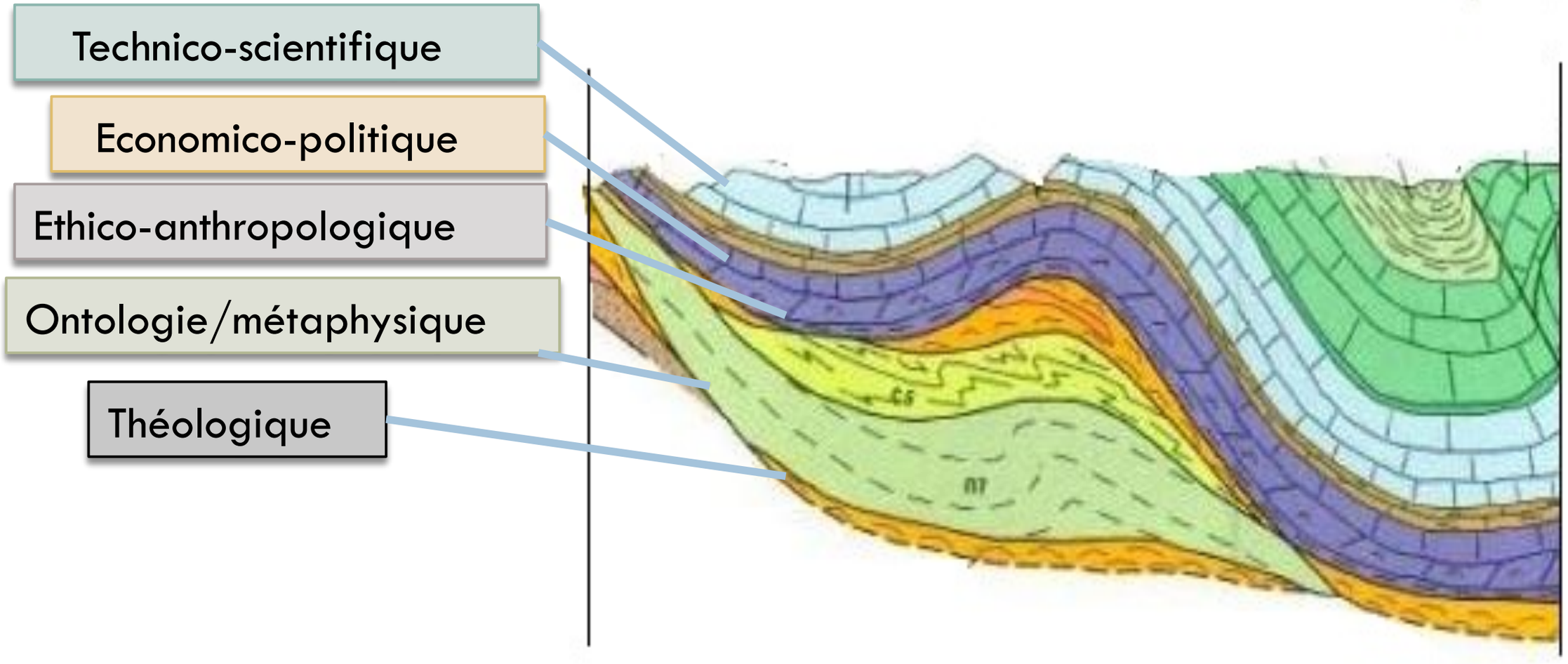
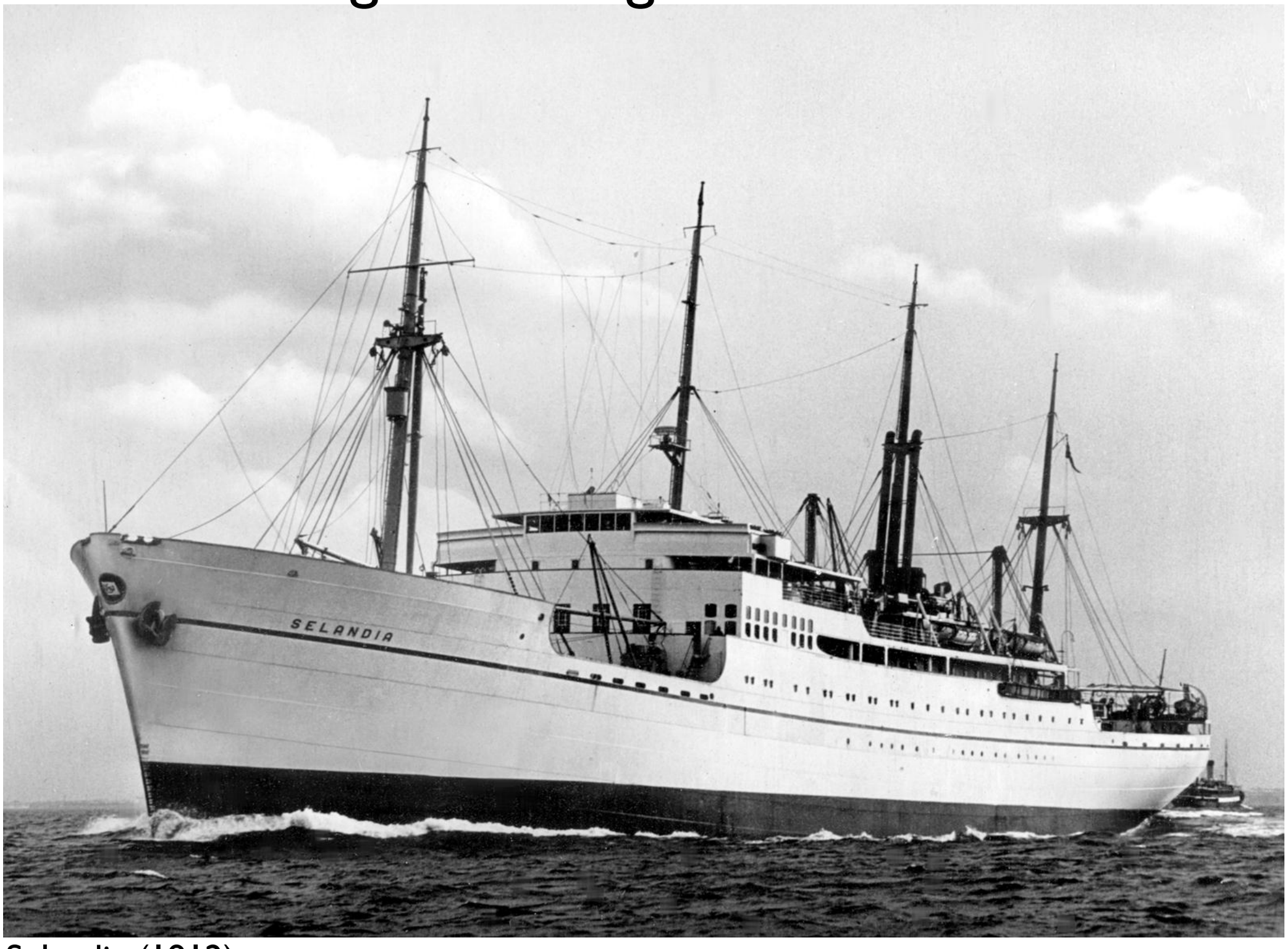
Today, let's dig the «technico-scientific» soil



source: Ch. Luyckx

Not suprisingly, efficiency was already a must one century ago and long before that



Selandia (1912)

Jobs for the engineers: efficiency and «green» energy

$$CO_2 = \frac{CO_2}{TEP} * \frac{TEP}{PIB} * \frac{PIB}{POP} * POP$$

Kaya's identity

Reduce energy intensity

Reduce CO2 emissions using renewable energy

- Efficiency of (energy) conversion
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  - EROEI, a central issue
  - Having plenty of renewable energy, a benefit?

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To define efficiency, let's look at a flying airplane

source: flightglobal.com

The fuel consumption of an airplane is a function of its drag (aerodynamics) of its mass (materials) and of its propulsion system (fuel conversion)

Improving all technologies helps improving the fuel consumption and thus the range of an airplane

$$R = \eta_{glob.} \left(\frac{L}{D}\right) \frac{PCI}{g} \ln\left(\frac{M_i}{M_f}\right)$$

Breguet's range equation

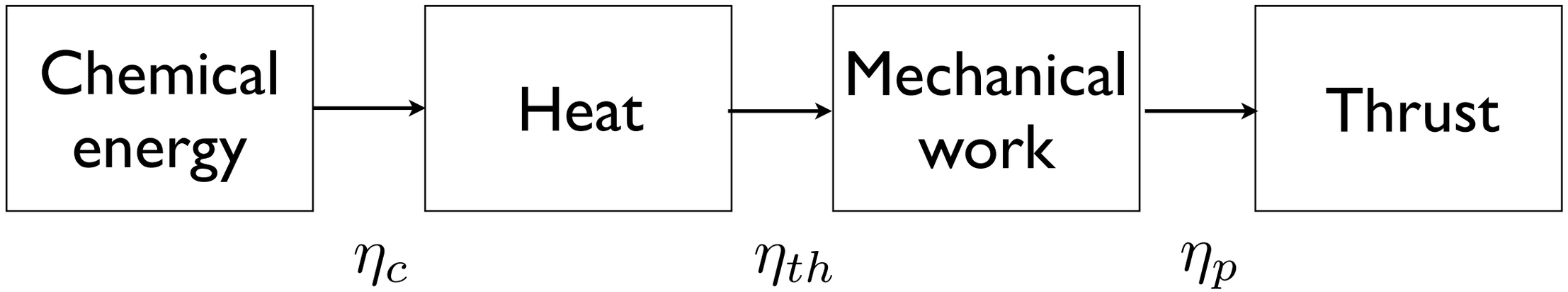
Improve propulsion

Improve aerodynamics

Improve materials

Improving is similar to being more efficient

Focusing on the propulsion system, efficiency is what you get from what you paid for



$$\eta_c = \frac{\text{Heat produced}}{\text{Fuel consumption}}$$

$$\eta_{th} = \frac{\text{Mechanical work}}{\text{Heat produced}}$$

$$\eta_p = \frac{\text{Thrust}}{\text{Mechanical work}}$$

$$\longrightarrow \quad \eta_e = \eta_c \times \eta_{th} \times \eta_p$$

```
\eta_c =\frac{\textnormal{Heat produced}}{\textnormal{Fuel consumption}}
```

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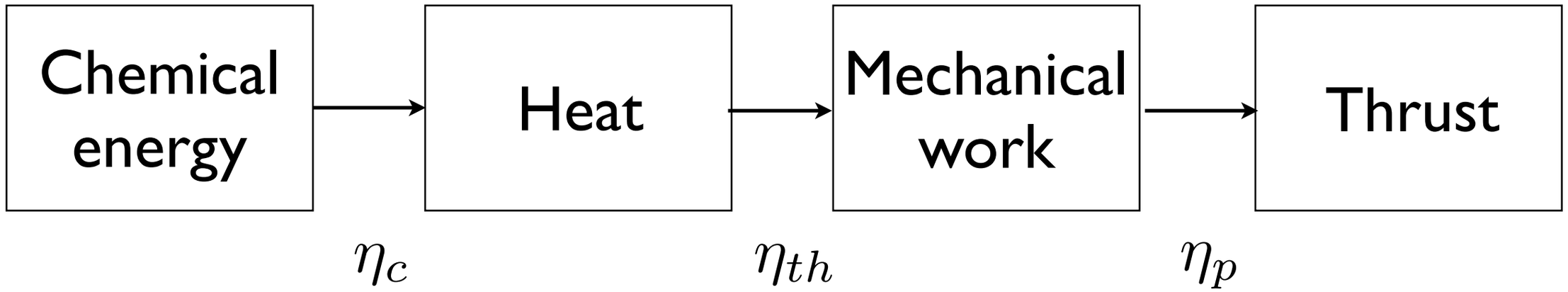
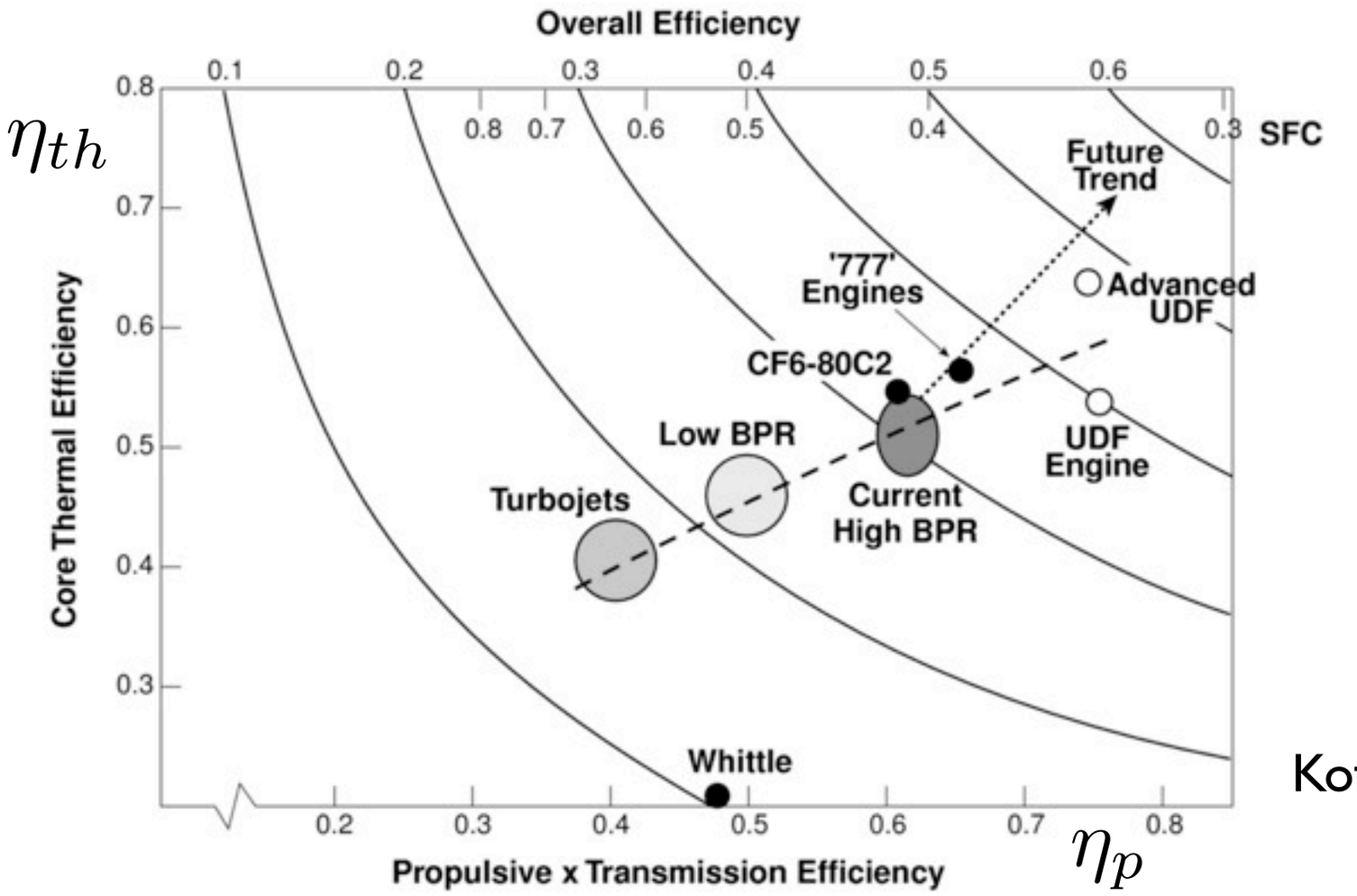
What are the trends in overall efficiency?

