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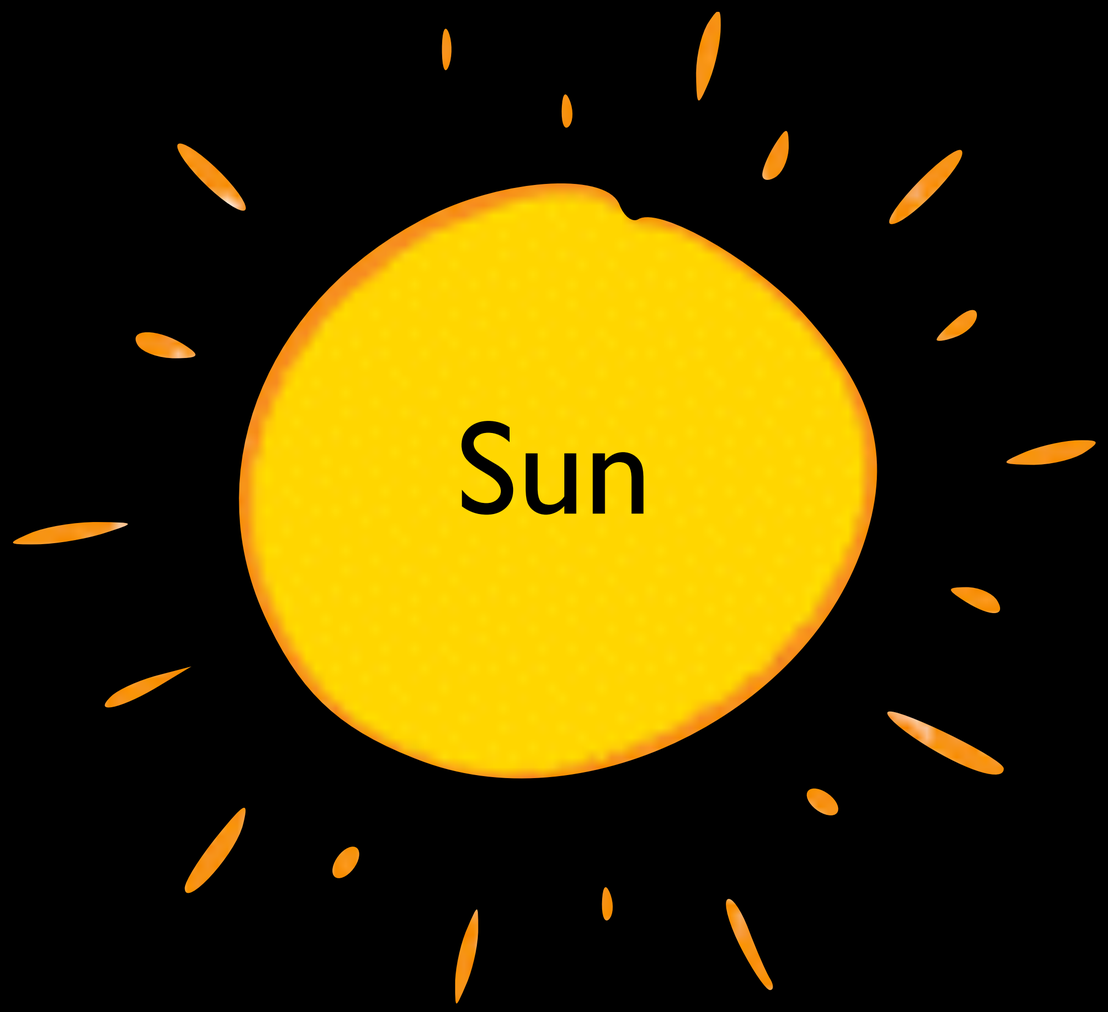
CO2 AND RENEWABLE ENERGY FOR AUTONOMOUS CITIES

Prof. François Marechal
Industrial Process and Energy System Engineering, EPFL, Switzerland

DO WE HAVE A PROBLEM OF ENERGY ?



1.5 hours

time needed to supply our needs

0.1%

surface to be covered by PV panels
to cover our needs

6500 years

number of years we can survive if we store
1 year of solar energy received

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MOTHER NATURE WAS A PROCESS ENGINEER

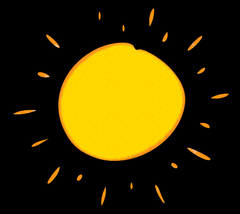
Stochastic summer energy

Stored energy

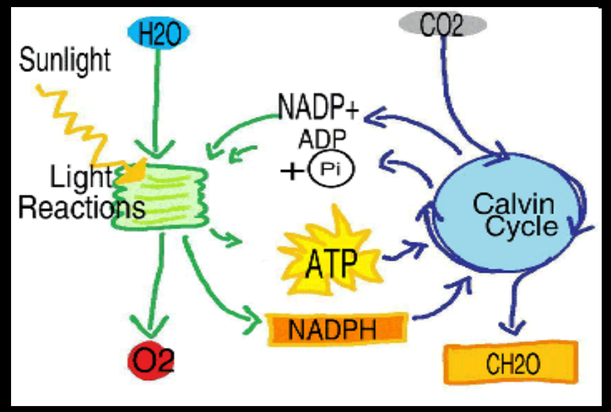
Photosynthesis

$CO_2 + H_2O => C(H_2O) + O_2$

Biomass



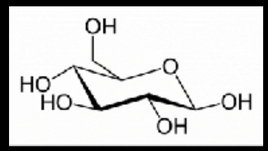
N, P, K

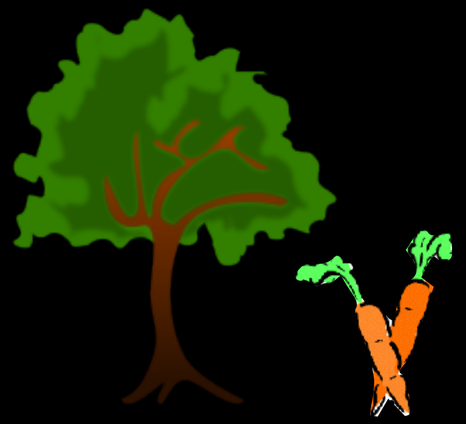


1961 Nobel Prize in Chemistry
Calvin cycle, Calvin–Benson-Bassham (CBB) cycle

(ATP) Adenosine-5'-triphosphate

(NADP+) Nicotinamide adenine dinucleotide phosphate





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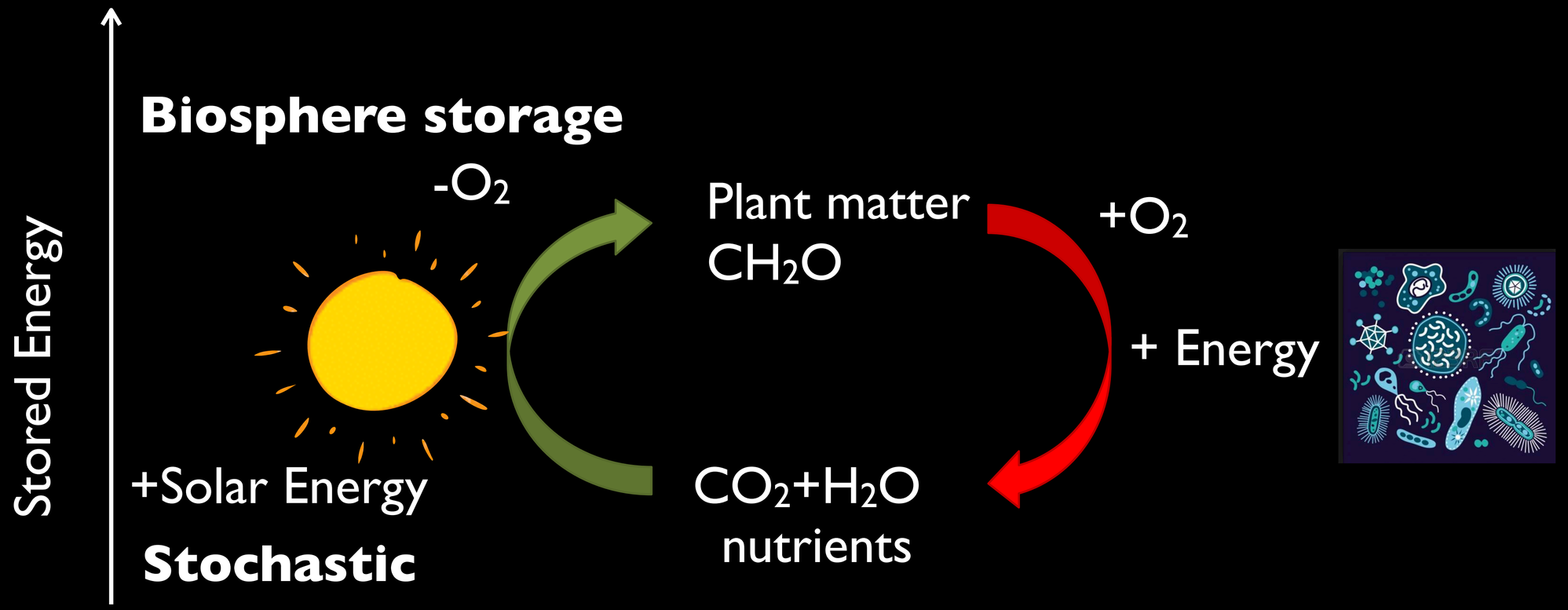
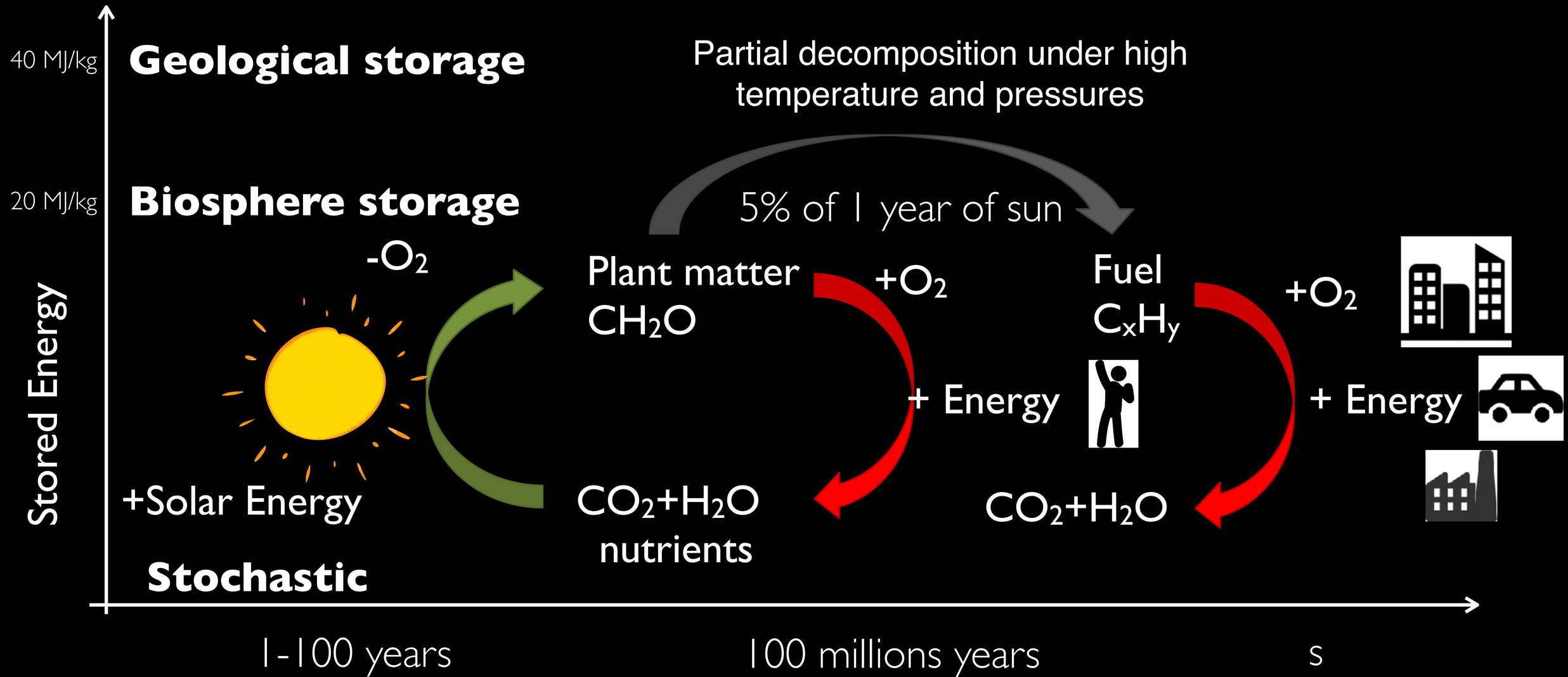
CIRCULAR ECONOMY …



CIRCULAR ECONOMY OR NOT ?



