UNIVERSITÀ DEGLI STUDI DI TRIESTE

Dipartimento di Ingegneria e Architettura

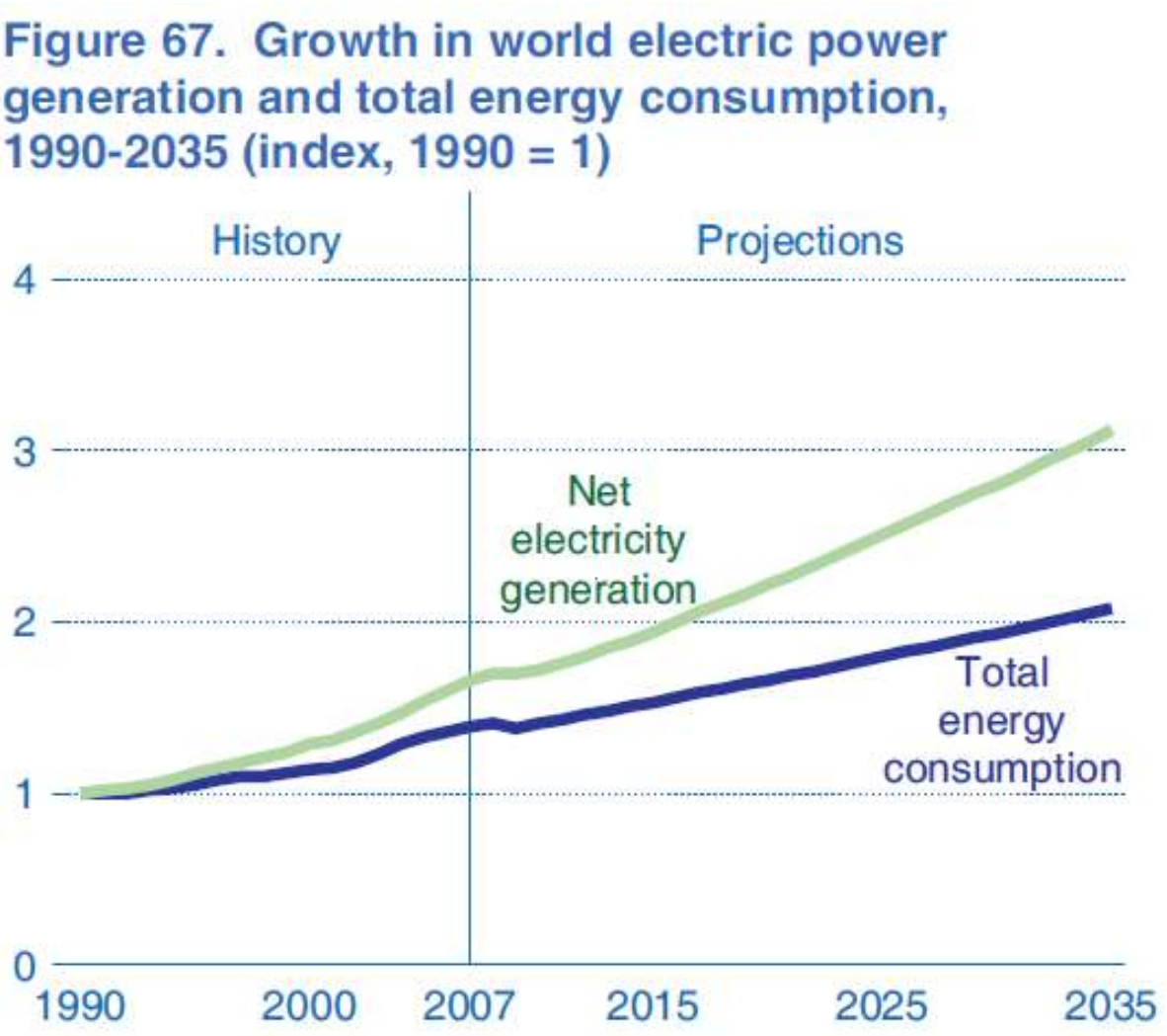
Introduction
Hydrogen and Renewable Energy Sources

Hydrogen and Fuel Cells [065IN]

Prof. Rodolfo Taccani
Prof. Marco Bogar

A.A. 2023-2024

Domanda di energia mondiale

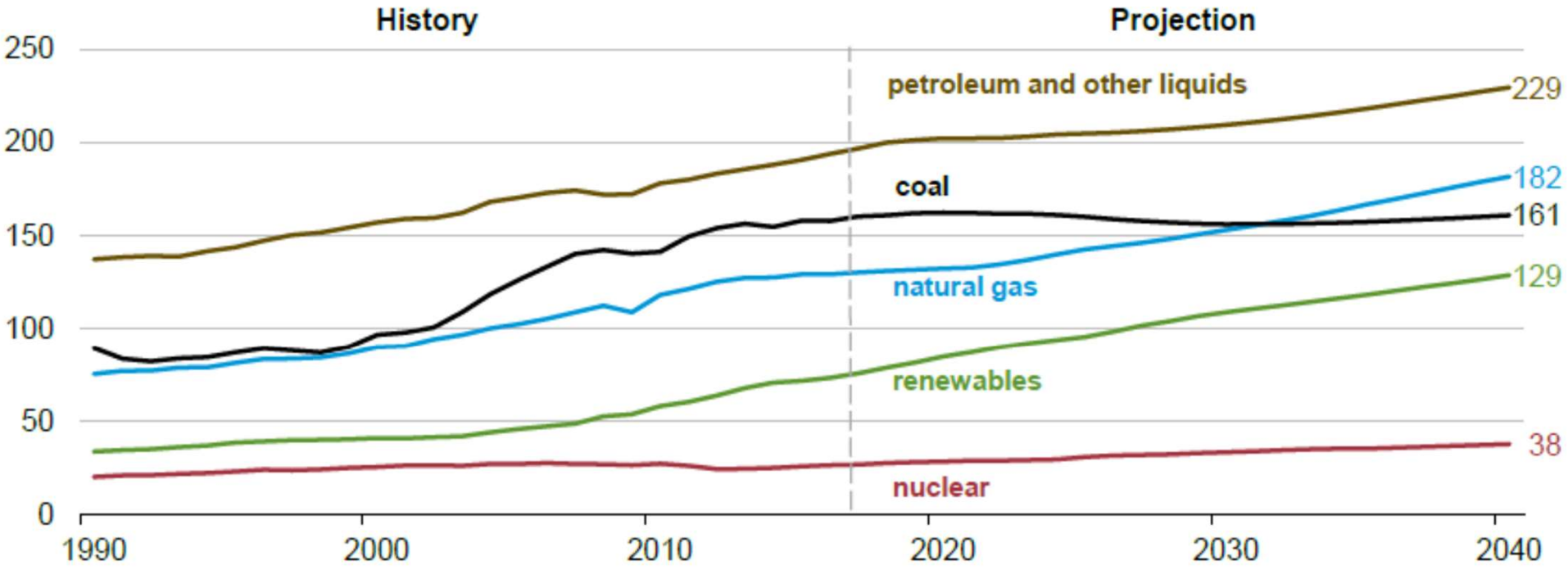


Energy Information Administration.
International Energy Outlook 2010

Domanda di energia mondiale

World energy consumption increases for fuels other than coal

IEO2018 Reference case
world energy consumption by energy source
quadrillion Btu

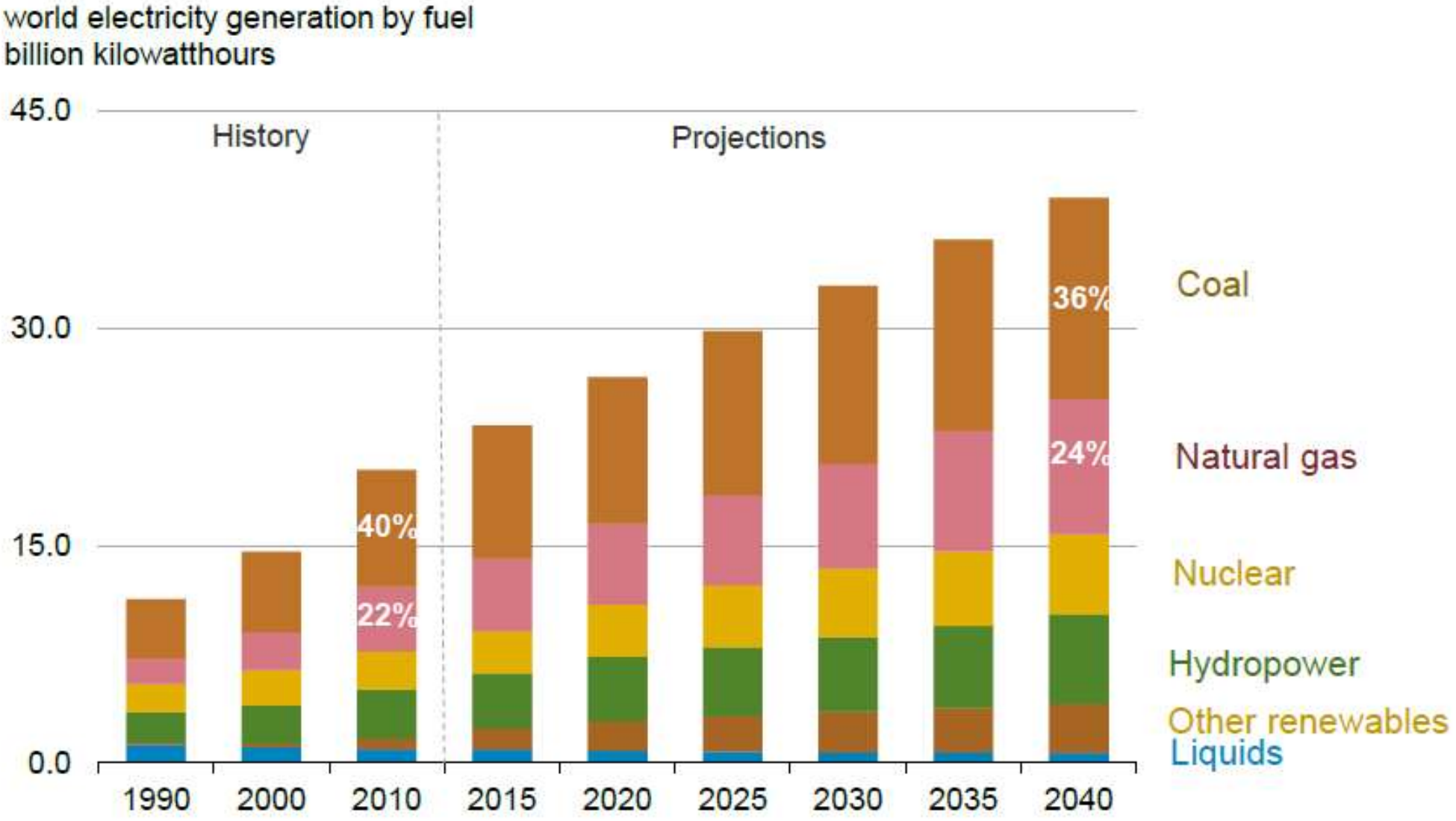


Source: EIA, International Energy Outlook 2018

https://www.eia.gov/beta/international/

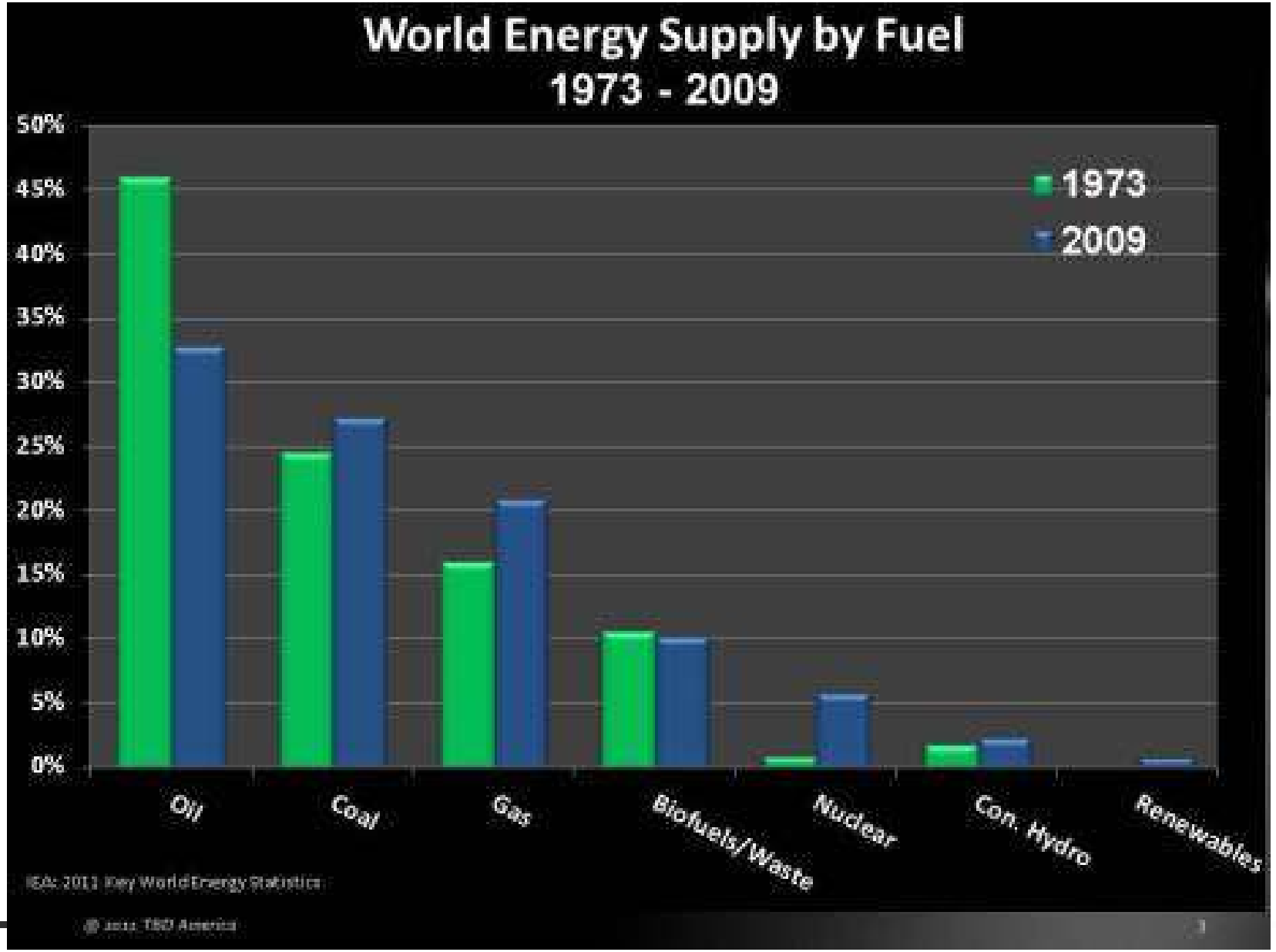
?

Where does electricity come from?



Source: EIA, International Energy Outlook 2013

Where does ENERGY come from (1973)



Iniziamo con un messaggio di ottimismo

il mondo ha più risorse energetiche oggi
di quante ne abbia mai avute nel passato

World Energy Resources
2013 Survey: Summary

Iniziamo con un messaggio di ottimismo

il mondo ha più risorse energetiche oggi
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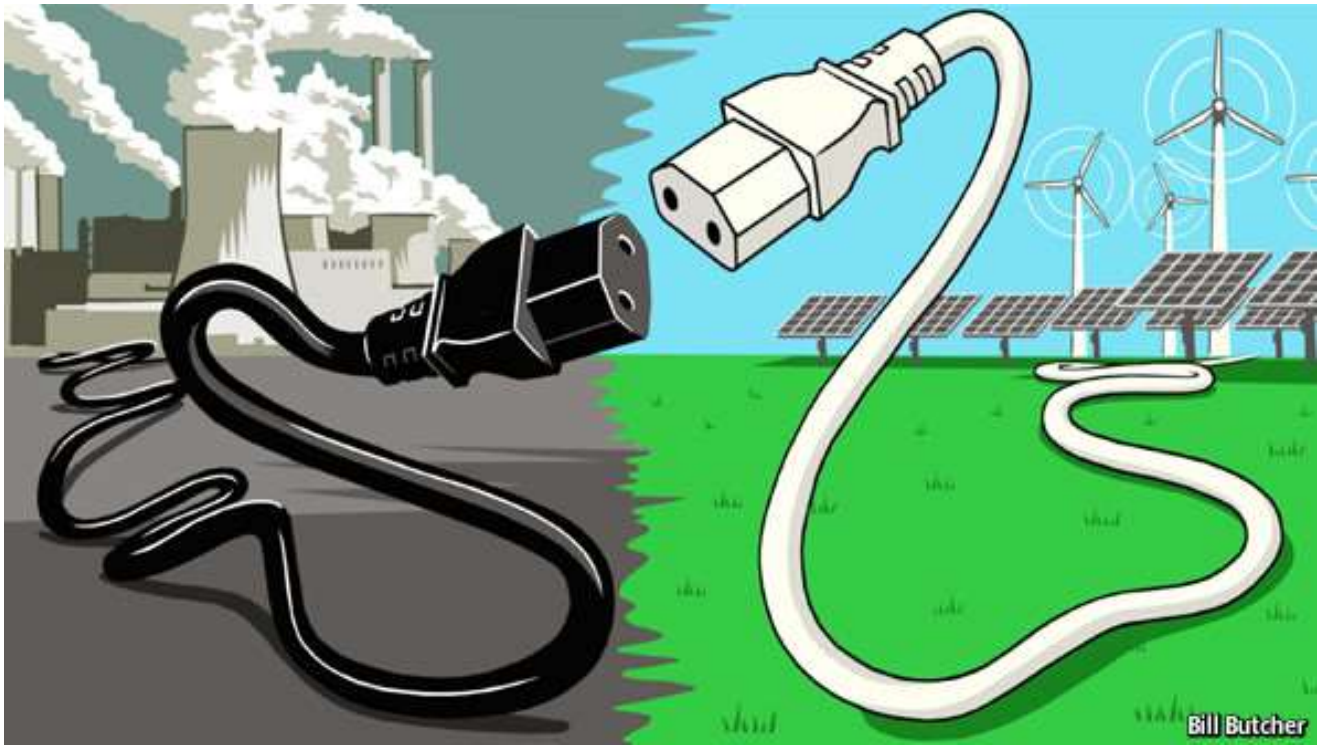
World Energy Resources
2013 Survey: Summary

Dobbiamo essere grati ai combustibili fossili: sono stati, sono e continueranno per molti decenni a essere il principale motore propulsivo dello sviluppo. I progressi tecnologici nel loro utilizzo sono stati formidabili, sia in termini energetici, sia, ancora di più, in termini ambientali.

