Energy management. Squaring the circle!

THE OIL ERA
FOR HOW LONG?

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PRIMARY ENERGY SOURCES

- FOSSIL ENERGIES = concentrated energies but not renewable [*solar E stocked during geological times*]

  ◊ Coal◊◊ Oil◊◊◊ Natural Gas

- NUCLEAR ENERGIES = very concentrated energies

  one gram U^{235} = as much E than one oil ton!, $1cm^3$ =19g U^{235} =47.5 tons of coal!

  ◊ Fission [*present day reactors*] ◊◊ Fusion […]

- RENEWABLE ENERGIES = diluted or diffuse energies but renewable

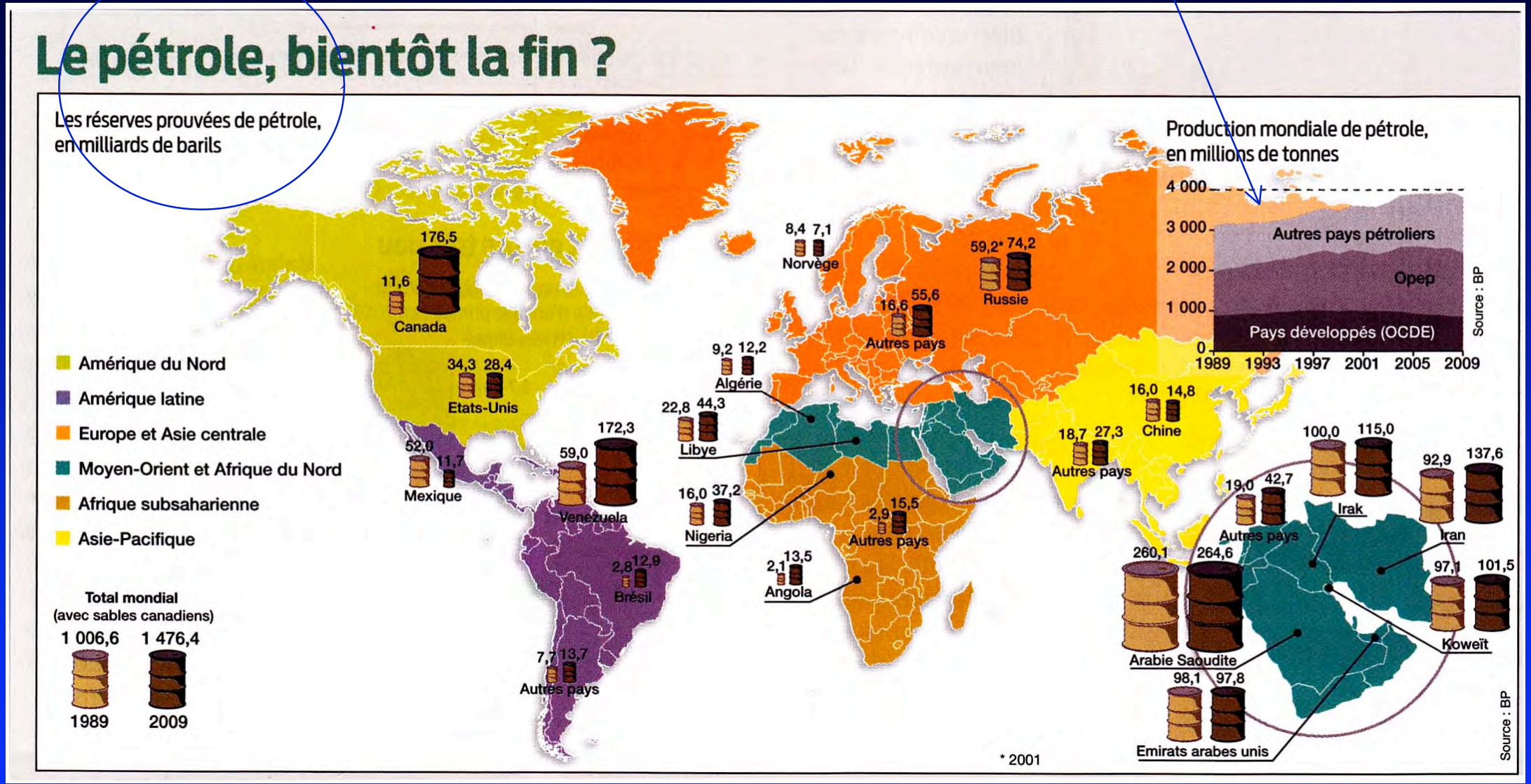
  ◊ Hydroelectric power◊◊ Solar ◊◊◊ Wind power

  ◊◊◊◊ Biomass ◊◊◊◊◊ Geothermal heat

in 1h the Sun produces 'our' Energy of a year!
i.e. 15000X our worldwide consumption at every moment

≠ reserves

1P-2P-3P c-sc-nc

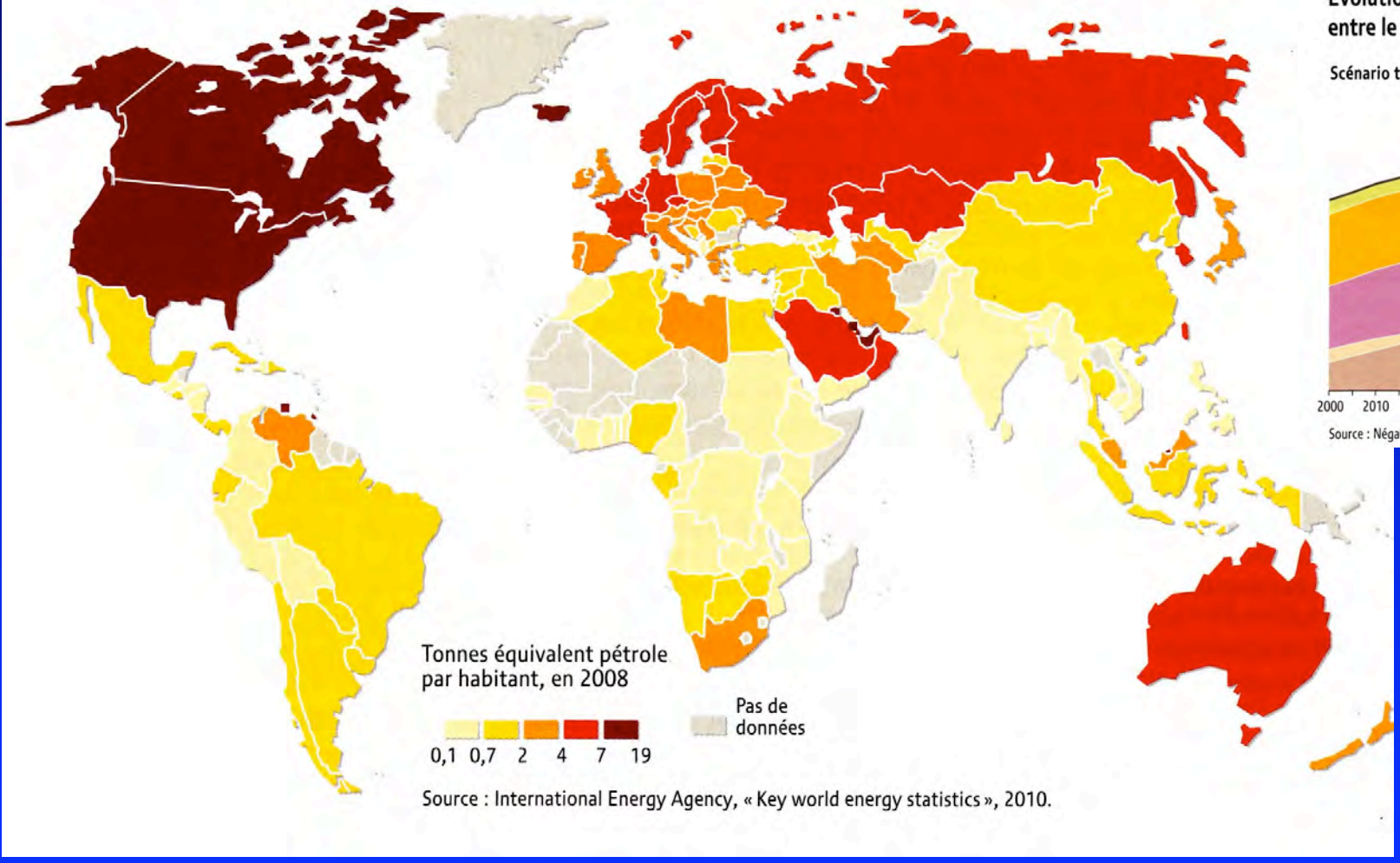


« We did not quit the Stone Age because of stones »

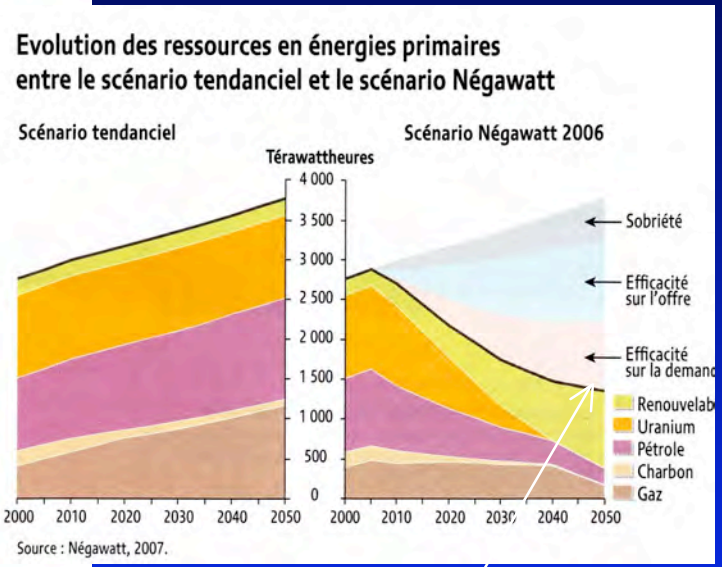
Sheikh Yamani, former Saudi oil minister (co-founder of OPEC)

Today: no coherent policy for the use of energy…

Consommation d'énergie primaire par habitant



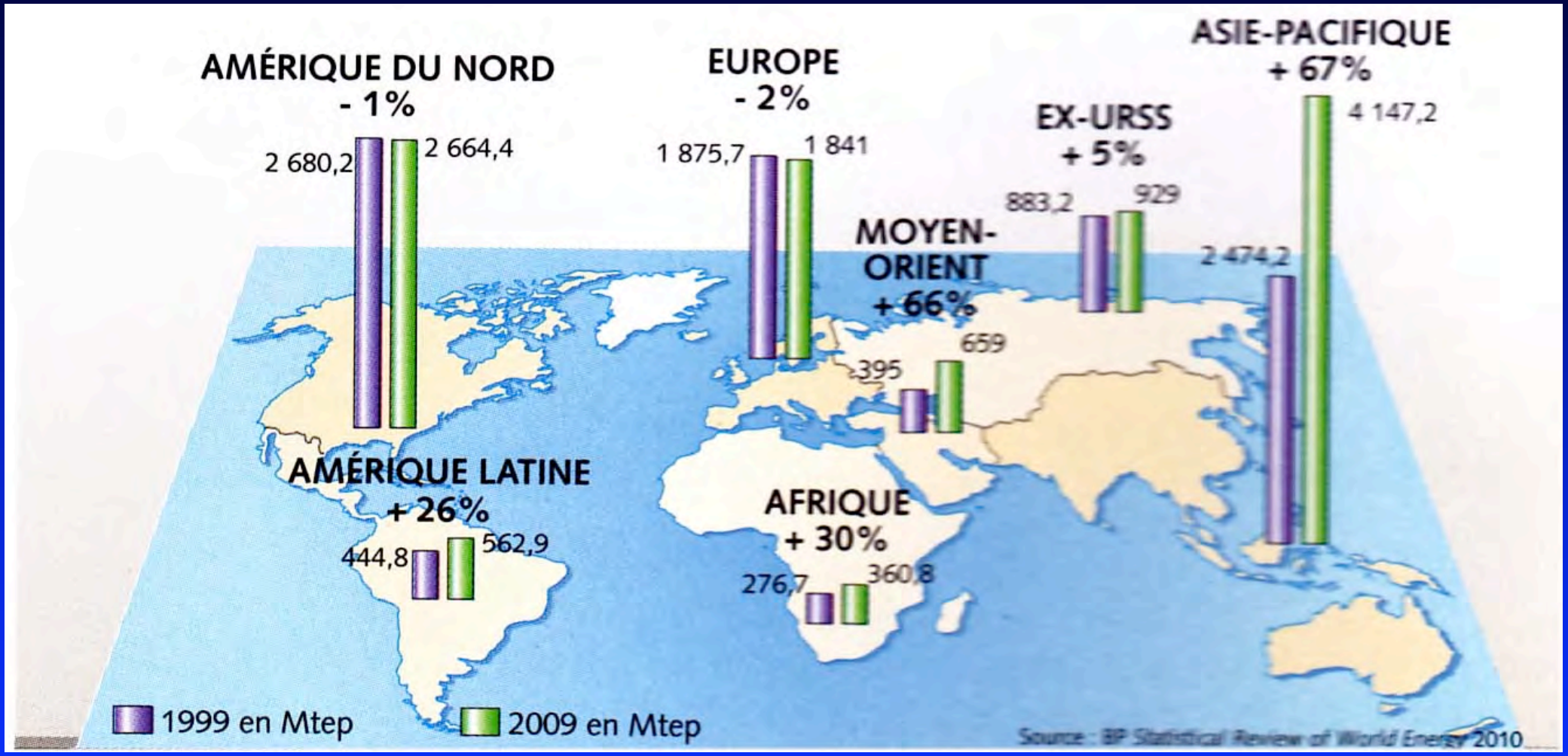
Source : International Energy Agency, « Key world energy statistics », 2010.



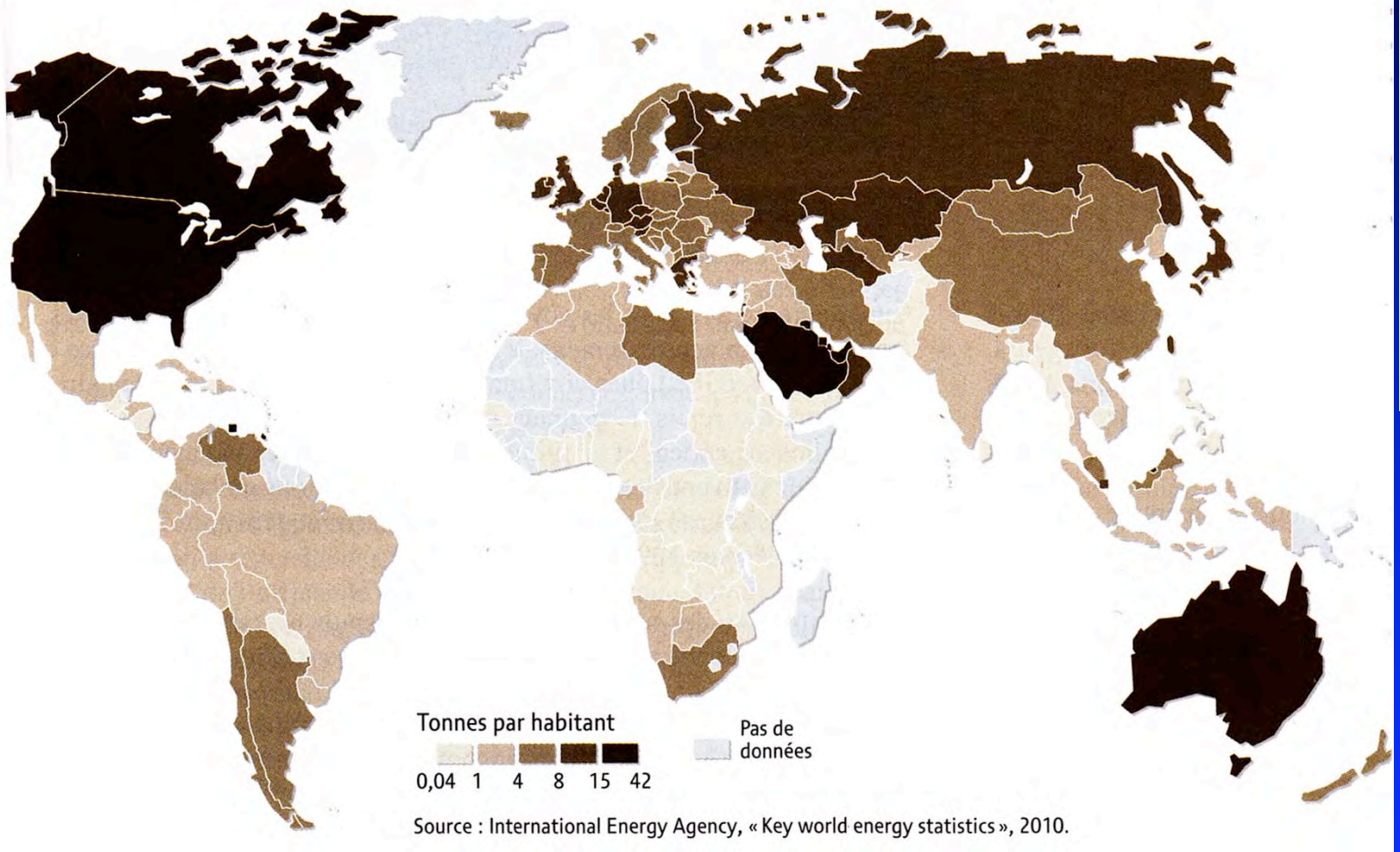
Source : Négawatt, 2007.

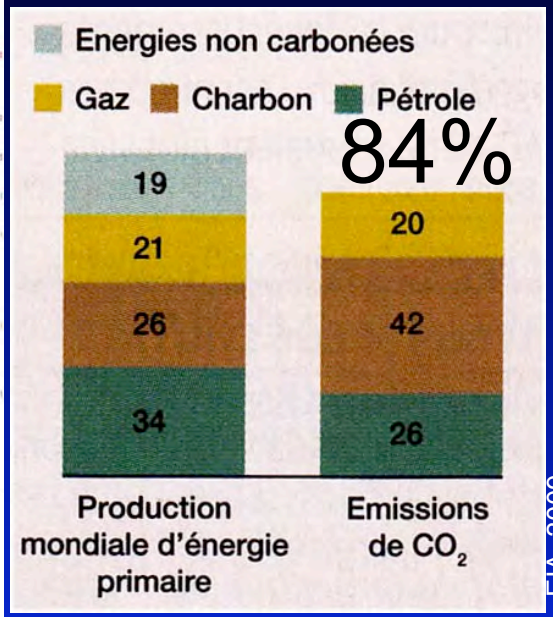
> 50%?

Oil consumption 1999-2009



Emissions de CO_2

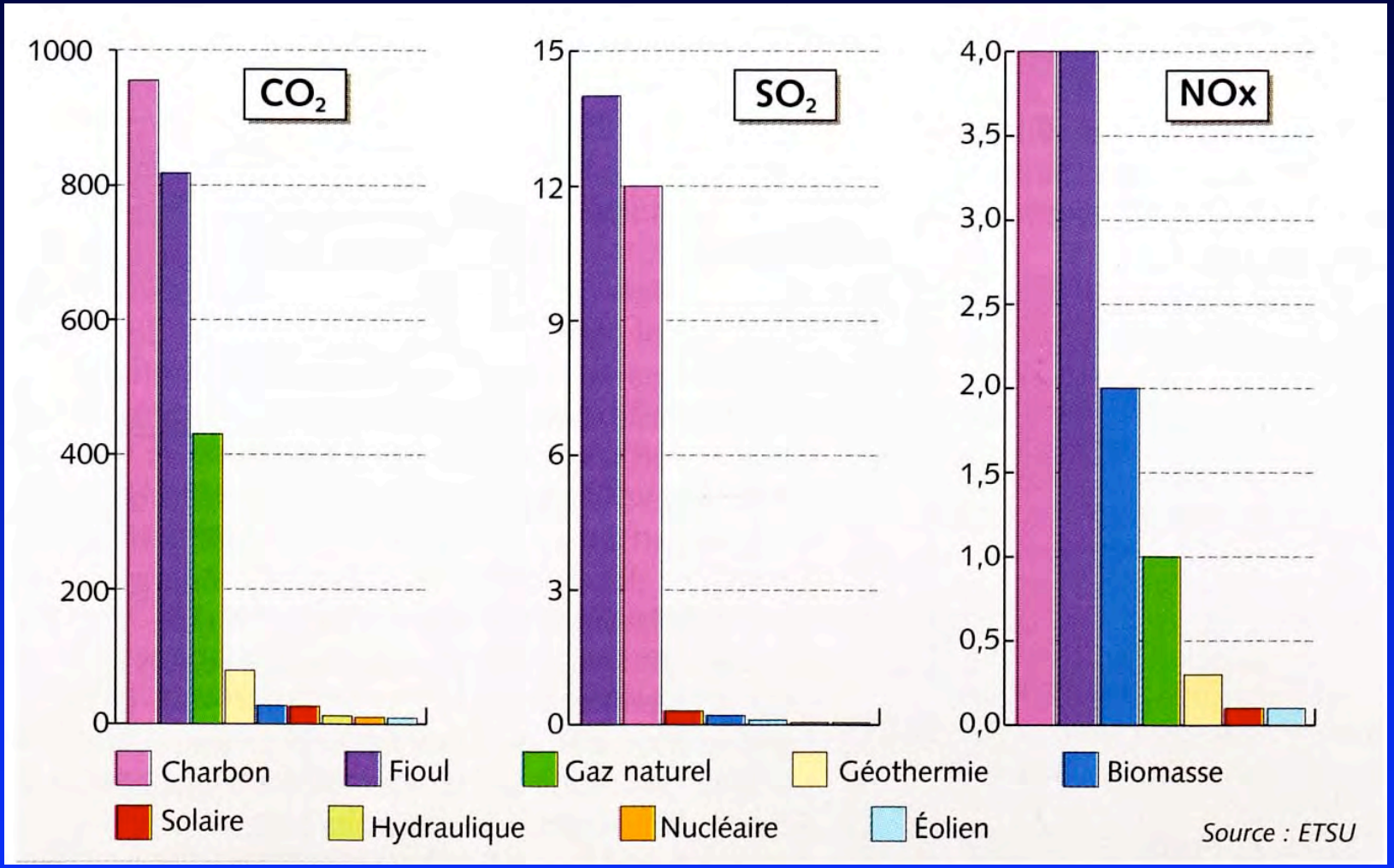


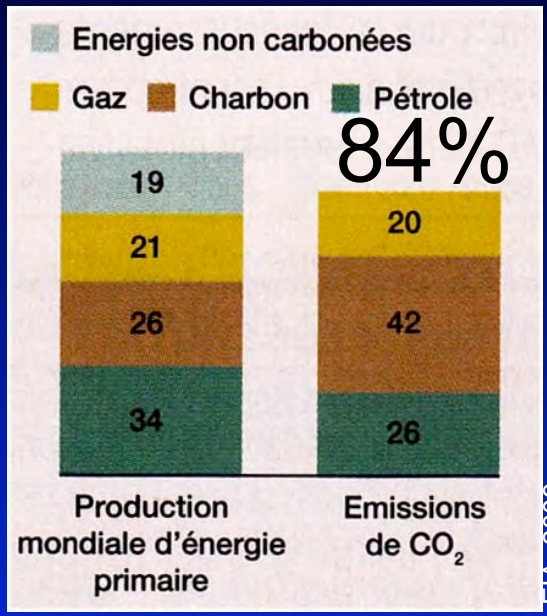


+39%

=

Increase of CO_2 emissions since 1990





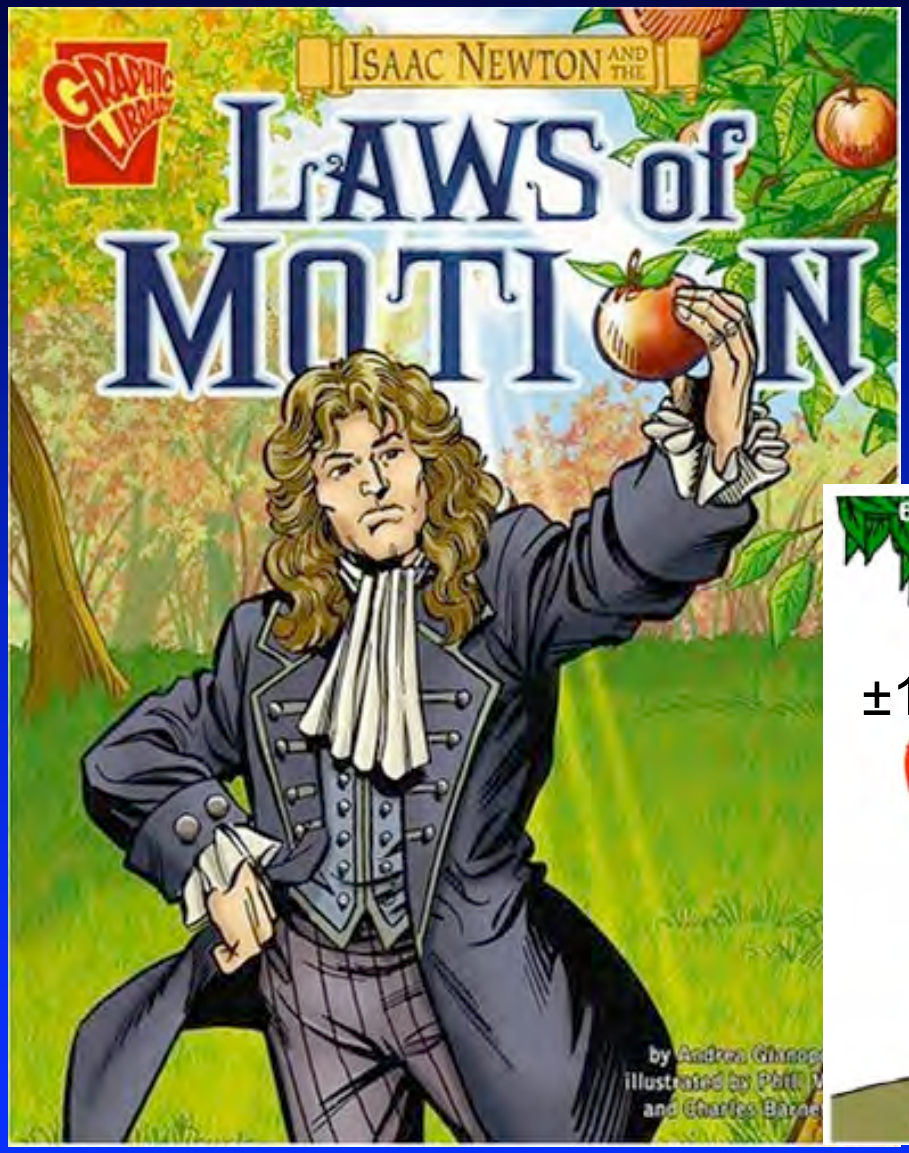
+39%

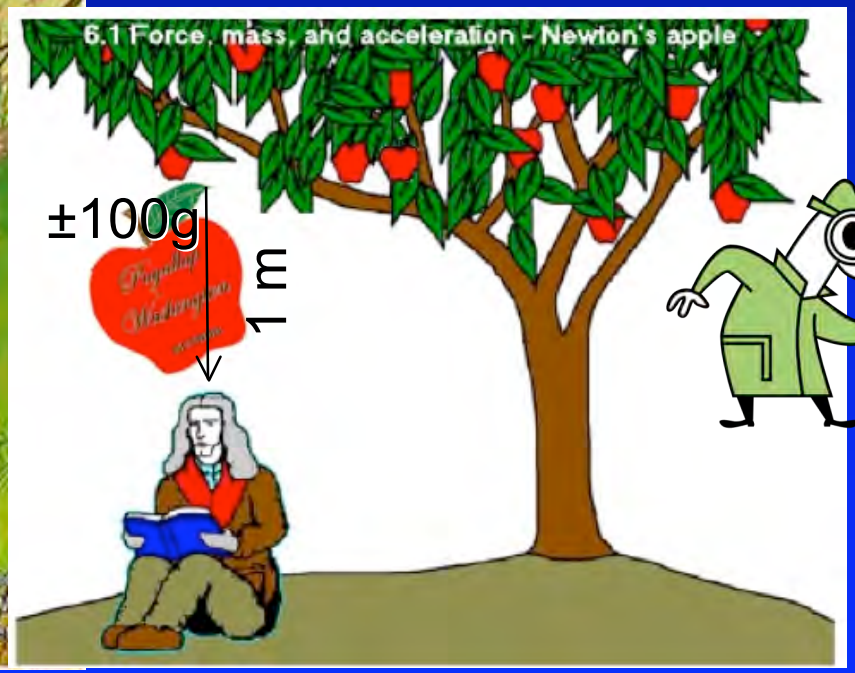
=

Increase of CO_2 emissions since 1990

The basic unit of energy in the international system is the Joule which is also Work and Heat

Work with a force of 1N whose point application moves 1 m in the direction force





(toe ton of oil equivalent

1 toe

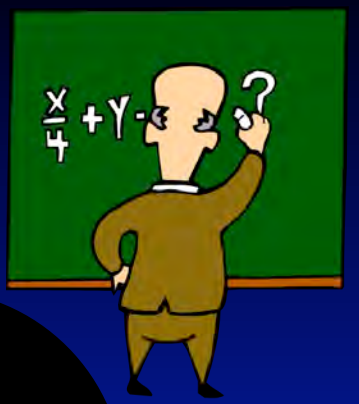
= 42 GJ

1 kJ = Energy released as heat by a person at rest every 10 seconds

- 1toe = ±42GJ =10^{10}cal or ±11,700kWh

1 calorie = 4,18 J (1cal = amount of heat to raise T° of 1g of water from 14.5° à 15.5°)
The jump of a flea = 10^{-7} J (about 4 ten-millionth of cal),
The man needs 10^{7} J of energy/d [±2 500Kcal] in the form of food, heat, …
A toe is therefore 1.5 year of our vital needs
[1bbl = ±$1_{1/2}$ yr, 1l = 3,6d]

- *A cyclone in the Caribbean = 3.8 x 10^{18} J i.e.100. 10^{6} toe*



1t ^{235}U ===>10 000 toe
1000m^3 gas p_{atm} ===> 0.9 toe
1t coal===> 0.7 toe

1 Nuclear Reactor of 1GW$_e$

= 100km^2 solar pv, i.e. 5000km^2 for all electricity in France
= 2 500 wind turbines (of 2MW) and 500km^2
= 50,000km^2 from geothermal heat
= 30,000km^2 from biodiesel (sunflower or rapeseed)

or 43µg ^{235}U(0.0000043g) = 70g gasoline = 3.6t of water from100m =1kWh

Tacona et al. 2009

General Context

5.7 % 2005

7.1 % 2009

Renewable energies

5 %

Hydroelectric power

Biomass

Solar energy

Wind turbin

Geothermal power

COMMERCIAL GLOBAL PRIMARY ENERGY CONSUMPTION (2009)

	ENERGY Gtoe	2008	2007	1998
	12 Gtep (2009) 33%-27%-20% = 80% wood excluded			
1	Oil	3.928	3.939	3.39
2	Coal	3.304	3.195	2.22
3	Gas	2.726	2.652	2.02
	Hydropowe	0.718	0.696	0.69
	Nuclear	0.620	0.623	0.63
	+ 1.176 (biomass)+ 0.057 (renewable)			
	TOTAL	11.3	11.1	± 9

5.7% 2005

7.7% 2009

2005

Wood10%

Hydropower 5%

Geothermal heat 0.5%

Biofuels 0.1%

Wind energy 0.05%

Solar power 0.05%

Photovoltaics < 0.001%

2010: 13 Gtep estimated (in 2008) i.e. ±12,000 nuclear reactors(today±450)

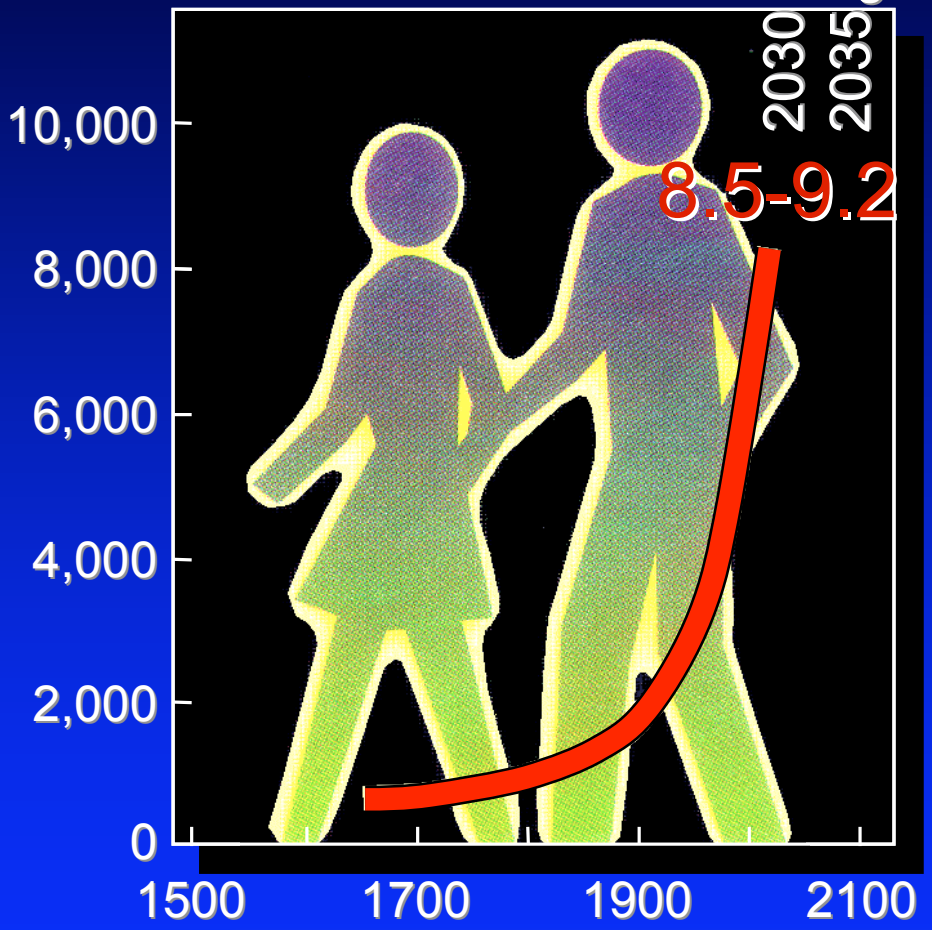
Renewable in 2030: 1.5 over ±17 Gtoe i.e. ± 9%

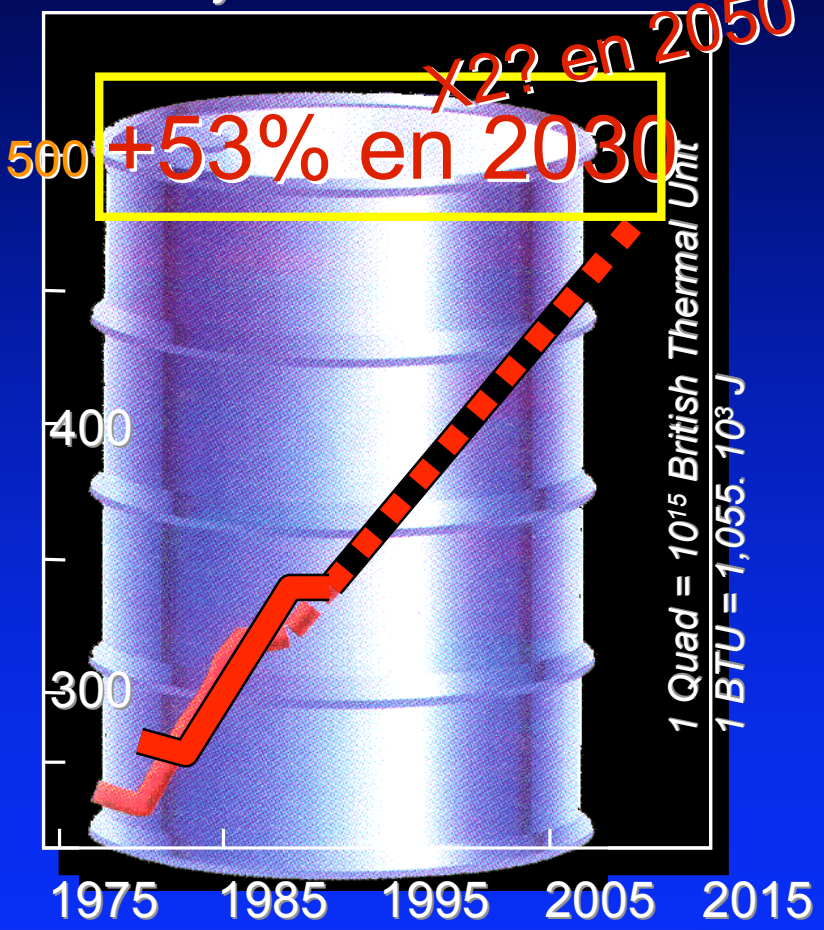
Population – Energy Needs

Will increase 'on average' by 1.5%/yr until 2030

Every day: 190 000 more people (N-D), i.e. ± 6 millions/month!

± Belgium bimonthly ...!





