POLITECNICO DI MILANO

Universities for Expo 2015

Impacts of Climate Change on Ecosystem Services

Politecnico di Milano - June 23, 2015

Mitigation of greenhouse gas emissions

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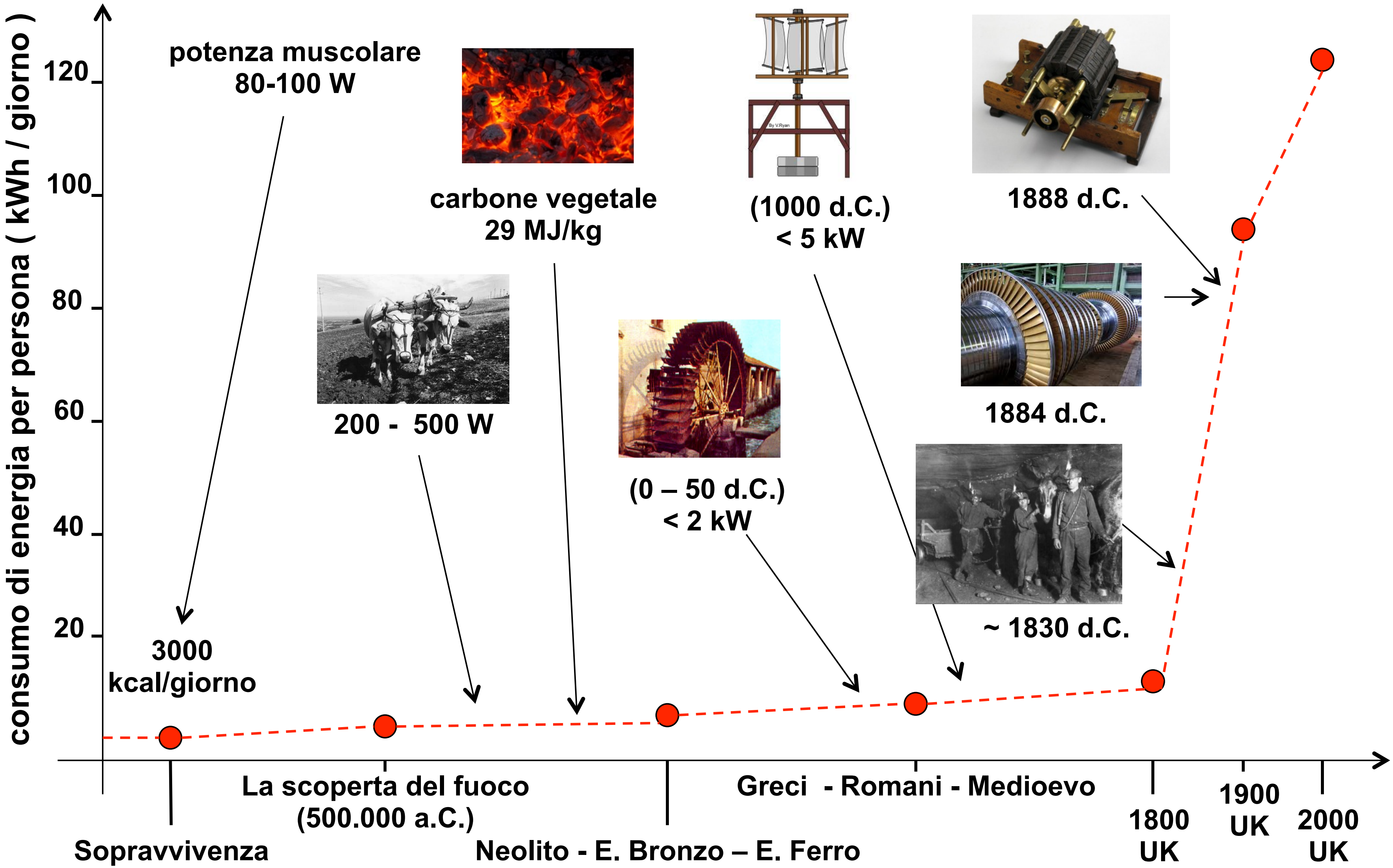
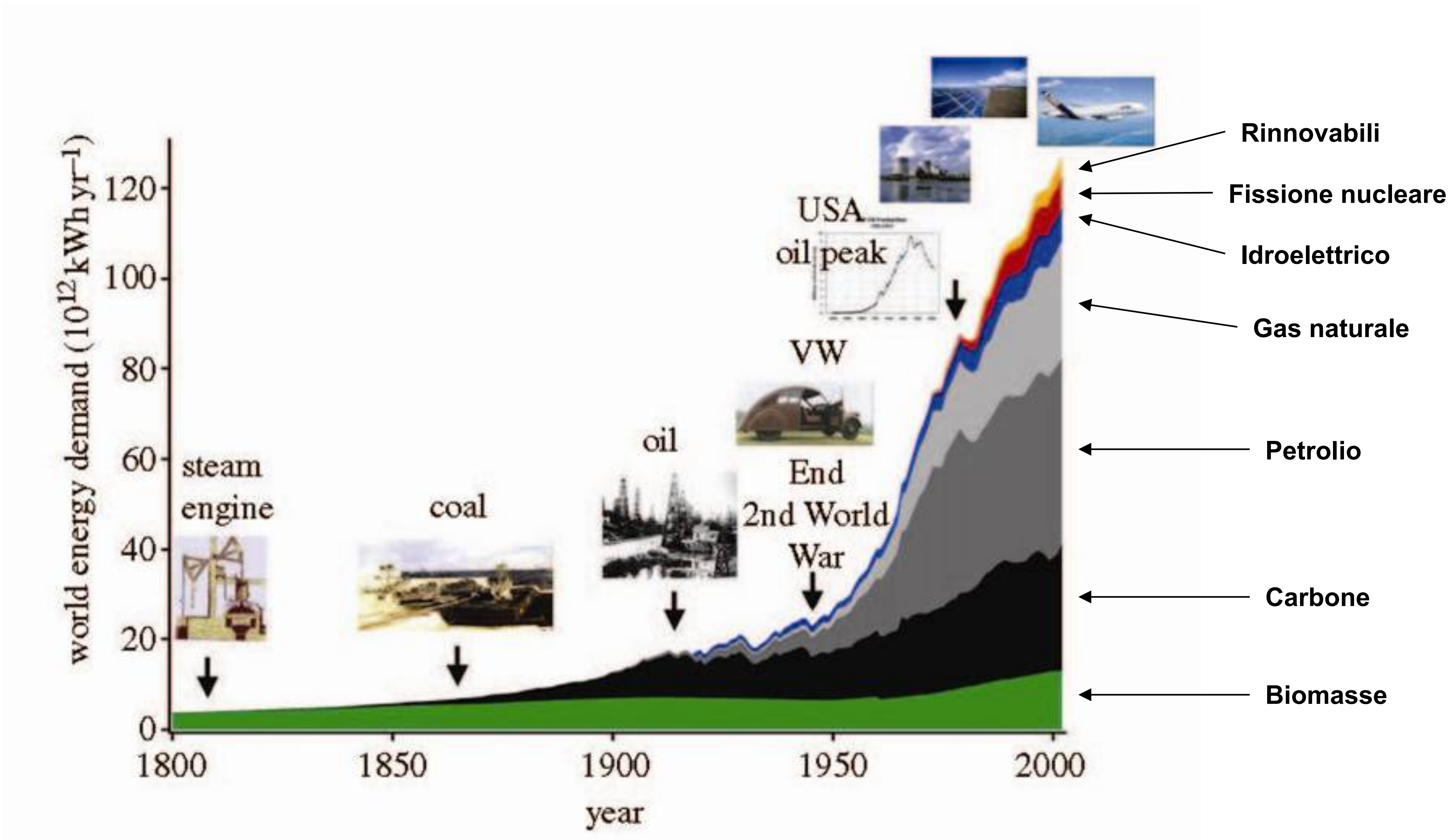
Energy and human development