Europe’s electricity providers face an existential threat

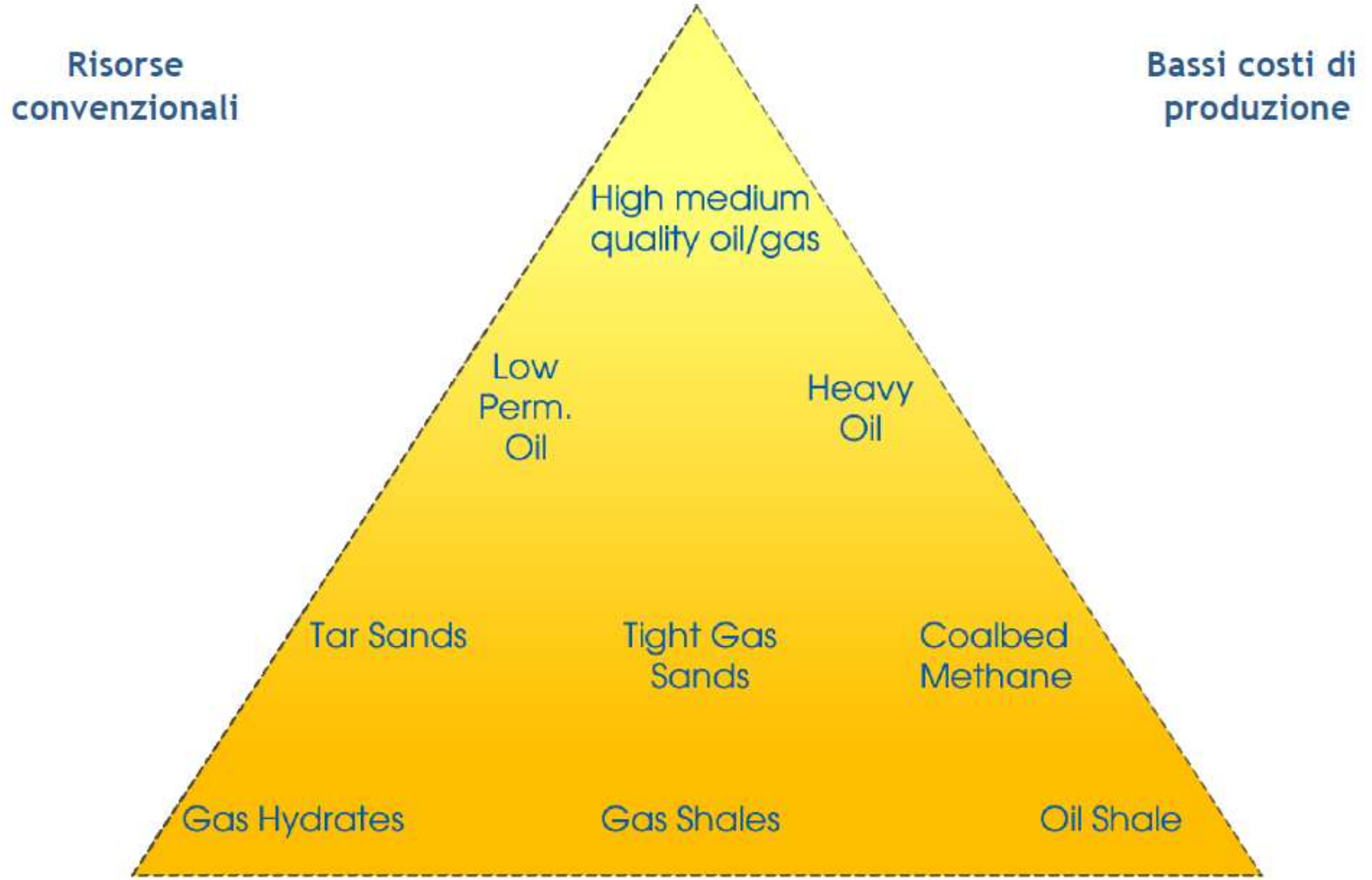
Oct 12th 2013 | From the print edition

The Economist

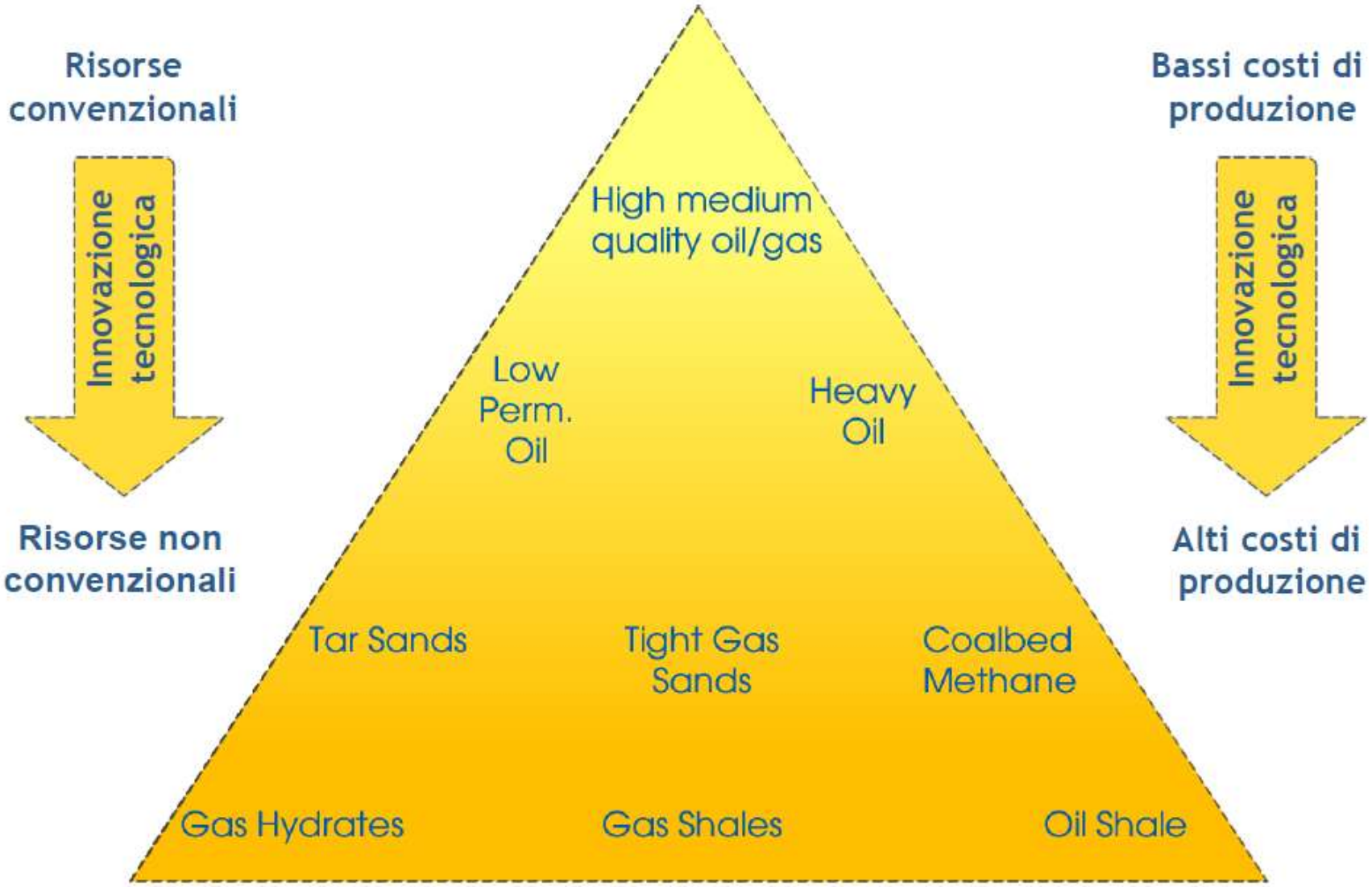


ON JUNE 16th something very peculiar happened in Germany’s electricity market. The wholesale price of electricity fell to minus €100 per megawatt hour (MWh). That is, generating companies were having to pay the managers of the grid to take their electricity. It was a bright, breezy Sunday. Demand was low. Between 2pm and 3pm, solar and wind generators produced 28.9 gigawatts (GW) of power, more than half the total. The grid at that time could not cope with more than 45GW without becoming unstable. At the peak, total generation was over 51GW; so prices went negative to encourage cutbacks and protect the grid from overloading…..

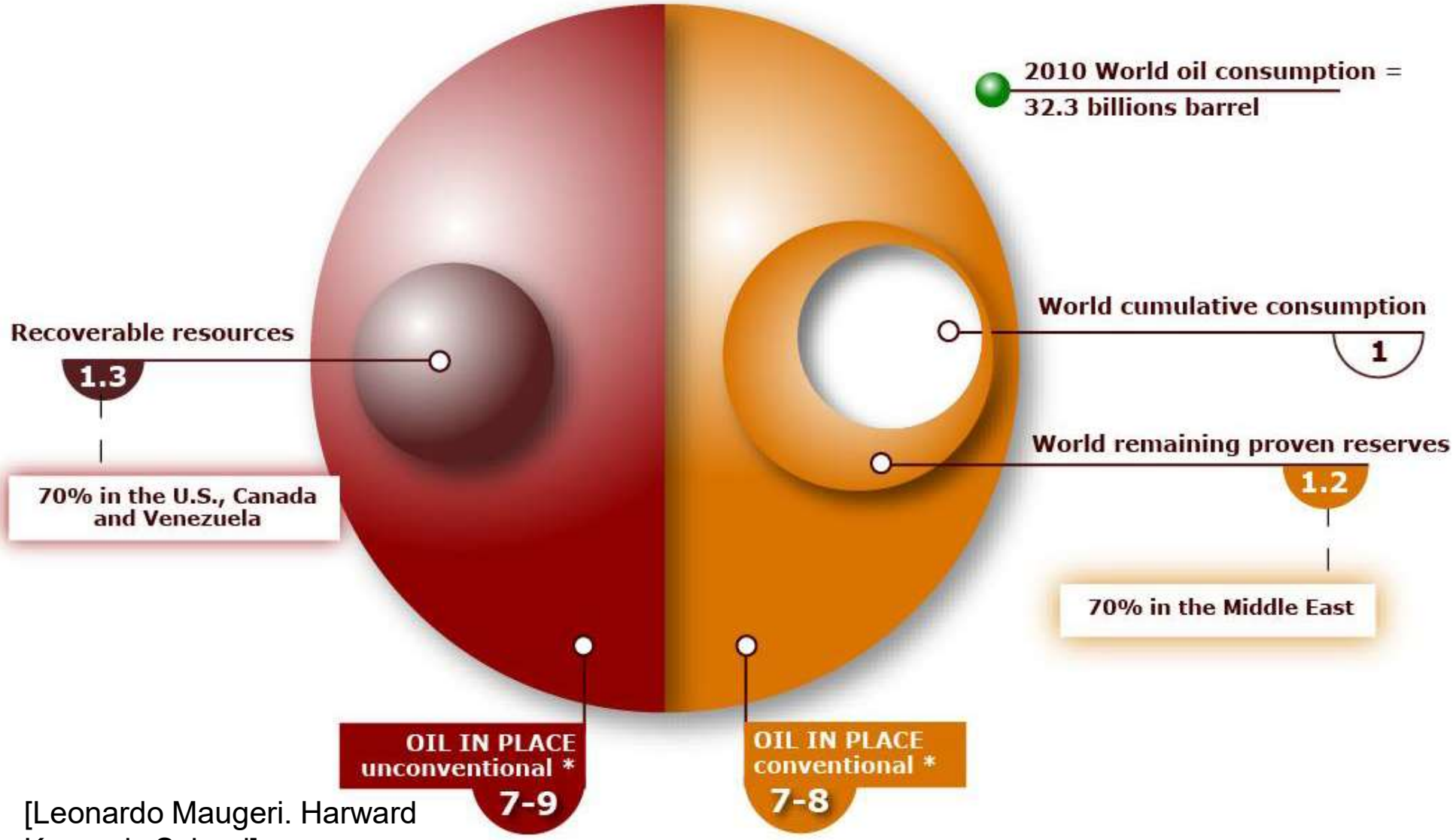
Andando verso la base del triangolo le risorse aumentano



Andando verso la base del triangolo le risorse aumentano

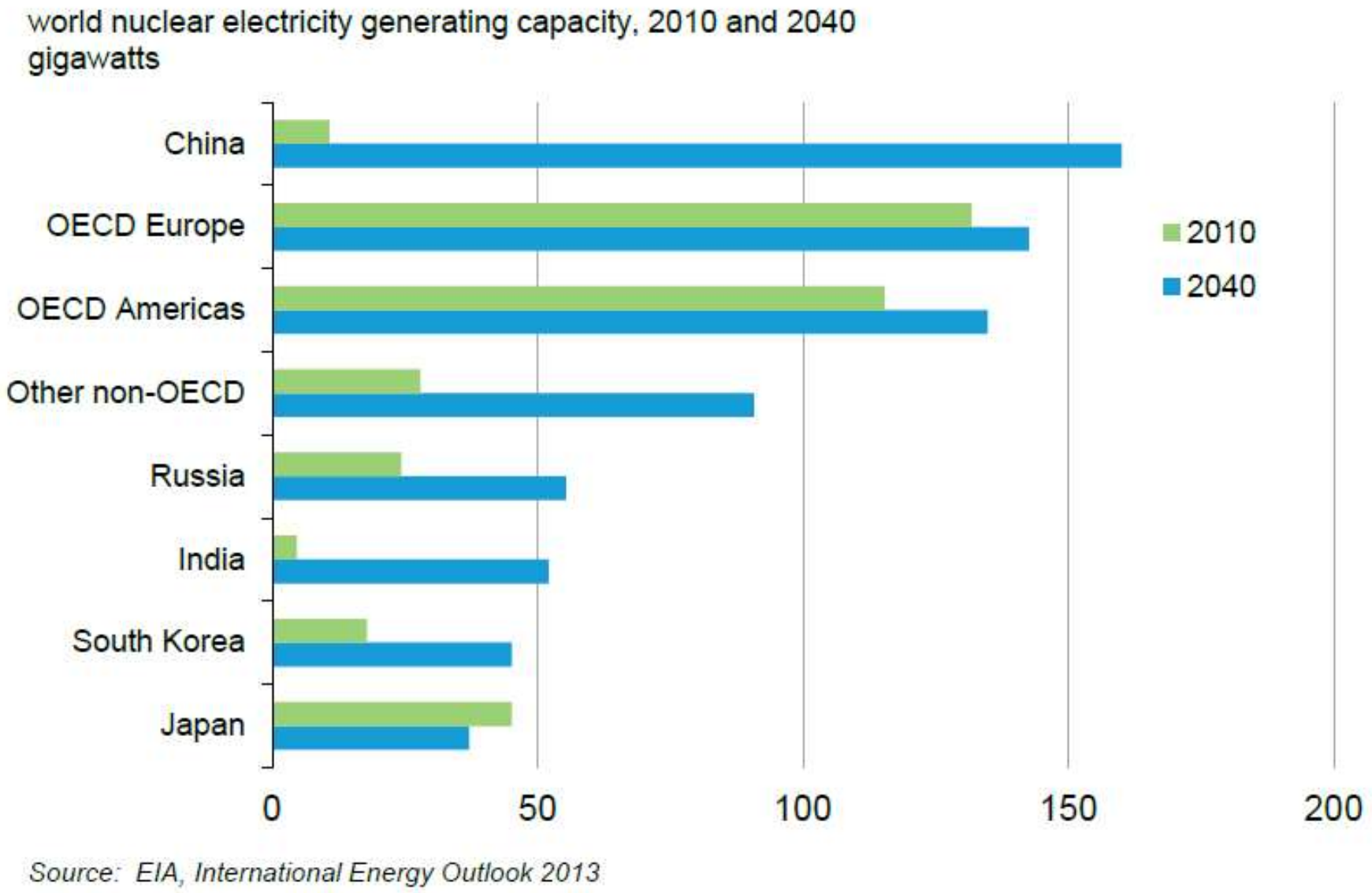


Le risorse di idrocarburi sono enormi: si inizia a non parlare più di picco del petrolio



[Leonardo Maugeri. Harward Kennedy School]

China accounts for more than 40 percent of the global net increase in nuclear capacity

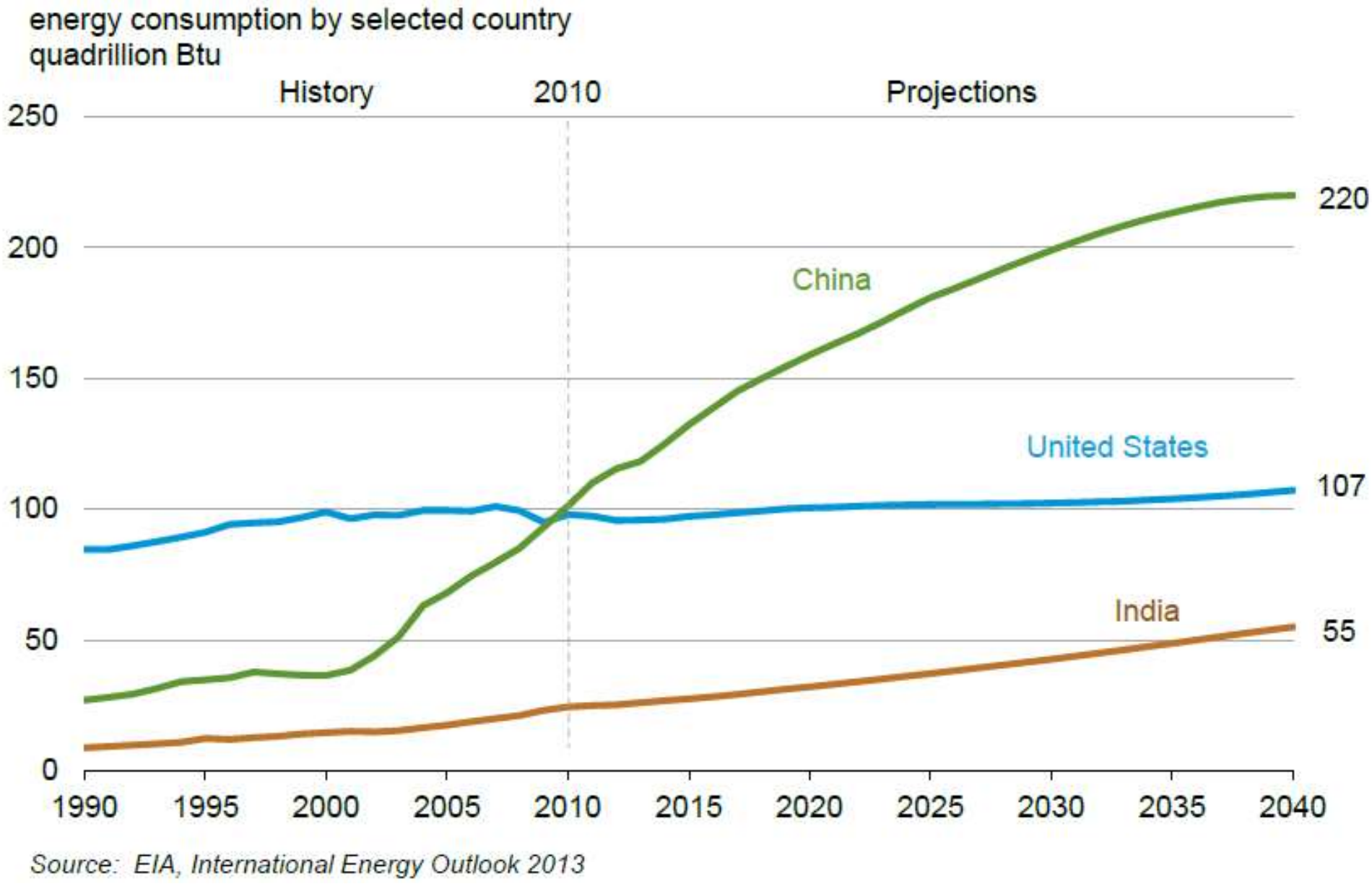


Source: EIA, International Energy Outlook 2013

OECD

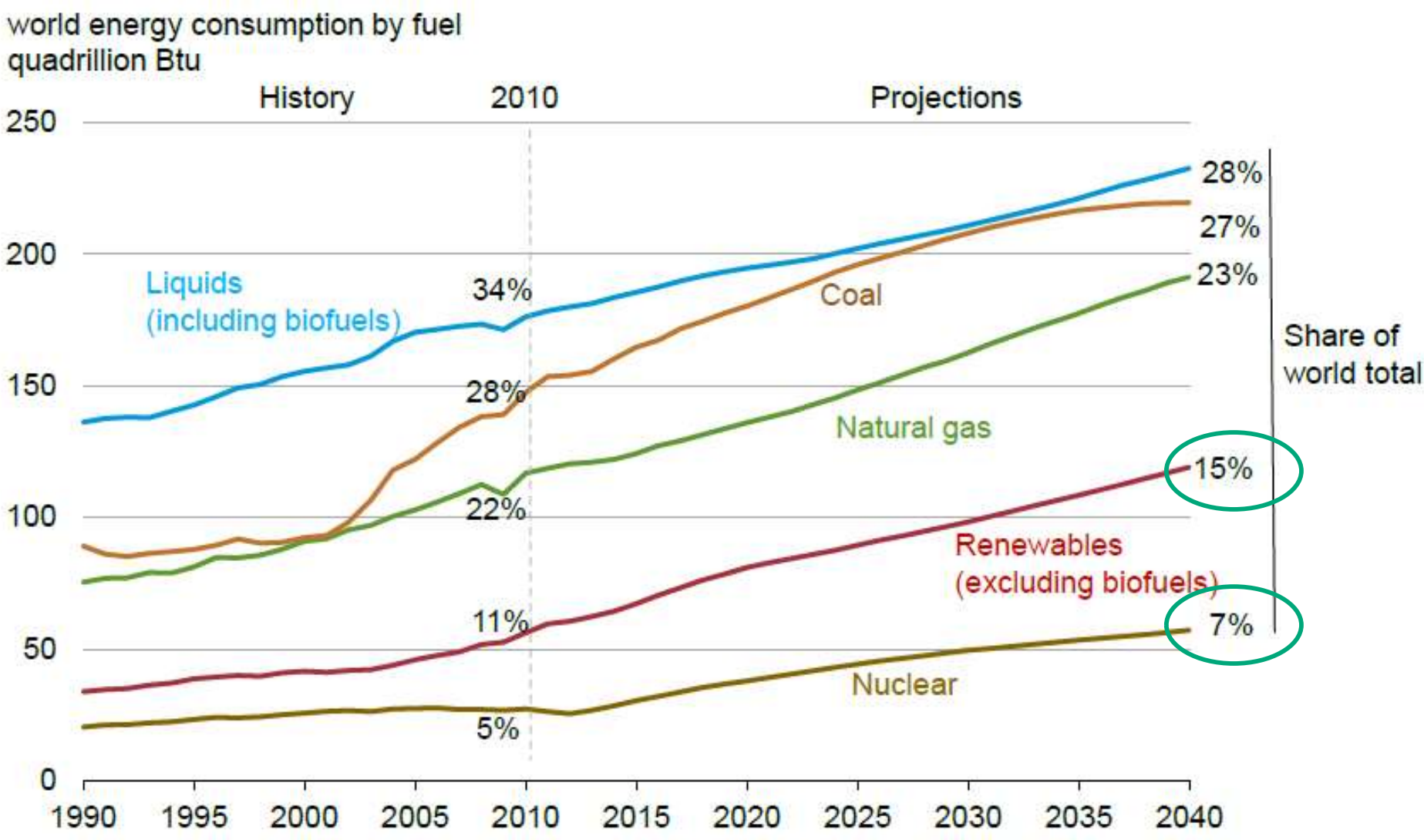
L'**Organizzazione per la cooperazione e lo sviluppo economico** (**OCSE**) (in inglese **Organisation for Economic Co-operation and Development** (**OECD**); in francese **Organisation de coopération et de développement économiques** (**OCDE**)) è un'organizzazione internazionale di studi economici per i paesi membri, paesi sviluppati aventi in comune un sistema di governo di tipo democratico ed un'economia di mercato. L'organizzazione svolge prevalentemente un ruolo di assemblea consultiva che consente un'occasione di confronto delle esperienze politiche, per la risoluzione dei problemi comuni, l'identificazione di pratiche commerciali ed il coordinamento delle politiche locali ed internazionali dei paesi membri].

By 2040, China's energy use will be double the U.S. level; India's a little more than half despite its faster GDP growth



Source: EIA, International Energy Outlook 2013

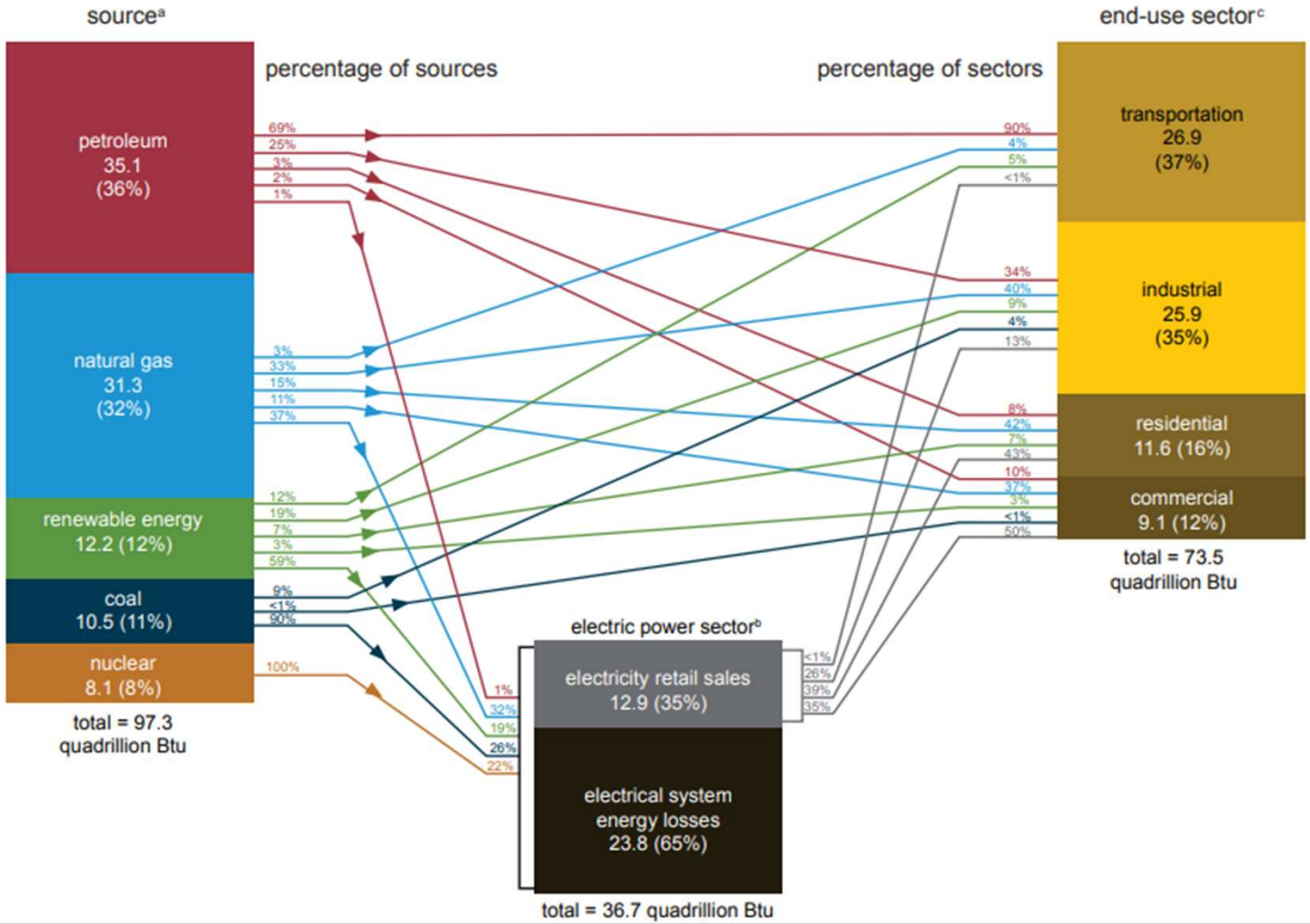
Energy mix over time



Source: EIA, International Energy Outlook 2013

U.S. energy consumption by source and sector, 2021

quadrillion British thermal units (Btu)



Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (April 2022), Tables 1.3 and 2.1-2.6.

