

# Energy, entropy, exergy

## Energy sustainability indicators?

### Exergy efficiency

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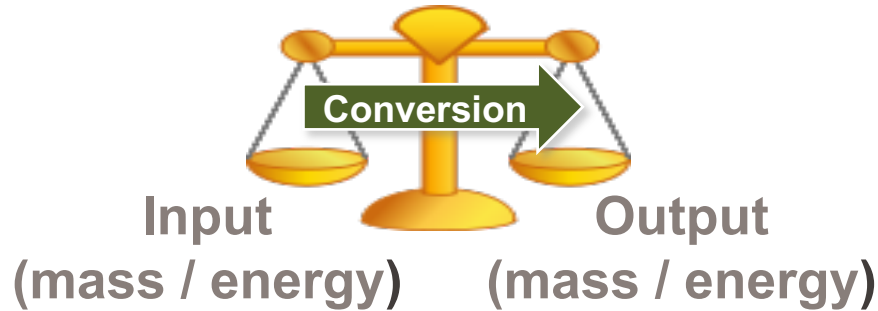
**"Die Energie der Welt ist konstant und die Entropie der Welt strebt einem maximum zu "**

"The energy of the world is constant and the entropy of the World tends towards a maximum"



Rudolf Emmanuel Clausius  
(1822-1888)

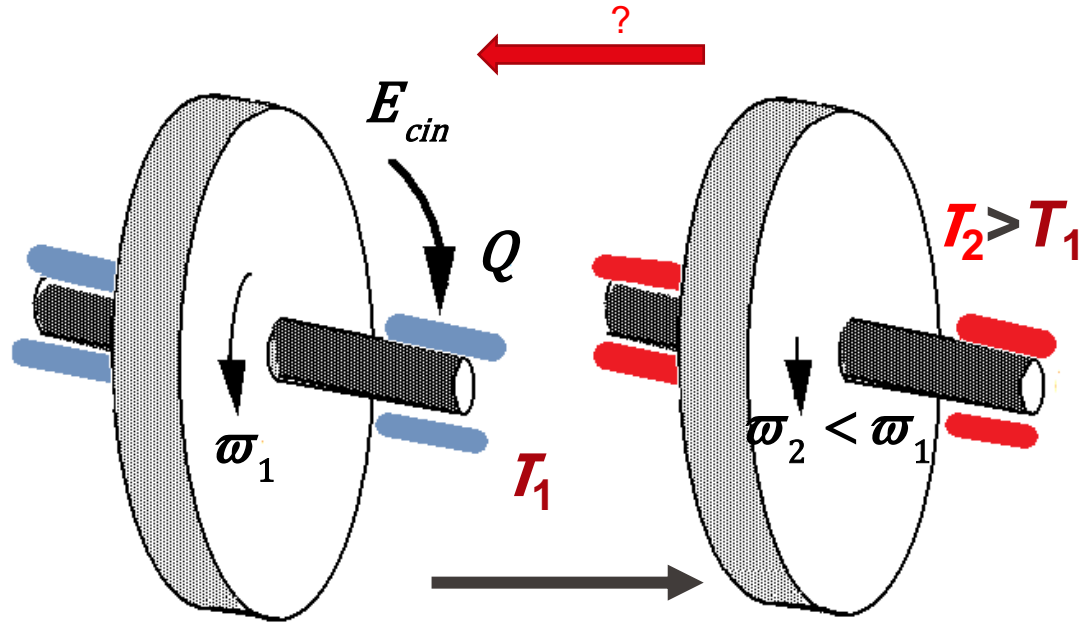
In other words:  
Energy can only be converted from one form into another  
Like the mass it is conserved  
While the entropy is increasing



- There is a confusion about the meaning of «energy»: Greek word "*ενεργεια*" (containing work)

In fact the work part of energy is **exergy**

## The arrow of time



The wheel slows down and stop

There is no way that it will reaccelerate without an input of work (exergy)