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OUR ENERGY NEEDS

Food
0.25 l/day

Oil
5.5 l/day

biomass $+O_2$ + Energy

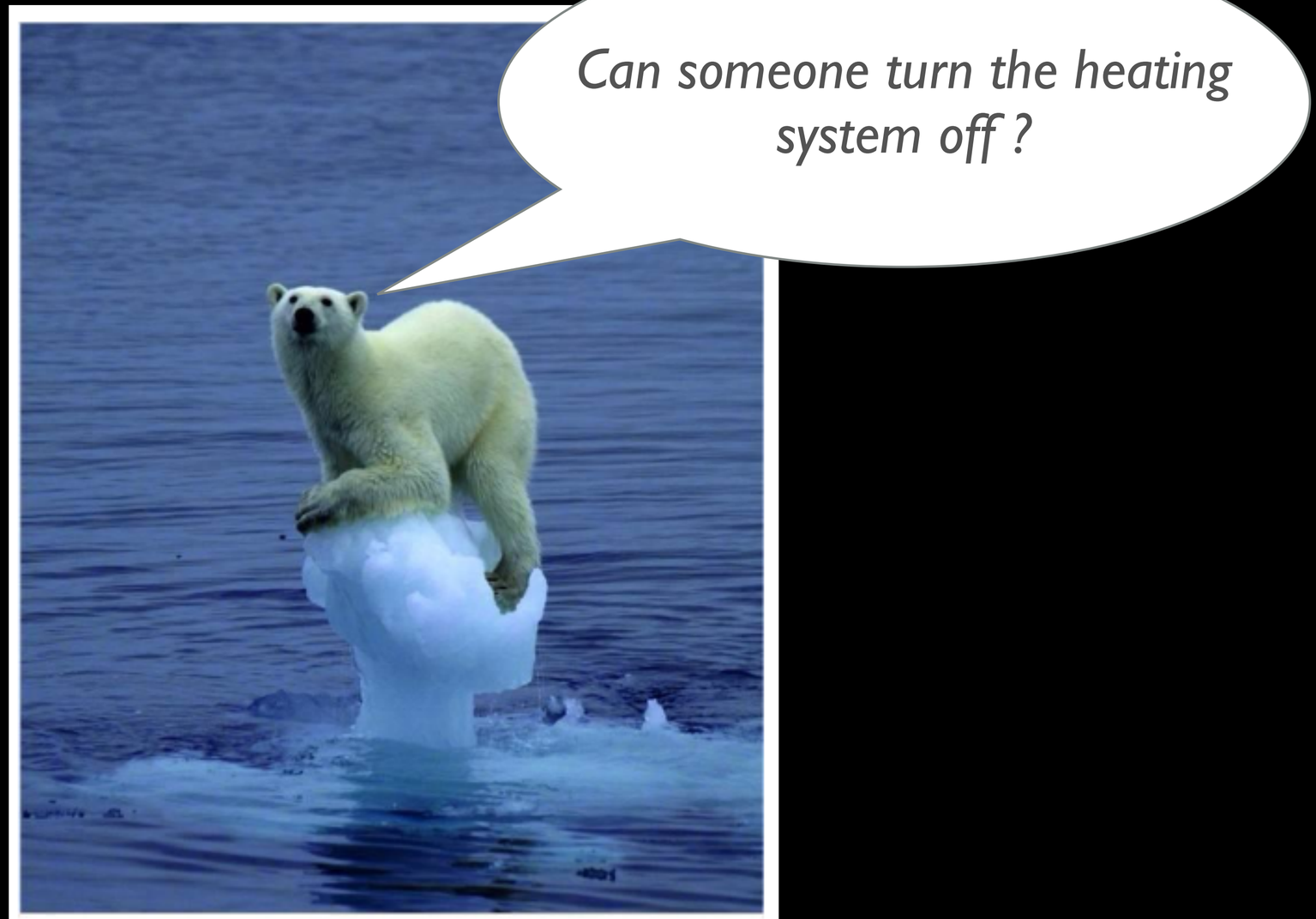
$+O_2$

+ Energy

Waste : 2 kg/day
BioWaste : 0.7 kg/day

CO2 :14 kg/day

CLIMATE CHANGE



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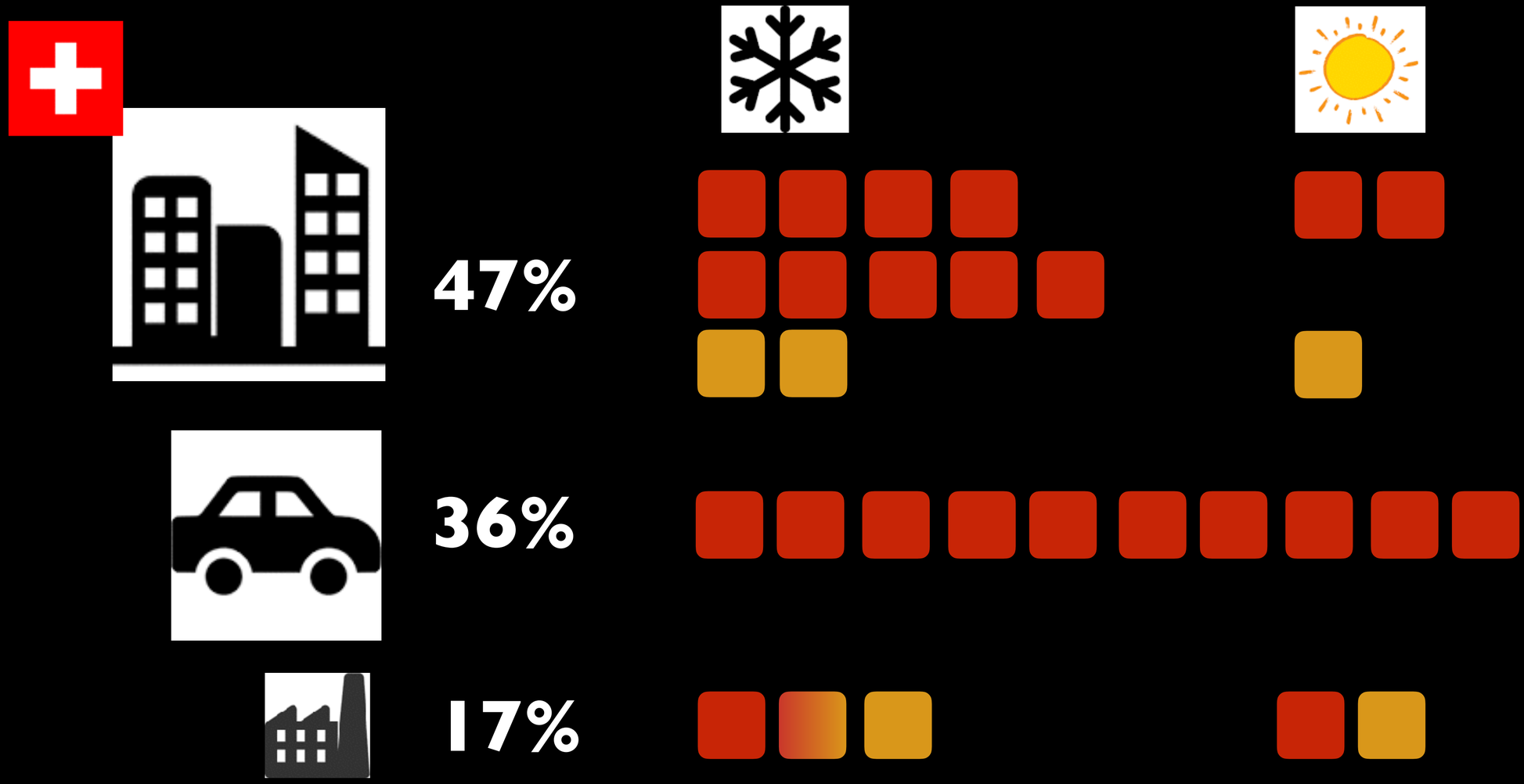
ENERGY NEEDS



100 l gasoline/hab/year

Electricity

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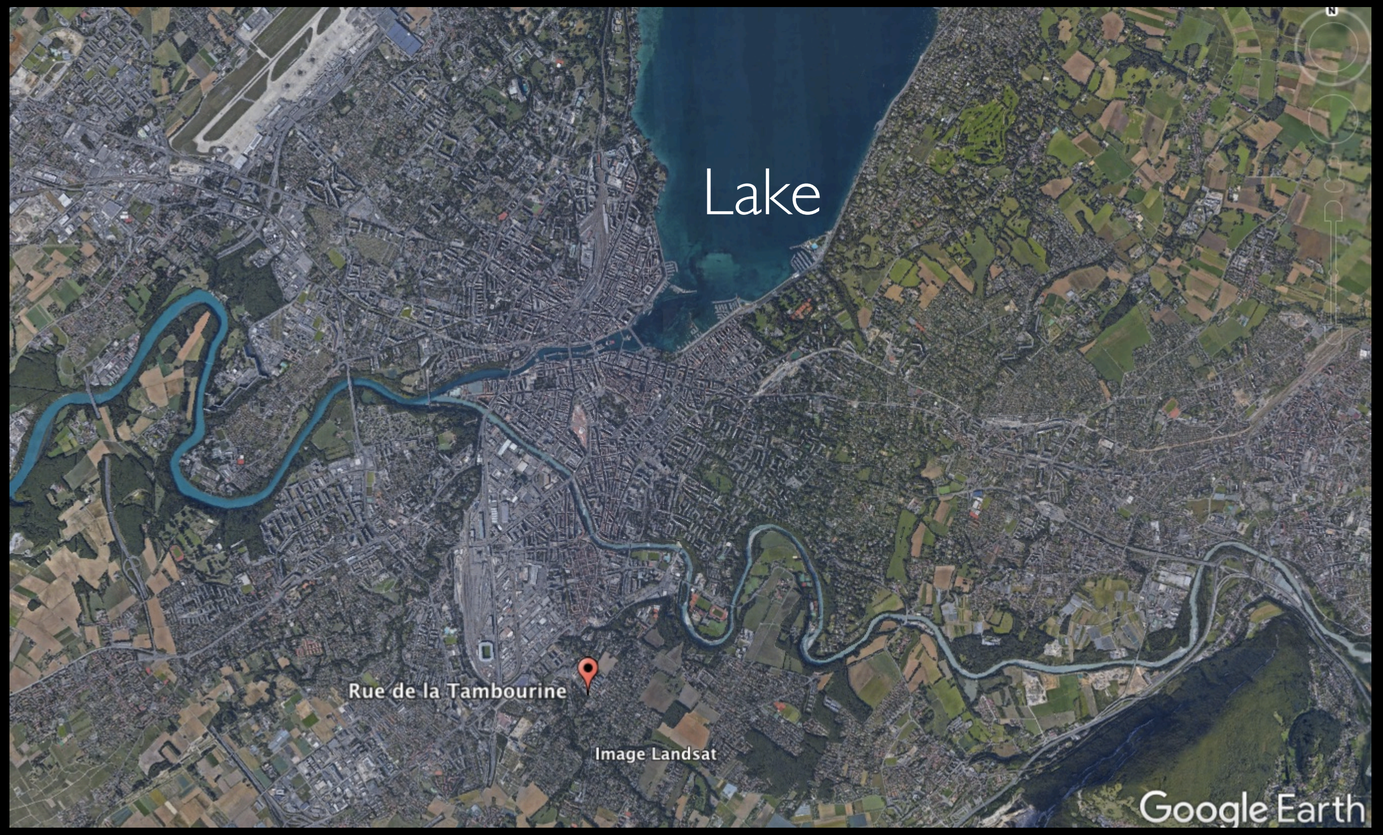
CITIES = 75% OF THE POPULATION

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.

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IS IT POSSIBLE TO MAKE THE CITY AUTONOMOUS ?

- without CO_2 emissions
- without importing energy
- without reconstructing the whole city
- without loosing money

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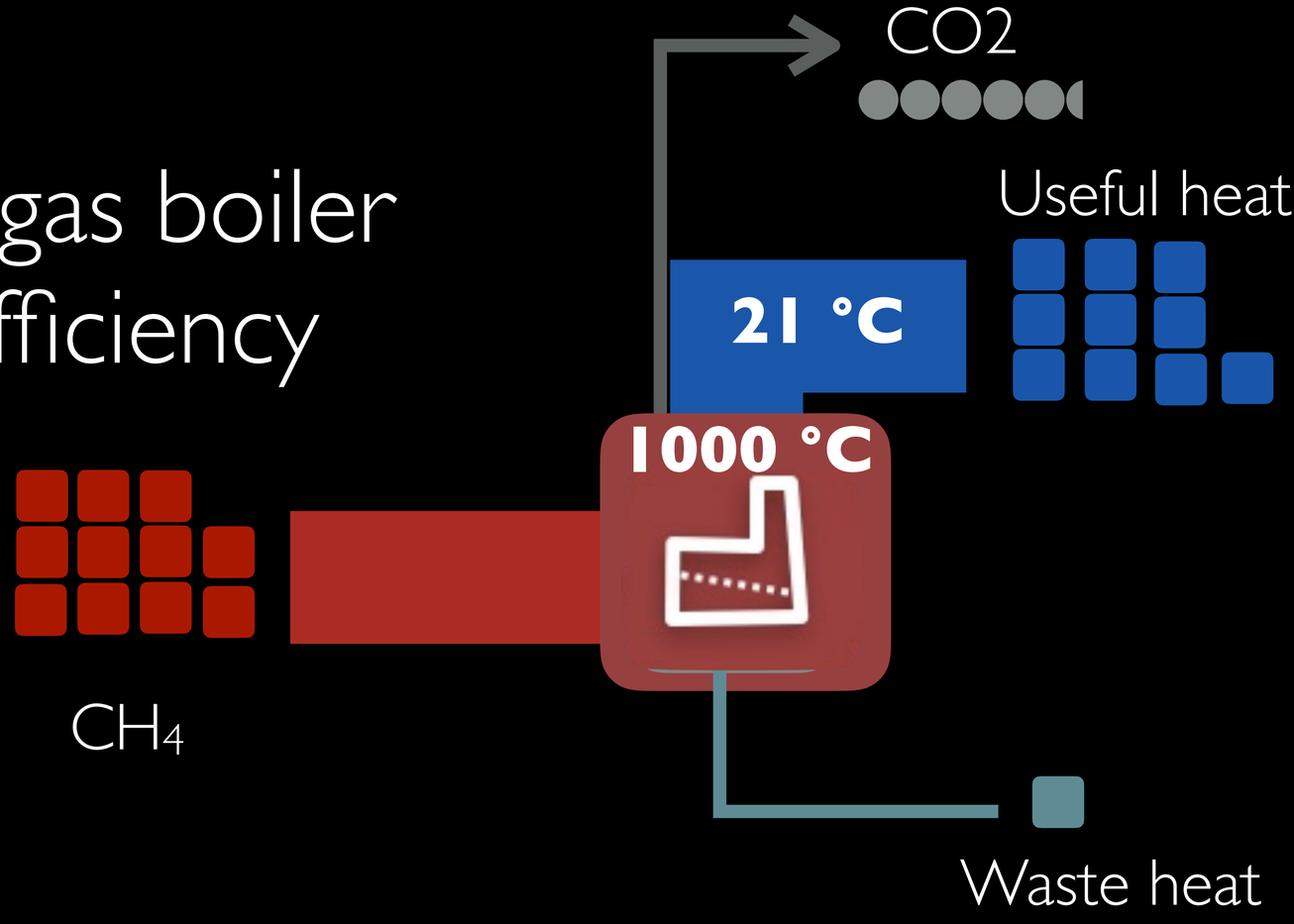
HEATING A BUILDING

