Lecture 2 : energy

Main goals:
concepts and definitions useful for energy graphs
orders of magnitude
energy and society

Scope

Greenhouse gases and human activities

Generalities

machines

Fossils, oil

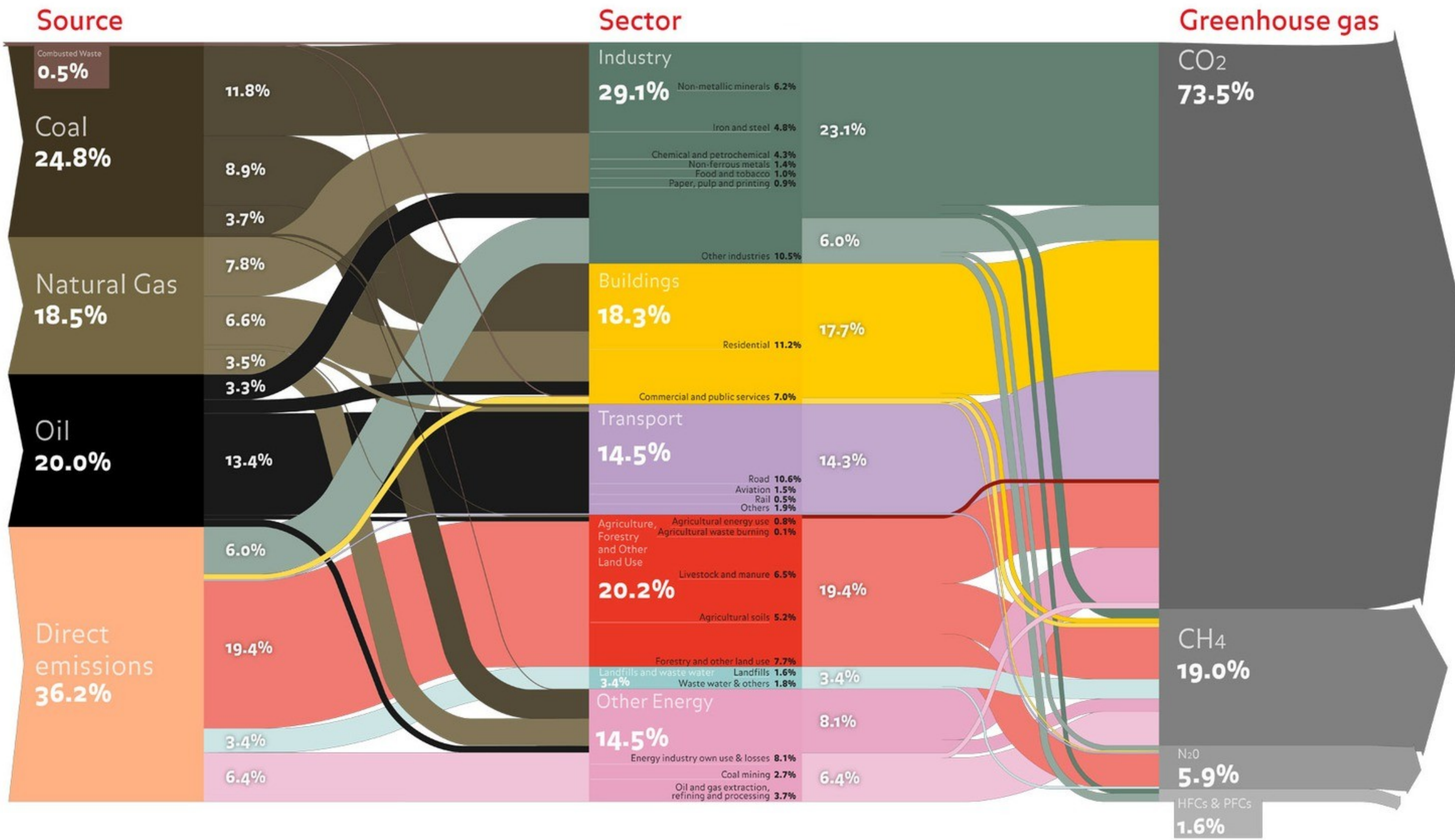
Energy and societies

Main references :

L'énergie à découvert, *Jeandel, Mosseri* (CNRS éditions)
Jean-Marc Jancovici website and lectures @Mines Paris Tech
International Agency of Energy reports
Web ressources for data

Human activities and GHG

Facing the issue with greenhouse gases



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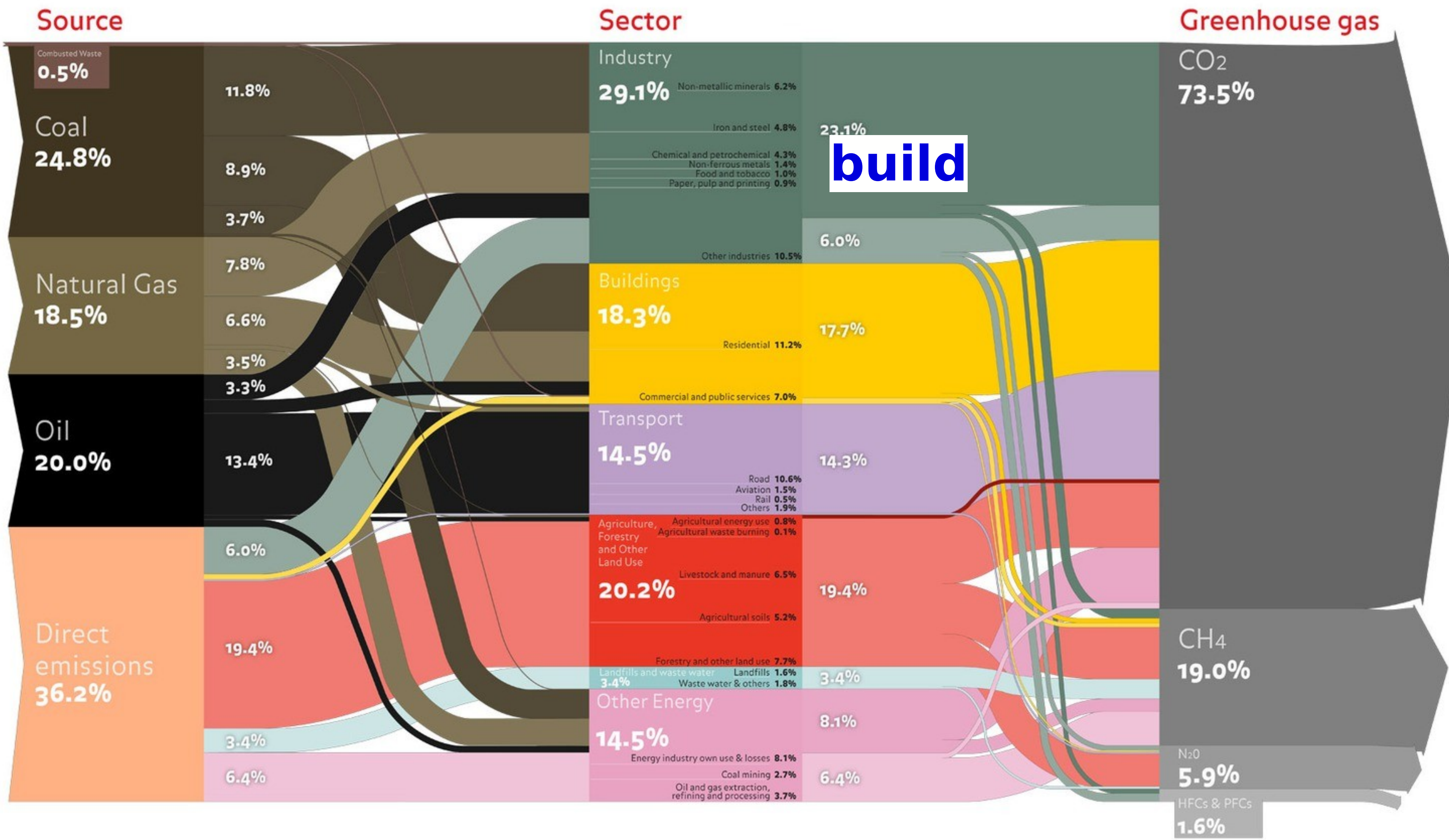

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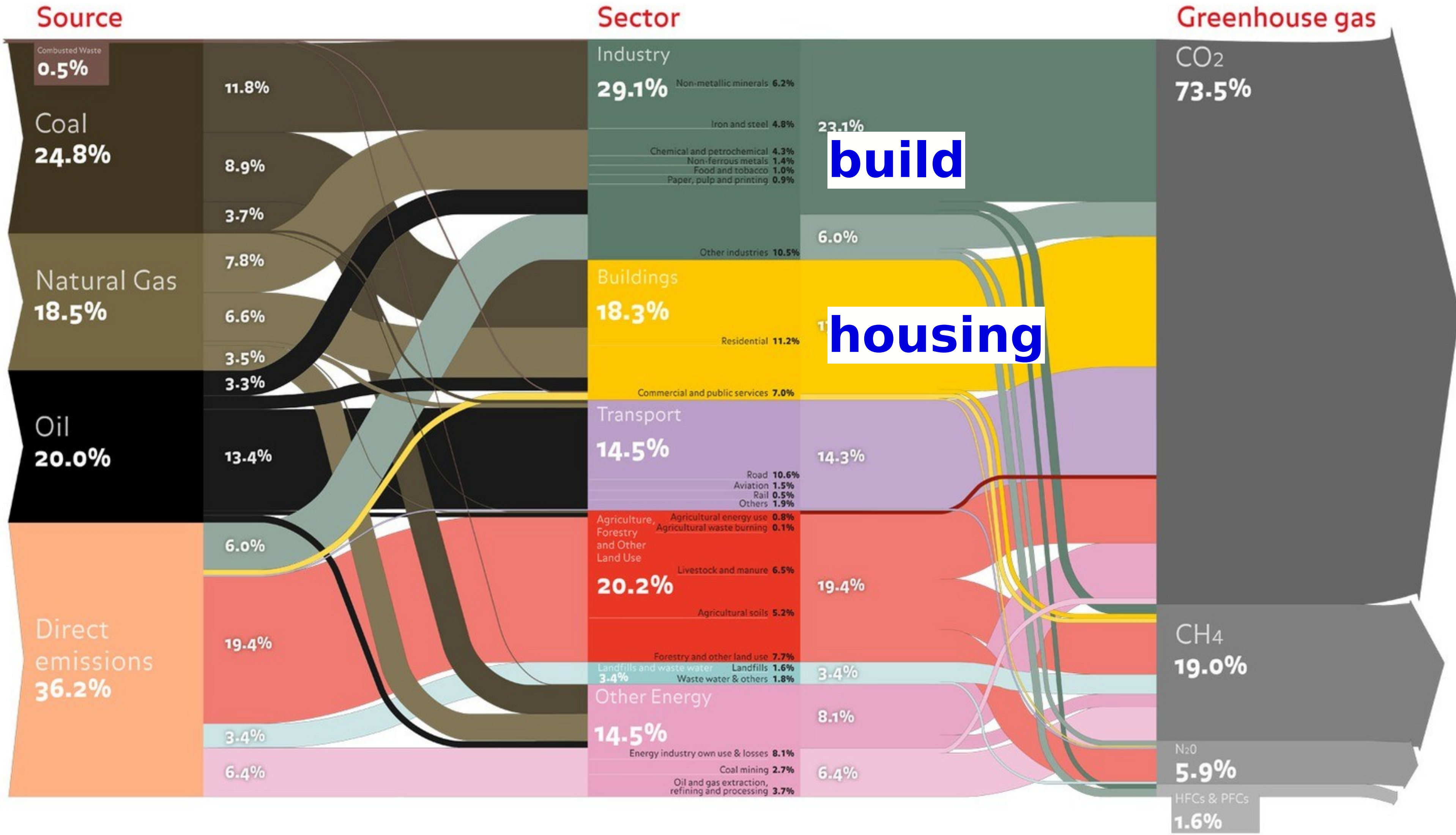

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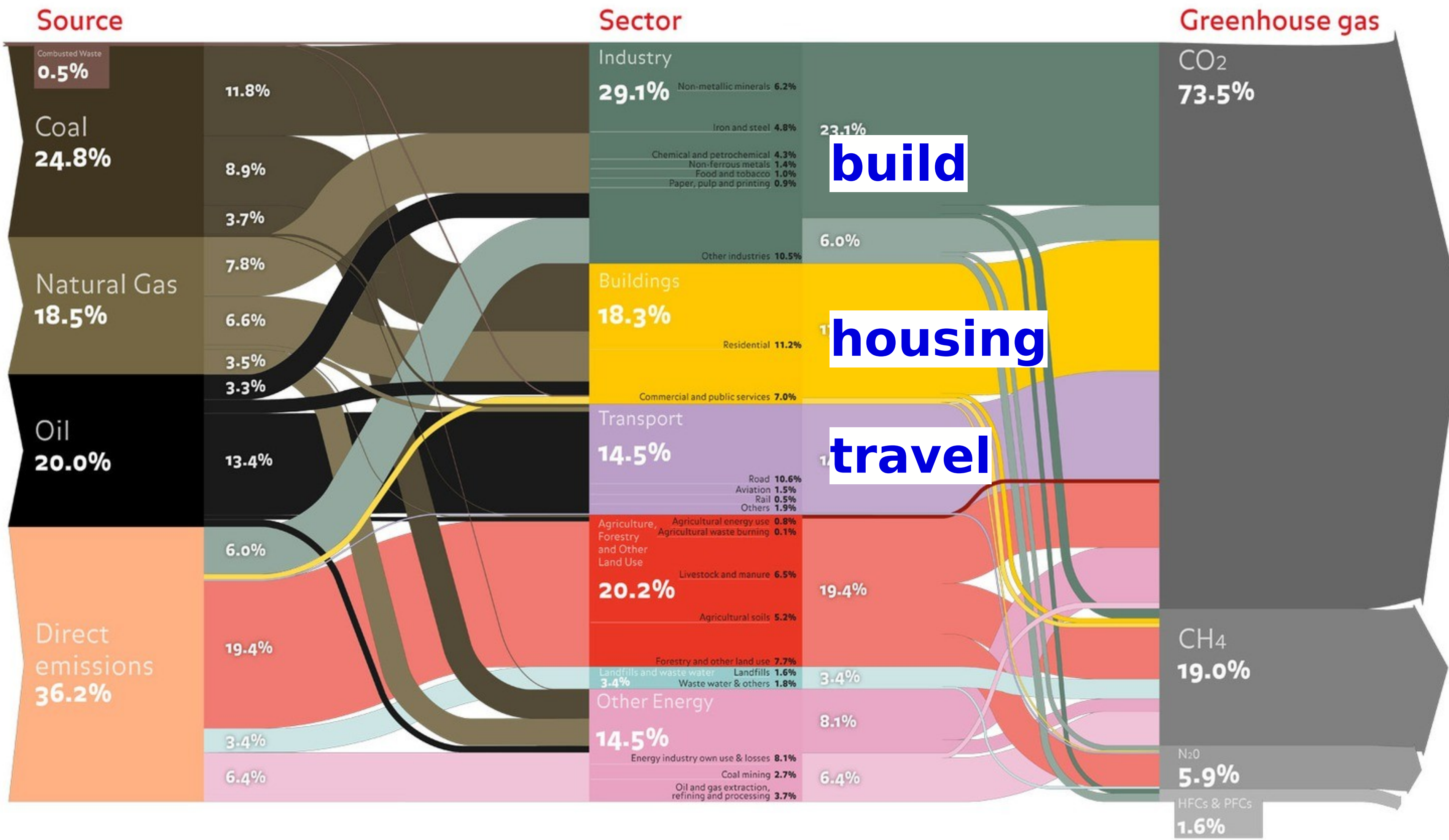

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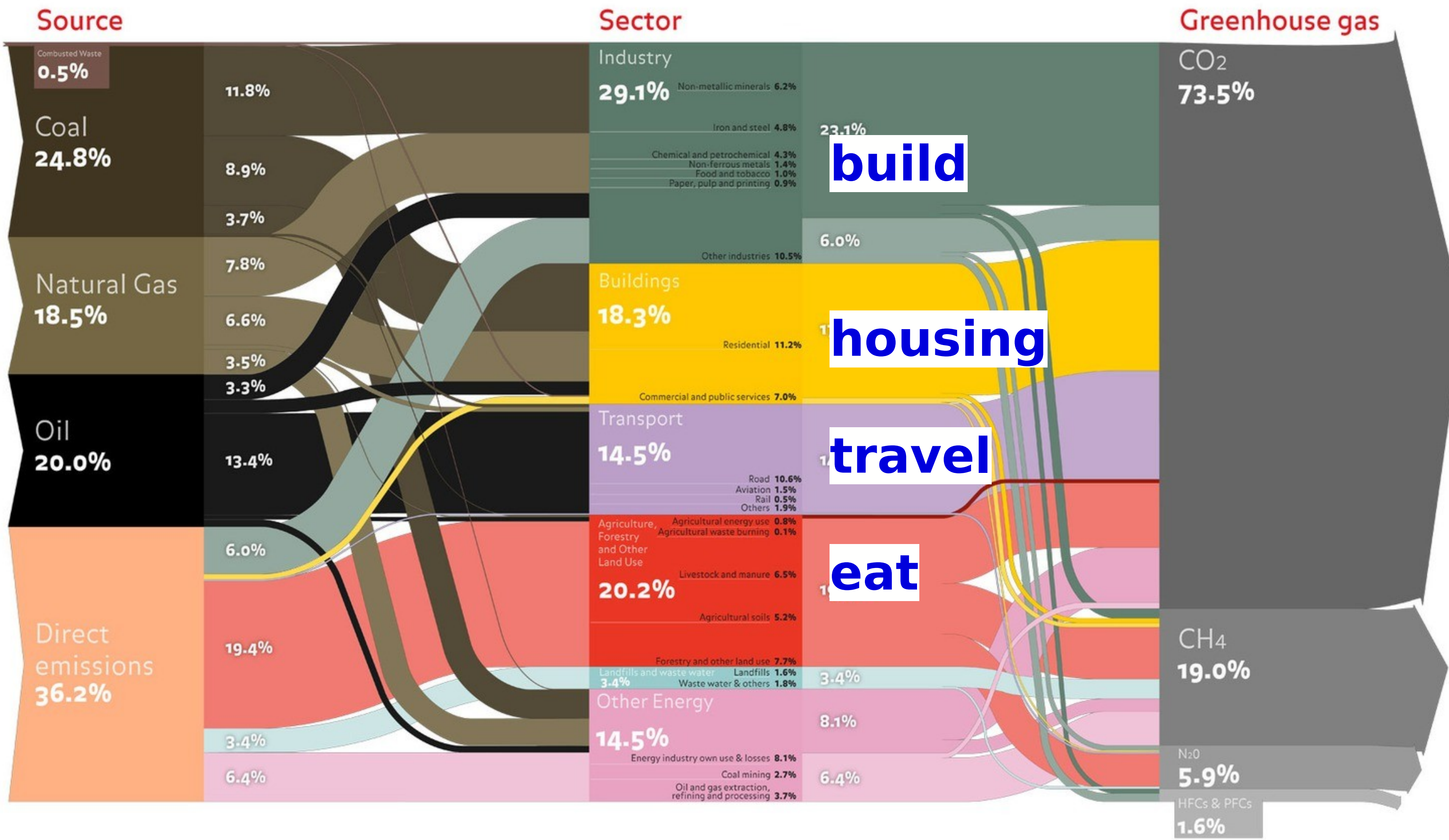


