Ecole Polytechnique
Fédérale de Lausanne

5TH GENERATION DISTRICT HEATING AND COOLING NETWORK

TOWARDS 100% RENEWABLE CITIES

Raluca Suciu, Dr Luc Girardin, Prof. François Marechal
Industrial Process and Energy System Engineering, EPFL, Switzerland
Ecole Polytechnique Fédérale de Lausanne - Campus Energypolis EPFL Valais Wallis CH-SION

ENERGY NEEDS

47%

36%

17%

products **2%**

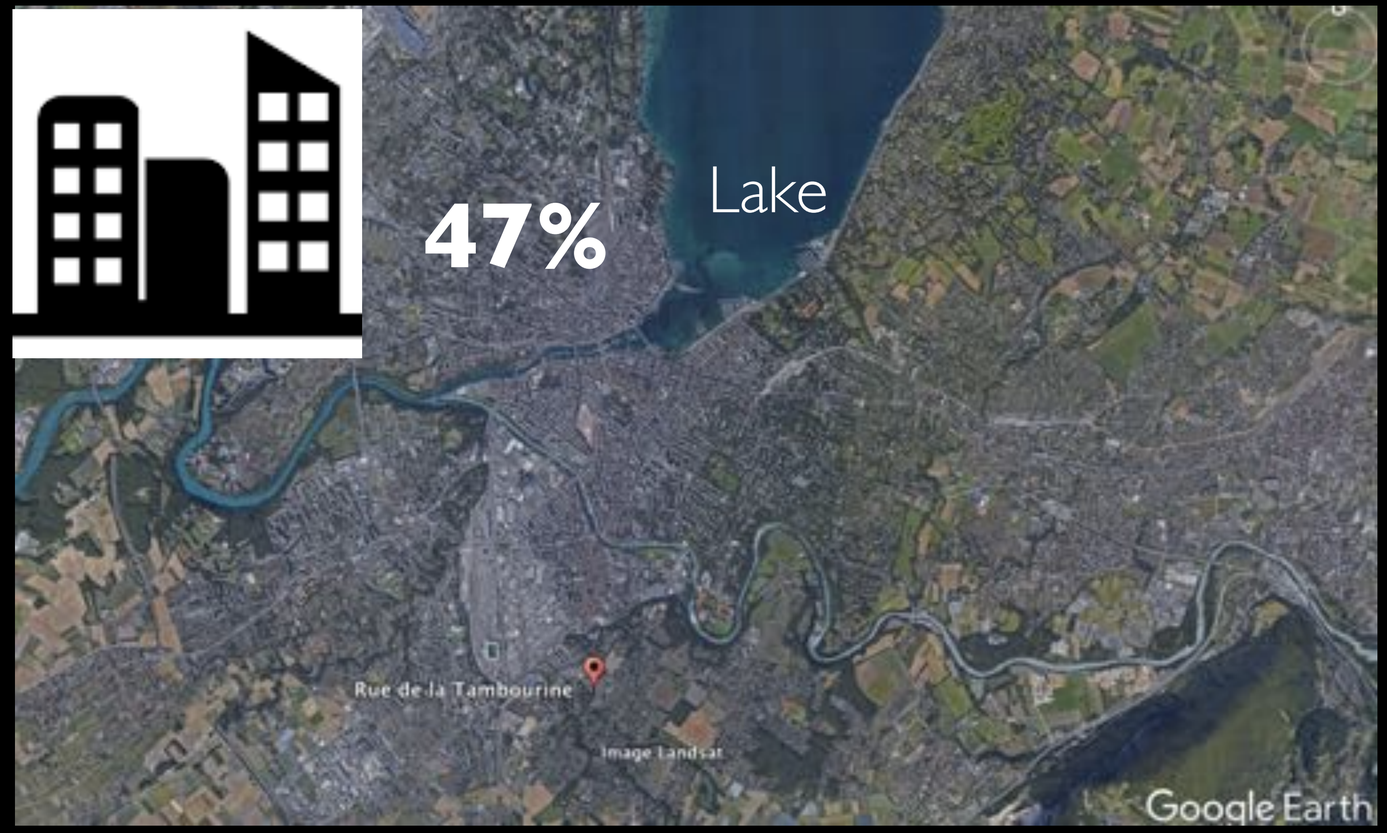
100 l gasoline/hab/year

Electricity

Ecole Polytechnique
Fédérale de Lausanne

CITIES = 75% OF THE POPULATION

Genève



200’000 hab

16 km^2

16 km^2 Heated

3.5 km^2 Built

260 Million litres/year

1 Million Tonnes/year

100’000 Tonnes/year

40’000 Tonnes/year

620 Million litres/year
Oil equiv.

Ecole Polytechnique
Fédérale de Lausanne

IS IT POSSIBLE TO MAKE A CITY AUTONOMOUS ?

- without CO2 emissions
- without importing energy
- without reconstructing the whole city
- without loosing money

THE CONVERSION CHAIN

$$[kJ_p/hab/an] = \eta_e[kJ_p/kJ_e] \cdot \eta_s[kJ_e/kJ_s] \cdot e_d[kJ_s/an/m^2] \cdot d_{hab}[m^2/hab] \cdot hab[hab]$$

Primary resource

→ Conversion resource->distributed

→ Efficiency distributed->service

→ Sobrety service->needs

→ Needs needs->hab

→ Population hab

THE NEEDS

Sobriety
service->m2 heated

*

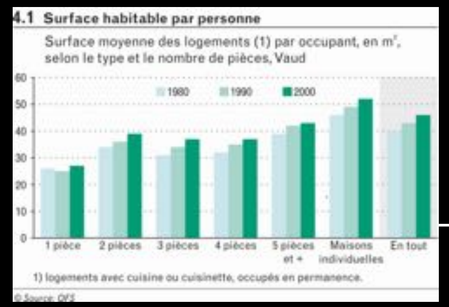
Comfort
m2->hab

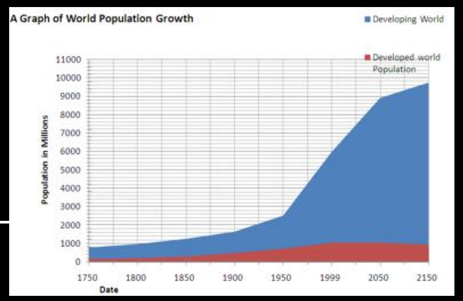
*

Population
hab

=

Service
service/hab





HOW TO SUPPLY HEAT IN BUILDINGS ?

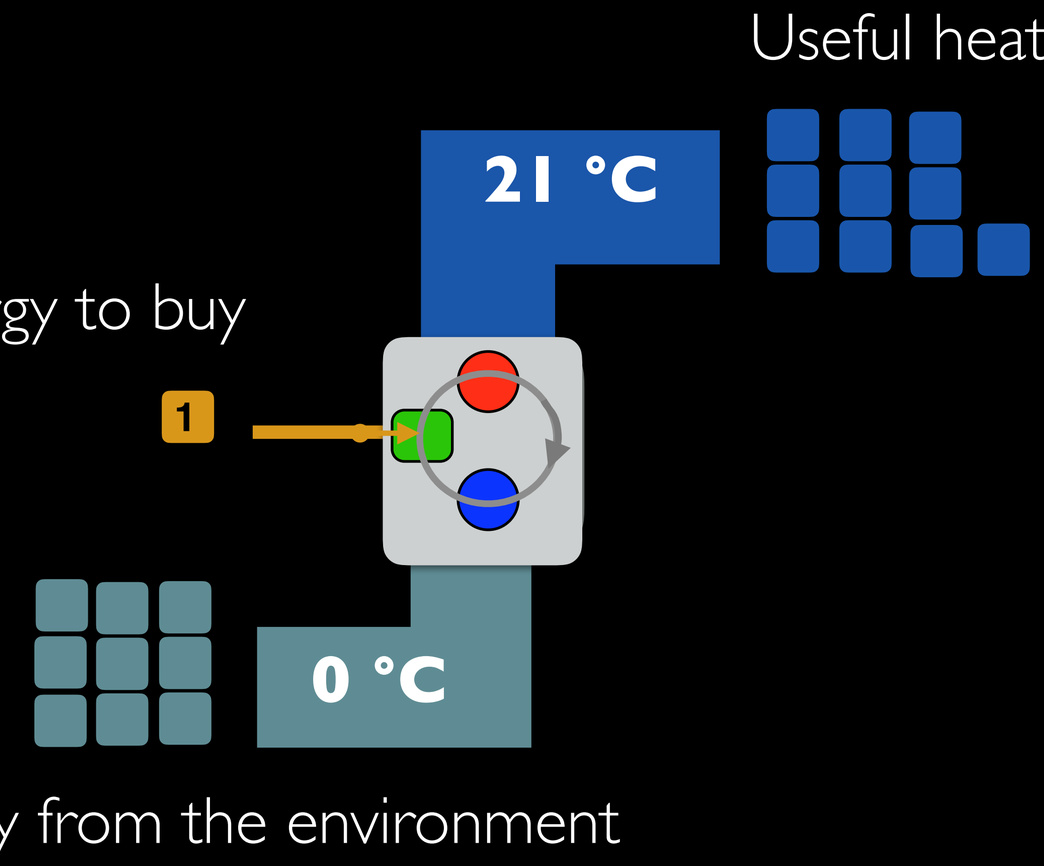
WHAT THERMODYNAMICS TELLS US ?

Thermodynamic minimum

Nicolas Léonard Sadi CARNOT (F)
1796 - 1832

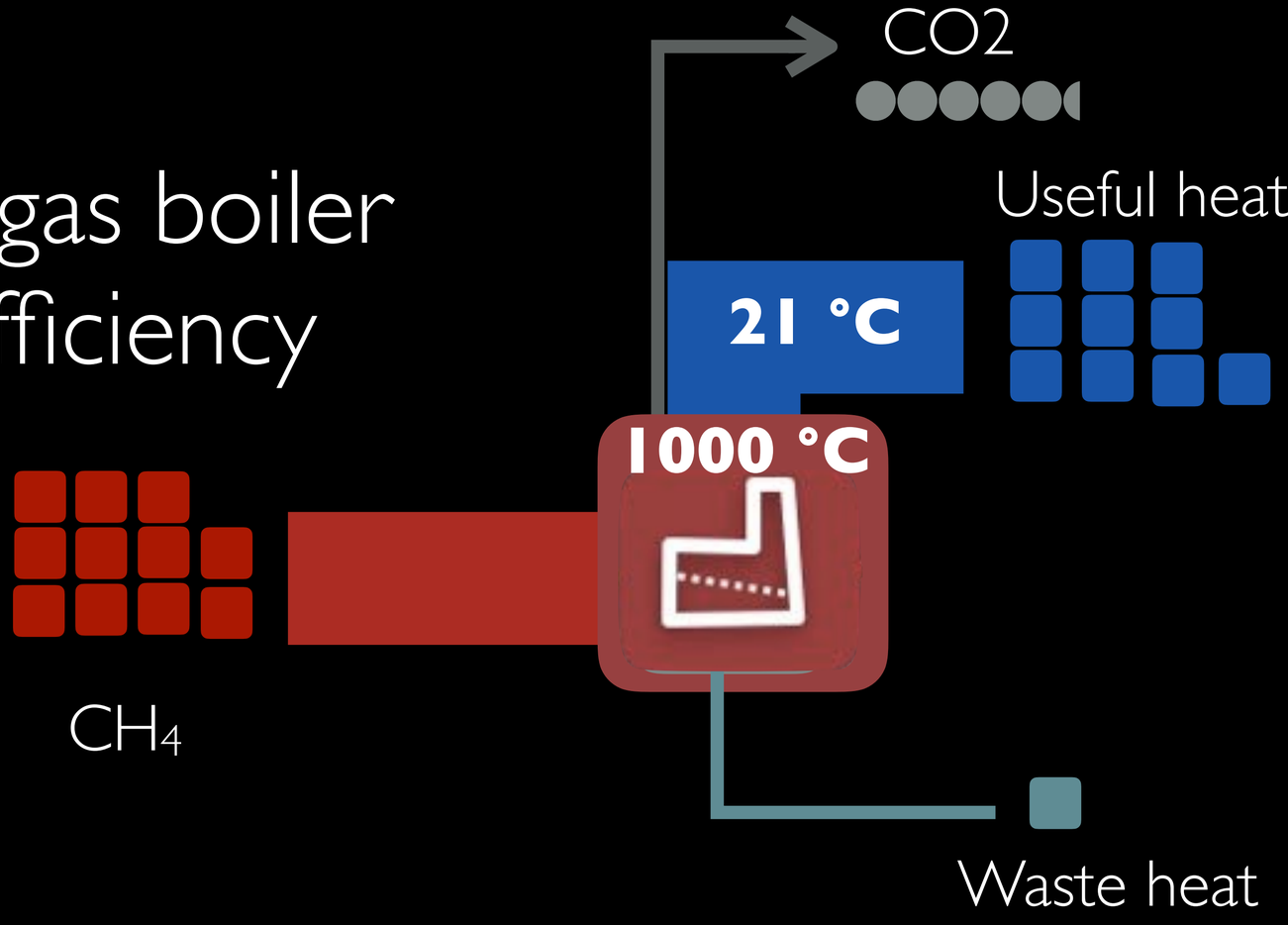
$$\dot{E} = \dot{Q}(1 - \frac{T_{cold}}{T_{hot}})$$

fraction to be taken in the environment



AND THE WAY WE DO IT TODAY

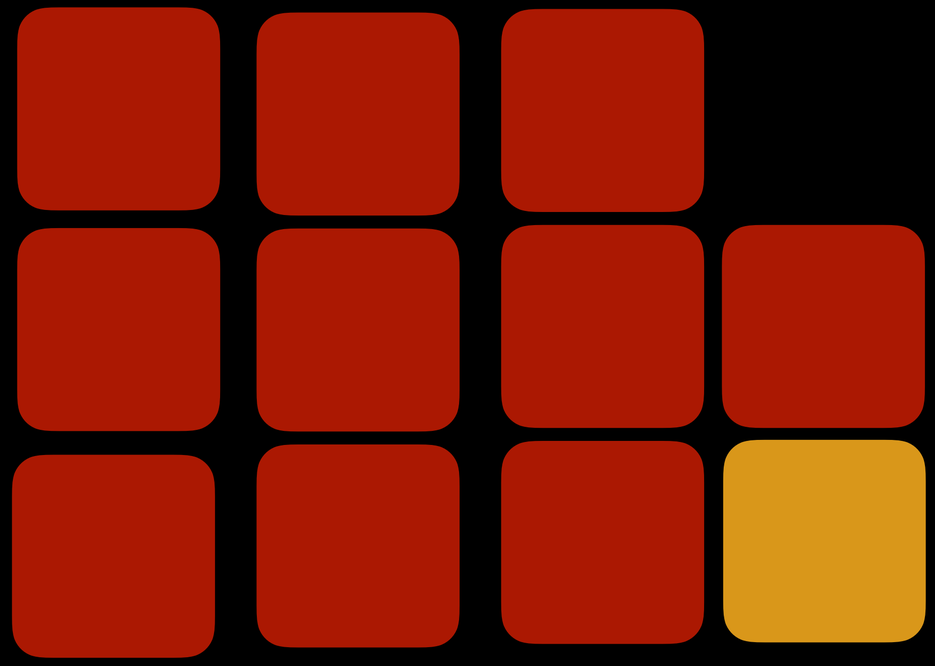
Natural gas boiler
90% efficiency



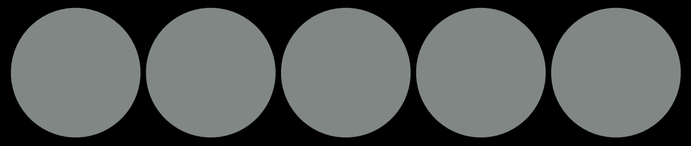
Ecole Polytechnique
Fédérale de Lausanne

WHAT IS WRONG ?
WHY DO WE BUY 11X MORE ?