Natural gas boiler
90% efficiency

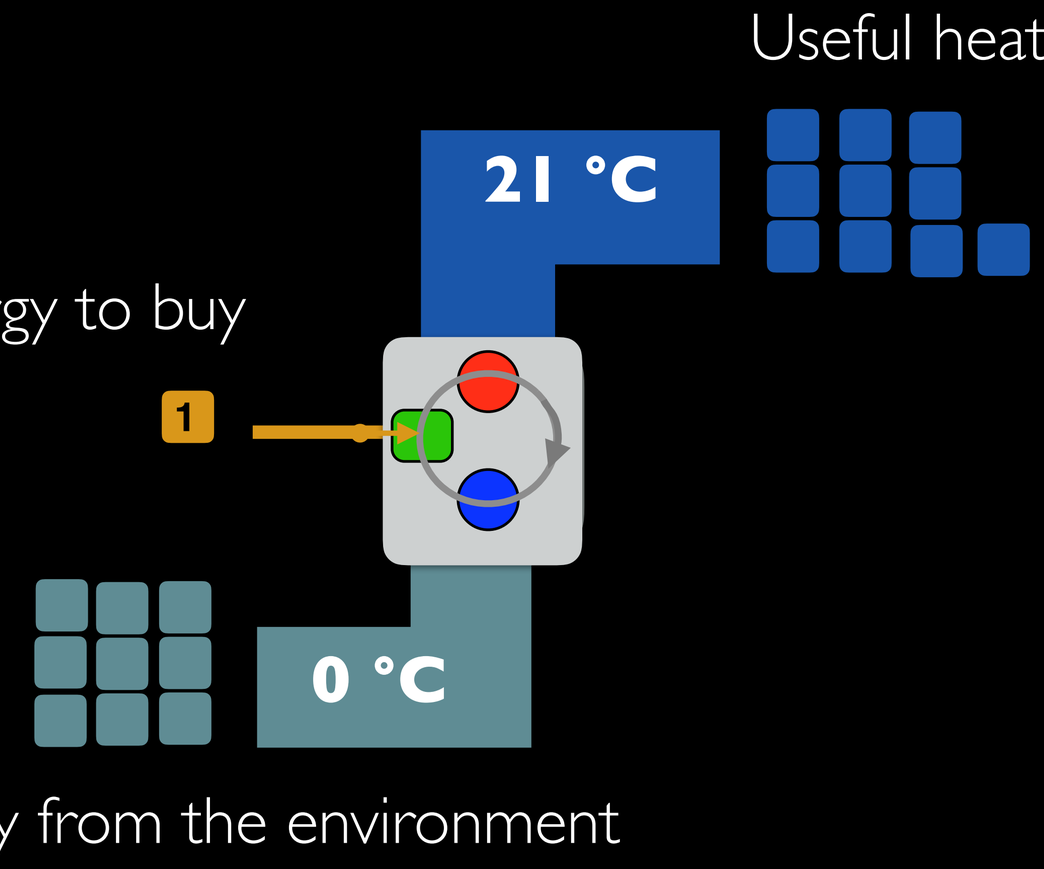


WHAT ARE THE NEEDS ?
HEATING BUILDINGS

Thermodynamic minimum

Nicolas Léonard Sadi CARNOT (F)
1796 - 1832

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



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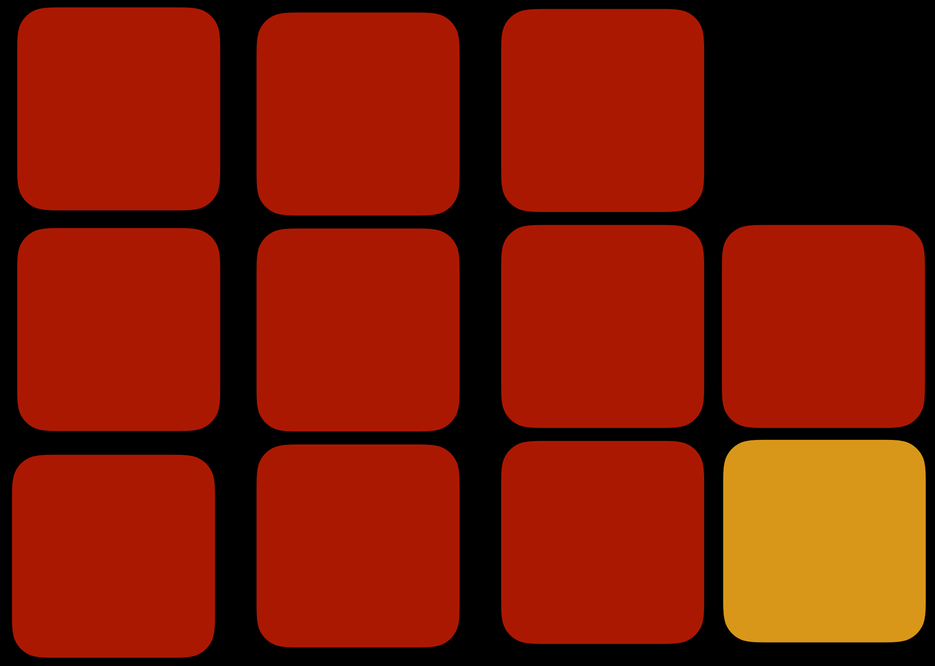
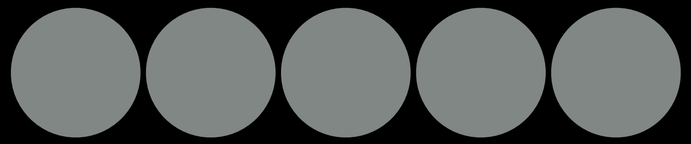
WHAT IS WRONG ?
WHY DO WE BUY 10X MORE ?

FUEL



CO2



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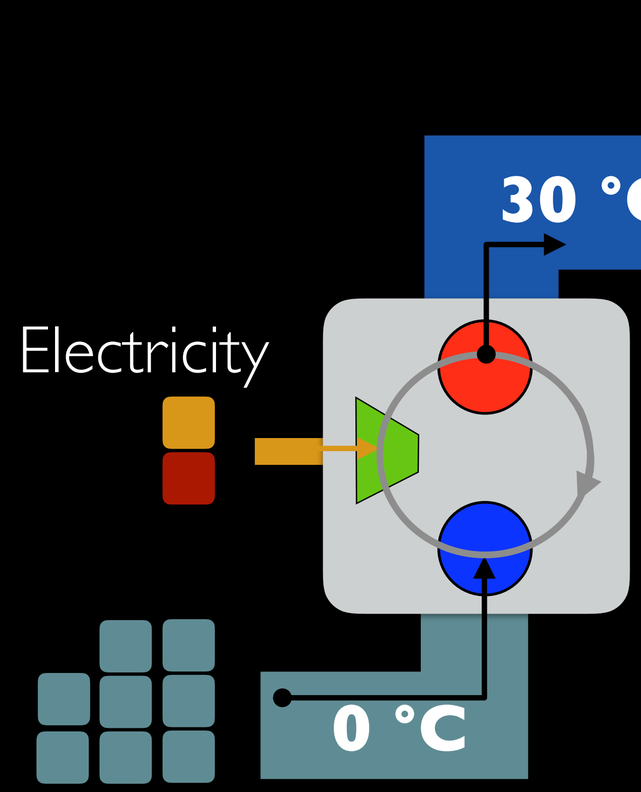
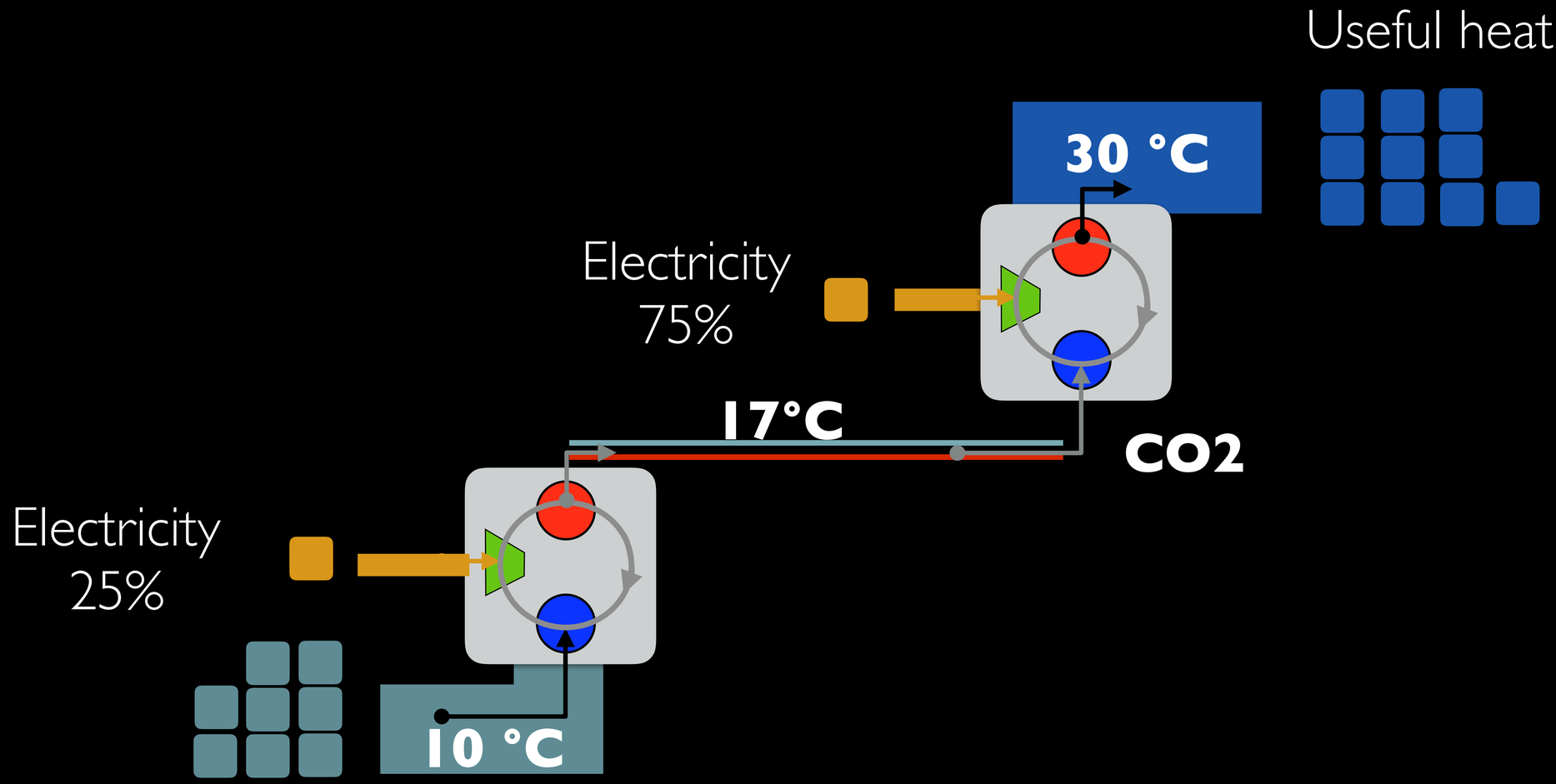
HEAT PUMP IS THE SOLUTION



