<u>Fall Term - 2013</u>

Woodrow Wilson School 585b

Living in a Greenhouse: Technology and Policy

Robert Socolow
Phil Hannam

Week Three, September 25, 2013

Primary energy, especially global oil

“Early Course Feedback”

PRINCETON UNIVERSITY
Woodrow Wilson School of Public and International Affairs

To: Instructors and students of WWS Graduate Courses — via email
From: R. Douglas Arnold
Date: Sept 24, 2013
Subject: Early Course Feedback

For nearly a decade, we have asked students in WWS graduate courses to provide early feedback about how their courses are going. The aim is to give instructors some feedback about what is working well, and what is working not so well, so that they can make midcourse adjustments.

Attached is the form developed by the MPA Program Committee and the Woodrow Wilson Action Committee.

Please fill out this form for each of the WWS Graduate Courses in which you are enrolled and return to 103 Robertson Hall or email to regina@princeton.edu. We will make copies for instructors. The feedback form is due by **Friday, September 27th*.***

This early feedback form is not a substitute for the required end-of-term student course evaluations, which are administered by the Graduate Program Office.

Best wishes for a great semester!
RDA

Any Questions about PS 1 Rosetta Stone?

You found the mass of the atmosphere, M_{atm}, from:

$$M_{atm}*g = P_{atm}*4*\pi*R_E^2,$$

where

P_{atm} = atmospheric pressure at sea level

g = acceleration of gravity (9.8 m/s^2)

R_E = radius of the Earth

What is the correction for mountains?

Re PS 1: The mole and the Rosetta Stone

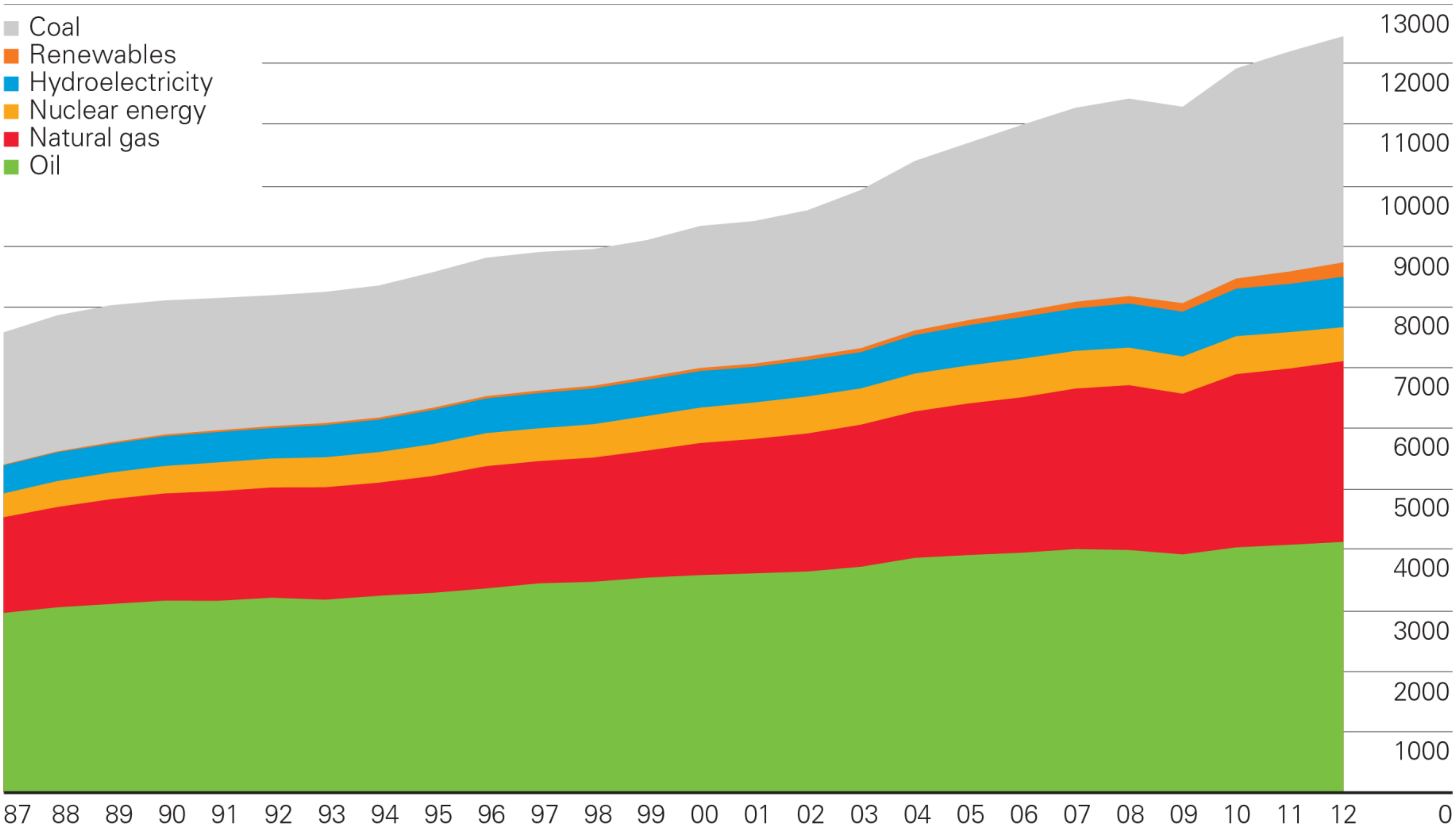
PS1 requires working out how many molecules are in the atmosphere and how many molecules are in a specific quantity of CO_2 (7.8 billion tons, or $7.8*10^{15}$ grams). Instead of counting molecules, one can count *moles,* because a mole is a specific number of molecules. That number is $6*10^{23}$. The word, *mole*, is like the word, *dozen*.

The *mole* links the scale of atoms to the scale of the macroscopic world, measured in grams. The atoms in this problem (C, N, and O) have simple relative weights: 12, 14, and 16, respectively.

a mole of O atoms has a mass of 12 grams;
a mole of N atoms has a mass of 14 grams;
a mole of N_2 molecules has a mass of 28 grams;
a mole of CO_2 molecules has a mass of 44 grams.

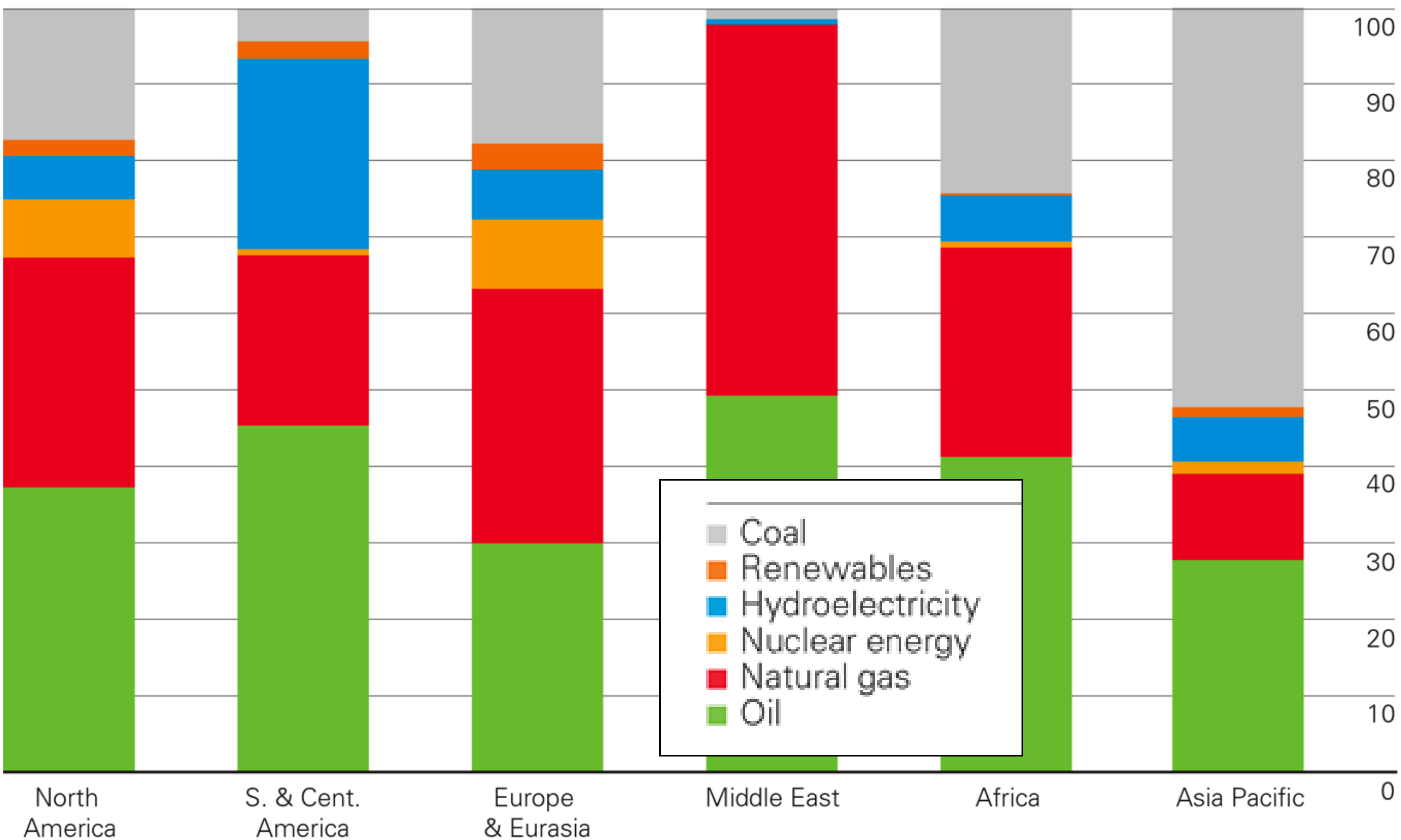
Primary energy world consumption

Million tonnes oil equivalent



BP Statistical Review of World Energy 2012 © BP 2012

Primary energy regional consumption pattern 2012
Percentage



ENERGY UNITS

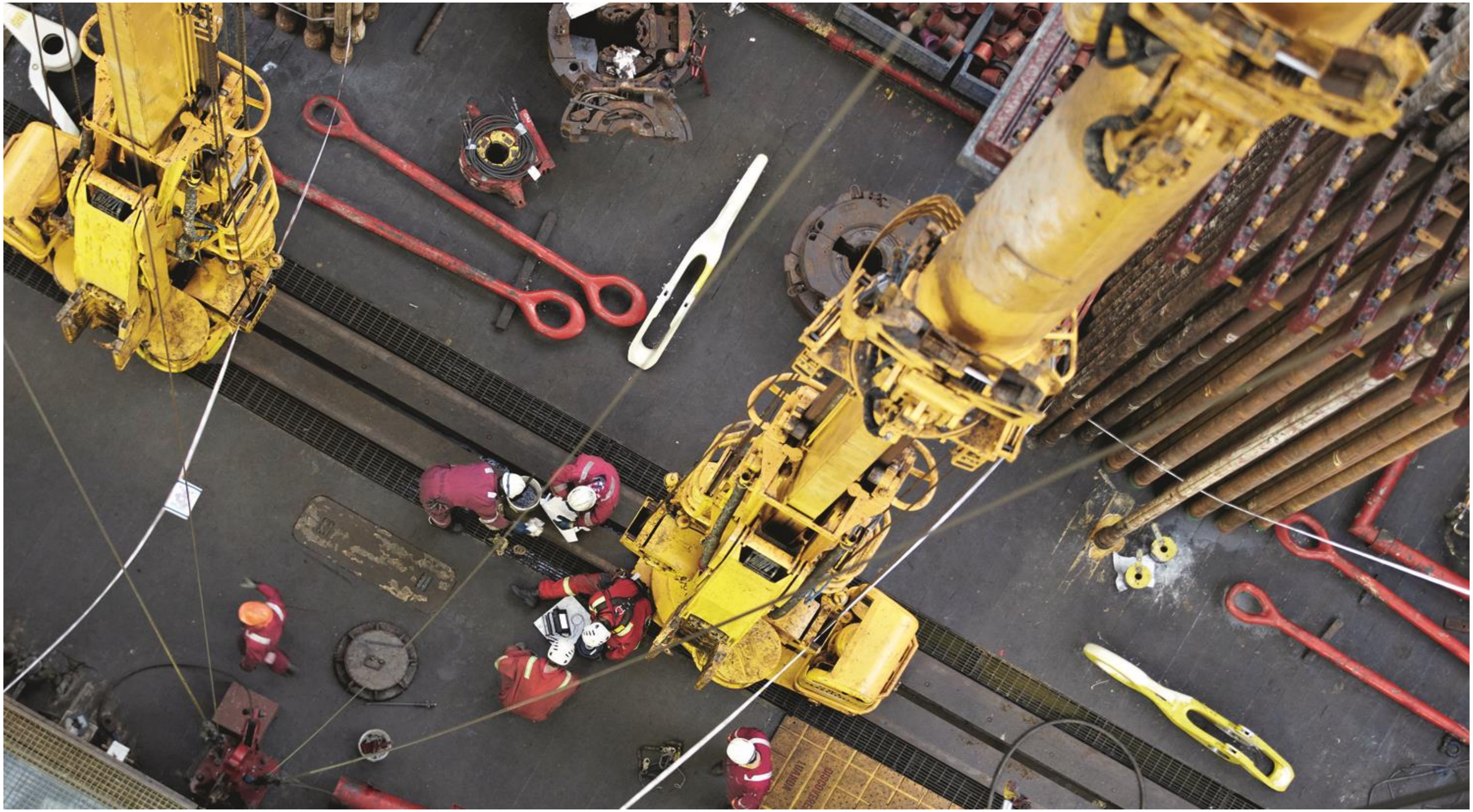
	Work Unit	**Heat Unit**
SI ("science") k = 10^3, M = 10^6, G = 10^9	Joule 1 kWh = 3.6 MJ, because 1 Watt = 1 J/second.	calorie
U.S. ("British")	Foot-pound	Btu = 1055J
Fuel-derived	tce (ton of coal equivalent) = 29.3 GJ toe (ton of oil equivalent) = 41.9 GJ	

Industry also uses volume units: gallons, liters, barrels, cubic feet, cubic meters. E.g., the scfd, pronounced "scuff," a standard cubic foot of natural gas per day.

BP Statistical Review of World Energy
June 2013

bp.com/statisticalreview

Oil



BP Statistical Review of World Energy 2013

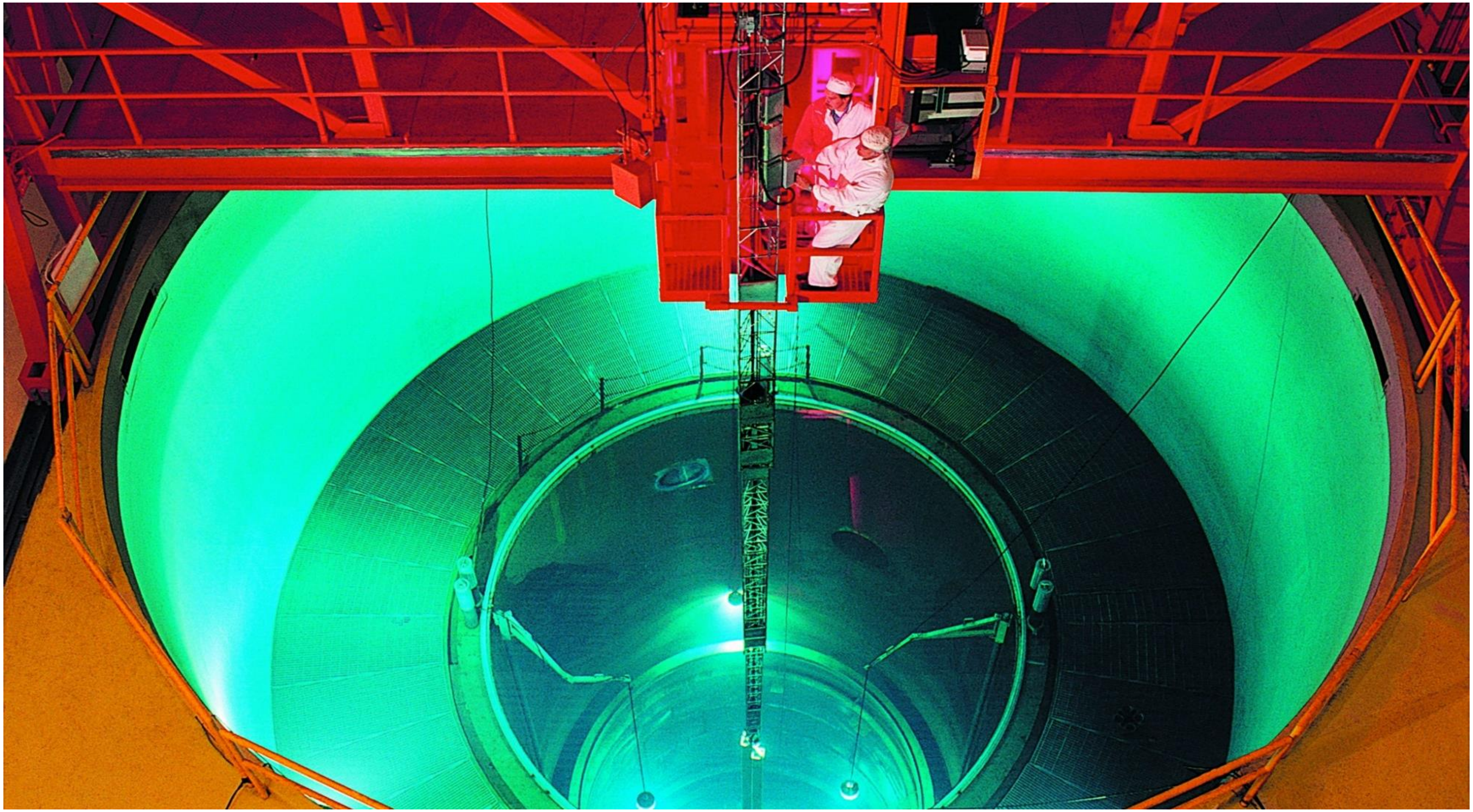
Natural Gas

BP Statistical Review of World Energy 2013

Coal

BP Statistical Review of World Energy 2013

Nuclear Energy



BP Statistical Review of World Energy 2013

Renewable energy

Outline for Lecture 3

A. **Oil in the ground**

B. **The future of oil**

Four World Views

		Are fossil fuels hard to displace?	
		NO	YES
Is climate change an urgent matter?	NO		
	YES		

Four World Views

		Are fossil fuels hard to displace?	
		NO	YES
Is climate change an urgent matter?	NO	A nuclear or renewables world unmotivated by climate.	Most people in the fuel industries and most of the public are here.
	YES	Environmentalists, nuclear advocates are often here.	OUR WORKING ASSUMPTIONS.

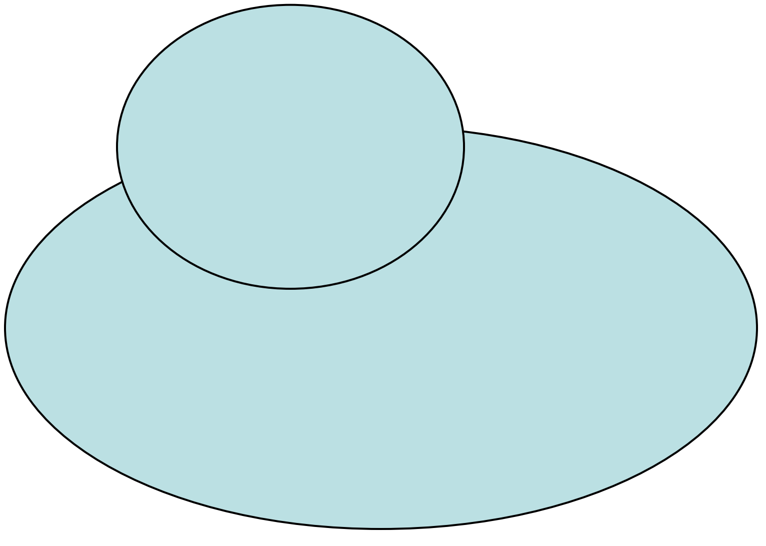
Four World Views

		Are fossil fuels hard to displace?	
		NO	YES
Is climate change an urgent matter?	NO	A nuclear or renewables world unmotivated by climate.	Most people in the fuel industries and most of the public are here. **5ºC.**
	YES	Environmentalists, nuclear advocates are often here. **2ºC.**	OUR WORKING ASSUMPTIONS. **3ºC, tough job.**

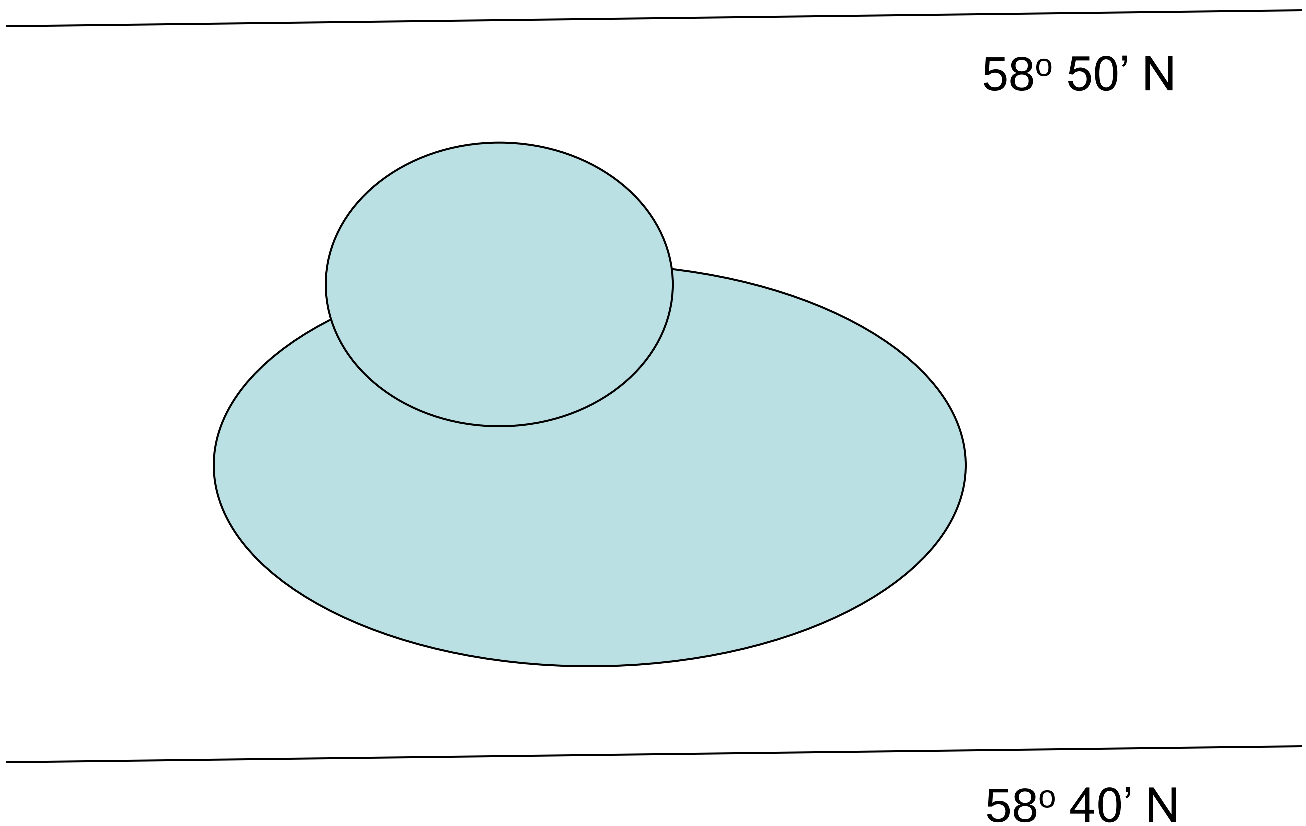
I’m thinking of a blob of hydrocarbons

Ask me yes-or-no questions to find out more about it.

