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COMMENT RENDRE LA SUISSE INDÉPENDANTE ET NEUTRE : LA PERSPECTIVE ENERGETIQUE

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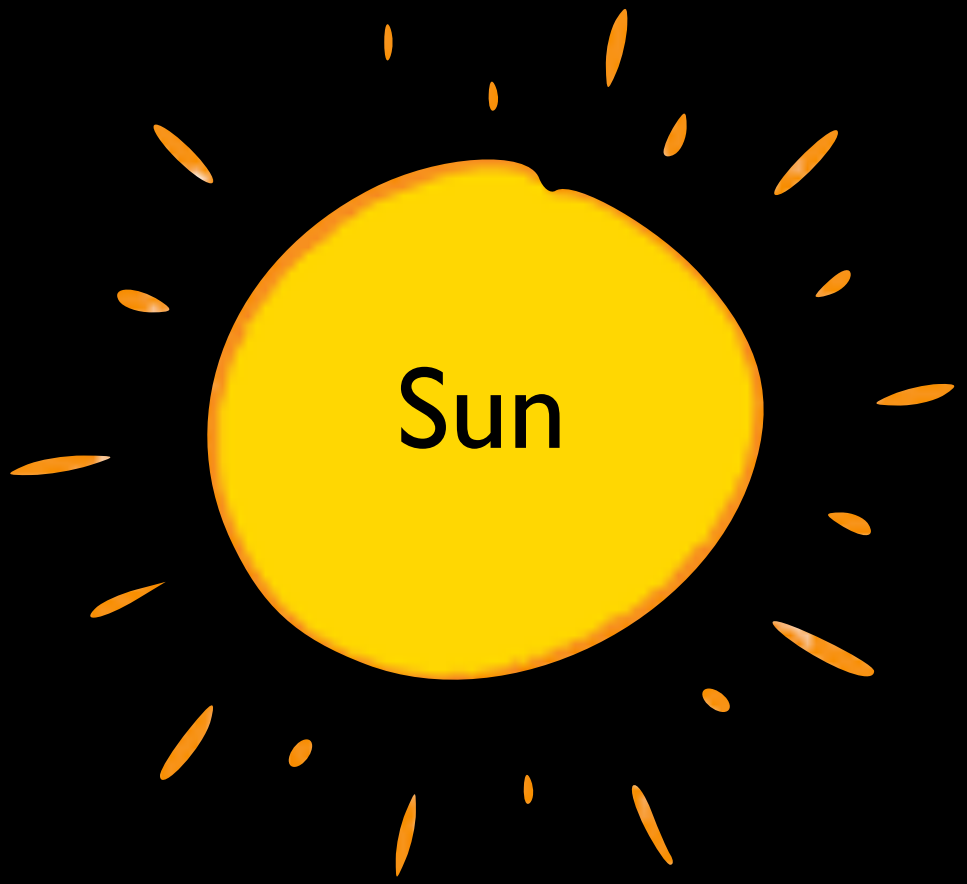
DO WE HAVE REALY A PROBLEM OF ENERGY ?



1.5 hours

time needed to supply our yearly needs

6500 years

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

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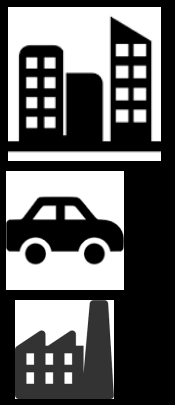
OUR ENERGY NEEDS

FOOD
0.25 l oil eq./day
100 l oil eq./year

100 l gasoline/hab/year

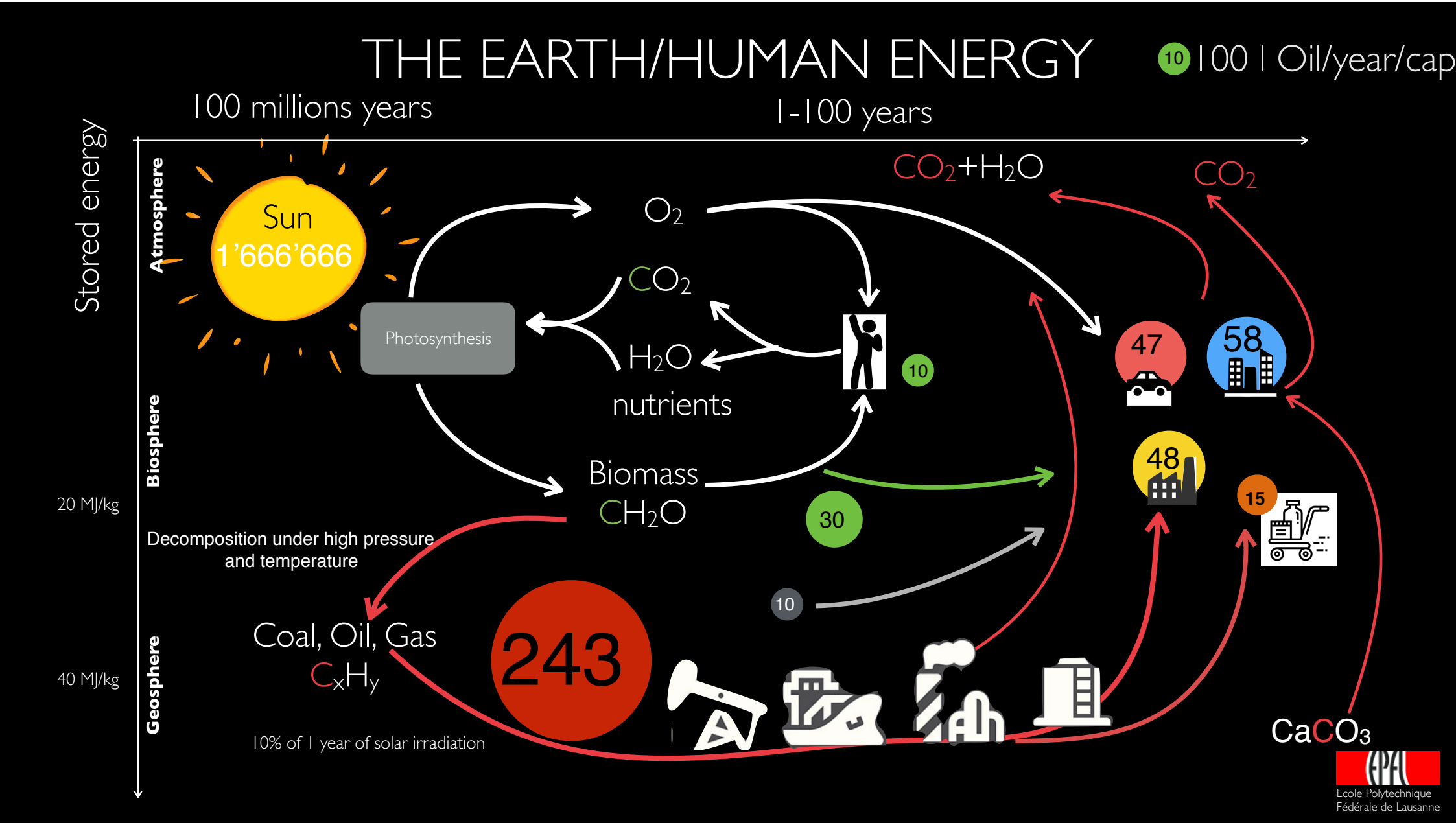
Oil
5.5 l/day



Waste : 1.3 kg/day
Bio-waste : 0.7 kg/day

CO2 :14 kg/day

Per capita consumption per day in Oil eq.


THE EARTH/HUMAN ENERGY
10 100 l Oil/year/cap
100 millions years
1-100 years
Stored energy
Atmosphere
Biosphere
Geosphere
20 MJ/kg
40 MJ/kg
Sun
1'666'666
Photosynthesis
O2
CO2
H2O
nutrients
Biomass
CH2O
Decomposition under high pressure
and temperature
Coal, Oil, Gas
CxHy
243
10% of 1 year of solar irradiation
CO2+H2O
CO2
10
47
58
48
15
30
10
CaCO3
EPFL
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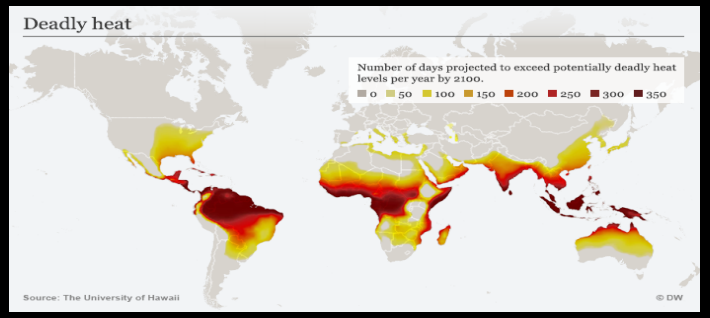
GLOBAL WARMING

The
ENGLISH WINE
Collection

IMPORTANT ALERTS

Floodings/slow hurricanes

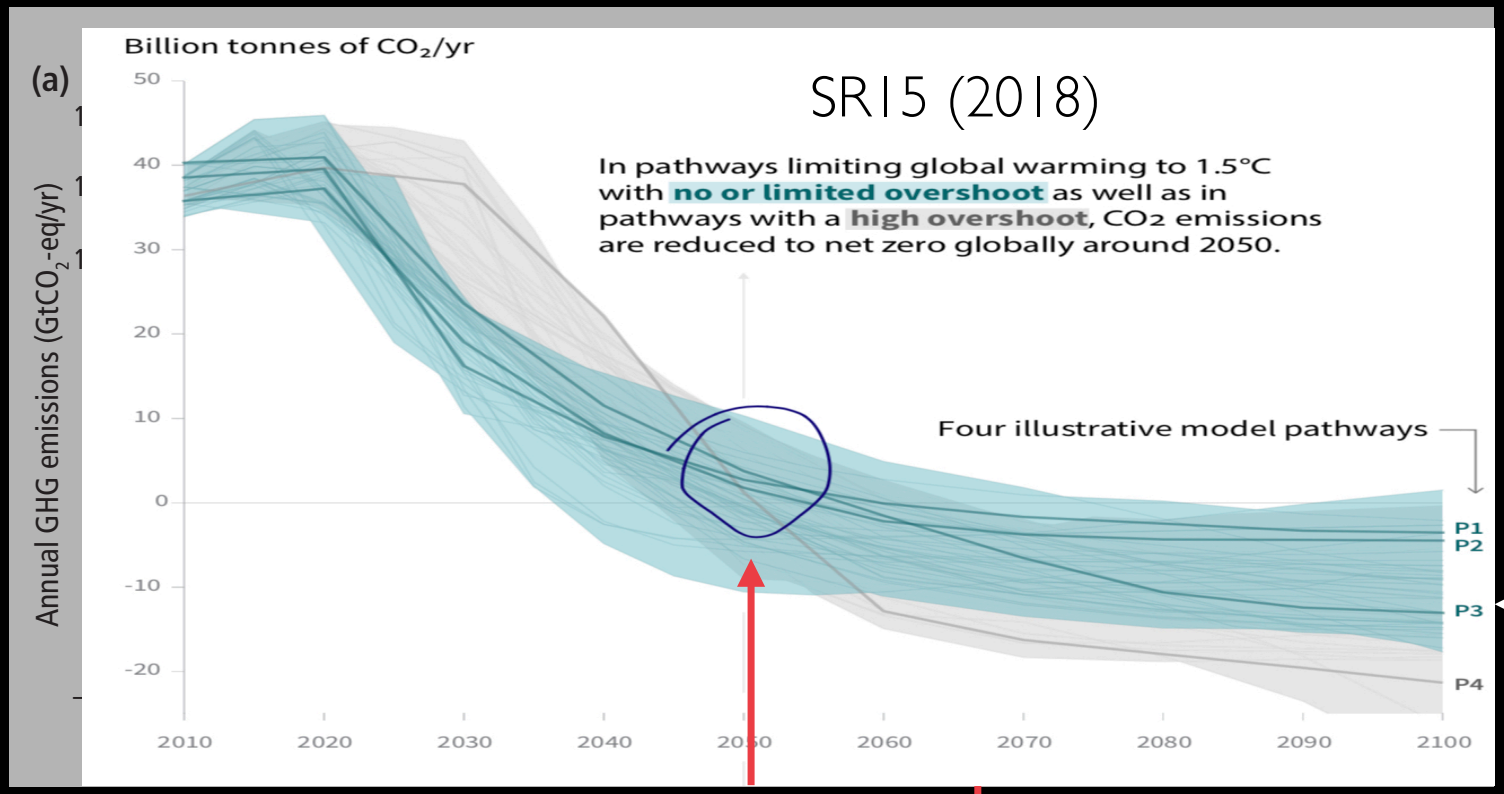
Heat waves



Fire/drought

Temperatures higher then dry bulb for human body ?