FUEL

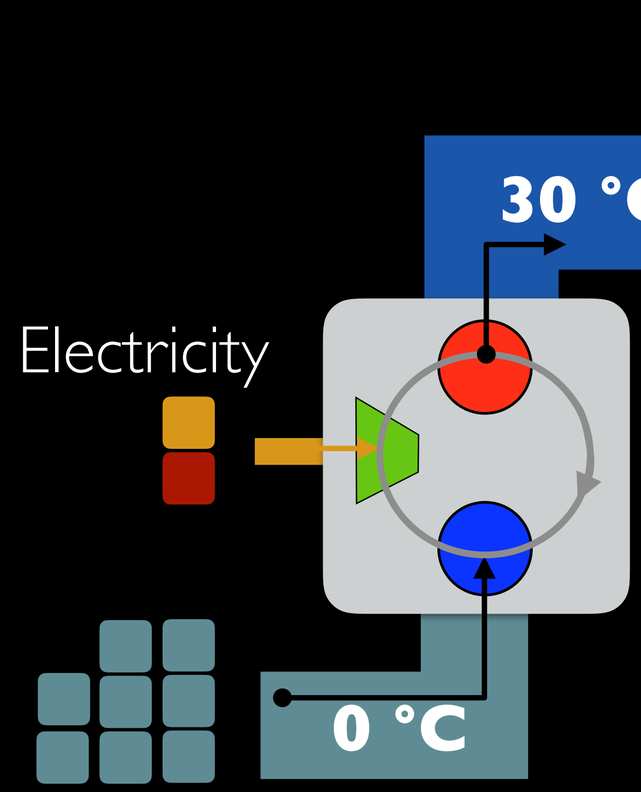


CO2



Ecole Polytechnique
Fédérale de Lausanne

HEAT PUMP IS THE ANSWER



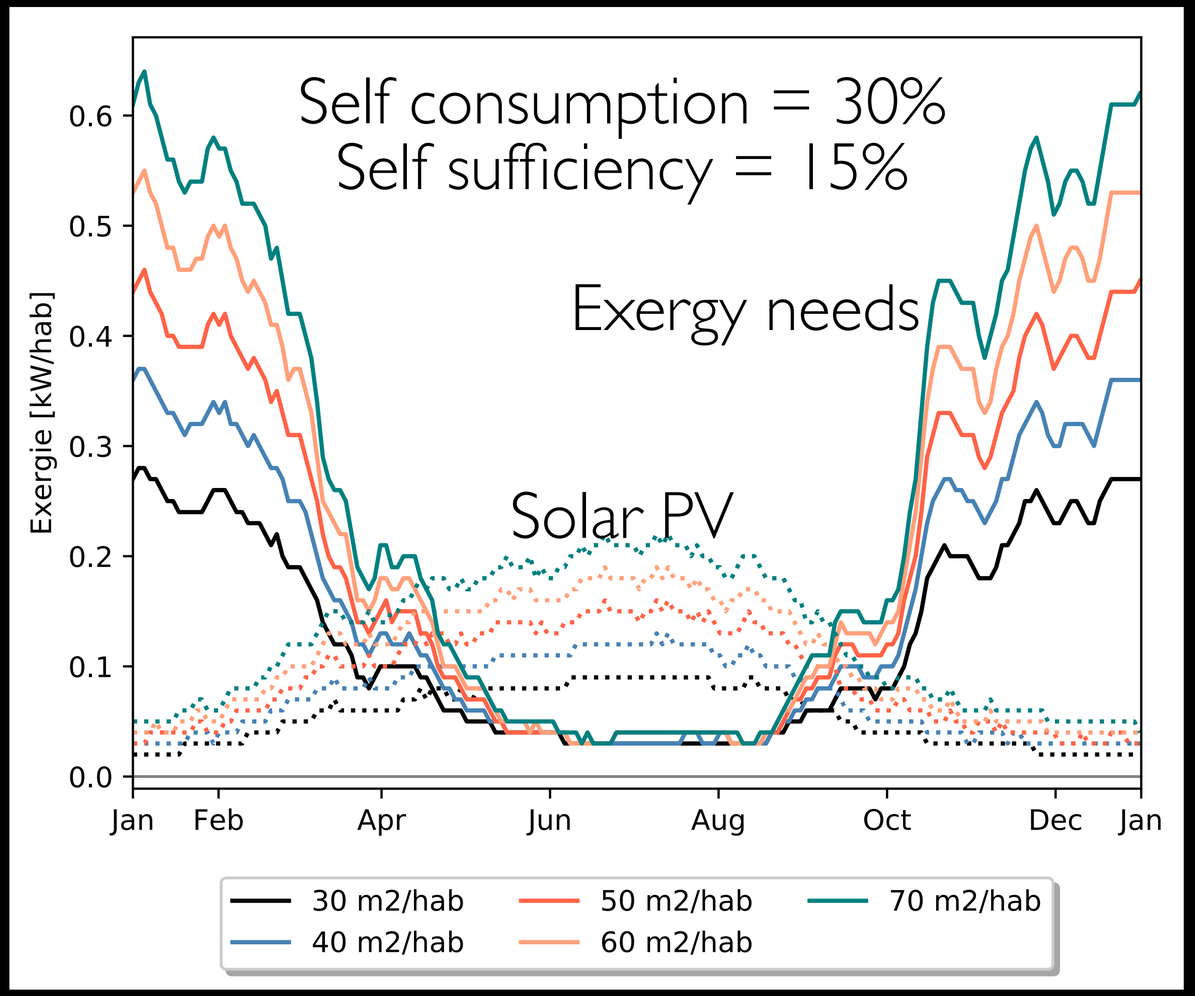
$$\dot{E} = \frac{1}{\eta_{Carnot}} \cdot \dot{Q} \cdot (1 - \frac{T_{cold}}{T_{hot}})$$

$$\eta_{Carnot} = 0.55 = \frac{\dot{E}_{min}}{\dot{E}}$$

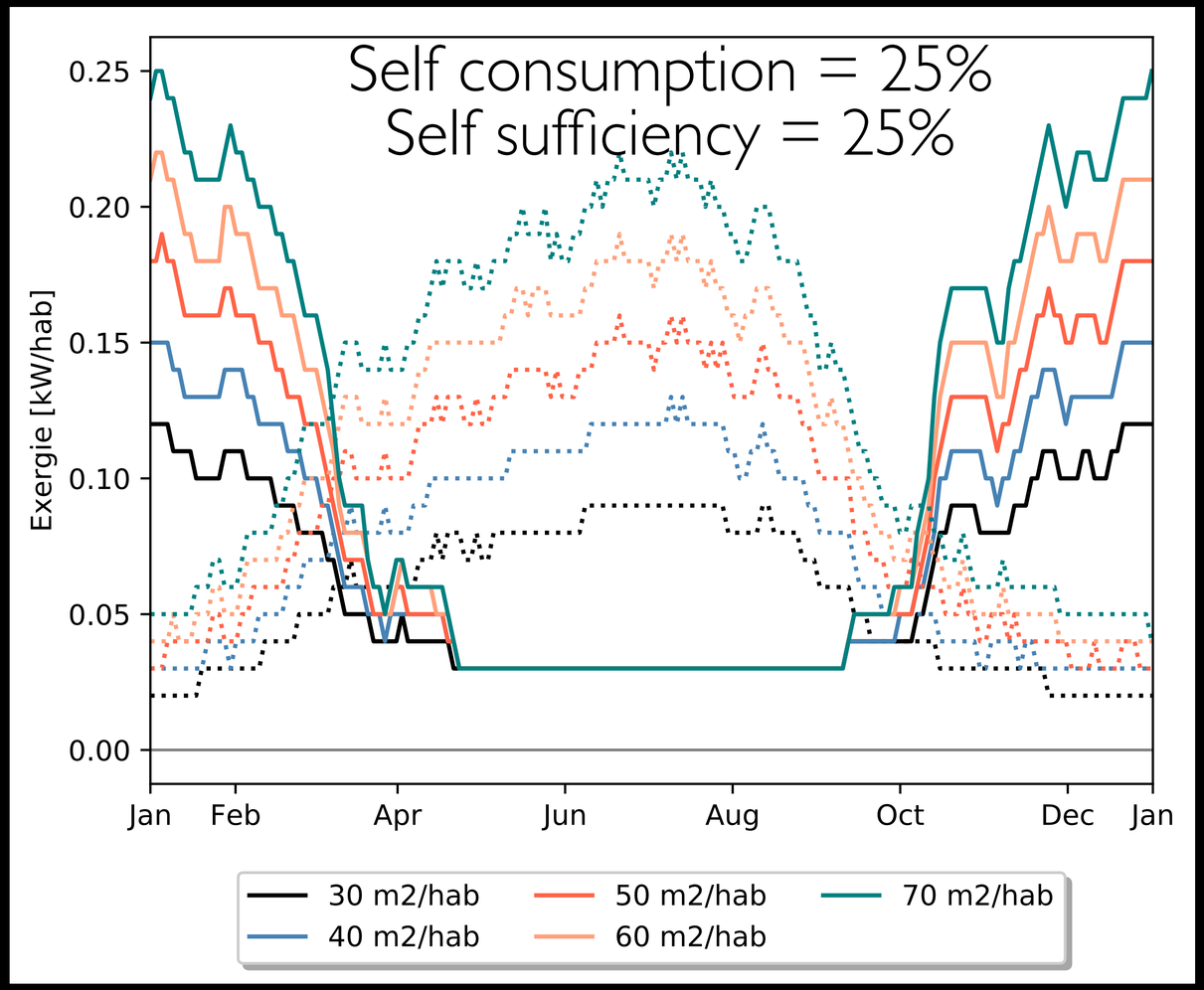
Ecole Polytechnique
Fédérale de Lausanne

COMBINING HEAT PUMP WITH SOLAR PV

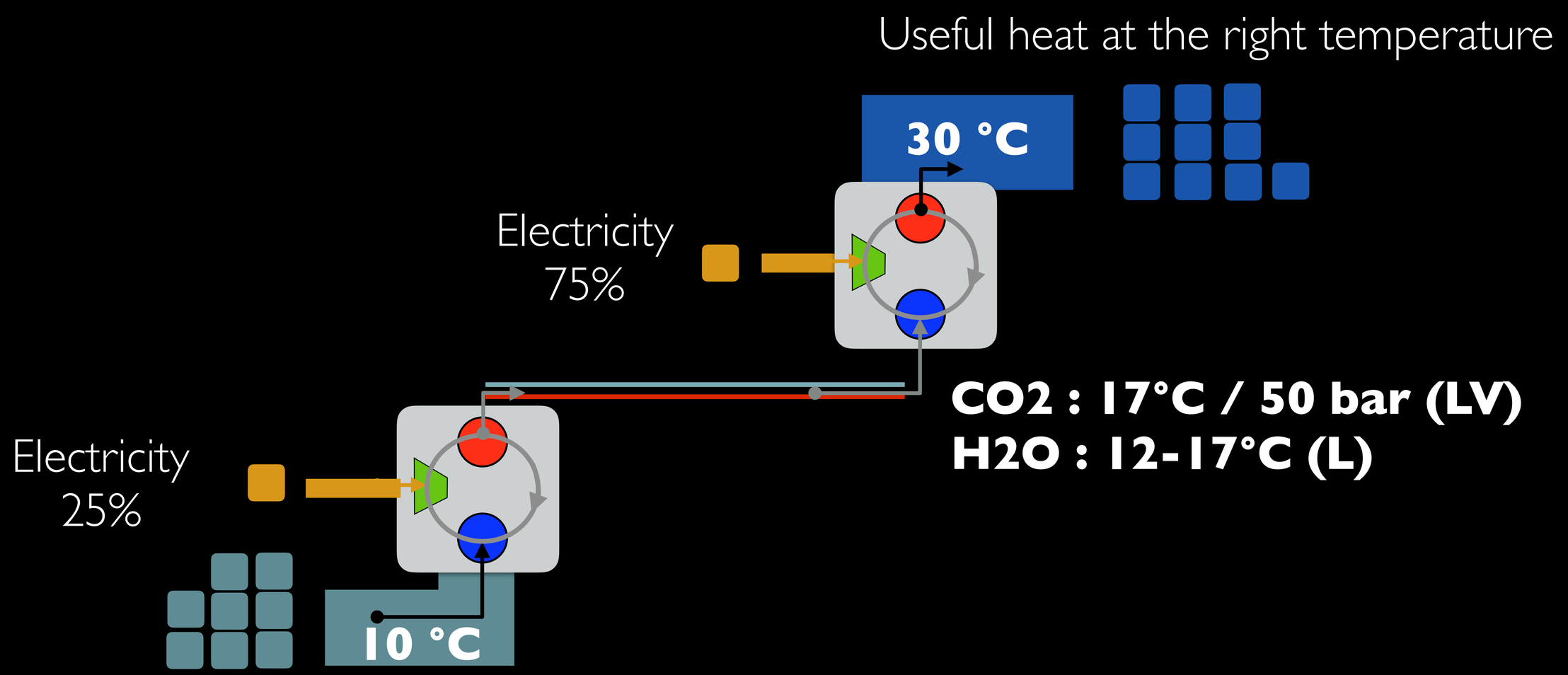
Non renovated building



After renovation



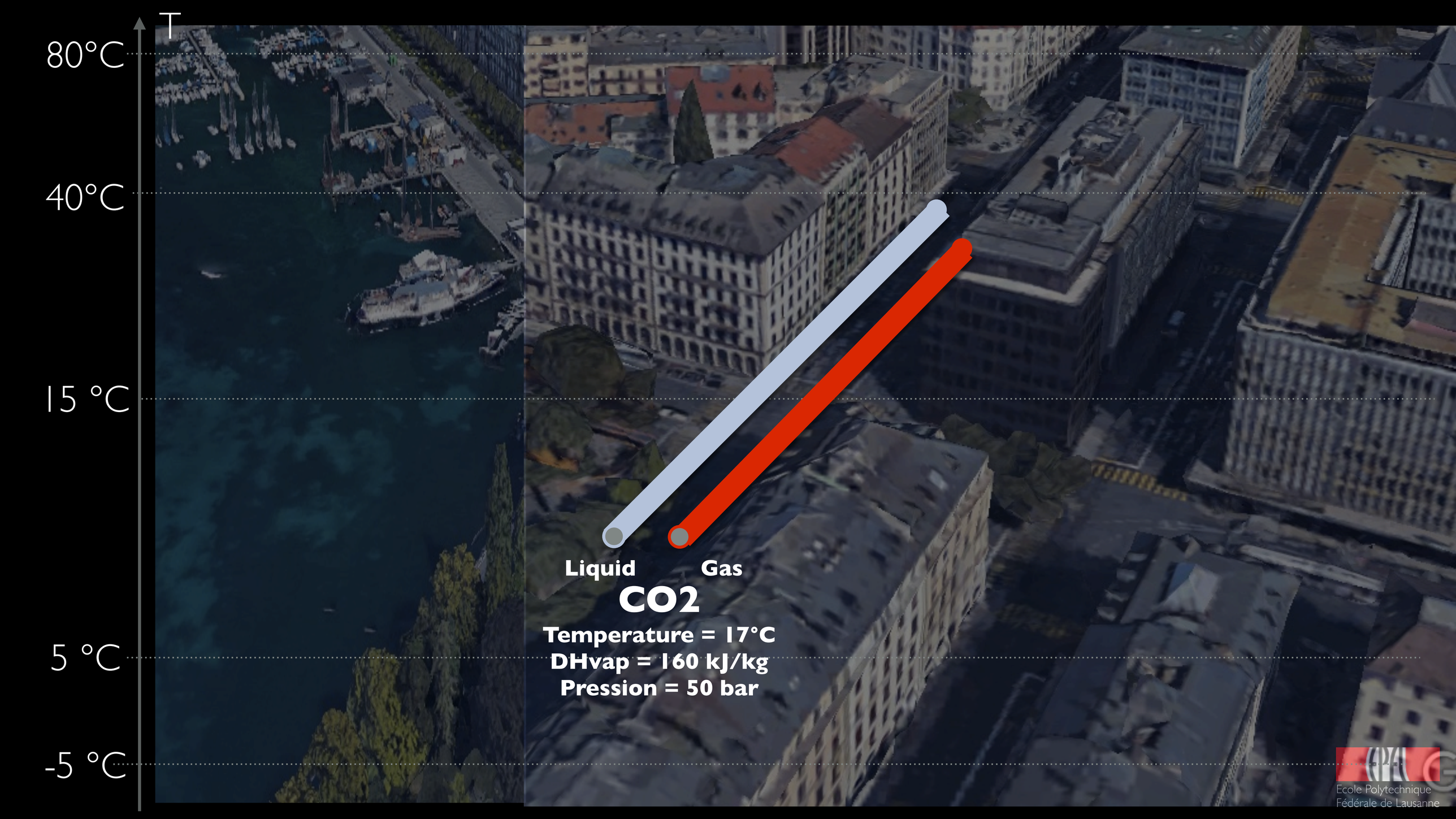
REACH THE GOOD RESOURCES
SUPPLY WHAT IS NEEDED