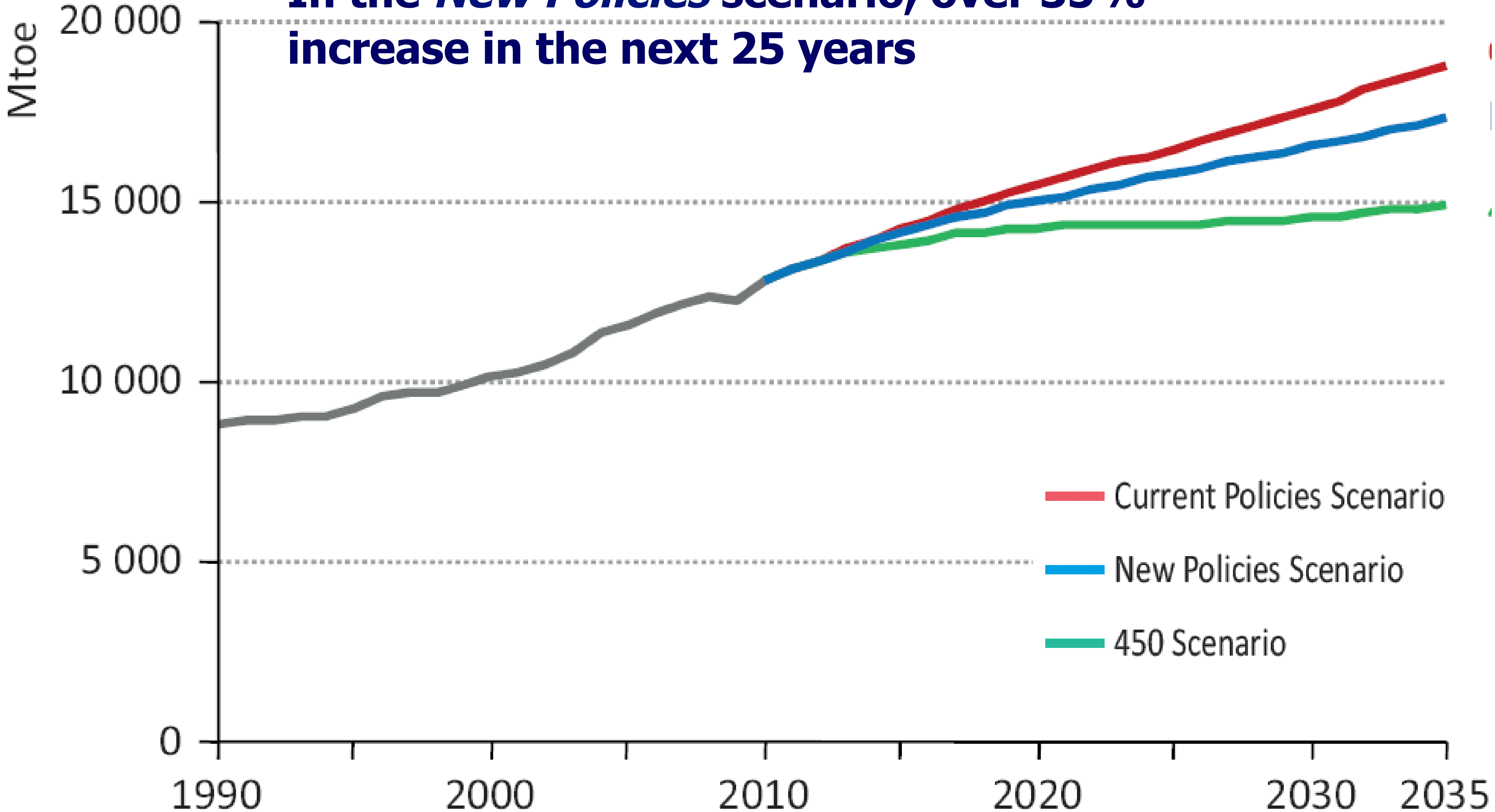
Energy and human development



fonte: Zuttel et al., 2010 – Hydrogen: the future energy carrier

World primary energy demand

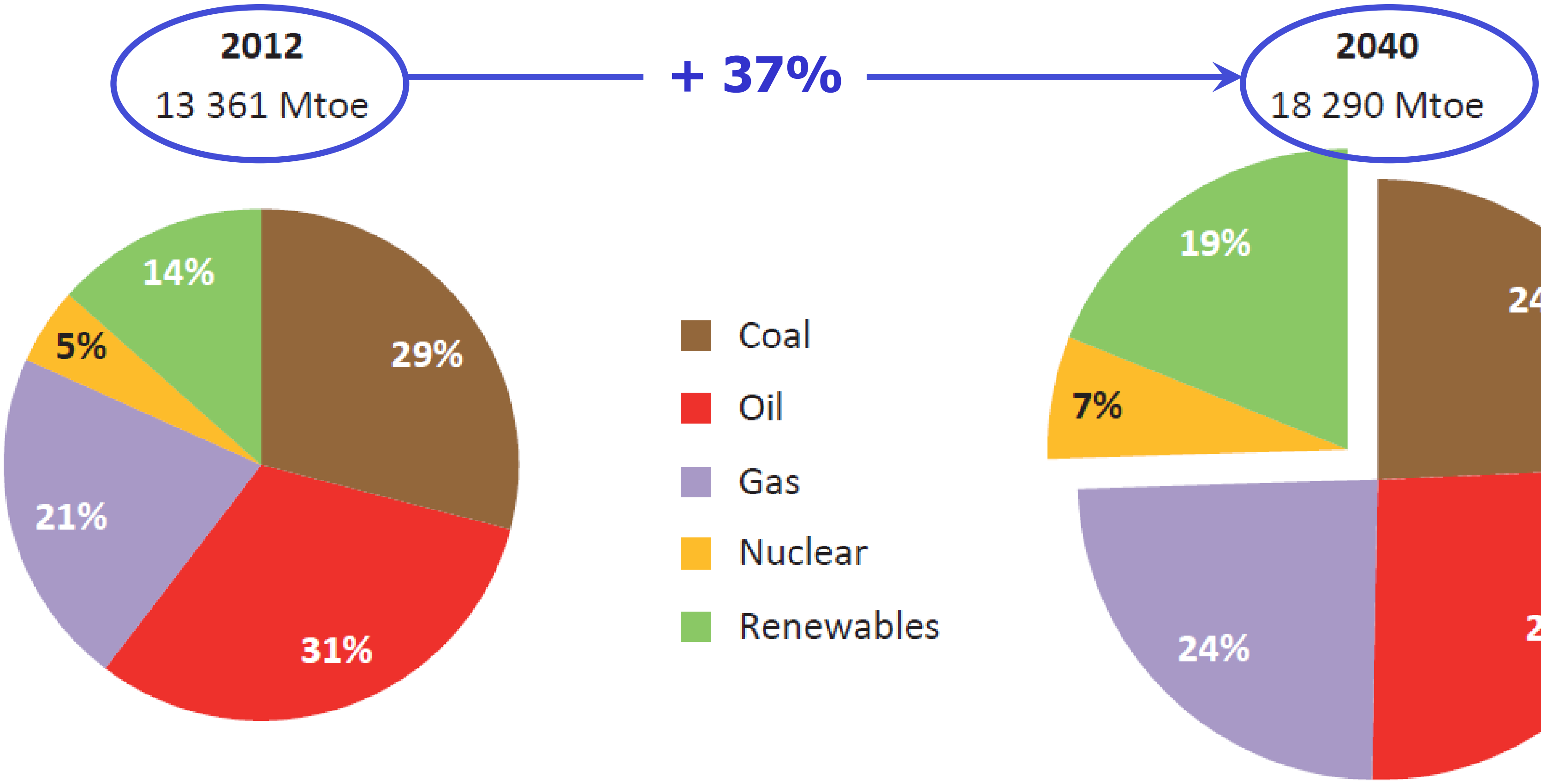
In the *New Policies* scenario, over 35% increase in the next 25 years



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

Primary energy demand - by fuel

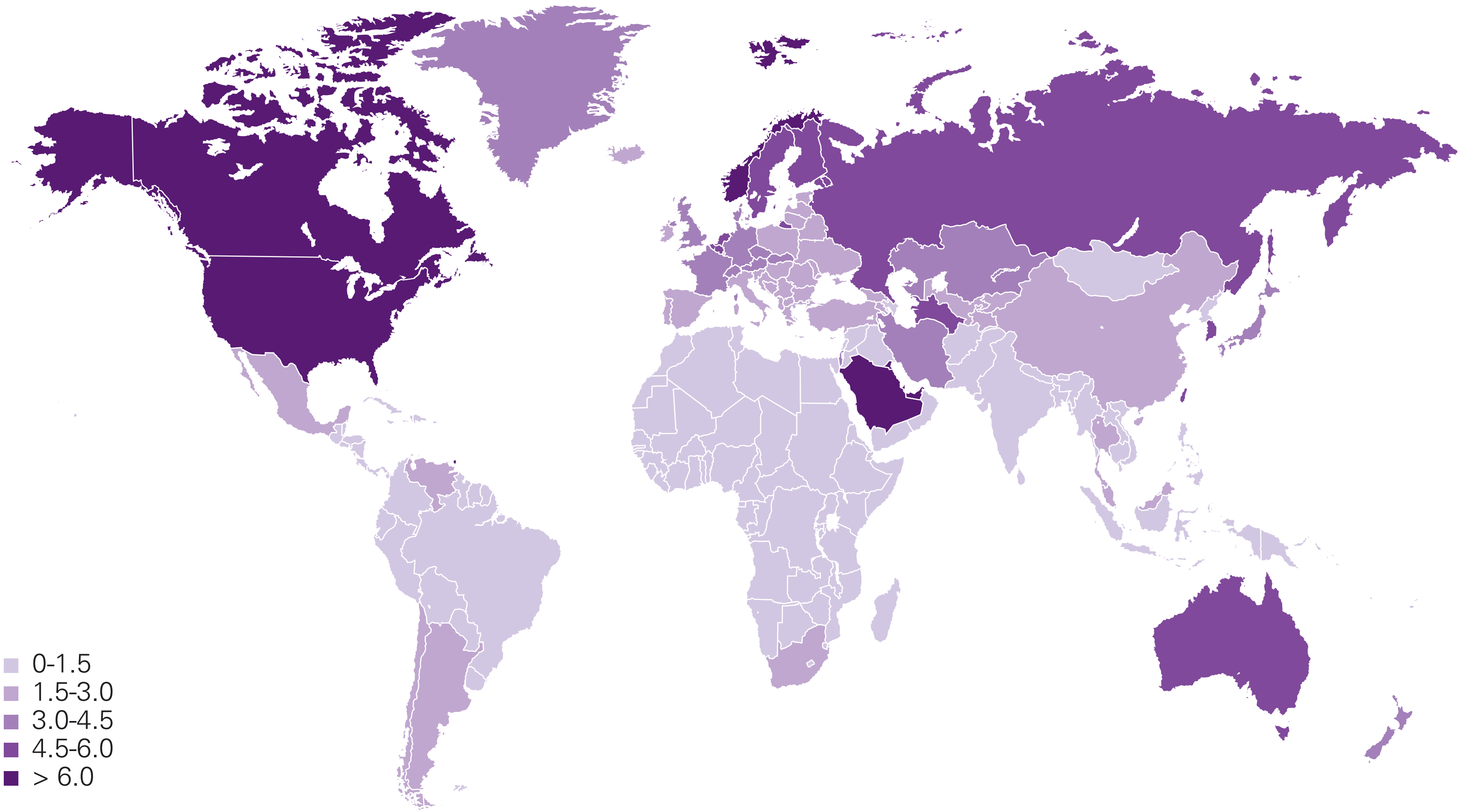
New Policies scenario



Source: World Energy Outlook ***2014****, International Energy Agency*

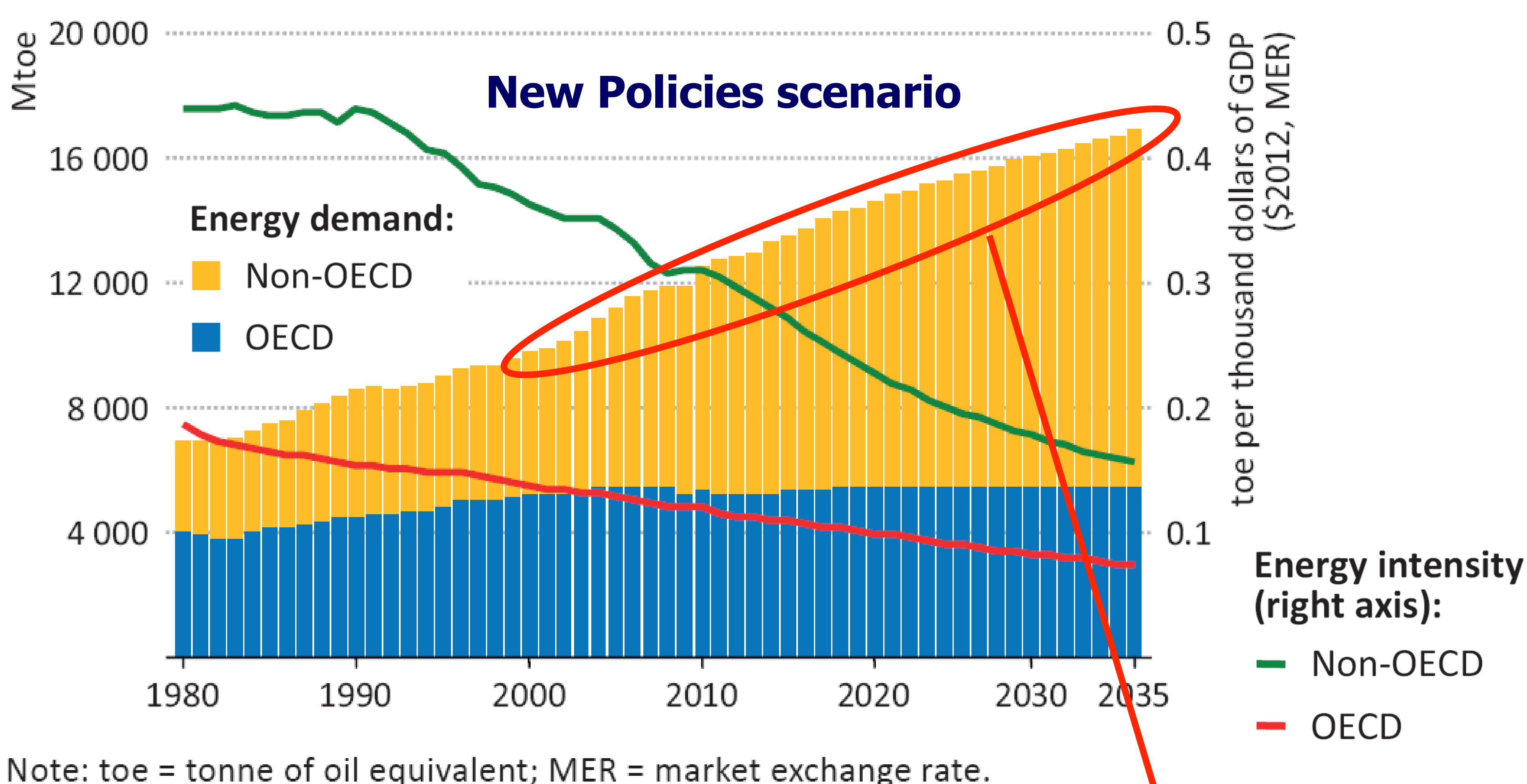
Primary energy consumption per capita (2013)[6]

Source: BP Statistical Review 2014



World average ~ 12.5 GToe / 7 billion people ~ 1.8 Toe per capita

The expanding role of developing countries



Increase in population and evolution of lifestyle overcome decrease of energy intensity --> increase of energy demand

Source: World Energy Outlook ***2013***
International Energy Agency

Primary energy demand - by fuel

Overwhelming role of fossil fuels: in 2010, 81% of total

New Policies scenario

	1990	2010	2015	2020	2030	2035	2010-35*
Coal	2 231	3 474	3 945	4 082	4 180	4 218	0.8%
Oil	3 230	4 113	4 352	4 457	4 578	4 656	0.5%
Gas	1 668	2 740	2 993	3 266	3 820	4 106	1.6%
Nuclear	526	719	751	898	1 073	1 138	1.9%
Hydro	184	295	340	388	458	488	2.0%
Bioenergy**	903	1 277	1 408	1 532	1 755	1 881	1.6%
Other renewables	36	112	200	299	554	710	7.7%
Total	**8 779**	**12 730**	**13 989**	**14 922**	**16 417**	**17 197**	**1.2%**

*Compound average annual growth rate. ** Includes traditional and modern biomass uses.

