Energy services, exergy concept and Swiss-Energyscope.ch

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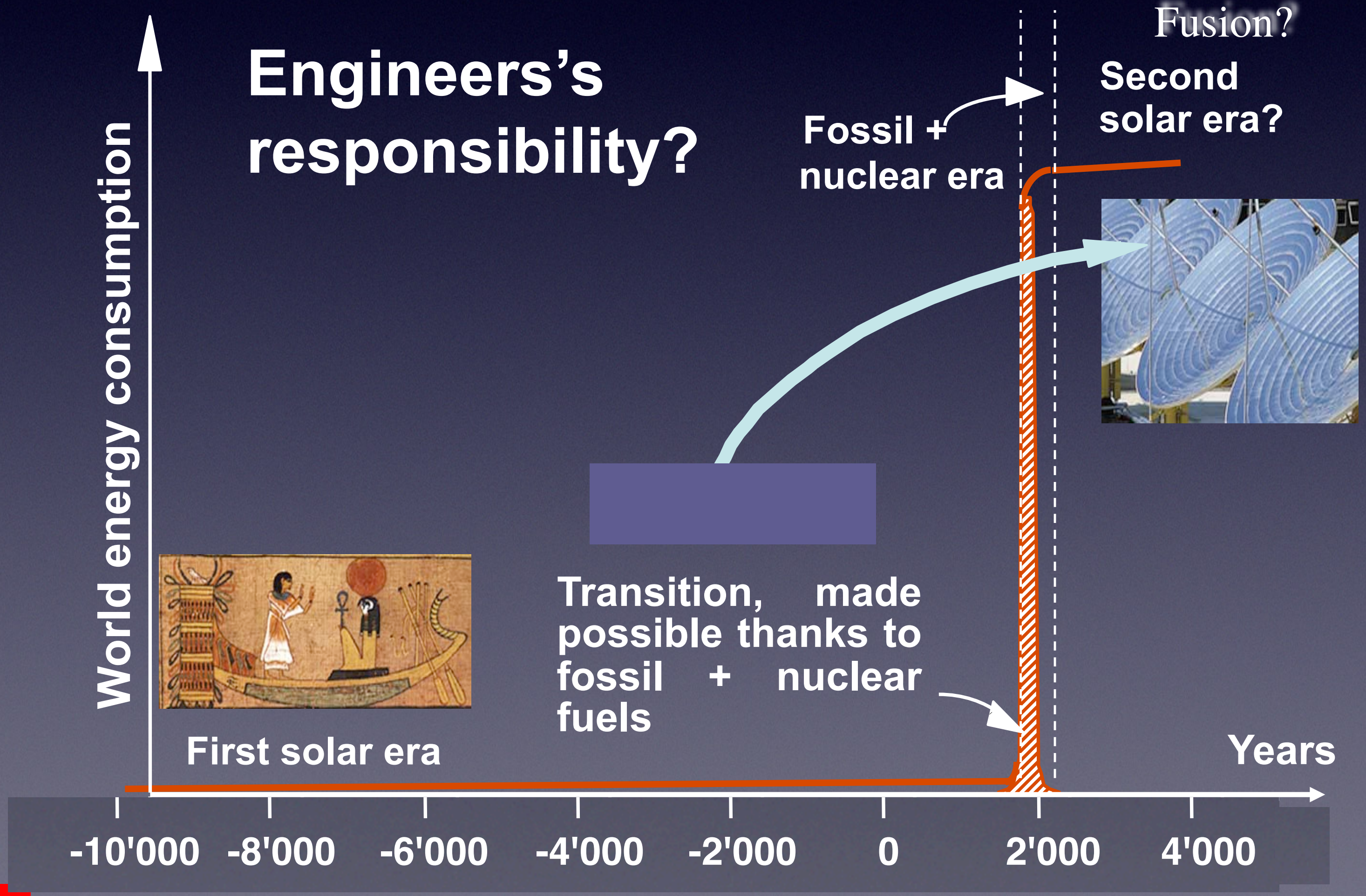
A transition era

- We live just a few centuries of unsustainable degradation (of stored resources) and ....innovation is crucial both to tend towards sustainability



From: Haldi P.A.

Innovation towards less degradation

- Physics: conservation of mass and energy
- The confusion about the term energy:
  - **from the Greek word ενεργεια, « containing work»**
- But: driving forces result from unbalances (of exergy levels, of concentration in materials and fluids,....)
- Nature is a story of degradation: By degrading high “exergy” value from the Sun, Earth is able to generate vegetation and ultimately fuels and food for animals and humans
- Degradation is part of life..... But

Degradation is part of life ...But

- would be sustainable if the tremendous potential of the Sun-Earth-Space unbalance would be used properly to:
  - satisfy energy services
  - recycle materials and wastes
  - clean or dessalinate water , ...

Concept of 2000 W society

- target of a 2000 Watt year/(year cap) proposed by the Council of the Swiss Federal Inst. of Technology end of the nineteenth
- corresponded to the World average at the time
- to be ideally realised by 2050
- 1/3 non renewable and 2/3 renewable
- also: 1 tonne CO_2/(year cap)
- controversial definition but good marketing approach for energy efficiency

http://www.novatlantis.ch/fileadmin/downloads/2000watt/Weissbuch.pdf

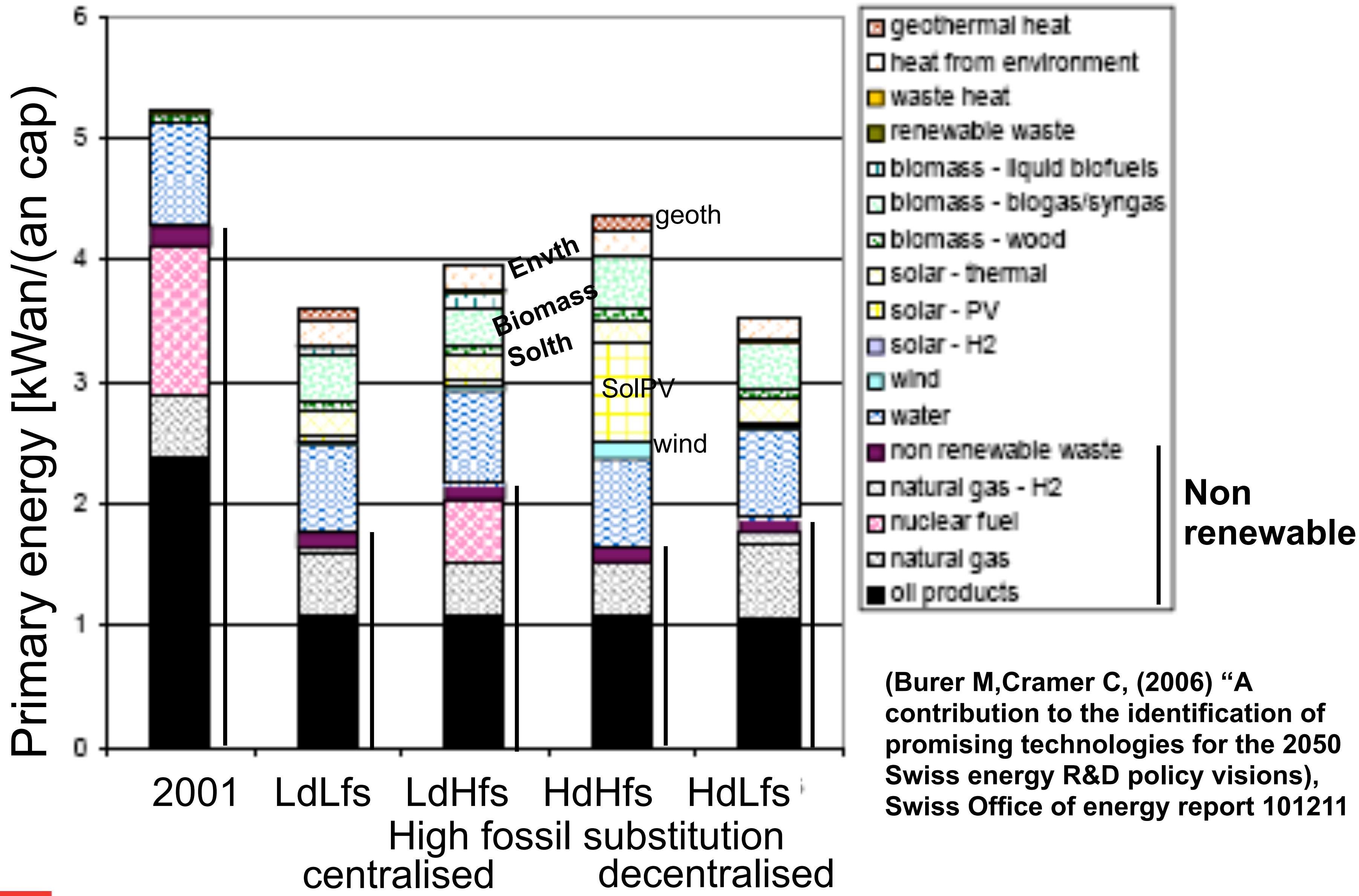
Marechal F, Favrat D, Jochem E, "Energy in the perspective of the sustainable development: The 2000 W society challenge" Resources, Conservation and Recycling 44 (2005) 245–262

" METHODOLOGICAL ASPECTS OF THE DEFINITION OF A 2 kW SOCIETY "

Haldi P.A., Favrat D in:
Energy 31 (2006), 3159-3170

advocating the use of exergy for a coherent approach

4 scenarii CORE Roadmap 2050

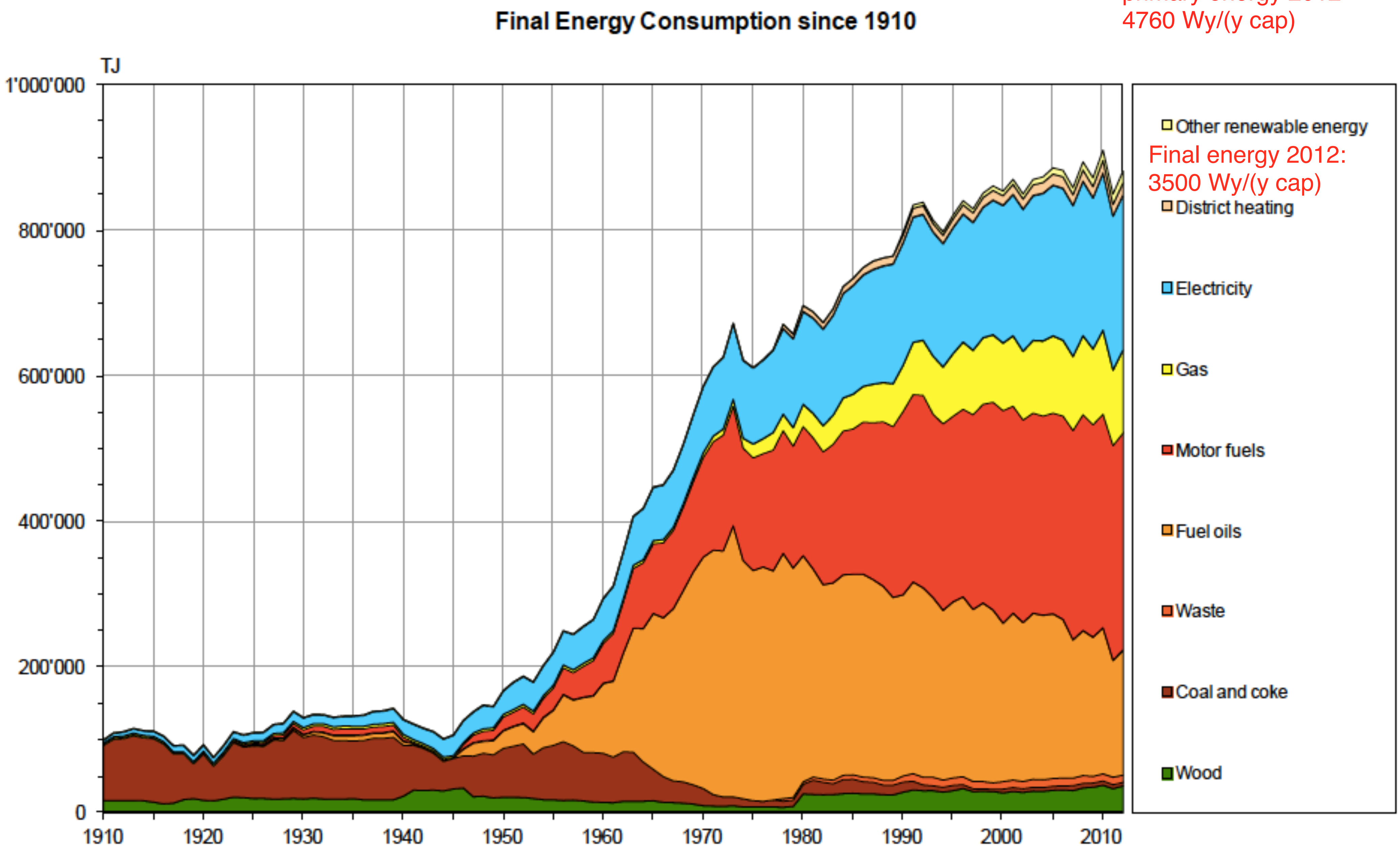


(Burer M,Cramer C, (2006) "A contribution to the identification of promising technologies for the 2050 Swiss energy R&D policy visions), Swiss Office of energy report 101211