Heat from the environment with the best quality

D. Favrat, C. Weber, CO2 based district energy system, U.S. Patent 2010018668

Ecole Polytechnique
Fédérale de Lausanne



T

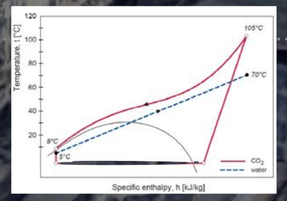
80°C

40°C

15 °C

5 °C

-5 °C



Hot water
CO2 heat pump

Heating
Conventional HP

Liquid **Gas**

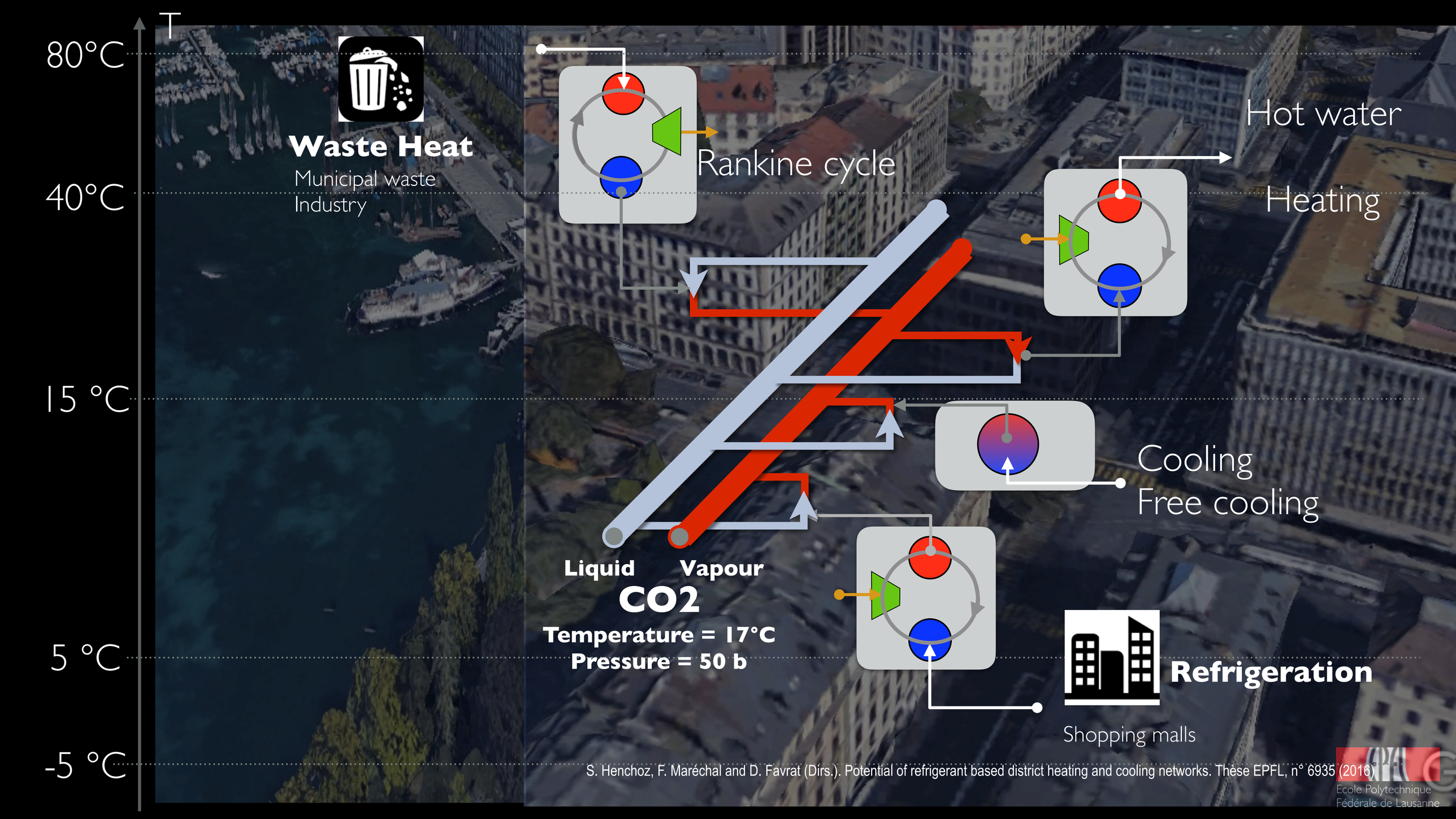
CO2

Temperature = 17°C

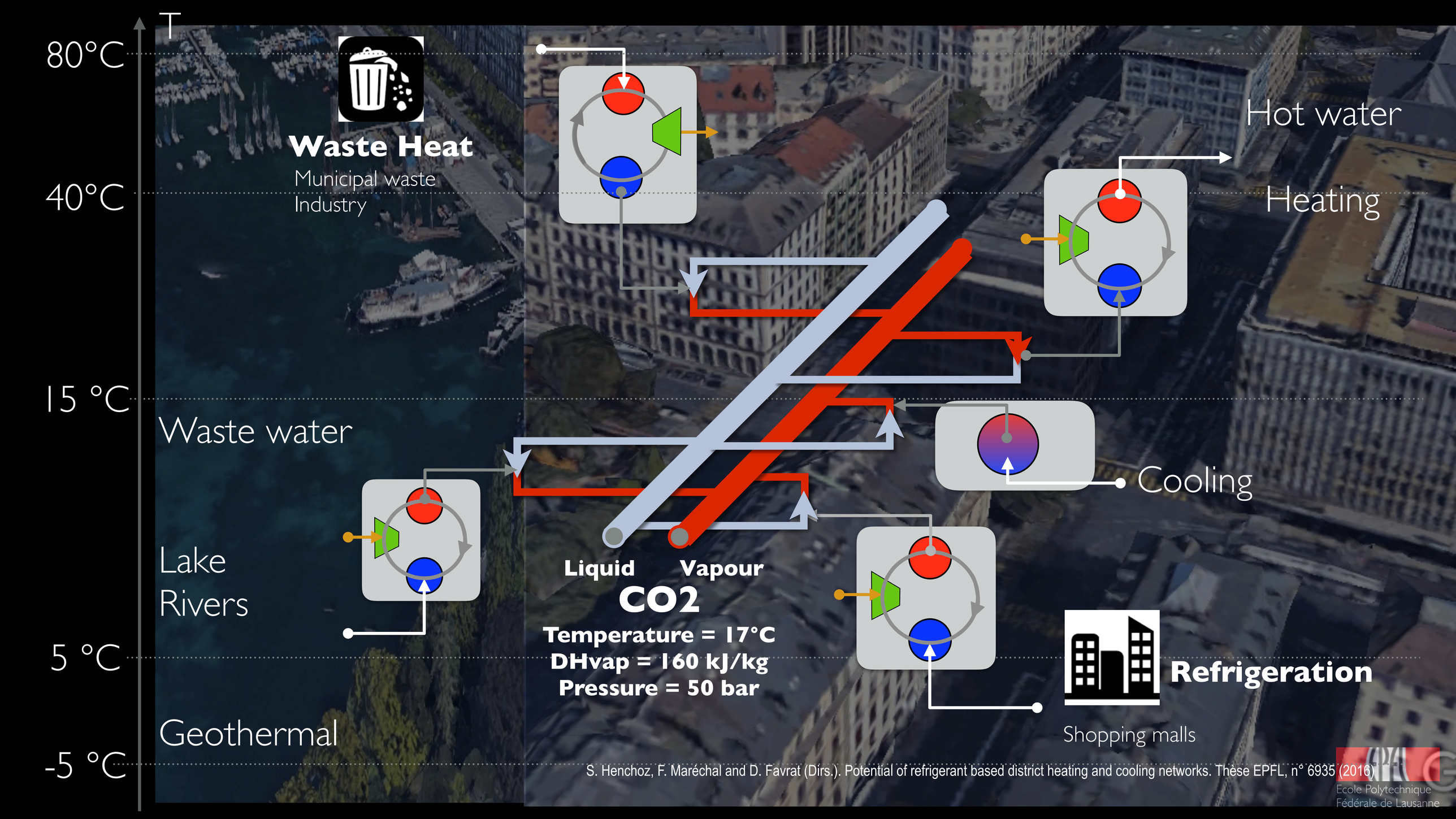
Pressure = 50 b

S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)

Ecole Polytechnique
Fédérale de Lausanne



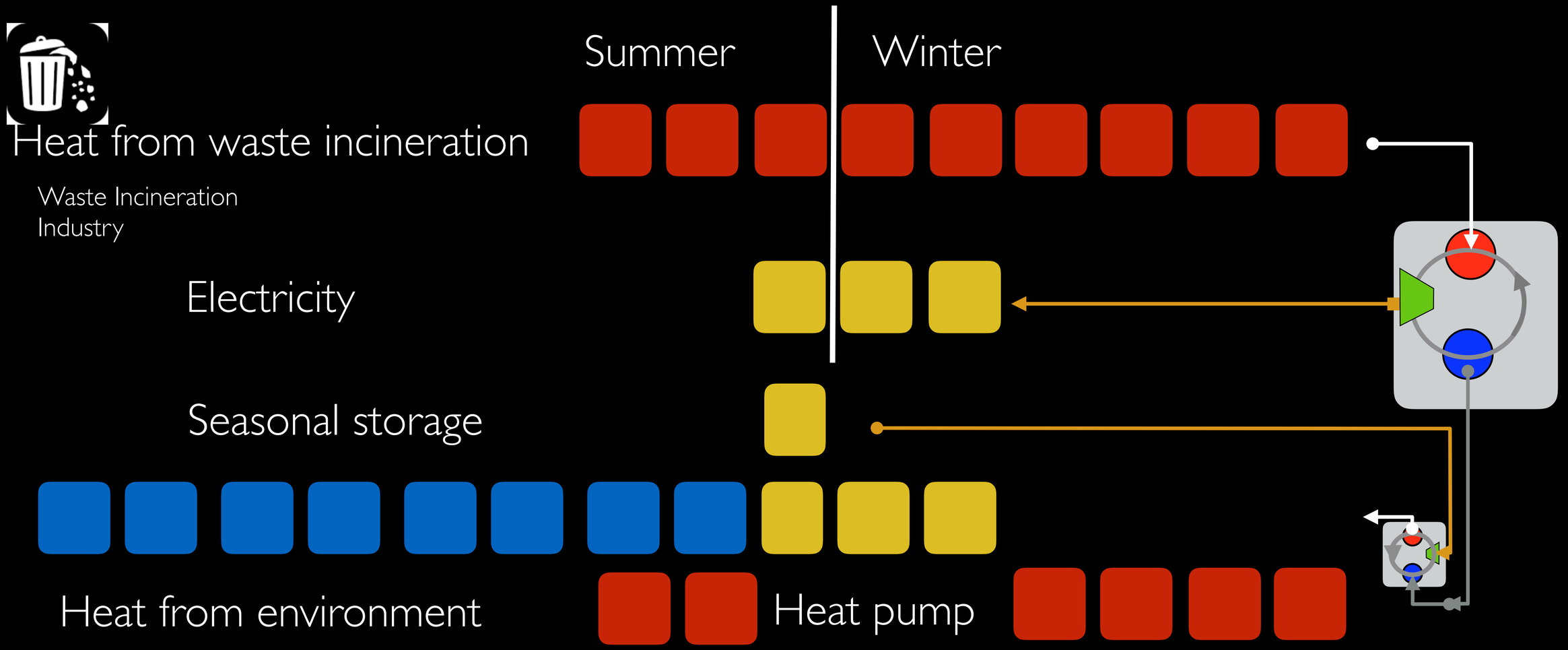
S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)



S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)

Ecole Polytechnique
Fédérale de Lausanne

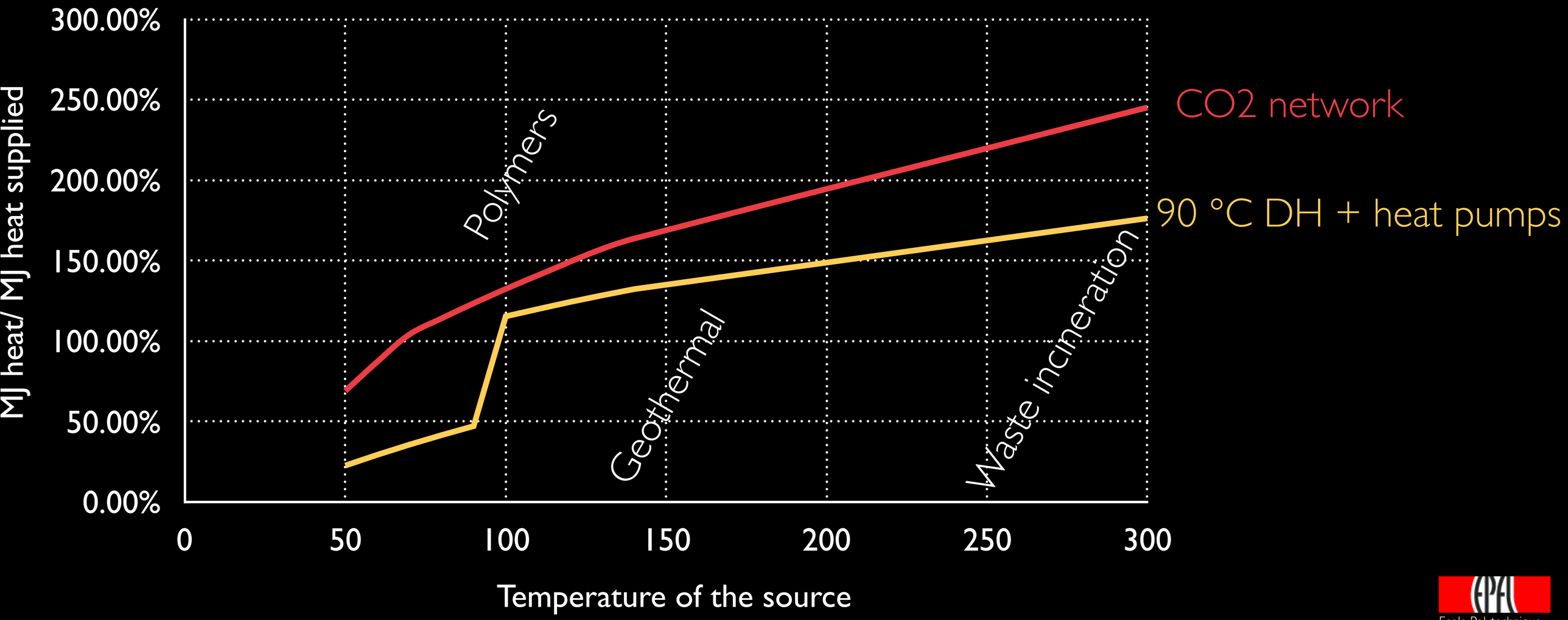
WASTE HEAT FROM WASTE INCINERATION



2.6 x more heat supplied

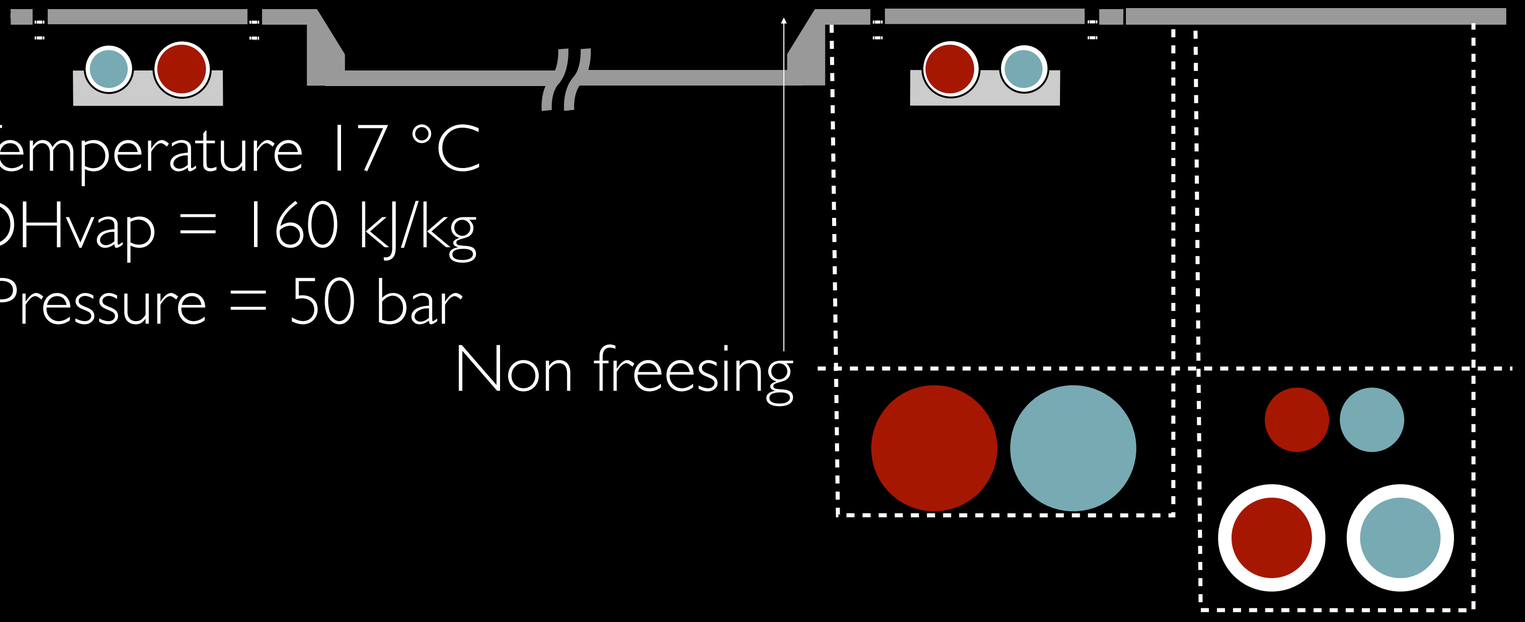
Ecole Polytechnique Fédérale de Lausanne

