uranium < 1.0 (because of diversion to weapons and sale as nuclear reactor fuel to other countries)
  - uranium a non-renewable resource and in scarce supply
  - breeder reactor technology still not practical after 40 yrs.
- ***nuclear fusion*** *(currently: 0%)*
  - current test beds demonstrating magnetically confined plasma fusion require helium for superconducting coils
  - helium comes from oil and gas wells and cannot be made now (though some could be made in a hypothetical continuously running fusion reactor)
  - a practical continuous-energy-generating fusion demo still several decades away (same prediction in 1980!)

Uranium production in France
(produces majority of its electricity from uranium)

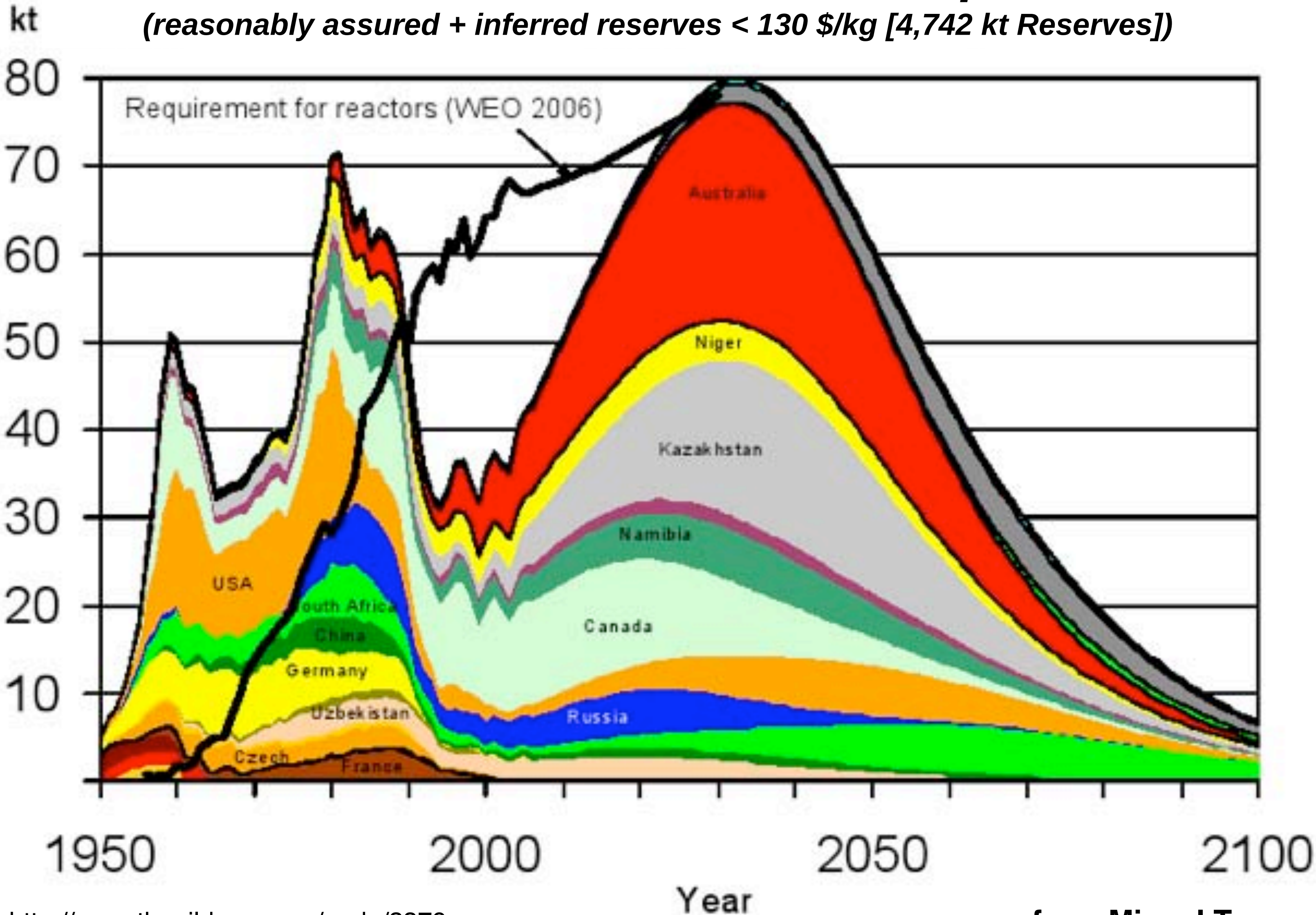


http://www.theoildrum.com/node/2379

from Miquel Torres

World Uranium Production and Requirements

(reasonably assured + inferred reserves < 130 $/kg [4,742 kt Reserves])



http://www.theoildrum.com/node/2379

from Miquel Torres

Possible Replacements – Renewable Sources

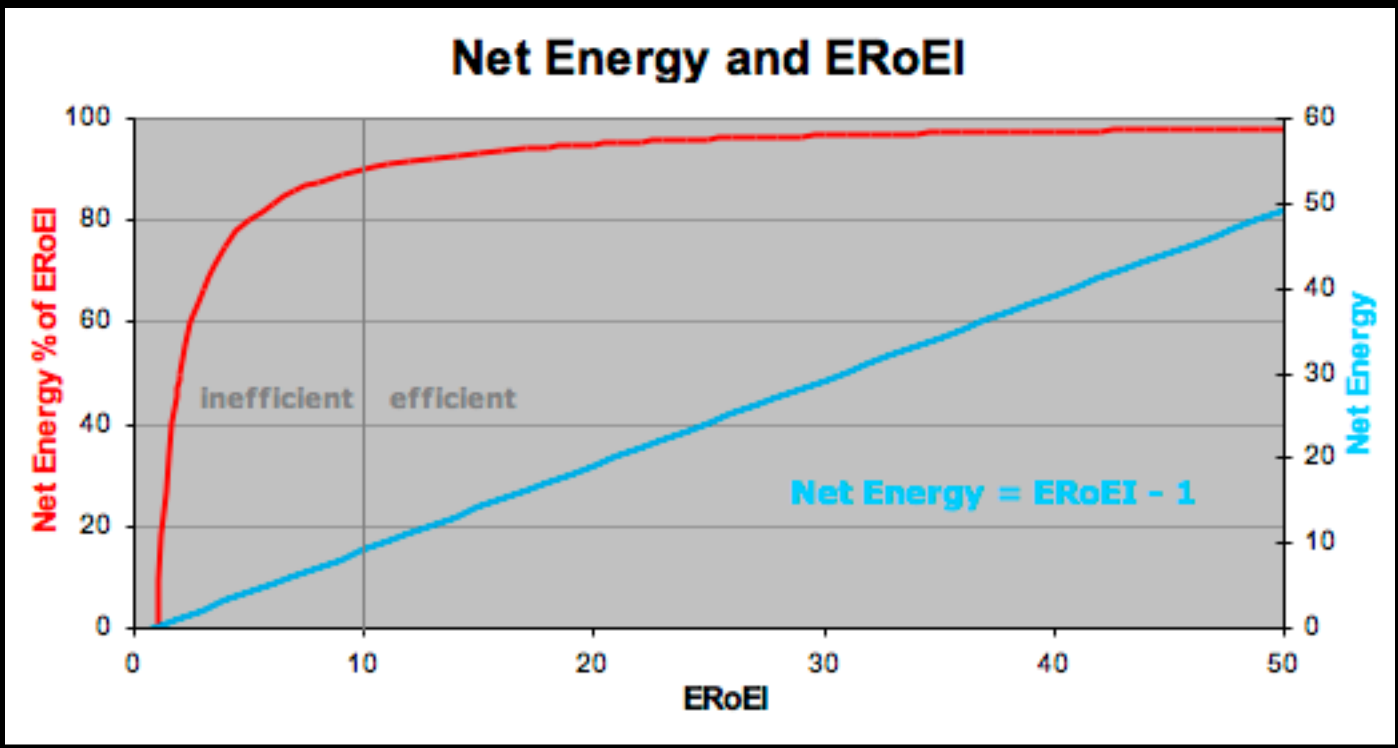
- ***hydroelectric*** *(currently: 2.3% total US energy)*
  - substantially tapped out, few new sites available
- ***wind*** *(currently: 0.07% total energy, 3% Calif. electrical)*
  - substantial growth possible in windy areas
- ***solar photovoltaic*** *(currently: 0.006% total, 1% CA electr.)*
  - costly, large: 20 kWh/day syst. is $50,000 and 500 sq ft
- ***solar heat-concentrating steam/Stirling systems***
  - possible replacement for centralized power generation
- ***local solar passive heating***
  - solar water heating systems common in 1900 before gas
- ***tides***
  - small demo systems exist
- ***solar from space, wires into space, cold fusion***
  - among other possibilities, none with practical demo