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

$$\eta_{Carnot} = 0.55$$

REACH THE GOOD RESOURCES
SUPPLY WHAT IS NEEDED



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

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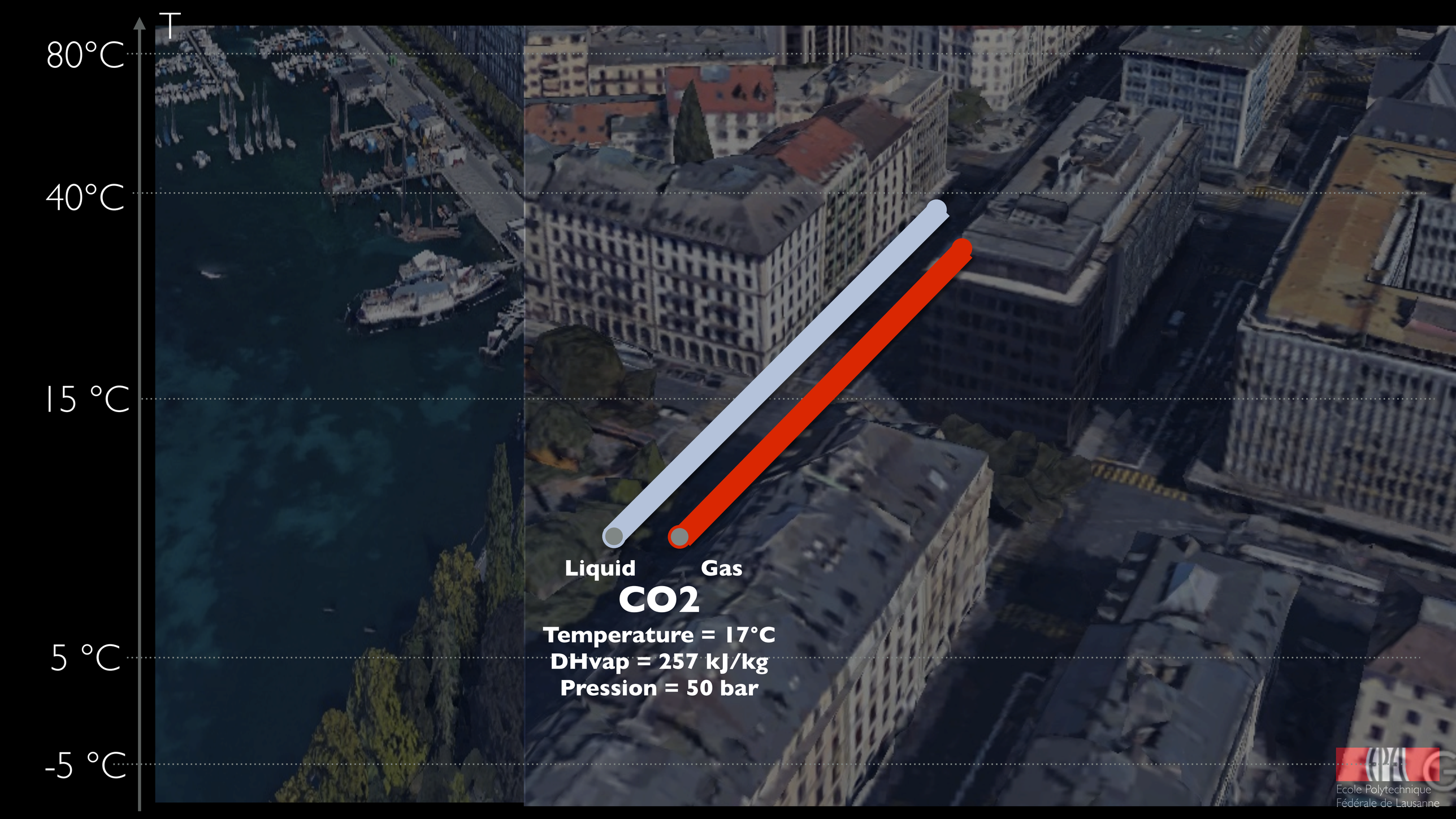


T

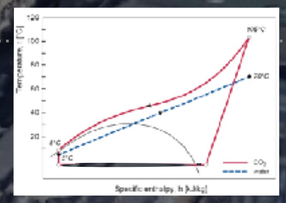
80°C

40°C

15 °C

5 °C

-5 °C



Hot water

Heating

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)

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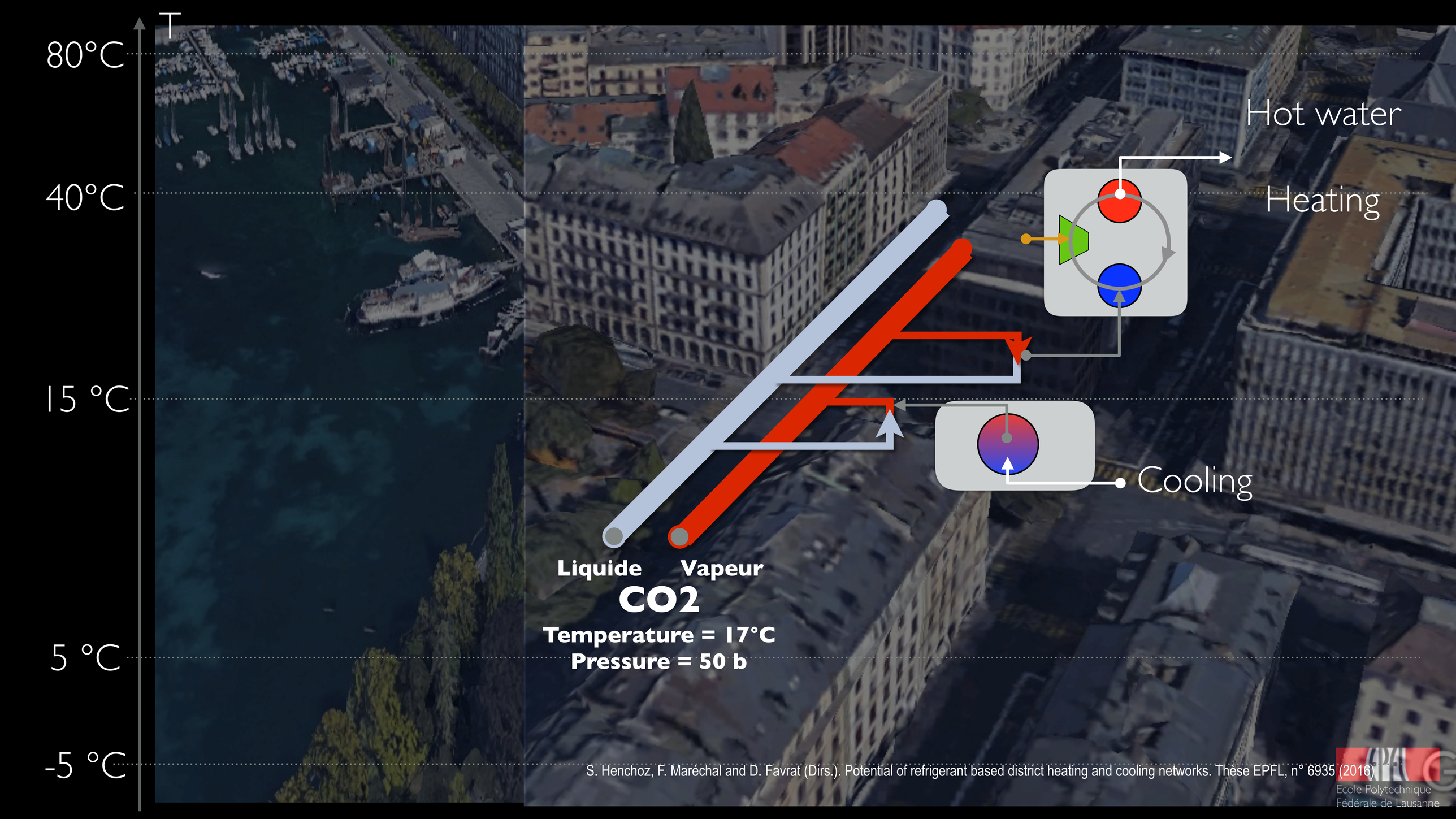

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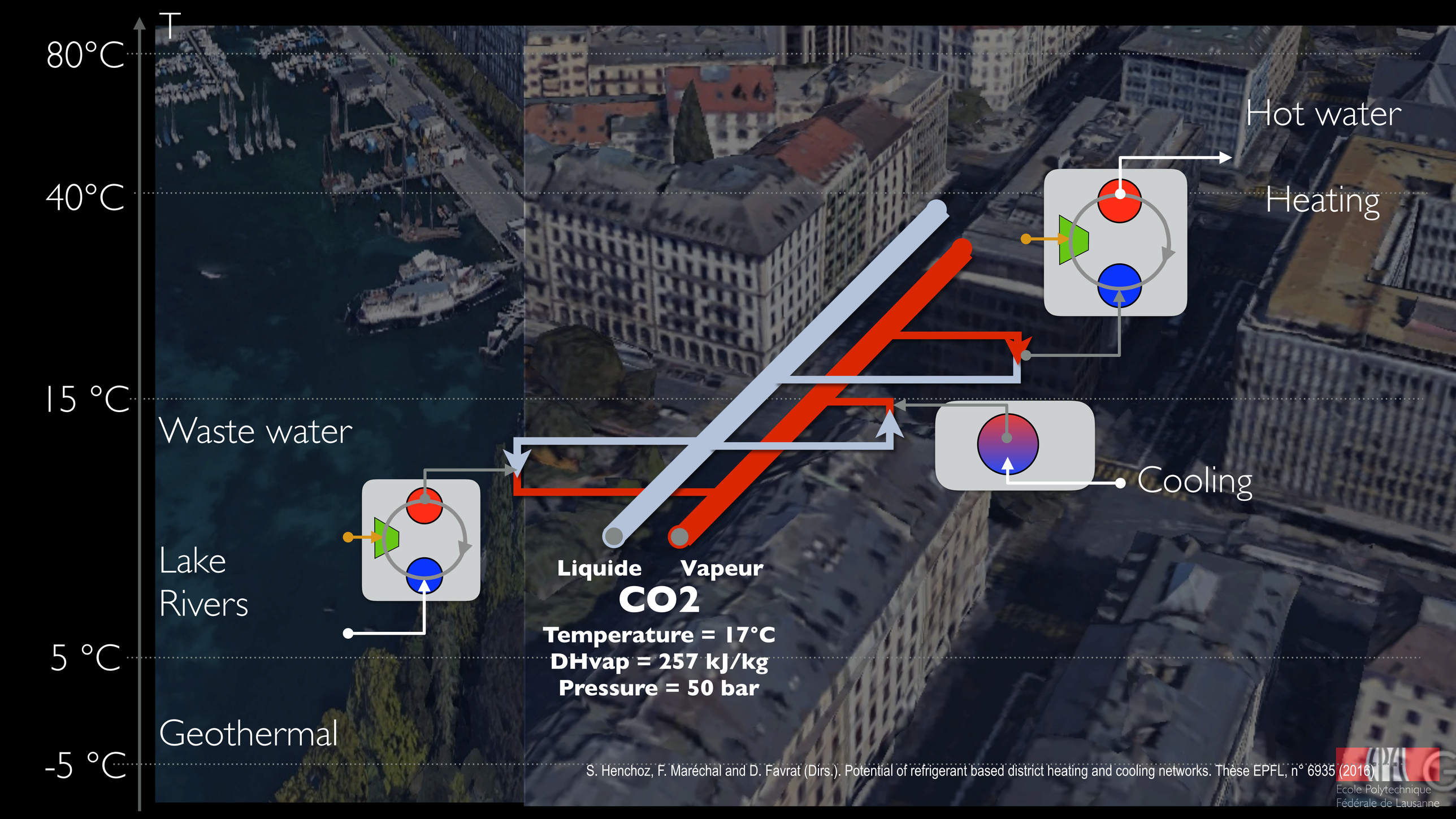

S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)

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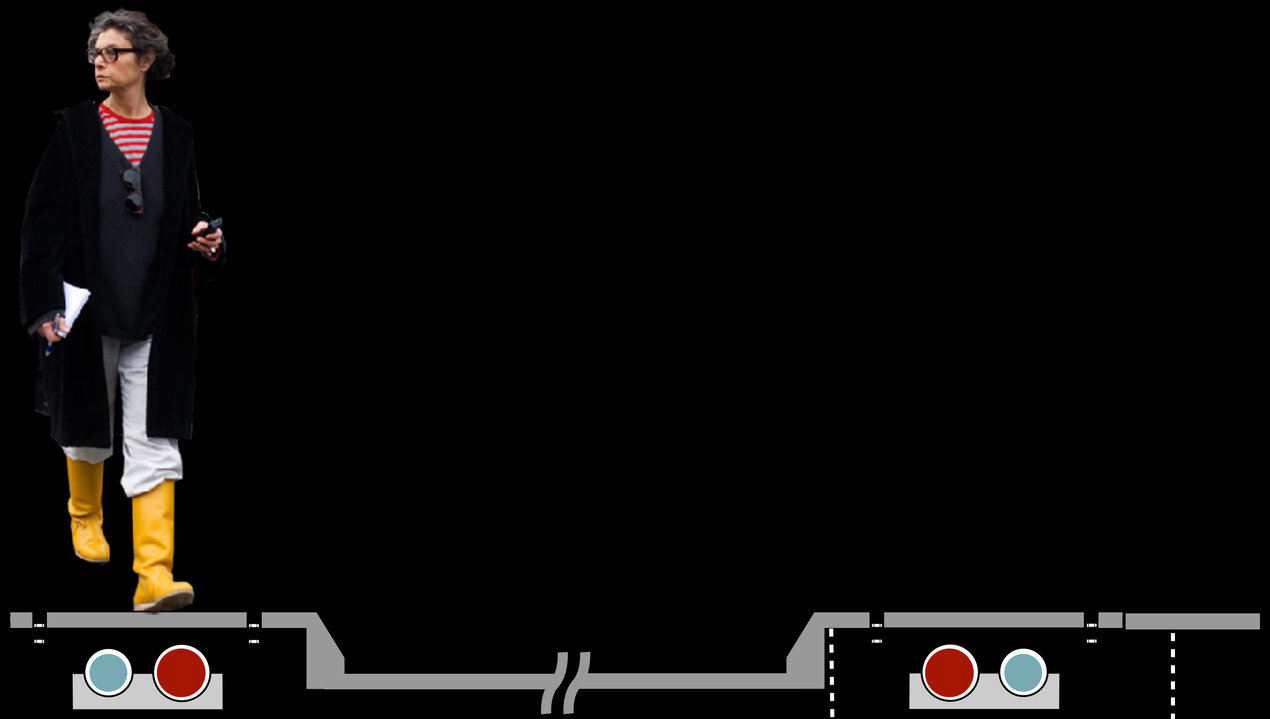
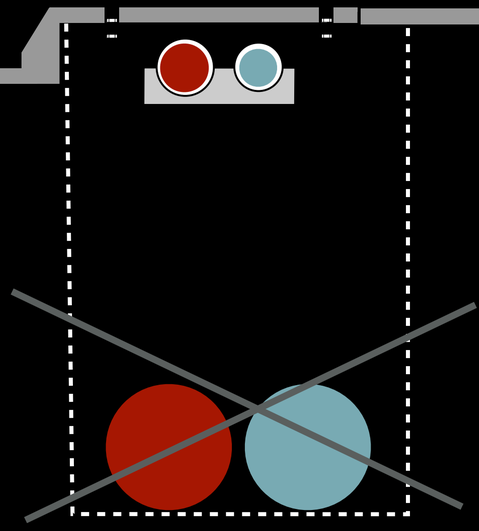
ADD THE PIPES IN THE PEDESTRIAN WAYS