HEAT SUPPLY AS A FUNCTION OF THE TEMPERATURE OF THE SOURCE



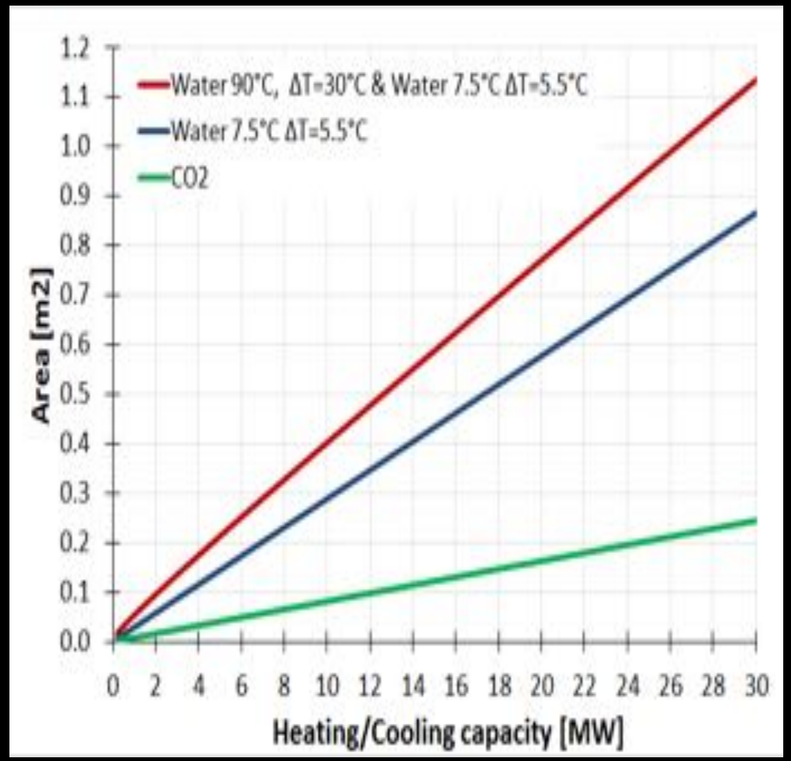
Ecole Polytechnique
Fédérale de Lausanne

ADD THE PIPES IN THE PEDESTRIAN WAYS



Temperature 17 °C
DHvap = 160 kJ/kg
Pressure = 50 bar

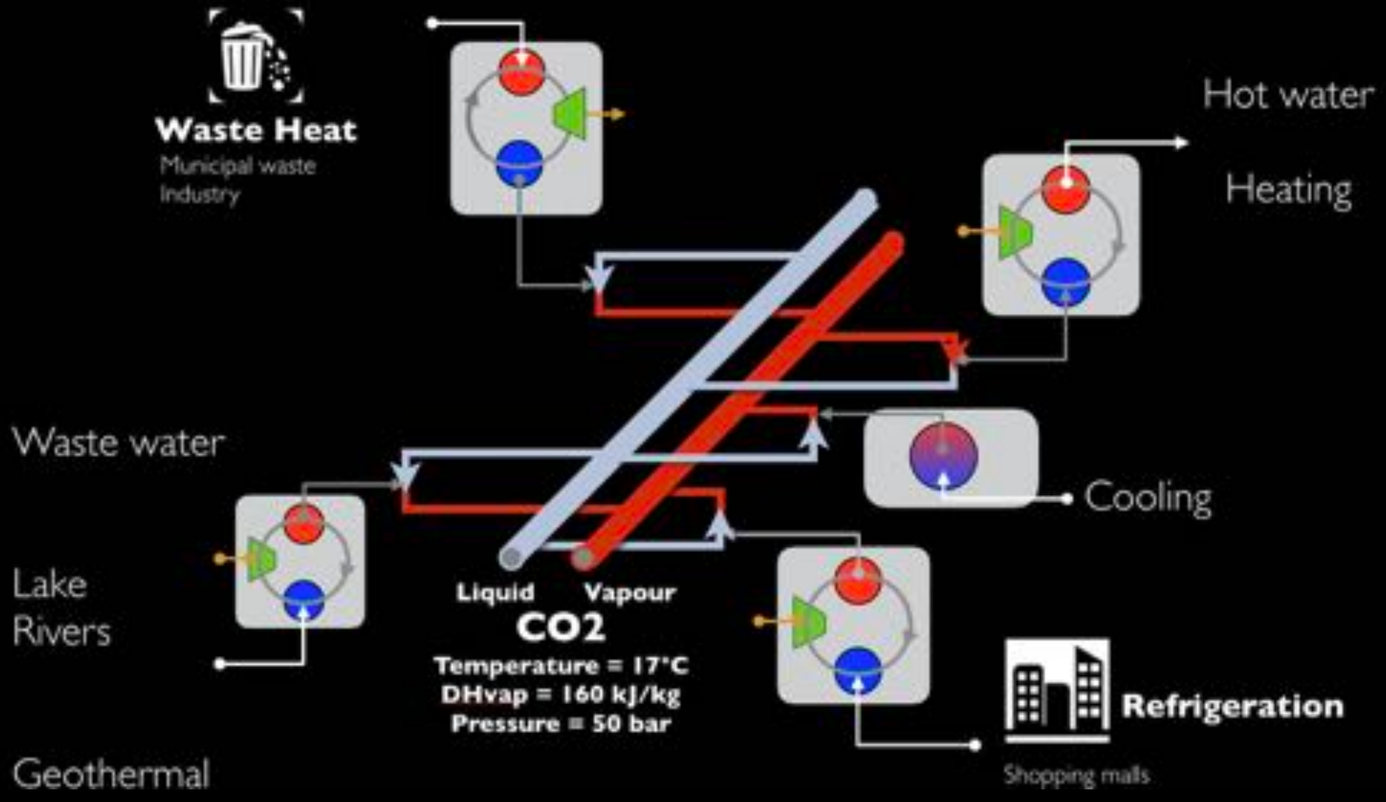
Non freesing



Instead of putting them underground

Ecole Polytechnique
Fédérale de Lausanne

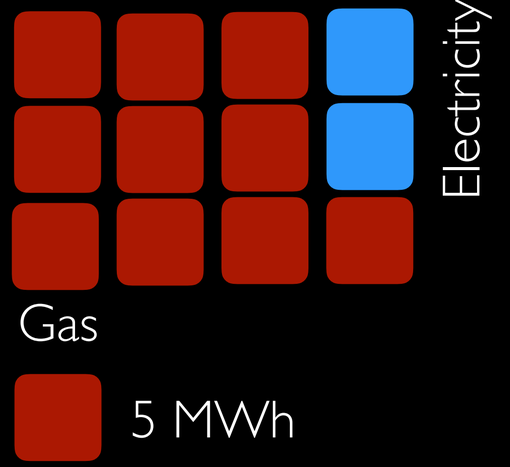
5TH GENERATION DISTRICT HEATING AND COOLING

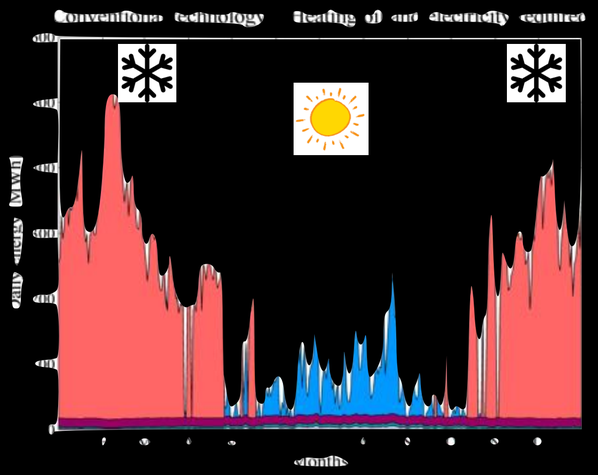


- Harvest and Distribute the heat from the environment
- Heating and cooling
- Two Pipes
- Electricity as energy source

Ecole Polytechnique
Fédérale de Lausanne

APPLICATION TO A DISTRICT

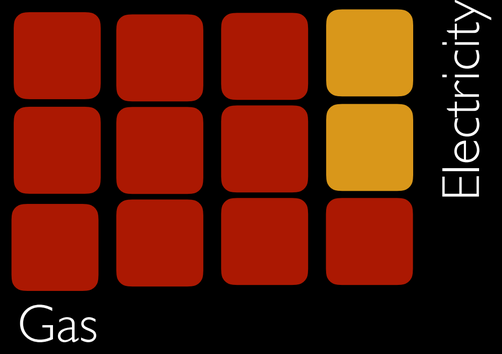




S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)

APPLICATION TO THE DISTRICT

Today

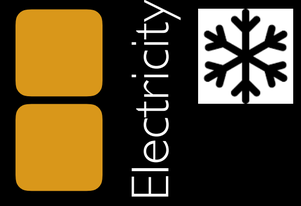


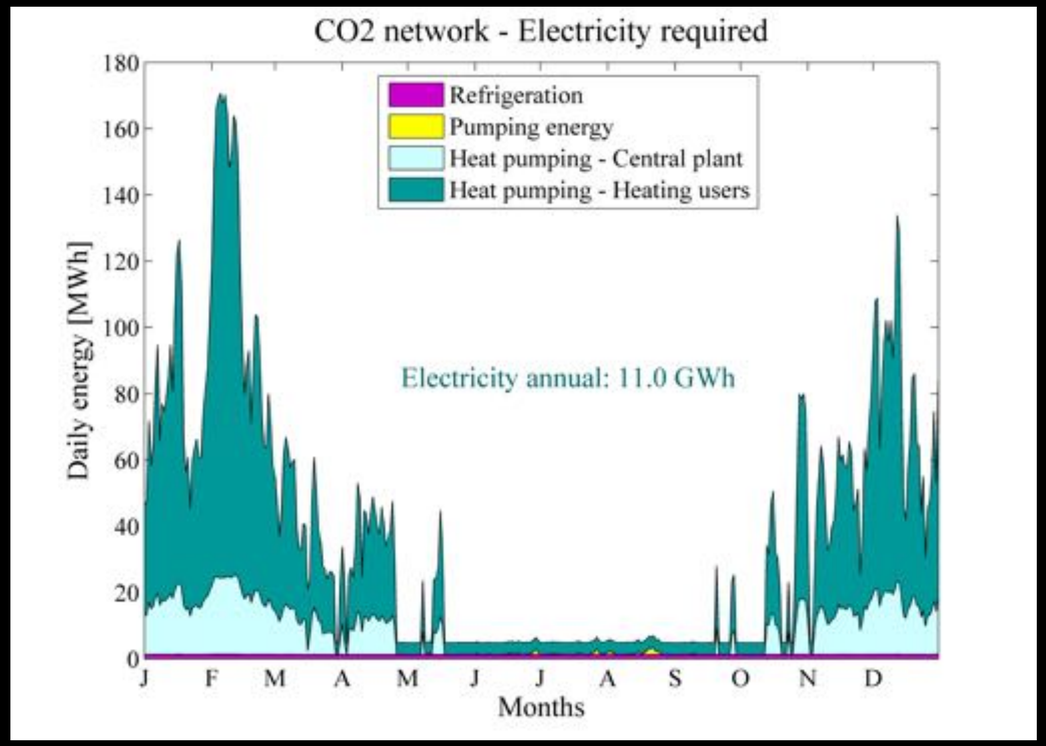
COP =5.7

-84 %

No boilers

Tomorrow

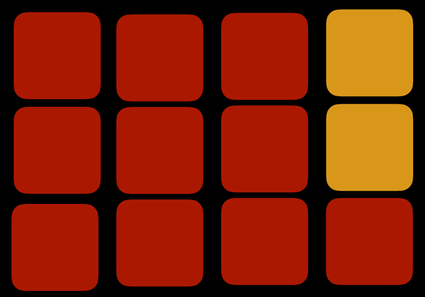




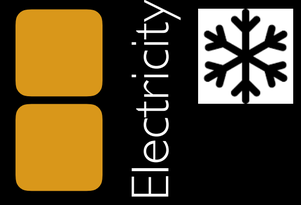
Ecole Polytechnique
Fédérale de Lausanne

APPLICATION TO THE DISTRICT

Today



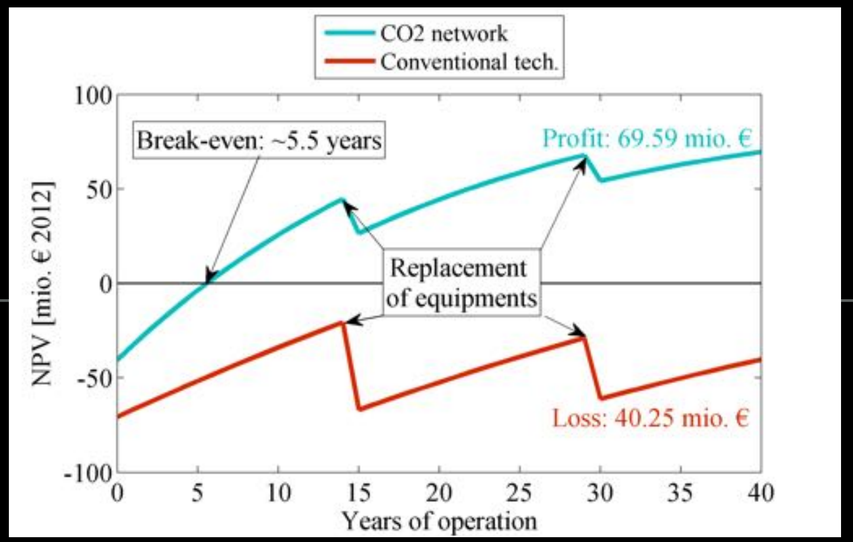
Tomorrow



-84 %
No boilers

Investment

Losses



Investment

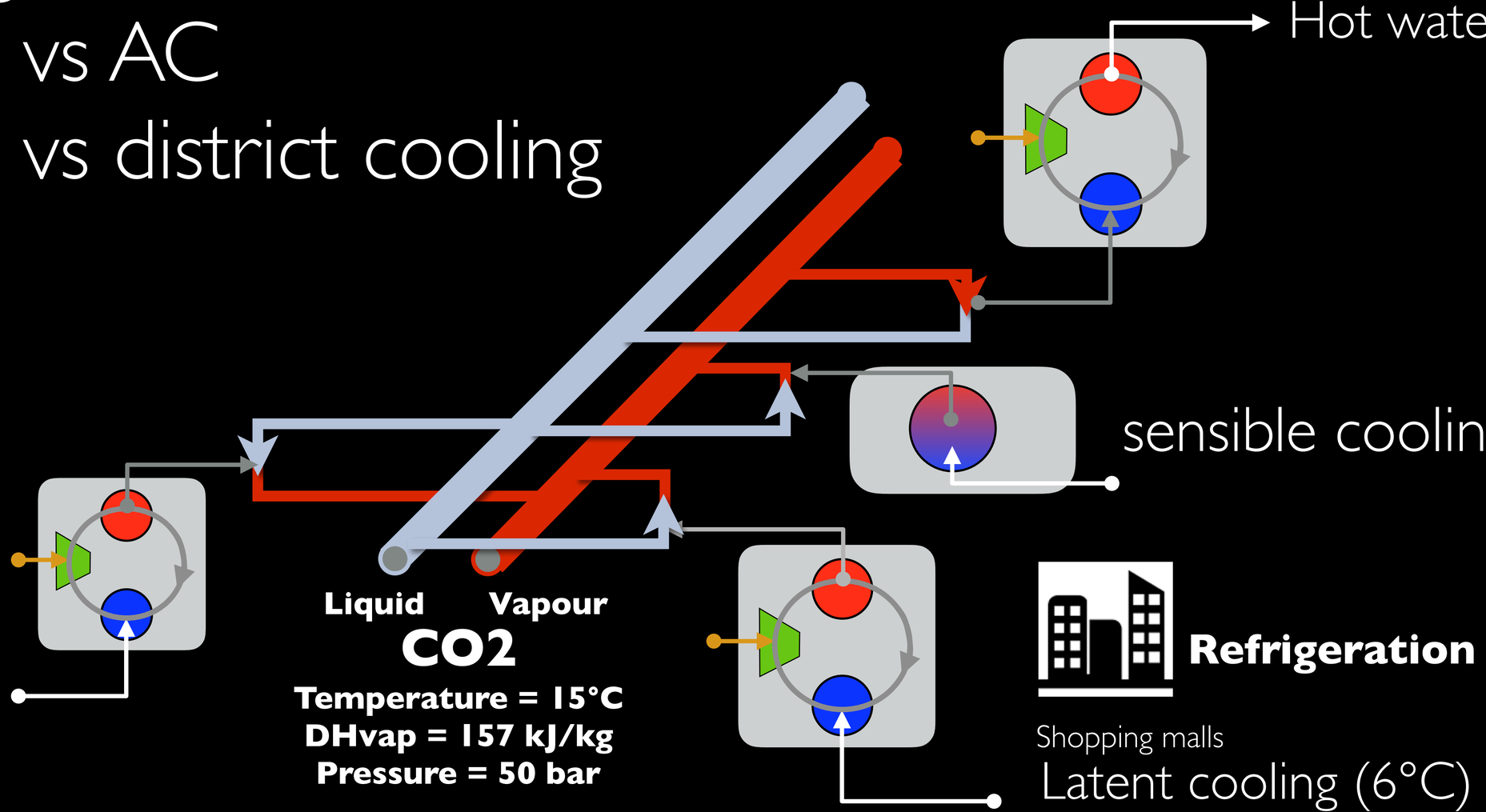
10 k€/cap

Profit

Henchoz, Samuel, et al. "Performance and profitability perspectives of a CO 2 based district energy network in Geneva's City Centre." *Energy* 85 (2015): 221-235.