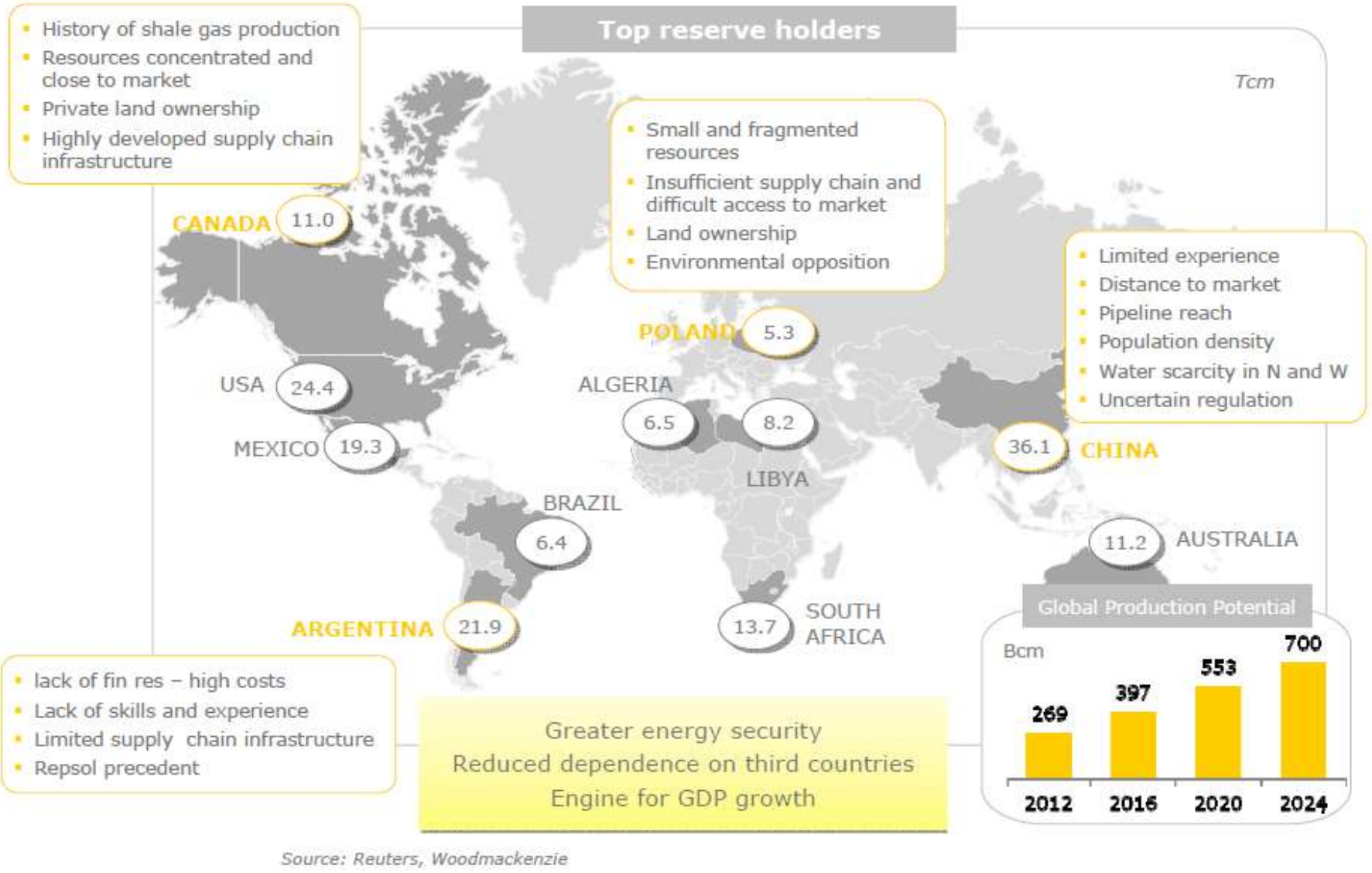
Note: Sum of components may not equal total due to independent rounding. All source and end-use sector consumption data include other energy losses from energy use, transformation, and distribution not separately identified. See "Extended Chart Notes" on next page.

[a] Primary energy consumption. Each energy source is measured in different physical units and converted to common British thermal units (Btu). See EIA's *Monthly Energy Review* (MER), Appendix A. Noncombustible renewable energy sources are converted to Btu using the "Fossil Fuel Equivalency Approach", see MER Appendix E.

[b] The electric power sector includes electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Energy consumed by these plants reflects the approximate heat rates for electricity in MER Appendix A. The total includes the heat content of are electricity net imports, not shown separately. Electrical system energy losses calculated as the primary energy consumed by the electric power sector minus the heat content of electricity retail sales. See Note 1, "Electrical System Energy Losses," at the end of MER Section 2.

[c] End-use sector consumption of primary energy and electricity retail sales, excluding electrical system energy losses from electricity retail sales. Industrial and commercial sectors consumption includes primary energy consumption by CHP and electricity-only plants contained within the sector.

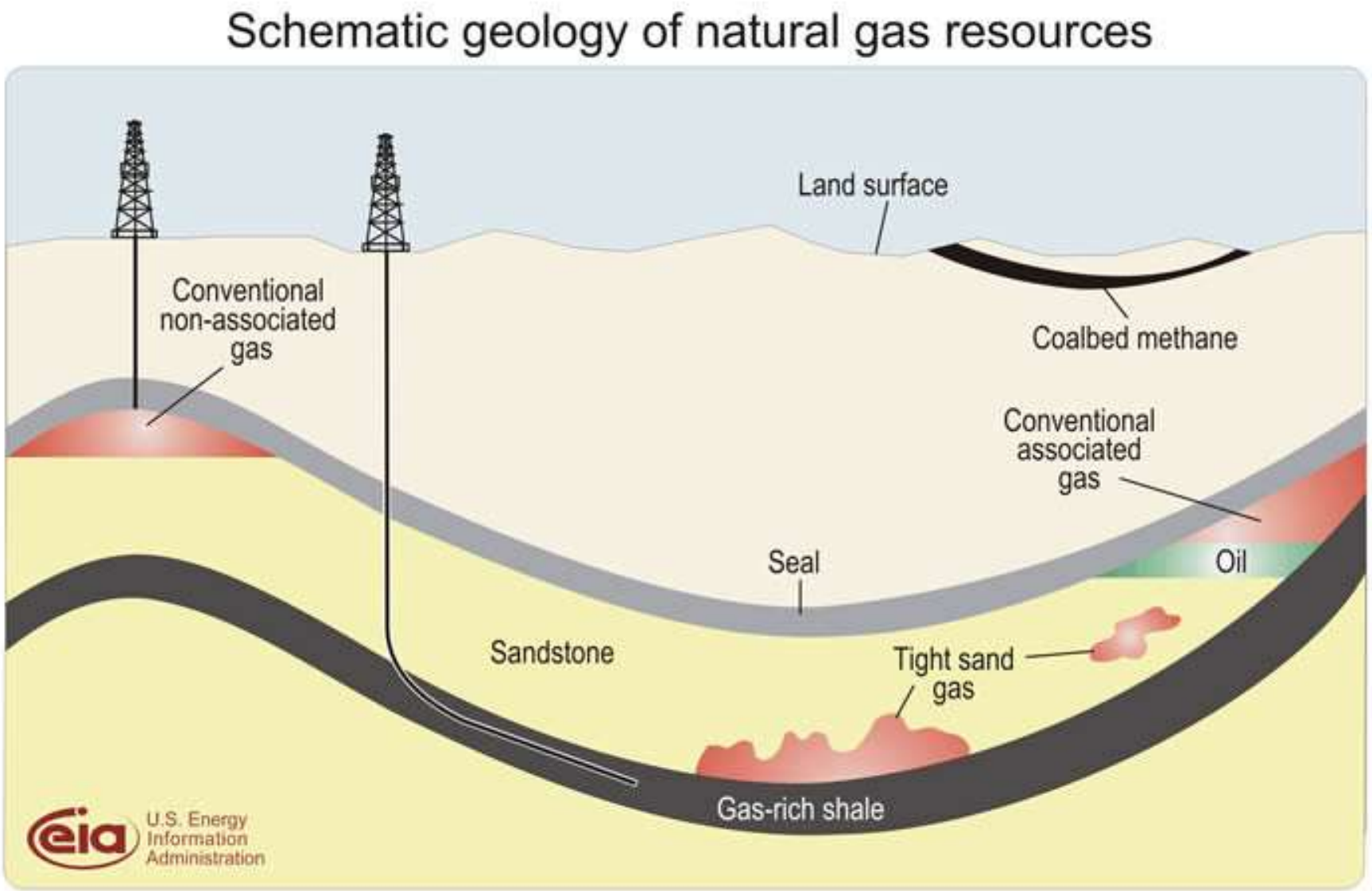
Scenario planning and Shale gas revolution



Source: Reuters, Woodmackenzie

[from Degiovanni ENI]

Shale gas


Schematic geology of natural gas resources
Land surface
Conventional non-associated gas
Coalbed methane
Conventional associated gas
Oil
Seal
Sandstone
Tight sand gas
Gas-rich shale
U.S. Energy Information Administration

The evolution of shale gas

1825
- First extraction in Fredonia, NY, in shallow low-pressure fractures

1920's
- First field-scale development of shale gas (Ohio Shale, Kentucky, Antrim Shale, Michigan)

1950's
- Hydraulic Fracturing becomes commercially viable (> 1 million wells)

1970's
- First patent for directional drilling
- First demonstration of massive hydraulic fracturing

1980's
- Horizontal drilling becomes commercially viable
- First large-scale hydraulic fracturing on shale well (Barnett, TX)

1992
- First horizontal shale gas well with hydraulic fracturing (Barnett TX)

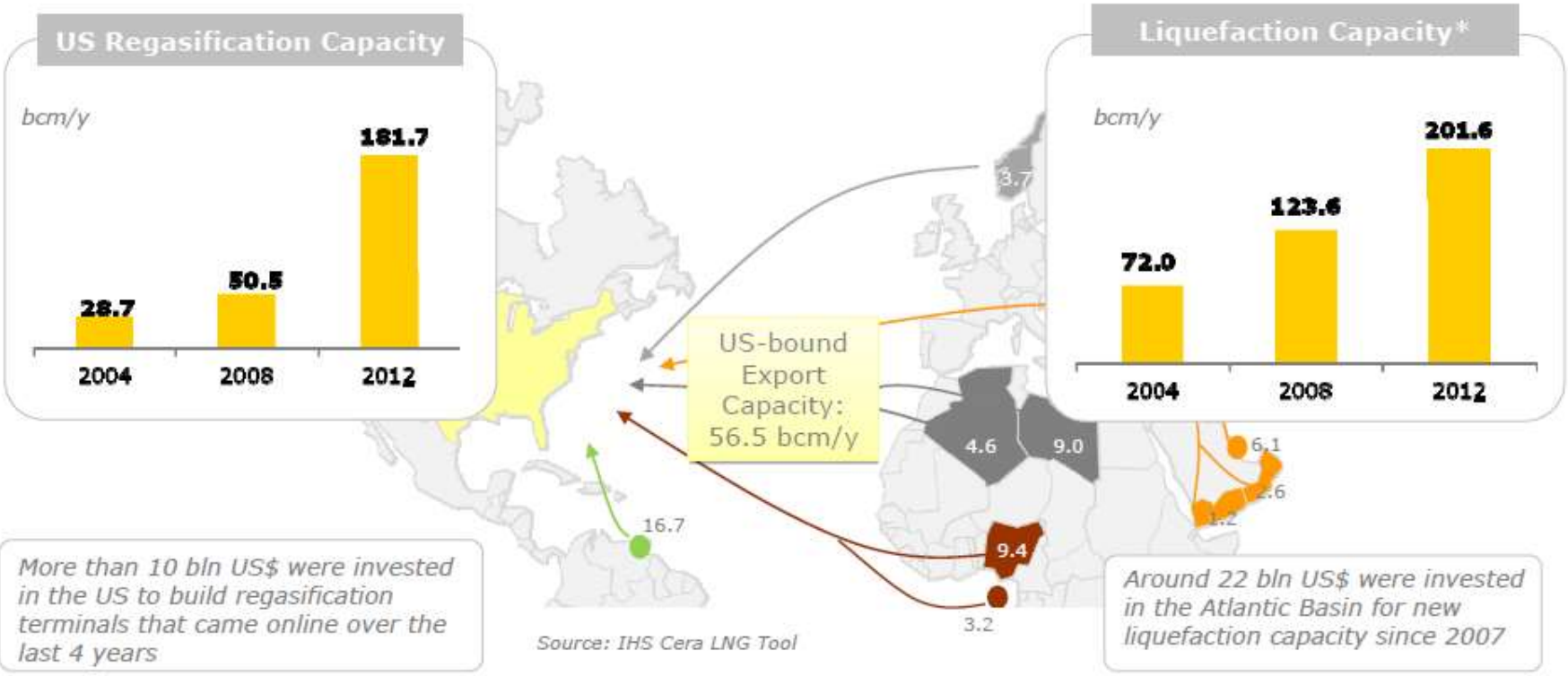
2005
- Shale gas production takes off

In 2012 US shale gas production alone ranks third globally, after US and Russia

[from Degiovanni ENI]

The shale gas phenomenon was unforseen

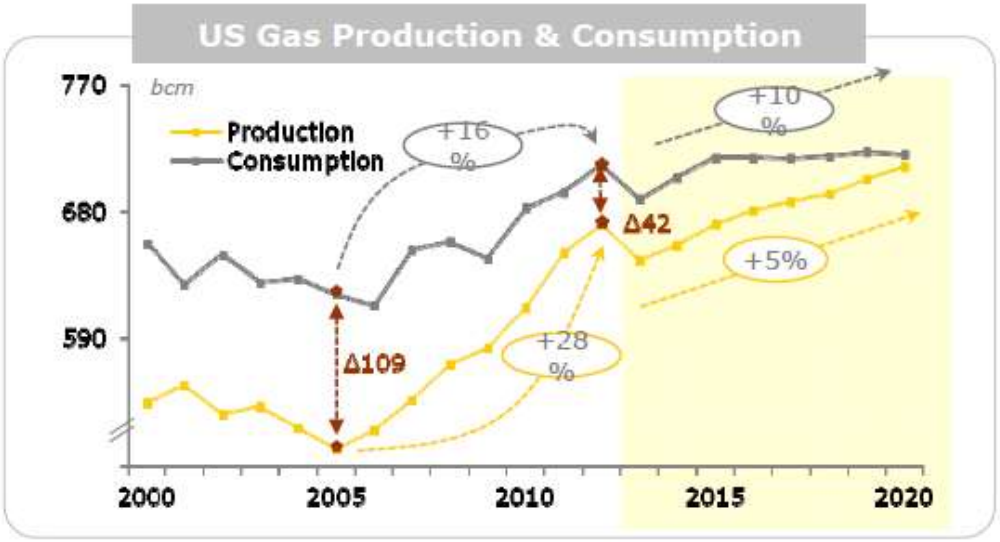
- The US expected a sharp decline in domestic gas production and LNG imports were the only solution to cope with gas demand
- Many IOCs invested in the LNG chain as a result of increasing US gas demand forecasts

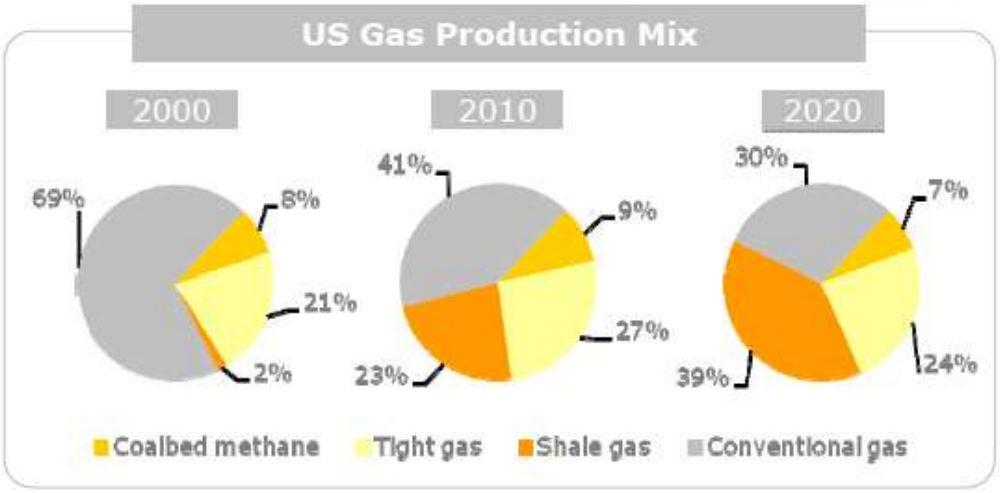


Today the US could have been the second largest LNG importing country after Japan

[from Degiovanni ENI]

Shale gas is reshaping US gas market



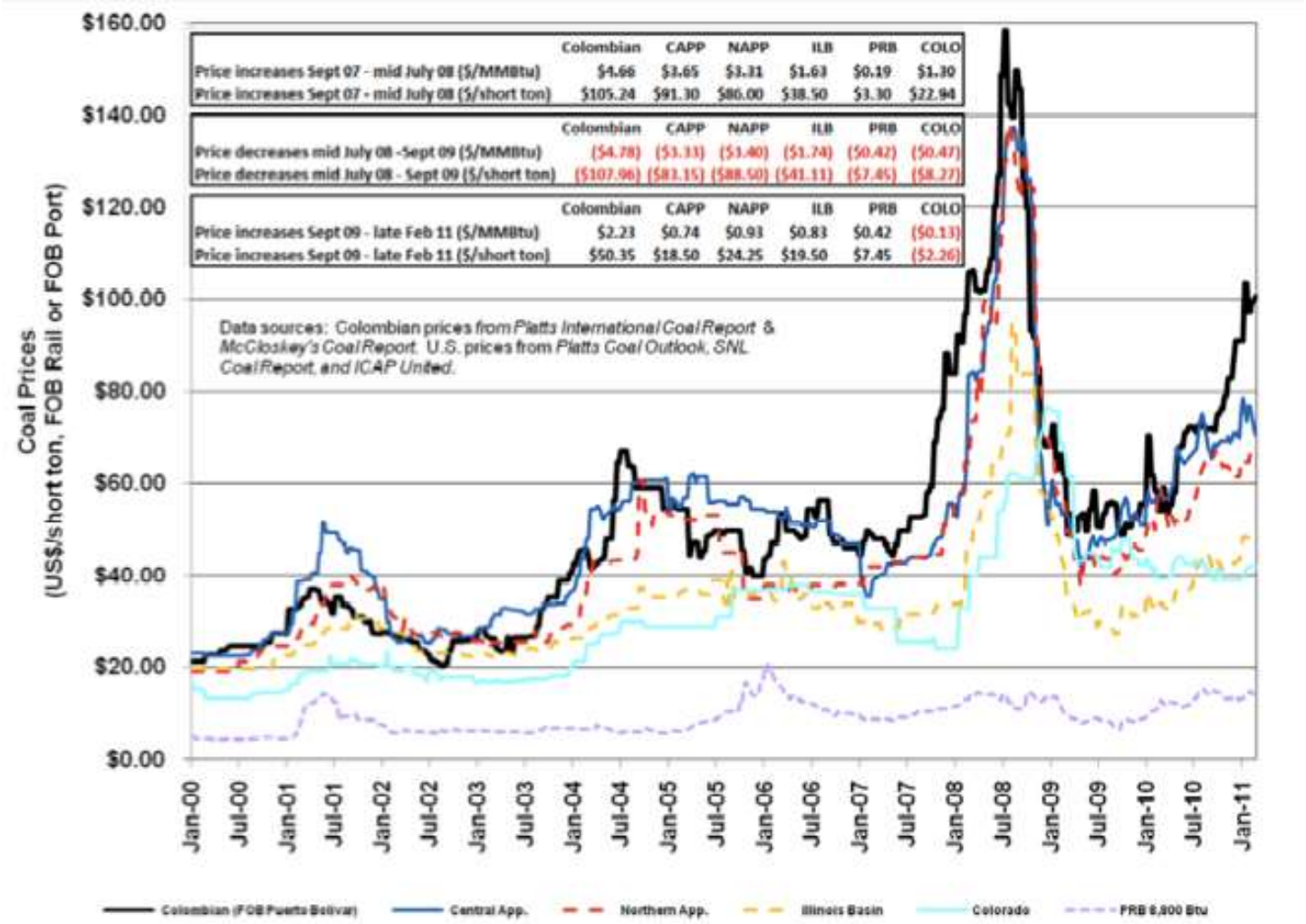


Source: eia

- Shale gas encouraged recovery and then growth of gas consumption after the financial downturn
- Consumption-to-production gap will slim down to less than 10 bcm in 2020
- Production will have to satisfy domestic consumption, to allow for LNG exports
- Shale production was less than 2% of total gas production in 2000 and reached nearly 35% in 2012
- In 2020, shale gas is expected to reach around 40% of total gas production although its growth will decrease to 5% yoy