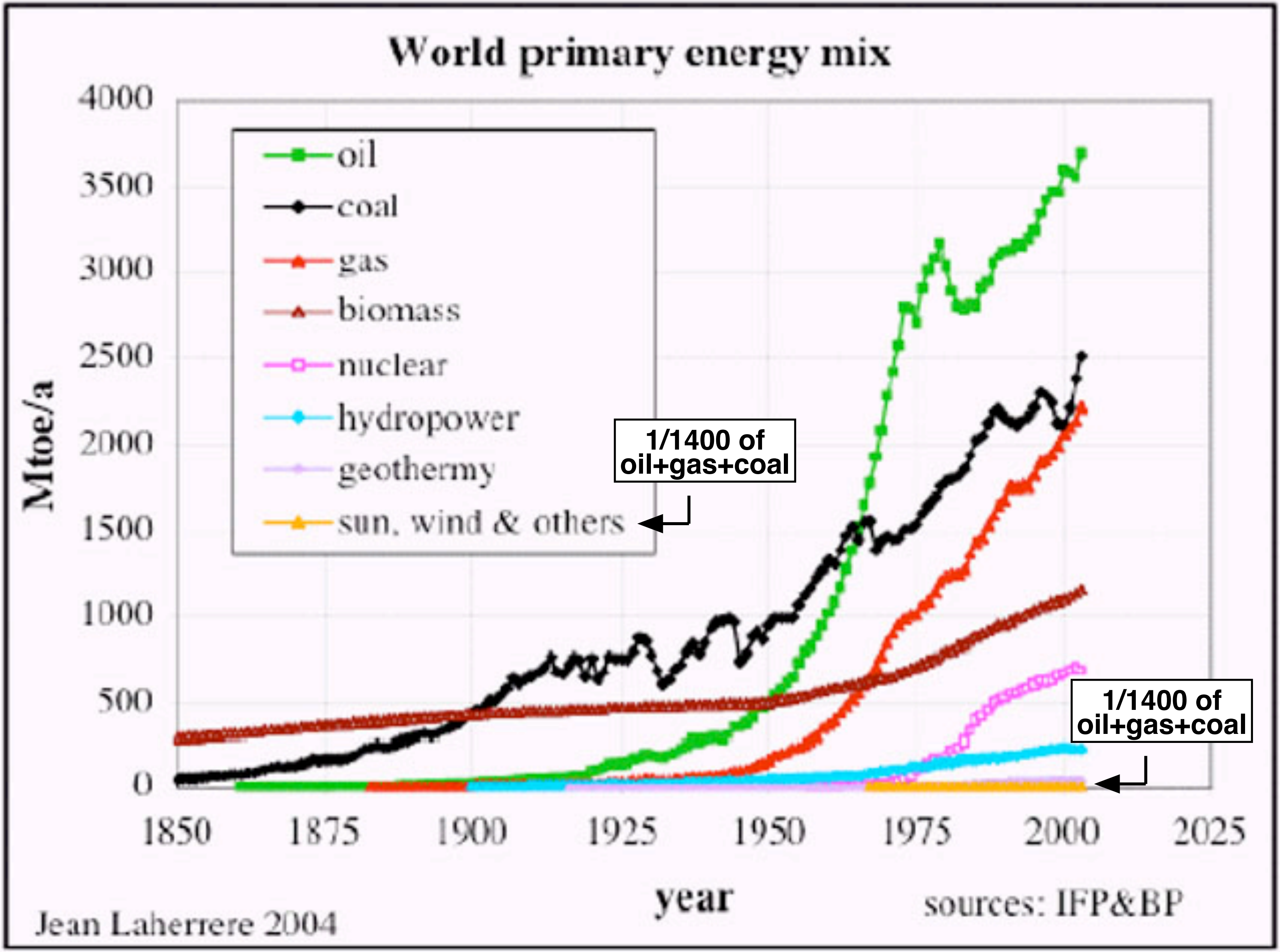
Energy Scavenging/Conversion

- ***biogas*** (anaerobic digestion of animal manure)
  - in small scale use for decades (esp. the Netherlands)
  - recovers some fossil fuel input to growing food/animals
- ***biodiesel*** (chemically modify plant vegetable oil w/10% alc.)
  - better EROEI and energy density than ethanol
  - water immiscible (no distilling step)
  - biodiesel for UK would require >100% of UK arable land
  - biodiesel for developed world would require all of Africa
- ***thermal depolymerization*** (cook tires, animal tissue waste)
  - currently: 0.0002% (500 barrels/d vs. 20 million/d used)
  - EROEI < 1.0 (recovers 85% of energy of inputs)
  - can recover part of fossil fuel inputs to tires, chickens
- ***ethanol*** (from fermentation of corn, switchgrass, sugar cane)
  - must be distilled from initial raw water-ethanol mixture
  - distillation step alone uses 40% of energy in final product
  - w/farming, almost energy-neutral (EROEI 0.8–1.25)

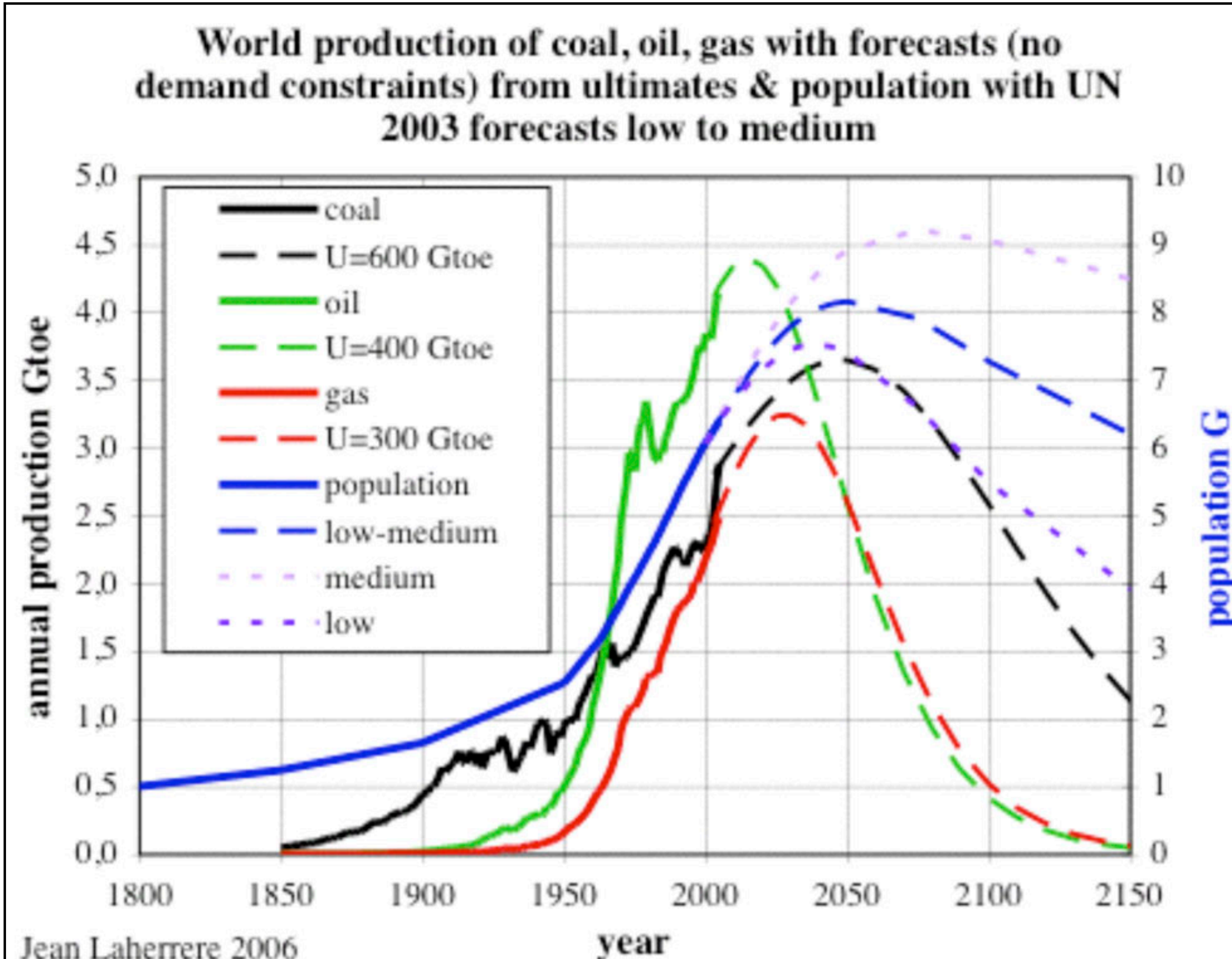
Real energy sources must have EROEI >5-10