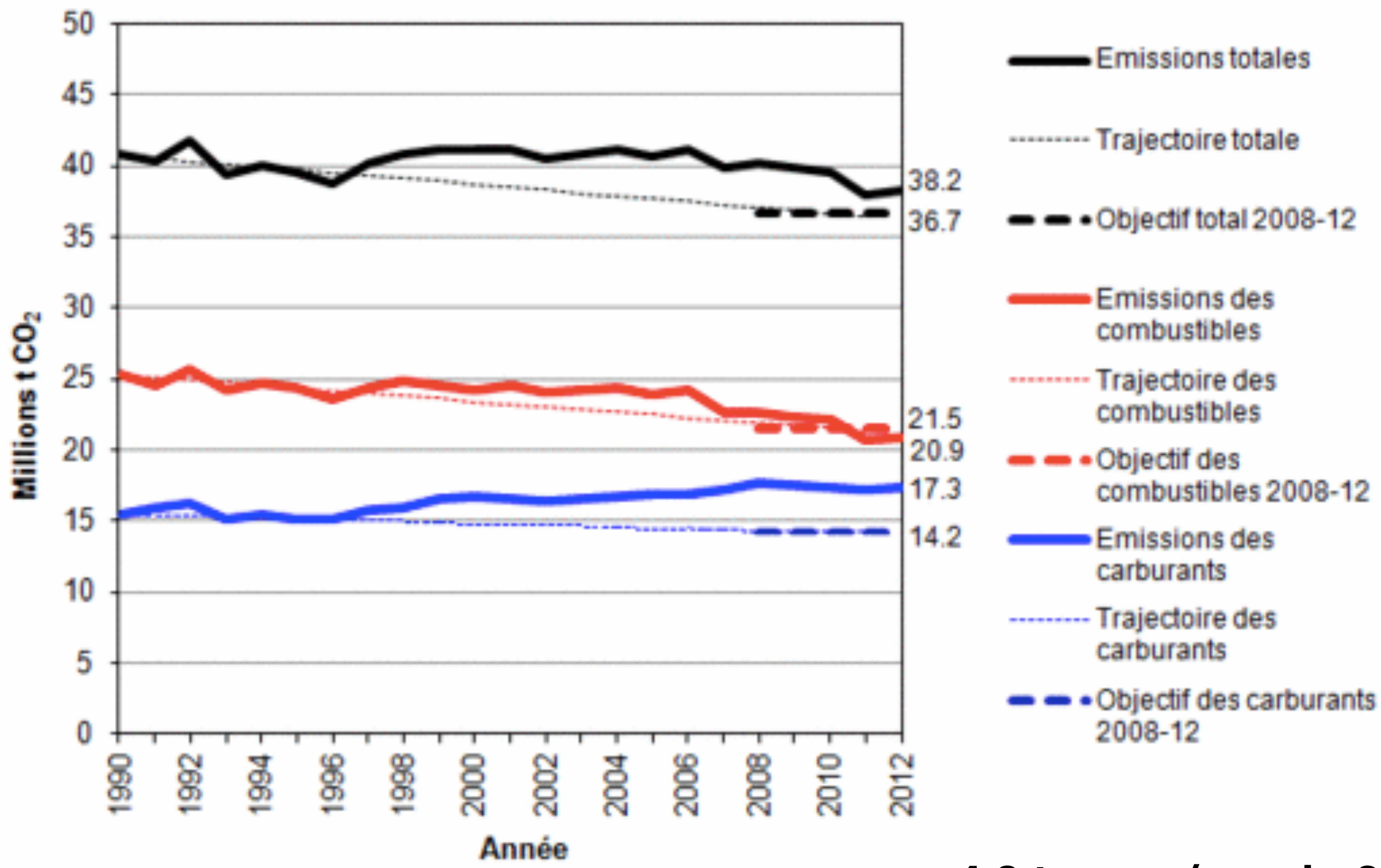
CORE= Swiss Committee for Energy Research

Swiss final energy

primary energy 2012
4760 Wy/(y cap)



Swiss CO_2 emissions



Evolution des émissions de CO2 selon la loi sur le CO2 (1990 à 2012)

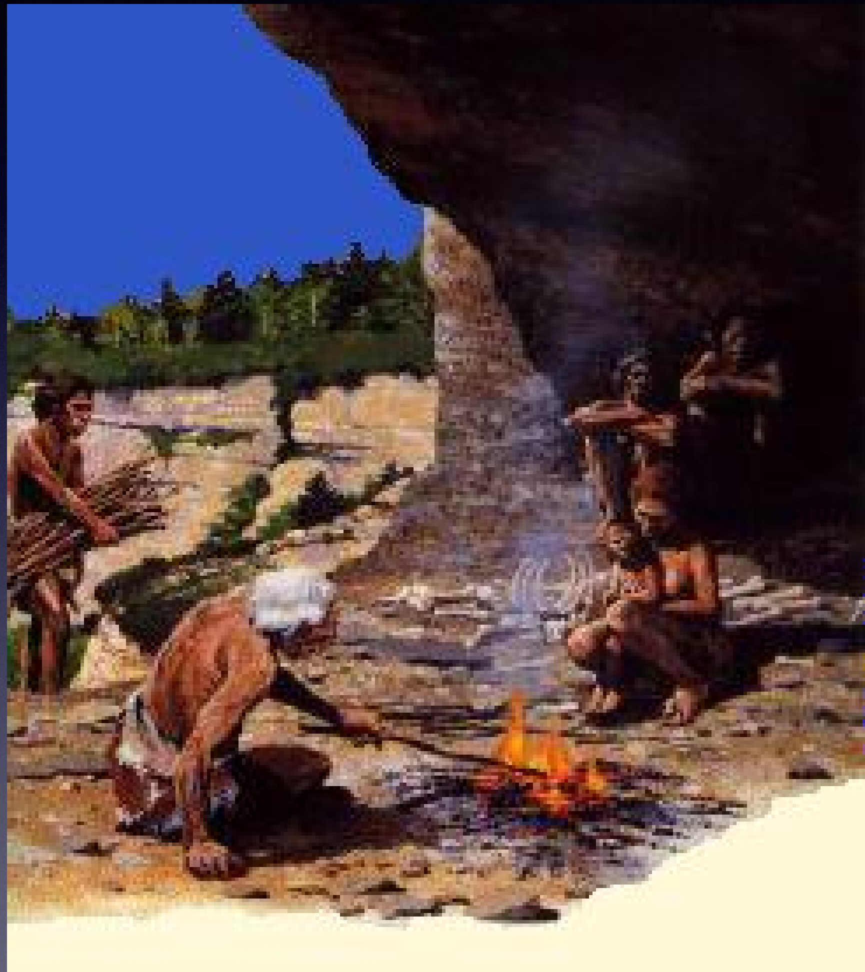
4.8 tonnes/ cap in 2012
target 2050= 1.0 tonne/cap

Innovation needed in terms of indicators

- Our present energy indicators based on energy efficiency (First Law of thermodynamics) are unfortunately inadequate (and too often misleading) to measure the quality of the energy conversion systems by humans (engineers)

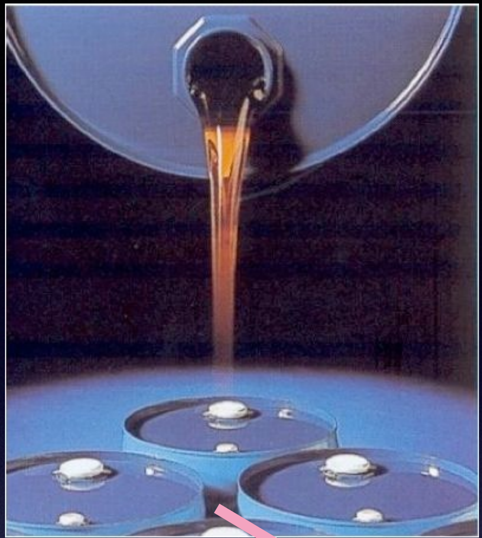
Example: Combustion and heating

- 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 ?



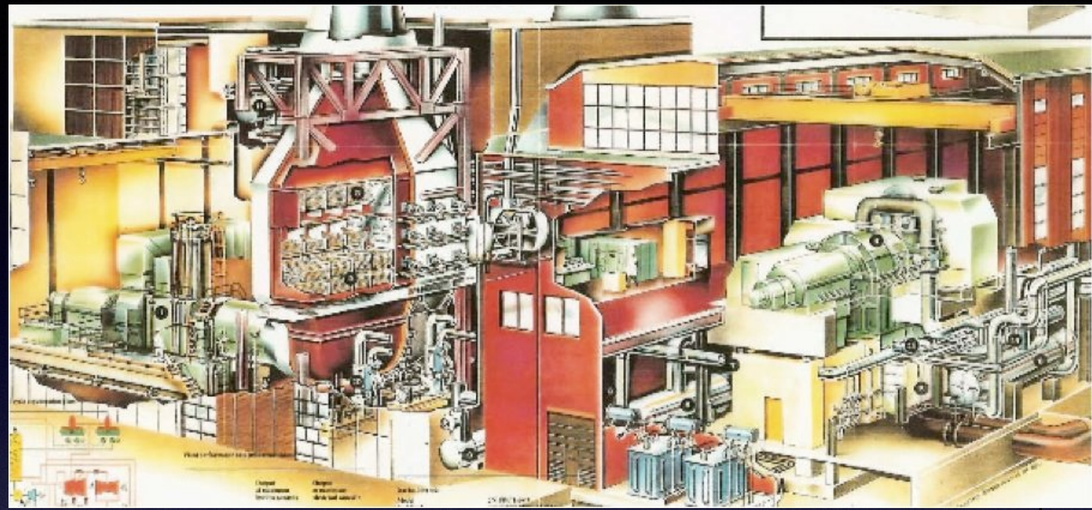
Of course not: exergy efficiency of around 6%

Alternatives for heating with the same fuel



1.00

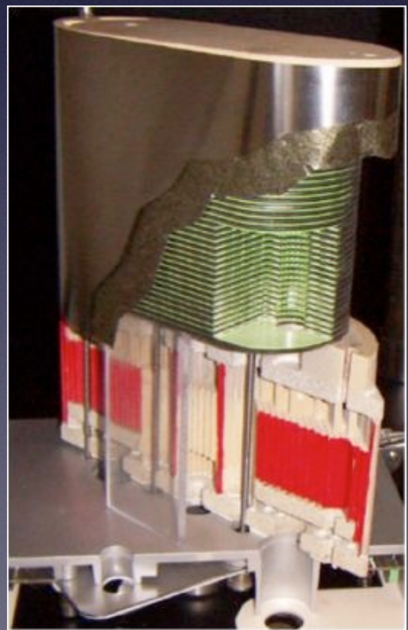
Combined cycle power plant



1.00

Electricity
0.57

Cogeneration with
fuel cell or engine



Electricity
0.44

Heat
0.46

Exergy efficiency of around 12%

Exergy

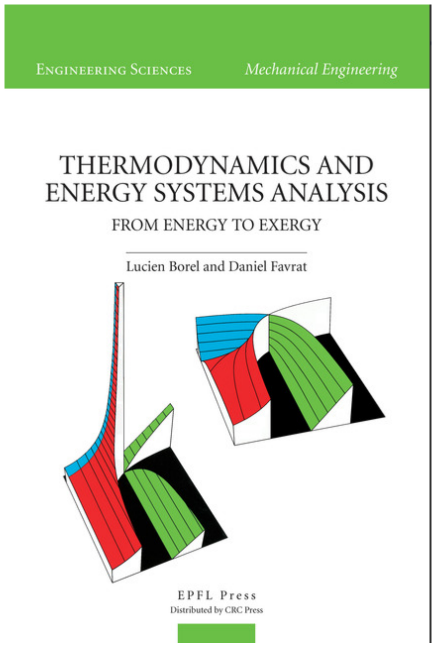
- The exergy associated with a transfer or a stock of energy is defined as the potential of maximum work (or maximum energy services) which could ideally be obtained from each energy unit being transferred or stored (using reversible cycles with the atmosphere as one of the energy sources either hot or cold).