One step further

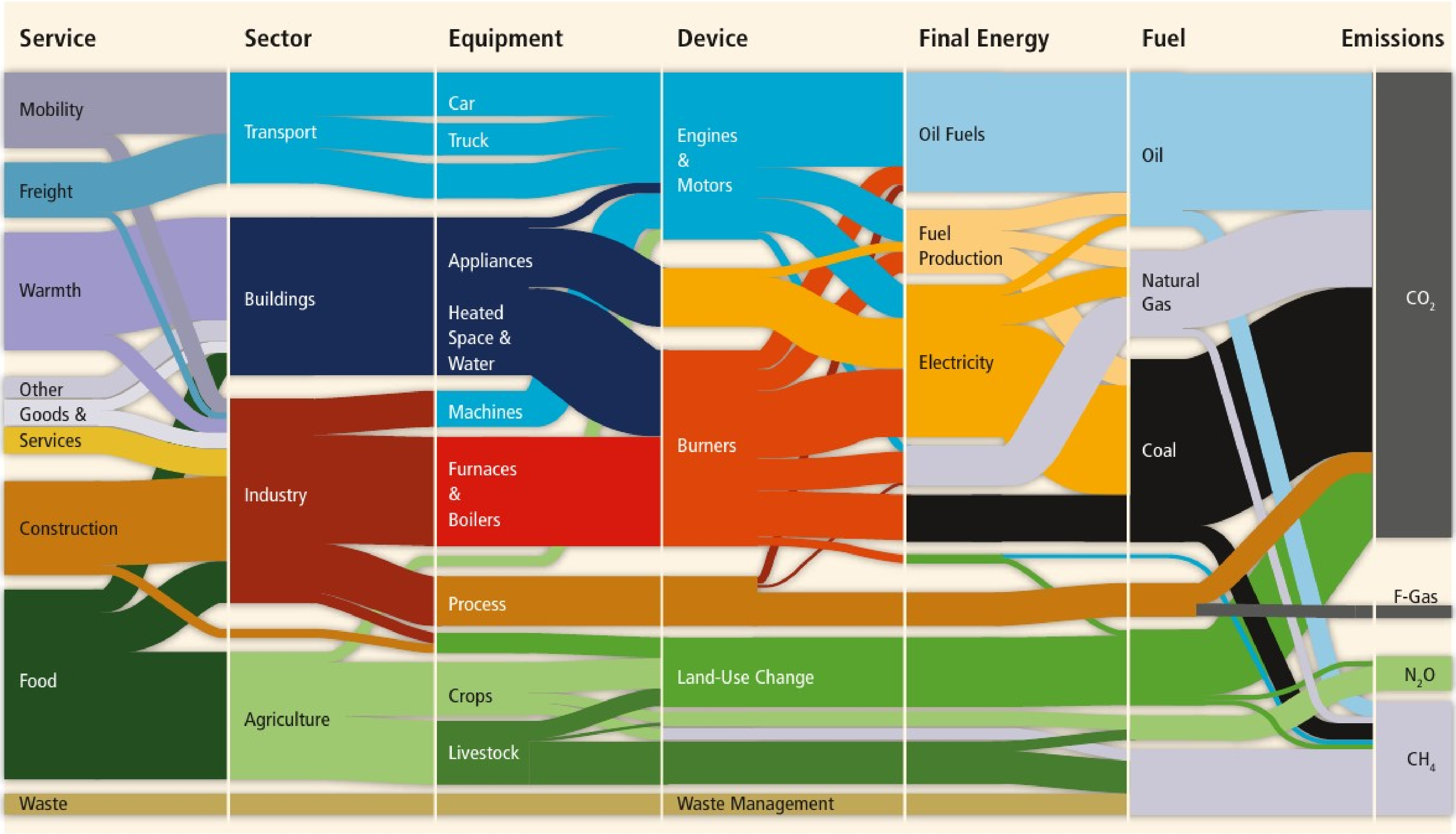
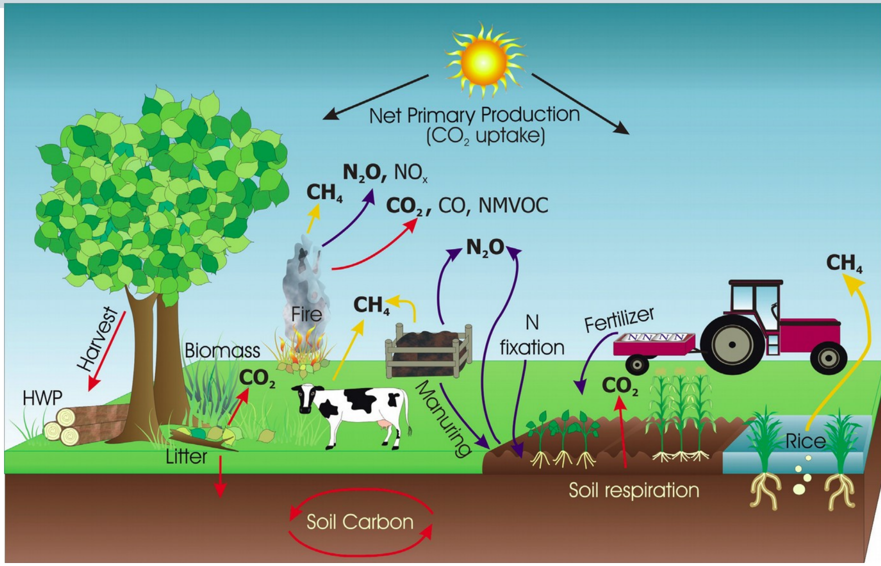


Figure 10.1 | A Sankey diagram showing the system boundaries of the industry sector and demonstrating how global anthropogenic emissions in 2010 arose from the chain of technologies and systems required to deliver final services triggered by human demand. The width of each line is proportional to GHG emissions released, and the sum of these widths along any vertical slice through the diagram is the same, representing all emissions in 2010 (Bajželj et al., 2013).

Radiative forcing from agriculture



- Not accounting for transportation and energy
- Change in land use, deforestation

- N_2O from liter
- CH_4 from rice
- CH_4 from cattles and liter

- A key perturbation on nitrogen cycle : the Haber-Bosch process

$$N_2 + 3\,H_2 \longrightarrow 2\,NH_3 \quad \Delta H^\circ = -91.8\ \mathrm{kJ/mol}$$

allows to fix hydrogen from air into amoniac => anhydrous ammonium nitrate (NH_4NO_3) and urea ($CO(NH_2)_2$), and many others... (combination with phosphorus and potassium).
Excesses form NOx in the air and Nitrates in the water => pollution

Industrial hydrogen comes from natural gas (fossil fuel!), requires energy

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

Generalities on energy

Energy

- Human activities rely on transforming matter from natural ressources thanks to energy using machines.

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- At human scale, energy is a useful accounting unit between tractable variables through the conservation of energy

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- Units in this lecture

  power : kW = 1000 *J/s*

  energy : kWh = 3.6 M *J*

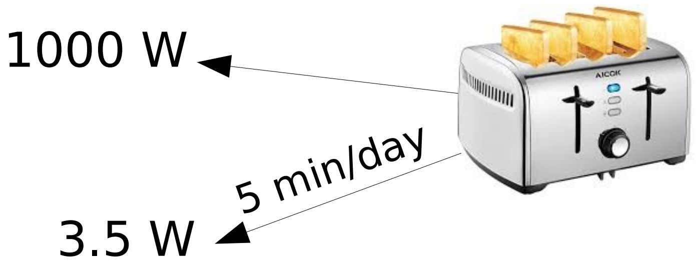
Power

- Instantaneous power (a feature of machines)

$$P(t)$$

- Mean power : associated to consumption

$$\bar{P} = \frac{1}{T}\int_0^T P(t)dt$$



- Needs for power : not a only a question of size, one has to overcome thresholds: dynamite, works, cooking, heating, plane takeoff...

- Intermittency of electrical production and consumption (in 2018)

  installed power in France : 133 GW => 2 kW / hab

  averaged producted power : 62.5 GW => 1 kW / hab

  averaged used power : 54 GW => 0.8 kW / hab

Energy accounting done by transactions

Ressources primaires
Disponibles dans la nature

Stock non renouvelables

- **Fossiles** (charbon, pétrole, gaz naturel)
- **Fissiles** (uranium, thorium)

Flux renouvelables

- **Rayonnement solaire**
- **Sous-produits solaires** (hydro, vent, houle, biomasse…)
- **Chaleur géothermique**
- **Interaction gravitationnelle terre-lune-soleil** (marées)

Pertes de transformation, de distribution…

Energie finale
Commercialisable, directement utilisable

- Combustibles solides

Charbon, bois…

- Combustibles liquides

Essence, gasoil, kérosène, éthanol, biodiesel…

- Combustibles gazeux

Gaz naturel livré au compteur, biogaz, hydrogène…

- Chaleur

Distribuée dans les réseaux

- Electricité

Livrée au compteur

Pertes de conversion

Energie utile :
Services énergétiques

- Eclairage
- Froid
- Chaleur

Basse et haute températures

- Mobilité

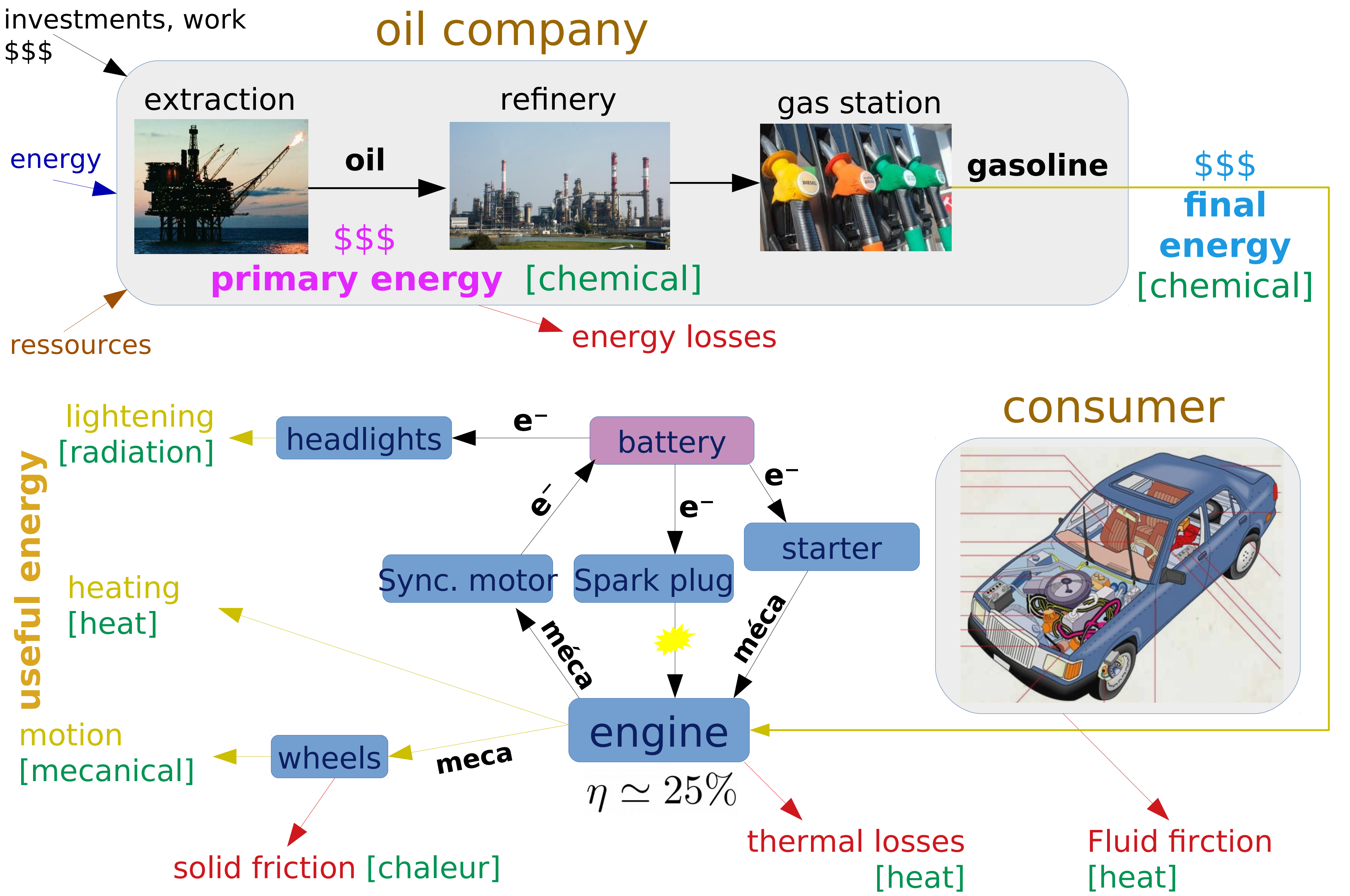
Terrestre, navale, aérienne

- Force motrice

Fabrication, ventilation, pompage, divers processus

- Procédés chimiques
- Traitement de l'information

The supply energy : cars

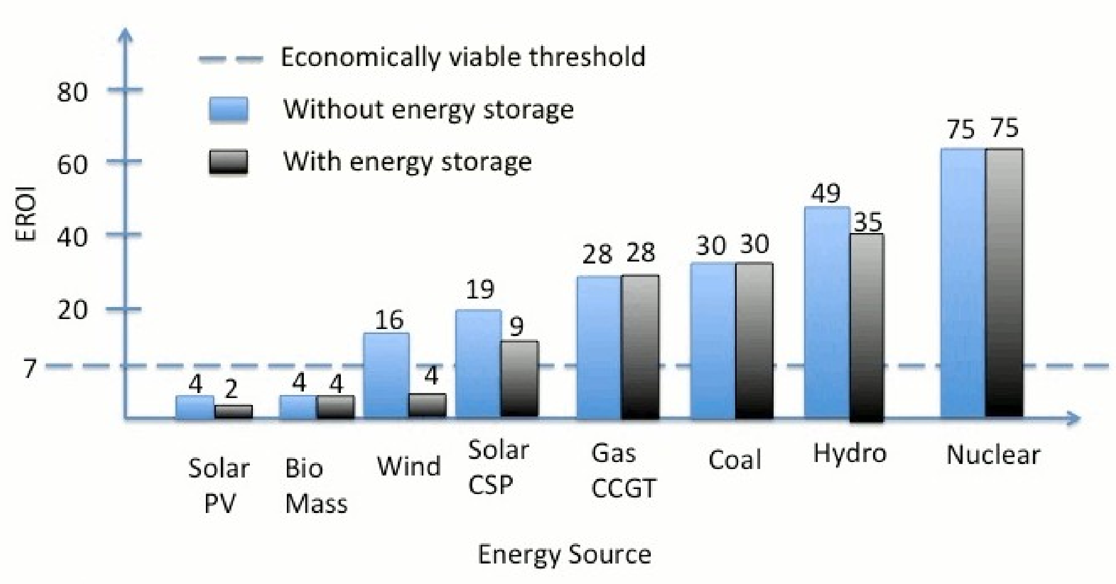


EROI

- Energy return on (energy) investment

$$EROEI = \frac{\text{Energy Delivered}}{\text{Energy Required to Deliver that Energy}}$$

- After D. Weissbach et al., (2013)



a concept that is more complicated that it seems, the energy used for extraction is difficult to quantify and depends on conditions, technology and economical viability depends on economical demand.

Using energy and order of magnitudes

“Elle a tout d’une grande! Pas assez chère mon fils...”

- Typical daily round trip 2x6 kms

	voiture	vélo
Durée du trajet	30 mins	1 heure
Énergie (8L/100km)	1L essence ~ 10 kWh	0.1 kWh
Puissance moyenne	20 kW	100 W
Puissance max	70 kW (100 Ch)	350 W
surcoût énergie	1,5€	0

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x100

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x250

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modèle	Pmax	Poids	Vmax	autonomie	Prix
twizzy	13 kW	470 kg	80 km/h	100 km	9 000 €
Tesla S	240 kW	2100 kg	225 km/h	420 km	82 000€

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Which is the most sold ?

Jevons effect and sociotechnical lockin

- Improving energy efficiency opens new possibilities, makes usage cheaped and increase consumption ! (Jevons effect) => SUV (heavy but more confortable and secure)

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- Democratizing a usage => move to suburbs, and then trapped

- Work at home, car sharing ?