- crude oil (e.g., EROEI=10) means 1 unit of energy expended (e.g., from other oil) to produce 9 units of useful energy
- ethanol at EROEI=1.2 means 5 units of energy expended (e.g., from other ethanol) to produce 1 unit of useful energy, greatly increasing overall energy usage

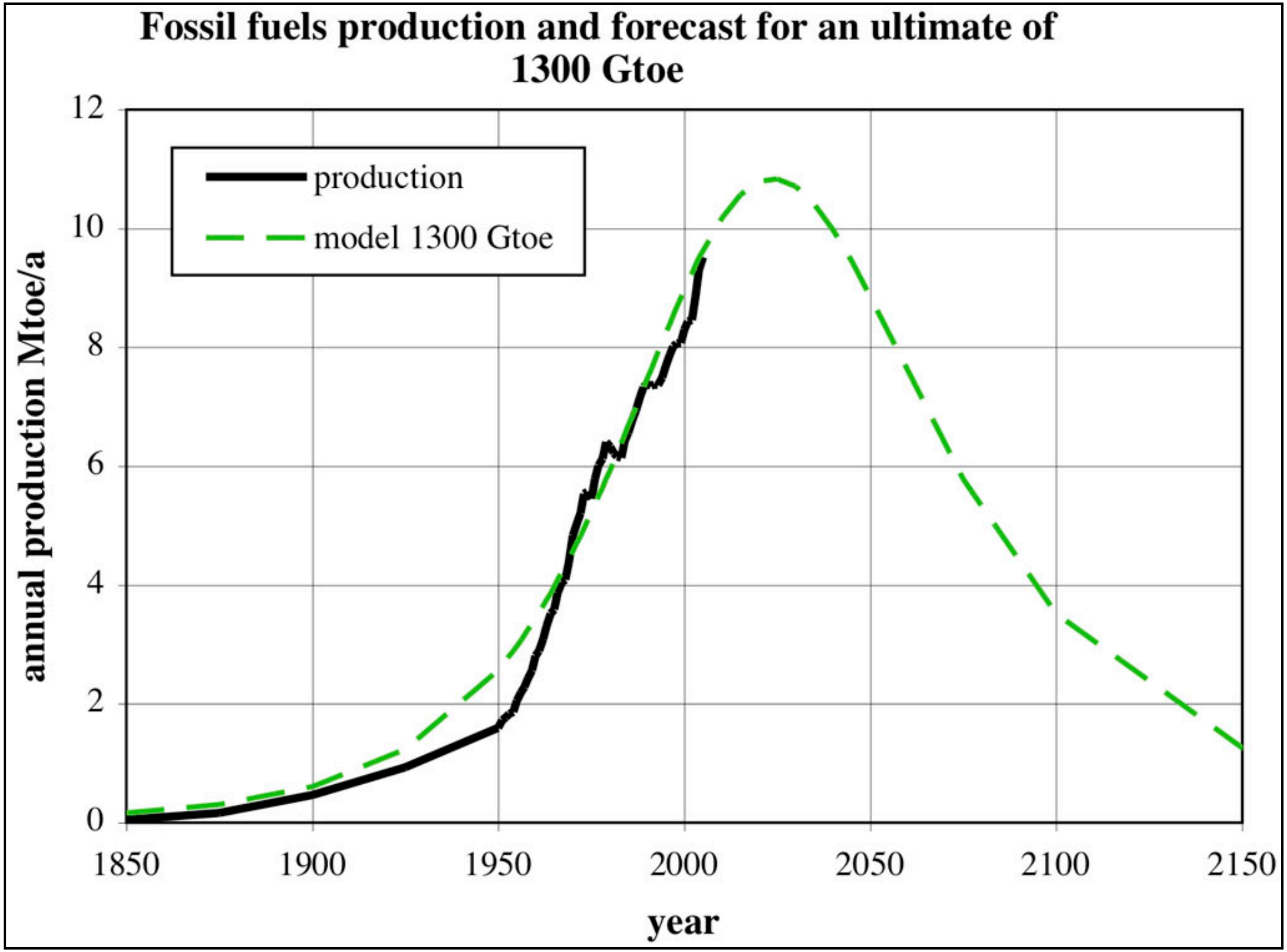



World primary energy mix
4000
3500
3000
2500
2000
1500
1000
500
0
Mtoe/a
oil
coal
gas
biomass
nuclear
hydropower
geothermy
sun, wind & others
1/1400 of oil+gas+coal
1/1400 of oil+gas+coal
1850
1875
1900
1925
1950
1975
2000
2025
year
sources: IFP&BP
Jean Laherrere 2004

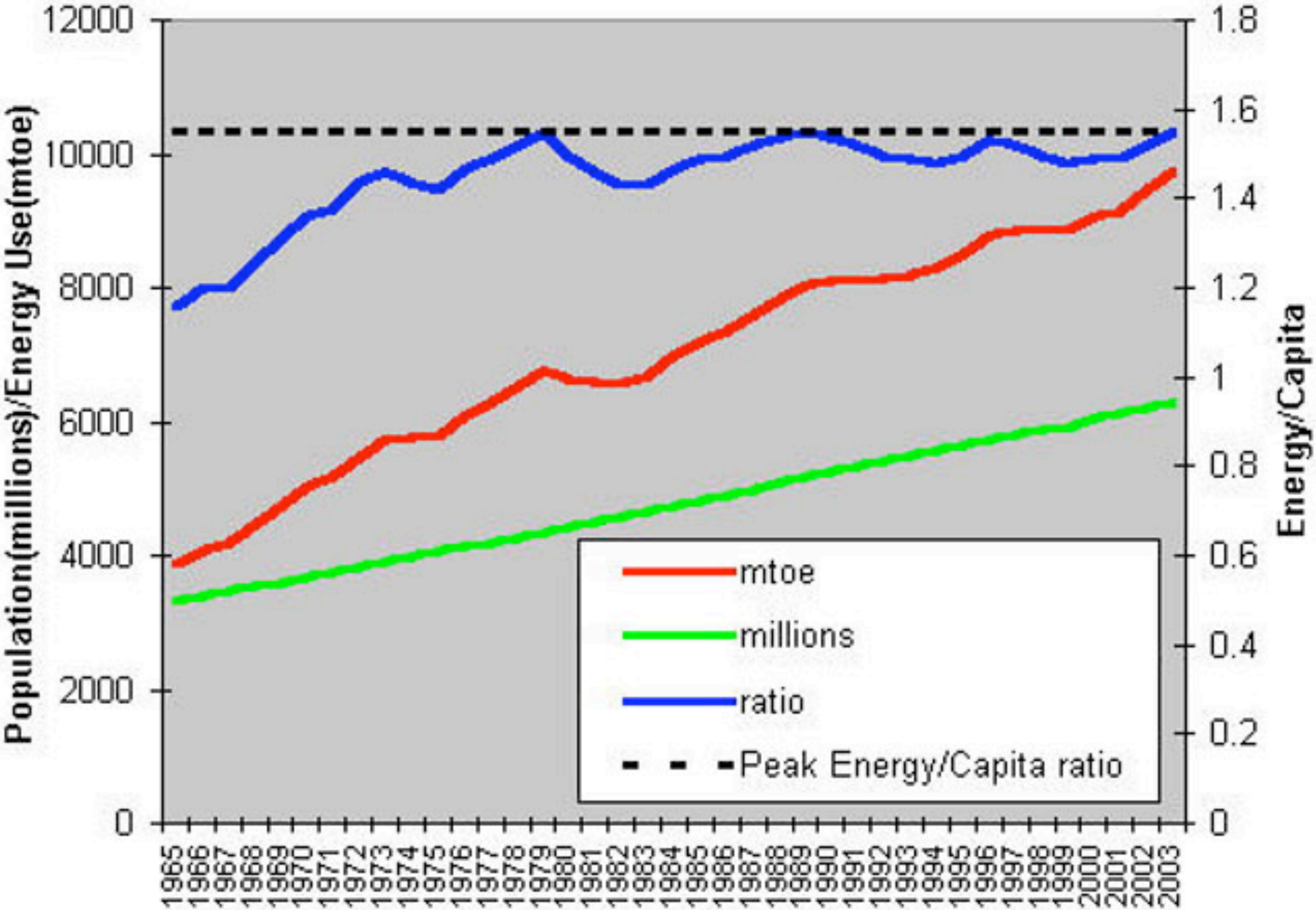
Peak Everything



Peak Everything



Total Energy per capita peaked in 1980



Summary of the Main Difficulties

- total oil used since 1850 – ***about 1000 billion barrels (Gb)***
- total conv. world reserves remaining – ***1000 billion barrels***
- percent oil currently in use discovered before 1973 – ***70%***
- time left, current world usage (29 billion/year) – ***33 years***
- time left, US uses only oil still left in US fields – ***3 years***
- time left, US grabs/uses all of Iraq's oil for itself – ***15 years***
- time left, whole world uses oil at US's current rate – ***6 years***
- percent US oil used in food production (*not* including packaging, refrigeration, trucking, cooking) – ***25%***
- physical human work equivalent of energy used to generate US diet for 1 person, 1 day – ***3 weeks***
- oil in US strategic reserves (< 1 billion) – ***1 month US use***
- percent world oil used by non-US-ians – ***75% and growing***