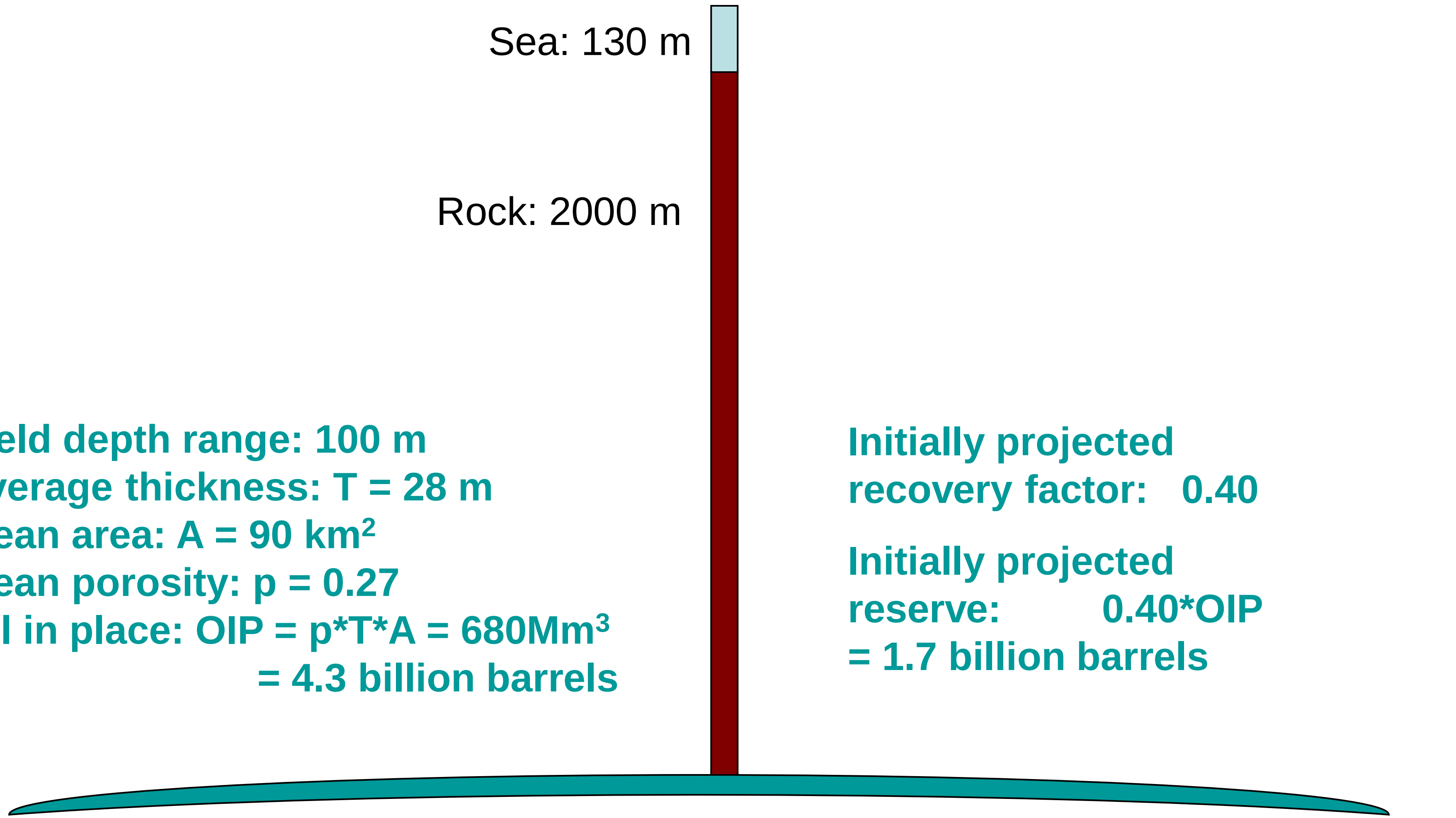
A plan view of the blob



A plan view of the blob



Data about the Forties field

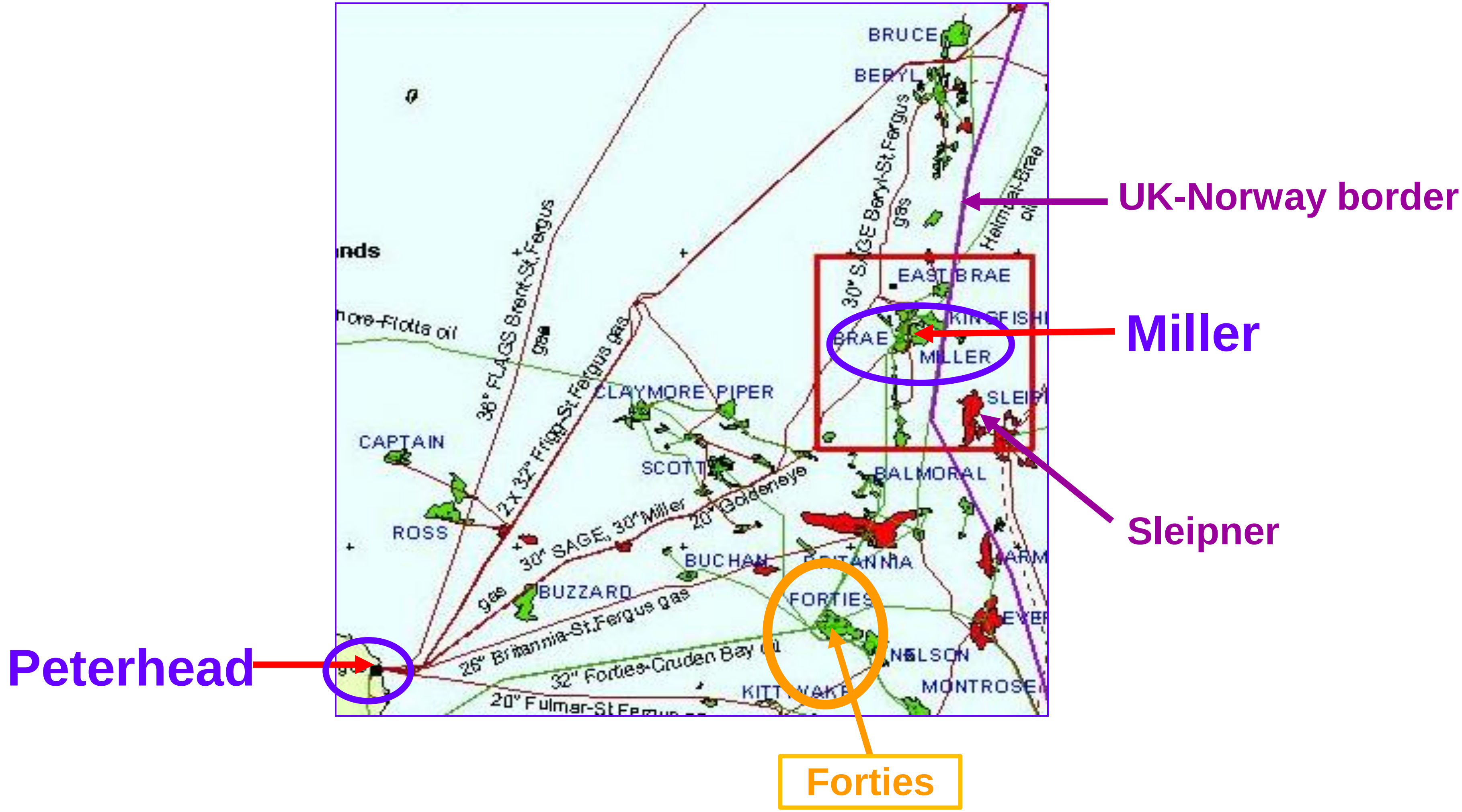


Field depth range: 100 m
Average thickness: T = 28 m
Mean area: A = 90 km^2
Mean porosity: p = 0.27
Oil in place: OIP = p*T*A = 680Mm^3
= 4.3 billion barrels

Initially projected recovery factor: 0.40

Initially projected reserve: 0.40*OIP
= 1.7 billion barrels

Forties and other North Sea fields



Aberdeen, 30 miles south

The Queen launches Forties

ON THIS DAY 3 November BBC NEWS

1975: North Sea oil begins to flow

The Queen has formally begun the operation of the UK's first oil pipeline at a £500,000 ceremony in Scotland.

The 130-mile (209-kilometre) pipeline from Cruden Bay to Grangemouth has been built by British Petroleum (BP).

The pipeline serves the Forties oilfield 110 miles east of Aberdeen, which the company discovered six years ago.

The Queen inaugurated the flow of oil by pushing a gold-plated button in BP's control centre at Dyce near Aberdeen.

She was accompanied by Prince Philip and Prince Andrew.

Prime Minister Harold Wilson also attended with the Scottish Secretary and other senior cabinet colleagues.

The inauguration by Her Majesty and the presence of so many high-ranking politicians in Dyce - a town scarcely on the map a year ago - is seen as testament to the importance being placed on North Sea oil.

'Tartan Army'

The Forties is the largest oilfield so far discovered in the British sector of the North Sea.

It is being mined with the help of a £370m loan from the British government.

Production will start this month at

Watch/Listen

The Tartan Army threatened to disrupt the ceremony

PLAY VIDEO

The BBC's Michael Buerk: "There had been threats to disrupt the ceremony"

In Context

Britain's North Sea oil did not emerge immediately as a key rival to that produced by nations in the Organisation of Petroleum Exporting Countries (Opec).

But output grew as major discoveries continued throughout the 1980s and into the 1990s.

However, the 1997-1998 oil price collapse had negative effects on North Sea production.

Norway, the Netherlands and Germany also extract oil from their portions of the North Sea but on a smaller scale.

After years of declining production and job losses, the industry in Scotland was given a boost in 2001 with the discovery of the Buzzard oilfield near Aberdeen.

It contains an estimated 400 million barrels of oil.

Another smaller find was made in

Stories From 3 Nov

- 2004: George W Bush wins second term
- 1957: Russians launch dog into space
- 1975: North Sea oil begins to flow
- 1964: Election triumph for Lyndon B Johnson
- 1985: Agents plead guilty in Rainbow Warrior trial
- 1997: Angry truckers blockade French ports

Web Links

- North Sea fact sheet

Forties: Subsequent history

Recall above:

> Original estimate of oil in place (OIP): 4.3 billion barrels (newer sources say 4.2)
>
> Originally assumed recovery factor 40%
>
> Original reserve estimate 1.7 billion barrels

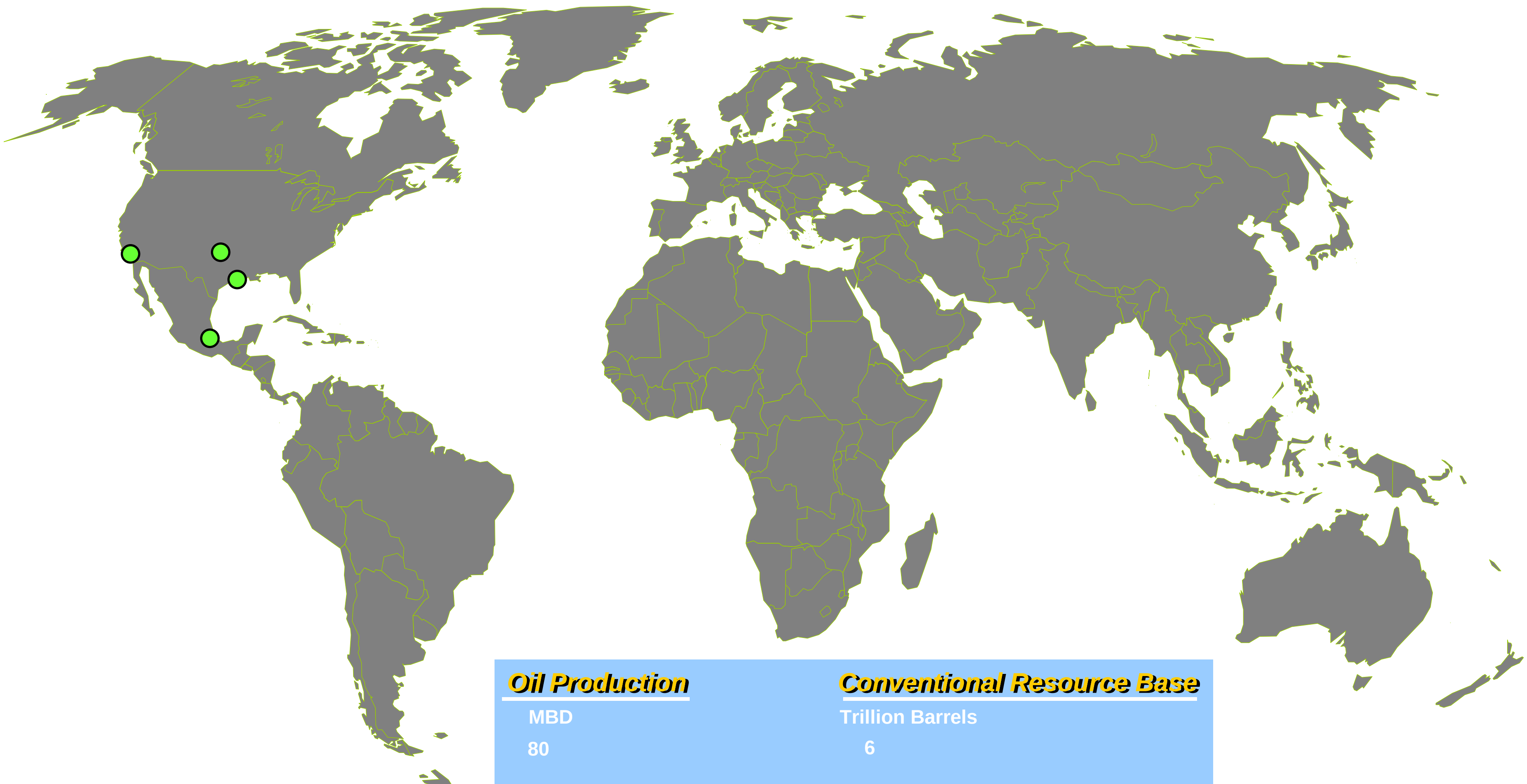
Production started in 1975 and peaked in 1979 at 0.50 mbd. Thereafter, water production rose as oil production fell. Total production to date is 2.6 billion barrels, corresponding to a recovery factor of 2.6/4.2 = 62%.

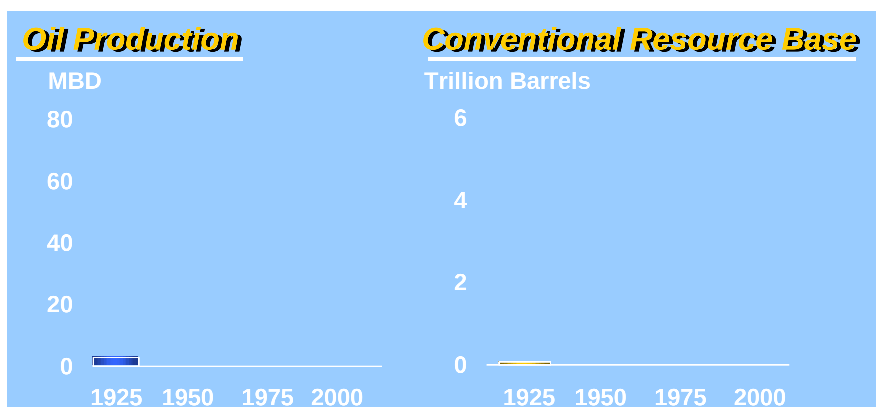
Apache commitments in 2003 to further investment added 0.8 billion barrels to OIP. Its production peaked at 81,300 b/d, double BP's 40,000 b/d production in 2003 and making Forties the third largest producer in the UK North Sea. In 2008, average production was 59,500 b/d (2008 Form 10K). Apache water injection started at 160,000 b/d and may reach 300,000 b/d.

Purchase price $630 M. BP still owns the pipeline to shore.