Flux, stock, density and prices

Usage does not only require low price but storage capacity and this relies on energy density

video of cyclist

type	forme	nature	Densité énergétique	Prix €/kWh
Réseau EDF	électrique	flux		0,15
accumulateur Li-Ion	électro-chimique	stock rechargeable	0.2 kWh/kg	1,1 stocké
Pile alcaline	électro-chimique	stock	0.16 kWh/kg	400
Essence	chimique	stock	8.8 kWh/L	0,17
Réseau Gaz naturel	chimique	flux		0,08
Bouteille Gaz butane	chimique	stock	13.7 kWh/kg	0,17
Bois séché	chimique	stock	4.2 kWh/kg	0,04
Pâtes alimentaires	chimique	stock	4 kWh/kg	0,4
Travail humain	mécanique	stock		182

Daily consumption

- Average daily energy consumption per inhabitant in kWh

region	primary	final	electrical
Monde	59	41	8
USA	210	149	32
France	117	73	18

- Typically at the individual scale

Forme d’énergie	Conso/production journalière en kWh	Puissance typique en kW
Alimentation humaine	3	0.125 (chaleur)
Travail humain (10h)	0.5 (jambes) 0.05 (bras)	0.05 (jambes) 0.005 (bras)
Frigo	0.13	0.1
Ordinateur portable	1	0.1
Eau chaude	2.2	2
chauffage	5	10
voiture	10	70

From microscopic to macroscopic

Machine	Puissance typique
humain	10-100 W
Cheval / bœuf	700-1500 W
Plaques électriques / four	2-3 kW
Convecteur électrique	2-4 kW
Moulins à eau / vent	3-30 kW
voiture	100 kW
Camion / engin de chantier	400 kW
Éoliennes modernes	100 kW – 2 MW
rame TGV / avion / fusée / data center	10 MW
Centrale solaire Cestas	40 MW
Tranche de centrale nucléaire	0.6 – 1.6 GW
Grosses centrales électriques (nucléaire, charbon, gaz, fioul)	4-8 GW
Barrage des trois-gorges	22 GW
Puissance électrique moyenne consommée en France	54 GW
Puissance moyenne consommée par les activités humaines dans le Monde	17 TW
Forçage radiatif terrestre dû aux activités humaines	765 TW

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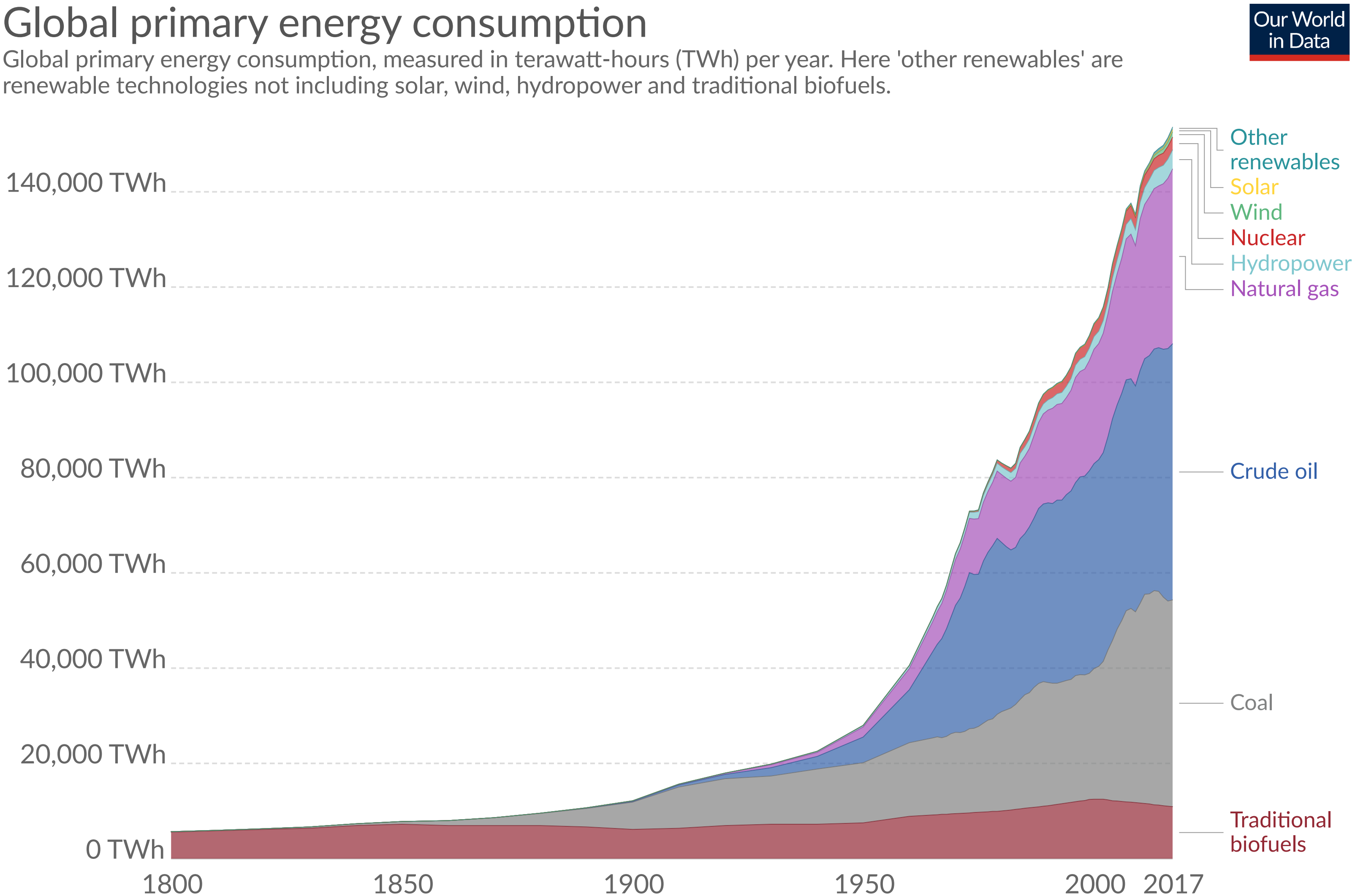
x100

x45

Total bill

Global primary energy consumption

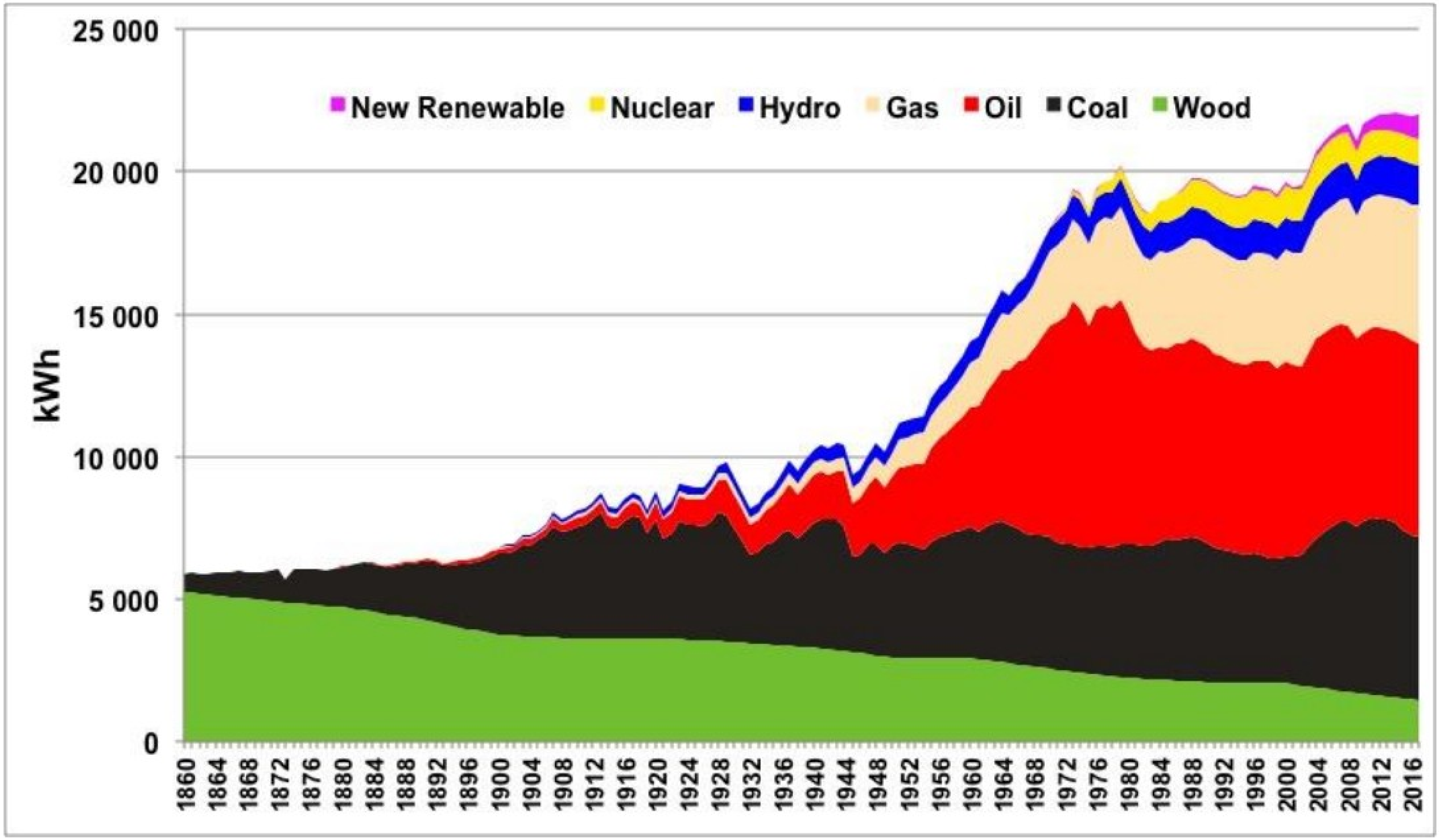
Global primary energy consumption, measured in terawatt-hours (TWh) per year. Here 'other renewables' are renewable technologies not including solar, wind, hydropower and traditional biofuels.



Source: Vaclav Smil (2017) and BP Statistical Review of World Energy

Total bill

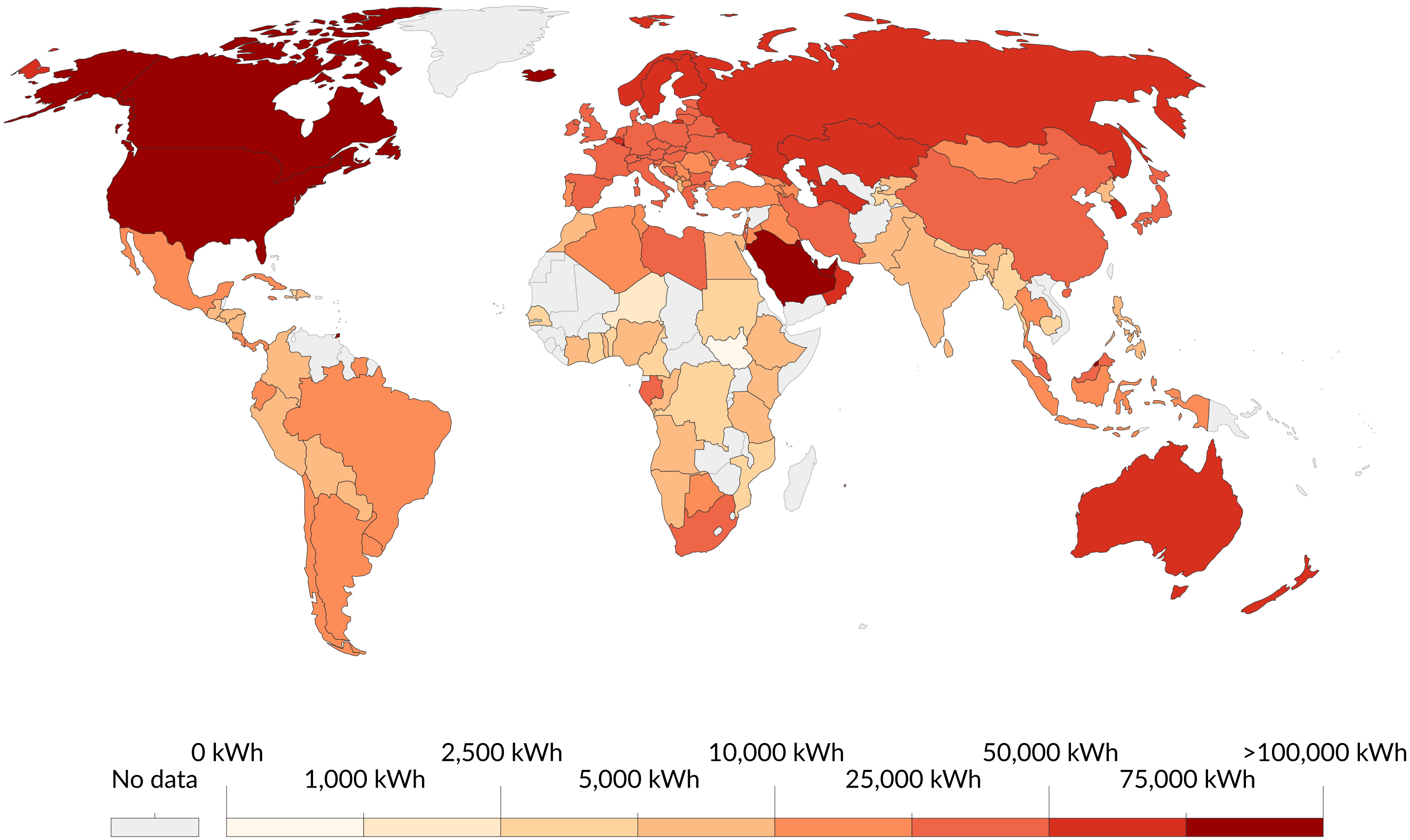
Energie primaire par habitant



Total bill

Energy use per capita, 2015

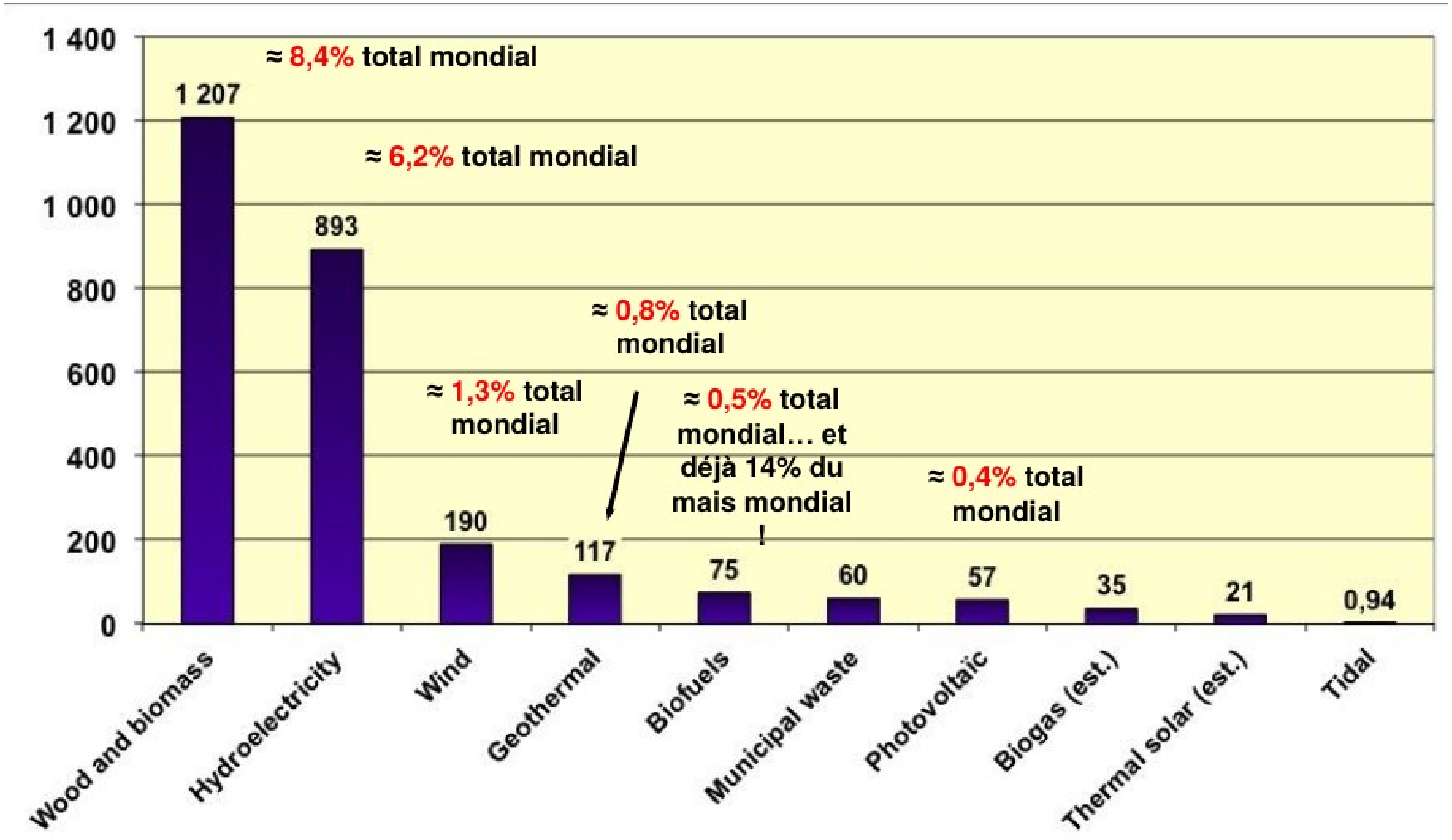
Annual average per capita energy consumption is measured in kilowatt-hours per person per year.



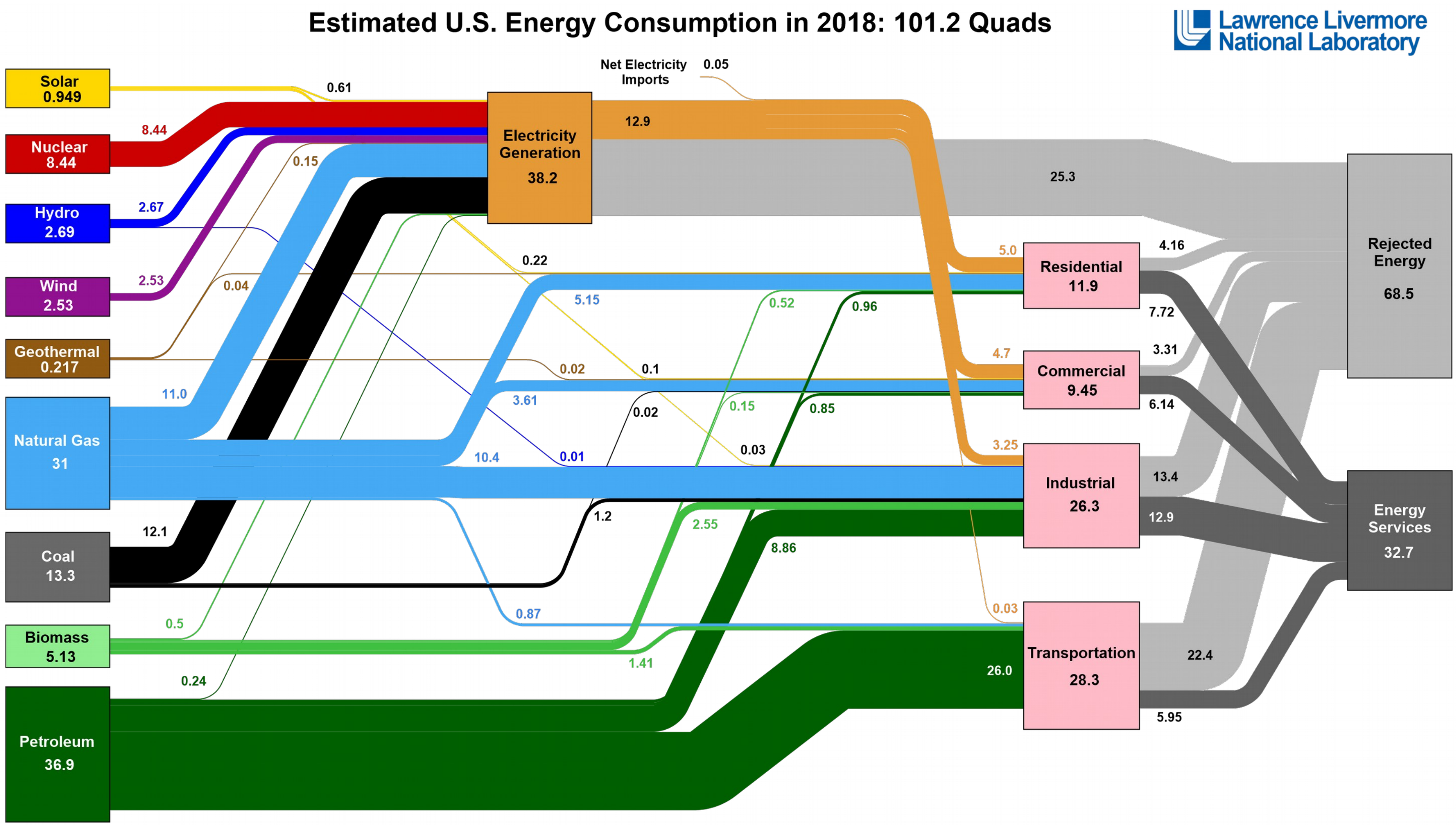
Source: International Energy Agency (IEA) via The World Bank