Getting closer to 0.4 only. So it seems there is room for improvement.



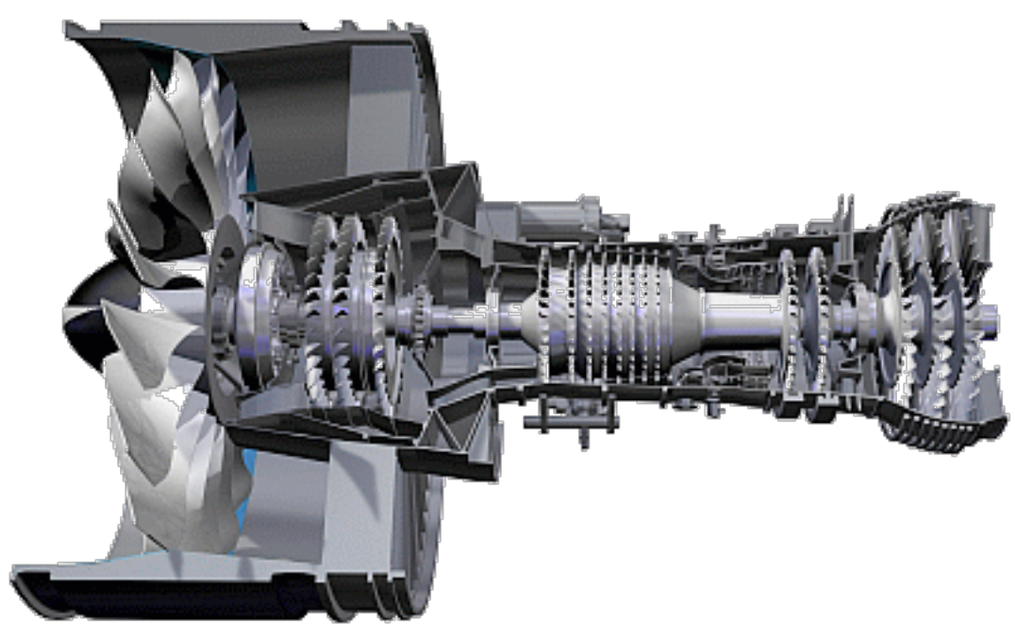


Koff, 1991

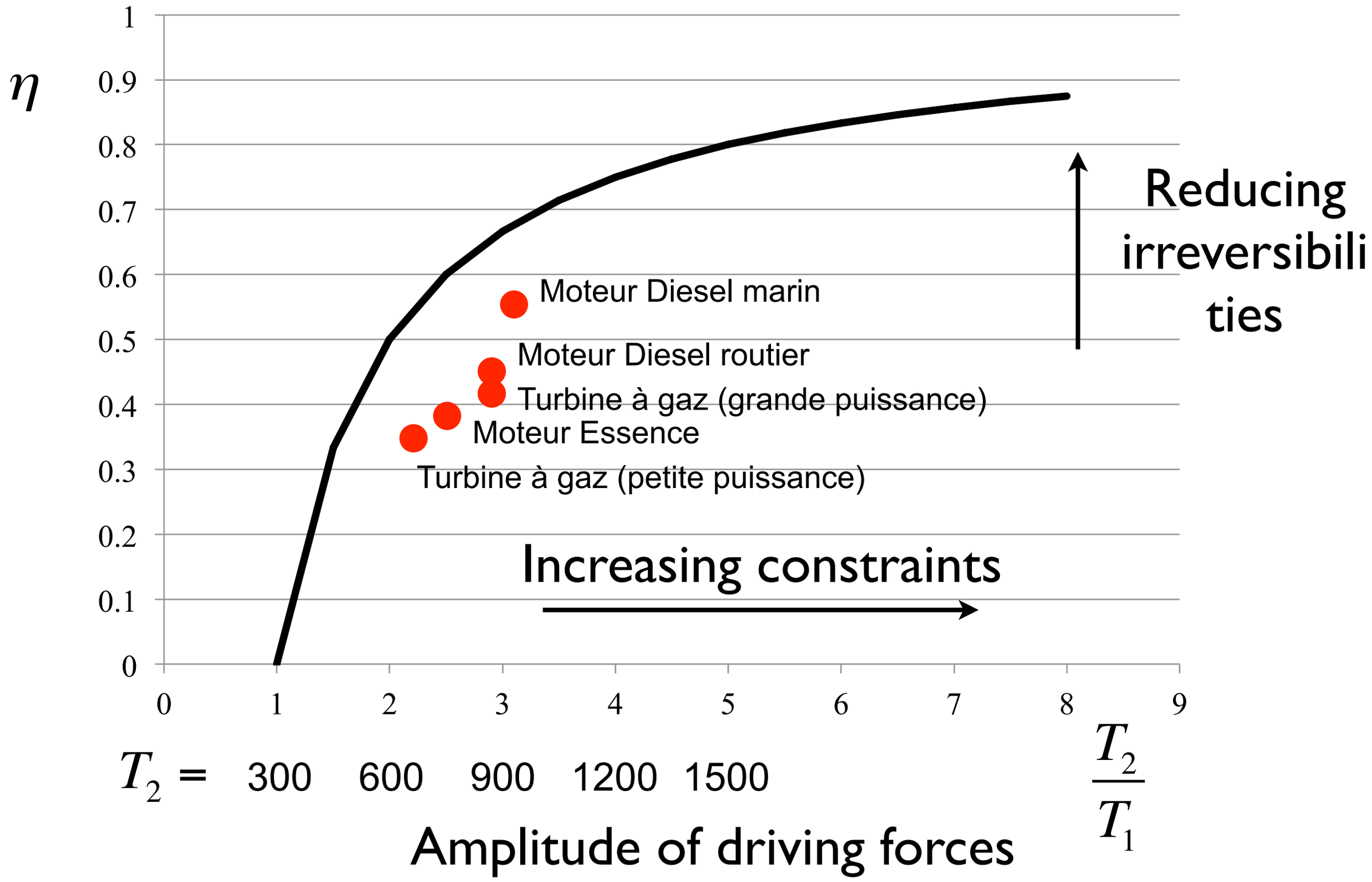
Advanced propulsion systems : a technology marvel leading to an overall efficiency of 0.5 only. Why?

UDF (unducted fan)

GTF (geared turbofan)



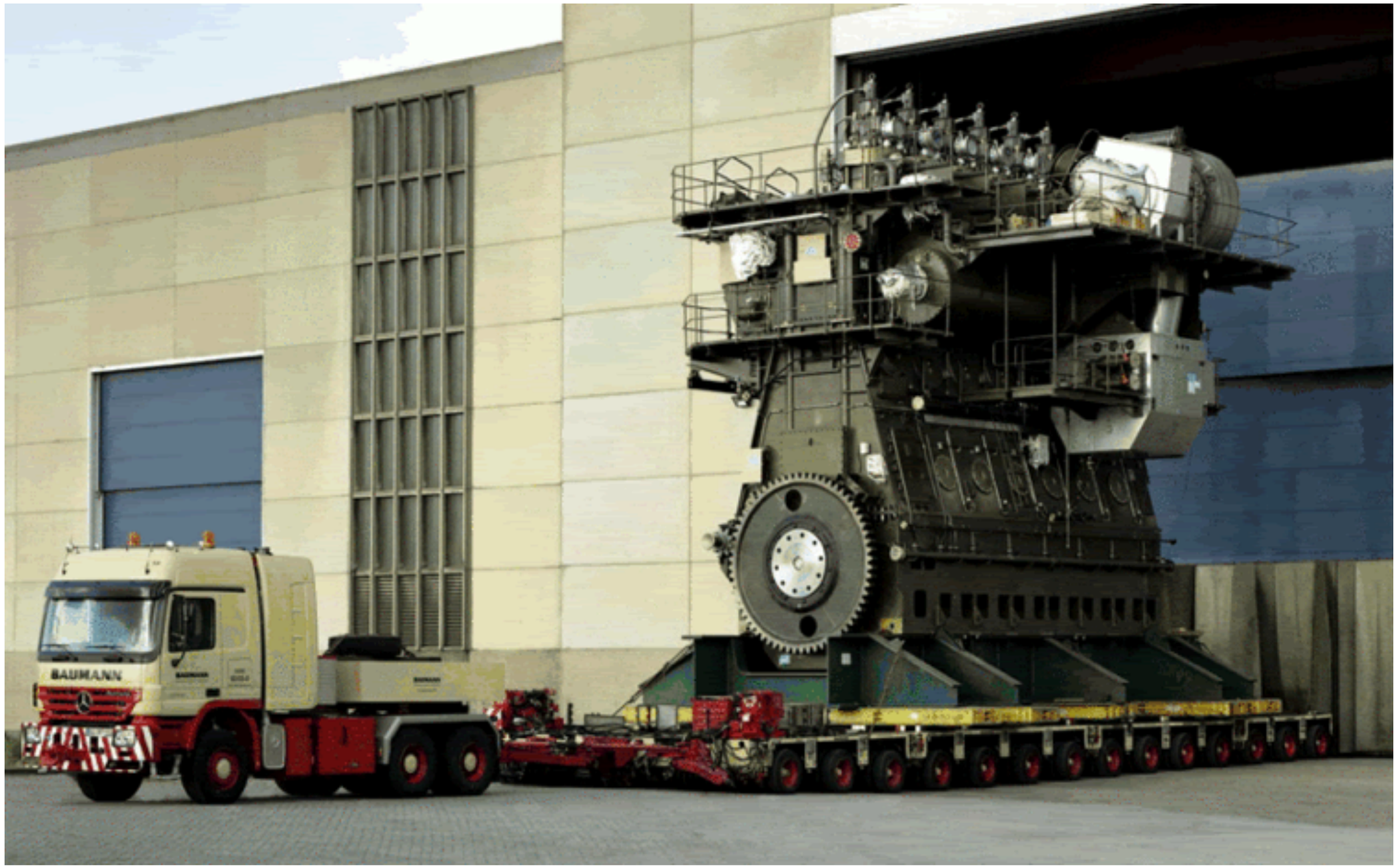
Thanks to the second principle of thermodynamics (i.e. physical limits), conversion of thermal energy into work is limited



Both technology level and size matter

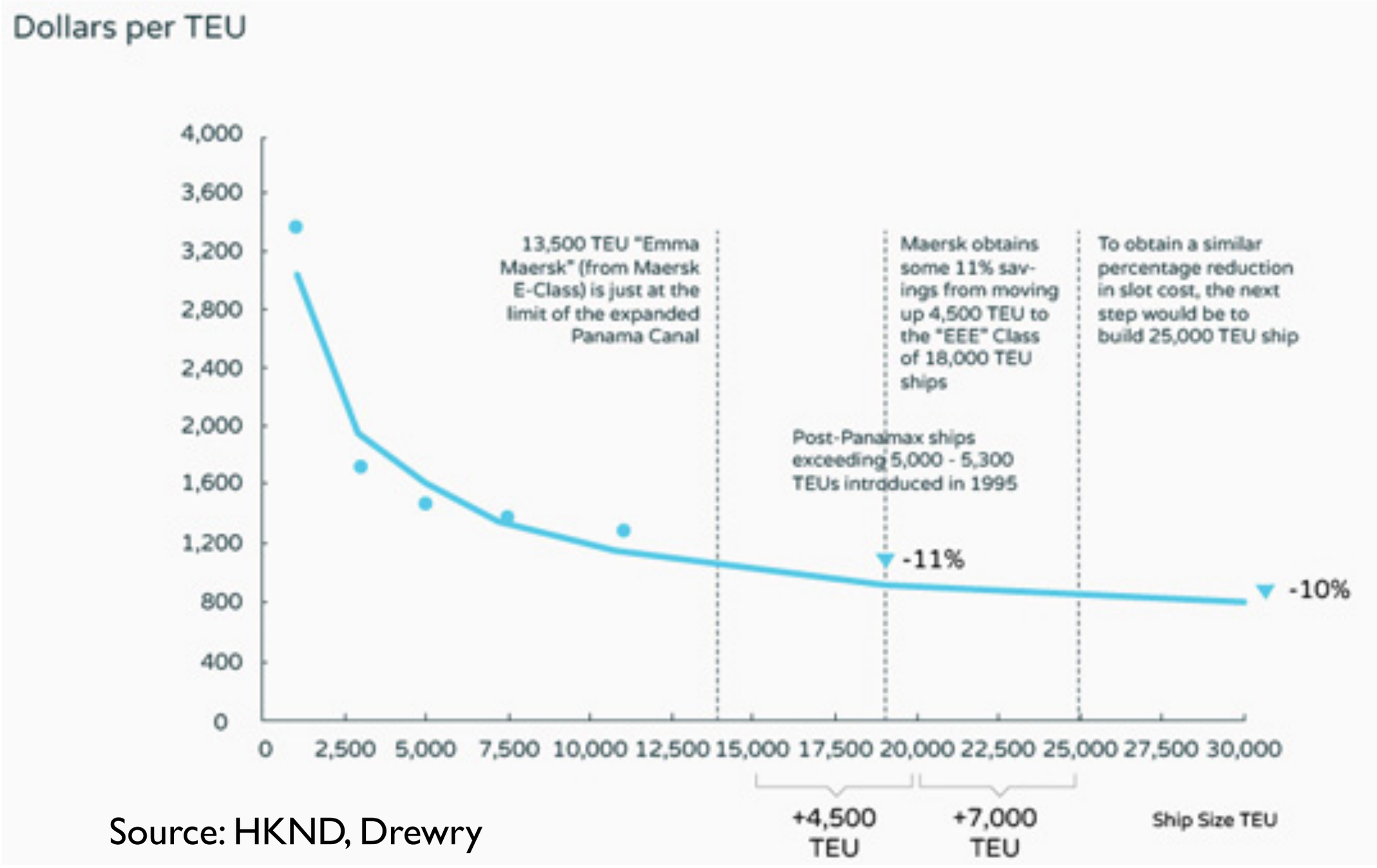
Engine	Efficiency
1860 Lenoir's engine	5%
1876 Otto's engine	20%
1896 Diesel's engine	25%
1912 Selandia's engine	30%
1986 Marine Diesel engine	48%
2011 Gas engine	45%
2011 Vehicle Diesel engine	42%
2011 Vehicle gasoline engine	35%
2011 Marine Diesel engine	54.4%

