Sustainability: Principles and Practices
Spring 2014

PPT Set 6

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Energy

Society's interest in energy derives from what services energy provides. Energy forms that can support such services economically and with minimal negative repercussions are acceptable.

Energy resources and their availability to a population will largely determine its rate of progress or growth as a community; energy begets progress/growth. Here we define progress/growth as the evolution of *more complex* socioeconomic structures (*e.g.*, increasingly sophisticated divisions of labor).

Energy resources (stocks)

Non-renewable

coal

oil

natural gas (CH_4)

Renewable

solar

wind

geothermal

hydro

biomass

nuclear*

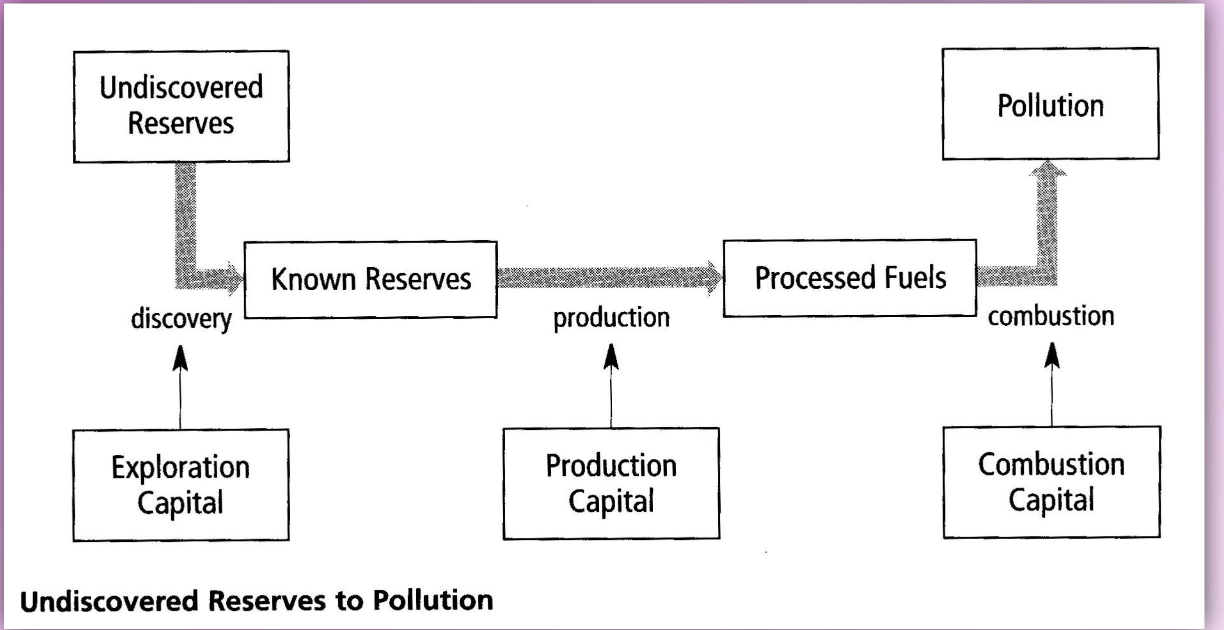
*not strictly renewable

Non-renewable resources are stock-limited. The entire stock is available at once, and can be extracted at any rate (limited mainly by extraction capital). But since the stock is not renewed, the faster the extraction rate, the shorter the lifetime of the resource.

Renewable resources are flow-limited. They can support extraction or harvest indefinitely, but only at a finite flow rate equal to their regeneration rate. If they are extracted faster than they regenerate, they may eventually be driven below a critical threshold and become, for all practical purposes, non-renewable.

Visualizing the use of non-renewable fuels in systems terms

resource depletion **climate change**



Which end of the flow of fossil fuels will be more limiting, the source or the sink?

Donella H. Meadows, *Thinking in Systems*, 2008

Where does anthropogenic atmospheric CO_2 come from?

Table 4.1: Total Carbon Dioxide Emissions in 2007
(in gigatons and percent of total)

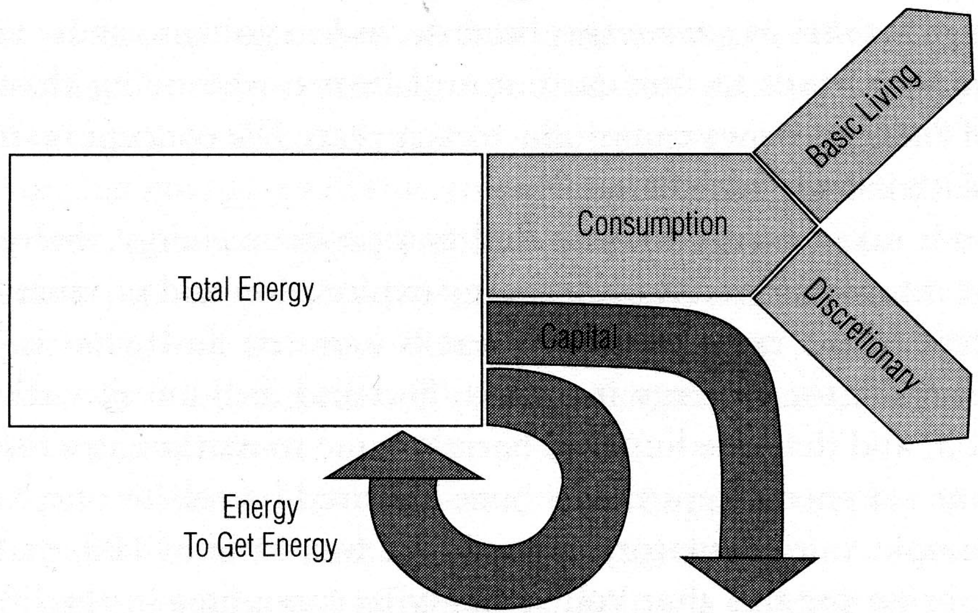
	G T	%
Total	36	100
Fossil fuels	29	81
of which: electrictiy	11.5	32
industry	8	22
transportation	6.5	18
residential	2	6
commercial	1	3
Deforestation	7	19

Source: Author's estimates based on fossil fuel emission estimates for 2005 from International Energy Agency (2007), extrapolated to 2007 assuming that all categories increase by 2.3 percent per annum during 2005–7. Deforestation is estimated to be 7 GT per year, based on World Resouces Institute (2007) for the year 2000. Note that industry includes emissions from cement due to direct materials transformation as well as fossil fuel use.

giga = billion = 10^9

J. Sachs, *Common Wealth*, 2008

Figure 15.1
Energy Budgeting



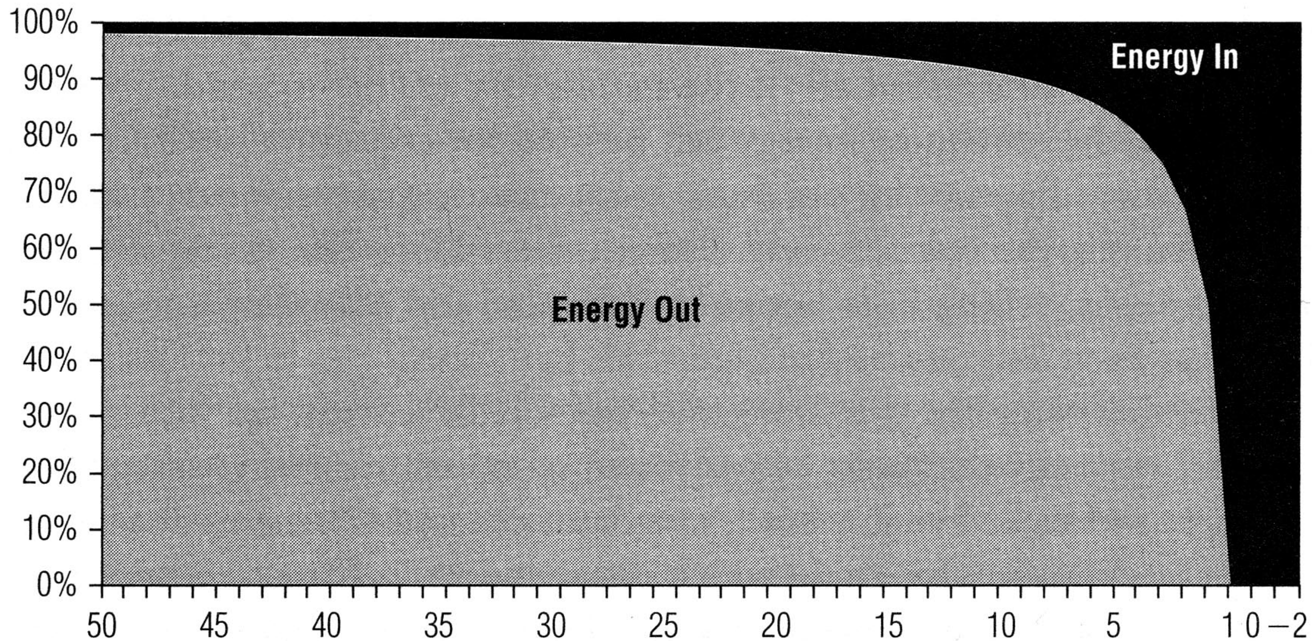
In this energy budget, a certain amount must be reinvested (darkest arrows), leaving the rest to be consumed by basic living and fully discretionary uses.

Image: Jeanine Dargis

Martenson, *The Crash Course*, 2011

Energy Return On Investment (EROI)

Figure 15.2
The Energy Cliff



This figure expresses the relationship between energy invested and energy returned. Note that together the invested and returned energy always sum to 100 percent and the lines hit zero percent at a reading of "1" where it takes one unit to find one unit for a zero percent return.

Martenson, *The Crash Course*, 2011

Hypothetical effect of technology on the cost per unit of a non-renewable energy resource over time

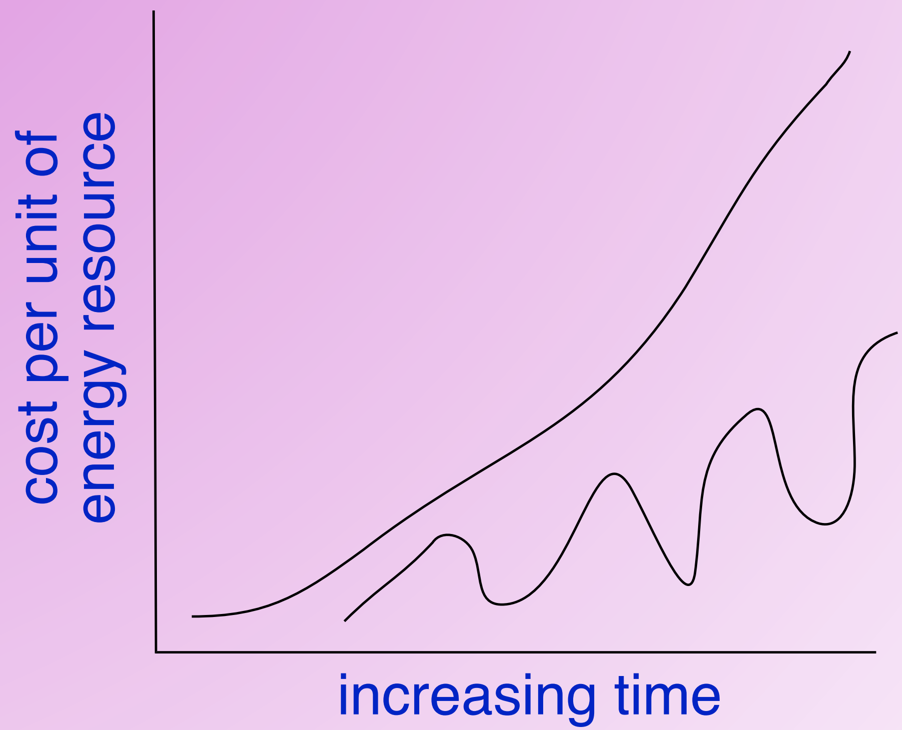
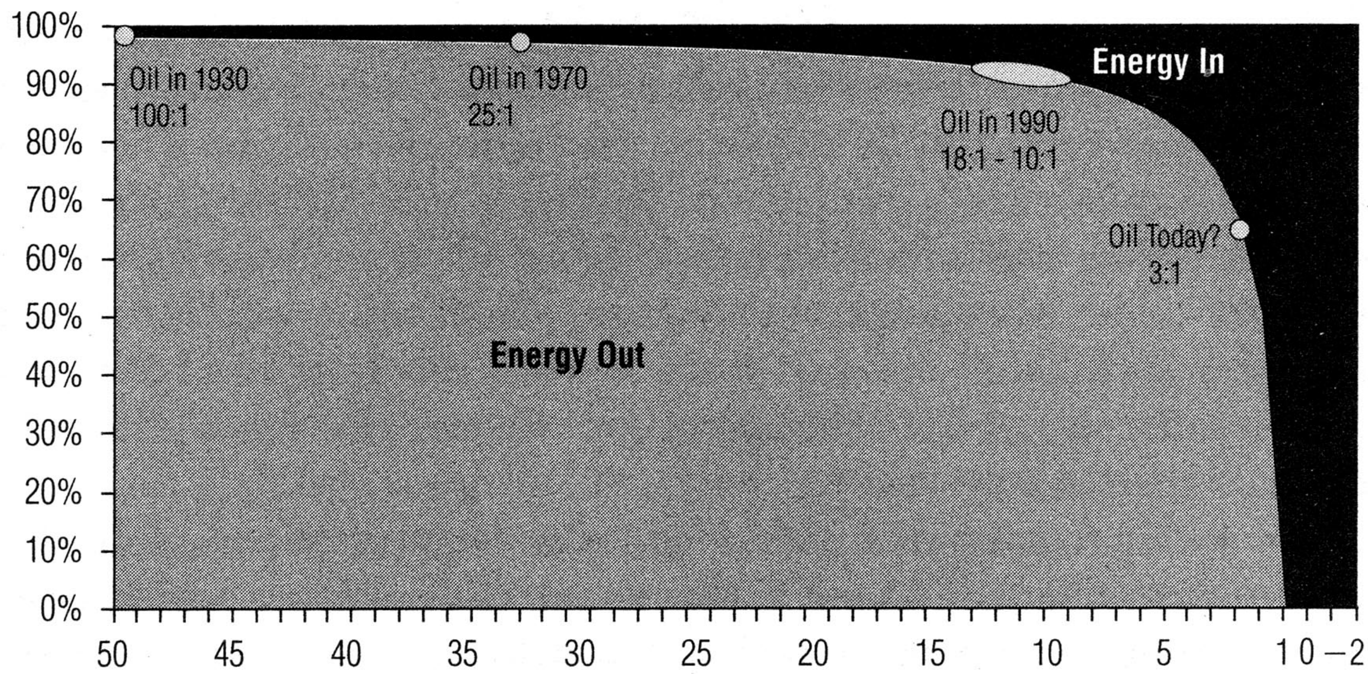