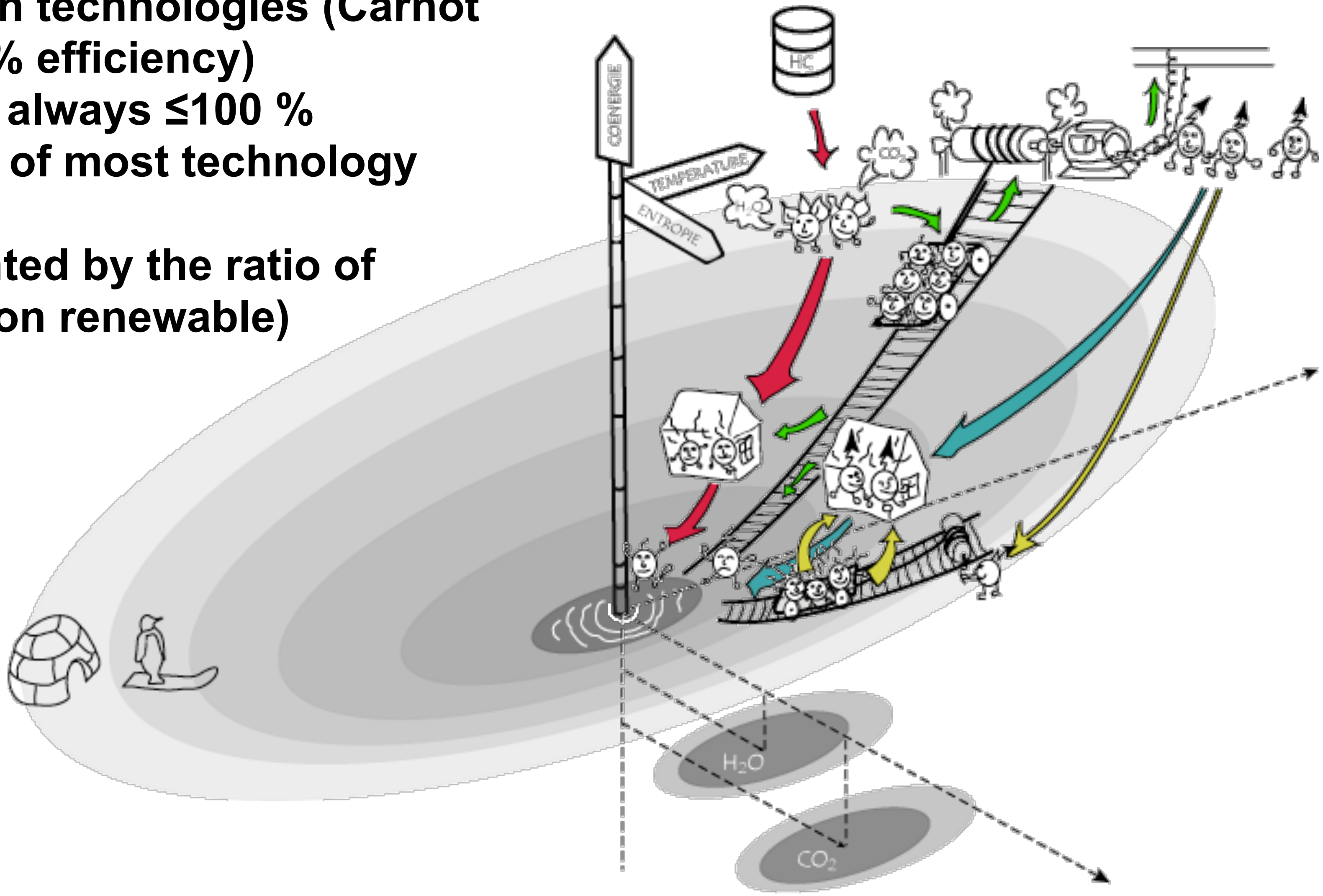
- Exergy accounts for First and Second Law of thermodynamics and can also be considered as the value of energy able to provide theoretically all energy services

- The only coherent way to characterize modern co- or tri-generation cycles (example: boiler 6%, cogen gas engine 50%)

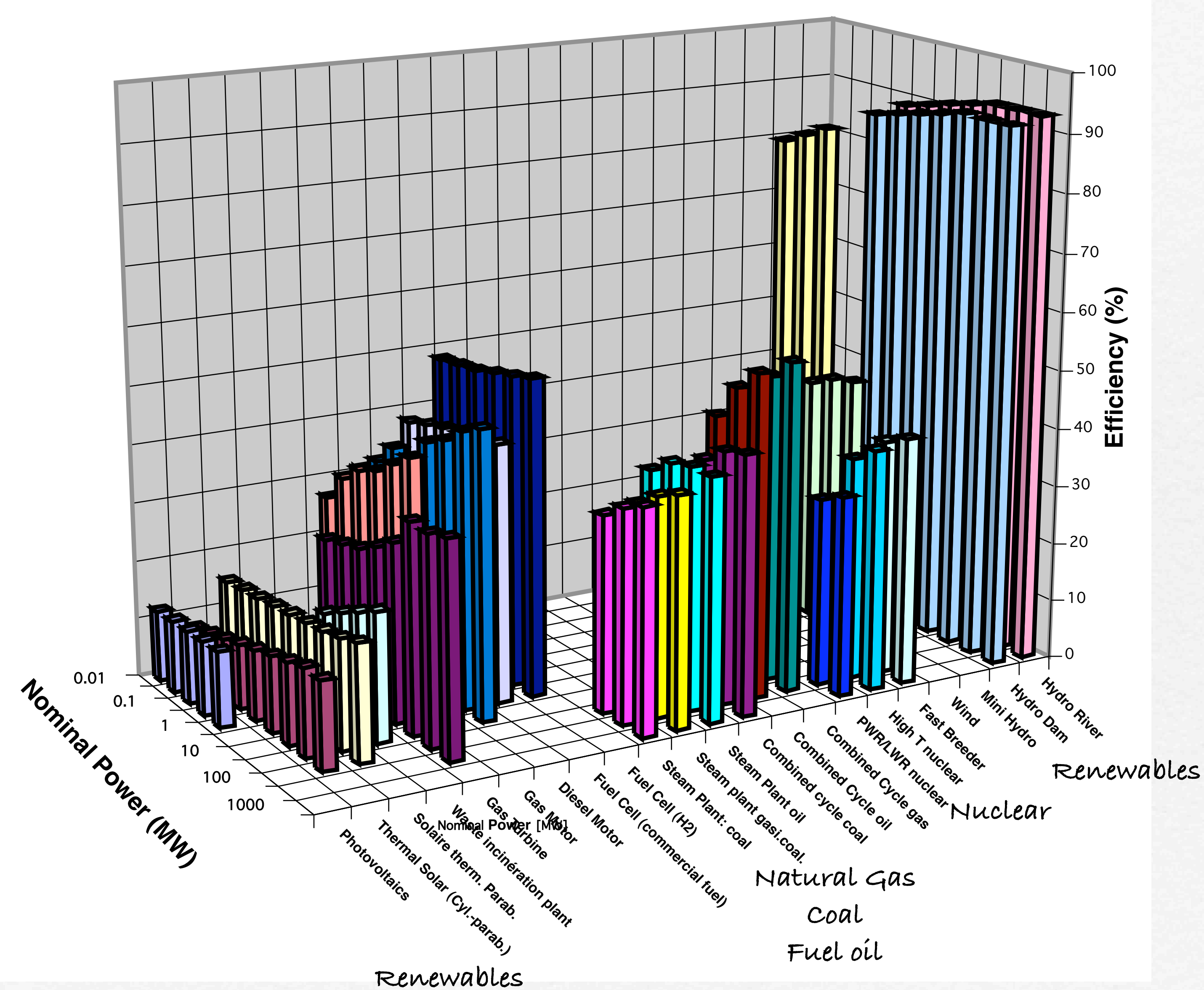
Exergy efficiency as a better indicator

- **Indicate the quality of human based energy conversion technologies (Carnot engine has a 100% efficiency)**
- **Exergy efficiency always ≤100 %**
- **Coherent ranking of most technology options**
- **To be complemented by the ratio of renewable over non renewable)**





Exergy conversion efficiency



Exergy efficiency in a Law on Energy in Geneva

Both:

- An exergy efficiency
- and a renewable energy ratio

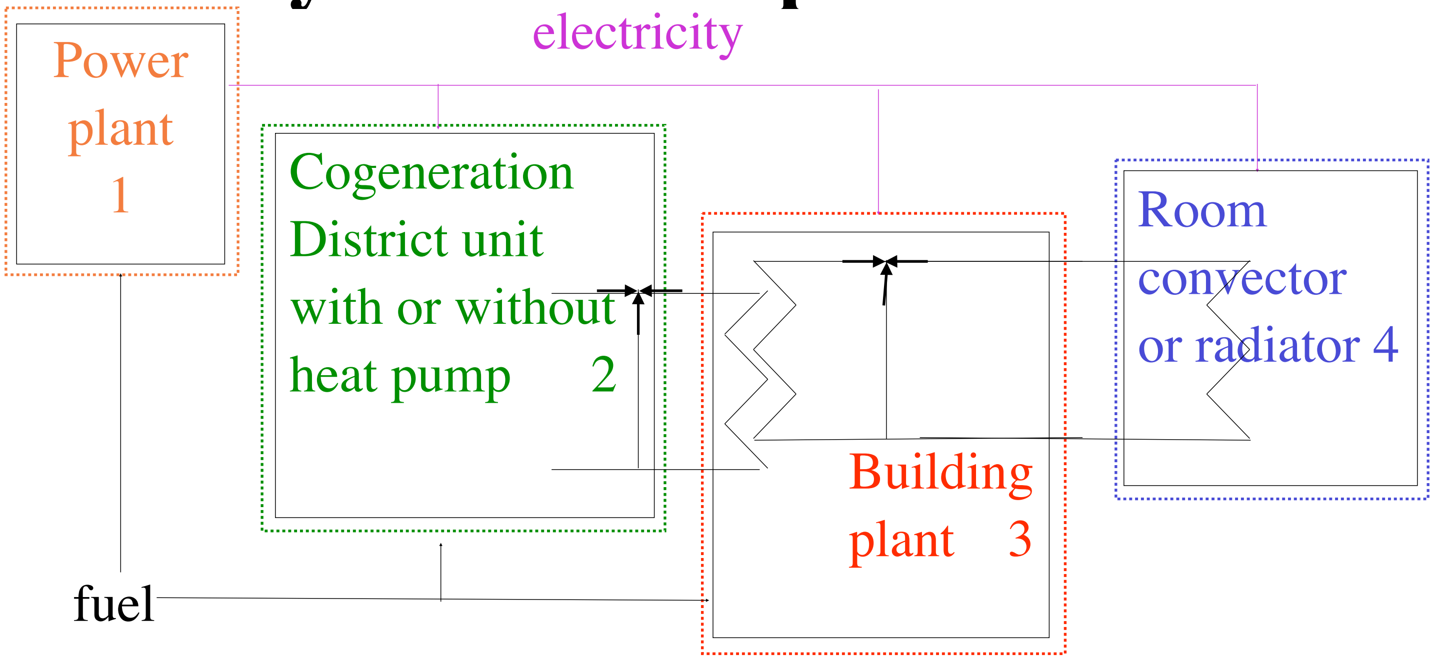
are required from developers of large projects (incl industrial parks)

The exergy presents the major advantage of defining efficiencies which can be adapted to every situation (cogeneration of heat , power, cold, fuel, etc.) and for all application domains. The exergy efficiency which is, always lower than 100%, gives an assessment of the relative quality of the different technical options.