DOES IT WORK FOR TROPICAL COUNTRIES ?

Savings :
65 % vs AC
40 % vs district cooling

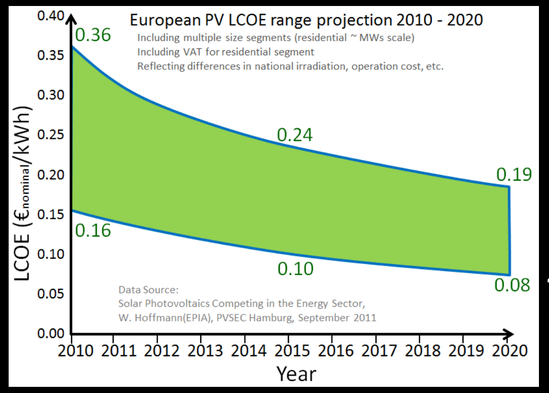


Lakes
Sea
Rivers

Geothermal

Ecole Polytechnique
Fédérale de Lausanne

SUPPLYING ELECTRICITY WITH THE SUN

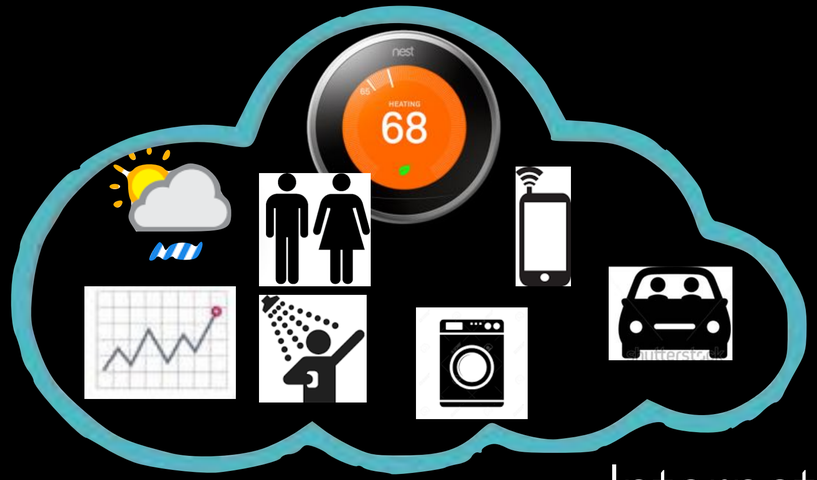


4.0cts USA
2.4cts Abu Dhabi
1.8cts Saudi Arabia

PV panels

Sensors

isolation



Internet

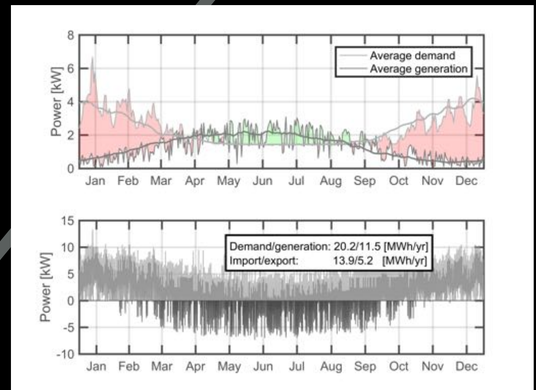
Water

Waste water

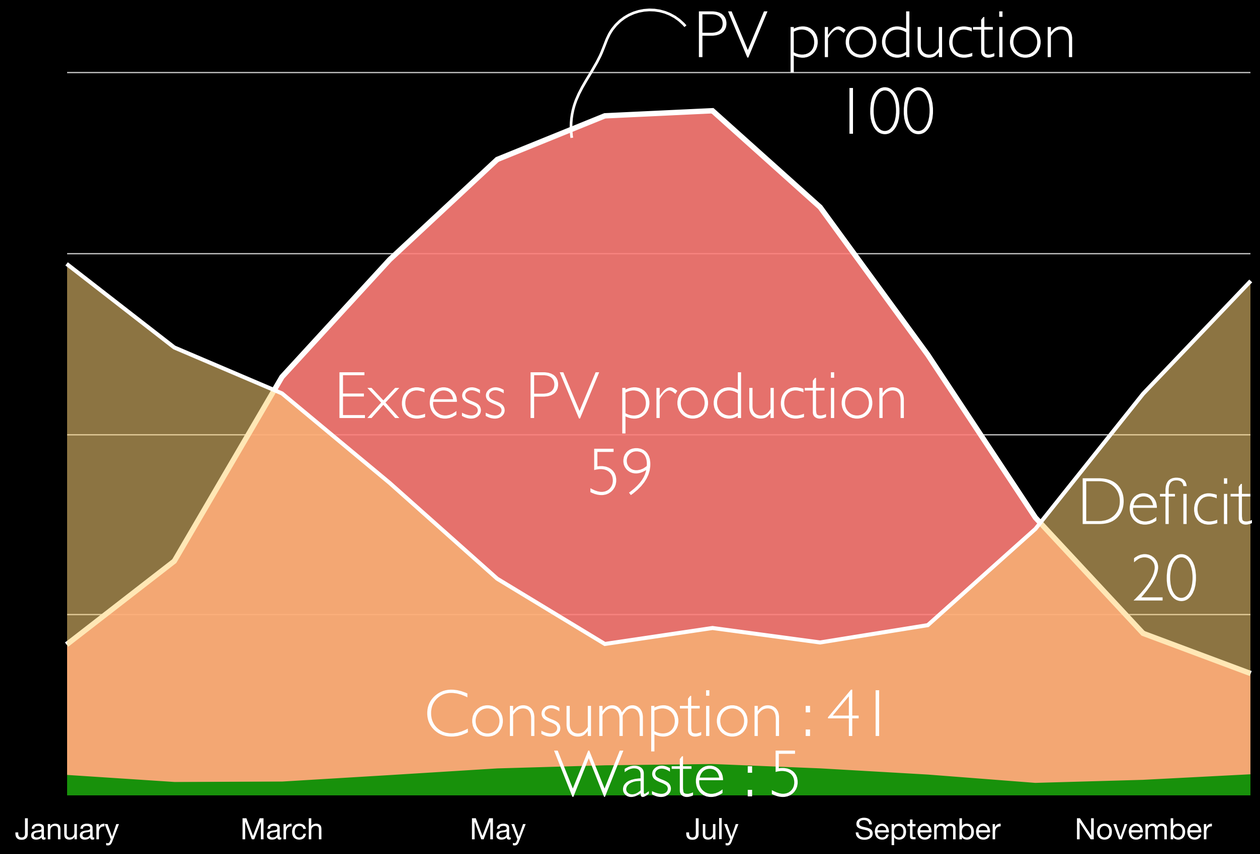
Predictive control

Bat

Heat pumps

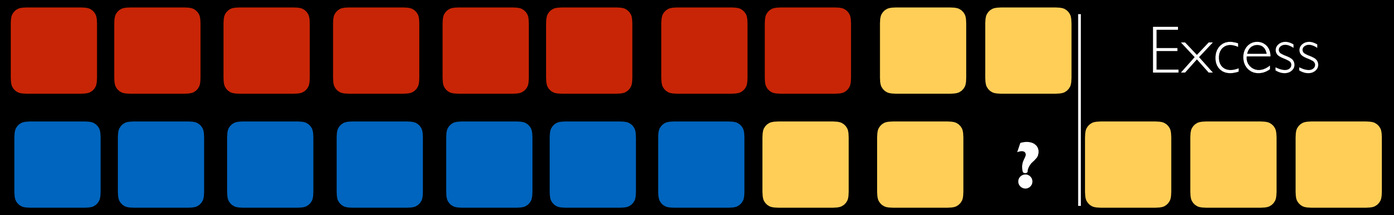


HOW TO SUPPLY ELECTRICITY ?

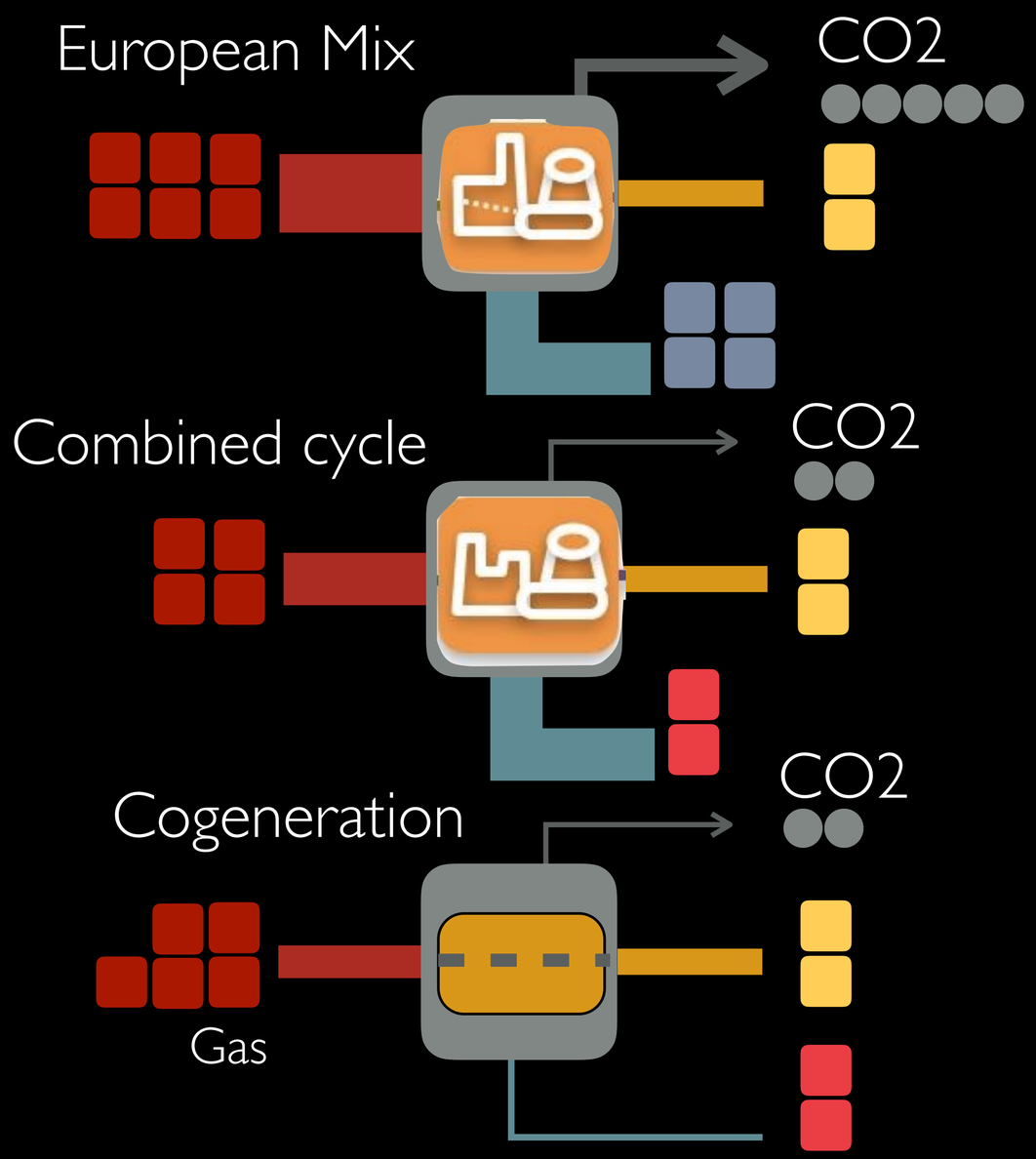


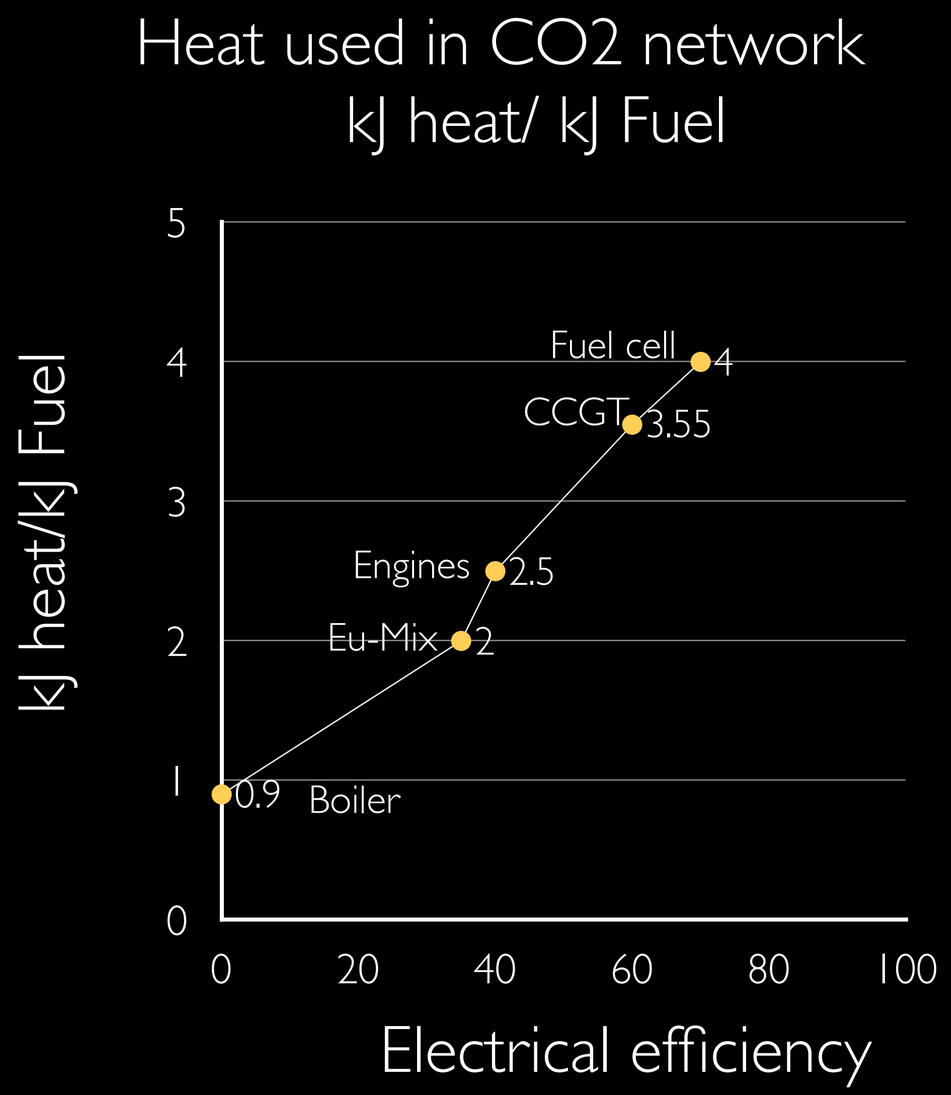
PV PANELS ON THE ROOF

PV efficiency = 20 %
Full roofs area covered (30 m2/cap)
Remaining energy to import = 10% of the total needs