Figure 15.3
The Energy Cliff (2) and Oil

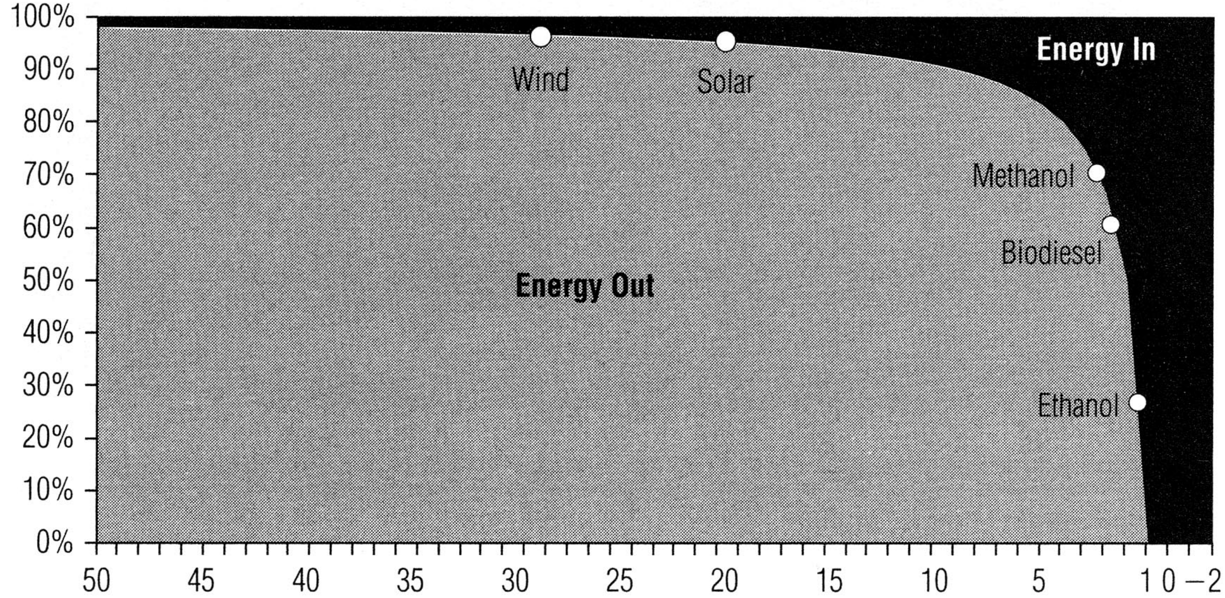


The energy returns of oil production over time have been declining.

Source: C.J. Cleveland, "Net Energy from Oil and Gas Extraction in the United States."

Martenson, *The Crash Course*, 2011

Figure 15.5
The Energy Cliff (4): Net Energy from Renewables



Not all energy forms are fully comparable on the basis of net energy returned. Solar and wind do not produce liquid fuels.

Net energy (*i.e.*, total energy extracted minus the amount of energy spent to extract it) for biofuels is comparable to oil at the moment, and considerably less attractive than net energy from renewables such as wind and solar.

Martenson, *The Crash Course*, 2011

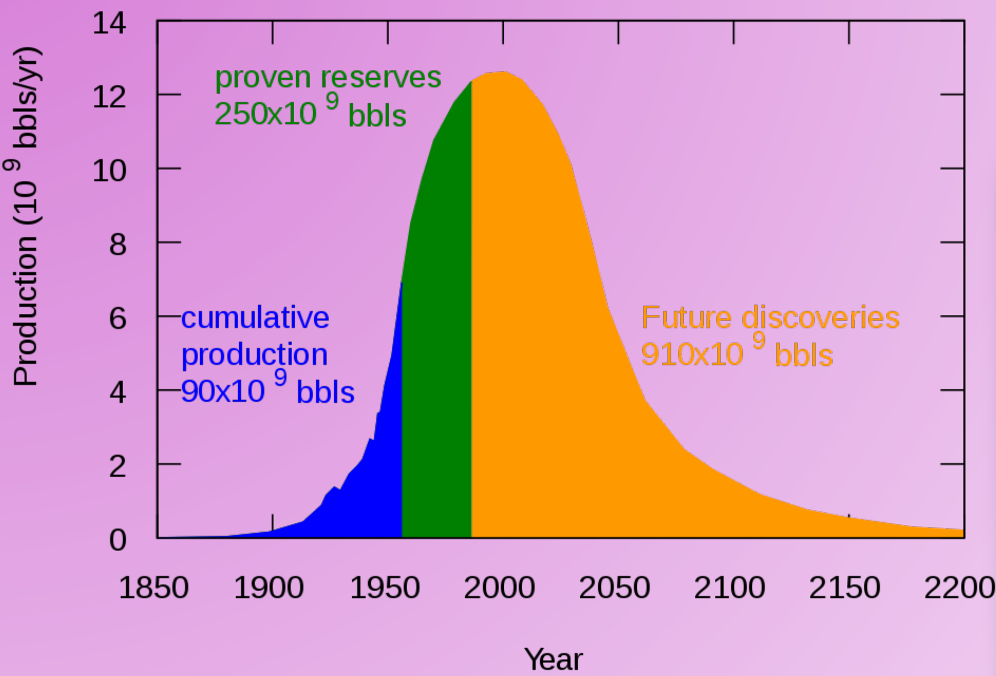
Production, reserve/production ratios, and resource life expectancy for gas, oil and coal

TABLE 3-1 Annual Production, Reserve/Production (R/P) Ratios, and Resource Life Expectancy for Oil, Gas, and Coal

	1970 Production (per year)	1970 R/P (years)	2000 Production (per year)	2000 R/P (years)	Resource Life Expectancy (years)
OIL	17 billion barrels	32	28 billion barrels	37	50–80
GAS	38 trillion cu. ft.	39	88 trillion cu. ft.	65	160–310
COAL	2.2 billion tons	2300	5.0 billion tons	217	very large

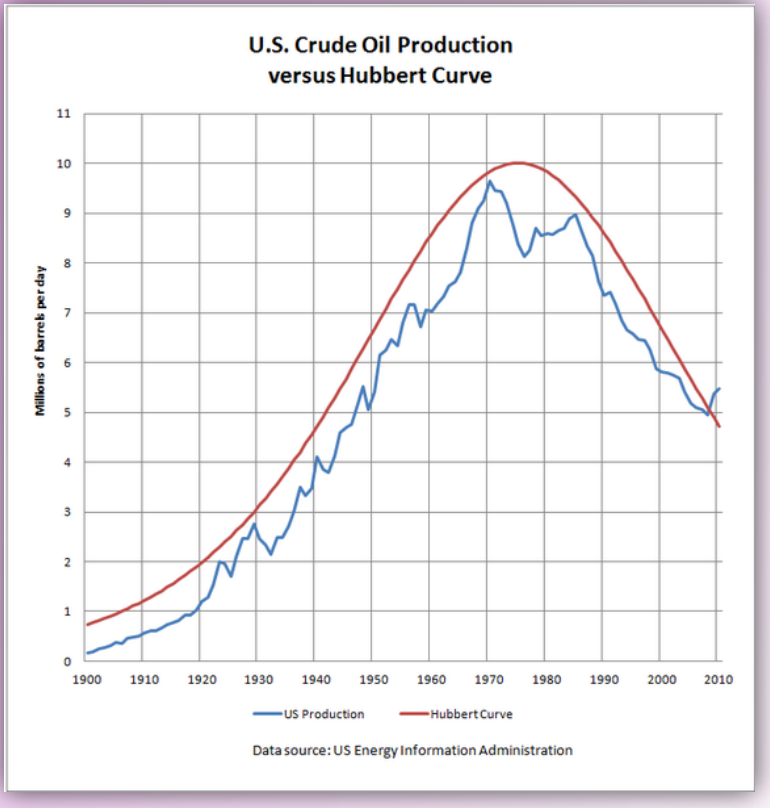
The estimates for resources are defined as the sum of "identified reserves" and "conventional resources remaining to be discovered." A resource divided by 2000 production yields 2000 life expectancy for that resource. The reserve figure for coal for 1970 is not comparable to the 2000 figure because of different definitions of reserves. Coal was and is still the most abundant fossil fuel. (Sources: U.S. Bureau of Mines; U.S. DoE)

Limits to Growth: The 30-Year Update, 2004



1 oil barrel (bbl) = 42 US gallons

The yellow area under the curve represents 73% of the total oil available for use; we have already consumed about 27%.



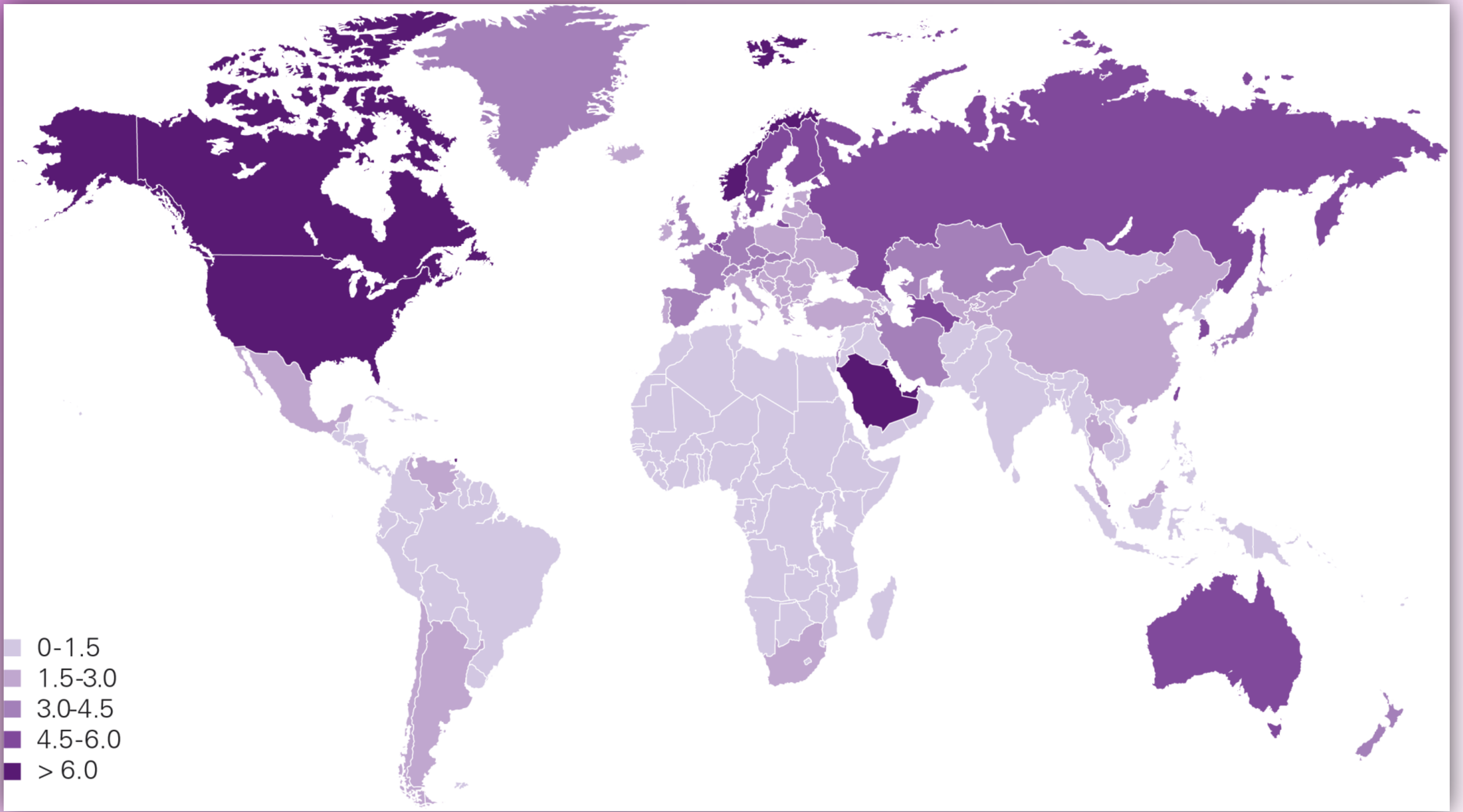
Marion K. Hubbert (Shell; 1956)

What these data mean

It is likely that most of the extractable oil and gas will be consumed within the next 50-100 years. After that, only coal will be available as a plentiful non-renewable fossil fuel. This is the reason why carbon capture and sequestration (CCS) has attracted considerable attention.