The challenge was how to simplify the calculation of exergy efficiency to simple energy services like heating and cooling (how to convince architects and owners that low T heating is the best)

Favrat D.,Marechal F., Epelly O.
"The challenge of introducing an exergy indicator in a local law on energy", Energy 33 (2008) 130–136

Exergy efficiency in a Law (Geneva): System decomposition



$$\eta = \eta_1 \ \eta_2 \ \eta_3 \ \eta_4$$

Example: Combined cycle power plant without cogeneration (1)+District heating heat pump (2) + DH heat exchanger in the building (3) +convector (4)

$$\eta = \left(\frac{\dot{E}^-_{el,1}}{\dot{E}^+_{y,1}}\right)\left(\frac{\dot{E}^-_{y,2}}{\dot{E}^+_{el,2}}\right)\left(\frac{\dot{E}^-_{y,3}}{\dot{E}^+_{y,3}}\right)\left(\frac{\dot{E}^-_{q,4}}{\dot{E}^+_{y,4}}\right) = \frac{\dot{E}^-_{q,4}}{\dot{E}^+_{y,1}}$$

Favrat D.,Marechal F., Epelly O.
“The challenge of introducing an exergy indicator in a local law on energy”, Energy 33 (2008) 130–136

Examples of technologies for room heating	Power	Dist. plant	Building plant			Room convector			**Overall exergy efficiency [%]**		
Supply/return temperatures			45°/ 35°	65°/ 55°	75°/ 65°	45°/ 35°	65°/ 55°	75°/ 65°	45°/ 35°	65°/ 55°	75°/ 65°
Direct electric heating (nuclear power)	0.32					0.07	0.07	0.07	2.2	2.2	2.2
Direct electric heating (combined cycle cogeneration)		0.55				0.07	0.07	0.07	3.7	3.7	3.7
Direct electric heating (hydro power)	0.88					0.07	0.07	0.07	6.0	6.0	6.0
District boiler		0.2	0.54	0.76	0.86	0.53	0.38	0.33	5.8	5.8	5.8
Building non-condensing boiler			0.11	0.16	0.18	0.53	0.38	0.33	6.1	6.1	6.1
Building condensing boiler			0.12			0.53			6.6		
District heat pump (nuclear power)	0.32	0.61	0.54	0.76	0.86	0.53	0.38	0.33	5.6	5.6	5.6
Domestic heat pump (nuclear power)	0.32		0.45	0.45	0.45	0.53	0.38	0.33	7.6	5.4	4.8
Domestic cogeneration engine and heat pump			0.22	0.25	0.26	0.53	0.38	0.33	11.8	9.4	8.7
District heat pump (combined cycle power)	0.54	0.61	0.54	0.76	0.86	0.53	0.38	0.33	9.4	9.4	9.4
Domestic heat pump (combined cycle power)	0.54		0.45	0.45	0.45	0.53	0.38	0.33	12.9	9.2	8.1
Domestic heat pump (cogeneration combined cycle power)		0.55	0.45	0.45	0.45	0.53	0.38	0.33	13.2	9.4	8.3
Cogeneration fuel cell and domestic heat pump			0.25	0.27	0.28	0.53	0.38	0.33	13.4	10.4	9.5
District heat pump (hydropower)	0.88	0.61	0.54	0.76	0.86	0.53	0.38	0.33	15.4	15.4	15.4
Domestic heat pump (hydropower)	0.88		0.45	0.45	0.45	0.53	0.38	0.33	21.2	15.1	13.3

Overall exergy efficiency of Air conditioning/refrigeration

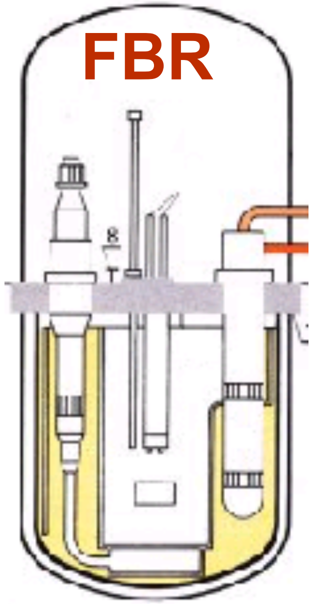
Power plant technologies	Power plant	Dist. plant	Building plant			Room convector			Overall exergy efficiency [%]		
Supply/return temperatures			10°/ 15°	5°/ 10°	0°/ 5°	10°/ 15°	5°/ 10°	0°/ 5°	10°/ 15°	5°/ 10°	0°/ 5°
Nuclear power	0.32		0.4	0.4	0.4	0.56	0.43	0.34	7.1	5.4	4.3
Gas motors	0.36		0.4	0.4	0.4	0.56	0.43	0.34	8.1	6.2	4.9
Combined cycle power plant without cogeneration	0.54		0.4	0.4	0.4	0.07	0.07	0.07	12.1	9.3	7.3
hydropower	0.88		0.4	0.4	0.4	0.53	0.38	0.33	19.8	15.2	12.0

Key messages:
Heat in the coolest way and cool in the warmest way

Primary Energy Quantification, the Nuclear "Headache"

It is based on the (limited as shown above) analogy that exists between fossil and nuclear "fuels" that, in the official statistics, the latter is generally accounted for at the primary energy level as the *thermal energy* "technically" released in the reactor core (usually, LWR reactors)

FBR



Correct Definition of the Nuclear Primary Energy ?

This implies that the value obtained strongly depends on the technology (reactor system) used!

What about breeding ?

Energy potential x 60-70 ⇒
apparent "efficiency" of some 2000% ?!

Present indicator confusion

- Energy efficiency of boilers close to 100% even though with the same amount of fuel one can technically get more than twice the amount of heat
- Present nuclear reactors efficiency bias leading to efficiencies > than 1000 for some fast breeder reactors !! In fact exergy efficiency of present reactors is < 1 (see Tani F., Haldi P.A., Favrat D. "Exergy-based Comparison of the nuclear Fuel cycles of light water and generation IV reactors, ECOS2010)

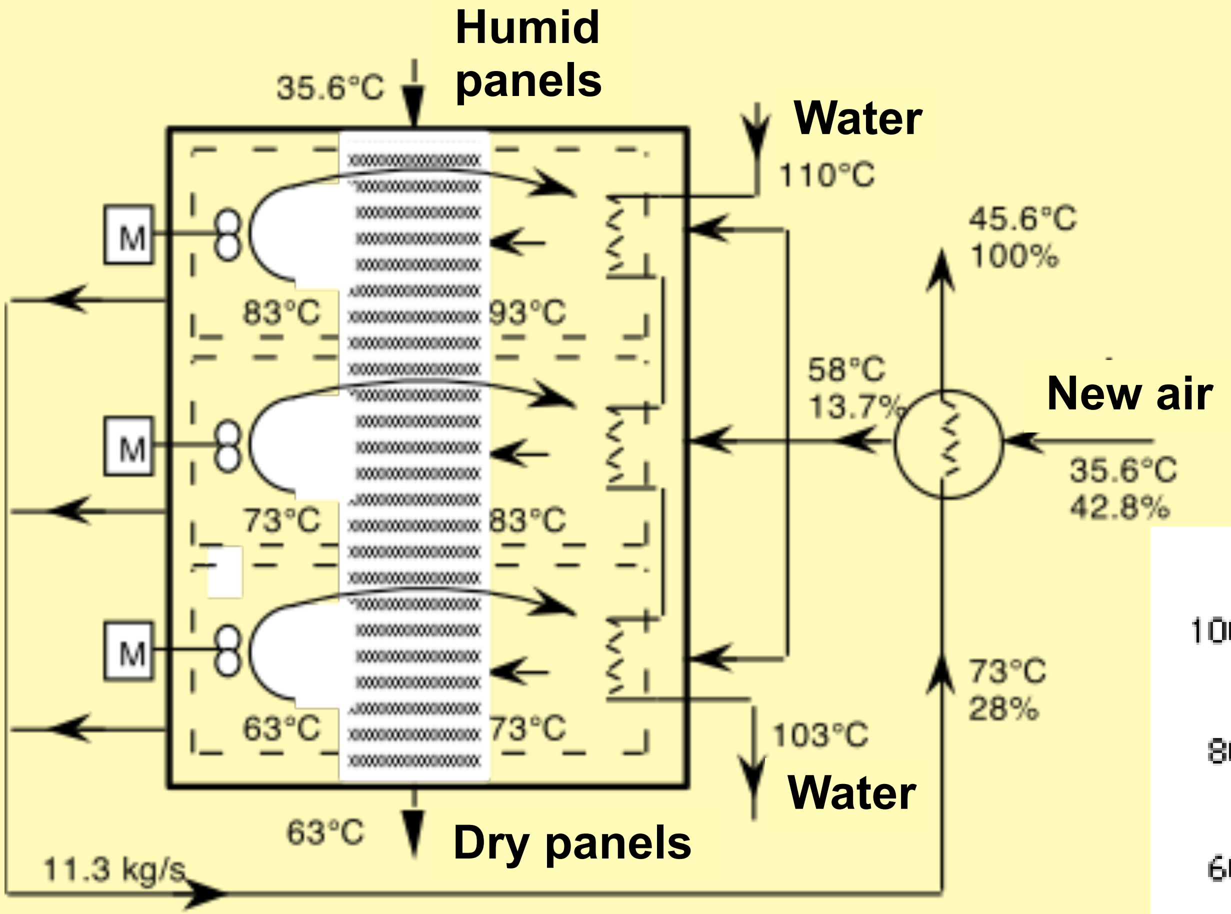
How can the engineers coherently inform the public about the potential of technologies and account for these options in scenarios. Exergy concepts can help

One problem right now is 4th generation research falls into a lack of financing between 3rd gen and fusion

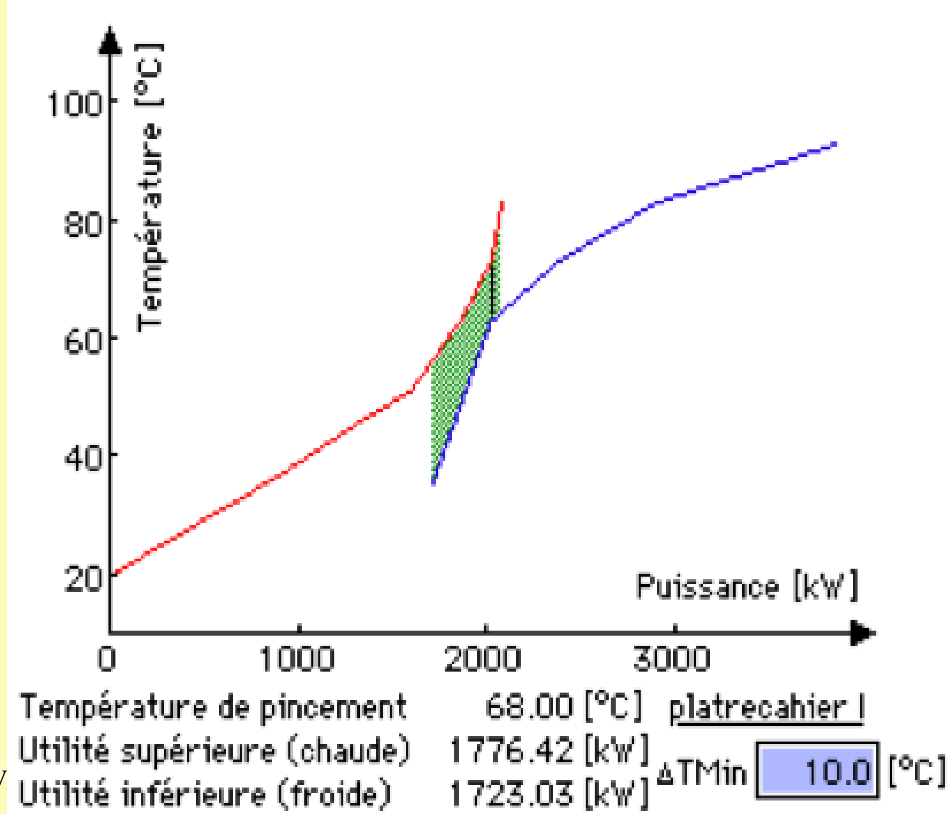
Grey energy (embedded energy)

- The importance of:
  - closing the loop
  - tradeoff between passive and active energy measures in building
  - etc.

Example:
Drying of plaster panels (1/2)