History

Historical Perspective on Oil Production - 1925



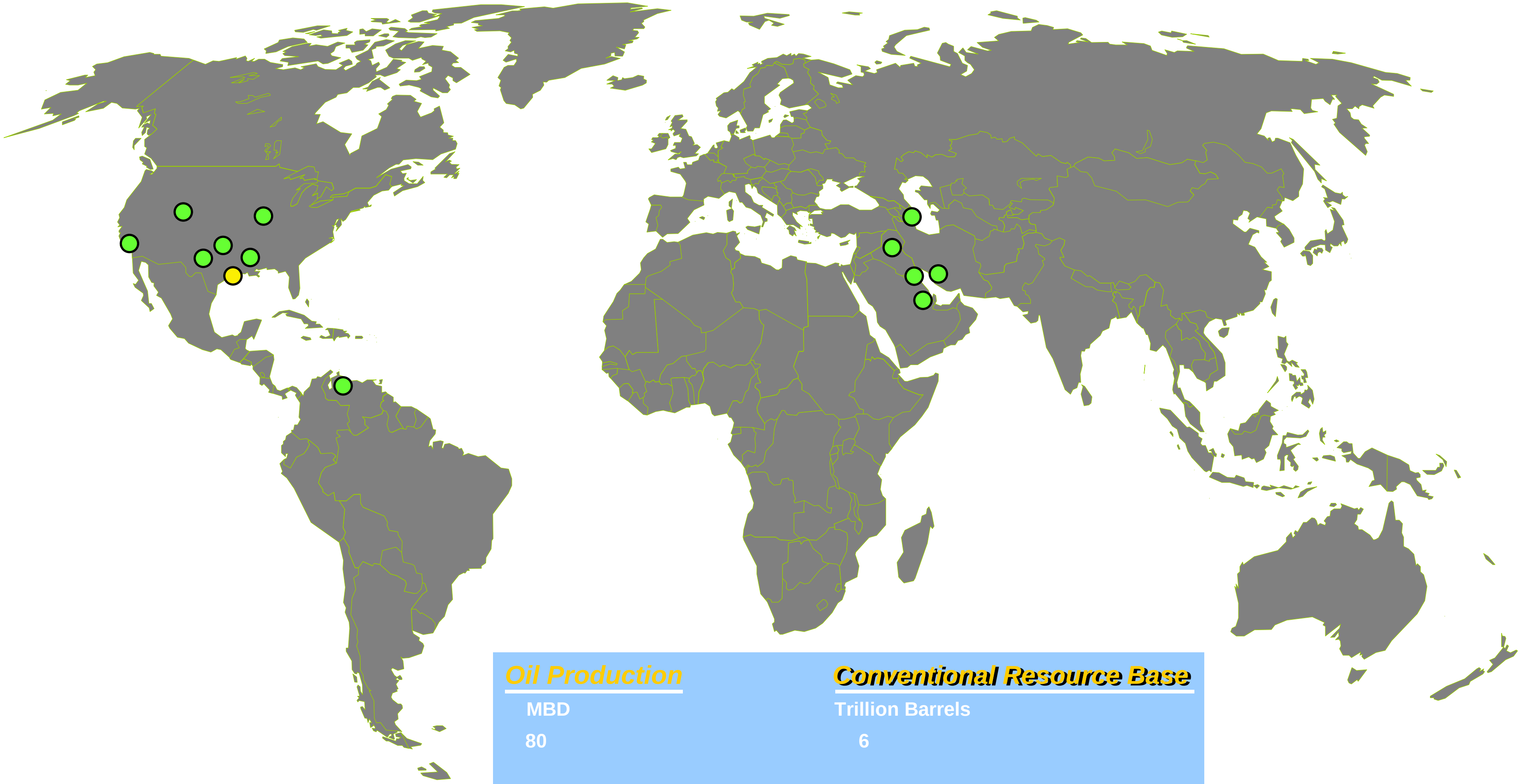


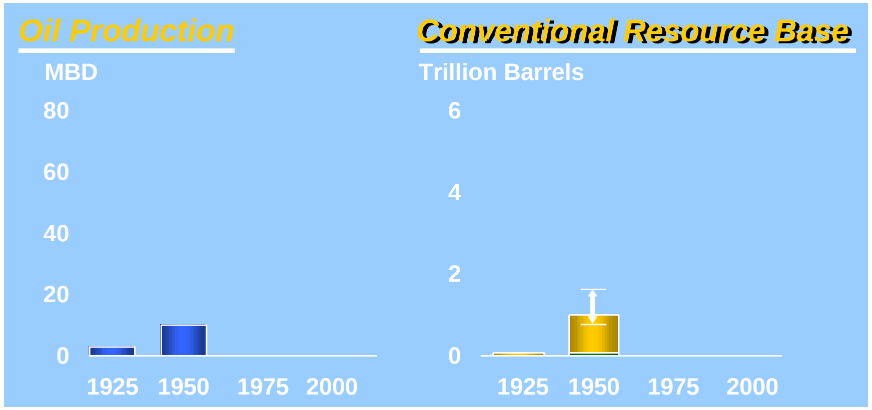
Producing Areas
>250 kBD

- **Land**
- **Offshore**
- **Coastal/Mixed**

Source: Vierbuchen (Exxon), Princeton lecture, fall 2005

Historical Perspective on Oil Production - 1950



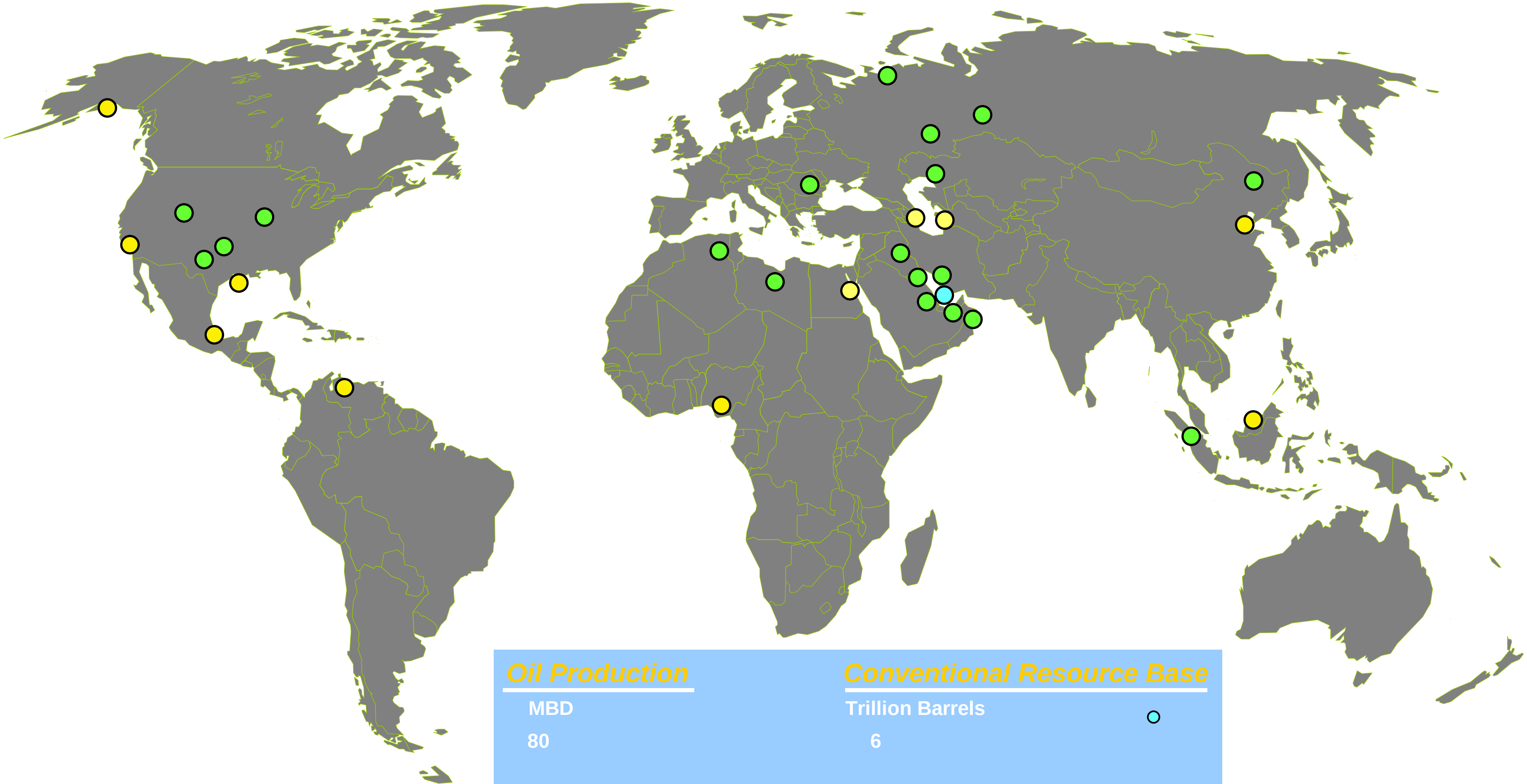


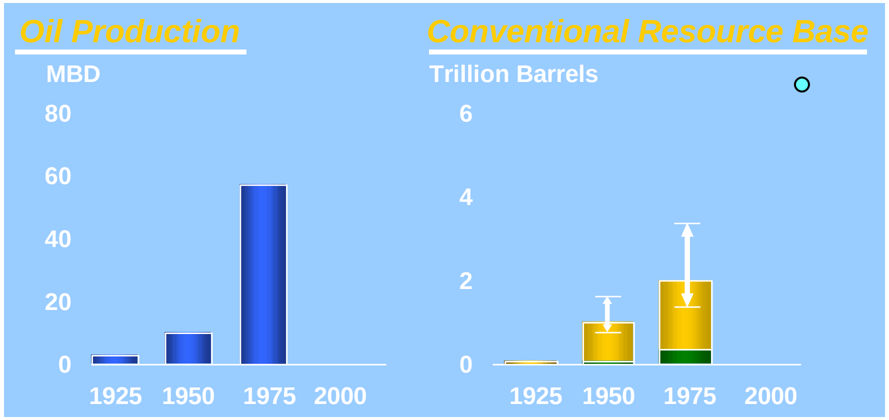
Producing Areas >250 kBD

- Land
- Offshore
- Coastal/Mixed

Source: Vierbuchen (Exxon), Princeton lecture, fall 2005

Historical Perspective on Oil Production - 1975



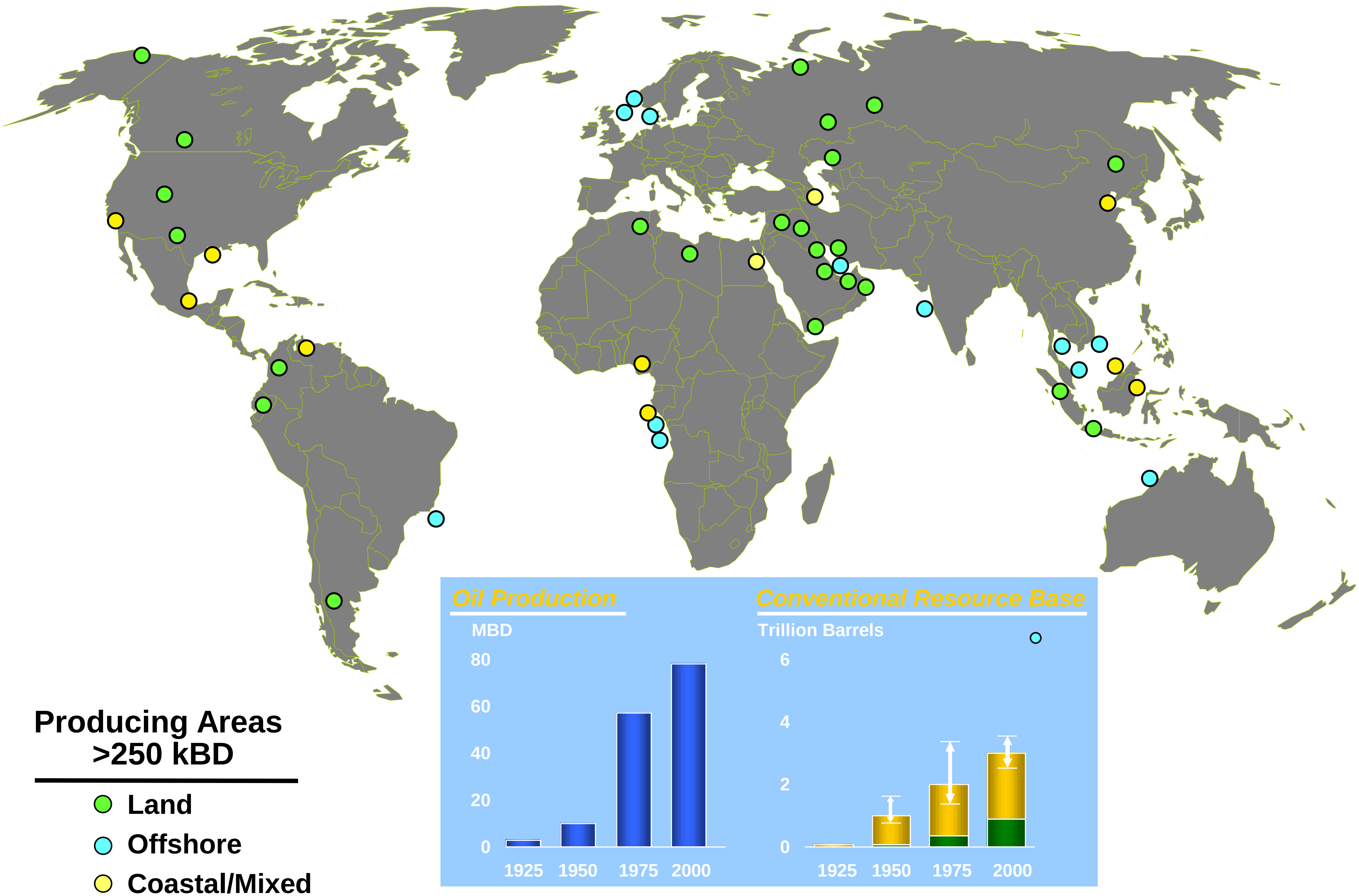


Producing Areas >250 kBD

- **Land**
- **Offshore**
- **Coastal/Mixed**

Source: Vierbuchen (Exxon), Princeton lecture, fall 2005

Historical Perspective on Oil Production - 2000



Source: Vierbuchen (Exxon), Princeton lecture, fall 2005

Reserves 101

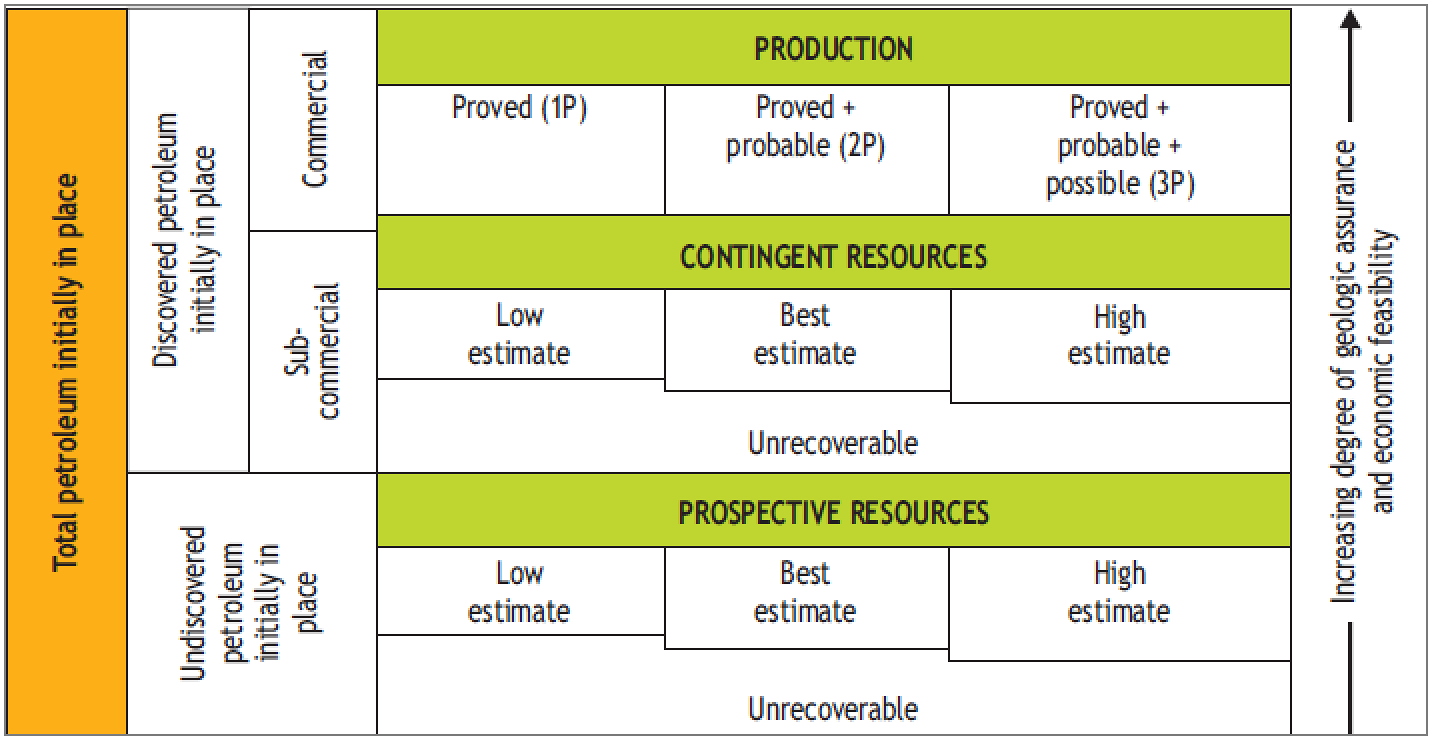
No energy and environment issue is as misunderstood as the concept of *reserves*.

The distinction is made between *resources* and *reserves*.

> *Resources* are a physical measure of stuff.
>
> *Proven reserves* are usually meant when “reserves” is unmodified. Proven reserves are those resources that can be produced competitively at a given time. Accordingly, they depend on assumed prices and commercial technology

Proven reserves grow when resources receive investments (exploration, production capacity), when technology improves, when political factors become more favorable, and when the price of the product rises.

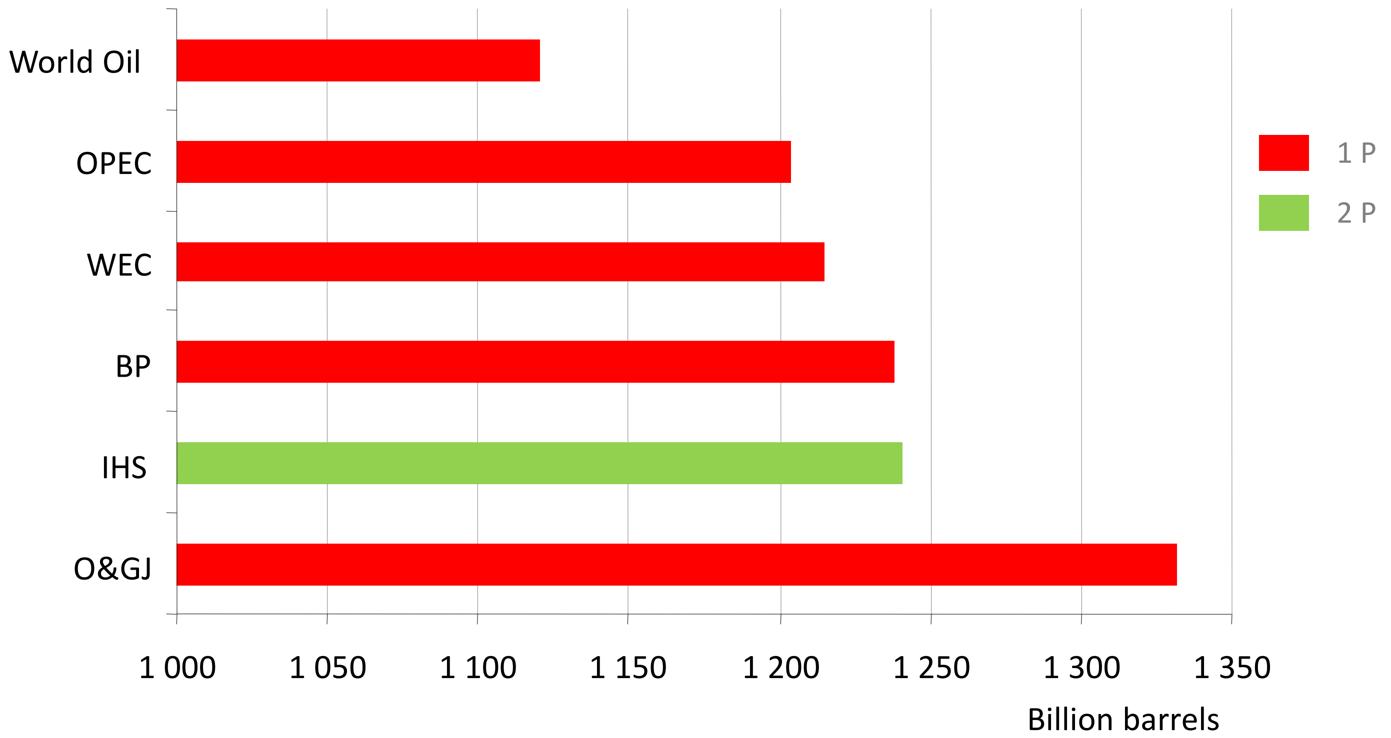
Classifying oil & gas resources



Progress has been made in harmonising definitions, but there is still no international agreed benchmark on how much proof is needed or on assumptions

Source: International Energy Agency, *World Energy Outlook 2008*

World oil reserves:
We used to say: “about one trillion barrels”

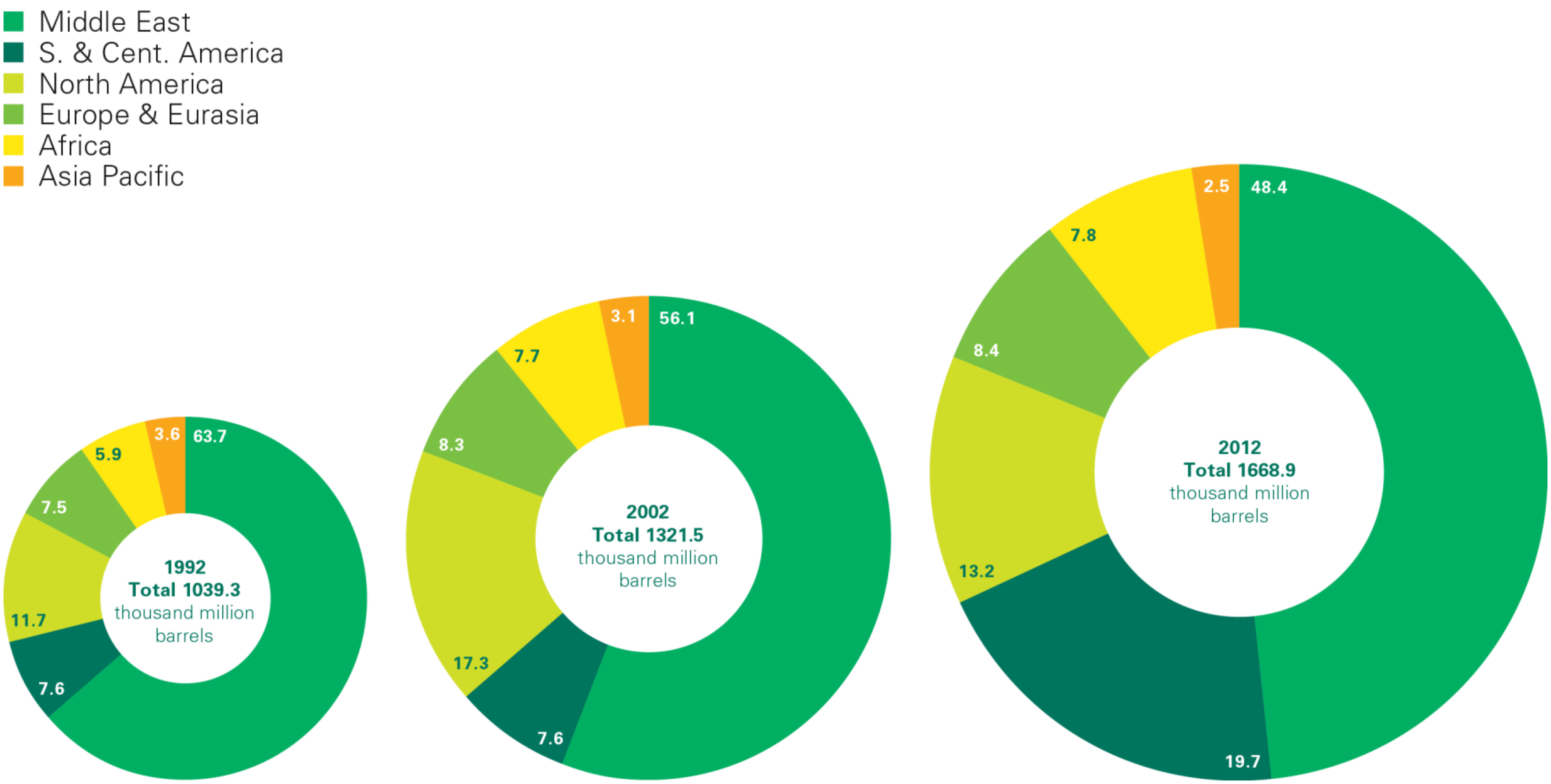


At 1.2 - 1.3 trillion barrels, remaining proven reserves of oil are equal to over 40 years of production at current rates, but uncertainties around these estimates exist