Renewable energies

- Yet a little fraction for the newest technologies



USA energy mix

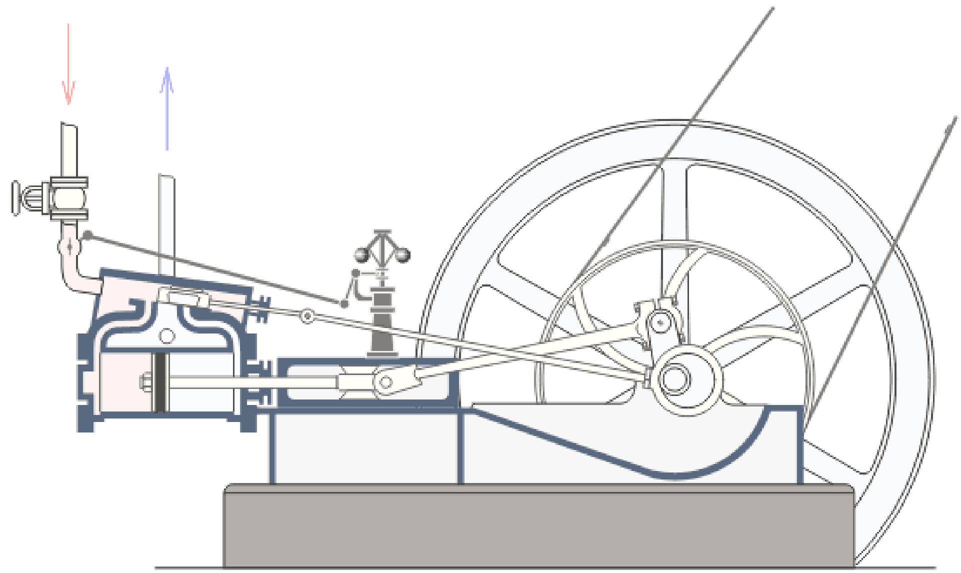


Source: LLNL March, 2019. Data is based on DOE/EIA MER (2018). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Machines and converter

From vapor machine to engines

- External combustion



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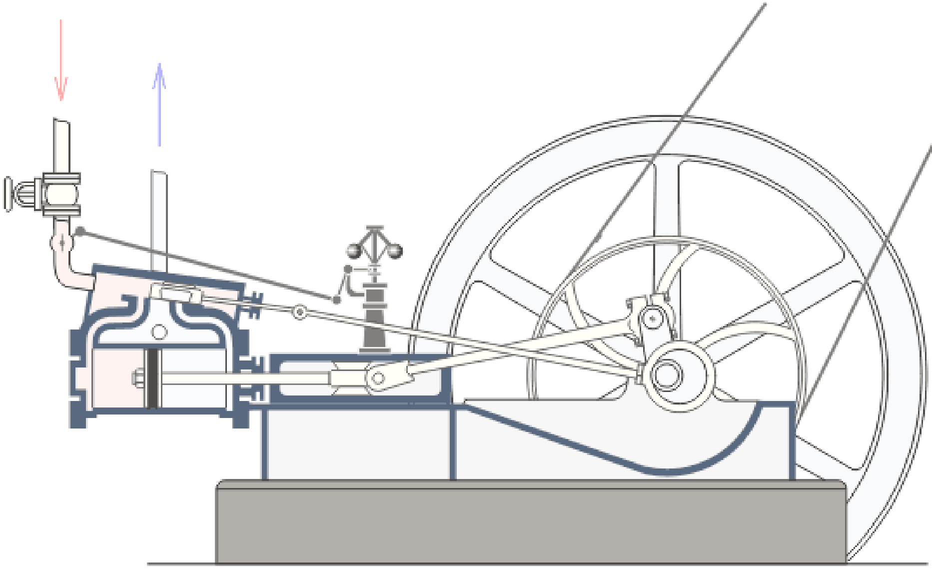
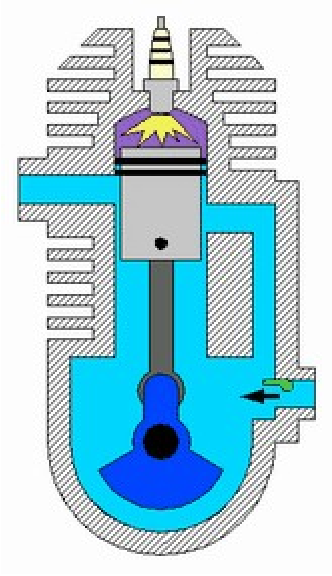


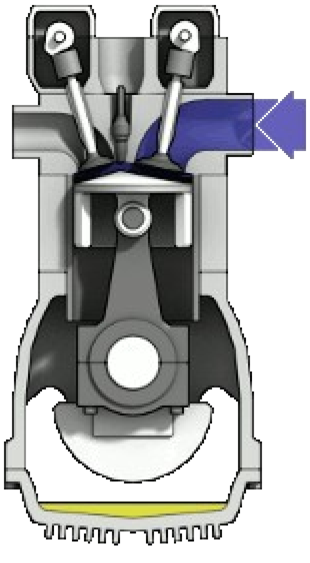
- Internal combustion :

2 strokes



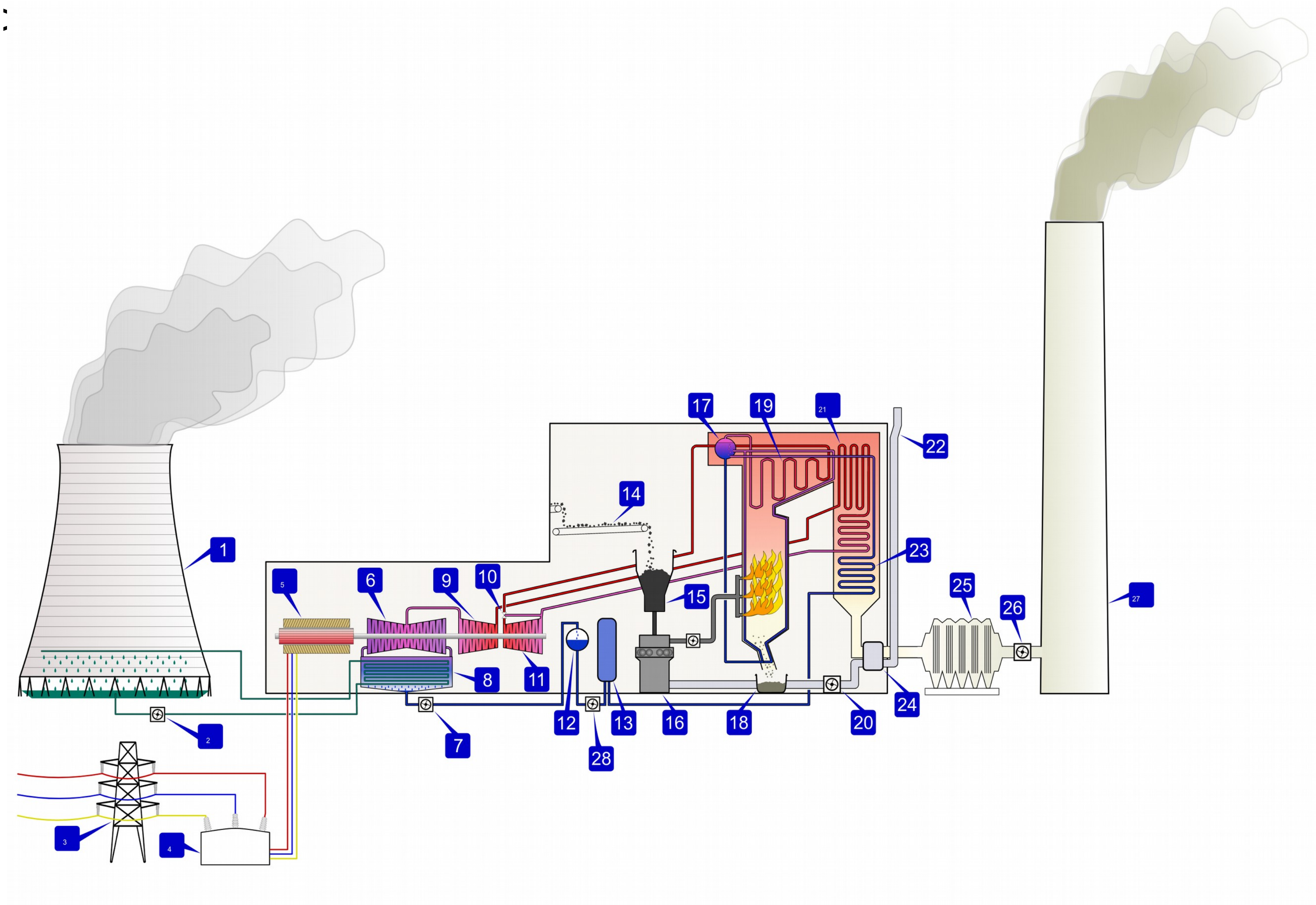
4 strokes

1



Producing electricity

- External combustion + steam turbine + electrical generator =:



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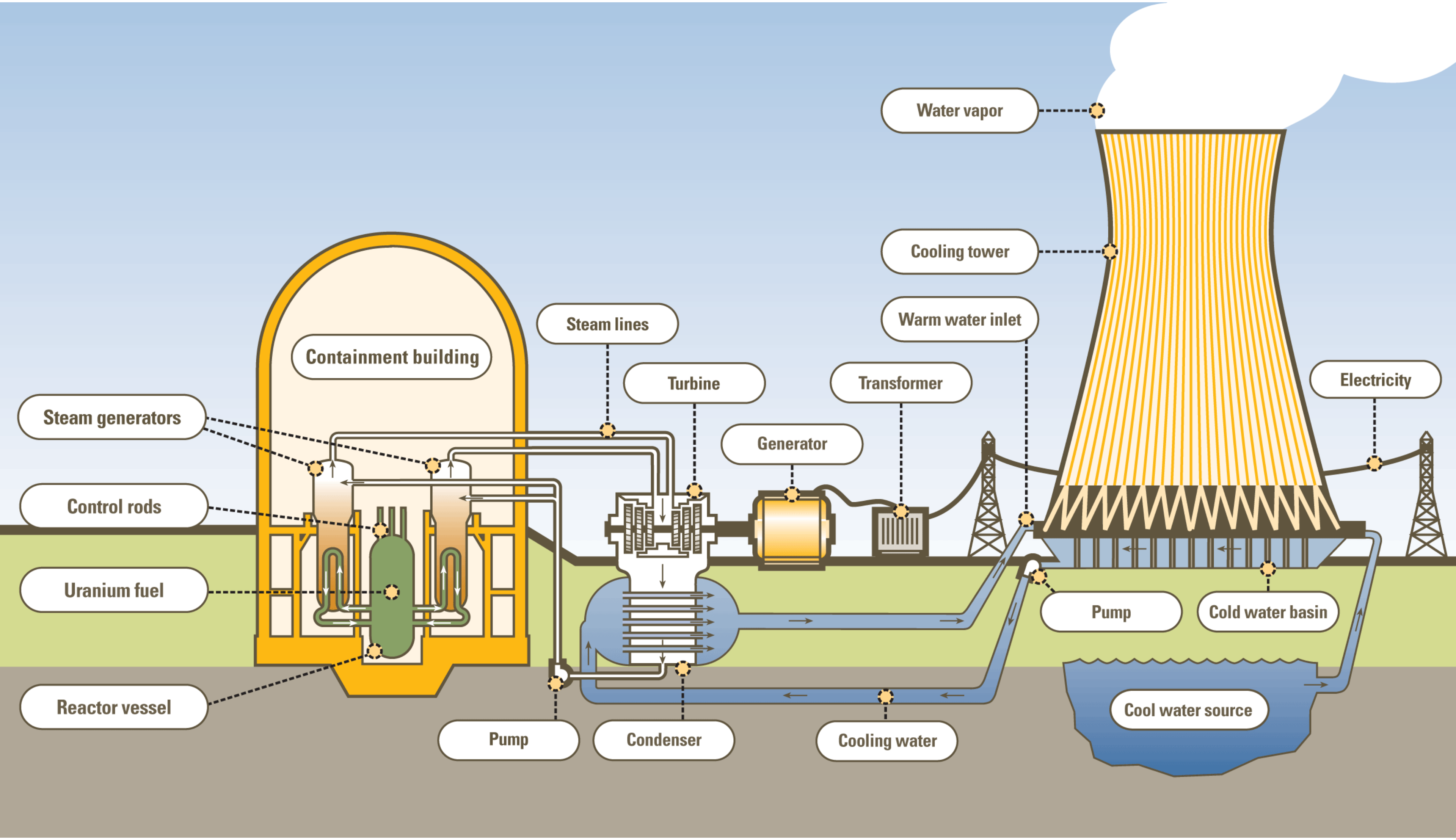
Nuclear power plant : one chimney missing

- External combustion + steam turbine + electrical generator

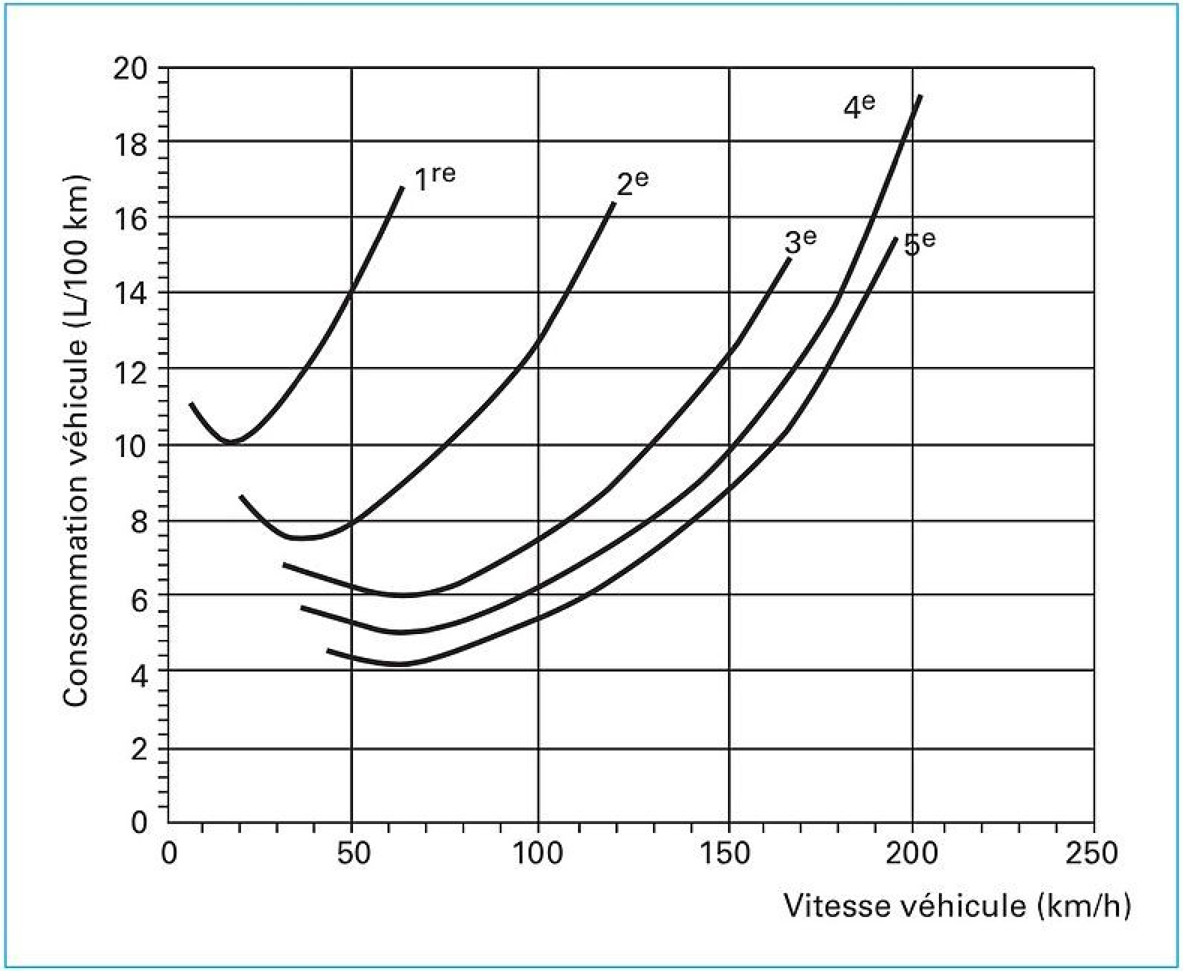


Nuclear power plant : one chimney missing

- External combustion + steam turbine + electrical generator

Cars and the functioning point

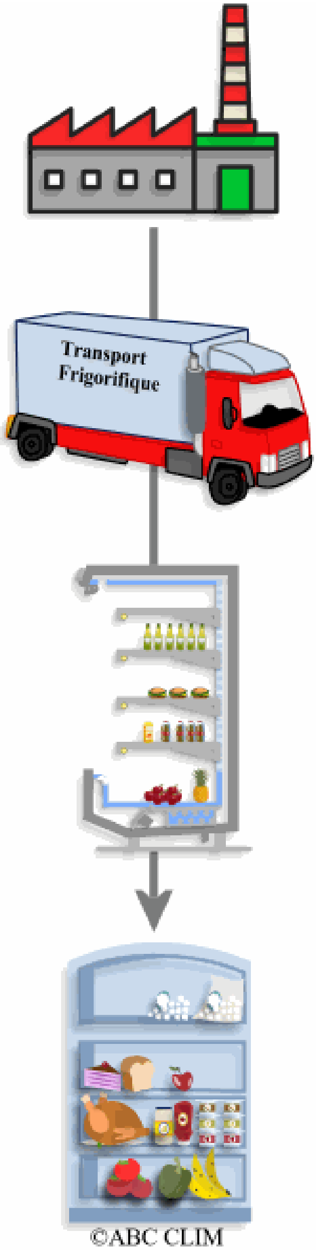
- Machines have an optimal efficiency functioning point
- Away from this point (usually because of usage), you are not using the machine at its best and this lowers the overall efficiency



Cooling system and threshold

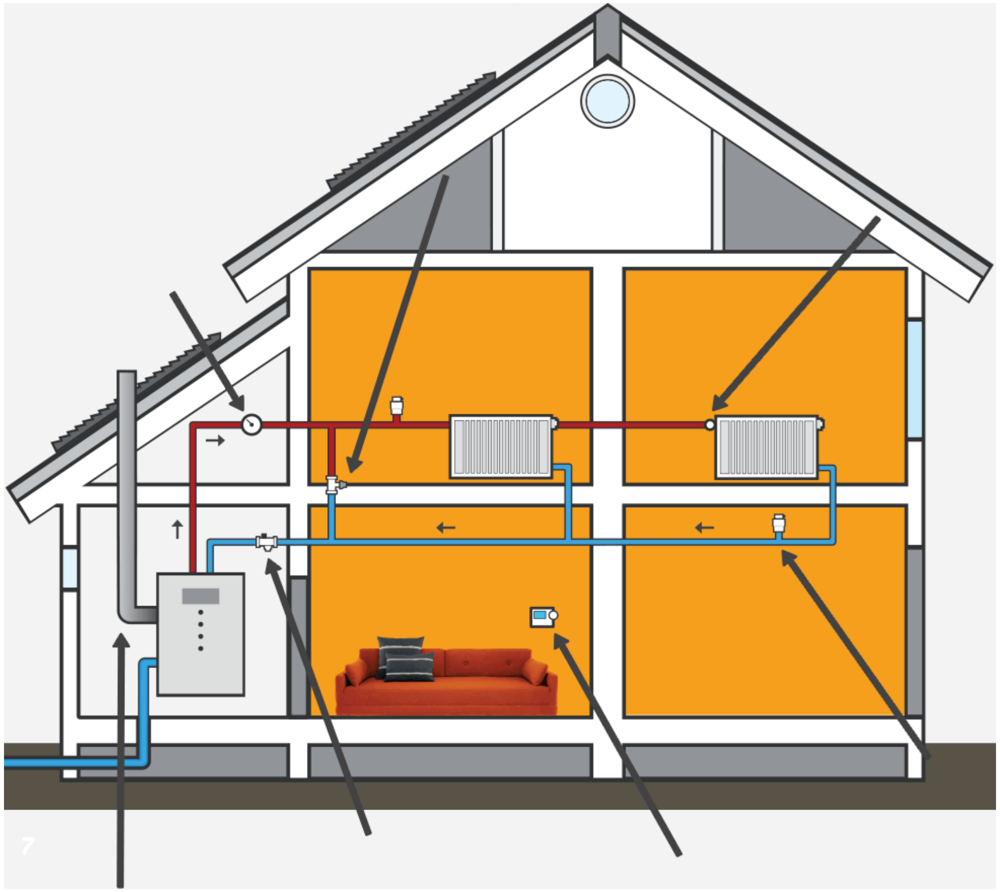
- Cooling systems are used to maintain food at cold temperature (cool chain)
- The power of the cooling system is designed to make it work at the maximal heat.
- With global warming, this threshold increases => one requires to consume more in standard regime temperature the rest of the year…

  or use water evaporation to help the condenser cool down



Automatisation of usage

- Energetic services have been greatly automized
- You don’t carry coal or wood, you don’t see the fumes, the system is regulated by thermostat and the gas is supplied by the network so you just forget about the consumption.