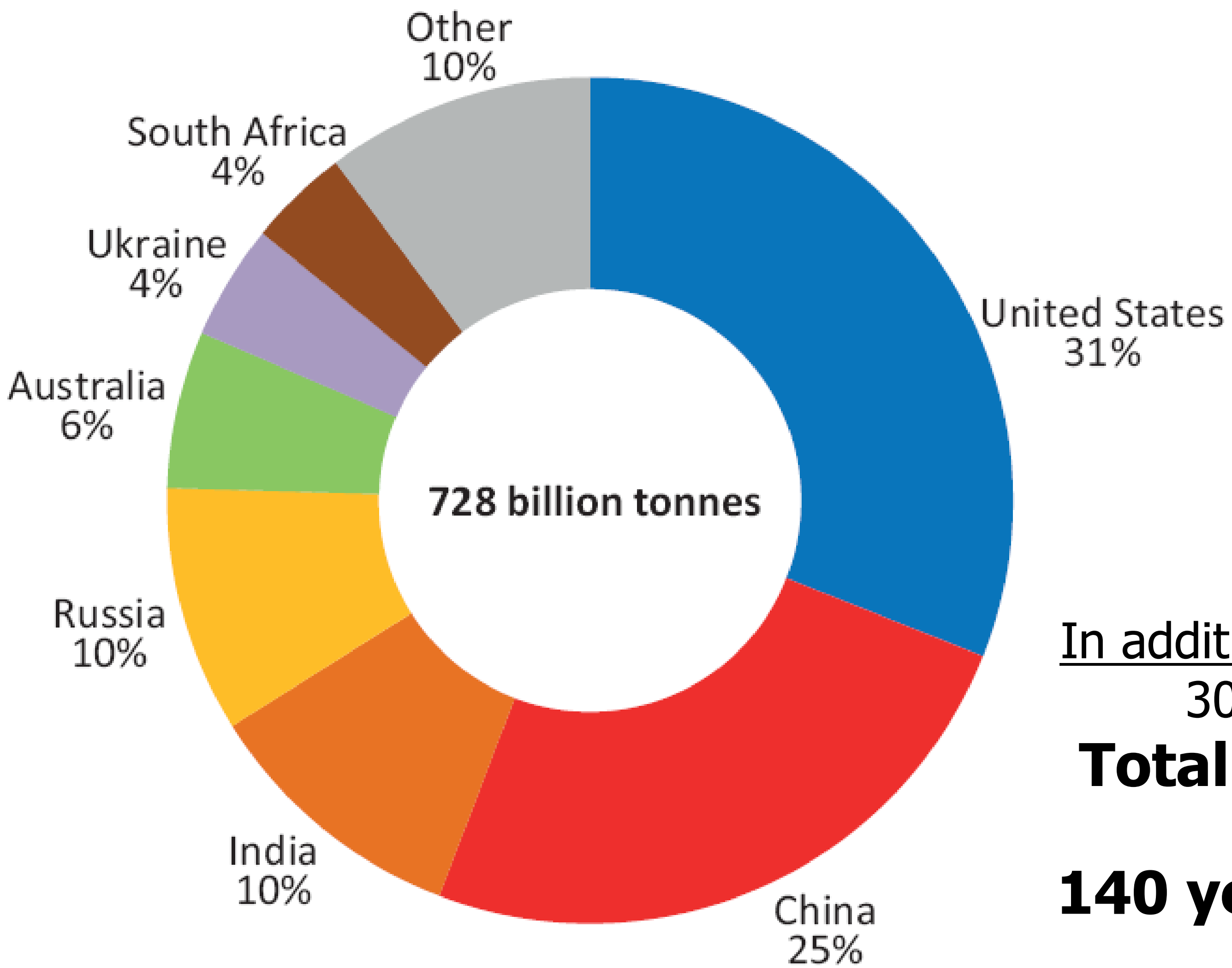
All data in Million Toe (except growth rate)

Bioenergy dominates non-fossil sources

35% increase over 25 years

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

World hard coal reserves at end of 2010



In addition, reserves for about 300 billion tons of lignite

Total of 1 trillion tons is equivalent to about **140 years** of current global coal production

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

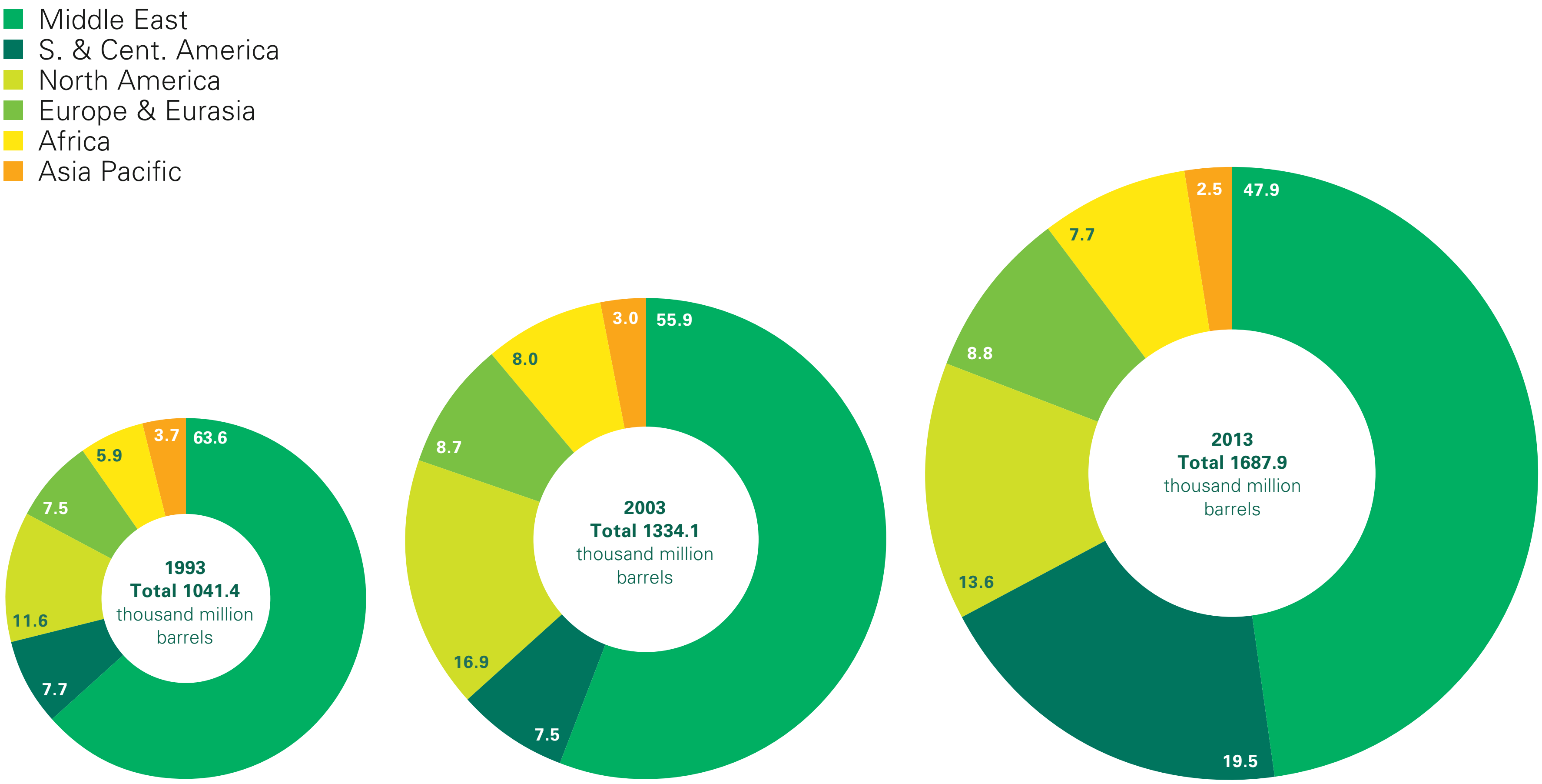
Reserves / Production ratio

$$\frac{R}{P}\,[\text{years}] = \frac{\text{Reserves [barrels]}}{\text{Production [barrels/year]}}$$

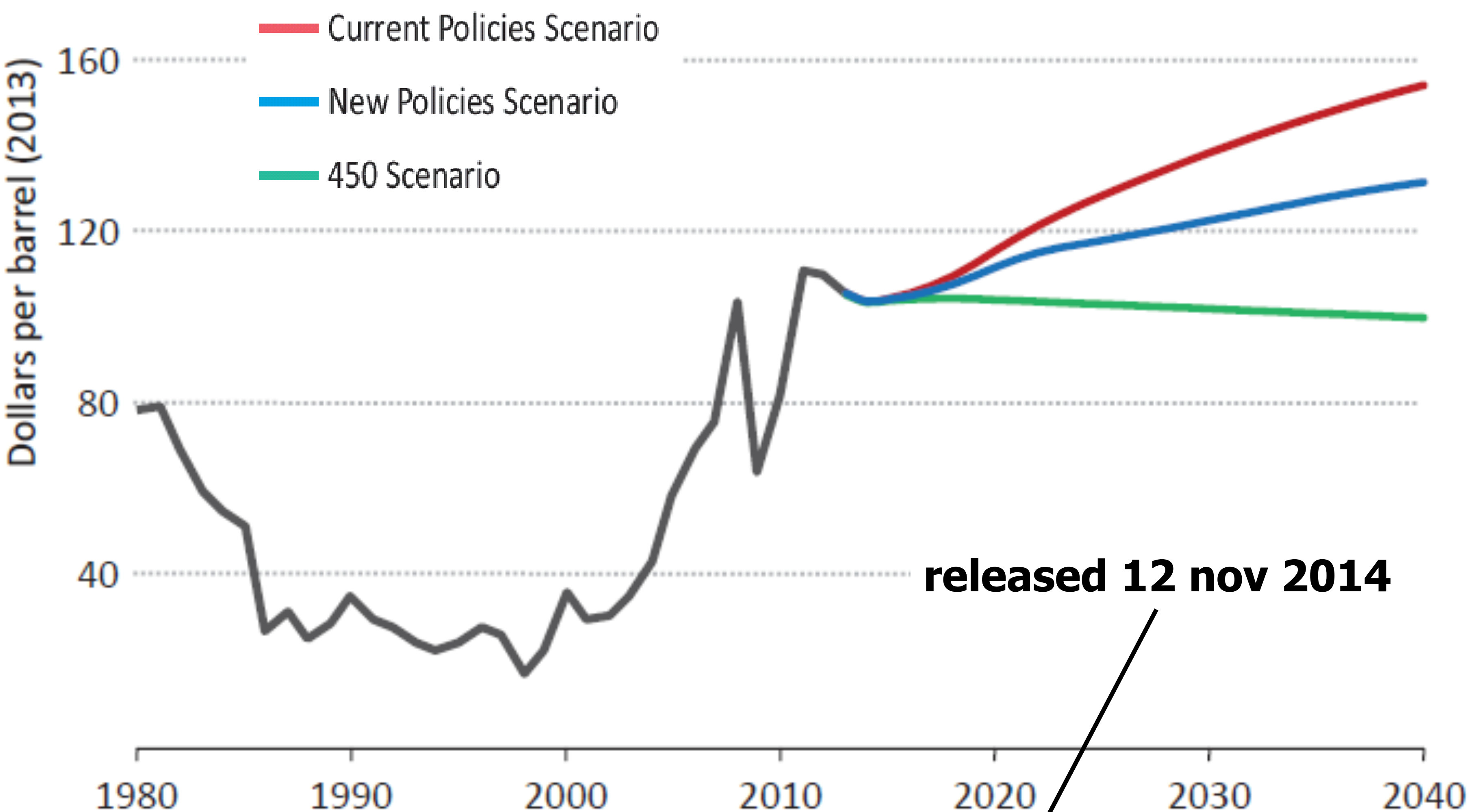
- The R/P ratio tells us for **how many years we can maintain current production until reserves are depleted**
- In a "STATIC" world where reserves, prices and production remain constant, the R/P ratio would progressively decrease year by year
- But in pratice the R/P ratio changes due to changes in:
  - Reserves
  - Prices
  - Production