Temperature 17 °C
DHvap = 257 kJ/kg
Pressure = 50 bar

Instead of putting them underground



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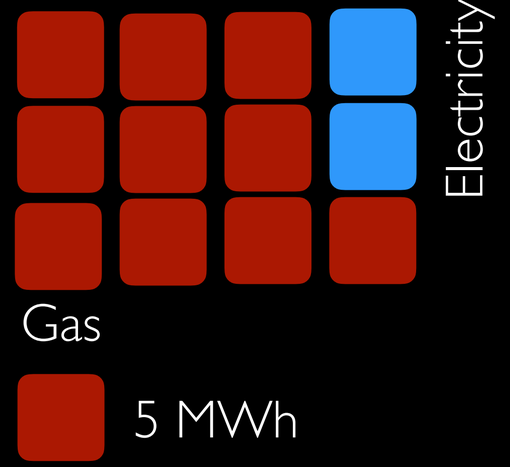
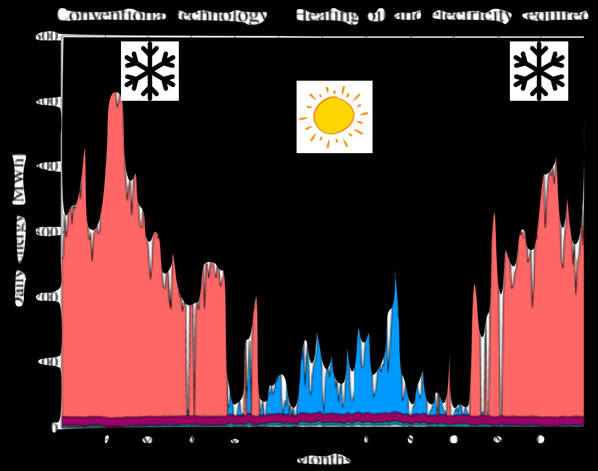
APPLICATION TO A DISTRICT

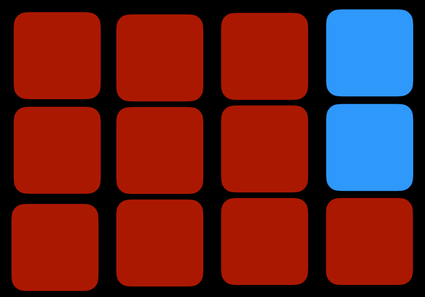




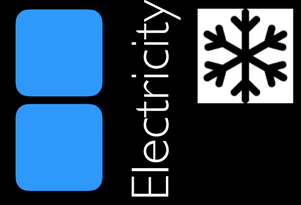
S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)

APPLICATION TO THE DISTRICT

Today

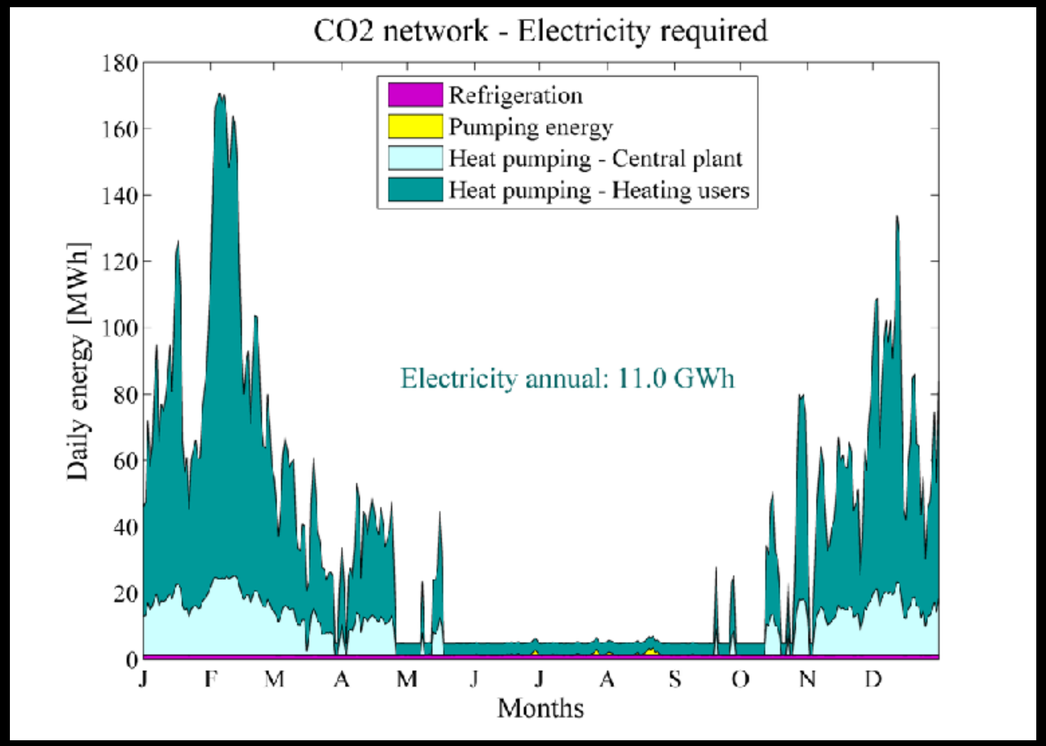


Tomorrow



-84 %

No boilers



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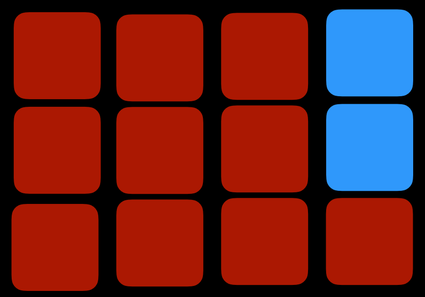
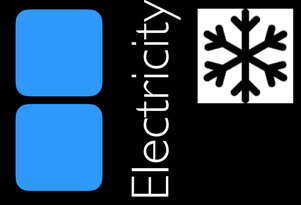
APPLICATION TO THE DISTRICT

Today



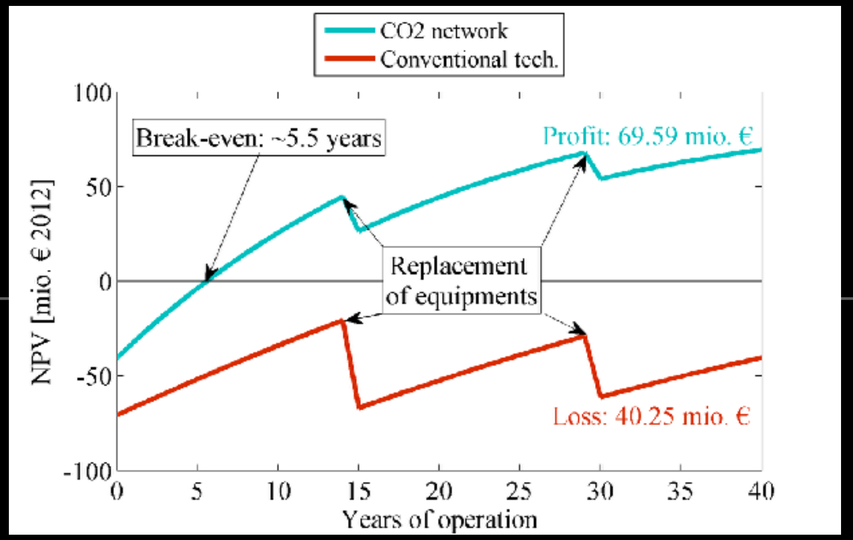
Tomorrow



-84 %
No boilers

Investment

Losses



Investment

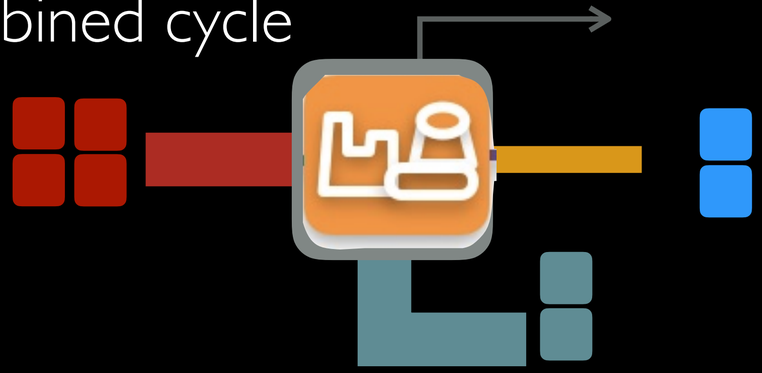
Profit

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.

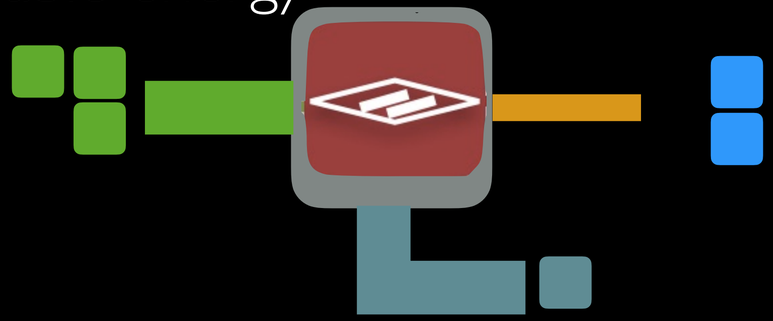
PRODUCING ELECTRICITY IN THE WINTER ?

European Mix

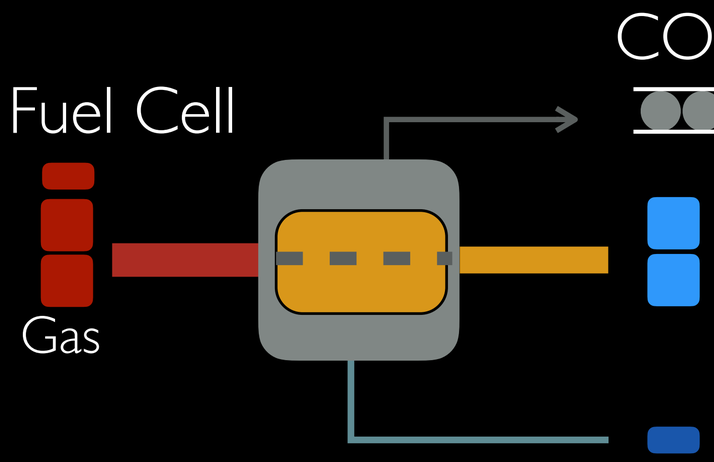
Combined cycle



Renewable energy



Fuel Cell



Products :

Electricity :80 %

Heat : 20%

CO2 captured

H2O

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

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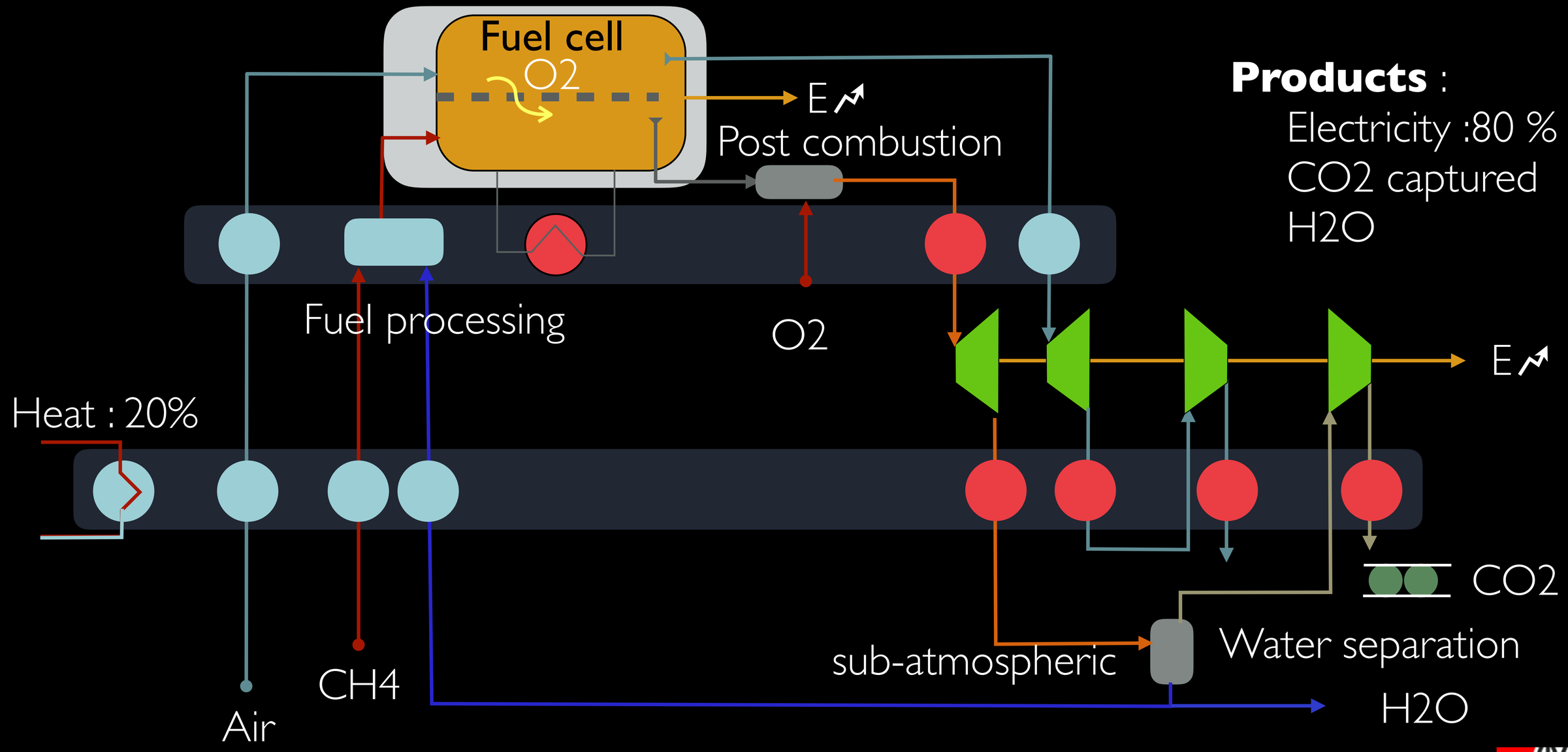
FUEL CELL SYSTEM



