ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Energy
Center

Advanced integrated systems and design methods for improved energy efficiency

http://powersave1200.tumblr.com/

World Future Energy Forum
2016, Beijing

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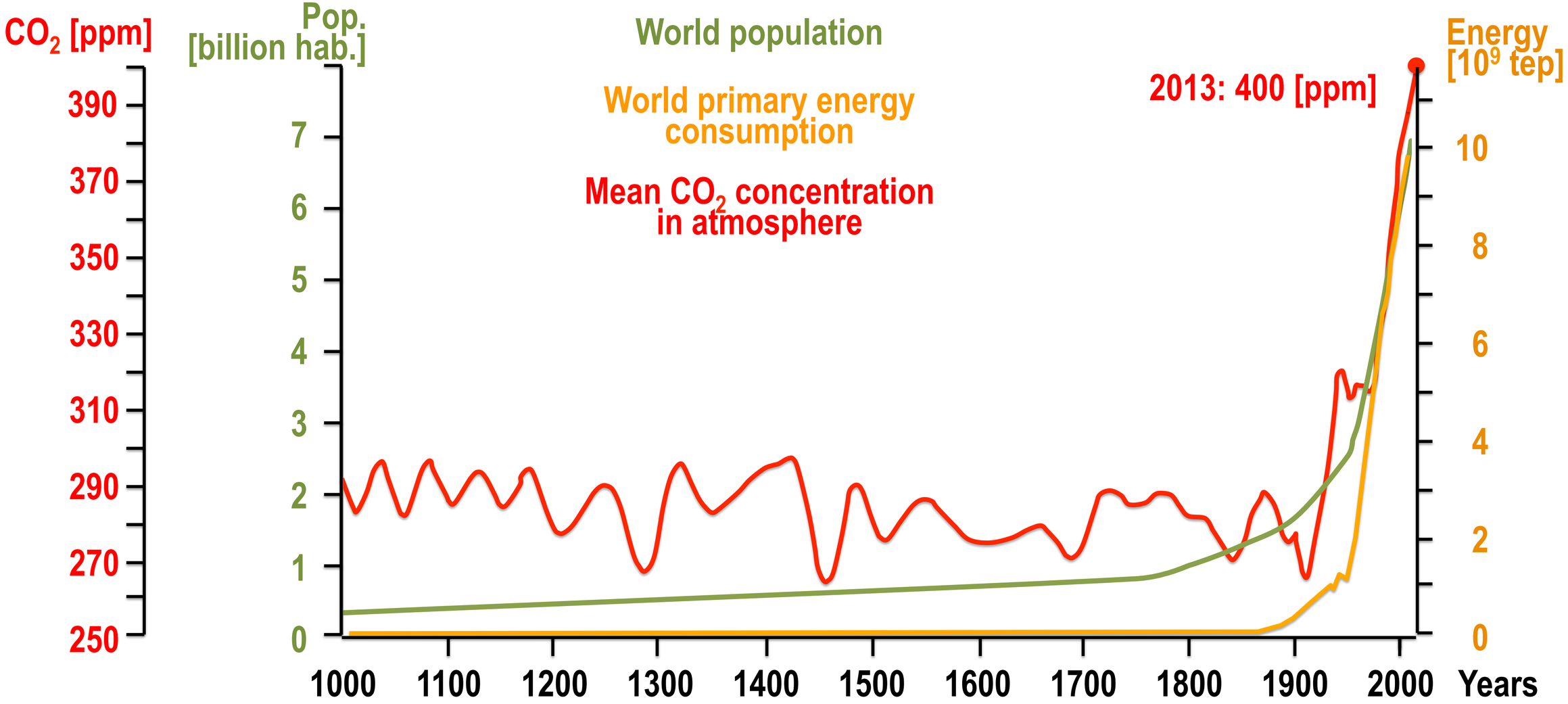
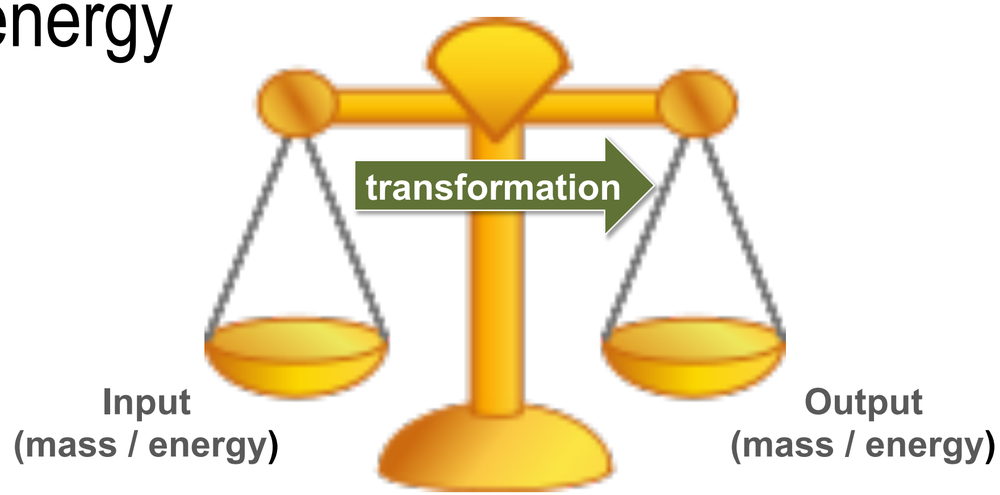
Energy, population, environment (historical evolution)



Technological innovation objective: → less degradation

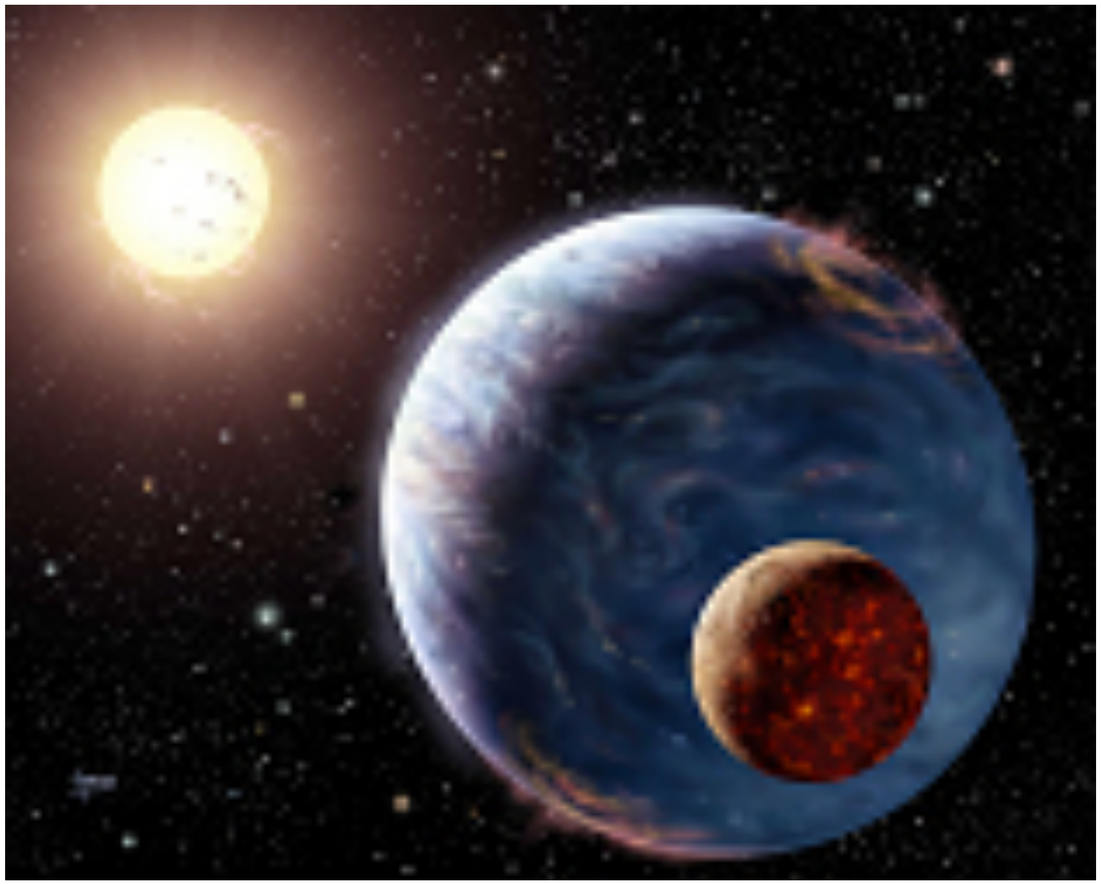
- Physics: conservation of mass and energy



- The confusion about the meaning of «energy»: Greek word "*energeia*" (containing work)

- But: driving forces result from un-balances (of exergy levels, of con-centration 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, food for animals and humans
- Degradation is part of life, but …

Technological innovation objective: → less degradation

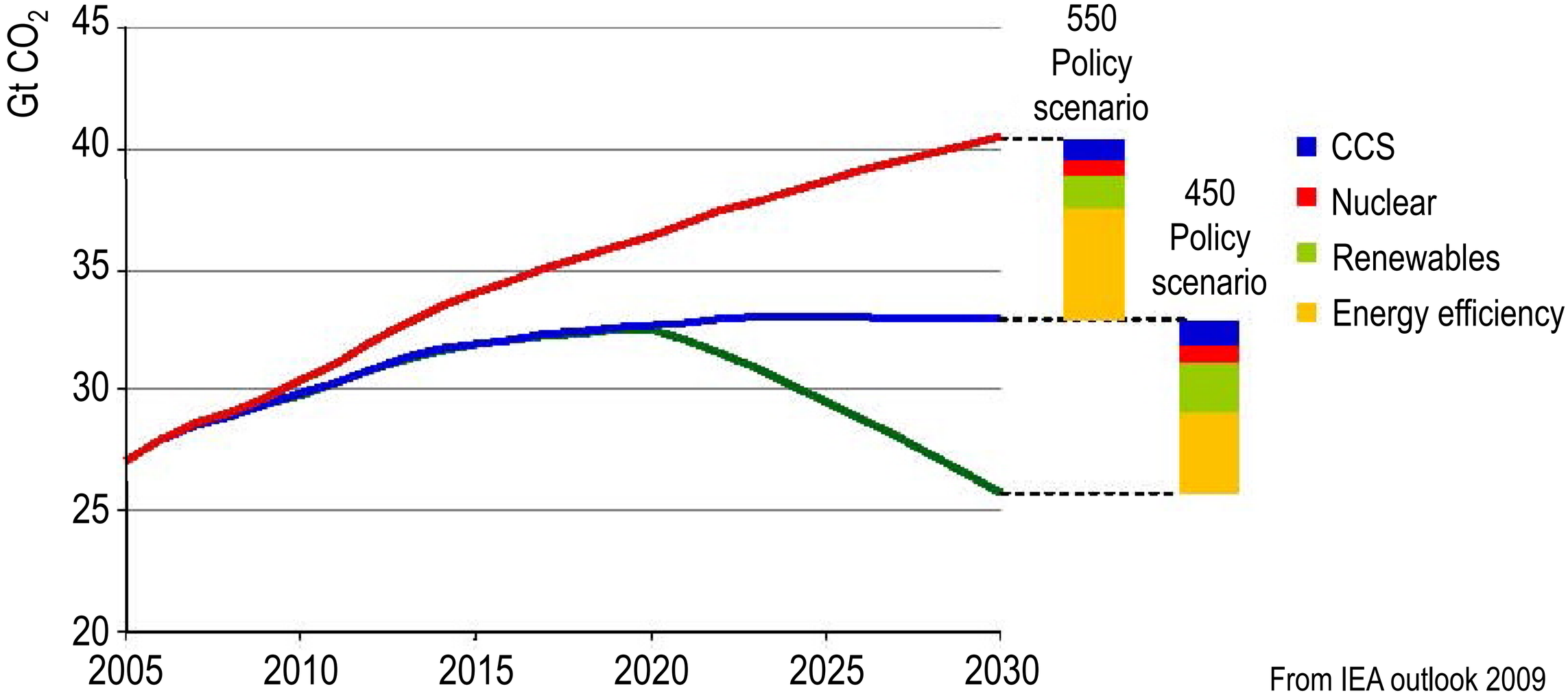


http://chandra.harvard.edu/edu/formal/ems/ems_earthMoon.html

… would be sustainable if the tremendous potential of the Sun-Earth exergy unbalance would be used properly to:

- satisfy energy services
- recycle materials and wastes
- clean or desalinate water
- …

Energy efficiency: best way to reduce CO_2 emissions

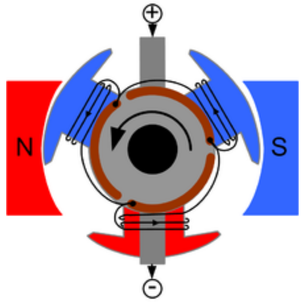


From IEA outlook 2009

Energy services

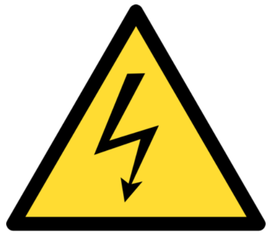
- Heat (from high temperature energy processes in industry to low temperature heating in building)

- Mechanical energy (pumping, compression, transport …)

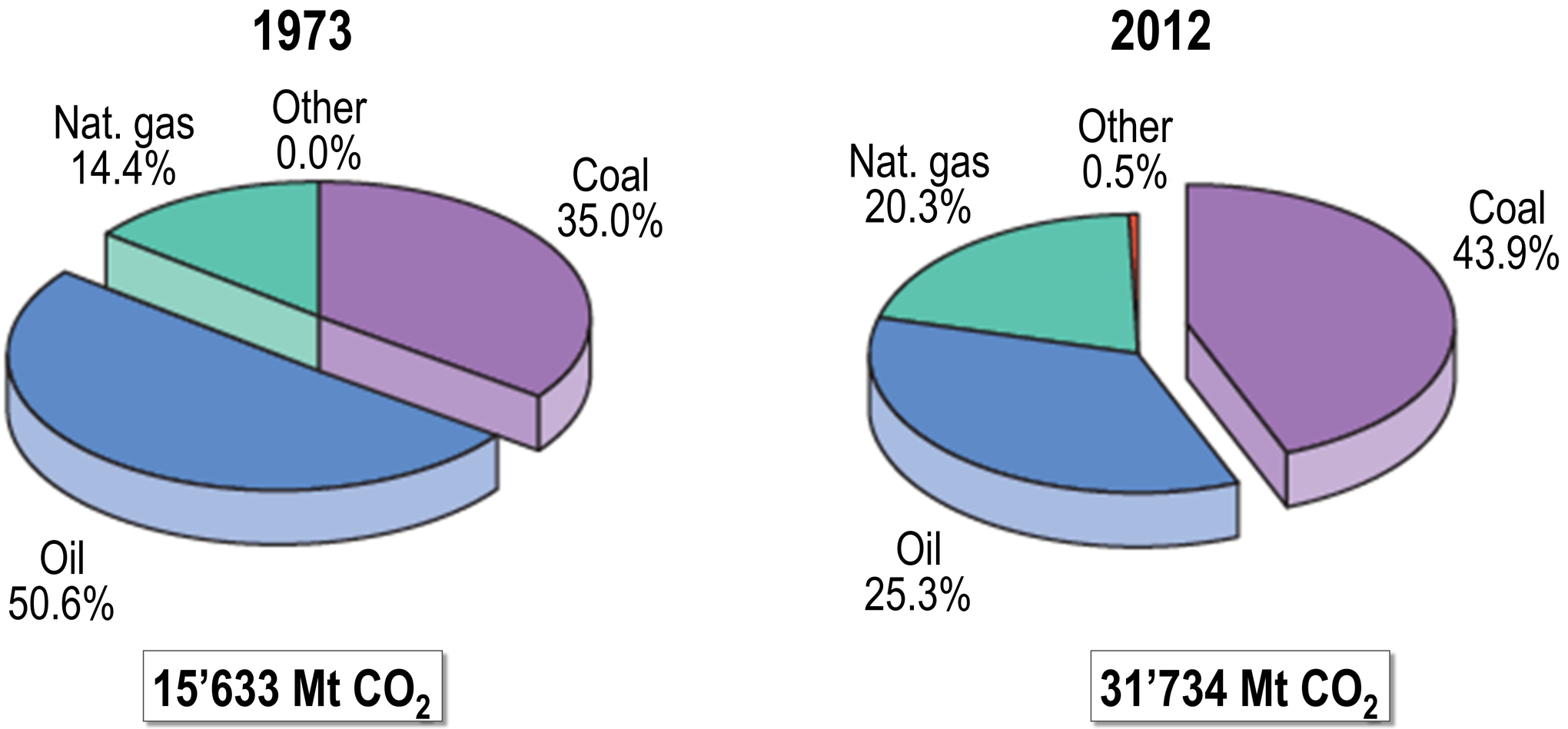


- Cold (from air conditioning to refrigeration, freezing and cryogenic processes)

- Electricity (previous services + cooking, lighting, computing, telecommunication, etc.)