PRODUCING THE ELECTRICITY DEFICIT





Ecole Polytechnique
Fédérale de Lausanne

BIO - METHANE FROM BIOWASTE

BIOMASS : C(H2O)
Organic waste

Synthetic Natural Gas

Heat => CO2 network

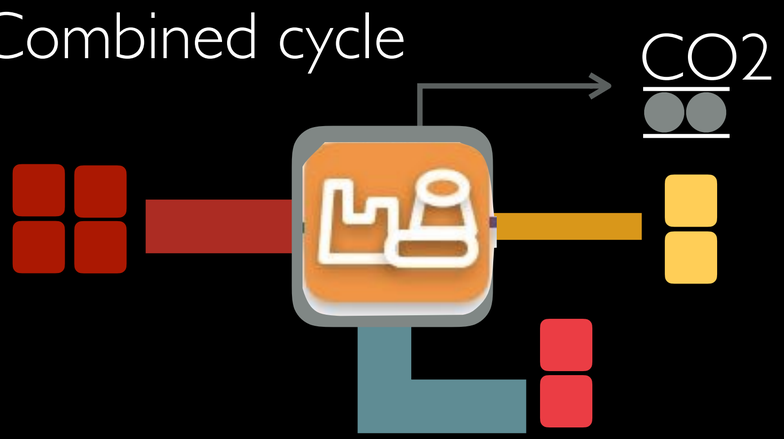
CO2

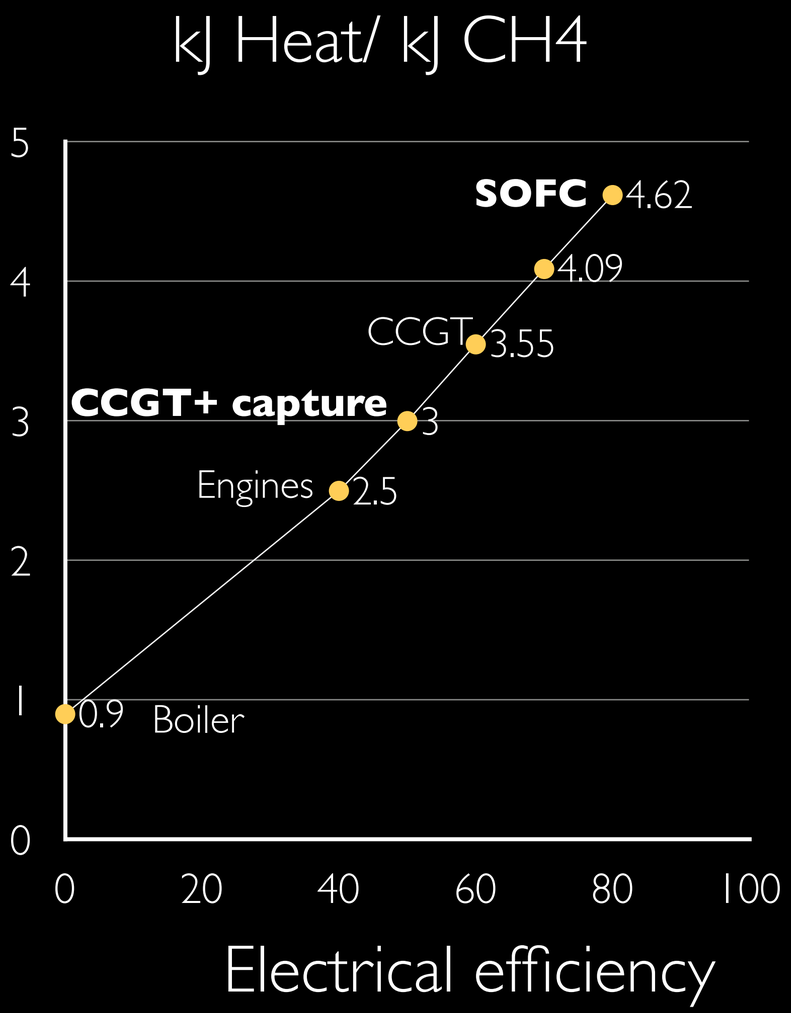
Biomethanisation
Hydrothermal gasification
Synthetic Natural Gas

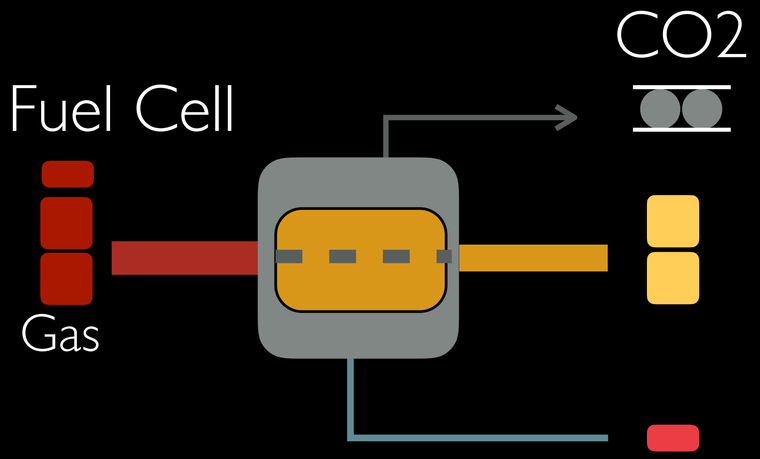
Gassner et al.,, Energy & Environmental Science 4, no. 5 (2011): 1742.

Gassner et al., Energy and Environmental Science 5, no. 2 (2012):

CO2 CAPTURE







Products :

Electricity :80 %

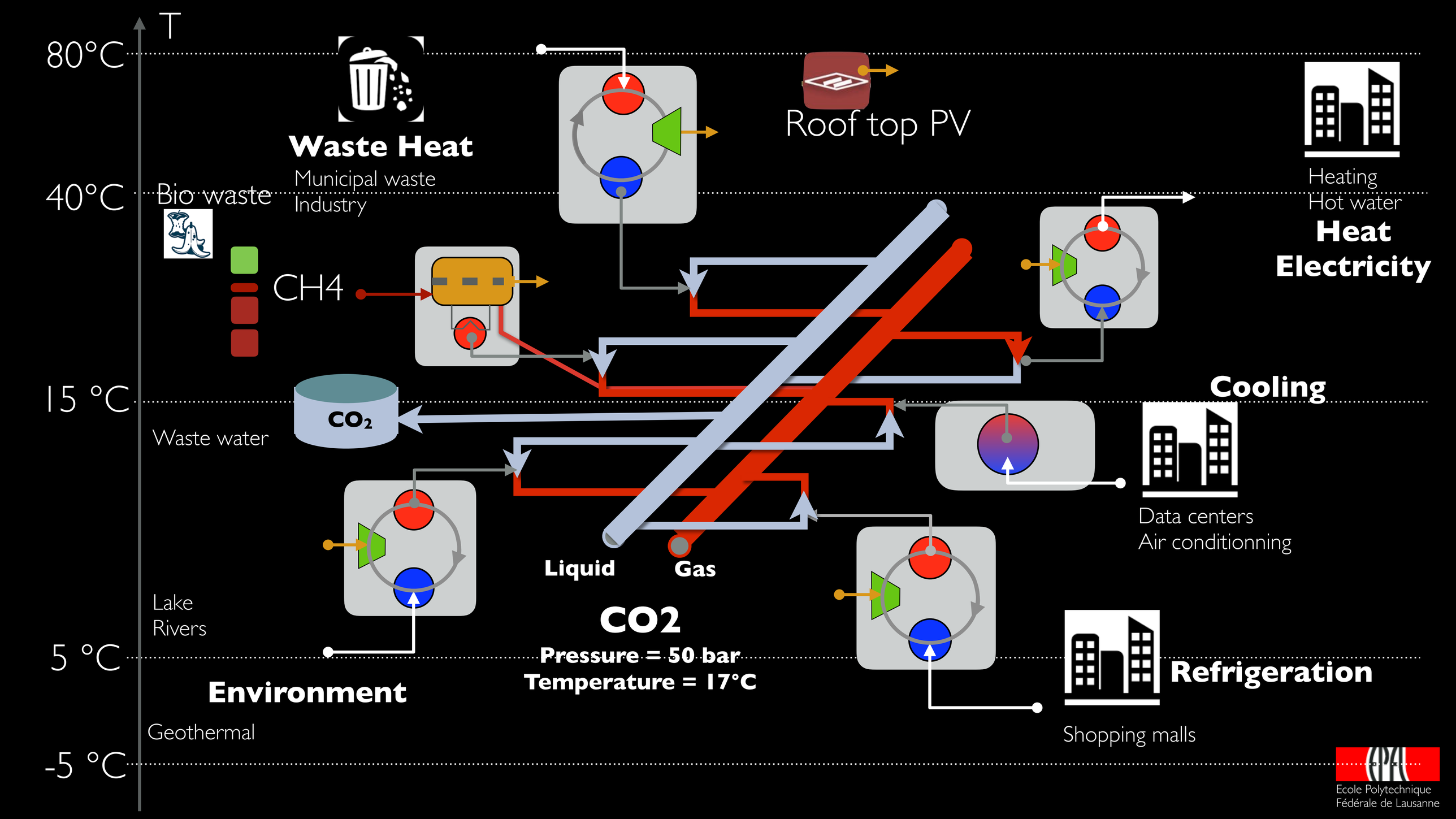
Heat : 20%

CO2 captured

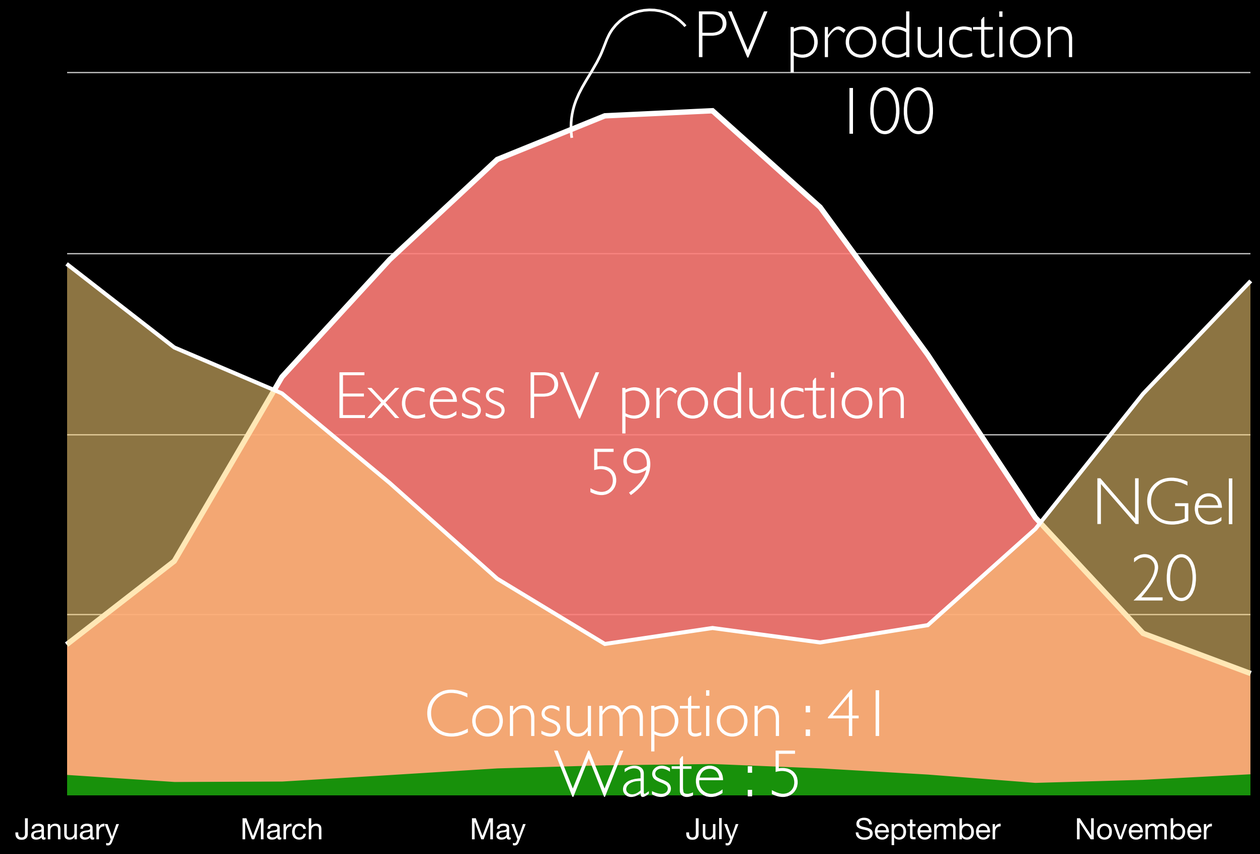
H2O

[1]Facchinetti, M, Daniel Favrat, and Francois Marechal. “Sub-atmospheric Hybrid Cycle SOFC-Gas Turbine with CO2 Separation.” *PCT/IB2010/052558, 2011.*

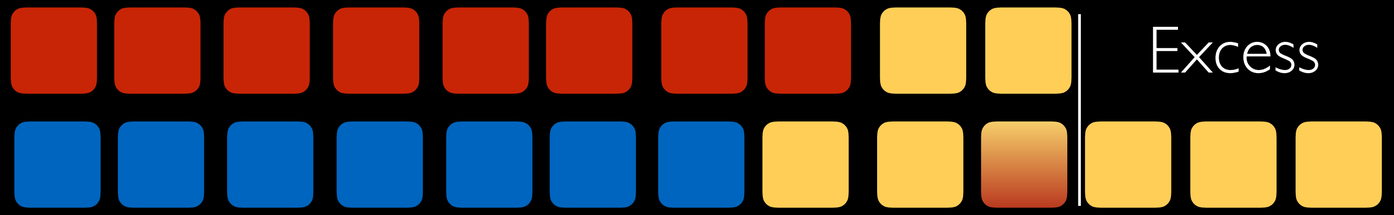
Ecole Polytechnique Fédérale de Lausanne


T
80°C
40°C
15 °C
5 °C
-5 °C
Waste Heat
Municipal waste
Industry
Roof top PV
Heating
Hot water
Heat
Electricity
Bio waste
CH4
CO2
Waste water
Cooling
Data centers
Air conditionning
Liquid
Gas
CO2
Pressure = 50 bar
Temperature = 17°C
Lake
Rivers
Environment
Geothermal
Refrigeration
Shopping malls
Ecole Polytechnique
Fédérale de Lausanne

HOW TO USE THE ELECTRICITY EXCESS ?



PV efficiency = 20 %
Total capacity
=> 70% Needs
=> 40% Self consumption
30% by CH4 and CO2 capture