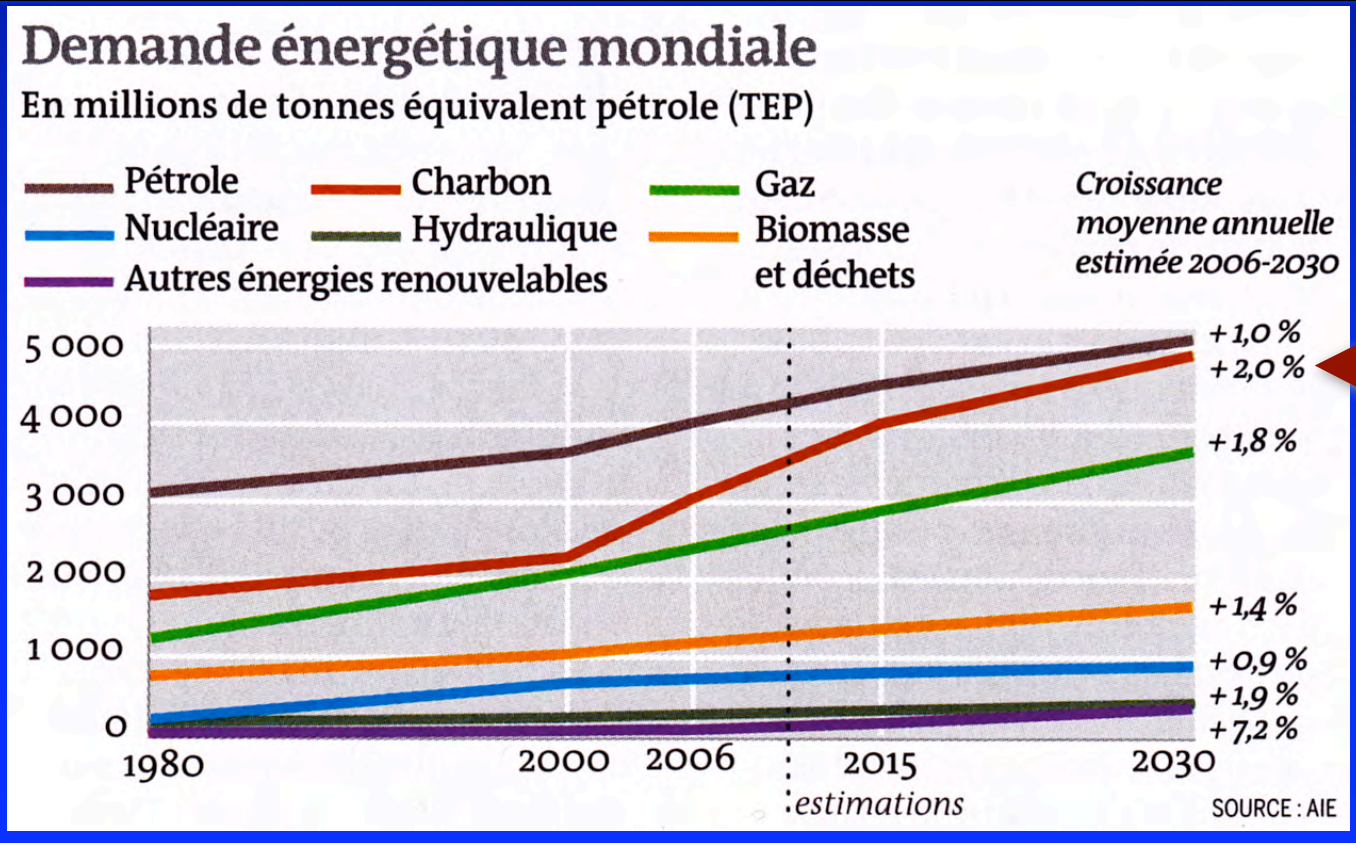
2000-2005: oil, coal, gas = 90% of the needs
(Am and Eur consumed 51% of global energy)
since1850 energy consumption= X150 to ?X1000

Population – Energy Needs

In 2008: CRISIS and BBL = $147!

1 OIL global consumption = -0.6% (negative for the first time!)
2 COAL global consumption >2.5% (+4.9% between 2000 and 2006)
(strongest increase for the 6th consecutive year)
3 GAS global consumption = +2,5%

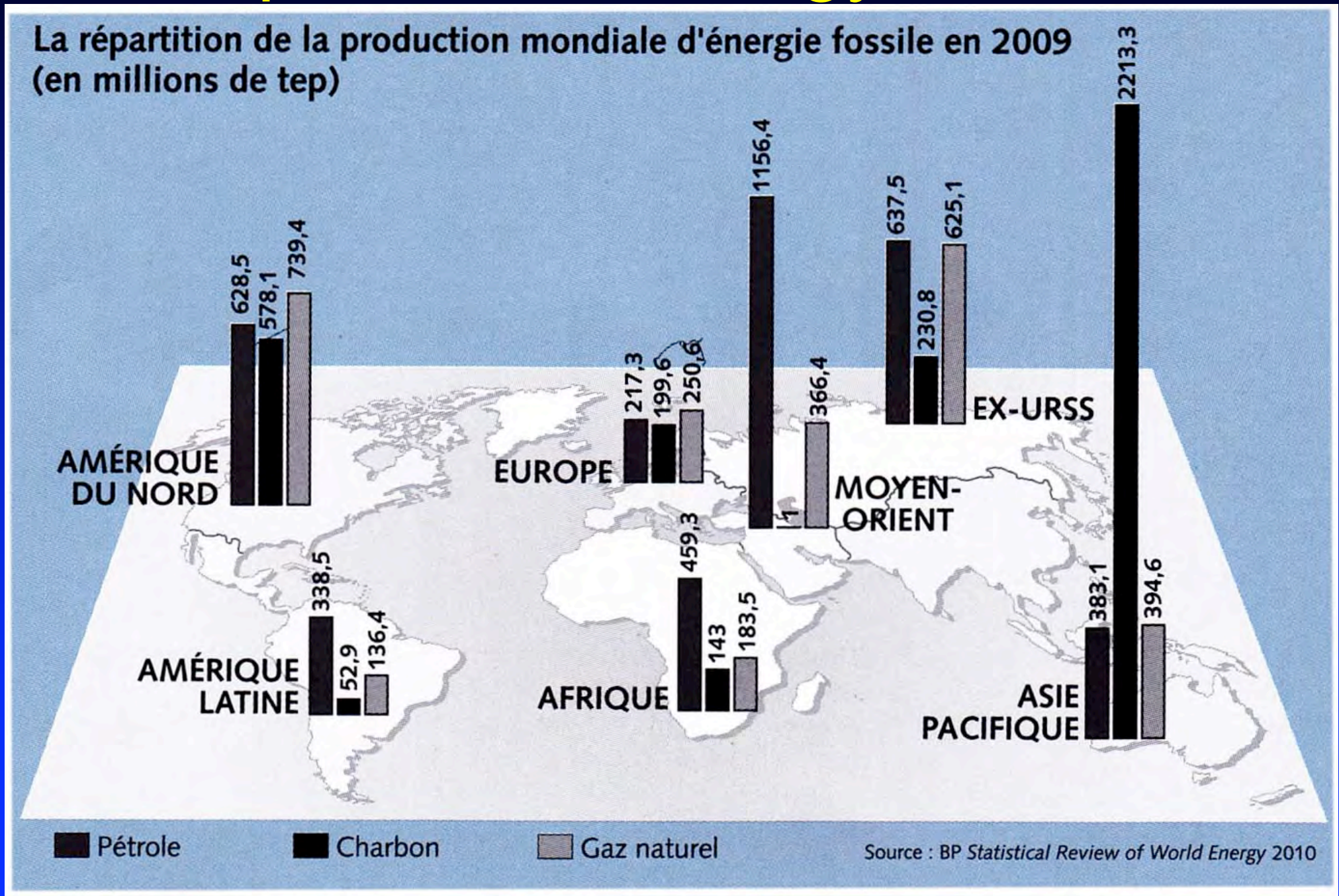
TOTAL: global primary energy consumption
increased by +1.4 % in 2008 (despite the crisis...) and decreased! by 1.1% in 2009



i.e. +60% between 2006-2030

Sequestration not before 2020?
and results in 2030 (EIA, 2008)

Population – Energy Needs



Population – Energy Needs

2005 (after AIEA-2007)

PRIMARY ENERGIY

fossil combustibles

80% or +...

ELECTRICITY PRODUCTION

fossil combustibles

65% [coal 40%]

Hydropower 16% Nuclear 15%

Nb. China, 2 coal plants/a week

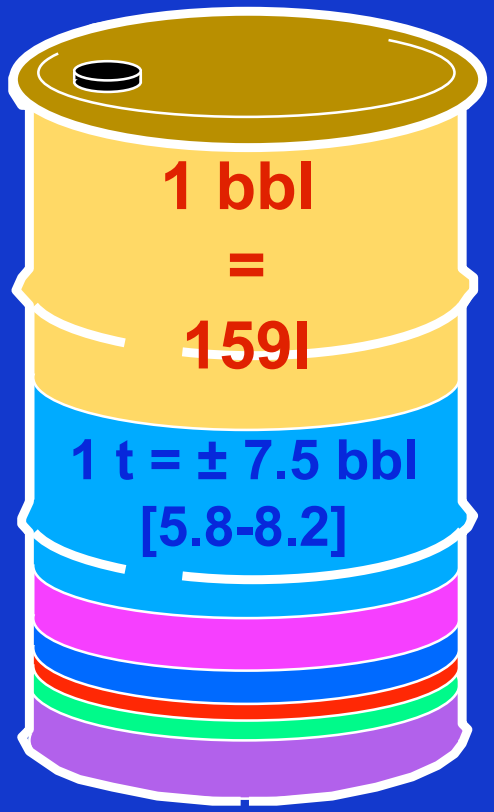
Nb: USA, 640 thermal (coal) plants, 140 will be built

since

2006 - ±85 M bbl/j

(75 c + 10 GL and Tar sands)

= work of 22 G slaves during 24h

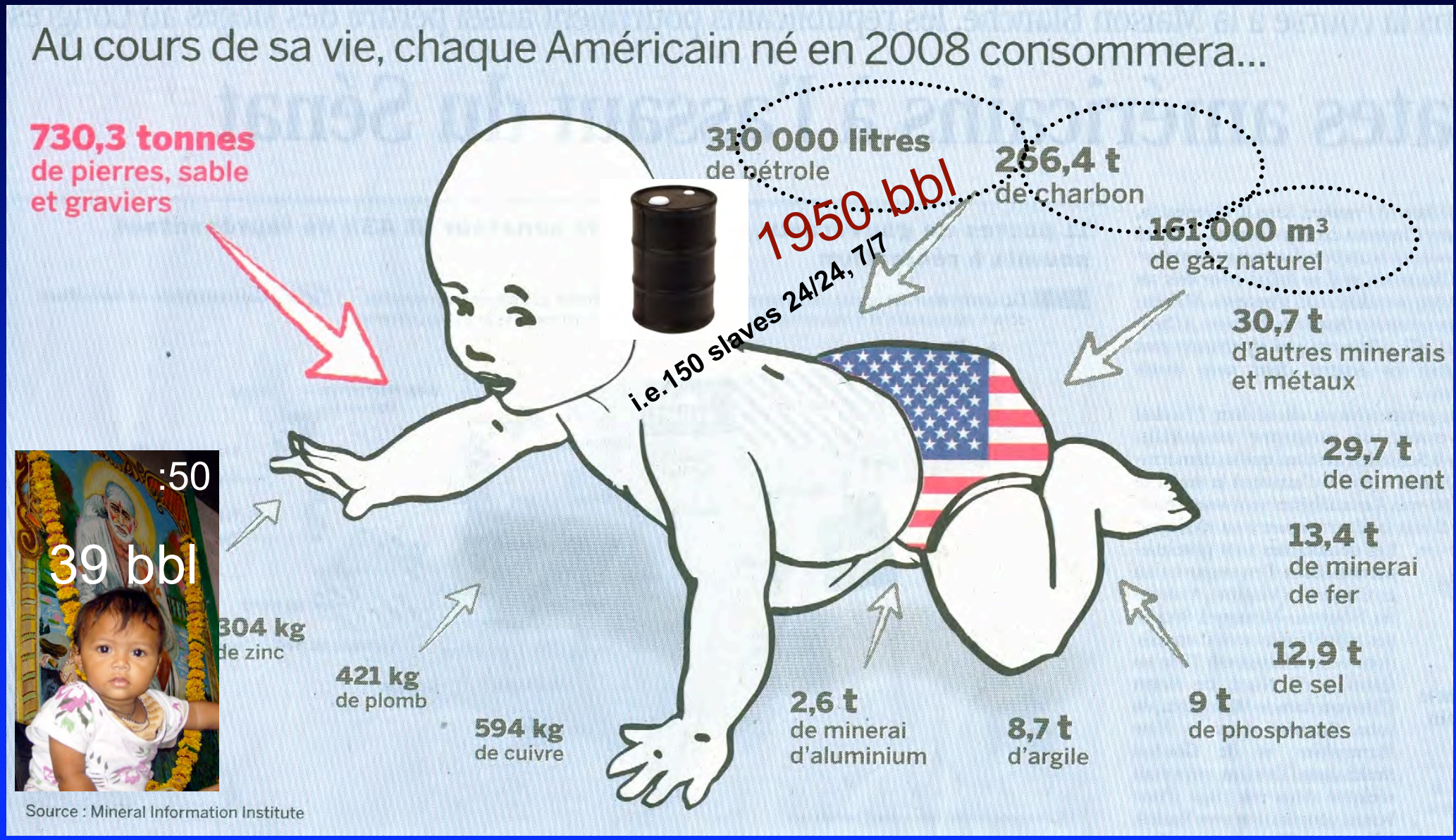


= 1000 bbl/sec

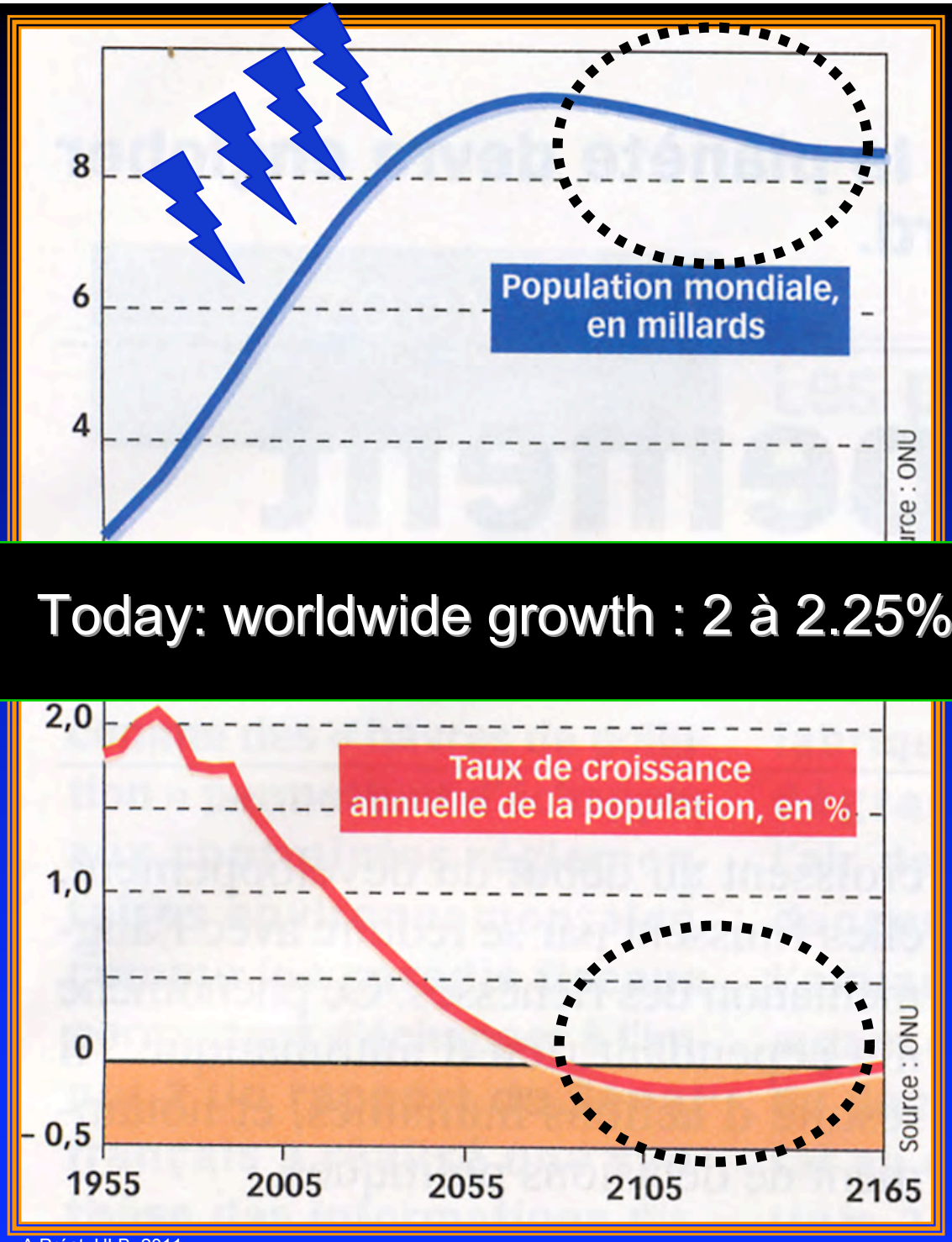
i.e. 5500/day

or 550/lecture

Population - Energy Needs



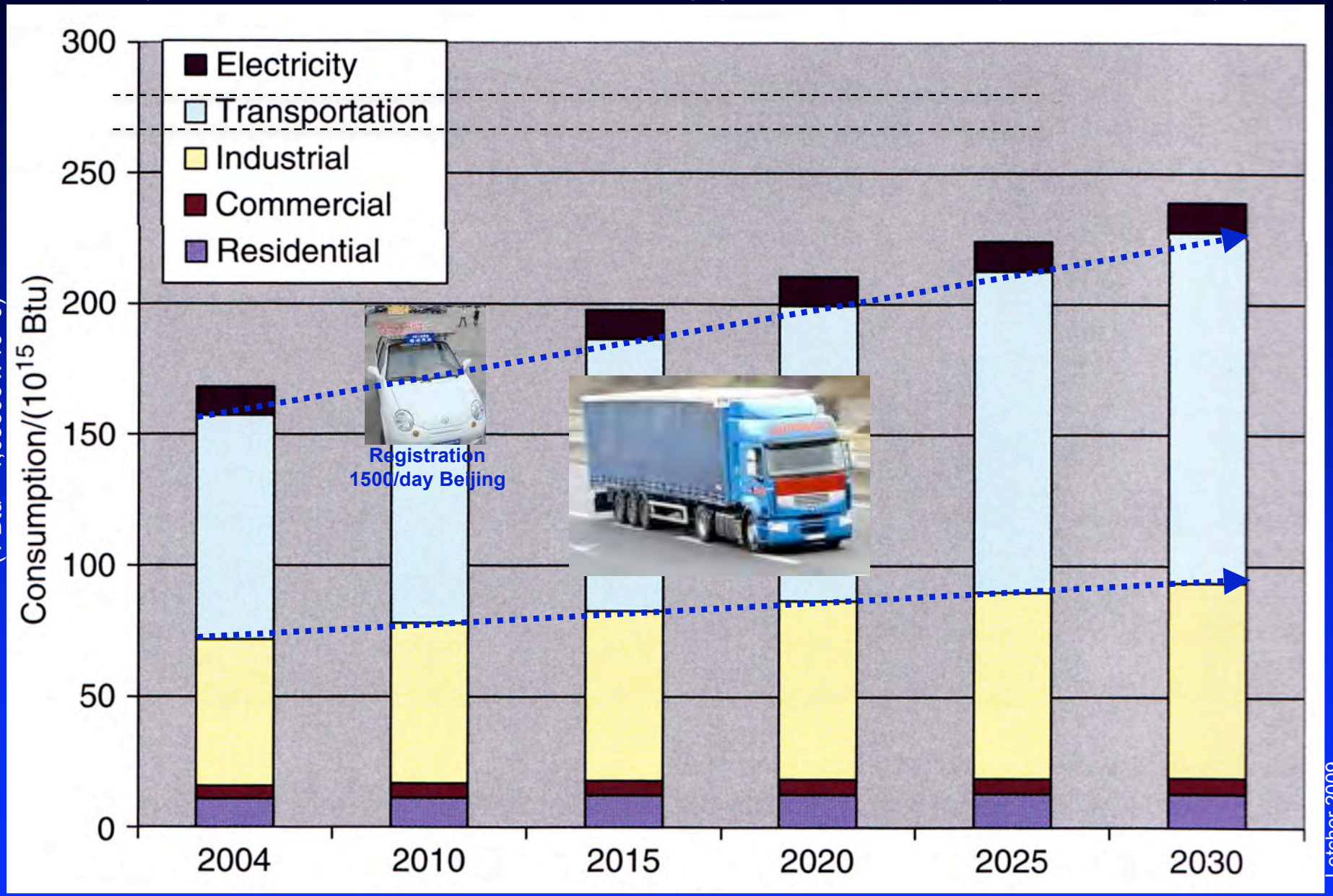
In 2006, yearly worldwide primary energy consumption /capita 1.7 toe (low value of not great significance)
0.024 tep/capita/yr ETHIOPIA to 8.6 toe/capita/yr USA (ratio X358) 4.5 Japan 4 Europe 1.3 China 0.4 India ….



Today: worldwide growth : 2 à 2.25%

In 2009 : 97% of global transport depends of oil

In 2009: only 2% of Chinese own a car =>3.5 million cars in Beijing are to be expected (today 1 car/minute in Beijing)



In 2009: 476,194 new cars were registred in Belgium i.e. 1305/d (= -11% relative to 2008) i.e. ± 1car/minute

In 2010: transport in Belgium = 27 millions of liters/day: i.e.± 170 000 bbl/day (60% for the State as taxes)

2009

1/3 of global E = transport

700 millions today

$3 bbl before1973
$18.50 1985-2000
$41.60 2000-2007
$98.50 2008

X4

Oil demand (conv.) = +1.1%yr
Declining Production? 5%

?

1.2 billion in 2020
2.9 billion in 2050

without greenhouse gas

. . . Short s y n t h e s i s . . .

In 2003: global E consumption = 12 TW
[i.e. equivalent of 12,000 reactors of 1 GW]
Forecast for 2050: 24 TW, stabilisation?

To compare : the 'RESERVES' [magnitude …] *[=proven]*

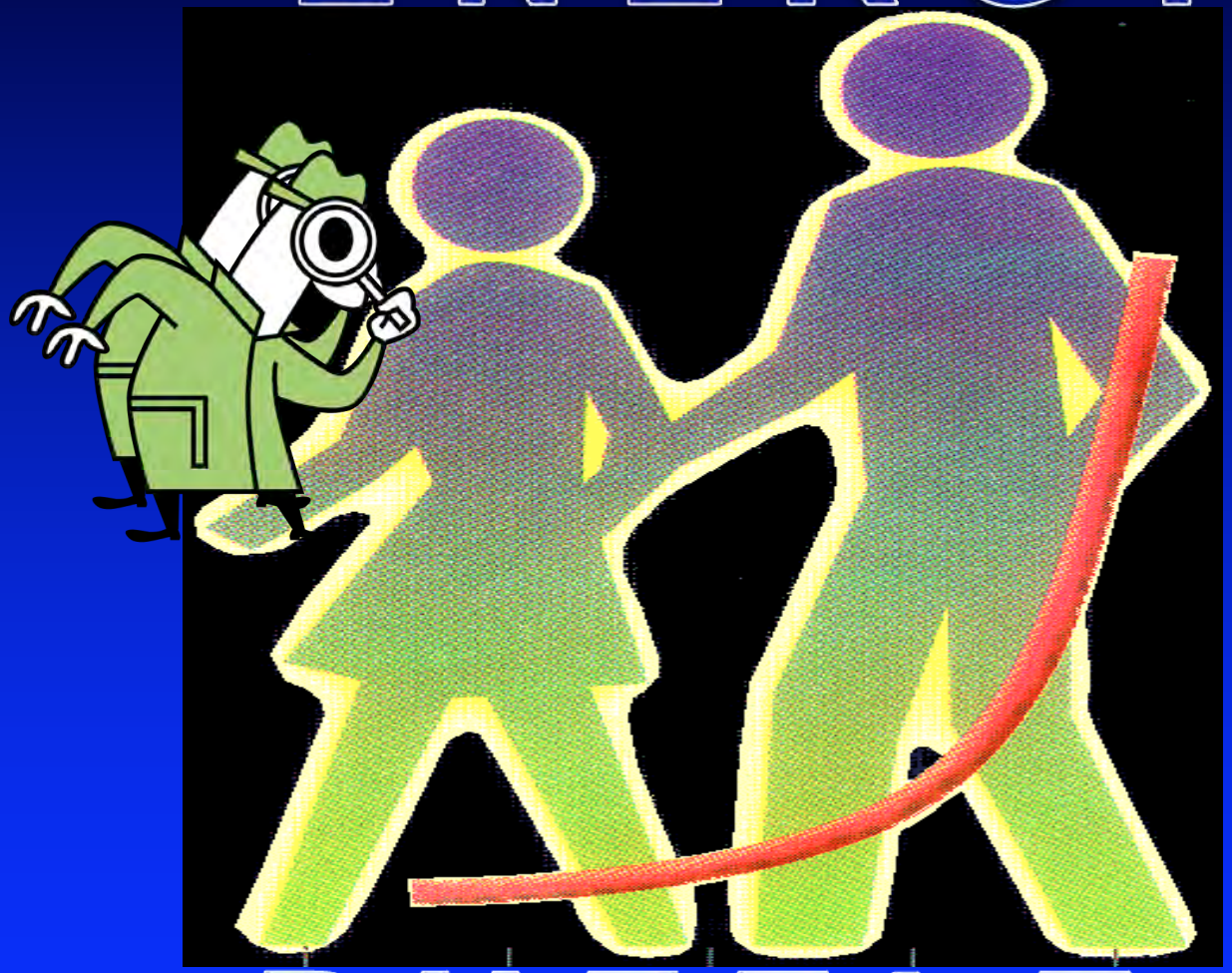
Oil 1200TW/24 = 40 to 50 years, Gas 1200TW/24 = 50 to 70 years
Coal 4800TW/24 = 200 years or more
Nuclear with slow neutrons(U^{235}) = 3000TW/24 = 40-50 yrs *C. Steffens, 2010 (pers.com.)+Areva, EDF*
Nuclear with fast neutrons (U^{238}, Th^{232}) = 30 000TW/24 = 200-250 yrs
Deuterium-tritium thermonuclear fusion : uncontrolled, cost effectiveness?
few 10^3 years, limited lithium availability
Deuterium-deuterium thermonuclear fusion : much more difficult,
Utopian? [we must reach a T° of 100 million of degrees…], few 10^9years!
Nb Total E emitted by the reactors has increased by less 6% during the last 10 years (i.e.< 1%/yr, counting from 2003)

Reeves, 2003

To compare : the 'Renewable' Energies

Hydropower, wind, thermal solar, photovoltaic… = 10^9 years
but efficiency STILL too low…

ENERGY PUZZLE



No RE source can ITSELF
replace oil anytime soon (and medium?) term
> nuclear proponents hope to benefit
the slow development of RE, and FE growth difficulties, 'to boost'
[even without greenhouse effect, but with waste...]

pending = energy puzzle

A VERY SERIOUS alternative
= SOBRIETY= Reduce E consumption
===> association NEGAWATT www.negawatt.org
Could be reduced up to 70% E consumption
compared to current trends in our countries!

2006

2006

pending = energy puzzle

3to4 %

An alternativ *VERY SERIOUS*

= SOBRIETY

25 %

or ¼ global production

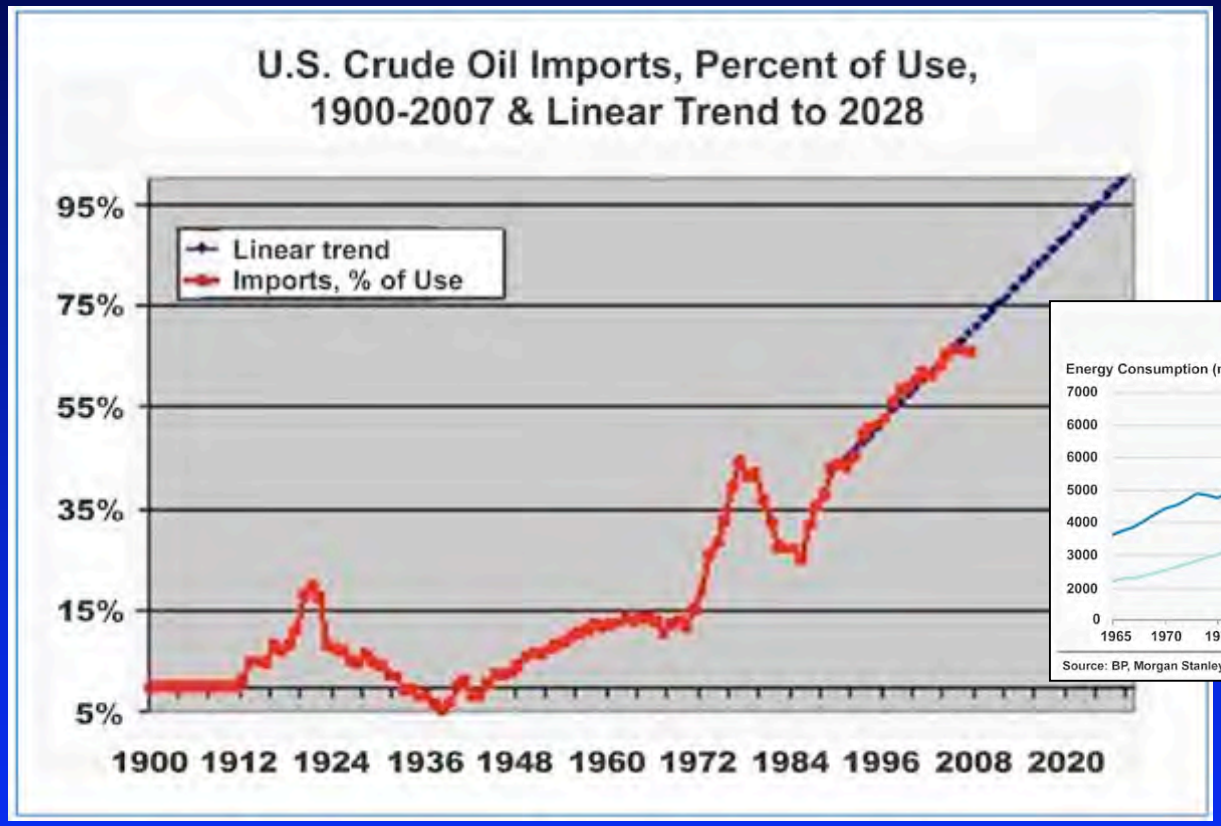
In 2009 USA imported 60% of oil....

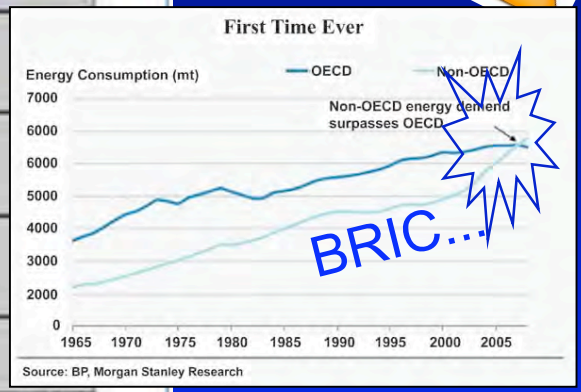
The TOP10 of oil consumers in 2008

2008	Mbbl/d
USA	19,4
China+HK	8,3
India	4,8
Japan	4,8
Russia	2,7
Germany	2,5
Brazil	2,4
S Korea	2,3
Canada	2,3
Saudi Arabia	2,2
	49,7

Σ ±85

BP 2009





Same type of graph to China since its economic takeoff

In 2009 China became the world's largest consumer of primary E with 2.2 Gtoe before the United States (2.1Gtoe)

Pending = energy puzzle
Population = Energy Needs

• Today: we consume 3 to 4 bbl [1] oil for 1 [5, 1960] discovered

- En 2004 dollars from 1869 to 2004, global oil price was
= $ 19.41 .... i.e.'cheap' .... (median= $ 15.17)
- In 2004: 3.5 billion Asians have consumed
20 million bbl/d and U.S. [293. 10^6 Hab].

In 2004: 1US 25bbl/yr, 1Japanese 18, 1European 12,
1 average Earthling 5, 1Chinese1.5 et 1Indian 1bbl/d

1 bbl = 1600 kWh

31 countries
16% Global Electr.

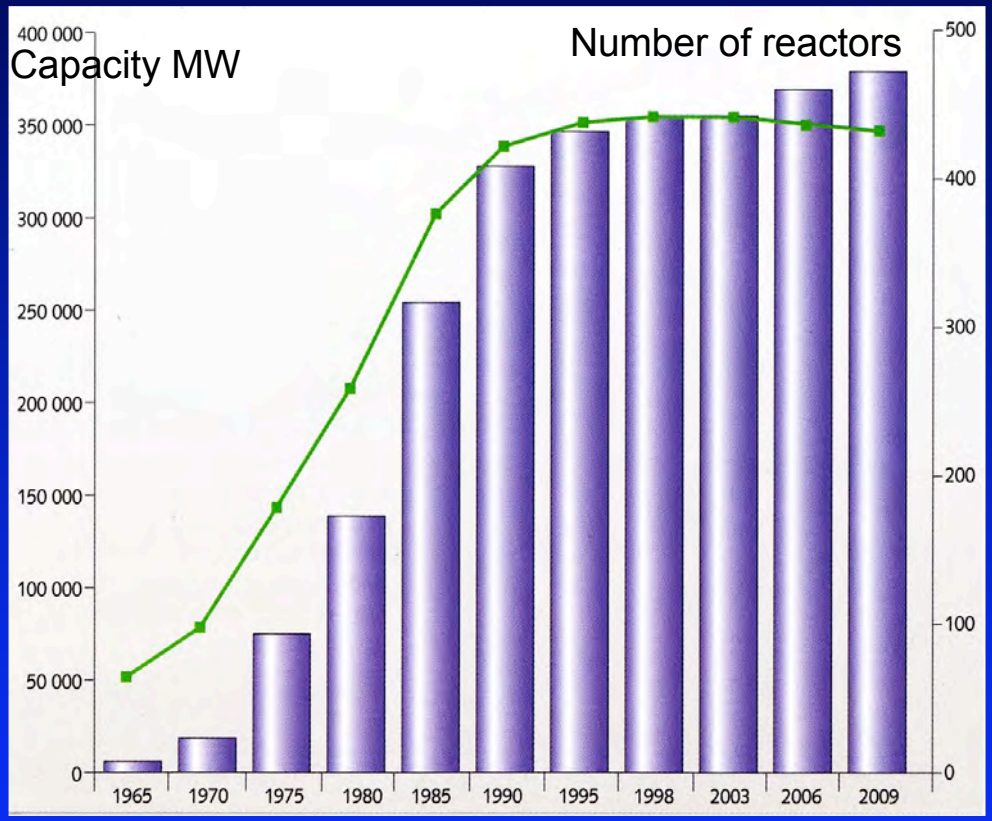
A Préat, ULB, 2011

2000 'current' nuclear reactors
needed to replace ¼ current production of oil

440 reactors in the world in 2008 (105 USA, 59 in France, 55 in Japan, 31 in Russia, 20 in South Korea…)
Belgium :11 stopped and 7 are working

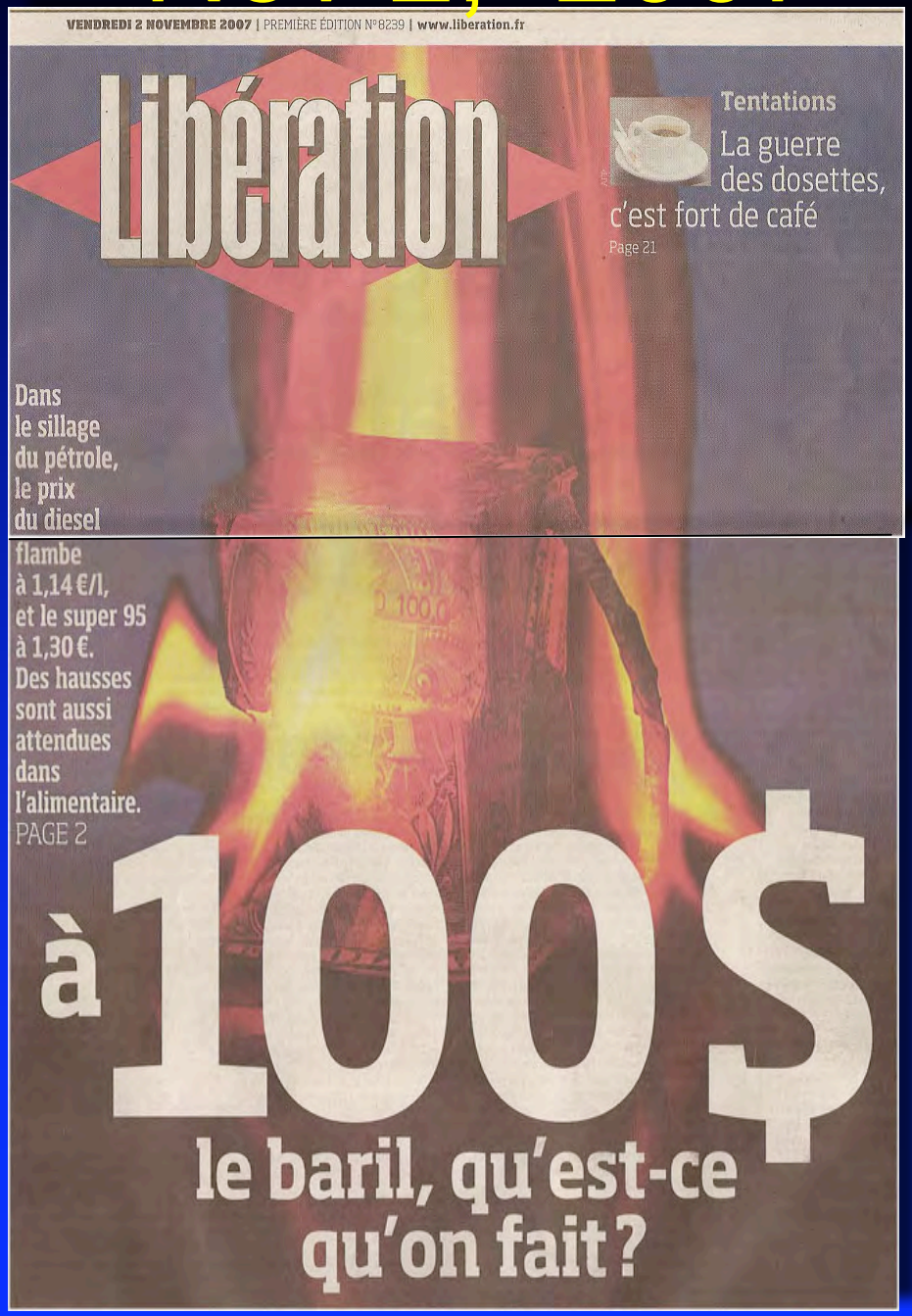
In 2006: 20 reactors in building [2Eur, 4China, 6Japan, 8India]
In Chine 2007: 15+5 ===> X2 in2020
In 2009 (World): 200 reactors for 2020

Energy puzzle?