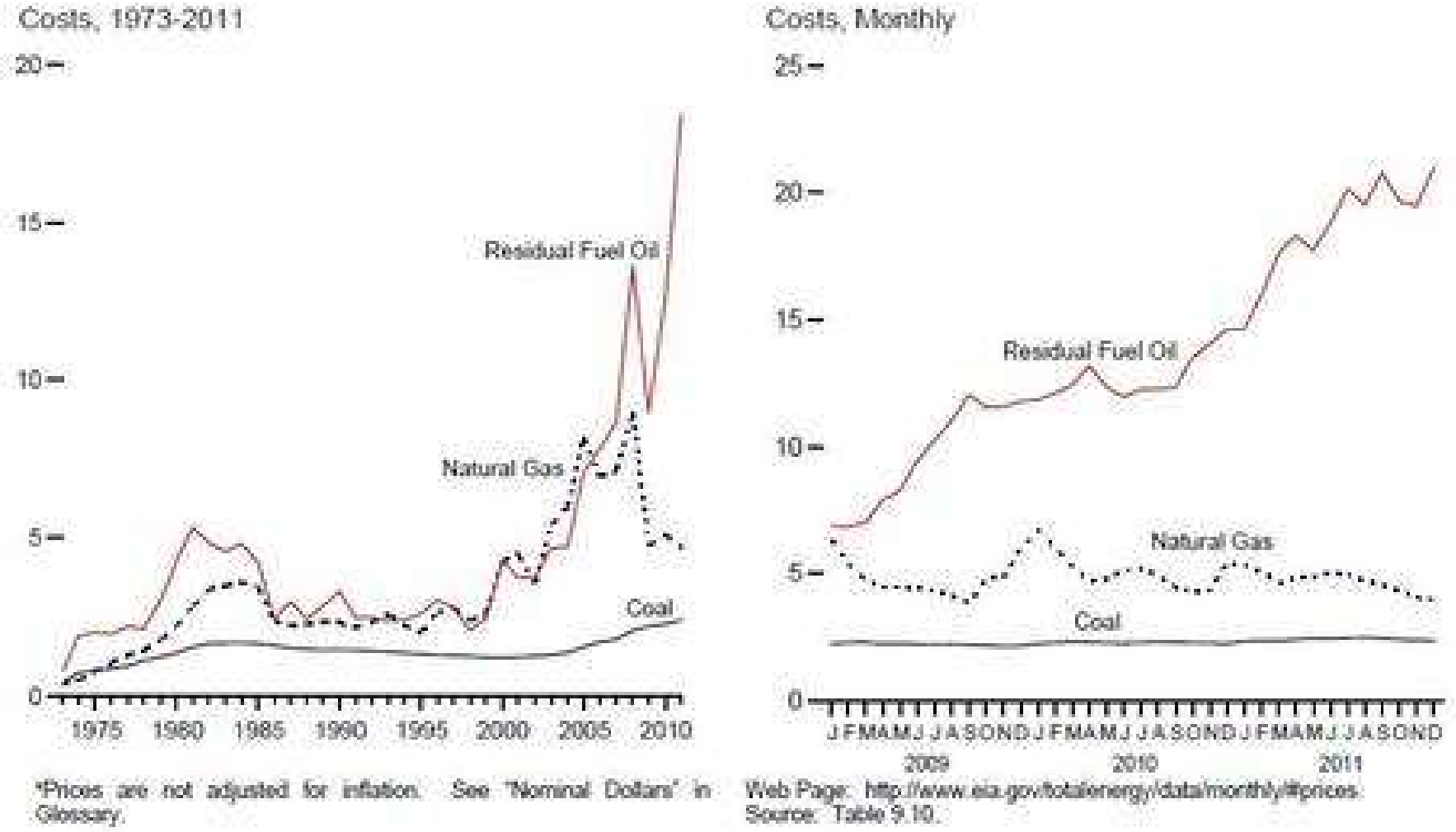
[from Degiovanni ENI]

Andamento costi combustibile



Andamento costi combustibile

Figure 9.3 Cost of Fossil-Fuel Receipts at Electric Generating Plants
(Dollars* per Million Btu, Including Taxes)

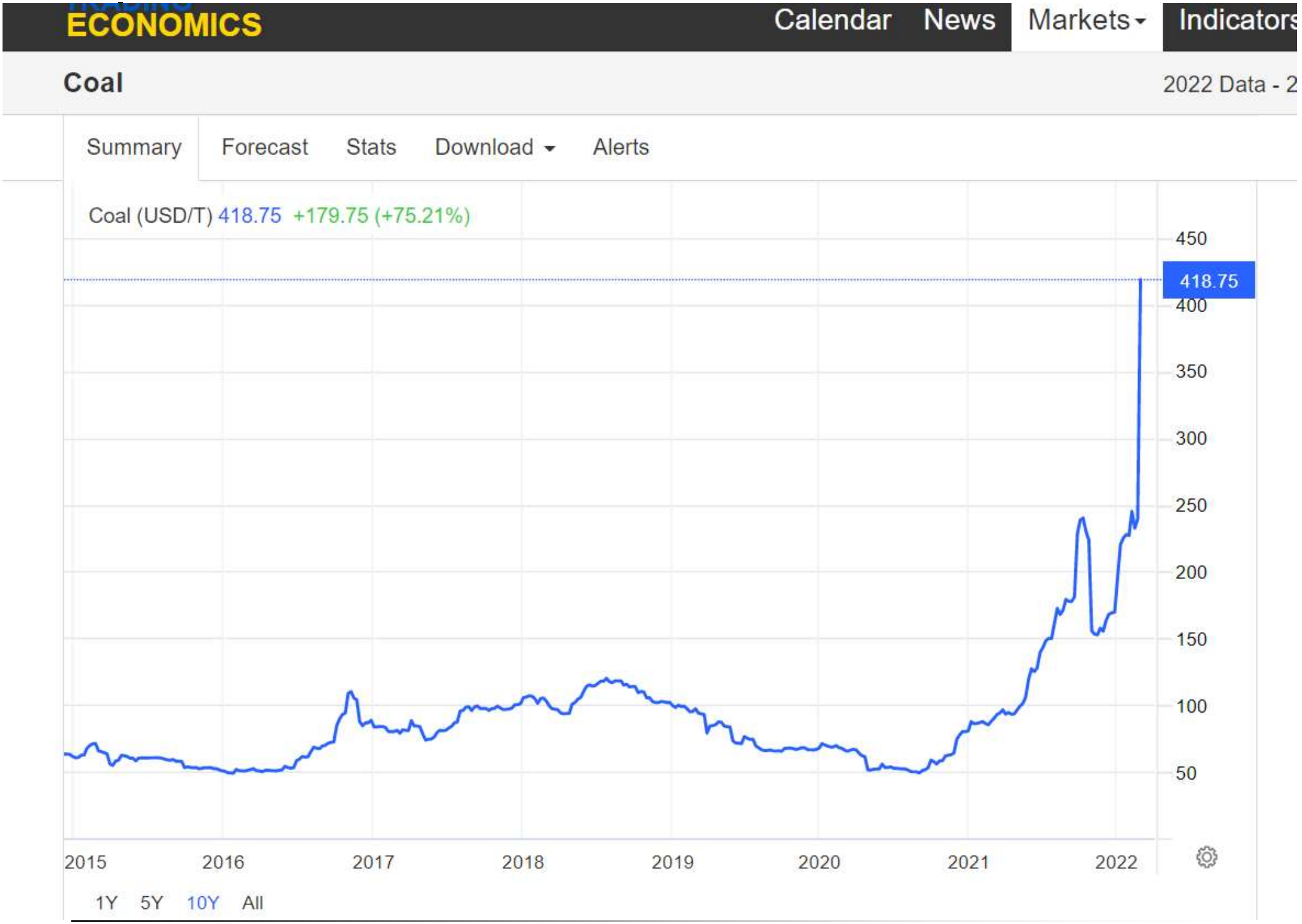


*Prices are not adjusted for inflation. See "Nominal Dollars" in Glossary.

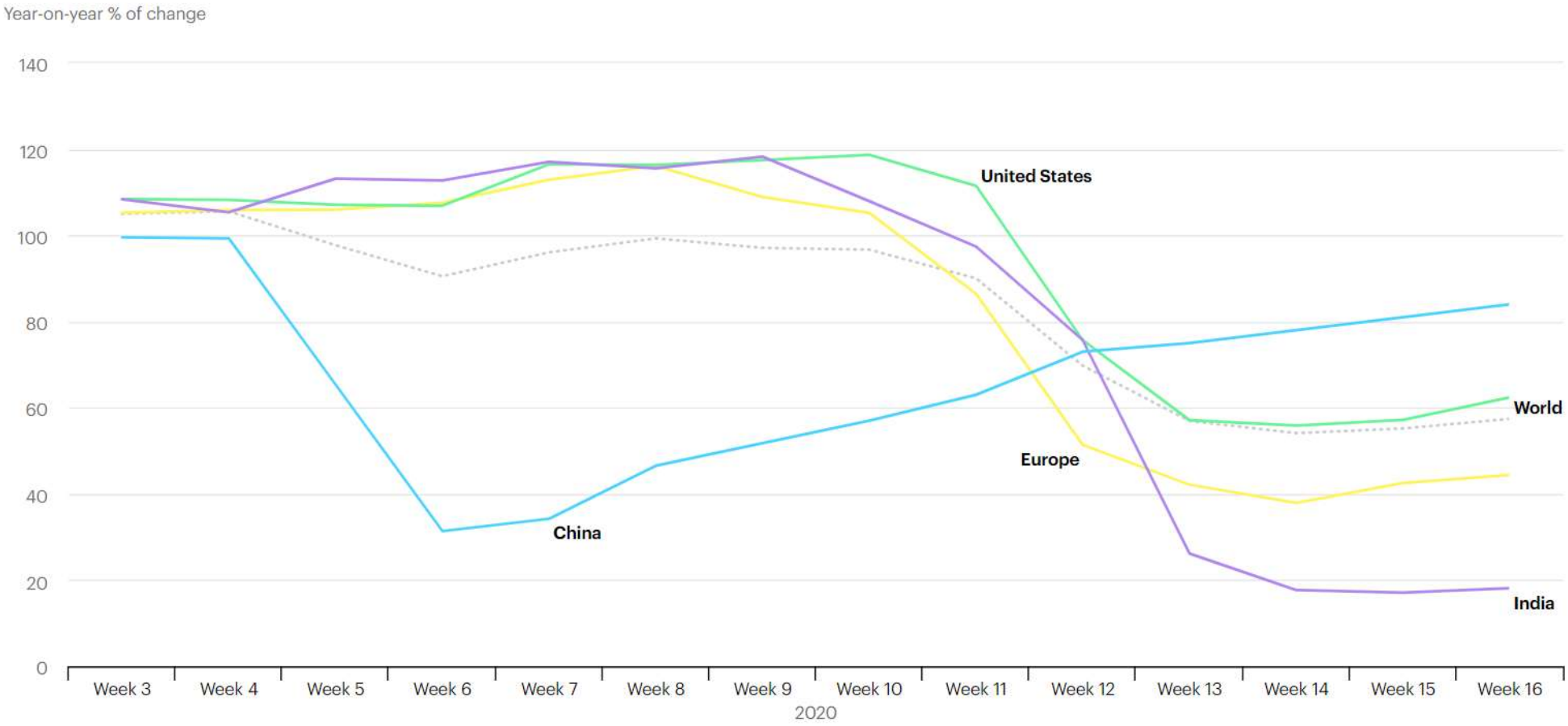
Web Page: http://www.eia.gov/totalenergy/data/monthly/#prices.
Source: Table 9.10.

Link

- Per esempio
- https://tradingeconomics.com/commodity/coal


TRADING ECONOMICS
Calendar
News
Markets
Indicators
Coal
2022 Data - 2
Summary
Forecast
Stats
Download
Alerts
Coal (USD/T) 418.75 +179.75 (+75.21%)
450
418.75
400
350
300
250
200
150
100
50
2015
2016
2017
2018
2019
2020
2021
2022
1Y
5Y
10Y
All

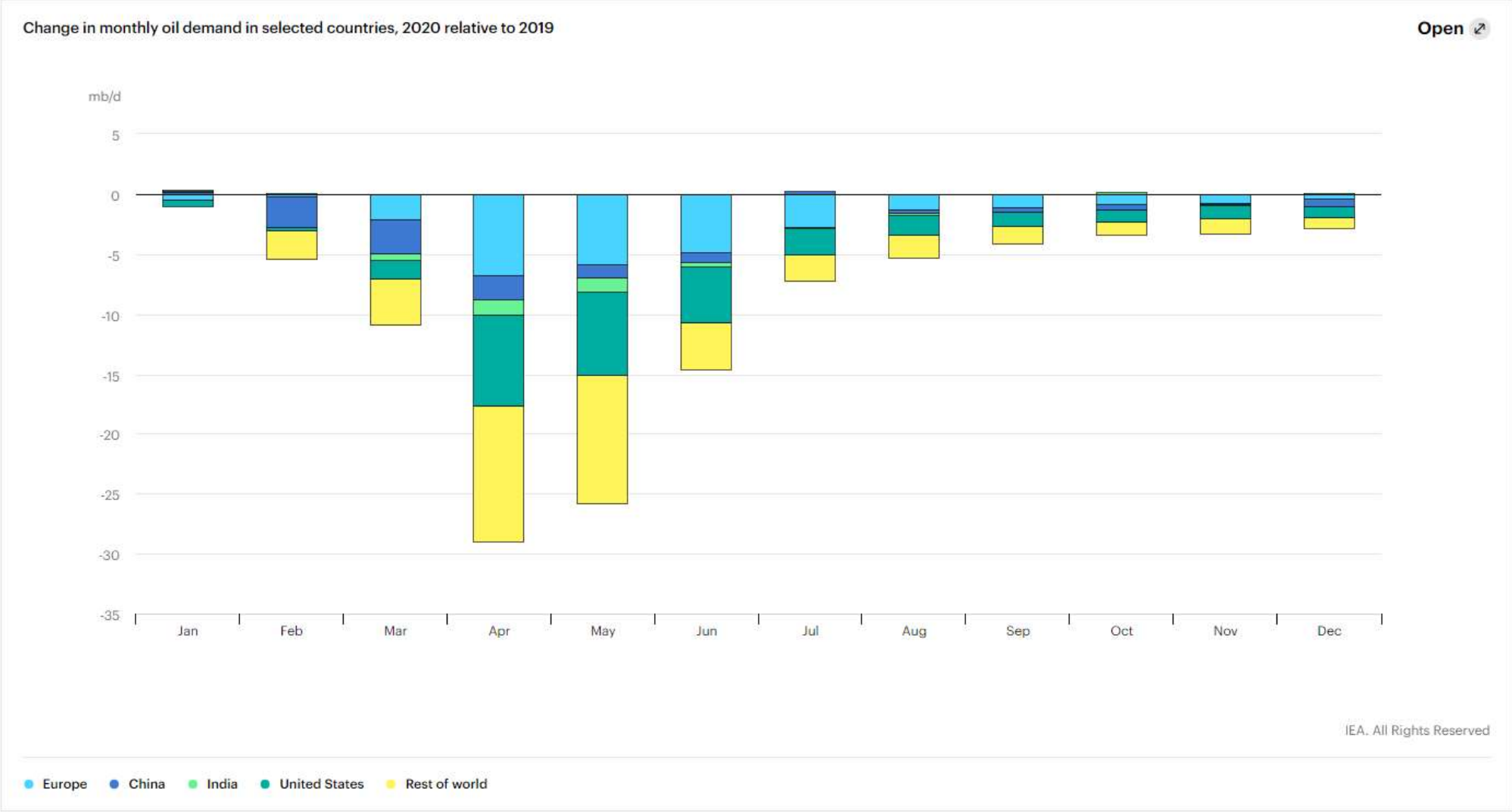
Evolution of road passenger transport activity in selected countries in early 2020- covid



2020 IEA

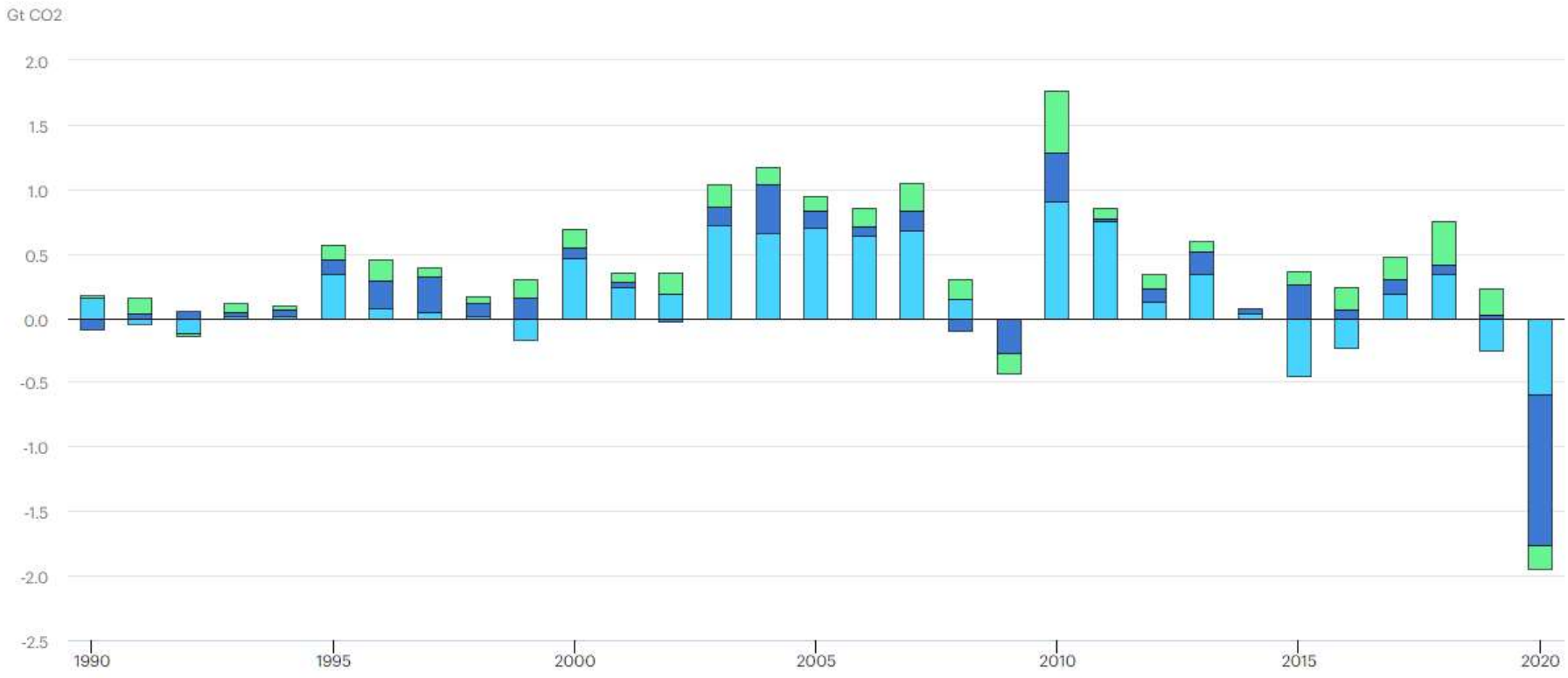
Evolution of road passenger transport activity in selected countries in early 2020- covid

Change in monthly oil demand in selected countries, 2020 relative to 2019



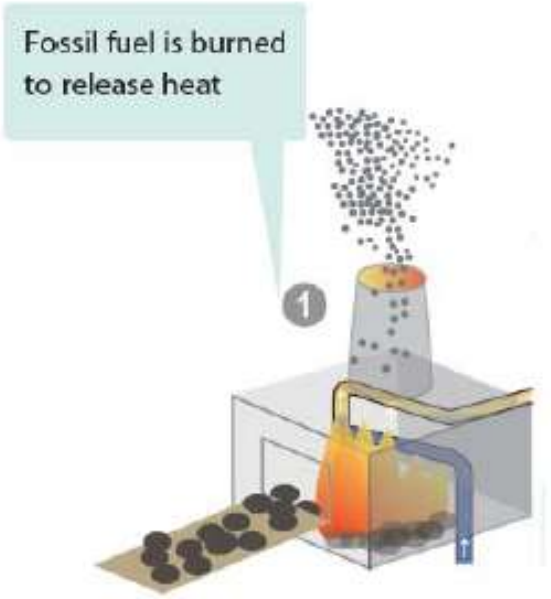
Change in CO2 emissions by fuel, 1990-2020