Products :
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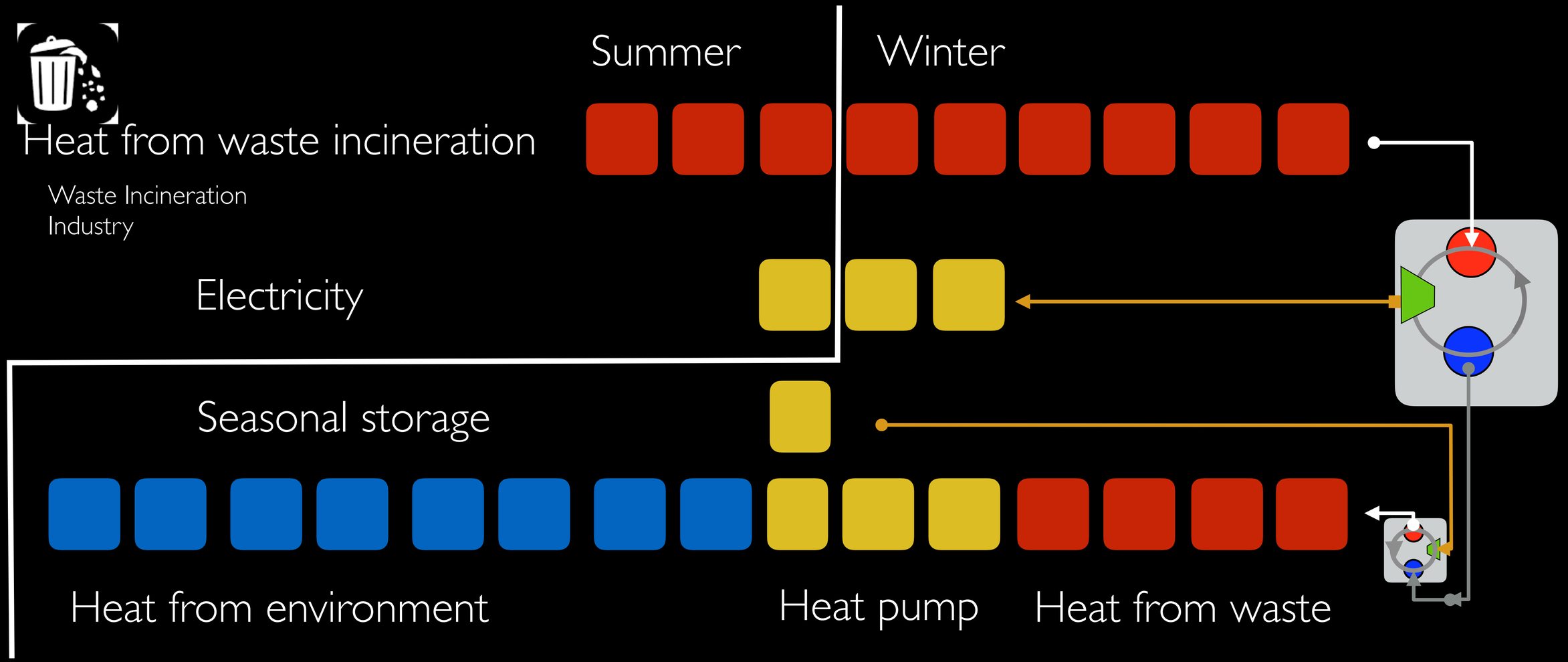
ON THE USE OF WASTE HEAT



2.6 x more heat supplied

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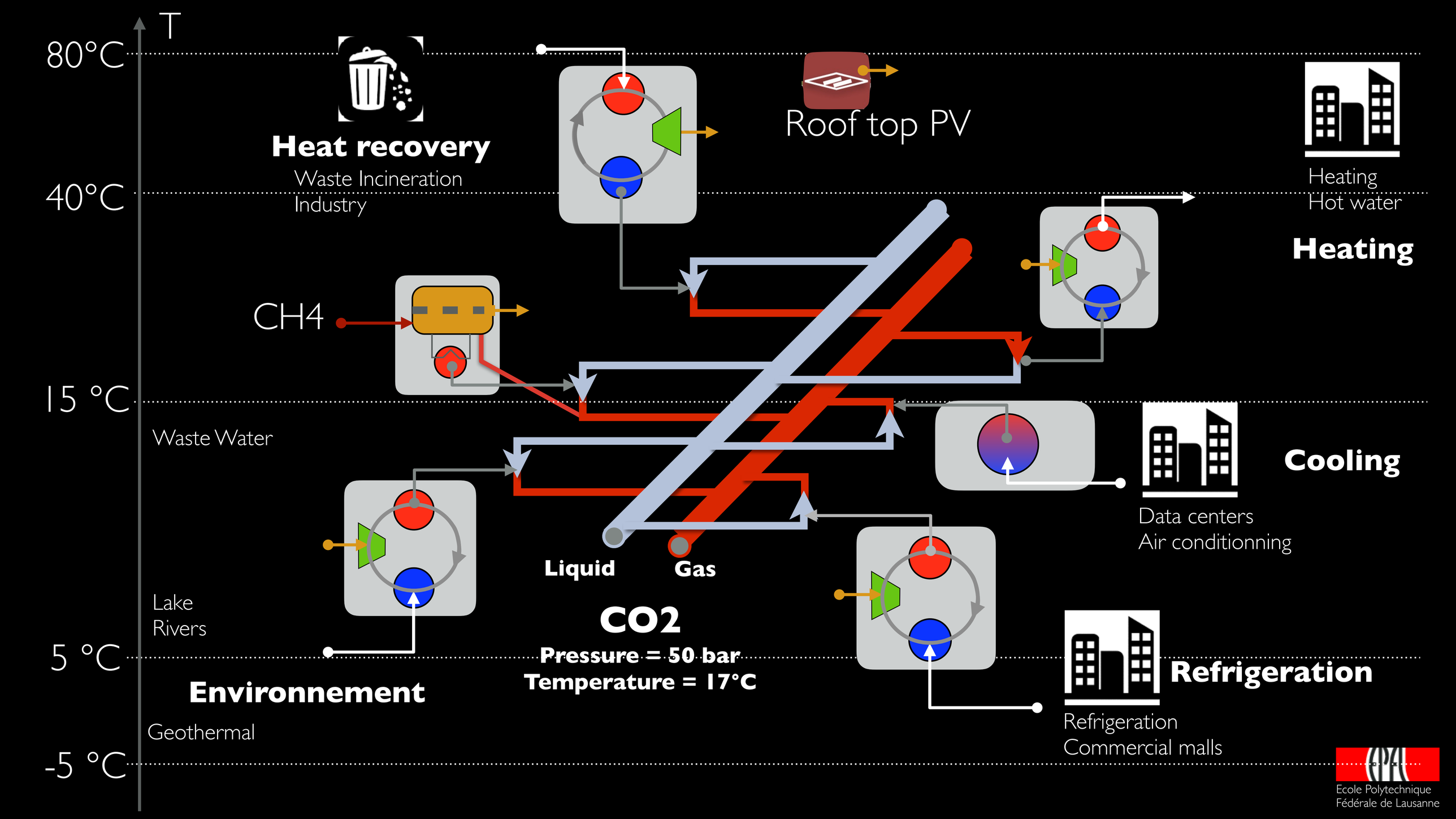
T
80°C
40°C
15 °C
5 °C
-5 °C
Heat recovery
Waste Incineration
Industry
Roof top PV
Heating
Hot water
Heating
CH4
Waste Water
Cooling
Data centers
Air conditionning
Liquid
Gas
CO2
Pressure = 50 bar
Temperature = 17°C
Lake
Rivers
Environnement
Geothermal
Refrigeration
Refrigeration
Commercial malls
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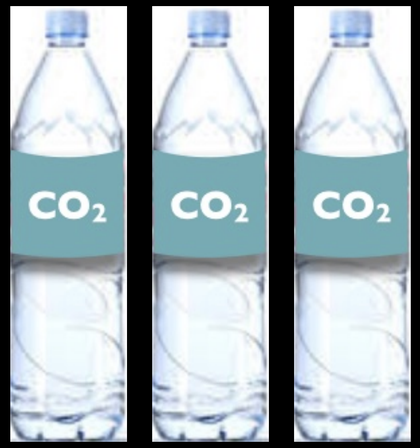
THE GIFTS OF MOTHER NATURE



SYNTHETIC NATURAL GAS PRODUCTION

Synthetic Natural Gas

=> FUEL CELL

Heat

CO2

BIOMASS : C(H2O)

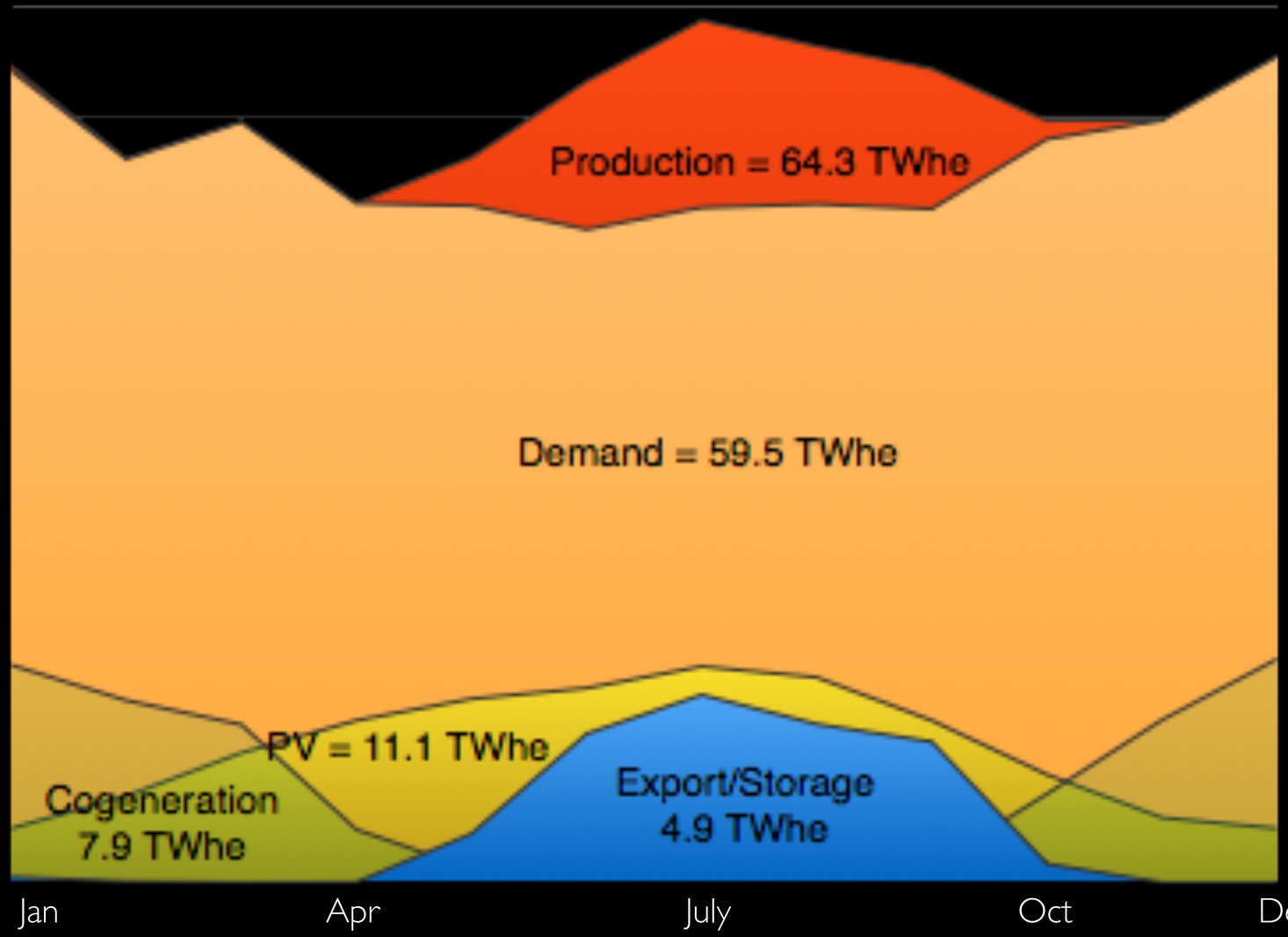
=> CO2 network

Biomethanisation
Hydrothermal gasification
Synthetic Natural Gas processes

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

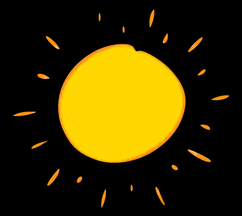
Gassner et al., Energy and Environmental Science 5, no. 2 (2012): 5768.

