Energy efficiency is key for more sustainable energy systems and cities

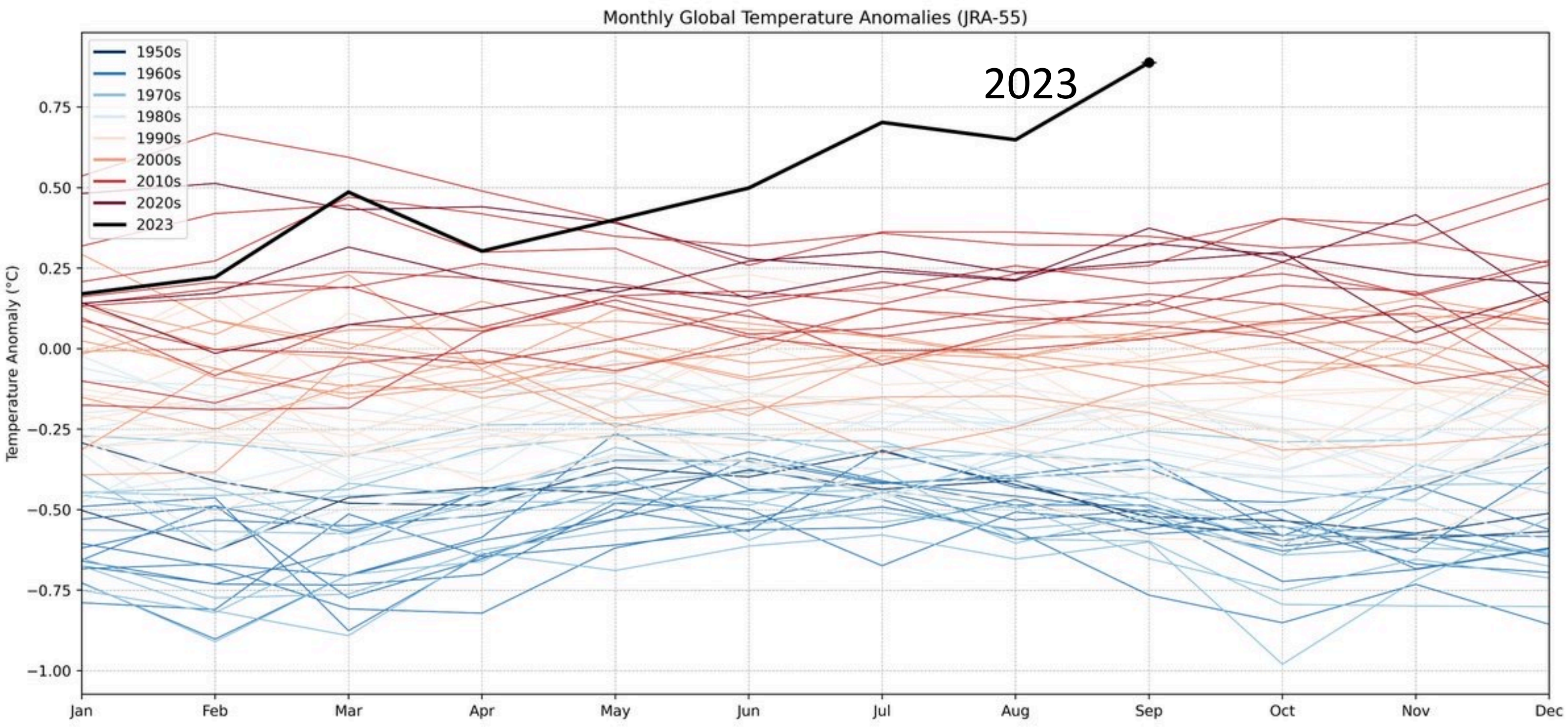
Daniel Favrat

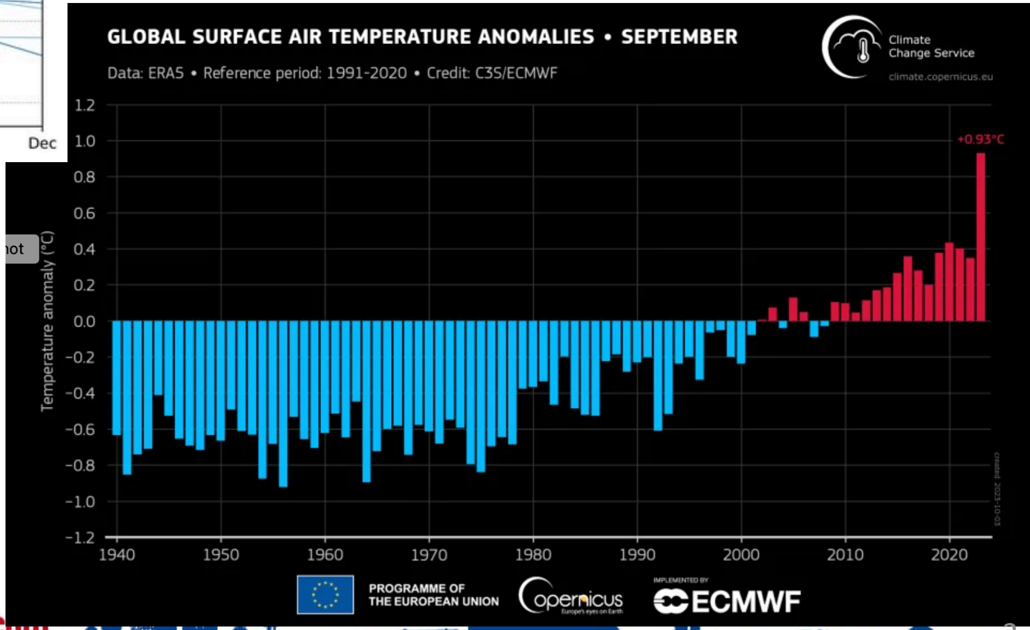
EPFL Energy Center

Vice-chair WFEO Energy Committee

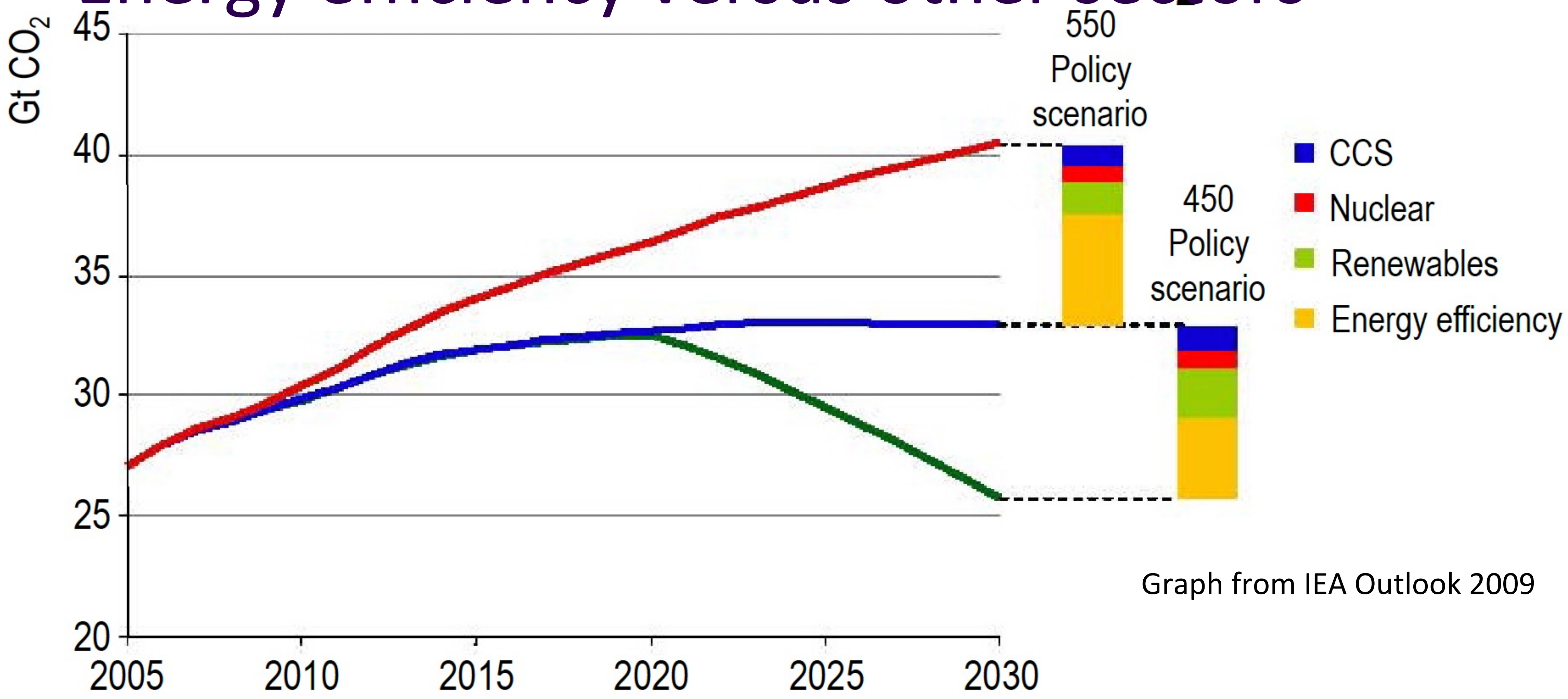
daniel.favrat@epfl.ch

Global warming status





Energy efficiency versus other sectors



Graph from IEA Outlook 2009

"Energy Efficiency is the most important fuel" repeats IEA in Energy efficiency 2022 report

Major energy inefficiencies and solutions

- Nuclear electricity: factor 50 from 3rd generation to Molten carbonate 4th generation
- Road transportation: factor 3 when going from thermal engine to electrical cars
- Direct electric heating (Joule effect): factor 3 to 5 when going to electric heat pump
- Fuel boilers: factor 2 to 3 when replacing with a combination of cogeneration and heat pumps (not necessarily at the same location)
- District Heating &Cooling (DHC) + local heat pumps in cities (without local pollutants/ with or without advanced cogeneration with CO_2 separation):

  factor >5 (this presentation) thanks for example to synergies with two innovative technologies:
  - very low Temperature CO_2 DHC and hybrid Solid Solid Oxide Fuel Cells (SOFC)