Download chart ↓ Cite Share



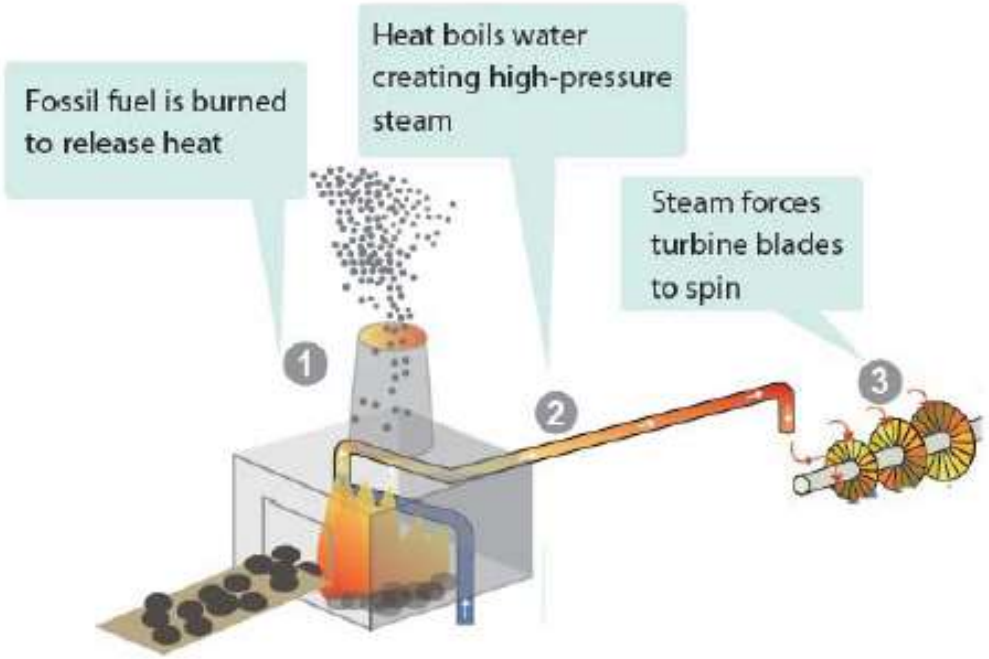
Electricity production

Heat



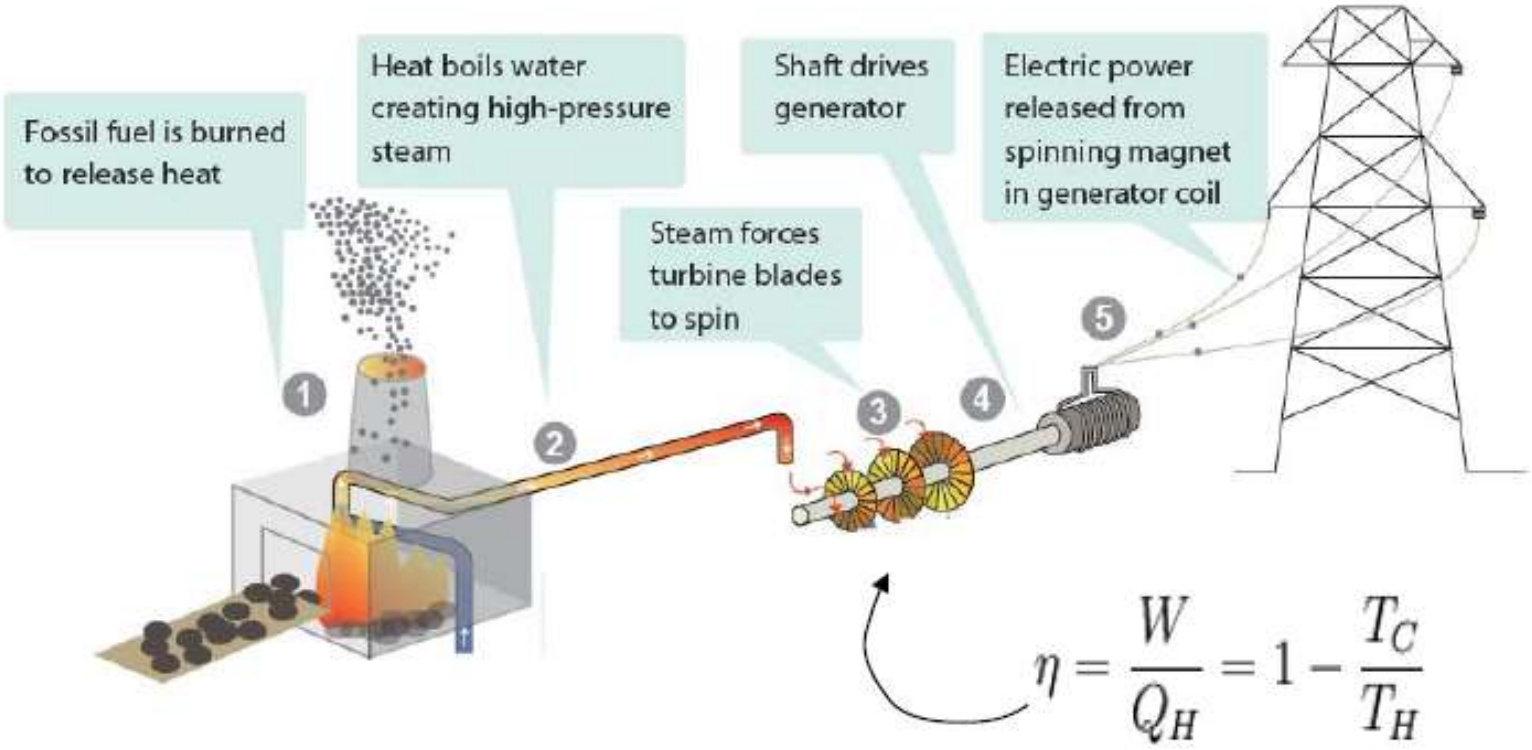
Electricity production

… from heat to steam

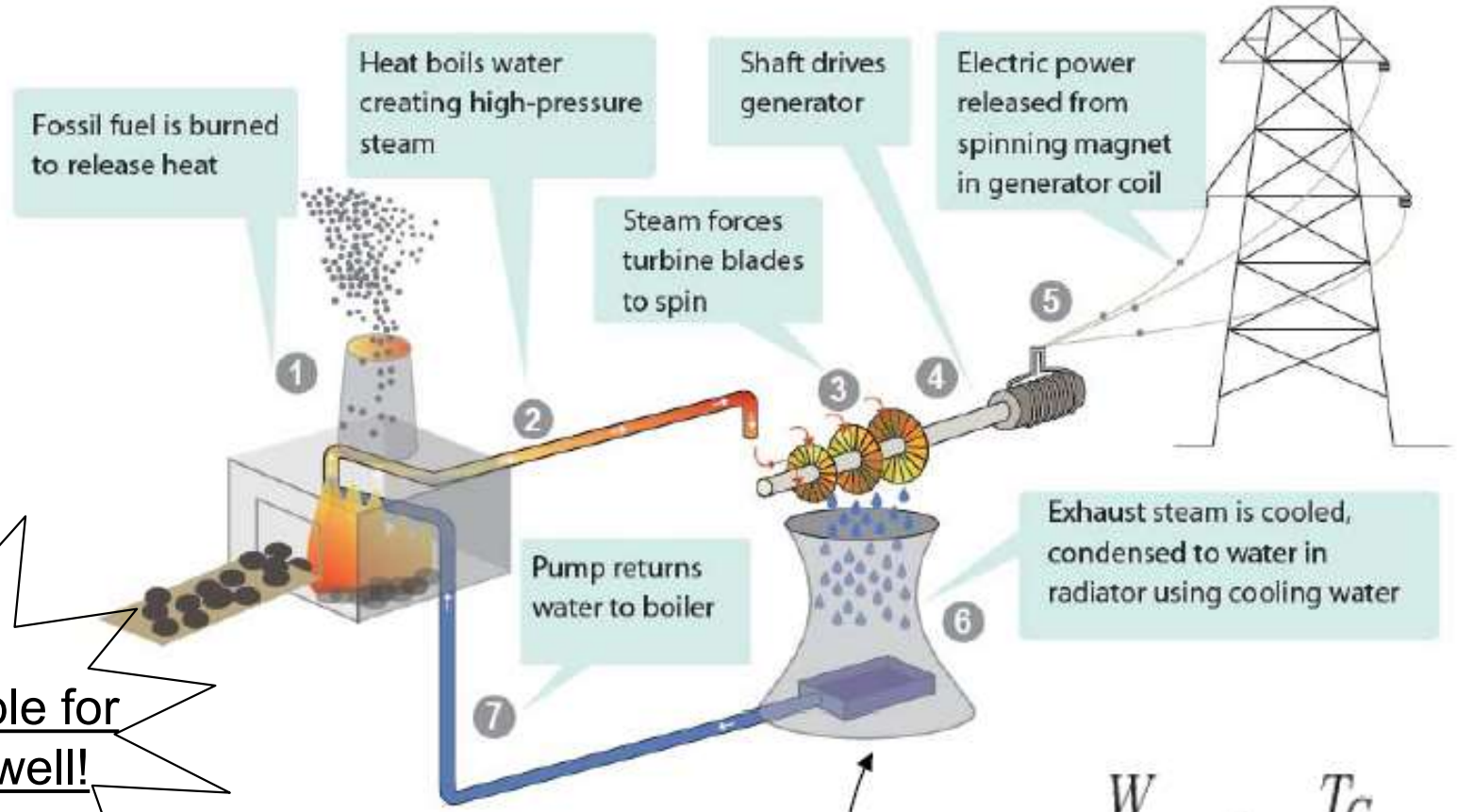


Electricity production

… from steam to electricity



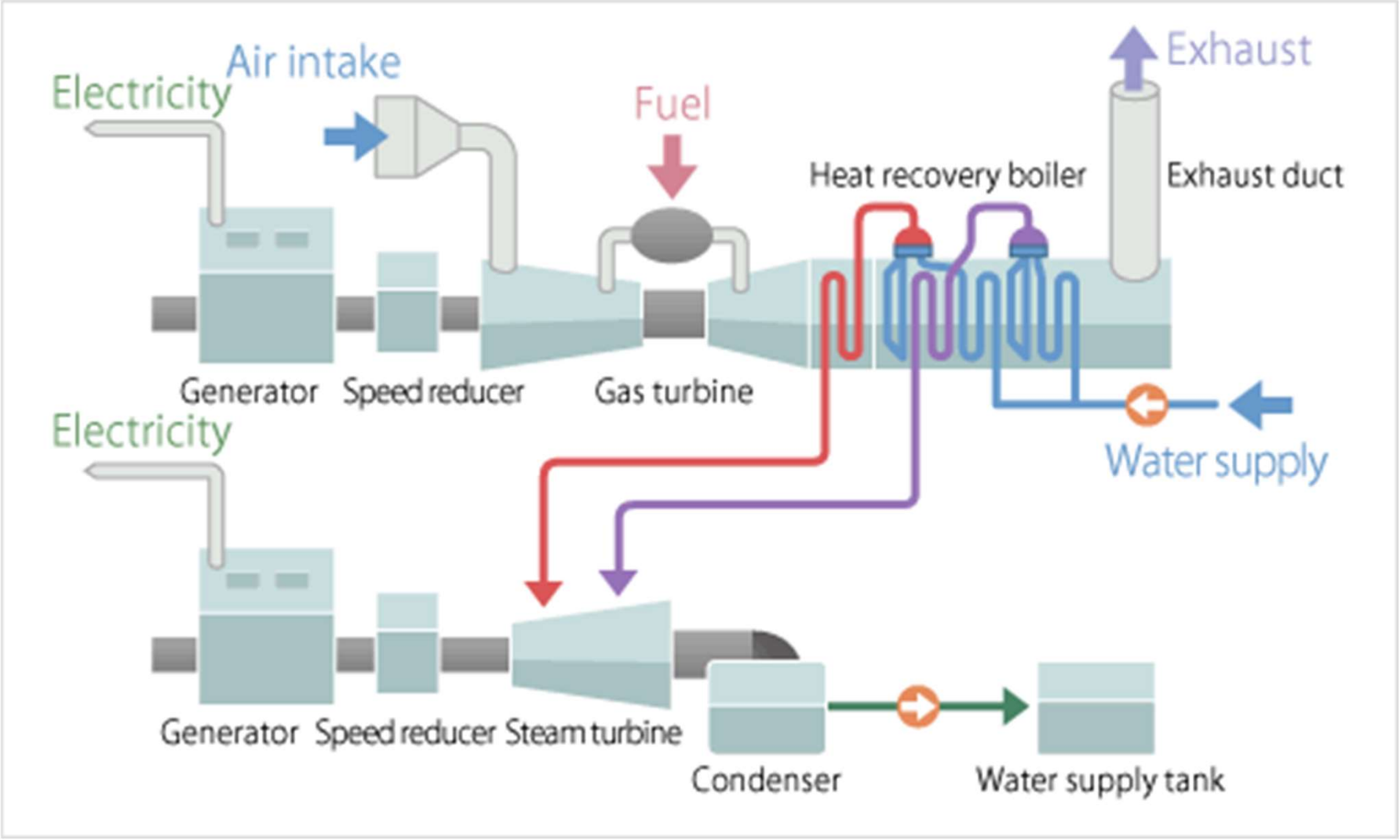
Electricity production



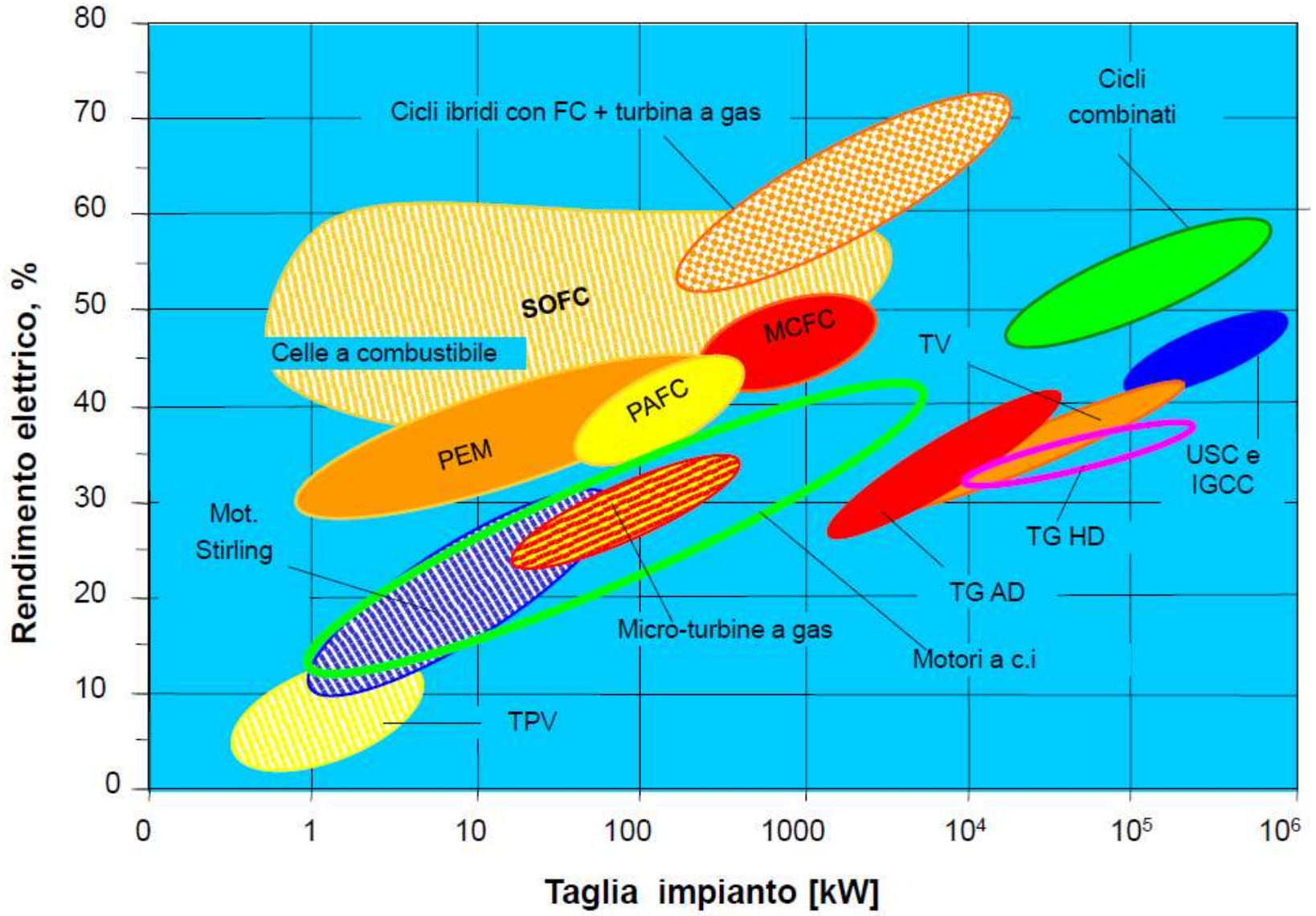
Same principle for nuclear as well!

$$\eta = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H}$$

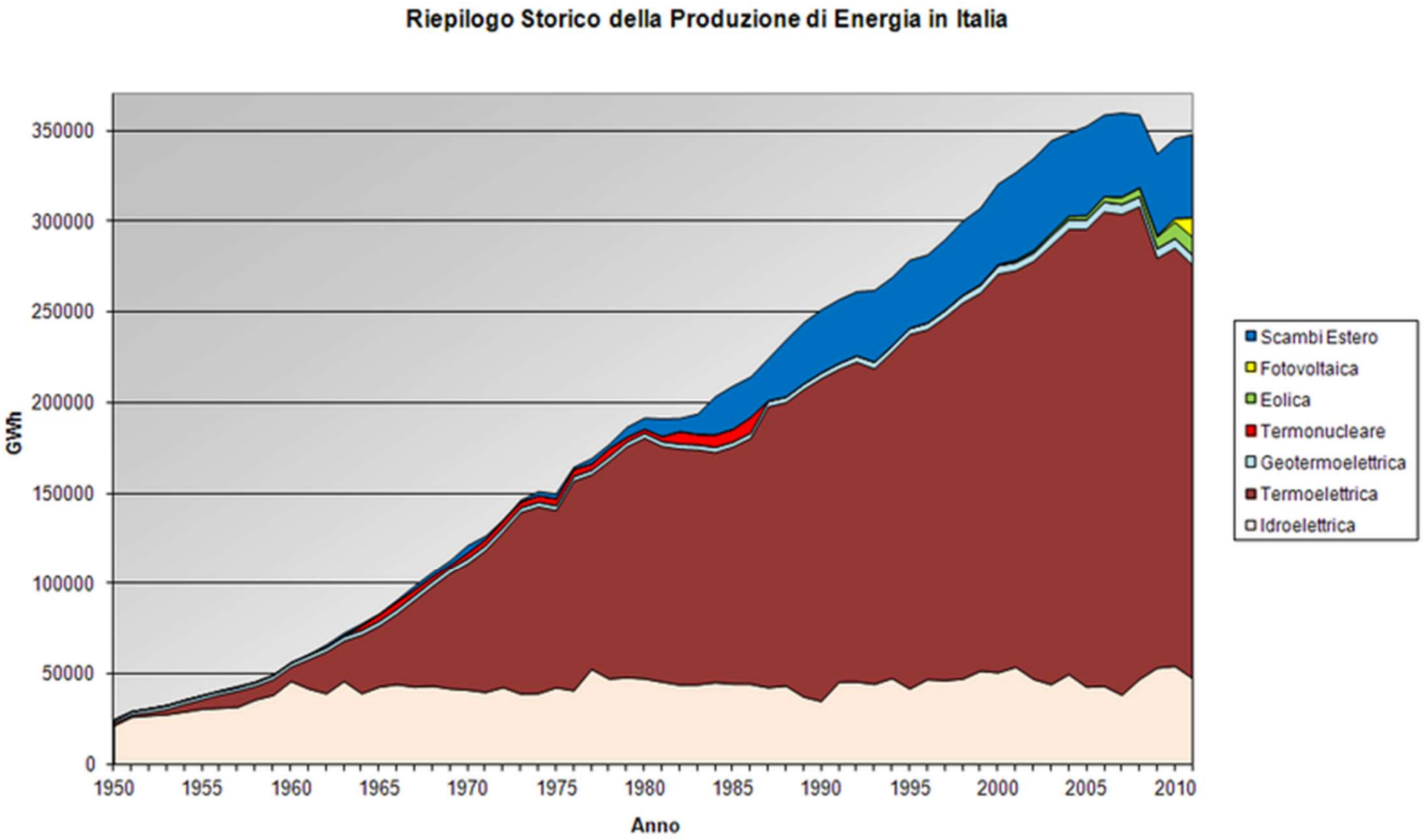
Combined cycle



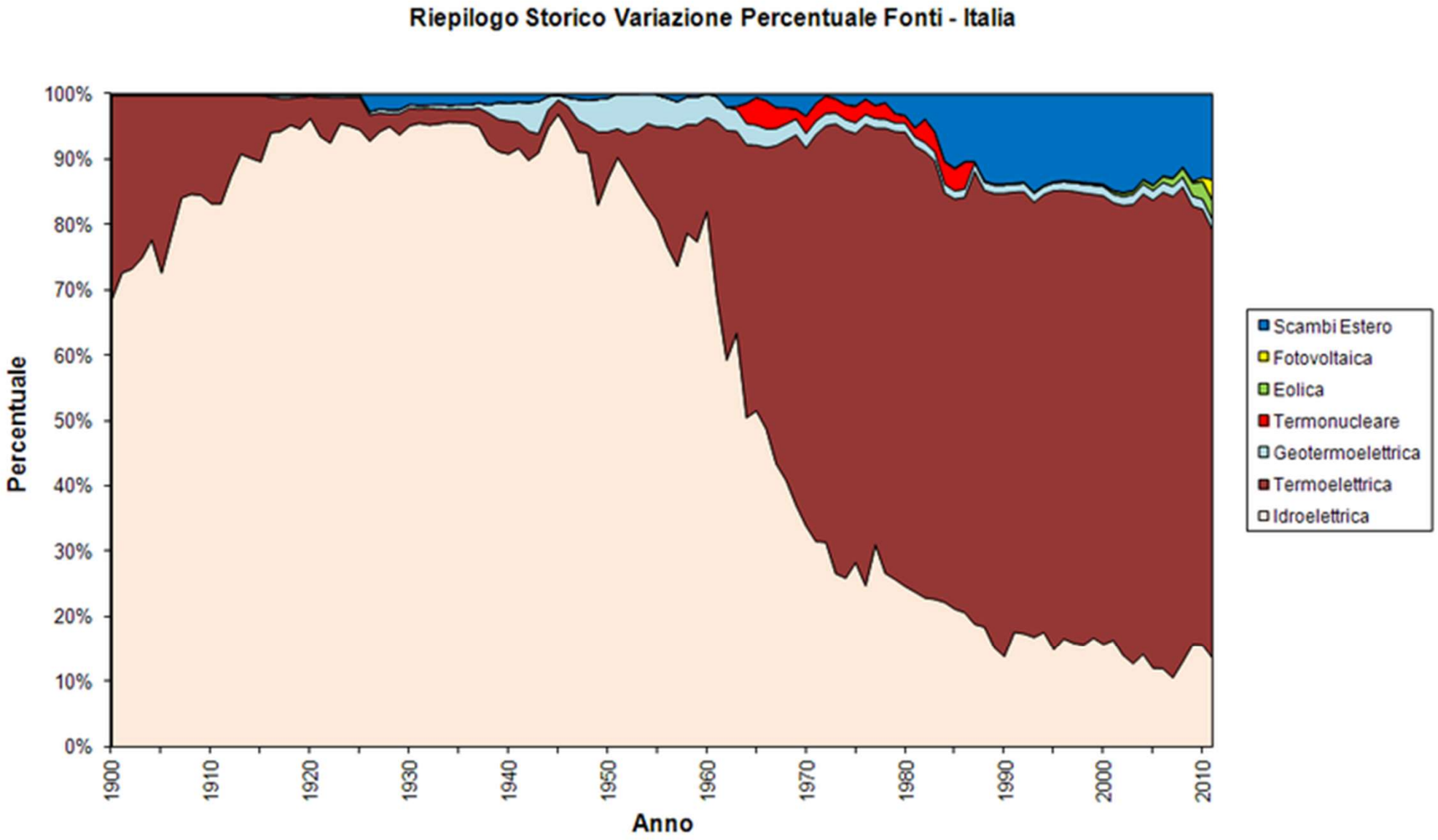
Impianti di generazione



Italia


Riepilogo Storico della Produzione di Energia in Italia
GWh
350000
300000
250000
200000
150000
100000
50000
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Anno
Scambi Estero
Fotovoltaica
Eolica
Termonucleare
Geotermoelettrica
Termoelettrica
Idroelettrica

Italia


Riepilogo Storico Variazione Percentuale Fonti - Italia
Percentuale
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Anno
Scambi Estero
Fotovoltaica
Eolica
Termonucleare
Geotermoelettrica
Termoelettrica
Idroelettrica

Potenza nominale ed efficiente degli impianti termoelettrici in Italia al 31 dicembre 2010

Produttori					
Sezioni		Potenza nominale		Potenza efficiente	
		Motori primi	Generatori	Lorda	Netta
	n.	MW	MVA	MW	MW
A) Impianti con sola produzione di energia elettrica					
combustione interna (CI)	**774**	**784,4**	**974,1**	**767,5**	**739,7**
-fino a 25	*774*	*784,4*	*974,1*	*767,5*	*739,7*
turbine a gas (TG)	**46**	**2.488,9**	**3.028,1**	**2.479,8**	**2.458,3**
-fino a 25	*17*	*142,7*	*162,6*	*134,6*	*133,2*
-oltre 25 fino a 50	*6*	*186,0*	*246,1*	*185,0*	*180,0*
-oltre 50 fino a 100	*19*	*1.666,6*	*2.059,4*	*1.666,6*	*1.655,2*
-oltre 100 fino a 200	*4*	*493,6*	*560,0*	*493,6*	*490,0*
a vapore a condensazione (C)	**134**	**21.714,6**	**25.225,2**	**21.595,5**	**19.709,7**
-fino a 25	*54*	*468,3*	*564,1*	*446,7*	*395,0*
-oltre 25 fino a 50	*5*	*193,8*	*285,5*	*193,8*	*174,8*
-oltre 50 fino a 100	*14*	*985,5*	*1.228,2*	*985,5*	*913,1*
-oltre 100 fino a 200	*21*	*3.327,0*	*3.907,5*	*3.314,5*	*3.070,8*
-oltre 200 fino a 500	*28*	*8.880,0*	*10.250,0*	*8.795,0*	*8.102,2*
-oltre 500	*12*	*7.860,0*	*8.990,0*	*7.860,0*	*7.053,8*
ciclo combinato (CC)	**53**	**23.589,8**	**30.654,2**	**23.049,2**	**22.604,9**
-fino a 25	*4*	*48,7*	*60,9*	*46,0*	*44,5*
-oltre 50 fino a 100	*2*	*120,0*	*157,9*	*120,0*	*117,0*
-oltre 100 fino a 200	*1*	*115,5*	*144,6*	*115,5*	*113,0*
-oltre 200 fino a 500	*33*	*12.779,4*	*17.657,1*	*12.437,2*	*12.213,6*
-oltre 500	*13*	*10.526,2*	*12.633,8*	*10.330,5*	*10.116,9*
turbo espansione (TE)	**12**	**37,4**	**42,6**	**34,8**	**33,2**
-fino a 25	*12*	*37,4*	*42,6*	*34,8*	*33,2*
ripotenziato (RP)	**8**	**5.317,6**	**6.160,0**	**5.317,6**	**5.068,4**
-oltre 200 fino a 500	*4*	*1.737,6*	*2.040,0*	*1.737,6*	*1.594,4*
-oltre 500	*4*	*3.580,0*	*4.120,0*	*3.580,0*	*3.474,0*
altro genere (V)	**7**	**167,3**	**204,4**	**165,7**	**158,7**
-fino a 25	*5*	*53,3*	*64,3*	*51,7*	*50,4*
-oltre 25 fino a 50	*1*	*42,0*	*50,0*	*42,0*	*39,9*
-oltre 50 fino a 100	*1*	*72,0*	*90,0*	*72,0*	*68,4*
Totale A	**1.034**	**54.100,1**	**66.288,5**	**53.410,0**	**50.772,9**