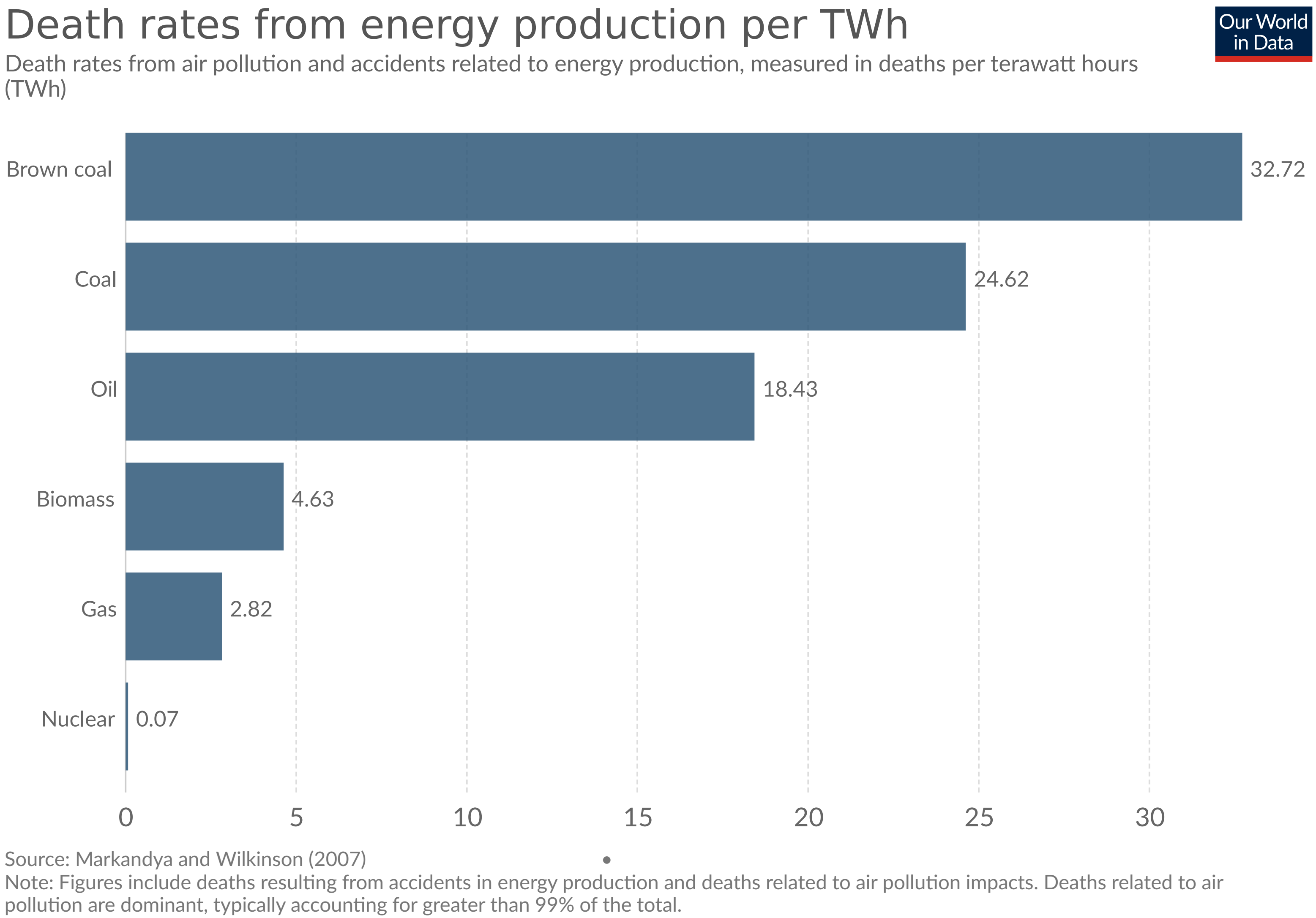


Fossils fuels

Cover all needs (transport, heat, electricity)
At all scales (individual => power plants)
easy to store, concentrated, controllable, optimised and cheap

But...
non-renewable
environmental issues : climate and pollutions
inequality distributed => geopolitical tensions
a few deaths

Casualties

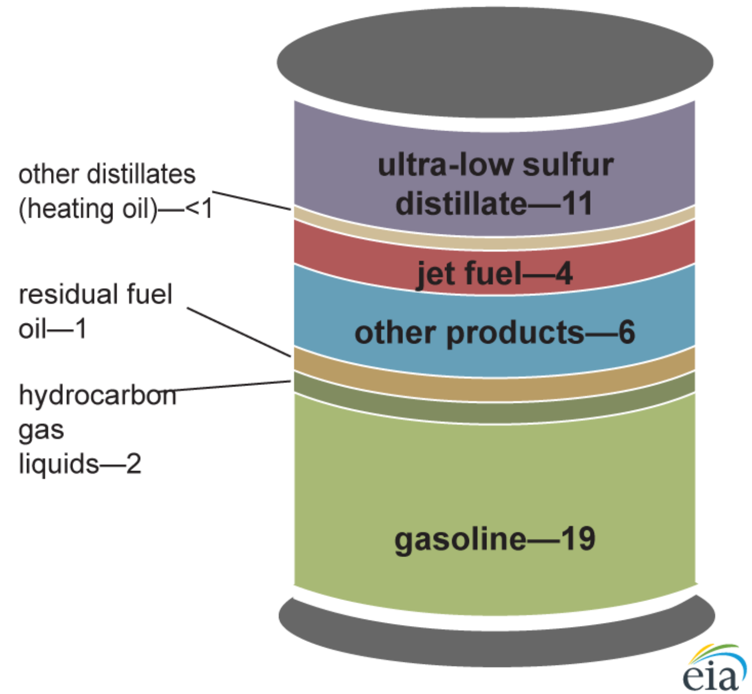


Death rates from energy production per TWh
Death rates from air pollution and accidents related to energy production, measured in deaths per terawatt hours (TWh)
Our World in Data
Brown coal
32.72
Coal
24.62
Oil
18.43
Biomass
4.63
Gas
2.82
Nuclear
0.07
0
5
10
15
20
25
30
Source: Markandya and Wilkinson (2007)
Note: Figures include deaths resulting from accidents in energy production and deaths related to air pollution impacts. Deaths related to air pollution are dominant, typically accounting for greater than 99% of the total.

Usage of oil

- Not only gasoline !
- Bitume for roads
- Chemistry based on derivates

Petroleum products made from a barrel of crude oil, 2018
gallons

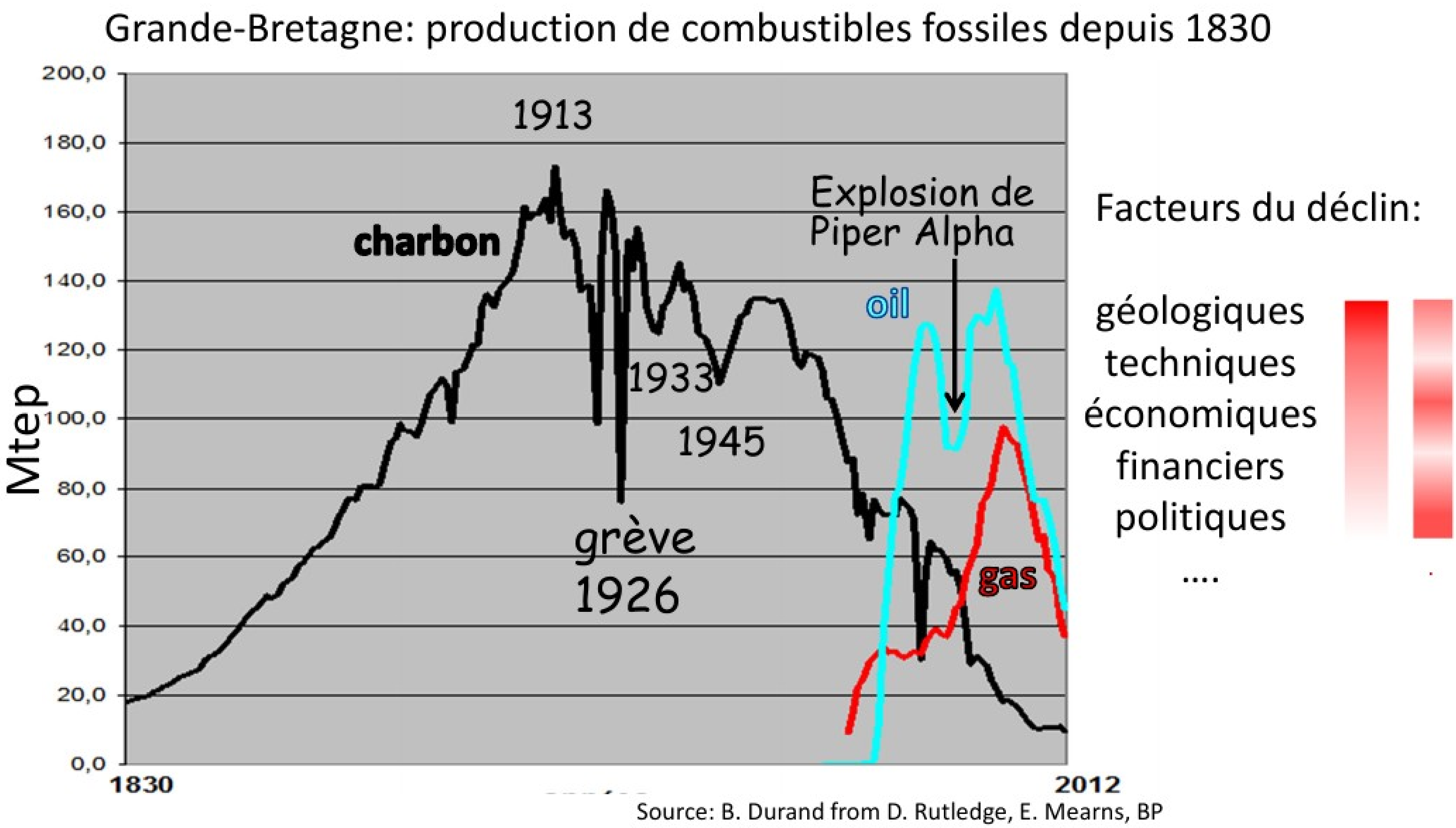


Note: A 42-gallon (U.S.) barrel of crude oil yields about 45 gallons of petroleum products because of refinery processing gain. The sum of the product amounts in the image may not equal 45 because of independent rounding.

Source: U.S. Energy Information Administration, *Petroleum Supply Monthly*, April 2019, preliminary data.

Everything has an end

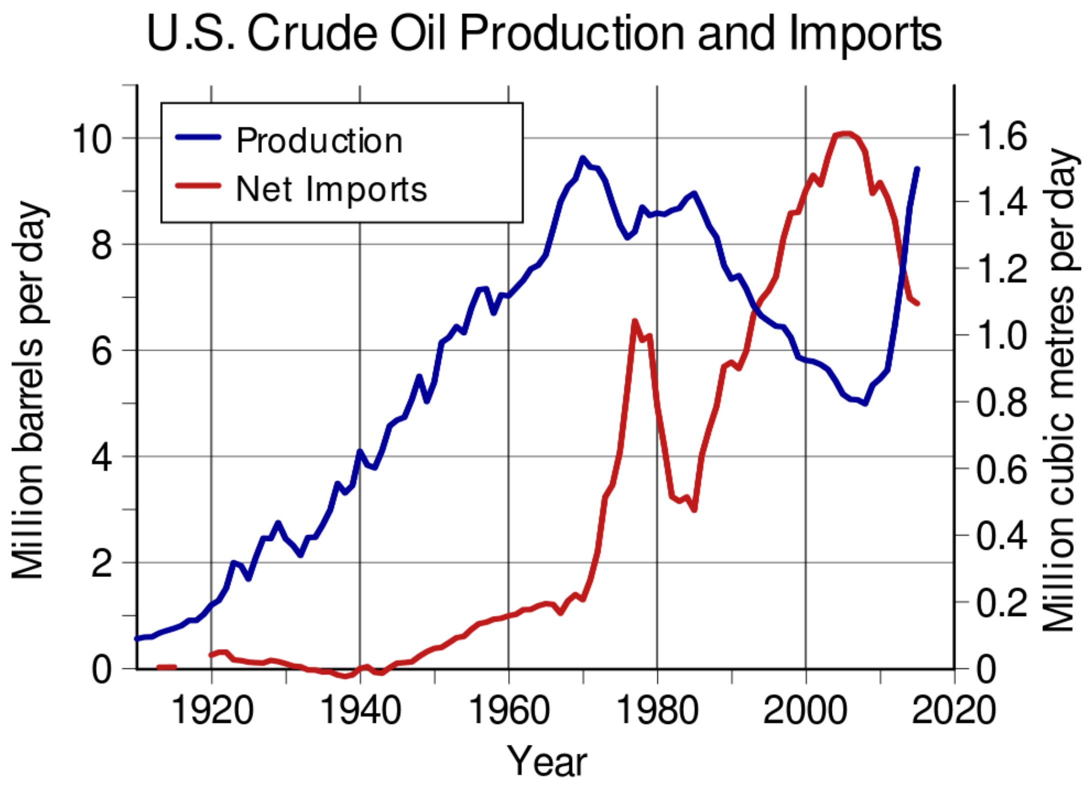
- UK fossil production



Everything has an end : not (yet) in the US!

- US oil production regained recently thanks to unconventional oil and gas (shale oil), EROI decays (requiresan oil price sufficiently large)

- Requires lost of financial investments and technological progresses



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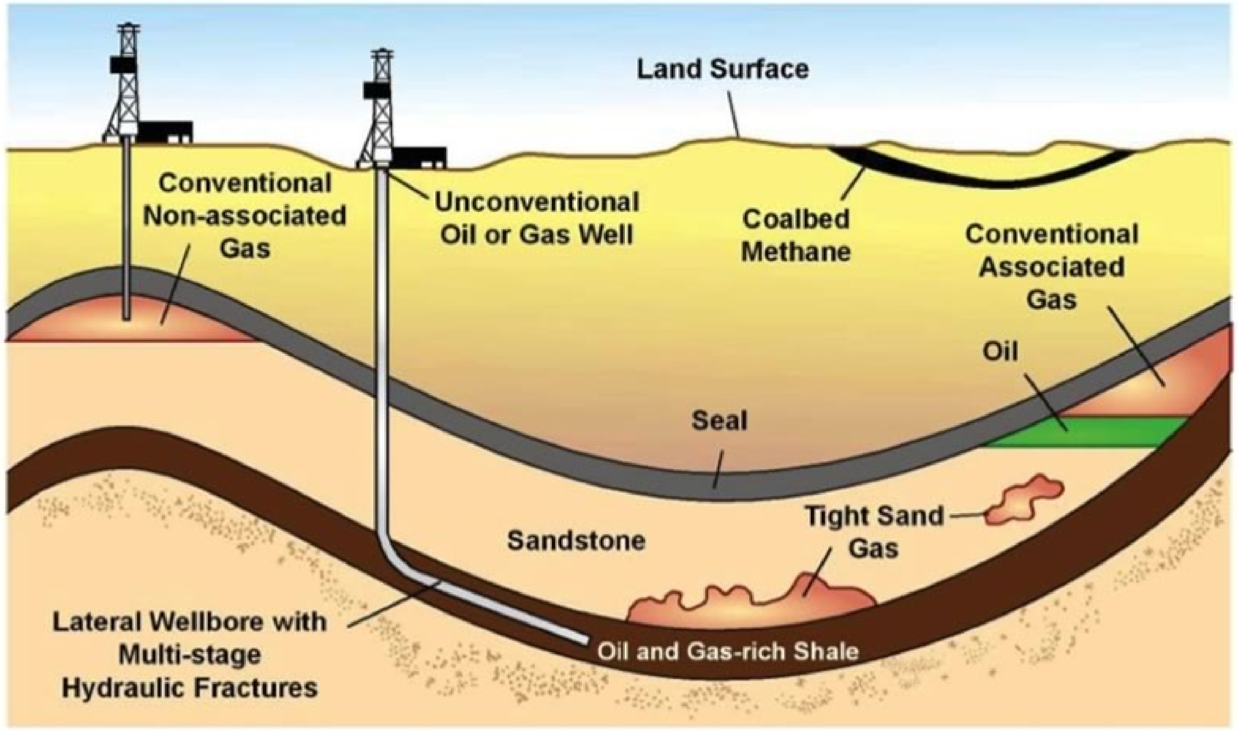
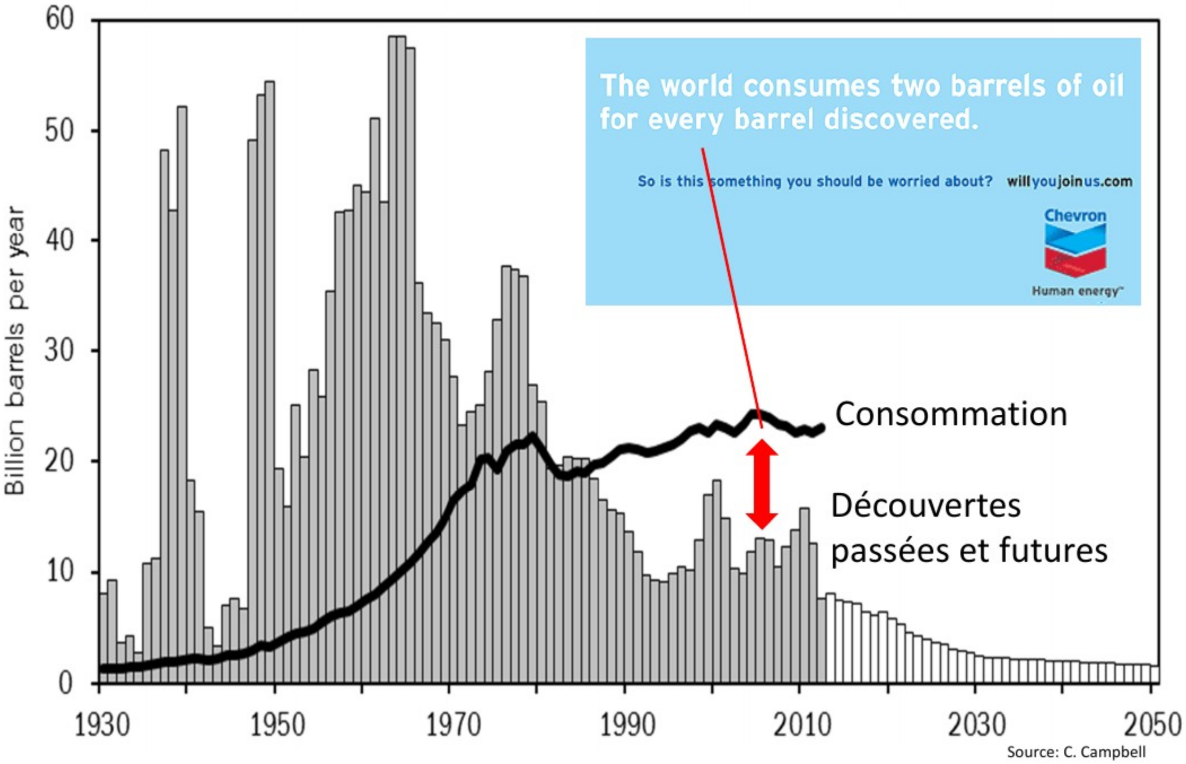
The Geology of Conventional and Unconventional Oil and Gas