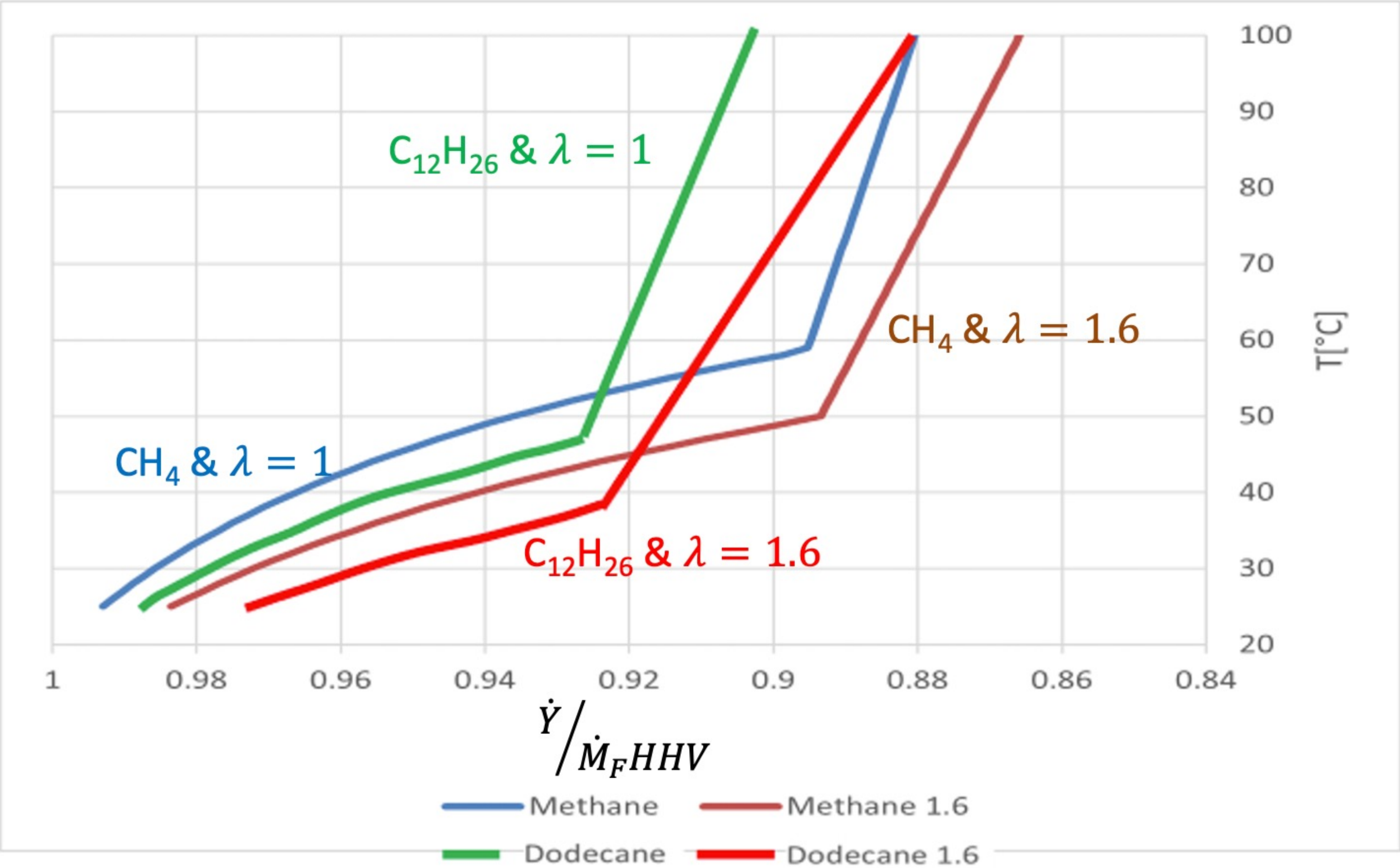
The ultimate failure

- Separate CO_2 from the atmosphere at 400 ppm while CO_2 concentration in most fluegas pipes is at least 300 times higher
- Factor 4 more specific energy required when capturing from atmosphere

Of course, also valid for the use of synthetic fuels with CO_2 capture
Reminder:
Synthetic fuels represent the main path to seasonal storage
They are expensive also in terms of energy and need to be converted efficiently

Borel Favrat, Thermodynamics and energy system analysis, EPFL Press, 2010

Part of the higher heating value that can be recovered when cooling



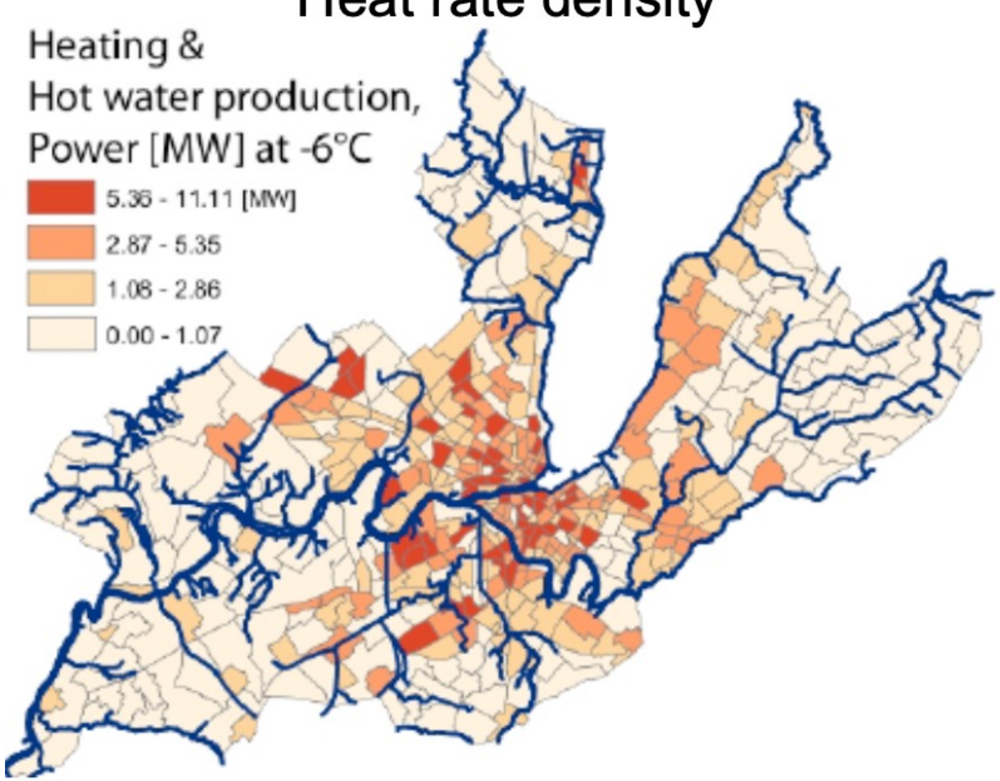
Fuel oil can be simulated by dodecane $C_{12}H_{26}$