Autoproduttori						ITALIA					
Sezioni	Potenza nominale			Potenza efficiente		Sezioni	Potenza nominale			Potenza efficiente	
	Motori primi	Generatori		Lorda	Netta		Motori primi	Generatori		Lorda	Netta
n.	MW	MVA		MW	MW	n.	MW	MVA		MW	MW
77	**127,5**	**155,6**		**123,3**	**119,1**	**851**	**911,9**	**1.129,7**		**890,8**	**858,7**
77	*127,5*	*155,6*		*123,3*	*119,1*	*851*	*911,9*	*1.129,7*		*890,8*	*858,7*
5	**36,8**	**42,8**		**36,8**	**36,1**	**51**	**2.525,7**	**3.070,8**		**2.516,6**	**2.494,4**
5	*36,8*	*42,8*		*36,8*	*36,1*	*22*	*179,5*	*205,3*		*171,4*	*169,3*
-	-	-		-	-	*6*	*186,0*	*246,1*		*185,0*	*180,0*
-	-	-		-	-	*19*	*1.666,6*	*2.059,4*		*1.666,6*	*1.655,2*
-	-	-		-	-	*4*	*493,6*	*560,0*		*493,6*	*490,0*
14	**211,4**	**276,7**		**207,1**	**195,4**	**148**	**21.926,1**	**25.502,0**		**21.802,6**	**19.905,2**
9	*54,9*	*68,7*		*50,6*	*47,5*	*63*	*523,3*	*632,8*		*497,3*	*442,5*
5	*156,5*	*208,0*		*156,5*	*147,9*	*10*	*350,3*	*493,5*		*350,3*	*322,7*
-	-	-		-	-	*14*	*985,5*	*1.228,2*		*985,5*	*913,1*
-	-	-		-	-	*21*	*3.327,0*	*3.907,5*		*3.314,5*	*3.070,8*
-	-	-		-	-	*28*	*8.880,0*	*10.250,0*		*8.795,0*	*8.102,2*
-	-	-		-	-	*12*	*7.860,0*	*8.990,0*		*7.860,0*	*7.053,8*
1	**58,0**	**73,3**		**58,0**	**55,3**	**54**	**23.647,8**	**30.727,5**		**23.107,2**	**22.660,3**
-	-	-		-	-	*4*	*48,7*	*60,9*		*46,0*	*44,5*
1	*58,0*	*73,3*		*58,0*	*55,3*	*3*	*178,0*	*231,2*		*178,0*	*172,3*
-	-	-		-	-	*1*	*115,5*	*144,6*		*115,5*	*113,0*
-	-	-		-	-	*33*	*12.779,4*	*17.657,1*		*12.437,2*	*12.213,6*
-	-	-		-	-	*13*	*10.526,2*	*12.633,8*		*10.330,5*	*10.116,9*
13	**124,2**	**162,0**		**116,1**	**113,0**	**25**	**161,6**	**204,6**		**150,9**	**146,2**
13	*124,2*	*162,0*		*116,1*	*113,0*	*25*	*161,6*	*204,6*		*150,9*	*146,2*
-	-	-		-	-	**8**	**5.317,6**	**6.160,0**		**5.317,6**	**5.068,4**
-	-	-		-	-	*4*	*1.737,6*	*2.040,0*		*1.737,6*	*1.594,4*
-	-	-		-	-	*4*	*3.580,0*	*4.120,0*		*3.580,0*	*3.474,0*
2	**14,0**	**18,4**		**13,6**	**12,9**	**9**	**181,3**	**222,8**		**179,3**	**171,6**
2	*14,0*	*18,4*		*13,6*	*12,9*	*7*	*67,3*	*82,8*		*65,3*	*63,3*
-	-	-		-	-	*1*	*42,0*	*50,0*		*42,0*	*39,9*
-	-	-		-	-	*1*	*72,0*	*90,0*		*72,0*	*68,4*
112	**572,0**	**728,8**		**554,9**	**531,8**	**1.146**	**54.672,1**	**67.017,4**		**53.965,0**	**51.304,8**

Energy consumptions

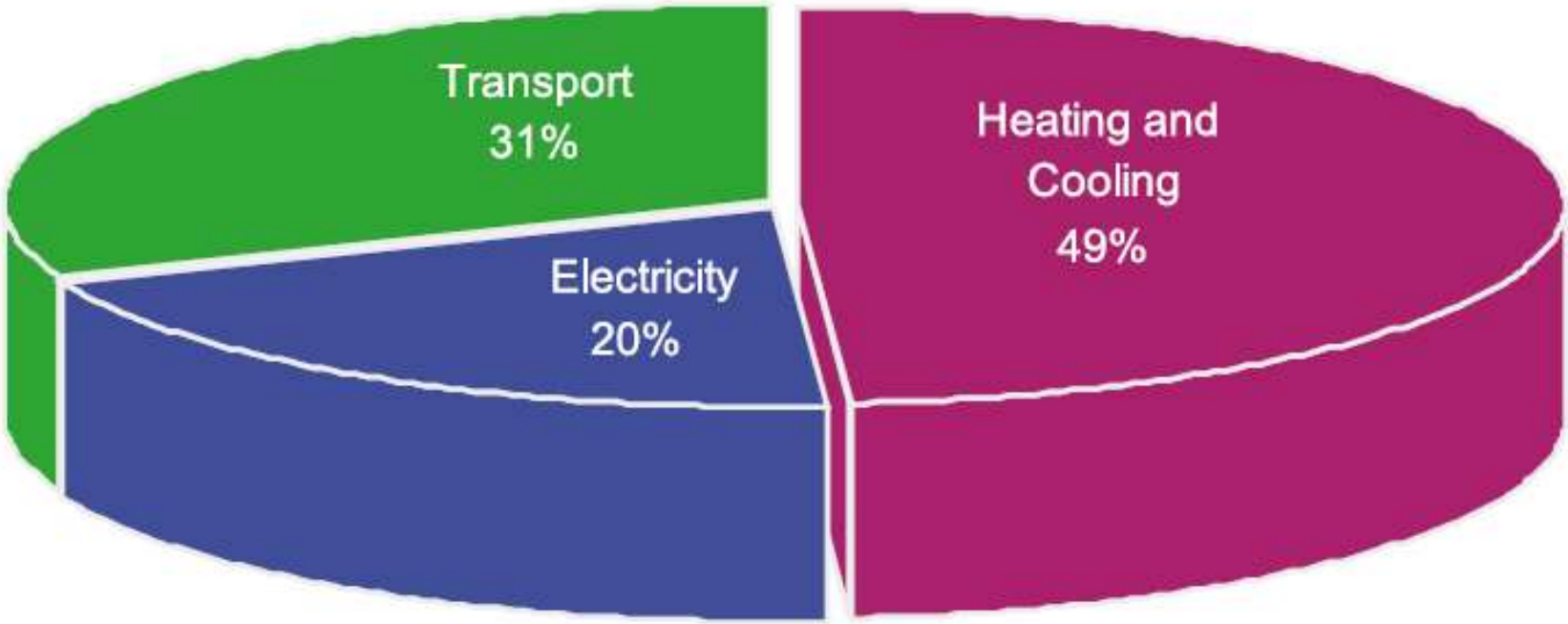
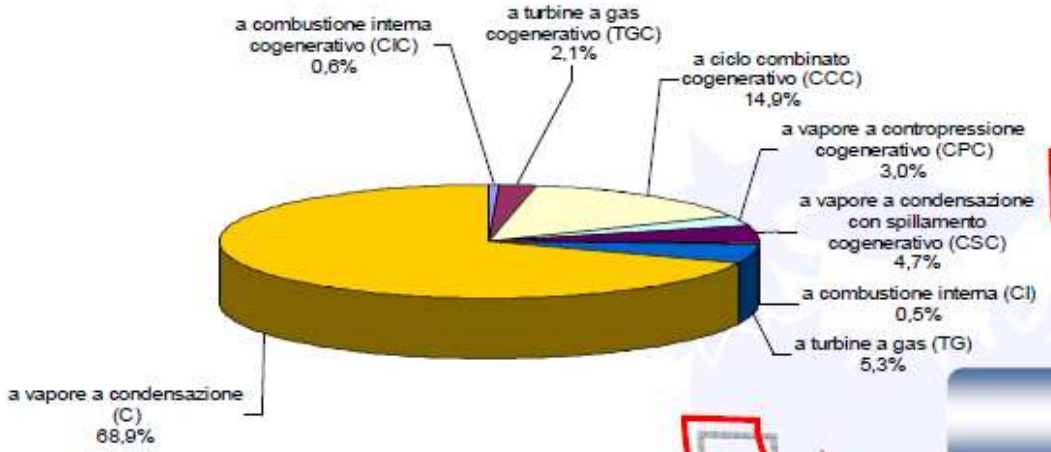


Figure 7: Final Energy demand in the European Union. (Source: EREC, 2006)

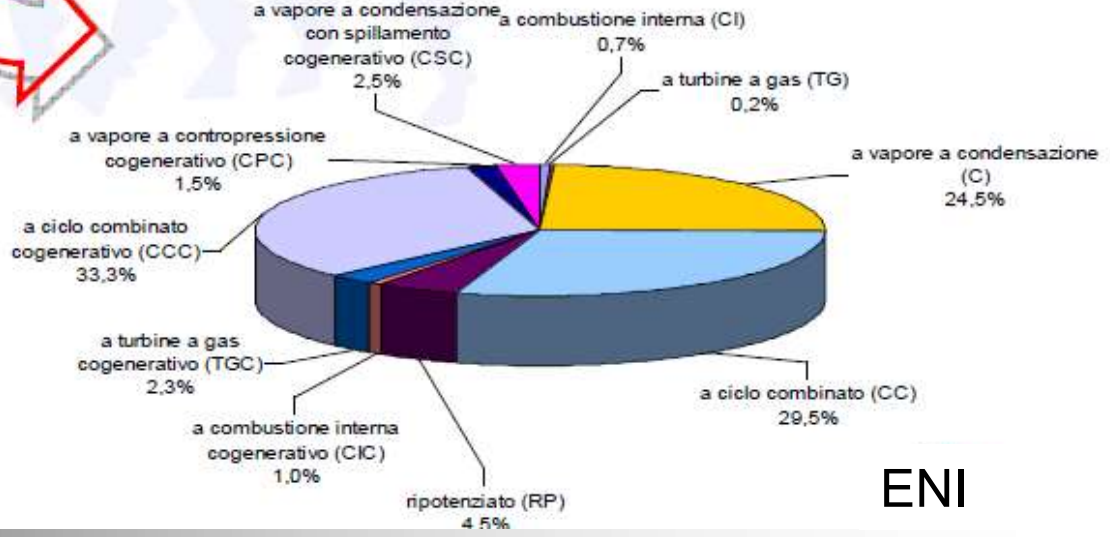
Produzione elettrica in Italia dal 1999 al 2008

Produzione totale 208.481 GWh



- Largo utilizzo del **Ciclo Rankine** – vapore a condensazione
- Limitate applicazioni **TG** e **cicli combinati cogenerativi**

Produzione totale 264.743 GWh



- Forte espansione del **ciclo combinato** sia **cogenerativo** che a **condensazione**
- **Repowering** ed interventi di **efficientamento** del parco esistente

ENI

Producers, net exporters and net importers of electricity

Producers*	TWh	% of world total
People's Rep. of China	4 716	21.3
United States	4 327	19.6
Russian Federation	1 053	4.8
India	1 052	4.8
Japan	1 043	4.7
Canada	637	2.9
Germany	602	2.7
France	557	2.5
Brazil	532	2.4
Korea	520	2.4
Rest of the world	7 087	31.9
World	**22 126**	**100.0**

2011 data

Net exporters	TWh
France	56
Paraguay	46
Canada	37
Russian Federation	23
Czech Republic	17
People's Rep. of China	13
Bulgaria	11
United Arab Emirates	8
Sweden	7
Ukraine	6
Others	58
Total	**282**

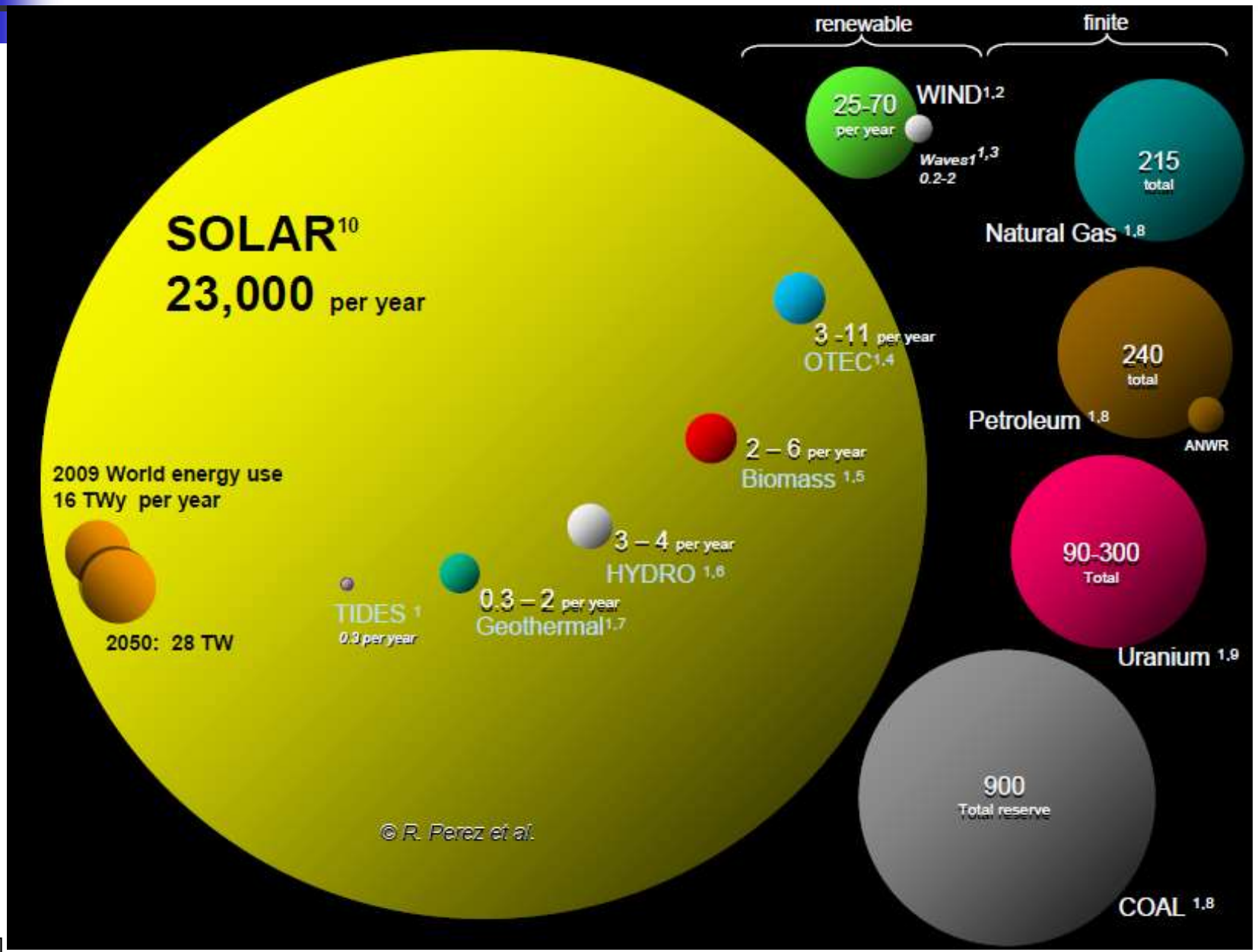
2011 data

Net importers	TWh
Italy	46
United States	37
Brazil	36
Finland	14
Argentina	10
Netherlands	9
Thailand	9
Hong Kong (China)	8
Austria	8
Croatia	8
Others	97
Total	**282**

**Gross production minus production from pumped storage plants.* 2011 data

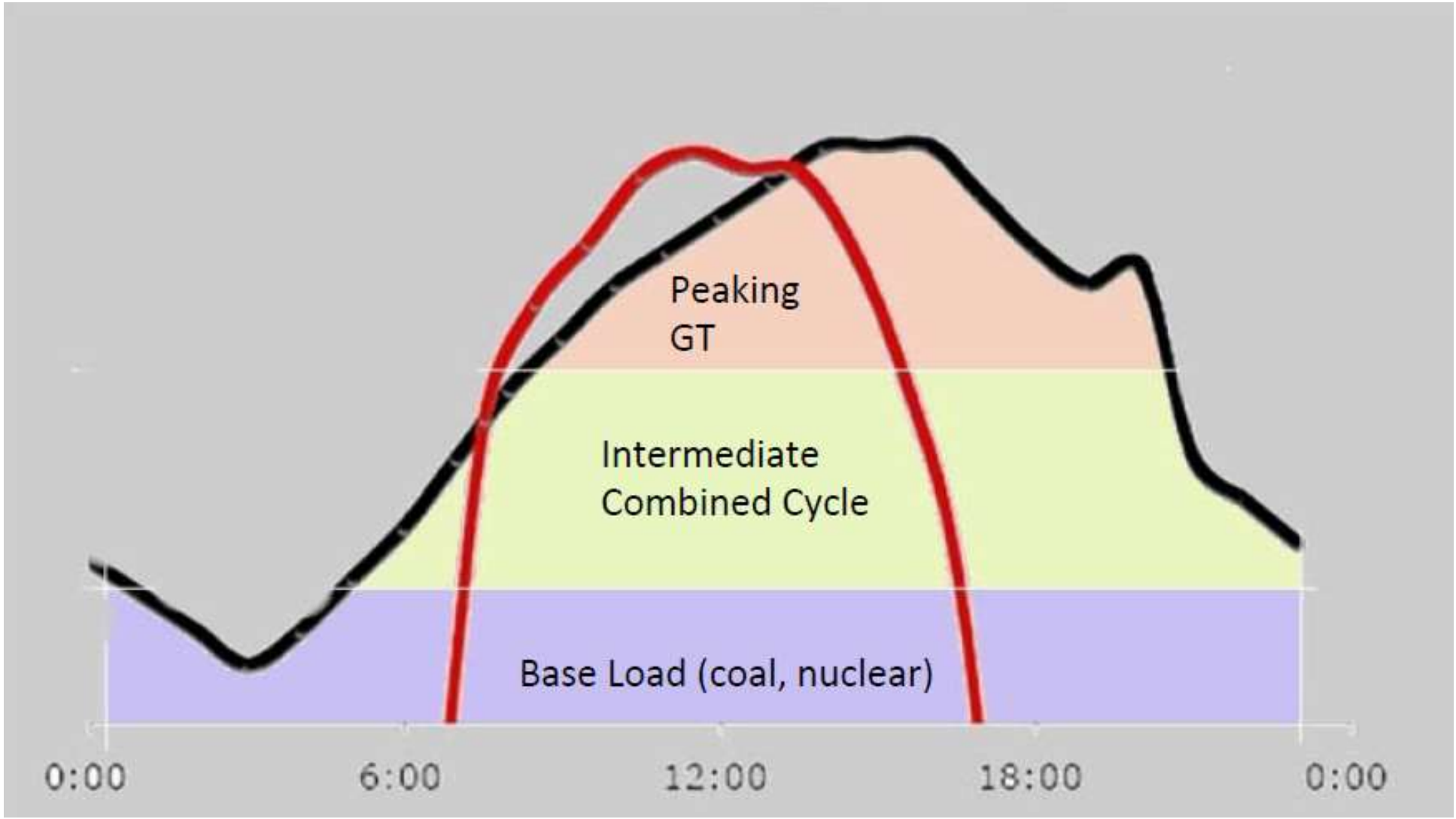
[IEA 2013]

Fonti rinnovabili di energia…

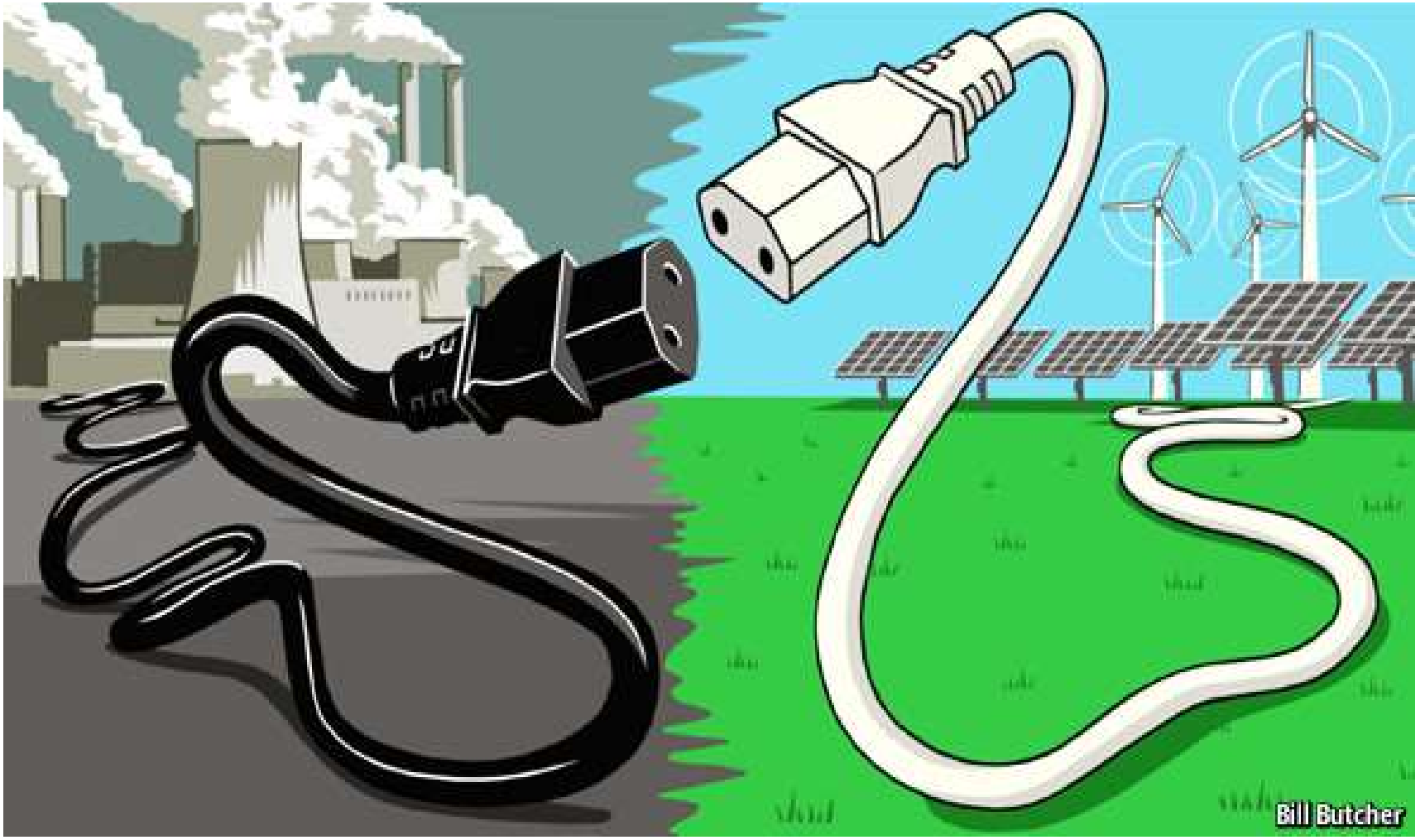


[Richard Perez]