Source: EIA

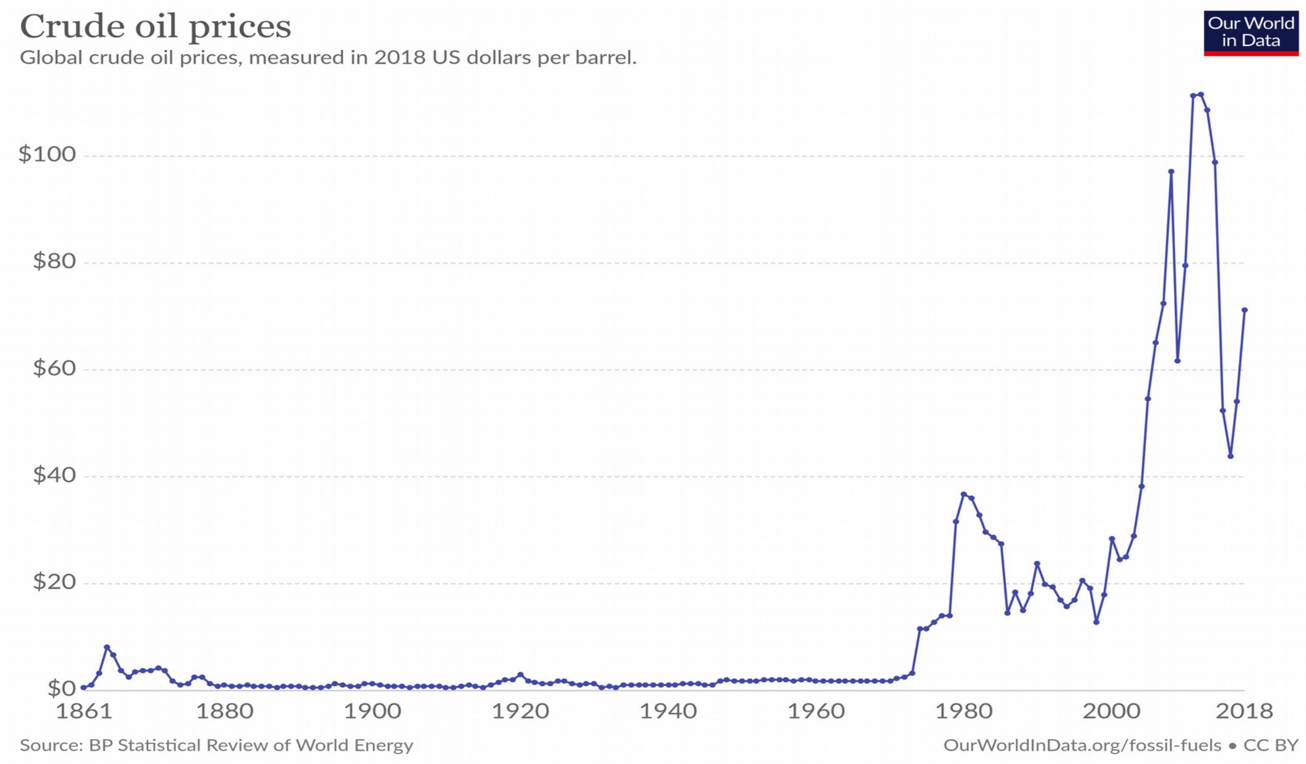
Oil discoveries

- We started by eating white bread, EROI decays
- New wells are non-conventional (deepwater, shale oil, bituminous sands)
- Reserves are finite while the world demand rises
- For conventional oil, International Energy Agency recognizes that peak has been certainly passed in 2006-2008



Oil price

- Increasing on the long-run



- Not at all dependent on reserves: currently, it depends mostly on

  * the demand from China and the state of the global economy
  * geopolitical instabilities and tension
  * strategic decision by OPEP regulating their offer on conventional oil by having the "hand on the tap"

- Have a look at the https://prixdubaril.com/ page to see traders motivation for increasing or lowering the price.

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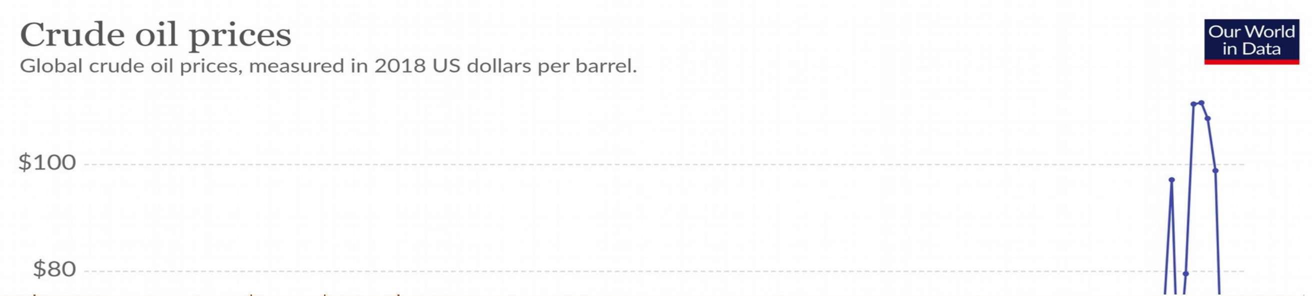

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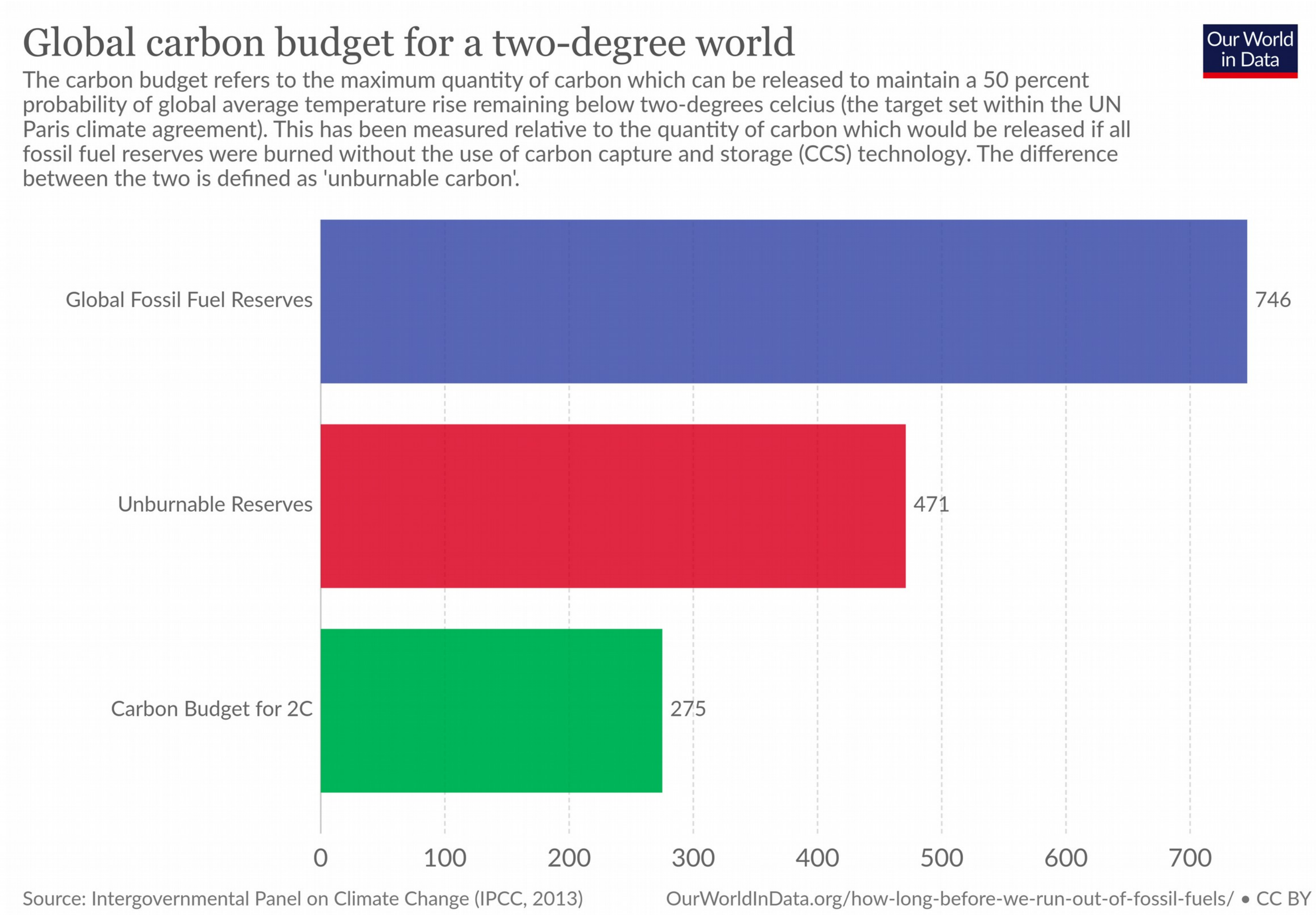
The second carbon constraint

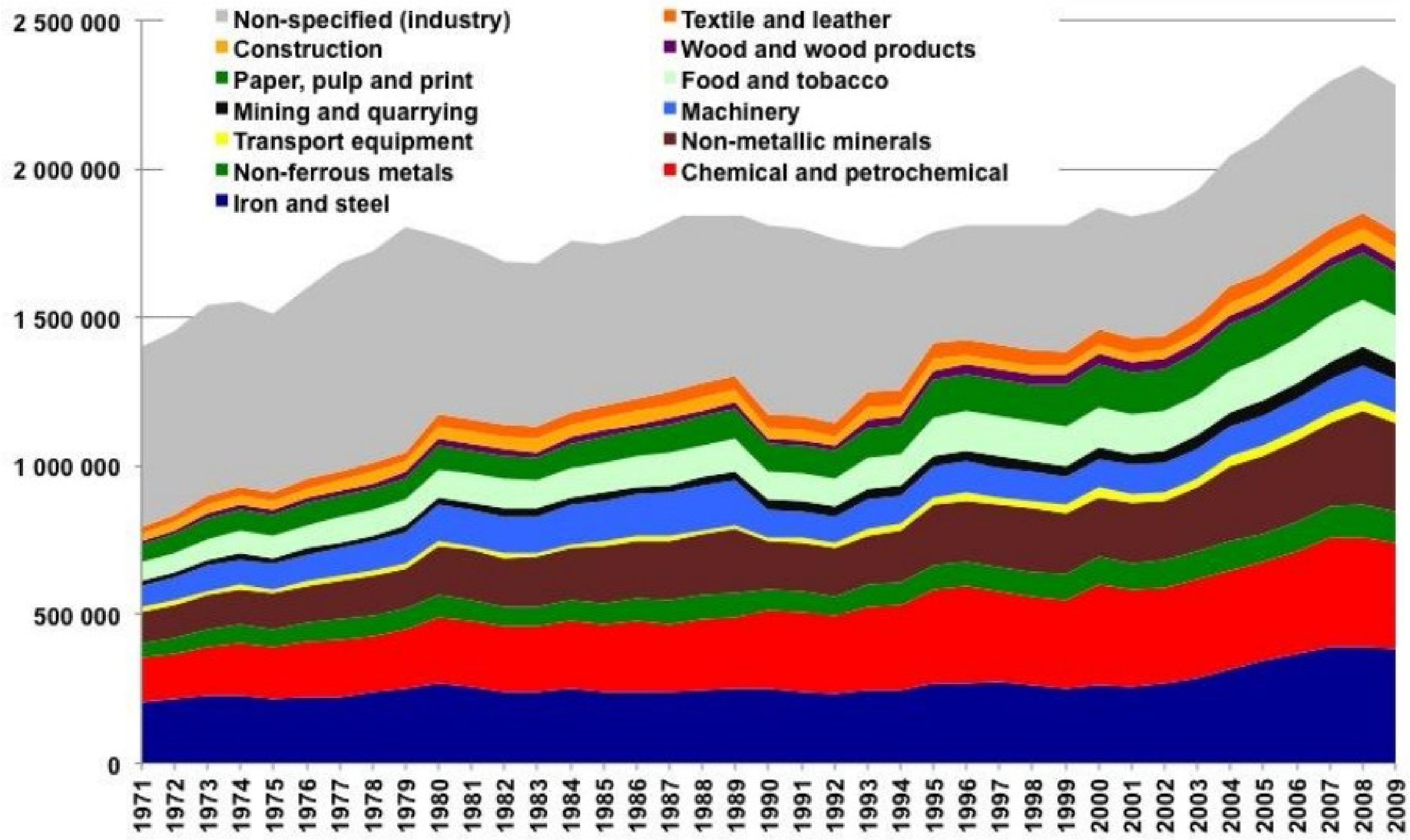
- We must leave some carbon buried !



Energy and wealth, development and direct changes in societies

Goods production

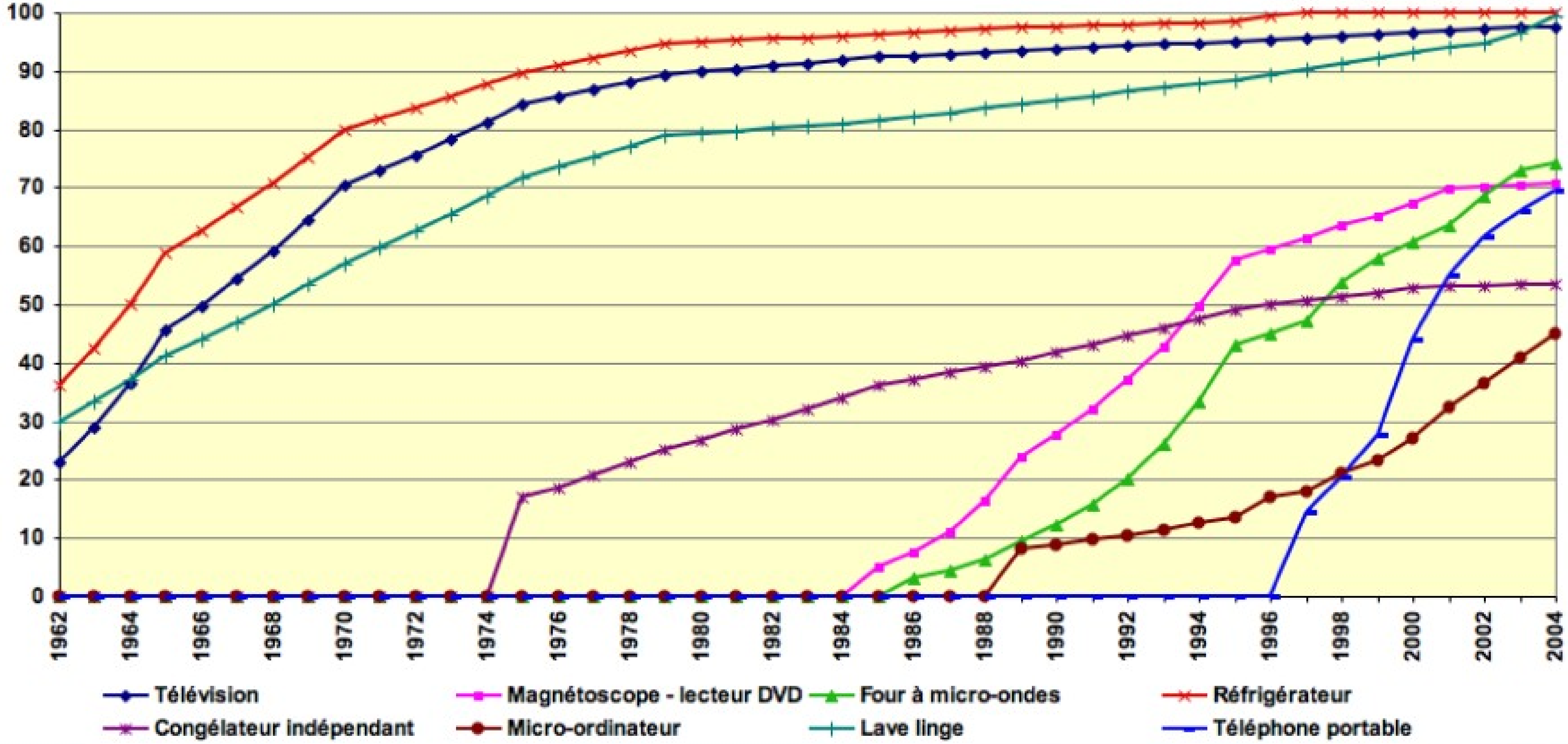
- Goods are made of ressources and energy



Énergie utilisée par secteur industriel (total monde) de 1971 à 2009, en milliers de tonnes équivalent pétrole. Source AIE