Source*: International Energy Agency, *World Energy Outlook 2008

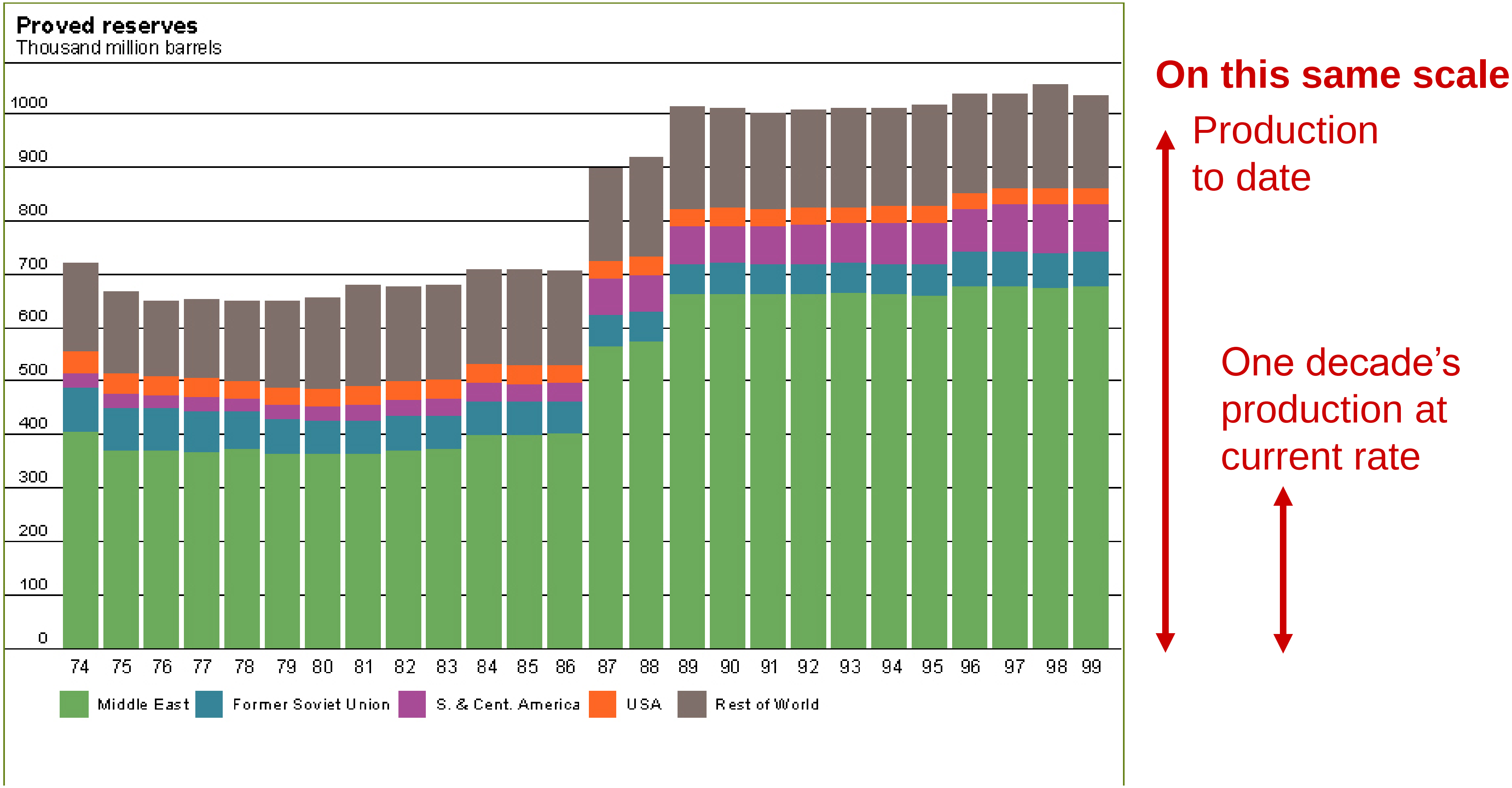
Distribution of proved oil reserves in 1992, 2002 and 2012

Percentage



BP Statistical Review of World Energy 2013

Dominance of Middle East reserves, 1974-99



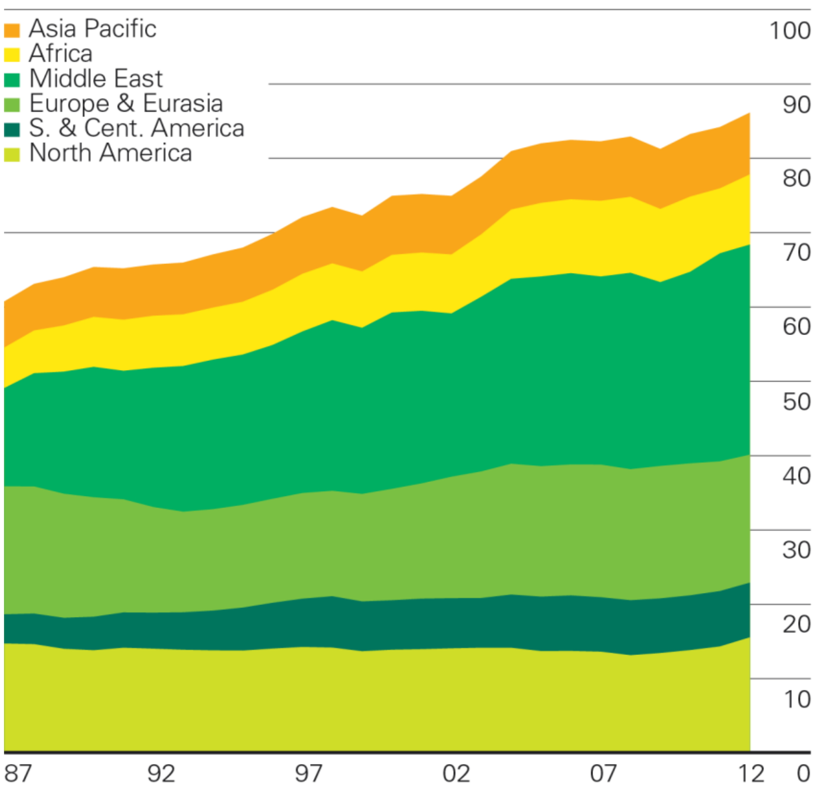
***Source*: BP Amoco Statistical Review of World Energy 2000**

Production

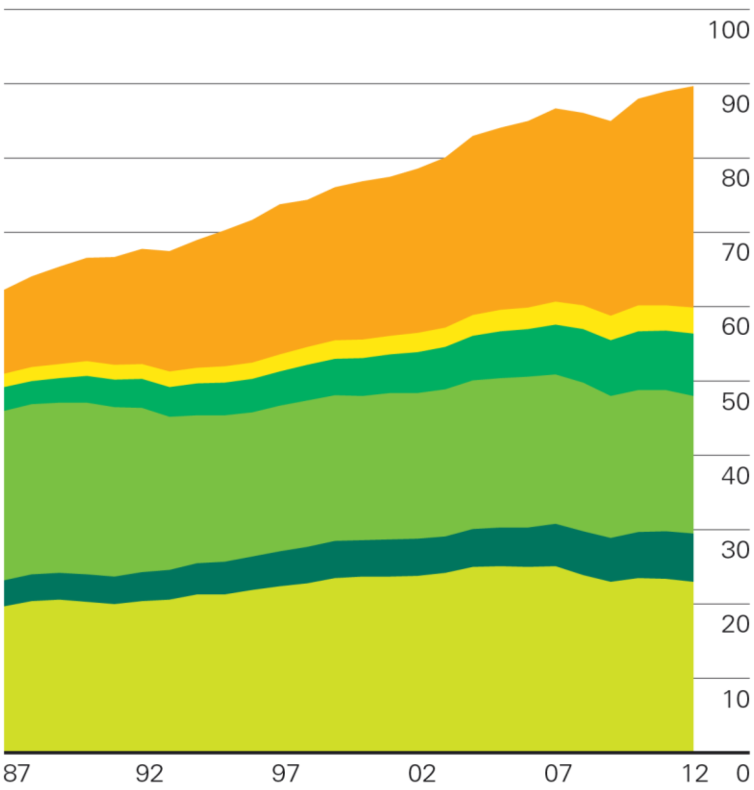
Oil production/consumption by region

Million barrels daily

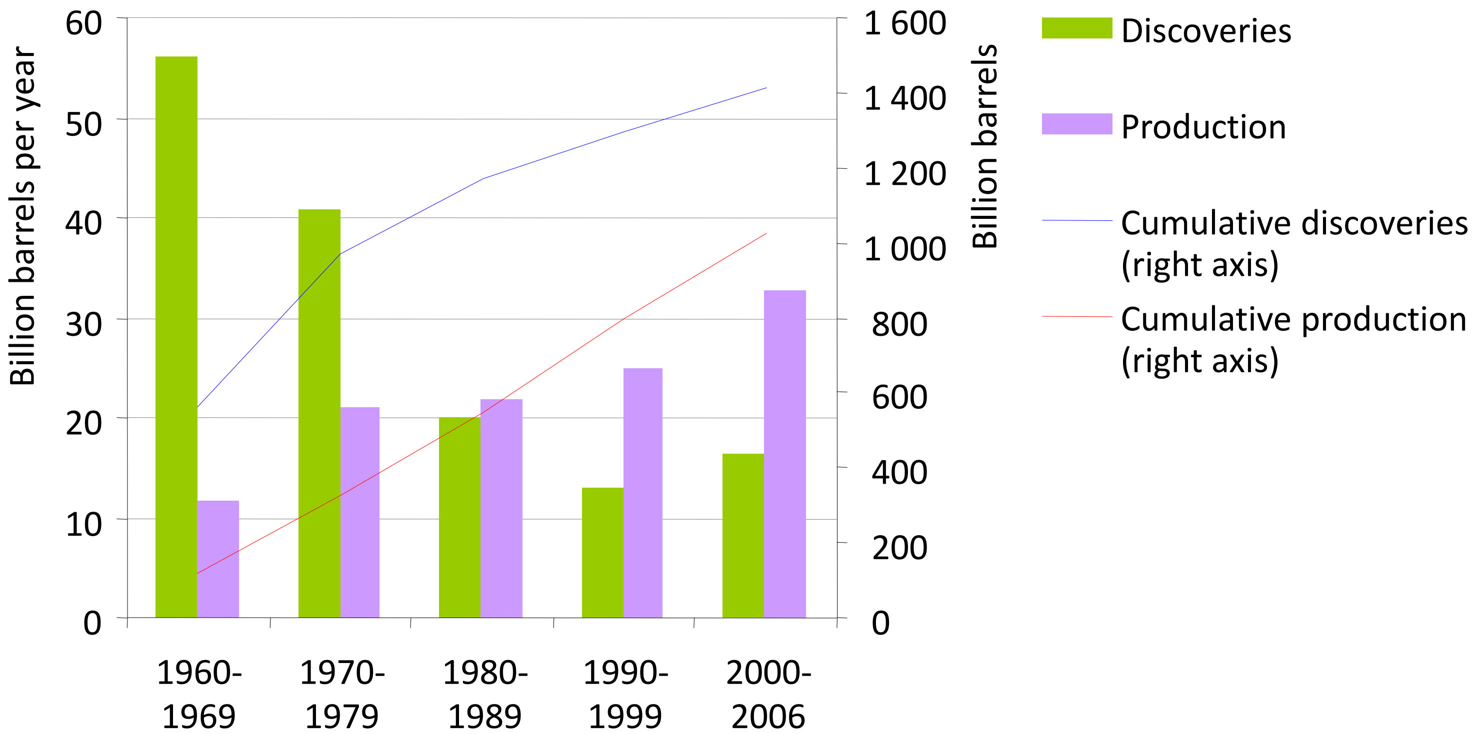
Production by region



Consumption by region



Oil production & discoveries

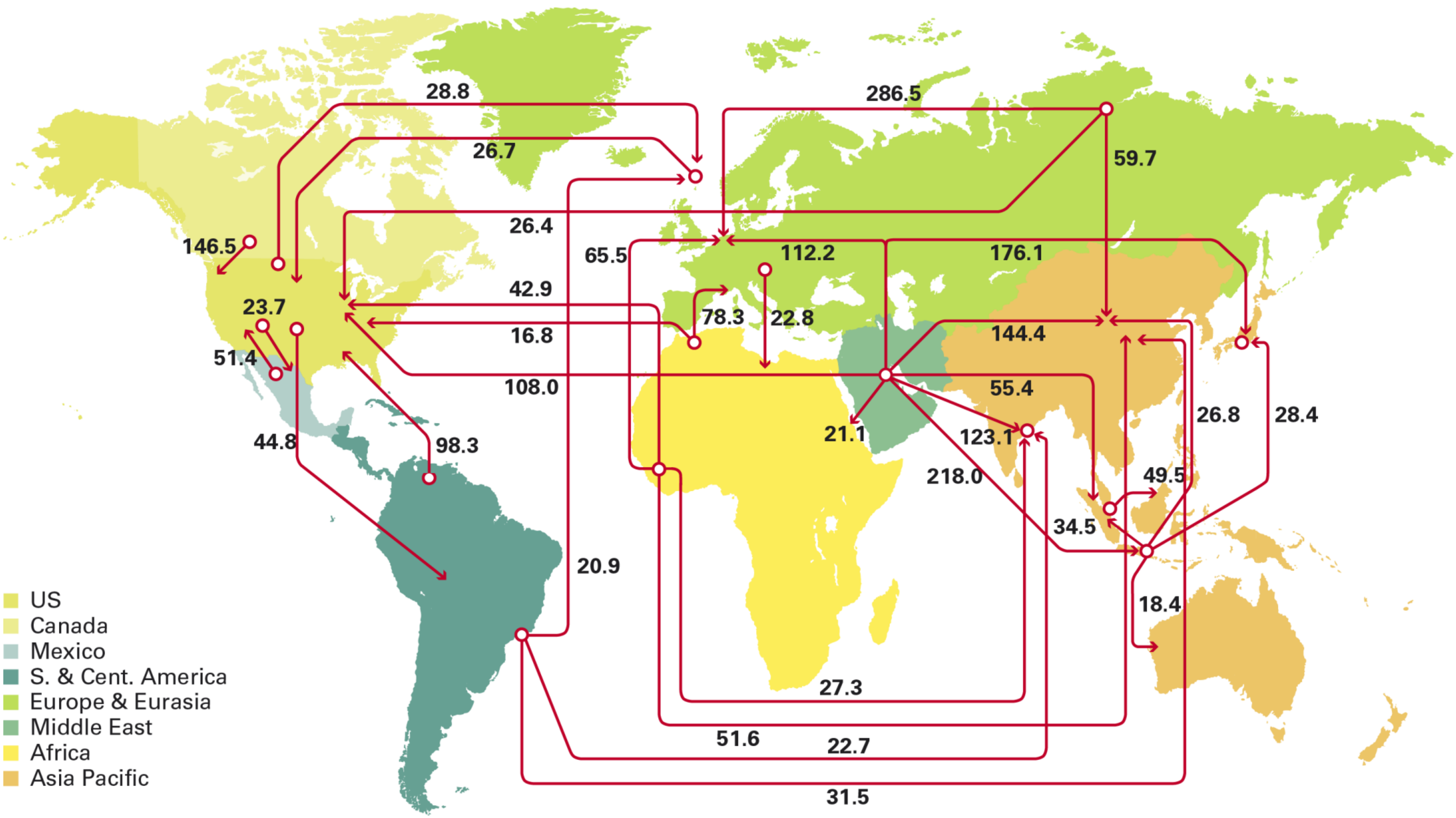


Production continues to outstrip discoveries, with a growing share of reserve additions coming from revisions (reserves growth)

Source*: International Energy Agency, *World Energy Outlook 2008

Major oil trade movements 2012

Trade flows worldwide (million tonnes)

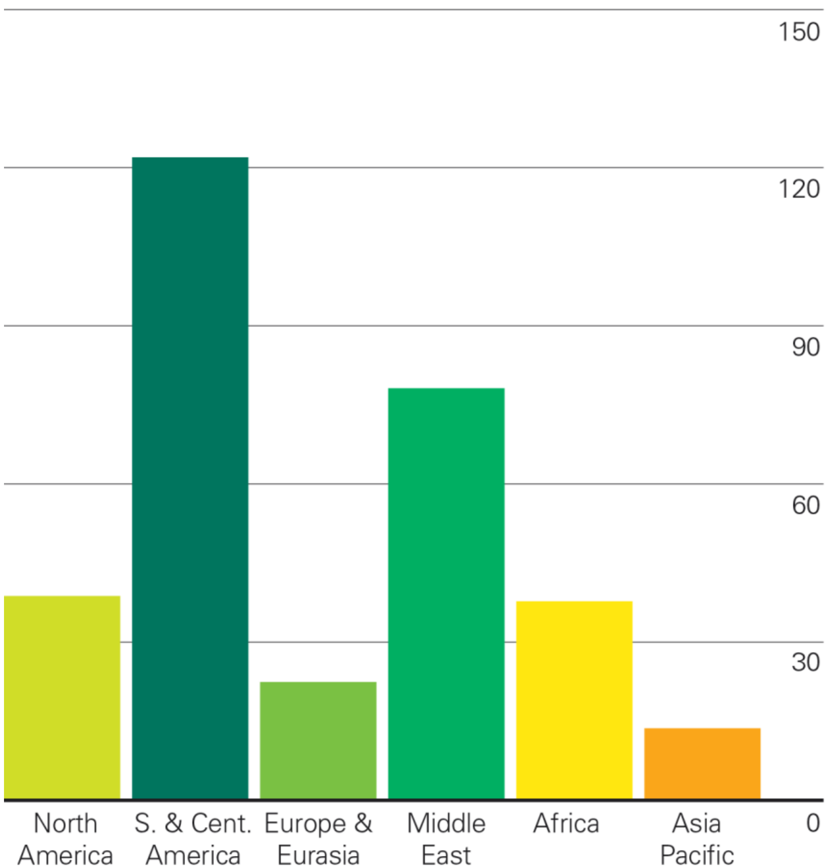


BP Statistical Review of World
Energy 2013

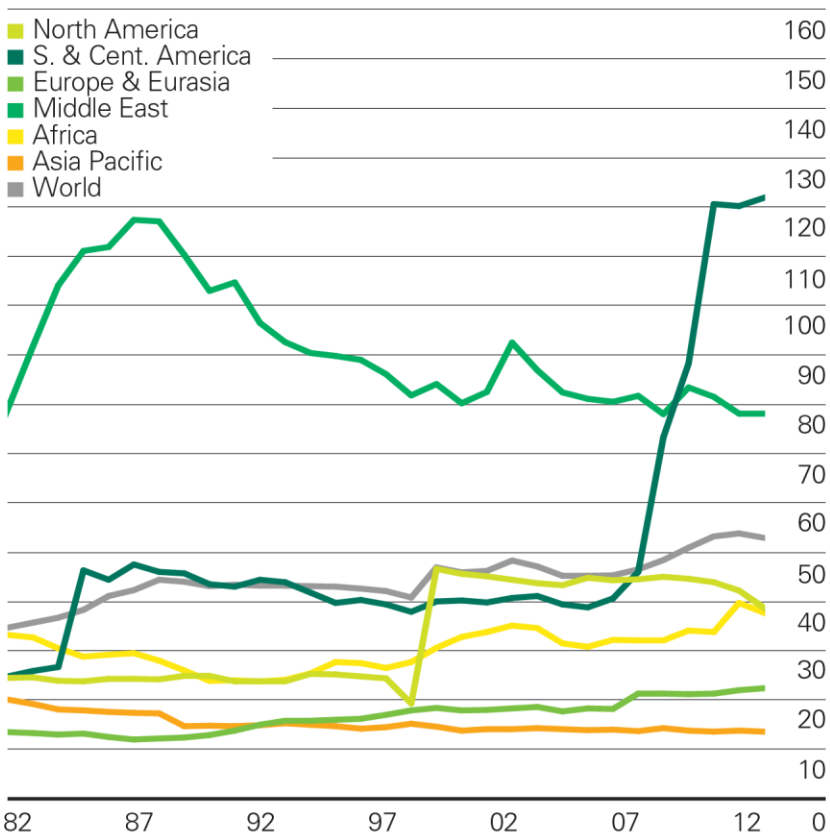
Oil reserves-to-production (R/P) ratios

Years

2012 by region



History



The Trap

Firms and governments report reserves (R). They also report production (P).

R/P is the number of years from now to the time when all current reserves are produced, at the current production rate..

R/P is widely misused as the amount of time until the resource is exhausted.
"We will run out of oil (aluminum, phosphorus) in R/P years."

On the other hand, we really do use up resources when we produce reserves.

BREAK

Required readings for Week 4
The Energy System and its Policies
(1 of 2)

Tester, J.W., Drake, E.M., Driscoll, M.J., Golay, M.W., & Peters, W.A. (Ed.). (2005). *Sustainable energy: choosing among options*. The MIT Press. [Read part of Chapter 1 pp. 1-32, and Chapter 2 pp. 52-83]. *[Introduction to patterns of supply and utilization, differences between power and energy, and efficiency]*

IEA World Energy Outlook 2012. [Chapter 6: Power sector outlook; pp.179-209]

Ziagos, J. & Berry, G. (2006). Visualizing Future CO_2 and Energy Flows for the U.S. & World. Lawrence Livermore National Laboratory. Available: http://gcep.stanford.edu/pdfs/DyUMPHW1jsSmjoZfm2XEqg/1.4-Ziagos.pdf *[This presentation collects several interesting figures, but there is far more available from the Lawrence Livermore Nat'l Labs website: https://flowcharts.llnl.gov/archive.html#energy_archive].*

Required readings for Week 4
The Energy System and its Policies
(2 of 2)

Davis, S. J., Caldeira, K., & Matthews, H. D. (2010). Future CO_2 emissions and climate change from existing energy infrastructure. *Science*, 329(5997), 1330-1333

Nakicenovic, N. (2002). “Technological Change and Diffusion as a Learning Process”. In Grübler, A., Nakićenović, N., & Nordhaus, W. D. (Eds.). (2002). *Technological change and the environment*. RFF Press.
[Theory of technology change, path dependence, and learning-by-doing]

Goldemberg, José. "Leapfrog energy technologies." *Energy Policy* 26.10 (1998): 729-741.