Evolution of proved oil reserves

Source: BP Statistical Review 2014

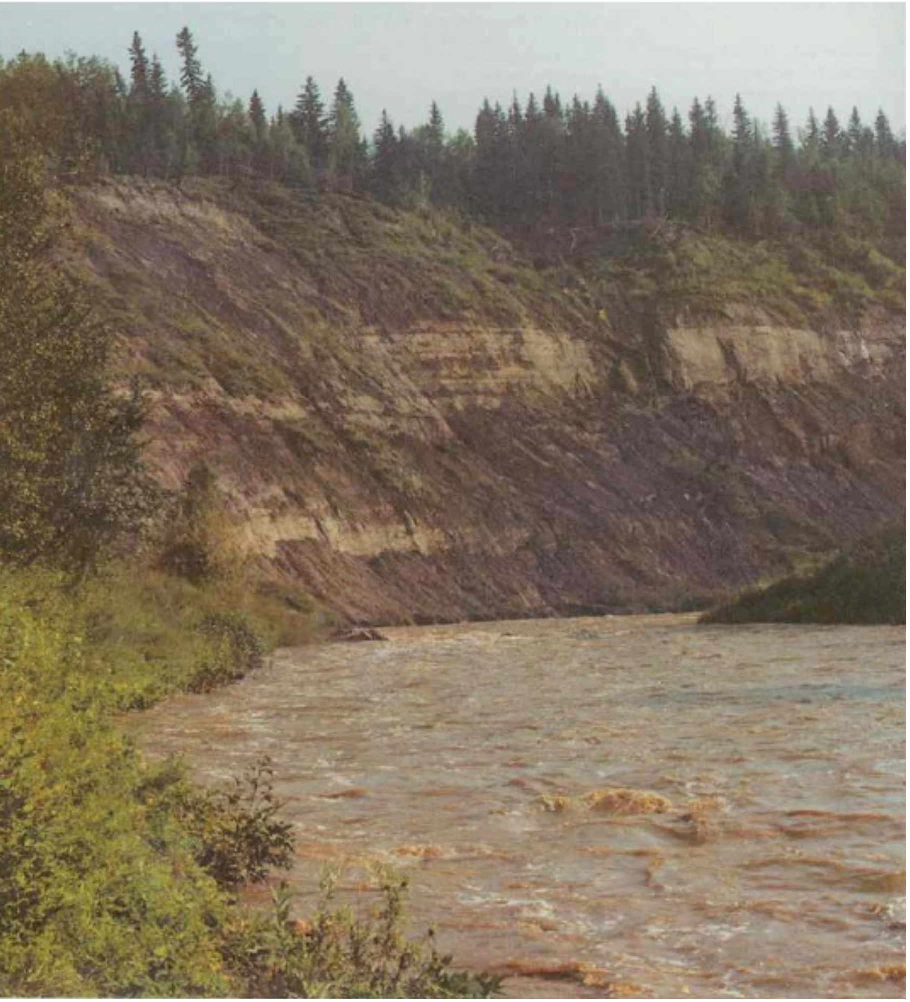


Average IEA crude import price - by scenario



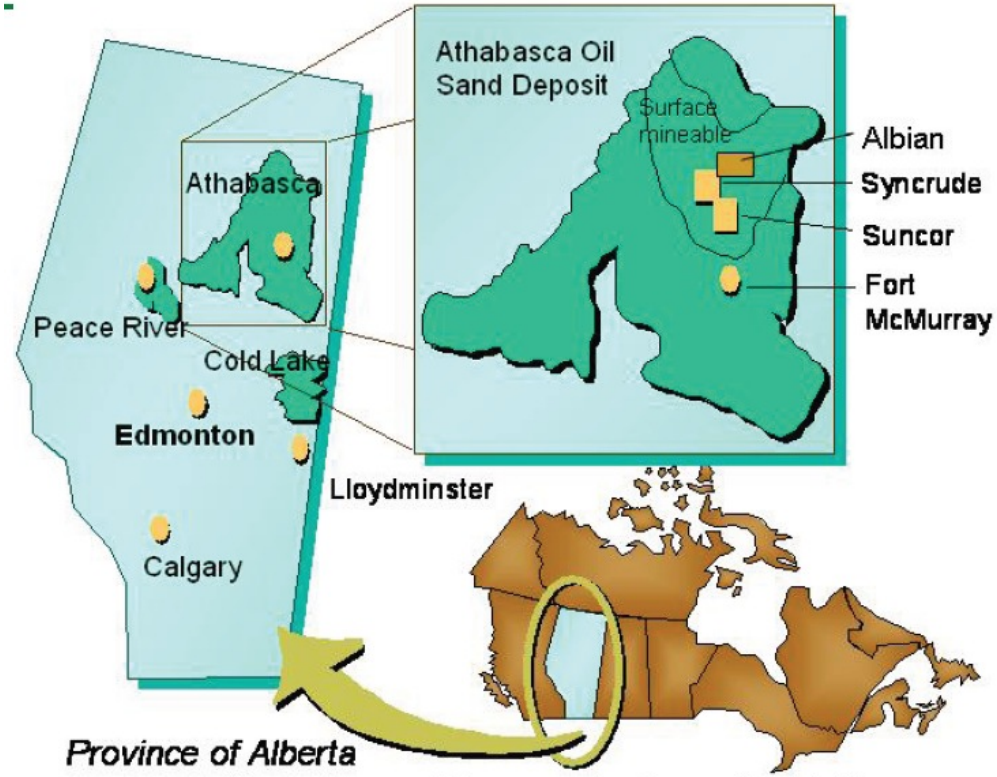
*Source: World Energy Outlook **2014**, International Energy Agency*

Un-conventional sources: Oil sands



Total bitumen in place: over 2500 billion bbl

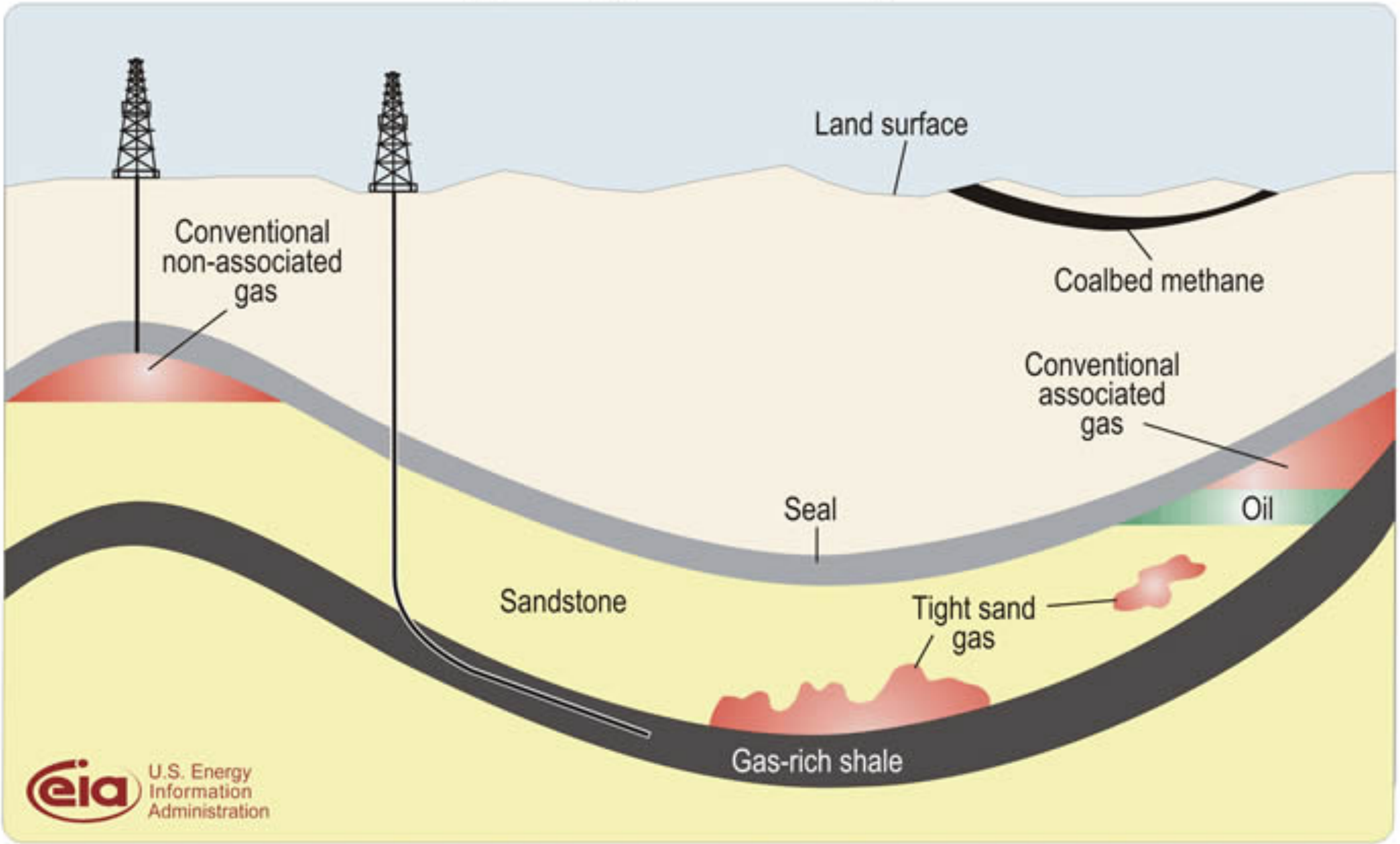
1300 billion in Athabasca



(Courtesy of Syncrude Canada Ltd.)

Shale gas

Schematic geology of natural gas resources



Fossil fuel reserves at end of 2011

	Coal* (billion tonnes)		Natural gas (tcm)		Oil (billion barrels)	
	Proven reserves	Recoverable resources	Proven reserves	Recoverable resources	Proven reserves	Recoverable resources
OECD	427	10 657	28	193	244	2 345
Non-OECD	576	10 551	205	597	1 450	3 526
World	**1 004**	**21 208**	**232**	**790**	**1 694**	**5 871**
Share of non-OECD	*57%*	*50%*	*88%*	*76%*	*86%*	*60%*
R/P ratio (years)	132	2 780	71	241	55	189

* For coal, the data are for 2010.