FOSSIL CARBON EMISSIONS



← COP 21 target

0 net Fossil carbon emissions in 2050

0 net Fossil carbon emissions in 2070

IPCC AR5 (2015)

IS IT POSSIBLE TO MAKE A COUNTRY AUTONOMOUS ?

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

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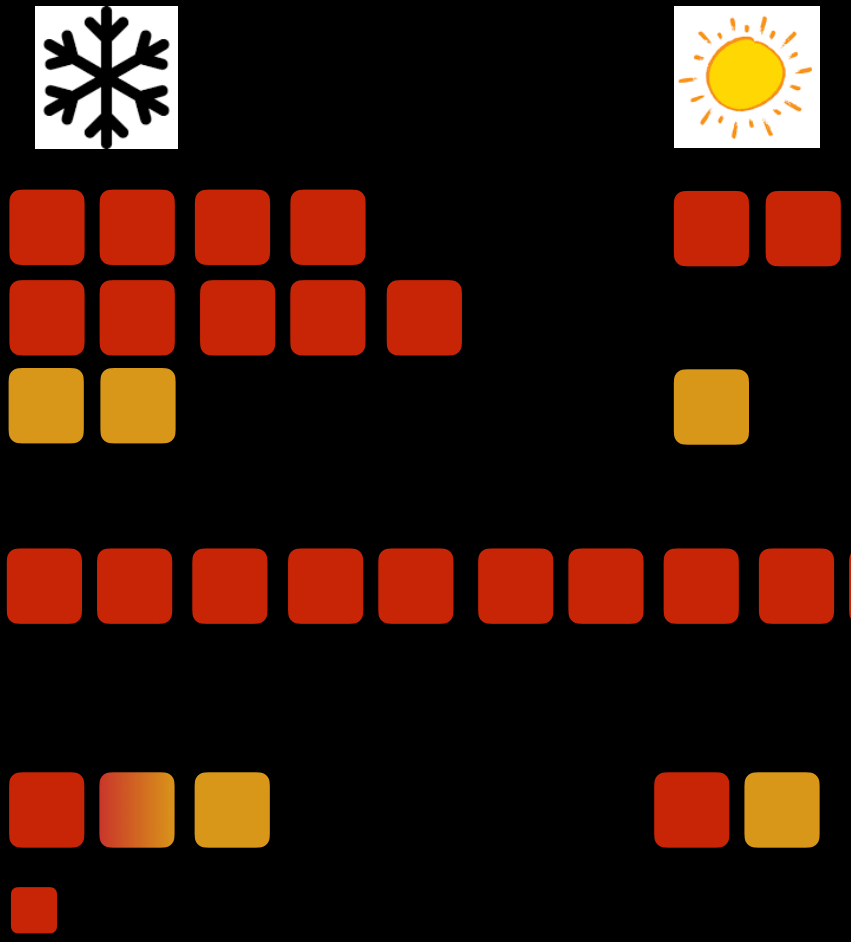
ENERGY NEEDS

47%

36%

17%

products 2%



100 l gasoline/hab/year

Electricity

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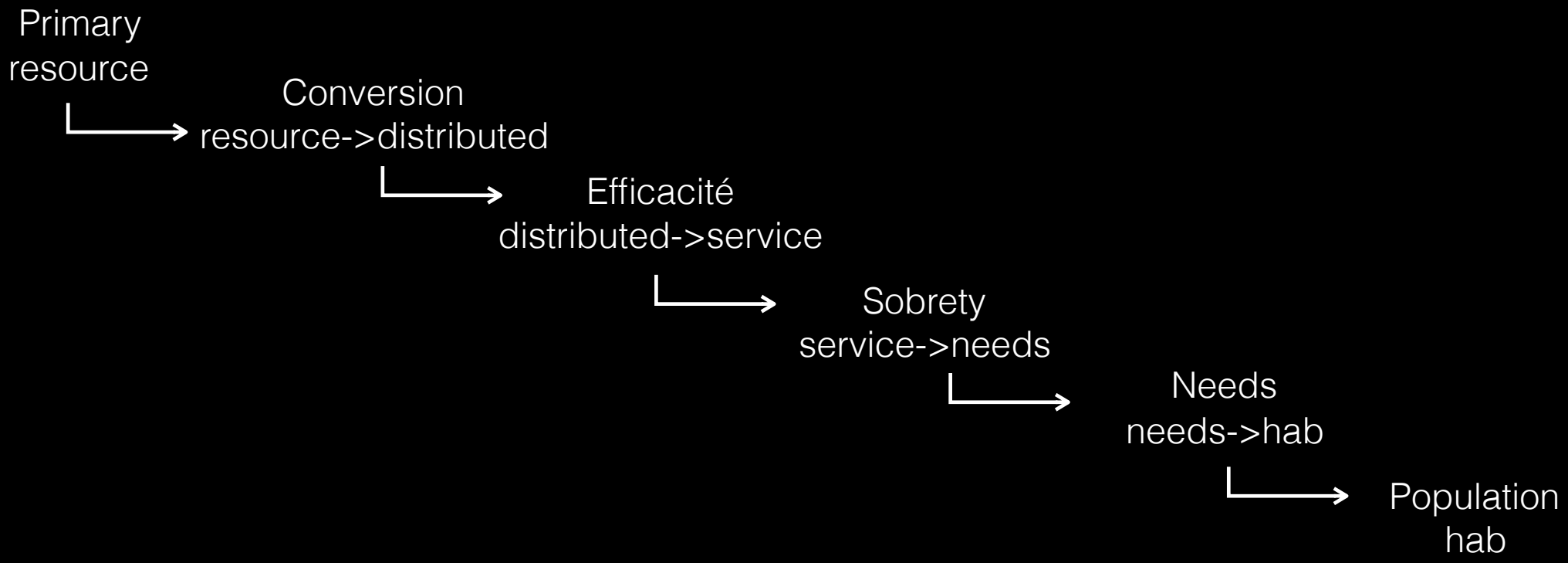
THE CONVERSION CHAIN

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



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THE NEEDS

Sobriety
service->m2 heated

*

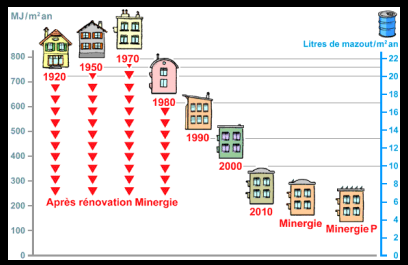
Comfort
m2->hab

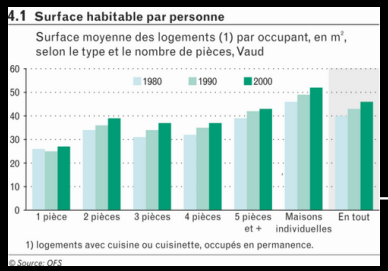
*

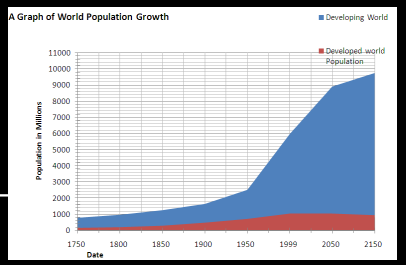
Population
hab

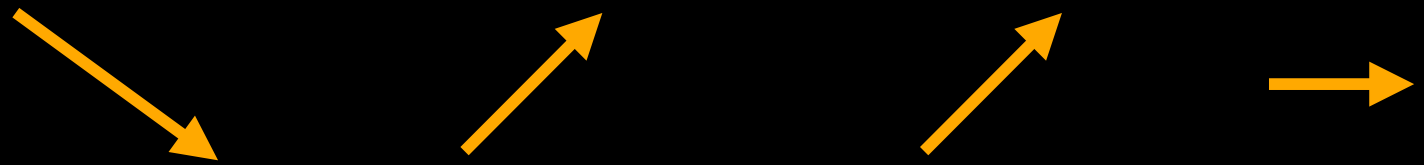
=

Service
service/hab









HOW TO SUPPLY HEAT IN BUILDINGS ?

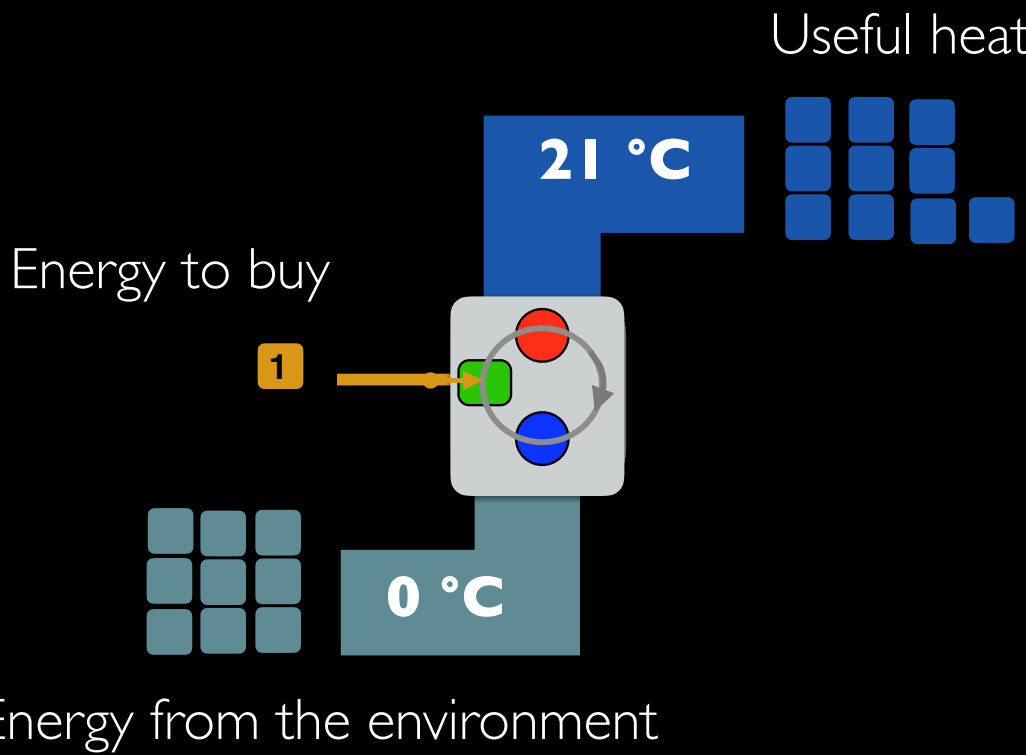
WHAT THERMODYNAMICS TELLS US ?