There is a degradation of mechanical energy into heat with creation of entropy

# We are all marvelous trigeneration energy systems

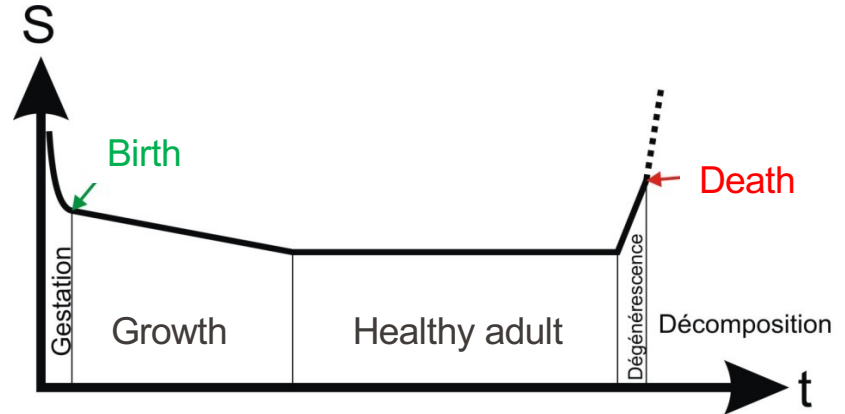
But we are not perfect !!

We generate entropy  
(disorder)