World fuel shares of CO_2 emissions

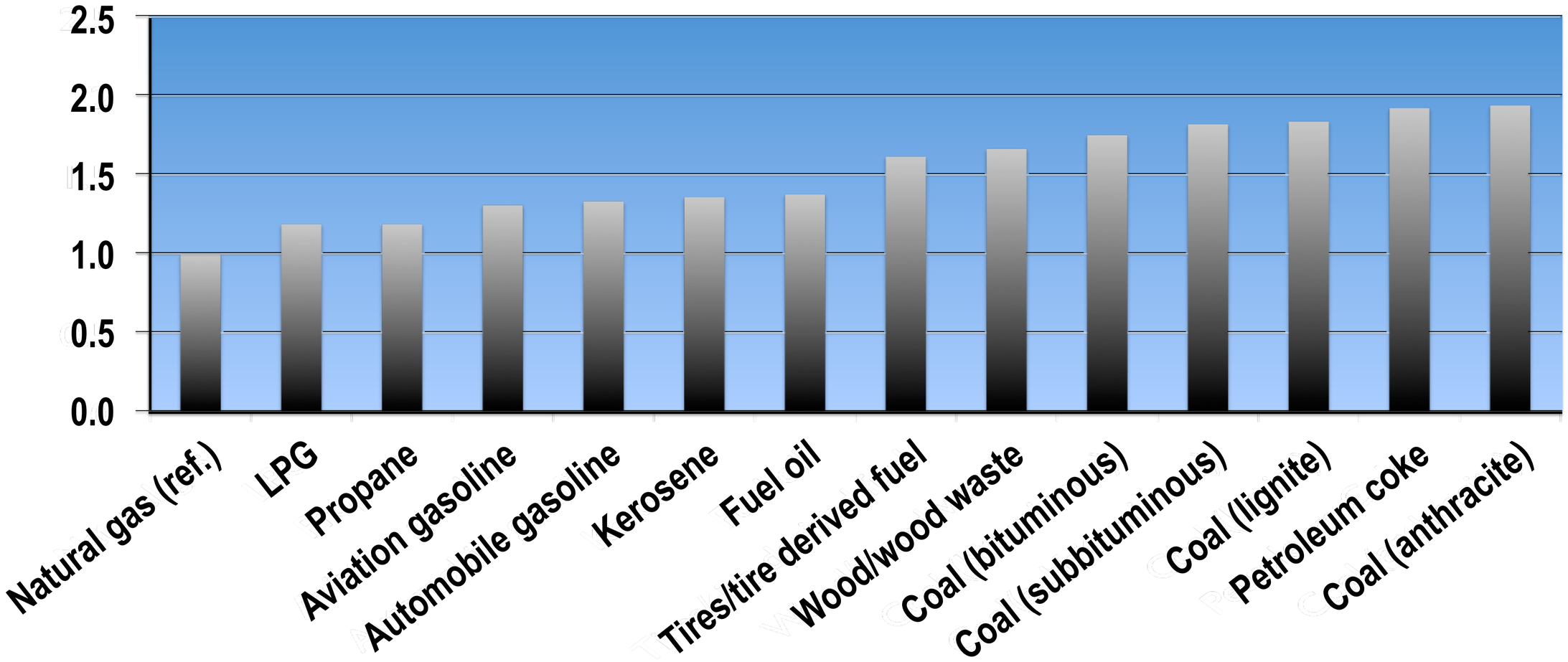


15'633 Mt CO_2

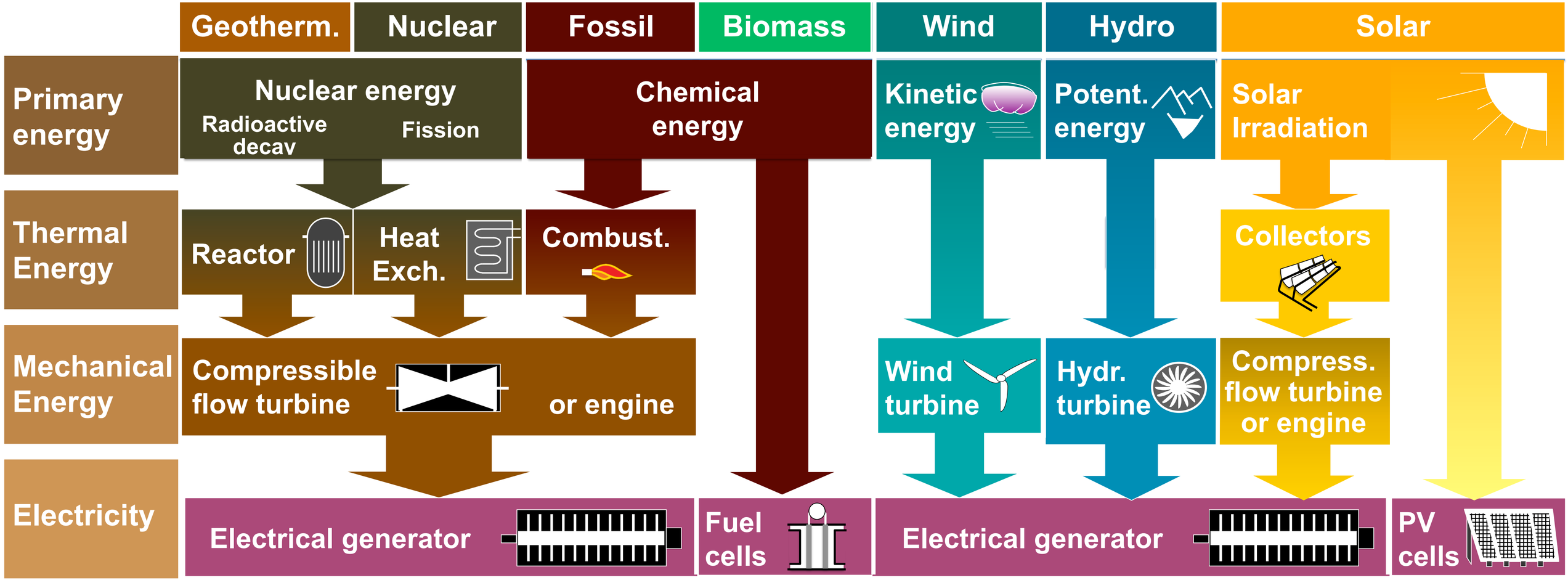
31'734 Mt CO_2

From IEA outlook 2014

Relative CO_2 emissions per unit of energy of main fuels

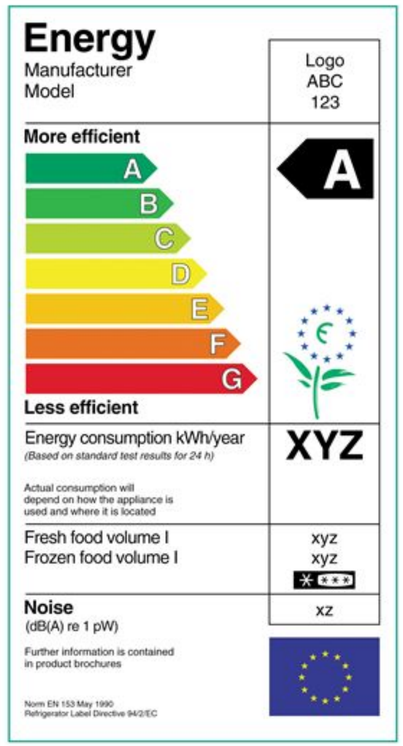


From primary energy to electricity



Favrat D. et al. "The information platform energyscope.ch on energy transition scenarios", Proceedings of ECOS 2016, Portoroz Slovenia.

Three main action paths towards energy efficiency

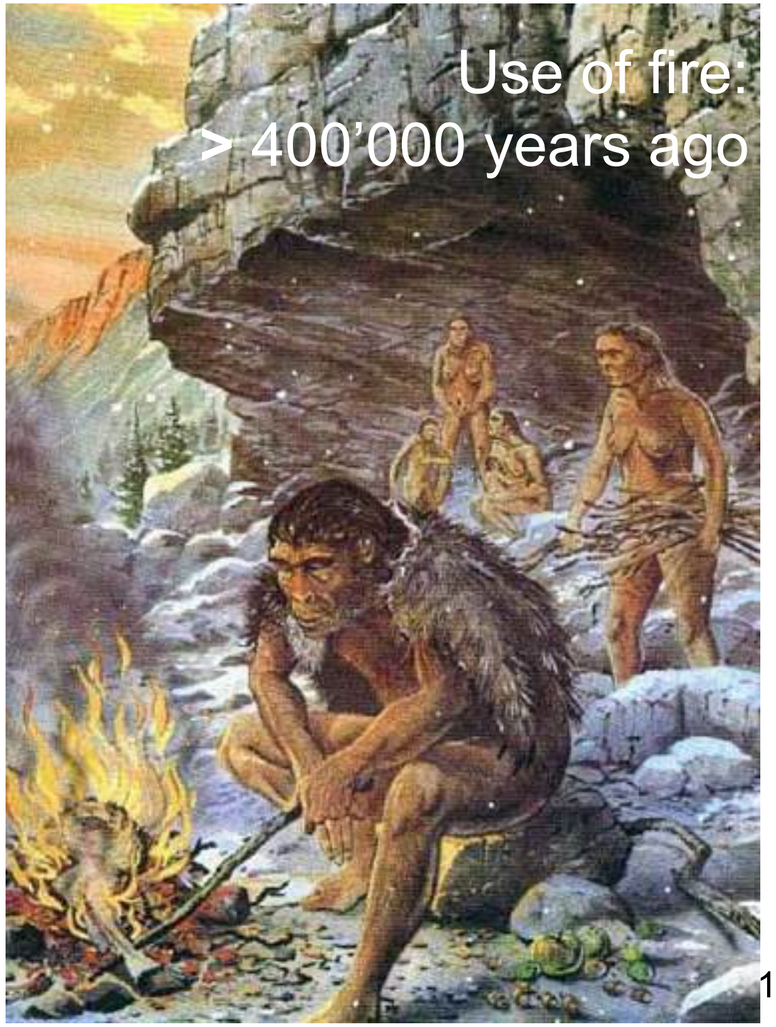


- Develop better indicators for ecoefficiency and sustainability (exergy efficiency, renewable energy ratio, ...)
- Develop improved design and planning methods (holistic, able to optimize complex integrated systems towards increased efficiency, …)
- Develop advanced technologies for a more rational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

http://solex-un.ru/energo/formaty-energomarkirovok /
http://www.purepropertycare.co.uk/commercial-services/insulation/

Example: combustion and heating

- Use of open fire for heating and cooking discovered more than 400'000 years ago
- Today's heating systems are still mostly boilers
- The energy efficiency of boilers is close to 100% (sometimes improperly claimed to be > 100% in the literature!)
- Can this however really be considered as a 21st century technology?



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

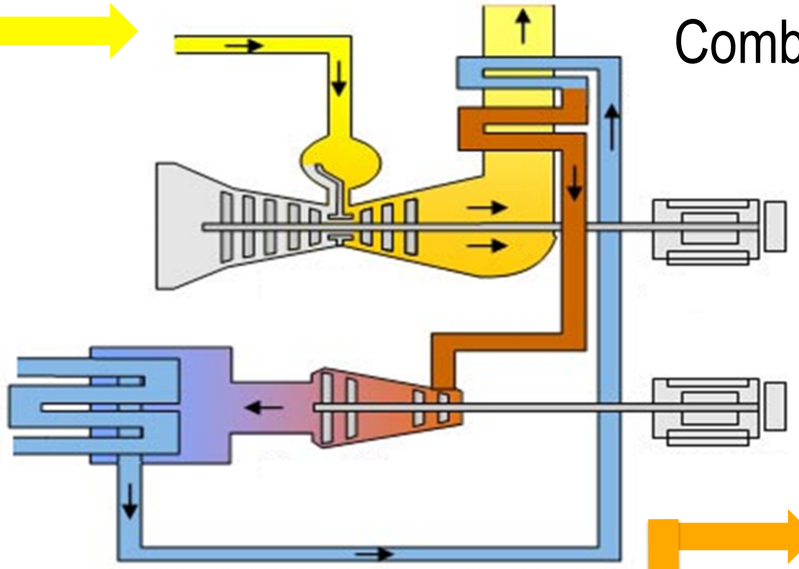
Better alternative for heating with the same types of fuel

Oil or (bio-)gas

1.0

1.0

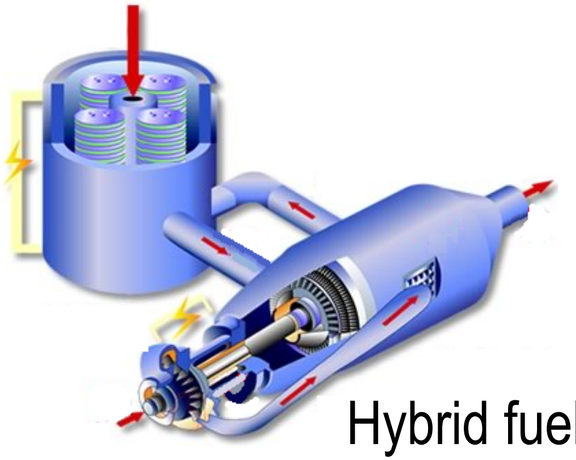
Combined cycle



0.6x4.5=2,7

0.6x4.5+0.3=3.0

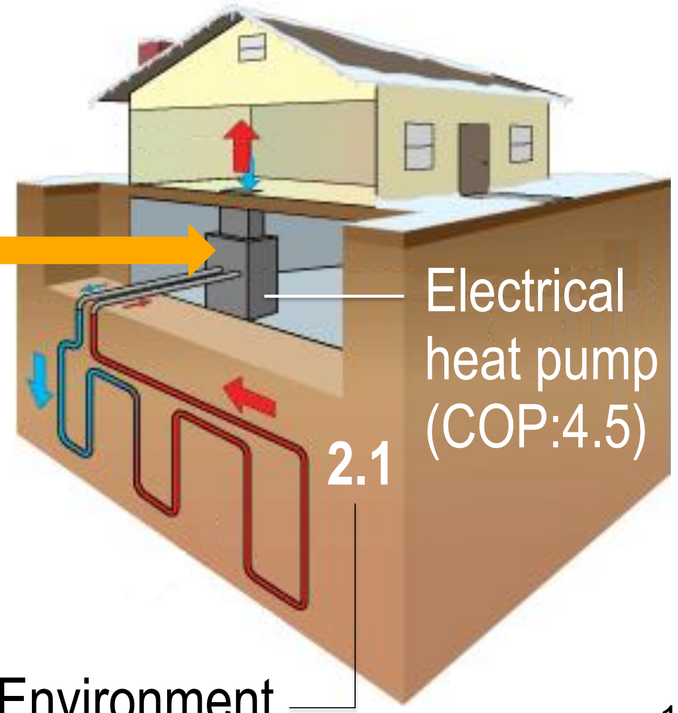
0.6



Hybrid fuel cell
SOFC + GT

0.6 (electricity)

0.3 (heat)

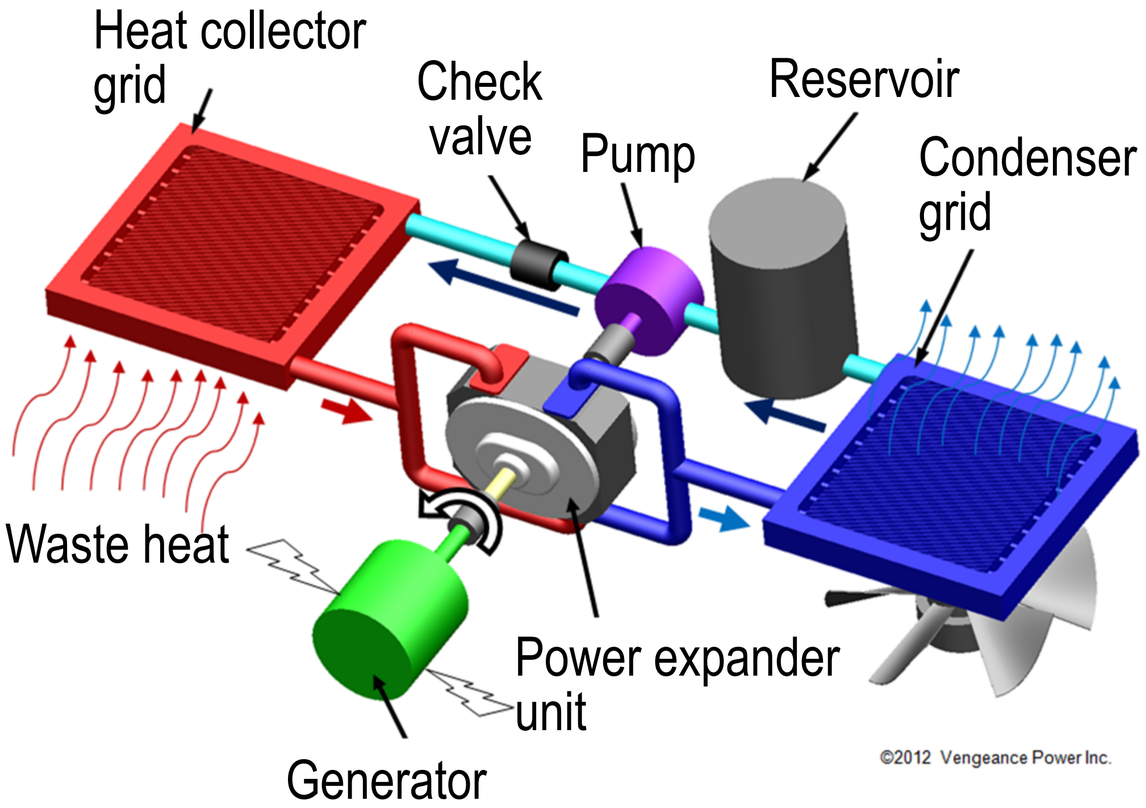


Exergy efficiency > 16%

http://www.ztekcorporation.com/sofc_turbine.htm; http://www.britannica.com/science/geothermal-energy; http://www.power-technology.com/projects/uskmouth/