Notes: R/P ratio = Reserves-to-production ratio based on 2011 levels of production. Resources are remaining technically recoverable resources.

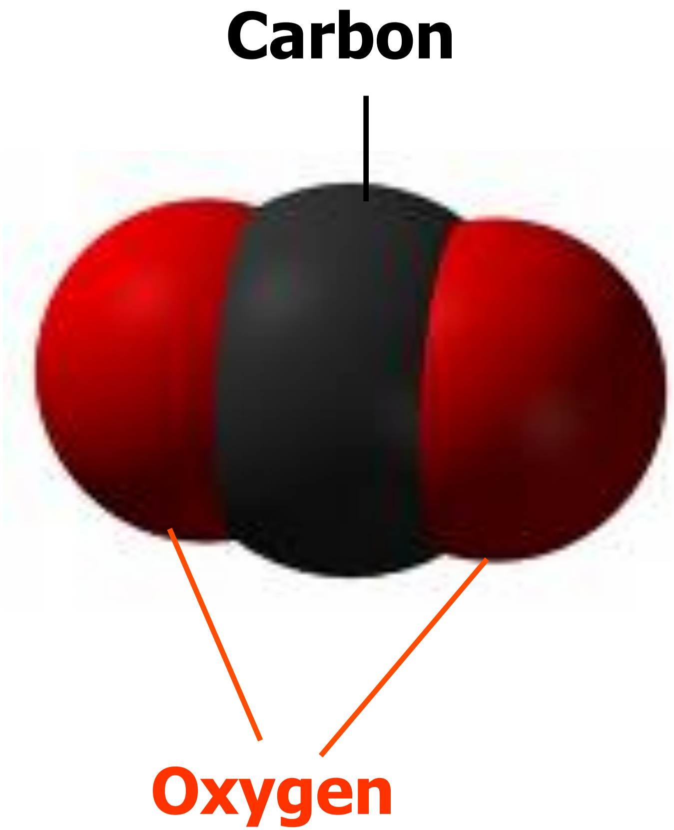
Sources: BGR (2011); O&GJ (2011); USGS (2000); USGS (2012a); USGS (2012b); IEA databases and analysis.

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

Outlook for Fossil Energy Sources

- When considering the contribution of unconventional sources and new technologies, the reserves of oil and natural gas appear capable of meeting world demand well within the XXII century
- Much longer prospects for coal
- Established, efficient and reliable allow the production of useful energy from fossil fuels at low cost
- In summary, the use of fossil fuels does NOT raise great concerns regarding their availability - at least for this century - nor about the technologies needed to use them
- Concerns are mainly related to ENVIRONMENTAL IMPLICATIONS

Impact on Environment: global scale



- **Main product of combustion process**
- **Basic product of biological processes: after being carried by blood, CO_2 is transferred to the respiratory system by lungs and it is eventually exhaled**
- **Basic input for chlorophyll photo-synthesis**
- **Widely used in the food industry (e.g. mineral water)**
- **Due to concerns on Climate Changes it may be considered a pollutant**
- **Being heavier than air, when stratified it can cause asphyxia**

The five routes for the long term

0) Do nothing (and adapt)

This looks risky

1) Reduce demand / increase efficiency

This is appealing, but it's not enough

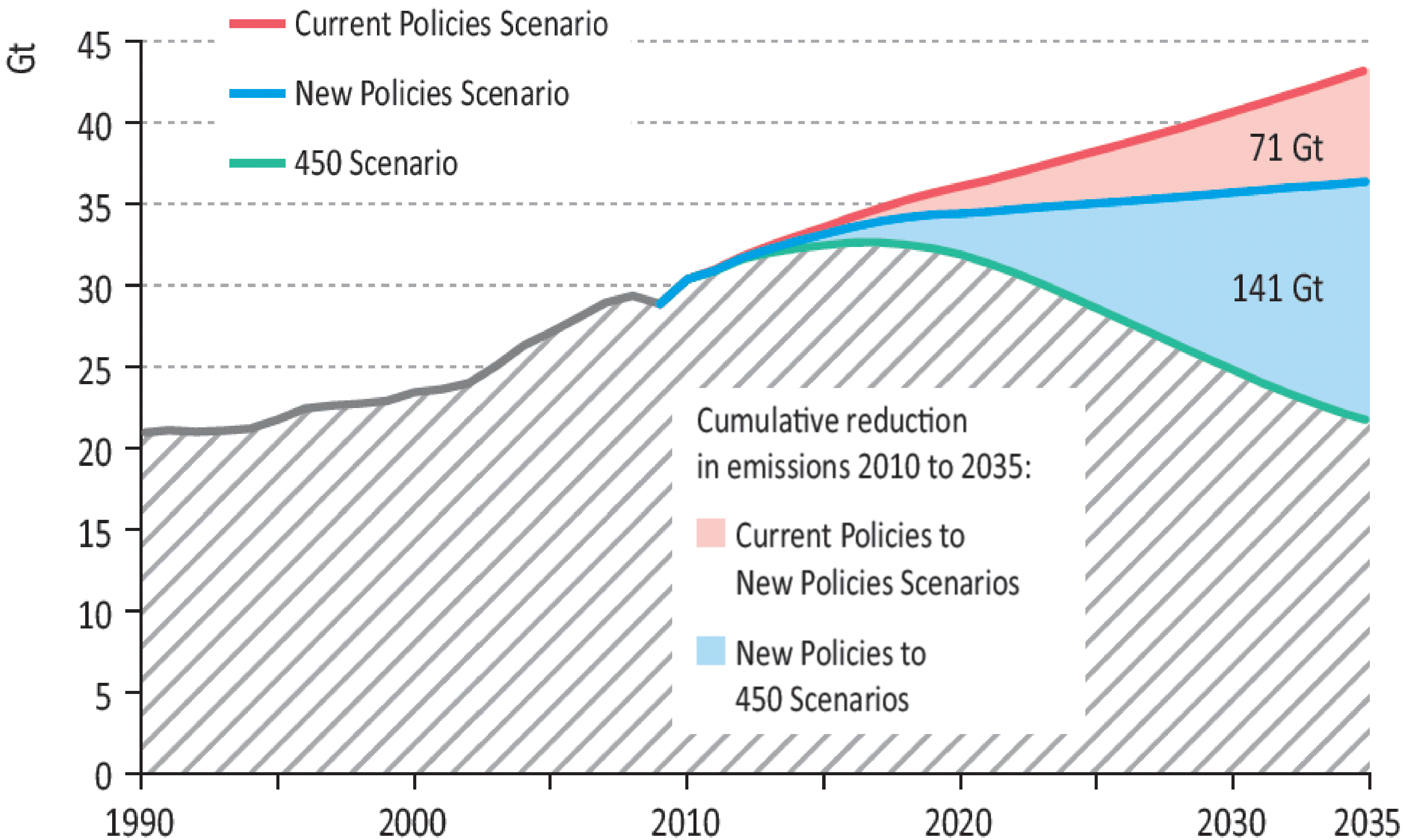
2) Renewable sources
- hydro
- biomass
- wind
- geothermal
- solar

3) Nuclear
- thermal fission
- self-breeding fission
- fusion

4) CO_2 Capture and Storage (CCS)
- a the stack
- from air

One or more of these ?

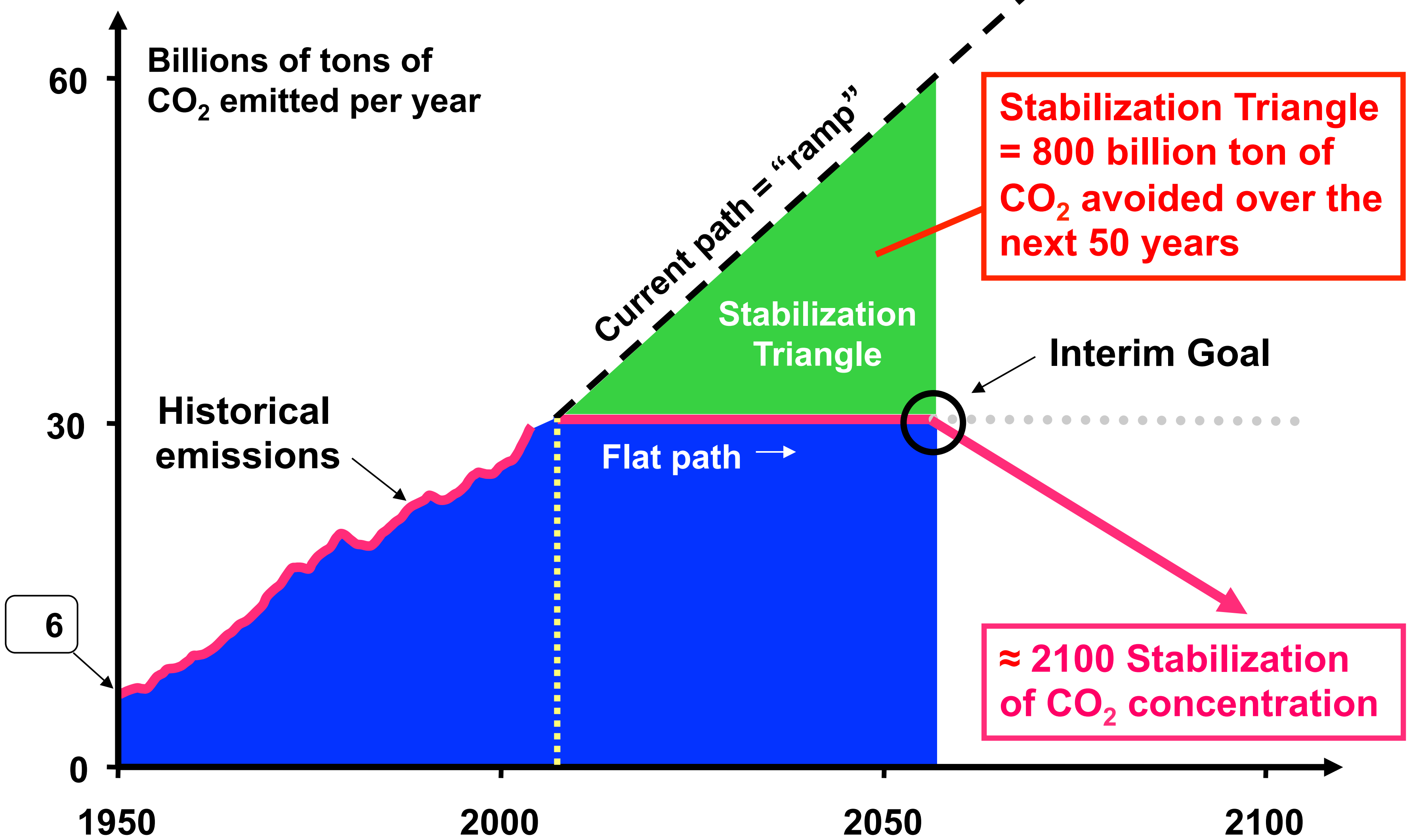
World energy-related CO_2 emissions - by scenario