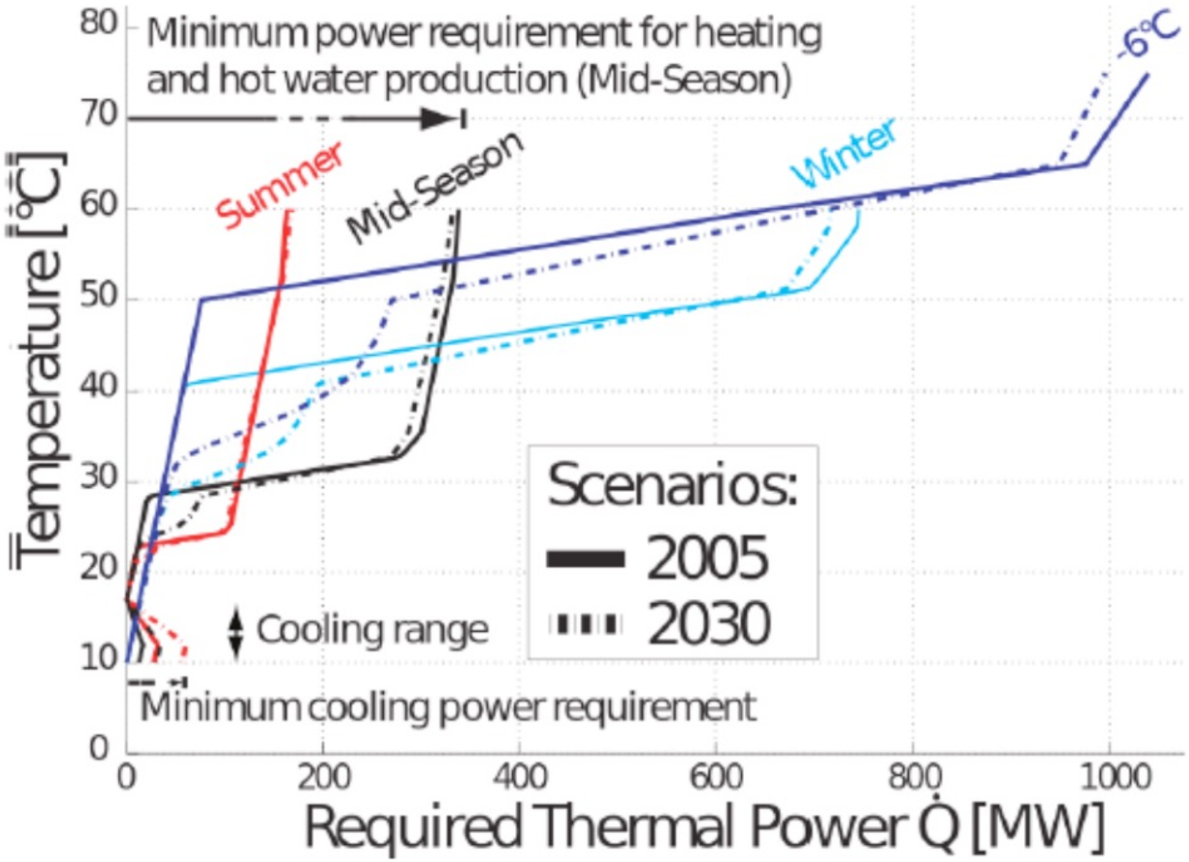
Natural gas can be simulated by methane CH_4