Peters et al. *"Growth in emission transfers via international trade from 1990 to 2008." PNAS 108.21 (2011): 8903-8908.*

Recommended readings for Week 4 The Energy System and its Policies

Grübler, A., Nakićenović, N., & Victor, D. G. (1999). Dynamics of energy technologies and global change. *Energy Policy*, *27*(5), 247-280. *[For those interested in economic modeling of technology change in the energy sector]*

Jakob & Marschinski (2012). Interpreting trade-related CO_2 emission transfers. *Nature Climate Change, 3(1), 19-23.* *[References here will allow you to pursue consumption-based accounting and traded emissions.]*

Reminder: Lovins, this Friday

What: Reinventing Fire: The Business-Led Transition Beyond Fossil Fuels talk by Amory B. Lovins

When: Friday, September 27, 2013 10:30am - 11:30am

Where: Robertson Hall Bowl 016

Upcoming deadlines

Tues. October 1 at midnight: First short paper. Think 1500-3000 words. (In Lecture 1 I said 2000-3000 words.)

Mon. Oct 7, 7-10 pm. Lecture 4

Tues. October 8 at midnight: "First interim statement" about the term paper. Think 500 – 1000 words.

Wed. October 9, 1-4 pm. Lecture 5.

Wed. October 16:

1 pm: Second problem set

1-4 pm: Lecture 6. James Hansen, guest, 3-4 pm

Mon. October 21: 7-10 pm Lecture 7

What makes a good paper?

Each short paper should be sharply focused on a single issue. The term paper can be more ambitious.

All papers should be interesting, focused, imaginative, partially quantitative, and coherent. They should be well written, well argued, and well presented.

An unusual requirement is that each paper should display some quantitative reasoning. For example, this can be a sample calculation that verifies a statement that you have read. You should show an interest in numbers.

It is fine to build on some comparative advantage; for example, you could choose a topic related to something you have done before or involving a country or town that you know.

You are encouraged to discuss all papers with Phil and me electronically, but only well ahead of the deadlines. Experience suggests that we will lead you to people in the Princeton community who may be helpful.

No matter what your topic, you will encounter sales pitches, masquerading as impartial analysis. Learning to deal with biased information is one of the aims of this course.

“First interim statement” about the term paper

The purpose of this interim statement is to start you thinking about a topic and to have Phil and me react to your proposal as early in the term as possible. Phil and I may be able to help you find subtopics within your stated areas of interest and a specific interesting individual or interesting project related to that subtopic.

The target length is 500 to 1000 words. Tell us enough about yourself, your interests, and (perhaps) your past experiences so that we can understand why you have chosen this particular topic. Your statement should demonstrate that you have done some preliminary investigating. It can include a short preliminary bibliography. It can suggest particular people you want to interact with.

A good paper will burrow into a subject, rather than hovering above it. But specificity comes in stages. It is fine not yet to have identified a specific area.

A good paper will demonstrate that you are pushing yourself to do simple calculations and to understanding societal implications.

Your choice of topic is absolutely not binding. Many students will change their topic. It is also fine to present two options, as long you have thought at least a little about each.

2012 Problem Set #2: Energy and carbon accounting

Due Oct 16 at start of class

Estimate the energy expenditure and CO_2 emissions that permit you to carry on some of the activities in your life over a few consecutive days. Equivalently, create an energy diary.

Convey your reasoning as thoughtfully as you can. Presenting fewer areas of consumption thoughtfully (and indicating which others you have omitted) is better than presenting more areas of consumption in a slapdash fashion.

It is OK to work in small groups, as long as you indicate who did what and there are no free-riders.

Outline for Lecture 3

A. **Oil in the ground**

B. **The future of oil**

Additions to reserves of oil

Decline rates at existing fields

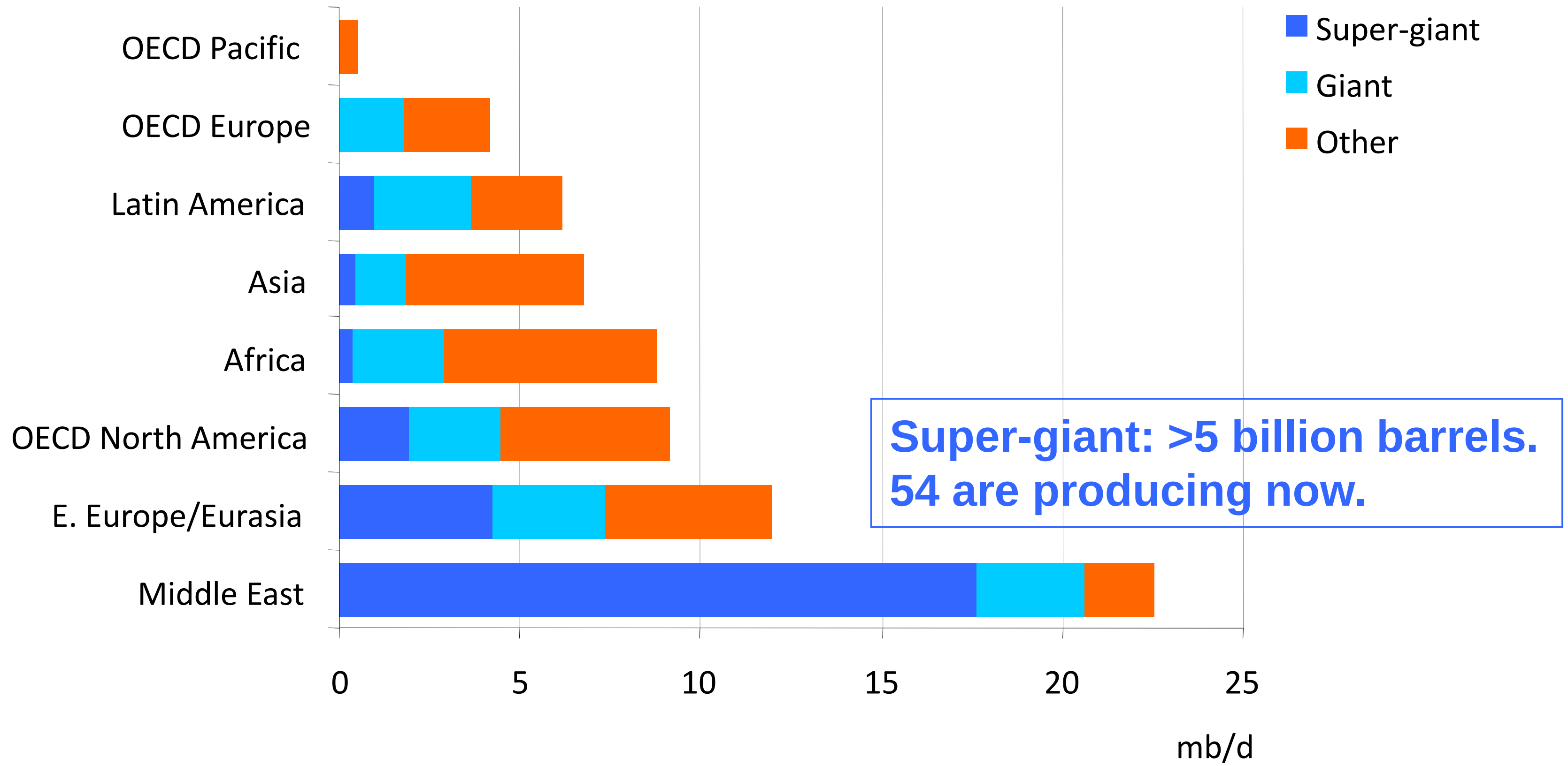
Enhanced oil recovery at old fields

New conventional fields

Non-conventional resources

OPEC/Non-OPEC

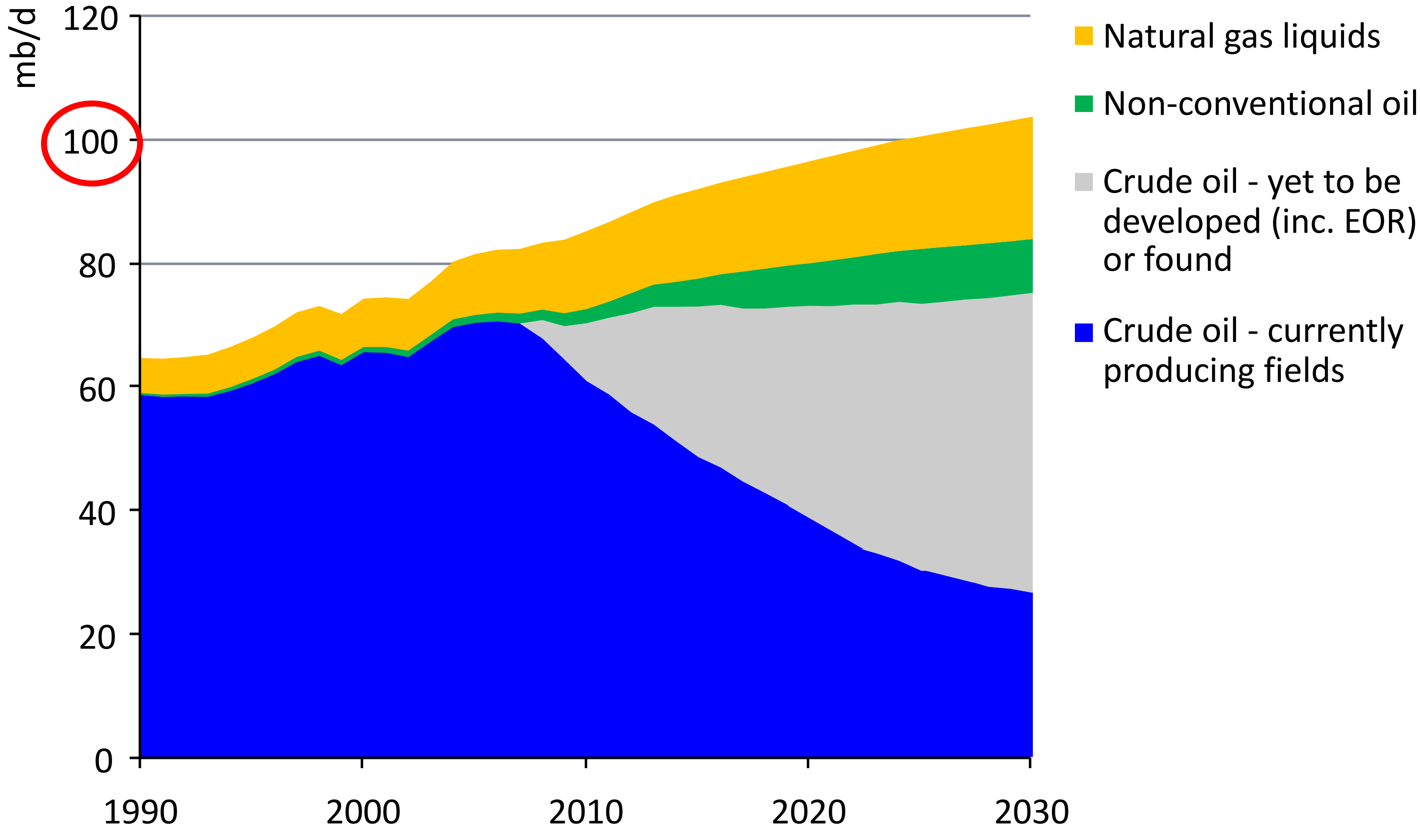
Crude oil production by field size & region



Big fields – mostly located onshore – dominate production in the Middle East, Russia & the Caspian

Source: International Energy Agency, *World Energy Outlook 2008*

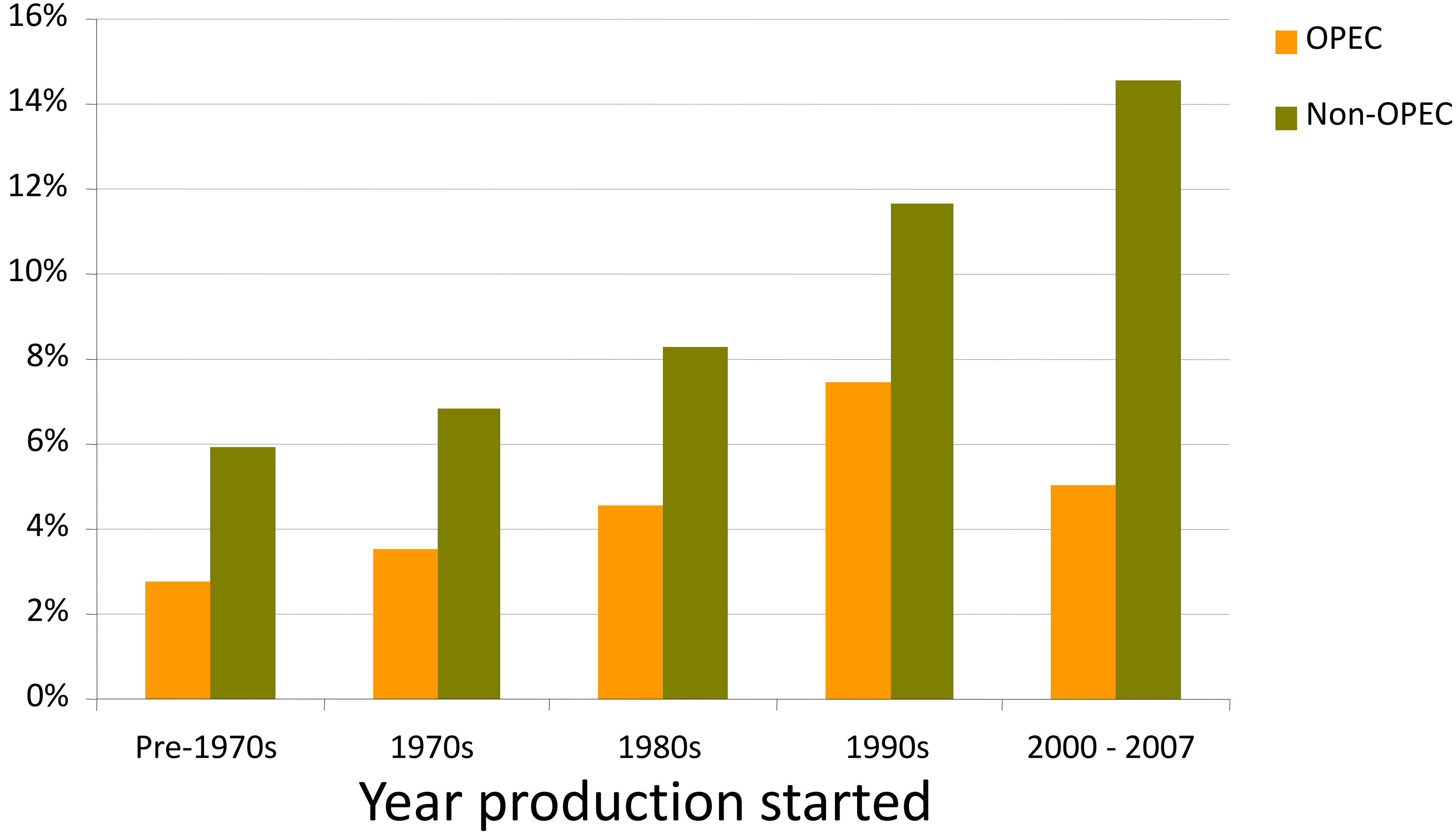
World oil production by source in the WEO 2008 Reference Scenario



Even if oil demand was to remain flat to 2030, 45 mb/d of gross capacity – roughly four times the capacity of Saudi Arabia – would be needed just to offset decline from existing oilfields

Source: International Energy Agency, *World Energy Outlook* ***2008***

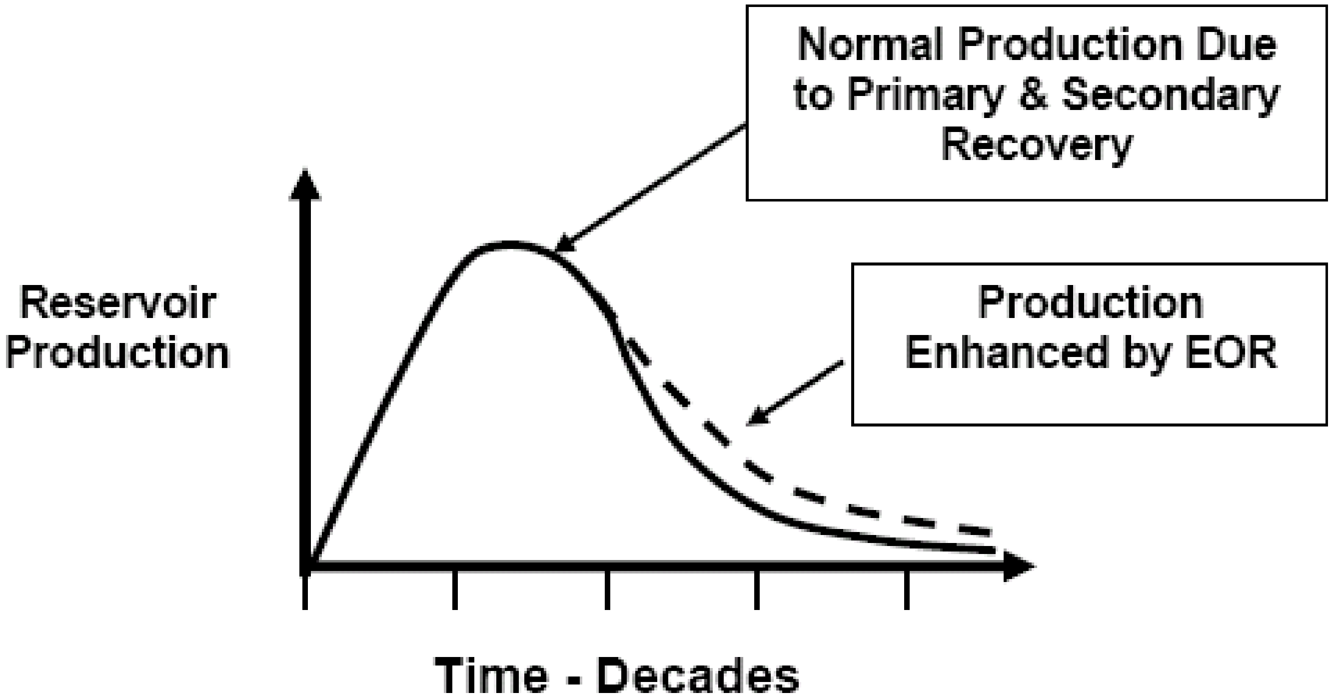
Average observed oilfield decline rates



The production-weighted average decline rate worldwide is projected to rise from 6.7%/yr in 2007 to 8.6%/yr in 2030 as productions shifts to smaller oilfields, which tend to decline faster

***Source*: International Energy Agency, *World Energy Outlook* 2008**

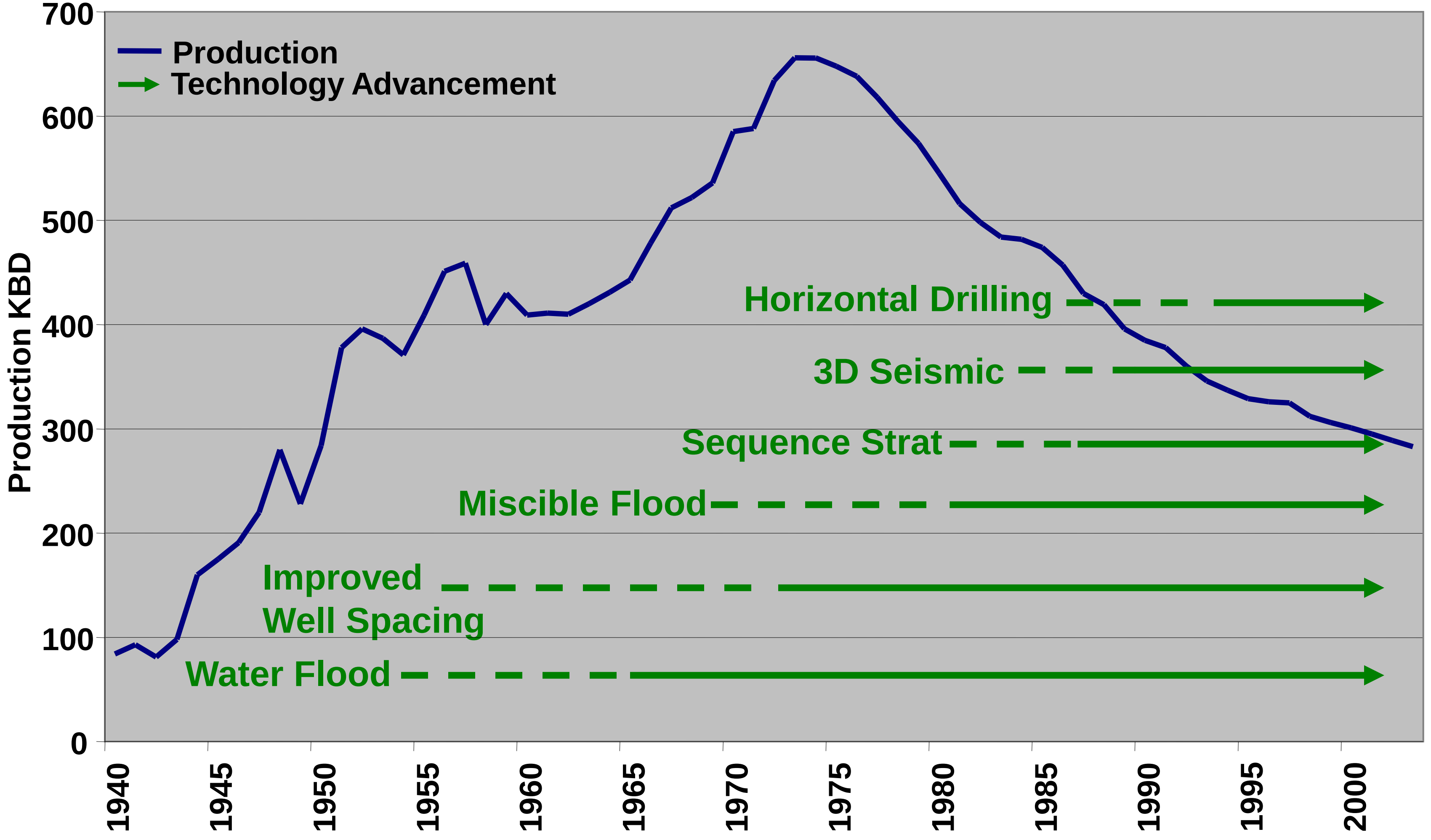
Enhanced Oil Recovery



To be discussed in detail in Lecture 9.