*Source: World Energy Outlook **2011,** International Energy Agency*

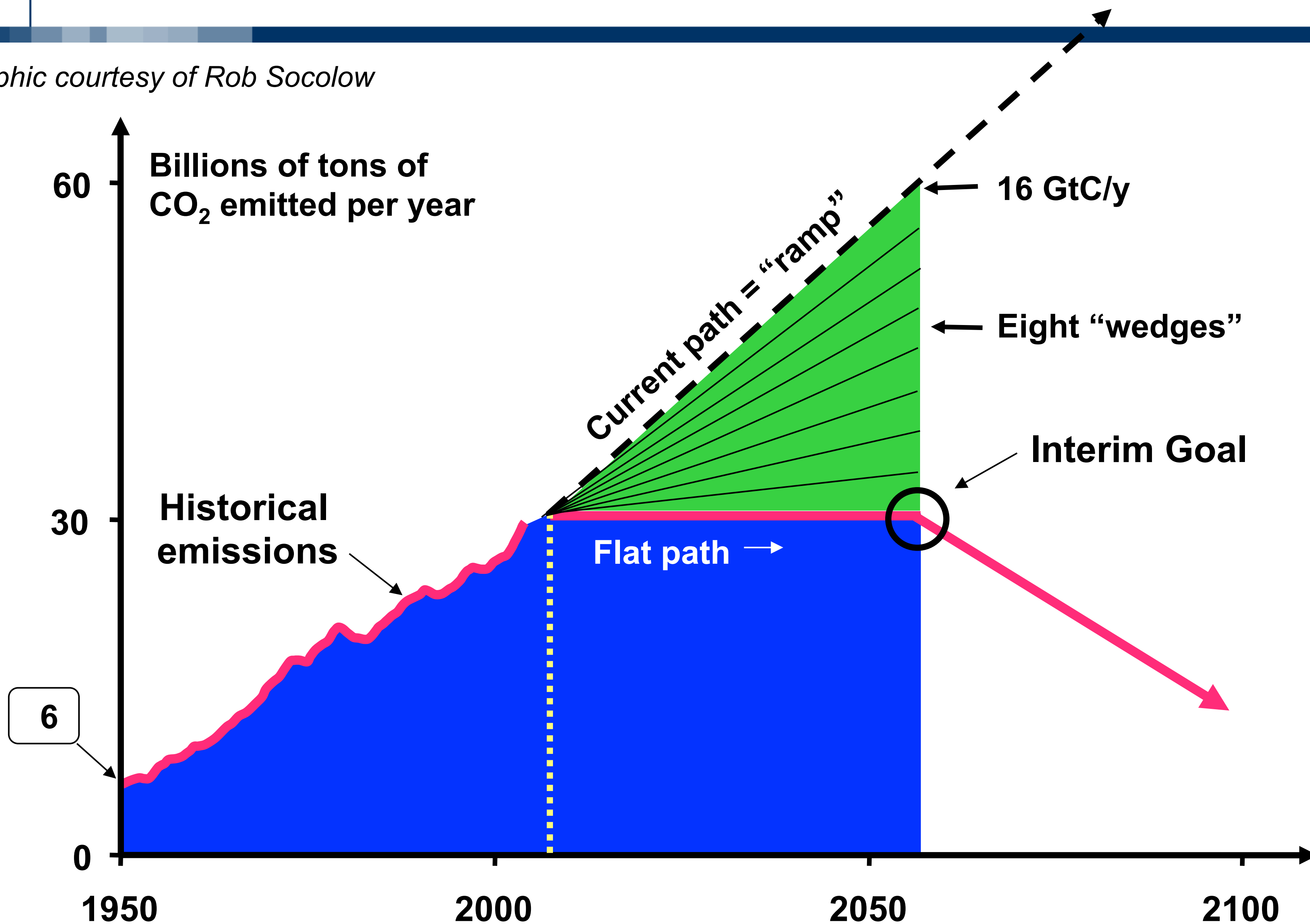
The Wedges approach: stabilization triangle

Graphic courtesy of Rob Socolow



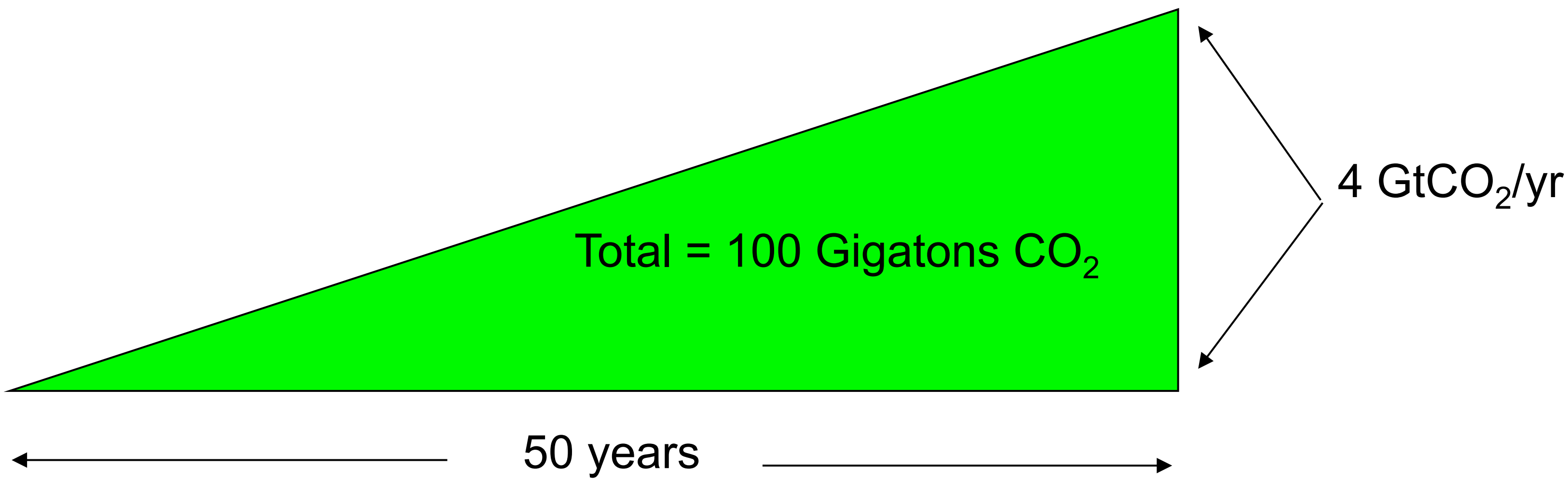
Stabilization Wedges

Graphic courtesy of Rob Socolow



What is a "Wedge"?

A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 4 $GtCO_2$/yr.
Such strategy accounts for **<u>1/8 of the stabilization effort</u>**



A wedge avoids the emissions of 100 $GtCO_2$.
This is six trillion dollars at \$60/tCO_2.

Graphic courtesy of Rob Socolow

Efficient use of fuel of Light Duty Vehicles (LDV)

Number of LDVs circulating in 2015 is ≈ 1 billion

At 12 km per liter, driving a LDV for 12,000 km emits ≈ 2,5 t of CO_2

In 2065, estimated 3 billion LDVs in 2065 will emit 7,5 Gt of CO_2

Effort needed by 2065 for 1 wedge (-4 Gt):

3 billion LDVs driven 12,000 km/yr at **not 12** but **25 km per liter**

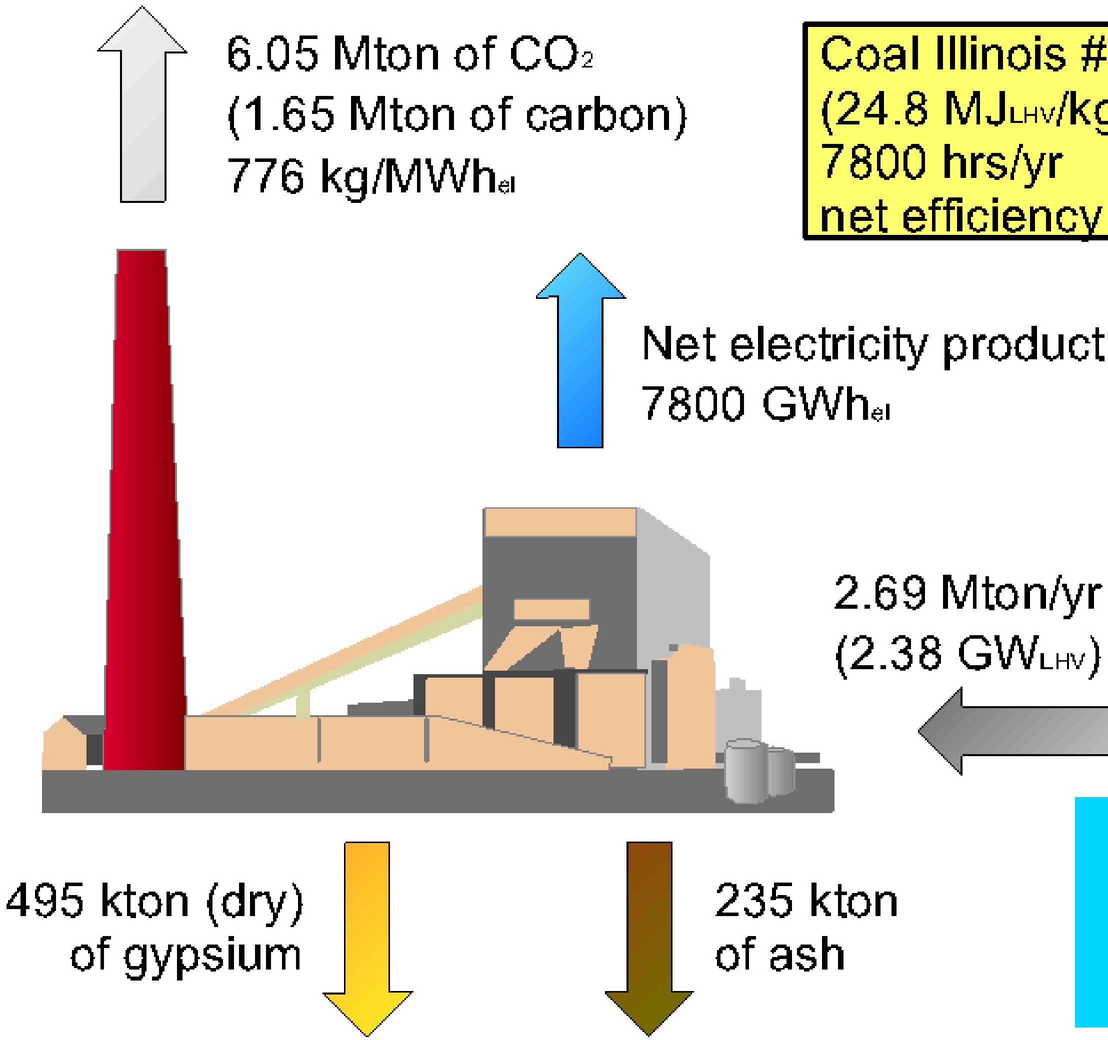
3 billion LDVs at 10 l/100km, driven **not 12,000** but **5,700 km/yr**

NOTE: *3 billion cars at **25 km/l AND driven 5,700 km/yr**: ≈ 1.5 wedges **--> effects do not add up !***