Both technology level and size matter



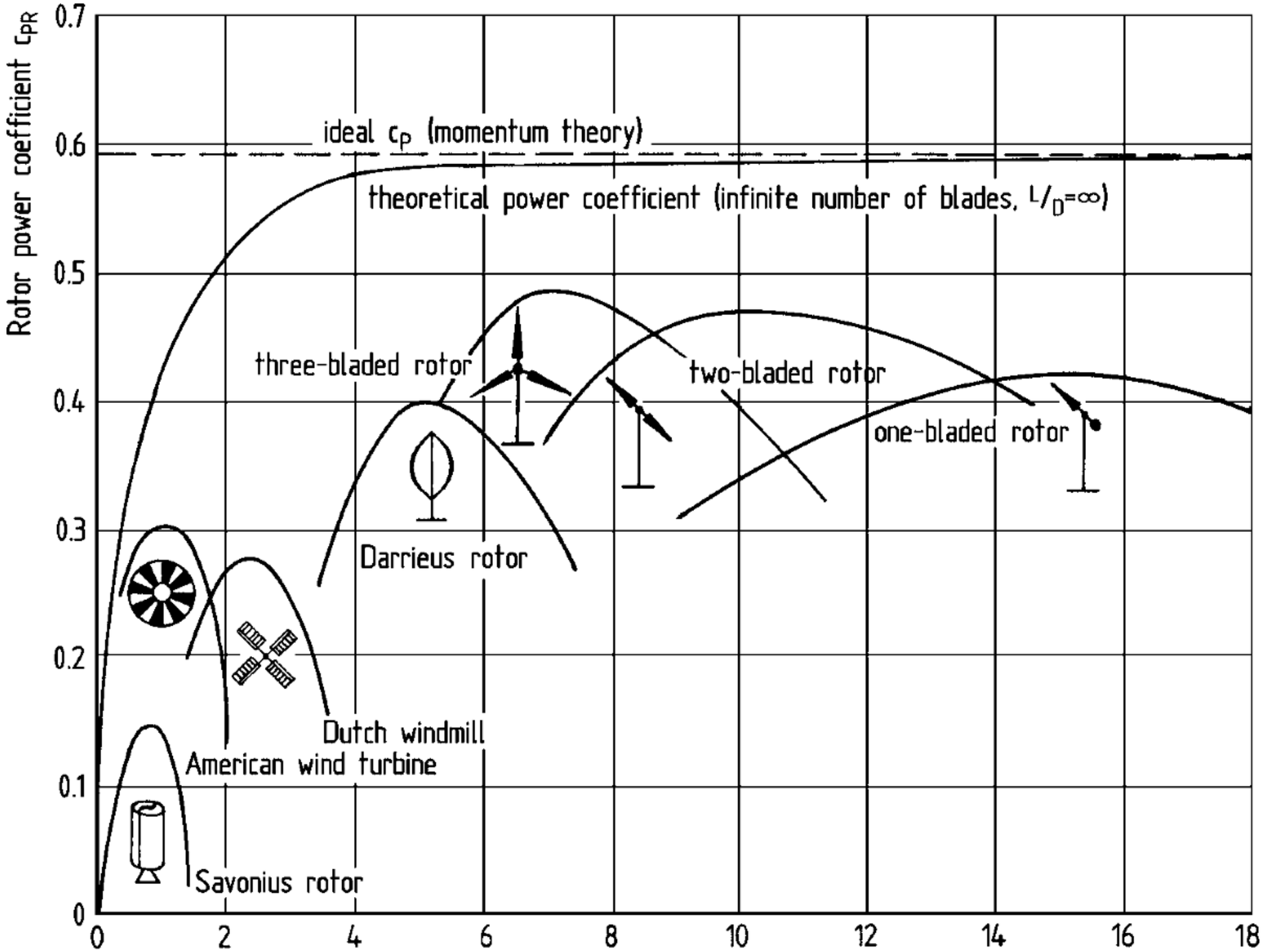
MAN S80ME-C7

Yes, size does really matter : example of ship transportation



Source: HKND, Drewry

Thanks to Betz (i.e. physical limits), wind turbine efficiencies are also limited. The standard technology is already close to the limit



Source: Wind turbine by Hau and von Renouard, Springer

This is true for a majority of processes (example of cement production) where expected gains are limited.

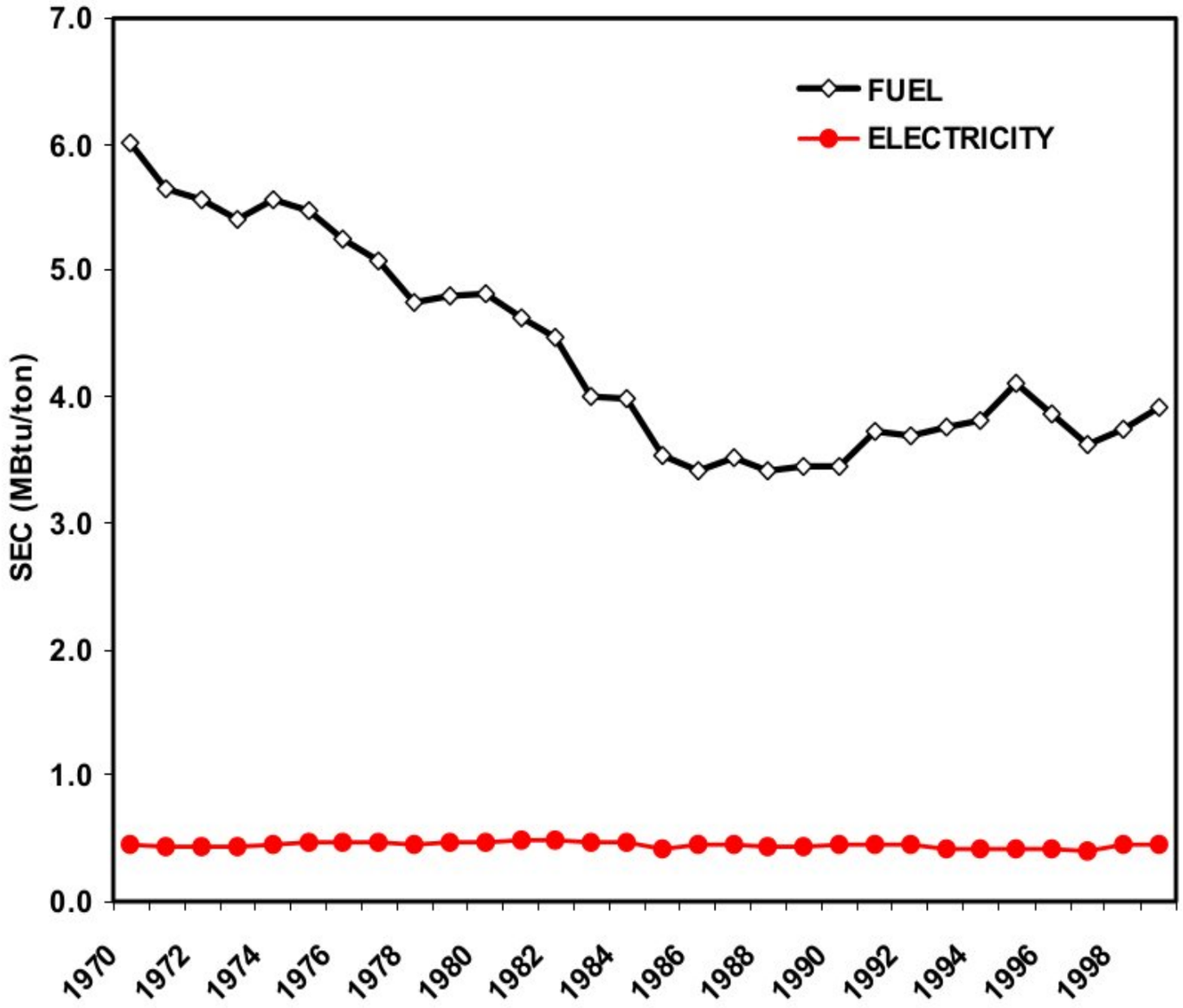
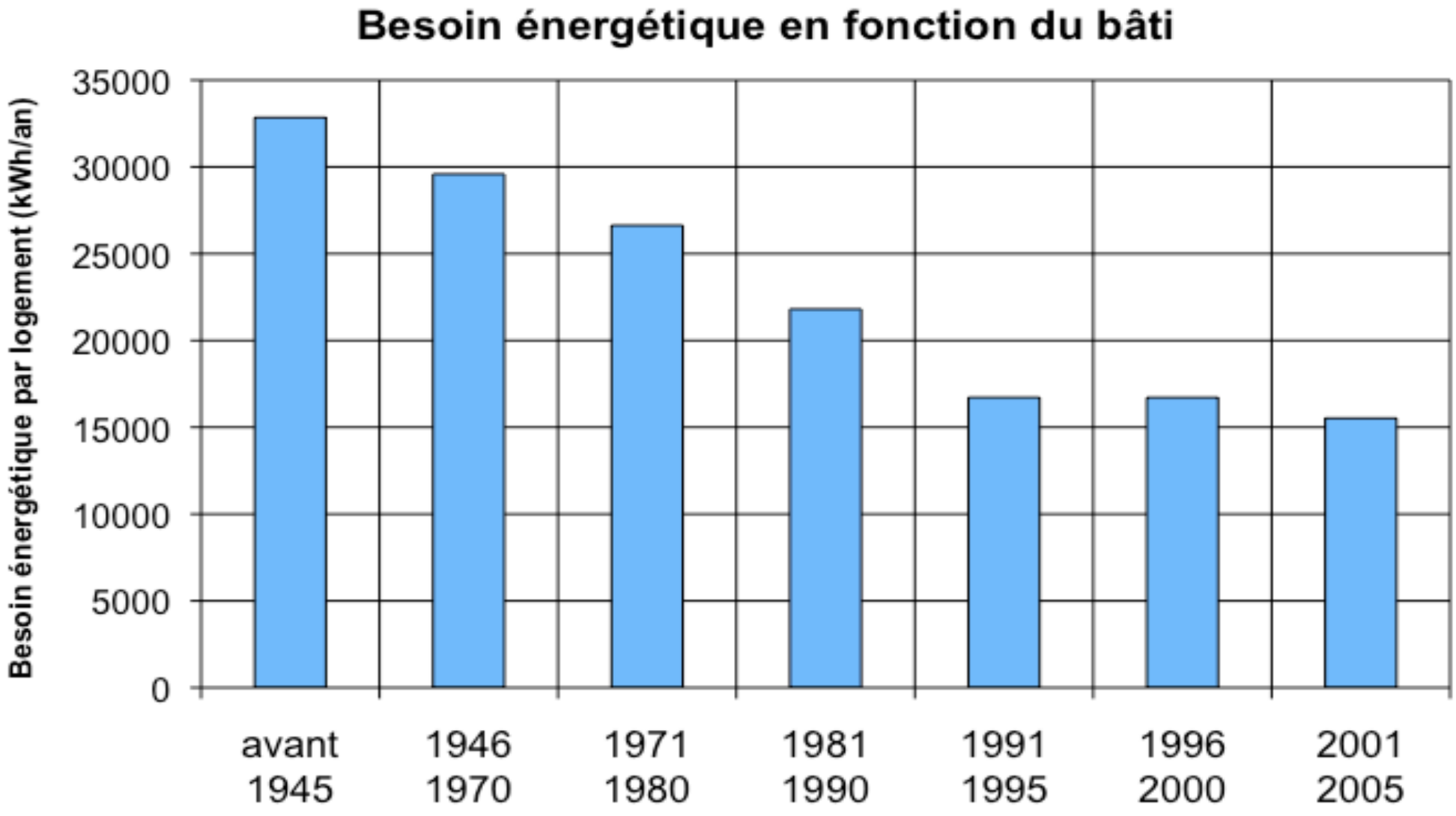


Figure 7. Specific fuel and electricity consumption per ton of cement produced. Energy is expressed as final energy (or site energy) and excludes power generation conversion losses. Fuels include waste fuel use estimates starting in 1977 (based on PCA data, and after 1993 on USGS reported data).

There are some exceptions like heating needs in buildings that could go down to zero



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It is also usually possible to obtain the same service for less. It is another form of efficiency.

Porsche 911
mass = 1600 kg

21 kW @ 120 km/h

260 kW @ 300 km/h (max speed)

Combined fuel economy = 12.3 l/100km

Small cars have a better fuel economy using less mass and a lower max speed

Renault Clio
mass = 1100 kg

P=20 kW @ 120 km/h

50 kW @ 167 km/h (max speed)

Combined fuel economy
gasoline : 4.3...5.5 l/100km
diesel : 3.2...3.4 l/100km

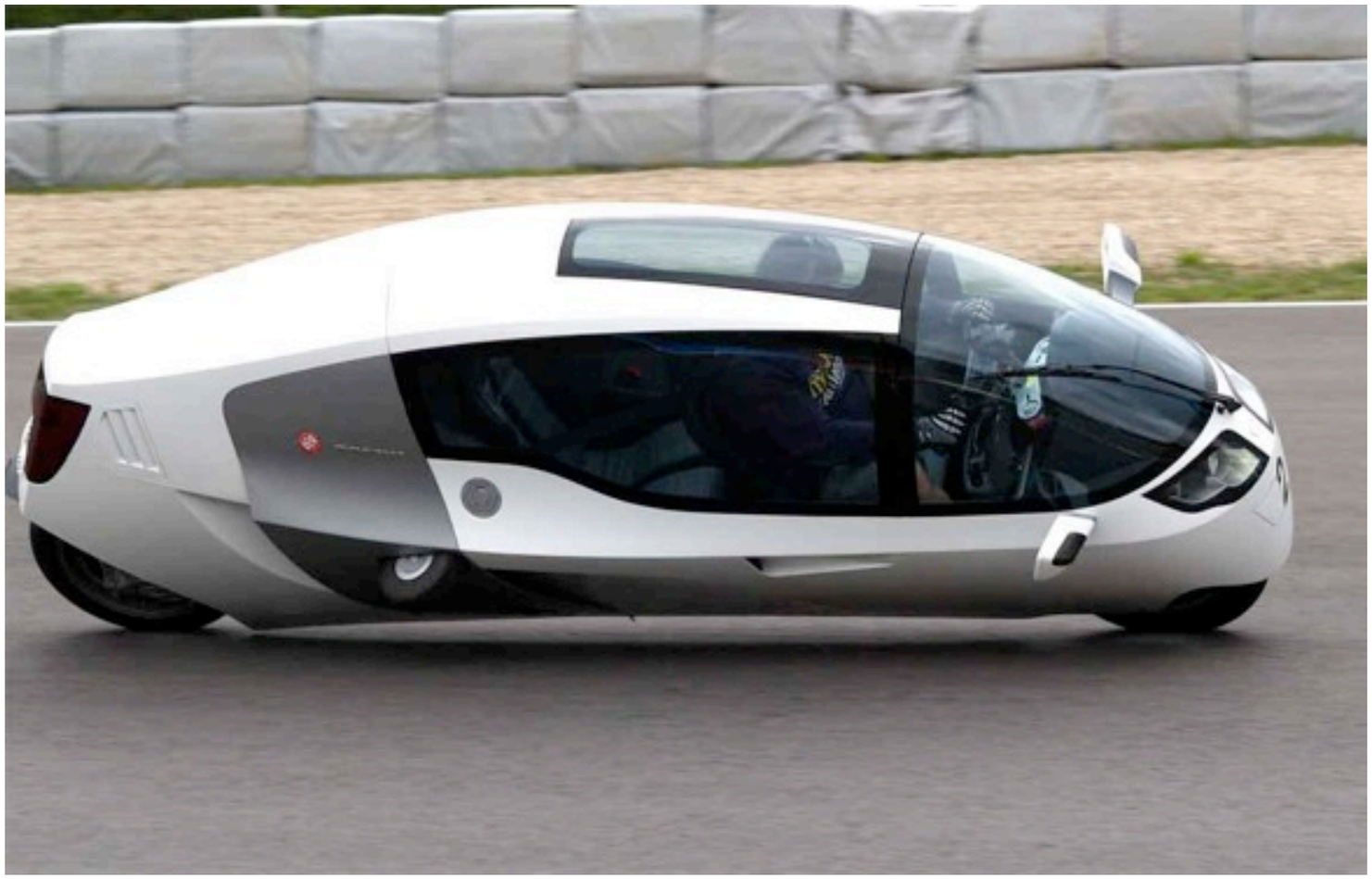
We can go even further by still reducing the mass and improving the shape. However, the service is not exactly the same.