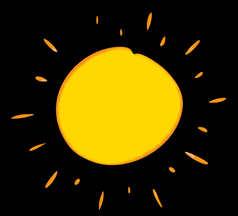


Ecole Polytechnique
Fédérale de Lausanne

SEASONAL STORAGE BY MOTHER NATURE

Stochastic summer energy

Stored energy

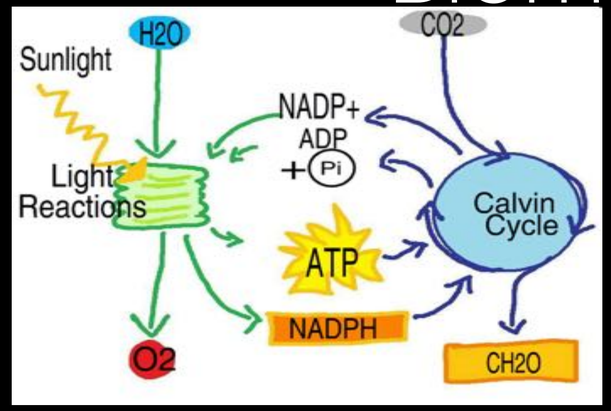


N, P, K

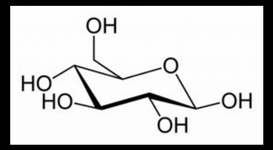
Photosynthesis

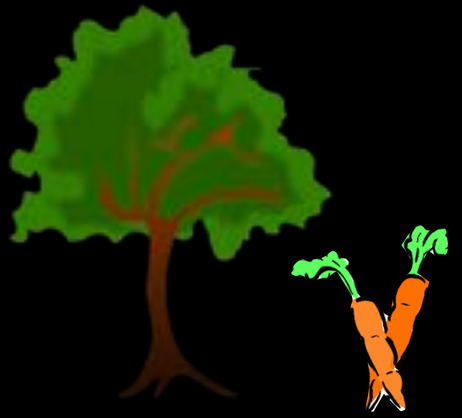
$CO_2 + H_2O \Rightarrow C(H_2O) + O_2$

Biomass



1961 Nobel Prize in Chemistry
Calvin cycle, Calvin–Benson-Bassham (CBB) cycle





Photosynthesis : 1-2 % Solar efficiency

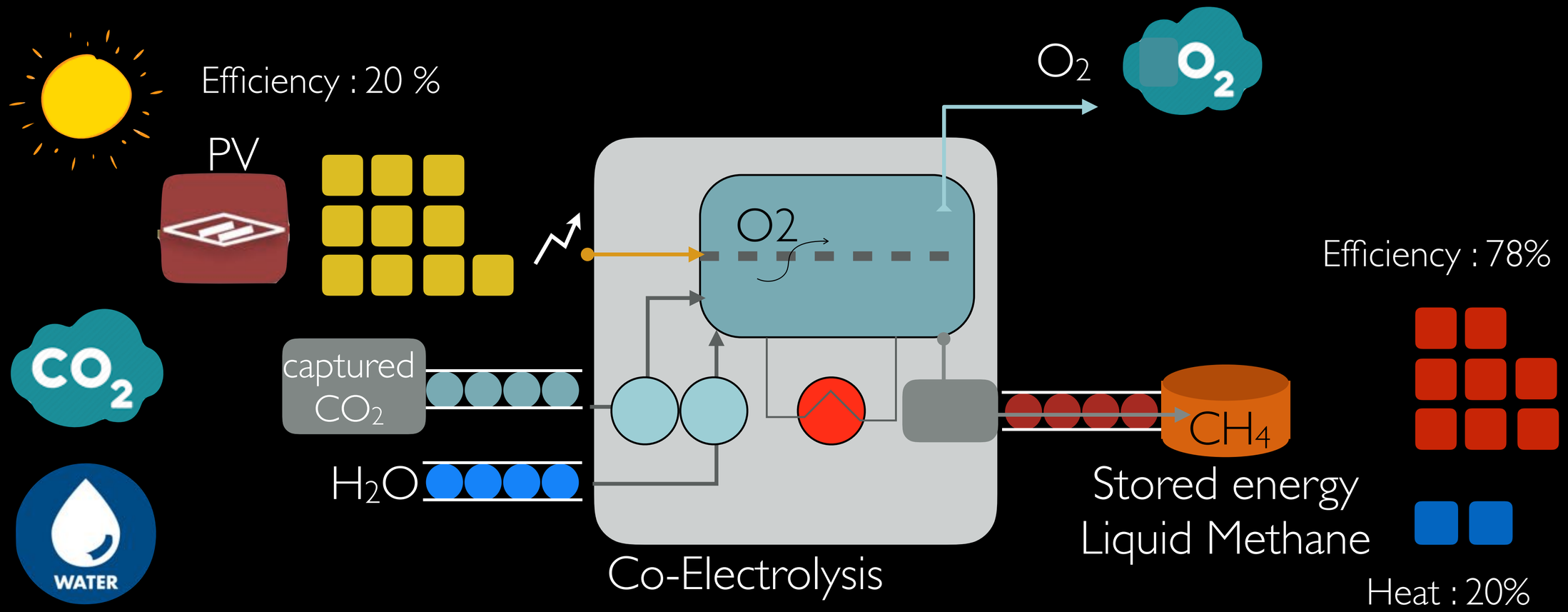
(ATP) Adenosine-5'-triphosphate

(NADP+) Nicotinamide adenine dinucleotide phosphate

www.sheppardsoftware.com
www.the-simple-homeschool.com

Ecole Polytechnique
Fédérale de Lausanne

MIMICKING MOTHER NATURE



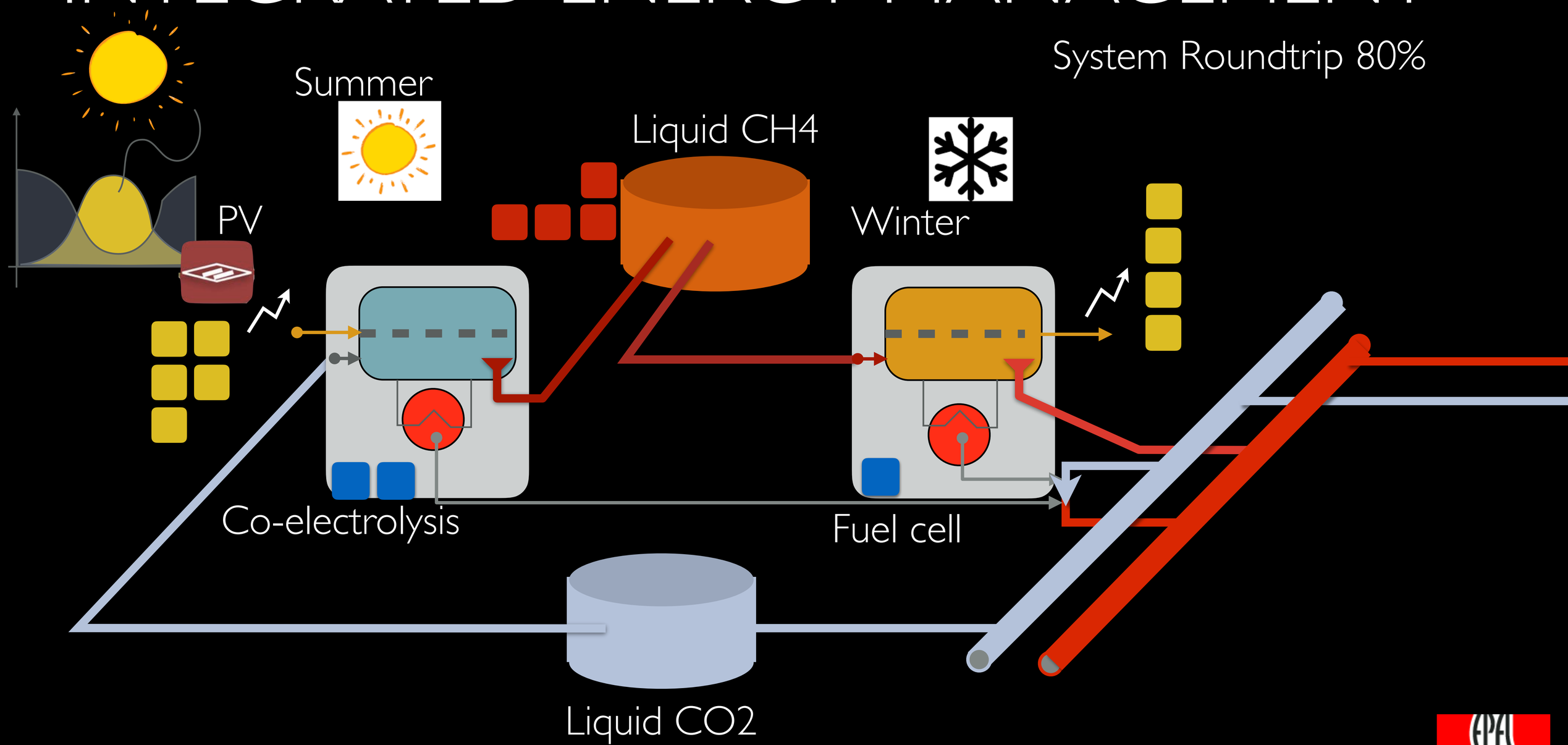
Artificial photosynthesis : 13-16 % Solar efficiency

L. Wang, et. al. Optimal design of solid-oxide electrolyzer based power-to-methane systems: A comprehensive comparison between steam electrolysis and co-electrolysis. Applied Energy (211), 2018, 1060-1079.

Ecole Polytechnique
Fédérale de Lausanne

INTEGRATED ENERGY MANAGEMENT

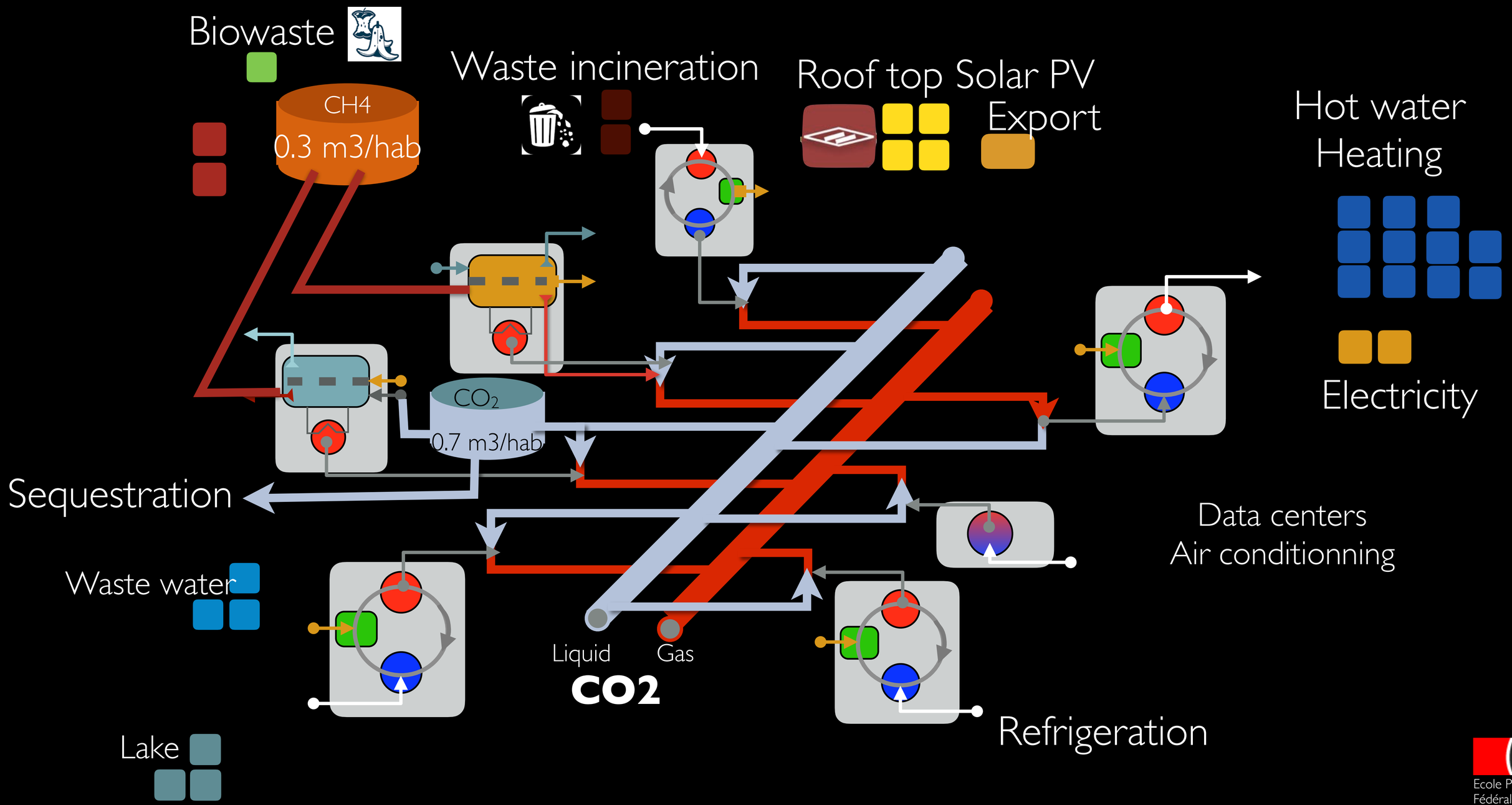
System Roundtrip 80%



Al-Musleh, Easa I., Dharik S. Mallapragada, and Rakesh Agrawal. "Continuous power supply from a baseload renewable power plant." *Applied Energy* 122 (2014): 83-93.

Ecole Polytechnique Fédérale de Lausanne

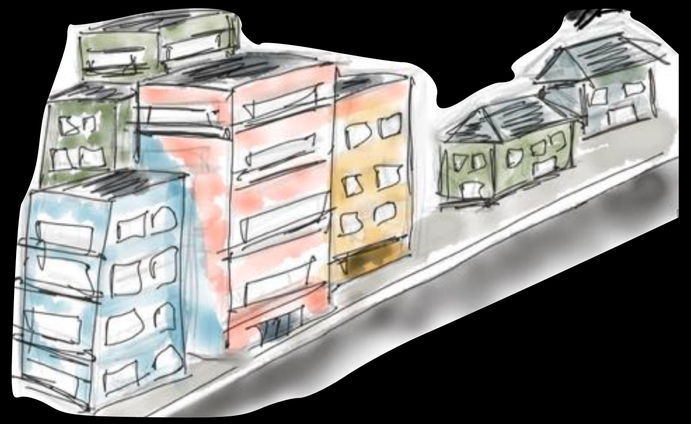
5TH GENERATION : MULTI-ENERGY GRIDS SYSTEM

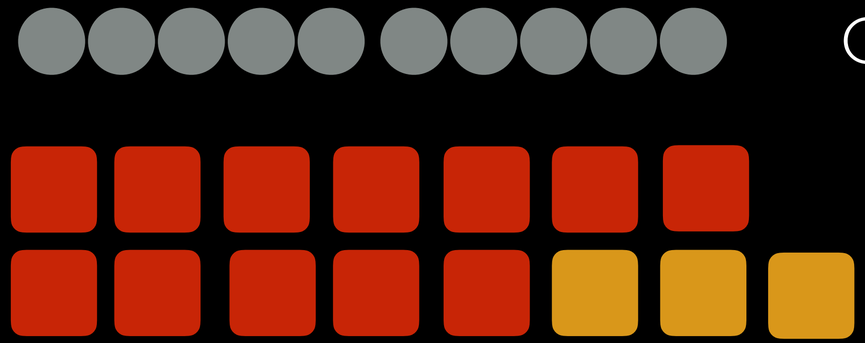


Ecole Polytechnique
Fédérale de Lausanne

A CITY 100% RENEWABLES AND CO2 NEUTRAL BY 5 G DHC

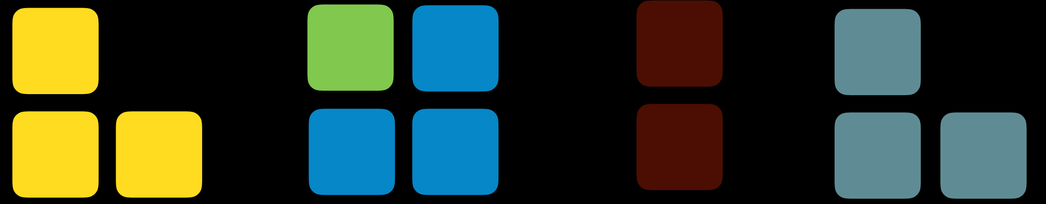
Before





After

Investment
25 kCHF/cap

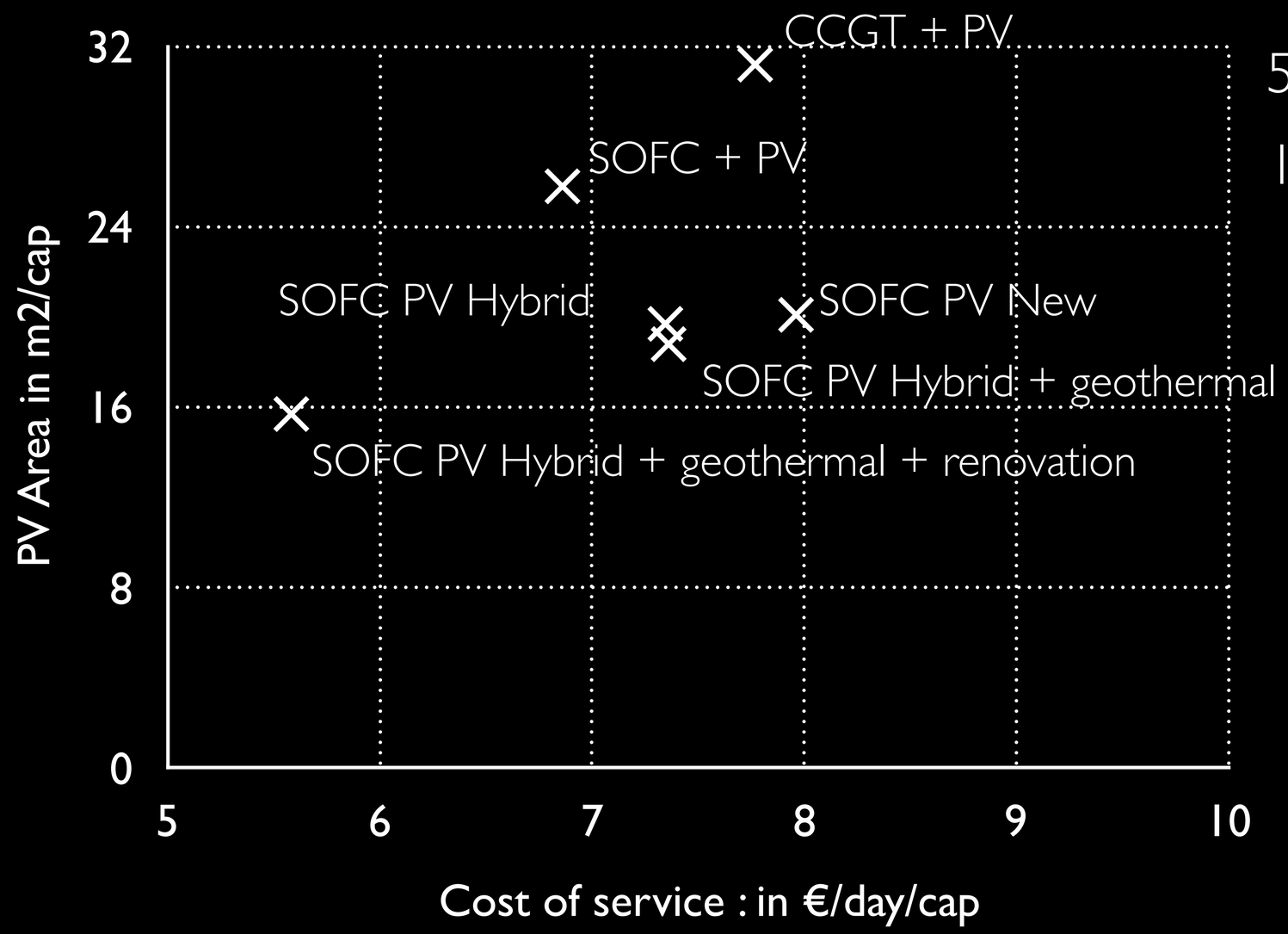


25 m2 PV/cap 1 m pipe/cap 12 kg/CO2/cap
Storage : 1 m3/cap

100 l gasoline/hab/year Electricity

R. Suciu et al., Energy integration of CO_2 networks and Power to Gas for emerging energy autonomous cities in Europe, ECOS 2017 Proceedings