Is CCS ecologically prudent, economical, and/or can it be scaled? Answers to these questions are currently unknown.

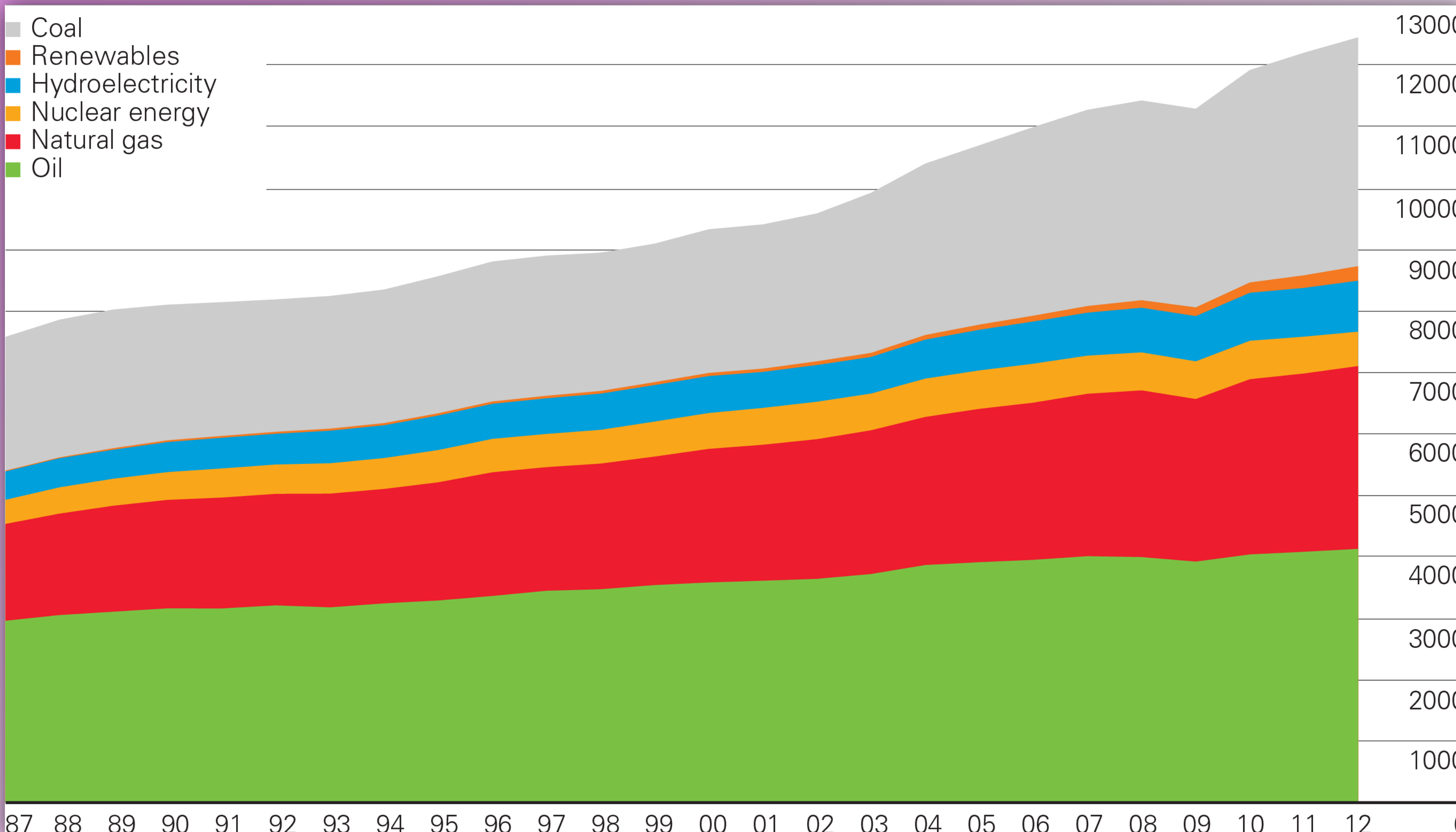
Primary energy consumption per capita 2012
(tonnes oil equivalent)



BP Statistical Review of World Energy, June 2013

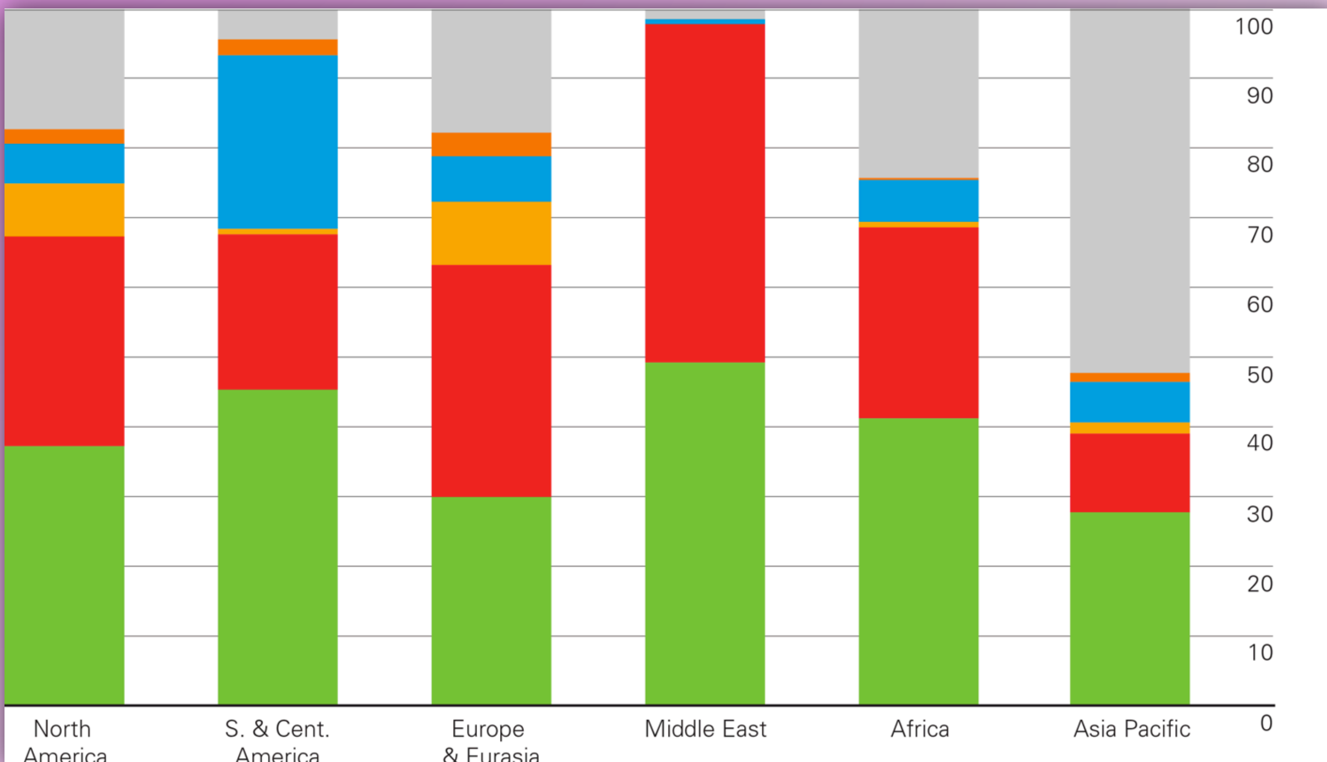
Primary energy world consumption

(million tonnes oil equivalent)



BP Statistical Review of World Energy, June 2013

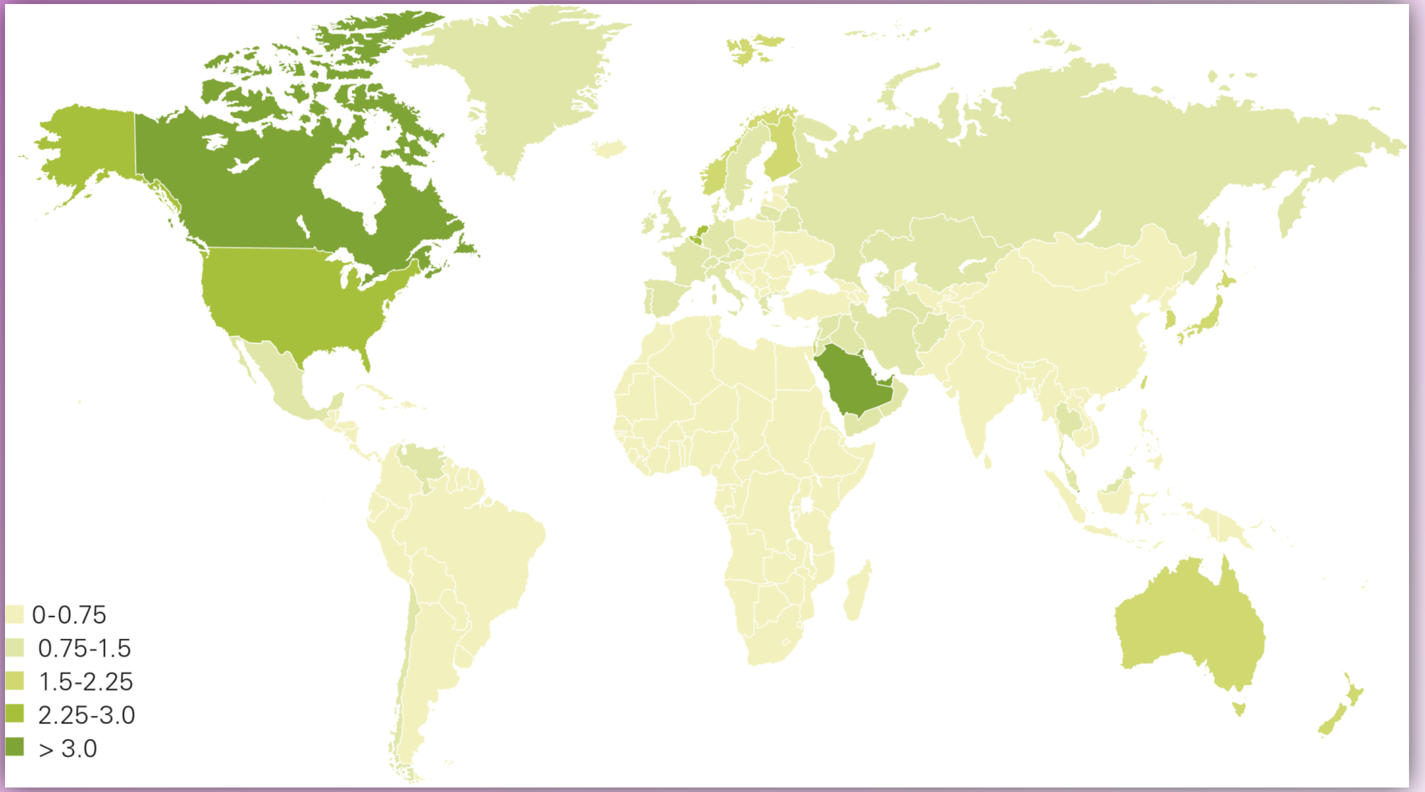
Primary energy - consumption by region
(percentage)



gray = coal
red = gas
green = oil
blue = hydro
yellow = nuclear
brown = renewables

BP Statistical Review of World Energy, June 2013

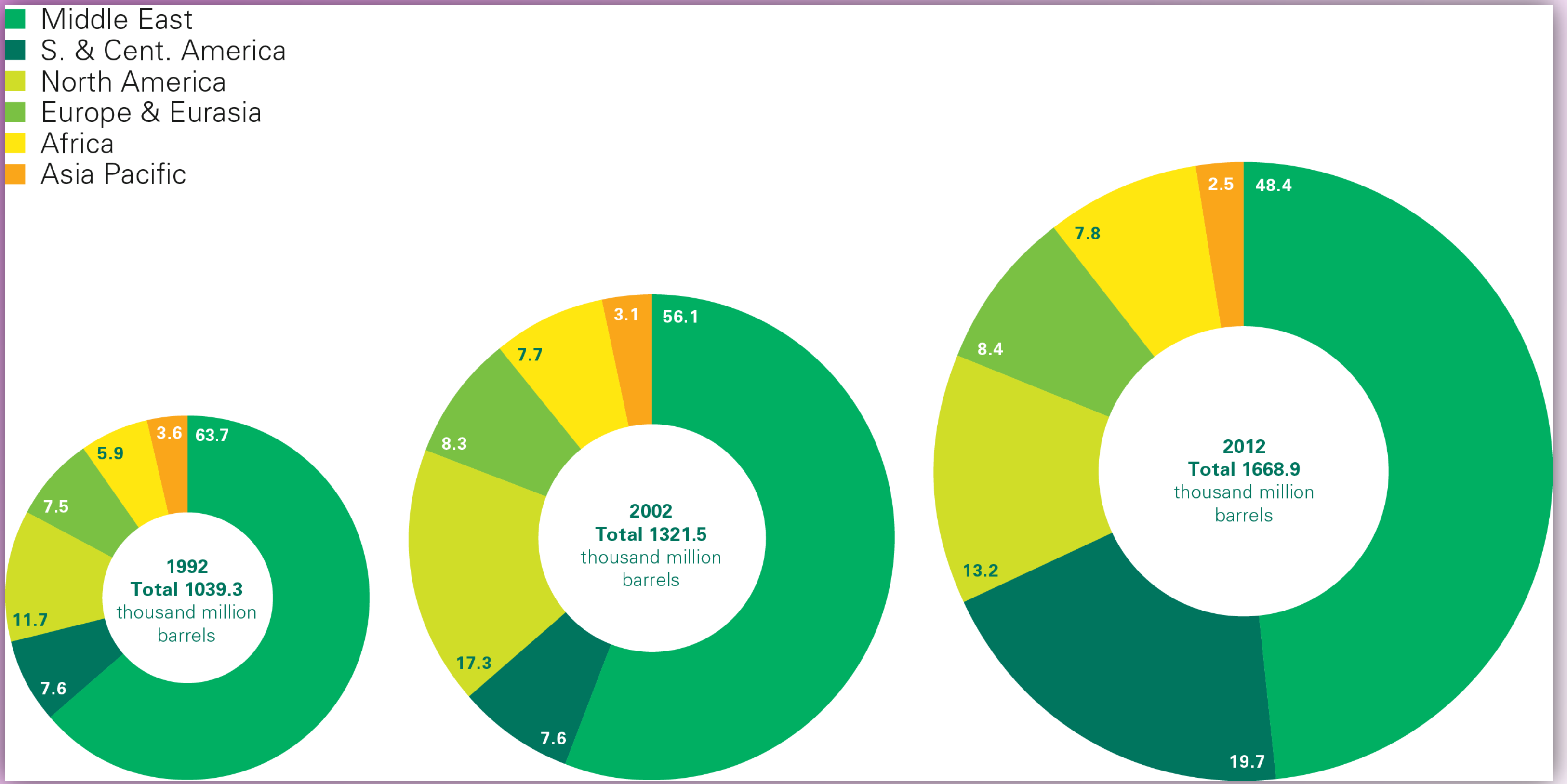
Oil consumption per capita 2012
(tonnes)



The highest per capita consumption of oil worldwide occurs largely on the North American continent (Canada and Saudi Arabia followed by the US).