Waste heat recovery with Organic Rankine Cycle (ORC)

- Power generation from waste heat



- Example: recovery from fluegas at mean q = 120°C

Thermal "efficiency": $\varepsilon = \frac{E}{Q} = \left[1 - \frac{T_a}{T}\right]$

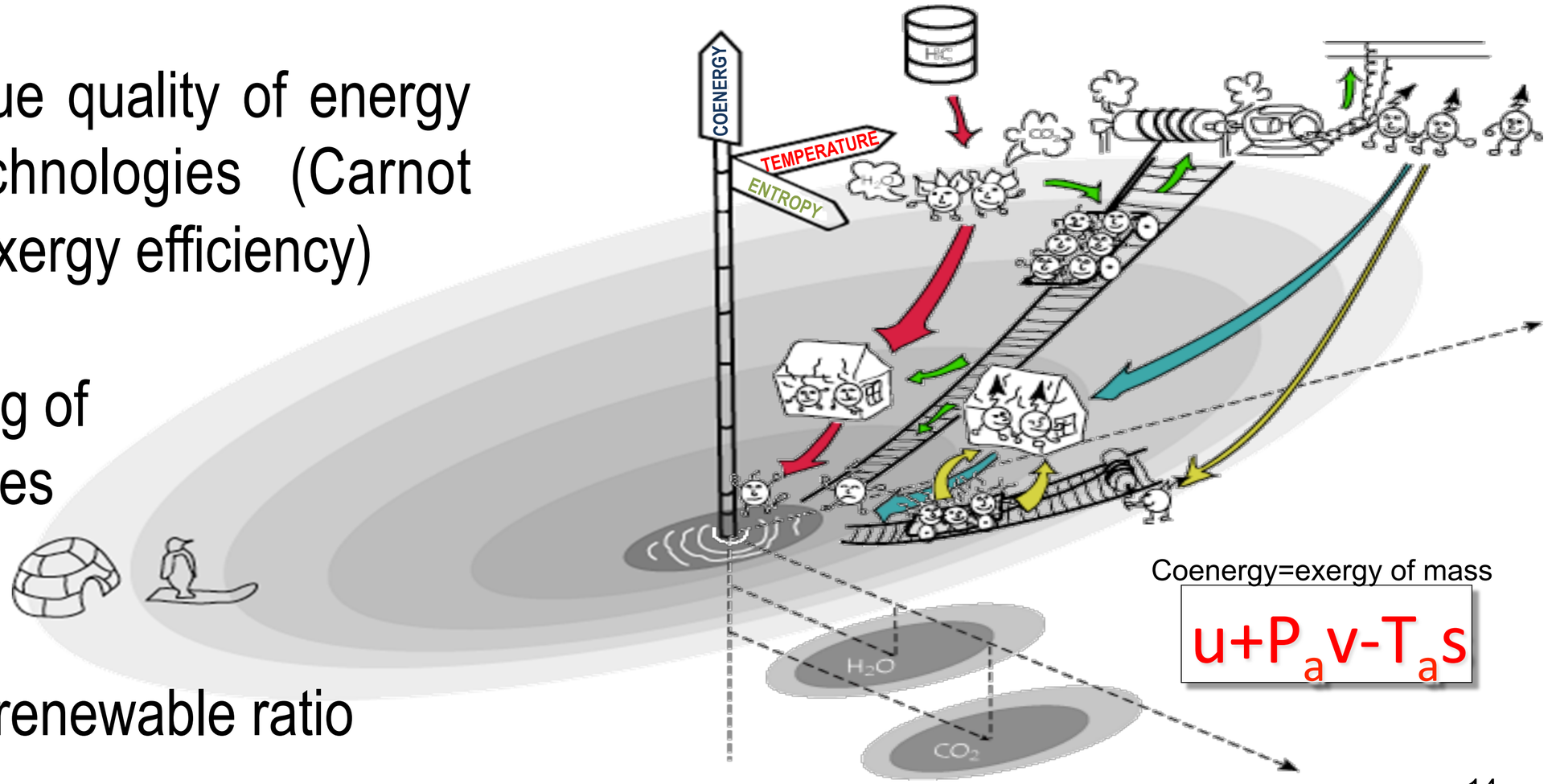
For q_a = 20°C, ε = 25%, but the true efficiency of a Carnot ideal engine is100%

Exergy efficiency: $\eta = \frac{E}{Q\,[1 - T_a / T]} = 1$

Exergy efficiency is a better indicator!

Exergy efficiency, a better indicator than 1st Law efficiency

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

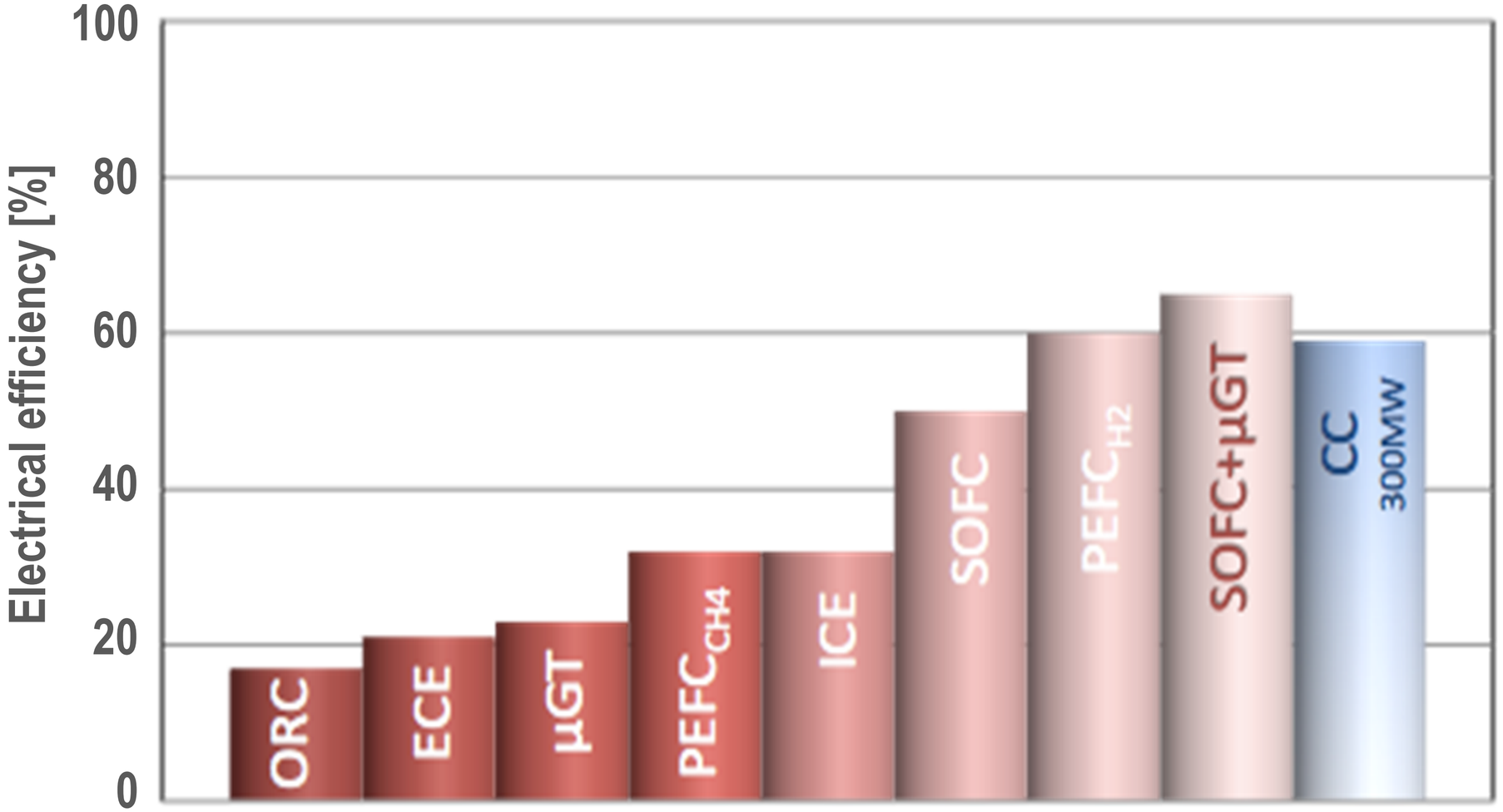


Coenergy=exergy of mass

$$u+P_a v-T_a s$$

BOREL L., FAVRAT D. *Thermodynamics and energy systems analysis.* EPFL Press (2010)