Development of (civilian) nuclear power in the world

Nov 2, 2007



November 7, 2007 : $ 98 (NY, Singapore)

- depletion (production decrease)
- Asian demand
- geopolitical tension (Turkey/Iraqi)
- speculation

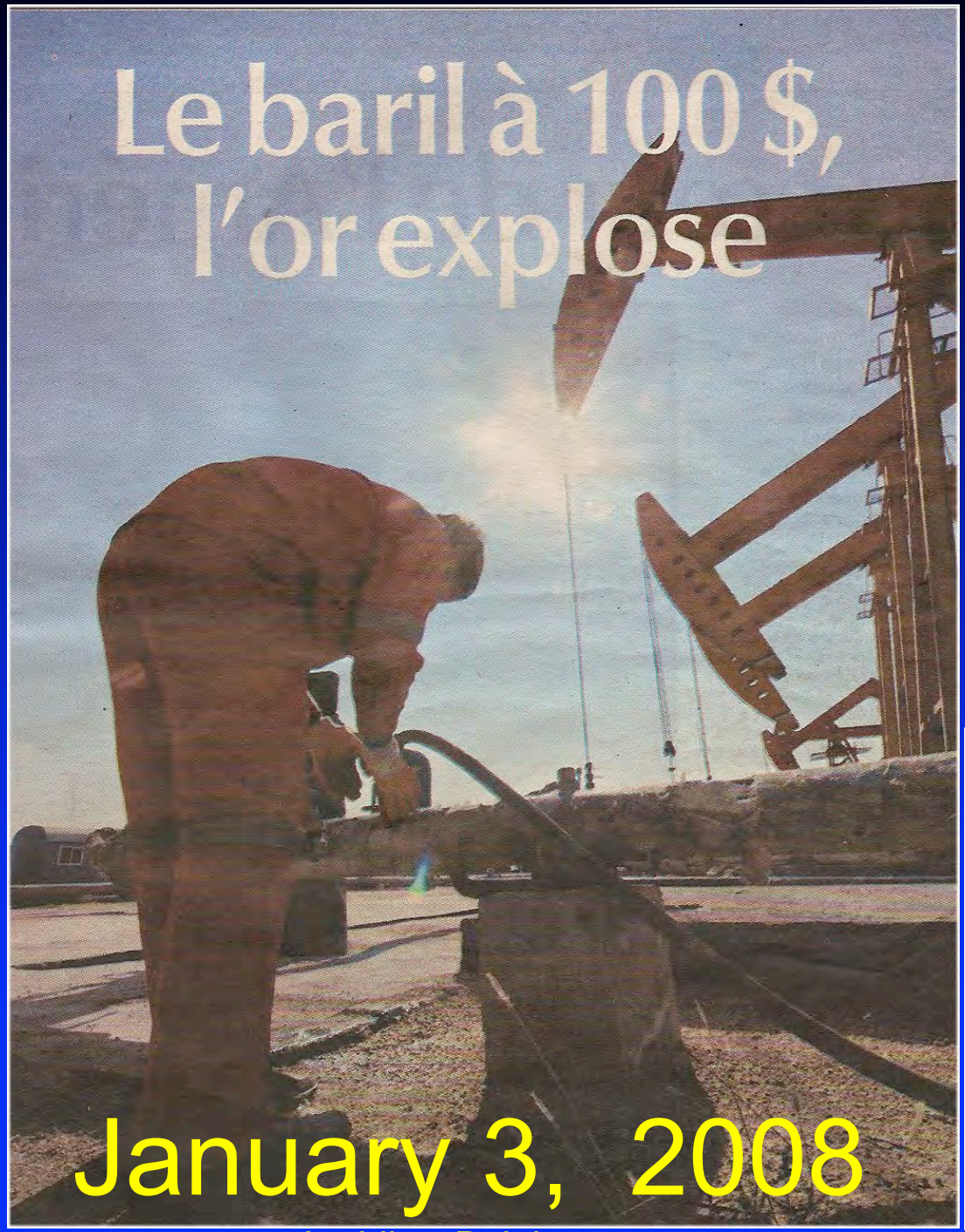
...

NO CLIMATIC CATASTROPH ,
NO WAR(S) ...

« grain of sand ».... > $100
[symbolic threshold]
... $ 200 .... $ 300

What to do? ° sobriety° transport....
In the absence of real policy:
Rich >< Poor

Ex: in 2001, question V Poutin
« with the abolition of social grants, what will become all miserables (*sic*) pocketing 30€/month? »
Answer: « They will die, sir, they will die ...»



January 3, 2008

- new Nigerian violence
  [first African producer]
- Pakistan (Bhutto assassination)
- Cold Winter USA (fall of stocks)
- No increase in OPEC production
  [if not reduced financial returns]

nb 21 Feb 2008: $ 100,10 'sutainable'?
26 Feb 2008: $ 101,40 'sutainable'?
28 Feb 2008: $ 101,45 'sutainable'?
7 March 2008: $ 105,42 'sutainable' ?

'nothing of special'

La Libre Belgique

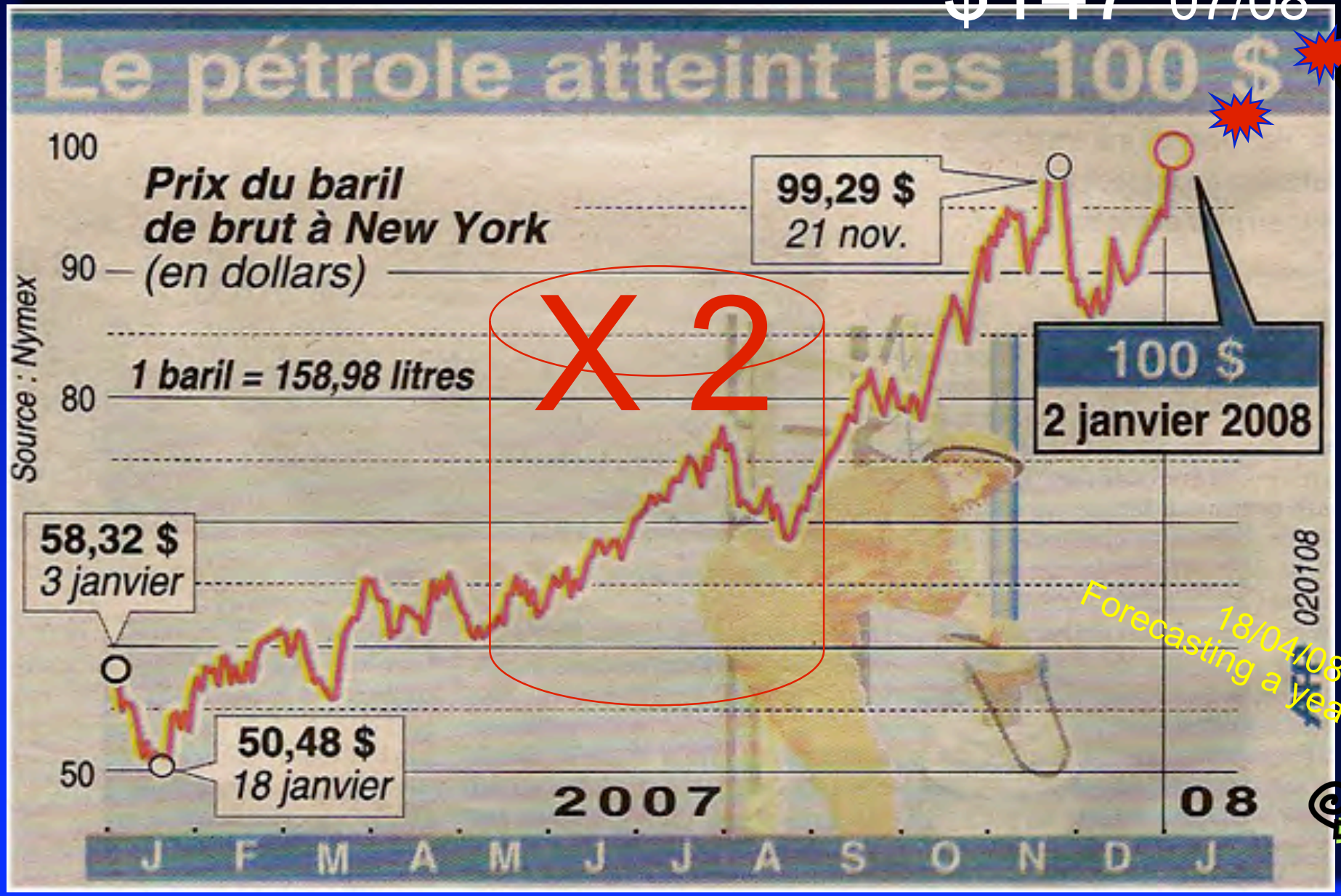
Les Echos 3 Jan 2008

January 3, 2008

La Libre Belgique

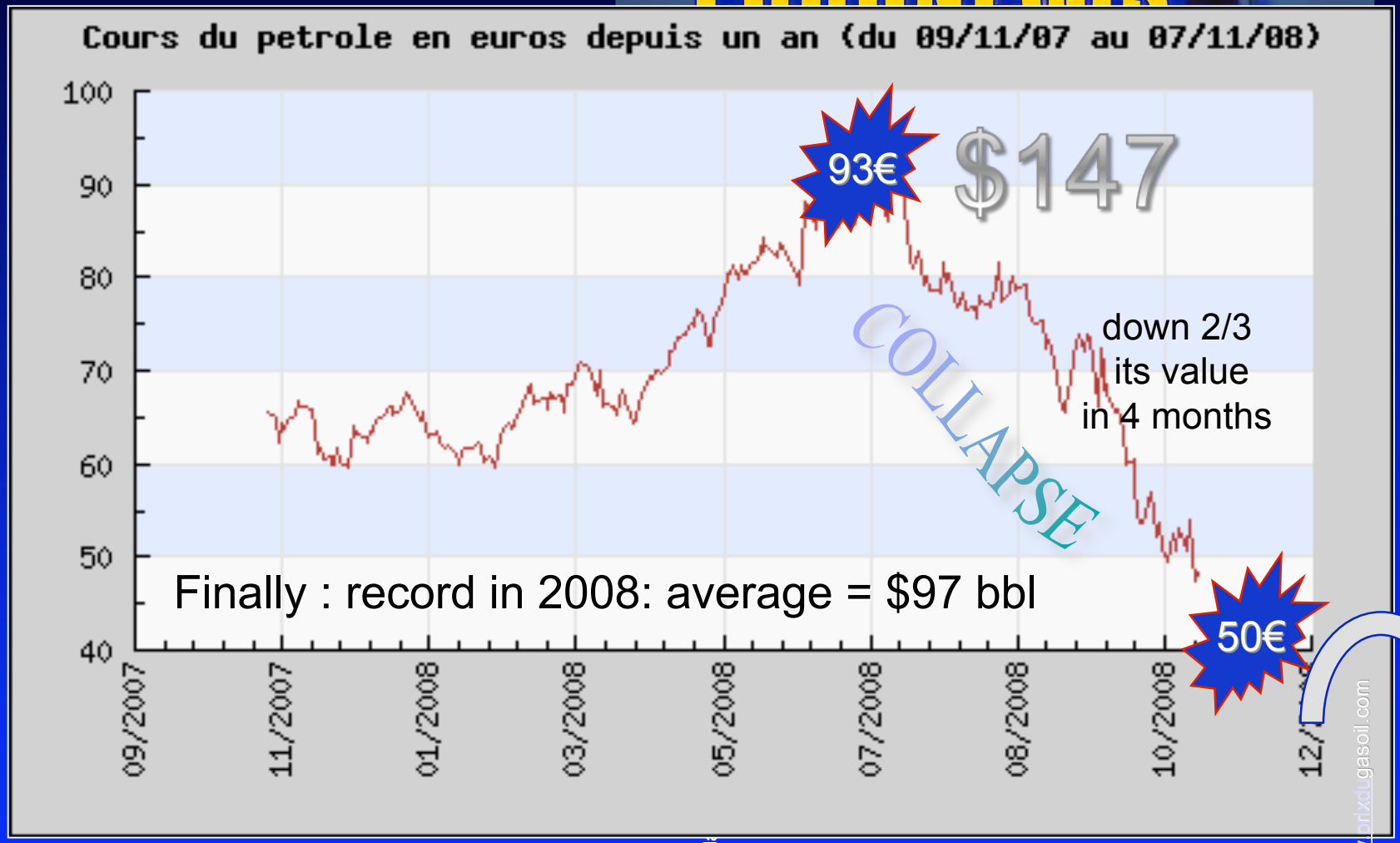
$147-07/08

Forecasting a year: 2/03/08 $ 132 ± $45



Forecasting a year: 18/04/08 $149 ± $45

Predictions of January 3, 2008 ... proved...

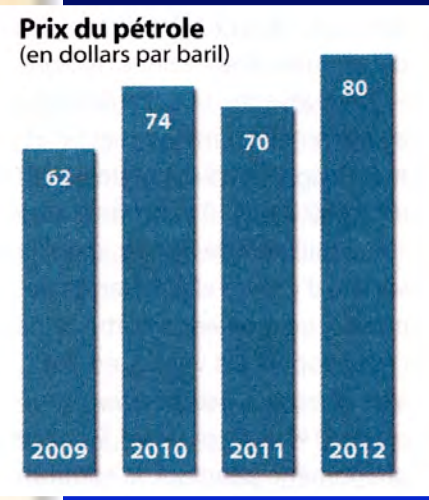


The demand for petroleum products fell 7.1% in the U.S. the four weeks (October) compared to the previous year

OPEC quotas decrease rapidly …. ?

± $35 - $40
beginning 2009

end 2009 = ‘row’ 80- ? $100



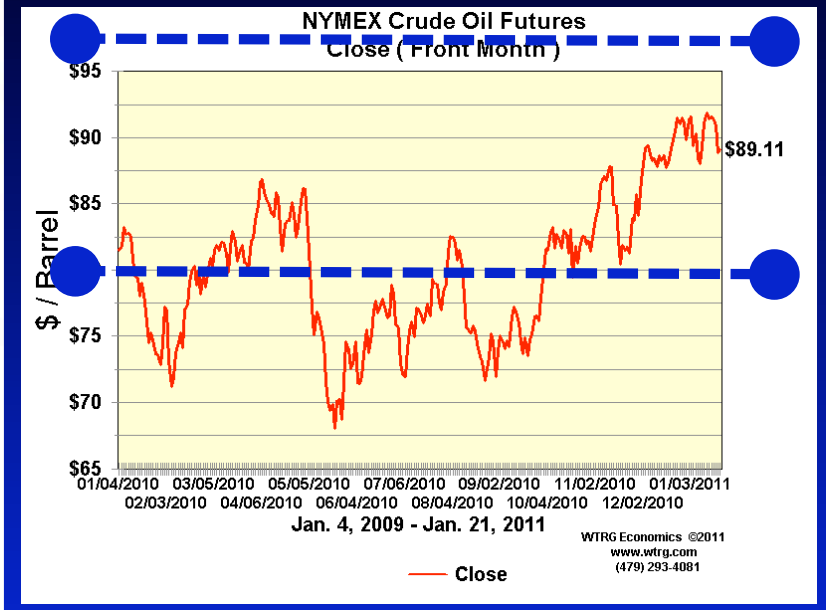
The Economist-Trends Dec 2009

end 2009

‘row’ $35-$50
(short term 1-3 months)

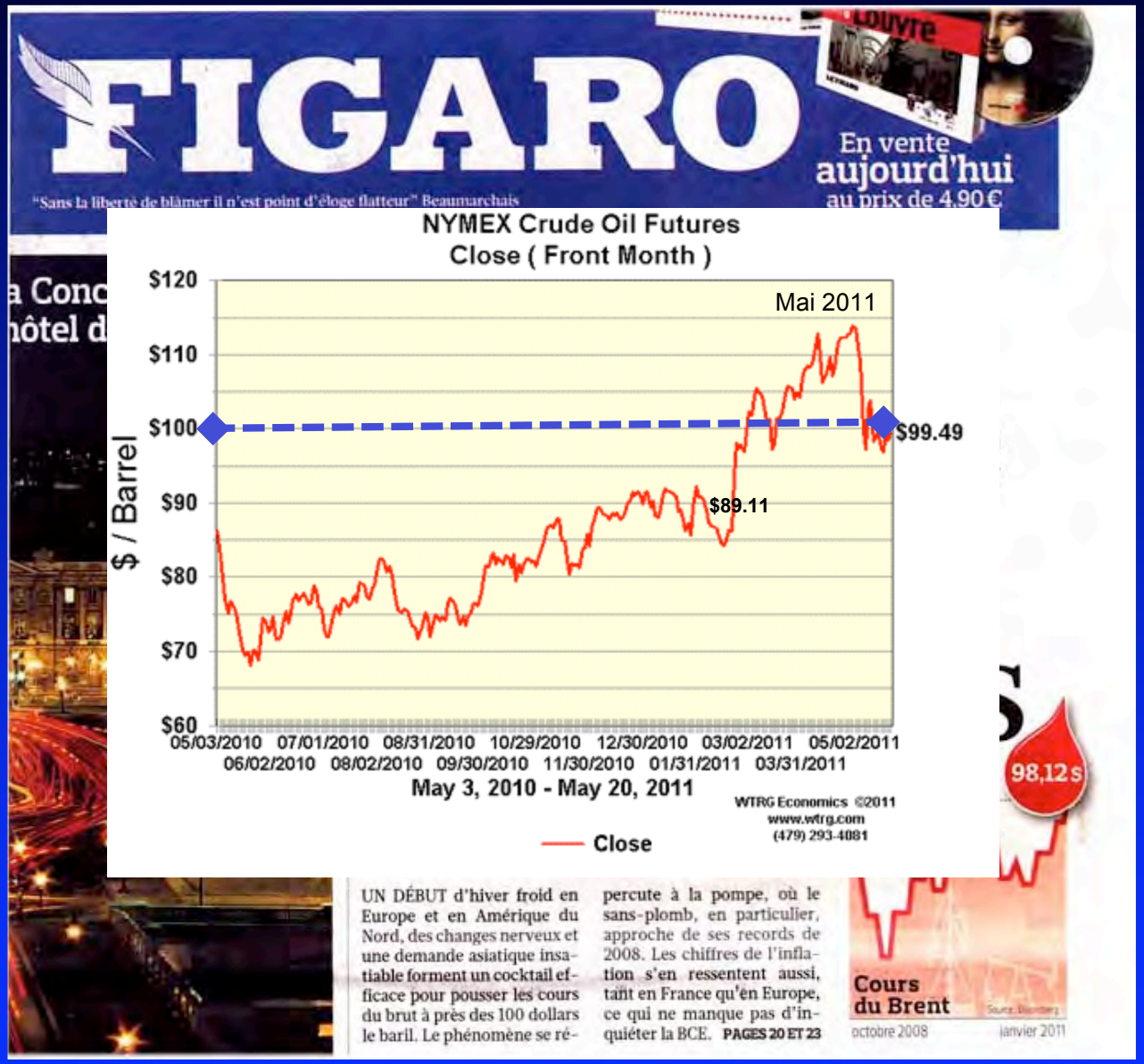
It did not last
=> new row
$80 to? $100
+ speculation:
Dec 2008 1bbl = $33
Nov 2009 = x2

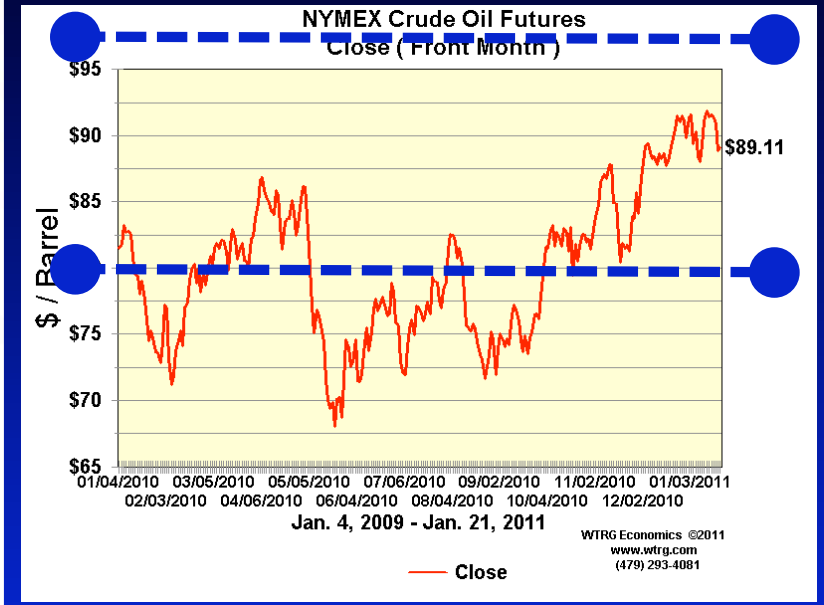
January 14, 2011 – $98.85 =? Cold Winter Eur-USA



February 3, 2011 – $101.93 =?Egypt, Gulf of Suez…

January 14, 2011 – $98.85 =? Cold Winter Eur-USA





February 3, 2011 – $101.93 =?Egypt, Gulf of Suez…

January 7, 2010 : $83 i.e.+80% in one year...

- cold (-1°C = 5% more E)
- 'economic recovery'
- weaker € vs $

PRICE VOLATILITY : short term
1997 /1998 1bbl = $9
End 2007 1bbl = $100
Consumption x11?, Production :11?

= speculation (financial transactions = 15x physical transactions)

= Asian crisis (prod. increase and declining demand) >< increasing demand and threats on supplies
[Iraqi, difficulties Ioukos, instability Venezuela and Nigeria]

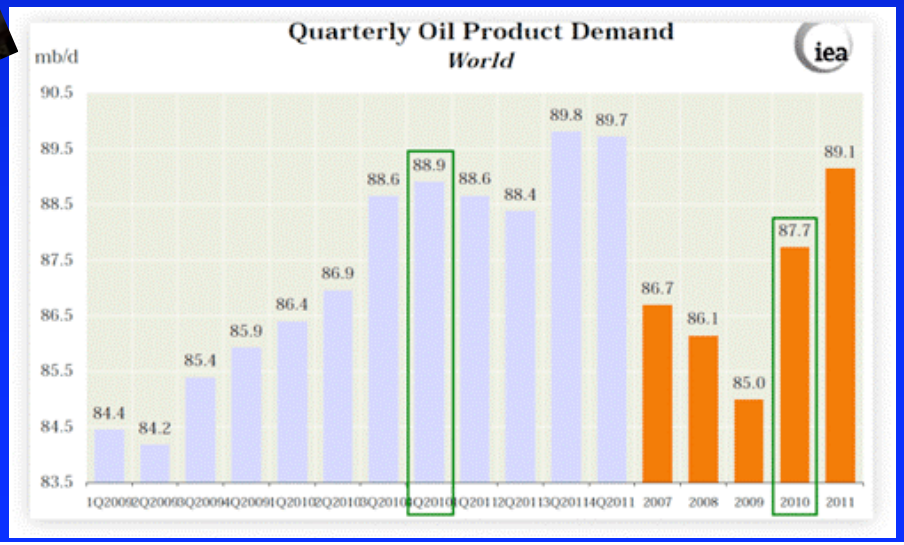
February 24, 2011 - $114.9

February 2011 (Libya, Bahrain…)

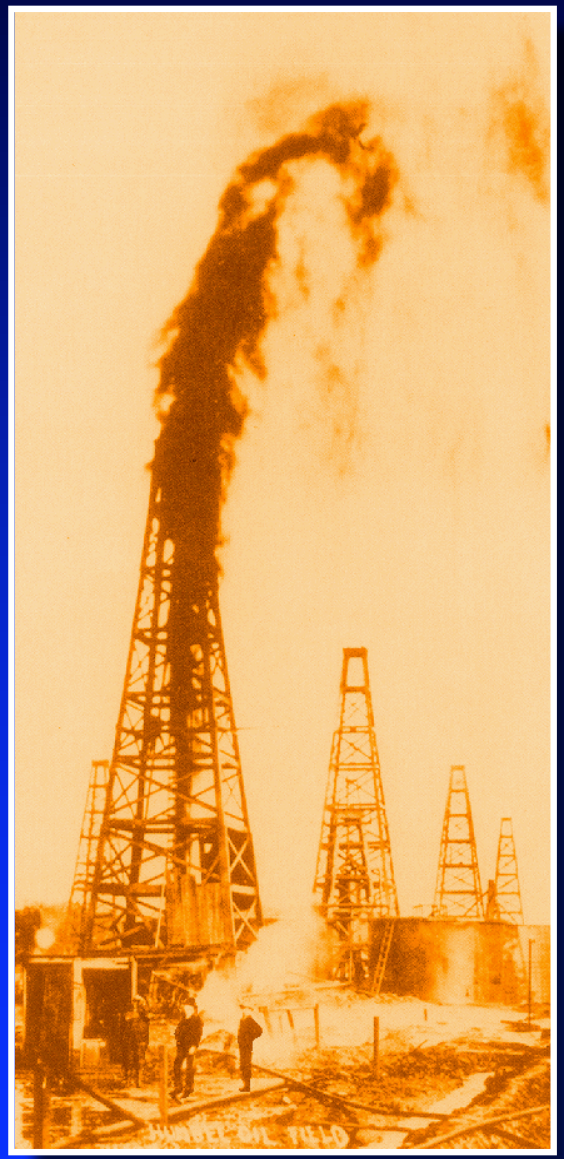
Resuming growth
'BRIC-BASIC'
China: +10% oil demand
⇒Saudi Arabia compensates…
⇒… how long?

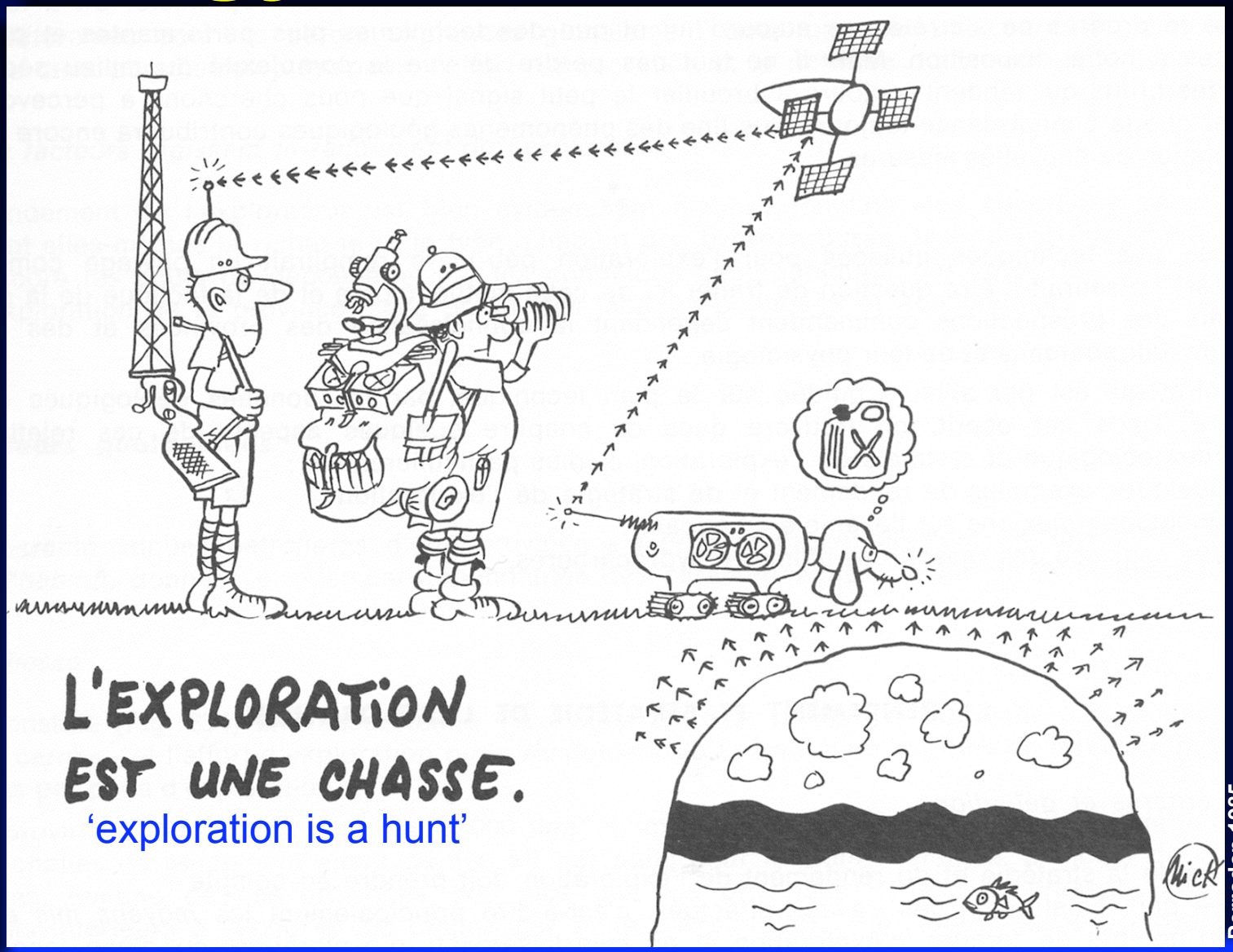
2009 85 Mbbl/d
2010 87.7Mbbl/d
2011 89.1 Mbbl/d

February 2011: Libya
- pumping crude du brut: -75%!
  => -1.2 million bbl/d
  => compensation = Saudi Arabia?
  (can compensate up to 3 Mbbl/d
- EU28: stocks of 145 days of imports
- If TRUE supply disruption
  => bbl > $ 200



Energy Search…





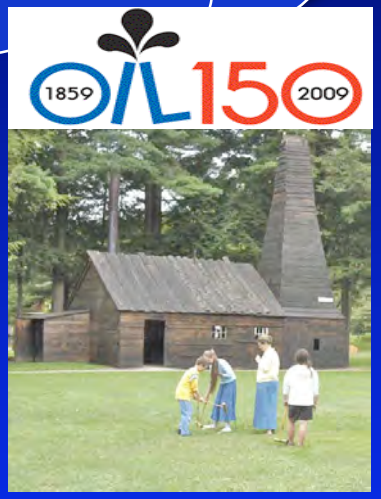
Reserves = Geological, Technological and Geopolitical Uncertainties

Reserves = Geological Uncertainties...

28-08-1859

Reproduction of an engraving of the 'Colonel' Drake drill at Oil Creek, 28/08/1859

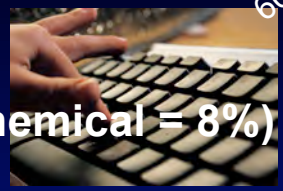
Died poor in 1880 after….
speculating on the oil market …



Came from very good quality oil at 70 feet with a rate ranging from 10 to 25 barrels/day (1.6 to 6.5m^3/d) in 1859

…June 1,1860: 19 wells on Oil Creek + 8 on two other sites and 25 000t in 1860

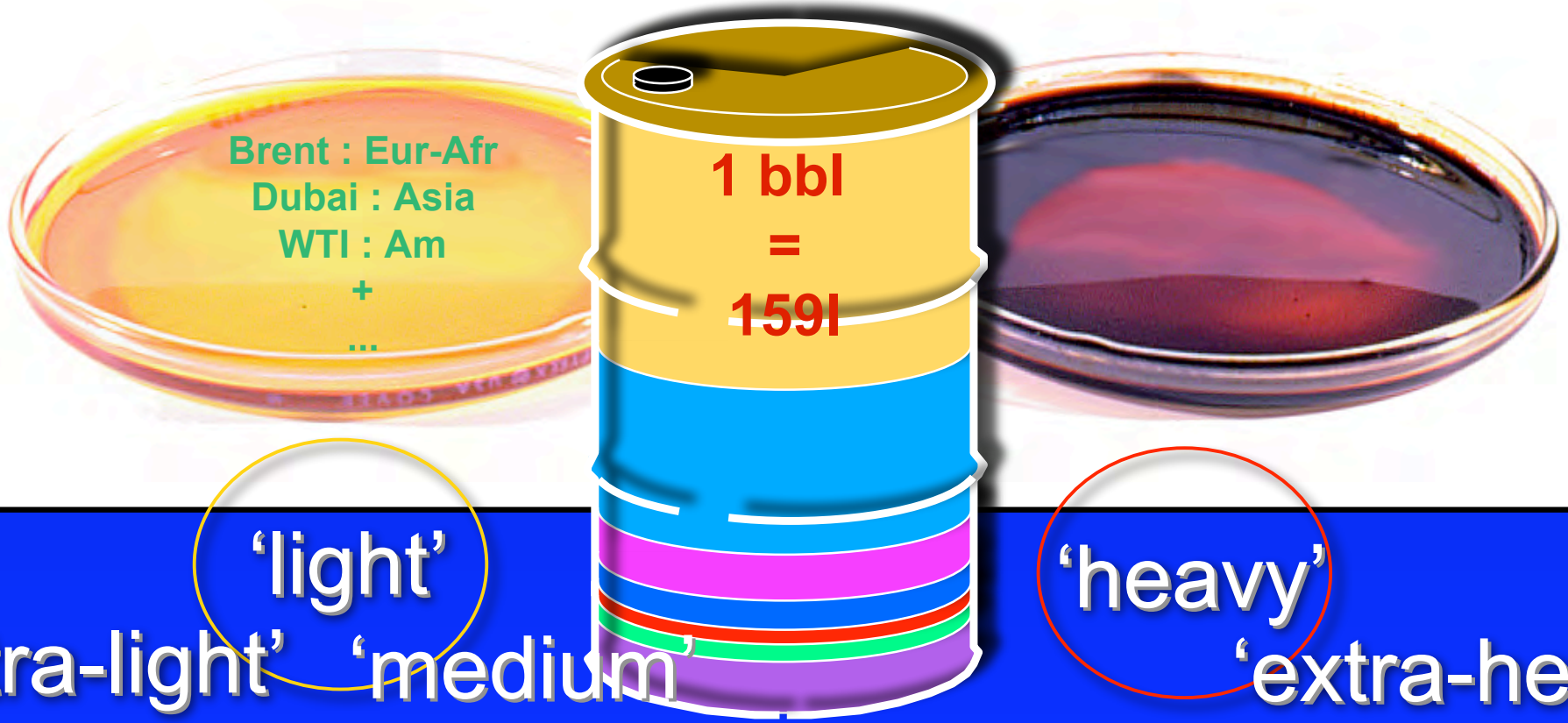
The Crude - “ The Black Gold”



The ‘oil’ enters the essential composition in nearly 300,000 products (petrochemical = 8%)
The crude is operated from about 70,000 oil fields

Light Texas Crude
Palo Pinto Field
North Texas

Heavy Texas Crude
Humble Oil Field
Southwest Texas

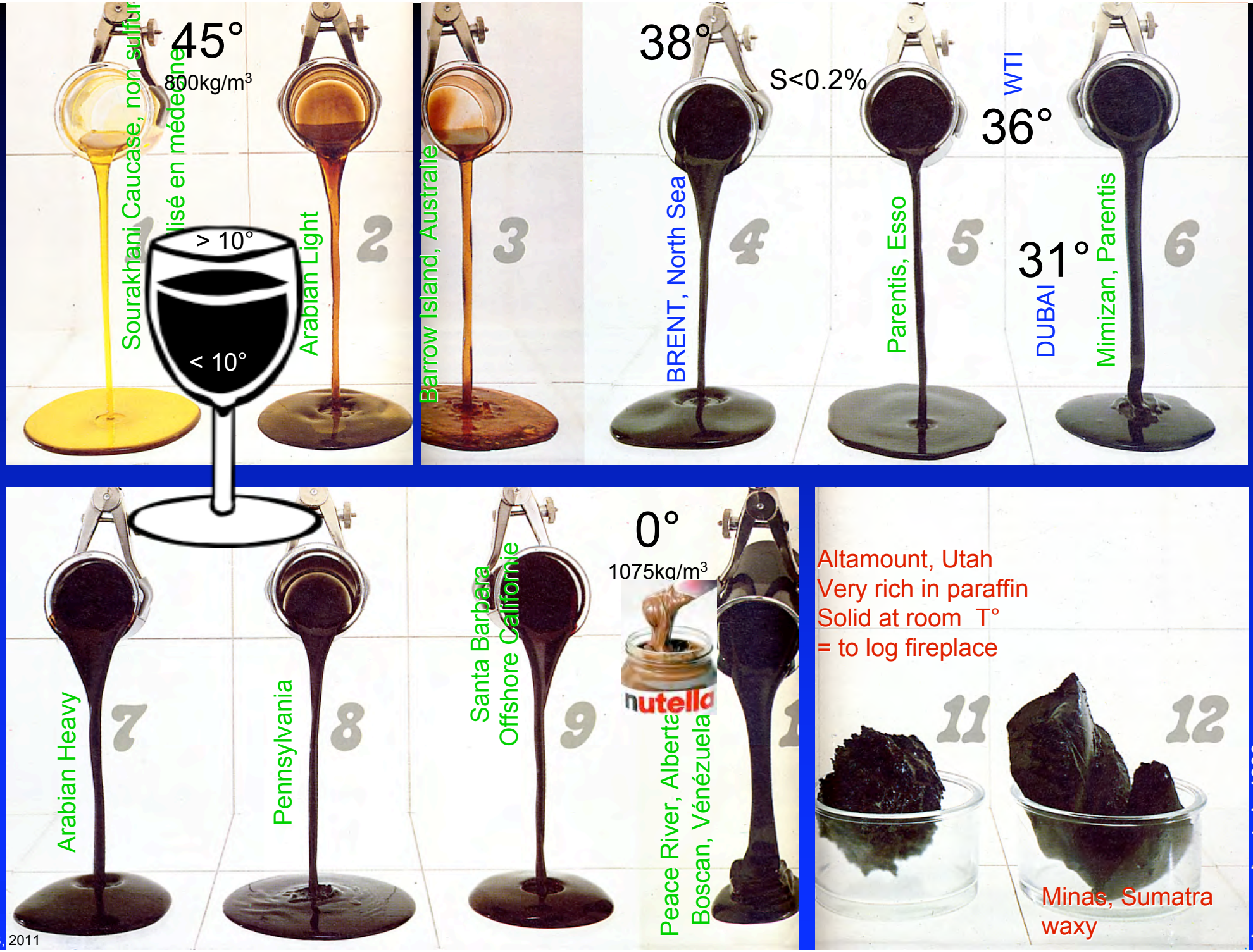


American Petroleum Institute, 1999

‘light’
‘ultra-light’ ‘medium’

‘heavy’
‘extra-heavy’

CRUDE EXXON



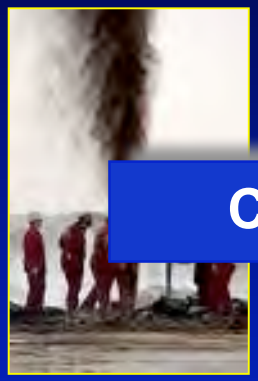
sour crude
sweet

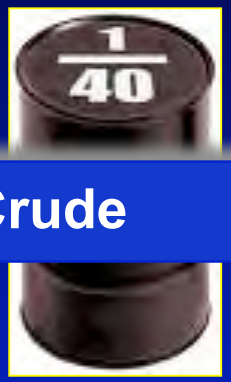
>1%
<1%

+ SULFUR

Leygonie et al., 1983

Simplified flowchart of refining crude oil to produce fuels





Crude → **purification** → **distillation**

Salts (a few g to a few kg/ton)
Sulfur...
...