SOLAR ENERGY



CH_NEP 2050 scenario
Electricity balance

www.energyscope.ch



Excess : 44 % of PV cells production

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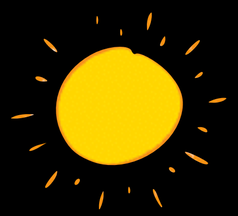
SEASONAL STORAGE BY MOTHER NATURE

Stochastic summer energy

Stored energy

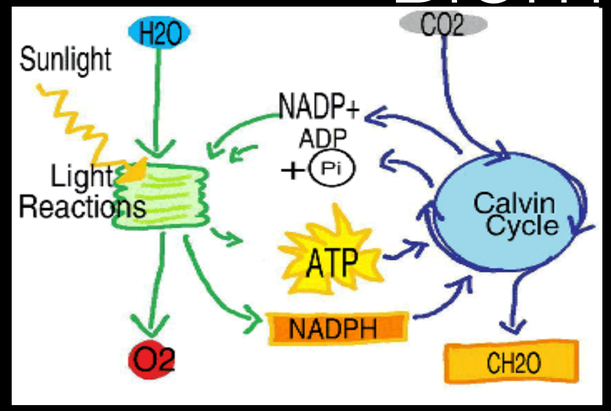


N, P, K

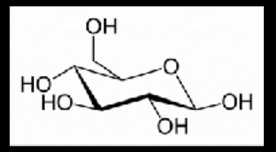
Photosynthesis

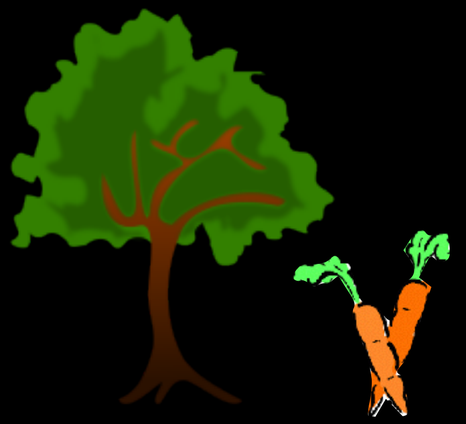
$CO_2 + H_2O \Rightarrow C(H_2O) + O_2$

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

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www.the-simple-homeschool.com

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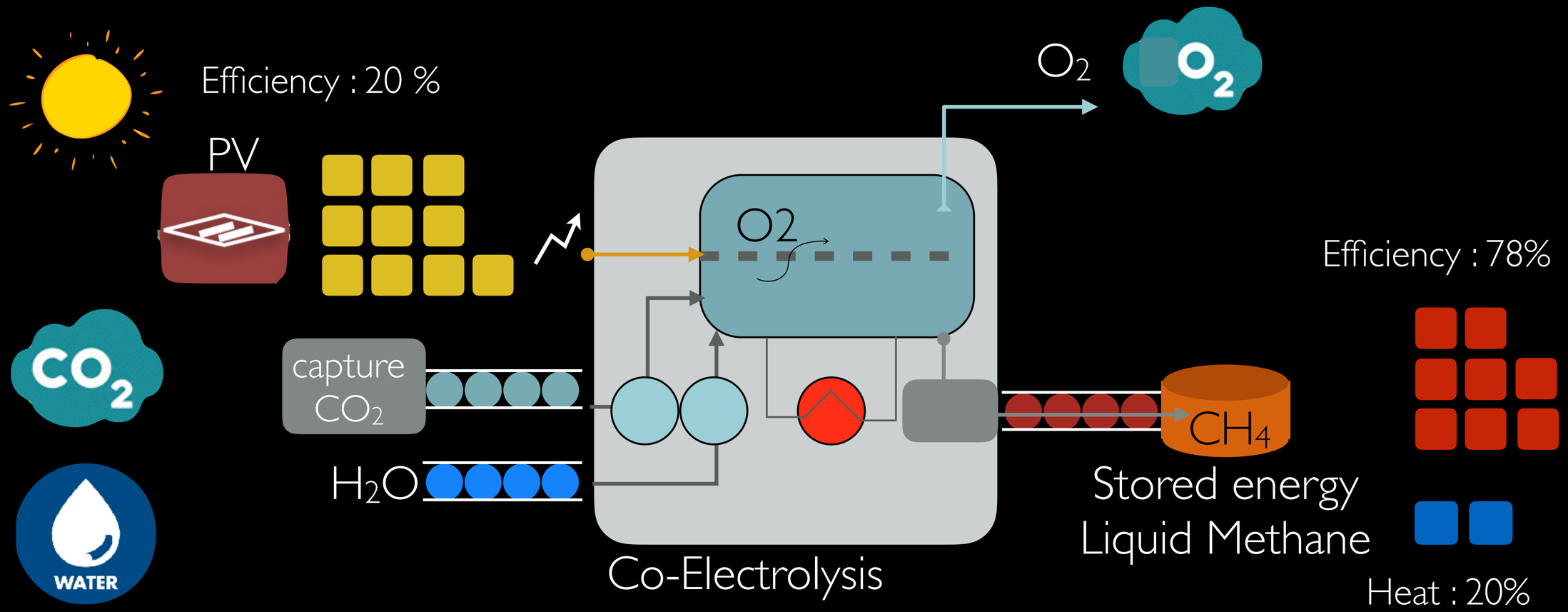
MIMICKING MOTHER NATURE



Artificial photosynthesis : 13-16 % Solar efficiency

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.

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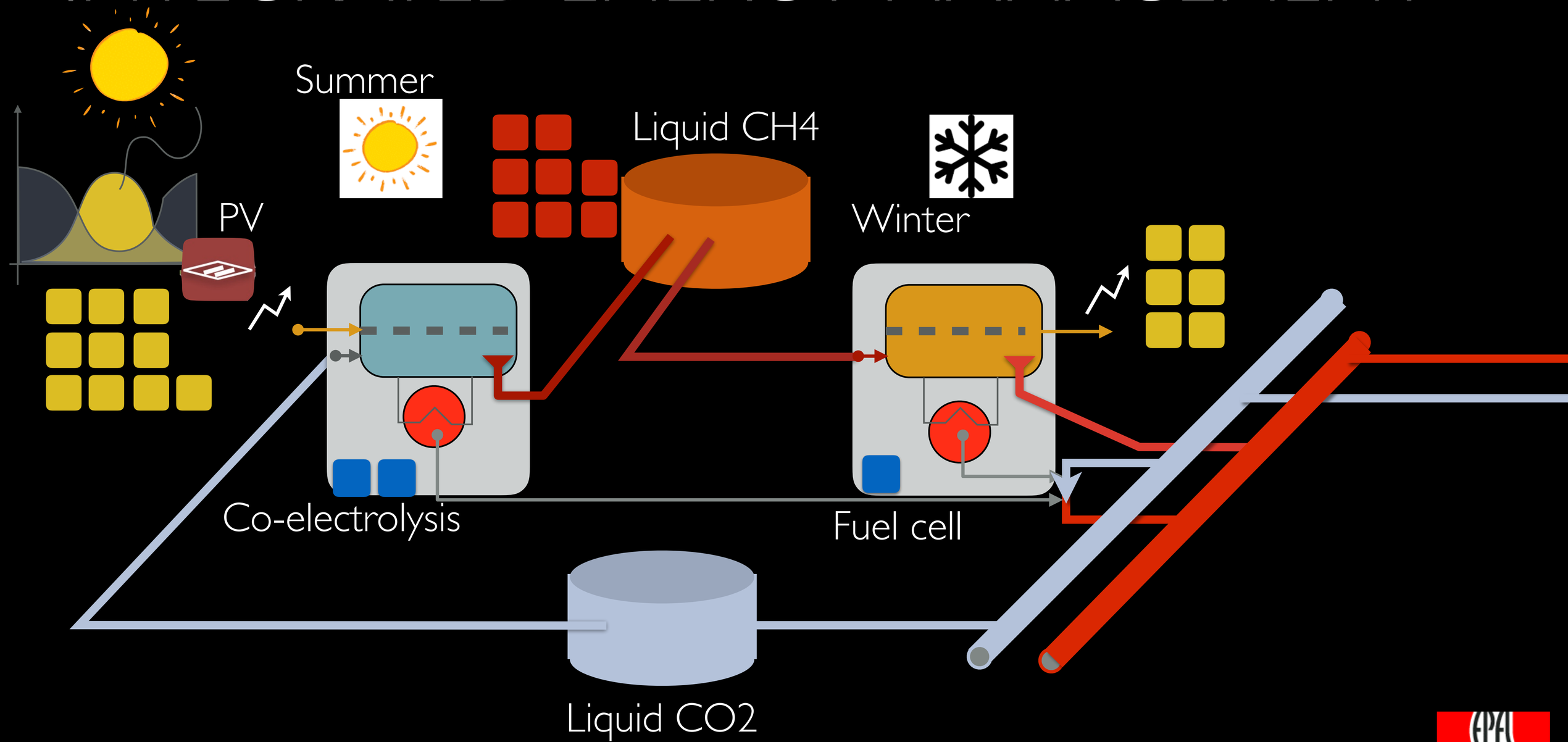
INTEGRATED ENERGY MANAGEMENT



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.

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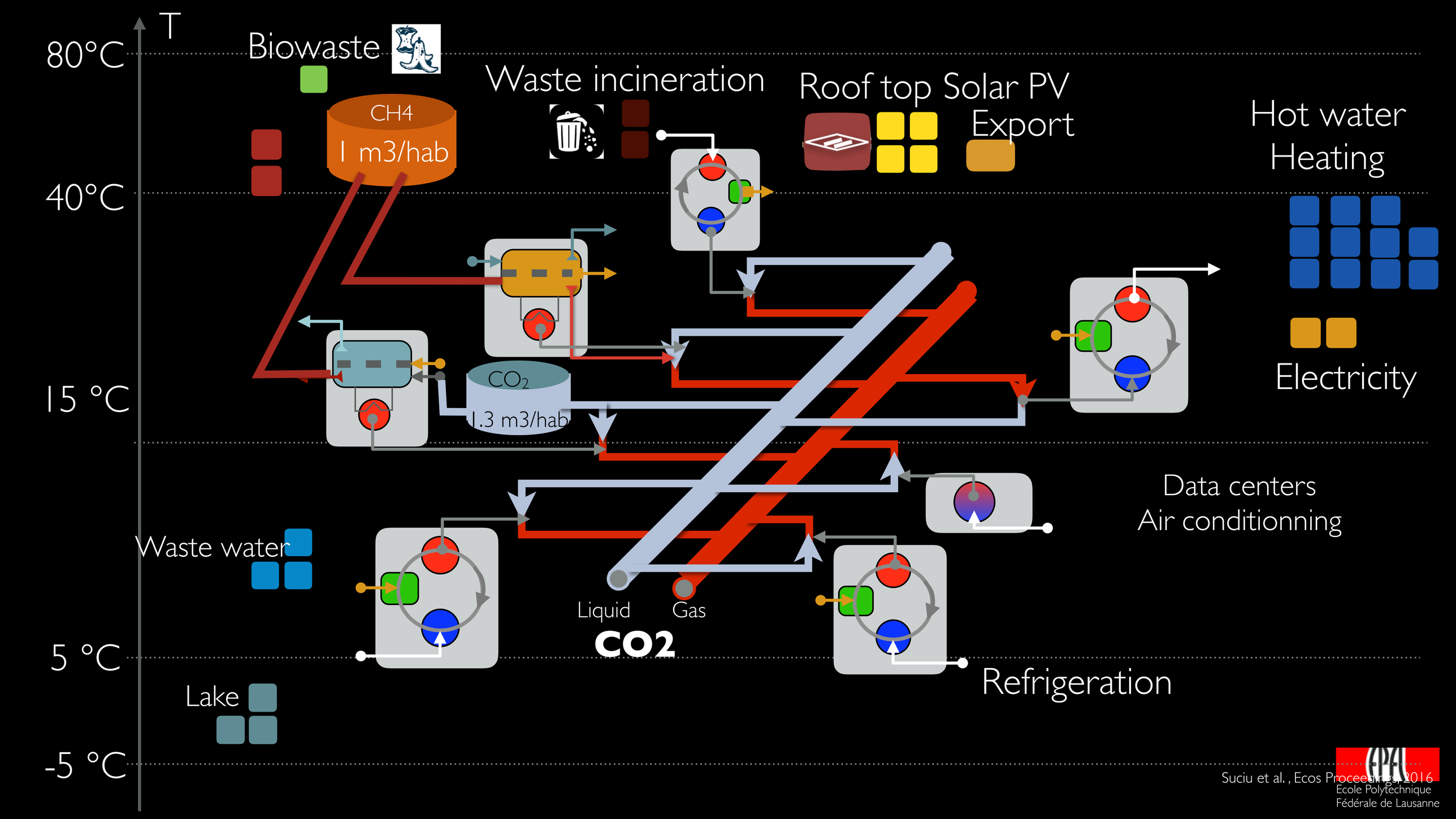


Suciu et al., Ecos Proceedings, 2016

AN AUTONOMOUS CITY IS POSSIBLE

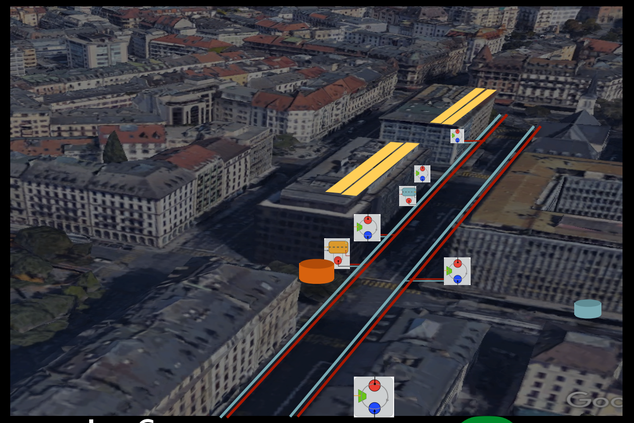
Before

CO_2

Gas

Electricity

After



Infrastructure $

Solar PV

Bio

Waste

Export

Waste water

Environment

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

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THE ENERGY SYSTEM

47%

Solar PV

Bio

Waste

Export

Waste water

Environment

?