Source: Hirsch, et. al, 2006. *Peaking of World Oil Production*, Fig VI-1

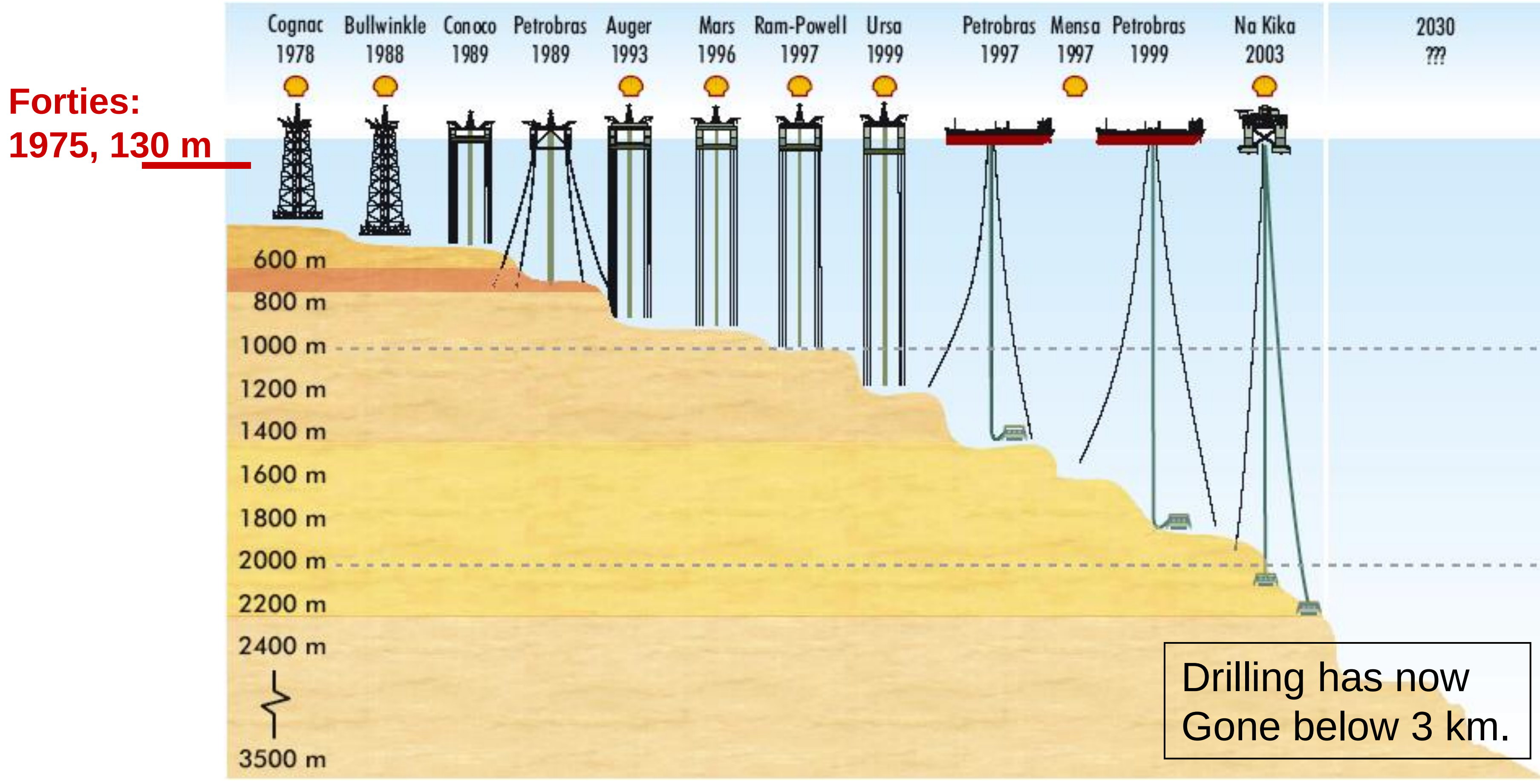
Permian Basin - Technology Application



Source: Vierbuchen (Exxon), talk at Princeton, fall 2005

Observation: non-conventional resources become conventional resources and then proven reserves

Evolution of Deepwater Technology

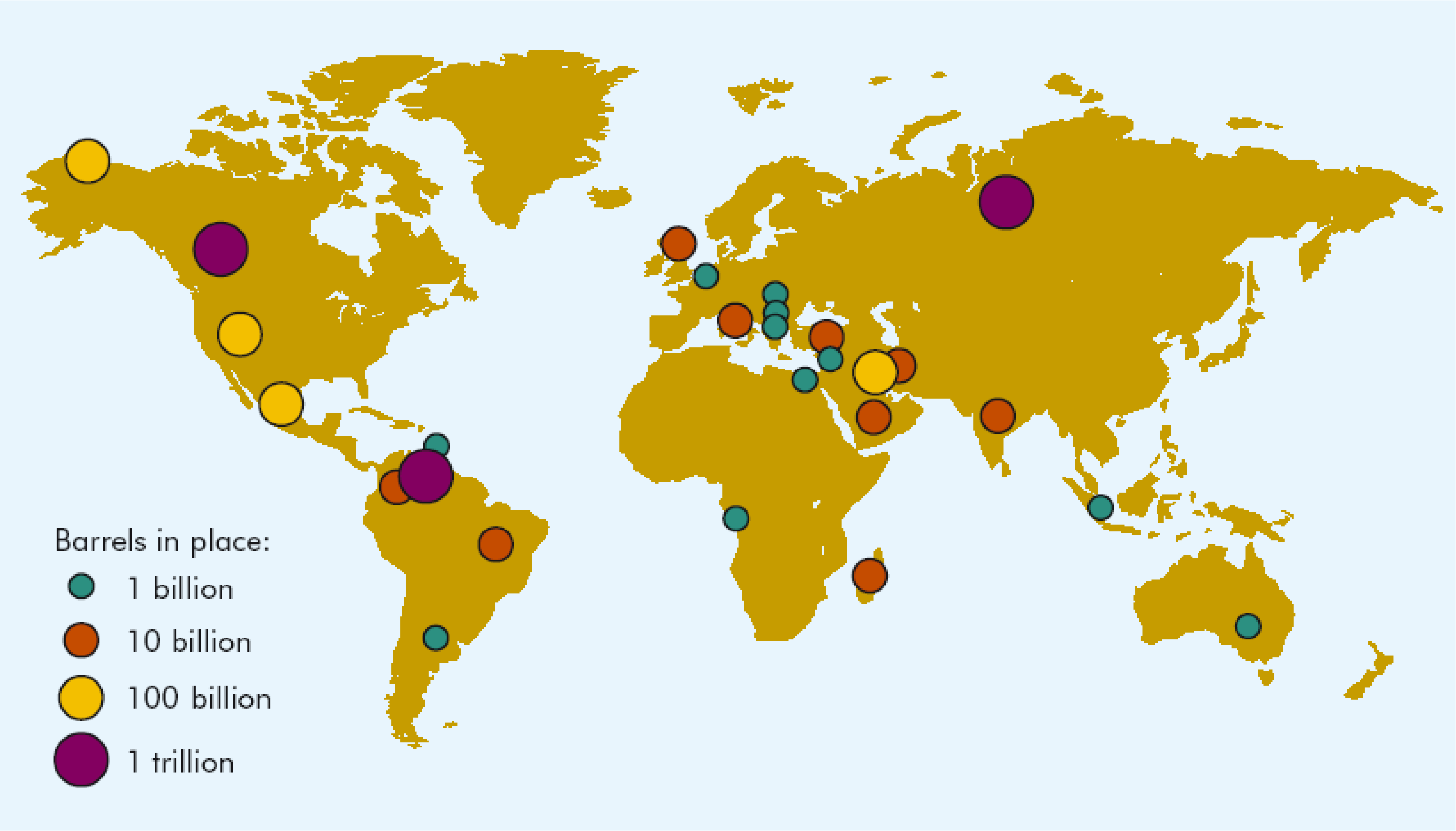


Reproduced in *Resources to Reserves* courtesy of Shell

Source: Antonio Pflueger (IEA), talk at Princeton, fall 2005

A World That Could Long Remain Dominated by Fossil Fuels: The Alberta Tar Sands

Heavy Oil Resources in the World

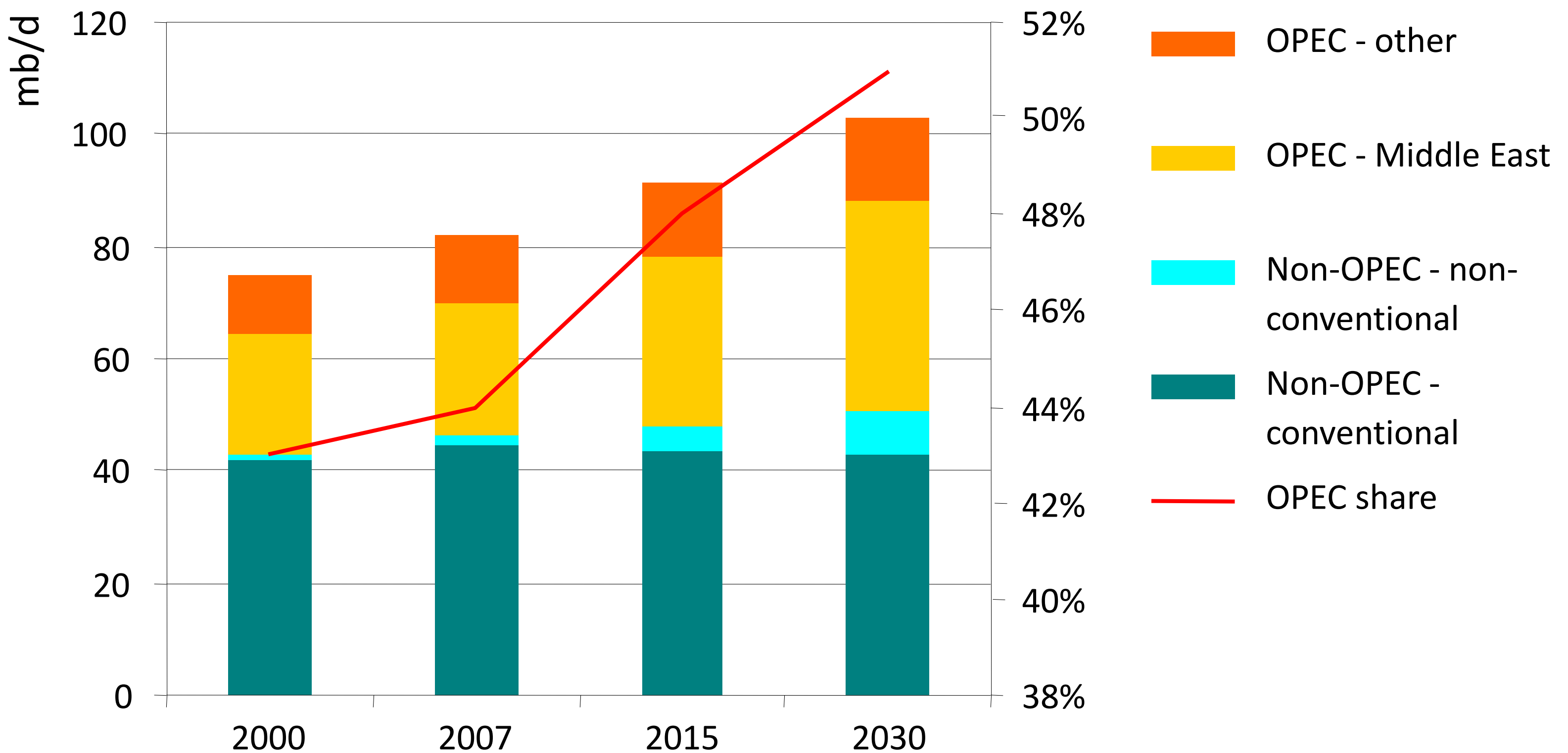


Reproduced in Resources to Reserves *with kind permission from the Energy Institute, originally published in* Modern Petroleum Technology *(**www.energyinstpubs.org.uk**), with thanks also to Maurice Dusseault, University of Waterloo, Canada, for pointing out this figure.*

Source: Vierbuchen (Exxon), talk at Princeton, fall 2005

OPEC and Non-OPEC

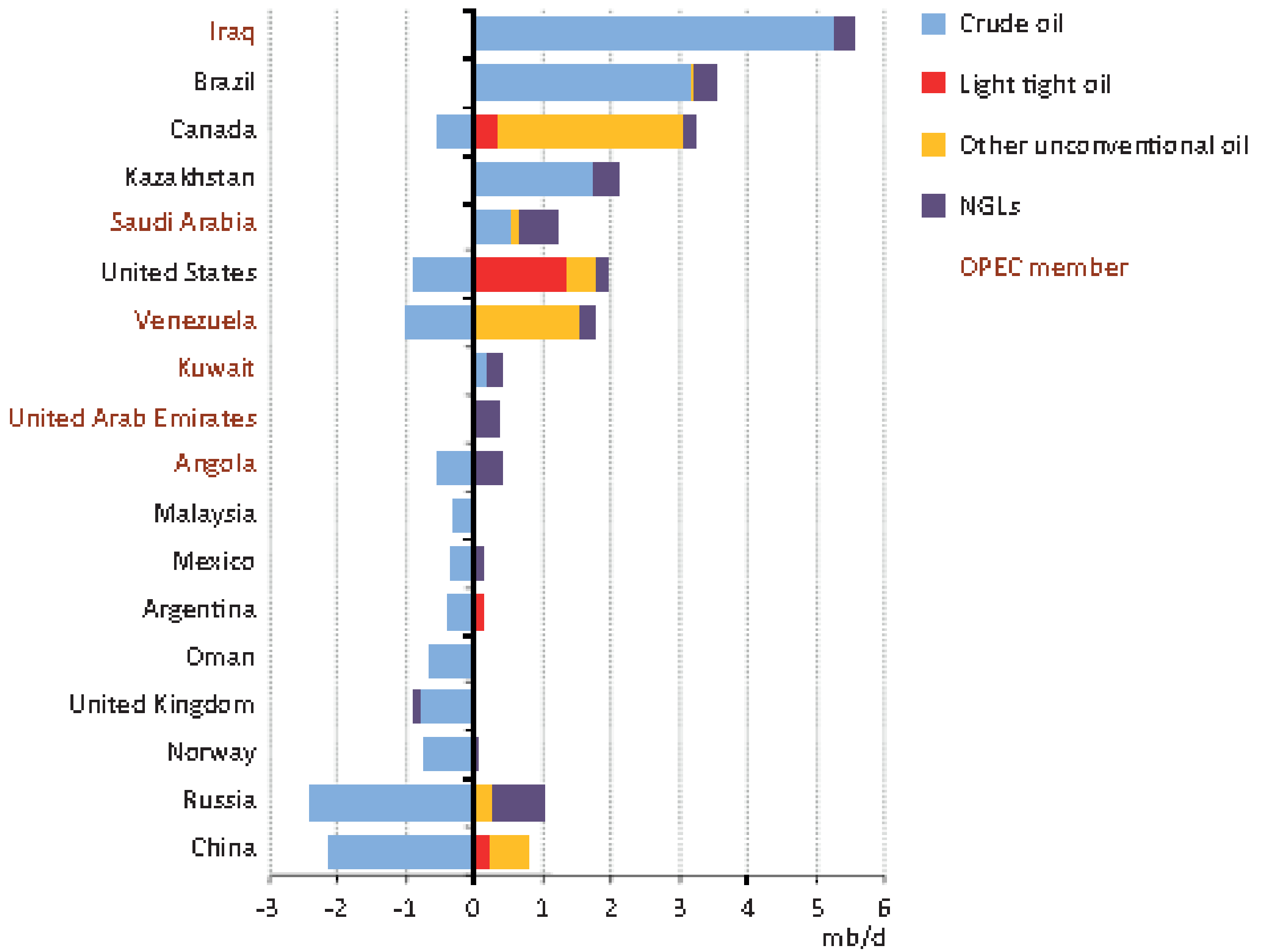
World oil production by OPEC/non-OPEC in the Reference Scenario



Production rises to 104 mb/d in 2030, with Middle East OPEC taking the lion's share of oil market growth as conventional non-OPEC production declines

Source: International Energy Agency, *World Energy Outlook* ***2008***

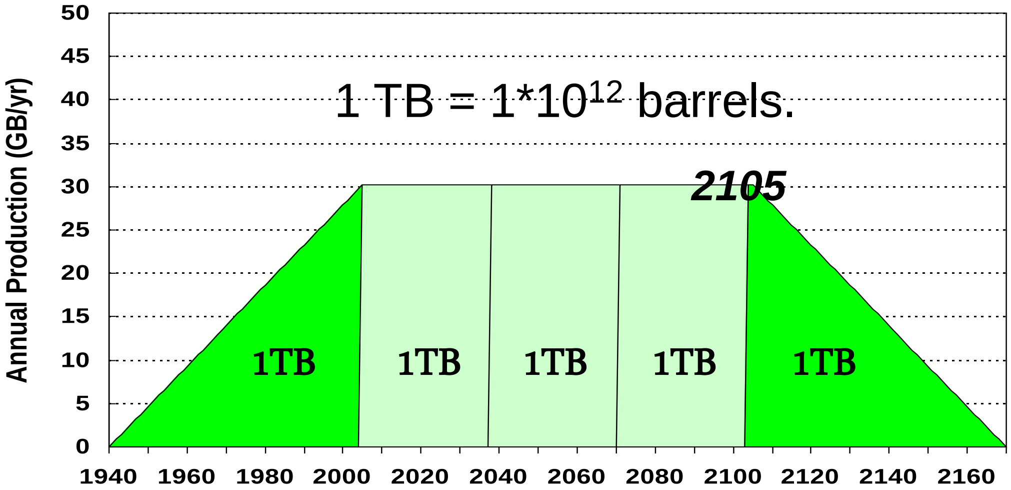
Figure 3.19 ▹ **Change in oil production in selected countries in the New Policies Scenario, 2011-2035**



Note: Libya also has a large increase in oil production between 2011 and 2035, as 2011 production was exceptionally low due to the conflict.

Source*: International Energy Agency, *World Energy Outlook 2012

A View of World Oil Supply



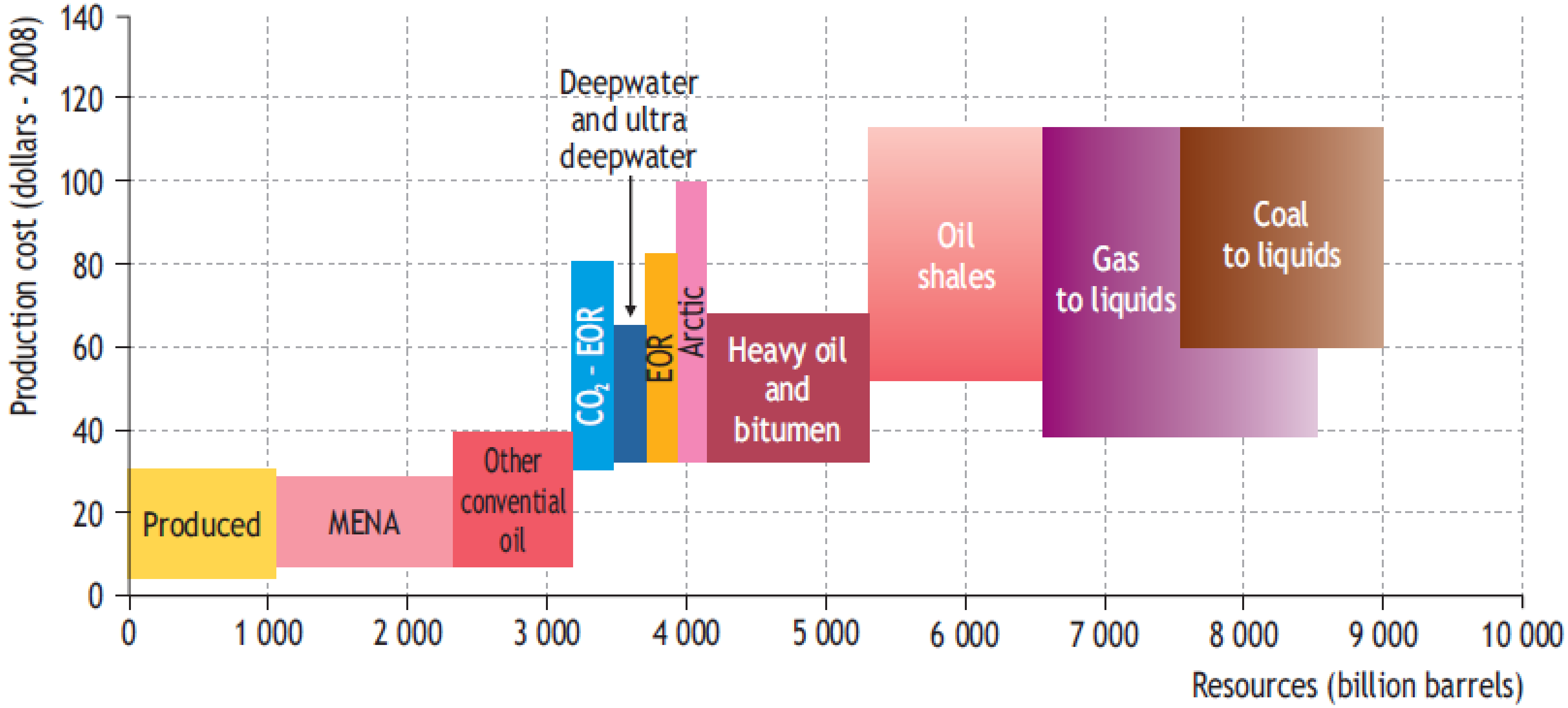
"Hubbard's peak" is a world with only 1 TB of new oil: the two dark triangles, back-to-back.