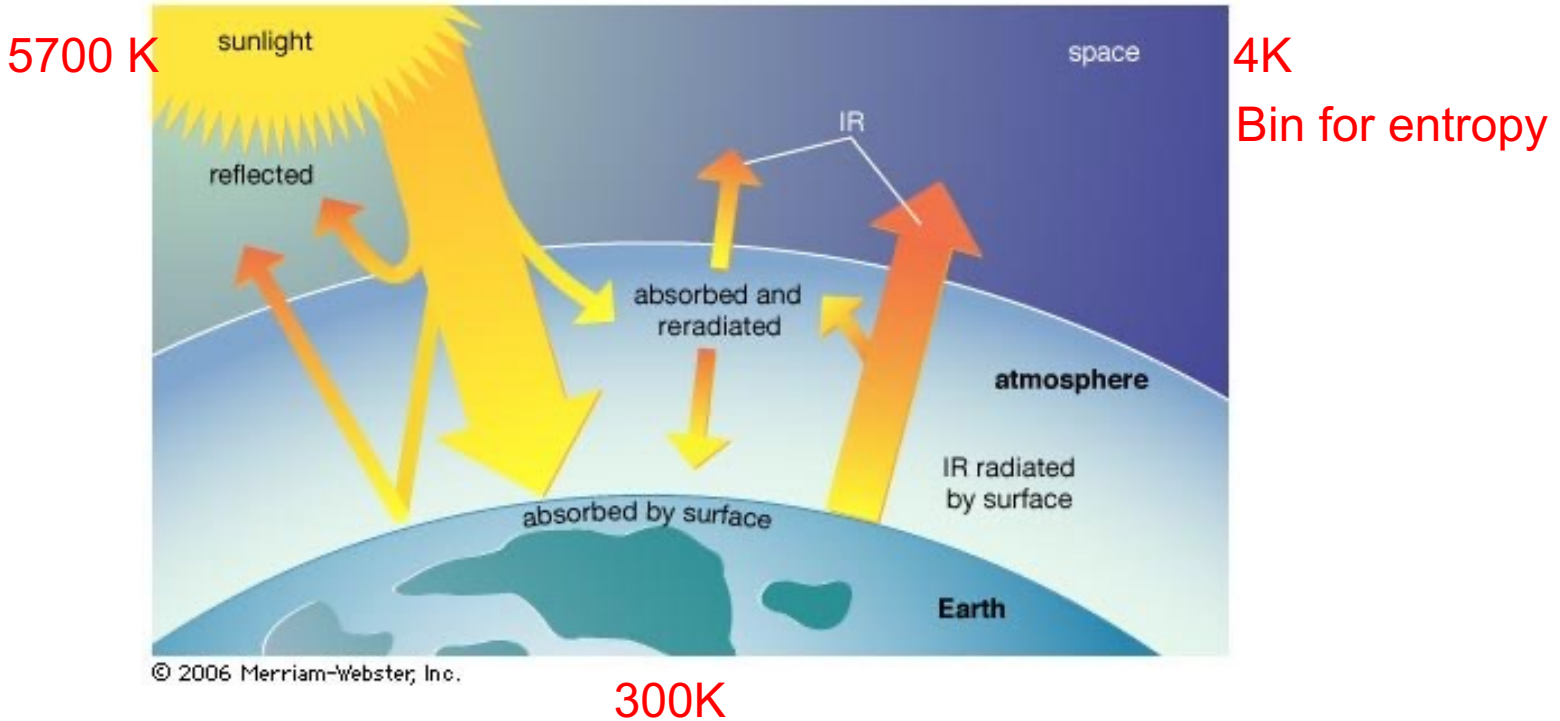
*Did your entropy increase last year?*

*Was there anytime in your life  
that your entropy decreased ?*



To keep our entropy constant, we all need a bin for entropy

# This also true for the Earth



Problem: with our emissions of GHG we partially block reradiation to space

# Exergy

$$\text{Energy} = \text{Exergy} + \text{Anergy}$$

Part  
corresponding  
to the  
maximum  
work possible

Part unable to  
do work

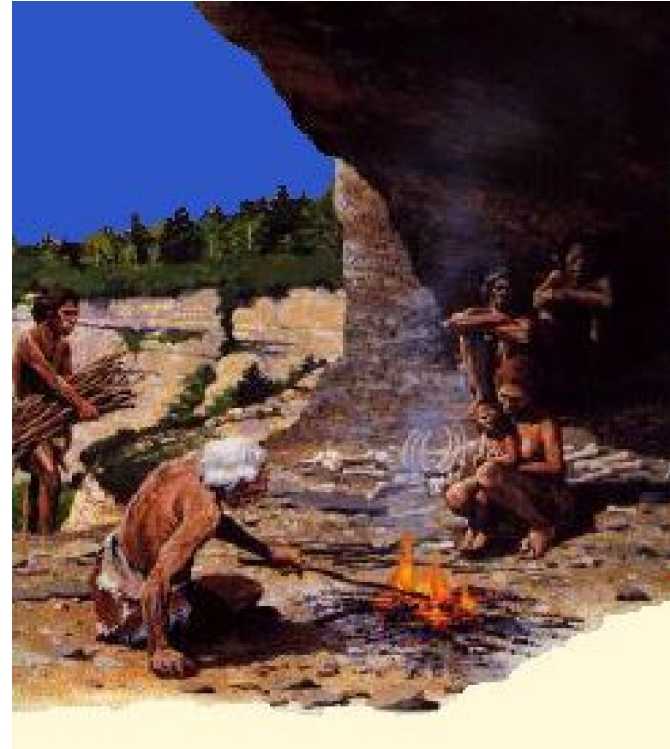
$$\text{Exergy efficiency} = \frac{\text{Exergy provided by the system}}{\text{Exergy given to the system}}$$

# Ex: Combustion and heating

- Simple combustion for heating since around 400'000 years
- Still today the majority of heating systems (boilers)
- Boilers = Energy efficiency close to 100% ! (sometimes >100%!!)
- Is it really a 21st century technology ?

Of course not!