Before retrofit



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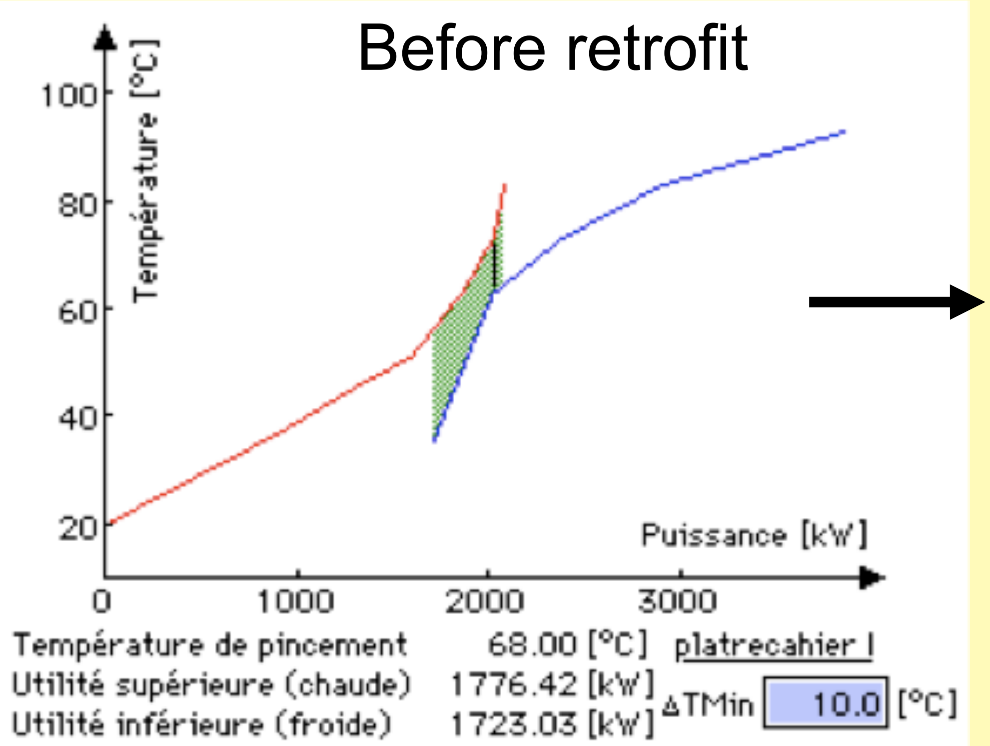
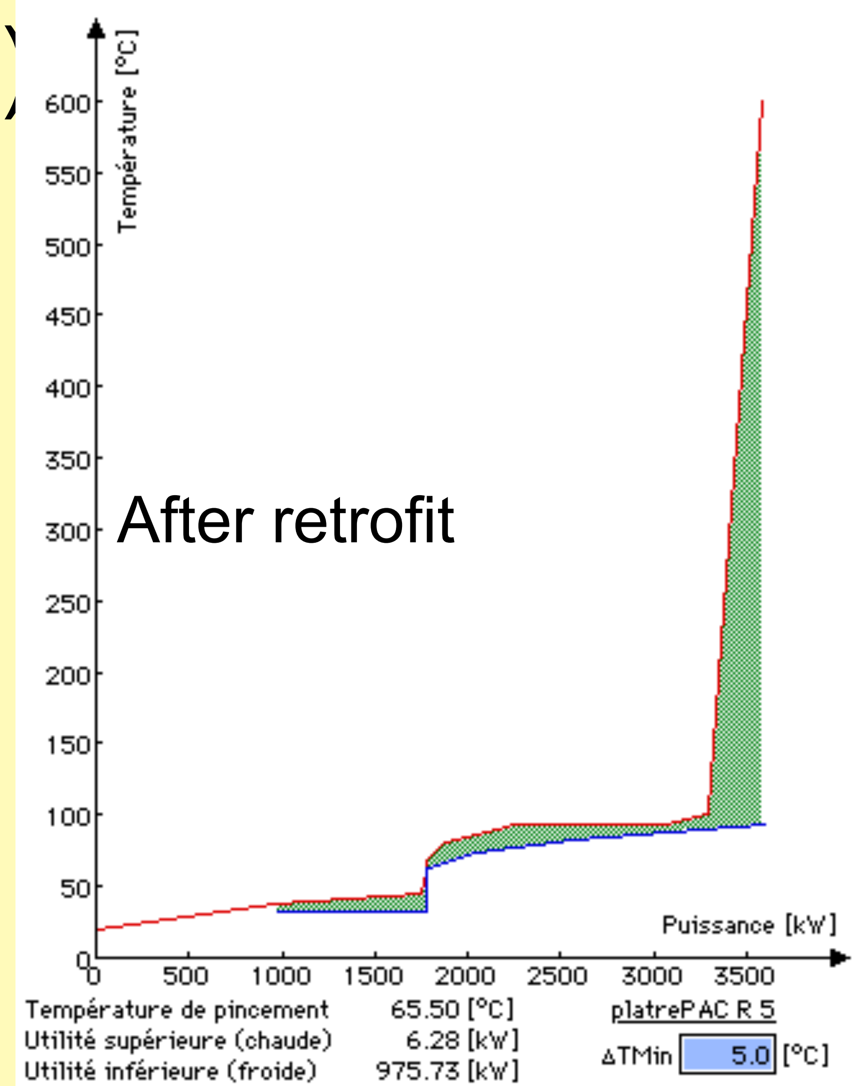
Drying of plaster panels (2/2)

(with 2 stage heat pump + cogeneration engine)

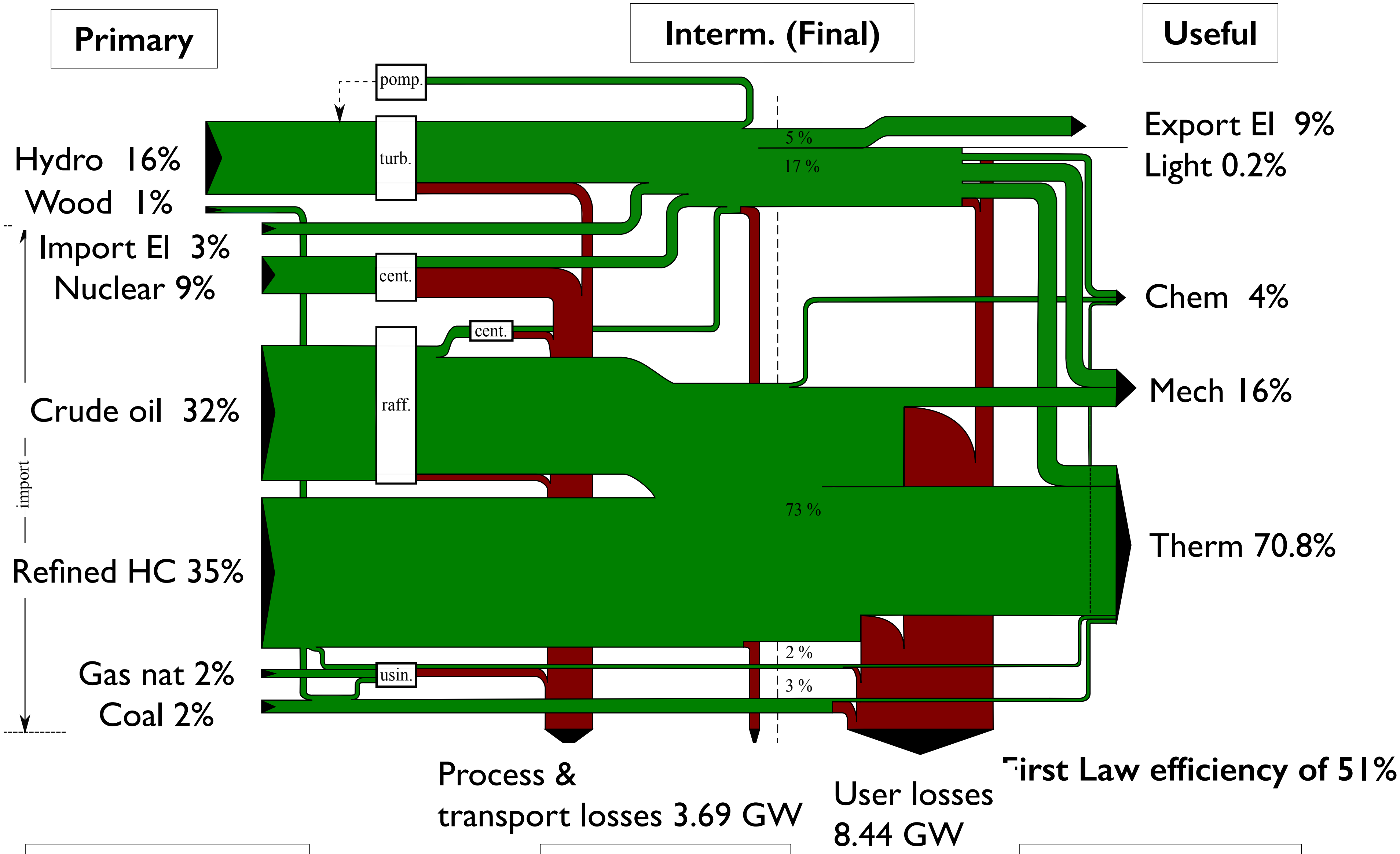




- Fuel consumption and exergy losses reduced by 40%
- In a LCA tradeoff assessment between passive and active measures for buildings for example it counts

Example of diagrams at a country level (CH 1974)

Energy: Sankey



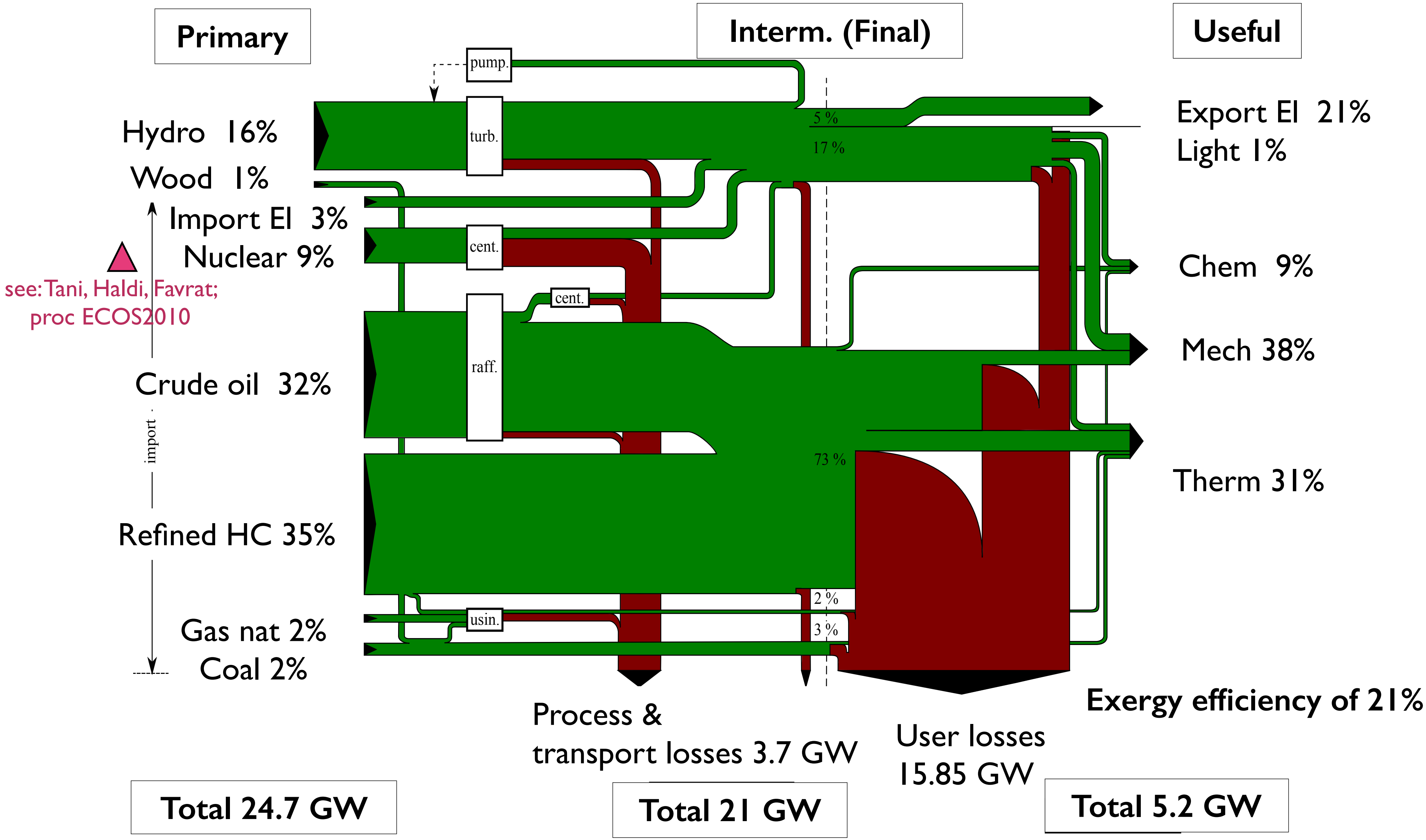
Total 24.7 GW

Total 21 GW

Total 12.6 GW

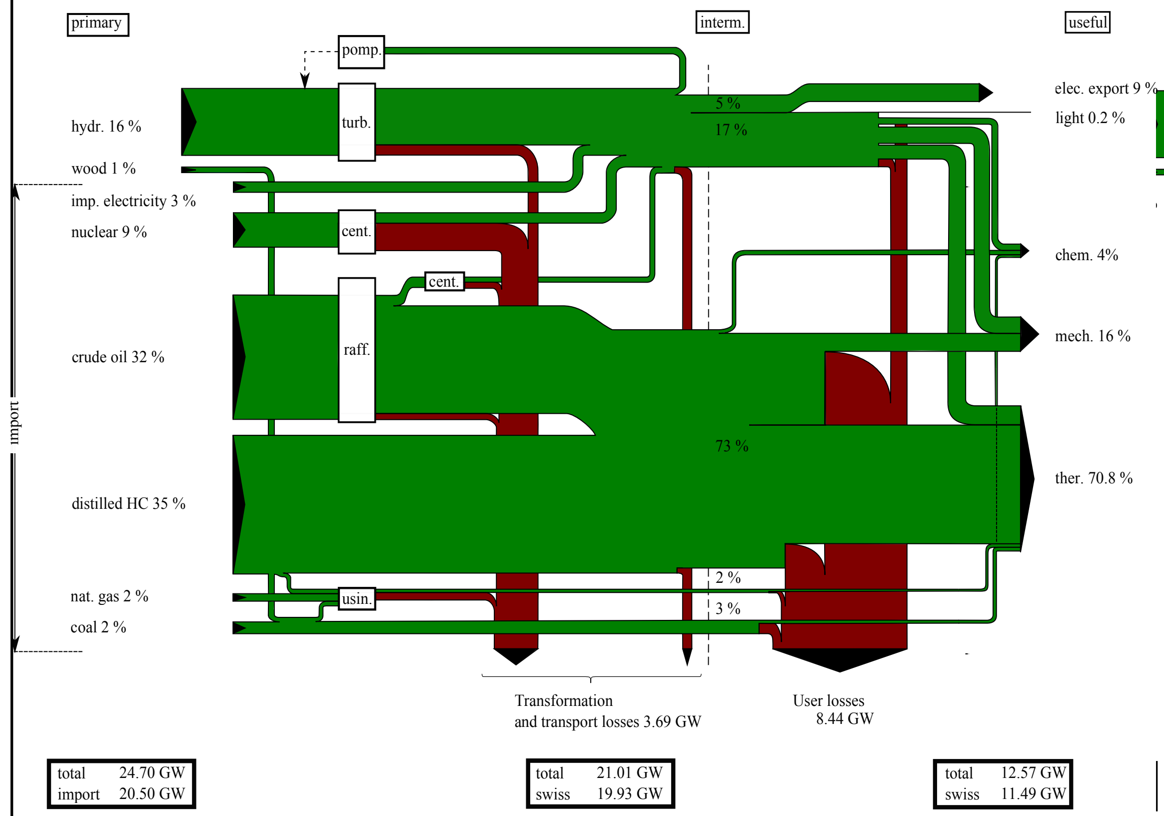
Diagrams at a country level (CH 1974)