Machines at home

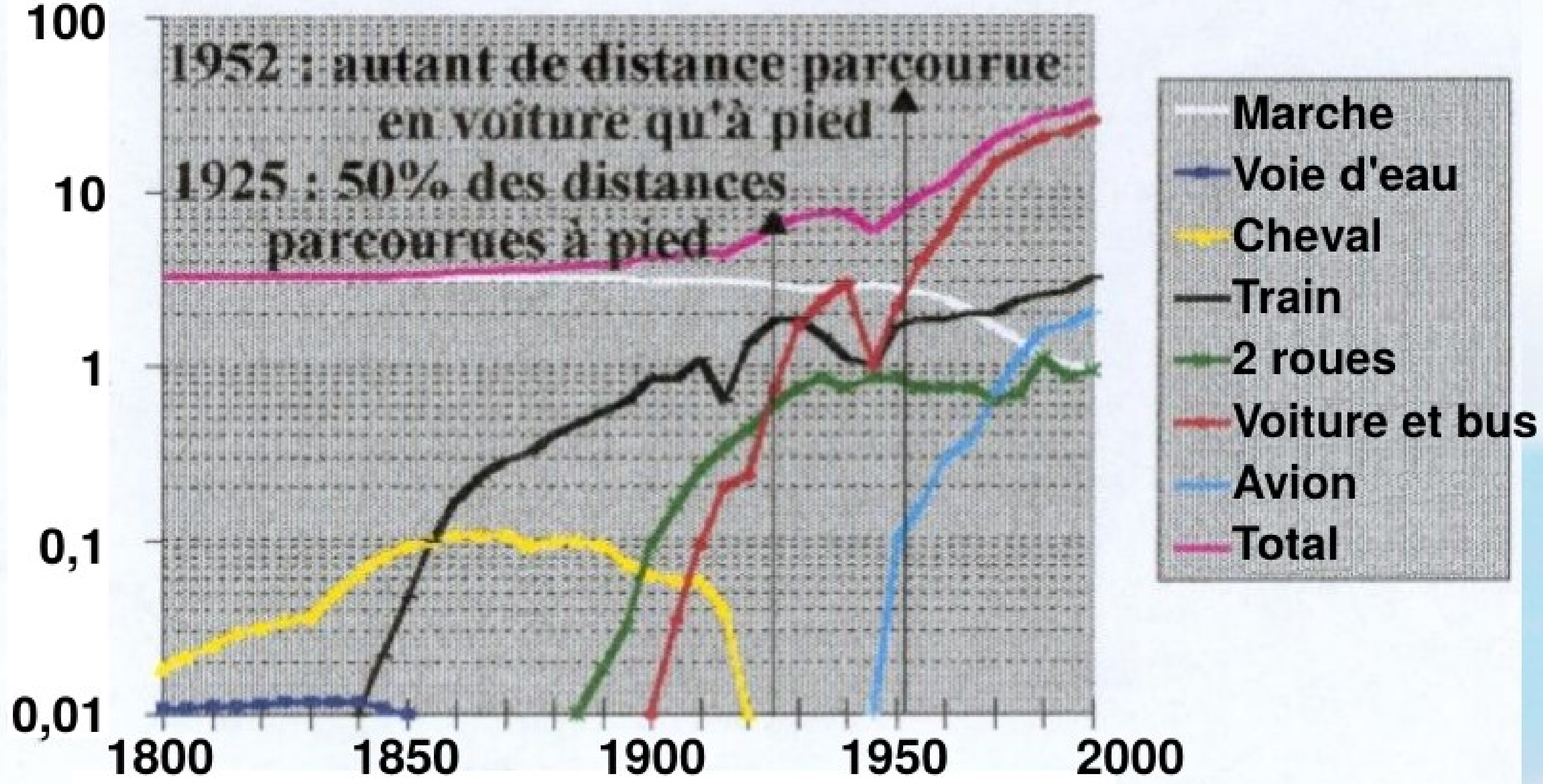
- Increase of equipment rate



Evolution du taux d'équipement des ménages français en appareils électroménagers de 1962 à 2004. Source : INSEE, 2010

Transport : historical facts

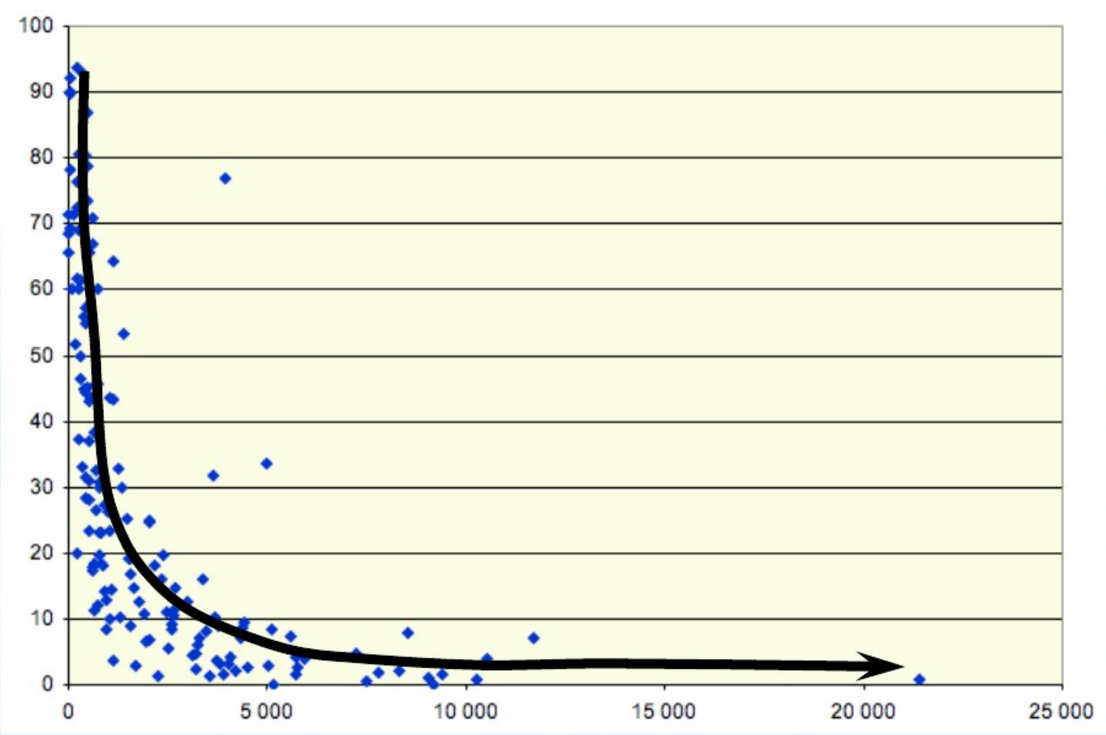
- More and « plus vite, plus haut, plus fort »



Evolutions des distances parcourues par personne et par jour, en France, depuis 1800.
Grübler & Nakicenovic, 1991 et estimations de Francis Papon pour la marche

Towards societies of services

- Societies without energy => agricultural dominated
- Energy+machines allow for development of secondary/tertiary sectors
- Services are also strongly dependent on energy
- Changes in society : way of life, urbanisation,...



Consommation d'énergie par personne et par an (kep) vs. % de l'emploi dans l'agriculture.
Sources WRI, US DOE

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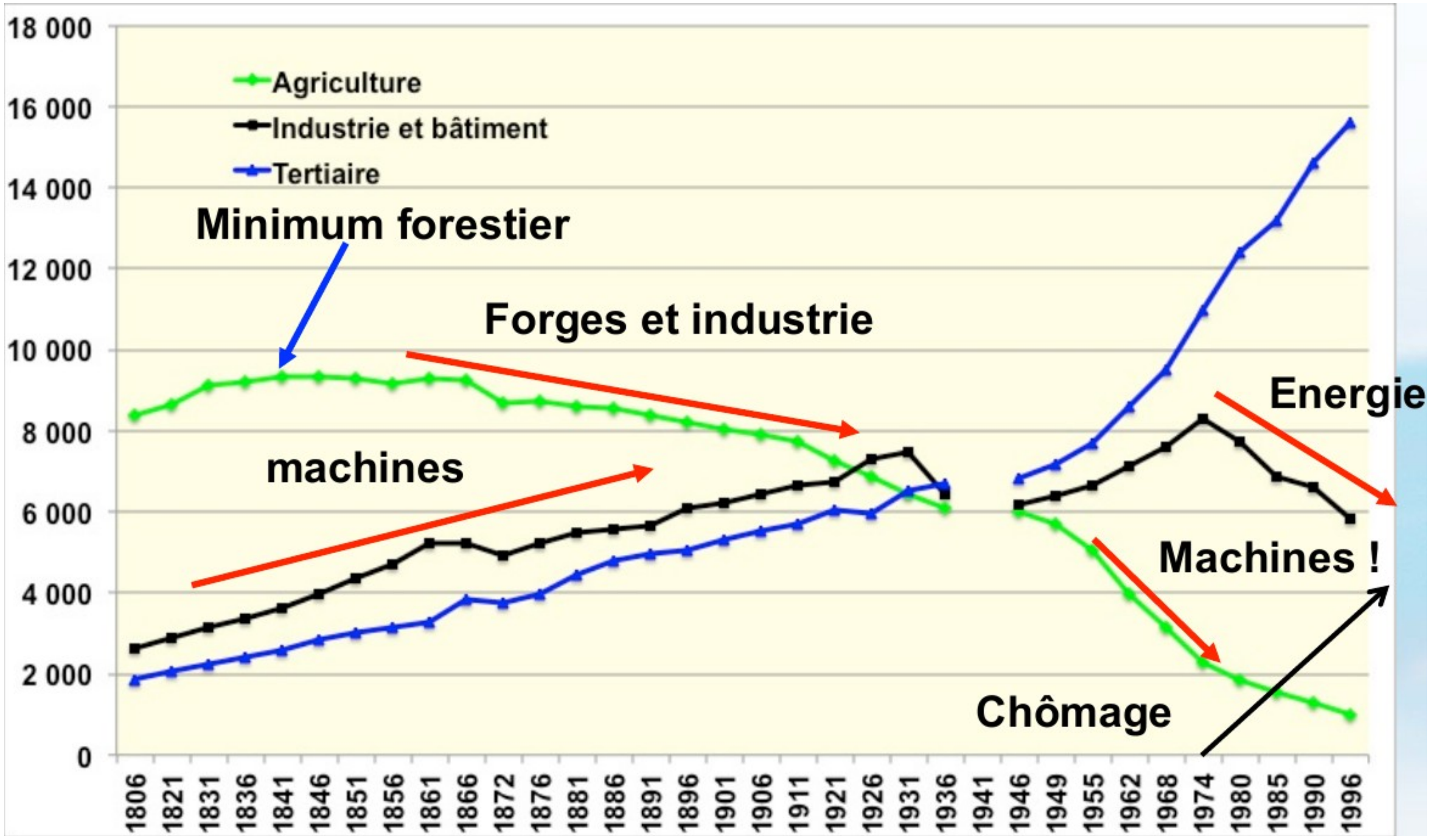
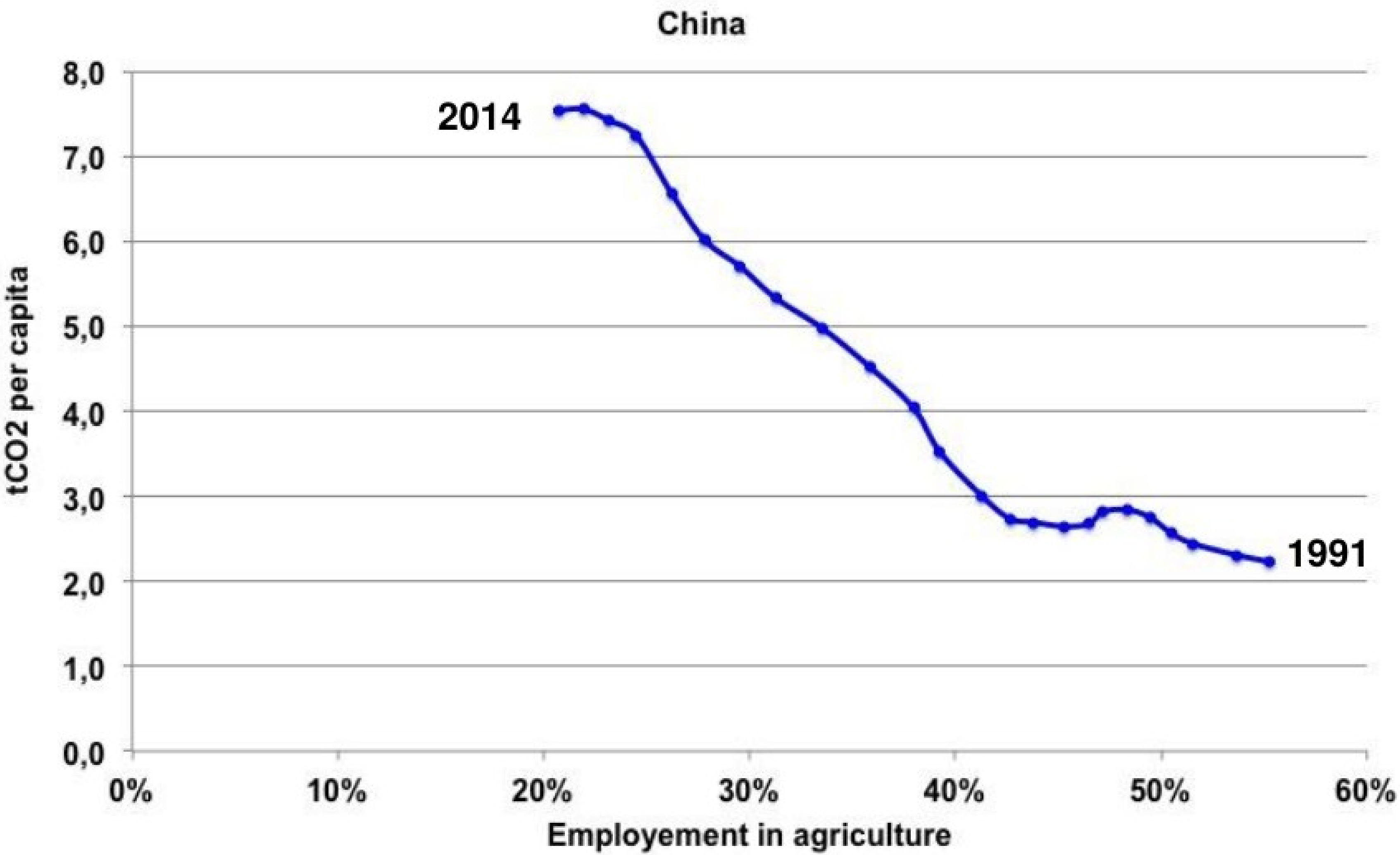


Nombre d'actifs en France par catégorie sur 2 siècles. Source INSEE.

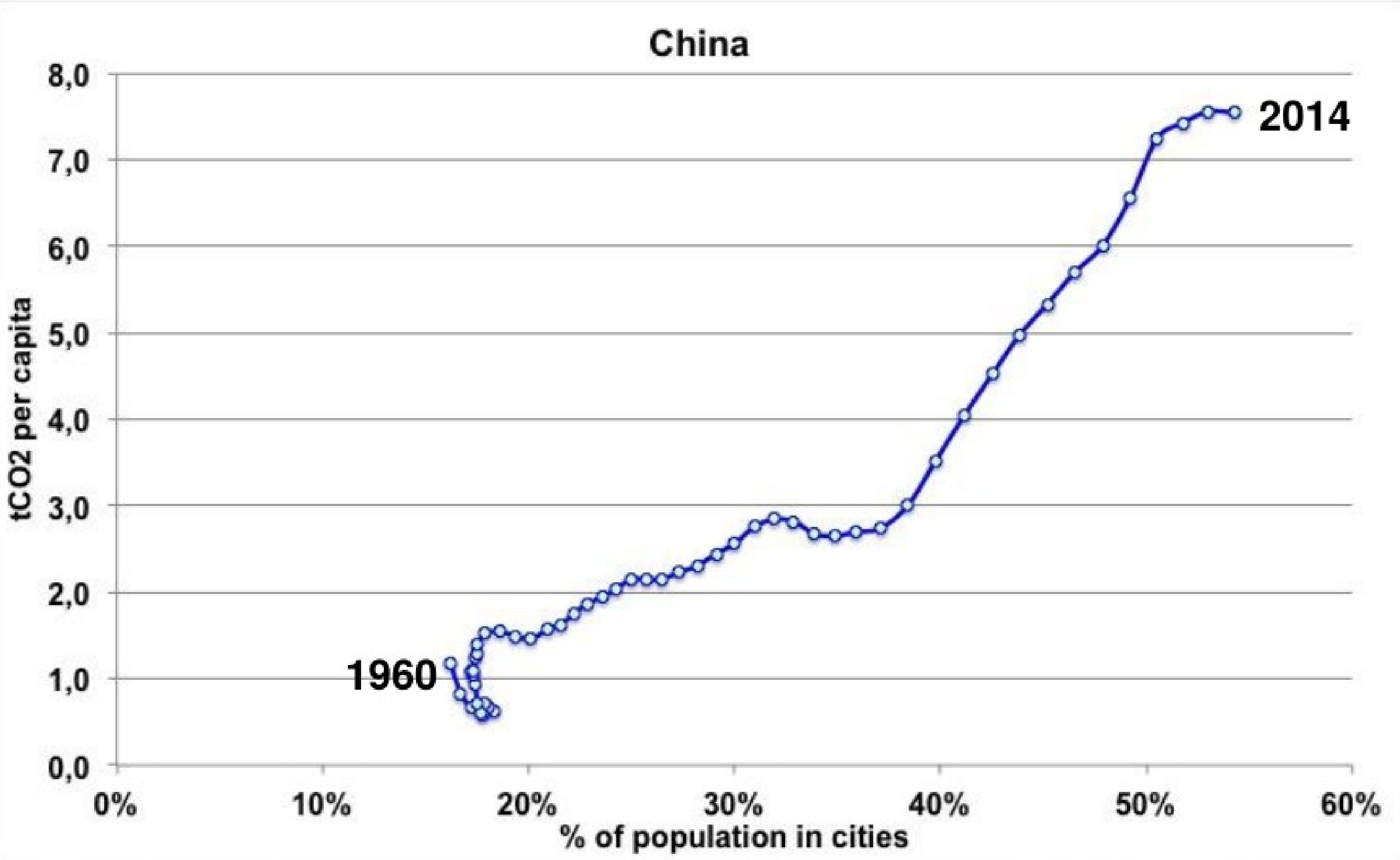
China

- Agriculture and energy



Energy and urbanisation

- Cities rely on energy to feed them and to allow for transportation and services. Denser cities are more efficient for transports…



Fraction de la population dans les villes vs émissions de CO2 par personne en Chine. Donnés Banque Mondiale