1 GW_{el} coal power station

660 GW of these coal-fired power stations emit 4 $Gton_C$/yr

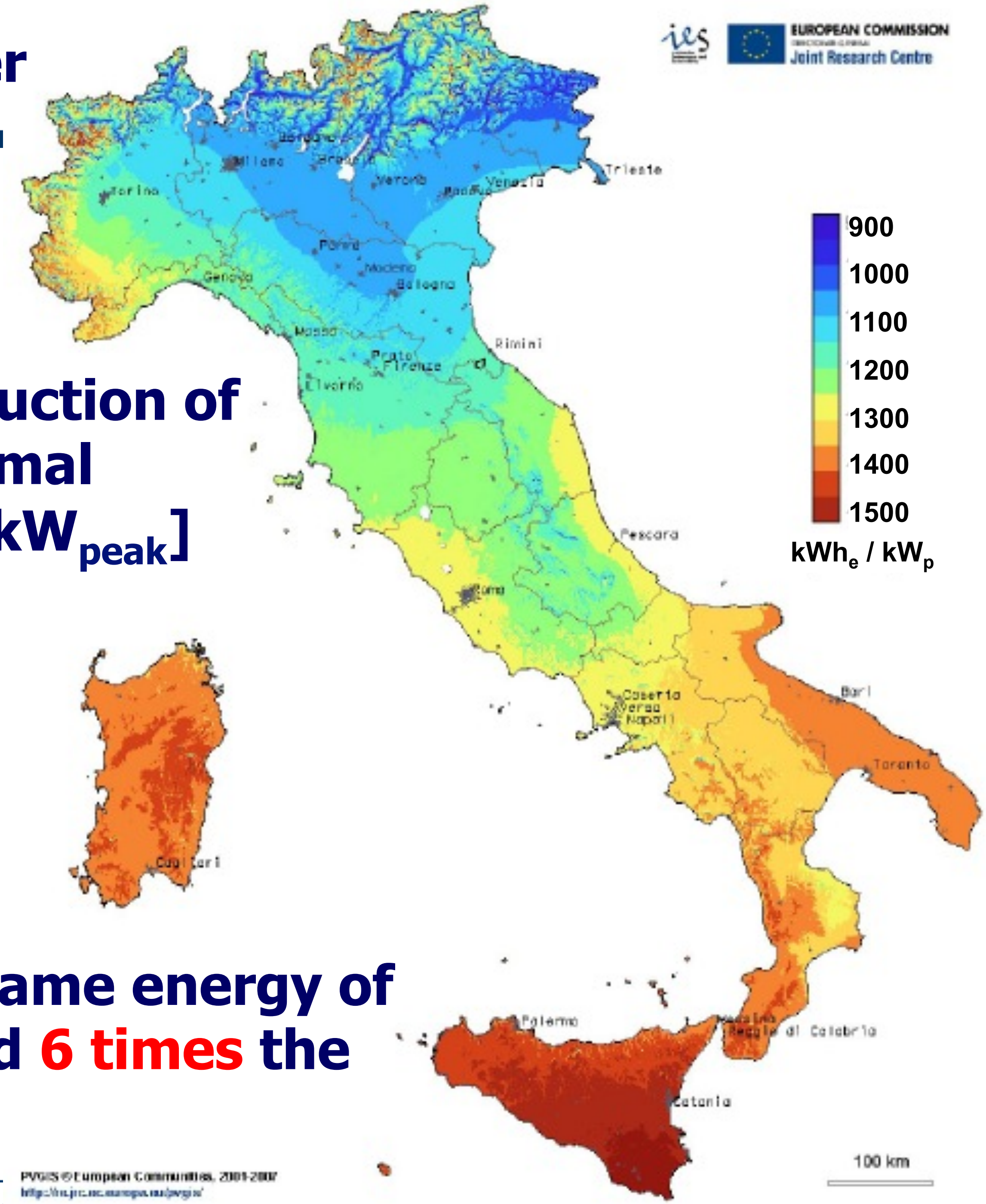
Coal Illinois #6
(24.8 MJ_{LHV}/kg, 0.613 kg_C/kg_{coal})
7800 hrs/yr
net efficiency 42%



1 electricity-supply wedge results from not installing such 660 GW capacity - or from capturing all the CO_2 it would generate

world coal-fired capacity expected by 2040: 2630 GW

Photovoltaic power



Yearly electricity production of PV cells placed at optimal inclination [kWh_e per kW_{peak}]

In Sicily, to produce same energy of a coal-fired plant need 6 times the installed power

Photovoltaic power

Effort needed by 2065 for one wedge:

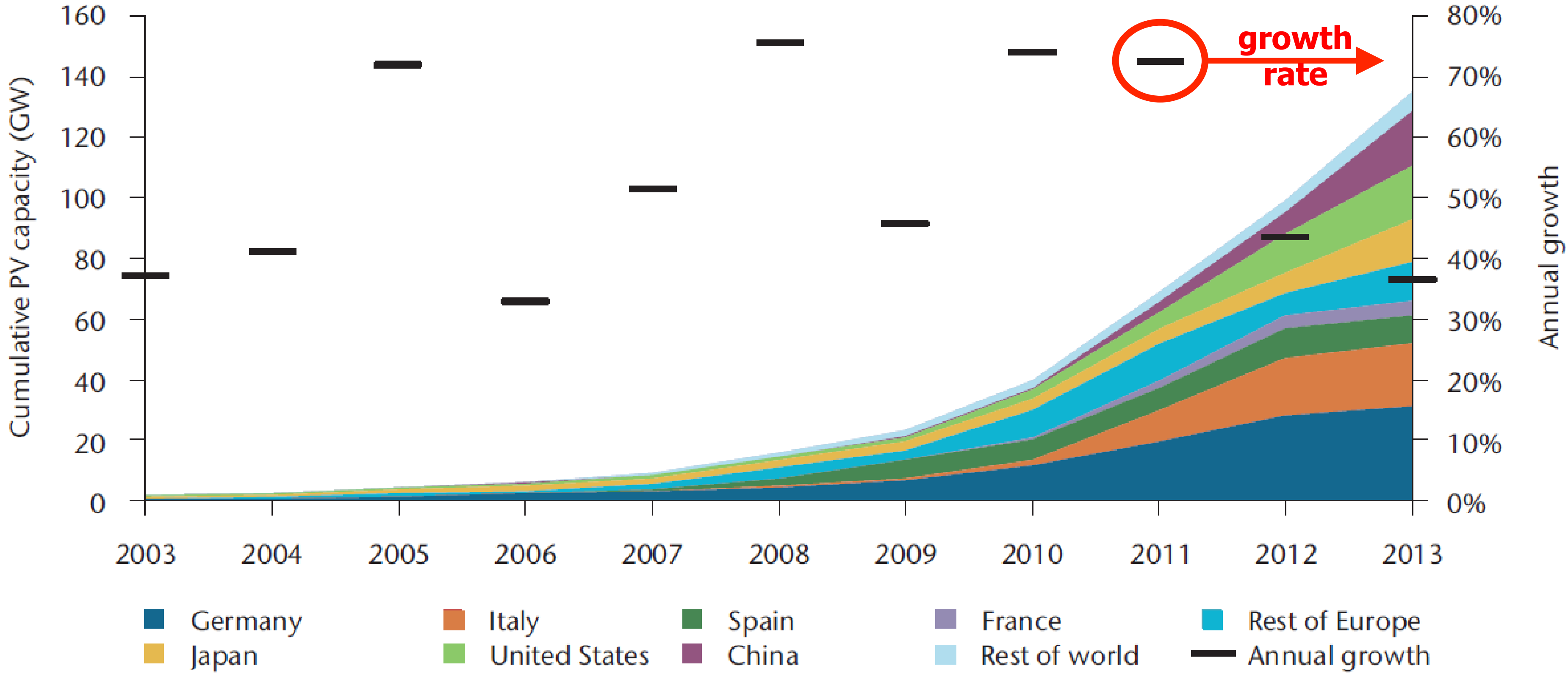
5300 GW_{peak} **if displacing coal**
(x 6 for intermittency + 1 to compensate storage losses)

more than twice if displacing nat gas

installed power in Italy in 2013: 18 GW_{peak}

at 7 m^2 of solar cells per kW_{peak} (avg efficiency 14%) the generation of 5300 GW_{peak} would require ≈ 33000 km^2 of PV cells

Growth of photovoltaic power



At end of 2014 installed power has reached 177 GW

a bit more than 3% of the power needed to make a wedge by displacing coal-fired power

Source: IEA Technology Roadmap Solar PV Energy - ***2014*** *edition*

Wind power

Effort needed by 2065 for one wedge:

2600 GW_{peak}

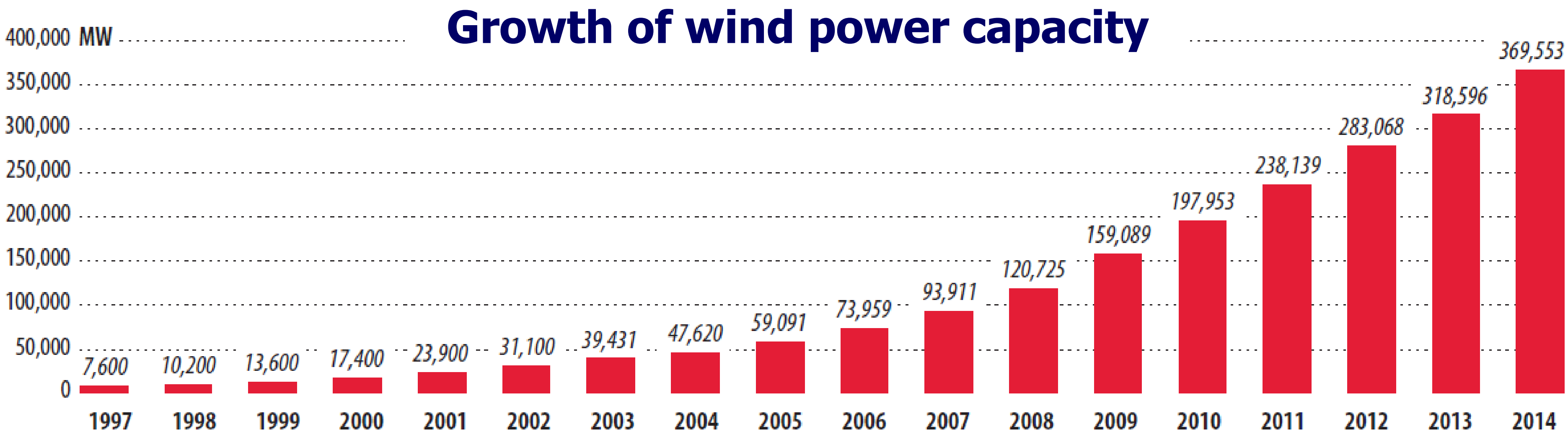
if displacing coal

(x 3,5 for intermittency + 0,5 to compensate storage losses)