BP Statistical Review of World Energy, June 2013

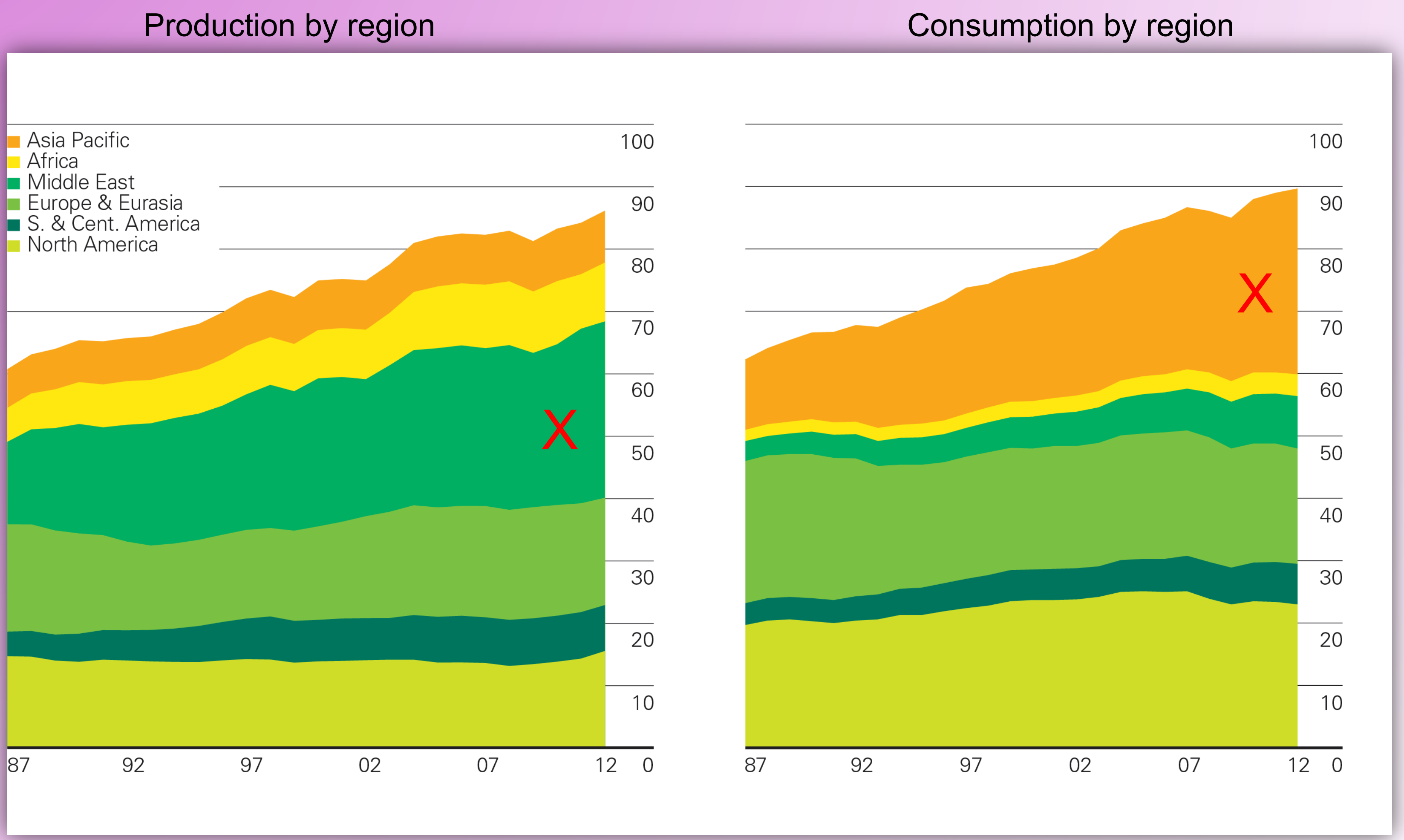
Distribution of proved oil reserves in 1992, 2002 and 2012
(percentage)



% Increase (20 years) = ~60%

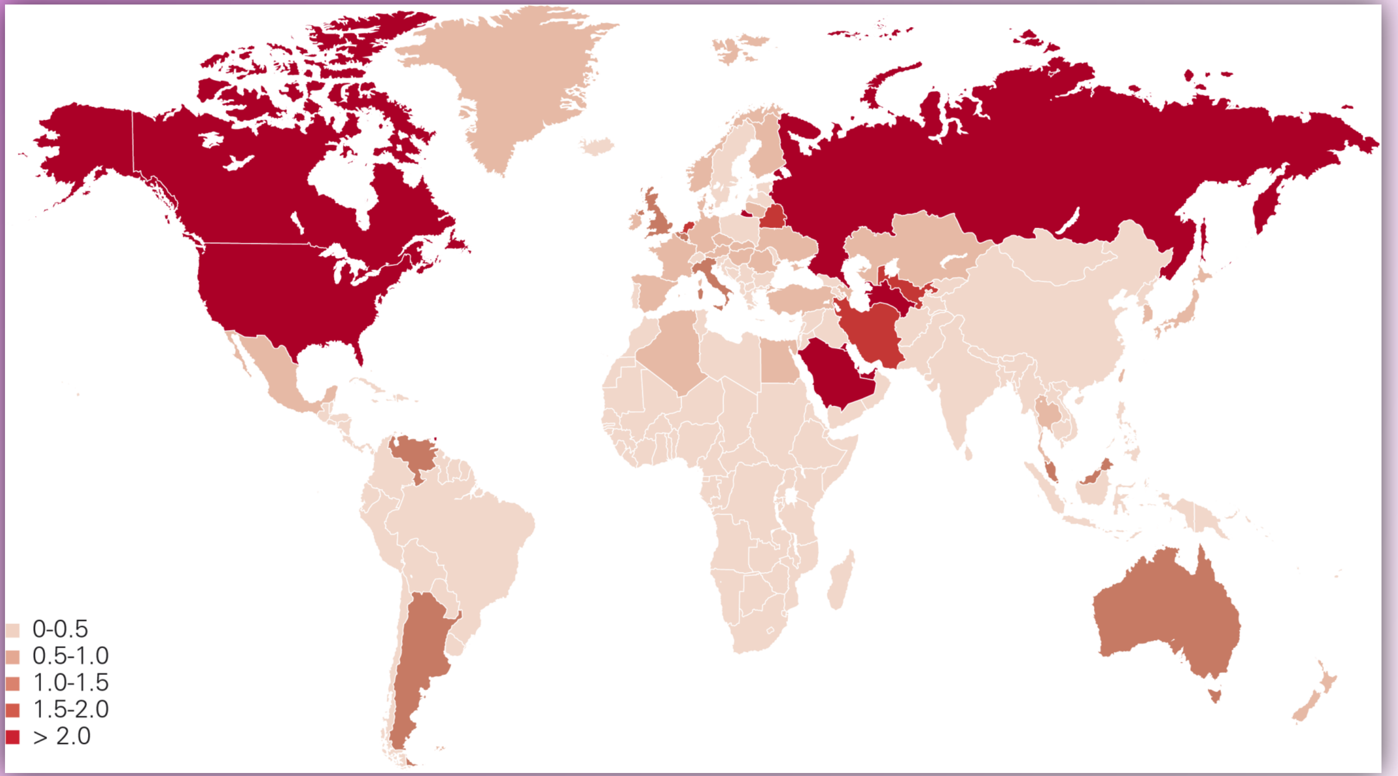
BP Statistical Review of World Energy, June 2013

Oil production/consumption by region
(million barrels daily)



BP Statistical Review of World Energy, June 2013

Gas consumption per capita 2012
(tonnes oil equivalent)

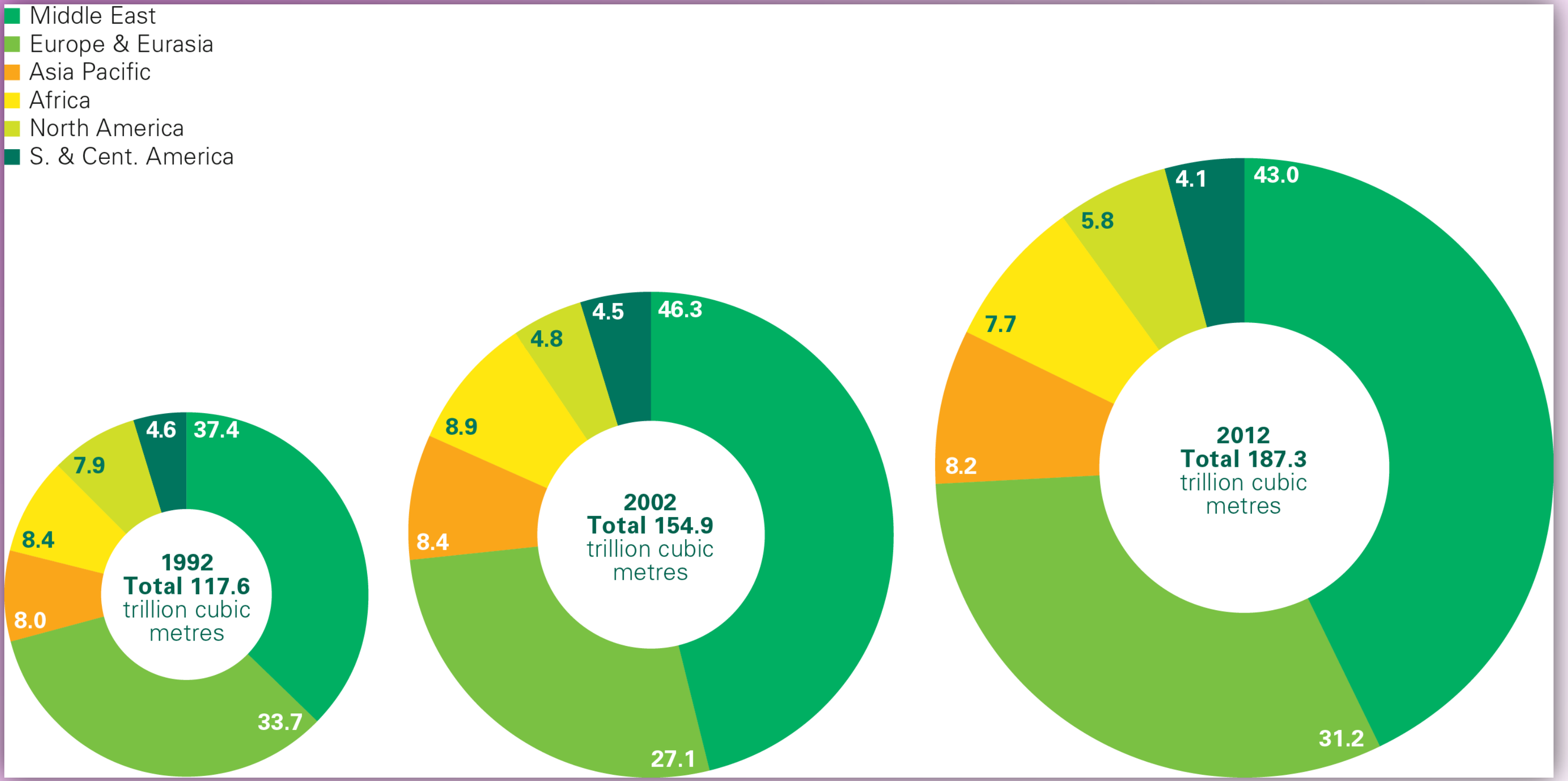


The greatest gas consumption per capita in the northern hemisphere occurs in Canada, Russia and the US. Australia, Argentina and Venezuela are the major per capita gas consumers in the southern hemisphere.