VW xl1
mass = 795 kg !

9 kW @ 120 km/h
21 kW @ 167 km/h

Combined fuel economy
1l/100km (NEDC standards)
2l/100km in practice

Down to this highly efficient transportation system. Is it still really a car? Does it impact our economy?



Peraves Monotracer
mass = 250 kg

5 kW @ 120 km/h

67 kW @ 300 km/h

Combined fuel economy <1l/100km

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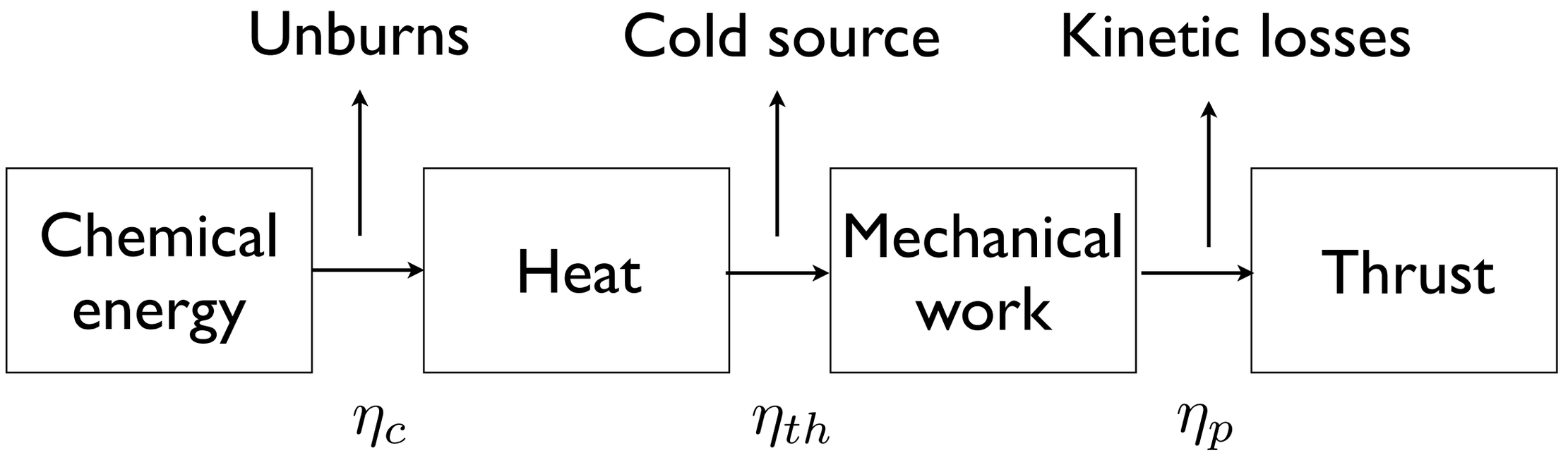
Energy is never lost. It is thus better to use the quality of energy, i.e. the exergy.



$$W = \left(1 - \frac{T_{atm}}{T}\right) Q$$

Max theoretical conversion into work / Heat source

Exergy content

Energy conversion is subject to strong exergy losses

Electricity ⟶ Heat

exergy = 1

energy = 1

exergy = 0.1

energy = 1

Source: Thomasnet.com

Examples of exergy content of energy

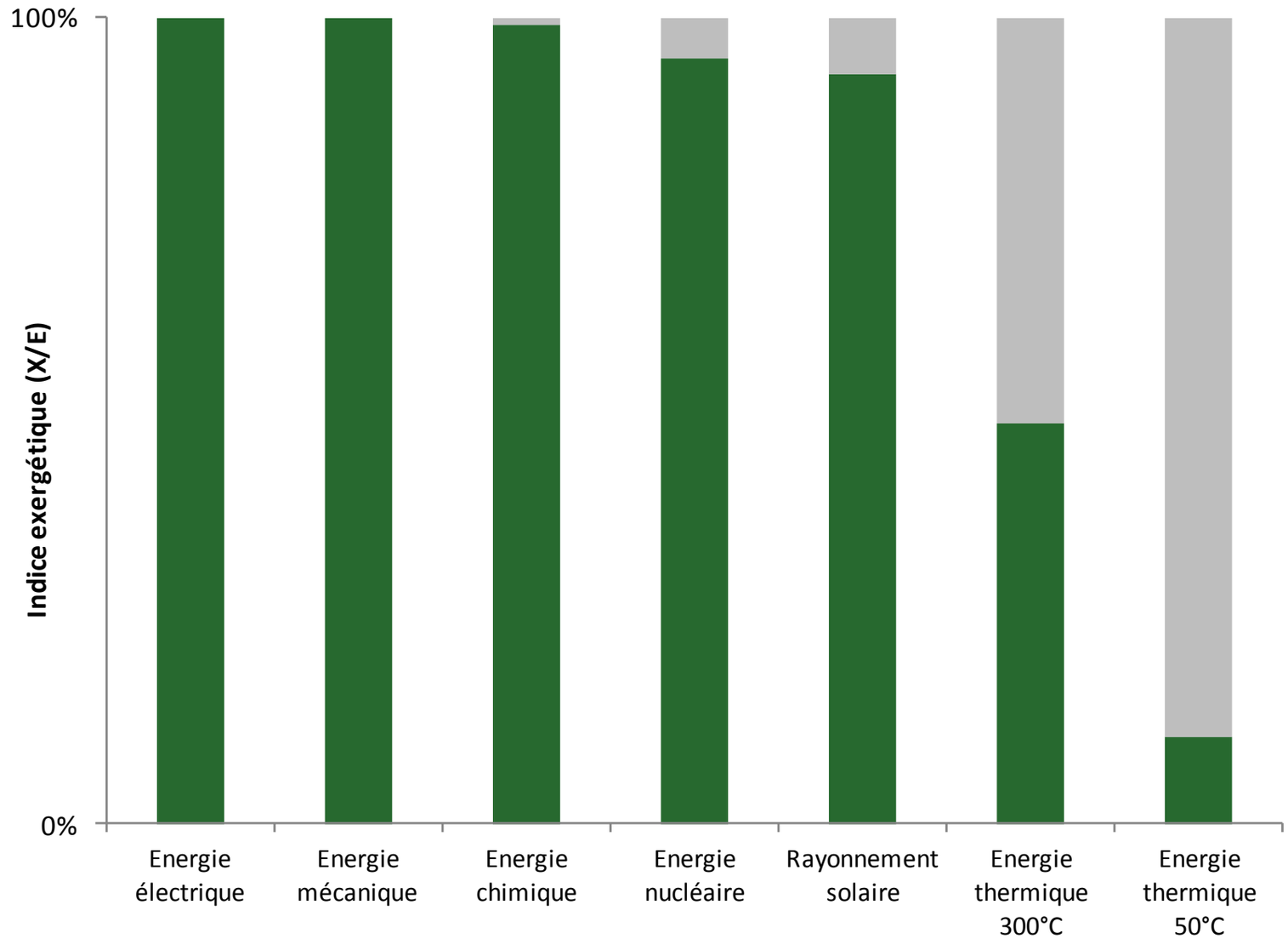


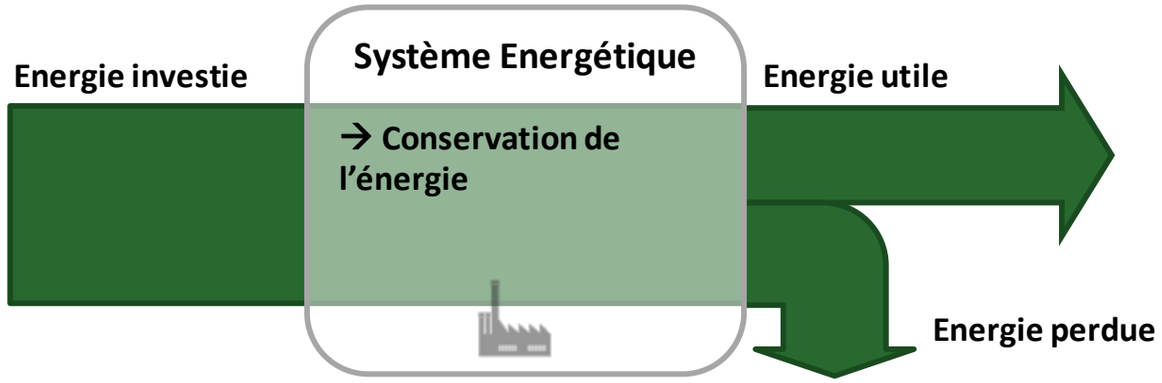
Figure 1 : Indice exergétique de différentes formes d'énergies. Température du milieu ambiant prise à 15 °C

Source: ENEA Consulting

We get more insight following the decreasing exergy content through the different conversion steps than following the conserved energy

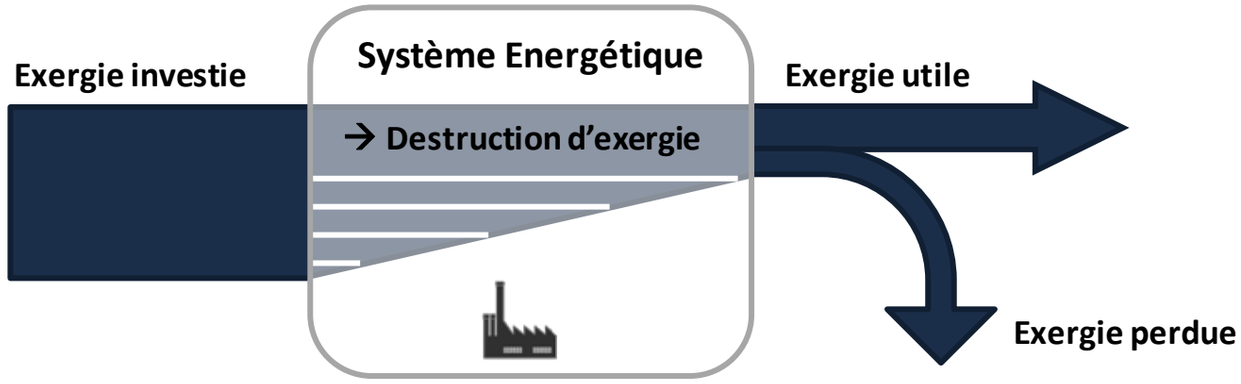
L'efficacité ou rendement énergétique se définit comme le rapport entre l'énergie utile et l'énergie investie dans une transformation ou conversion.

$$\eta_{en} = \frac{Energie\ utile}{Energie\ investie}$$



L'efficacité ou rendement exergétique se définit comme le rapport entre l'exergie utile[2] et l'exergie investie dans une transformation ou conversion.

$$\eta_{ex} = \frac{Exergie\ utile}{Exergie\ investie}$$



Contrairement à son pendant énergétique, **la forme exergétique du rendement prend en compte non seulement les flux énergétiques perdus, mais également la diminution de qualité des flux énergétiques.**