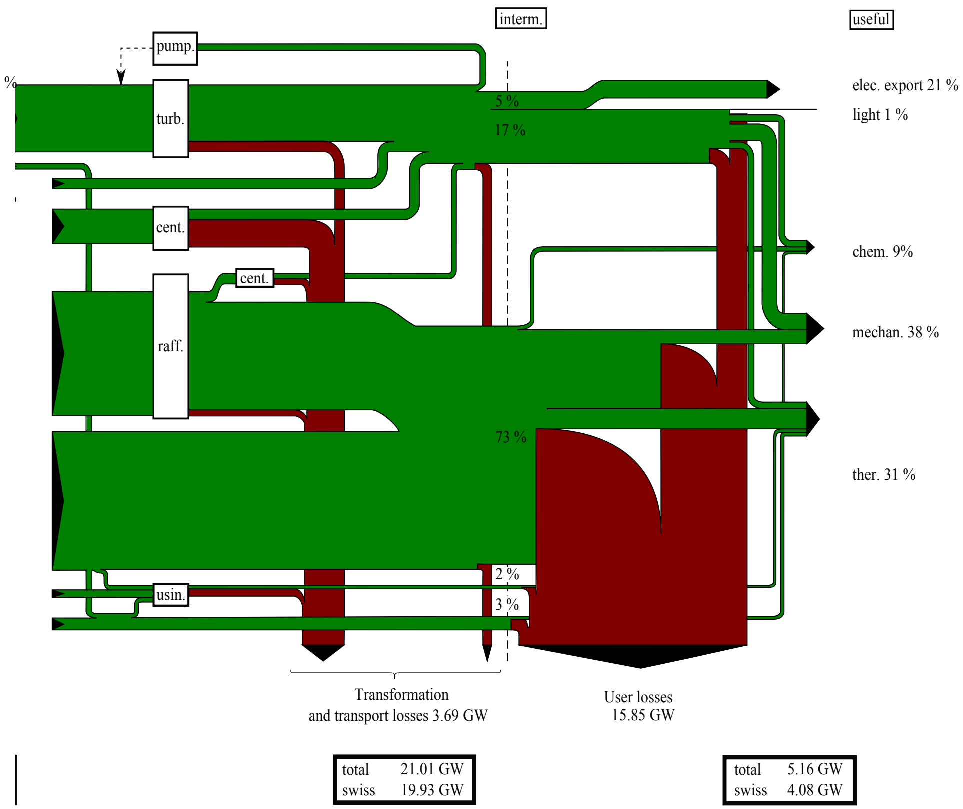
Exergy: Grassmann diagram



Diagrams at a country level (CH 1974)

Energy versus exergy
Sankey versus Grassmann





First Law efficiency of 51%

Exergy efficiency of 21%

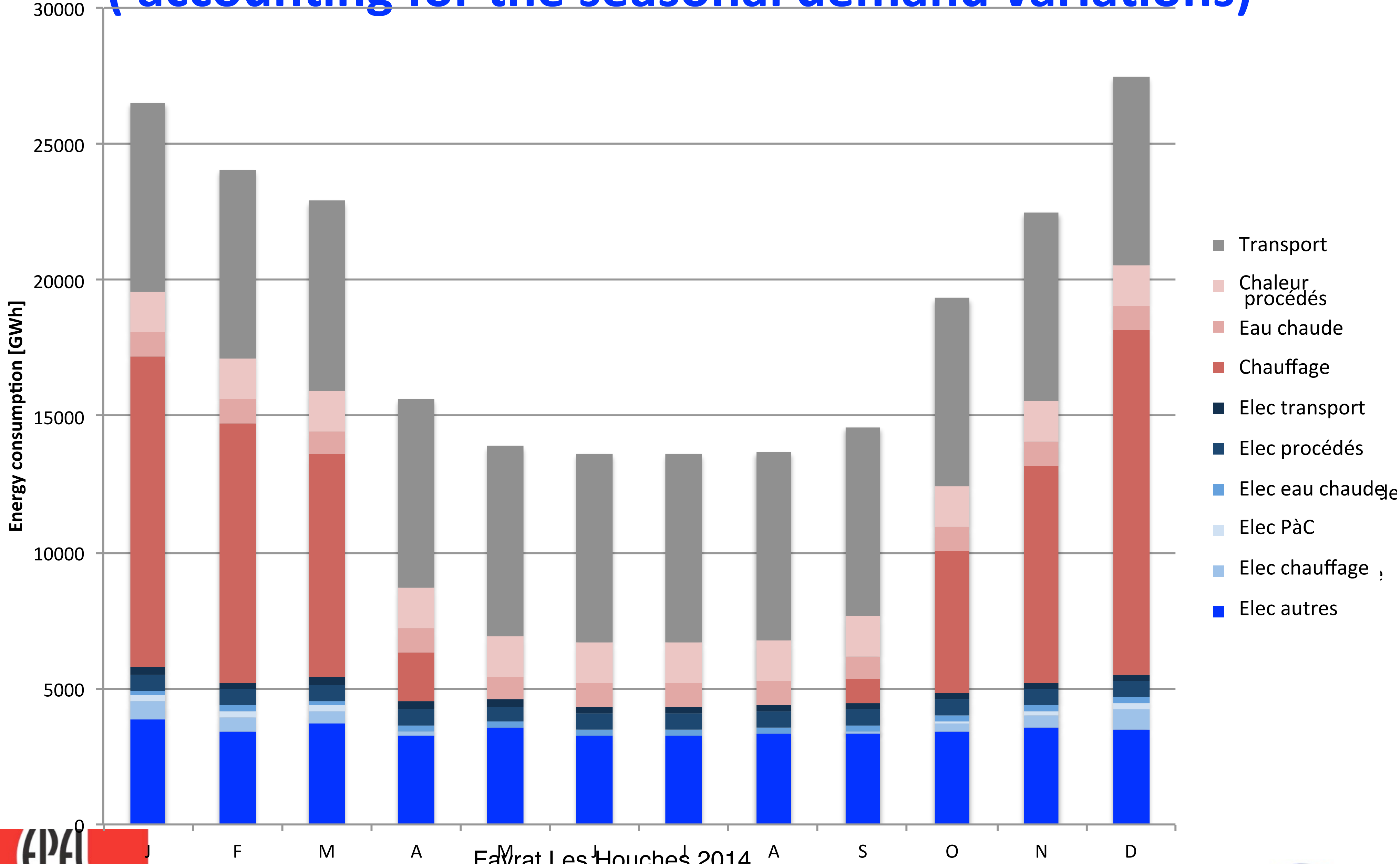
Main obstacles to efficiency

- 1986 à 2006: 20 years of extremely low energy and mineral resources prices
- Less concerns for global environment and resources
- Major financial efforts diverted to IT and Health

3 main action paths to energy efficiency

- Develop better indicators for ecoefficiency and sustainability (exergy efficiency, renewable energy ratio, ...)
- Develop improved design and planning methods (holistic, able to optimize complex integrated systems towards increased efficiency, …)
- Develop advanced technologies for a more rational use of both non renewable and renewable

Swiss energy transition
(accounting for the seasonal demand variations)



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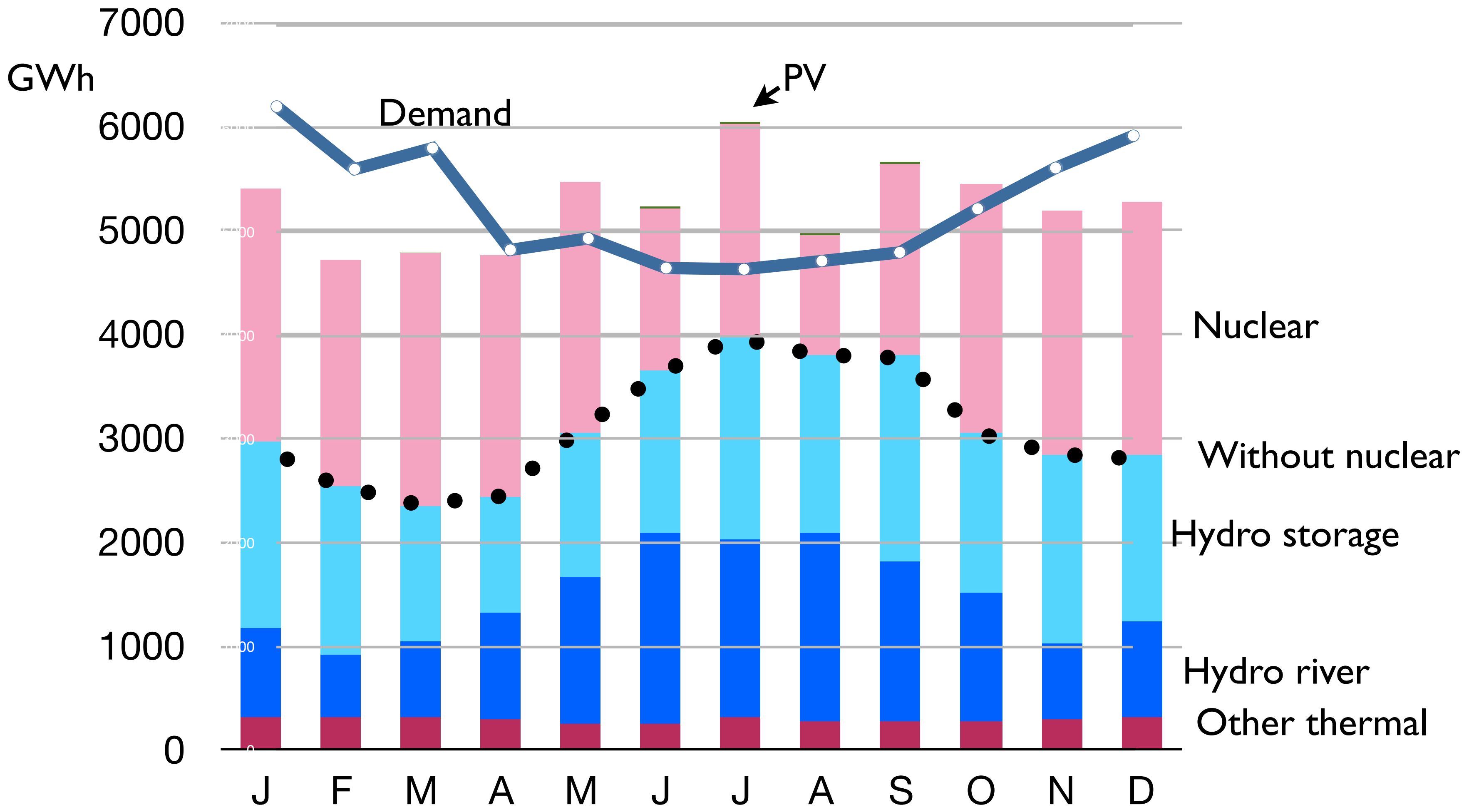
Favrat Les Houches 2014