Suggestions

- *reduce* oil production/use now (so coming fall less steep)
- expand, electrify rail (4-6x as efficient as trucks, cars)
- plan for de-globalization, local food production, economy
- locally co-generate heat and electricity (cf. Sweden)
- utilize fossil fuel to construct renewables while we still can
- “the market” will probably not save us:
  - it won’t trump geology, it can’t change Maxwell’s equations, make hydrogen more compressible, make fusion work next year, or contract gracefully
  - it doesn’t look far enough into the future (it decided to *disinvest* in renewables from late 80's until 2004!)
  - it can fail industrial civilization/population
- there is still time: the technological-literary-demographic collapse of Rome, the Maya, etc. took centuries

Other Relevant Problems

- economic (US)
- social (US)
- climate

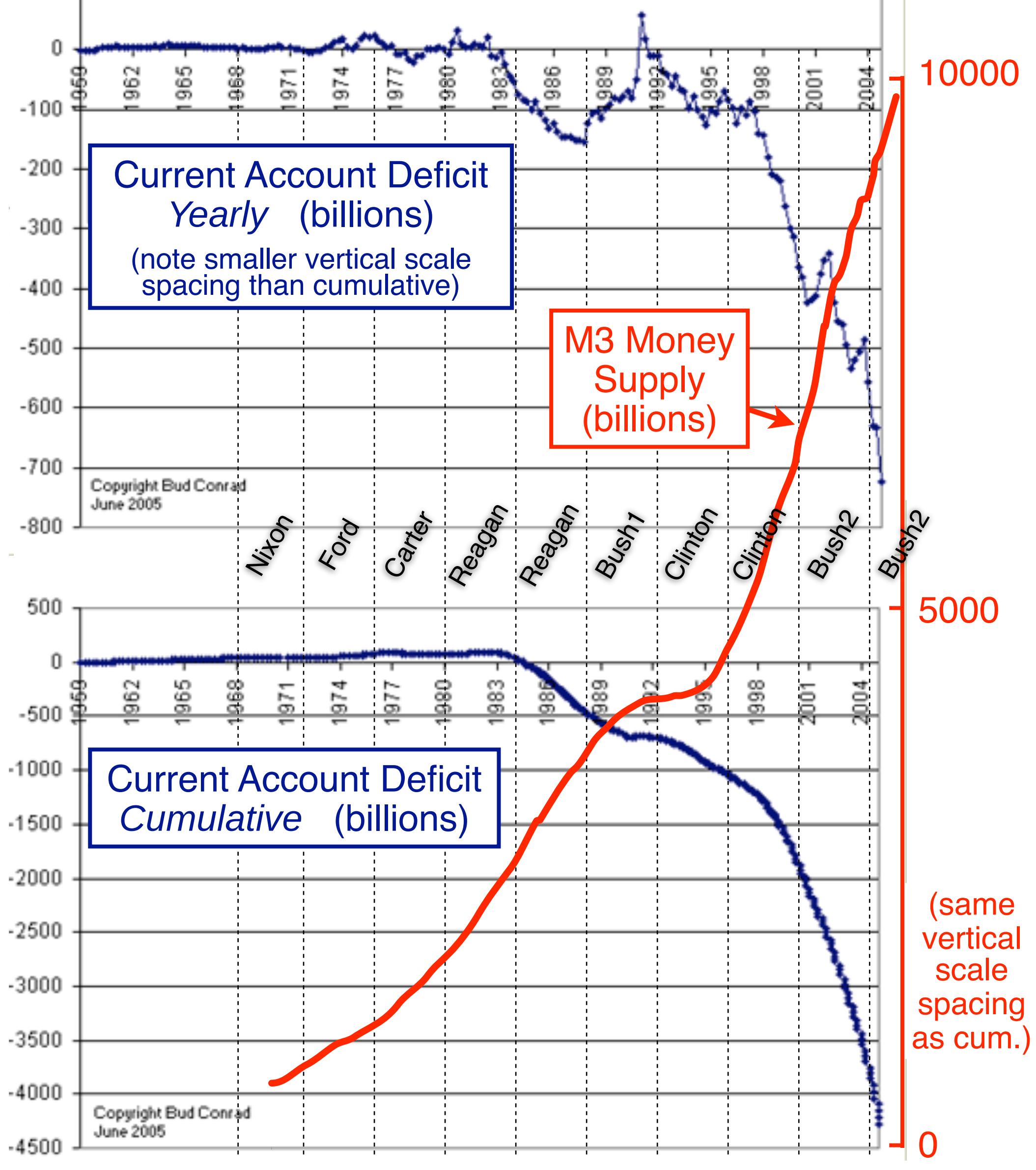
Money supply, M3*, & US Deficit Growth Look Unstable

Total money, M3, doubled after 1995 (new Fed policy?)

Cumulative curr acct debt explodes to 50% of GDP (striking mirror-image of M3)

2005 comparisons for scale (billions):

GDP US, year:	*11,000*
GDP Calif., year:	*1,500*
Total assets US:	*38,000*
Total debt US:	*40,000*
Residential debt US:	*6,800*
Consumer debt US:	*1,700*
Foreign-own assets:	*8,000*
daily currency trans:	*1,700*
GDP World, year:	*43,500*
opt/fut/bask/hedge:	*300,000 (!)*

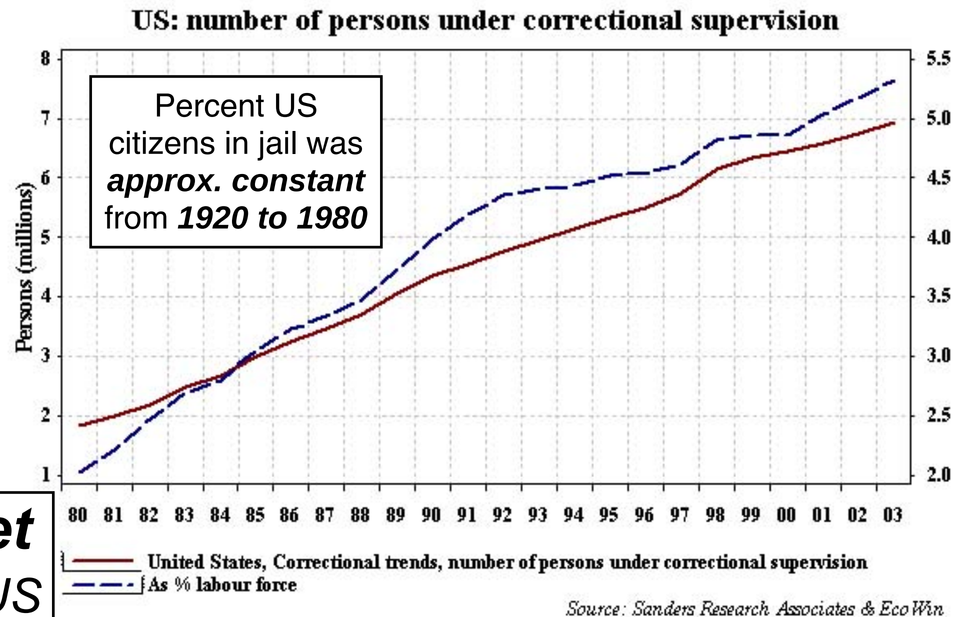


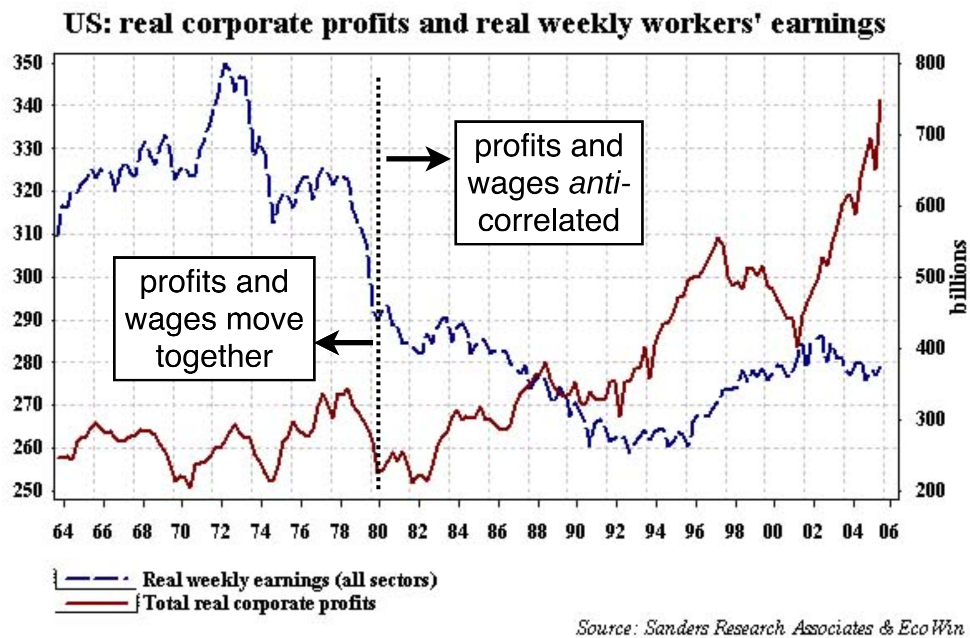
*update, the Fed discontinued reporting M3 on March, 2006

http://www.kitcocasey.com/displayArticle.php?id=133
http://research.stlouisfed.org/fred2/series/WM3NS/