Example of GIS structured heating demand

District in Geneva

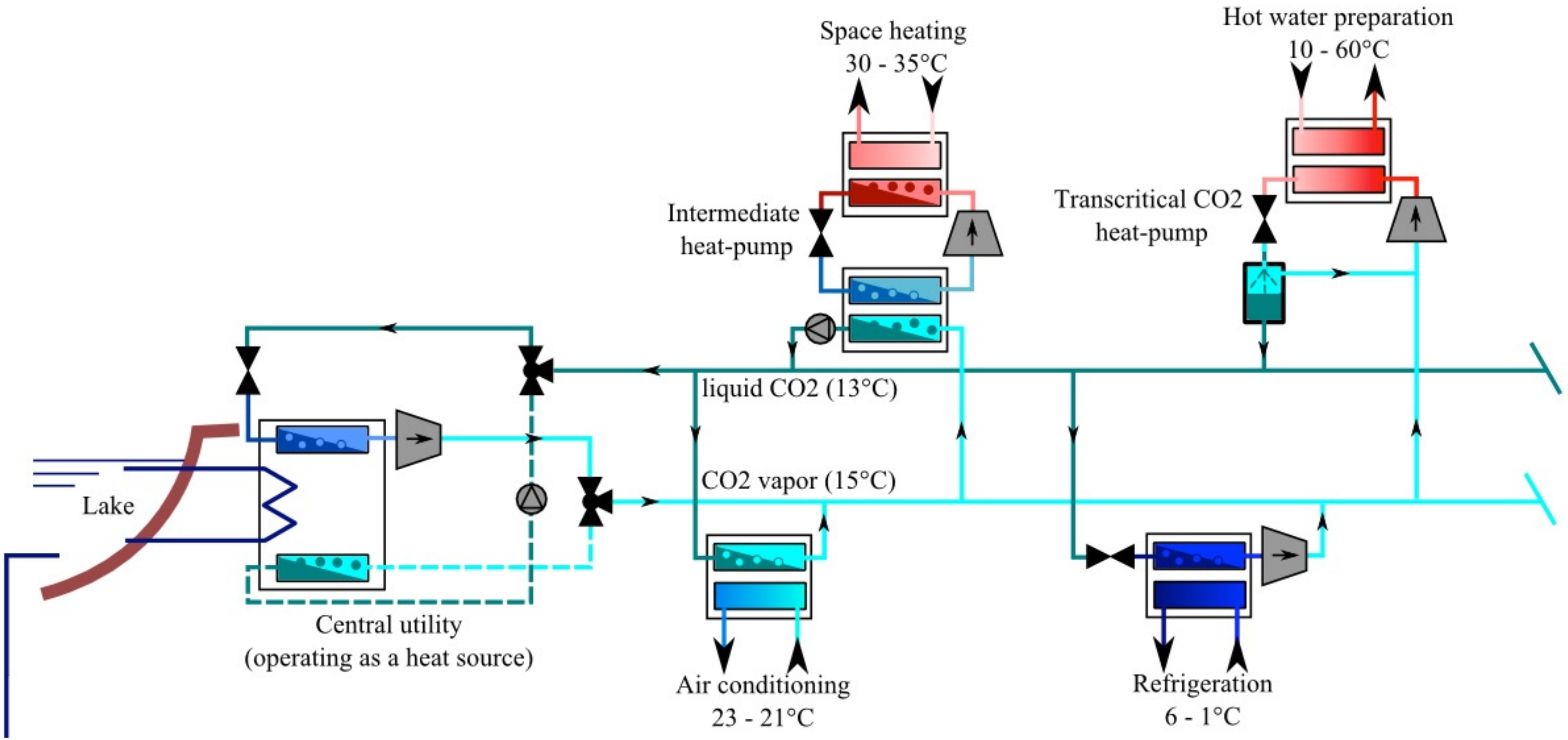
Heat rate density





Girardin L. et al., Energy 35 (2010) 830–840

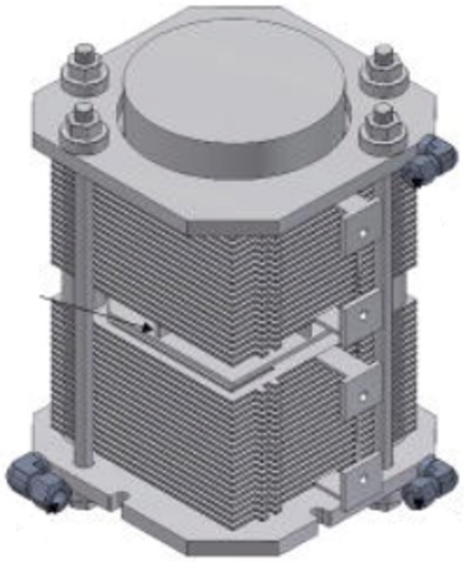
Low temperature District heating and cooling with CO_2 as heat transfer fluid