Source: ENEA Consulting

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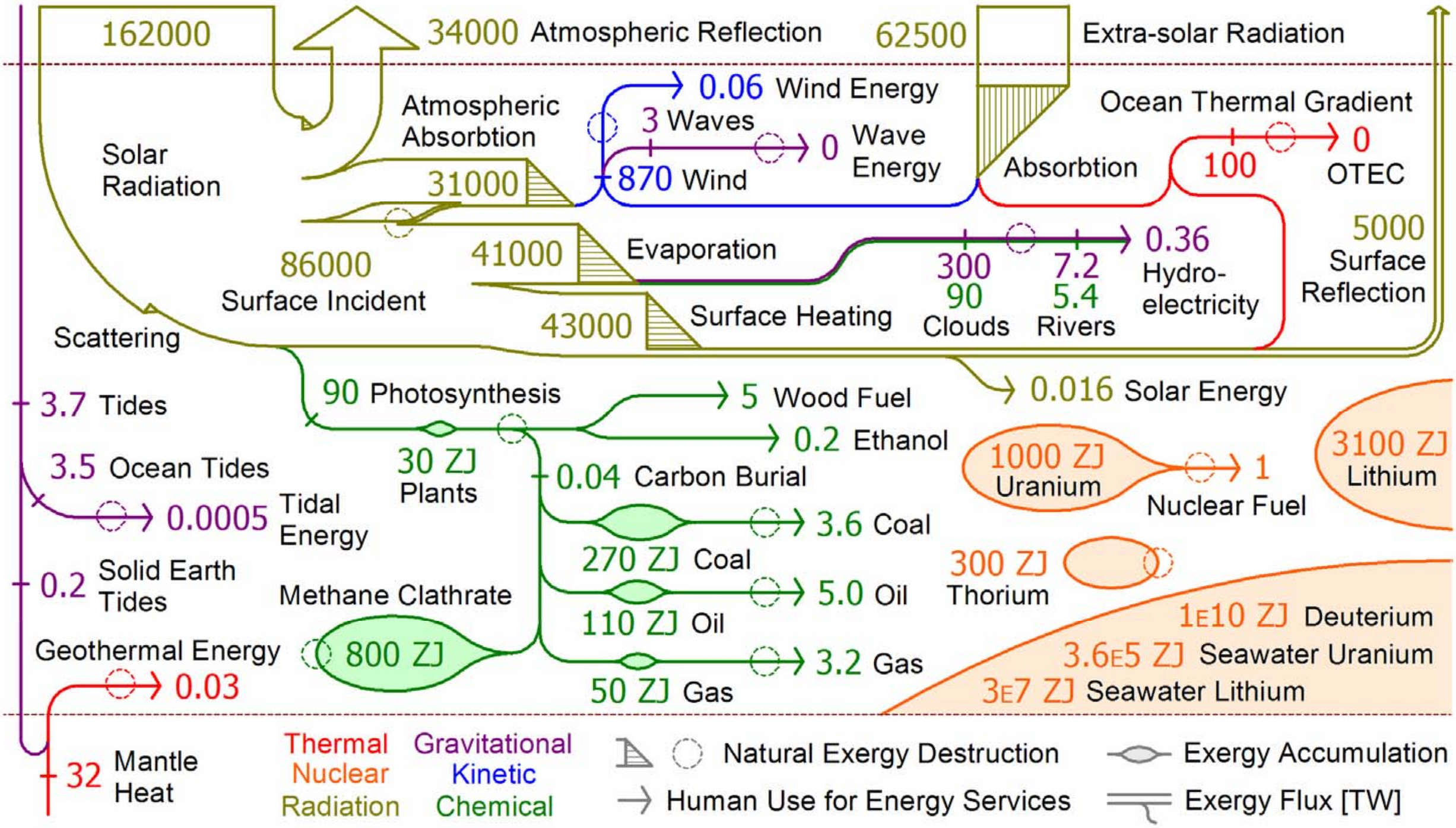
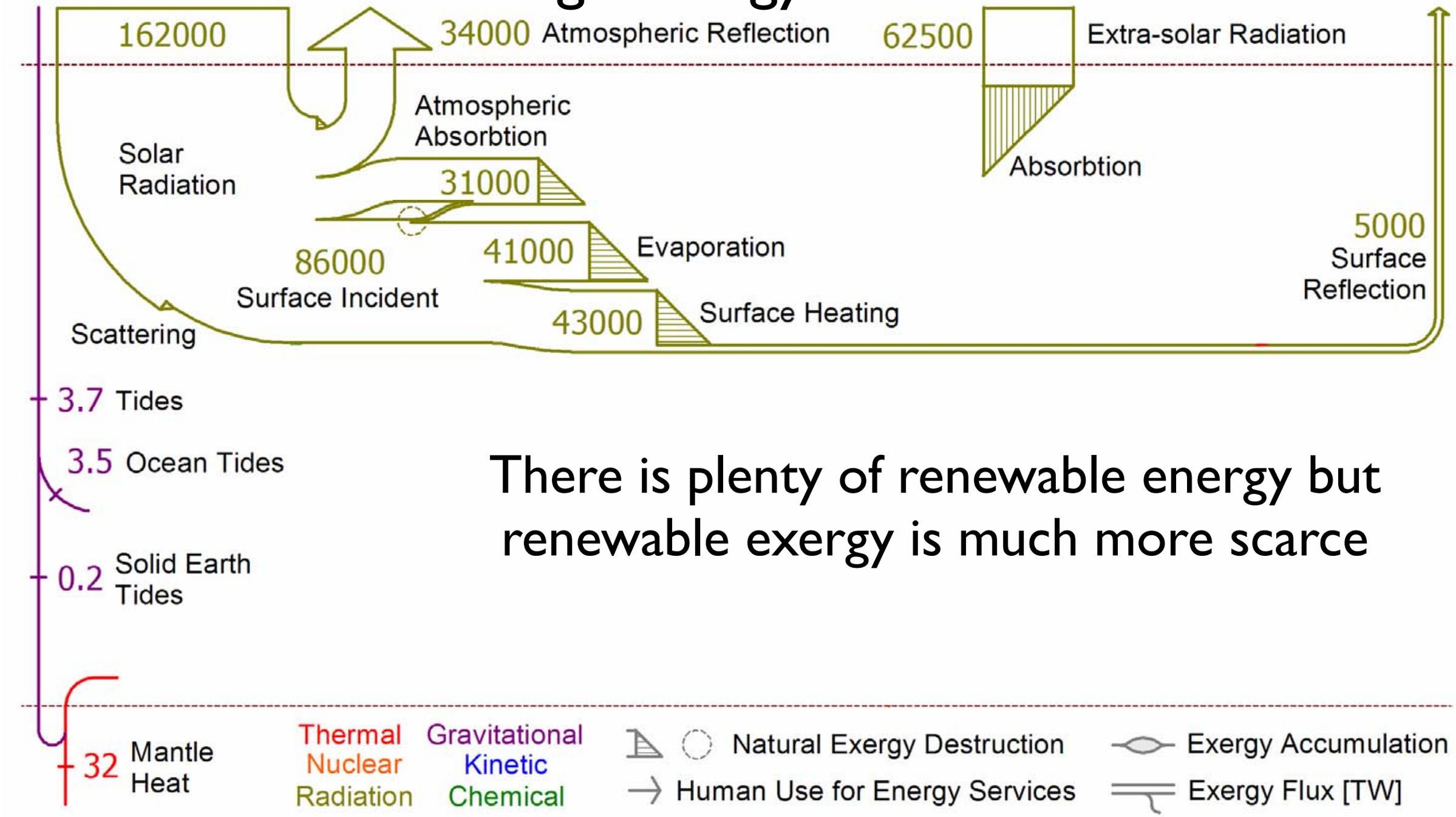
This is true for renewable energy



Source: Hermann (2006)

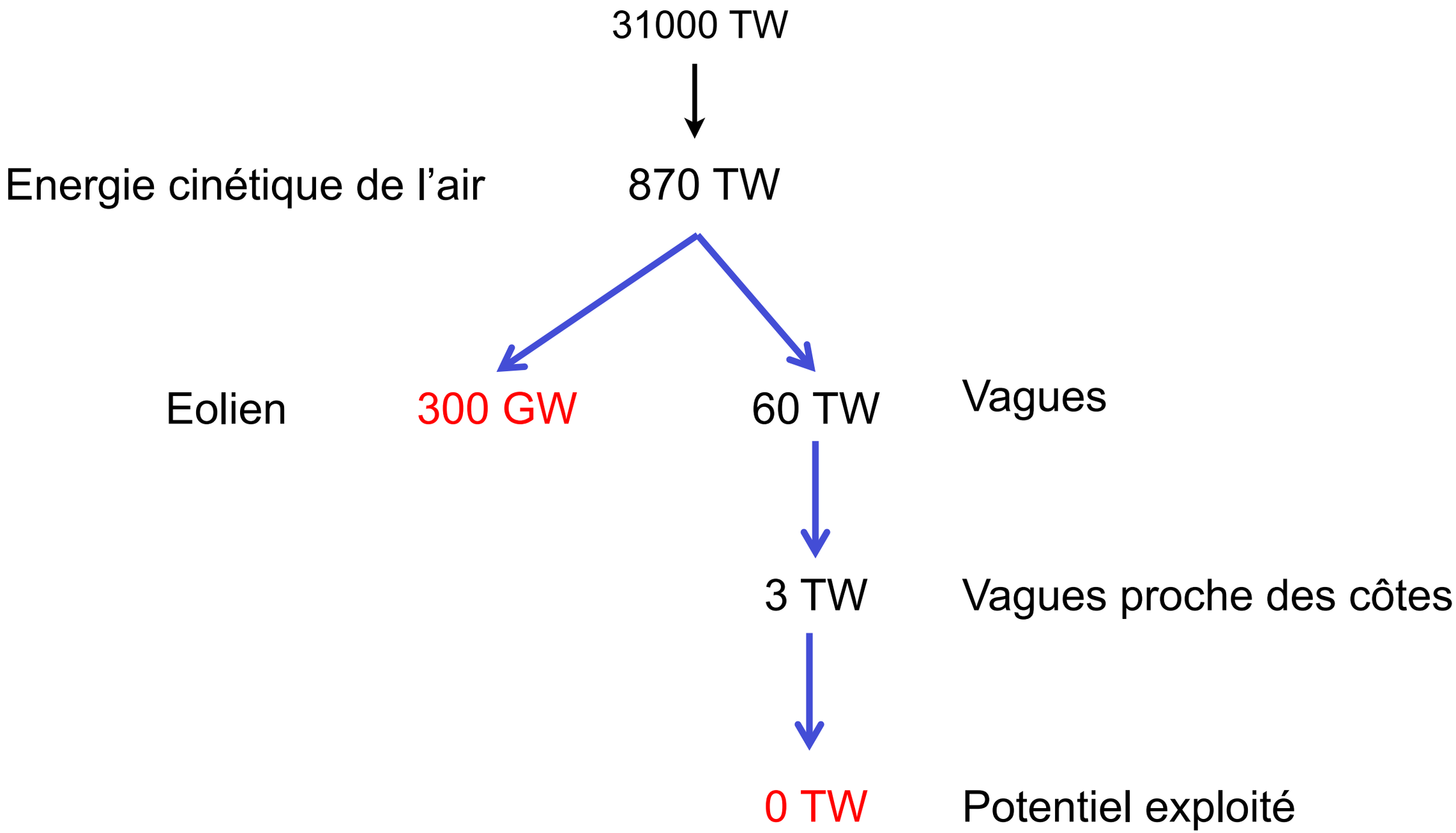
The main source of renewable energy is the sun. Conversions to wind, biomass, etc. suffer from large exergy losses.



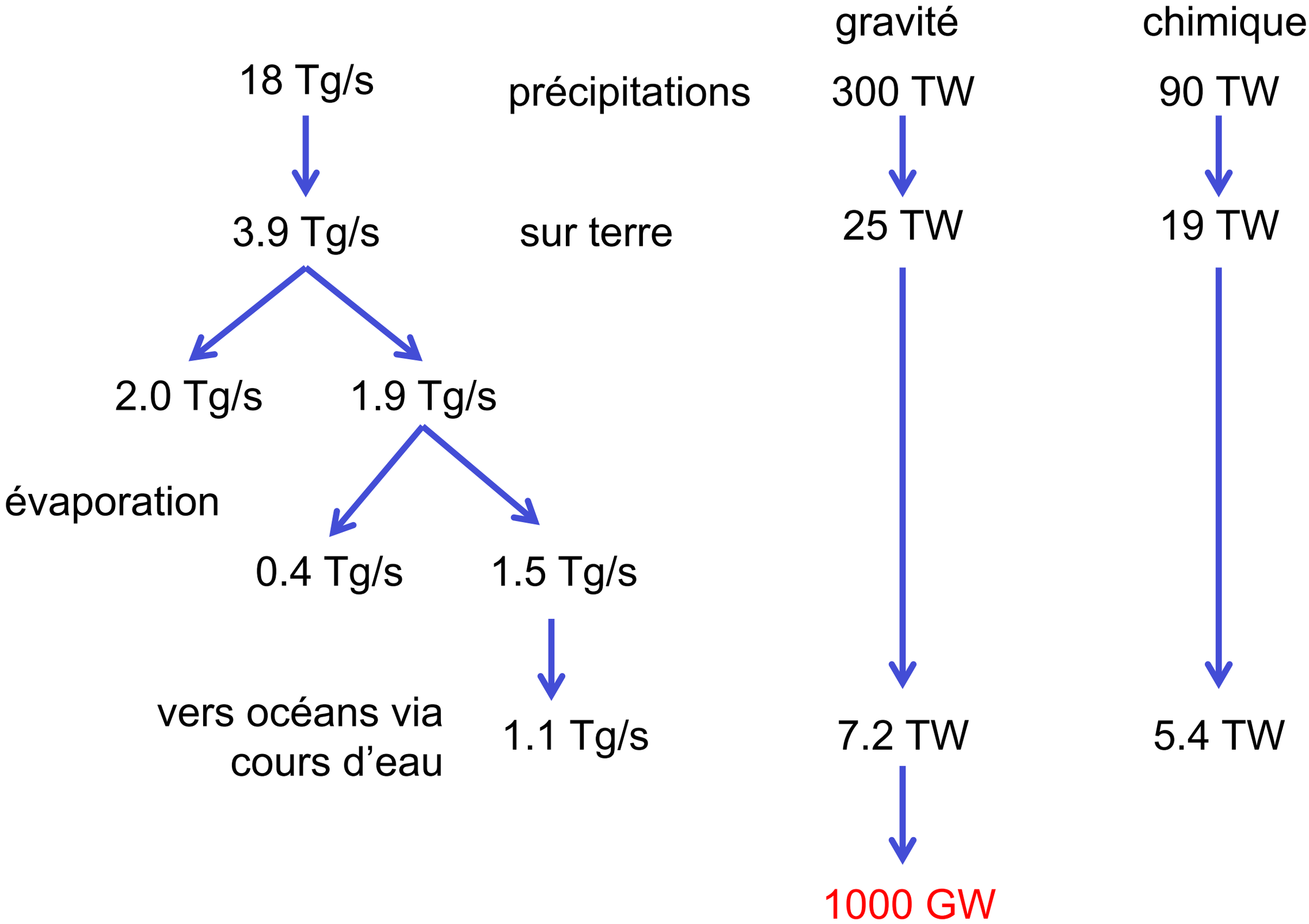
There is plenty of renewable energy but renewable exergy is much more scarce

Source: Hermann (2006)