For 10 units of heat take 9 in the environment and buy one in form of electricity

Nicolas Léonard Sadi CARNOT (F)
1796 - 1832

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

fraction to be taken in the environment



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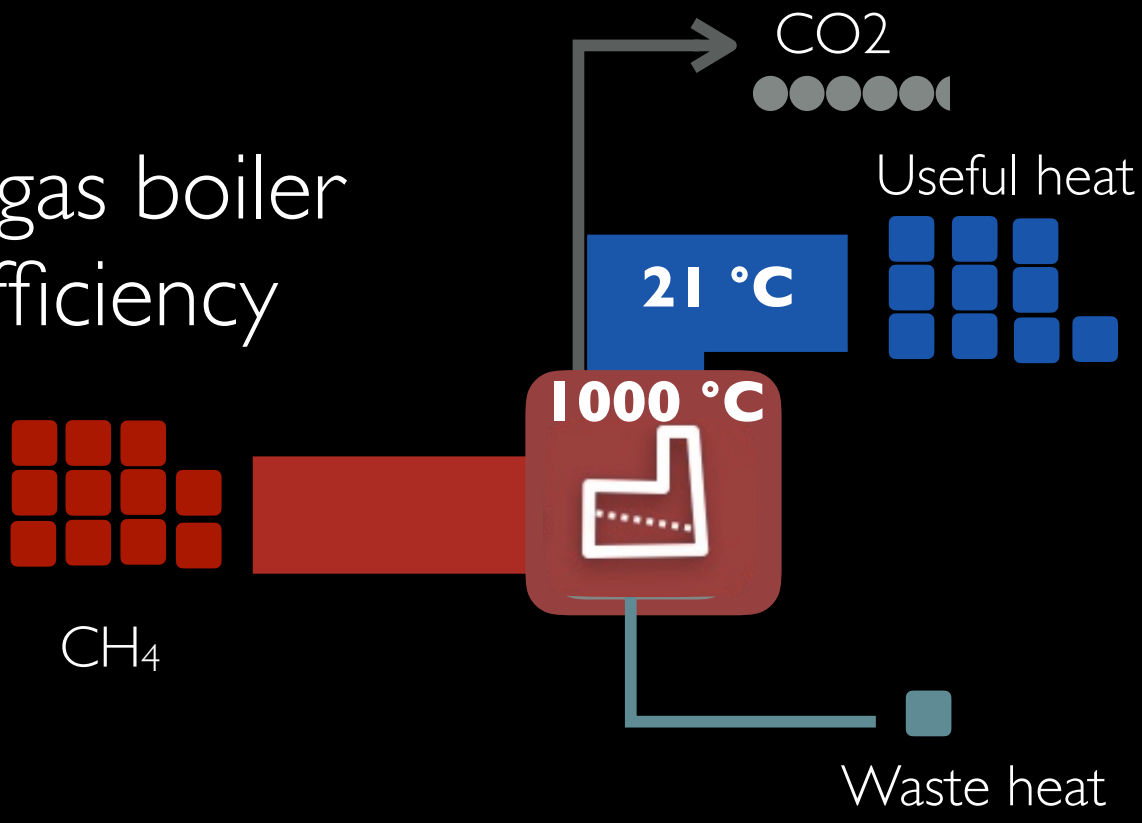
HEATING A BUILDING

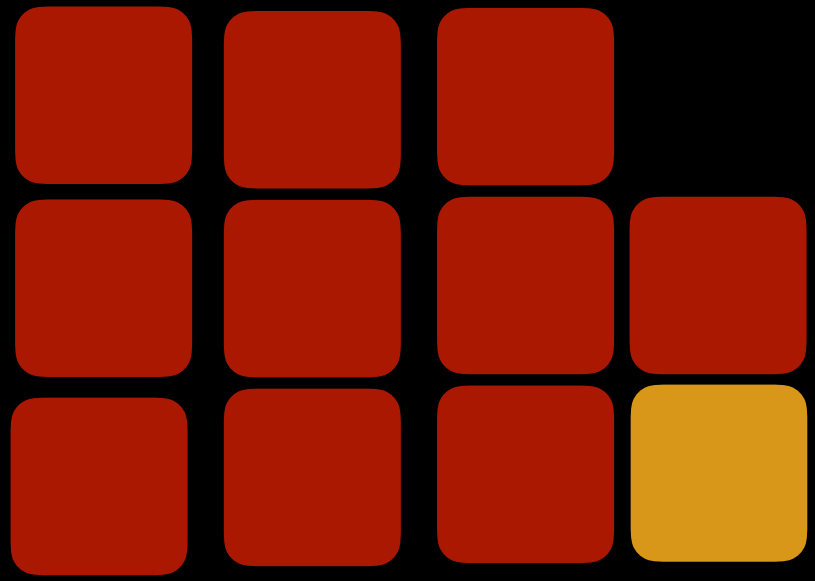
47%

Natural gas boiler
90% efficiency

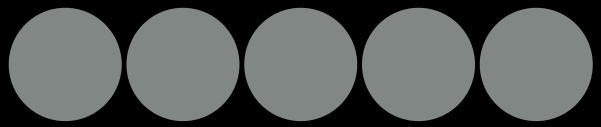


WHAT IS WRONG ?
WHY DO WE BUY 10X MORE ?

FUEL



CO2



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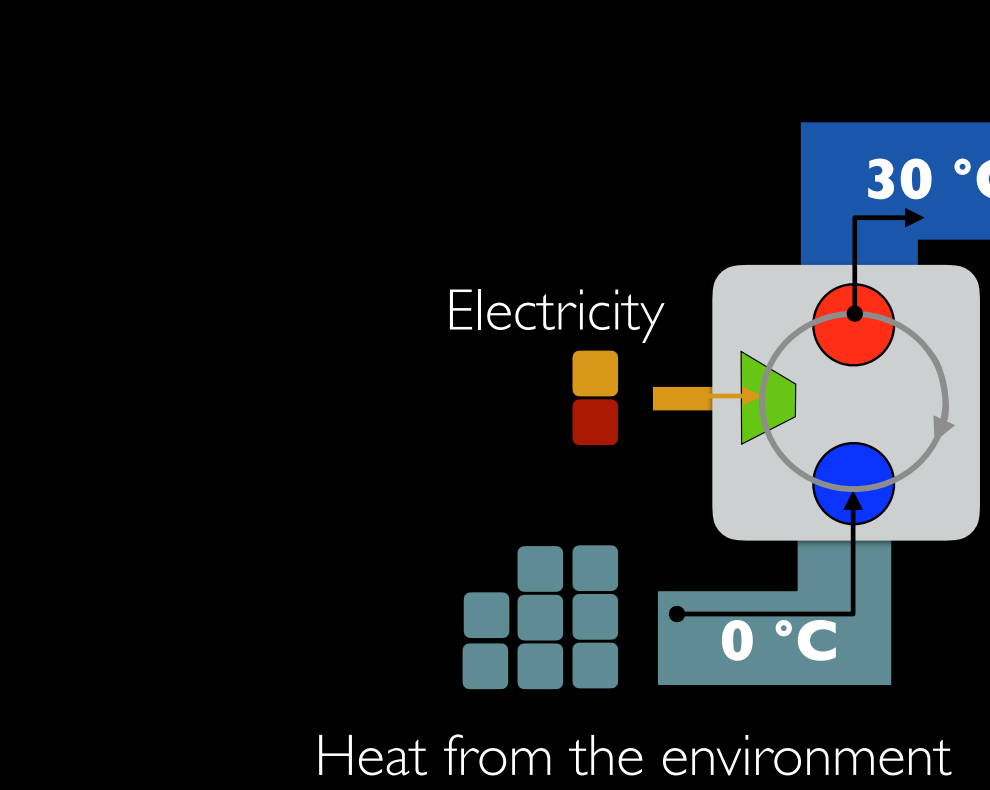
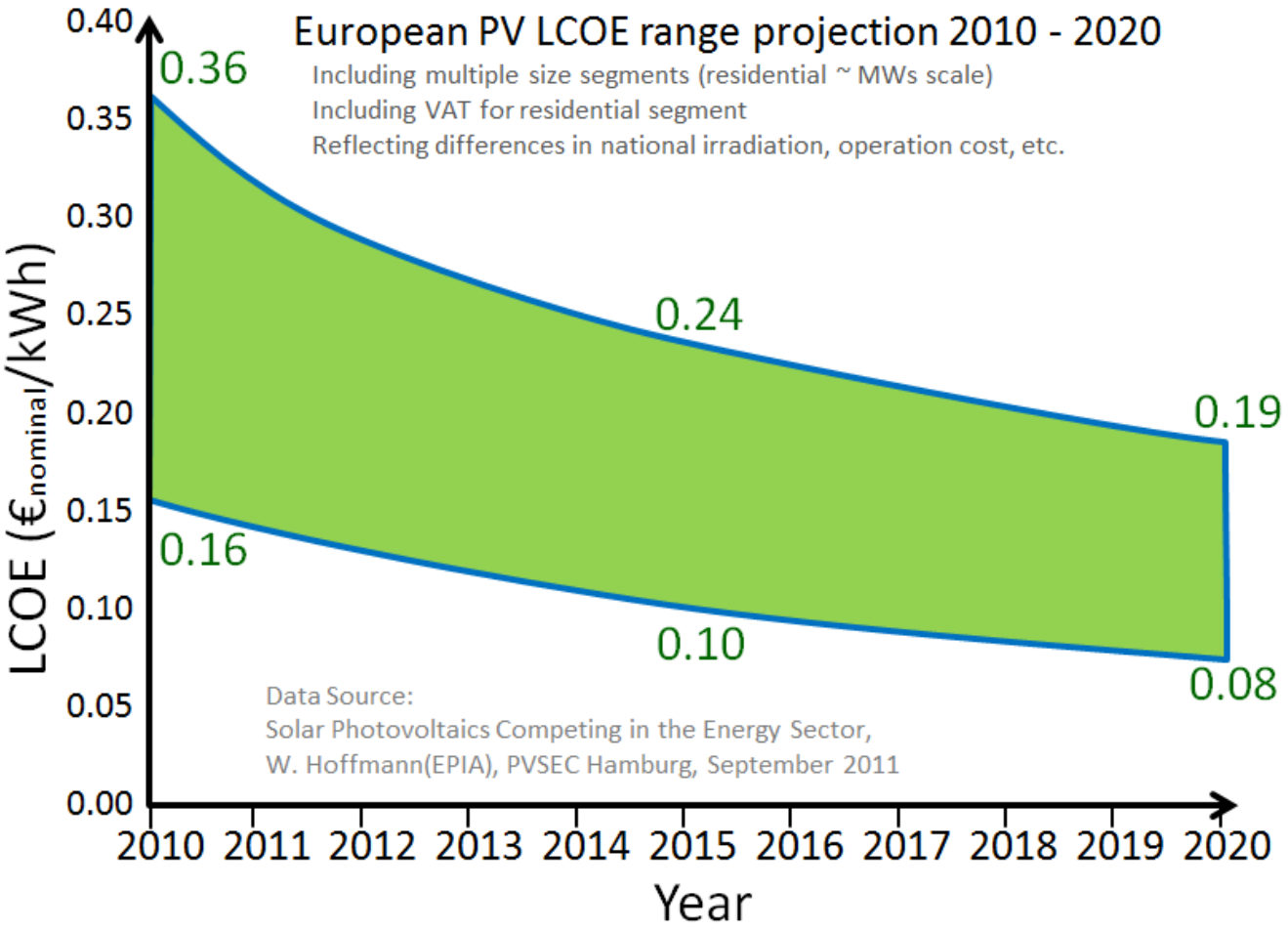
HEAT PUMP IS THE SOLUTION