Electric efficiency of different technologies



ORC
Organic Rankine Cycle

ECE
External Combustion Engine

ICE
Iinternal Combustion Engine

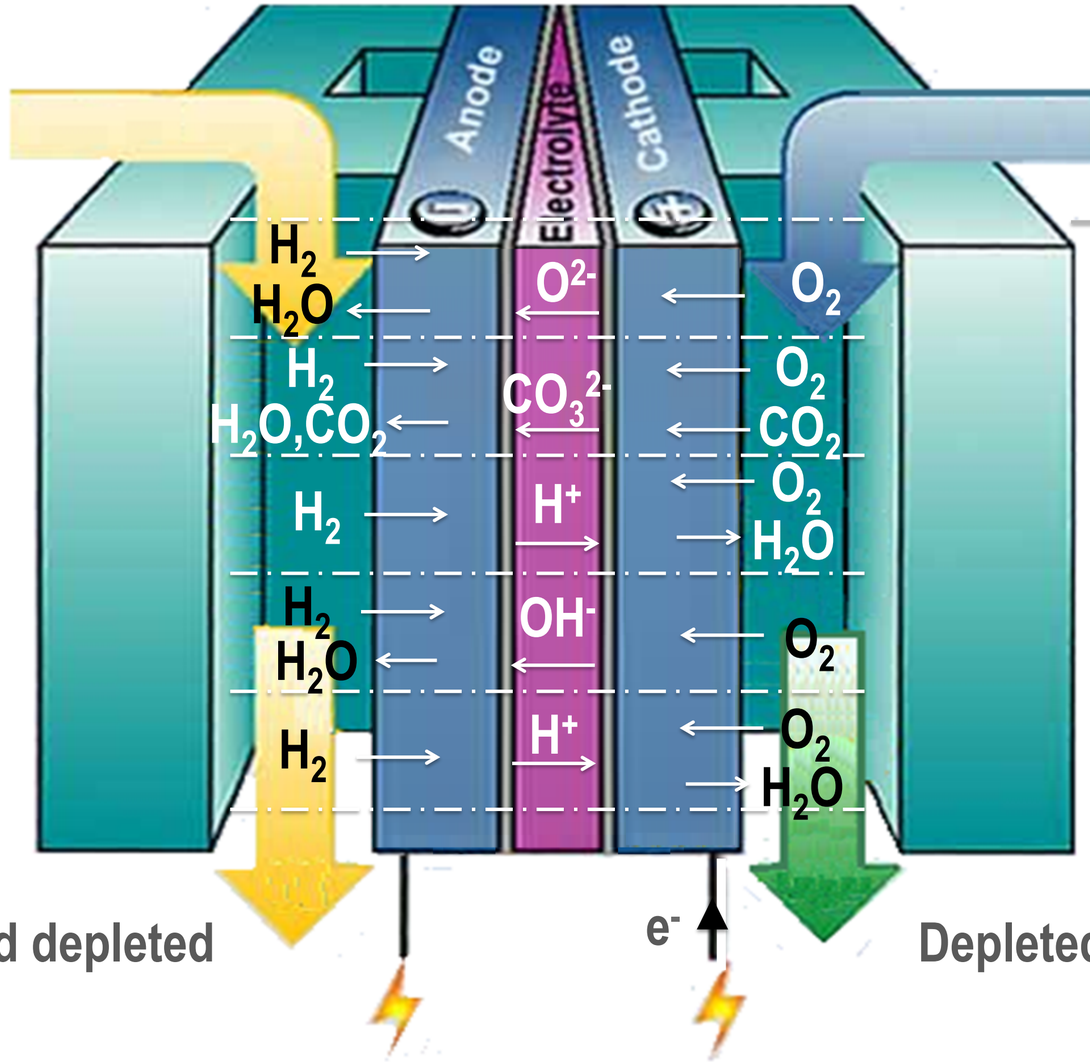
µGT
Micro-gas turbine

PEFC
Polymer electrolyte FC

SOFC
Solid oxide fuel cell

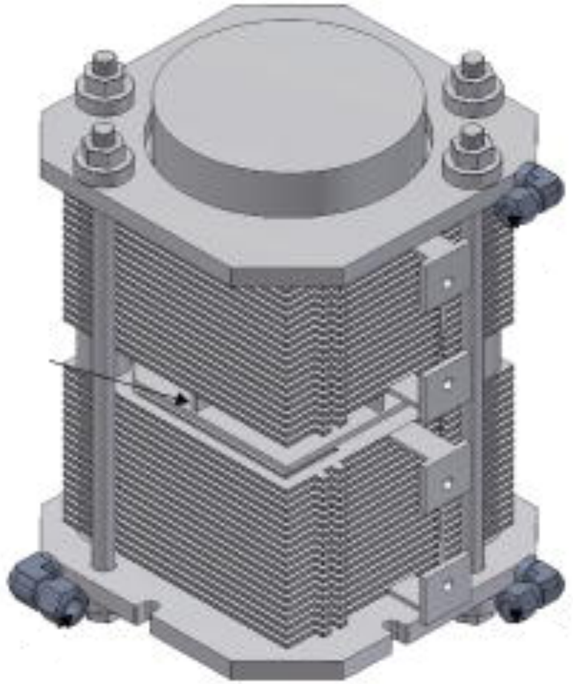
CC
Combined cycle

Fuel cell technologies



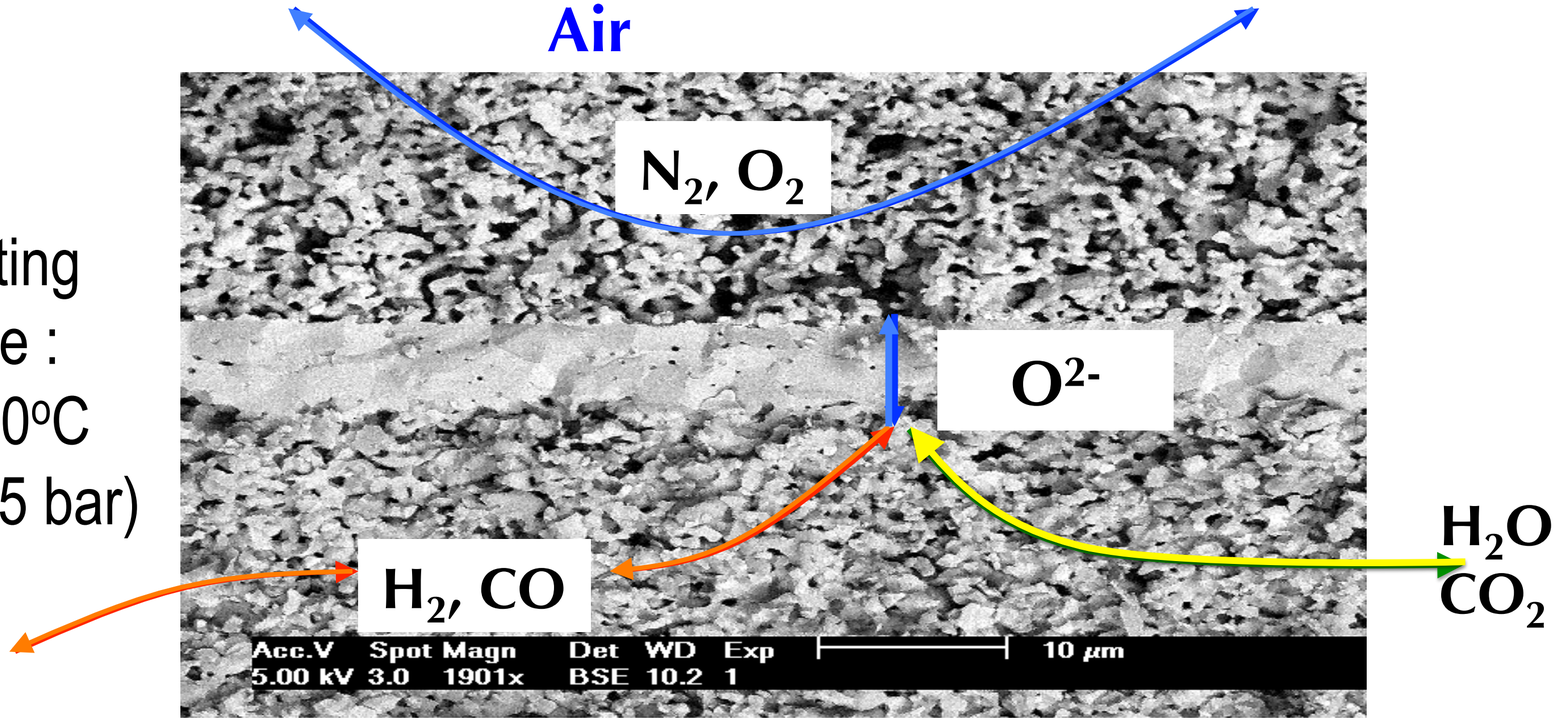
	$T_{operation}$
SOFC	650-1000°C
MCFC	650°C
PAFC	200°C
AFC	50-100°C
PEFC	50-100°C

Cogeneration with Solid Oxide Fuel Cell (SOFC)



Solid Oxide Fuel Cell stack

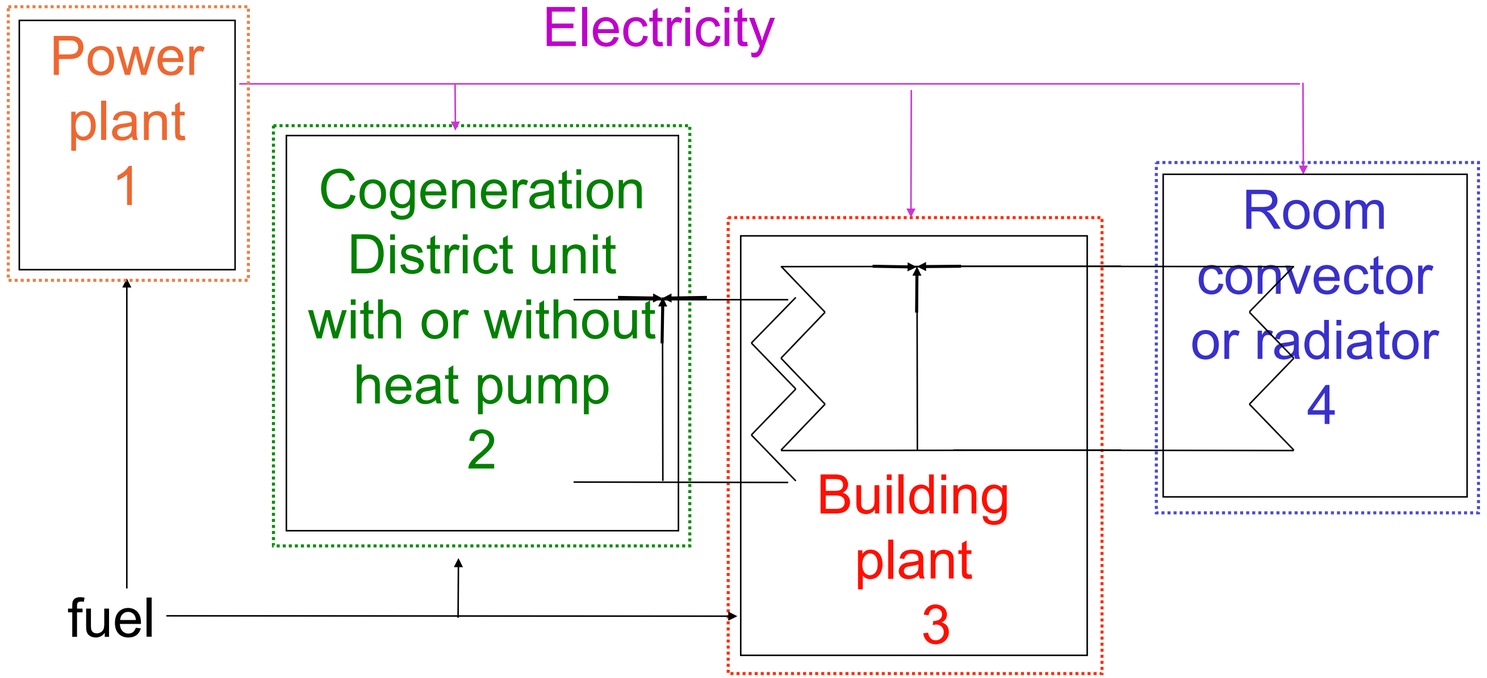
Operating regime :
700-800°C
1 bar (to 5 bar)



Reformed Natural Gas

Can potentially be inversed
(High temperature electrolyser for storage)