BP Statistical Review of World Energy, June 2013

Distribution of proved gas reserves in 1992, 2002 and 2012

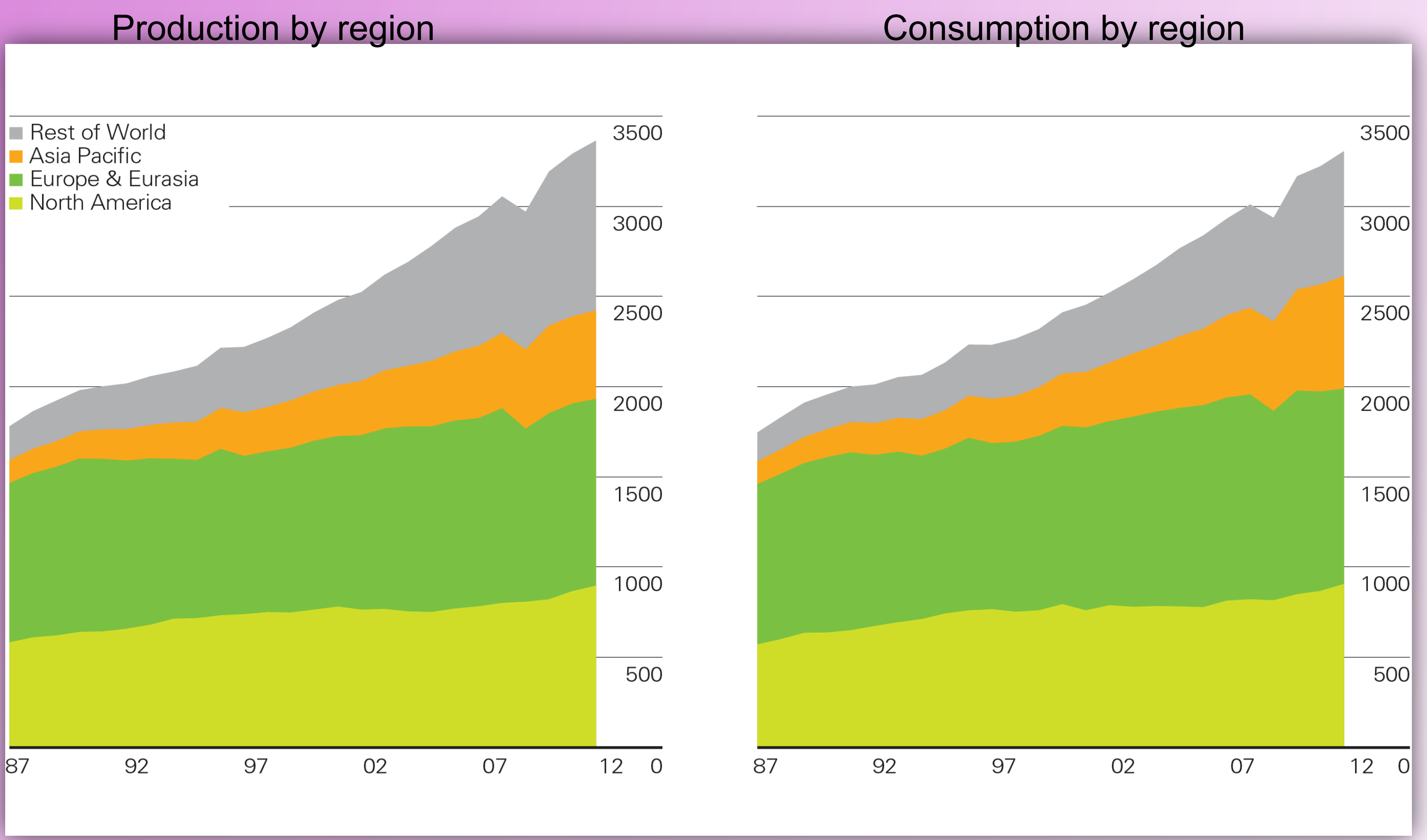
(percentage)



Total gas reserves have increased by ~60%.

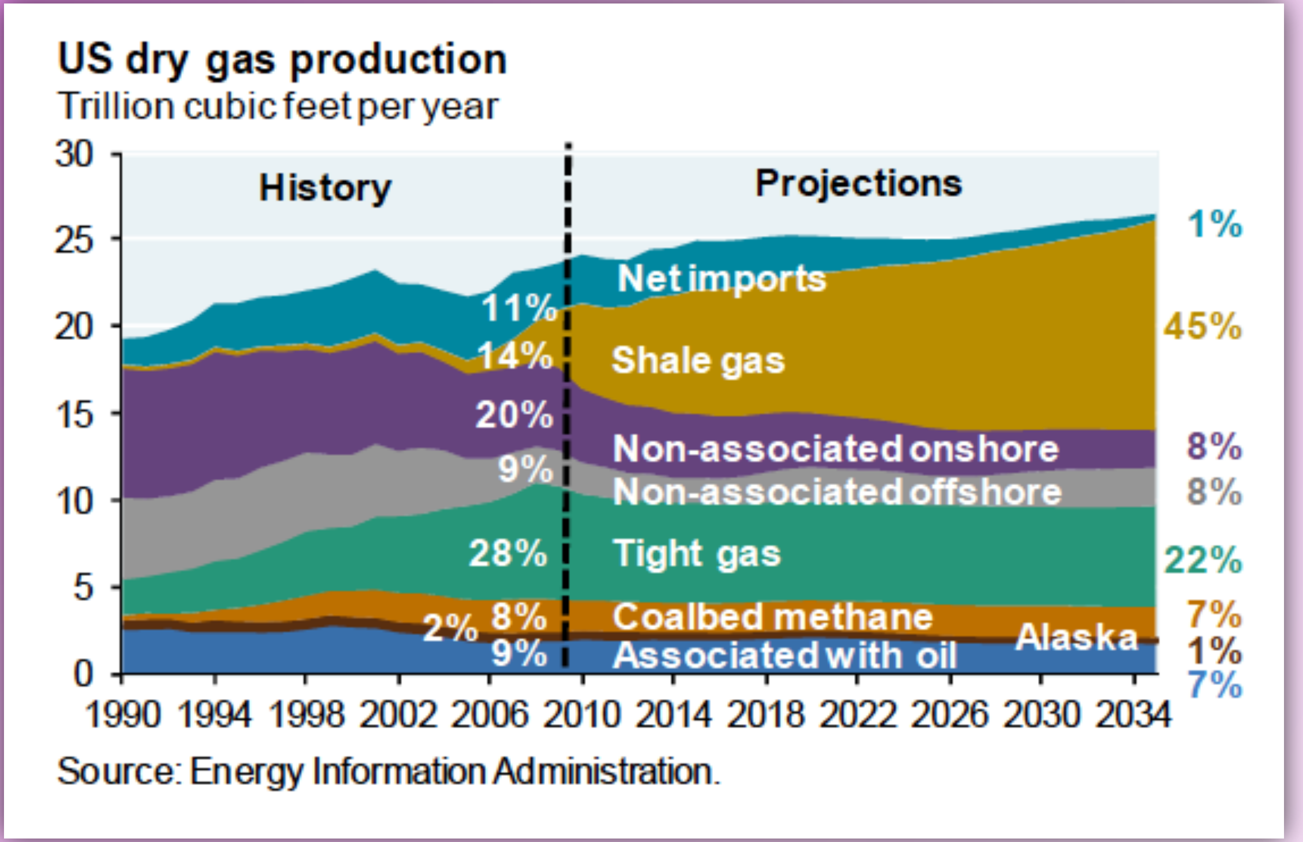
BP Statistical Review of World Energy, June 2013

Gas production/consumption by region
(billion cubic metres)



Gas production increased ~90% from 1987 to 2012, and gas consumption increased by approximately the same percentage. In the US, consumption increased ~4% while production increased ~5%.

BP Statistical Review of World Energy, June 2013

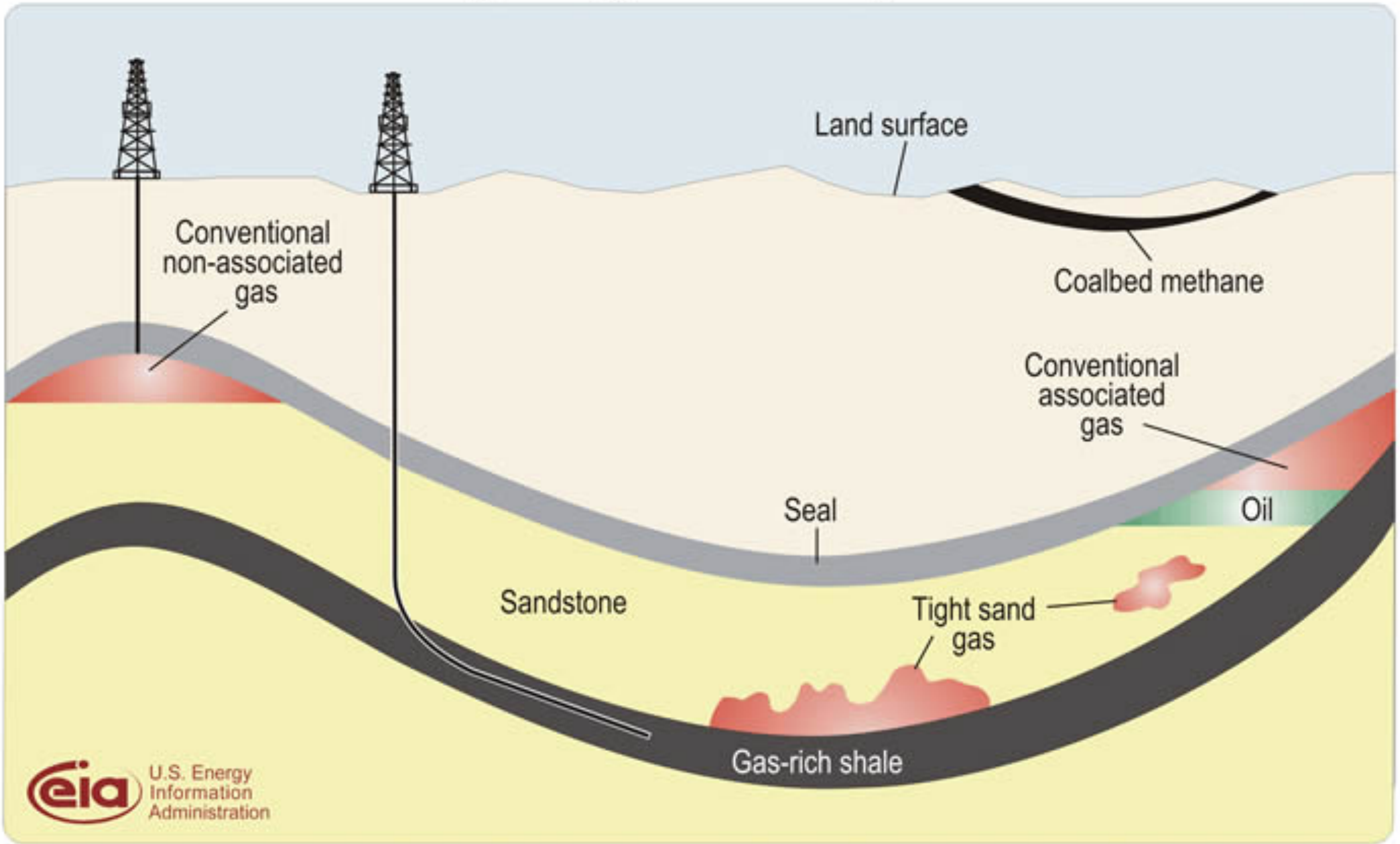


Commercial natural gas is mainly CH_4 (methane).

Shale gas: an unconventional natural gas trapped in shale formations; hydraulic fracturing (fracking) creates extensive artificial fractures around well bores to promote gas extraction from the shale.

Tight gas: an unconventional natural gas that is difficult to access because impermeable rock and sand surround the deposit; extensive fracking is needed to access this gas.

Schematic geology of natural gas resources



Coal consumption per capita 2012
(tonnes oil equivalent)

The US, South Africa and Australia have very high per capita consumption of coal, along with some areas of Eurasia. China is also a high per-capita coal consumer.