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

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

The energy source for heat pumps : photovoltaics

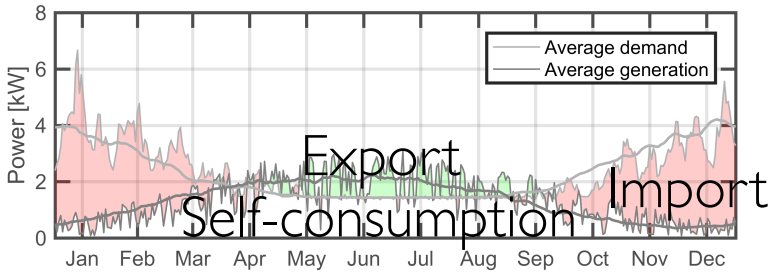


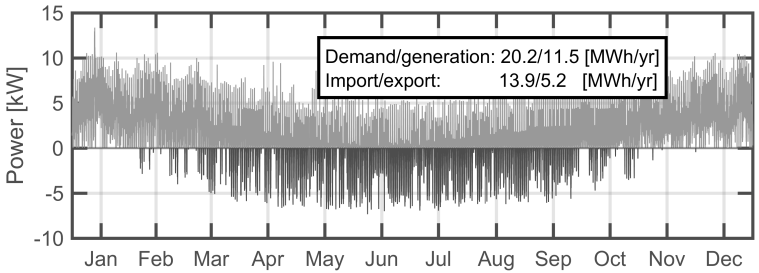
4.0cts USA

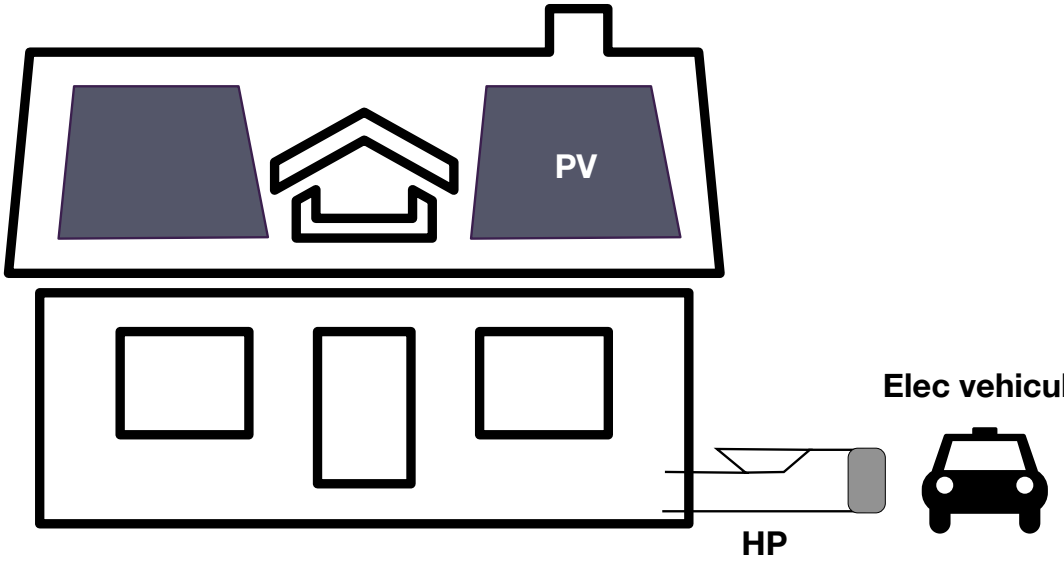
2.4cts Abu Dhabi

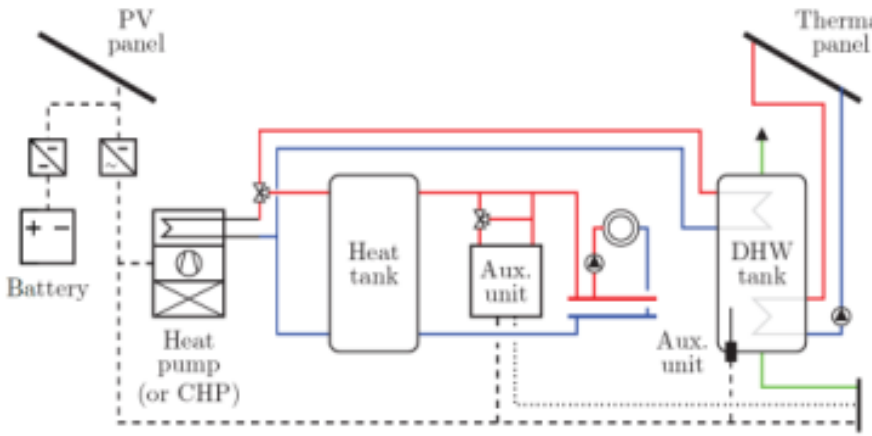
1.8cts Saudi Arabia

Smart energy system
Integration of renewable energy sources in the built environment









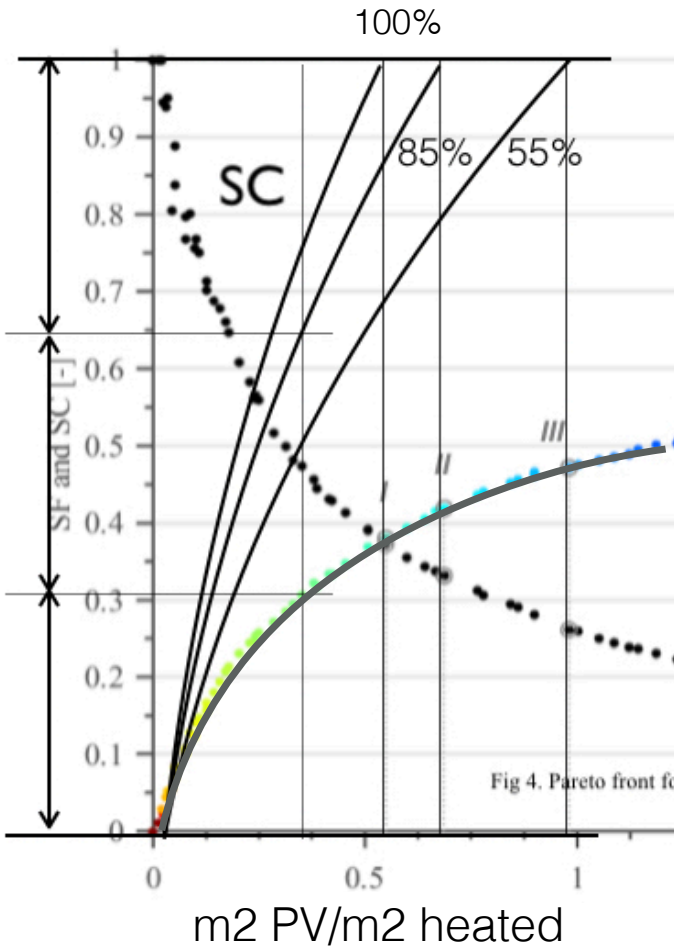
Multi-energy grids

Defosilizing the housing sector
Integration of renewable energy sources in the built environment

Import

Seasonal storage

Self-consumption



The grid is a seasonal battery

Case I

Energy system		Off-site storage	
PV array	88 m^2	Redox Battery	
Battery	4.95 *kWh*	8.14 *MWh*	
HW tank	2.43 m^3	406.9 m^3	(20 Wh/l)
Heat Pump	3.59 *kW*	4'070'000 €	(500 €/kWh)

Annual energy balance

Case II

Energy system		Off-site storage
PV array	109.7 m^2	Redox Battery
Battery	7 *kWh*	10.8 *MWh*
HW tank	2.46 m^3	540.2 m^3
Heat Pump	3.5 *kW*	5'400'000 €

Long term storage : 85%

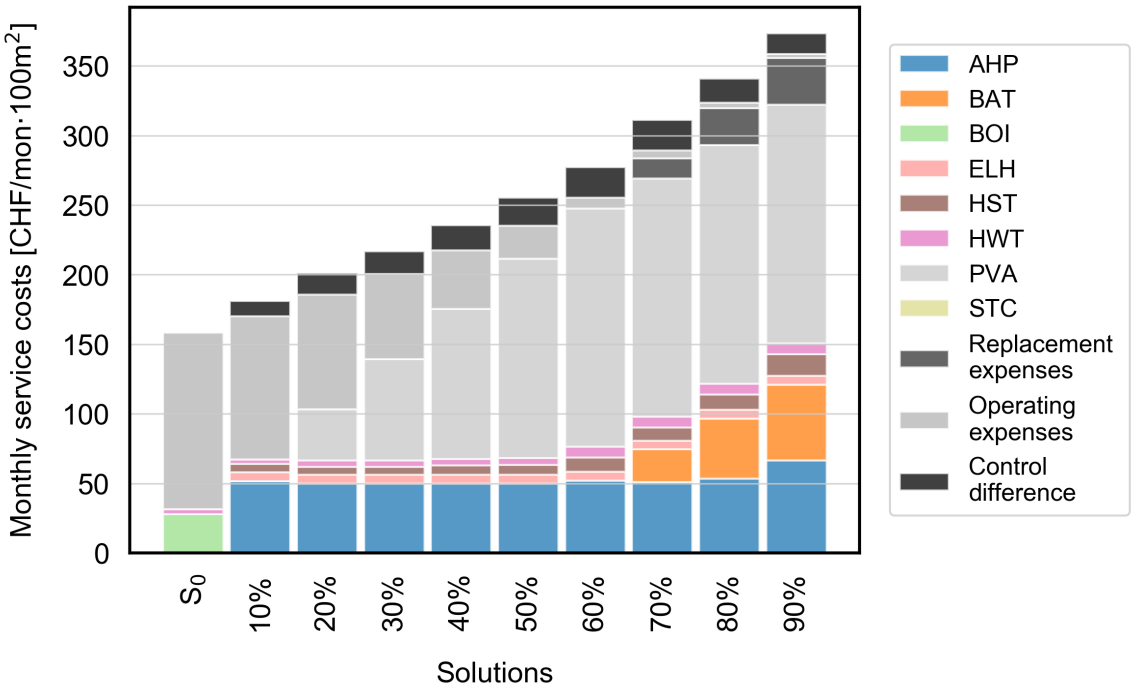
Case III

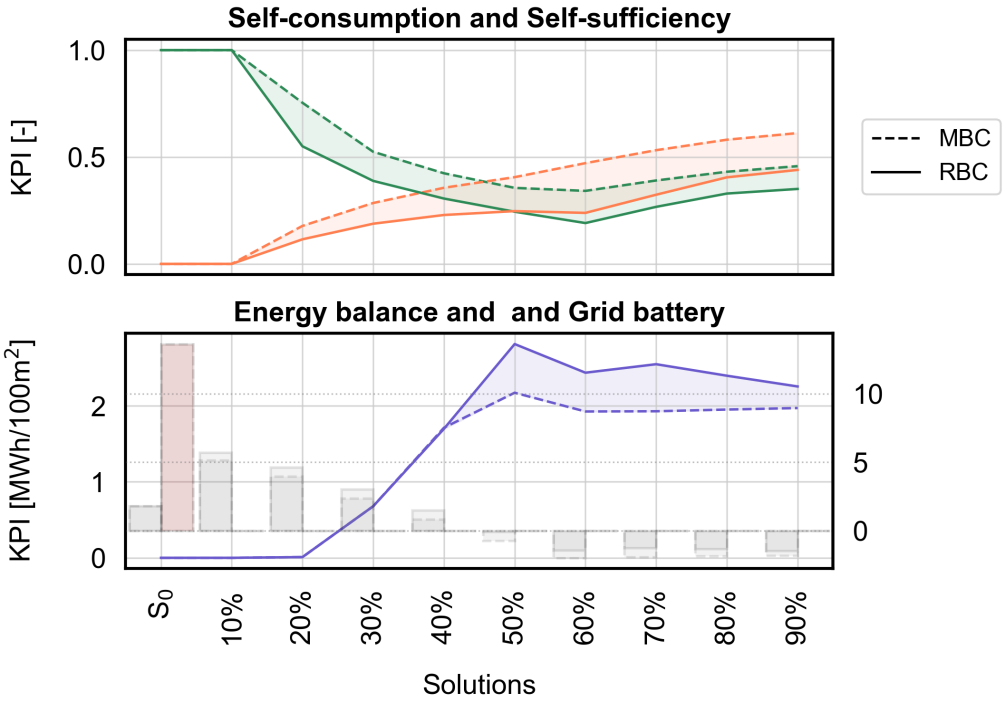
Energy system		Off-site storage
PV array	156.9 m^2	Redox Battery
Battery	8.63 *kWh*	17.1 *MWh*
HW tank	2.39 m^3	854.6 m^3
Heat Pump	3.7 *kW*	8'550'000 €

Long term storage : 55%

Single family house - 160 m2 - Heat pump

Solutions with heat pump & PV as a function of investment





Single family house 1980 Heat pump/ no renovation

Investment : +180 CHF/month/100 m2 soit + 4% real estate value (geneva, CH)
Operation : -100 CHF/month of Oil avoided (50 $/bbl)

Defosillising Cities : Energy Policy

Considering the complete building stock

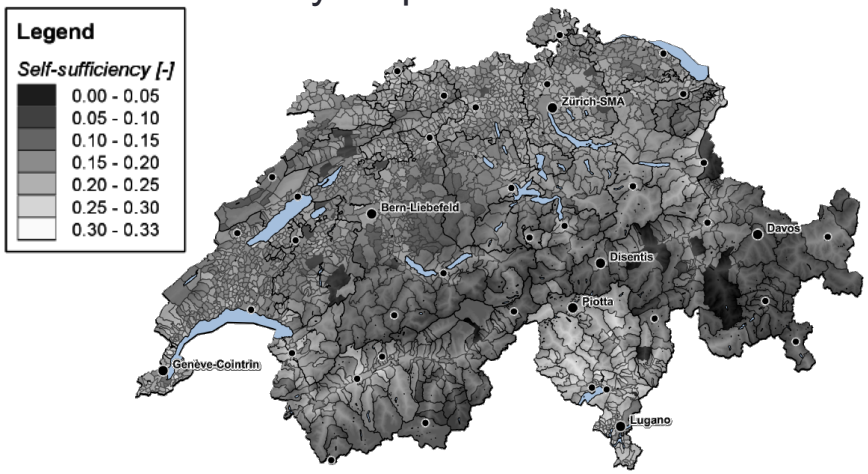
(a) 19 billion CHF/yr for factor 5 CO2 emissions reduction.