Heat pump city energy awarded to ExerGo
Sept 28, 2023

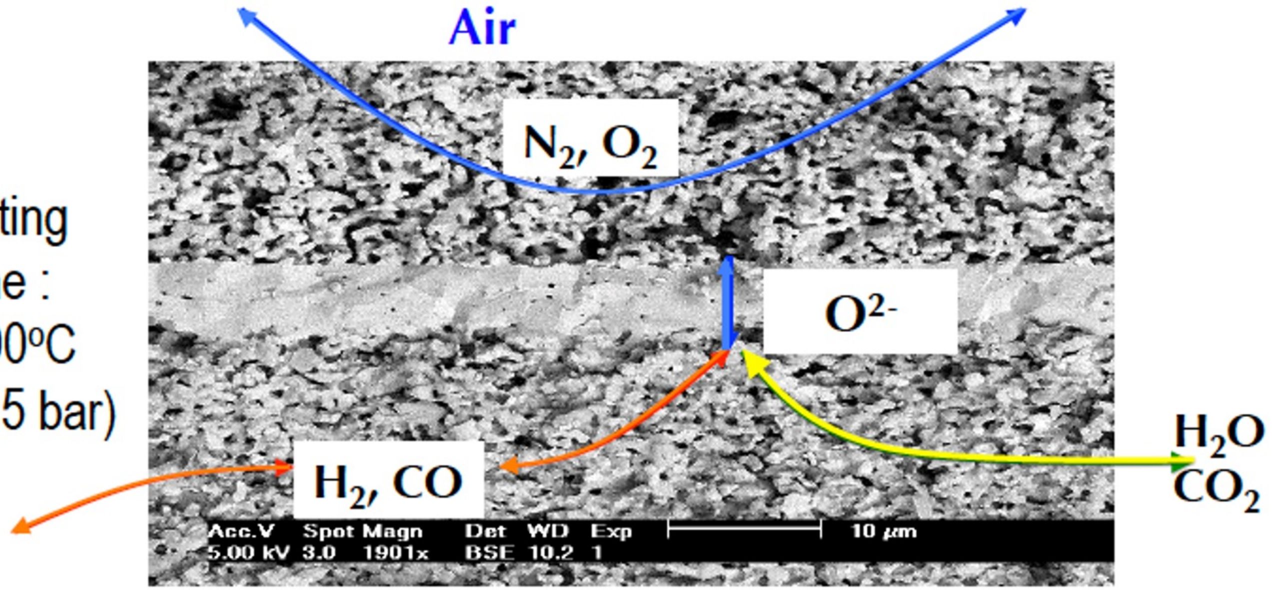
SOFC

Power to gas and gas to power



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

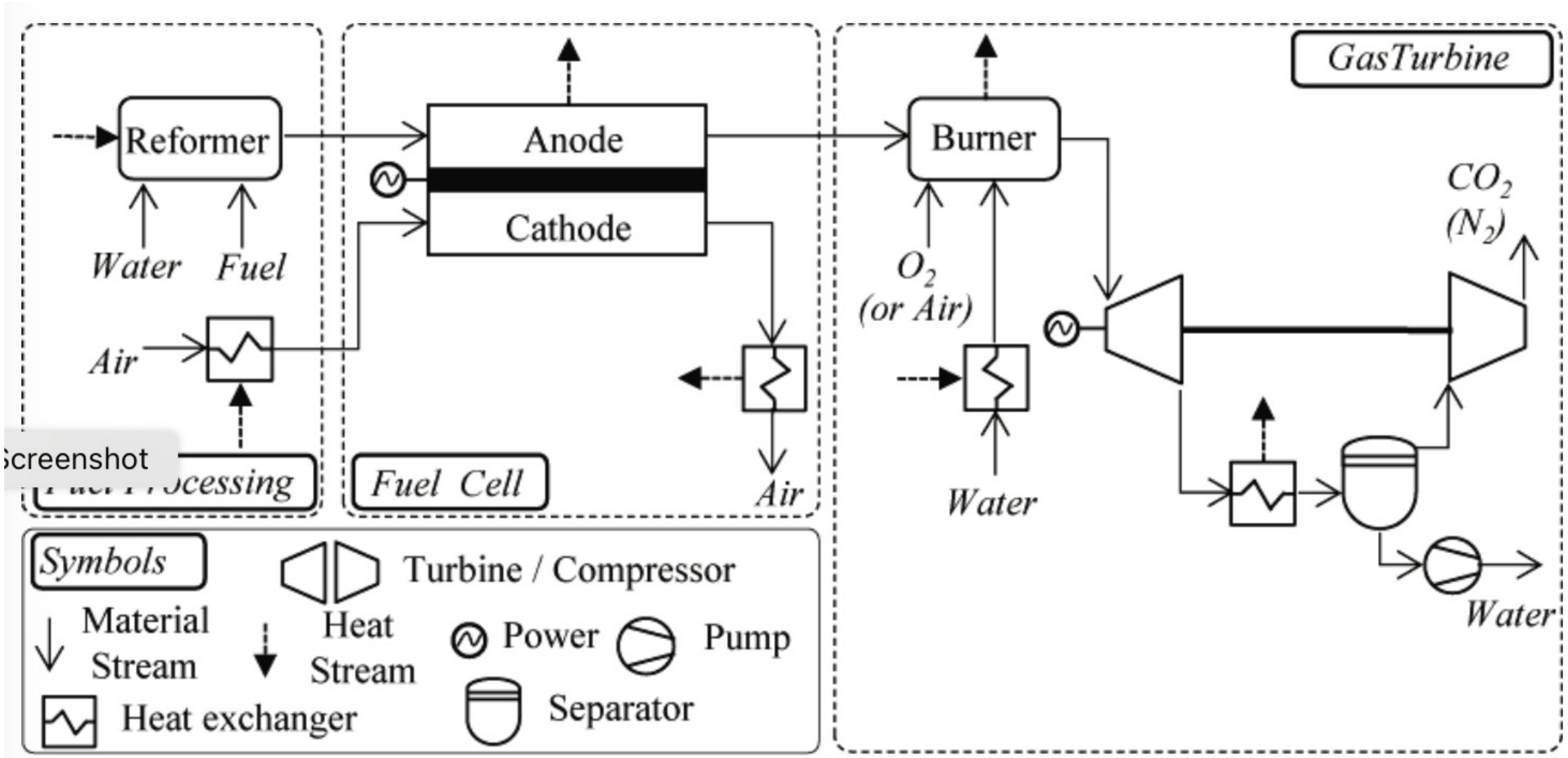
Solid Oxide Fuel Cell stack

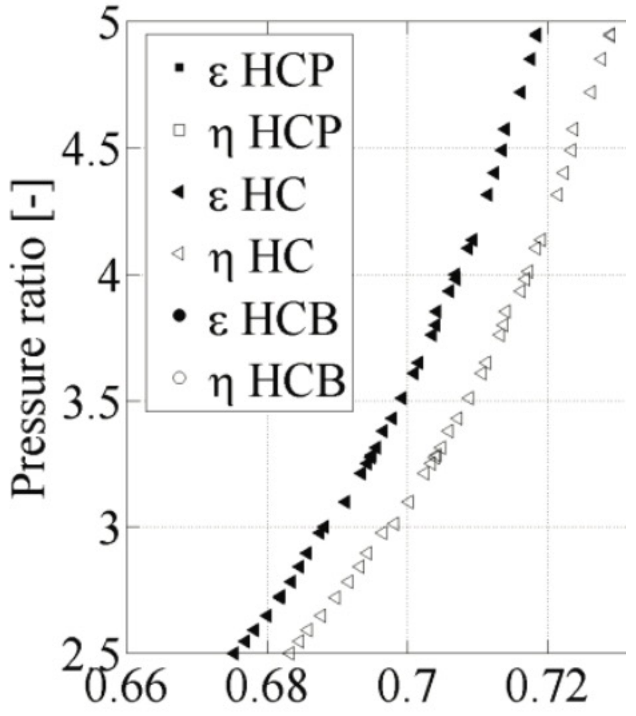


Reformed Natural Gas

Can potentially be inversed
(High temperature electrolyser for storage)