Exergy efficiency in a Law (Geneva): System decomposition

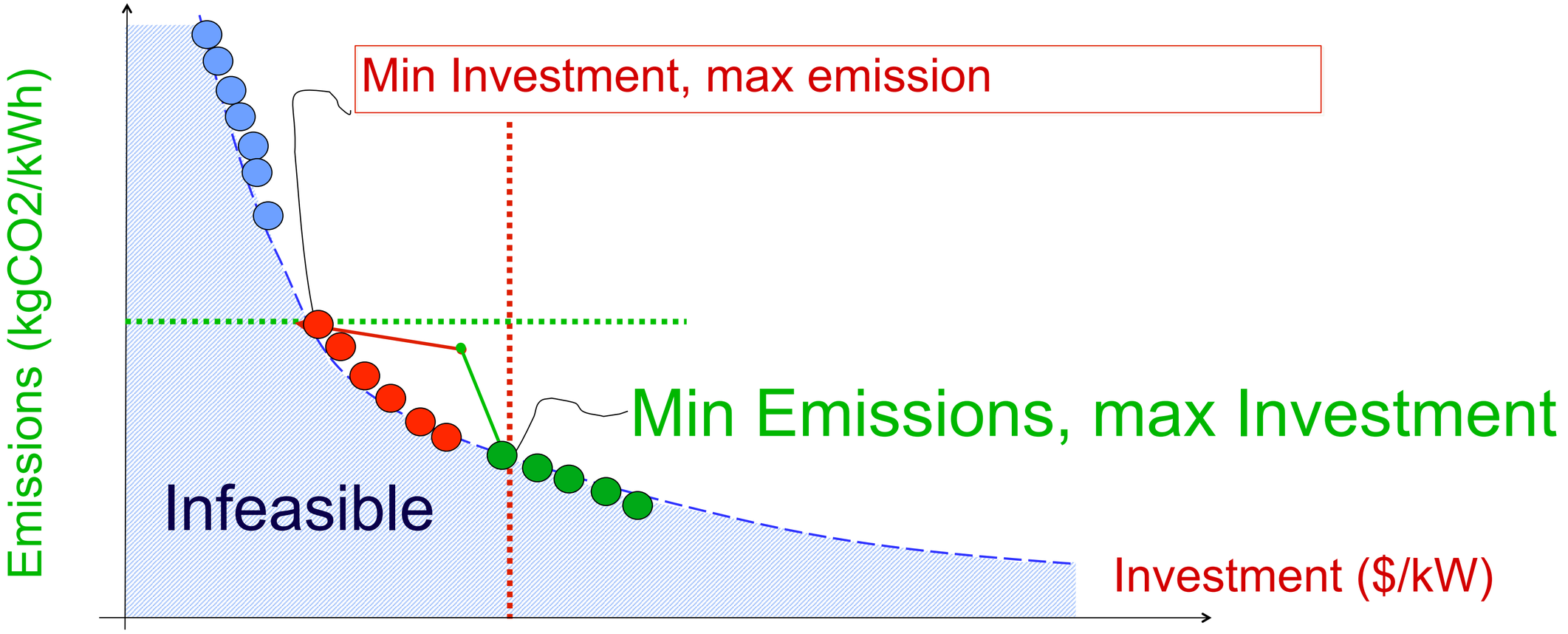


Key messages from exergy analysis:

- Heat in the coolest way (heating temperature the closest to the need)
- Cool in the warmest way (cooling temperature the closest to the need)

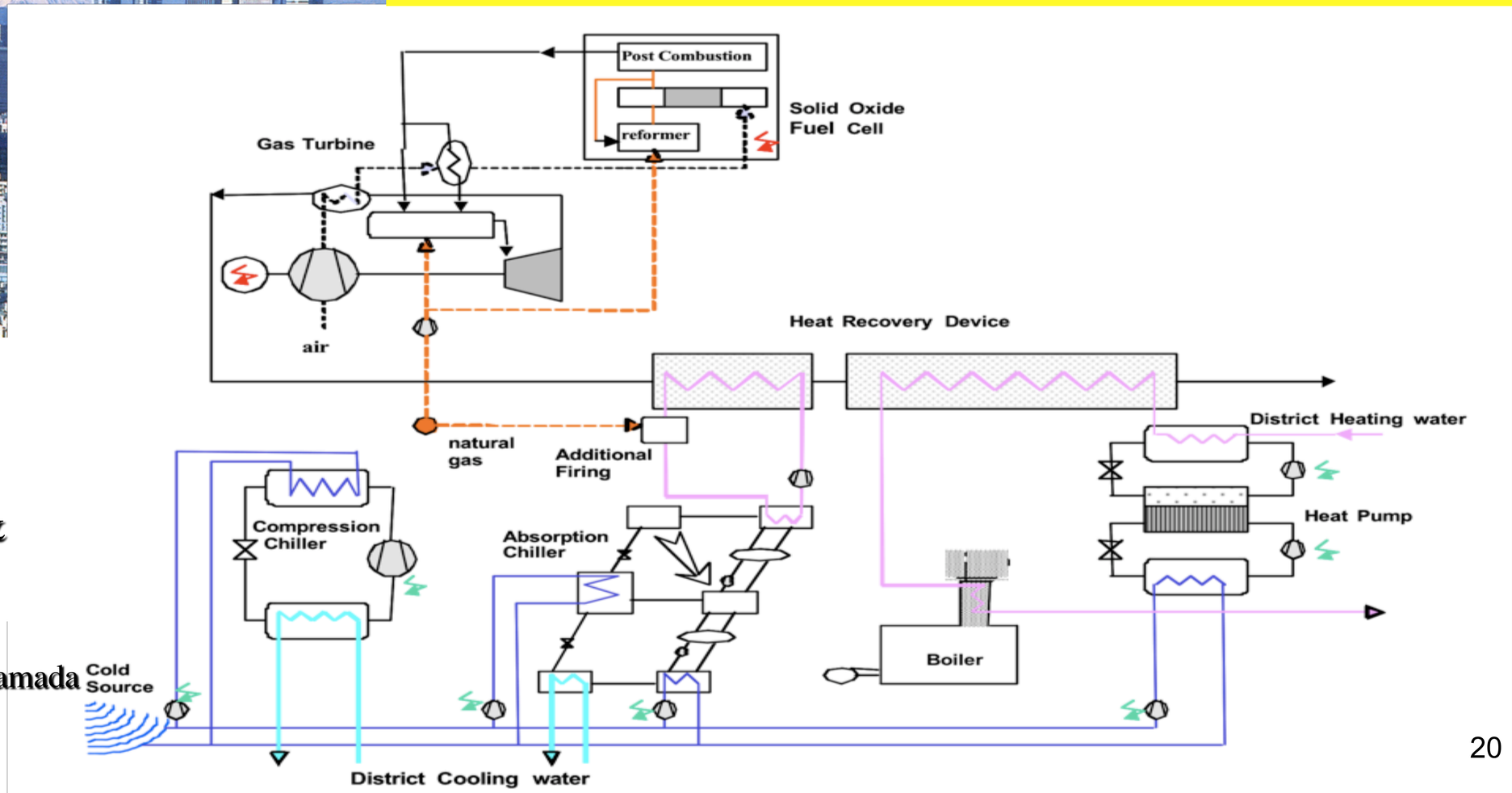
FAVRAT D., MARECHAL F., EPELLY O. *The challenge of introducing an exergy indicator in a local law on energy.* Energy,33, No2, pp130-136 (2008)

Managing the complexity of integrated systems: multi-objective optimisation



Ex: multi-objective optimisation of a trigeneration plant in a city

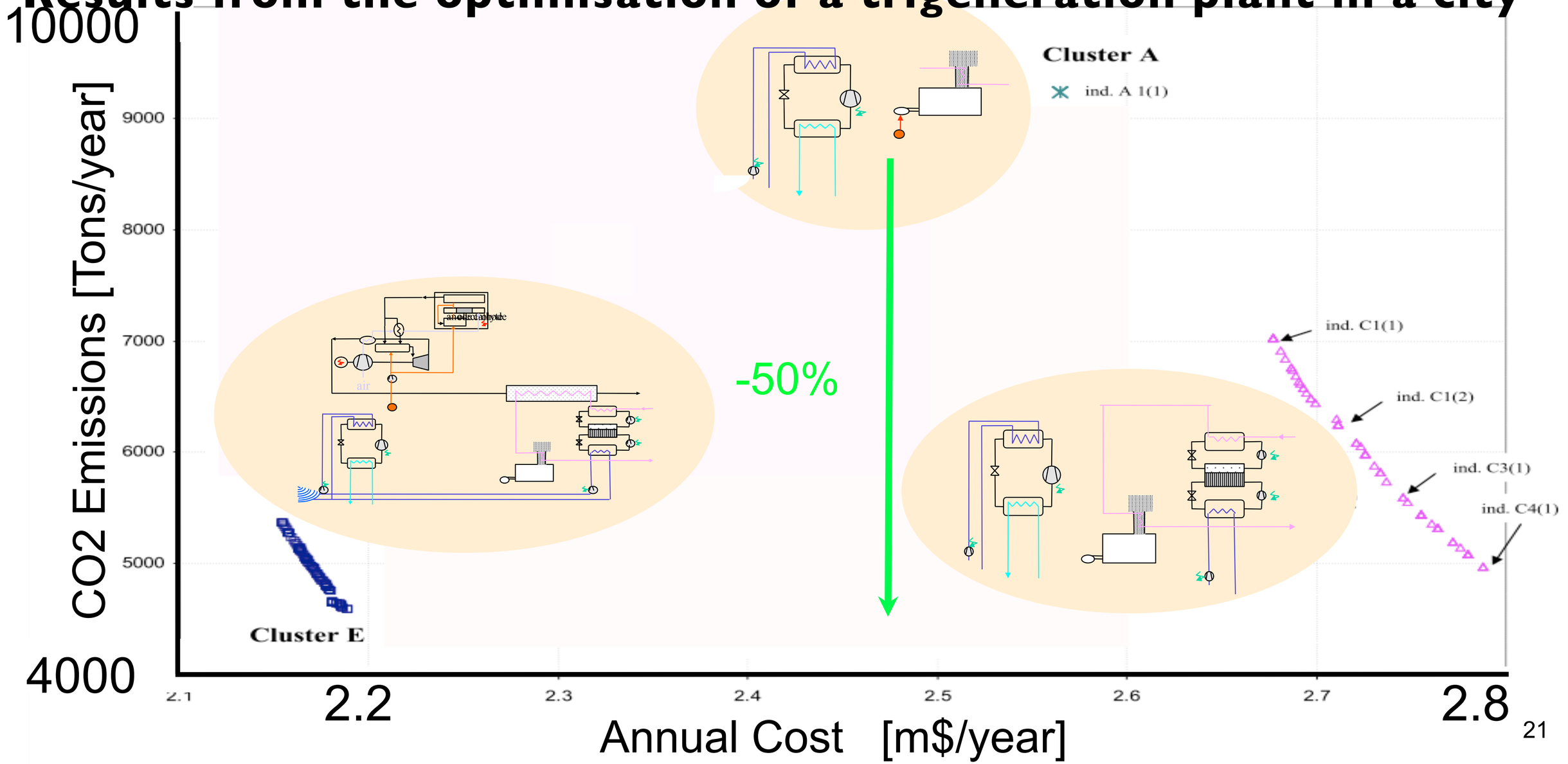
From GIS to advanced integrated energy systems