36%

17%

100 l gasoline/hab/year

Electricity

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MOBILITY

36%

SCCER-EIP, 2016

Z. K. Dimitrova,. *Environomic design of vehicle integrated energy systems.* Thèse EPFL,2015

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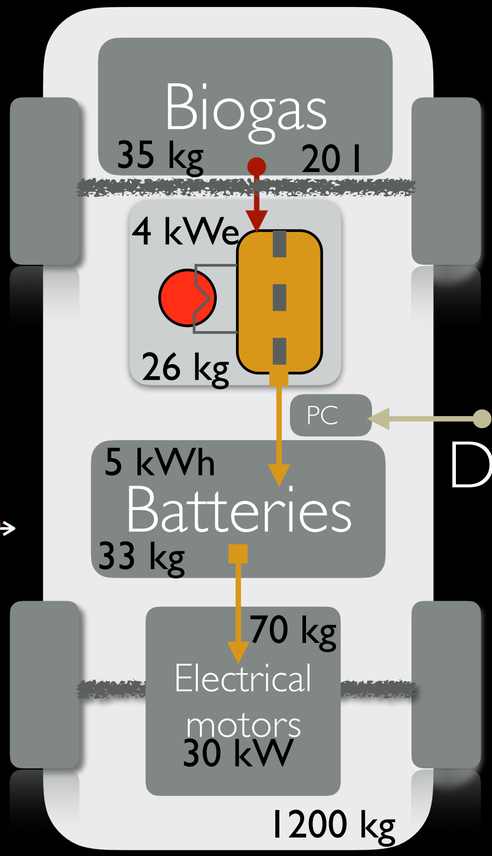
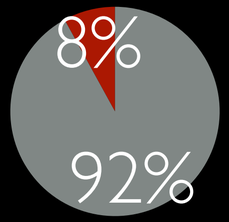
SMART CARS

Driving mode

Autonomy : 950 km
Cons : 1.1l/100 km



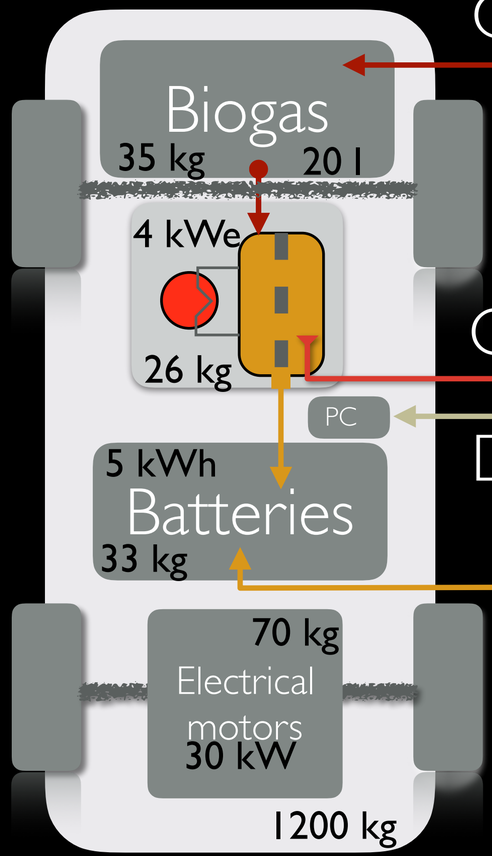


SOFC-GT
Hybrid car

Data Grid

Parking mode

Power plant : 3.5 kWe (eff. >70%)
Battery : 5 kWh



Gas Grid

CO2 Grid

Data Grid

Micro
El. Grid

Dimitrova, Zlatina, and François Maréchal. "Environomic design for electric vehicles with an integrated solid oxide fuel cell (SOFC) unit as a range extender." *Renewable Energy* 112 (2017): 124-142

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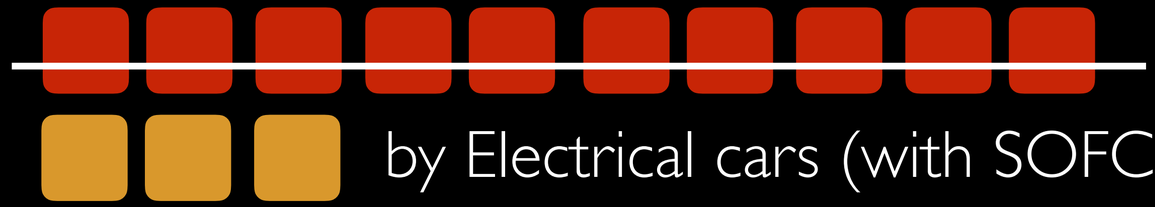
MOBILITY

36%

Efficiency



by Electrical cars (with SOFC range extender)

100 l gasoline/hab/year

SCCER-EIP, 2016

Z. K. Dimitrova,. *Environomic design of vehicle integrated energy systems.* Thèse EPFL,2015

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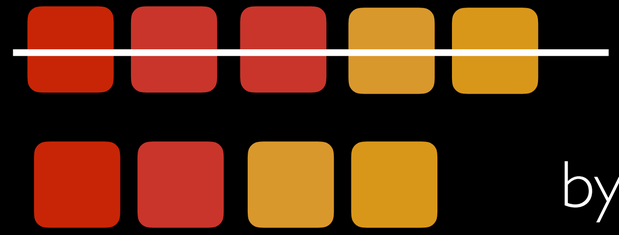
INDUSTRY

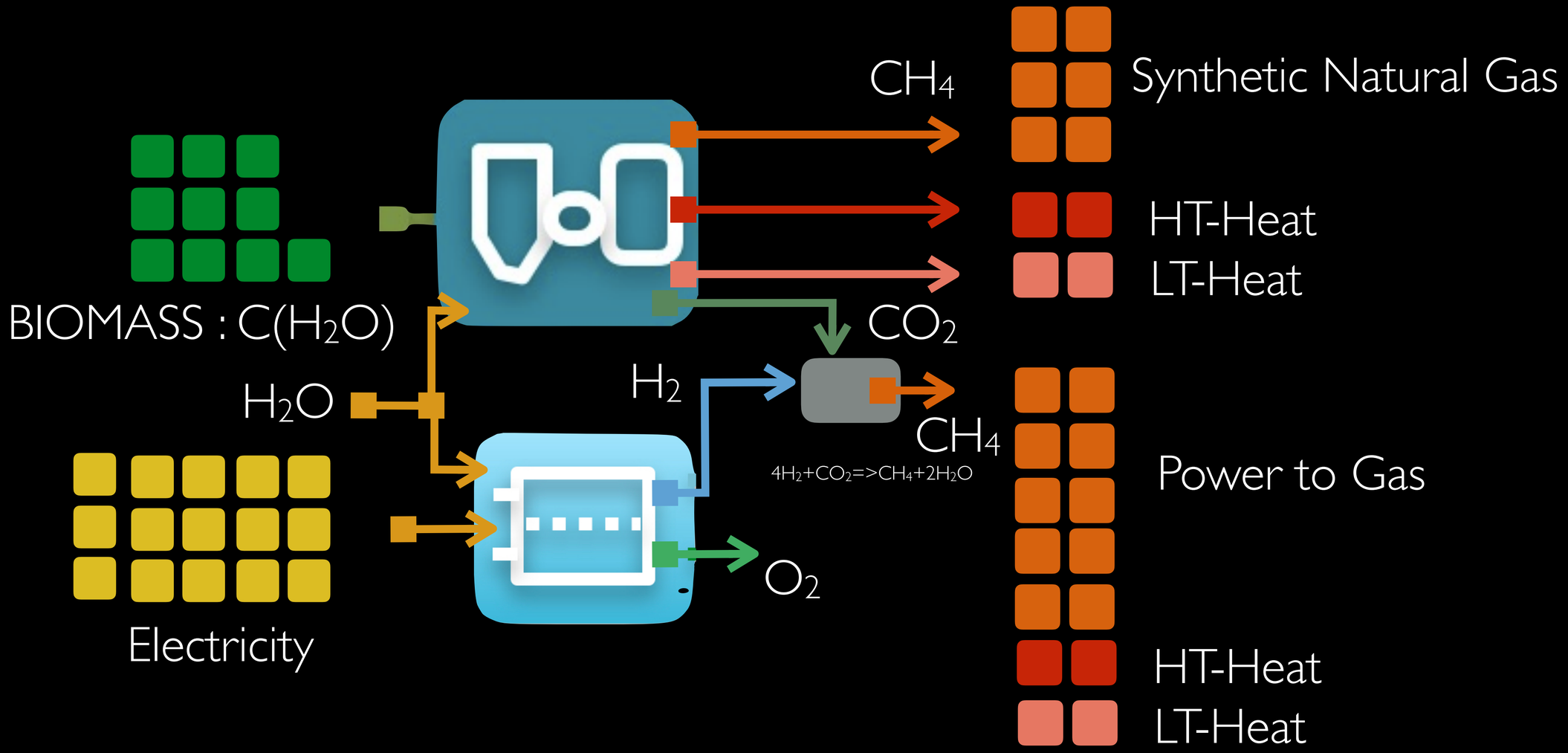
17%

Efficiency



by Heat integration

SYNTHETIC NATURAL GAS COGENERATION



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.

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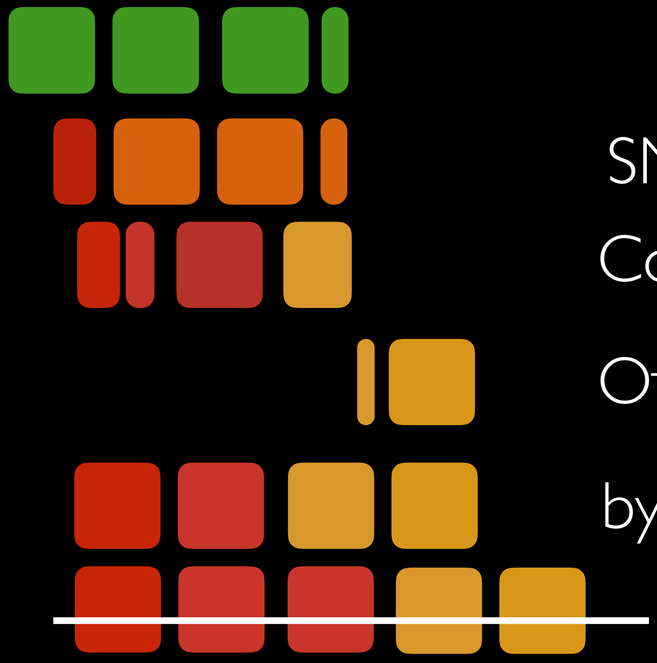
EFFICIENCY IS THE 1rst RESOURCES !

Biomass



SNG production

Cogeneration

Other sources

by Heat integration

Efficiency

17%

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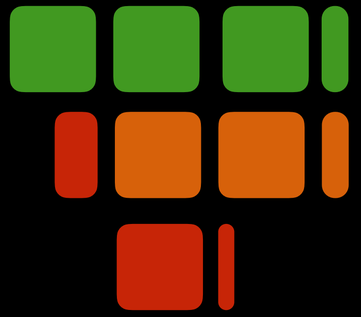
LES RESSOURCES RENOUVELABLES

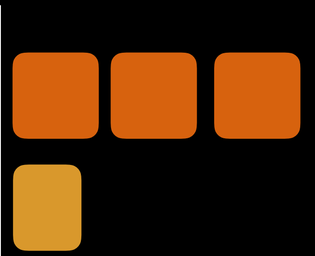
Biomass

Synthetic natural gas

HT heat



SNG

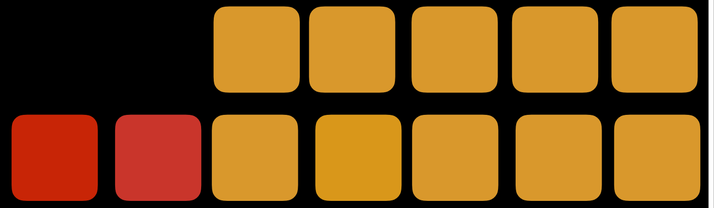


Seasonal storage by SNG

Industrial cogeneration

Wind and hydro

Needs (53%)



Industry

Electrical cars

100 l gasoline/hab/year

data : www.energyscope.ch

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SWITZERLAND CAN BE AUTONOMOUS

47%

36%

17%

PV

Bio

Waste

Waste water

Environment

Biomass

Wind and Hydro

Export

Storage capacity

and a net exporter of biogas

100 l gasoline/hab/year

Electricity

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KEY MESSAGES

- Do not forget thermodynamics
- Tap in the environment/substitute the environment
- Efficiency is the most important resource
- Learn from nature but industrialise the learnings
- THINK SYSTEM !

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Thank You !

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