Prison planet

begins 1980 in US

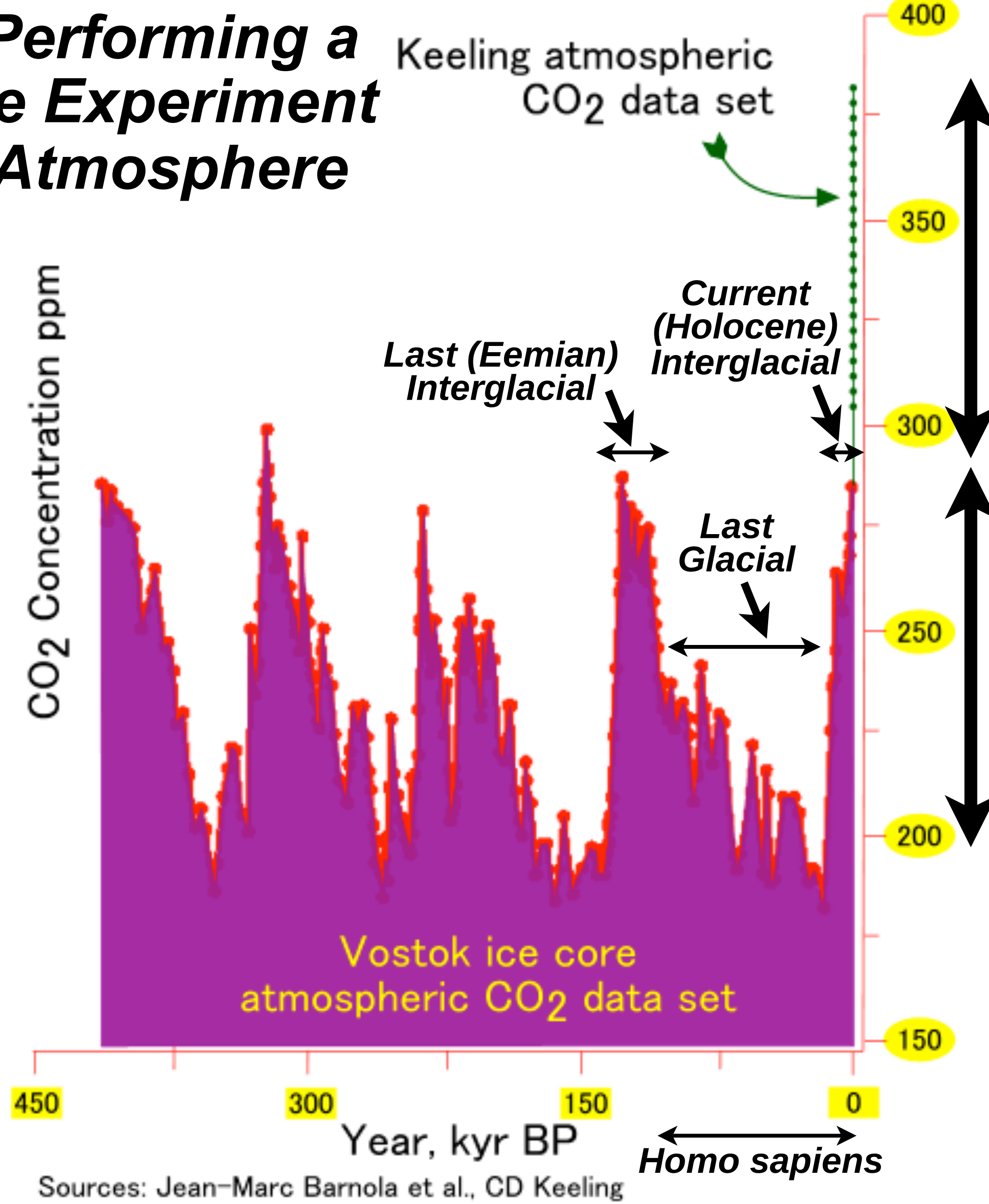




Corporate planet

corporate dominance, anti-correlation of corporate profits, workers' earnings begins 1980 in US

We are Performing a One-Time Experiment on Our Atmosphere

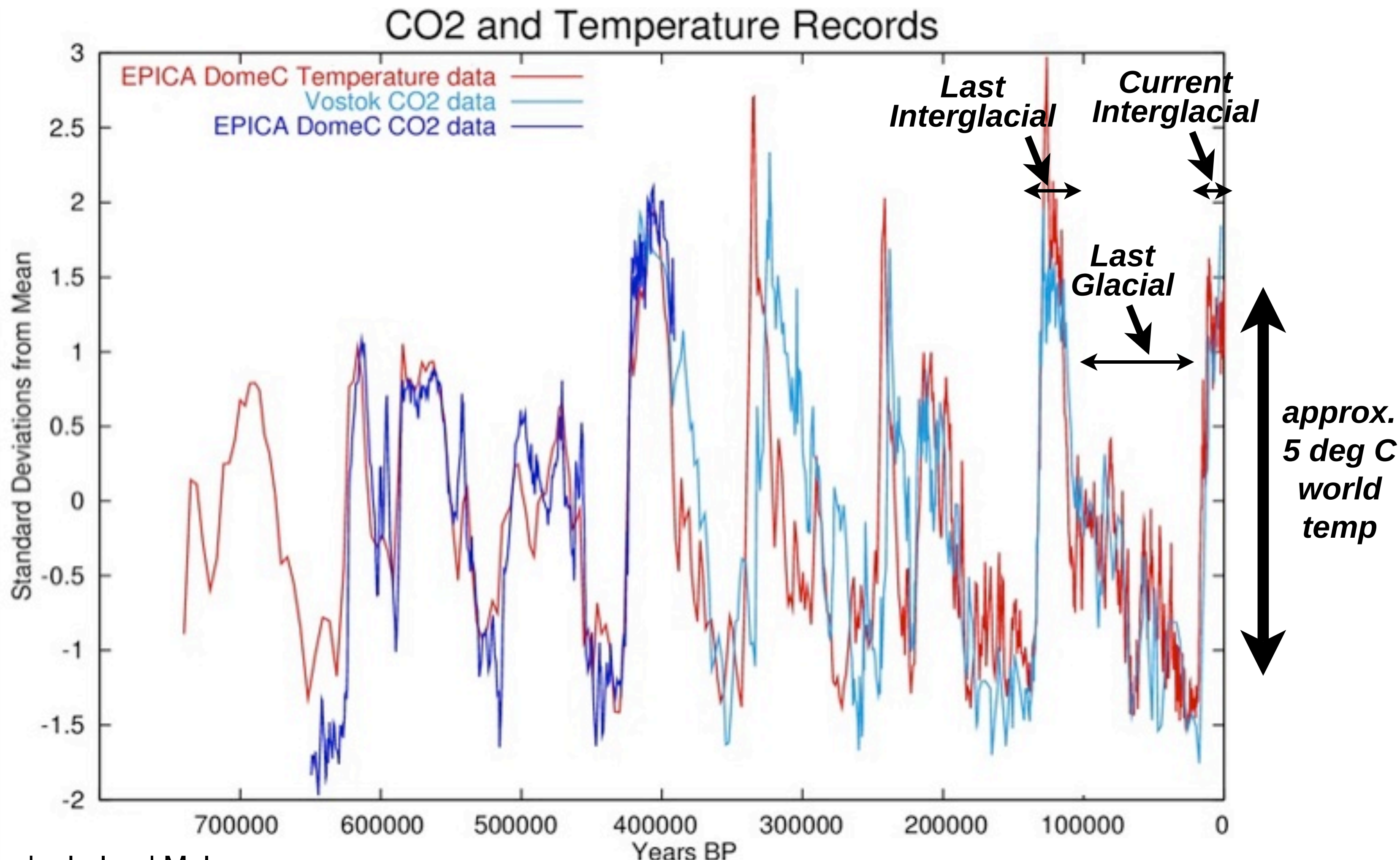


CO_2 injected by industrial humans over last 0.1 kyr equivalent to glacial/interglacial difference