(b) Boiler phase out before renovation

(c) PV and renovation

Further reduction needs seasonal storage

Self-sufficiency maps



CH-Map of solution nº 50 (upper investment bound)

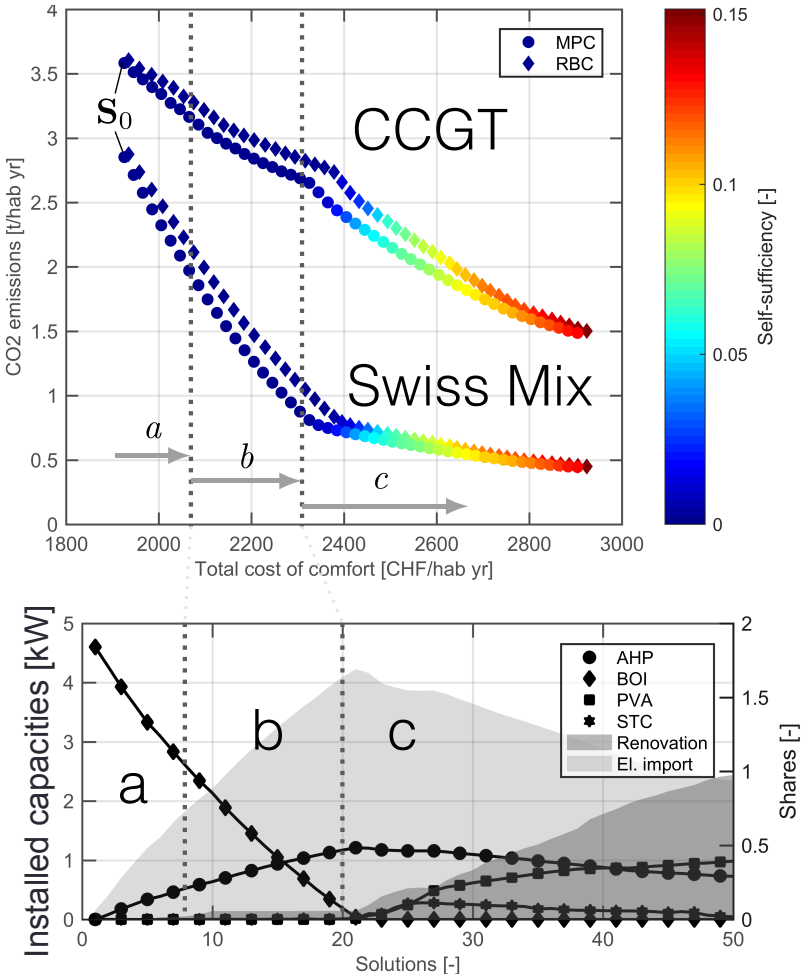
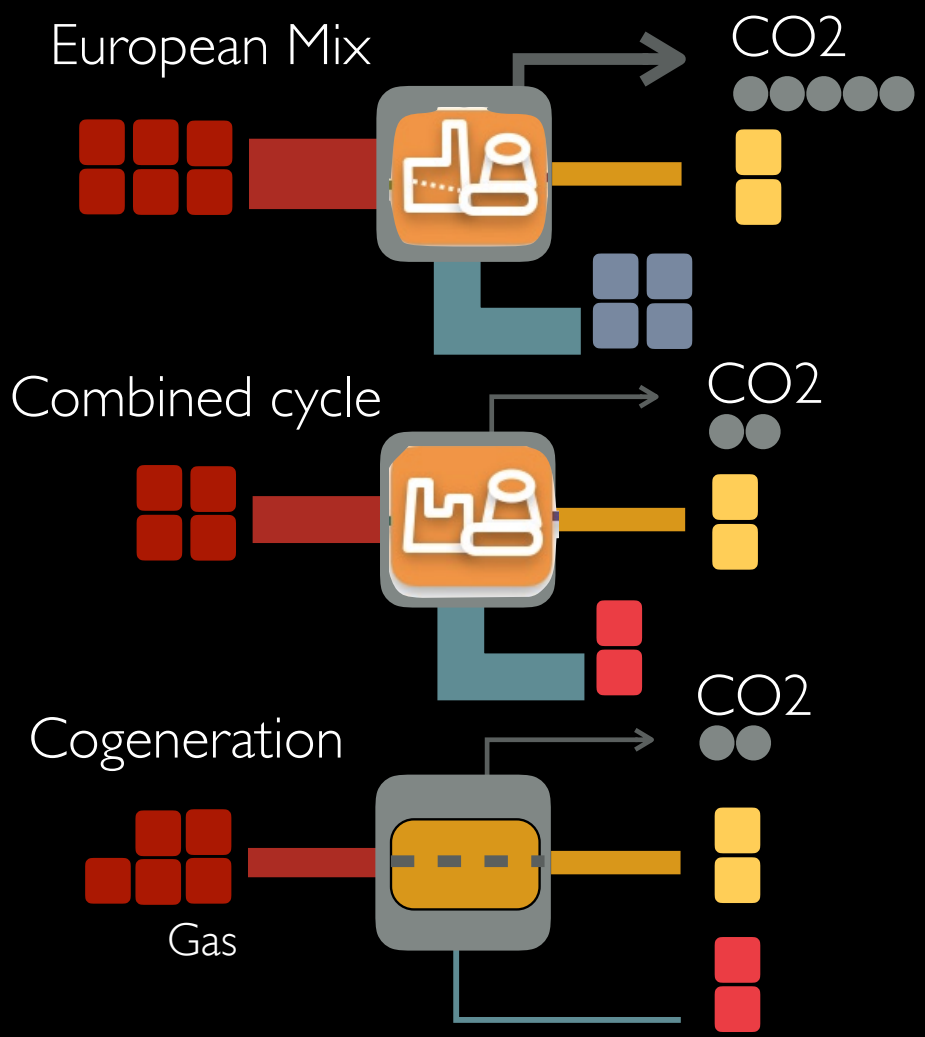
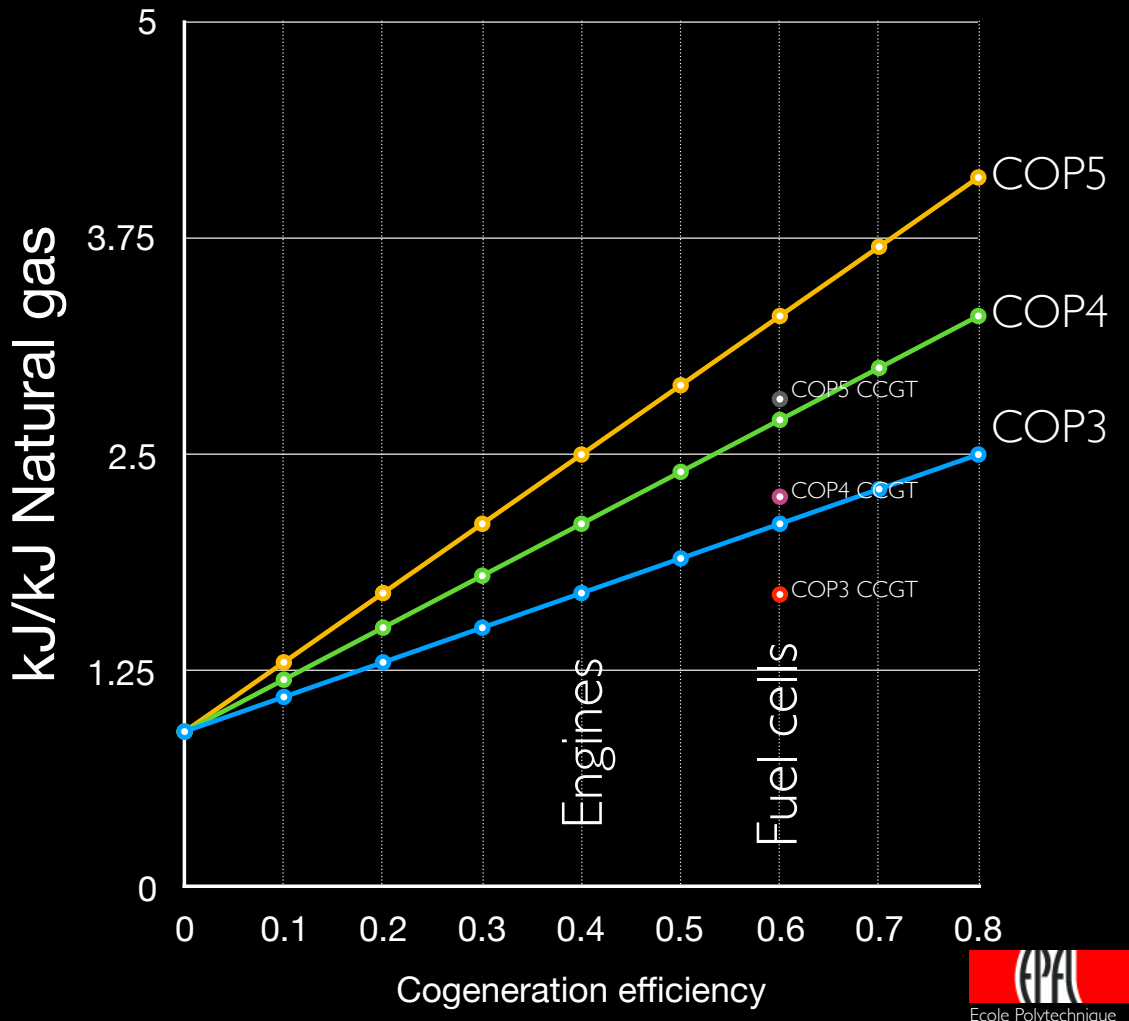


FIGURE 12 | Pareto fronts for Switzerland when applying MPC (circles) and RBC (diamonds). The marker size reflects the renovation share of the current built environment.

PRODUCING THE ELECTRICITY DEFICIT





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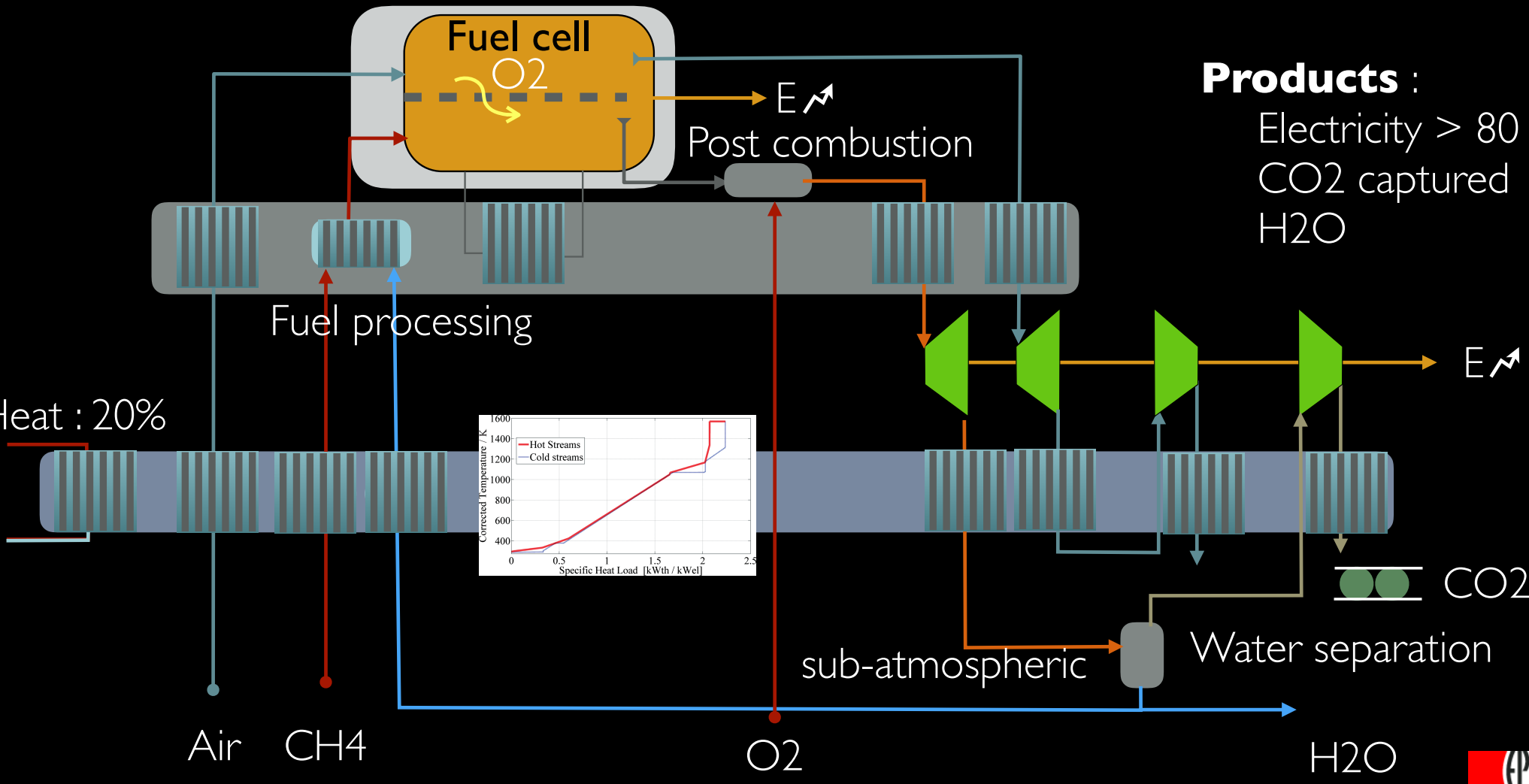
PRODUCING ELECTRICITY WITH ADVANCED FUEL CELL SYSTEM