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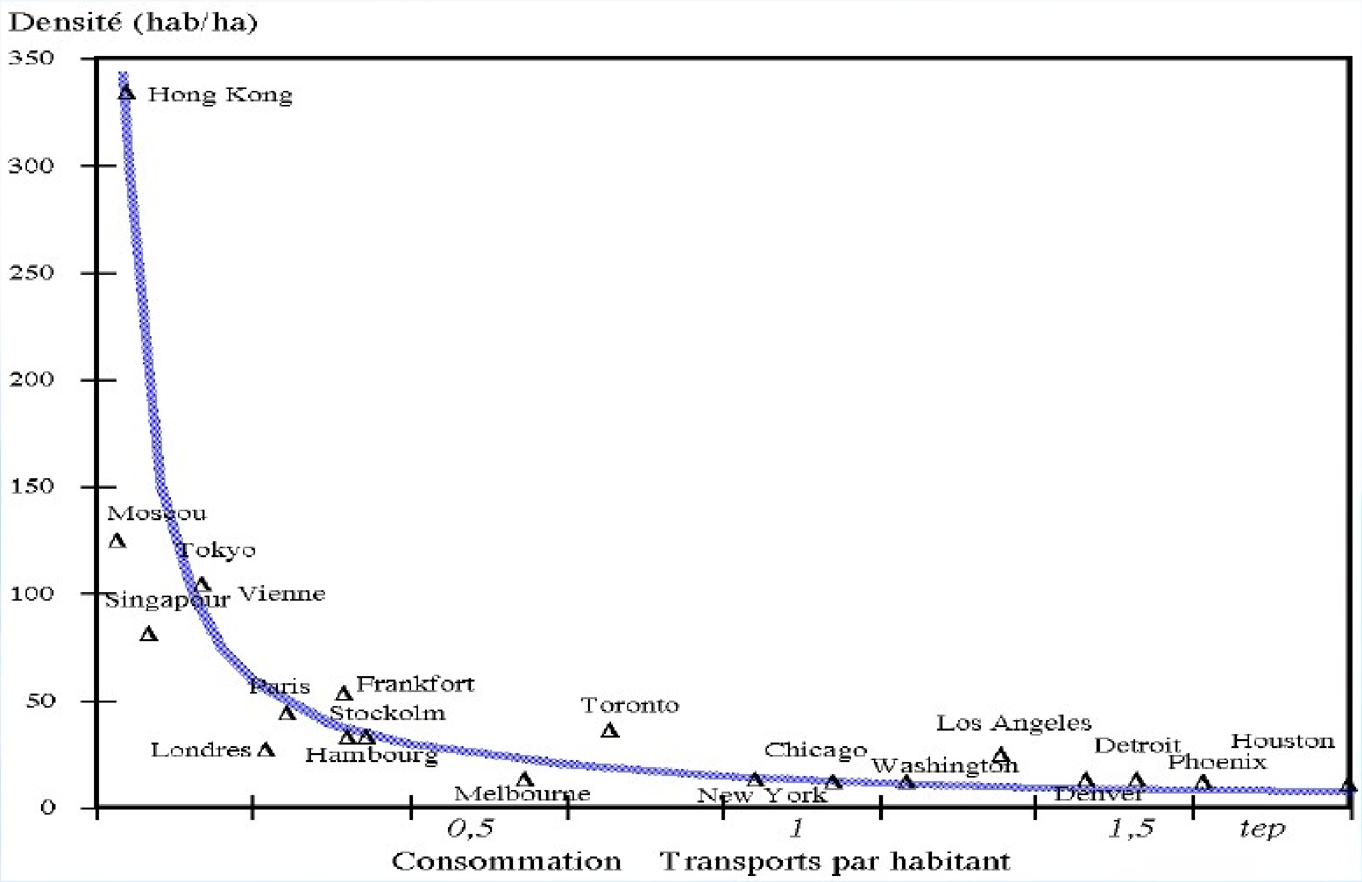
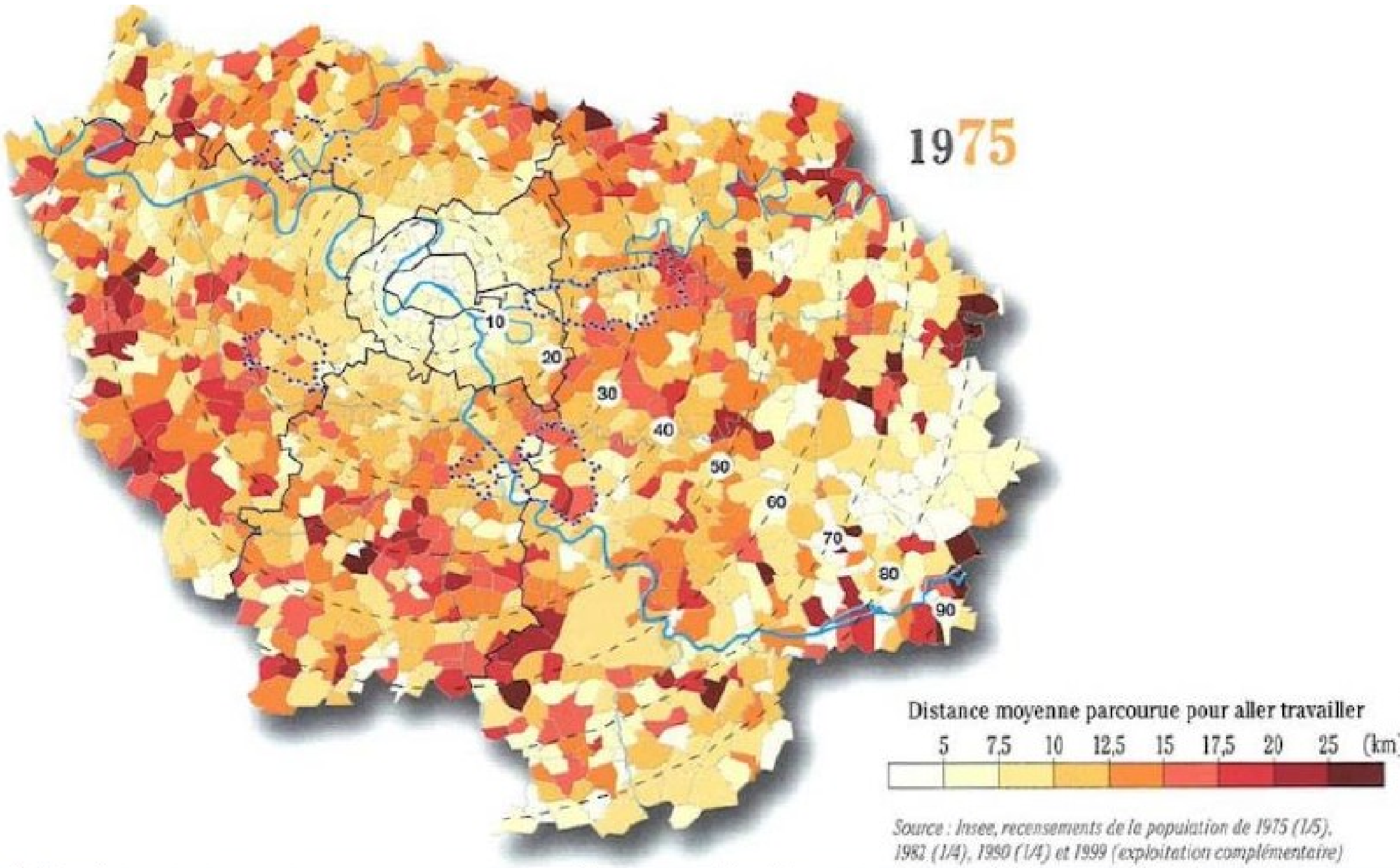


Consommation énergétique par habitant liée aux transports urbains (axe horizontal, en tonnes équivalent pétrole par an) en fonction de la densité de la zone urbaine (axe vertical, en habitants à l'hectare).
Source : Newman and Kenworthy, " Cities and automobile dependance ", Gower, 1989

Suburbian evolution driven by energy

- Distance to work



Distance moyenne au travail dans le « Grand Paris ». Source INSEE

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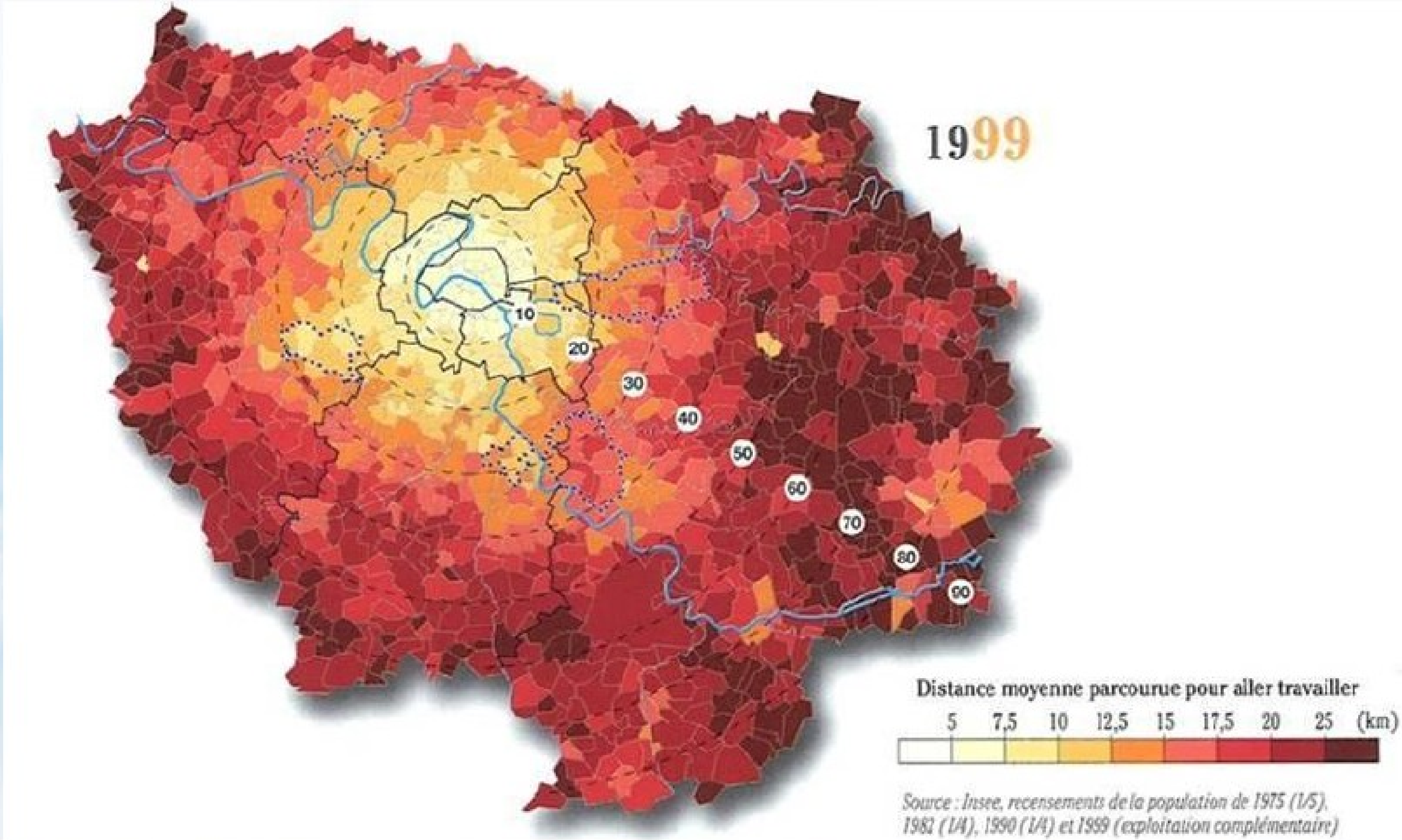

Distance moyenne au travail dans le « Grand Paris ».
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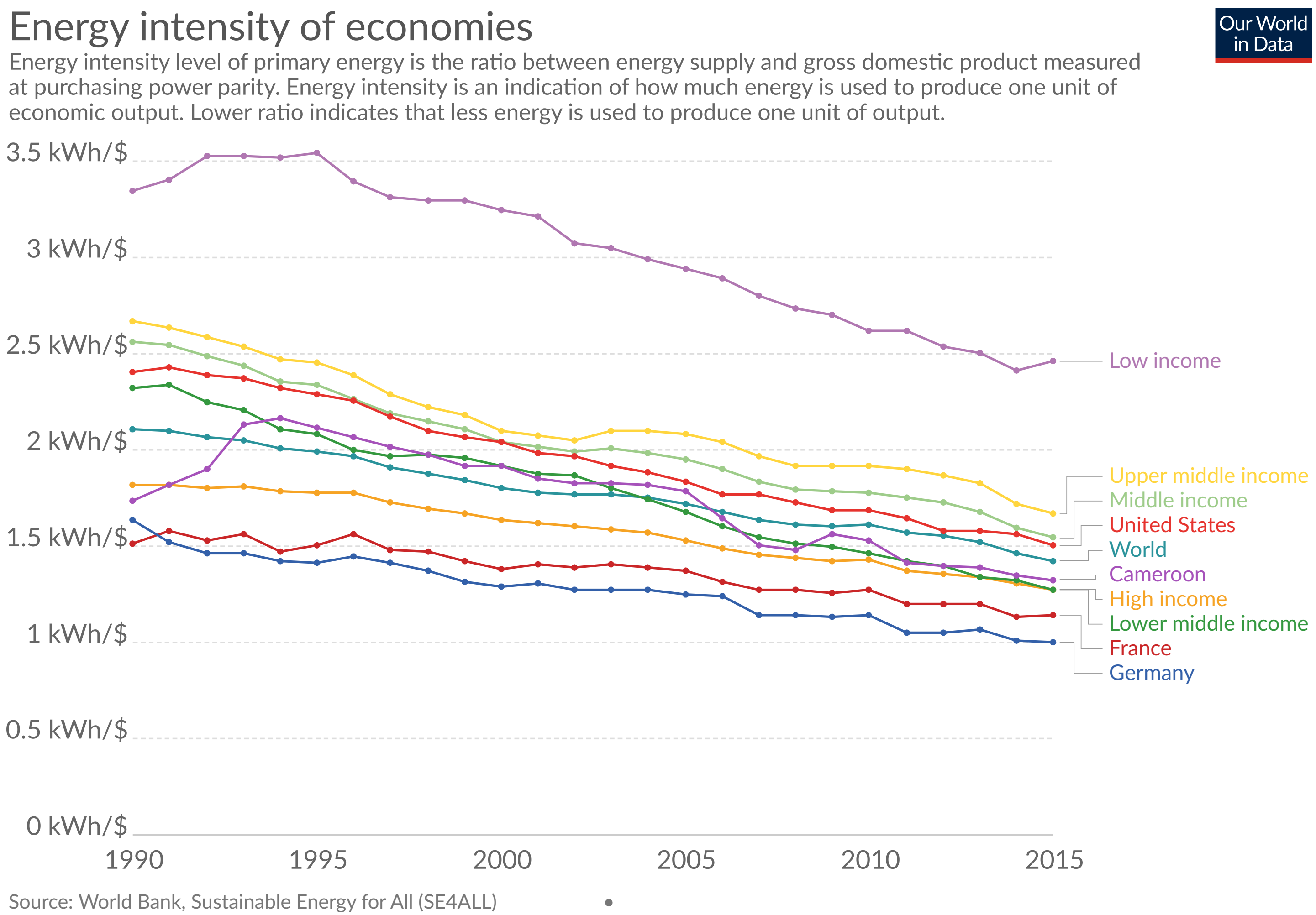
Energetic intensity of economies

1.5 kWh / $ PIB, no economical activities without energy



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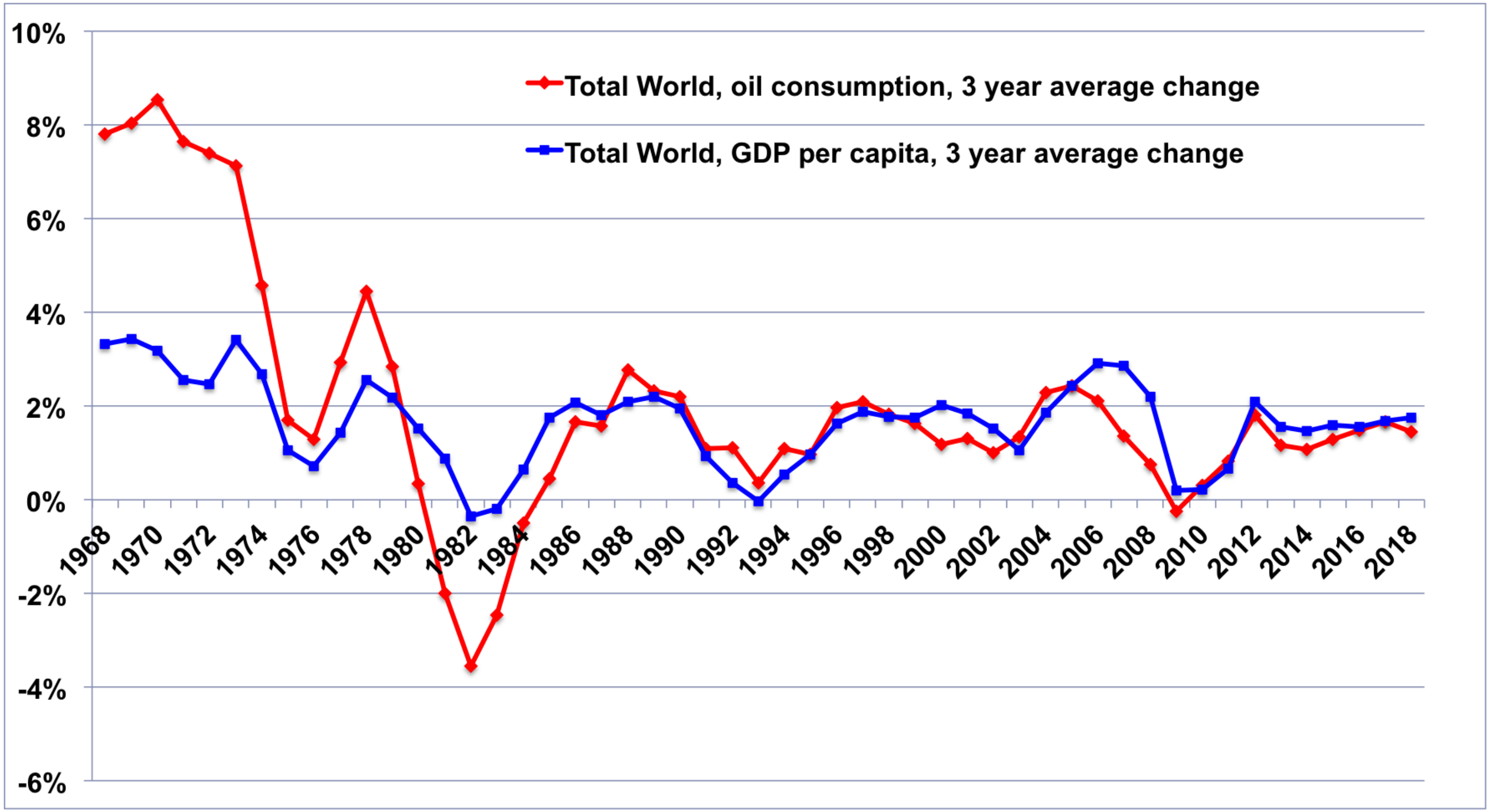

Conclusion

The dominant economical and development model of societies is intrinsincally fed by cheap fossil energies. Changing the energy mix to meet the 2 carbon constraints is one of the strongest challenge for the 21th century.

The conception of our large scale machines dates back to the 19th and 20th centuries and their efficiency has little improved since them, not enough to counteract the great increase of demand.