Year-by-year increases in CO_2 have recently jumped; 2004 and 2005 increments are almost double the 1970-2000 average. This may reflect positive feedback:

- *albedo reduction from ice melting*
- *warming-induced decomposition*

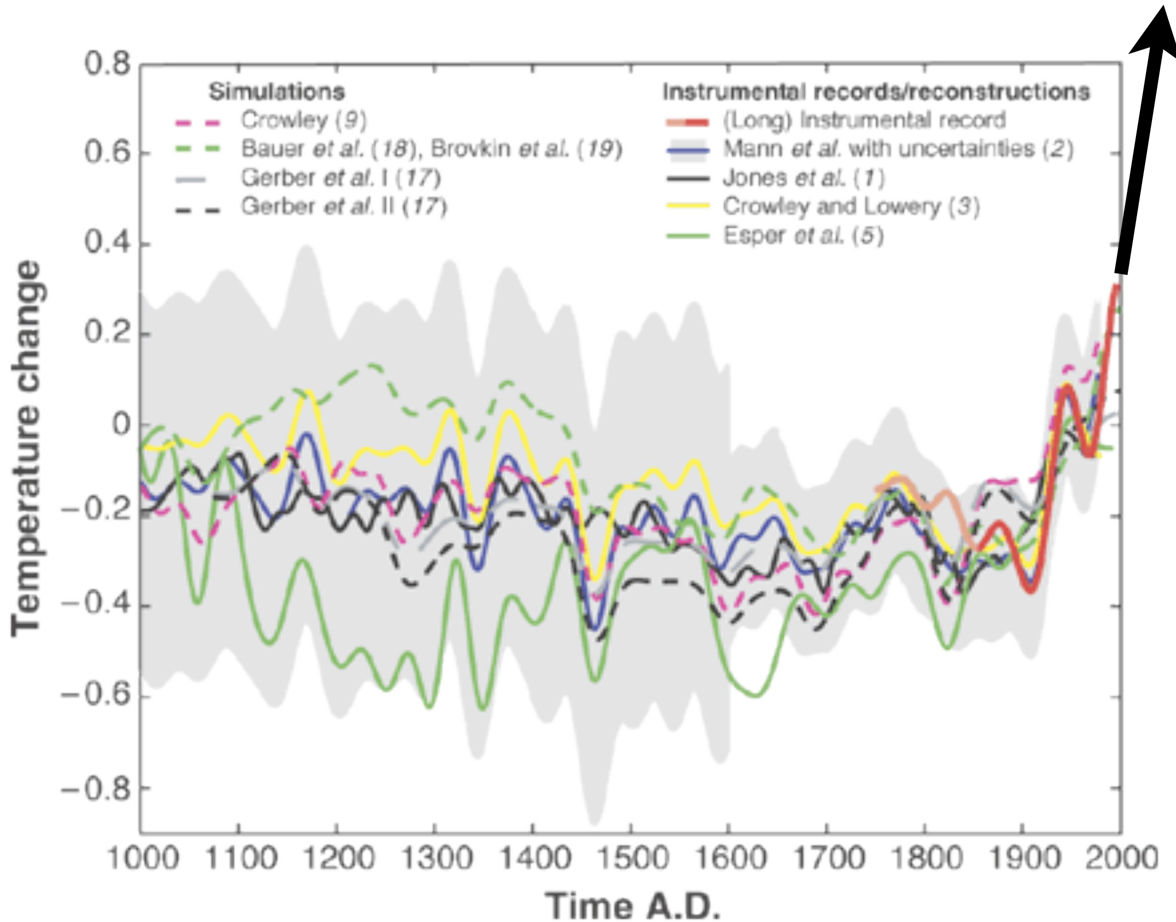
Temperature has been strongly correlated with CO_2 for the last 650,000 years



by Leland McInnes, from public sources

http://en.wikipedia.org/wiki/Image:Co2-temperature-plot.png

Measured warming this millennium (via proxies) matches model predictions



Glaciers across the entire planet have begun a rapid retreat in the second half of the 20th century

http://www.sciencemag.org/cgi/content/full/297/5586/1481

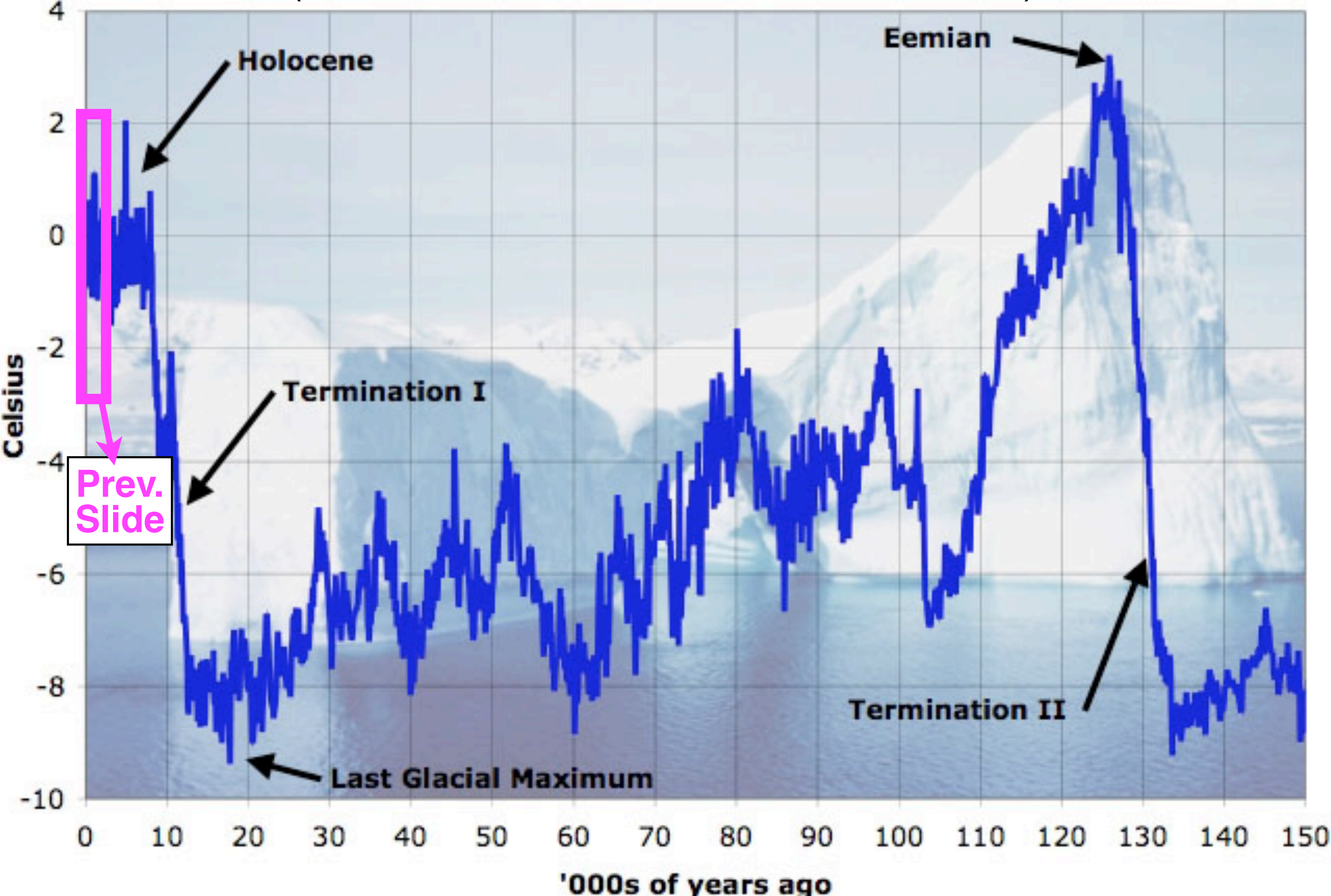
http://www.worldviewofglobalwarming.org/pages/glaciers.html