- **Gas** 4% ±180°
- **Gasoline Light solvent** 46% ±250°
- **Kerosene** 10% ±360°
- **Diesel** 27%
- **Residues** >500° cracking

T°

Dubois 2007

States exporting producers refine very little
1. USA 20.1% global i.e. ± 850 million tons (2004)
2. China 6.9%, 3 Russia 6.4% ... 9. Saudi Arabia 2.4%

Today the refining capacity is used to its maximum (2007 [92%] and does not follow the pace of oil increase
2003-2004: 0.8% >< 4.4%
===> Hurricane Katrina ...

nb investment of refinery stopped since1976 in the USA!
[a modern refinery with large capacity = $ 2.5 billion]

→ nb petrochemistry: 900 to 2000°C

Geopolitical Uncertainties

REFINING

Usa96%, World92% [2006]

SHIPPING

- **7200 supertankers under convenience flags [5 states have 50% tonnage of the world tanker fleet]**
- **Strong aging of the tanker fleet**
- **?shortage of tankers vs. oil demand growing**

- In 2007-2008, the gap between capacity and demand was about 2 %
  > 'grain of sand' =cyclones =disorders (Nigeria...) etc.
- 85% of world production= NATIONAL companies
  - No investment... because no incentive (the money goes anyway)
  - 80 % platforms are 'rusty' (no maintenance when the bbl was down....)
  - 500 rigs to rebuild = investment of $ 250 billion ....(+ price of Fe)
  - maritime transport bottlenecks ('accident', crises…) = Hormuz Strait


Uncertainties
HYDROCARBONS
Bitumens
from latin bitus
= softwood
or
Confusions
Bitumens are not 'bituminous sands!
Bitumens are produced by refining oil, they are therefore
REFINERY RESIDUES
… not to be confused with
• bituminous shales or 'oil shales,'
[Wyoming, Colorado -USA, Orinoco-Brazil]
[= 'young or immature' oil -there is no bitumen!, not always shale!!]
• tar sands or extra heavy oil [Venezuela] and
oil sands or 'tar sands' [Athabasca River , Canada]
[= bacterial oxydation] and consistency of 'Nutella!'…
Sables Athabasca, Sc et Av 2005
A Préat, ULB, 2011

HUBBERT CURVE : SIMPLIFIED CASE OF THE CURVE OF OIL c WORLD PRODUCTION

1903-1989
prédiction 1956

ASPO www.oleocene.org

Milliards de barils

Pic de production

Déplétion

easy and cheap

difficult and expensive

R/P increase

R/P decrease

?

1re moitié exploitation « facile »

2e moitié exploitation difficile

If no new discoveries

±1200:±30Gb=40yrs

±1200:±40Gb=30yrs

82Mb/d

109Mb/d

±1000 Gbbl [conventionnel]

±1200 Gbbl+ ? ['conventional']

St-Laurent 12600m³/s during11yrs

1859

2015

2150

Années

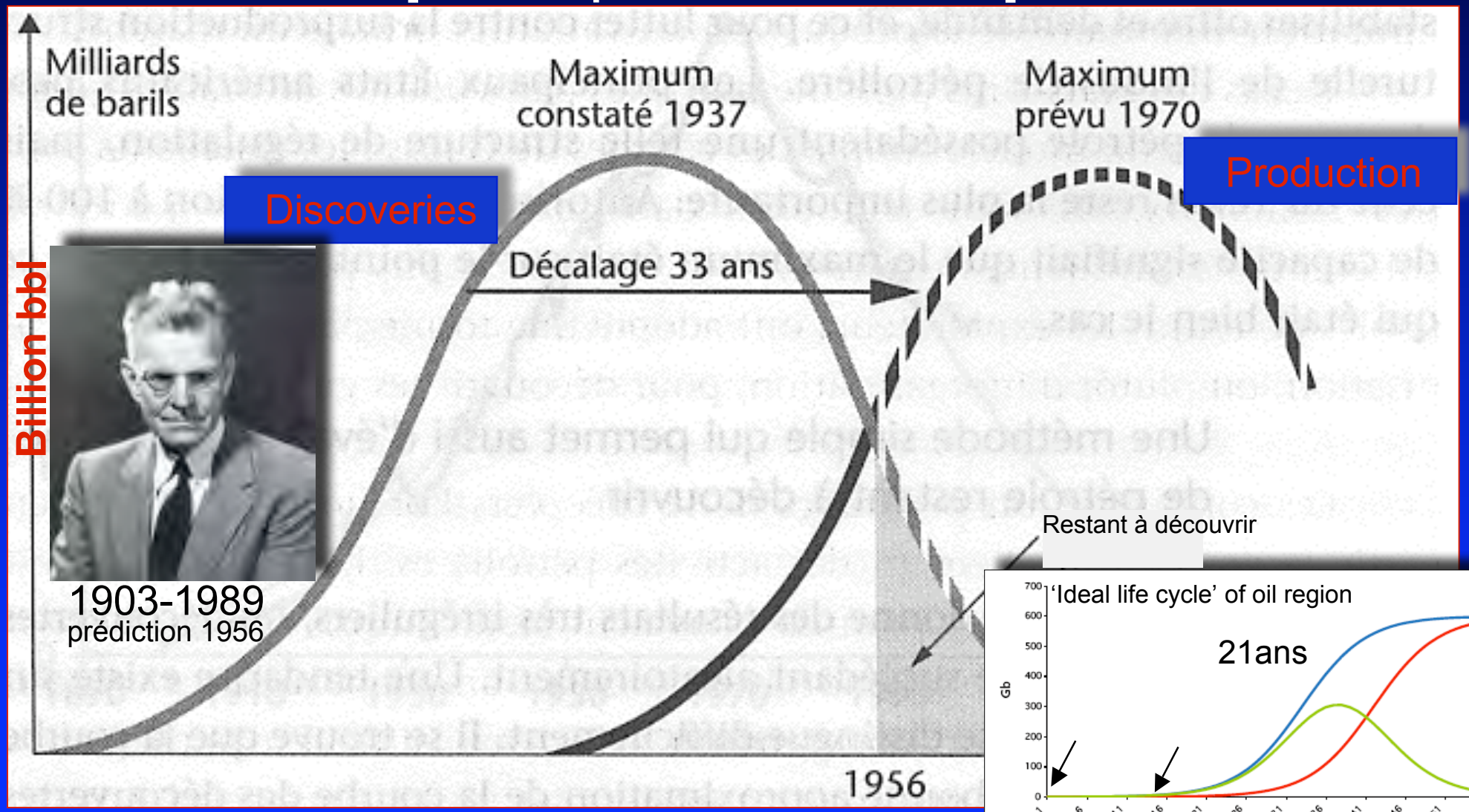
Wingert 2005

Available reserves after one year (Gt, Gbbl…)

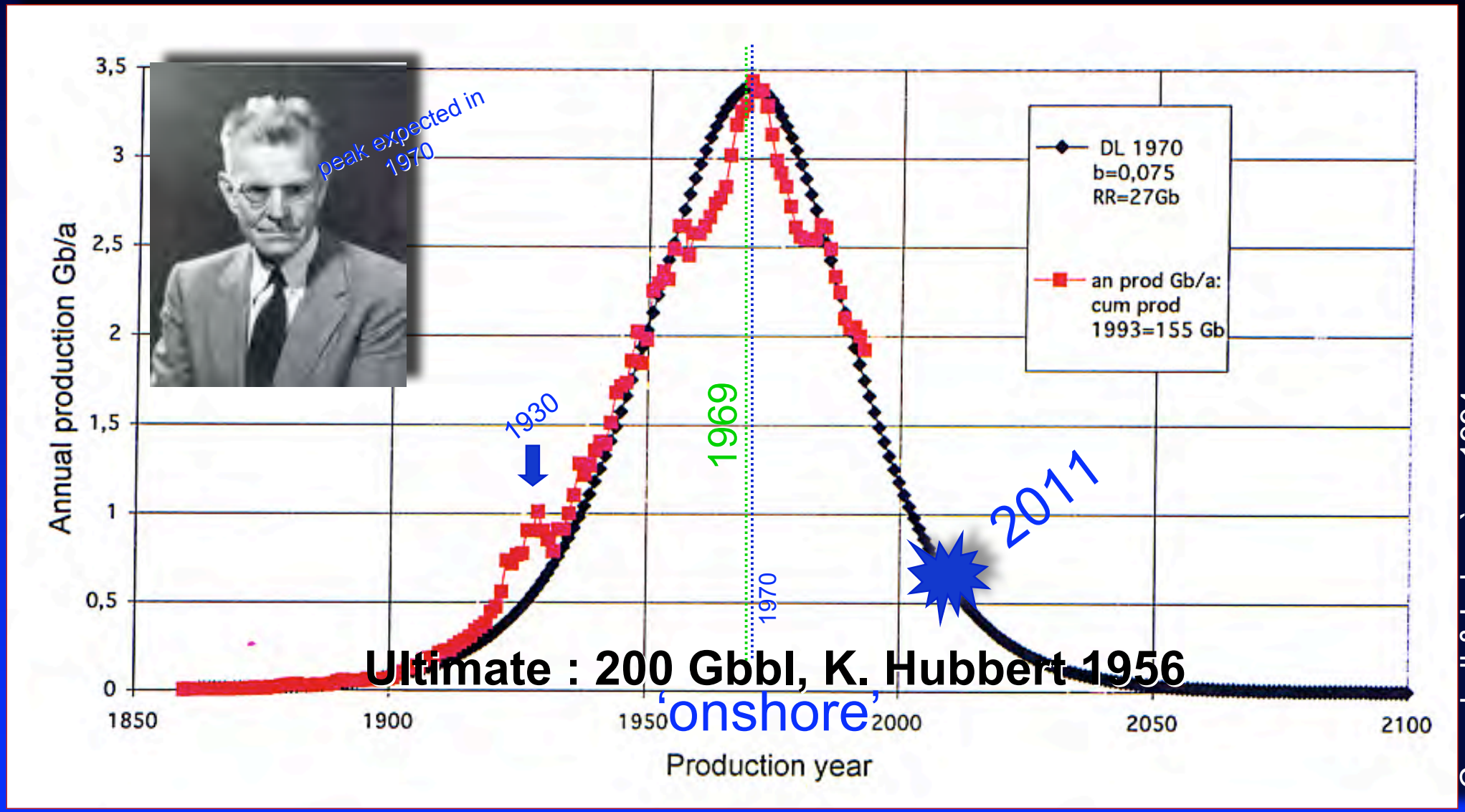
Production during this year (same unit)

PRINCIPLE OF THE THEORY OF HUBBERT's CURVES FOR THE UNITED STATES [48 STATES]

[Data simplified to the extreme]



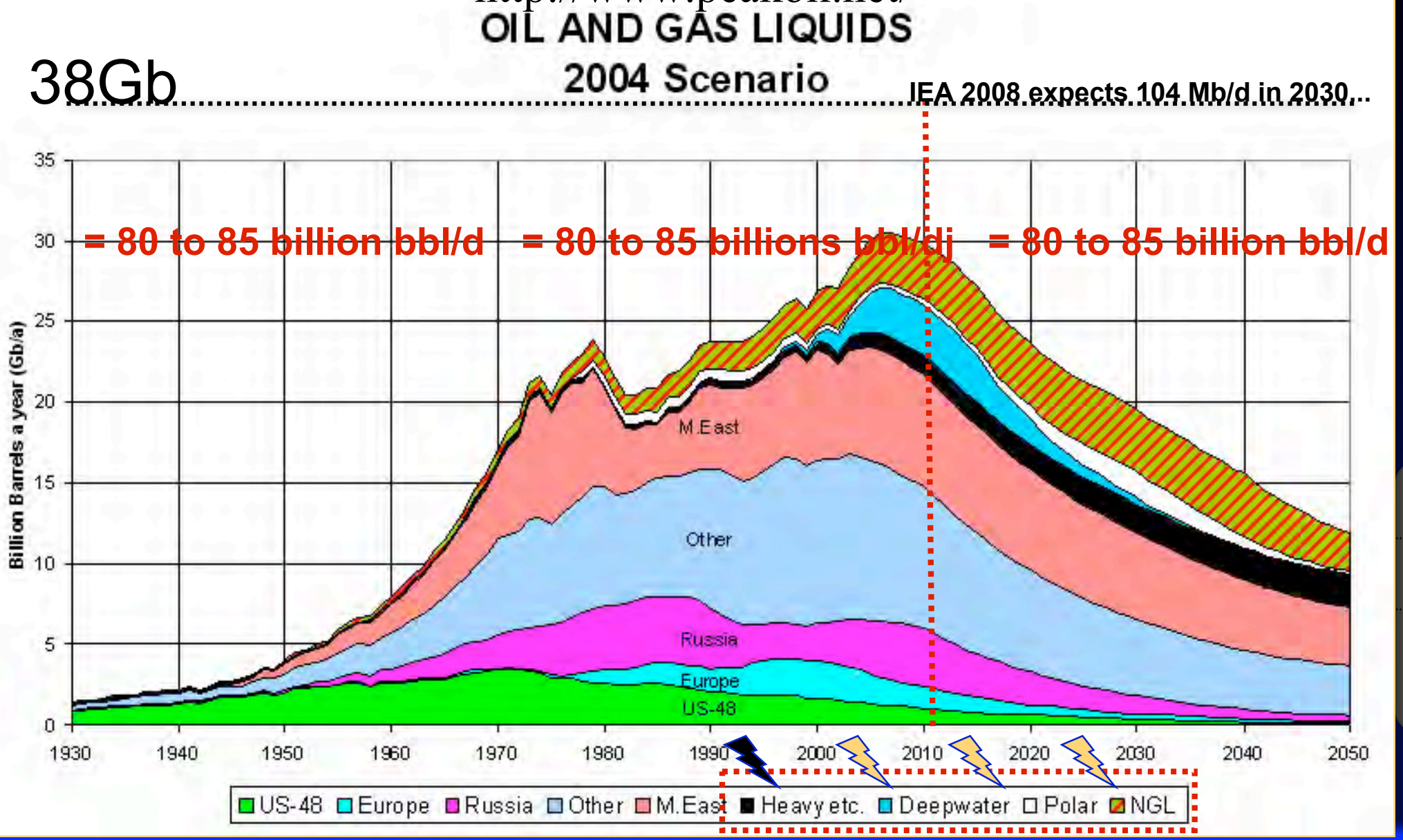
48 US States : Hubbert's curve (bell-shaped), depletion model



Nb USA peak discoveries USA: 1930' => 4 cents per bbl < drinking water

ULTIMATE: 6000 (...) G bbl c and 7000 G bbl nc

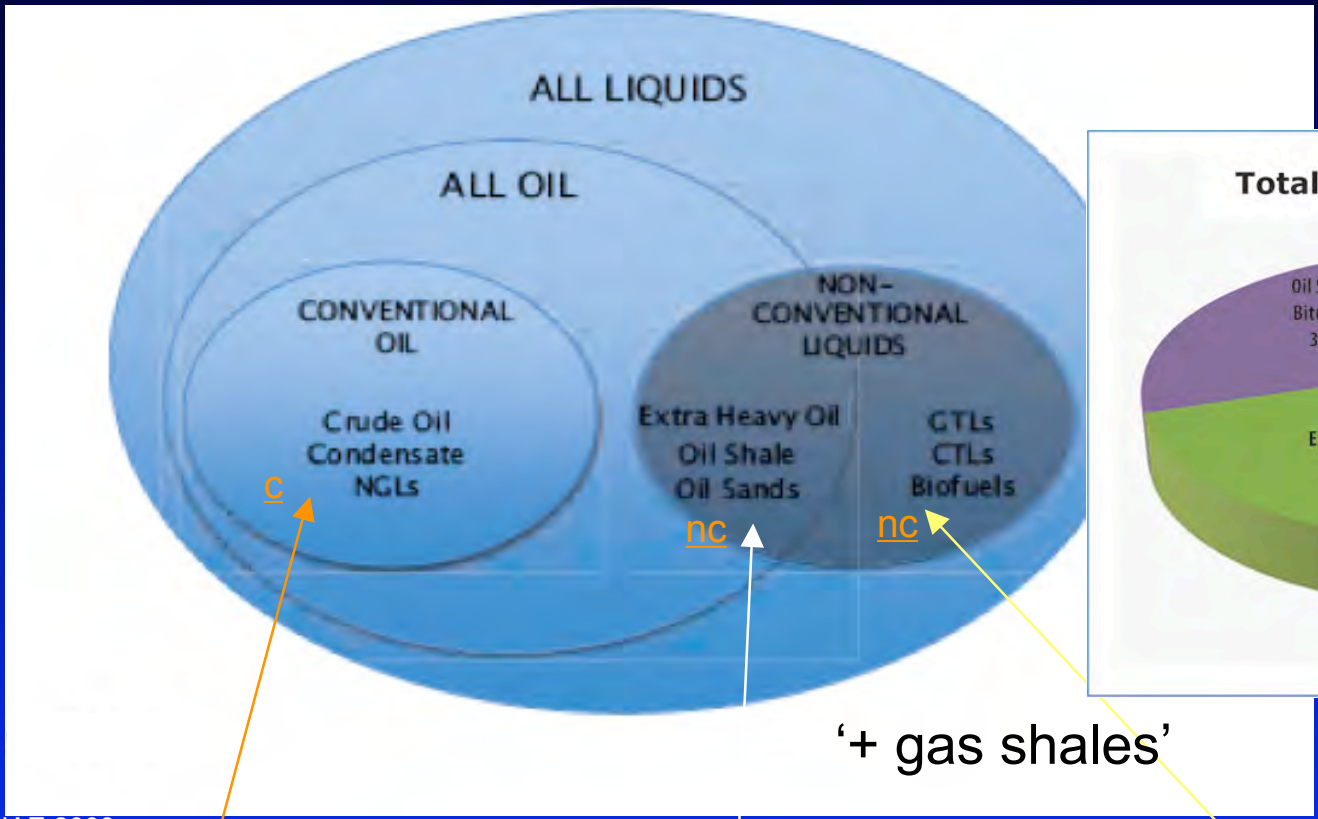
http://www.peakoil.net/



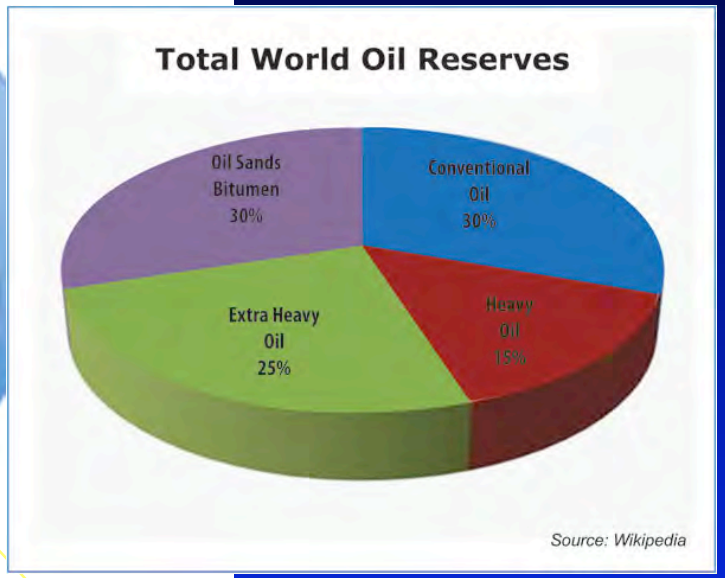
sc
nc
c

Nb NGL = Natural Gas Liquefied [-160°C for methane] 'flash steam': 1m³ = 600 m³

ULTIMES: 6000 (...) G bbl c and 7000 G bbl nc



IAE 2008



Crude Oil : mixed HC
Condensate : ultra light oil (C_{5+}) from condensing natural gas (p,T surface)
NGLs : light liquid HC in natural gas (methane-ethane, propane, butane)
Extra Heavy Oil : crude, API < 10° (density): very viscous, steam injection
Oil Shales : bituminous (kerogen) shales , must be pyrolised (>400°C)
Oil Sands: extra-heavy or heavy oil-impregnated sands, 'mining'+processes => syncrude
CTLs : synthetic liquid fuel produced by coal gasification followed by Fischer-Tropsch process
GTLs synthetic liquid fuel produced by methane liquefaction (Fischer-Tropsch, 1923)
Biofuels : synthetic fuels produced from biomass (bio-ethanol, bio-diesel)

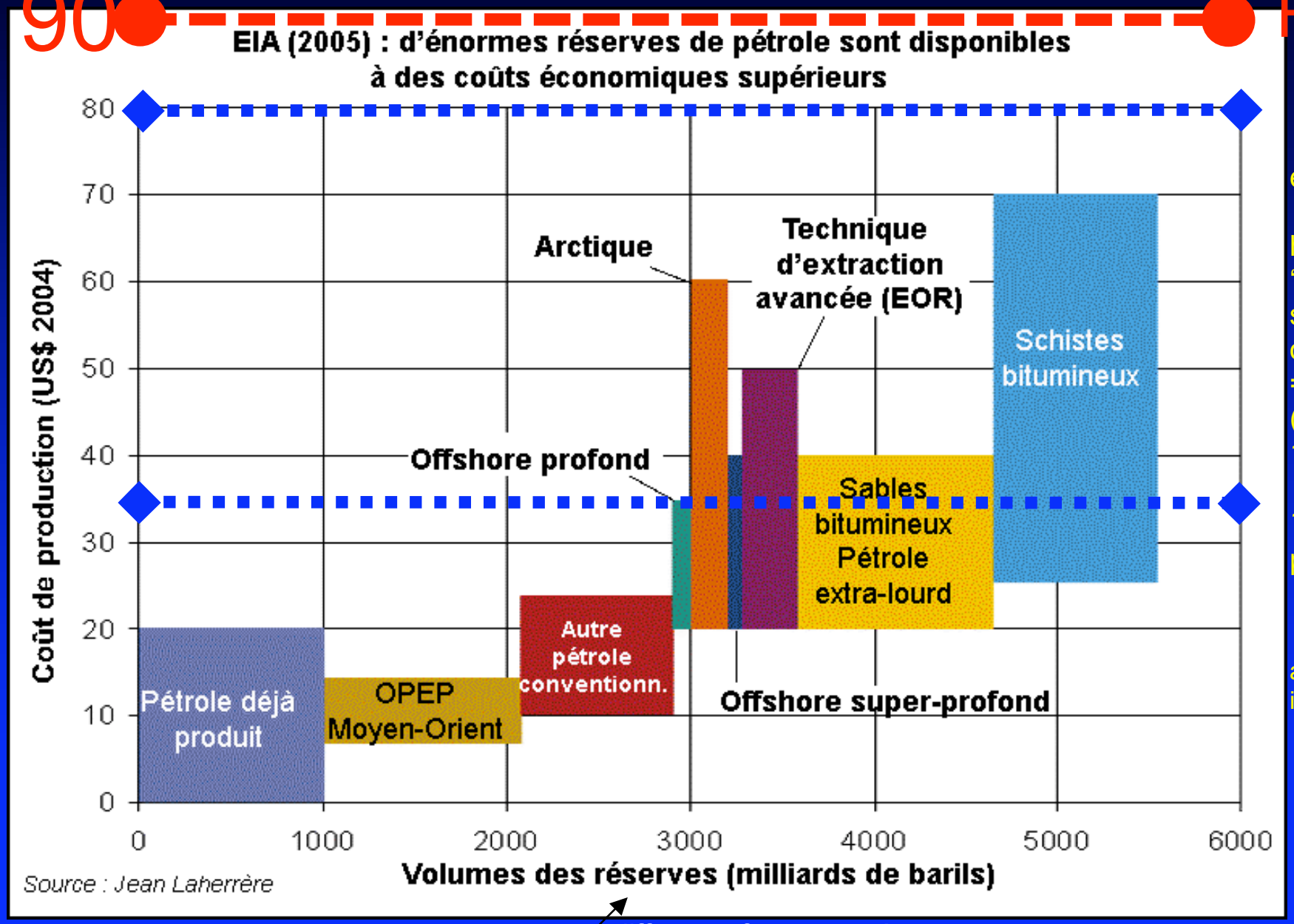
120 Apr2011

ULTIMATE: 6000 (...) G bbl c and 7000 G bbl nc

90 Feb2011

Beginning 2010

End 2008/ 2009



different of resources!
here = ± ultimate recoverable resources

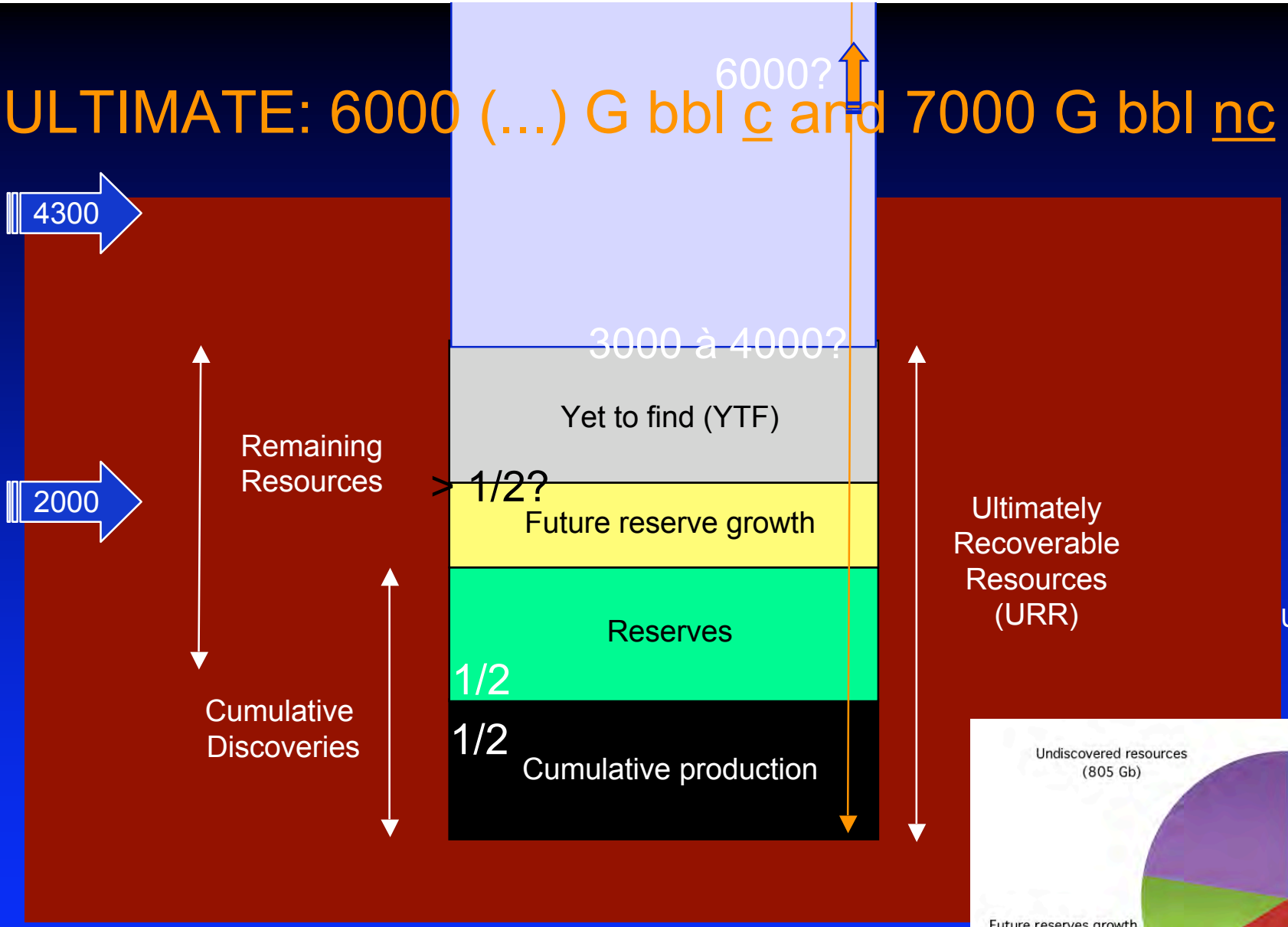
ex:

heavy oil or 'bituminous' sands of Canada =1750 Gbbl (today 10% = reserves)

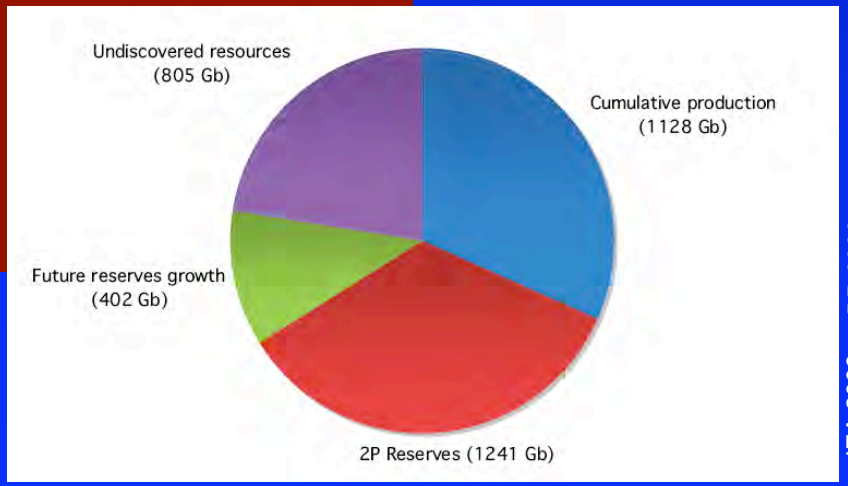
1,8 Gb already produced in 2007

already operated in 1930'

ULTIMATE: 6000 (...) G bbl c and 7000 G bbl nc



URR = economically extractable



IEA 2008 BP 2008

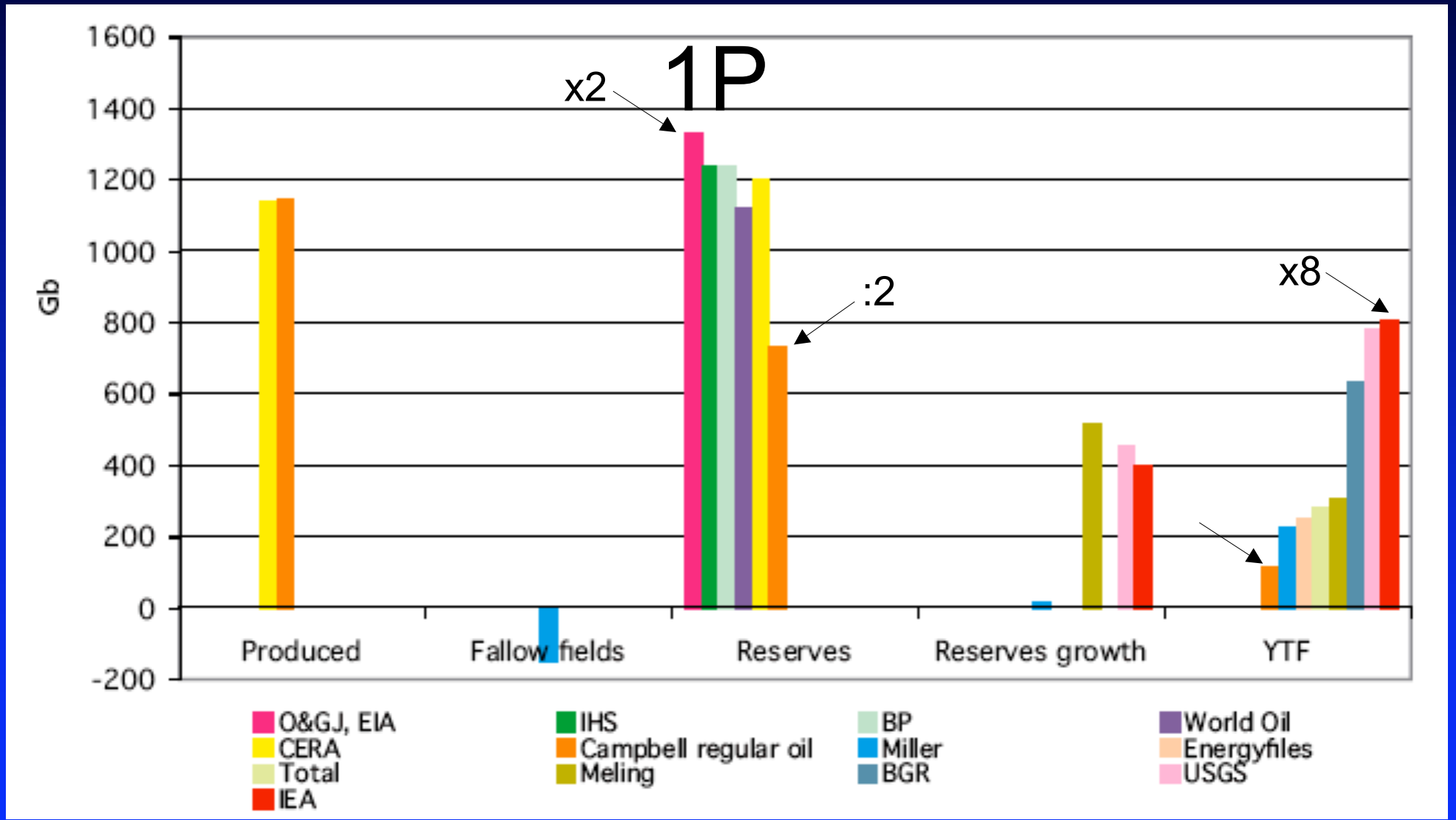
2009 : URR oil c 2000-4300 Gb (2-4X cumulated prod up to 2007)

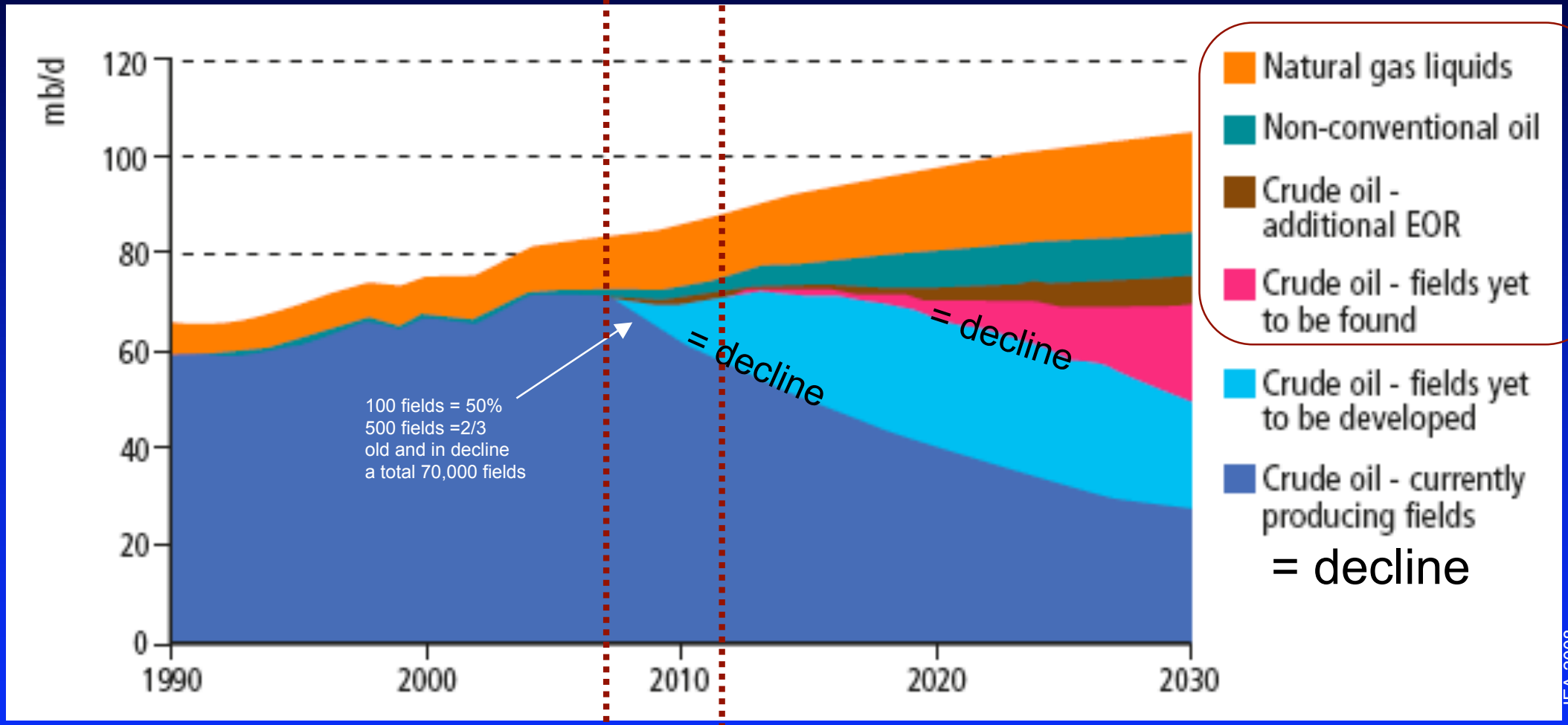
Remaining recoverable resources oil c : 870-3170 Gb