Innovative hybrid SOFC+under-atmospheric gas turbine (GT) with CO_2 capture

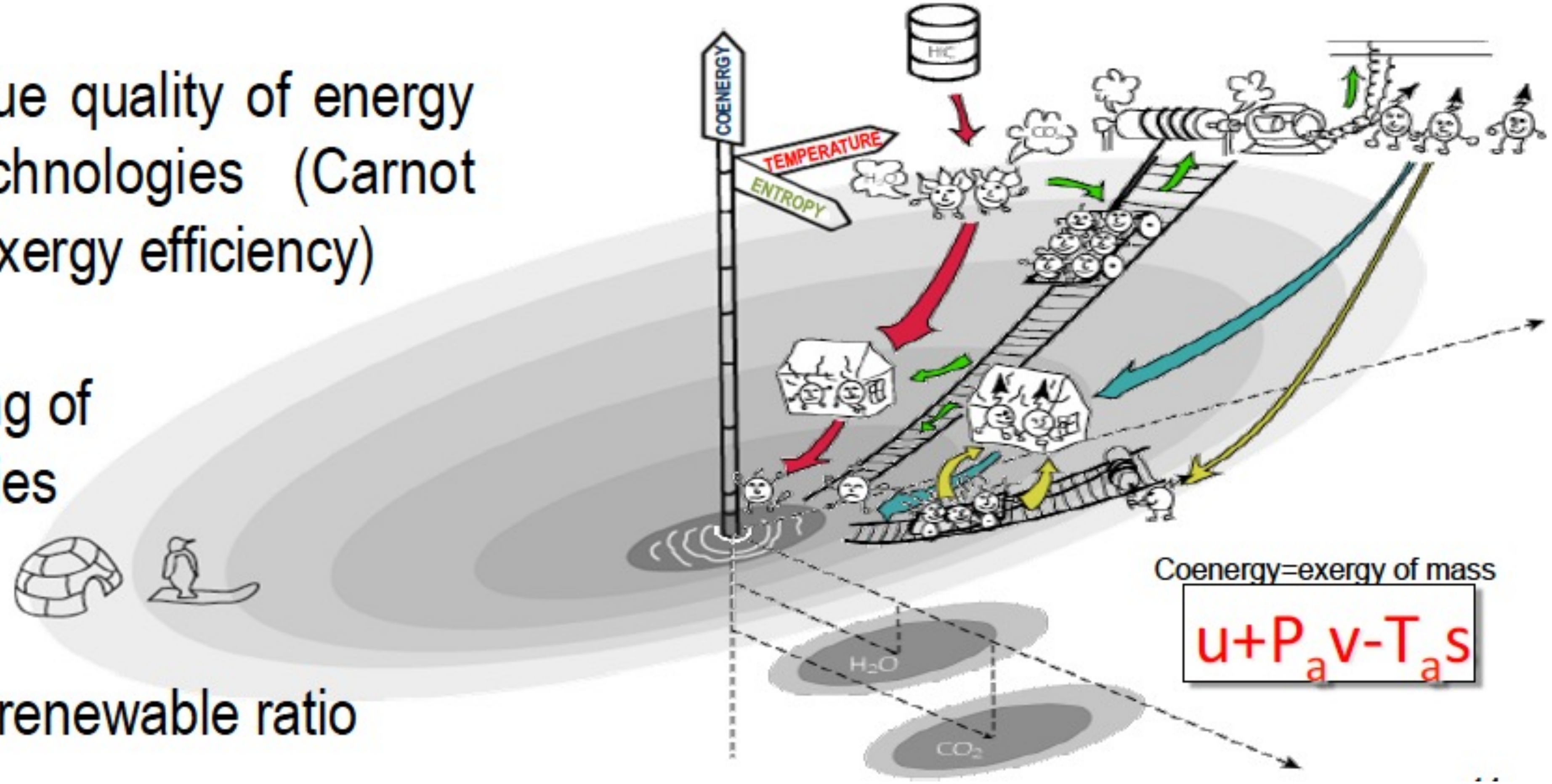




Efficiency versus GT pressure ratio

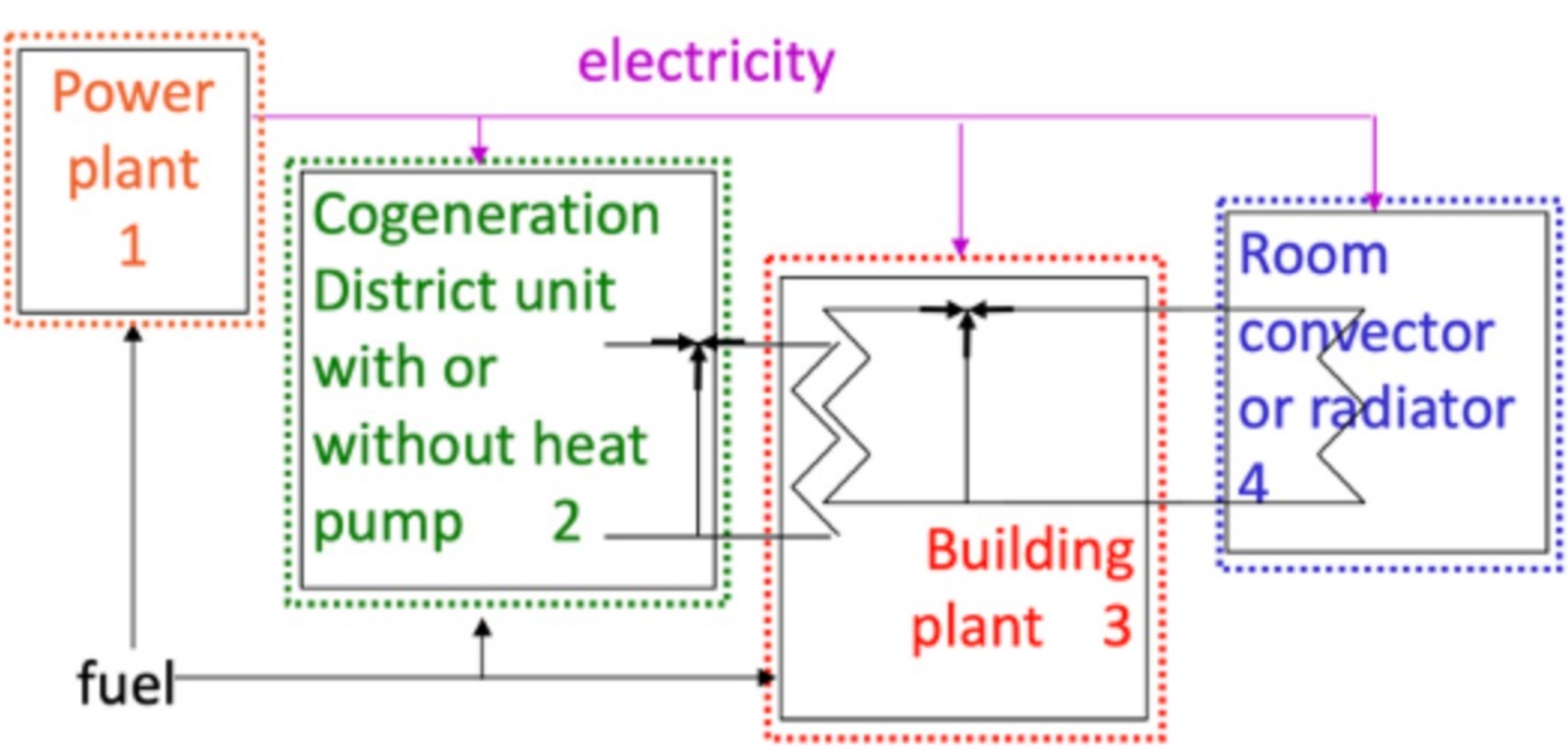
EXERGY EFFICIENCY AS A BETTER INDICATOR

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



Borel L, Favrat D., Thermodynamics and energy systems analysis, EPFL Press 2010

Exergy efficiency of heating or cooling



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

Example of exergy efficiency of heating technologies

Technologies	Power plant	DH plant	Building plant		Room convector		Overall exergy efficiency (%)	
Supply/return temperatures			45°/35°	65°/55°	45°/35°	65°/55°	45°/35°	65°/55°
Direct electric heating (hydro power)	0.88				0.07	0.07	6.0	6.0
Building non-condensing boiler			0.11	0.16	0.53	0.38	6.1	6.1
Building condensing boiler			0.12		0.53		6.6	
District heat pump (combined cycle plant)	0.54	0.61	0.54	0.76	0.53	0.38	9.4	9.4
Domestic heat pump (cogeneration combined cycle power)	0.54		0.45	0.45	0.53	0.38	12.9	9.2
District heat pump(hydropower)	0.88	0.61	0.54	0.76	0.53	0.38	15.4	15.4
Domestic heat pump (hydropower	0.88		0.45	0.45	0.53	0.38	21.2	15.1

Example of exergy efficiency of air-conditioning technologies

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

Heat at the lowest temperature as possible
Cool at the highest temperature as possible

Conclusion

- Major gains can be achieved in energy efficiency by technologies like:
  - 5th generation DHC with decentralized heat pumps
  - SOFC and even more by hybrid SOFC-GT with CO_2 separation, for example from fossil or synthetic natural gas or wet biomass
- Better performance indicators are needed like exergy efficiency

Think clever, think efficiency!