Global warming – 5 key points

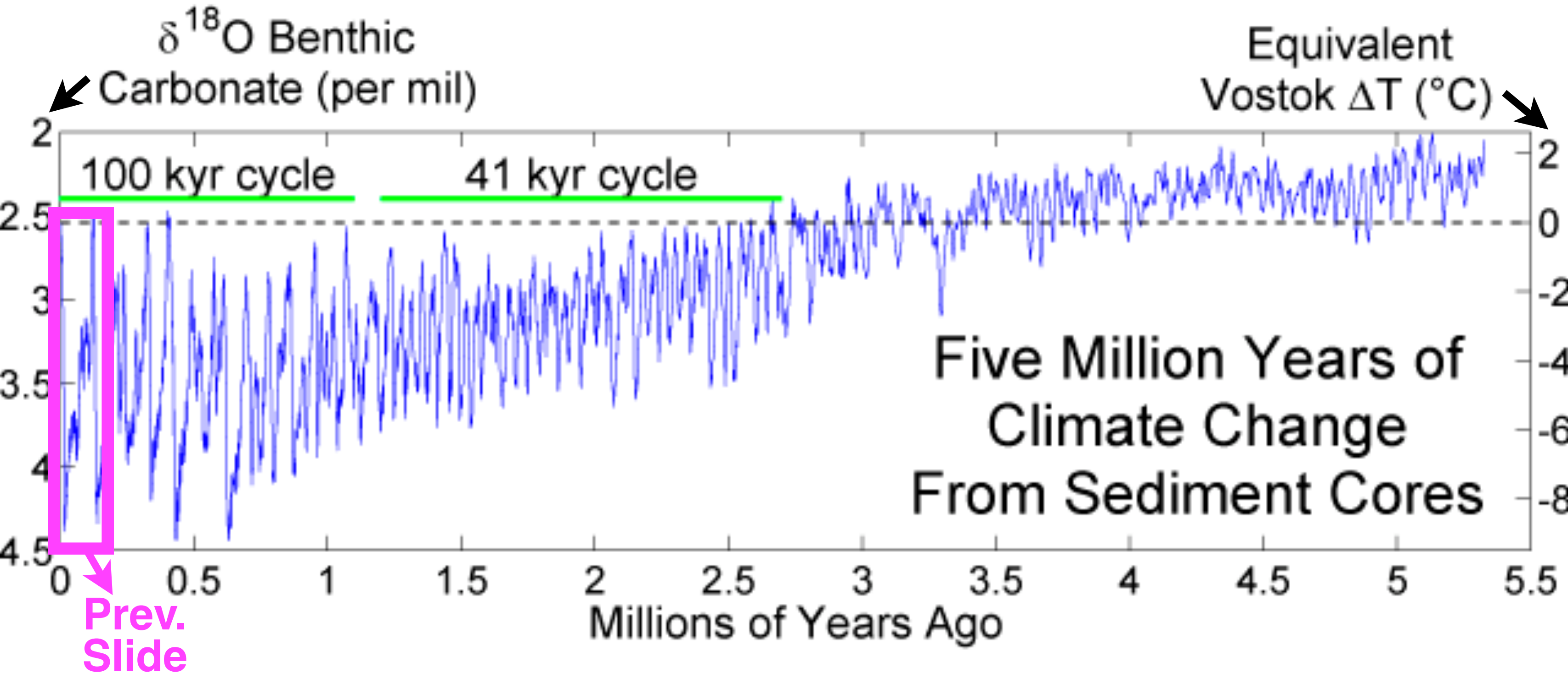
- previous glacial-interglacial climate 'flips' triggered by small variations in 'forcing' (e.g., periodic orbital wobble) that vary seasonal distribution (vs. amount) of radiation
- over the past million years, CO_2 increases ***follow*** temperature increases by an average of 700 years during the initial stages of warming observed at glacial-interglacial transitions
- initial CO_2 increases then amplify warming over the full 5000 years of the cold-warm climate flip
- polar ice covers didn't melt in previous warm periods, but they are melting now, esp. northern
- humans are now in control of climate -- warming caused by anthropogenic CO_2 (and CH_4) is a new regime

Global Temperature – 0.15 million years

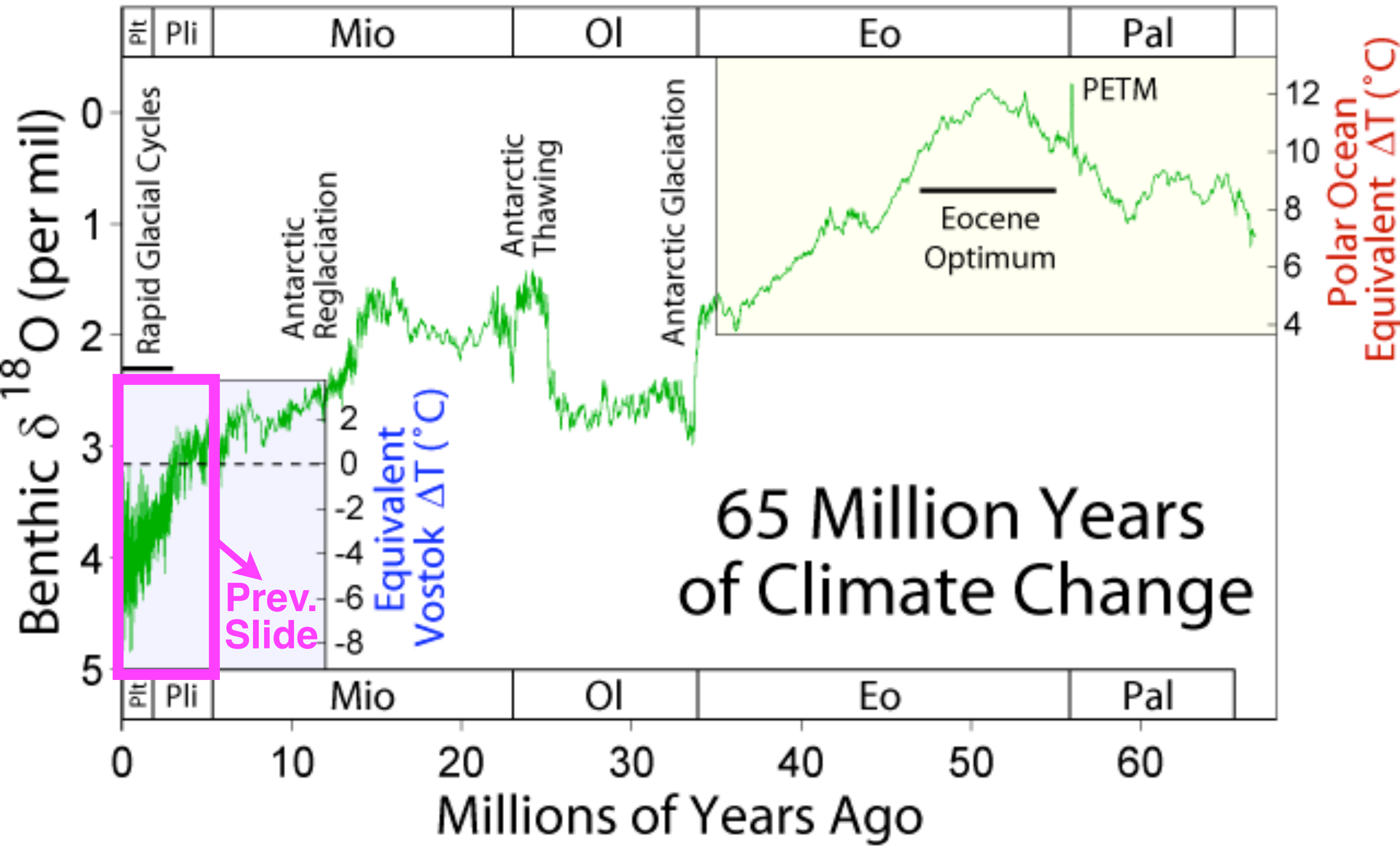
(***more recent*** *to* ***left*** *in this and next 3 slides)*