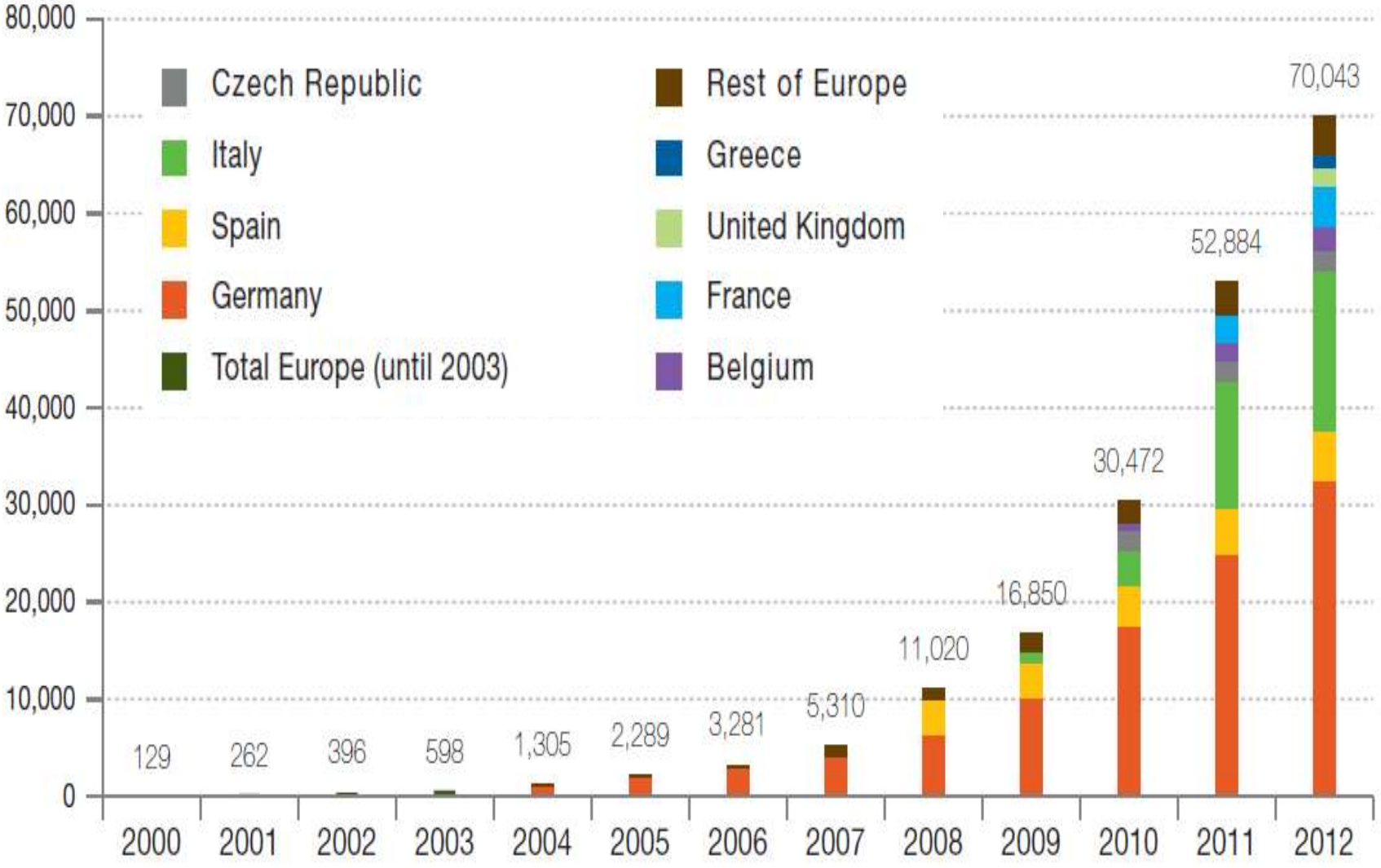
Typical electricity load profile



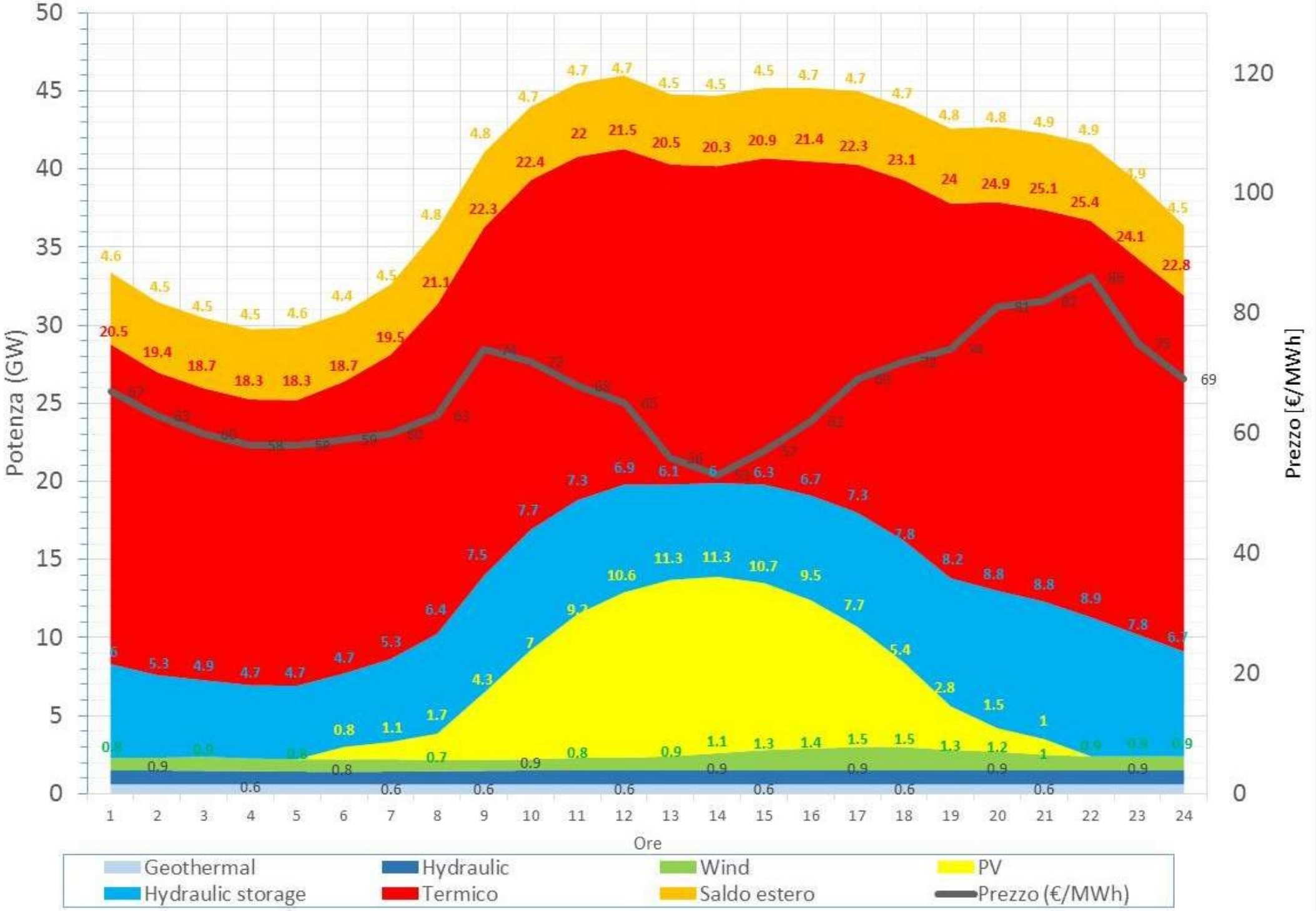
Case study: PV in Italy and Europe



Case study: PV in Italy and Europe

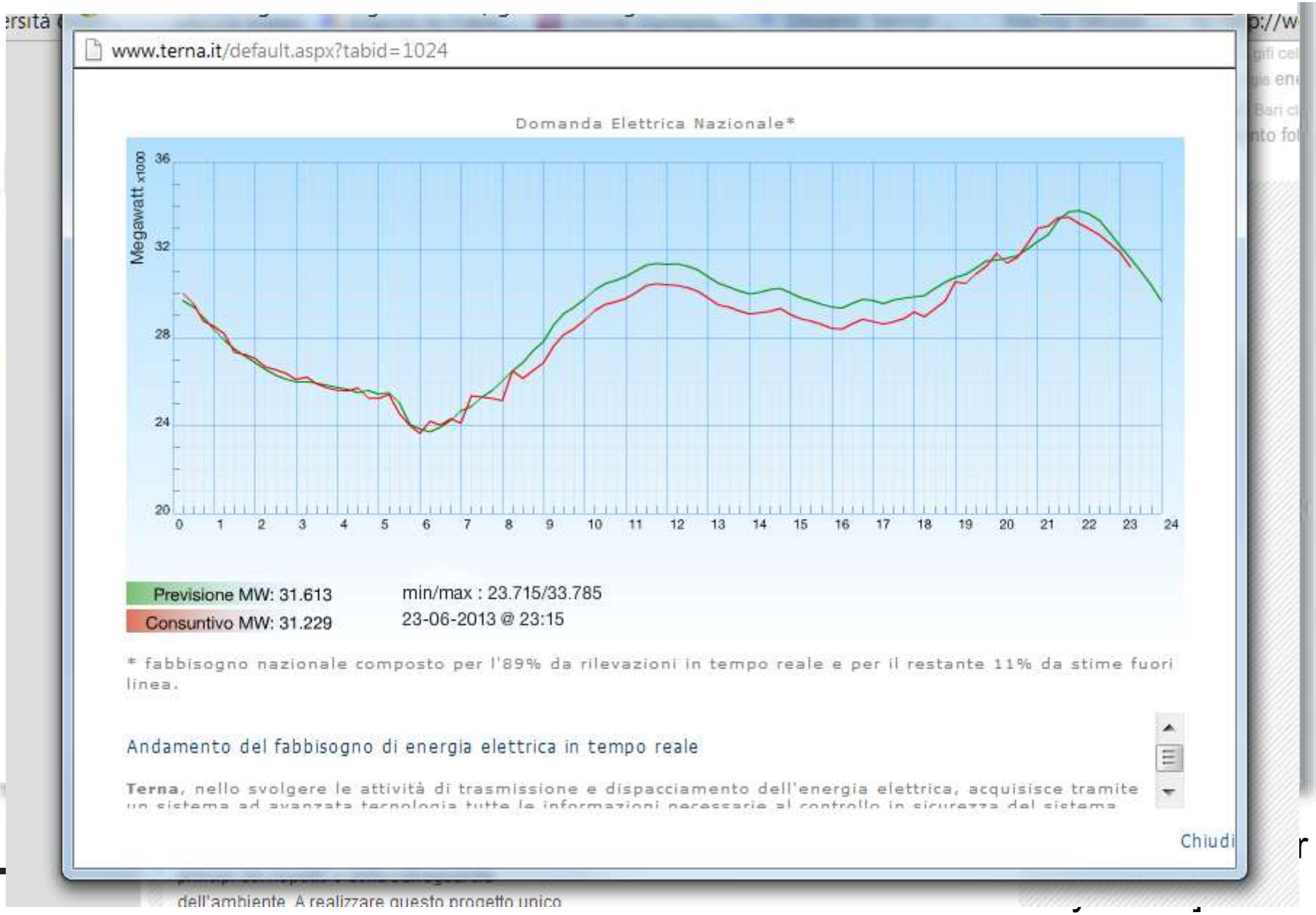


[EPIA]

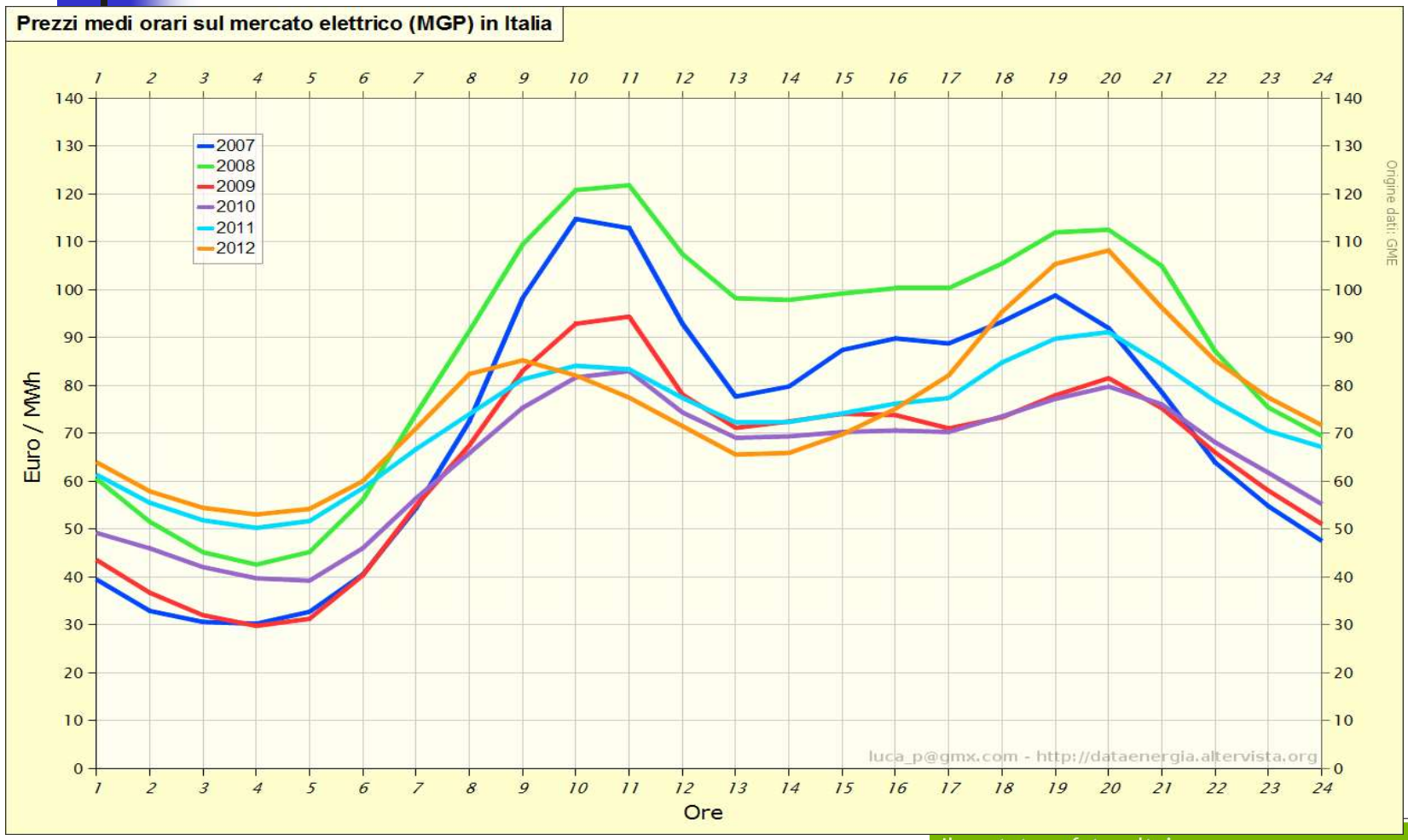


[Elaborated from Terna and http://dataenergia.altervista.org/]

Daily load profile

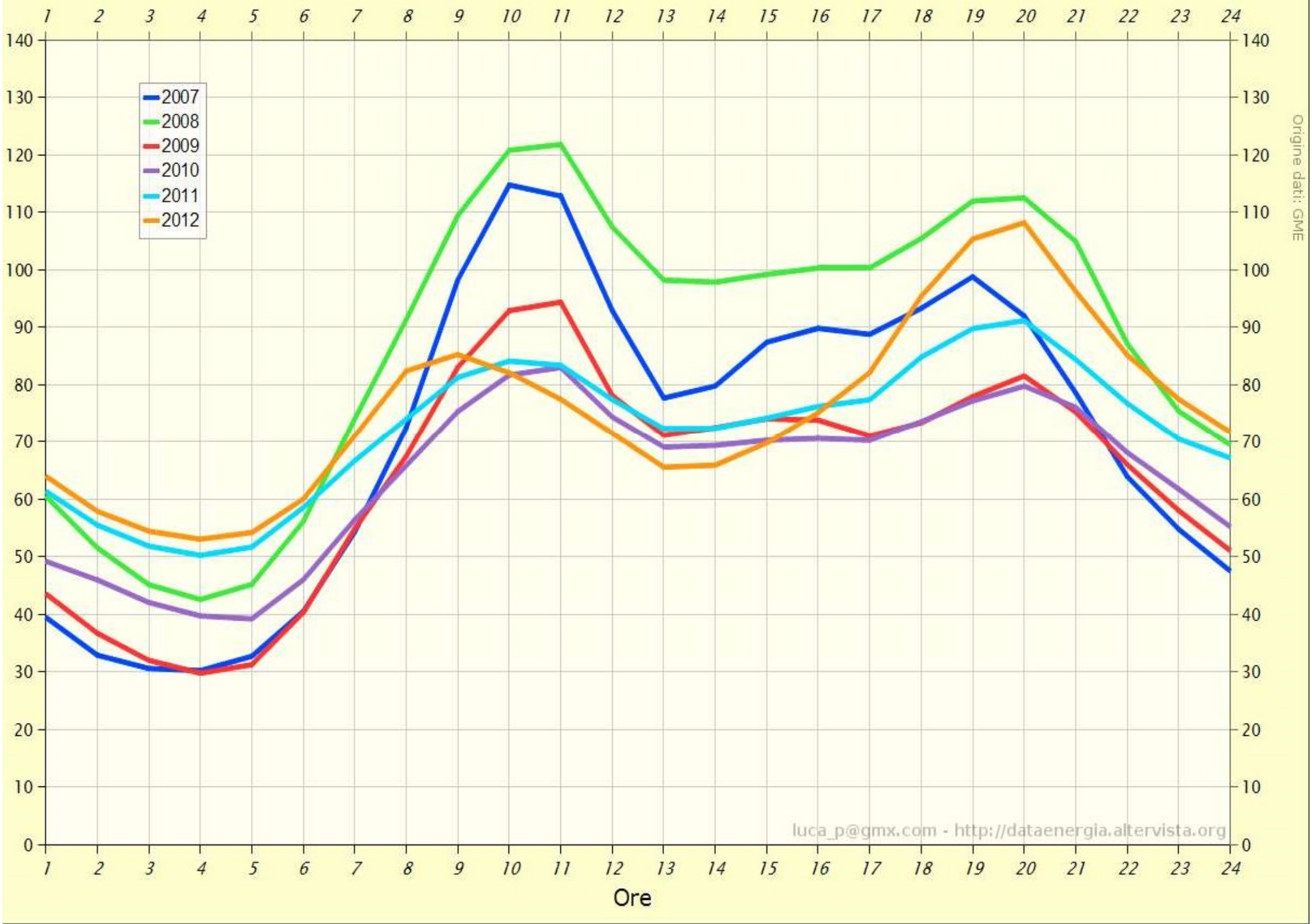


Italy: electricity price

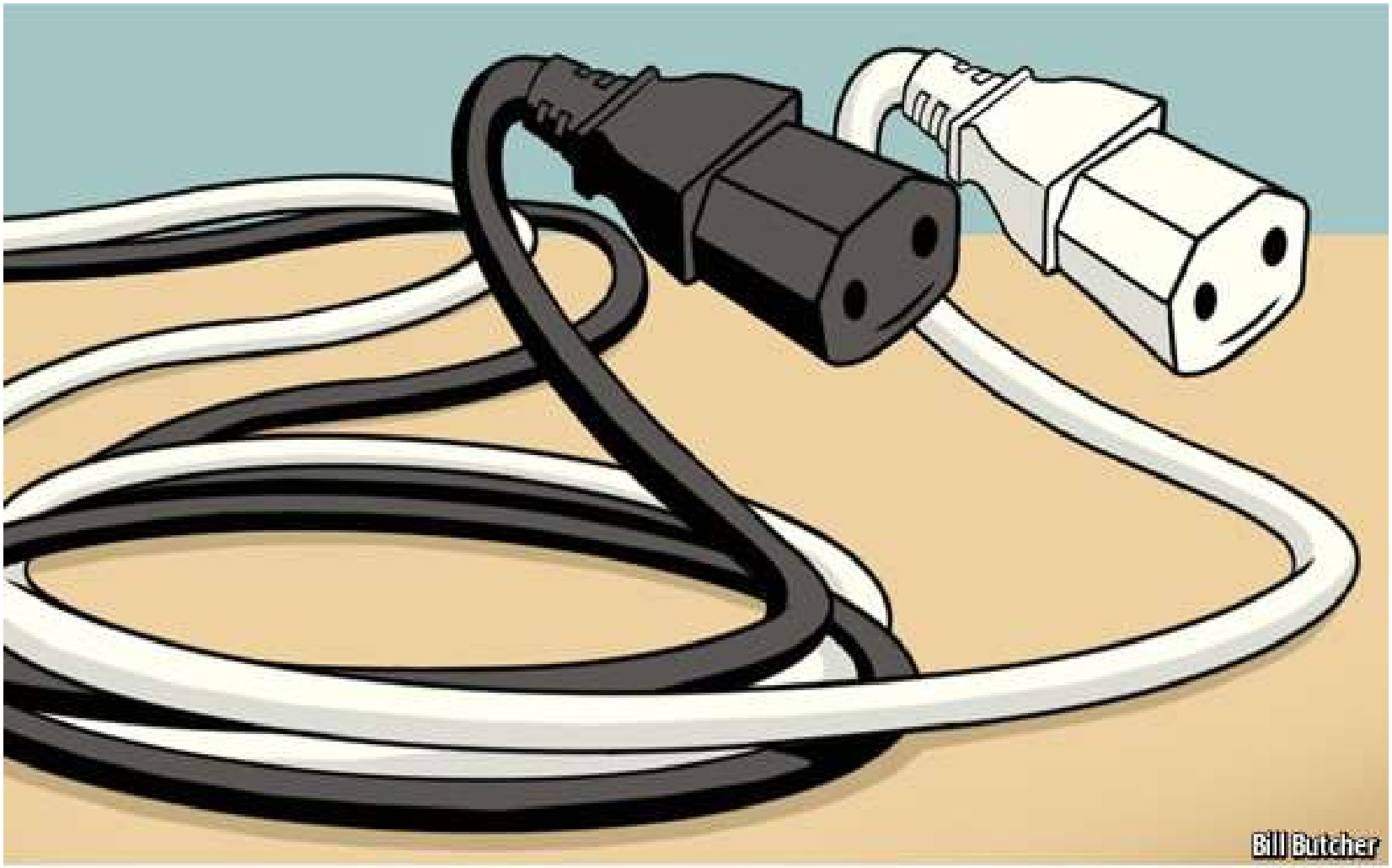


[http://dataenergia.altervista.org/]