(Max = 4Xmin)

RECOVERABLE OIL c

(IEA, 2008, UK Energy Centre 2009)

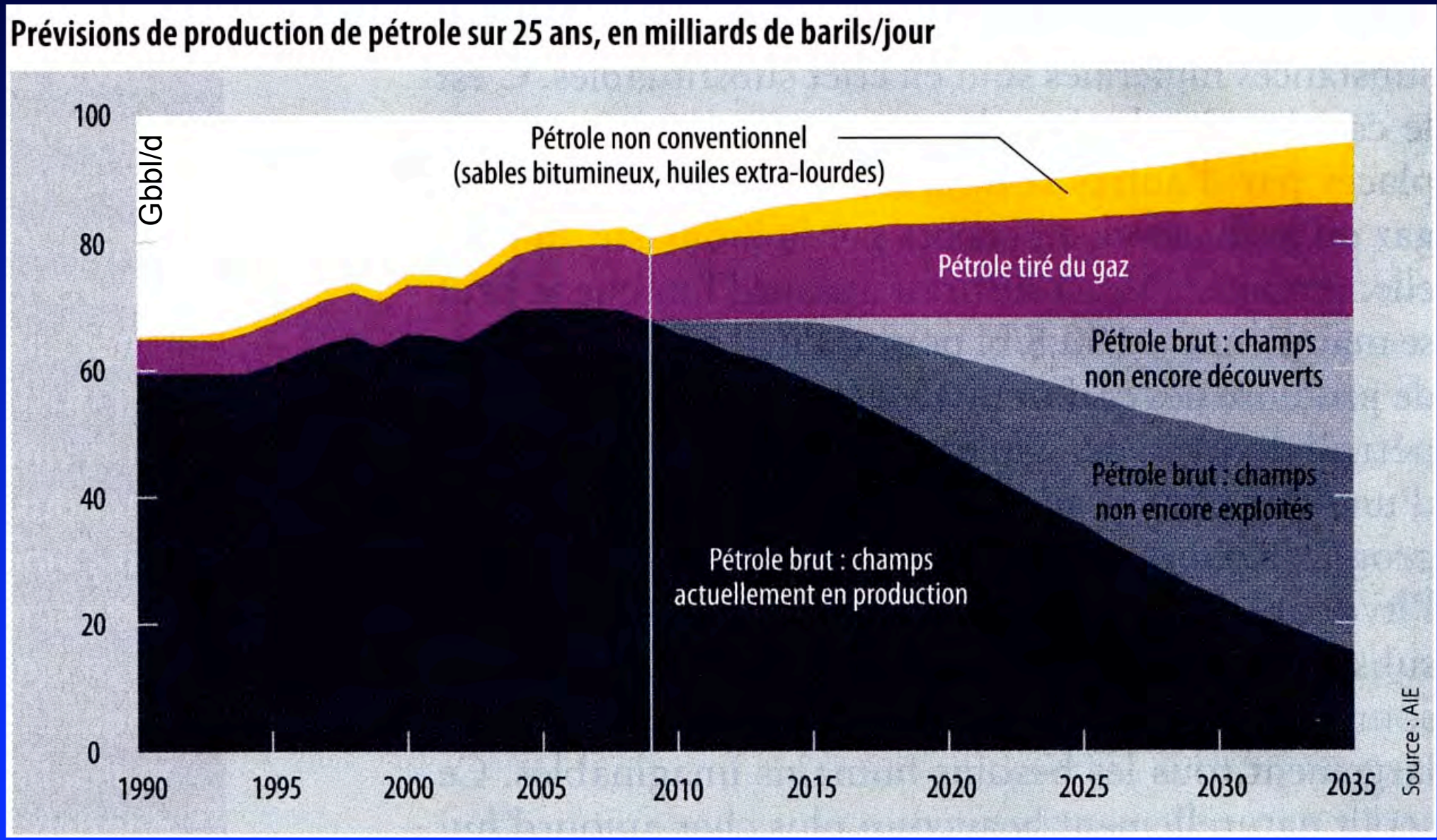



mb/d
120
100
80
60
40
20
0
1990
2000
2010
2020
2030
100 fields = 50%
500 fields =2/3
old and in decline
a total 70,000 fields
= decline
= decline
Natural gas liquids
Non-conventional oil
Crude oil - additional EOR
Crude oil - fields yet to be found
Crude oil - fields yet to be developed
Crude oil - currently producing fields
= decline
IEA 2008

2008

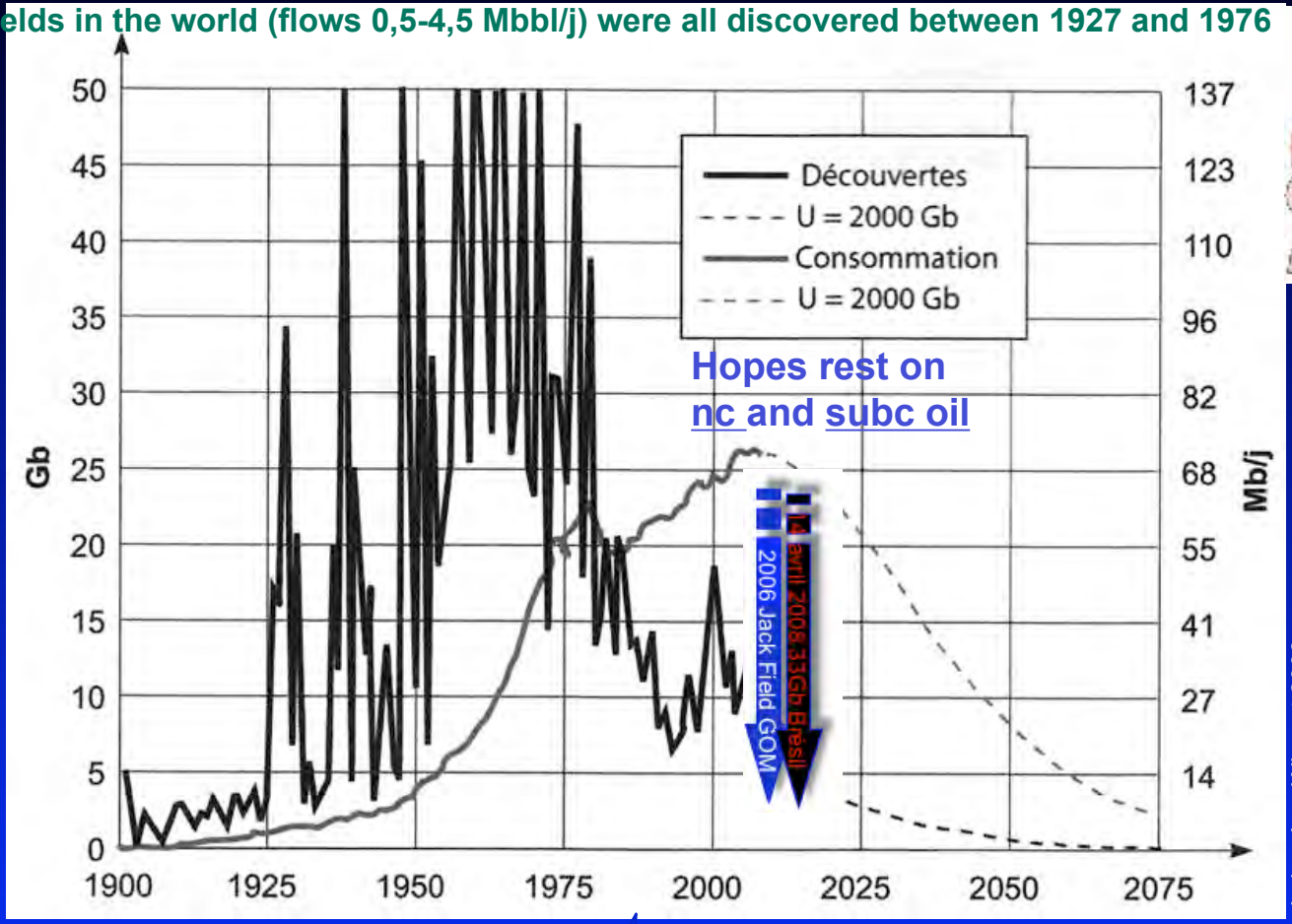
2011

Forecast oil production of 25 years

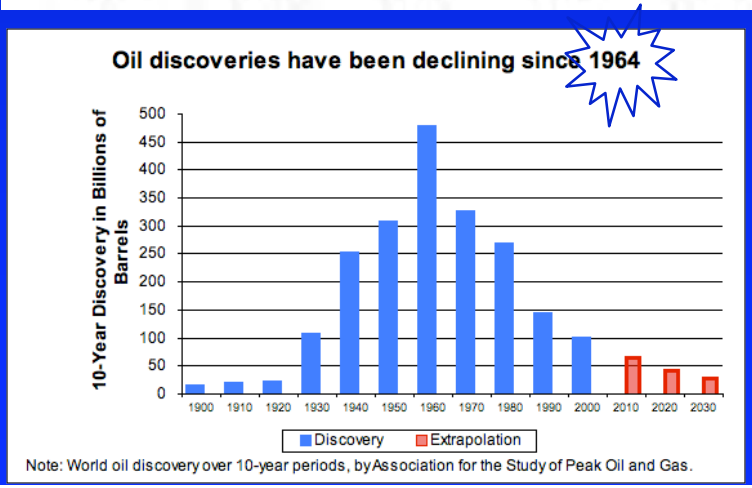


Now: we consume 3 to 4 bbl [1] oil for 1 [5, 1960] discovered

The 10 largest fields in the world (flows 0,5-4,5 Mbbl/j) were all discovered between 1927 and 1976



Laherrère, Wingert 2008



They 40,000 accumulations,
hierarchical distributed in 70,000 fields

Production 2008
From 1001 MAJOR or GIANT fields

The real market= the production

Of the 192 countries of the planet, 30 are producing oil significantly and only 17 of them export more than 500,000 bbl/d ==> geography AND politics limit choices. Importers diversify supplies, each from a dozen countries or less…

PRODUCERS

1. **Saudi Arabia 8.03 millions bbl/d *with 1560 wells [2001]***
2. **Russia 7.05**
3. **USA 5.80 *with 563,160 wells [2001]***
   Average annual return of one well in 1985: 2.2.10^{3}t i.e. 44bbl/dou 0.08l/s <0.1l/s

4. **Iran 3.72 Average annual return of one well in 1985: 1514.5x10^{3}t i.e. 30,500bbl/d or 56l/s**

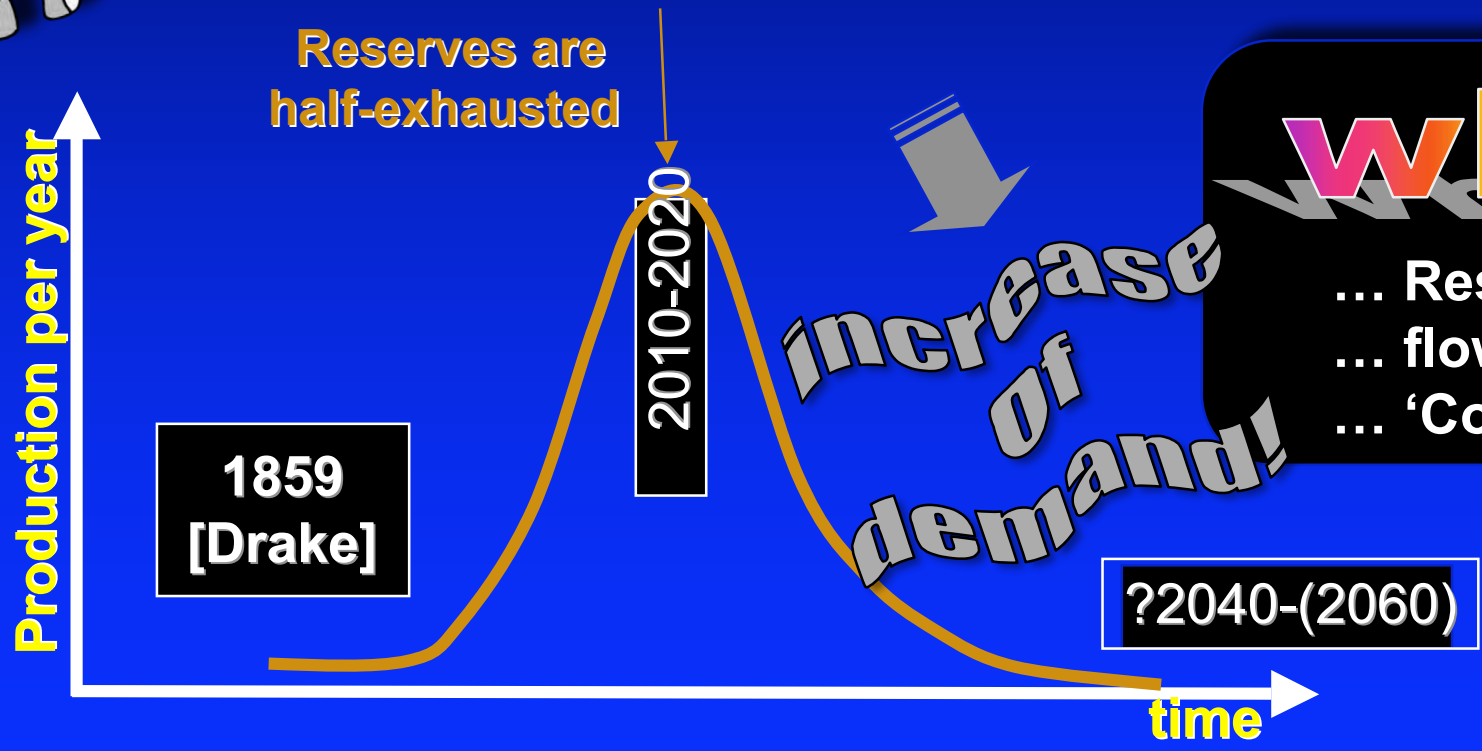
...

[the largest field of the world: Ghawar = 50% Saudi Arabia production]

ULTIMATE: 6000 (...) G bbl c and 7000 G bbl nc

With ?280 Gt or ± 2100 Gbbl [Res 1P] THE MAXIMUM OF PRODUCTION AROUND 2010-2020…?

‘Cheap’ oil is OVER!
The world will be EVEN more dependent from the Middle East producing countries



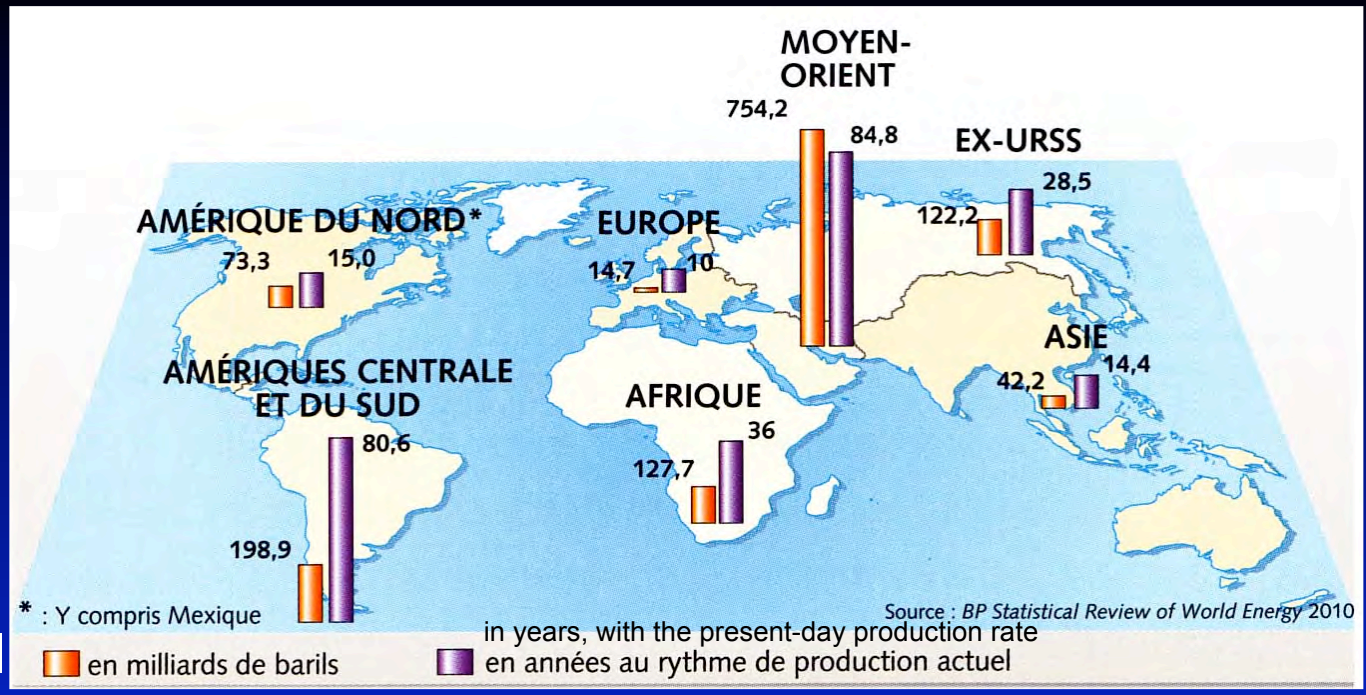
why?

… Reserves
… flows
… ‘Cost Oil’

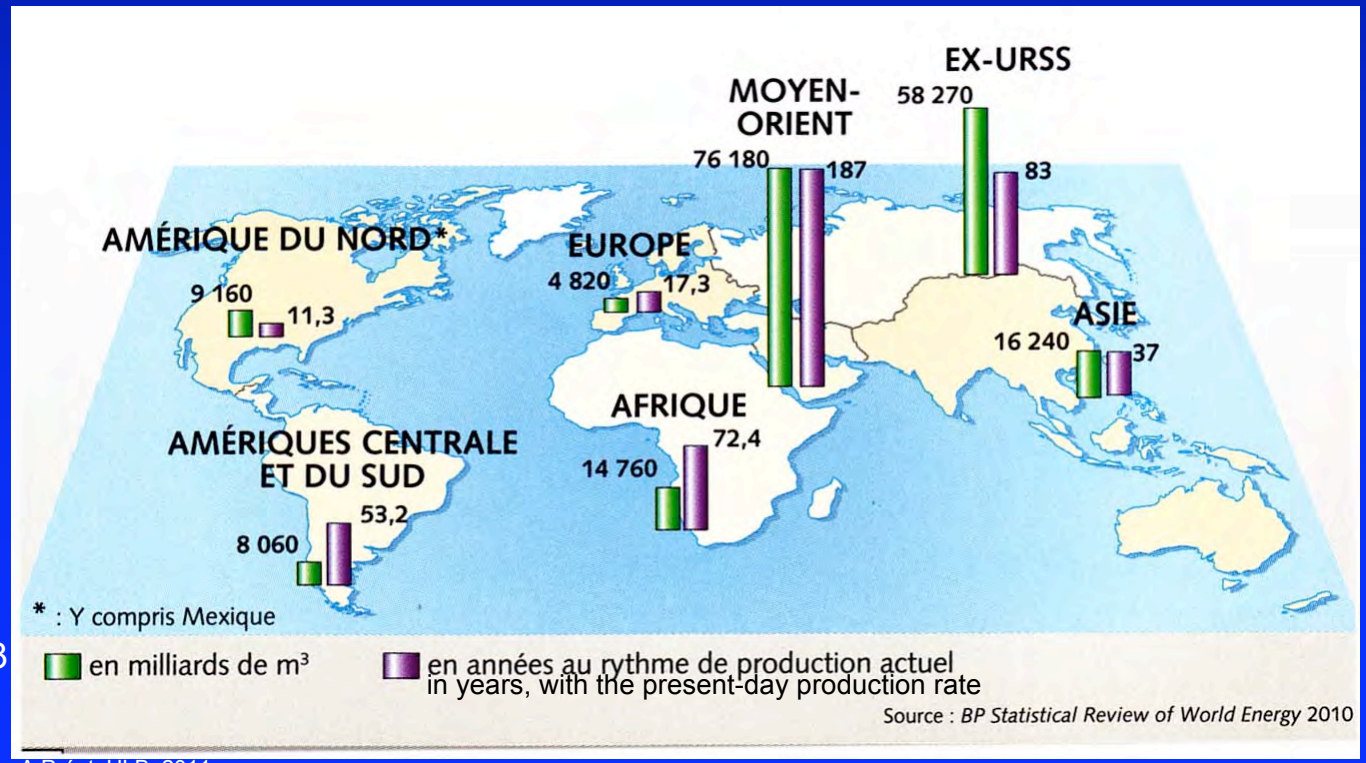
End of the exploitation ?

‘last drop’ 2150...

G bbl


MOYEN-ORIENT
754,2
84,8
EX-URSS
28,5
122,2
AMÉRIQUE DU NORD*
73,3
15,0
EUROPE
14,7
10
ASIE
14,4
42,2
AMÉRIQUES CENTRALE ET DU SUD
80,6
198,9
AFRIQUE
36
127,7
* : Y compris Mexique
Source : BP Statistical Review of World Energy 2010
en milliards de barils
en années au rythme de production actuel
in years, with the present-day production rate

G m^3


EX-URSS
MOYEN-ORIENT
58 270
76 180
187
83
AMÉRIQUE DU NORD*
9 160
11,3
EUROPE
4 820
17,3
ASIE
16 240
37
AFRIQUE
72,4
14 760
AMÉRIQUES CENTRALE ET DU SUD
53,2
8 060
* : Y compris Mexique
en milliards de m³
en années au rythme de production actuel
in years, with the present-day production rate
Source : BP Statistical Review of World Energy 2010

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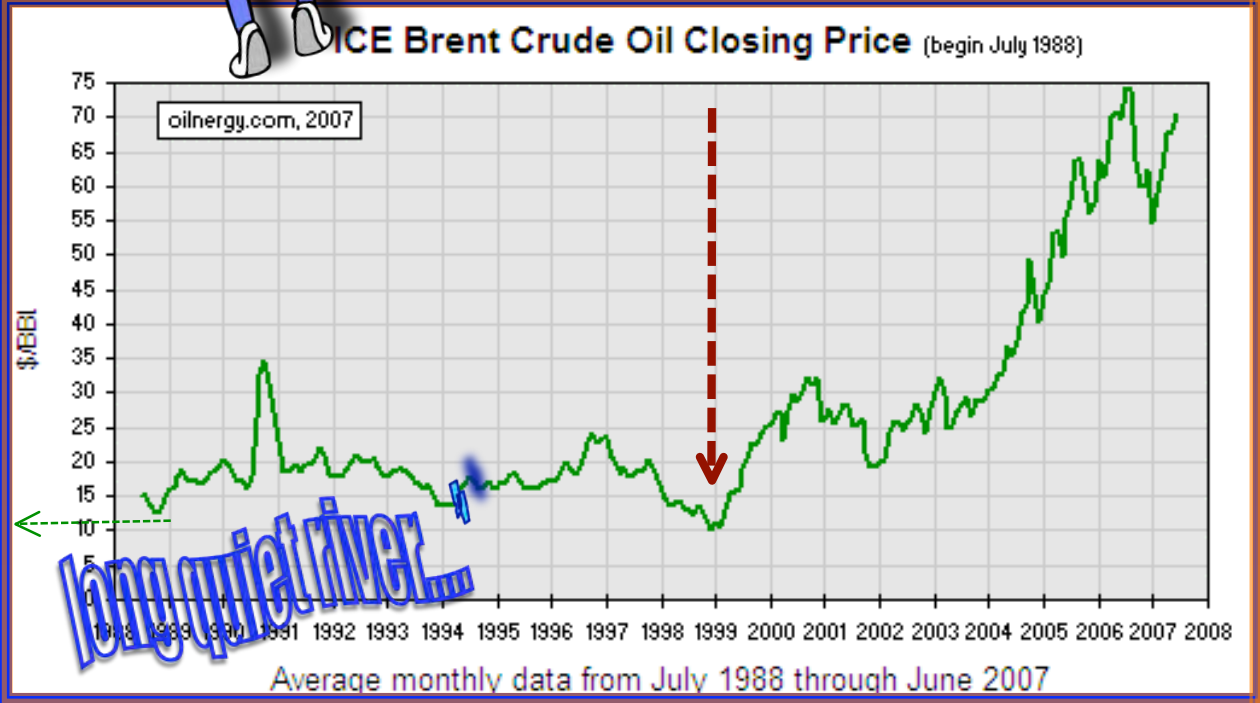
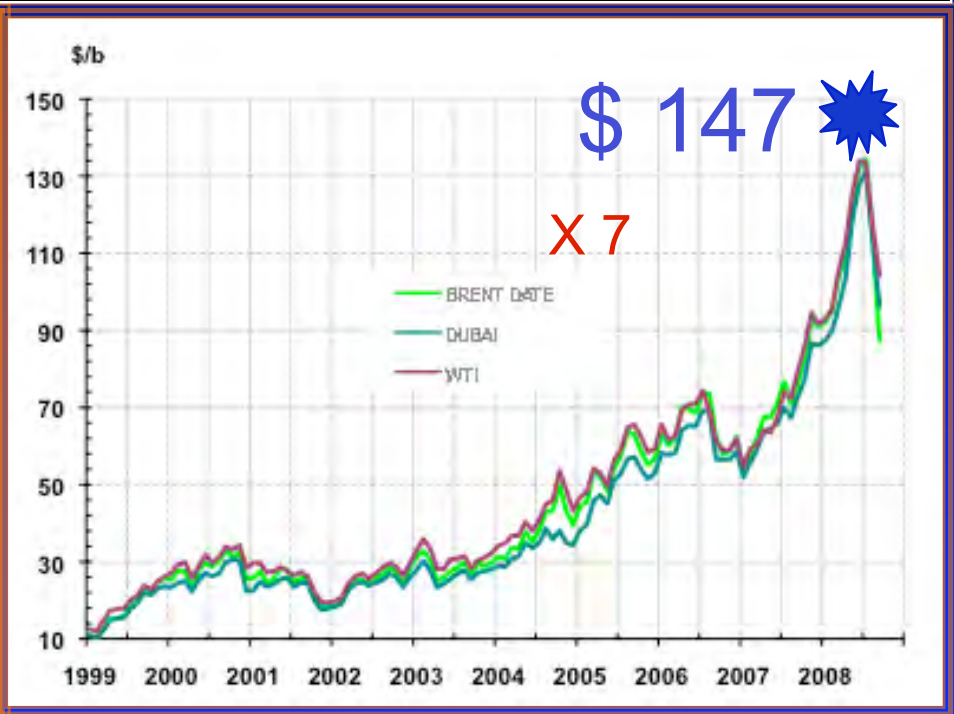


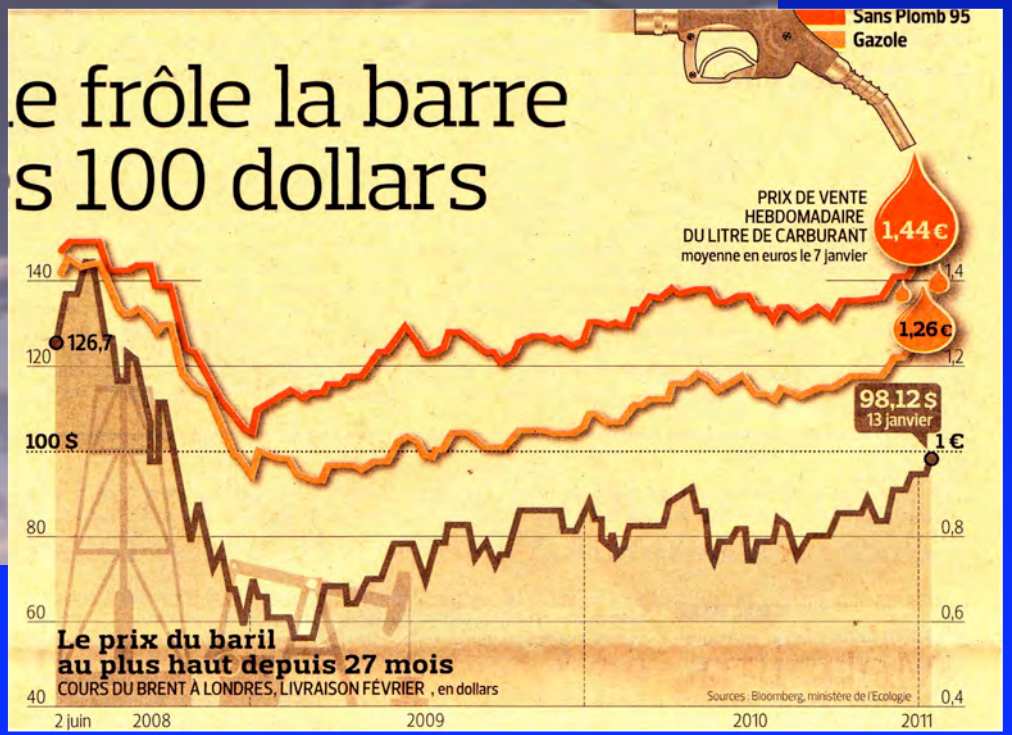


Nb from 1859 to end of 20th century : average annual production increase by 2%

Nb bbl cost in 1930 (USA onshore peak discoveries = 4 cents < drinking water)

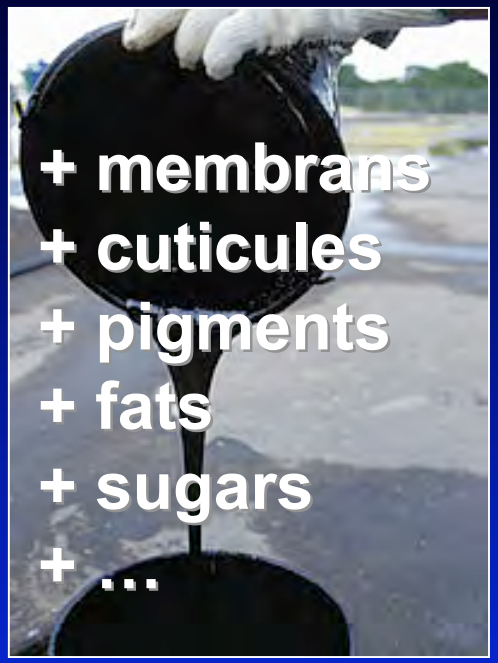
Until 2035 (EIA) ?

Cheap Oil is OVER



But where does OIL COME FROM?

ORGANIC MATTER
Proteins
Carbo-hydrates
Lipids
....

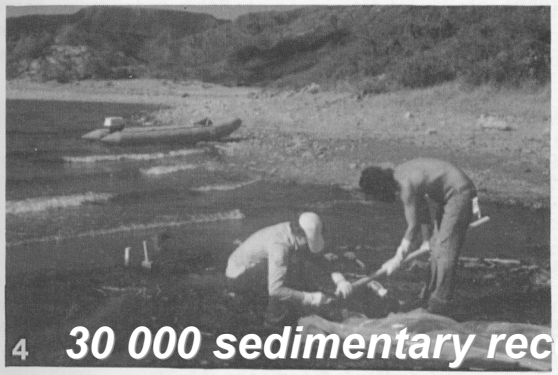


That the majority of organic constituents [up to 70%] likely to turn into oil. They are abundant in ALGAE, and especially BOTRYOCOCCACEAE and DIATOMS [phytoplancton, 2µm-1mm]

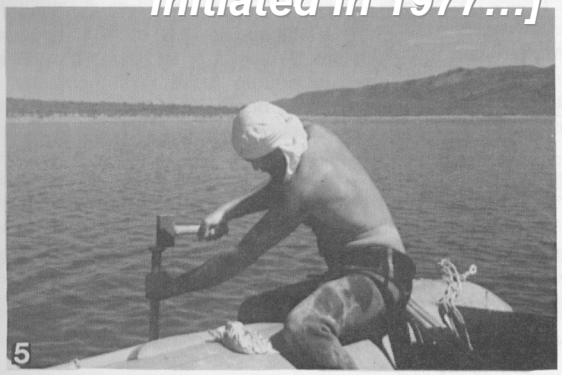
Some diatoms excrete droplets of oil in order to increase their buoyancy! They contain up to 70% lipids (dry weight)

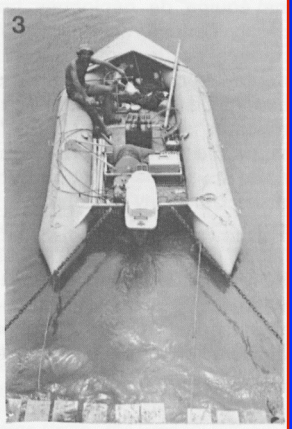
Hemi-graben of Baringo-Bogoria

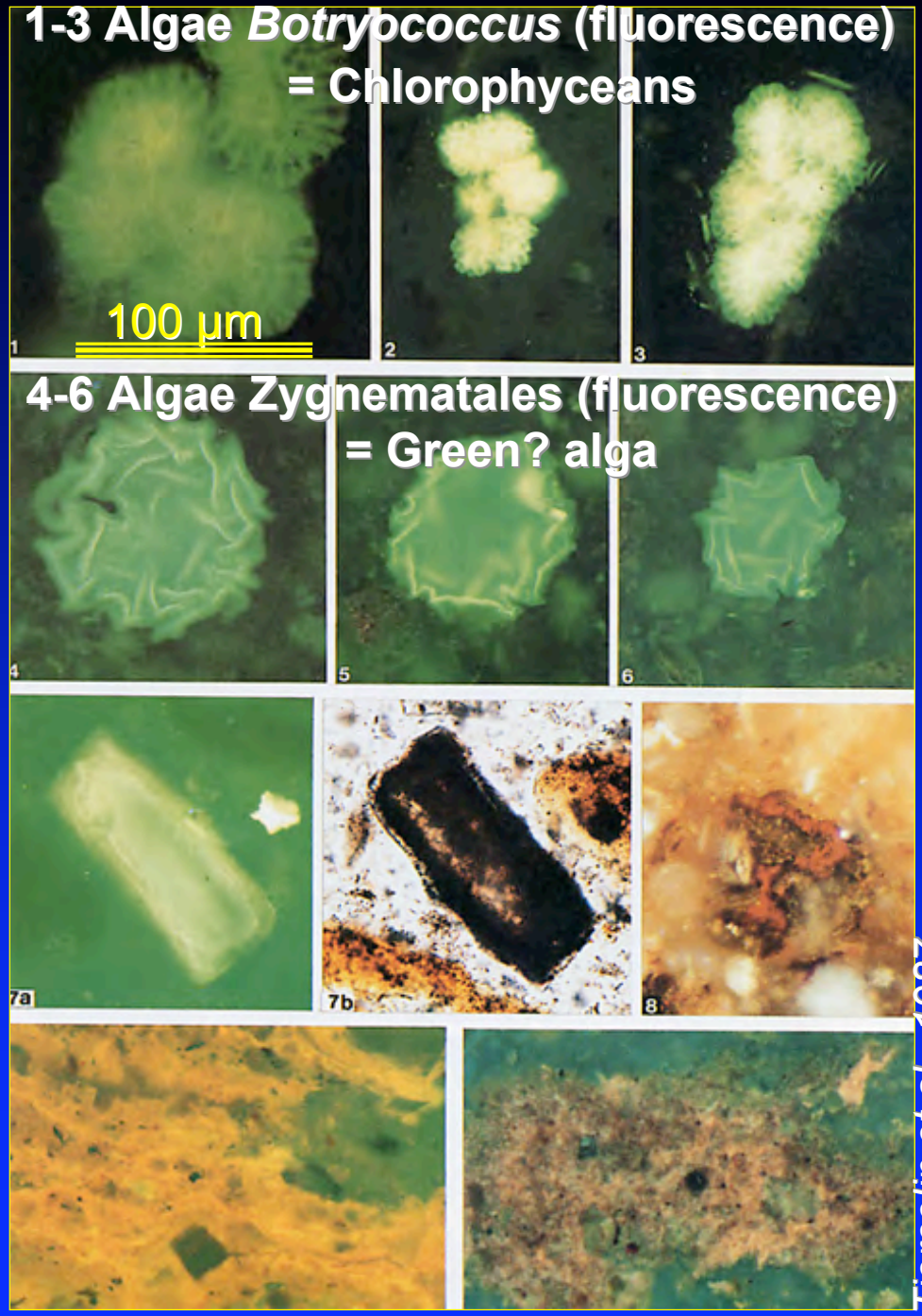
Rift Gregory Kenya
989m altitude, ± 30km²
Max depth : 11,50m



30 000 sedimentary record
Coring up to 16 m
initiated in 1977…]







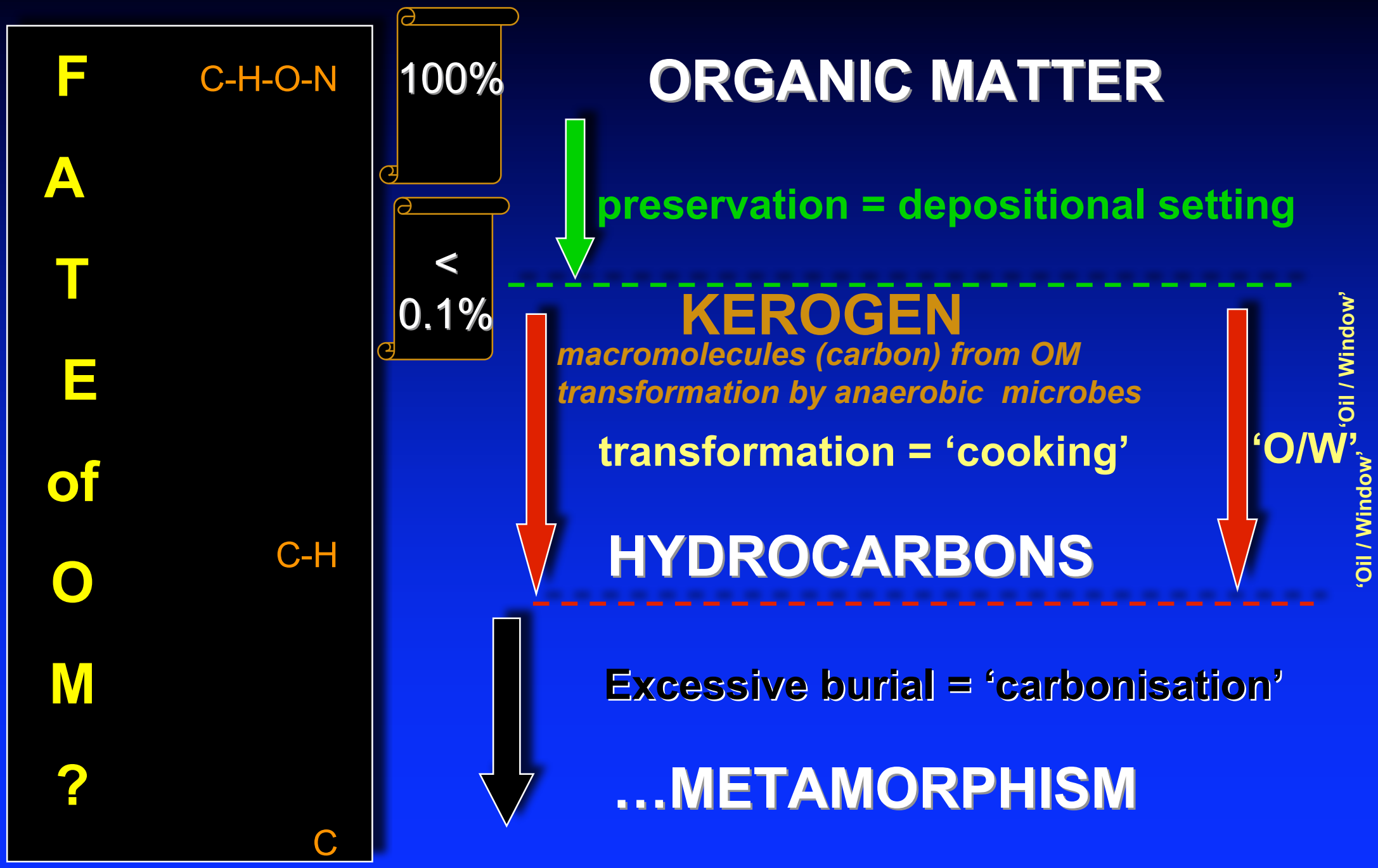
Tiercelin et al., 1987

+ Diatoms

Finally, the biomass is composed of a small number of major groups of organisms

Marine and lacustrine planktons = microscopic algae with 50% proteins, 25% carbohydrates, 5% lipids
[Diatoms are much richer in lipids]
The bacteria = mainly 'water' + proteins, and up to 10% lipids forming C_{10} - C_{30} hydrocarbons
Terrestrial higher plants = 30 to50% cellulose, and 15 to 25% lignin, some with very abundant lipids

The organic matter from plankton, algae and bacteria, sediments on site or on the same vertical = AUTOCHTHONOUS
The organic matter from plants is fed into the sedimentary basins (wind, rivers..) = ALLOCHTHONOUS


FATE of OM ?
C-H-O-N
C-H
C
100%
< 0.1%
ORGANIC MATTER
preservation = depositional setting
KEROGEN
macromolecules (carbon) from OM
transformation by anaerobic microbes
transformation = 'cooking'
'O/W'
'Oil / Window'
'Oil / Window'
HYDROCARBONS
Excessive burial = 'carbonisation'
…METAMORPHISM

Fossil fuels are the result of a tiny 'saving' of OM from huge cycles (...)