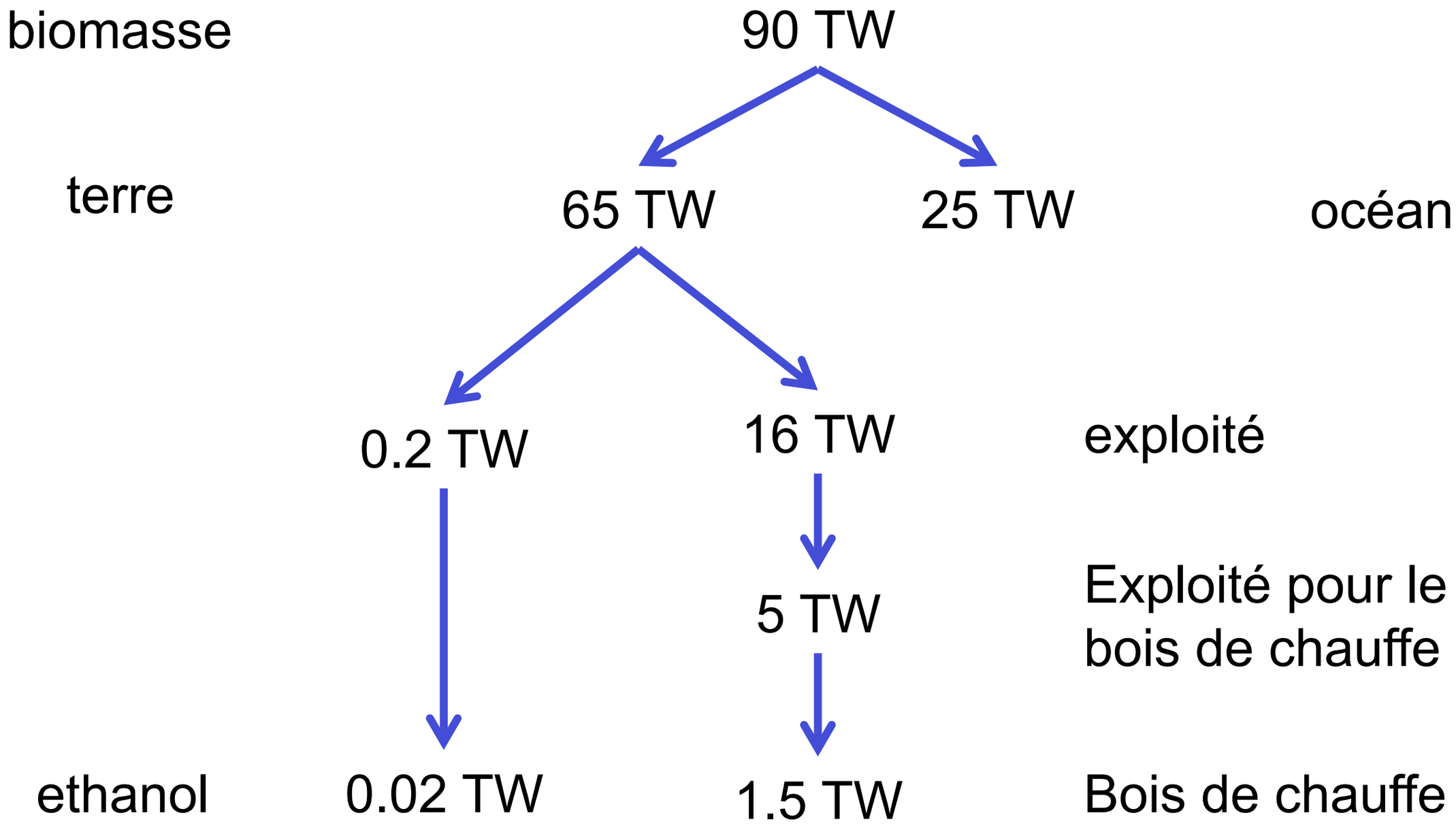
Example of wind energy



Example of hydraulic energy



Example of biomass



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EROEI Energy Return On Energy Invested

To get energy we must invest energy

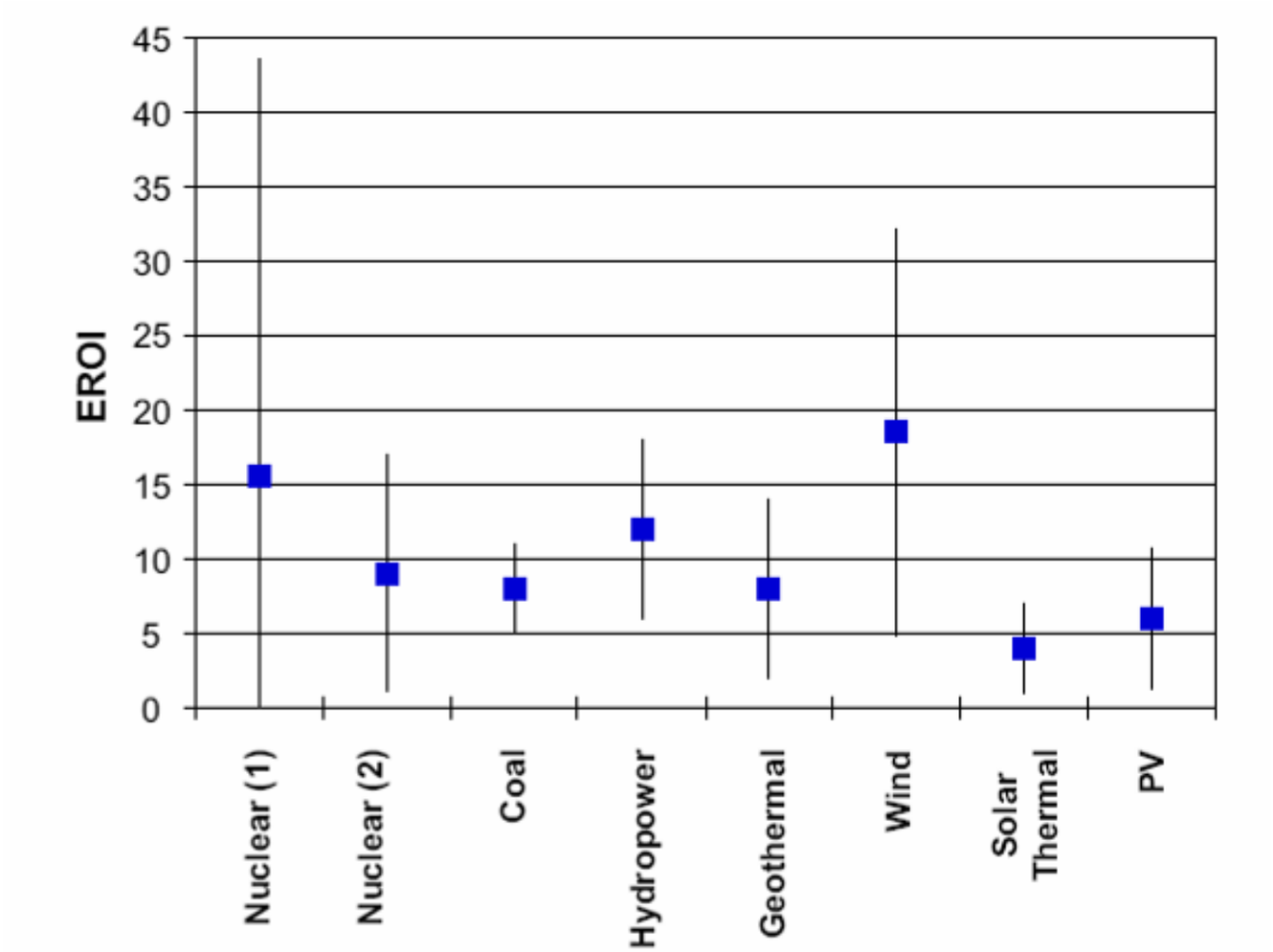
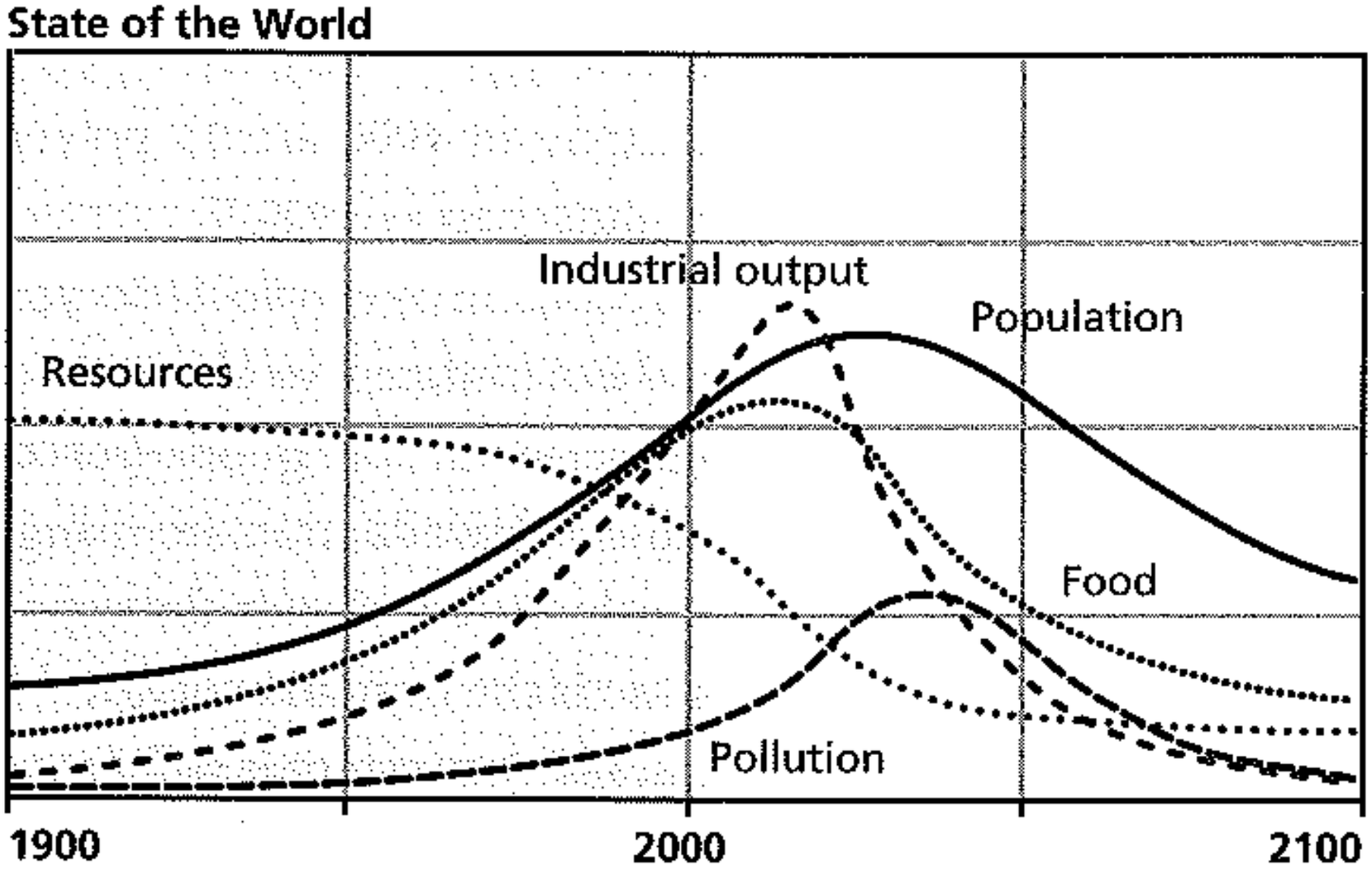


Fig. 6. EROI for power generation systems. Nuclear (1) represents the average and standard deviation for the entire sample of analyses reviewed by Lenzen [14]. Nuclear (2) omits the extreme outliers from Lenzen's survey, and thus represents a better assessment of what the EROI for nuclear is likely to be. See text for description of further sources.

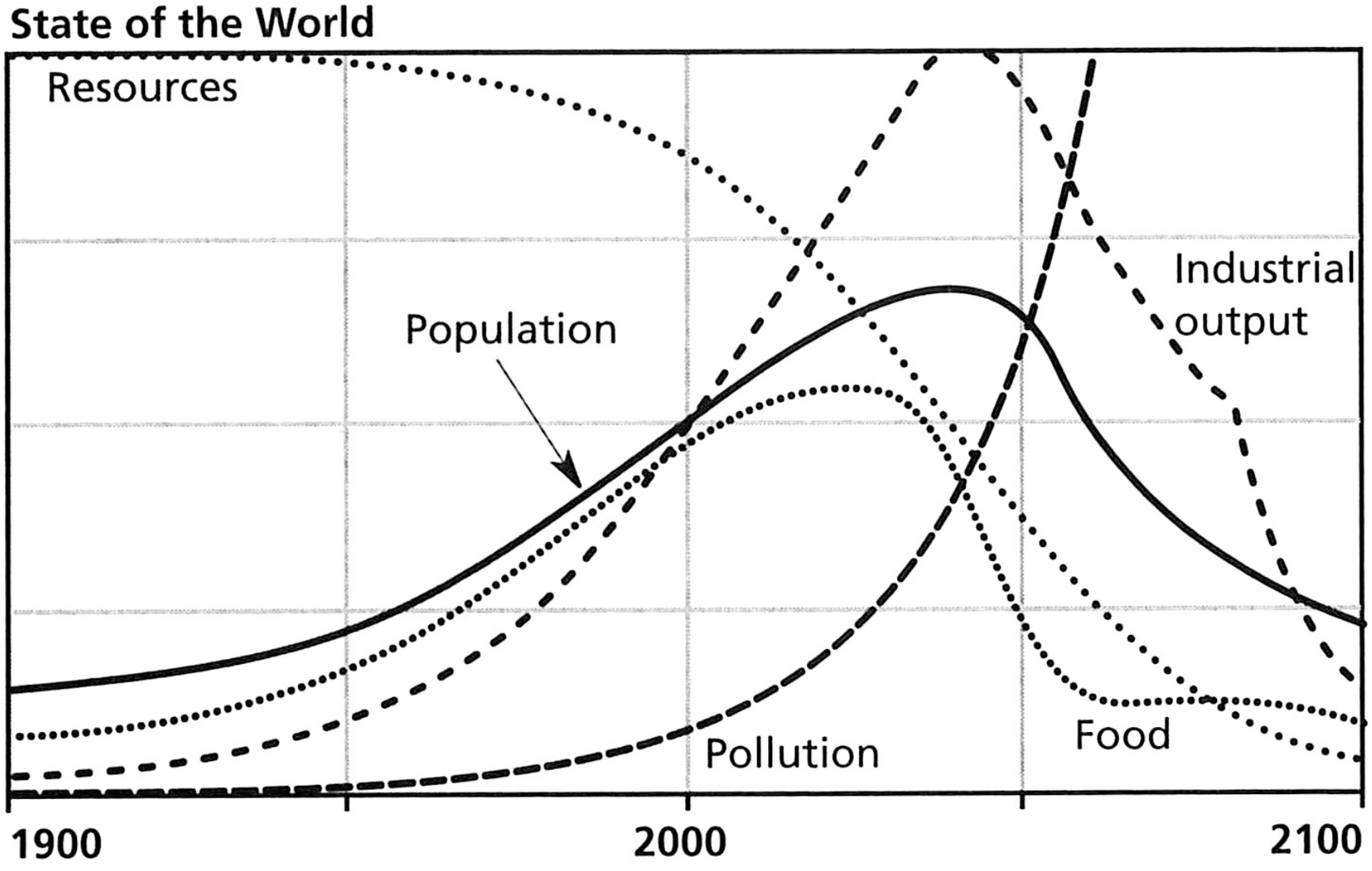
Source: Kubiszewski et al., Ren. En., 2010