http://energycenter.epfl.ch

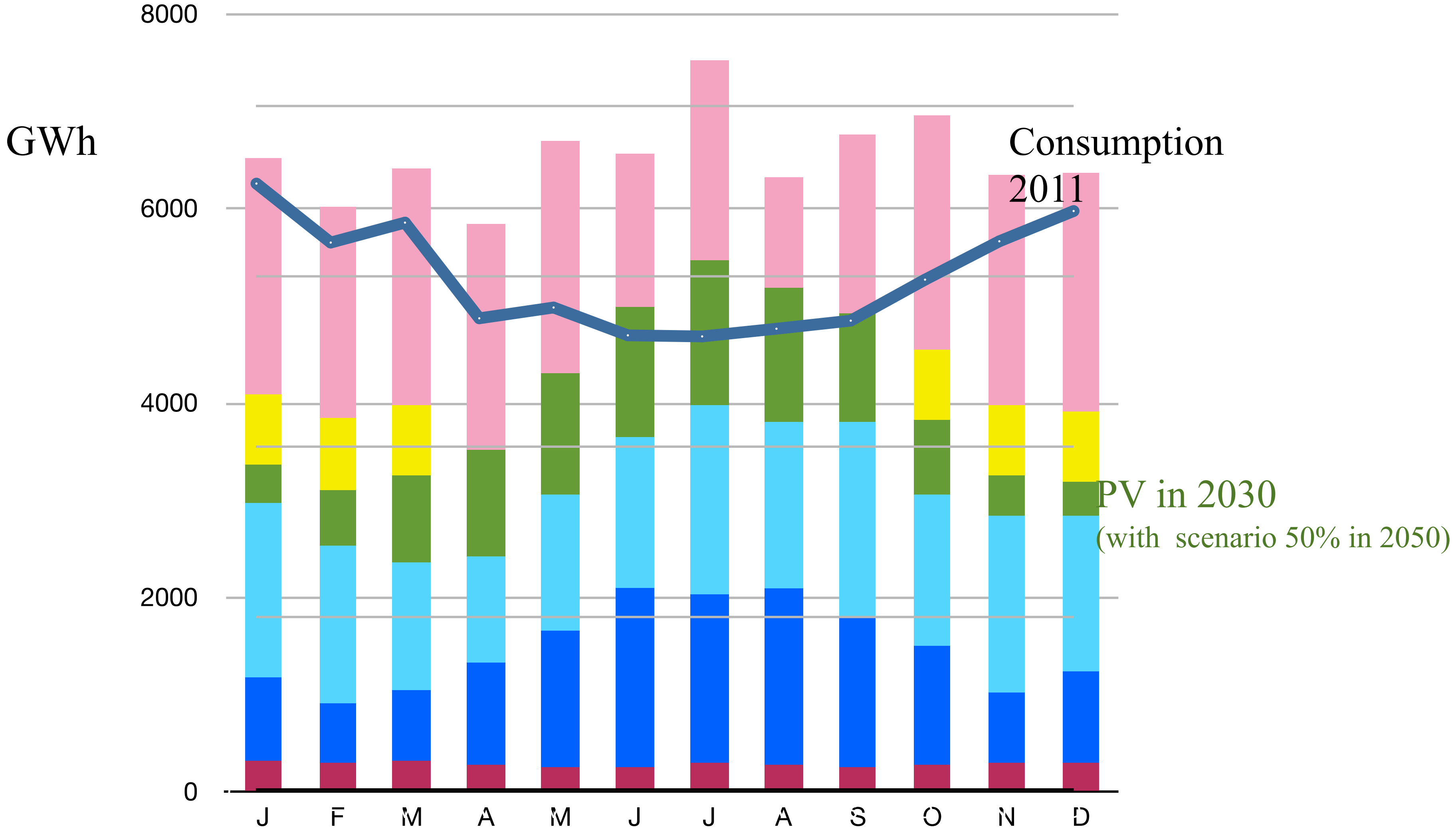
Swiss Monthly production and consumption of electricity in 2011



- En 2011, biomass =0.67%, solar PV =0.24%, wind=0.11% (mais forte croissance pour PV et éolien mais problème économique intermédiaire actuel : en été PV acheté à 40cts/kWh et revendu à l'Italie à 8cts/kWh)

Even before Fukushima Switzerland suffers from deficit of production in Winter

Monthly production of electricity in Switzerland with max PV 2030 and 2 gas power plants (2*500 MW)



Seasonal storage: Major opportunities for synthetic fuels

Information structuring about future scenarios

- Starting points:
  - weak knowledge about energy in the population (non experts)
  - need to rationalise teaching in the different academic sections ("experts")
  - need for a calculator that can be adapted to both
  - inspired by Mackay in UK but adapted:
    - to Swiss situation
    - to account for the seasonal asymmetry

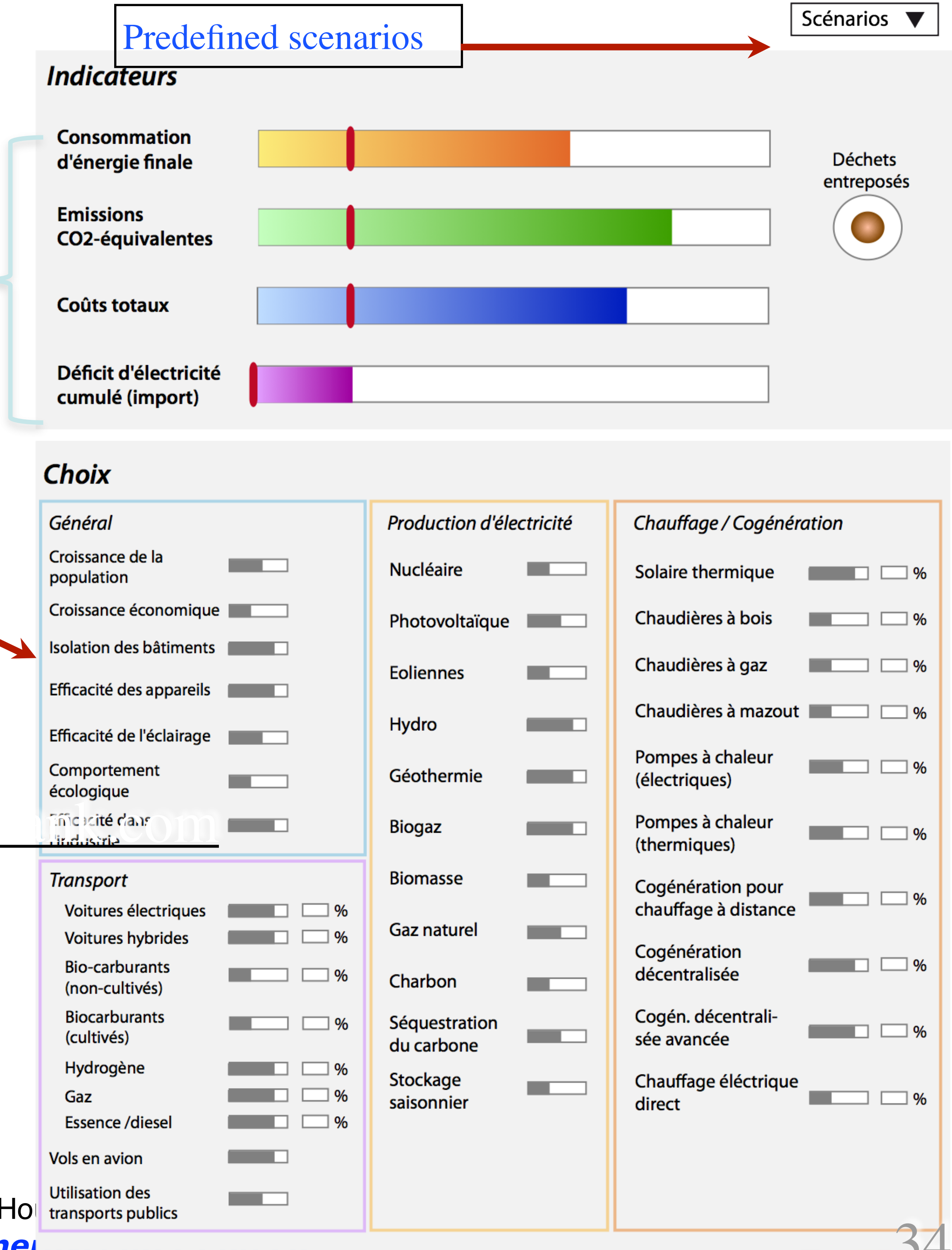
Swiss Energy-Scope

General structure

5 key indicators,
Calculated based on:
Predefined scenarios
Calculator User choice

User choices:

Sliders for the variables



FAQ

Blog h

MOOC

2 levels

Book / Ebook

Scenario realistic 2050

General indicators

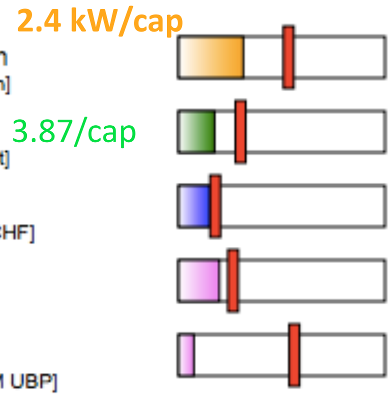
Final energy consumption
Projected value: 187925 [GWh]

CO2-equiv. Emissions
Projected value: 34794 [1000 t]

Total cost
Projected value: 30448 [MM CHF]

Electricity deficit
Projected value: 3952 [GWh]

Deposited waste
Projected value: 1845822 [MM UBP]



Detailed graph

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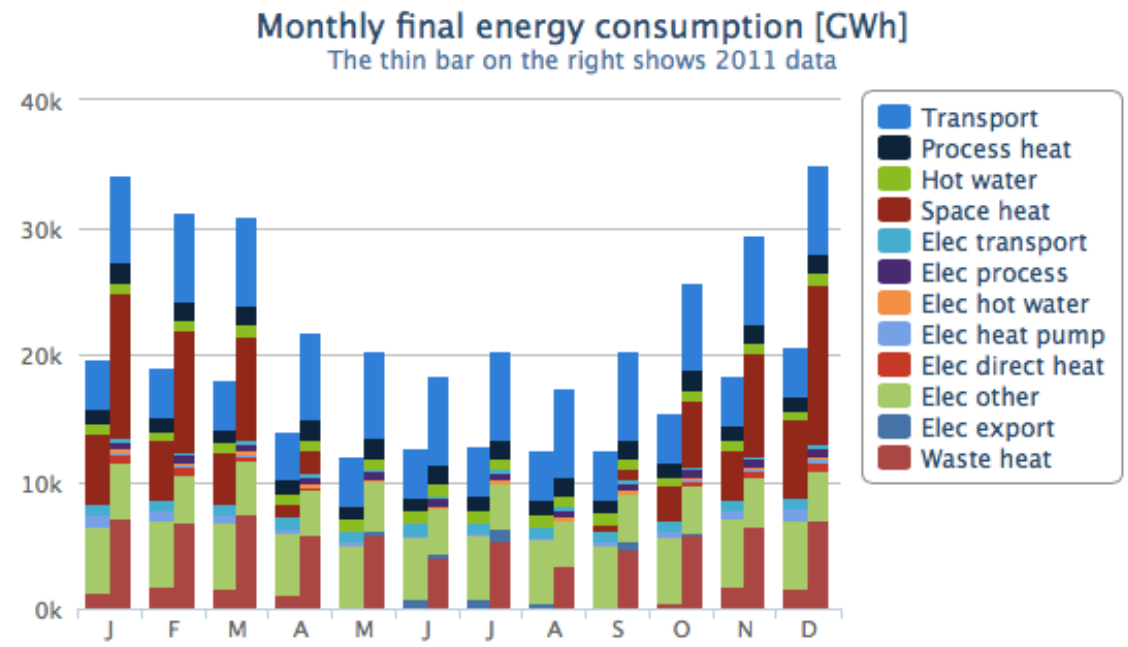


Target Year

Please select the year you want to do computation for.