HC

= 10,000 billion tons of fossil carbon

accumulated in ± 500 Ma, i.e. 20.000 t/yr
that escaped the cycle of Life
[over the available 5500 billion, i.e. 0.5×10^{-6}/yr]

O_2

WHY SO FEW?

because oxygen is almost everywhere, and aerobic microorganisms biodegrade dead organic matter [if not free O_2, the anaerobic bacteria will take it in SO_4, NO_3….]

when free and combined oxygen are exhausted
THE OM PRESERVATION IS INFINITE!

To form a source-rock, we must retain the organic matter

NOT OBVIOUS…

at the death of organisms 99.9% of C is recycled into the food chain

it remains 0.1% escaping
and trapped in soils and sediments

…and for a rock (old sediment) becomes a source-rock
it must contain at least 2% of organic matter

on average		Source-rocks
sediments << 0.5% O.M..	⟷	2-10% ou >

THREE POSSIBILITIES FOR THAT… 1, 2, 3

WHERE THAT DOES OCCUR? = in very confined environments

where atmospheric oxygen has no access…

fine-grained and compacted sediments at sea or lake bottoms

1. Tropical river mouth, delta….

Deltas of Niger, Mississippi, Gange, Mahakam…

2. Zones of upwellings

Pérou (cf fishing vs EU), SW Africa (Angola), Walvis bay, Chilian and Californian coasts…

Formation of very rich sediments with 4 to 7% organic matter.

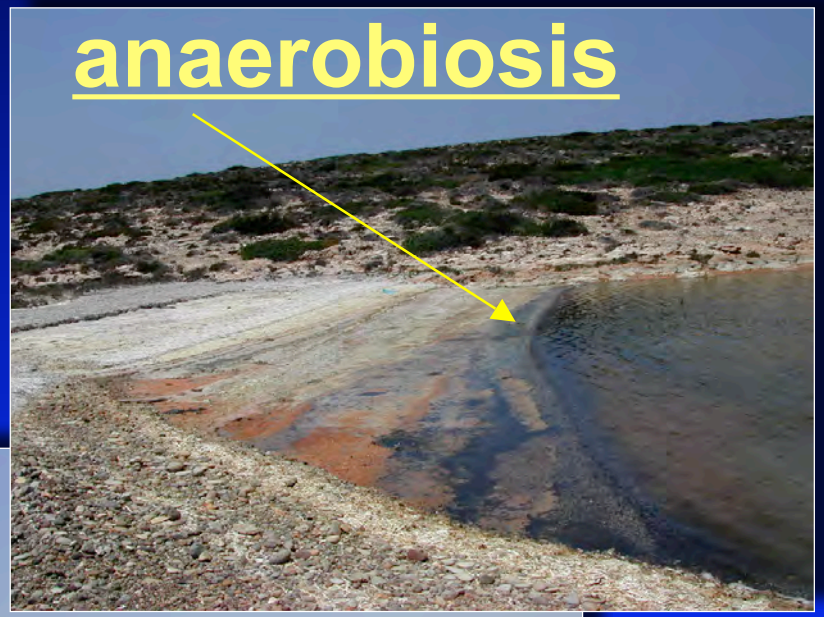
3. Anaerobioses

Black Sea, Baltica Sea, Caspian Sea, Gulf of California, Lagoon of Maracaibo…

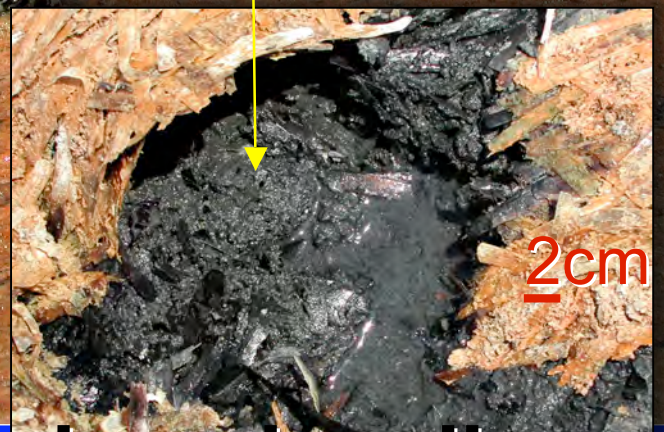
Ex: Black Sea>3% OM and >0.2g C/m^2/day

POSIDONIA SEAGRASSES

Cyclads, Greece 2003



It takes Nature a min. of
1 to 2 million yrs to form 1 l of oil
and at least 10 million yrs to
constitute a FIELD



Préat, 2003

reduced sediment

EFFICIENCY...!

an unknown number …

**FOR A LITRE OF PETROL,
IT NEEDS THAT 23 TONS OF
ORGANIC MATTERS ARE
TRANSFORMED TO A PERIOD
AT LEAST 1 MILLION YRS**

MASON B Oct. 2003, Nature, Plant-to-oil Equation Point Up Unsustainable Profligacy

CONCLUSION

SOURCE ROCK= NECESSARY CONDITIO

Kerogen is the HC precursor

= DEGRADATION

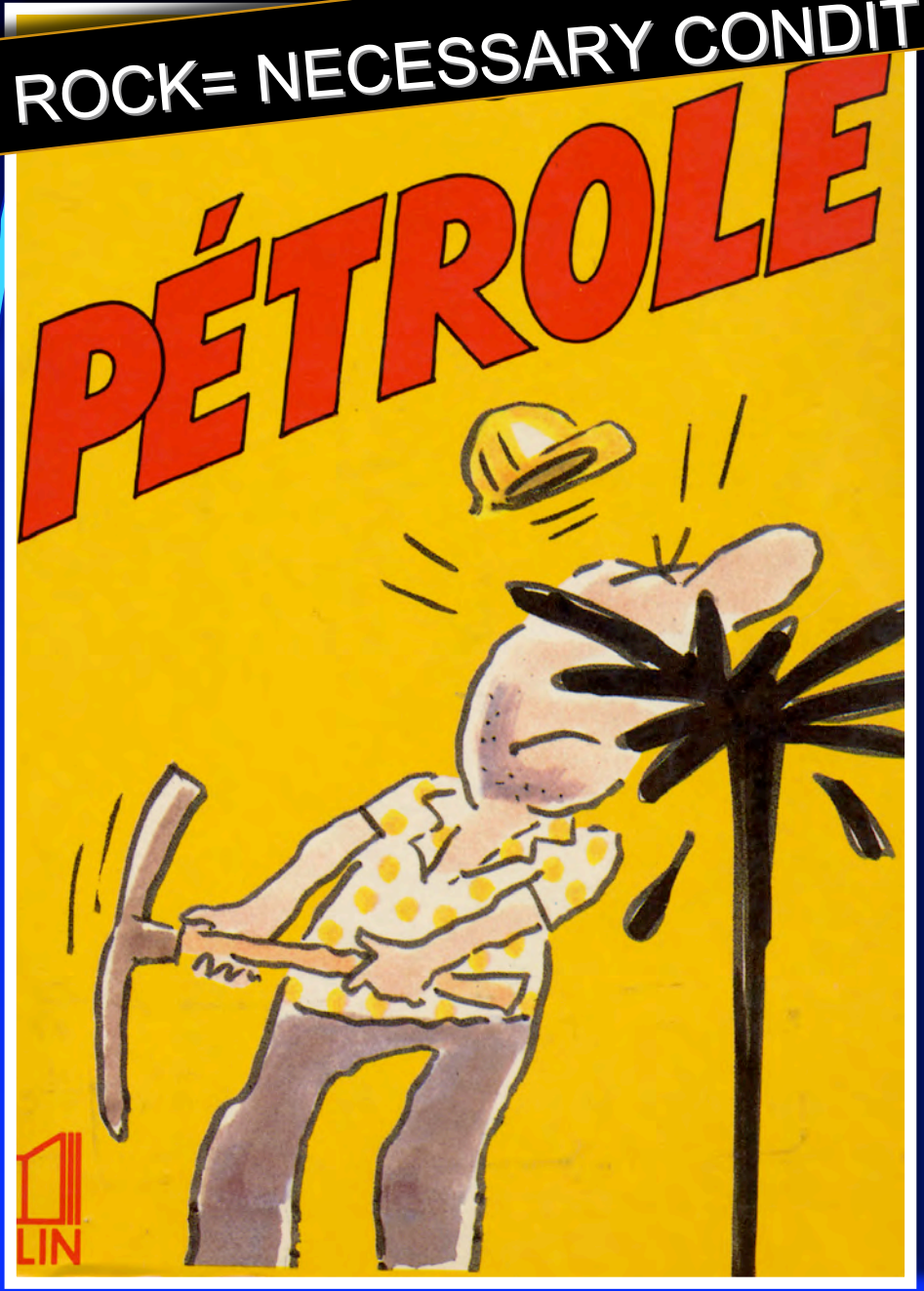
POLYCONDENSATION

INSOLUBILISATION

of OM altered by microorganisms

[bacteria and fungi]

starts in the first cm of burial



Restlé, 1986

t h e n. . .

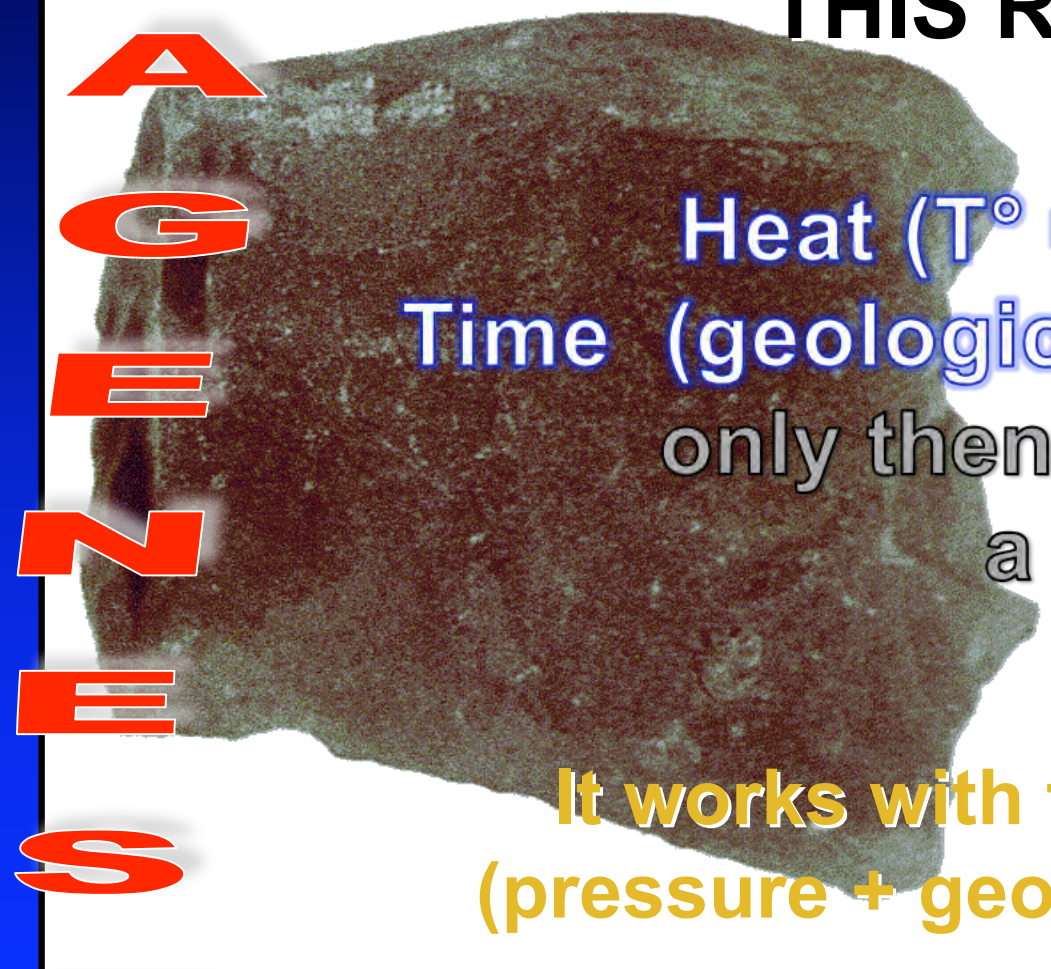
THERMAL DEGRADATION of the KEROGEN

OIL GENESIS = DIAGENESIS + CATAGENESIS

DIAGENESE

CATAGENESE

the kerogen is not oil
THIS REQUIRES



Heat (T° = 10'-100'°)

Time (geological scale = 10' Ma)

only then –hopefully-

a trap

It works with the subsidence

(pressure + geothermal gradient)

Source rock
Rich in Organic Matter

Thermal Maturation
of Organic Matter

OIL

A Préat, ULB, 2011

FROM KEROGEN TO OIL…

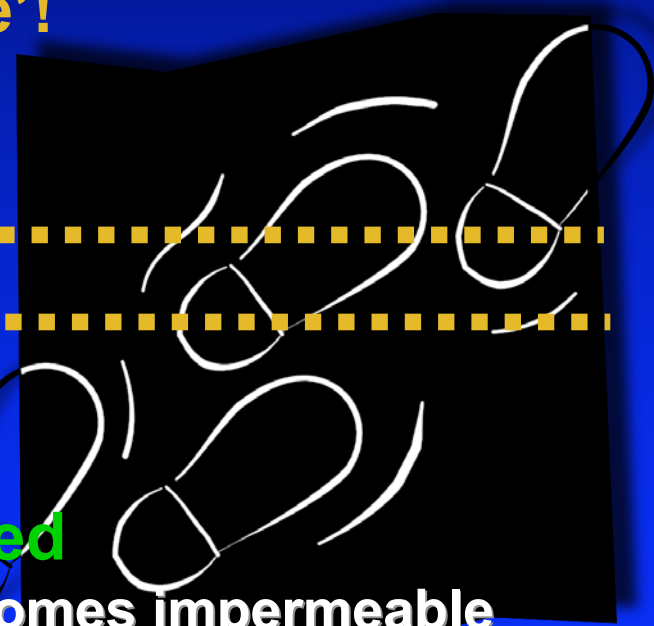
DIAGENESE

O.M. [= the kerogen] is buried due to the subsidence…

NOT VERY FAST = from 0.005 mm/yr to a MAX of 0.5 mm/yr

i.e. between 5 m and 500 m per million of years

No problem… geological times are 'huge'!



Tracking 'step by step' this burial

- from -3 to -10m: 'abiotic' milieu
  - in a few 10'm kerogen loses its nitrogen as NH_3
- then the sediment is more and more buried
  - pressure increases, the compacted sediment becomes impermeable
  - interstitial water is expulsed, a small part remains in the pores
  - temperature increases slowly

DIAGENESE

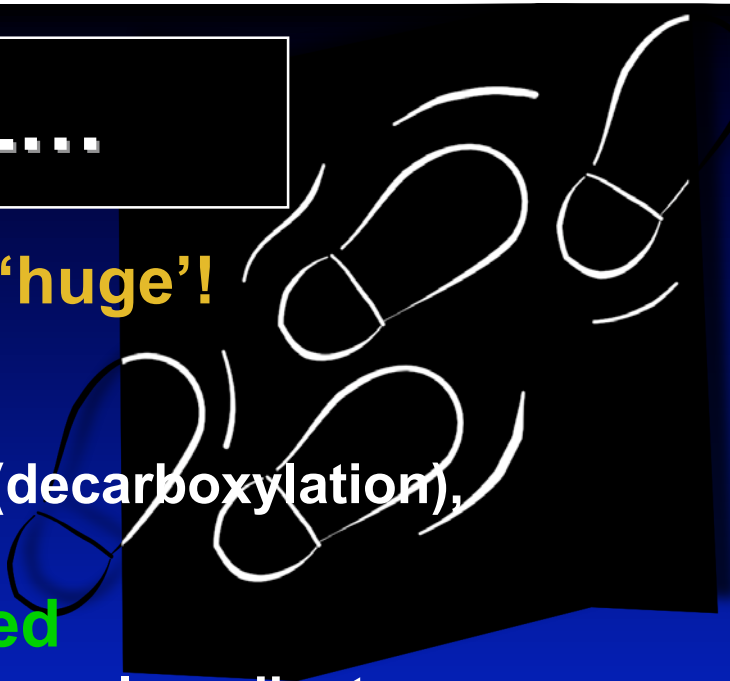
FROM KEROGEN TO OIL…

… no problem… geological times are ‘huge’!

!

- -600 m, 41°C ‘’gentle heat’
  - the kerogen is decomposed, CO_2 goes out (decarboxylation), as H_2O (dehydratation)…
- the sediment is more and more buried
  - the temperature increases due to the geothermal gradient

= 1°C every 30 to 40 m



and the sediment is heated to 60°C at 1200 m and 120°C at 3000 m

=

OIL WINDOW

FROM KEROGEN TO OIL …

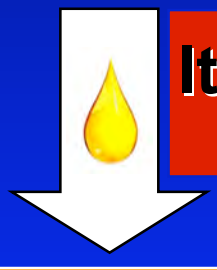
… no problem… geological times are ‘huge’!

= O I L W I N D O W

DIAGENESE

CATAGENESE

kerogen breaks and releases smaller molecules: biomarkers trapped in the network and small ‘pieces’ in excess of large molecules (geopolymer)



It is the CATAGENESIS i.e.…

…the OIL formation

the ‘juice’ of mature kerogen giving oil

km0 km±1.5 km±4 km±7

±6Ma ±12Ma

IMMATURE ZONE
Biogenic CH_4
CO_2, H_2O

DIAGENESE

O:W
HUMIDS GAS

CATAGENESE

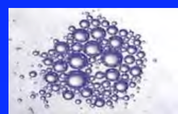
hydrocarbons are C_{18}-C_{40}

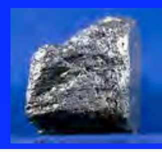
DRY GAS

METAGENESE

[...300°C]
'GRAPHITE'

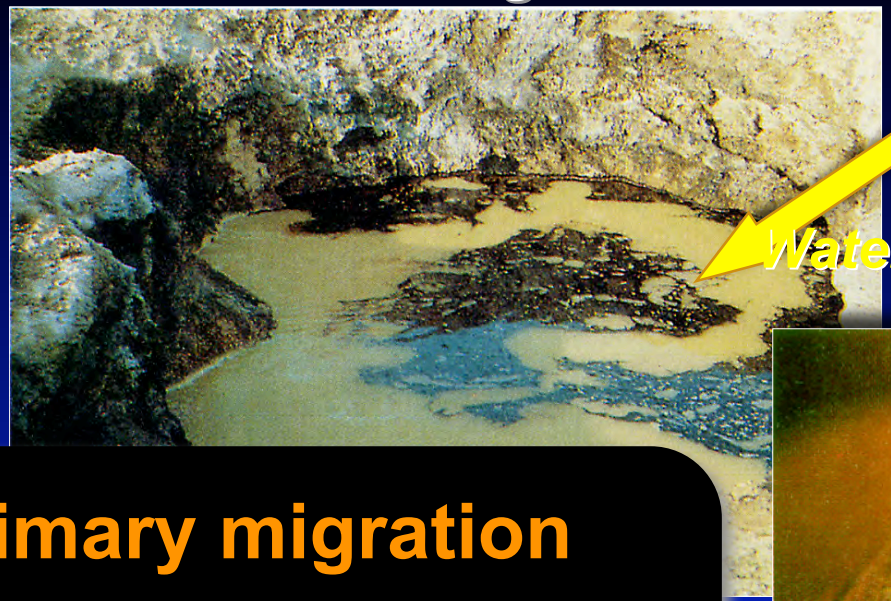
METAMORPHISM





A Préat, ULB, 2011

Often it begins …



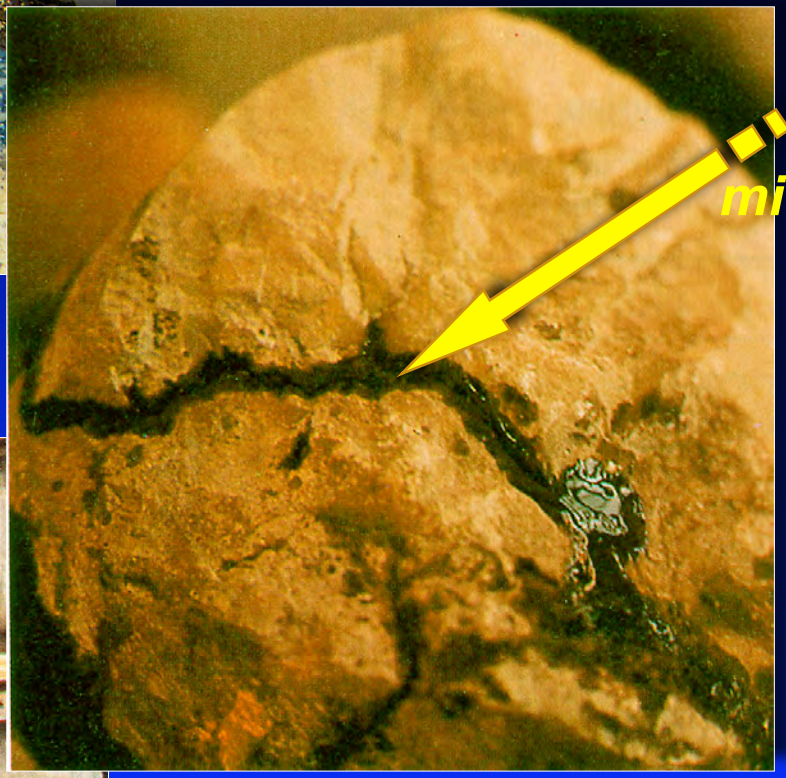
Water table

… by natural seepages of hydrocarbons

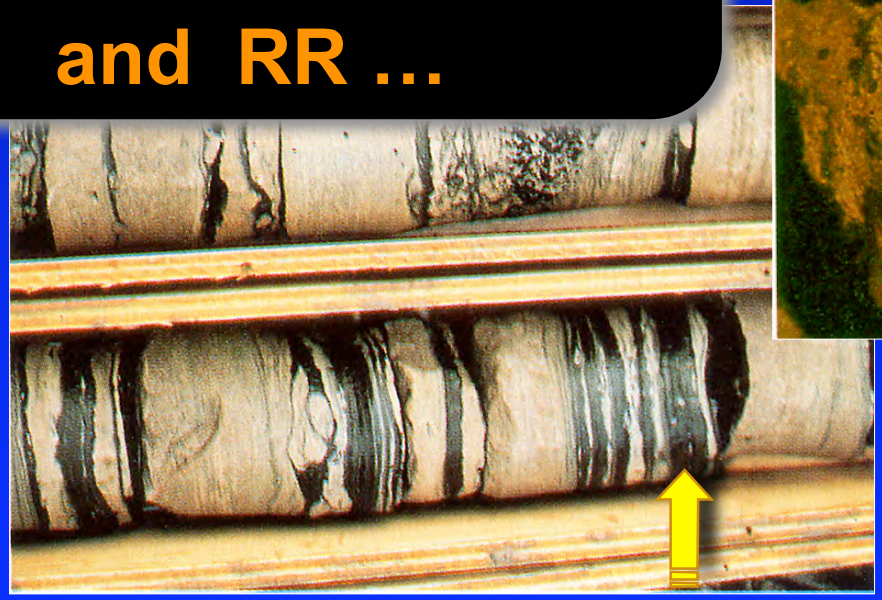
Primary migration

Secondary migration

and RR …

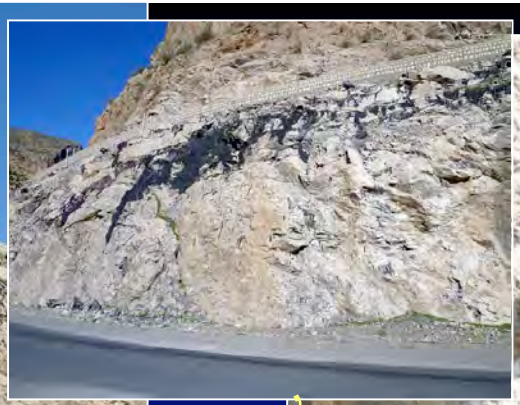


microfracture



… by ‘oil shows’

cores



‘Dysmigration’

‘Dysmigration’

Préat 2011

Préat 2011

'Dysmigration'

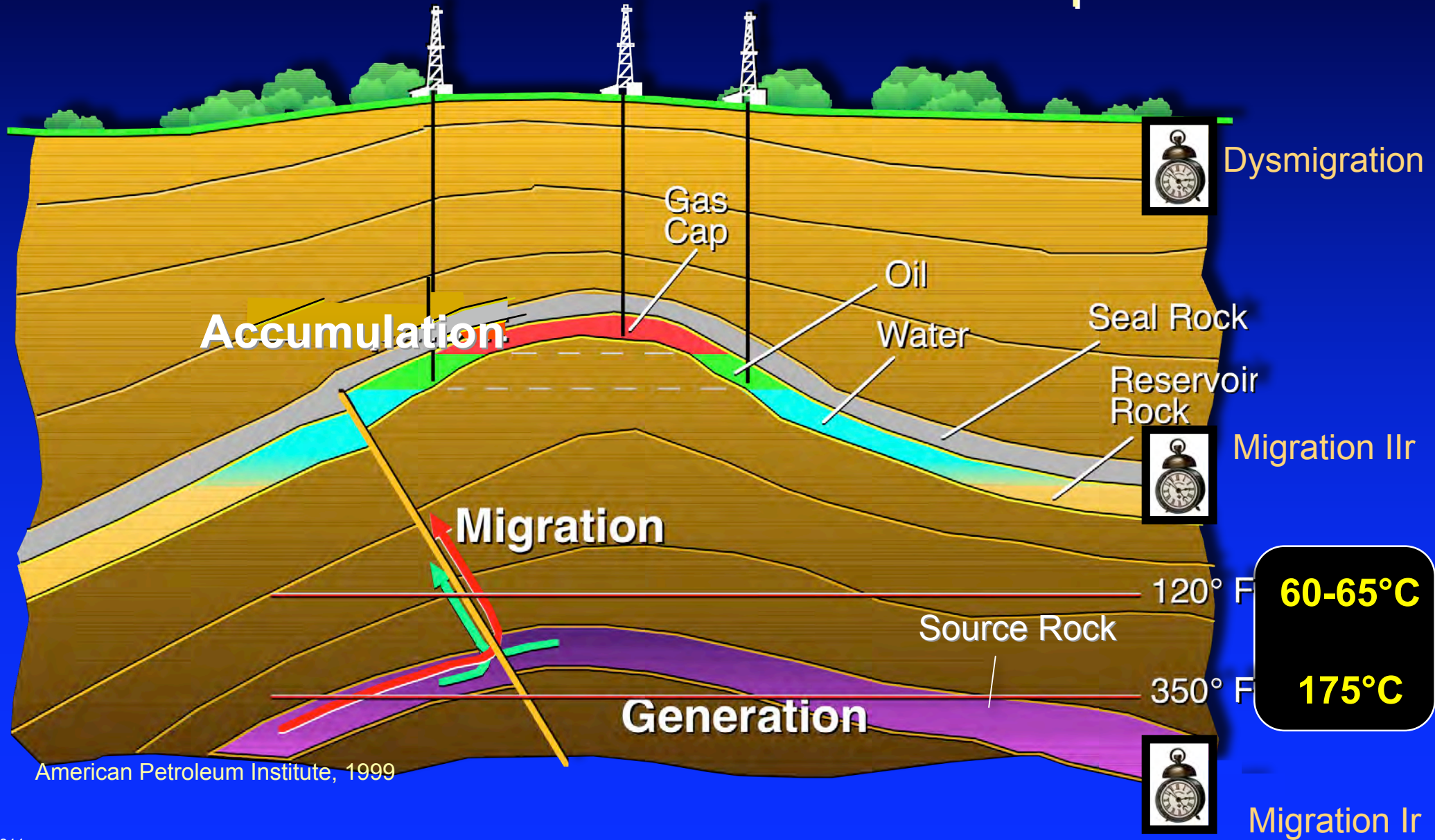
'Dysmigration'

A Préat, ULB, 2011

R e m e m b e r : Reserves = Geological Uncertainties...

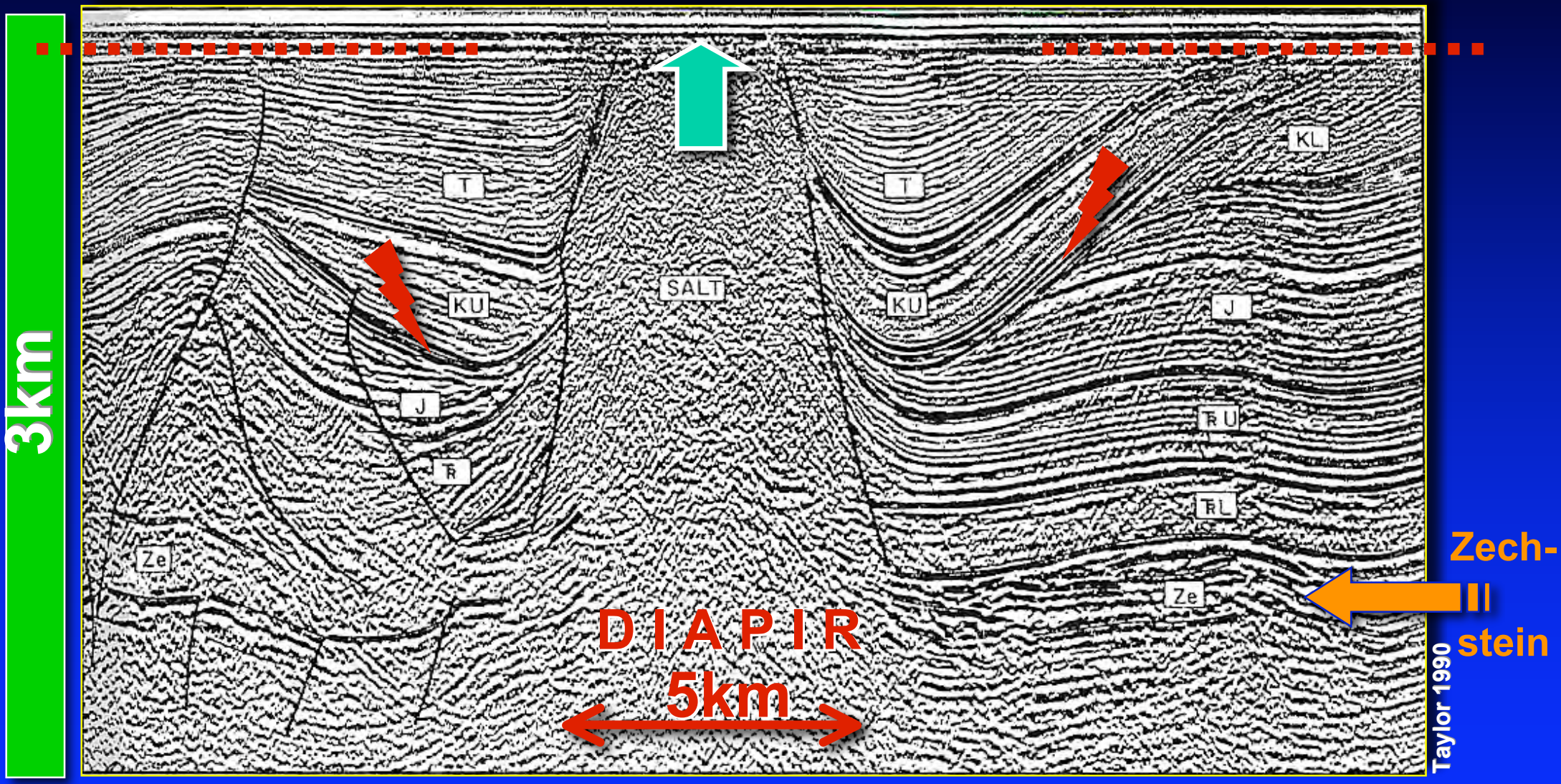
Processes in the Petroleum Systems

Oil accumulated in closed structural traps



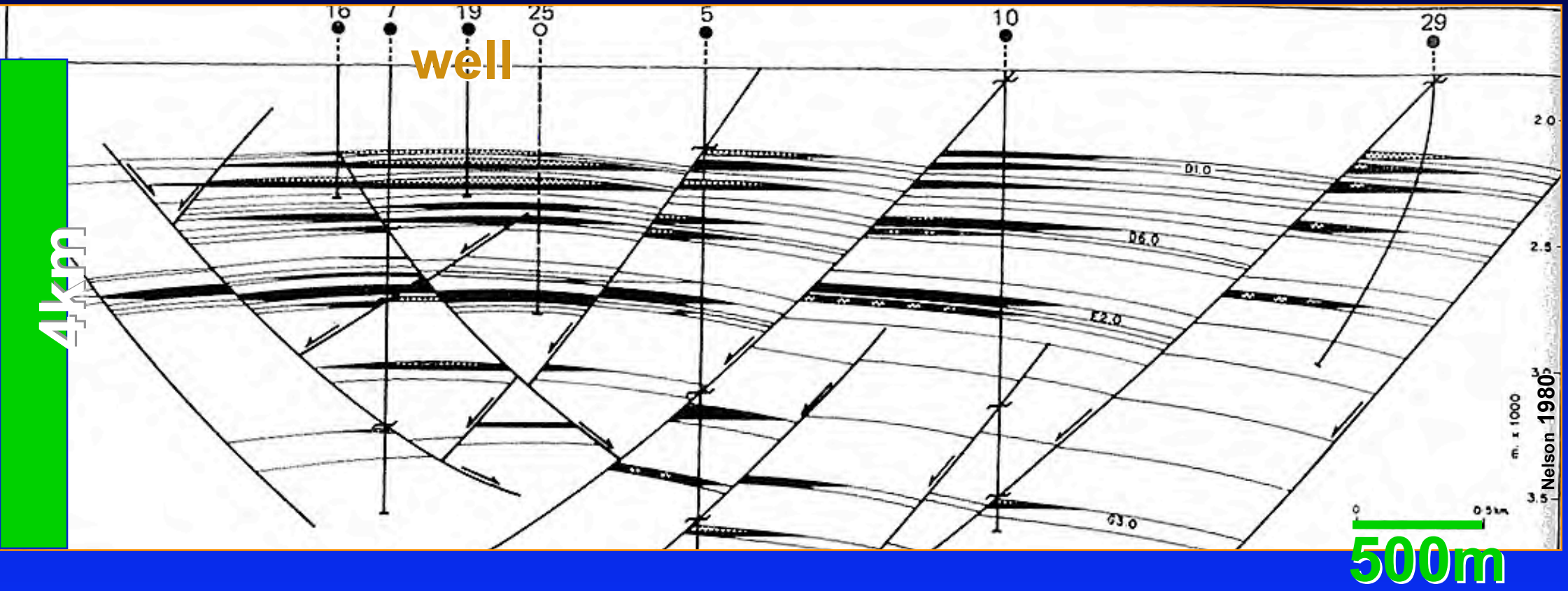
Seismic Profile, North Sea

[25kmX3km, resolution ± 15 m]



Zechstein = very large epicontinental sea, upper Pm [245Ma]
Halocinesis, Cretaceous-lower Tertiary [135-55Ma]