Sources of New Oil	Low Case (TB)	High Case (TB)
Production	1.0	1.0
Reserves	1.0	1.0
Exploration	0.25	0.75
Reserves Growth	0.5	1.0
Non-conventional	0.25	1.25
Total	**3.0**	**5.0**

Figure above shows high case.

Source: Ian Vann, talk at London Geological Society, October 12, 2005

Long-term oil-supply cost curve, with GTL and CTL



The total recoverable oil-resource base is estimated at 9 trillion barrels (including 2.5 trillion barrel of GTL/CTL) of which we have so far produced 1.1 Tb

***Source*: International Energy Agency, *World Energy Outlook* 2008**

Fossil substitutes for petroleum: plentiful, but pricey

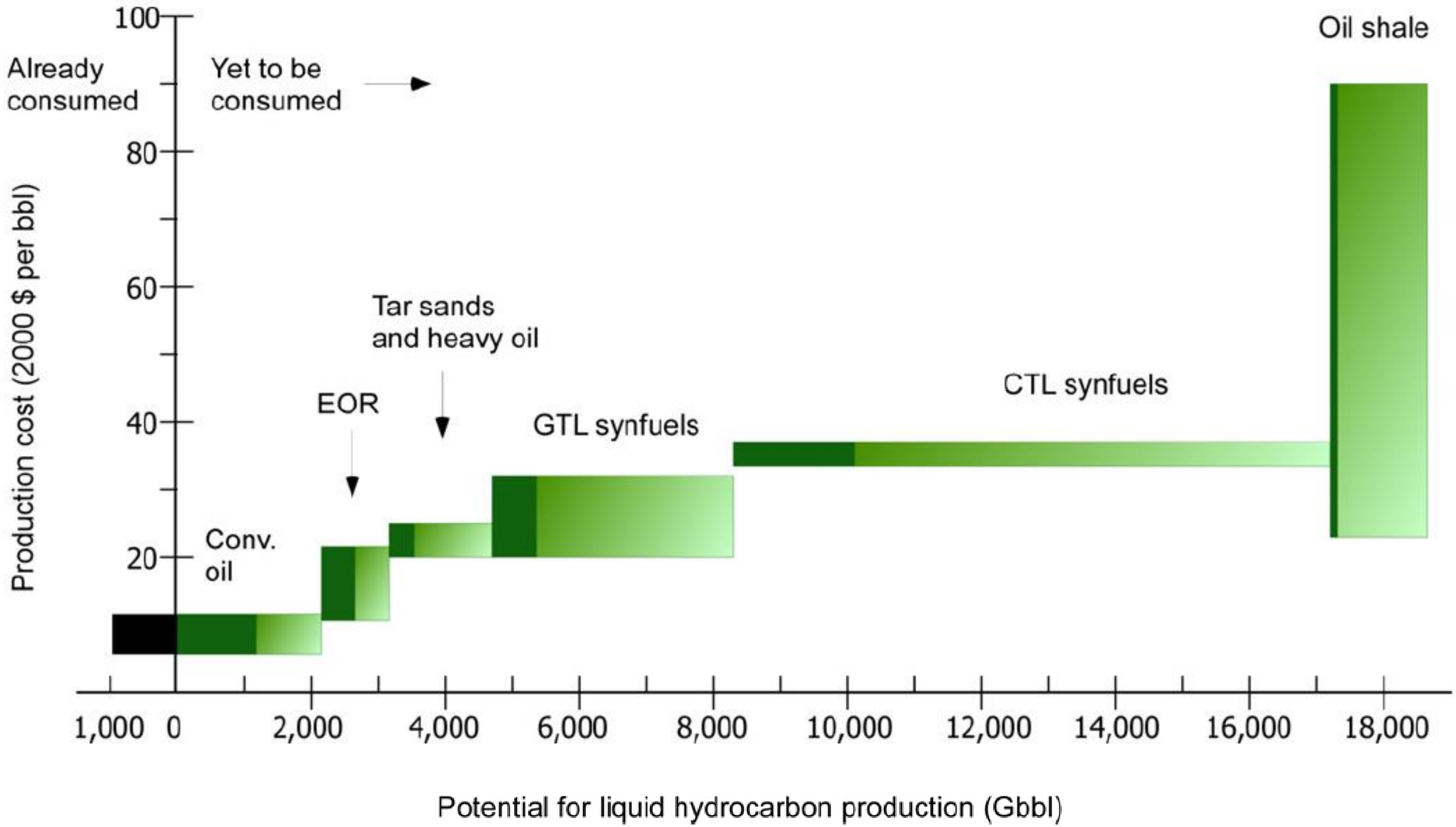


Fig. 1, Farrell and Brandt (2006) *Environ. Res. Lett.*, vol. 1

Fossil substitutes for petroleum incur increased GHG emissions

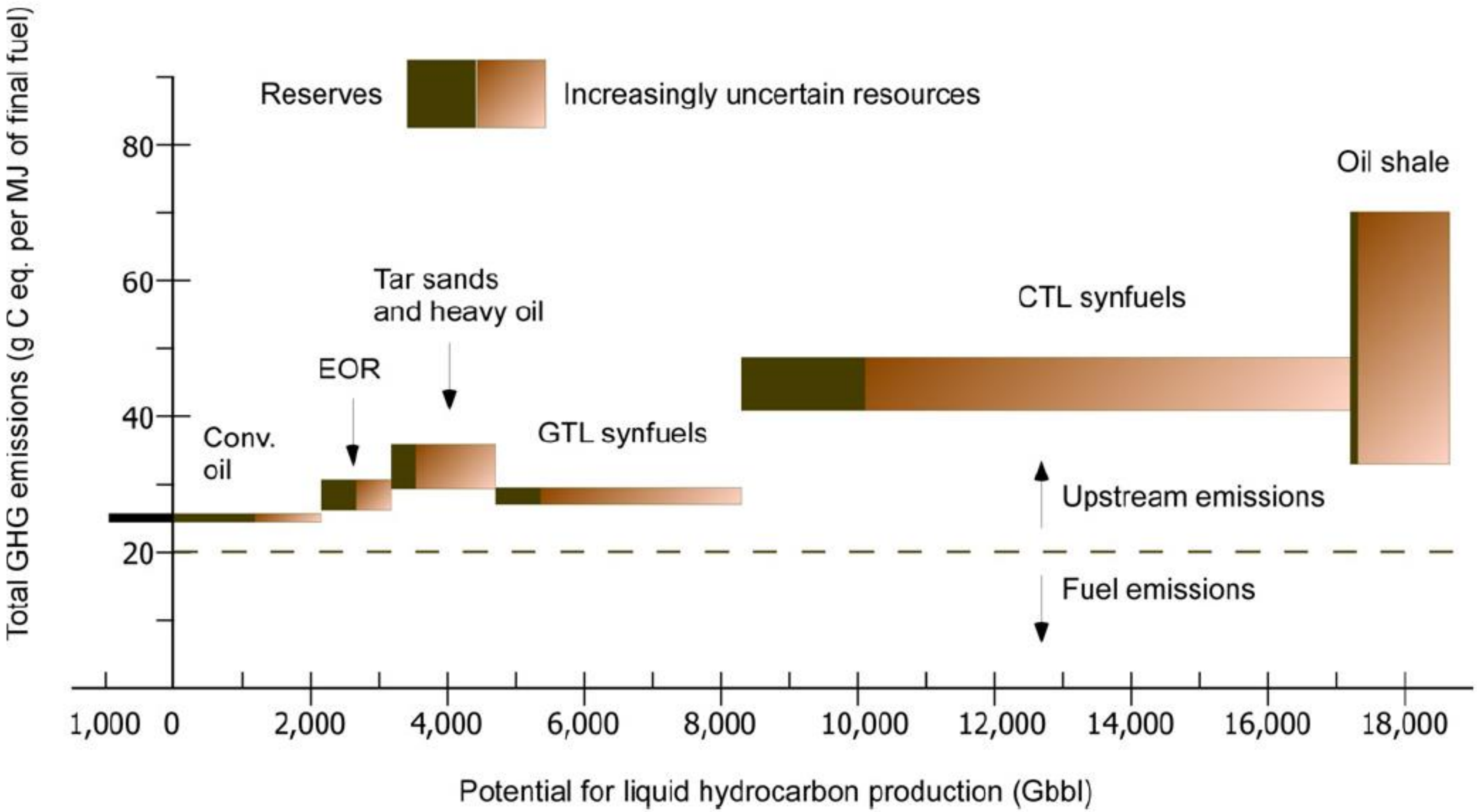


Fig. 1, Farrell and Brandt (2006) *Environ. Res. Lett.*, vol 1.

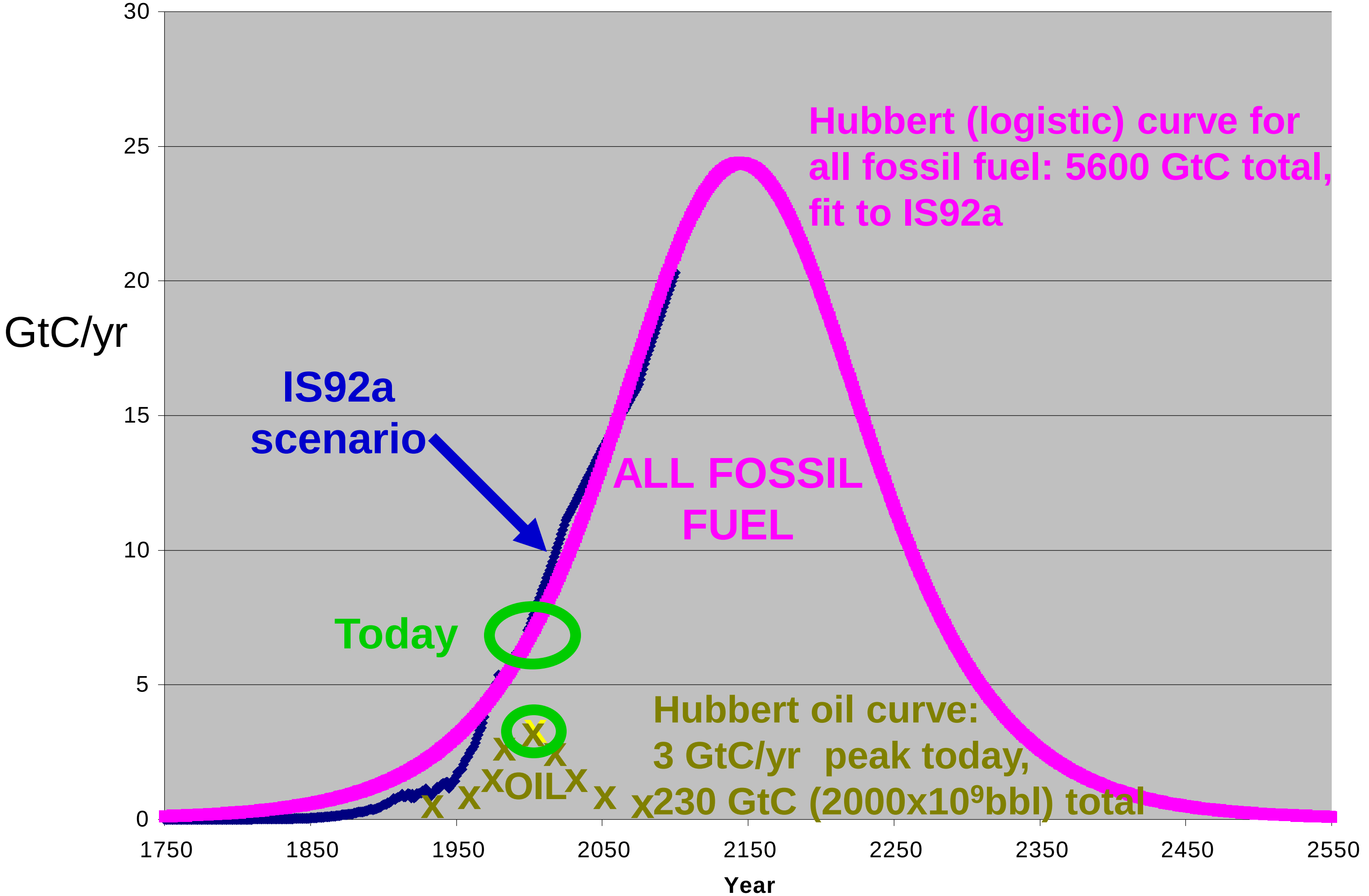
Global Fossil Carbon Resources

	Resource Base, GtC	Additional, GtC
Conventional oil (85 wt. % C)	**250**	
Unconventional oil	440	1550
Conventional nat. gas (75% C)	**240**	
Unconventional nat. gas	250	220
Clathrates		10600
Coal (70% C)	3400	2900
Total	*4600*	*15300*

2.1 GtC = 1 ppm. Today's consumption rate: 8 GtC/yr.
OIL DEPLETION WON'T SAVE US FROM THE GREENHOUSE EFFECT.

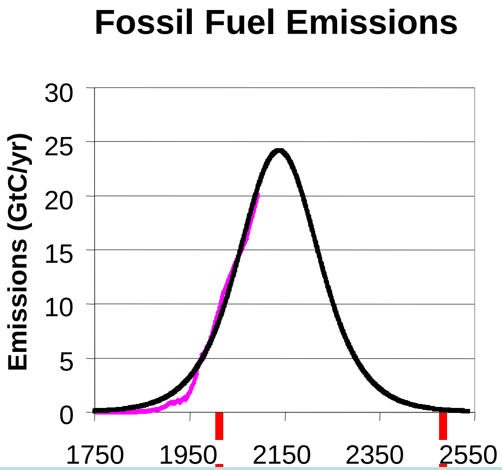
Source Rogner, *Ann. Rev. Energy and Env. 22*, p. 249. Also used: 1 toe = 41.9 GJ; 20.3 kg(C)/GJ(oil); 13.5 kg(C)/GJ (gas); 24.1 kg(C)/GJ(coal).

Conventional oil: a negligible fraction of fossil fuel

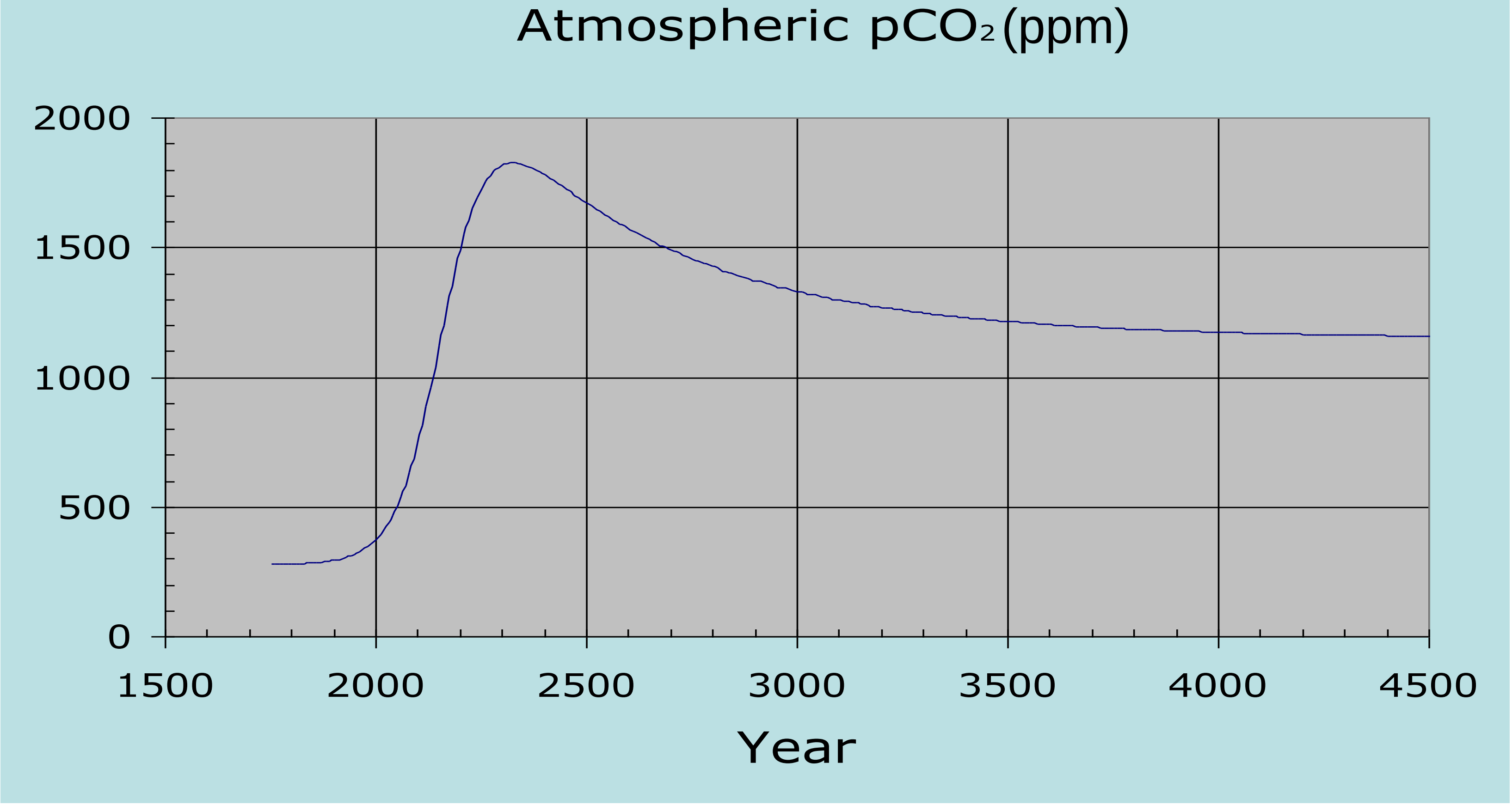


Source for "all fossil fuel": Bryan Mignone

Atmospheric CO_2 with 5600 GtC emissions



Integral ≈ 5,000 GtC ≈ 20,000 $GtCO_2$ → 10^oC.