more than twice if displacing nat gas

in 2011 installed power was 240 GW

Wind power

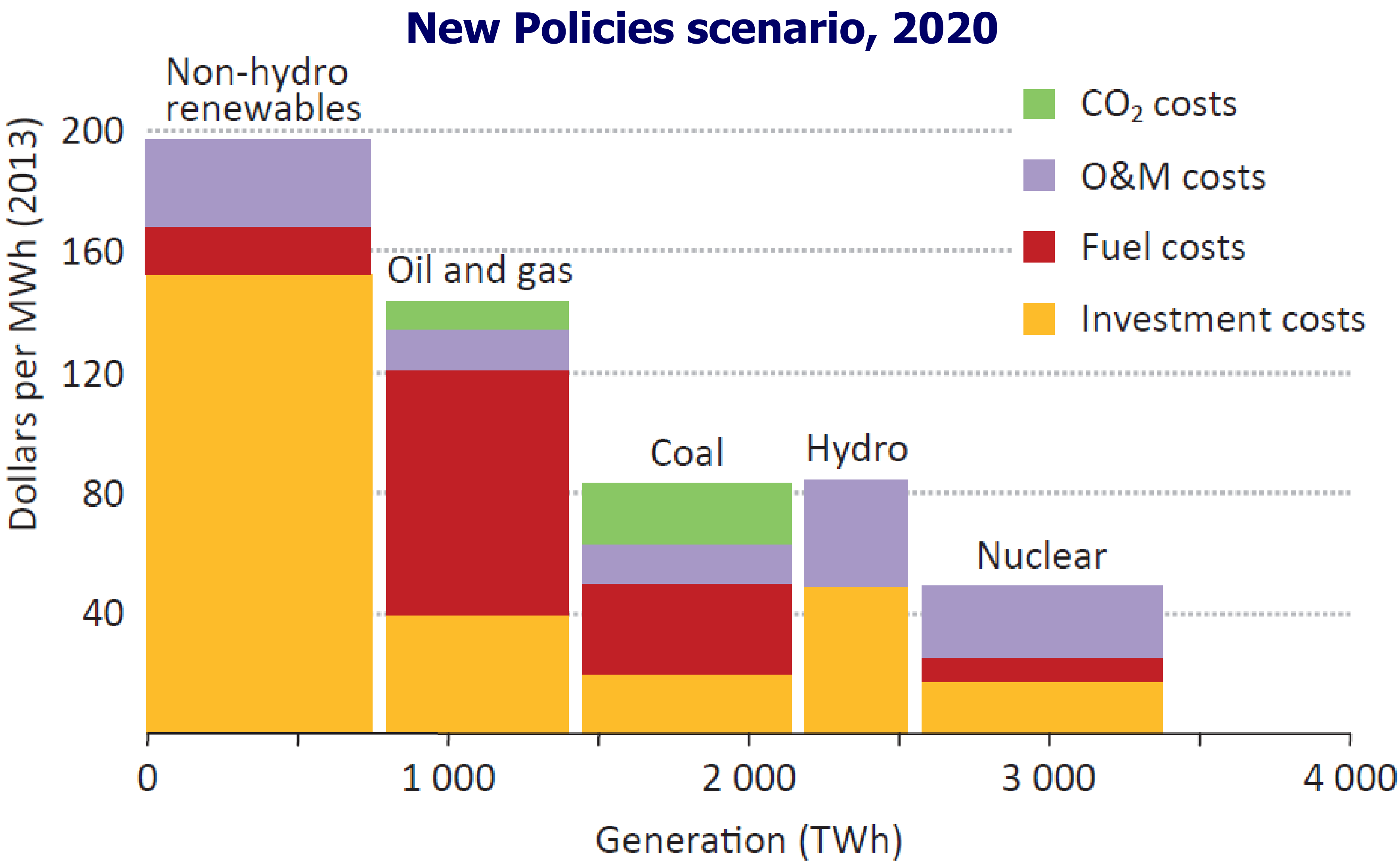


Country	MW	% SHARE
PR China*	114,763	31.0
USA	65,879	17.8
Germany	39,165	10.6
Spain	22,987	6.2
India	22,465	6.1
United Kingdom	12,440	3.4
Canada	9,694	2.6
France	9,285	2.5
Italy	8,663	2.3
Brazil**	5,939	1.6
Rest of the world	58,275	15.8
Total TOP 10	**311,279**	**84.2**
World Total	**369,553**	**100**

To make a wedge, capacity installed at end of 2014 (370 GW) must increase by a factor of 7

Source: Global Wind Energy Council - ***2014*** *statistics*

Electricity production costs



*Source: World Energy Outlook **2014**, International Energy Agency*

The cost of promoting renewable energy

1) In Italy, expenditure for incentives to:
   - hydro
   - biomass
   - wind
   - geothermal

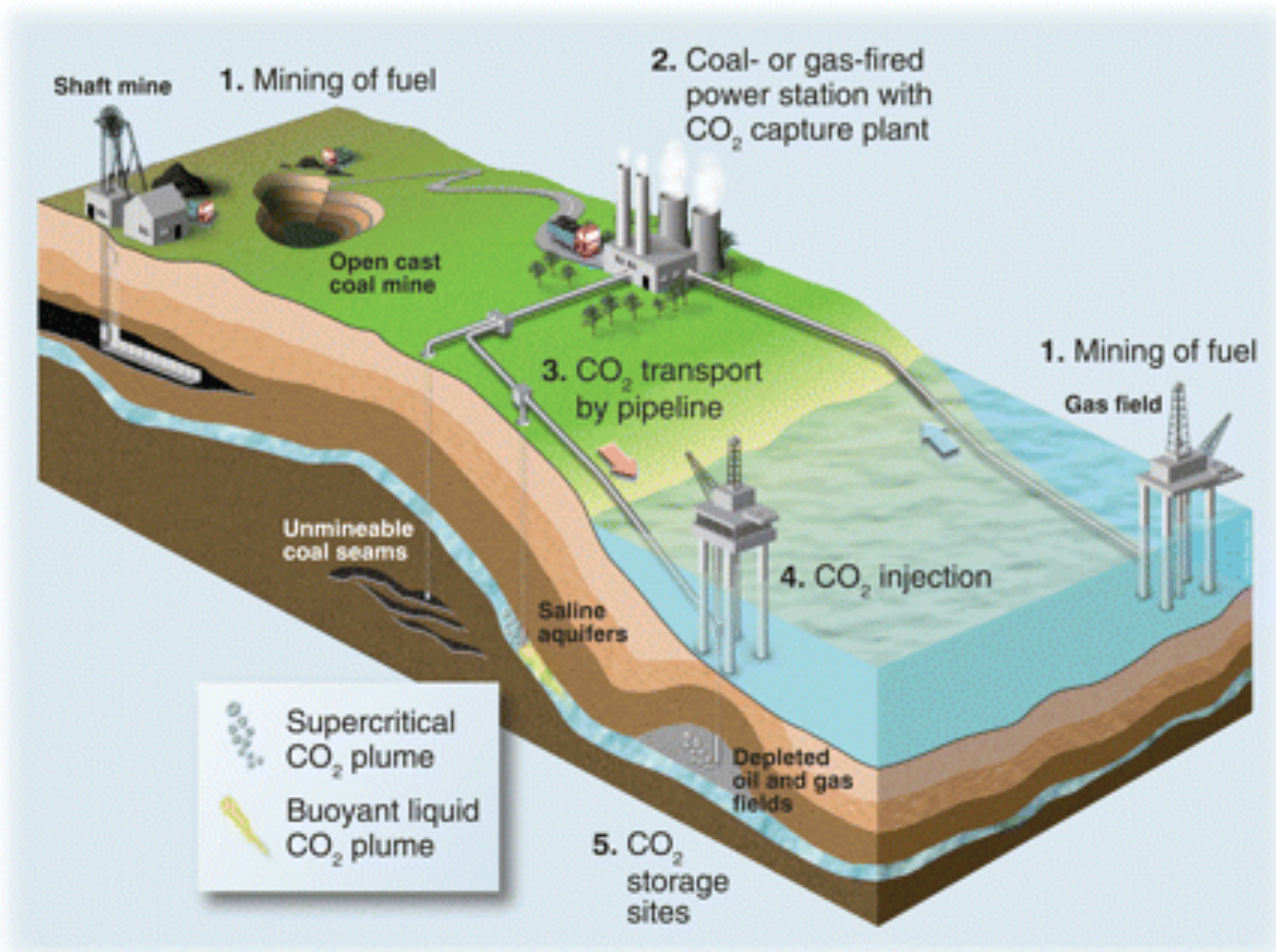
   has nearly reached the cap of **5.8 billion Euros/yr**

2) In 2015, incentives to PV will approach **7 billion Euros**, bringing total incentives to about **12.5 billion Euros**

3) The nearly 7 billion Euros of incentives for PV avoid the emission of about 10 million tons of CO_2, for a specific cost of **700 € per ton avoided**

4) The 5.8 billion of incentives for other renewables avoid the emission of about 25 million tons of CO_2, for a specific cost of **230 € per ton avoided**

CCS: Capture + Transport + Storage of CO_2



The peculiar role of Carbon Capture & Storage

- CCS gives the possibility to DECOUPLE the use of fossil fuels from CO_2 emissions
- Given:
  - the overwhelming dominance of fossil fuels
  - the sheer cost of the energy infrastructure
  - the time and the resources needed to change the current situation
  - the costs and the many issues still raised by renwable sources

  the shift from fossil sources to low-carbon-emission sources (renewables / nuclear) REQUIRES TIME
- CCS can give us the time we need

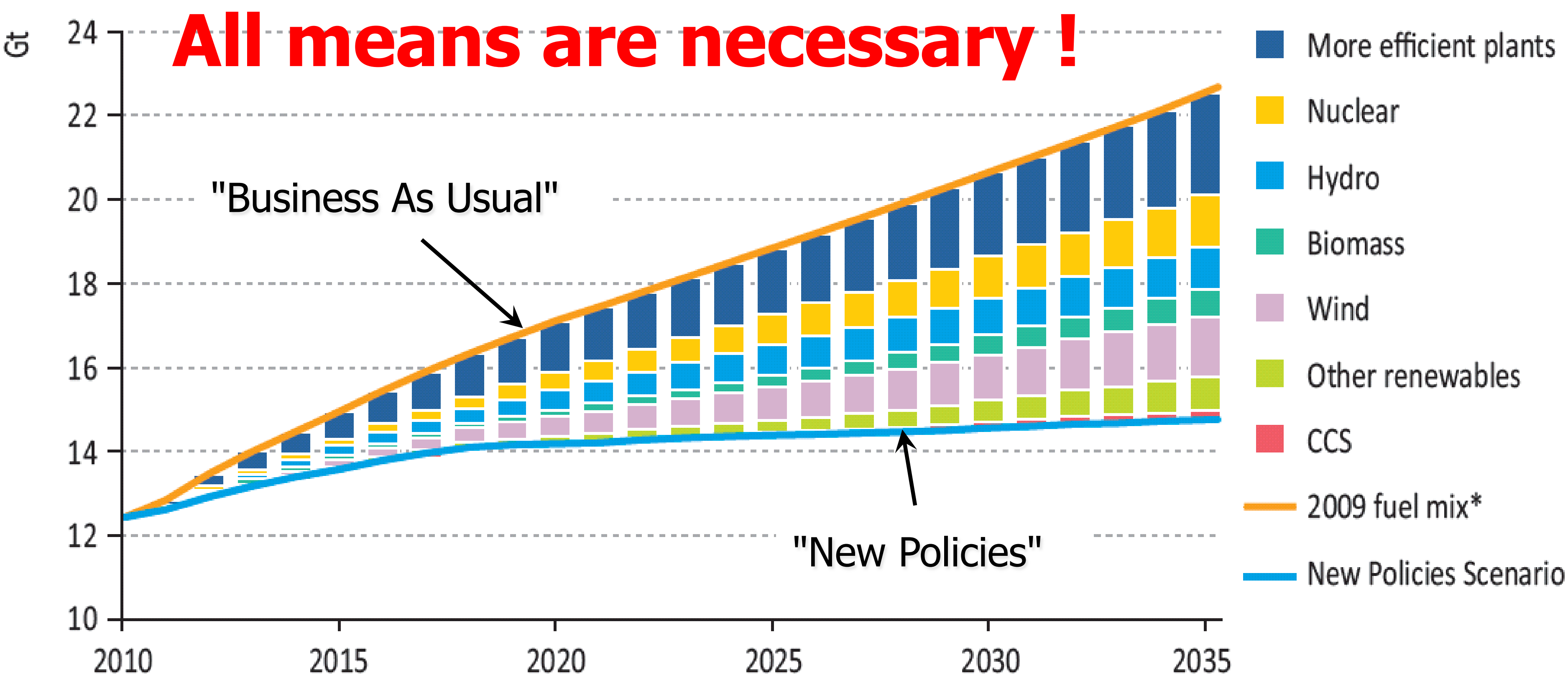
Sleipner (North Sea)

Conclusions

- **Stabilizing and reducing GHG emissions poses daunting challenges**
- **The sheer size of the job to be done may leave us in despair, but ...**
- **.... there are reasons for optimism:**
  - **the world energy system is still very inefficient**
  - **the same for incentives / carbon tax schemes**
  - **the same for international cooperation**
  - **we do have degrees of freedom**
  - **most of the 2065 physical plants is not yet built**
  - **human ingenuity may bring further options**

Final message

New Policies scenario



*The emissions savings compared with the emissions that would have been generated for the projected level of electricity generation were there no change in the mix of fuels and technologies, and no change in the efficiency of thermal generating plants after 2009.

Source: World Energy Outlook ***2011****, International Energy Agency*

Thank you for your attention !

Laboratorio Energia e Ambiente Piacenza

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