EFFICIENCY VS COSTS



5.5 - 8 €/day/cap

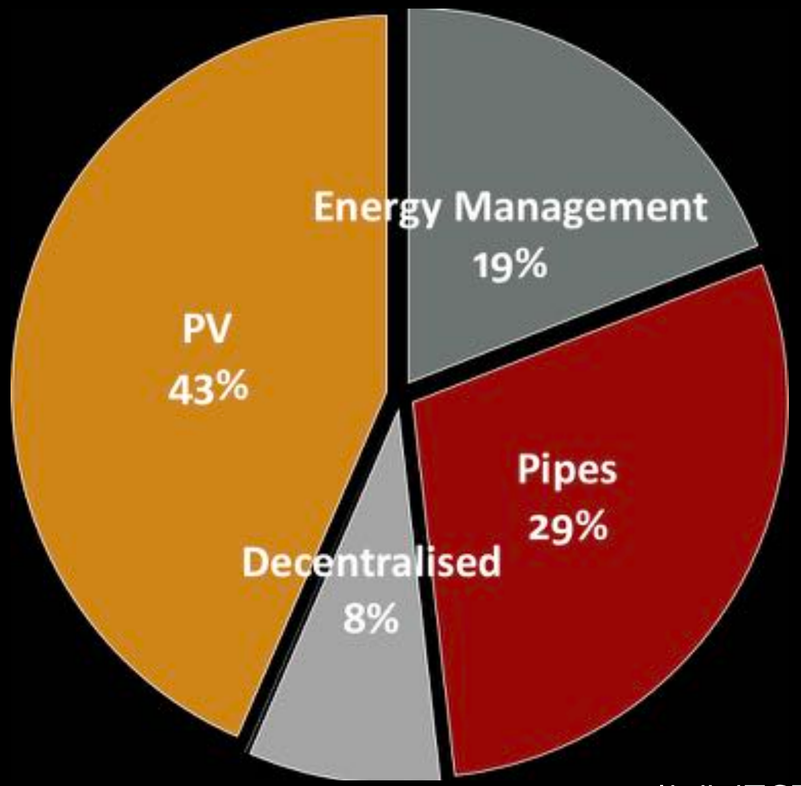
16 - 32 m2 PV/cap

- Advanced Cogeneration
- Perovskite PV
- Hybrid PV
- Geothermal storage
- Buildings renovation

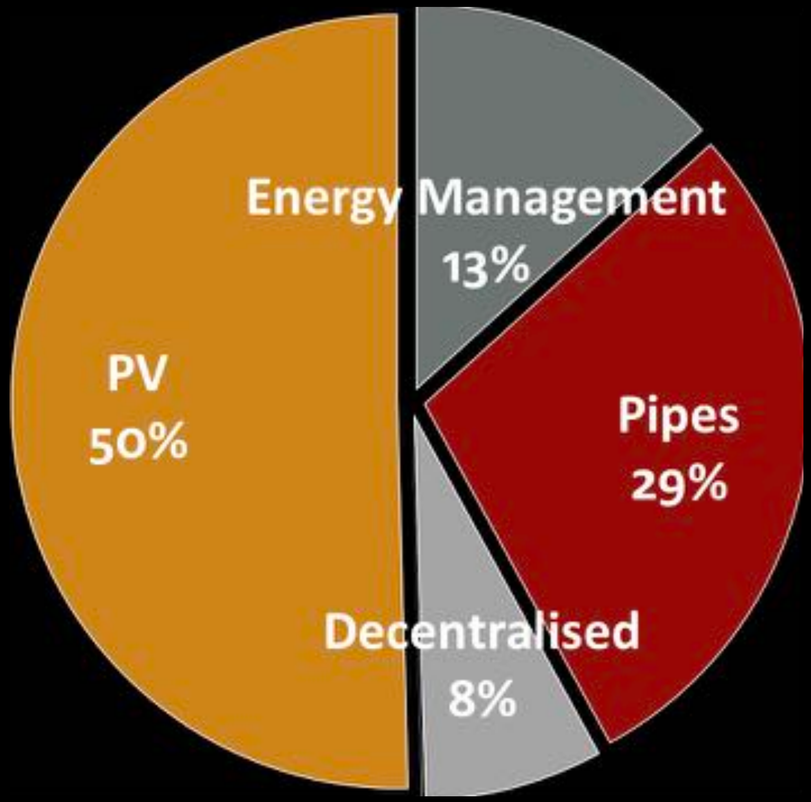
PV cost 300 €/m2

INVESTMENT : 330-440 CHF/M^2

SOFC



CCGT



INVESTMENT 330-440 CHF/M^2

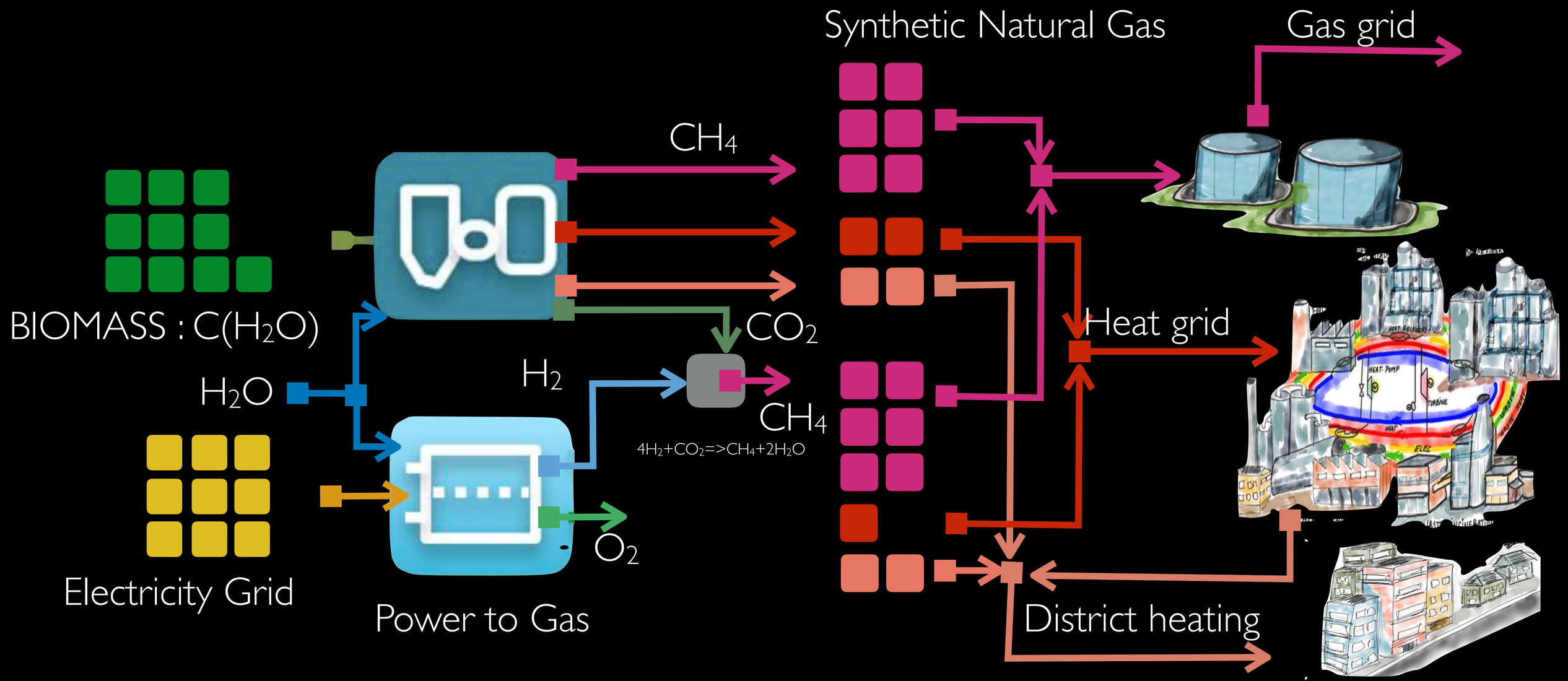
10% of the real estate value

50% private
50% Infrastructure and operation

NO MORE FOSSIL IMPORTS MEANS …

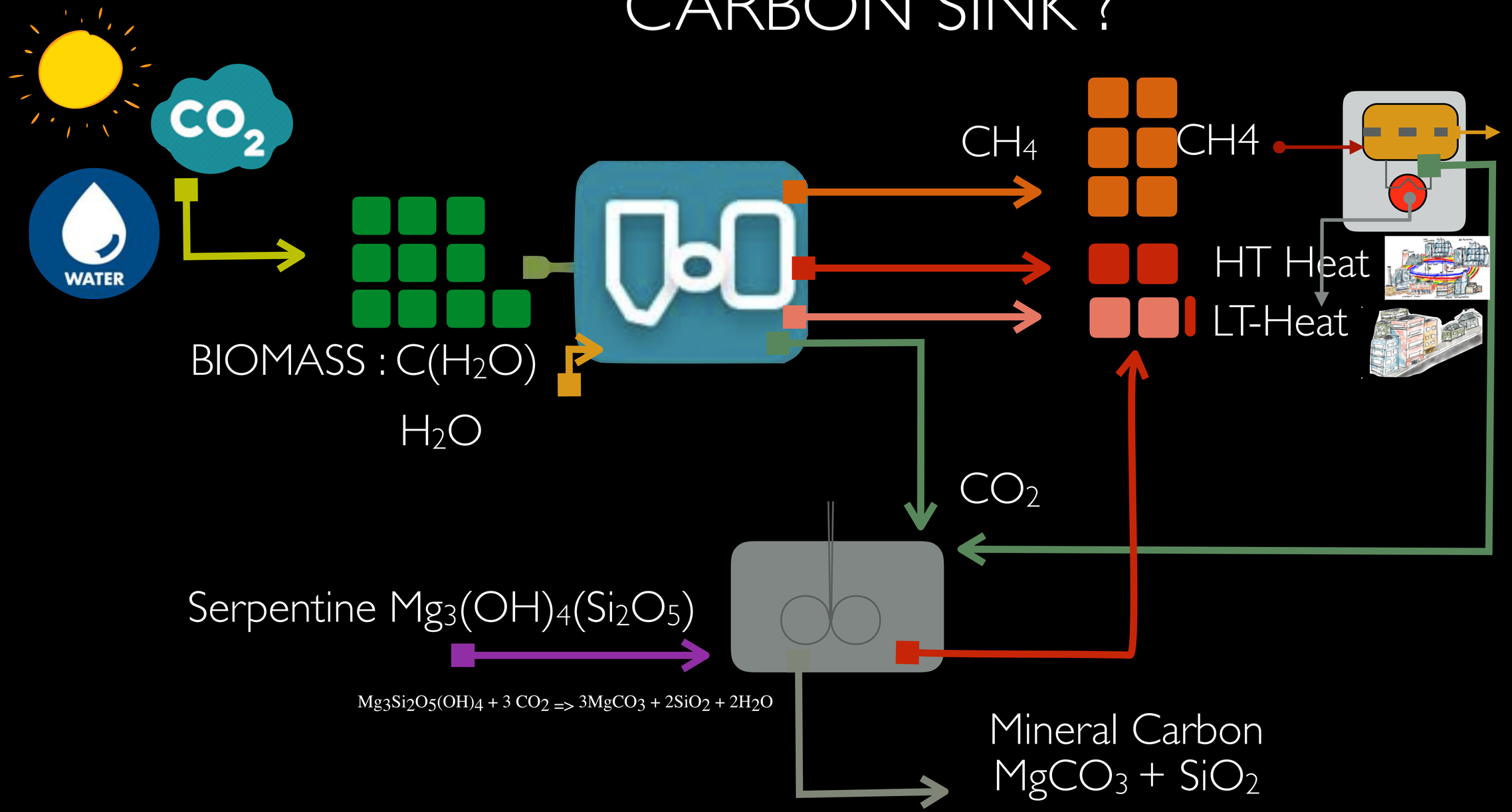
YOUR MONEY IS USED FOR YOUR SERVICES AND CREATES JOBS

A HOLISTIC VISION CONVERTING BIOMASS



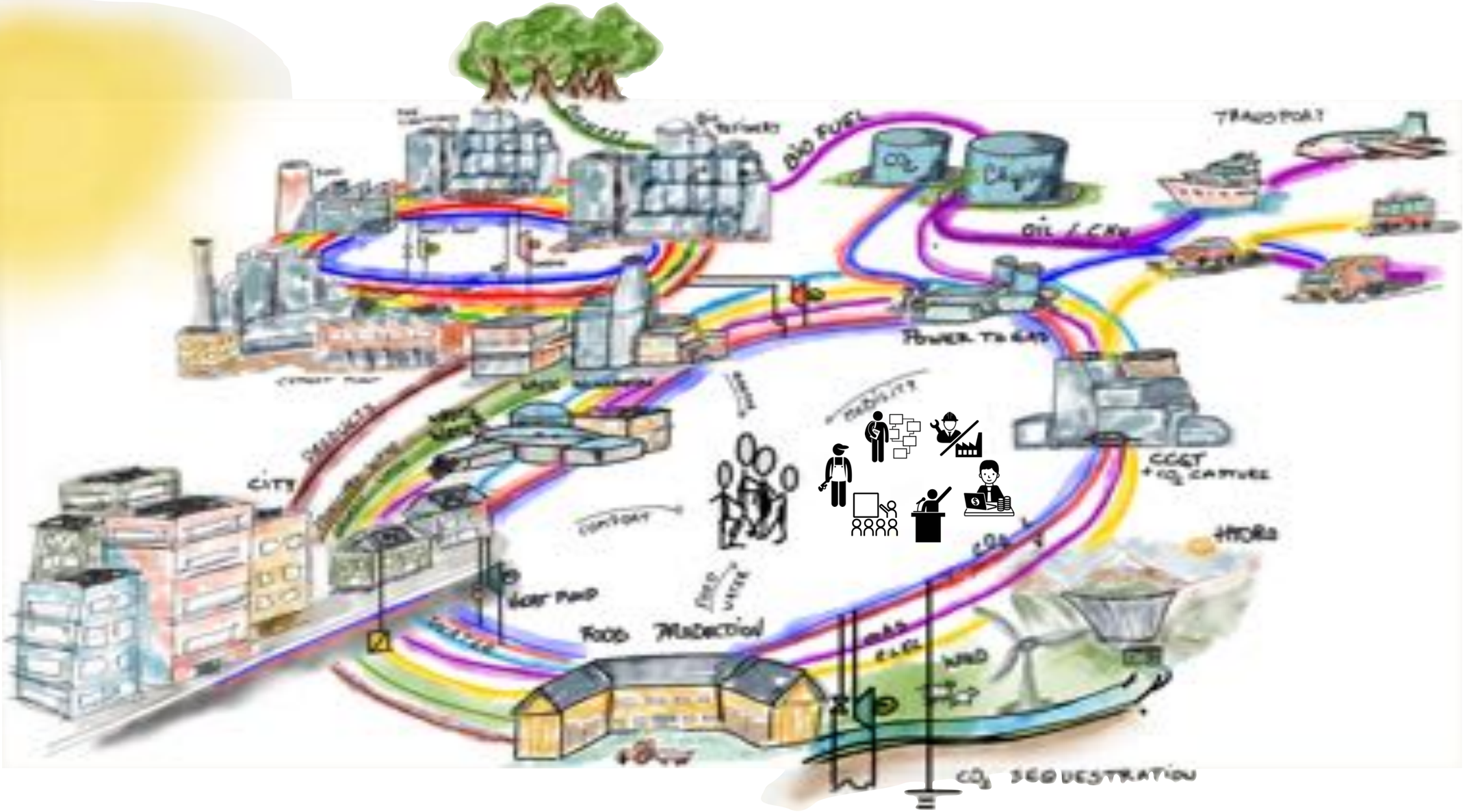
Gassner, Martin, and François Maréchal. "Thermo-economic optimisation of the integration of electrolysis in synthetic natural gas production from wood." Energy 33.2 (2008): 189-198.

CARBON SINK ?



Ecole Polytechnique
Fédérale de Lausanne

A HOLISTIC VISION FOR THE 5th G DHC



ACKNOWLEDGMENTS

- **Sun** : for the energy supply
- **Mother Nature** : to show us the way to store energy
- **Carnot** : to show us the importance of ambiance
- **Industry** : to give us the technologies
- **Engineers** : to assemble and use the technologies in the right way at the right time
- **Research** : to educate the population that solutions exists
- **(Authorities)** : to develop the infrastructure
- **(Finance)** : to ethically use (our) money for the right goals

ACKNOWLEDGMENT

- EOSHolding
- InnoSuisse
- SCCER - Furies
- EXERGO.ch

Ecole Polytechnique
Fédérale de Lausanne