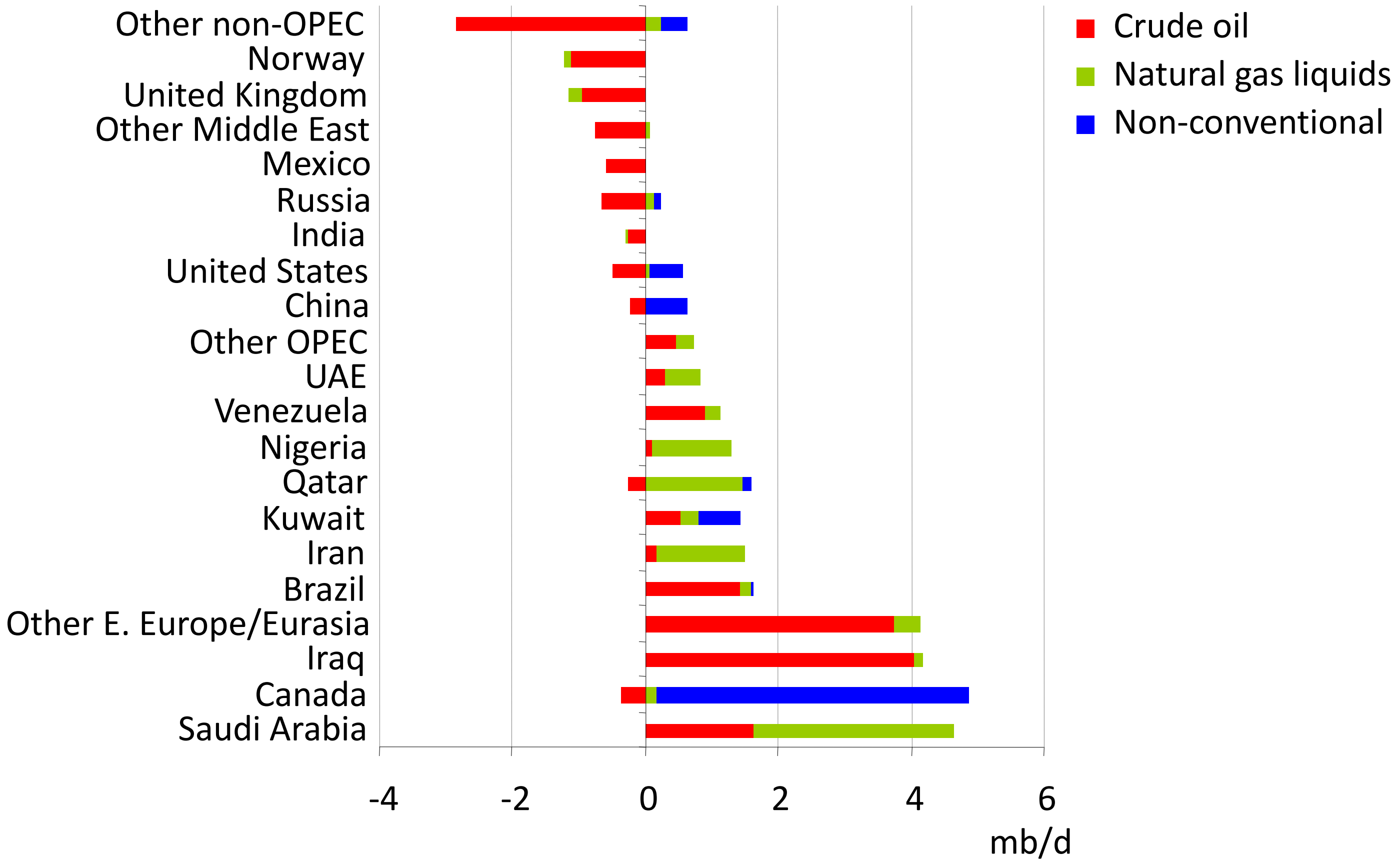


Next lecture (Lecture 4, Mon evening, Oct 6)

A. **Other primary fossil energy (coal, unconventional oil and gas)**
B. **Conversion of primary energy to electricity and fuels**

Extra Slides

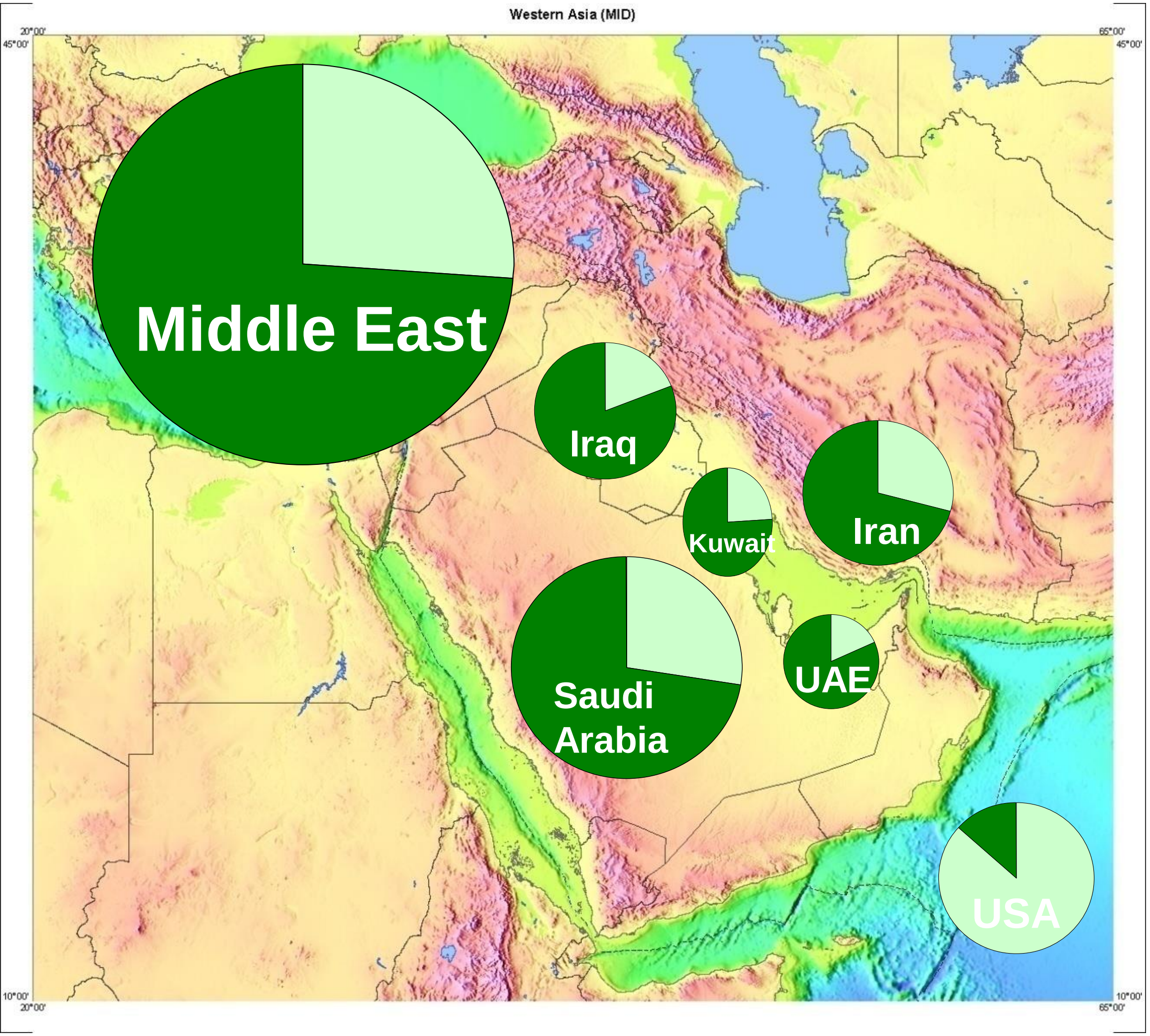
Change in oil production by country/region in the Reference Scenario, 2007-2030

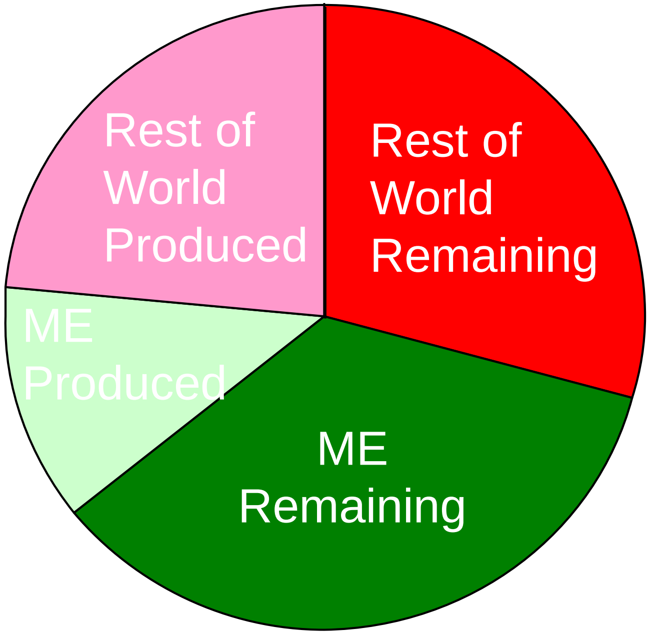


Saudi Arabia sees the biggest increase in output – from 10.2 to 15.6 mb/d – mainly thanks to NGLs

***Source*: International Energy Agency, *World Energy Outlook* 2008**

Middle East Liquids Reserves



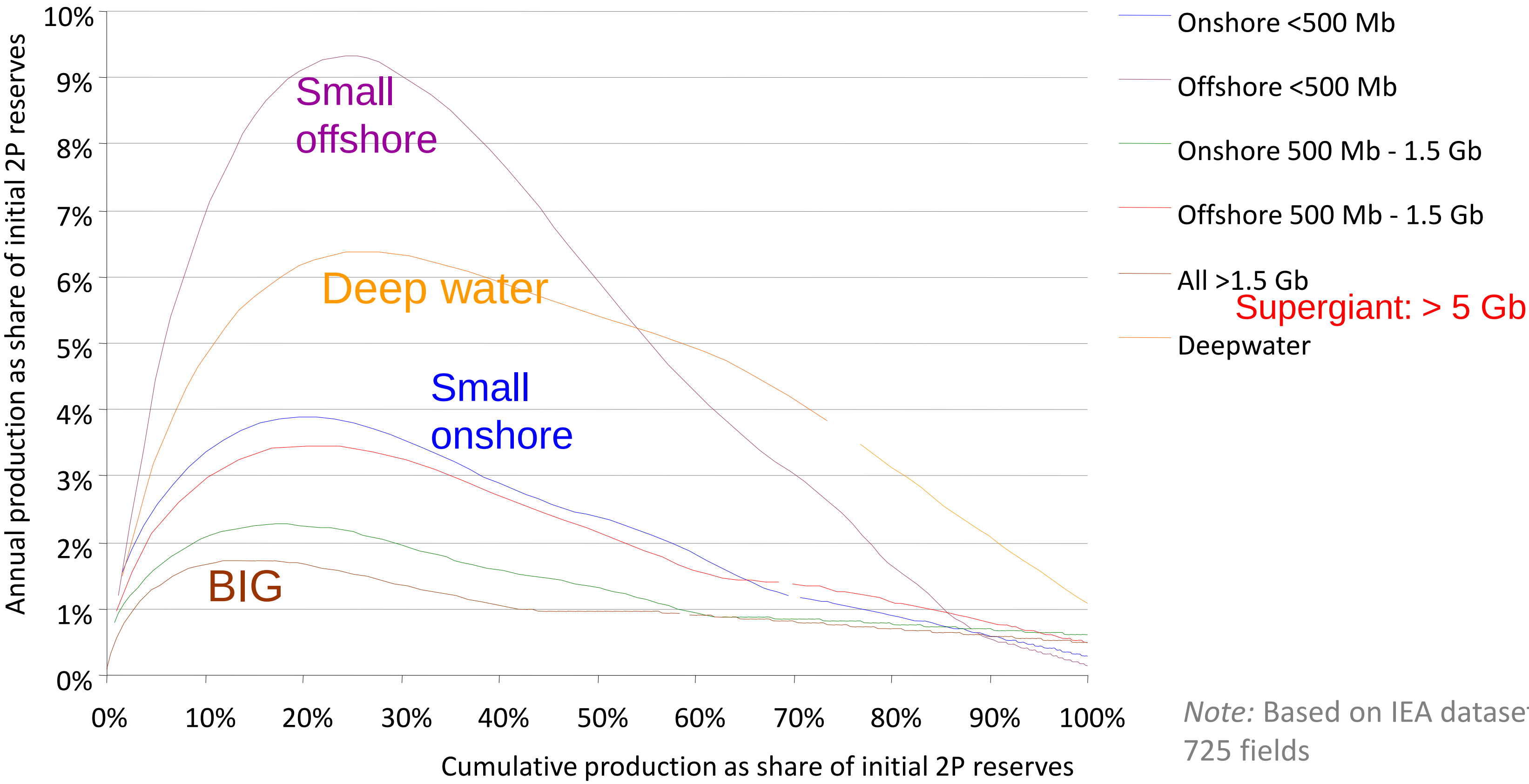


Source IHS

Produced Remaining

***Source*: Vierbuchen (Exxon), talk at Princeton, fall 2005**

Standard production profiles, by category of oilfield



Note: Based on IEA dataset of 725 fields

Peak production relative to reserves is highest & depletion rates quickest for offshore (especially deepwater) & small fields – for technical, economic & policy reasons

Source*: International Energy Agency, *World Energy Outlook 2008

The decline rate at oil fields

“We estimate that the average production-weighted observed decline rate worldwide is currently 6.7% for fields that have passed their production peak. In our Reference Scenario, this rate increases to 8.6% in 2030.

Average decline rates:

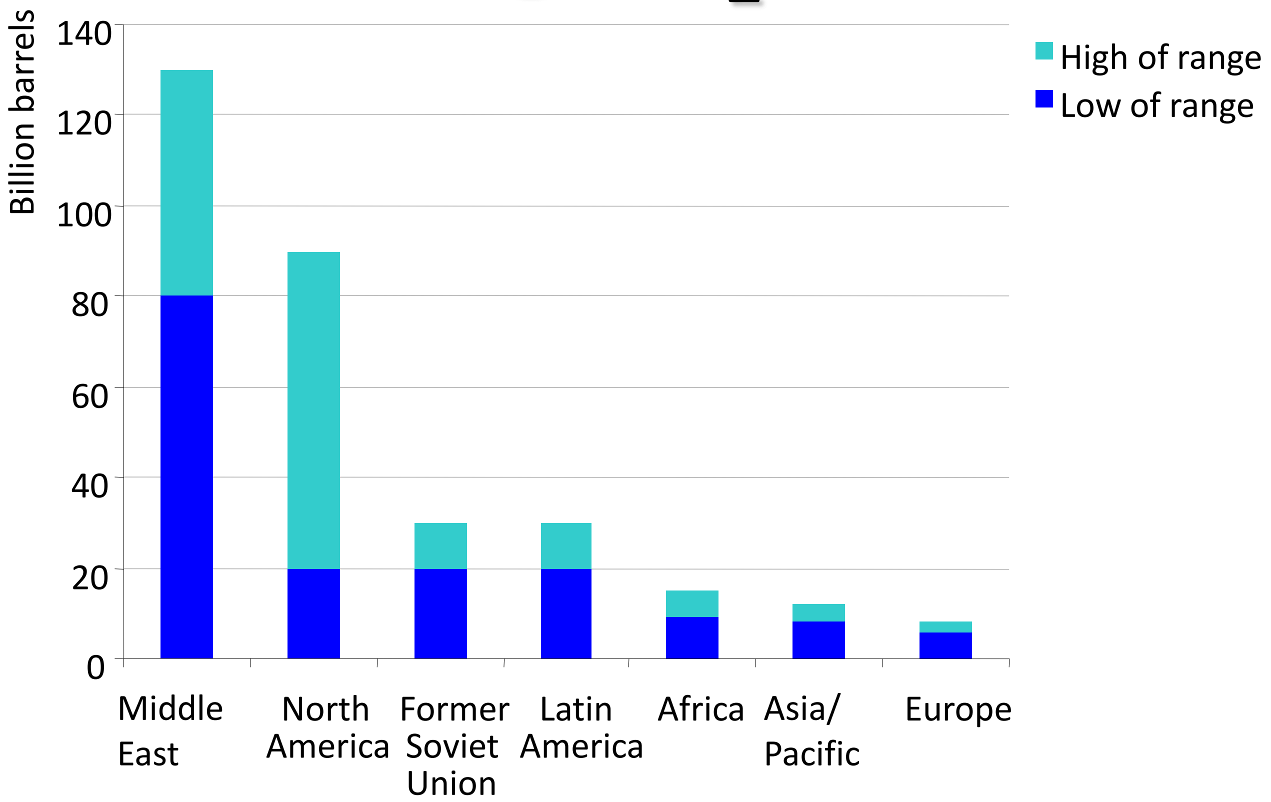
- 3.4% for super-giant fields
- 6.5% for giant fields
- 10.4% for large fields.

“Observed decline rates vary markedly by region; they are lowest in the Middle East and highest in the North Sea. This reflects, to a large extent, differences in the average size of fields, which in turn is related to the extent to which overall reserves are depleted and whether they are located onshore or offshore.”

In short, faster decline rates in smaller fields and in offshore fields.

Source: OECD/IEA, 2008. *World Energy Outlook 2008*, p. 43

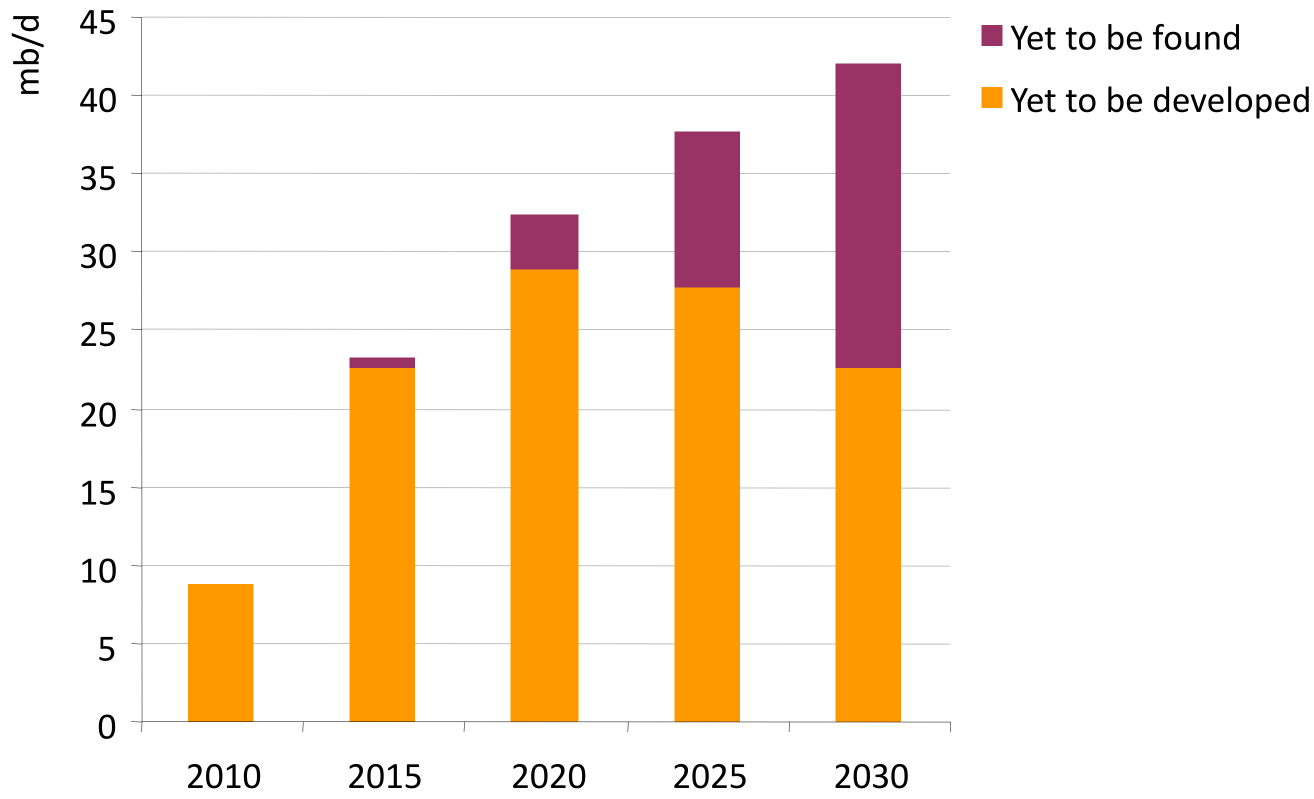
Potential additional recoverable oil resources using CO_2-EOR



Enhanced oil recovery – especially involving CO_2 injection – holds the potential to significantly boost recoverable resources & raise production in the long term

Source: International Energy Agency, *World Energy Outlook 2008*

New fields, already found and still to be found

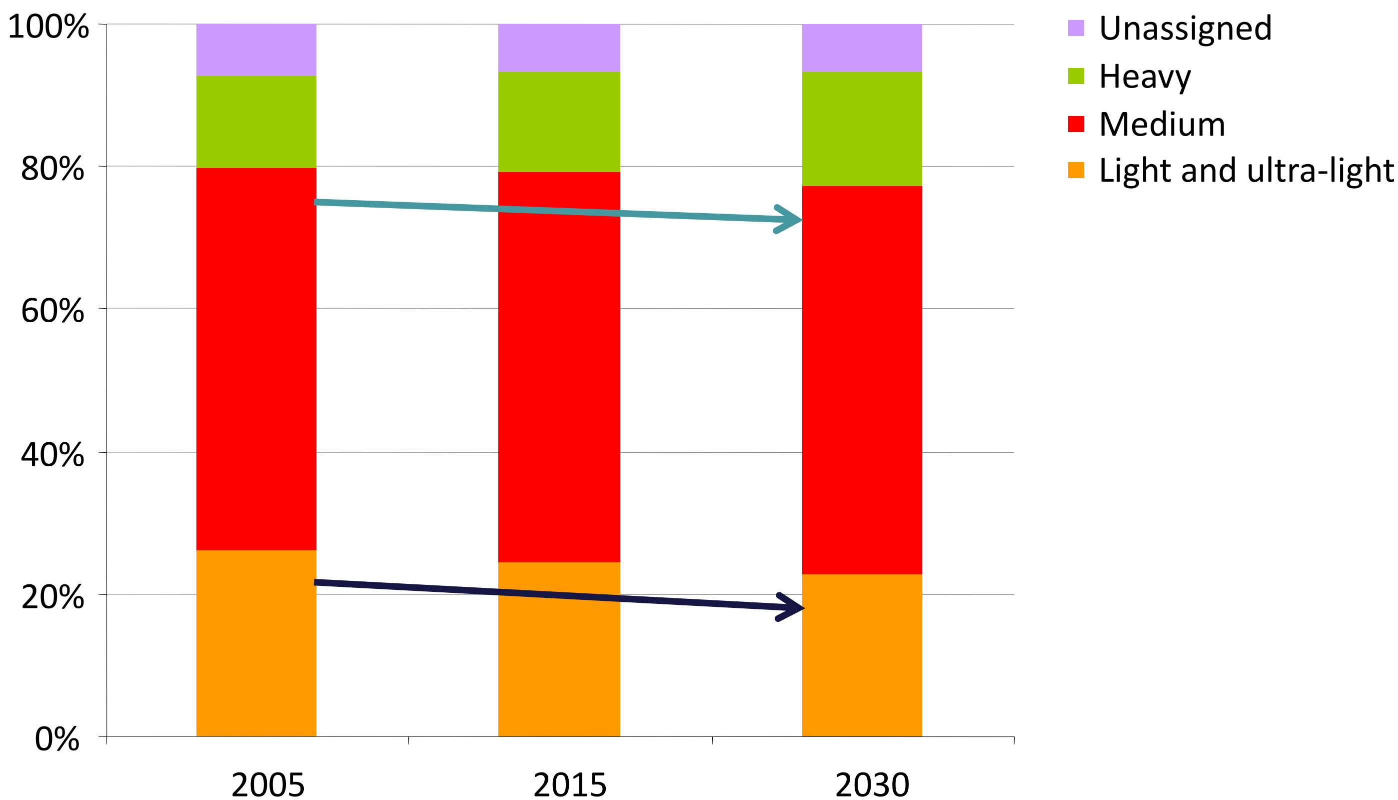


Close to half of all production from new fields in 2030 comes from fields that are yet to be found

(according to the WEO 2008 Reference scenario)

Source*: International Energy Agency, *World Energy Outlook 2008

Crude oil quality degradation is anticipated



Globally, crude oil is set to become heavier (and sourer) as more valuable light/sweet resources are depleted

(according to the WEO 2008 Reference scenario)

Source: International Energy Agency, *World Energy Outlook* ***2008***