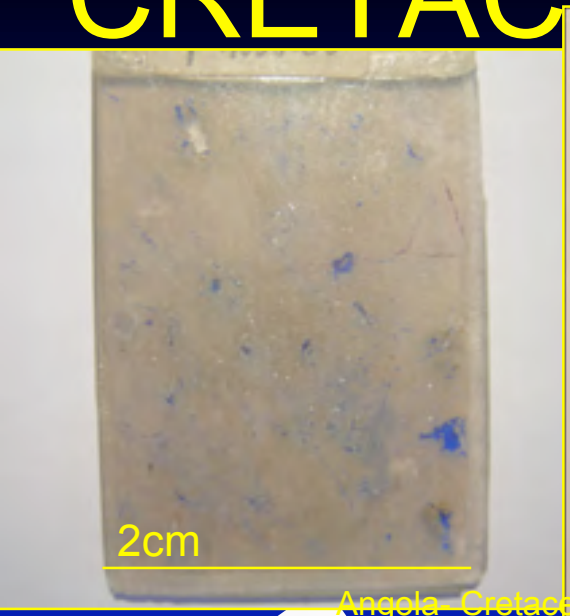
For a good structural interpretation, seismic spacing must be close the shortest distance betewen the faults

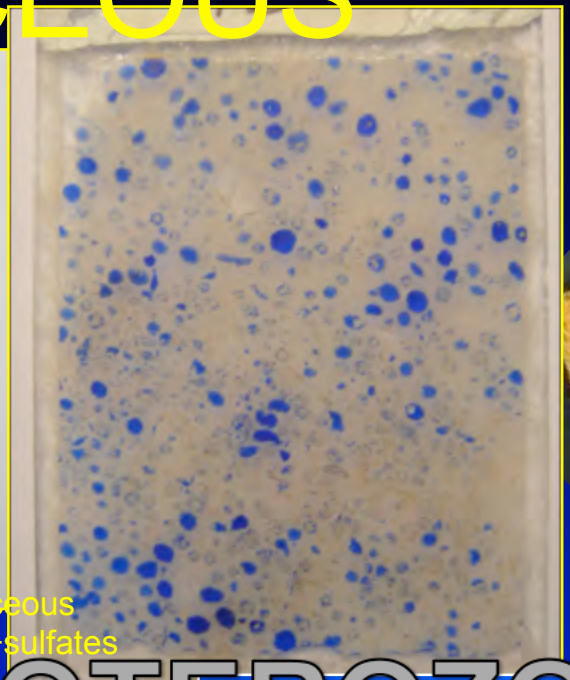


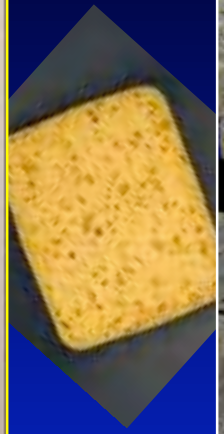
‘Nembe Creek Structure’ = complex anticline 15kmL X 6kml [Nigeria]
strongly faulted (conjugated networks) ===>faulted bloks

NET OIL SDST = 11 intervals totalising 145 m
NET GAS SDST = 8 intervals totalising 87 m

CRETACEOUS



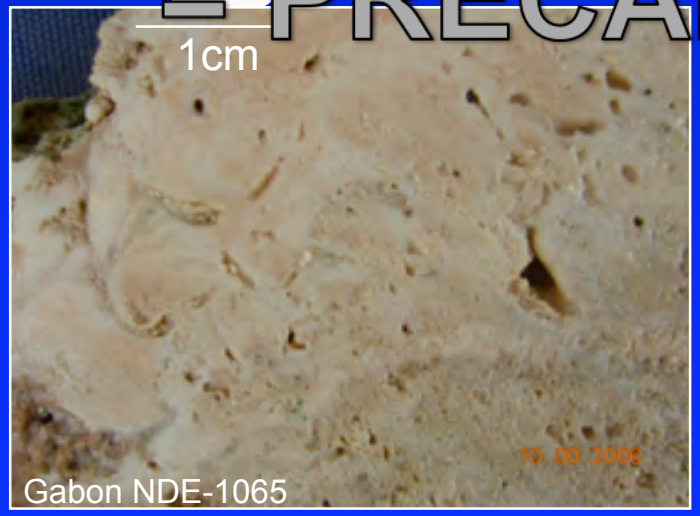




Angola- Cretaceous
Oolites-oncolites+sulfates

Gabon- EOU-232

NEOPROTEROZOIC = PRECAMBRIAN

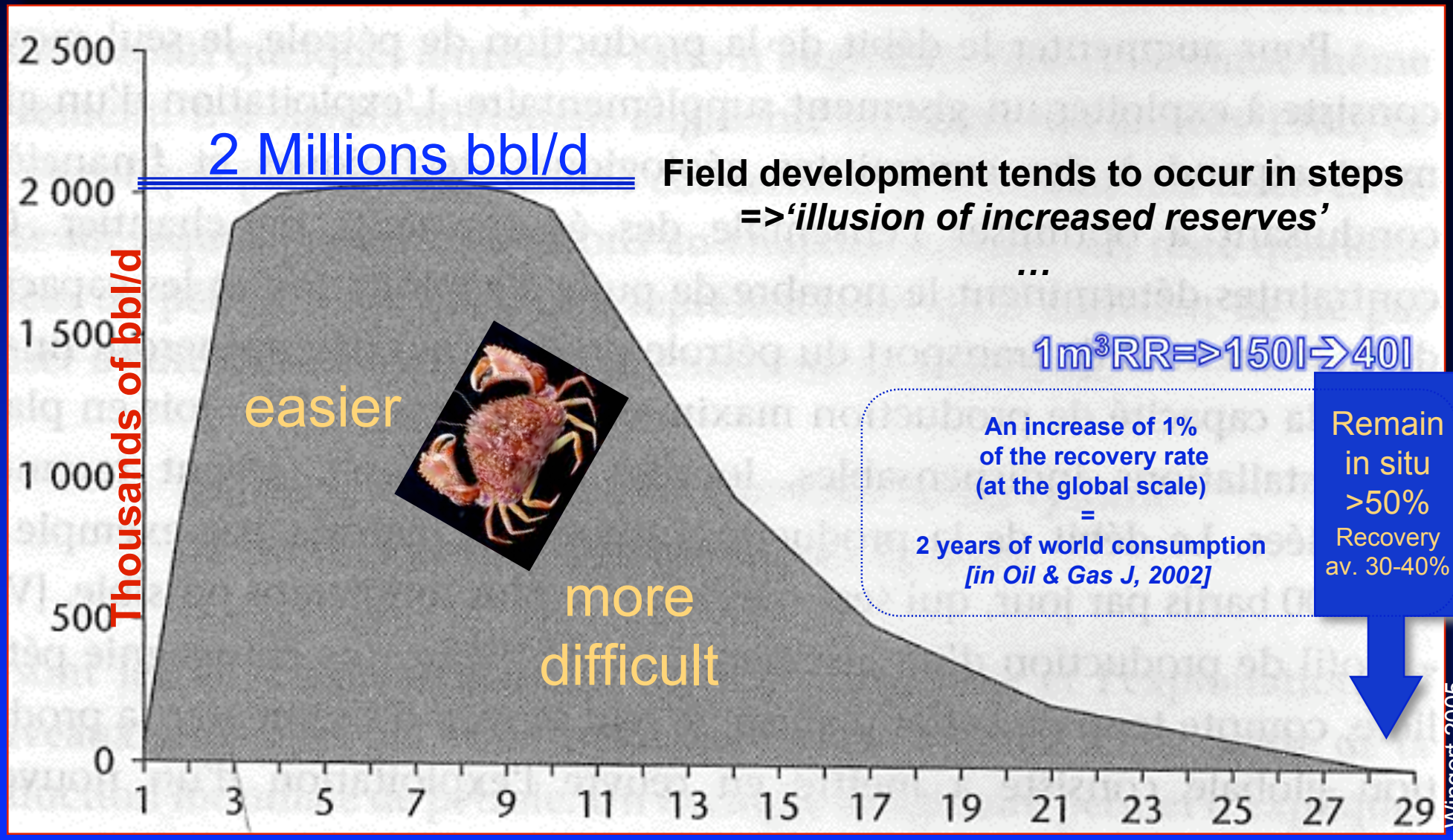


Gabon NDE-1065

Préat 2008

A Préat, ULB,

PRODUCTION TYPE PROFILE OF A FIELD



Field development tends to occur in steps
=>'illusion of increased reserves'
…

1m³RR=>150l→40l

An increase of 1%
of the recovery rate
(at the global scale)
=
2 years of world consumption
[in Oil & Gas J, 2002]

Remain in situ >50%
Recovery av. 30-40%

Oil c
20%
15-35
5-10
Σ 40-(65)

Oil nc
15%

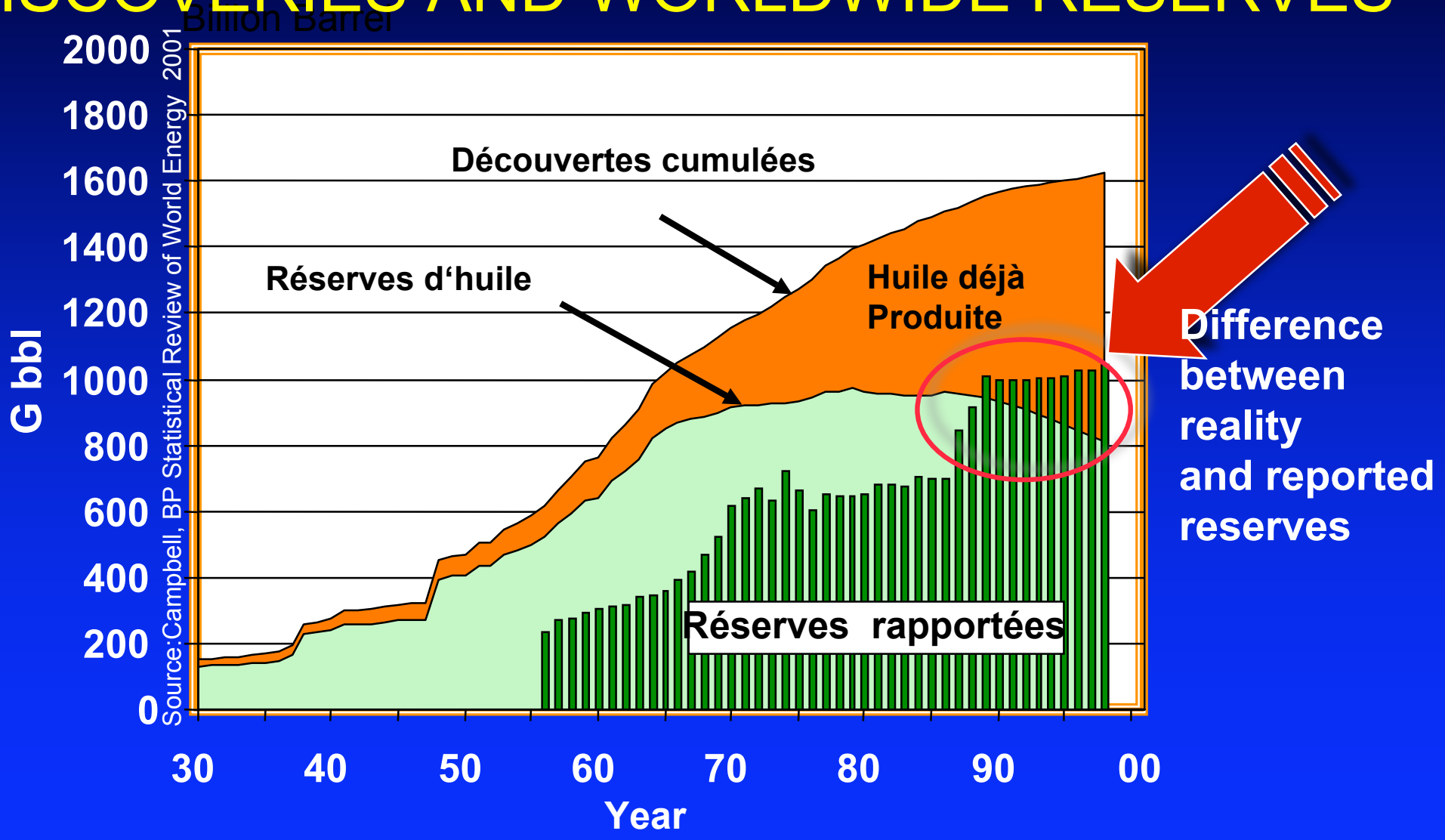
Oil shale
60-70%

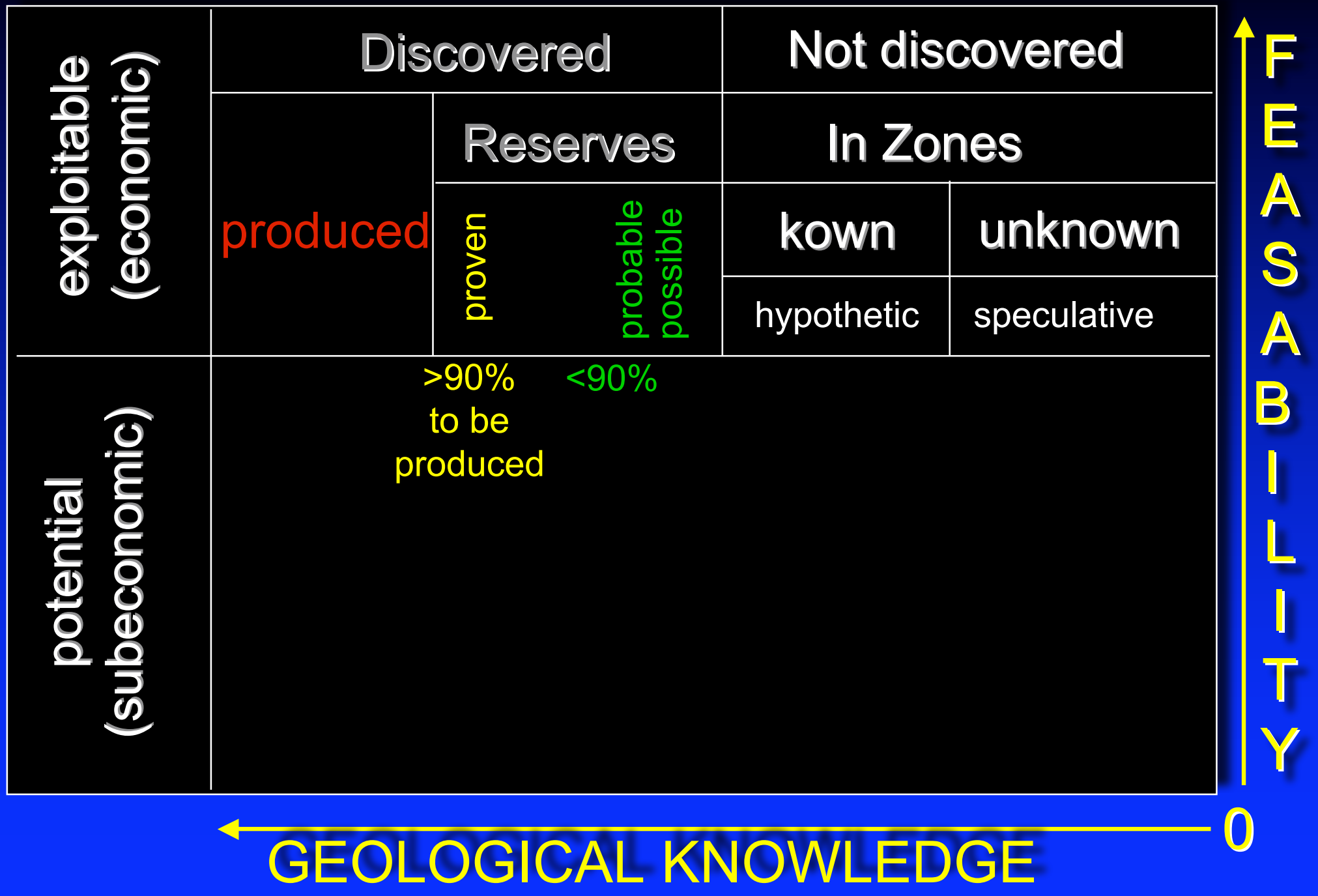
Gas
75%

Wingert 2005

Ex. a giant field of 10 Gbbl spread over 30 years with a 2 Mbbl/d maximum.
The curve is not symmetrical …
The pressure decrease is 12.5% (average)/yr in the North Sea (analysis of 77 fields)
The 'world' overall decline is 5 to 6%...

DISCOVERIES AND WORLDWIDE RESERVES





A Préat, ULB, 2011

THE '3 P' RULE [proven-probable-potential]

The proven reserves '1P' are defined and measured qualitatively and quantitatively about 20% by interpolation between drillcores and extrapolation relied on faithfull seismic data

= > 90% … to be realized

The probable reserves '2P' are estimated by extrapolating a well and geophysical structure, or one or several well known geologically adjacent structures

In this context: probable = 40 to 80% chance of discovery

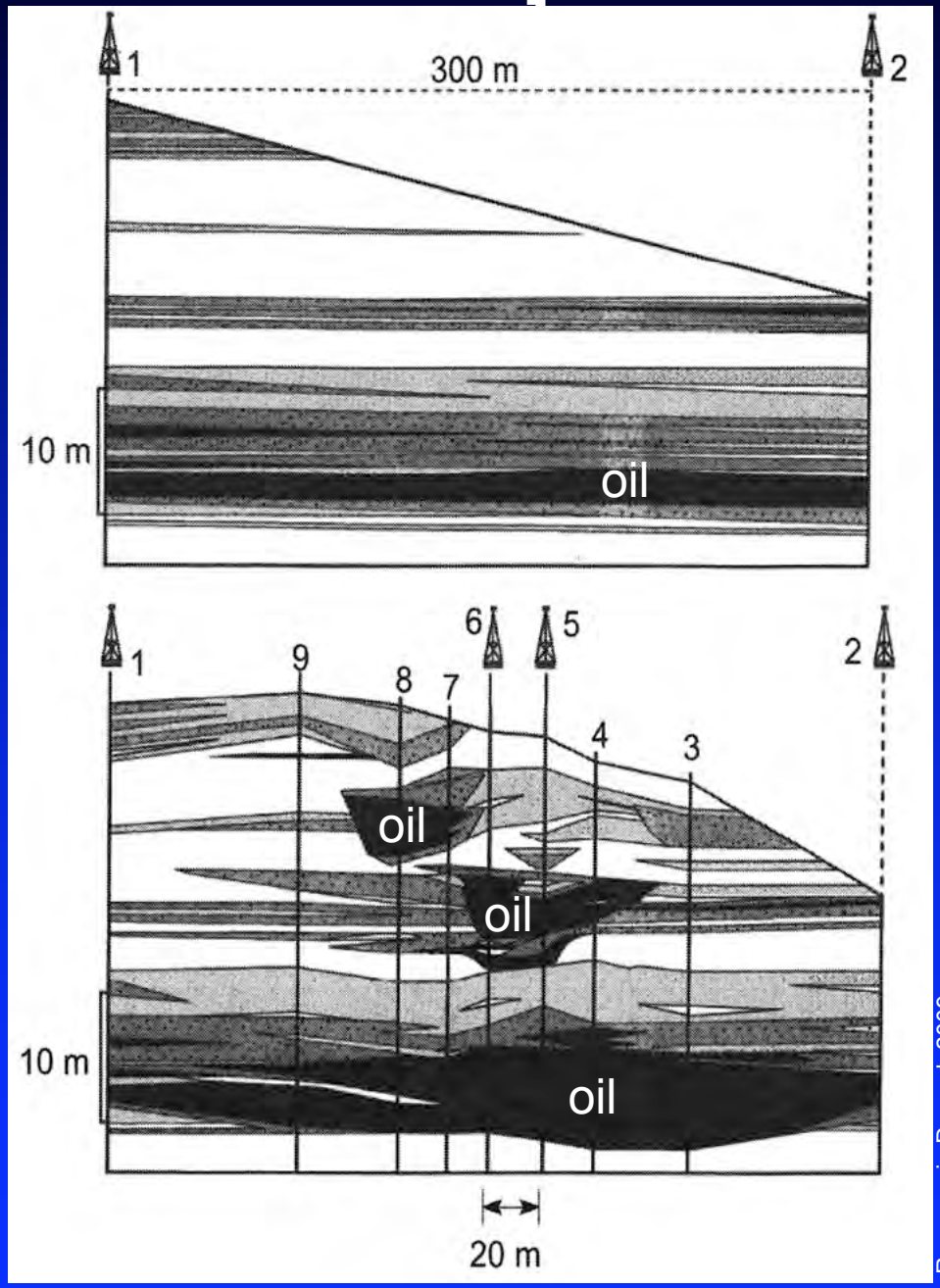
= > 50% … to be realized

The possible or potential reserves or 'ressources' '3P' are Hypothetical : < 40 % of discoveries, generally 5 to 10%

= > 10% … to be realized

THE '3 P' RULE [proven-probable-potential]

Case of a sandstone body (geometry , porosity....)



Ravenne in Durand, 2009

Two wells
Unrealistic model
(here)

probable?

Nine additional wells
More realistic model
(here)
proven

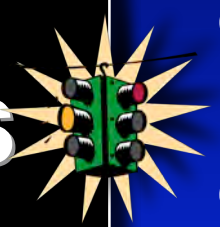
FINALLY

Flexible concept (technical, economics)

Fixed volume difficult to assess

PROVEN RESERVES

ULTIMATE RESERVES



Passing from one to another in both directions

RESOURCES

Proved developed reserves: the fish is in your boat, you weighed. You can feel it and you will eat.
Proved undeveloped reserves: the fish has swallowed the bait and you are ready to leave the water. You can even evaluate the size (he always looks larger in water than in reality!).
Probables reserves : they are fish in the lake. You even caught yesterday. Maybe you can even see them, but you have not caught today.
Possibles reserves : Lake exists. Some have even told you it contains fish. But your boat is still on the trailer and you prefer to play golf.

In Legault A 2007

Why?

GEOLOGICAL UNCERTAINTIES AND ...?

Recent example

In 2002, BP announced that the Caspian undeveloped fields [surveyed in 90'] does not conceal 200 G bbl as expected
BUT 39 G bbl bad quality oil! (too much sulfur)
= geology and sedimentary basins

nb 200 Gbbl = total USA, 220 = Russia, 75 = Europe, Middle East = 680 (estimated ASPO/2006

- **Recent example : January 9, 2004, SHELL announced that its reserves were OVERSTATED by 20% (its President had resign, the Company being over-estimated on the Exchange Market ….**
- **Recent example : in 2002, the DUMA passed a law: reveal Russian gas and oil reserves is a crime punishable by seven years in prison! = (geo)political…**

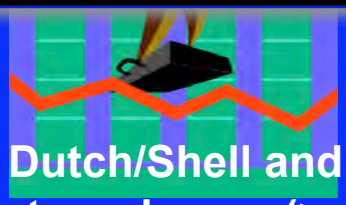
5 milliards bbl of excess!

nb reserves held by oil Cies = 'only' 5 to 15 %

2003 (business activity)
1 Royal Dutch/Shell 269 G$
2 Exxon Mobil 237
3 BP Amoco 232.6
4 Total 131.6
5 Chevron Texaco 113
…

December 9, 2003
The Explo-Prod responsible wrote to the CEO of Shell

‘ I am sick and tired of lying about problems concerning the increase of our reserves and downward revisions that need be done in response to earlier announcements, widely too aggressive and optimistic….’



nb The Royal Dutch/Shell and Exxon Mobil one of the largest producers (> 4 millions bbl/d)

Reserves = Geopolitical Uncertainties...

The Oil Market's Future in the Long Term ...

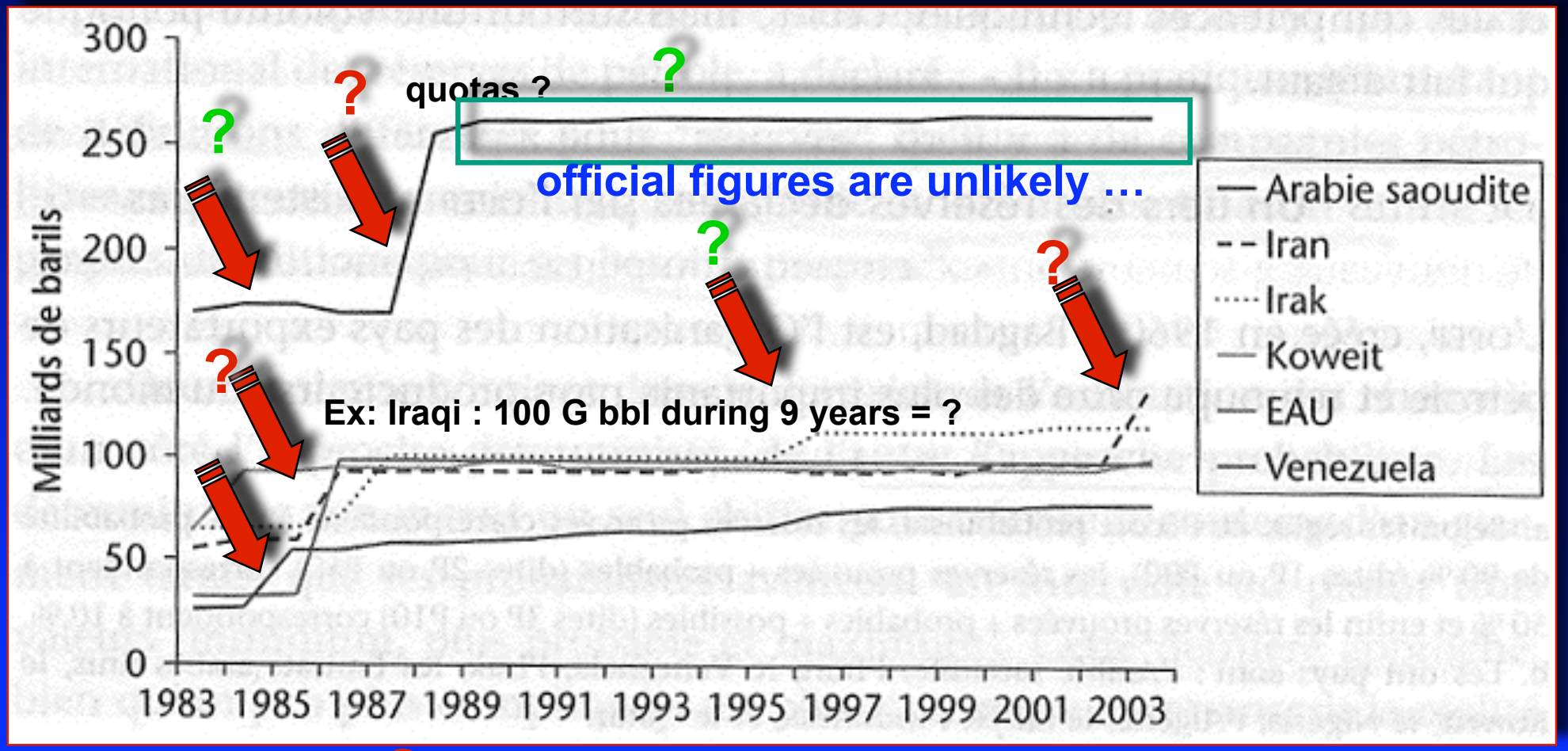
All numbers are wrong...
that much we know.

THE ONLY QUESTION IS:
BY HOW MUCH?

DECLARED RESERVES OF MAJOR OPEC COUNTRIES

? Sudden increase in reserves announced late 80'

? Amount of reserves unchanged over long periods
as if the new discoveries compensated ALWAYS production …



? Increases after-cons oil shock of 1986

[collapse bbl = :2! = 'paper barrels', finally really existed!]

Reserves = Technological Uncertainties ...

ultimate

Planet 20G bep $x10^3$

↓

10G c

↓

5 à 10G Recoverable

↓

Prov Res 2.2G

↓

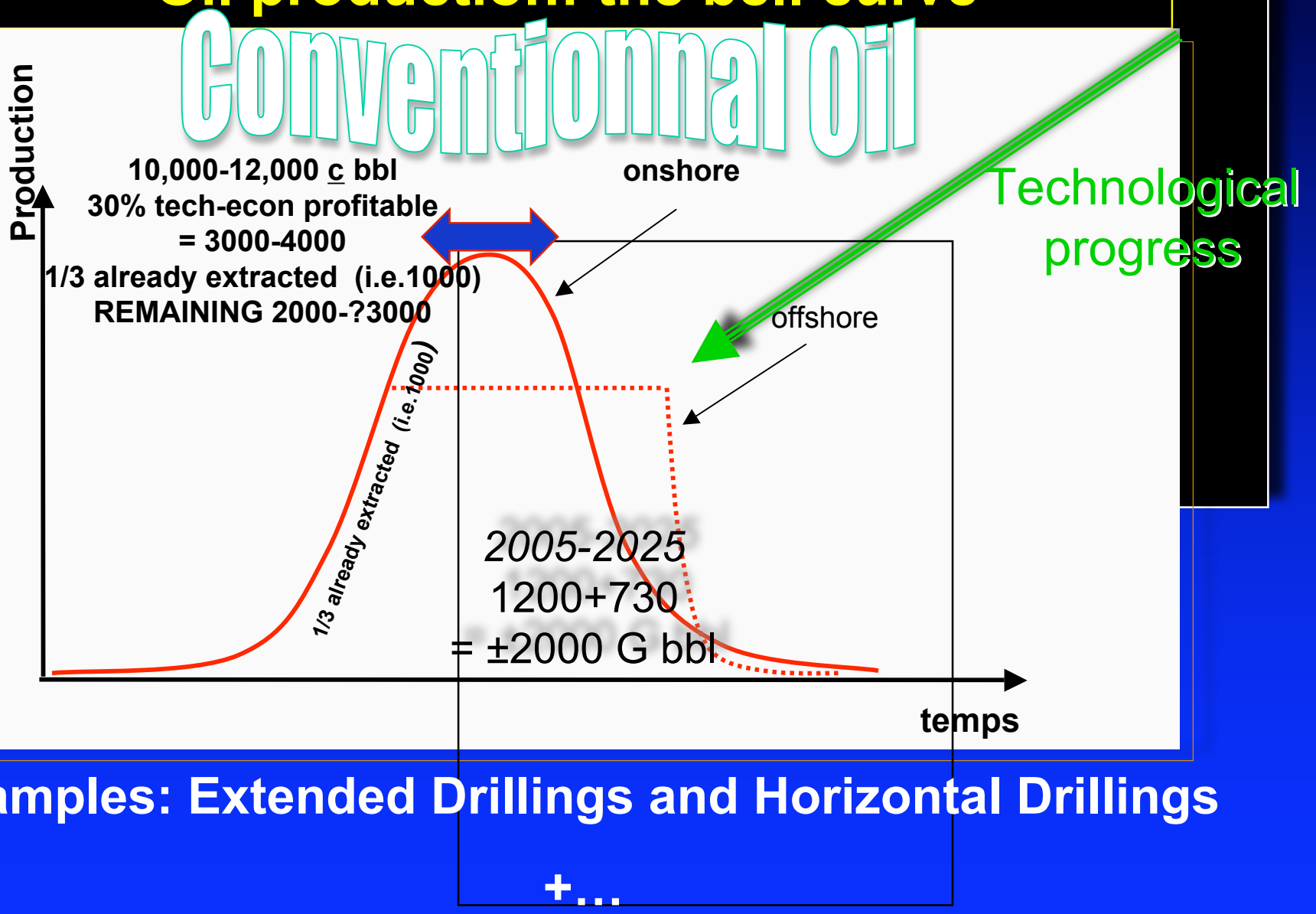
Prov Res 1995-2025 1.2G bbl

↓ $x10^3$

Increase Prov Res 2005-2025 0.73G bbl

AIE 2005, IEO 2005 etc

Oil production: the bell curve



Examples: Extended Drillings and Horizontal Drillings

+...

‘Extended’ drillings (directional or hztal)

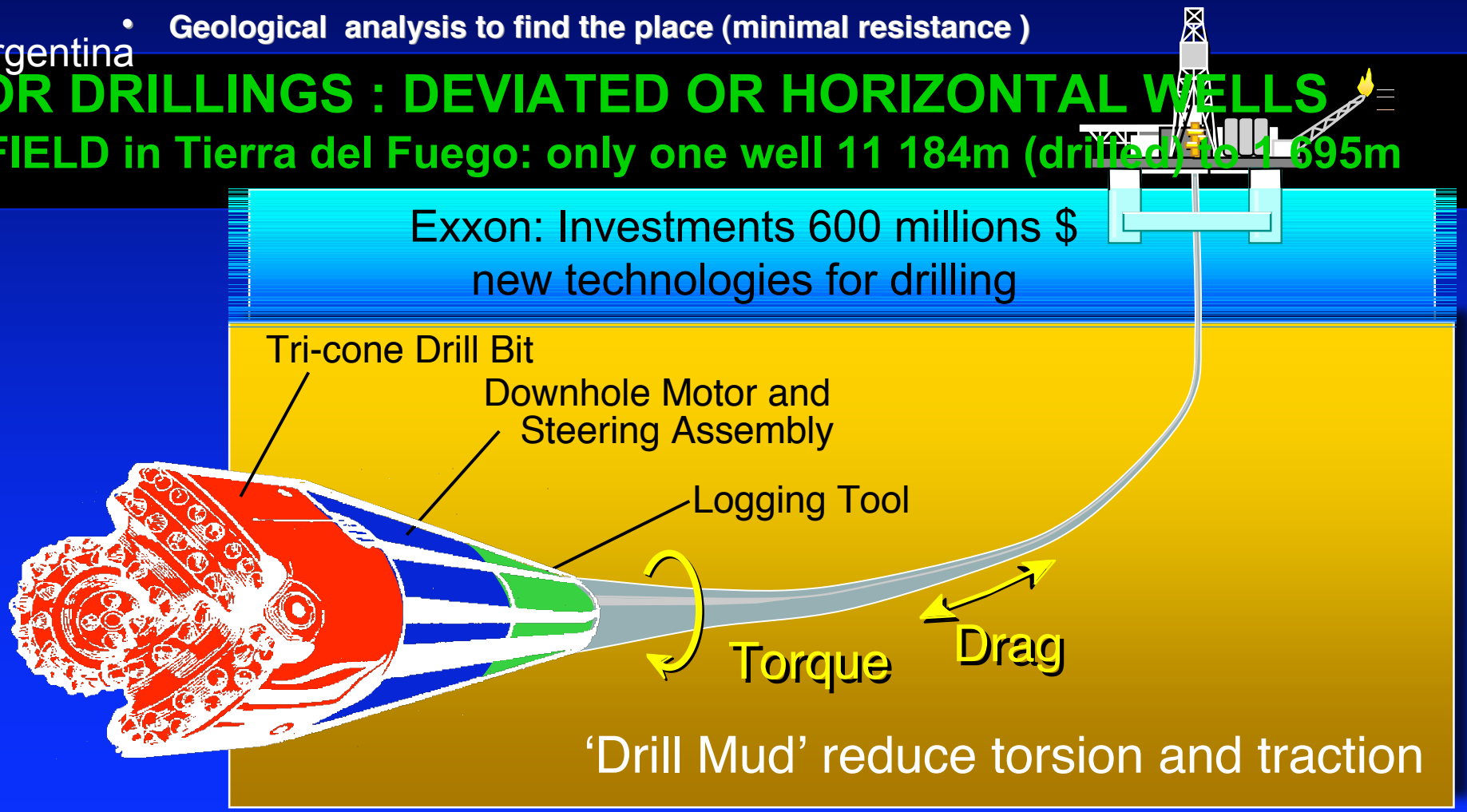
The technology allows gains in harder wells

- Friction decrease
- Geological analysis to find the place (minimal resistance)

1998-Argentina

MAJOR DRILLINGS : DEVIATED OR HORIZONTAL WELLS

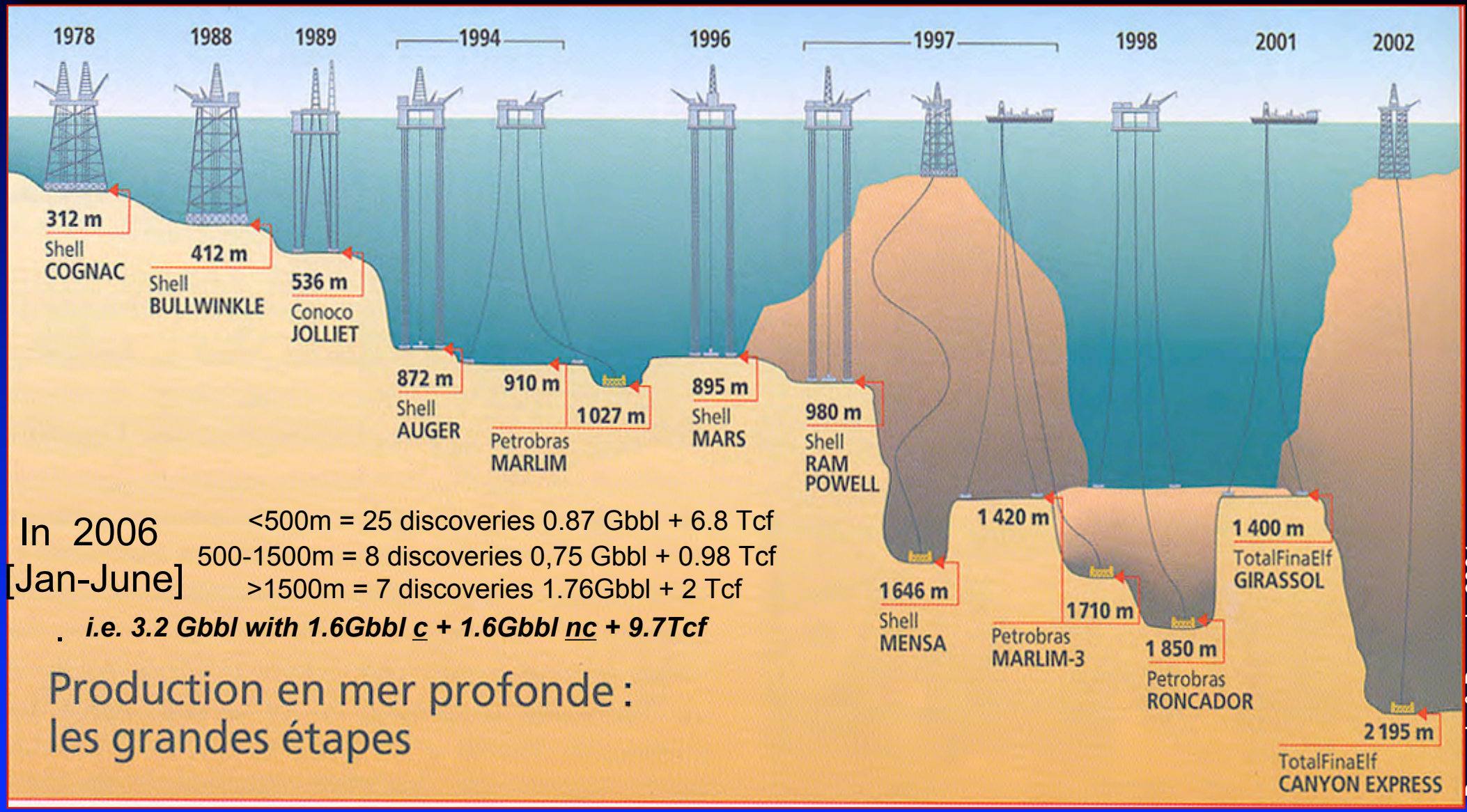
ARA FIELD in Tierra del Fuego: only one well 11 184m (drilled) to 1 695m



1891? First tests …

1985: first well [chalk, USA]-1990 = 1500 wells [World]-2000 = ± 20,000 wells [id]

TO THE ULTRA-DEEP> 3000 m

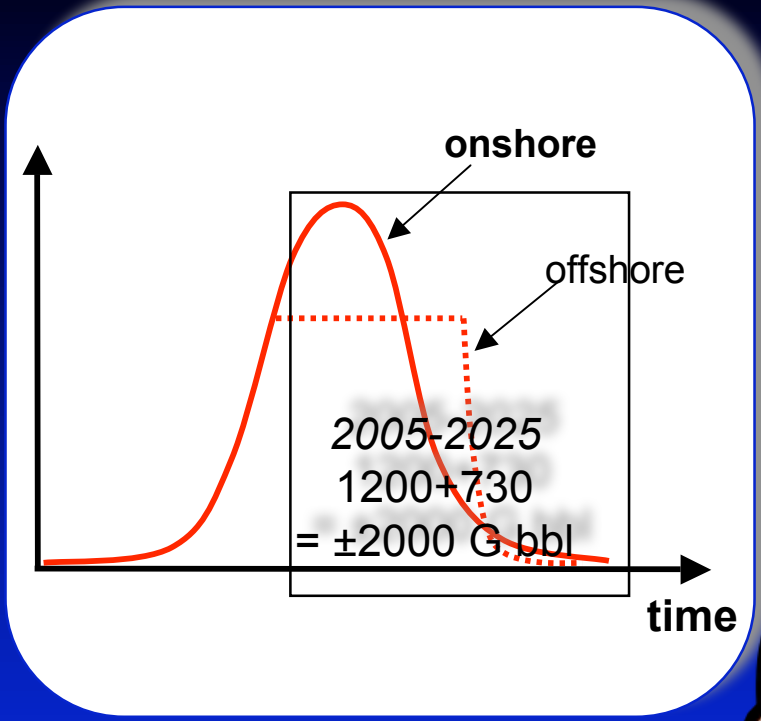


In 2006 [Jan-June]

<500m = 25 discoveries 0.87 Gbbl + 6.8 Tcf
500-1500m = 8 discoveries 0,75 Gbbl + 0.98 Tcf
>1500m = 7 discoveries 1.76Gbbl + 2 Tcf

. ***i.e. 3.2 Gbbl with 1.6Gbbl c + 1.6Gbbl nc + 9.7Tcf***

In 2000, the deep offshore >200m represented 20%
In 1970 it counted for less than 5%



WHY?
see numbers…

90-95%

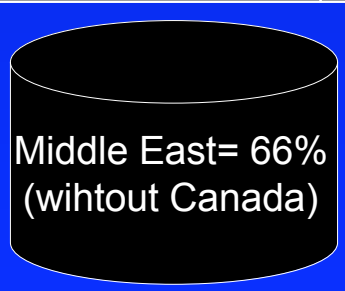
…of PROVEN world reserves

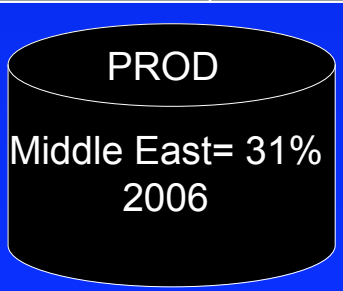
Oil c

Proven Reserves 2004/2005 [±5%?]