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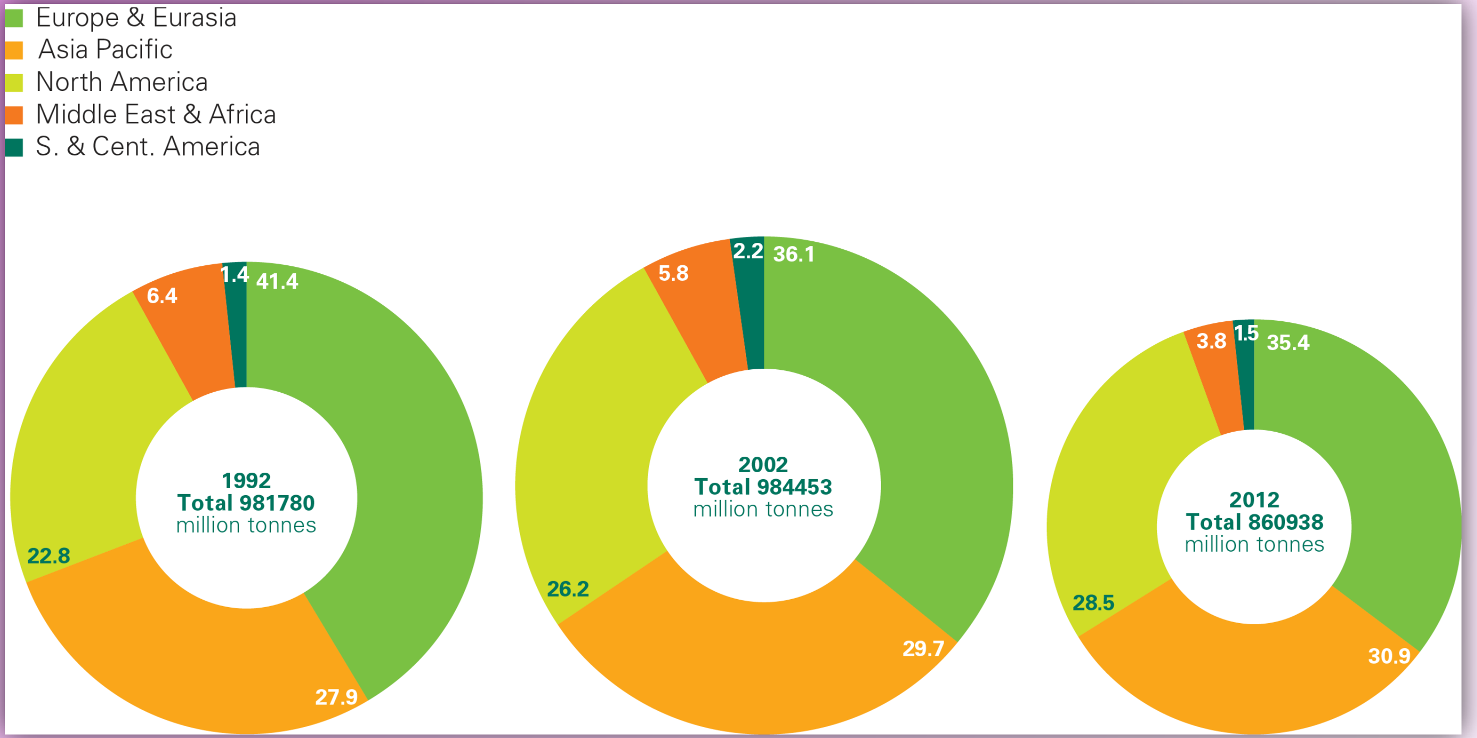
Distribution of proved coal reserves in 1992, 2002 and 2012
(percentage)



Global distribution of coal reserves has not changed significantly over the past 20 years. High percentages of reserves (23-41%) lie in Europe/Eurasia, North America and the Asia-Pacific region.

Global coal reserves dropped by ~12% from 1992 to 2012.

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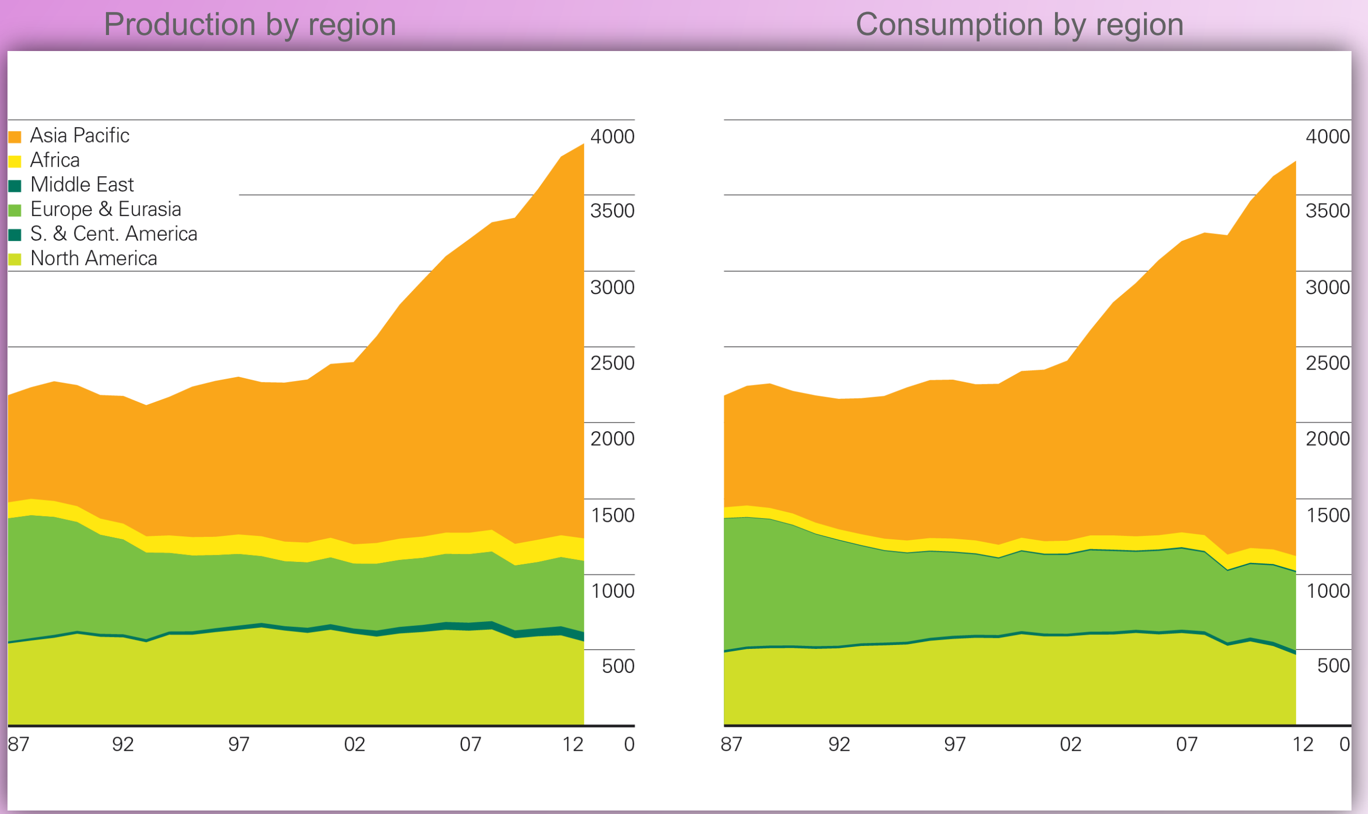
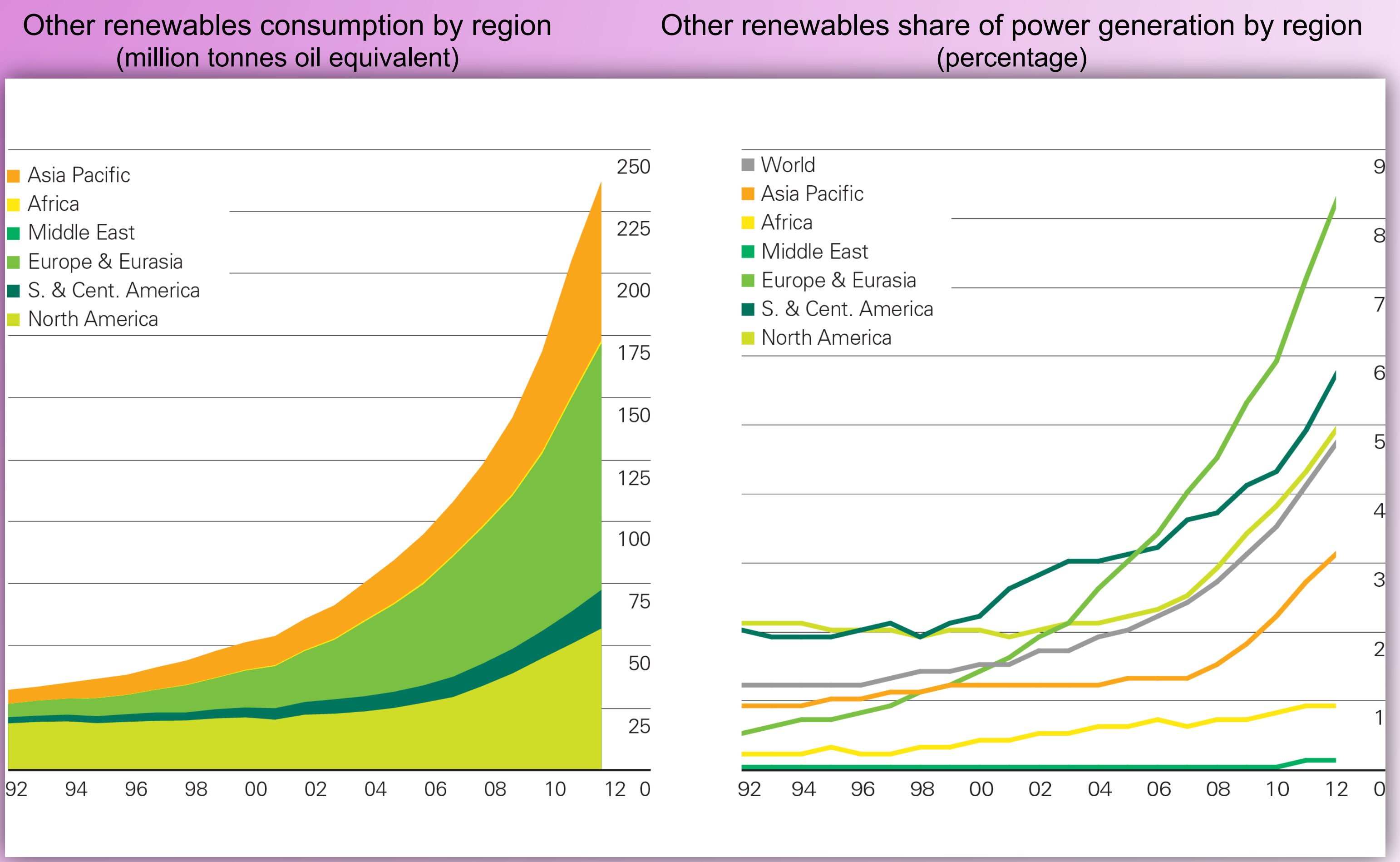
Coal production/consumption by region
(million tonnes oil equivalent)



Global coal production grew ~2% from 2011 to 2012; most of this growth came from China and Indonesia. Global coal consumption grew ~ 2.5% (*i.e.*, consumption exceeded production), with much of this growth occurring in China.

BP Statistical Review of World Energy, June 2013

Renewable energy consumption/share of power by region



Of global power generation, 4.7% comes from RE (record in 2012).

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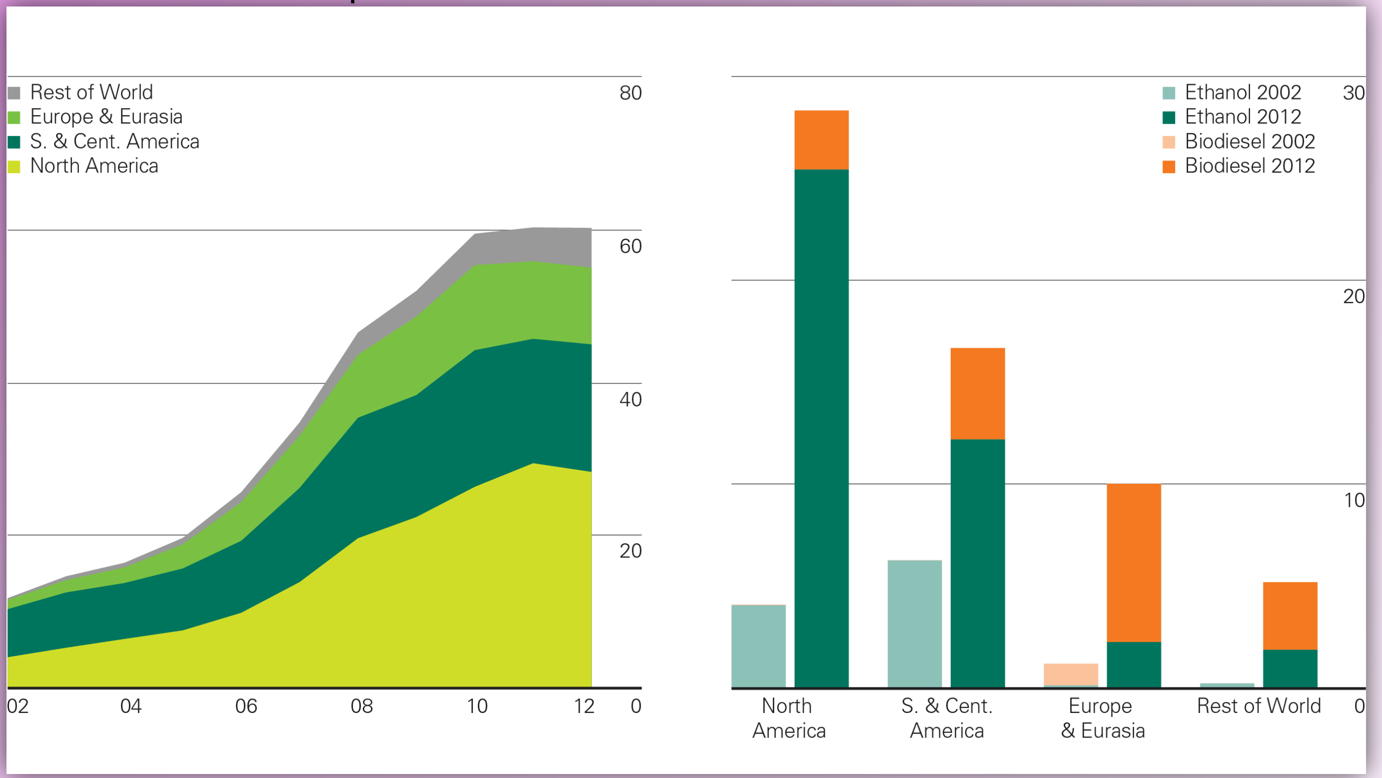
Biofuels production by region
(million tonnes oil equivalent)