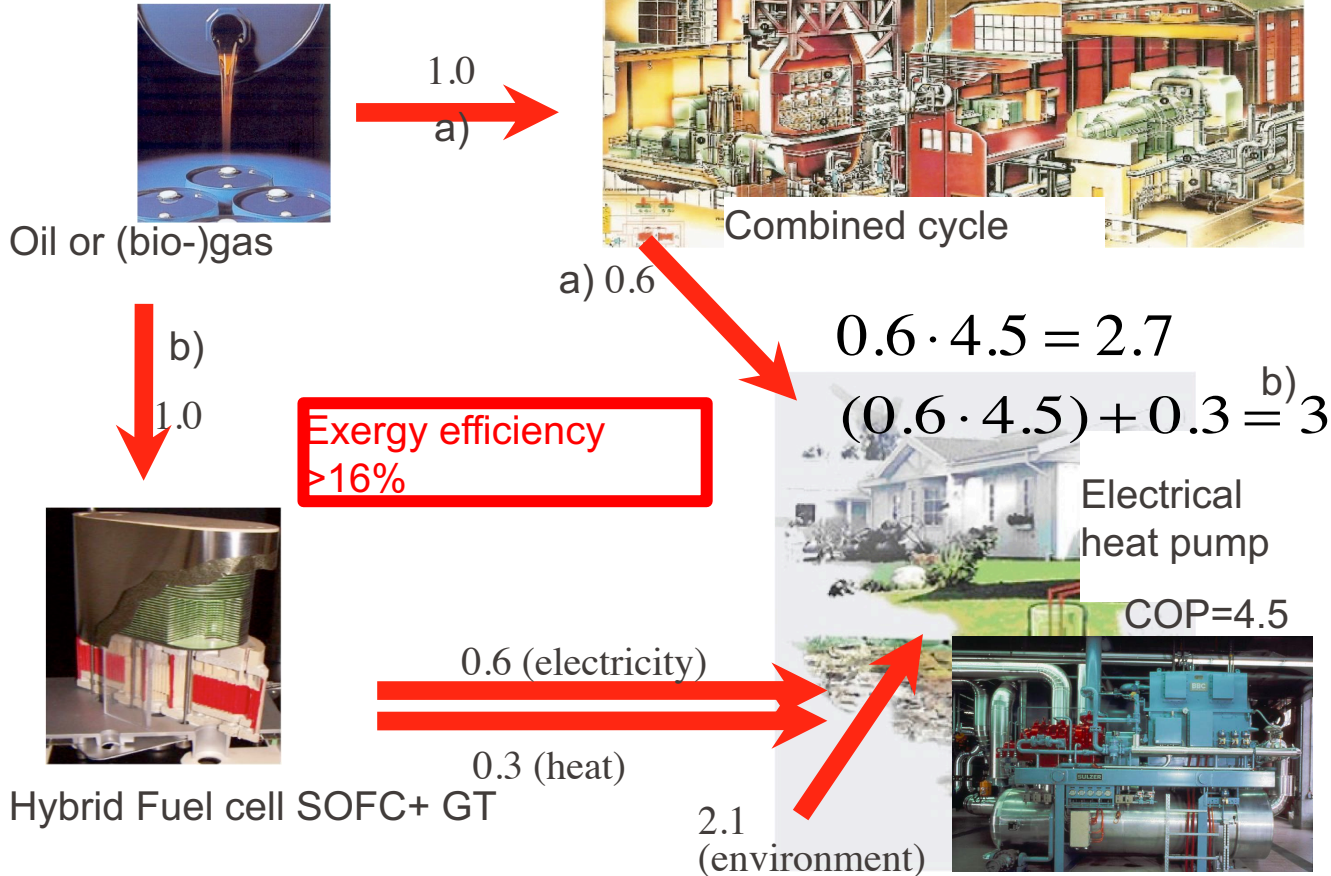
Boiler **exergy** efficiency is only 6%



FAVRAT D., MARECHAL F., EPELLO O. *The challenge of introducing an exergy indicator in a local law on energy.* Energy,33, No2, pp130-136 (2008)