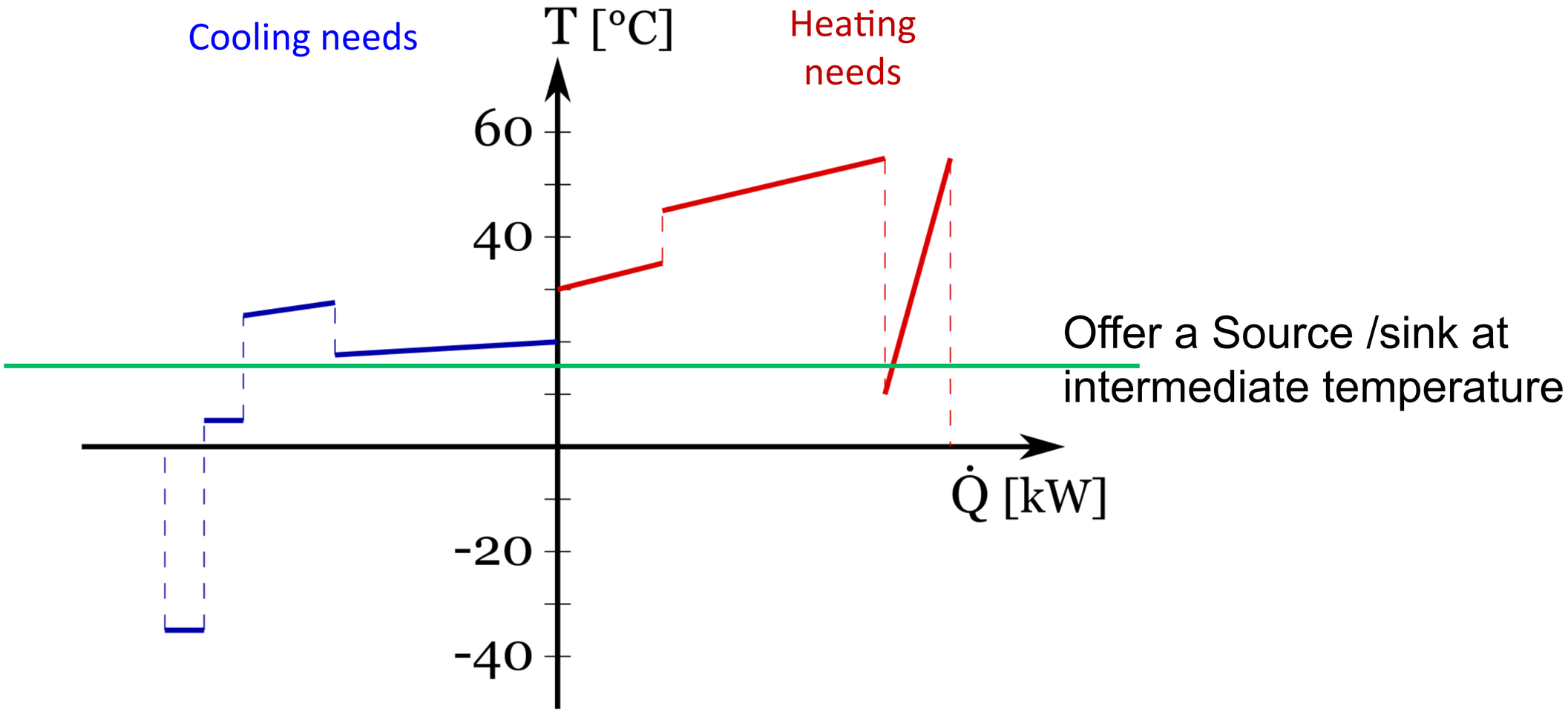
Alliance of Global Sustainability
Tokyo half:
A collaboration with MIT & University of Tokyo:

[Bürer M. , Tanaka K. , Favrat D. , Yamada K. in: Energy 2003]

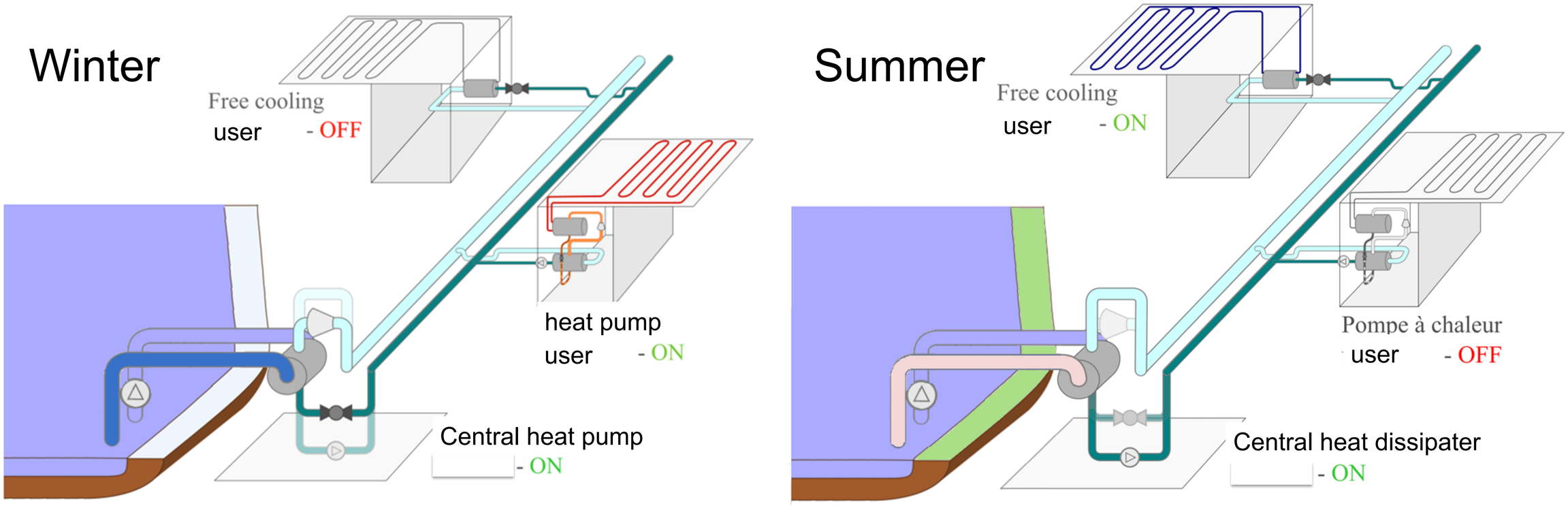
Results from the optimisation of a trigeneration plant in a city



Advanced urban networks for increased synergy between users

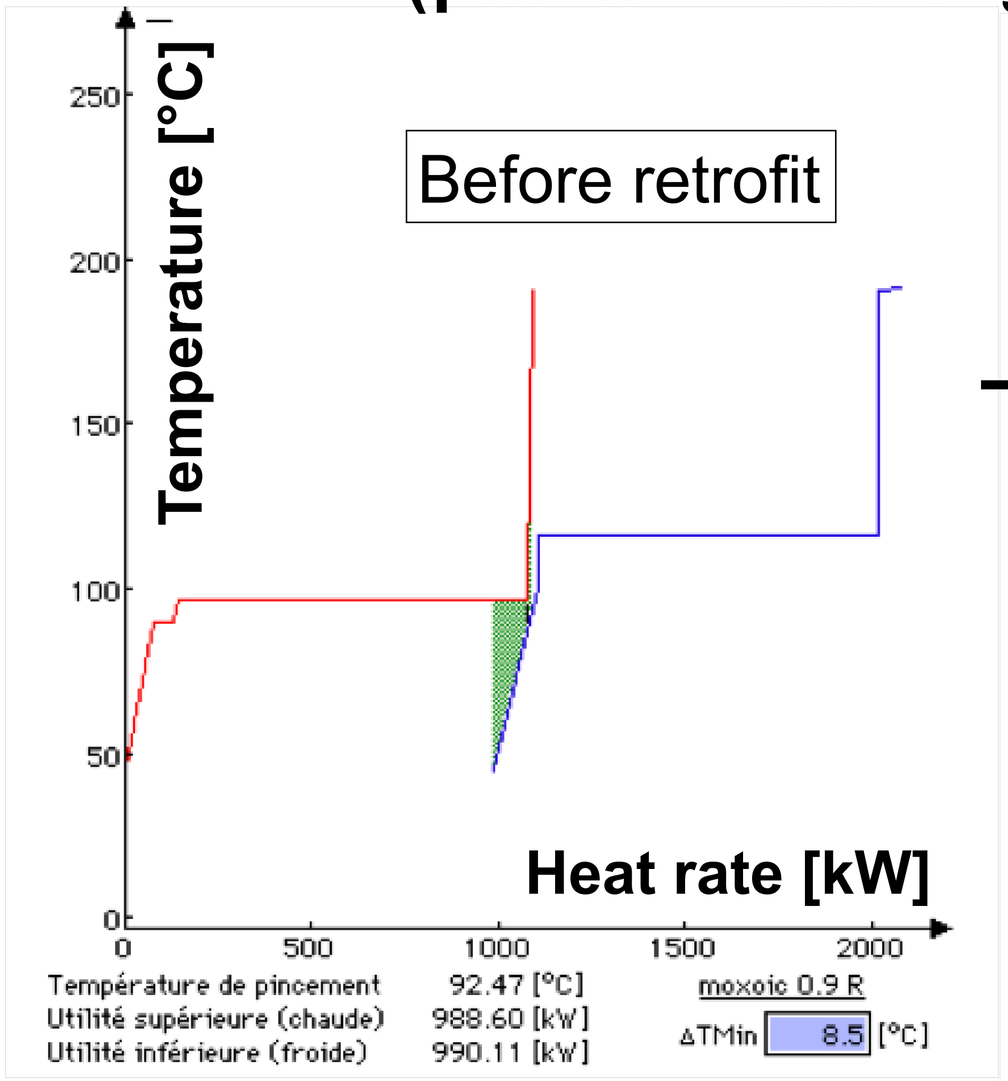


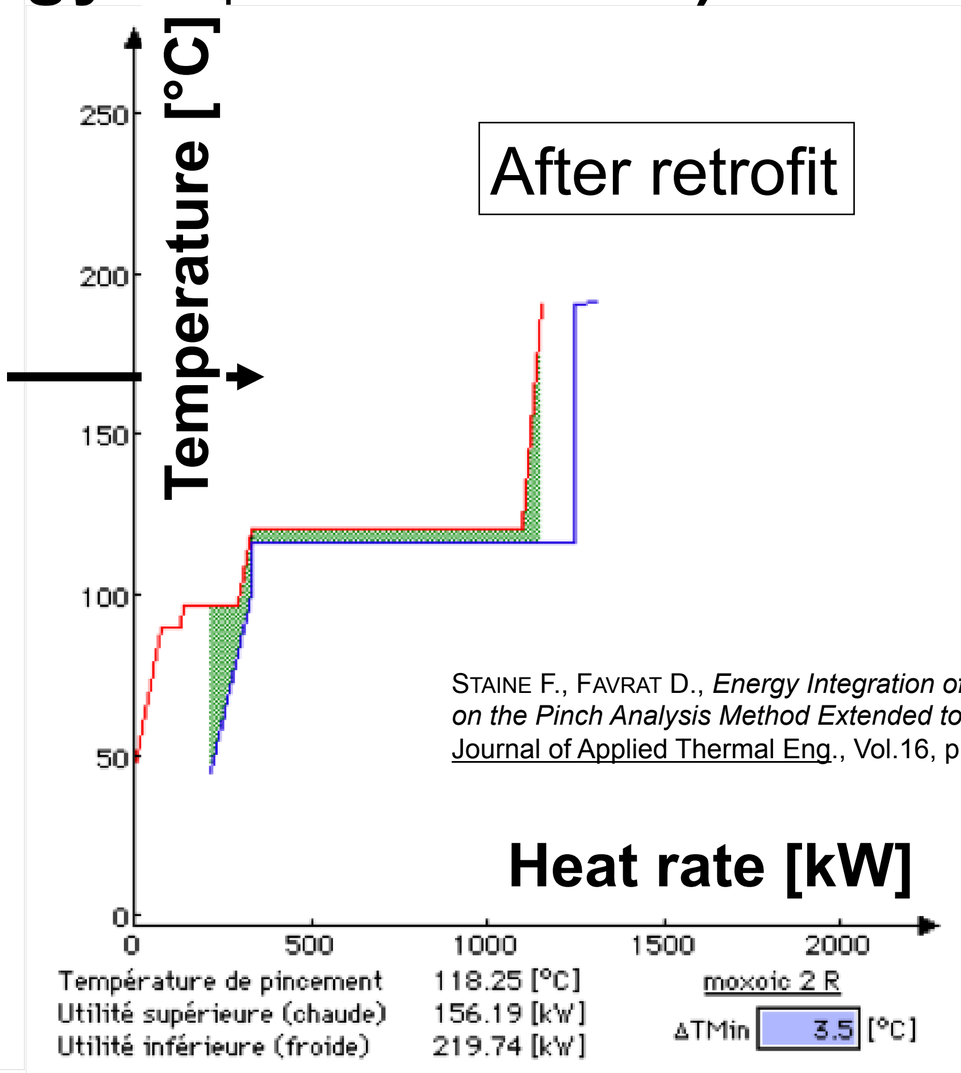
District heating and cooling CO_2 network