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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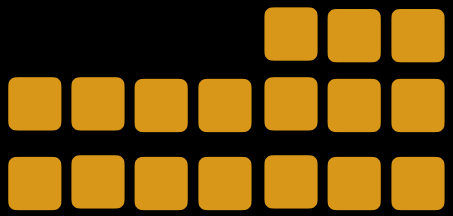
BIO - METHANE FROM BIOWASTE

BIOMASS : C(H2O)
Organic waste

Synthetic Natural Gas



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):

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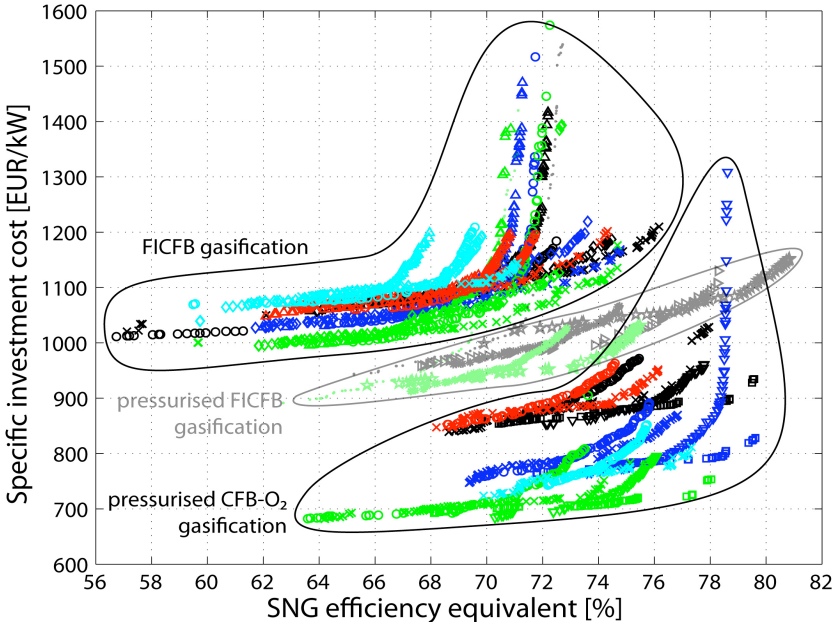
BIOMASS TO SYNTHETIC NATURAL GAS

Collection of solutions exists

Thermo-economic Pareto front (cost vs efficiency):



Gasification:
FICFB
- air drying
- + torrefaction
- steam drying
- + torrefaction

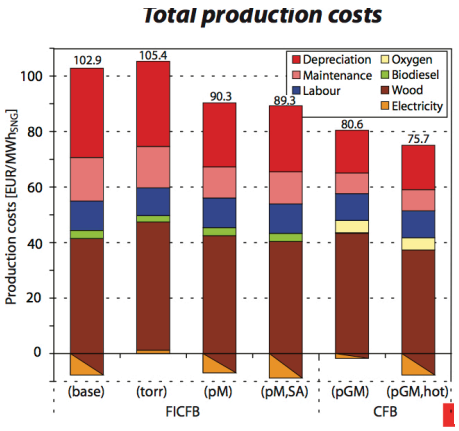
pressurised FICFB
- air drying
- air drying, gas turbine
- steam drying, gas turbine
- + hot gas cleaning

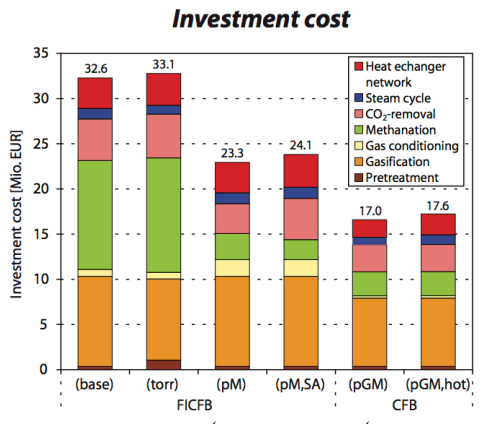
CFB-O_2
- air drying
- + hot gas cleaning
- steam drying
- + hot gas cleaning

Separation:
PSA
- downstream
- upstream of methanation

Phys. abs.
- downstream
- upstream of methanation

Membranes
- downstream of methanation





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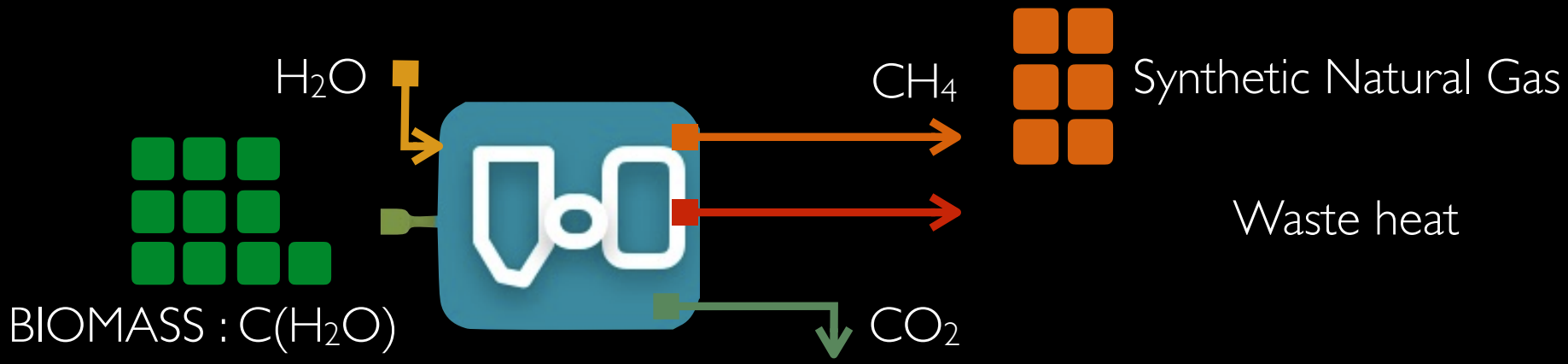
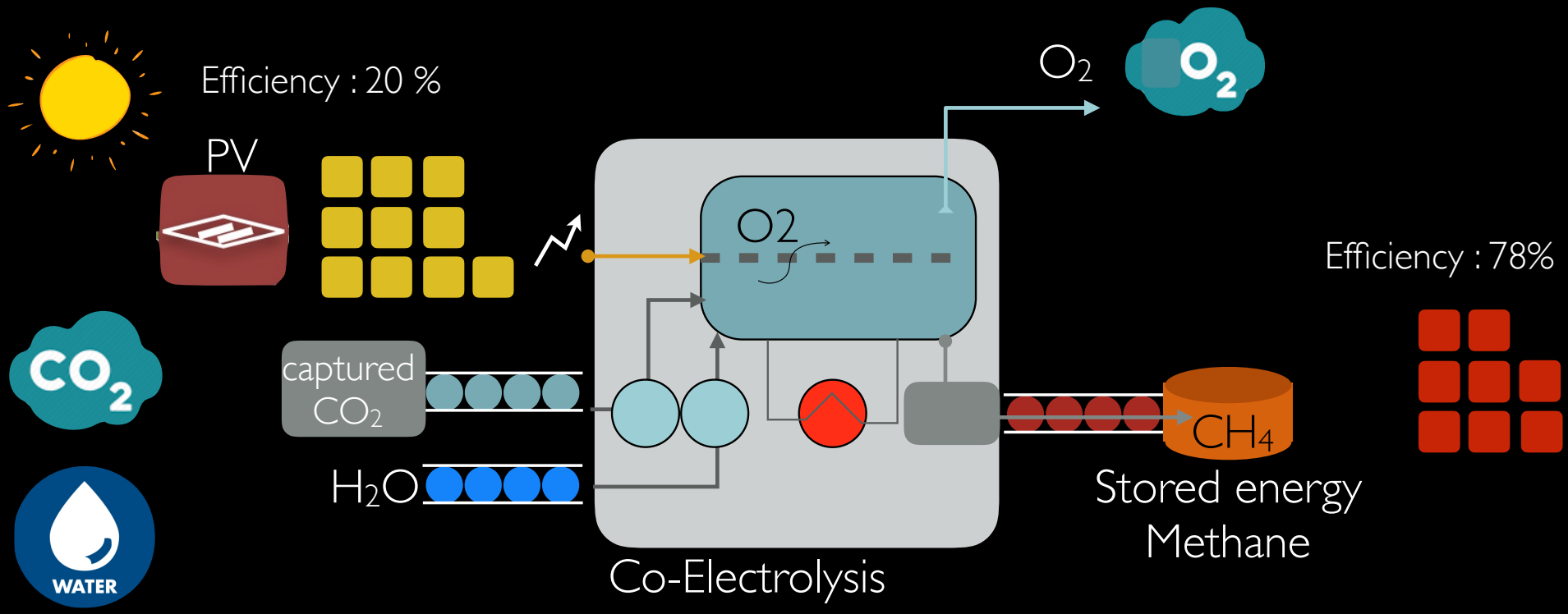
BIOMASS BASED COMBINED FUEL AND HEAT PRODUCTION



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

STORING EXCESS OF ELECTRICITY



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.