World biofuels production

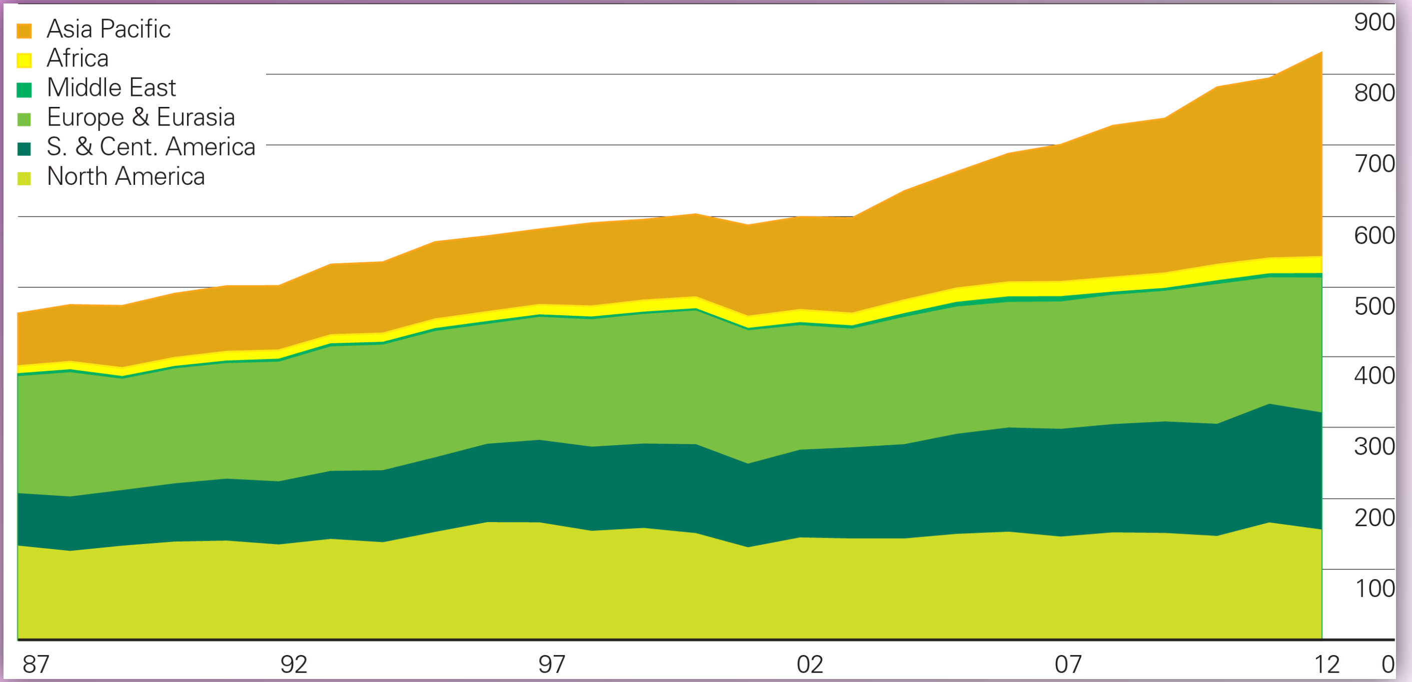


Global biofuel production declined by ~0.4% in 2012.

BP Statistical Review of World Energy, June 2013

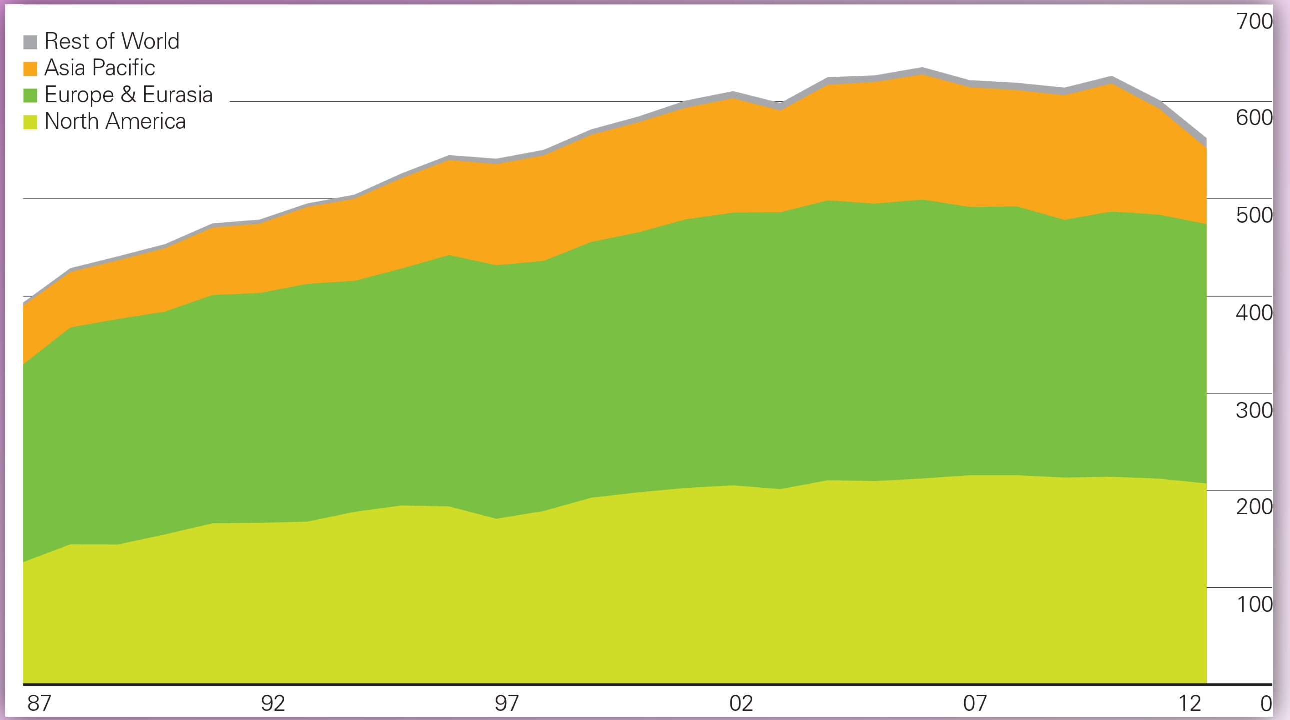
Hydroelectricity consumption by region

(million tonnes oil equivalent)



BP Statistical Review of World Energy, June 2013

Nuclear energy consumption by region
(million tonnes oil equivalent)



BP Statistical Review of World Energy, June 2013

Nuclear energy has the associated problems of proliferation and security (terrorism).

Nuclear energy cannot be ramped up fast enough to impact short-term CO_2 emissions. Because nuclear energy is not CO_2 neutral, its effect on reducing climate effects over the short term is modest.

Costs are rising for nuclear, but falling for many renewables.

Some nuclear energy externalities

a. Uranium ore mining – hundreds of metric tons of sulfuric acid, nitric acid and ammonia are required
b. Extraction of 0.2% U_3O_8 from ore
c. Converting U_3O_8 into UF_6
d. Enriching UF_6
e. Fabricating fuel pellets of UO_3 and packing fuel rods
f. Constructing the reactor (typically ~12 y)
g. Operating the reactor
h. Reprocessing spent fuel
i. Conditioning spent fuel
j. Storage of radioactive waste on-site (cooling)
k. Transporting waste to permanent storage facility
l. Storing waste at a permanent facility
m. Decommissioning reactor
n. Reclaiming uranium mines and other facilities

What Will Work, K. Shrader-Frechette, Oxford, 2011

Some information about the nuclear power industry

a. US utilities were pressured into the nuclear-electricity business for military reasons
b. France's nuclear industry is state-subsidized; does not need to be profitable; is commonly bailed out by government
c. There is no nuclear renaissance; no new nuclear construction is occurring on *the free market*; there are large taxpayer-government subsidies; many new reactors were begun two decades ago; growth in renewables is challenging the economics of nuclear
d. Why not more renewables? Skewed energy subsidies
e. Energy mix
f. Uranium depletion

What Will Work, K. Shrader-Frechette, Oxford, 2011

Clean Coal

Carbon capture and sequestration (CCS)

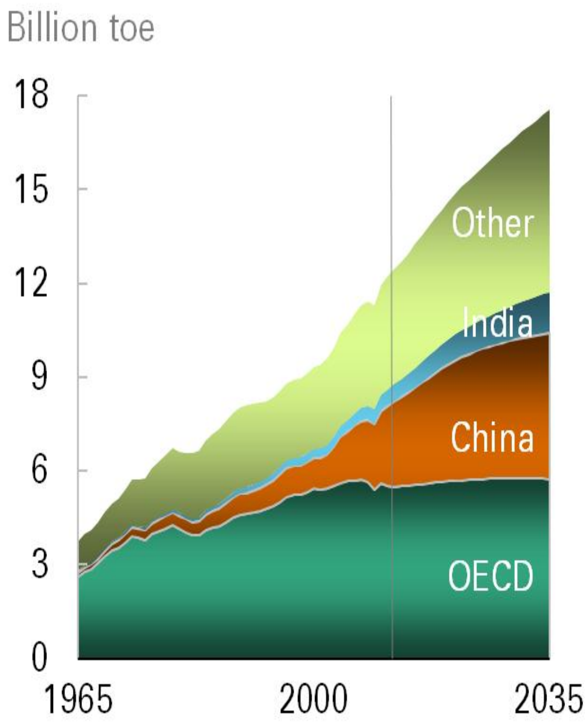
a. Cleaning up coal is not only a carbon issue
b. No assurance of long-term success with CCS
c. Health/financial liabilities from CO_2 venting
d. Costs of permanent sequestration uncertain
e. Long-term reliability of sequestration uncertain

Clean coal technology cannot be implemented fast enough to meet short-term GHG emission targets.

BP Forecasting

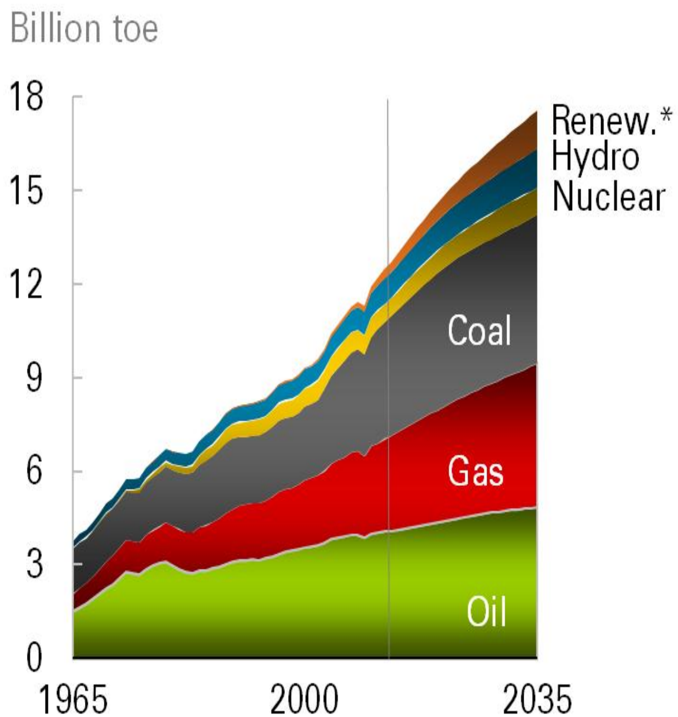
Primary energy consumption growth slows

Consumption by region



The slowdown in China and industry is reflected in coal

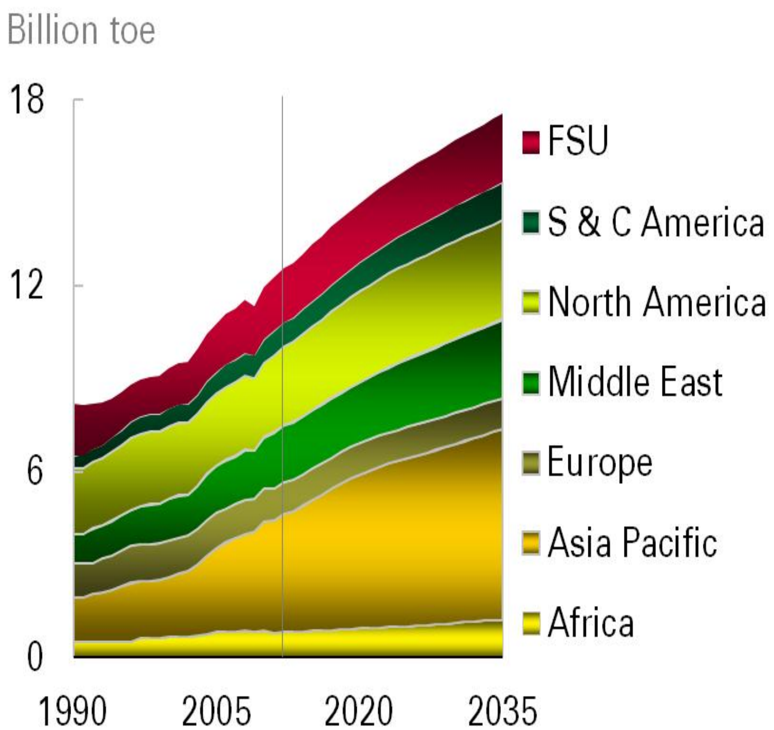
Consumption by fuel



*Includes biofuels

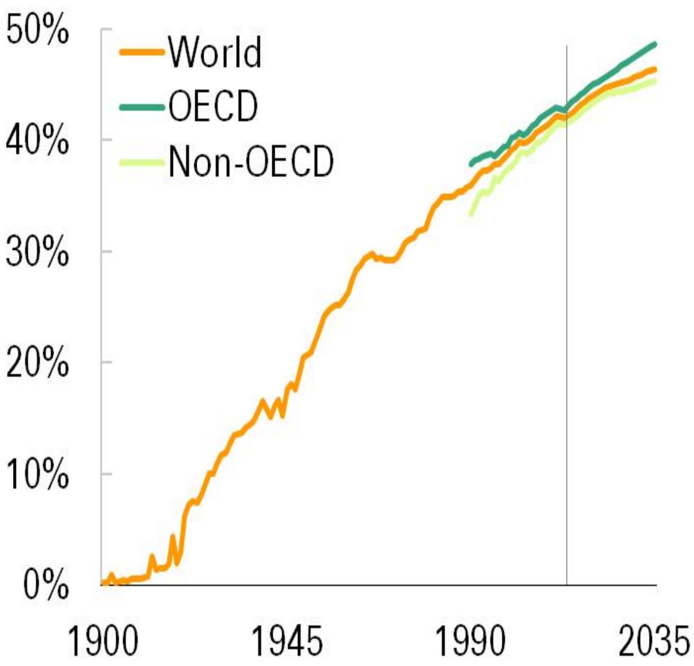
New sources help to supply sufficient energy