Henchoz S., Favrat D., et al. "Key energy and technological aspects of three innovative concepts of district energy networks" in Energy, June 2016

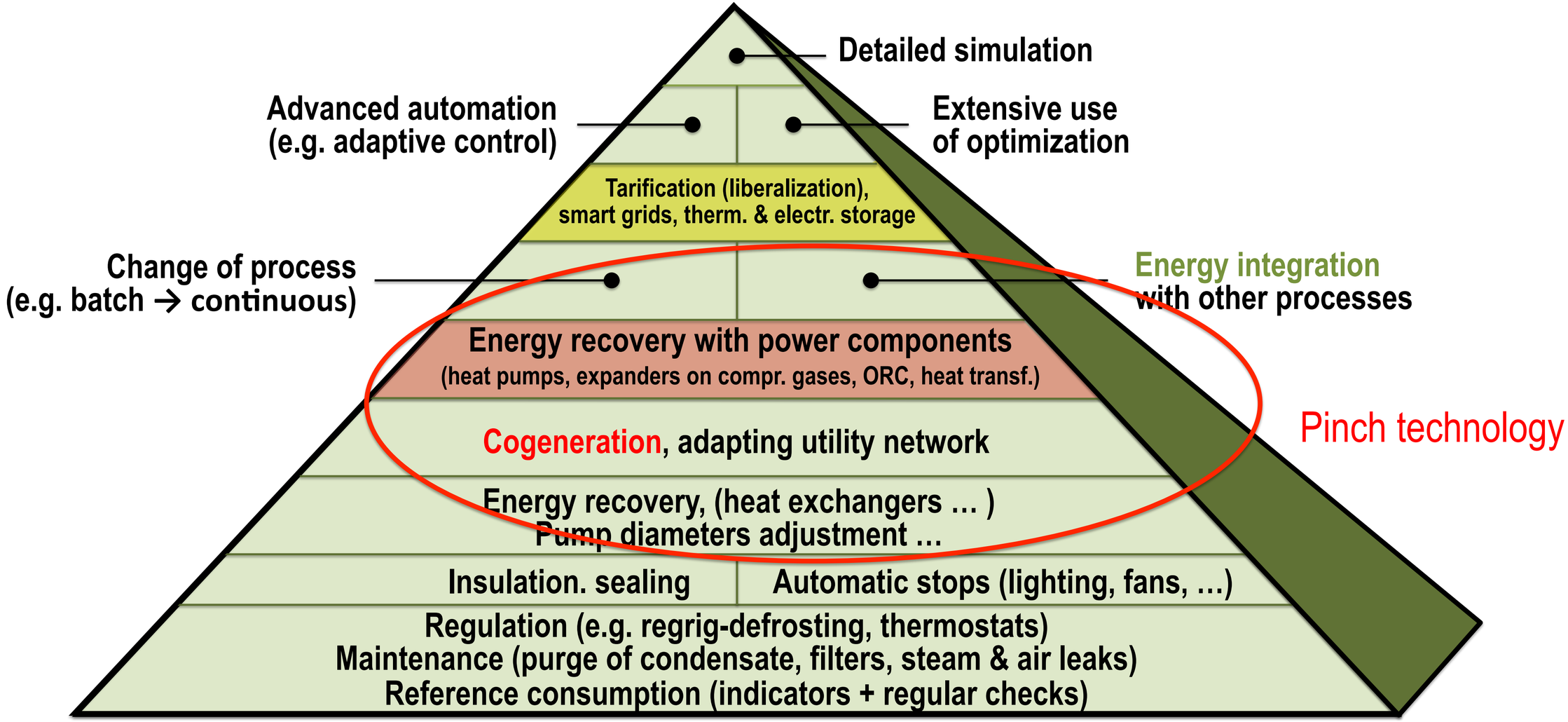
Mechanical vapor recompression in industrial processes (pinch technology representation)





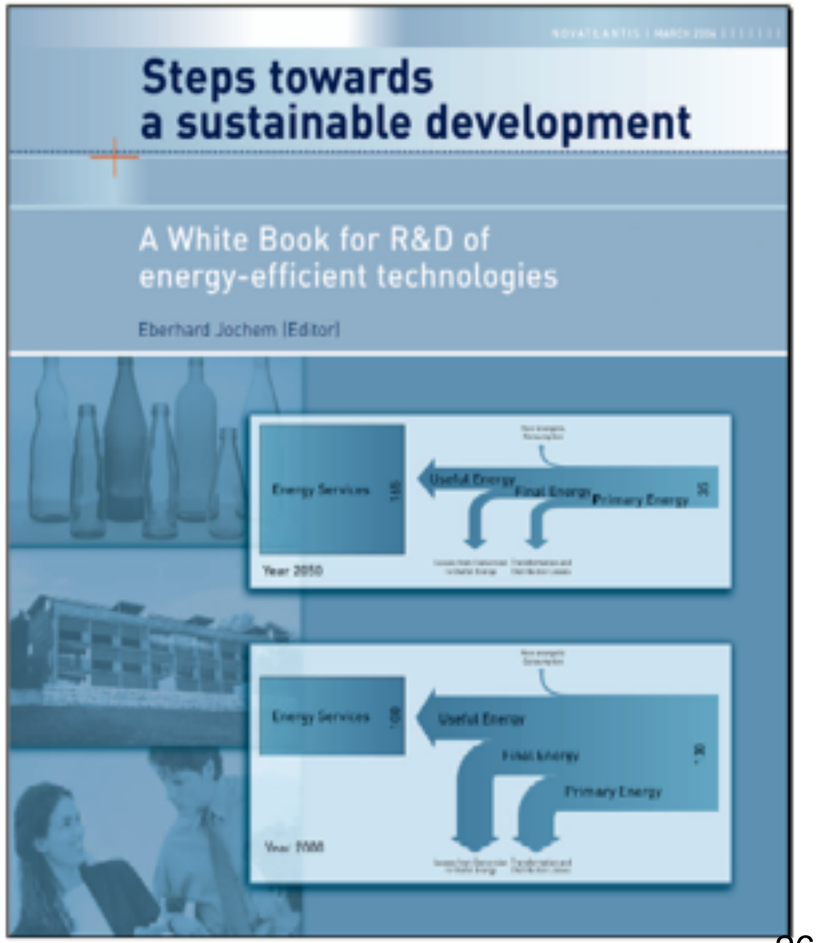
STAINE F., FAVRAT D., *Energy Integration of Industrial Processes Based on the Pinch Analysis Method Extended to Include Exergy Factors*. Journal of Applied Thermal Eng., Vol.16, pp. 497–507, 1996

Hierarchy of energy saving actions in industry



Towards a 2000 watts society

- Target of a 2000 W.year/(year.cap) (average world consumption in year 2000)
- 1 t CO_2/(year.cap)
- Controversial definition and objectives but intended to give a marketing impulse to the look for a better energy efficiency

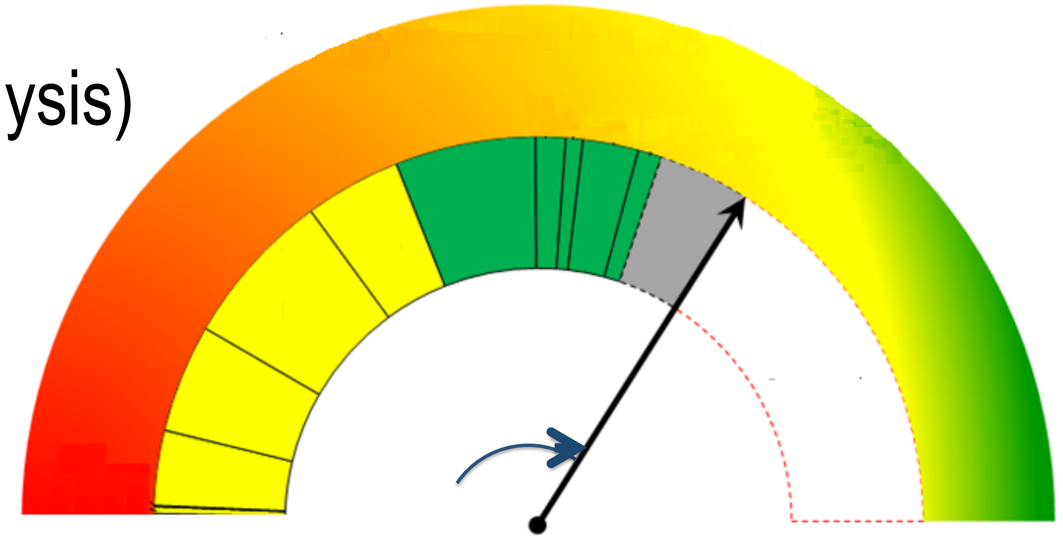


http://www.novatlantis.ch/fileadmin/downloads/2000watt/Weissbuch.pdf
Marechal F, Favrat D, Jochem E, "Energy in the perspective of the sustainable development: The 2000 W society challenge" Resources, Conservation and Recycling 44 (2005) 245–262

HALDI PA, FAVRAT D., *Methodological aspects of the definition of a 2 kW society.* Energy, vol 31, issue 15, Dec 2006., pp 3159-3170

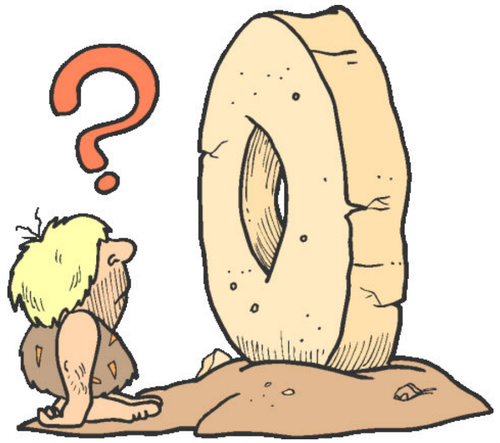
Key energy saving approaches: a summary

- Better indicators (exergy efficiency)
- Better design methods:
  - For energy integration (pinch analysis)
  - Multi-objective optimization
- Better technologies:
  - Heat pumps
  - Fuel cells
  - Co- and tri-generation
- Better integration between electric and gas grids with storage



http://energycoalition.eu/indicative-national-energy-efficiency-targets-fall-short

The stone age did not end because of lack of stones
(attributed to sheik Yamani !)



Let us not wait until the end of fossil fuels and an unbearable global warming to induce the necessary energy transition

Thank you for your attention

Also thanks to the contribution of Dr Pierre-André Haldi