2035 | 2050

General | Transport | Heating & Cogeneration | Electricity

General

Population growth (%/year): 0.30 — 0.2 to 1.5

Economic growth (%/year): 0.50 — 0.0 to 3.0

Building efficiency: 2.00 — 1.0 to 3.0

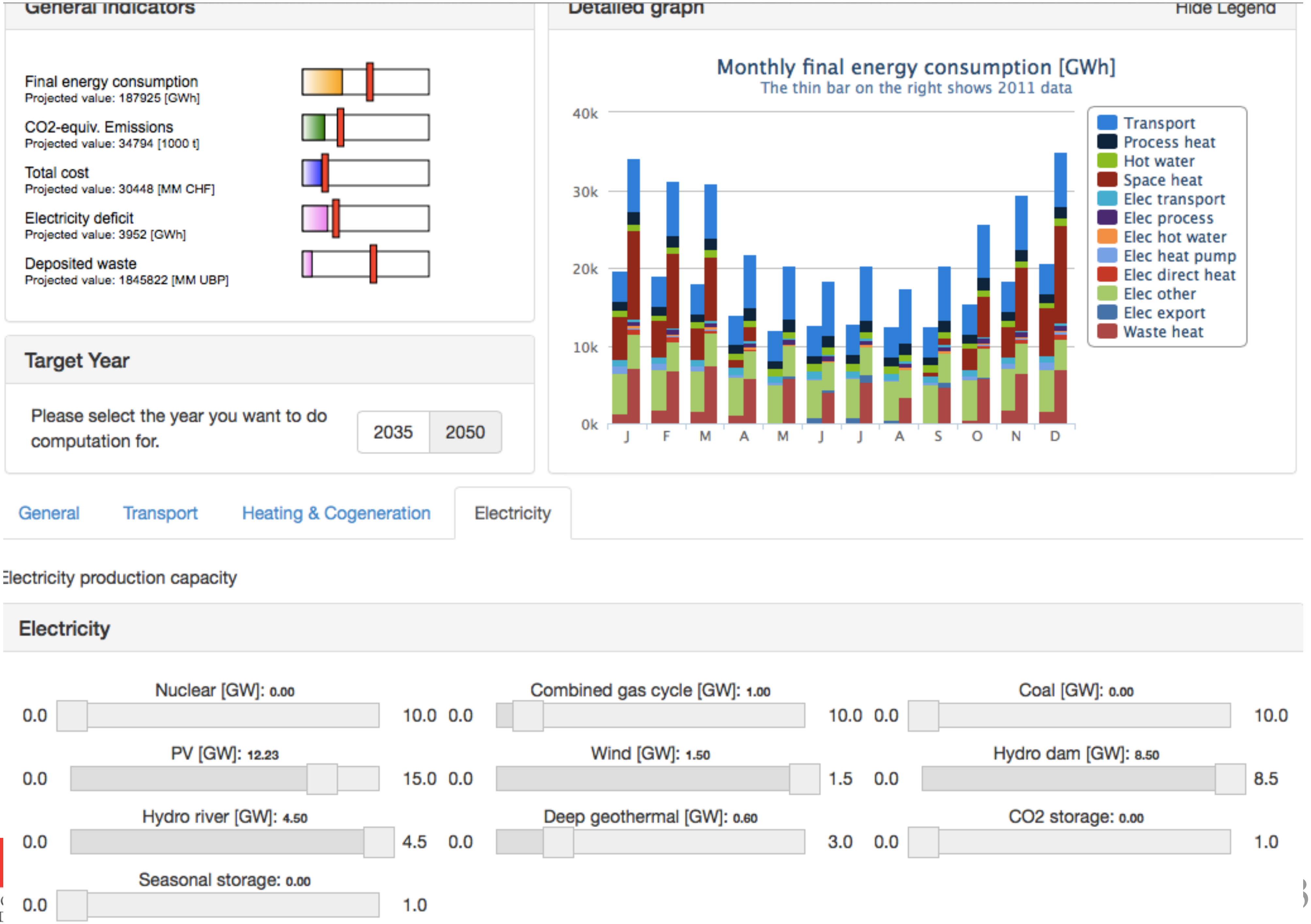
Industry efficiency: 2.00 — 1.0 to 3.0

Appliances efficiency: 2.00 — 1.0 to 3.0

Lighting efficiency: 2.00 — 1.0 to 3.0

Ecofriendly behaviour: 1.00 — 1.0 to 3.0

Scenario realistic 2050 elec



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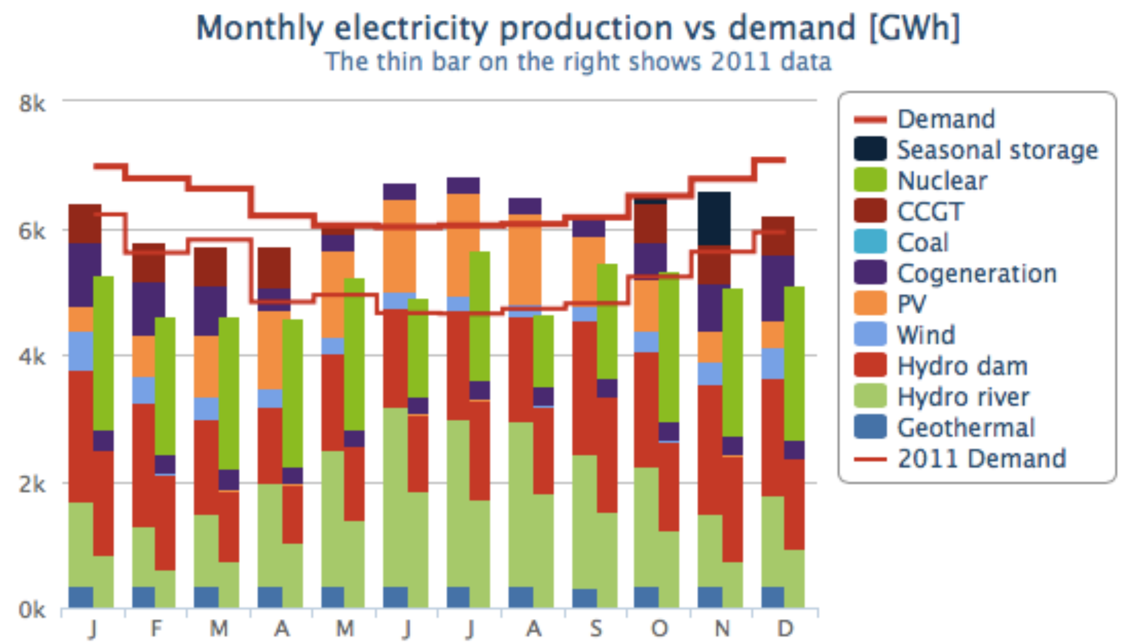

Target Year

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General | Transport | Heating & Cogeneration | Electricity

lectricity production capacity

Electricity

Nuclear [GW]: 0.00 — 0.0 … 10.0

Combined gas cycle [GW]: 1.00 — 0.0 … 10.0

Coal [GW]: 0.00 — 0.0 … 10.0

PV [GW]: 12.23 — 0.0 … 15.0

Wind [GW]: 1.50 — 0.0 … 1.5

Hydro dam [GW]: 8.50 — 0.0 … 8.5

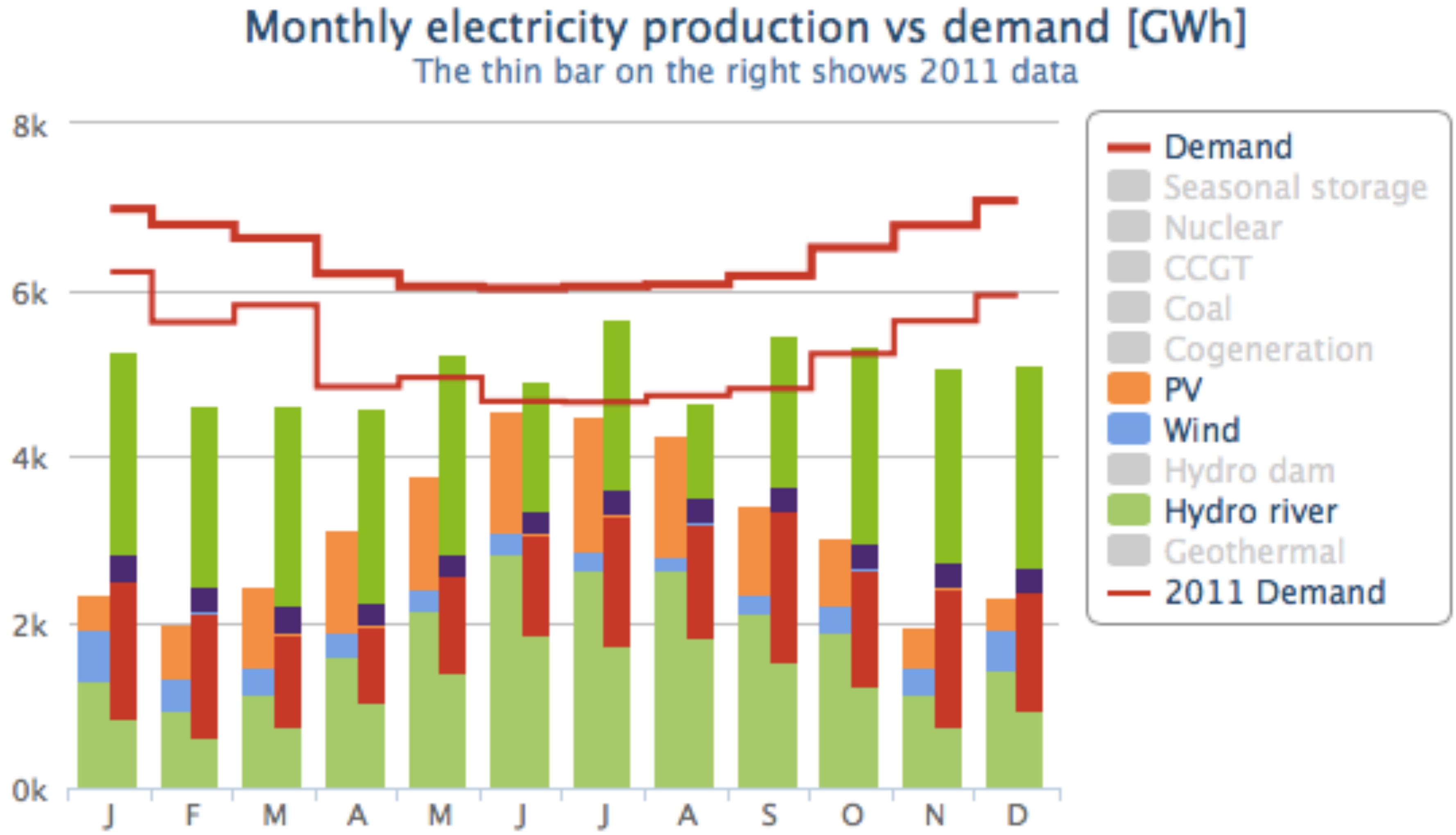
Hydro river [GW]: 4.50 — 0.0 … 4.5

Deep geothermal [GW]: 0.60 — 0.0 … 3.0

CO2 storage: 0.00 — 0.0 … 1.0

Seasonal storage: 0.00 — 0.0 … 1.0

Scenario realistic 2050 elec



Scenario realistic 2050 elec

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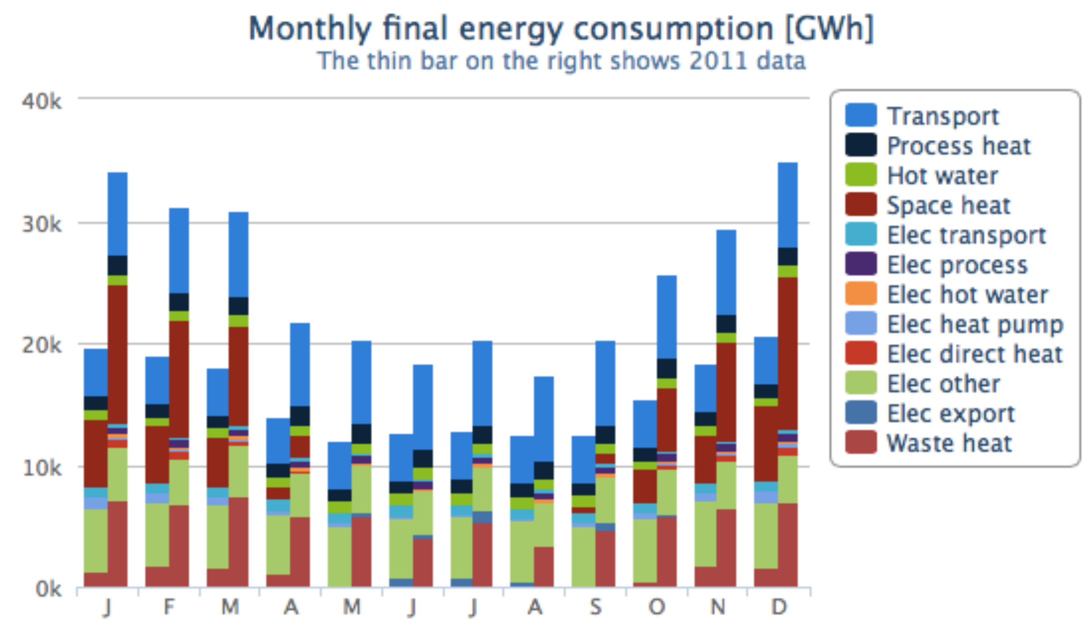

Target Year

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2035 | 2050

General | Transport | Heating & Cogeneration | Electricity

Electricity production capacity

Electricity

Nuclear [GW]: 0.00 (0.0 – 10.0)	Combined gas cycle [GW]: 1.00 (0.0 – 10.0)	Coal [GW]: 0.00 (0.0 – 10.0)
PV [GW]: 12.23 (0.0 – 15.0)	Wind [GW]: 1.50 (0.0 – 1.5)	Hydro dam [GW]: 8.50 (0.0 – 8.5)
Hydro river [GW]: 4.50 (0.0 – 4.5)	Deep geothermal [GW]: 0.60 (0.0 – 3.0)	CO2 storage: 0.00 (0.0 – 1.0)
Seasonal storage: 0.00 (0.0 – 1.0)		

Conclusions

- **Present non sustainable path (global environment)**
- **Major risks (global warming, availability of key materials)**
- **Major opportunities:**
  - **Better indicators and methods for cleaner production and “exergy" is one**
  - **Advanced technologies (heat pumping, co- or tri-generation, recycling)**
- **Importance of energy storage and synthetic fuels in a more renewable society**
- **We need to improve information transfert to politicians and society in general**

Yes we can …… with appropriate methods, indicators and education

- Stone age did not end due to lack of stones
- Let's not wait until the end of oil …. to act more intelligently

Attributed to sheikh Yamani

Regarding Swiss Energyscope, thanks in particular to PhD students Victor Codina and Stefano Moret, to Prof F.Marechal and to Routerank programmers and Claude Comina for communication

Any lesson to learn?

Aren’t we overloading our environment?