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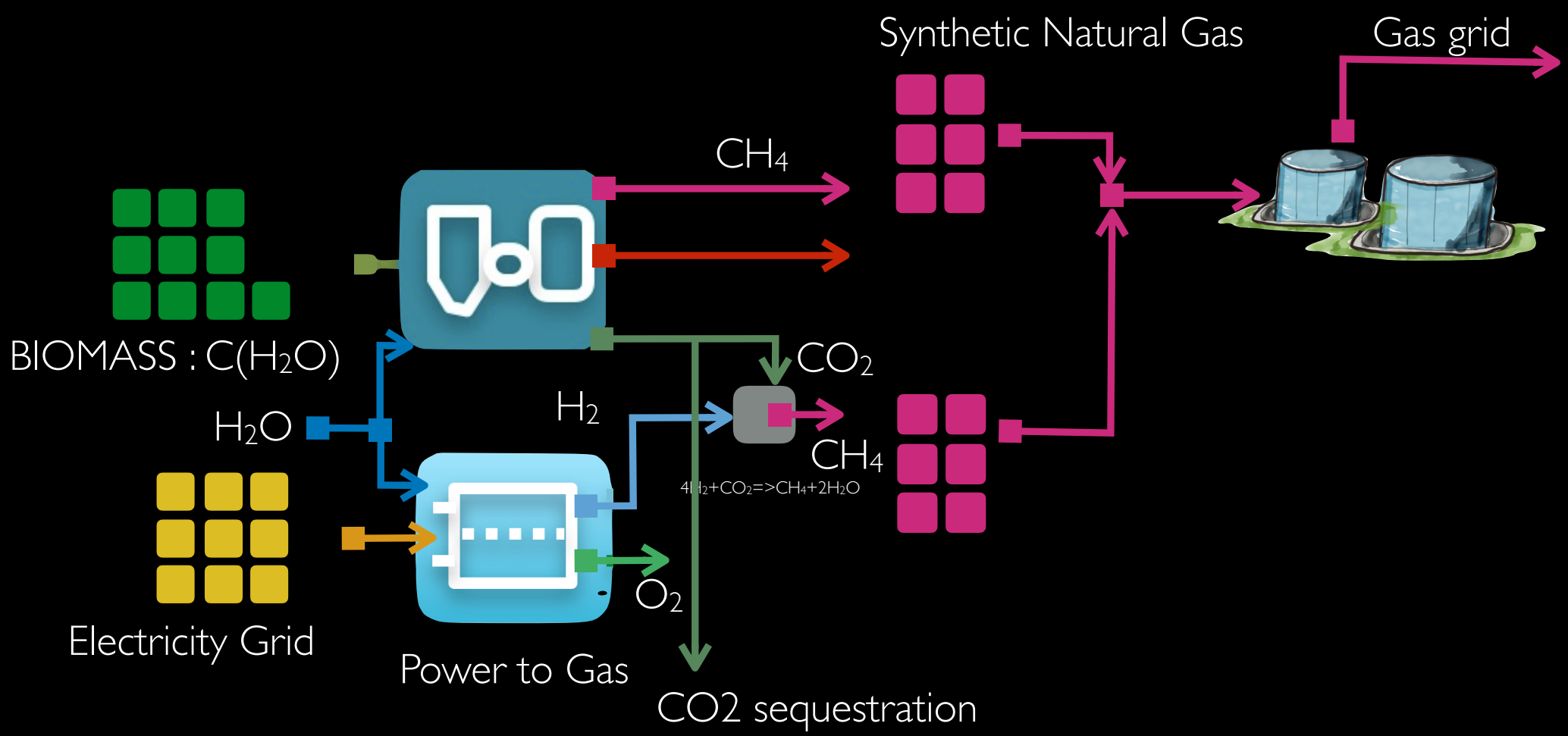
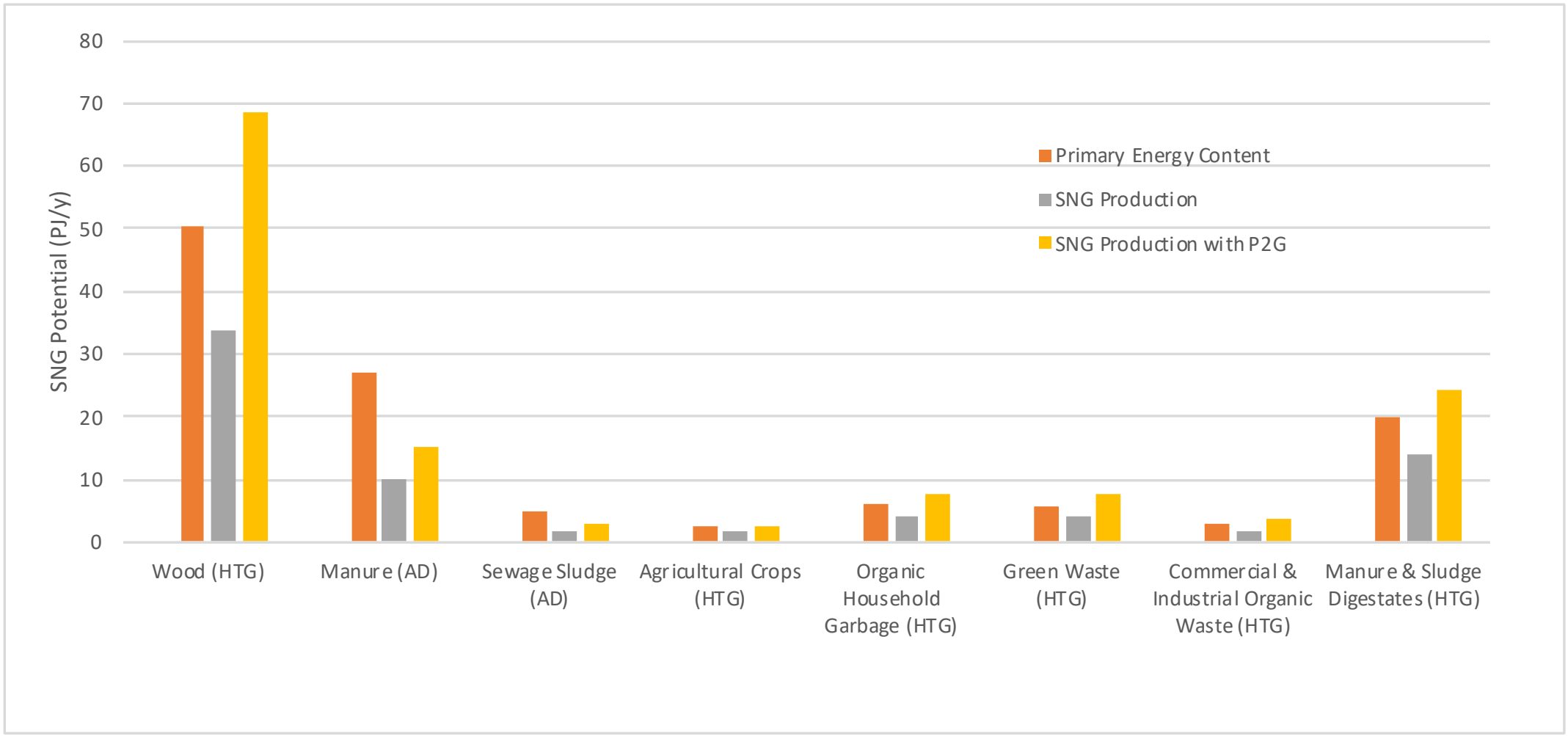
ON THE USE OF THE BIOMASS AS AN ENERGY SOURCE

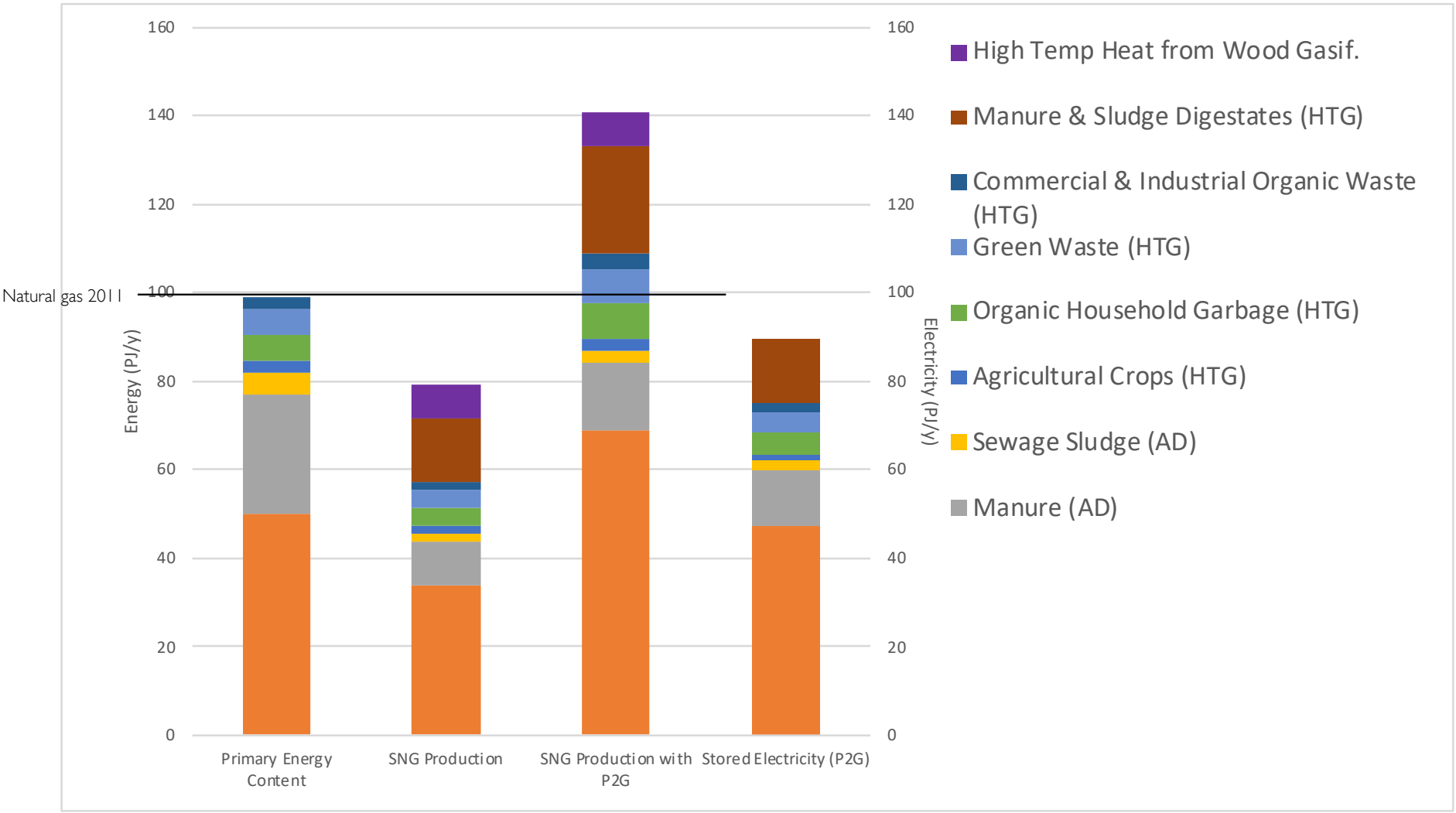


Gassner, Martin, and François Maréchal. "Thermo-economic optimisation of the integration of electrolysis in synthetic natural gas production from wood." Energy 33.2 (2008): 189-198.

SNG from biomass potential in Switzerland

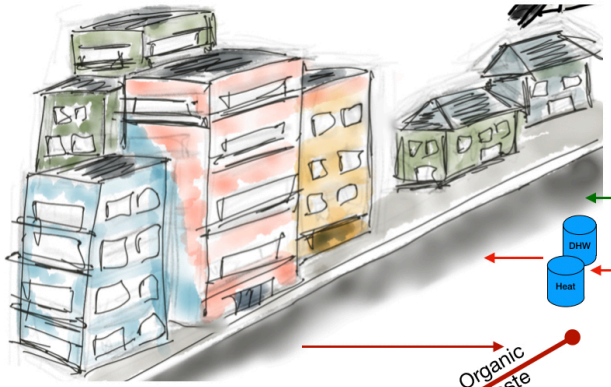


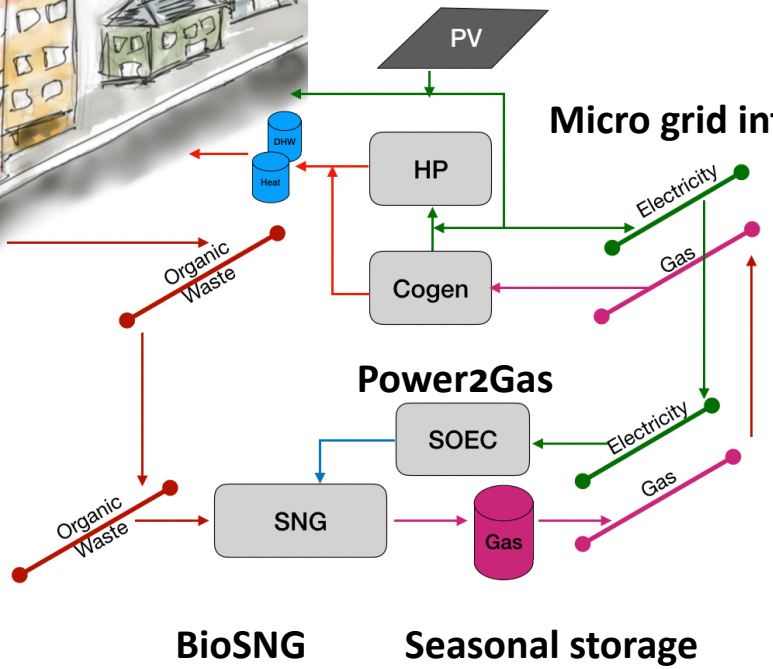
SNG from biomass potential in Switzerland