In Meadows' work, EROEI is killing us



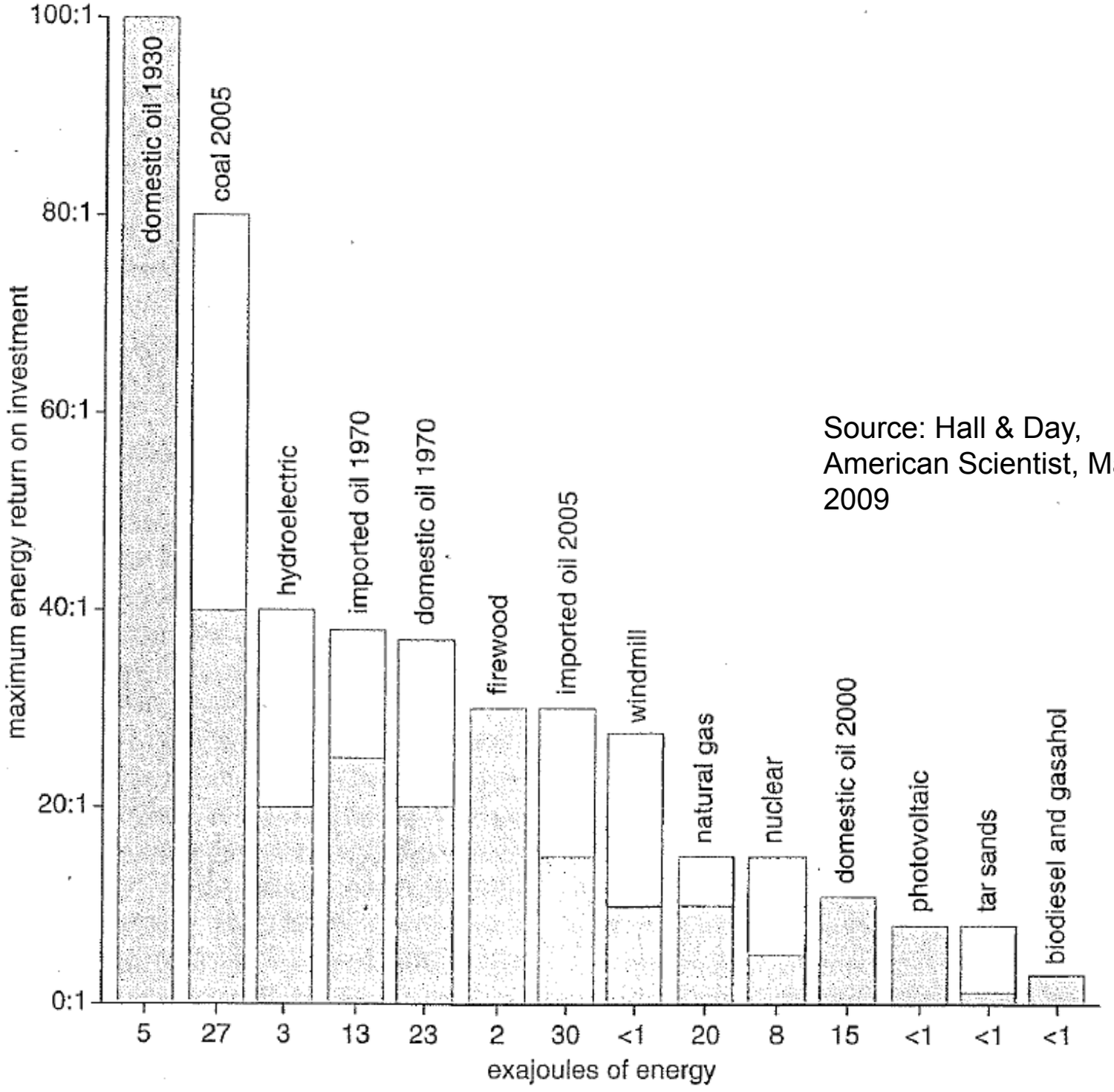
Source: Limits to growth - The 30 year update

By the way, having plenty of cheap resources is not sufficient to save us



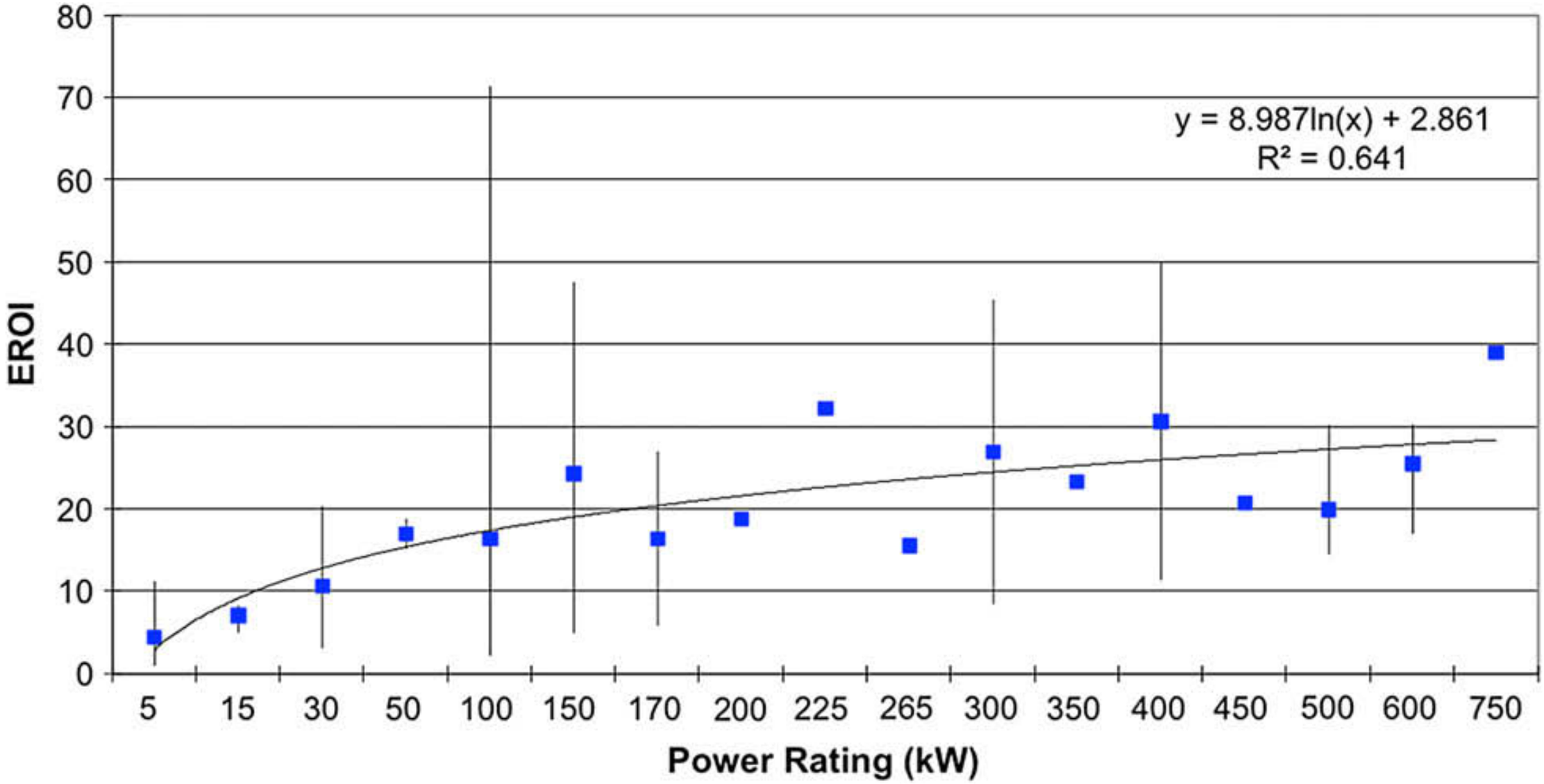
Source: Limits to growth - The 30 year update

Other examples of EROEI



Source: Hall & Day, American Scientist, May 2009

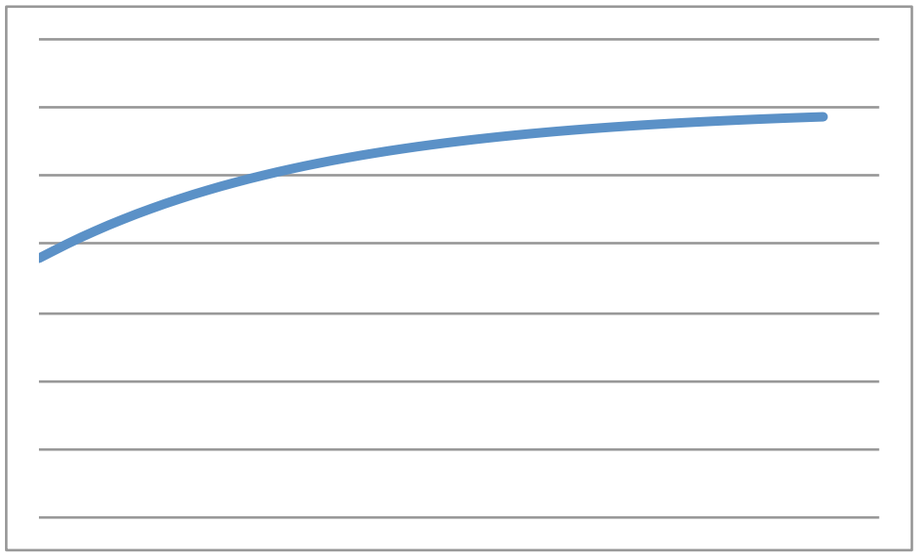
But again size does matter



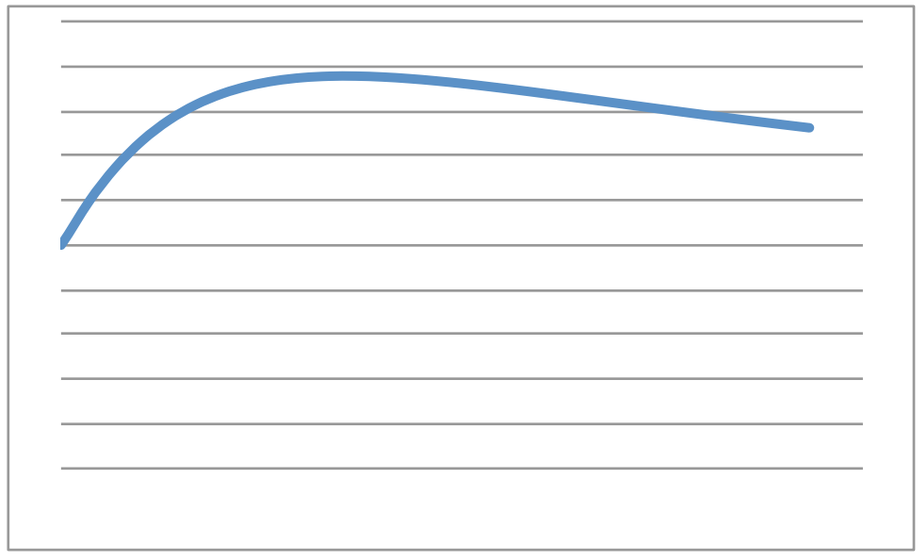
Source: Kubiszewski et al., Ren. En., 2010

EROEI and renewable energy development

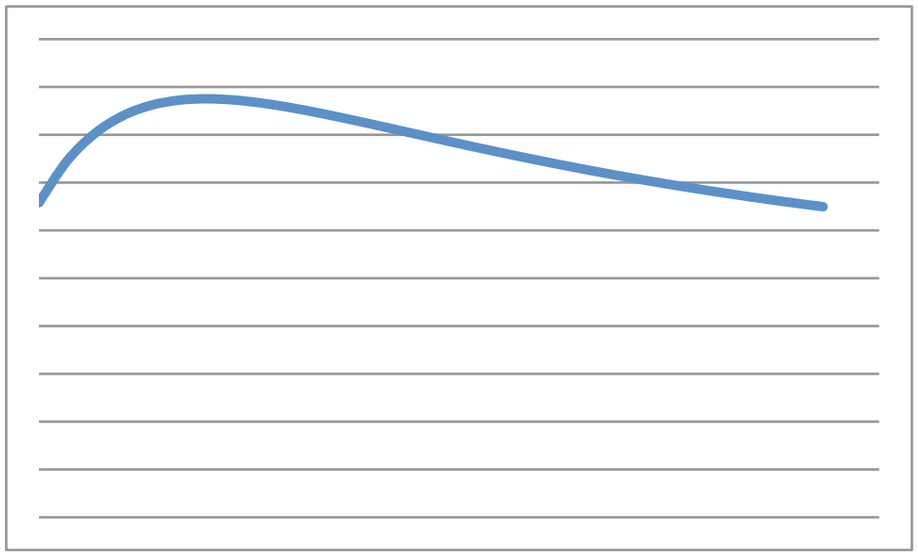
η



RE development



EROEI



RE extension

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Extensive use of renewable energy?

Consommation électrique en Belgique : 82700 GWh (2008)

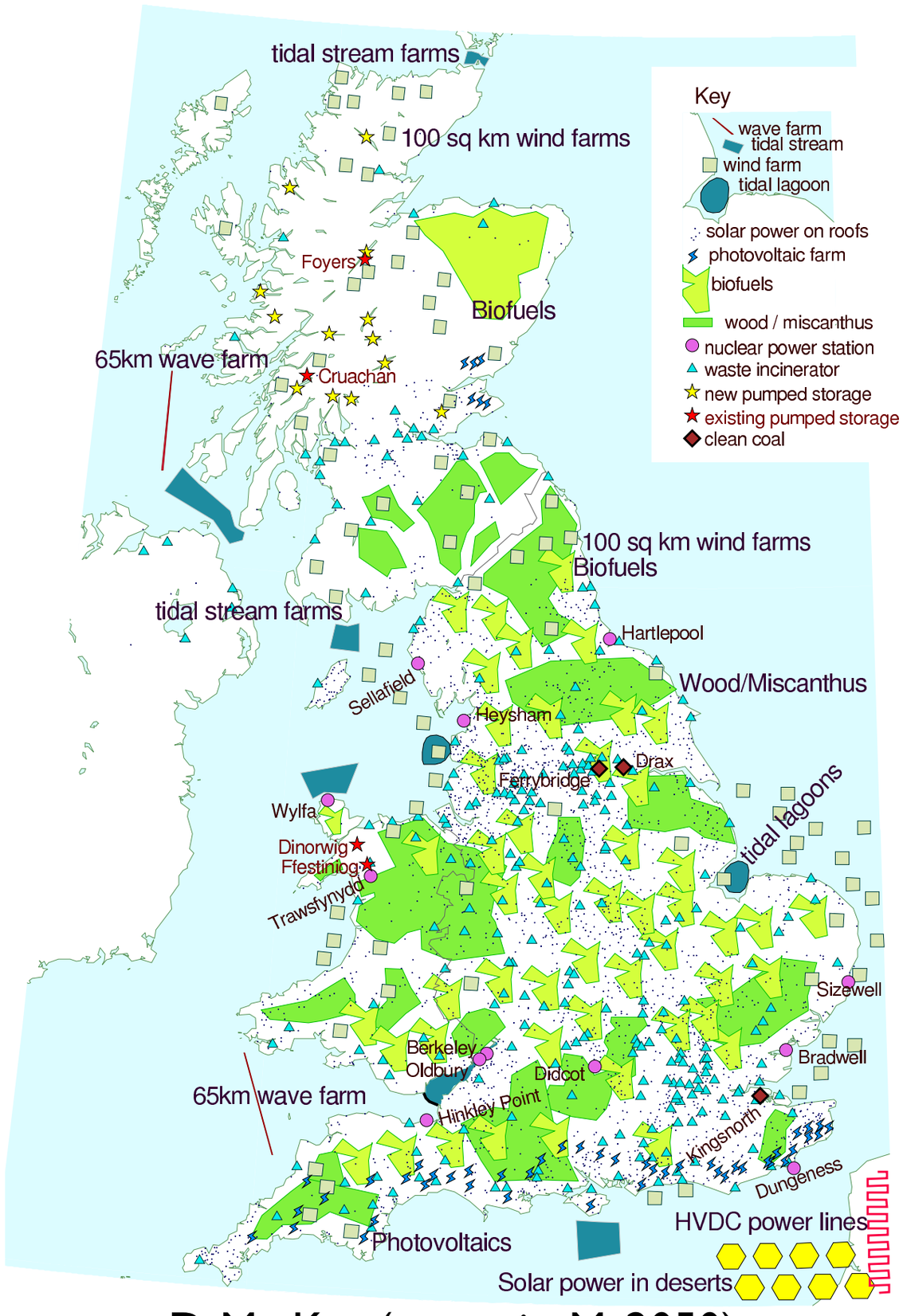
Pour satisfaire cette consommation il faudrait environ 11000 éoliennes de 3 MW (facteur de charge 0.3).
Actuellement, l'équivalent de 300 d'entre-elles est installé.