Primary energy production

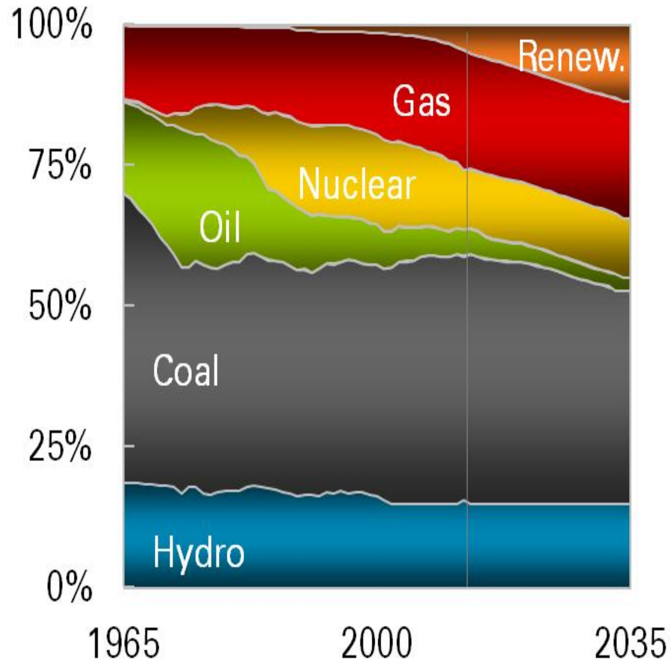


The power sector takes an increasing share of energy

Inputs to power as a share of total primary energy

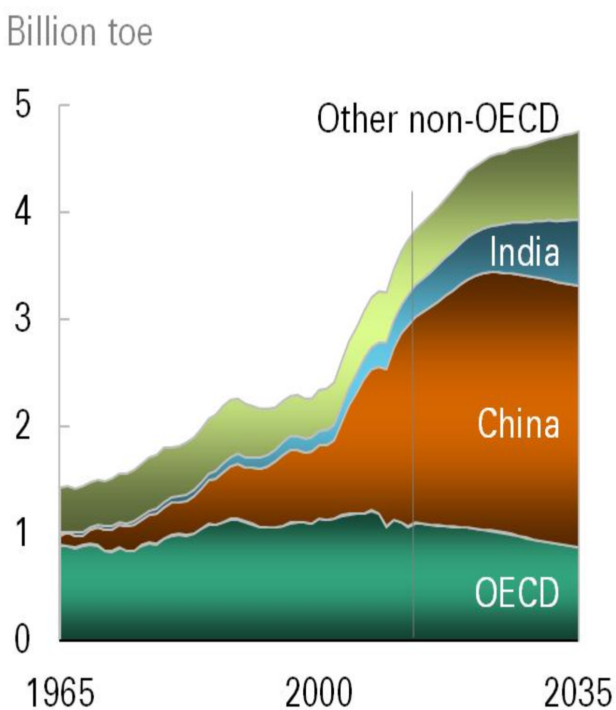


Primary inputs to power

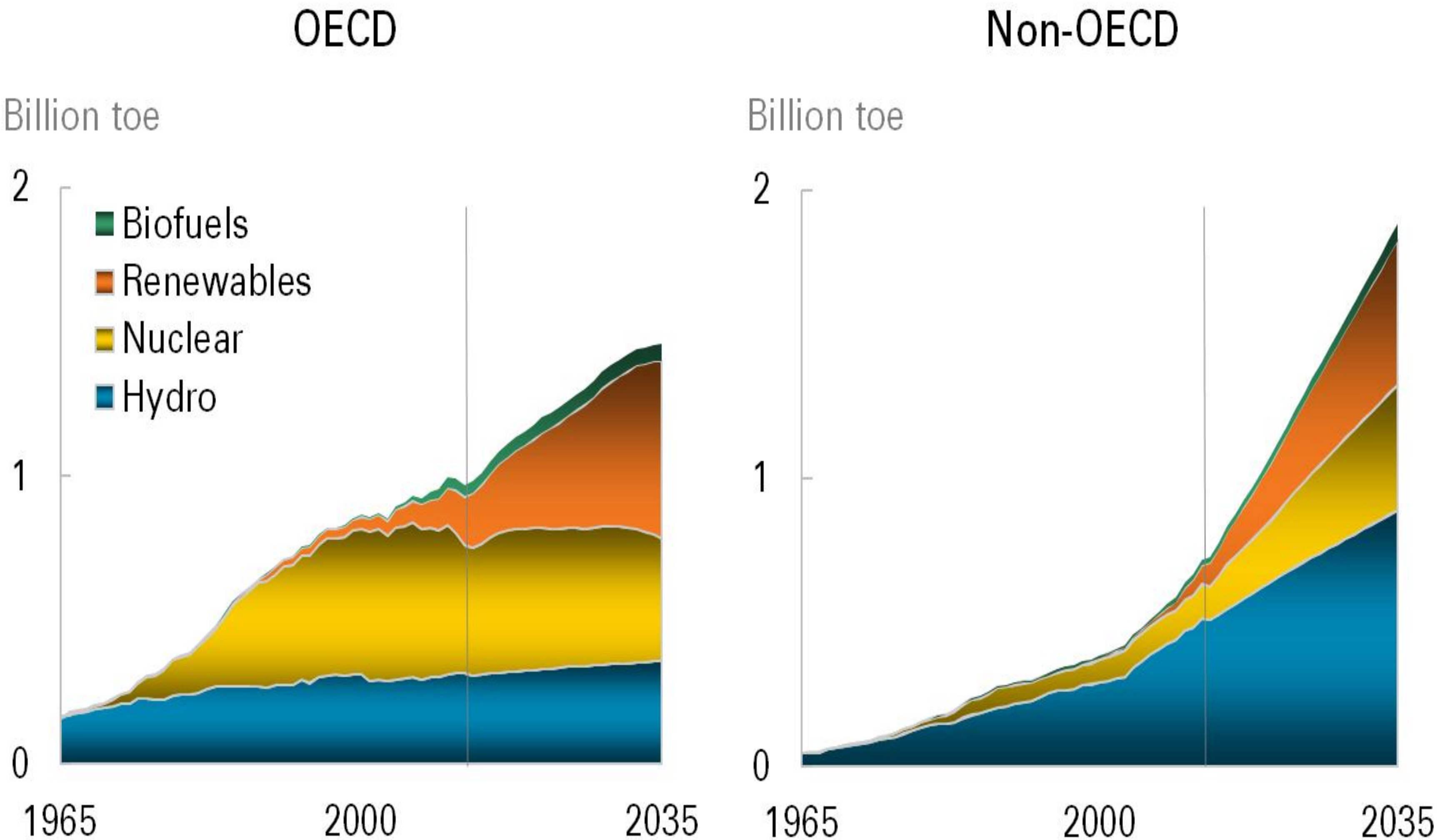


Coal consumption growth slows in the non-OECD

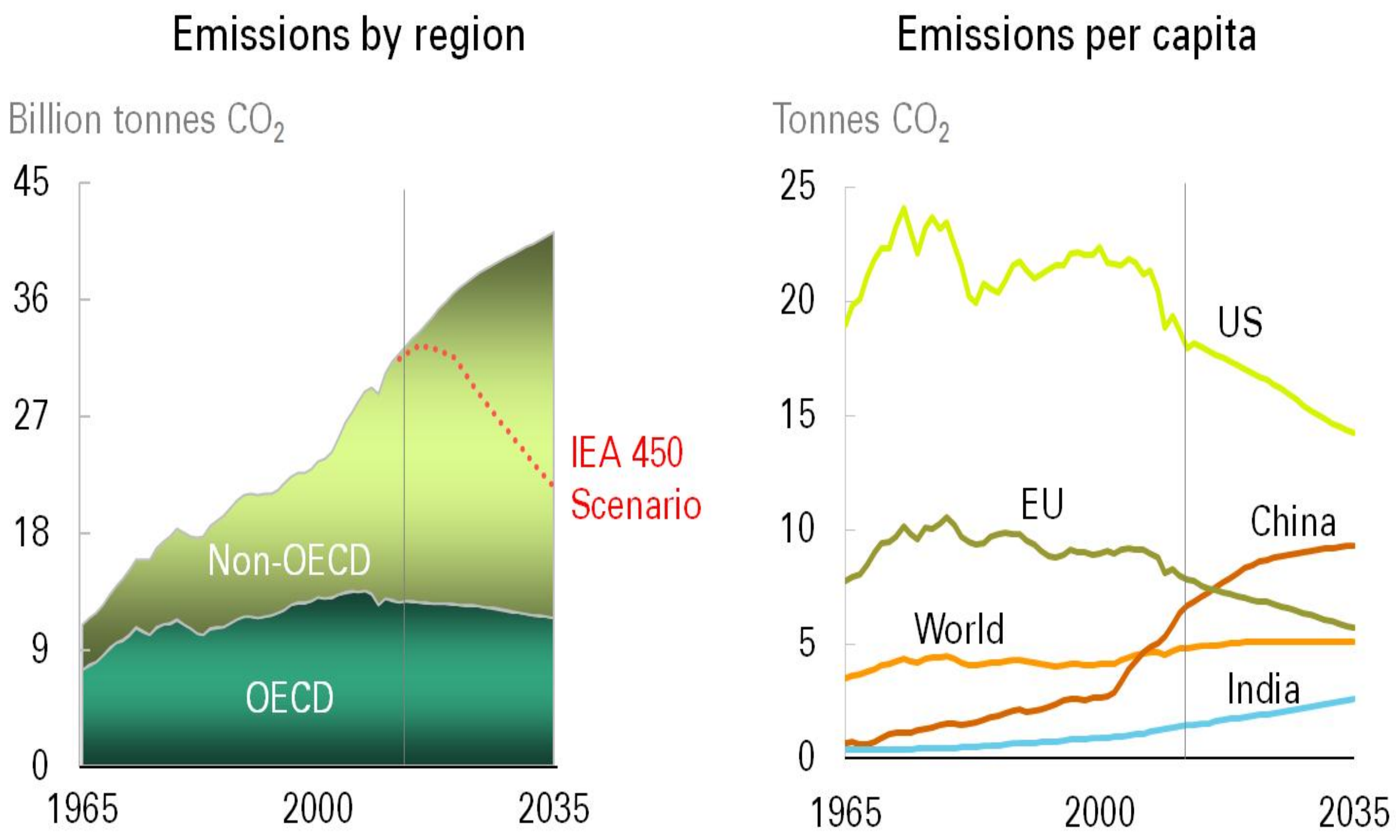
Consumption by region



Non-fossil fuels grow rapidly

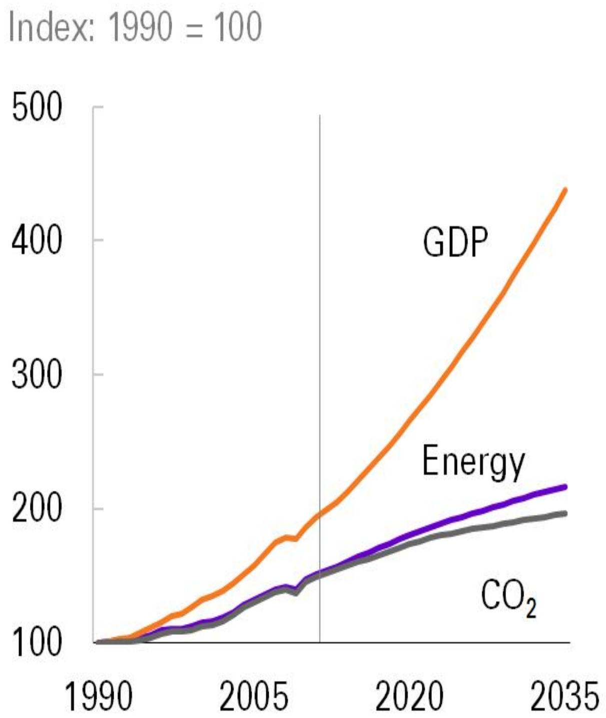


CO_2 emissions from energy use continue to rise



Energy efficiency and fuel mix restrain emissions growth

GDP, energy and emissions



Emissions growth 2012 to 2035