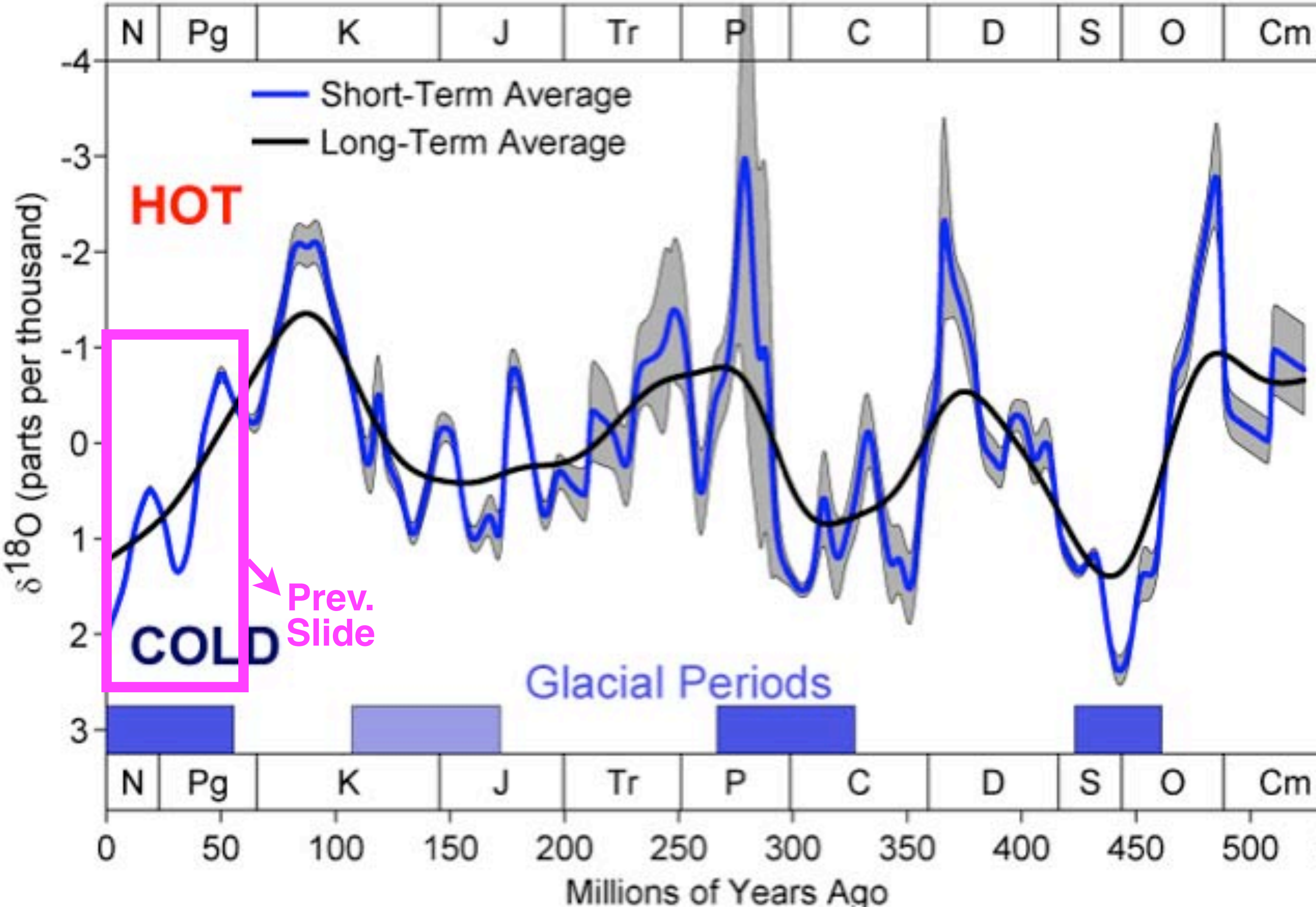
Global Temperature – 5.5 million years



Global Temperature – 60 million years

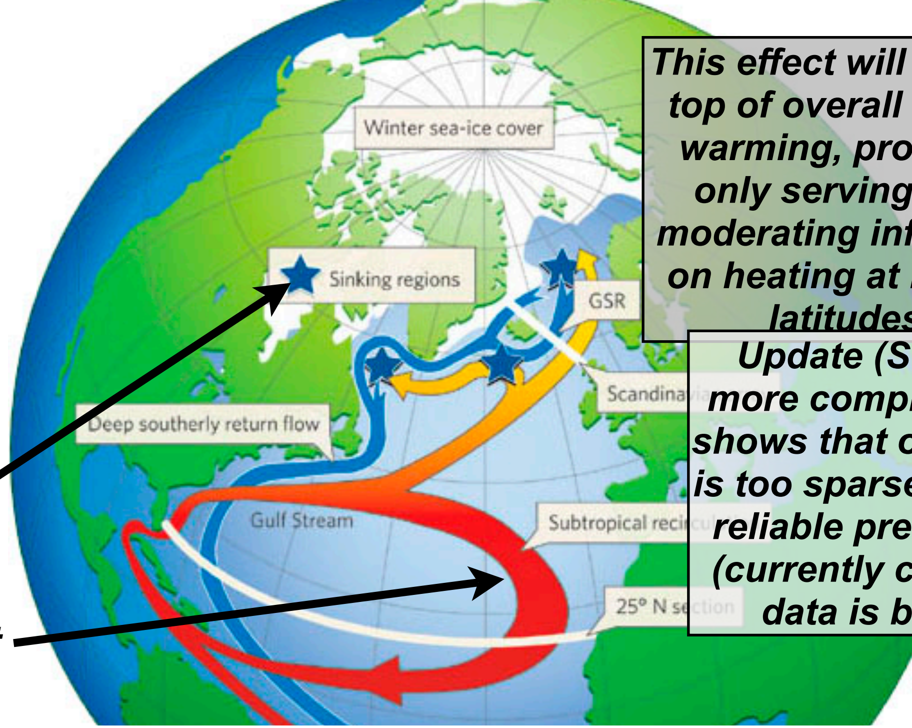


Global Temperature – 500 million years



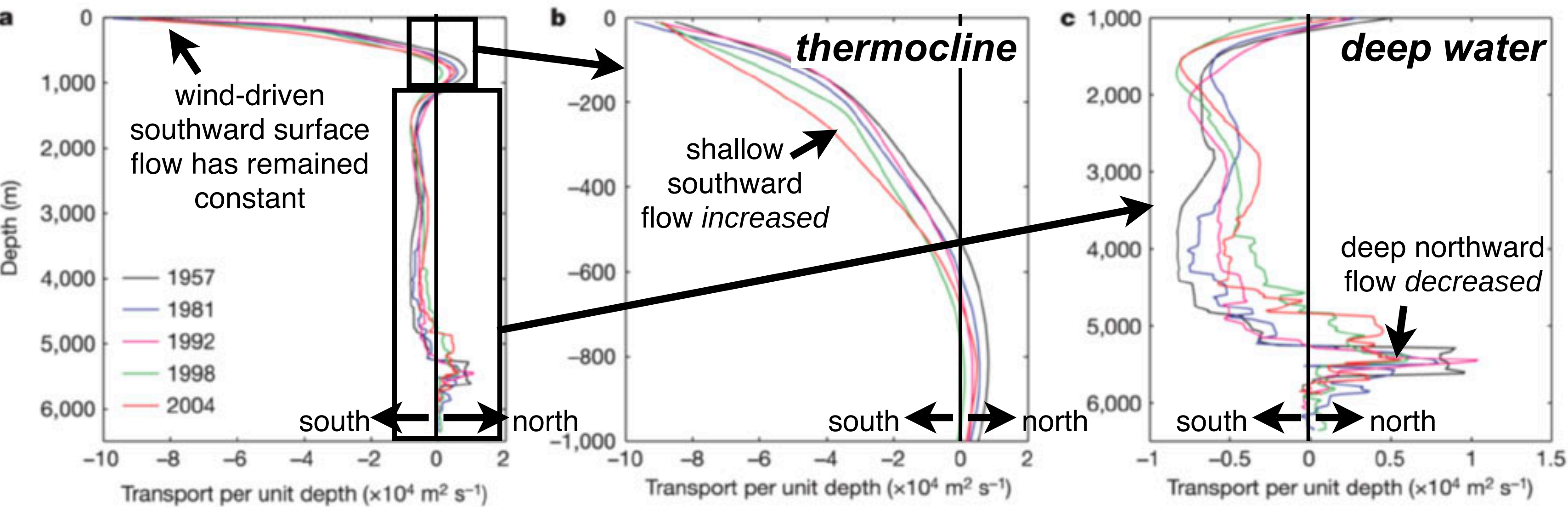
The North Atlantic 'heat conveyor' appears to have slowed by 30%

Cold fresh water from melting northern ice reduces northern descending return currents of cooled salty water, which results in more warm northeasterly water taking a subtropical shortcut back to the equator



This effect will ride on top of overall global warming, probably only serving as a moderating influence on heating at higher latitudes

Update (Sep'07): more complete data shows that older data is too sparse to make reliable predictions (currently collected data is better)



Speculations (June 2005)

- US continues military actions, base-building near mideast oil
- oil price increases initially lead to stagnation plus inflation
- oil production peaks (2008) as Ghawar, Cantarell decline
- coal use for power/synfuels increases sharply to 2030 peak
- fossil methane use increases (outside US) to 2030 peak
- new US nuclear plants commissioned, begin online by 2015
- local co-generation of heat/electricity prevented by NIMBY
- wind and solar increase 100x (to 7% of 2005 oil+gas+coal)
- large CO_2 increase, warming from extra coal use by 2030
- magnetically-confined fusion fails to ever come online
- slow collapse of global industrial civilization begins 2030
- population/technology/military contraction complete by 2100

Speculations (August 2007)

- same as June '05, except now clear Canterell peaked 2004