Proven Res	Oil Gb	%	Gas %
Saudi Arabia	267.9	20.7	3.8
Canada	18.0	14.1	< 1
Iran	128.7	9.9	15.3
Iraqi*	117.7	9.1	1.8
Kuwait	101.3	7.8	< 1
UAE	100.1	7.7	3.4
Venezuela	79.6	6.1	< 1
Russia	61.4	4.7	26.7
Libya	36.8	2.8	< 1

Proven Res	Oil Gb	%	Gas %
Nigeria	25.6	2.0	2.8
USA	23.2	1.8	2.9
China	18.7	1.4	< 1
Mexico	16.0	1.2	1.8
Norway	10.7	0.8	1.3
Algeria	8.7	0.7	2.5
Qatar			14.5
Australia			2.3
Indonesia			2.1





Reserves 1P (world): 1200 G bbl c i.e.+79% 1980-2005

Images Econ du Monde 2005

OIL c

Proven Reserves
2008 (BP)
[±5%?]

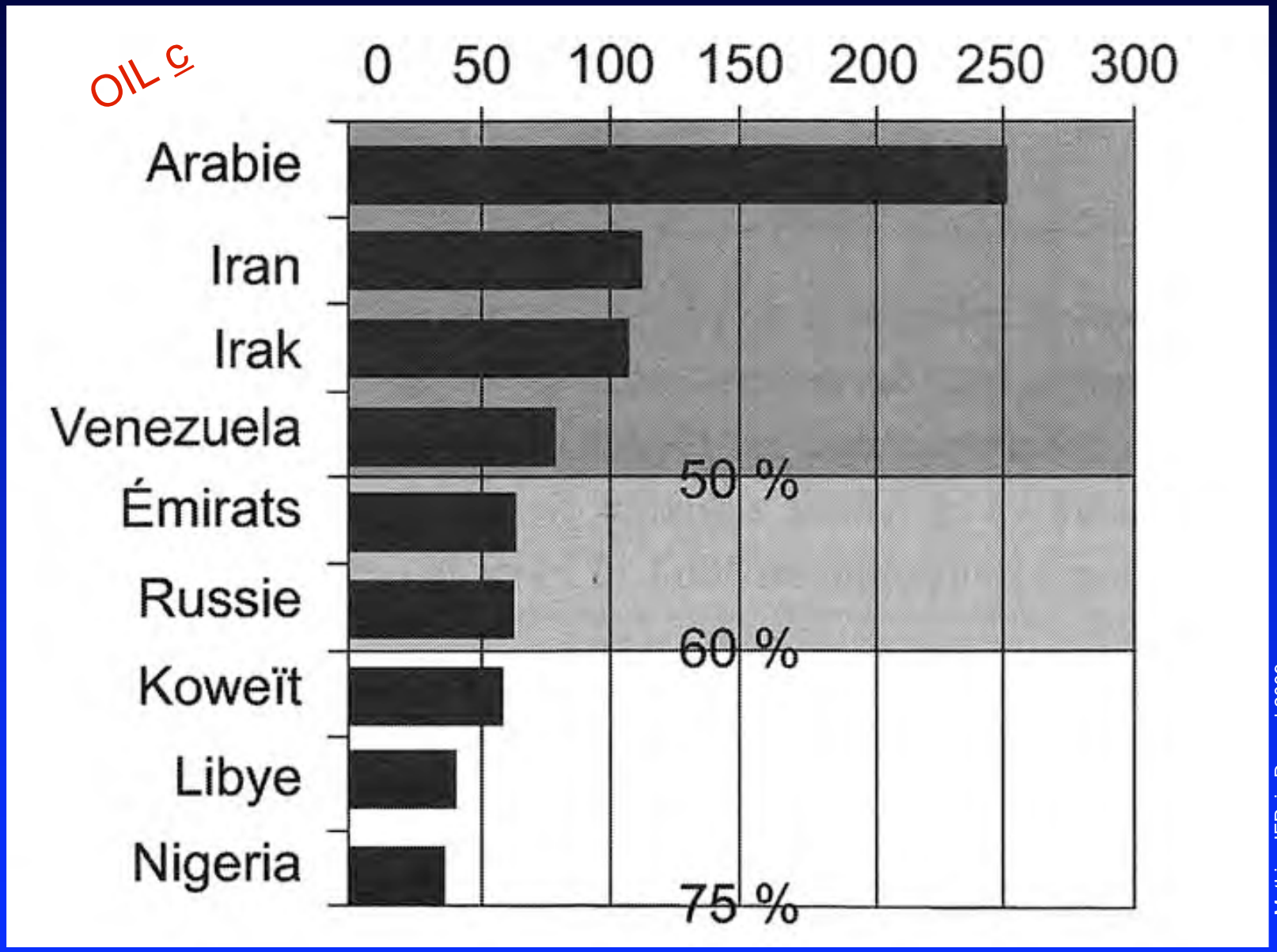
Proven Res	Oil Gb	%	Gas %
Saudi Arabia	264.1	21	4.1
Canada	28.6	2.3	0.9
Iran	137.6	10.9	16.0
Iraqi	115.0	8.1	1.7
Kuwait	101.5	7.8	1.0
UAE	97.8	7.8	3.4
Venezuela	99.4	7.9	2.6
Russia	79.0	6.3	23.4
Libya	43.7	3.5	0.8

Proven Res	Oil Gb	%	Gas %
Nigeria	36.2	2.9	2.8
USA	28.6	2.3	3.6
China	15.5	1.2	1.3
Mexico	11.9	0.9	0.3
Norway	7.5	0.6	1.6
Algeria	12.2	1.0	2.4
Qatar	27.3	2.2	13.8
Australia	4.2	0.3	1.4
Indonesia	3.7	0.3	1.7

http://www.bp.com/

Images Econ du Monde 2005

The nine countries with 75% of proven reserves



Mathieu IFP in Durand 2009

They are countries----------?

OIL nc (recoverable rate 10 to 20%)
[±7000Gb Ultimate]
Heavy oils 10-20°API = 23%
Bituminous Sands = 39%
Bituminous Shales = 38%

Canada	36%
USA	32%
Venezuela	19%
Russia et 'satellites'	7%
Africa	3%
Middle-East	1%
Others	2%

Data BP - 2005

2008
600Gbbl? recoverable
20 to 50 yrs production
porosity 11-12%
Alberta: 600 cies (oil)
Cost prod. 2008: $40
> $70 with the crisis!

OPEC =
±3/4 Oil c
NOPEC = ± 3/4 Oil nc
[*N Am = 68% nc*]

Middle East + Russia = ±2/3 Gas

[Gas producers 2008: 1 Russia, 2USA, 3Canada, 4 Iran]


Alaska
Canada
Groenland
Norvège
Roy.-Uni
France
Italie
Espagne
Etats-Unis
Maroc
Libye
Chine
Golfe du Mexique
Venezuela
Guyane
Nigeria
Equateur
Brésil
Congo Brazzaville
Angola
Madagascar
Offshore profond
Sables bitumineux
Schistes bitumineux
Pétrole lourd
Source : Greenpeace, campagne « vivement-la desintox.com »

The most likely scenario of the future (1P)

	Exhaustion in		ULTIMATE Res = off technology and current economy
OIL c	40 yrs	min.	120-140
GAs	70 yrs		150-300
COAL	227 yrs		<400
CLATHRATES	?10x Oil c		+nc 120-130

Bobin et al., 2001; Ngô, 2002

2000': fossil fuels represent,
80-90 % of primary energy consumption
in the world

Réserves ultimes de pétrole conventionnel et non conventionnel estimées

ASPO

YEAR 2010: THE MOST OFTEN ADVANCED FOR THE OIL c PRODUCTION PEAK

[Gas ± 2030..., Coal between 2035 and 2055...]

after, it is the year 2020...

(USGS = 2037)

OPEC

'MAJOR'

K Deffeyes (U. Princeton, oil expert after K Hubbert) Thanksgiving Day

2005 IS THE WORLD OIL PEAK

with 1000.6 G bbl produced since the beginning ot the Oil Era!

RANKING OF COUNTRIES BY THEIR POTENTIAL ENERGY

	Res in Gtoe =>	Oil	Gas	Coal	U	total
1	USA	3.8	4.7	122.0	3.2	133.7
2	Russia	8.2	42.8	68.7	1.6	121.3
3	China	2.4	1.4	58.9	0.1	62.9
4	India	0.7	0.7	55.6		57.0
5	Venezuela	11.2°+41*	4	0.3		56.5
6	Australia	0.4	2.3	41.6	8.6	52.9
7	South Africa			33.0	3.4	36.4
8	Canada	0.9+25**	1.5	3.3	4.0	34.7
9	Kasakhstan	1.2	1.7	21.7	7.9	32.5
10	Saudi Arabia	25.1°	5.7			30.8

* = heavy oil, ** = bituminous sands,
• ° = figures modified by the author

Source: BP, Rev annuelle sur l'énergie et OCDE
Renardet 2004

11 Germany (mainly coal), 12 Iran (mainly gas), 13 Ukraine (coal), 14 Iraqi (oil), 15 Poland (coal) 16 Qatar (gas), 17 Kuwait (oil), 18 UAE (oil-gas).

Total n°18 = 10.4

ANALYSIS OF DATA OF THE TABLE

1. The United States ALSO have the advantage of technology and effectiveness in operating techniques
   Russia has the ADVANTAGE of diversification in its sources
2. Three European countries are rich in coal (Germ., 'Ukr.', Poland)
3. Some countries (Australia, Kazakhstan, Canada) have diversified enough reserves INSTEAD of Venezuela
4. The Middle East has high enough energy resources, BUT consist exclusively of hydrocarbons.

SUMMARY AND SHORT TERM LIKELY SCENARIO

1. **50'-60': period of plenty oil**
2. **80' : coexistence of oil with other energy resources**
   = period of relative abondance
3. **2010 : transition conventional - non conventional (nc)?**
   Nb the production cost of nc oil decreases
   $0.5-1 bbl/year!

Most oil Cies evaluate the profitability of their investments
based on a bbl to $18, even $16 for BP in 2005.
In 2005: 1 bbl of ± $ 45 (beginning 2005) to ± $ 65 (late 2005)

LIKELY SCENARIO IN THE MEDIUM TERM = XXIth

1. **Optimize production in mature areas**

   now: 70% World Prod. = fields put in production there are > 20 years

   (4-D seismic, re-entered by horizontal drains)

2. **Satellite and marginal fields located close to known**

   now: it takes advantage of existing infrastructure + difficult fields HP/HT

3. **Deep and ultradeep offshore**

   •deep= >500m, 30% World Prod. in 2004 with 2,000 wells, $30x10^6km^2$, only 5% of license,
   GOLDEN TRIANGLE : BRAZIL-MEXICO-ANGOLA(NIGERIA), 80% identified RR by 500-1500m water
   •ultradeep = 1500-3000m (300bar), 8% World Prod. in 2010?,

4. **Arctic (polar)**

5. **Oil nc**

   tar sands et extra-heavy oils = bacterial oxidation
   + bituminous shales = OM incompletely transformed
   ===> recovery rate 2004 = 8% ===>?25% en 2020
   ===> in 2004: difference prod. bbl North Sea and Orinoco oils nc = $ 3/bbl

TECHNOLOGY...

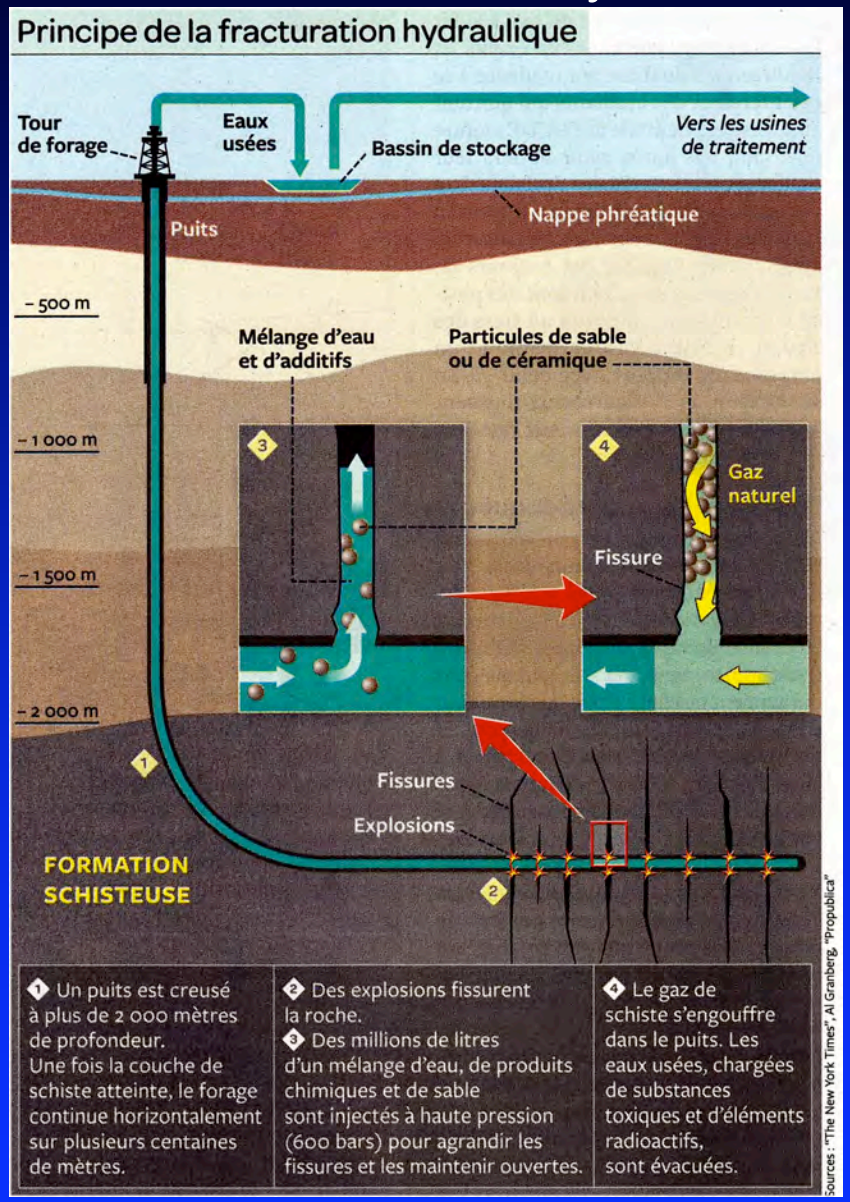
'Historical ' examples
1.In mid-1980s, the technical cost of production of a offshore (> 200m) bbl
2.was estimated at $13-15
===> in 2005 = 5 to $ 7
2. The recovery rate does not exceed 20% in the 1960's is now 30%.
The transition from 30 to 38%, achievable in 25 years
would increase reserves of 500 G bbl
... this is the order of magnitude
of total reserves held by Saudi Arabia...!

etc…

MEDIUM TERM

‘SHALE’ GAS = gas of marls or gas of pelite

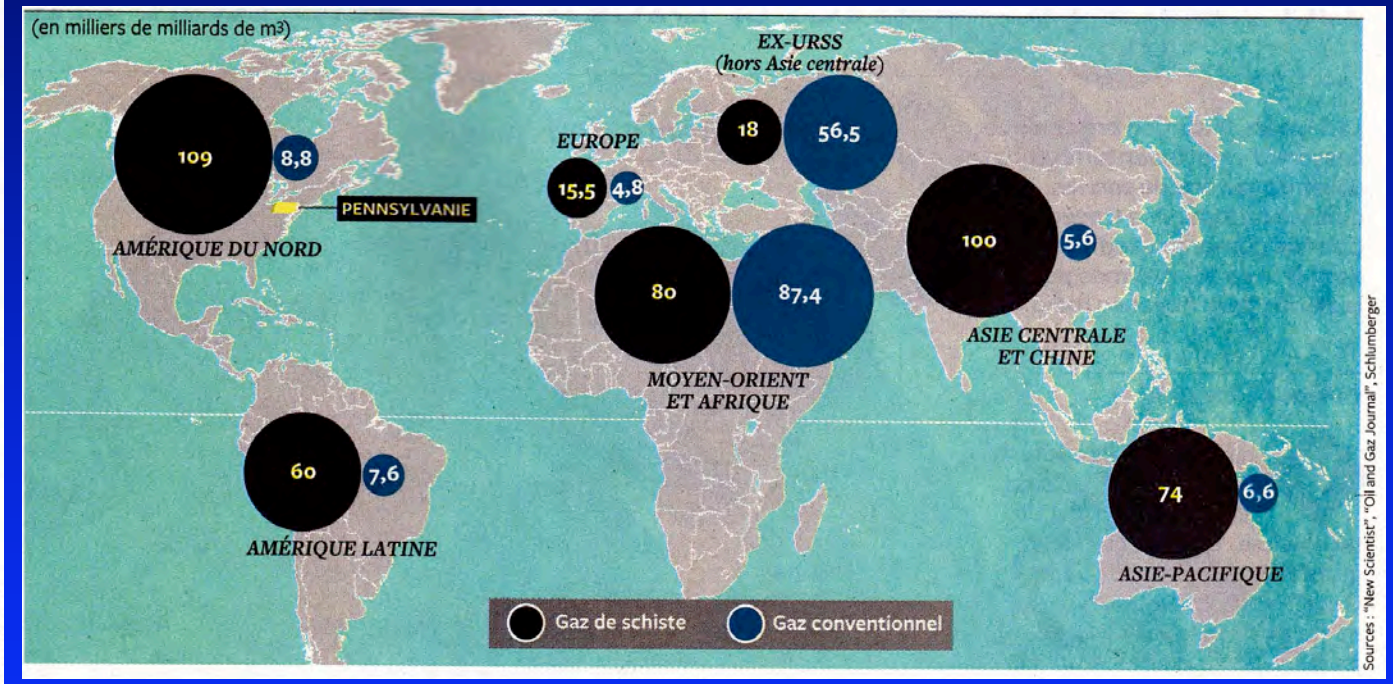
A horizontal well every 1 to 4 km



Reserves such as gas c or > soit 500.10^{12} m^3

Better distributed than the gas c

> 100 years? (USA)



‘FRACKE’ = hydraulic fracturing

10 to15,000 m^3 water (sand+additives)/drilling

2009 : 493,000 wells USA

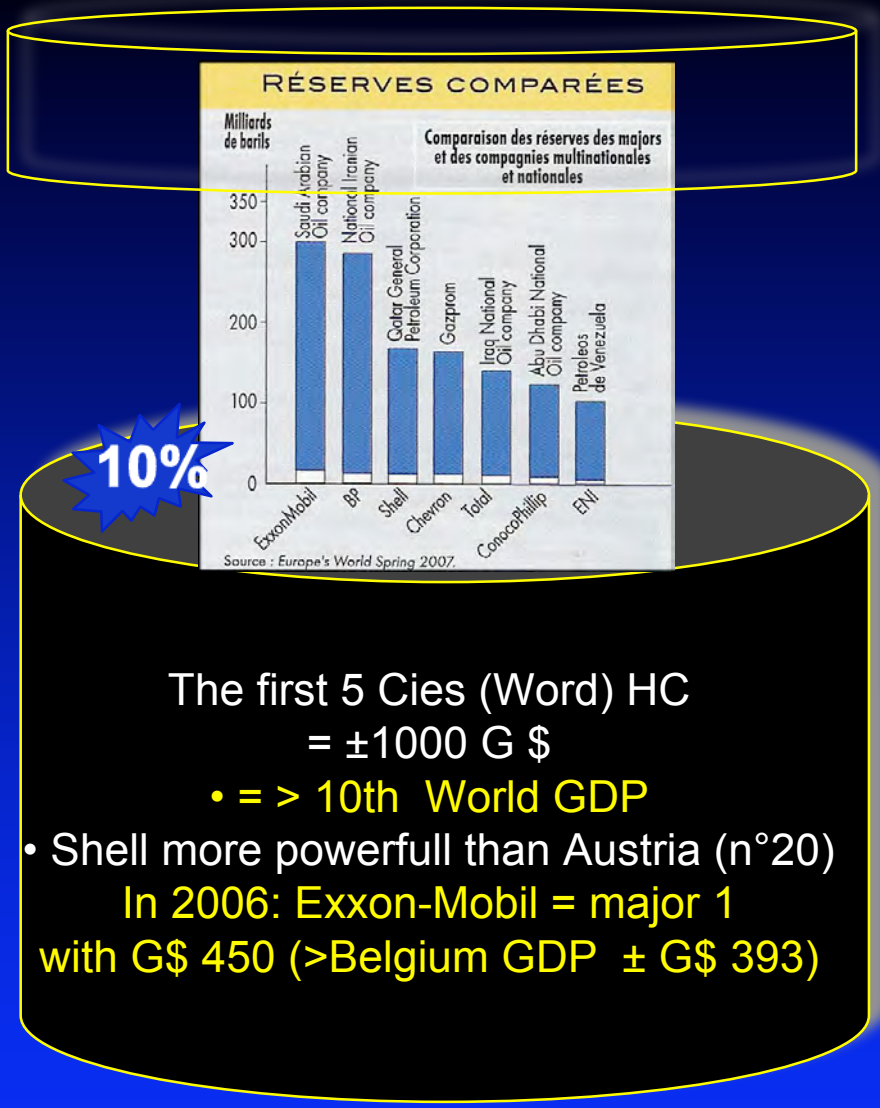
2010: 3000 operating licences in Pennsylvania (117 in 2007)

Attention to environmental problems (benzene, toluene, radioactivity…)

‘Clout of the *majors* (multinational)’

			G $ [2002]
1	Wall-Mart *USA*	distribution	233.3
	ExxonMobil *USA*	oil	191.7
	General Motors *USA*	automobile	178.2
	Royal Dutch Shell *PB/UK*	oil	171.2
	BP *UK*	oil	170.5
	Ford *USA*	automobile	155.1
	Daimler-Chrysler *All/USA*	automobile	149.5
	General Electric *USA*	conglomerate	125.6
	Toyota *Jap*	automobile	119.8
	Mitsubishi *Jap*	automobile	103.0
	Total *France*	oil	102.5
	Mitsui *Jap*	chemistry	102.3
13	Chevron Texaco *USA*	oil	94.0

in A Nonjon 2007



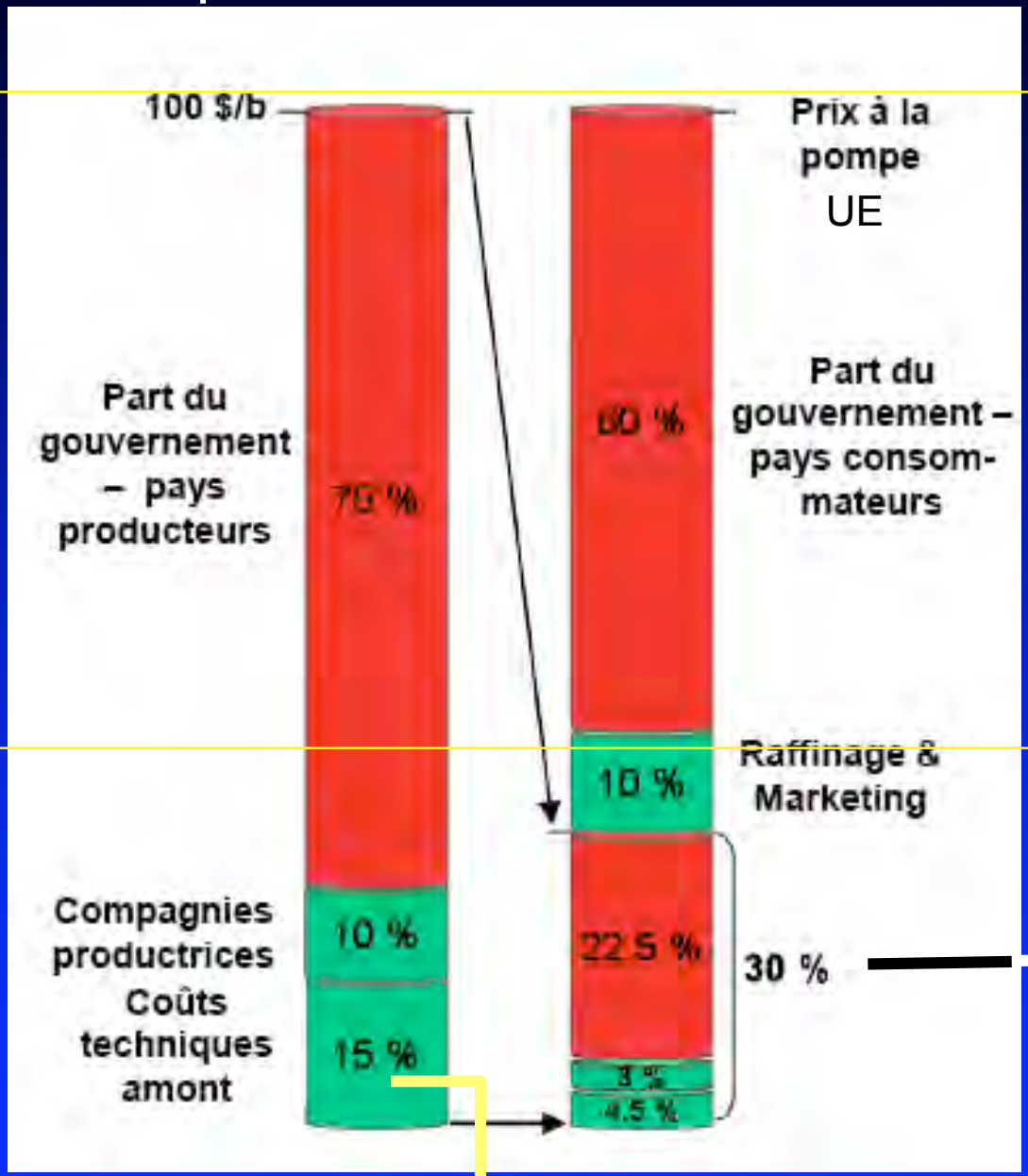
The first 5 Cies (Word) HC
= ±1000 G $
- = > 10th World GDP
- Shell more powerfull than Austria (n°20)

In 2006: Exxon-Mobil = major 1
with G$ 450 (>Belgium GDP ± G$ 393)

In 2004 : the15th first oil Cies

With > 1500 G $ more or less the Chinese (n°7) GDP

The price of the crude 2009-2011



P Mauriaud TOTAL

It is almost same thing

30% = cost pump

World average cost

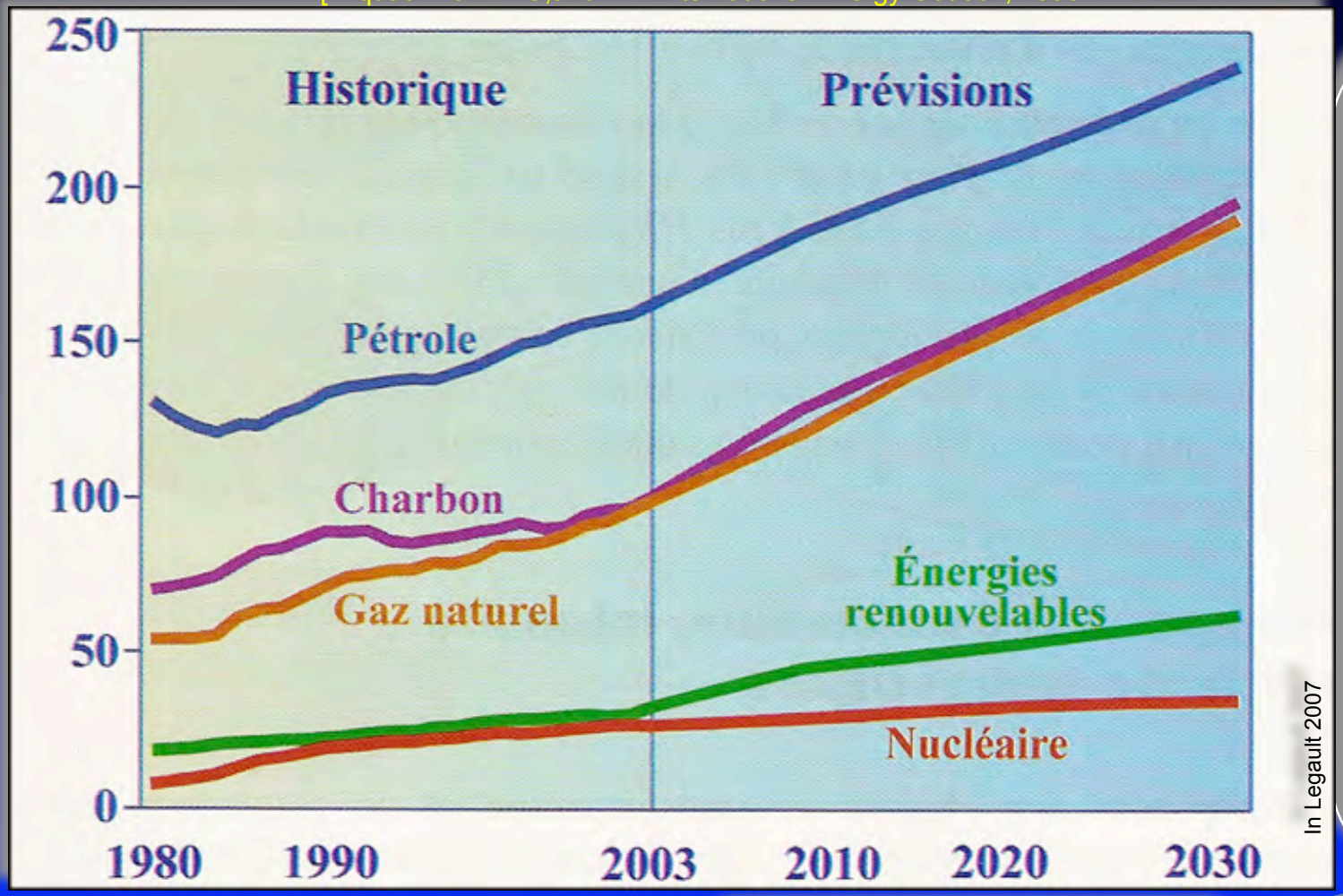
CONCLUSION

The XXIth CENTURY SHOULD SEE THE PEAK THEN THE DECLINE OF THE WORLD OIL PRODUCTION, BUT THE DECLINE WILL BE PROBABLY VERY PROGRESSIVE, SINCE IT WILL BE ACCOMPANIED BY PRICE INCREASES ALLOWING THE EXTRACTION OFNEW RESERVES FRO ALREADY KNOWN RESOURCES

http://www. peakoil.net

WORLD PRIMARY ENERGY CONSUMPTION

[in quadrillion BTU,and EIA International Energy Outlook, 2006l



In Legault 2007

NOW. 2011

1.DELAY INVESTMENT

[Refining....]

2.LONG TERM REQUEST

[Sustained growth of emerging countries, China, India....]

3. INSTABILITY of PRODUCERS

+ 71 %

in

... 2/3 = developing countries

27 years

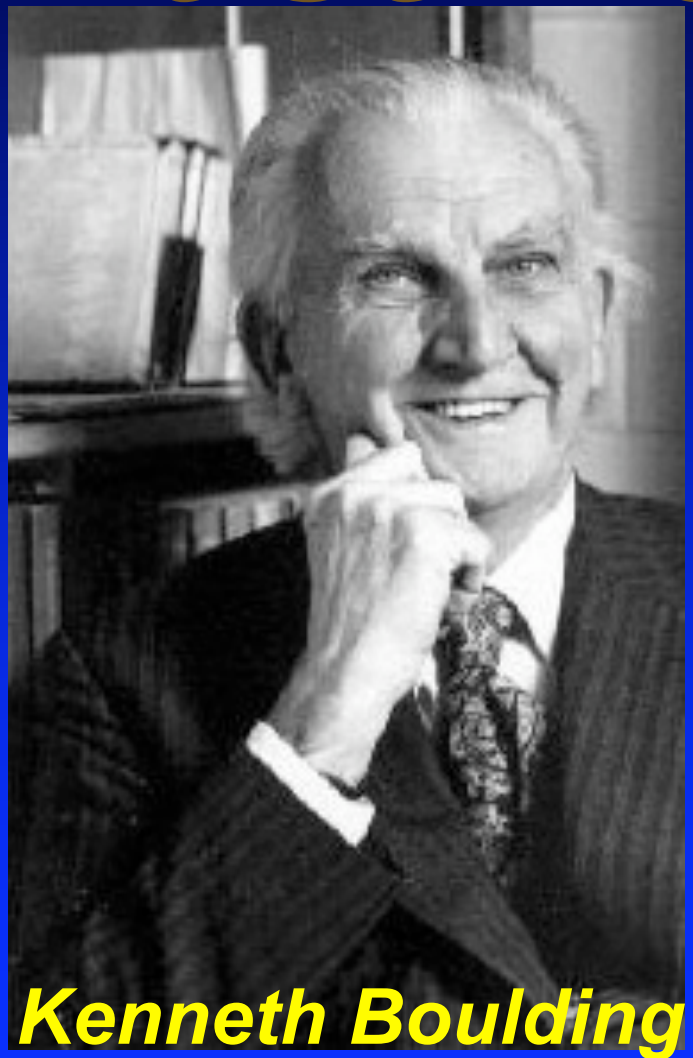
China ... 150 airoports

Malaga... 400/d

24000 planes/24h/2007

i.e.±7 planes/sec

The last word...



Kenneth Boulding

1910-1993

President of the American Economic Association

The last word...

‘Anyone believing that exponential growth can last indefinitely in a finite world is either a madman, or an economist’

Kenneth Boulding

1910-1993

President of the American Economic Association

Also King Hubbert « Our ignorance is not as vast as our failure to use what we know »