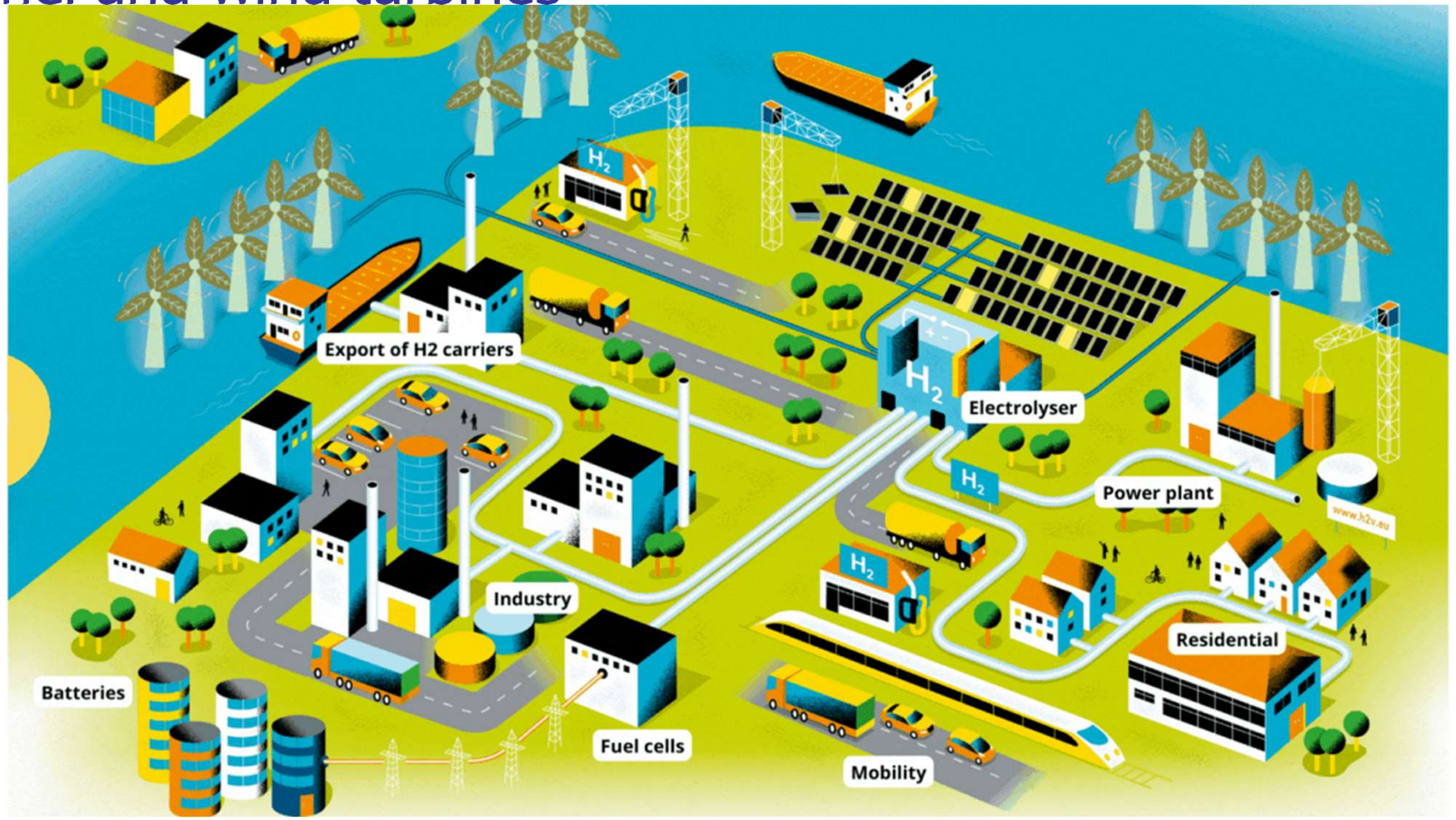
zzi medi orari sul mercato elettrico (MGP) in Italia



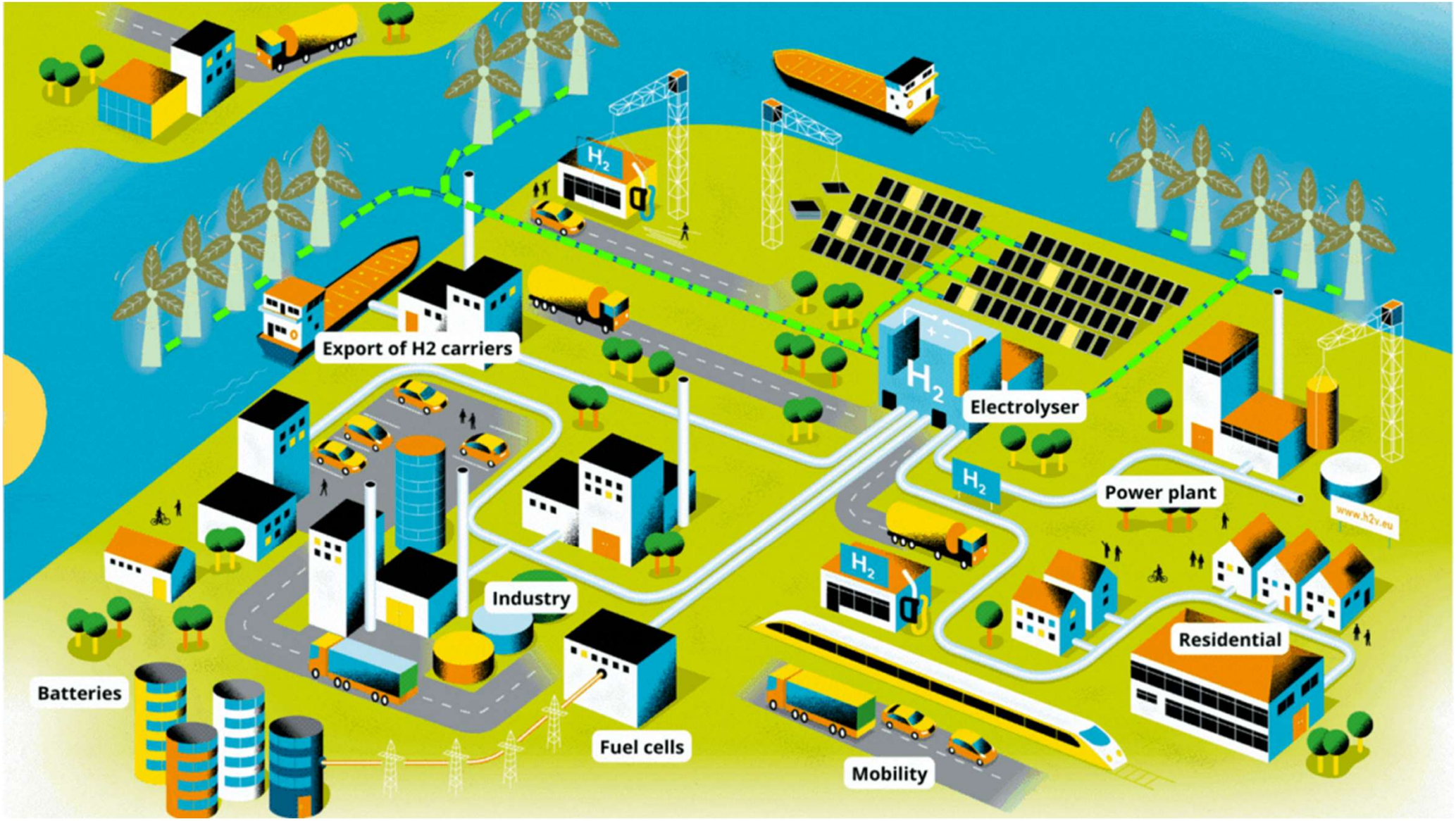
… possible? When? How?



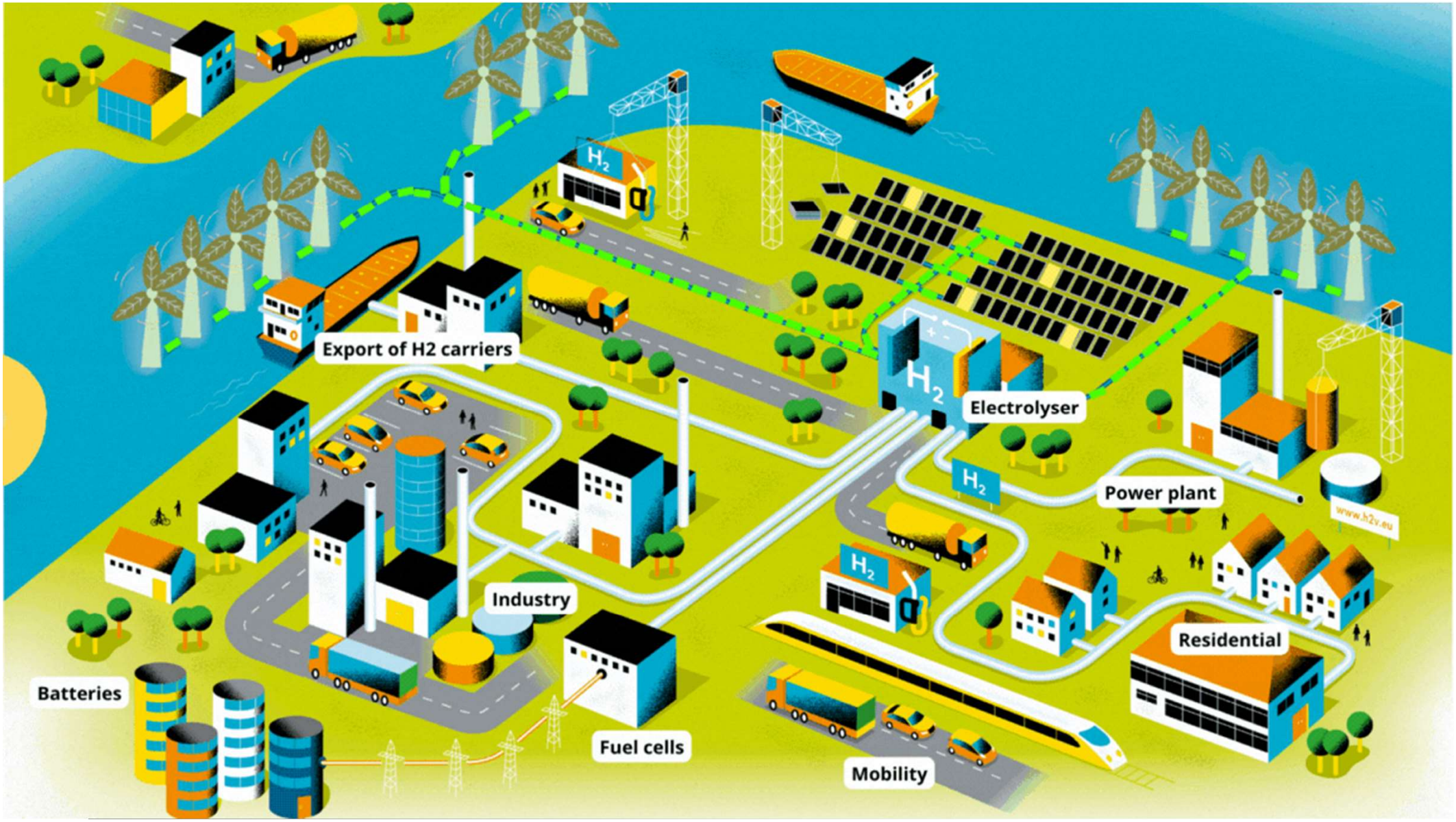
1 slide – base
solar panel and wind turbines



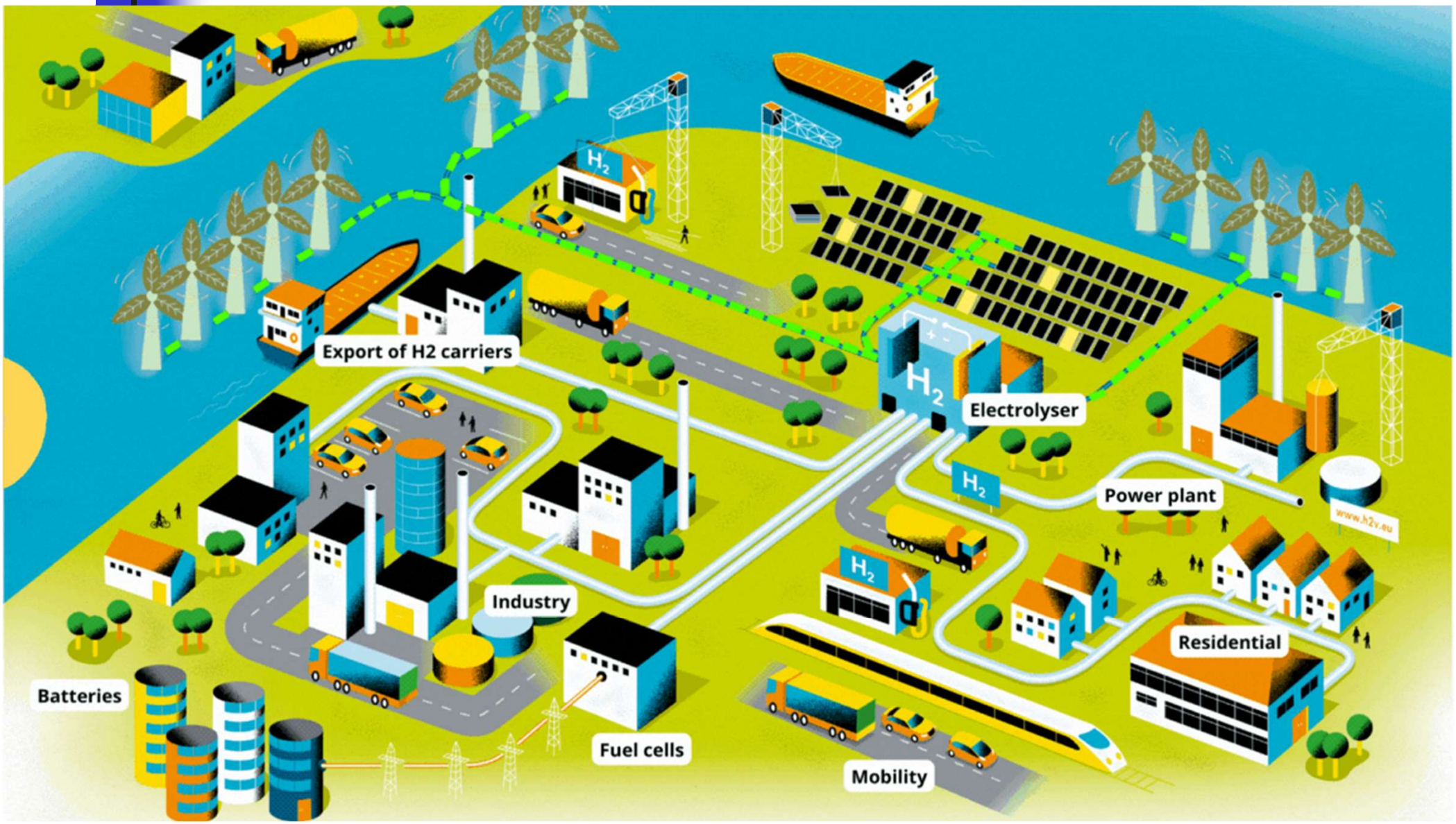
Energy to industry



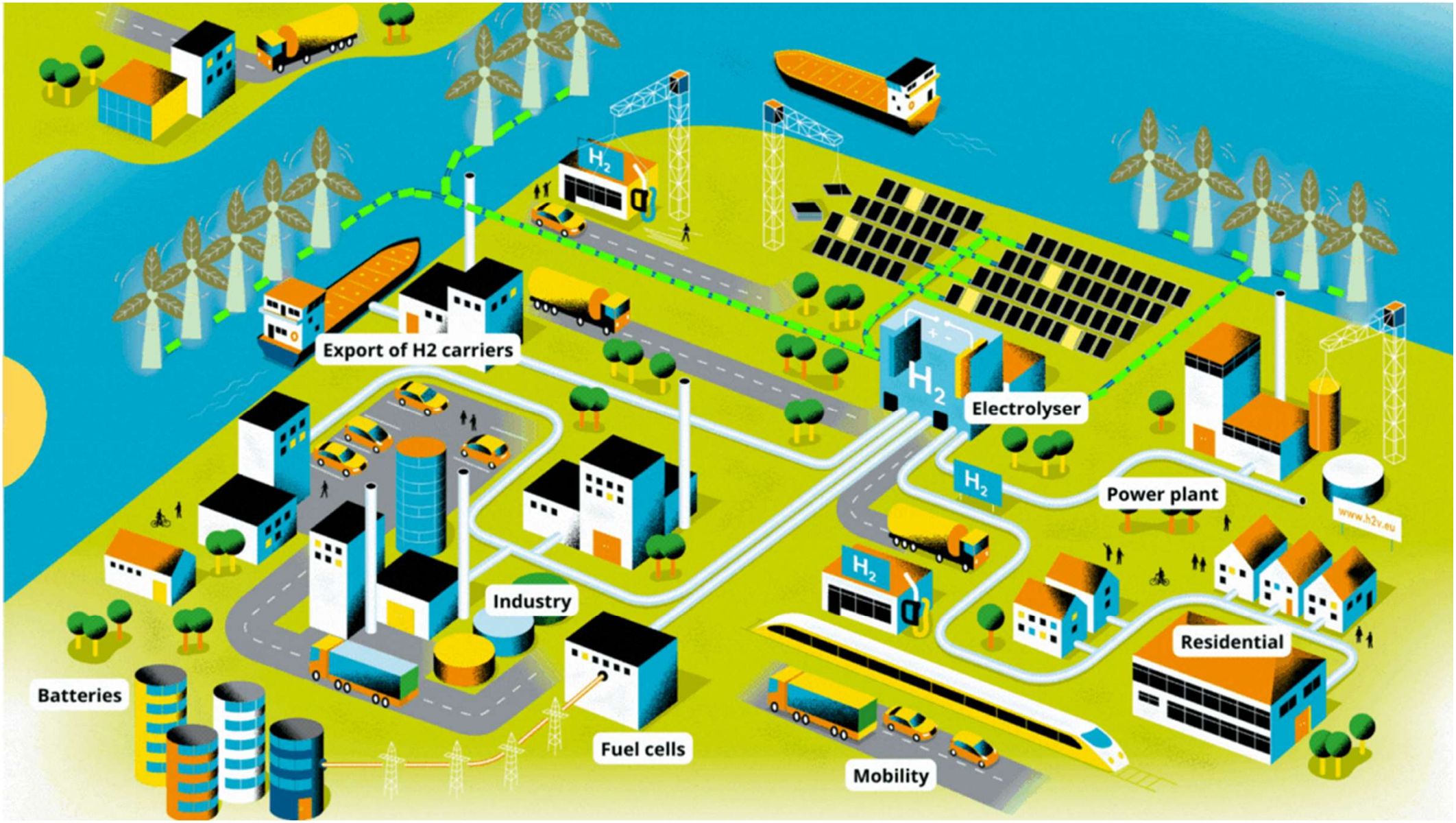
RES to export



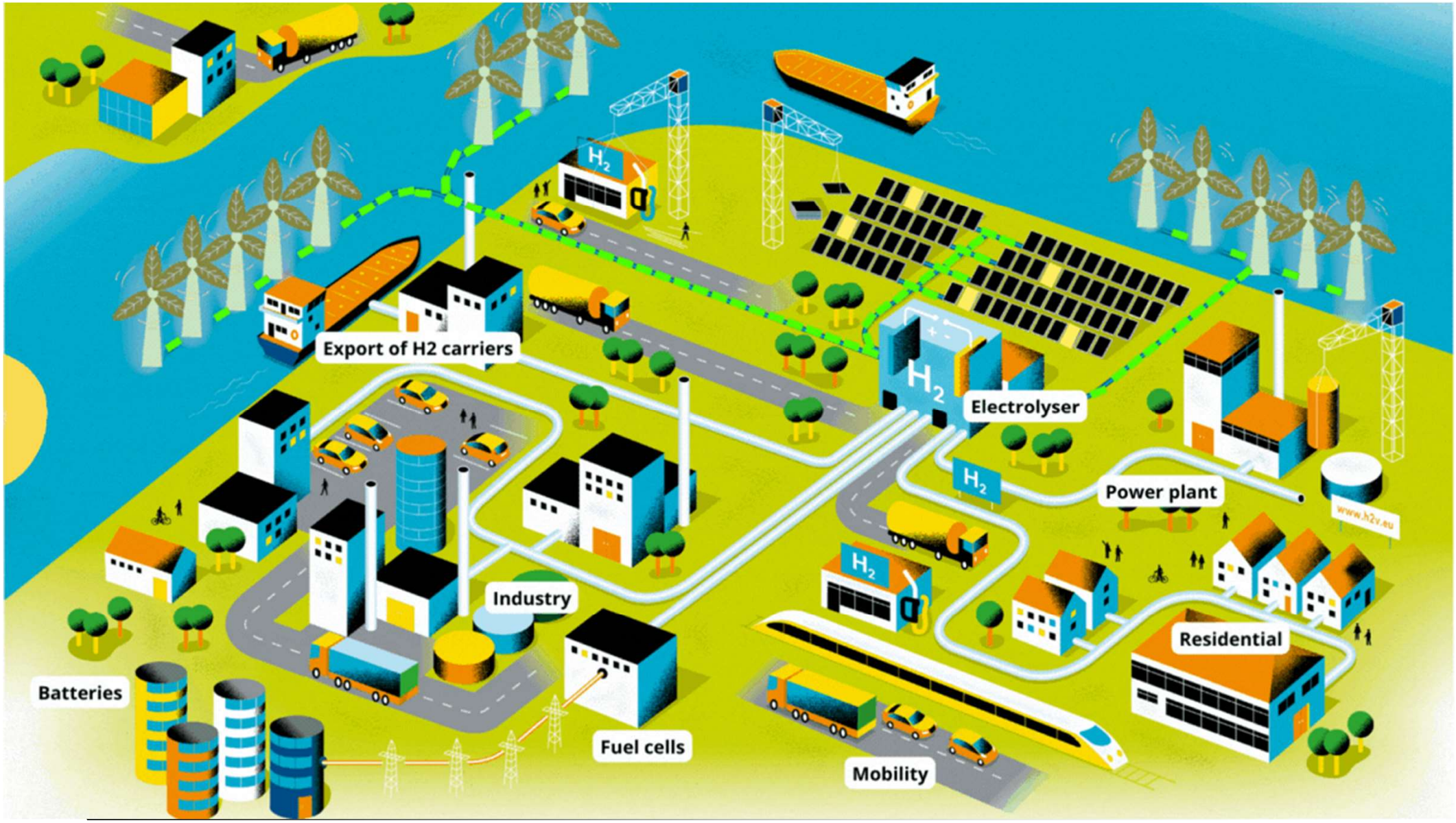
Energy to residential

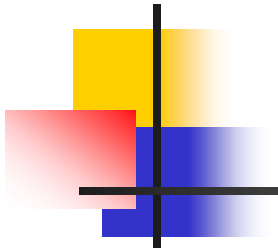


RES to mobility



RES back to electricity





Grazie per l’attenzione