SET2014 Favrat <http://energycenter.epfl.ch>

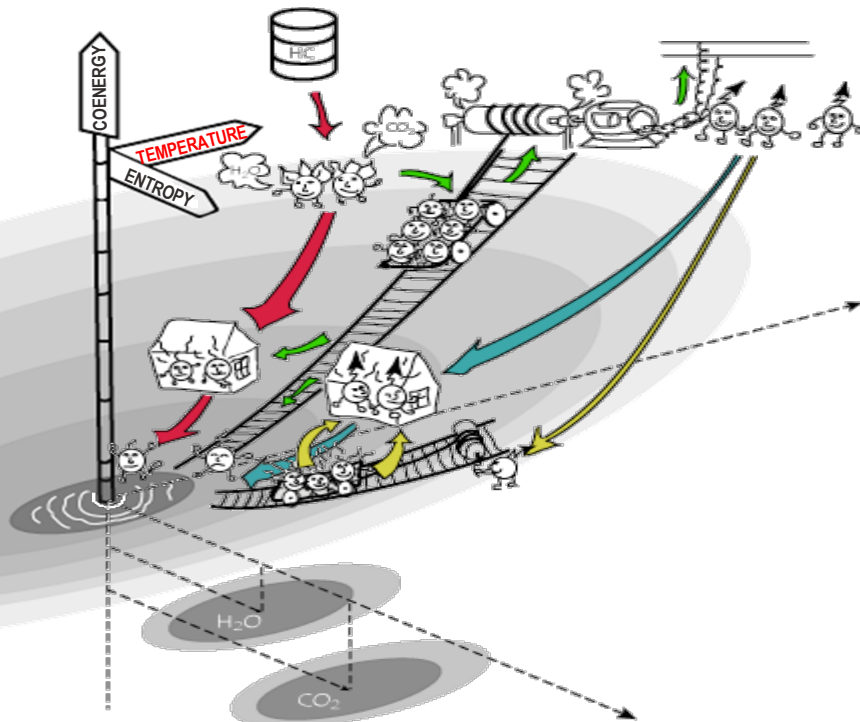
# Alternative for heating with the same fuel





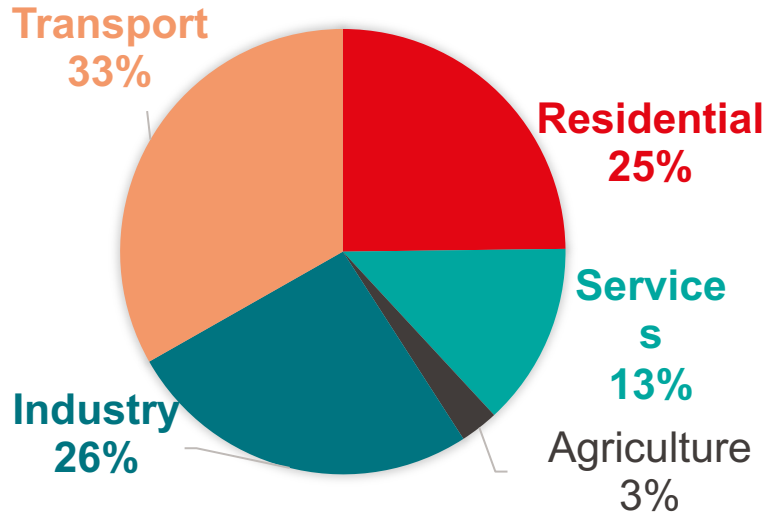
# Exergy efficiency, a better indicator than 1<sup>st</sup> Law efficiency

- Indicates the true quality of energy conversion technologies (Carnot engine: 100% exergy efficiency)
- Always  $\leq 100\%$
- Coherent ranking of most technologies
- To be complemented by renewable/non-renewable ratio



# Exergy efficiency is key: Example of EU

- Focus on major sectors:
- 38% for residential and services (mainly for building heating)
  - 33% for transport (of which only <1% using electricity)



**Major potential of efficiency gains in these 2 major sectors by :**

- Heat pumps and cogeneration (with District Heating & Cooling in cities, more compact, see [exergo.ch](http://exergo.ch))
- Electric vehicles (incl. drones and autonomous)

**But:**

- Requires efficient and low carbon energy conversion to electricity
- + efficient recycling

# Sustainability assessment

- **Exergy efficiency is a much better tool to evaluate and rank technology options**
- **It really allows to assess what is the remaining potential for a more efficient and sustainable society**
- **Ideally it should include the embedded exergy to implement energy technologies**
- **An additional important indicator is the ratio between fossil and renewable energy supply of any project**