Pour satisfaire cette consommation il faudrait exploiter plus de 41000 km^2 de biomasse (10t/ha/an, rendement des centrales 0.4).

Pour satisfaire cette consommation il faudrait installer 827 km^2 de panneaux photovoltaïques (100kWh/m^2/an). En 2012, 15 km^2 étaient installés.

et si tout devenait électrique nous devrions construire 8 fois plus de tout

Renewable energy will affect our environment



source: D. Mc Kay (scenario M, 2050)

Alta Wind Energy Center (USA)

500 éoliennes

1320 MW

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L'économie néoclassique a besoin de progrès technique pour assurer la croissance

$$Y = AL^{1-\alpha}K^{\alpha}$$

Y=Production

L=Travail

K=Capital

Productivité multifactorielle

=

Progrès technique

Pourquoi a-t-on besoin de croissance?

L'économie écologique a besoin d'énergie et de progrès technique pour assurer la croissance

E=Energie

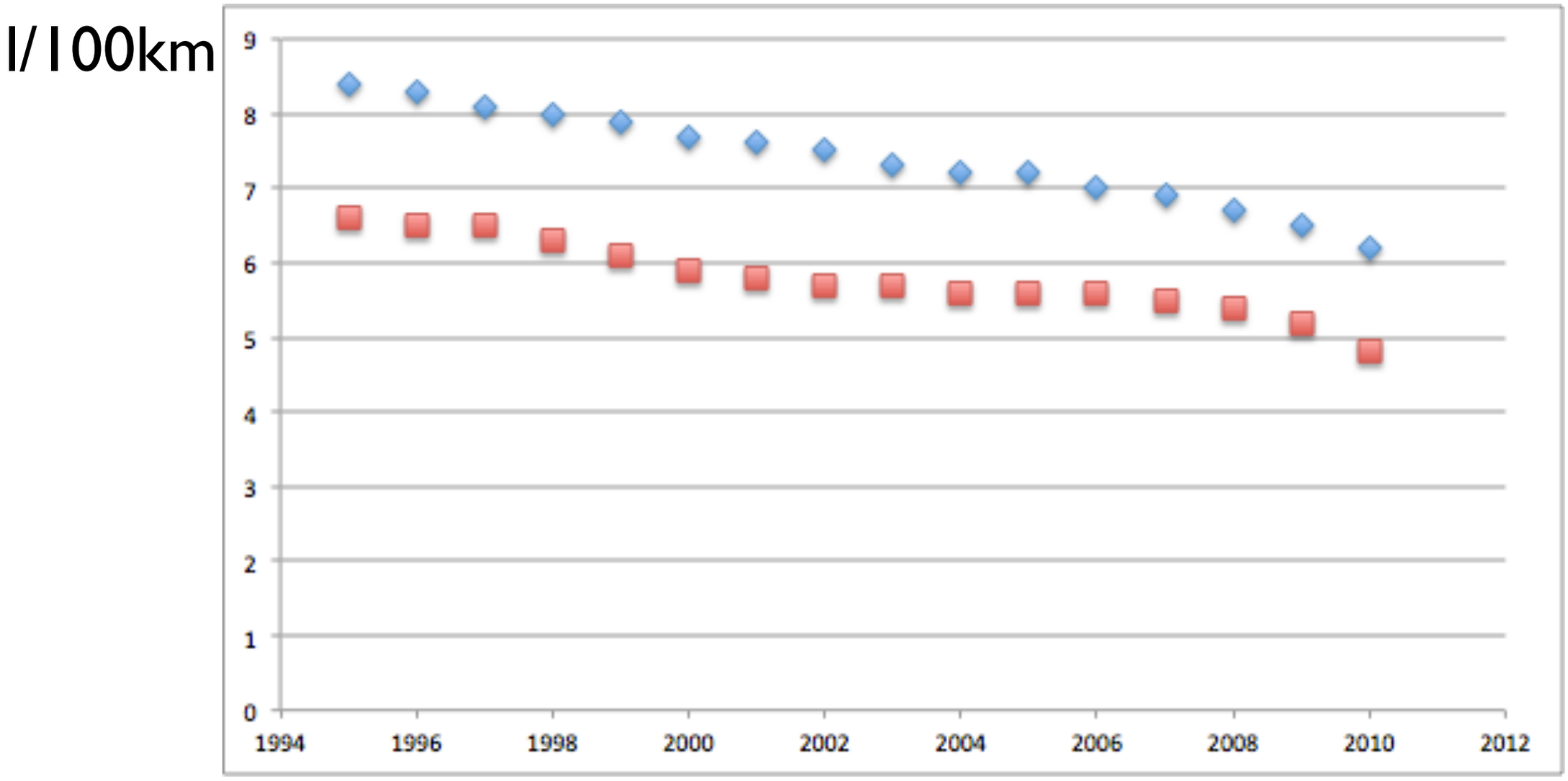
$$Y = \left((1-\gamma) \left(A_L L^{\alpha} K^{1-\alpha} \right)^{\phi} + \gamma \left(A_E E \right)^{\phi} \right)^{1/\phi}$$

Stern 2011

Productivité multifactorielle
=
Progrès technique

meilleure technologie et meilleure qualité de l'énergie

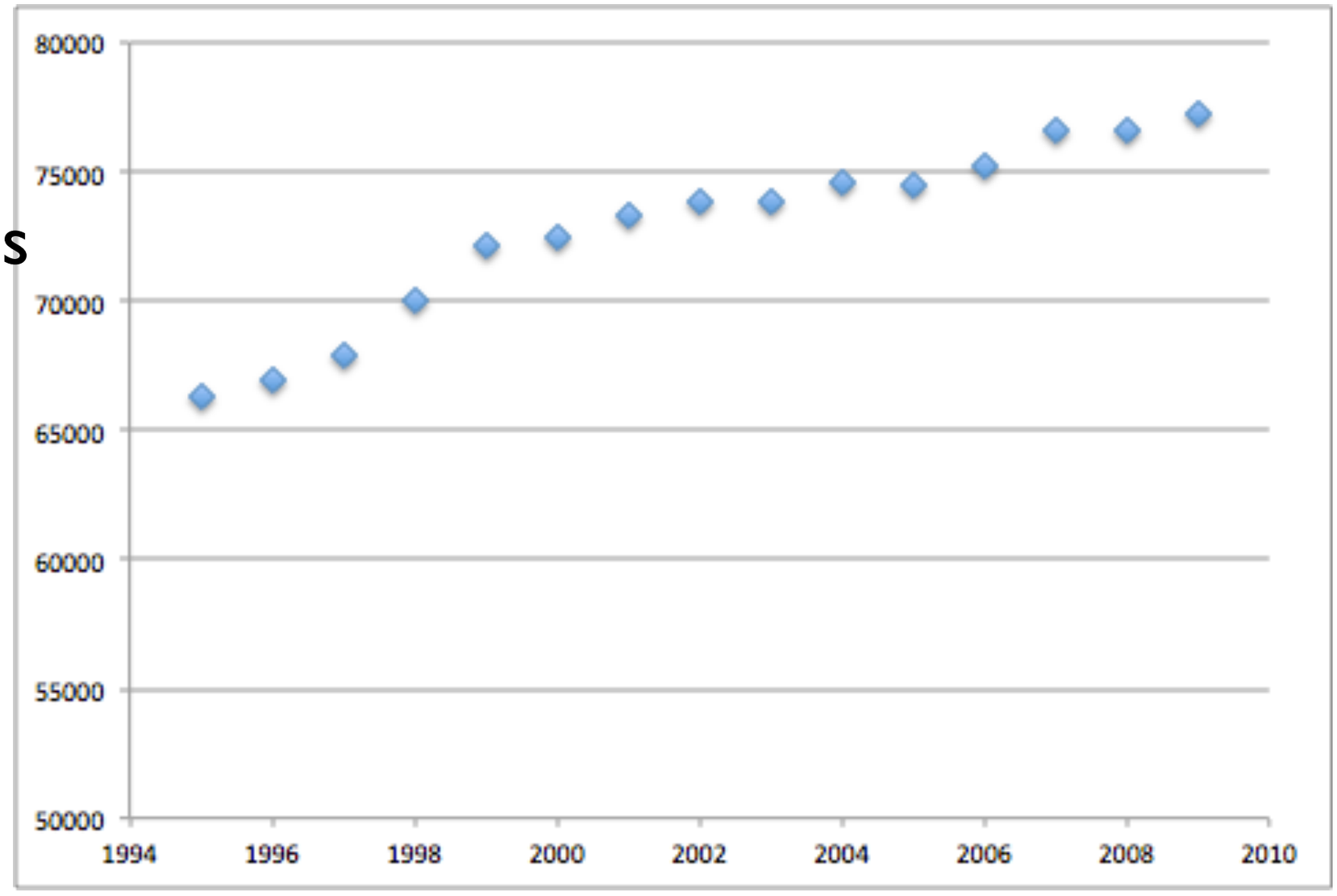
Exemple 4 : Les améliorations restent possibles (cas des automobiles)



source: Bureau fédéral du plan

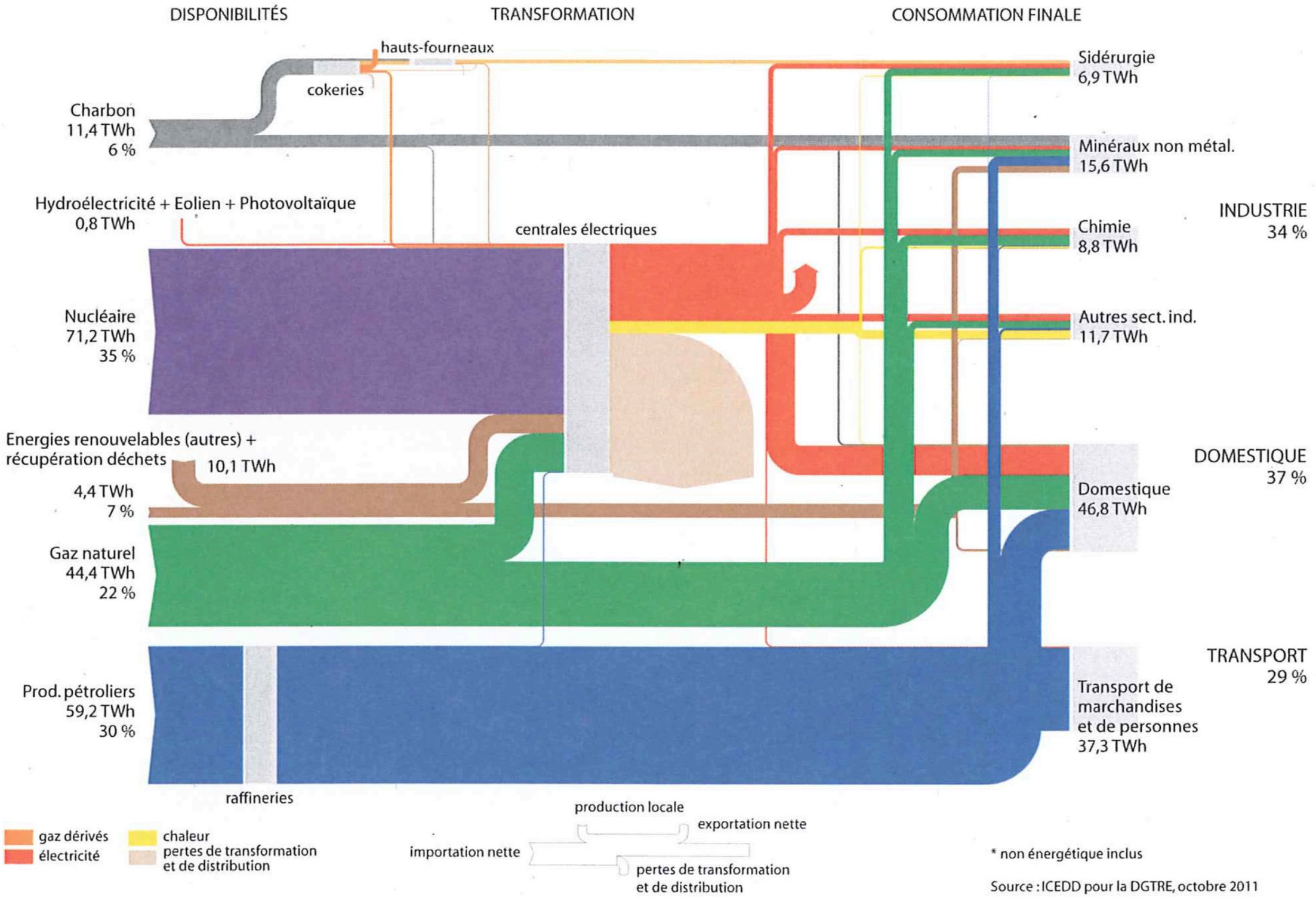
Exemple 4 : Mais les km parcourus augmentent. C'est l'effet rebond !

millions de km parcourus



source: Bureau fédéral du plan

FLUX ÉNERGÉTIQUE - WALLONIE 2009



Source: ICEDD