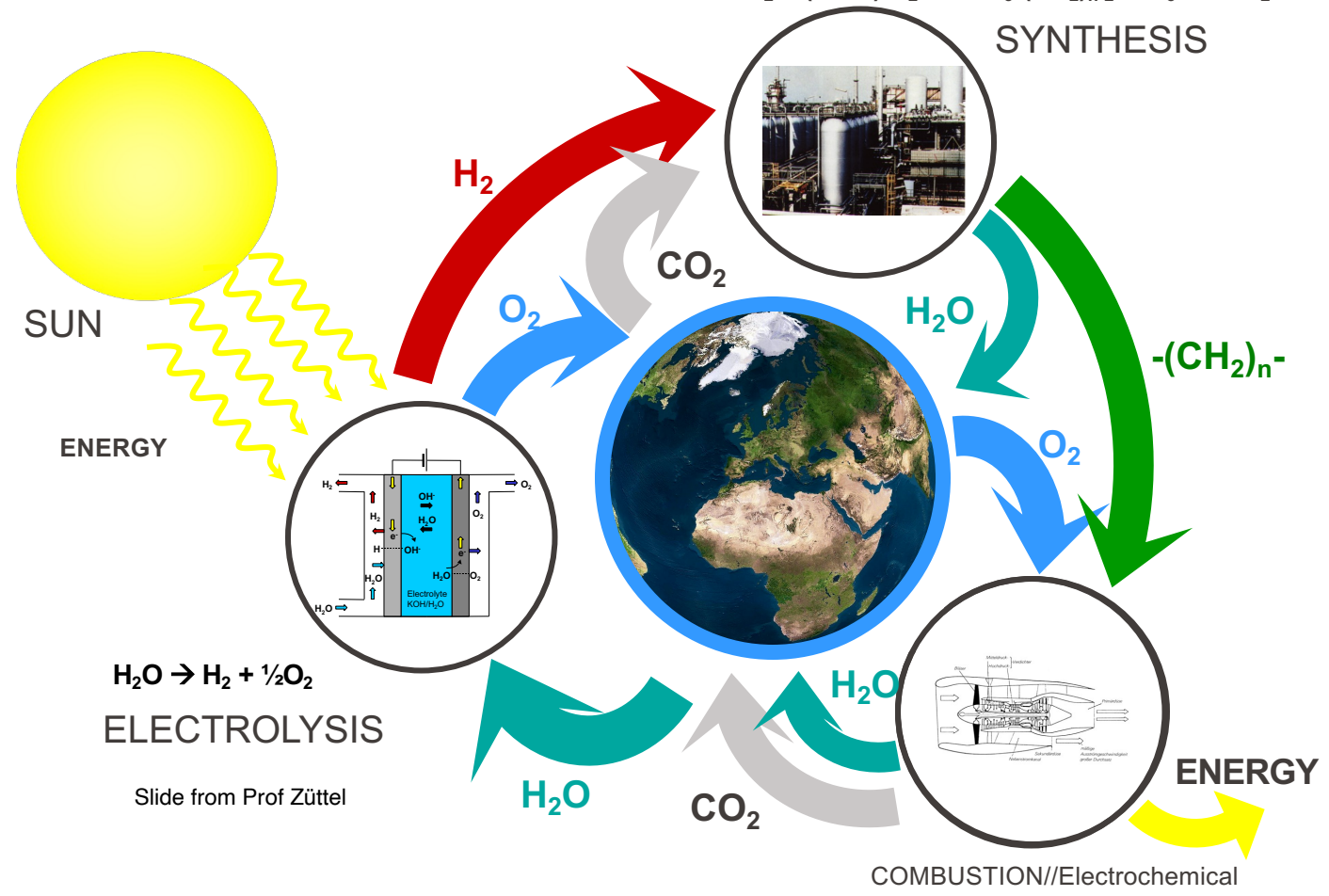
# Innovation towards sustainability

- From a non sustainable abundance to:
  - An energy and materials moderated approach (eco efficient energy and materials use, increased use of renewable, proper waste management including for CO<sub>2</sub> and nuclear wastes)
- Need for innovation
  - with advanced indicators (both technical and economical)
  - Novel design and planning methods (holistic, LCA, using GIS in cities, etc.)
  - Integrated systems with advanced technologies, in particular for (syn-)fuels with fuel cells



**Thanks for your attention**

# Seasonal storage: SYNTHETIC HYDROCARBONS



$\text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2}\text{O}_2$   
ELECTROLYSIS

Slide from Prof Züttel

SYNTHESIS

COMBUSTION//Electrochemical