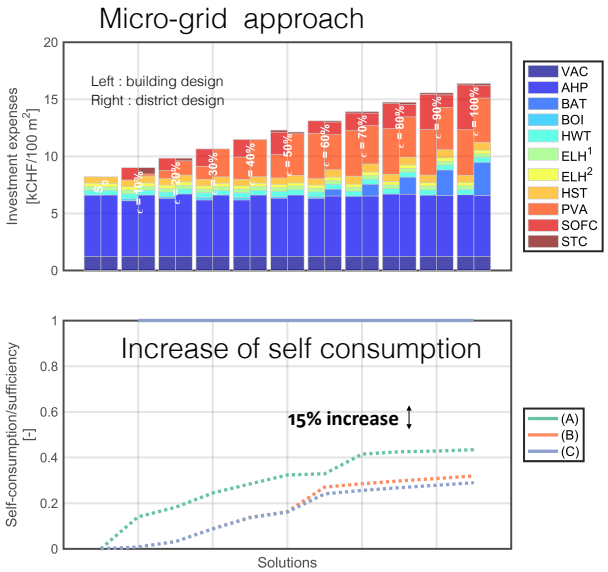


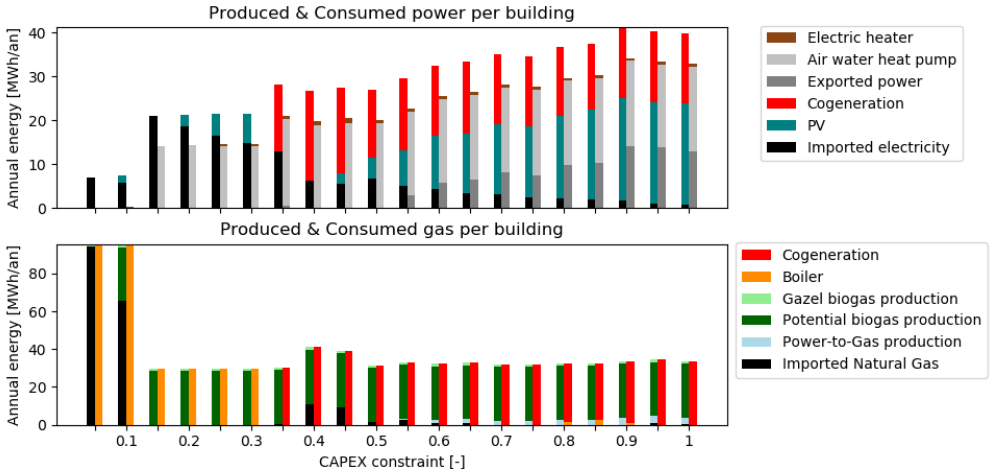
Integrating Renewable Energy Sources : Biogas + PV+ Power2gas

- Replacing oil boilers







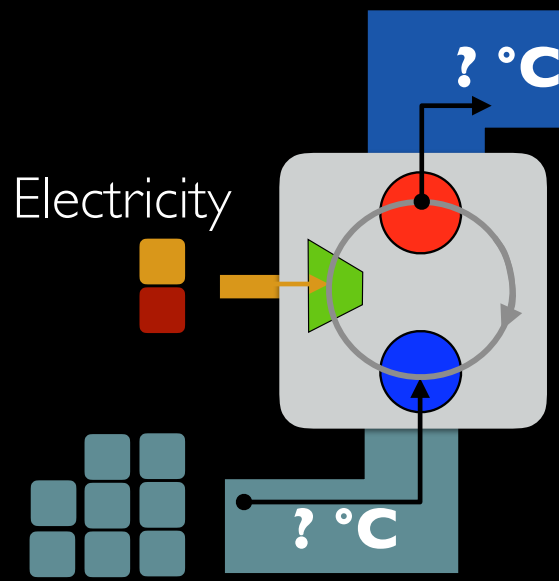


SCCER-BIOSWEET, SCCER-FURIES & SCCER-JA S&M
Support from Gaznat

HEAT PUMP IS THE SOLUTION

Useful heat

Old building 65°C
New buildings 30 °C



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

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

Waste heat : 30°C
Waste water : 13-20 °C
Ground water : 10 °C
Lake water : 7°C

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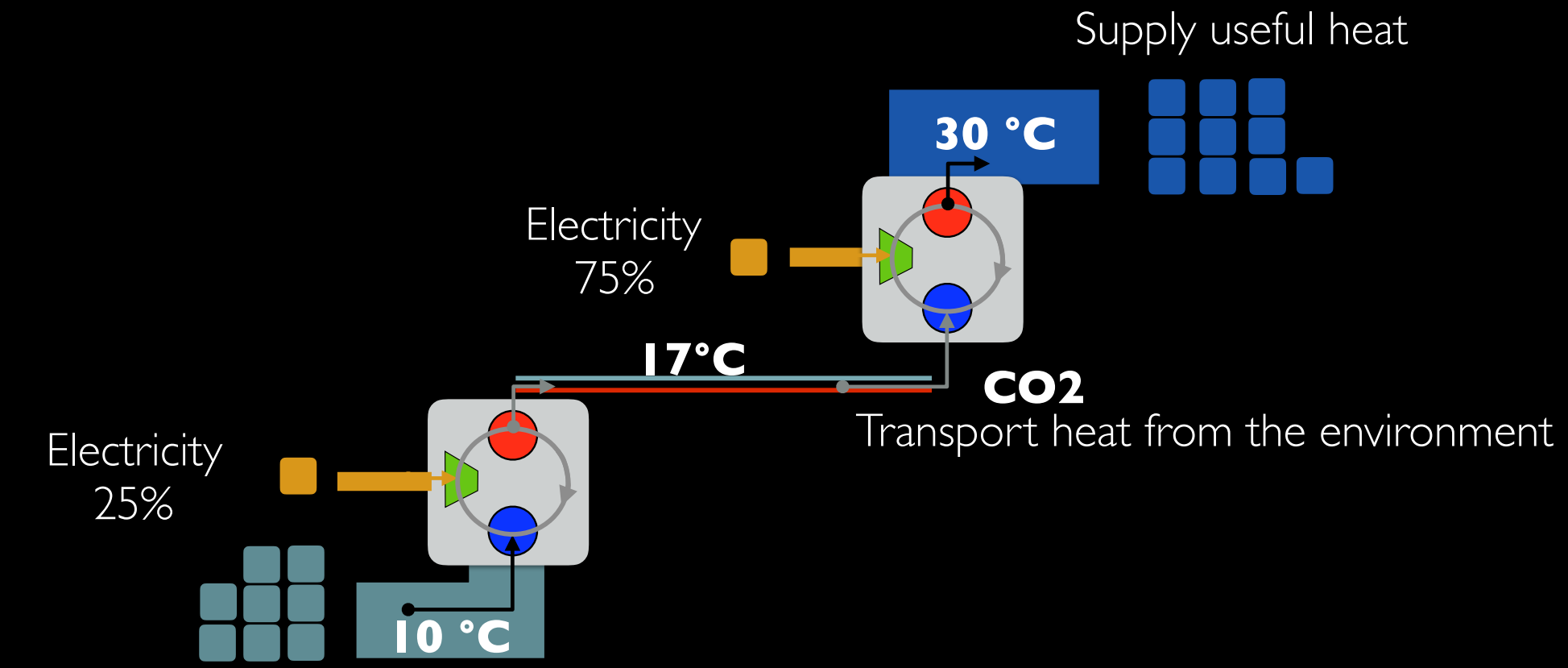
REACH THE GOOD RESOURCES
SUPPLY WHAT IS NEEDED



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

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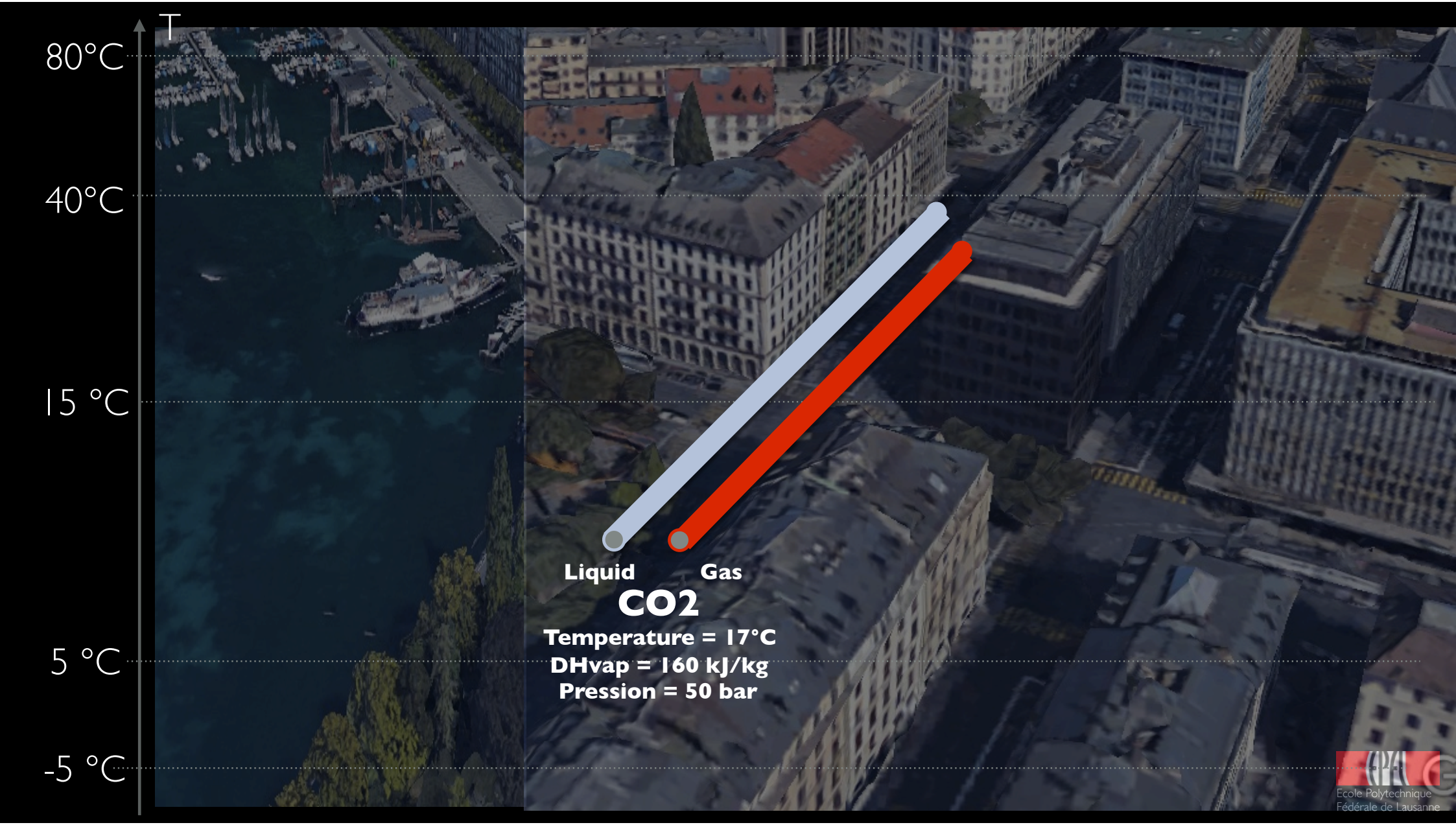
T
80°C
40°C
15 °C
5 °C
-5 °C
Liquid
Gas
CO2
Temperature = 17°C
DHvap = 160 kJ/kg
Pression = 50 bar
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Fédérale de Lausanne

T

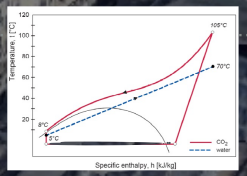
80°C

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)

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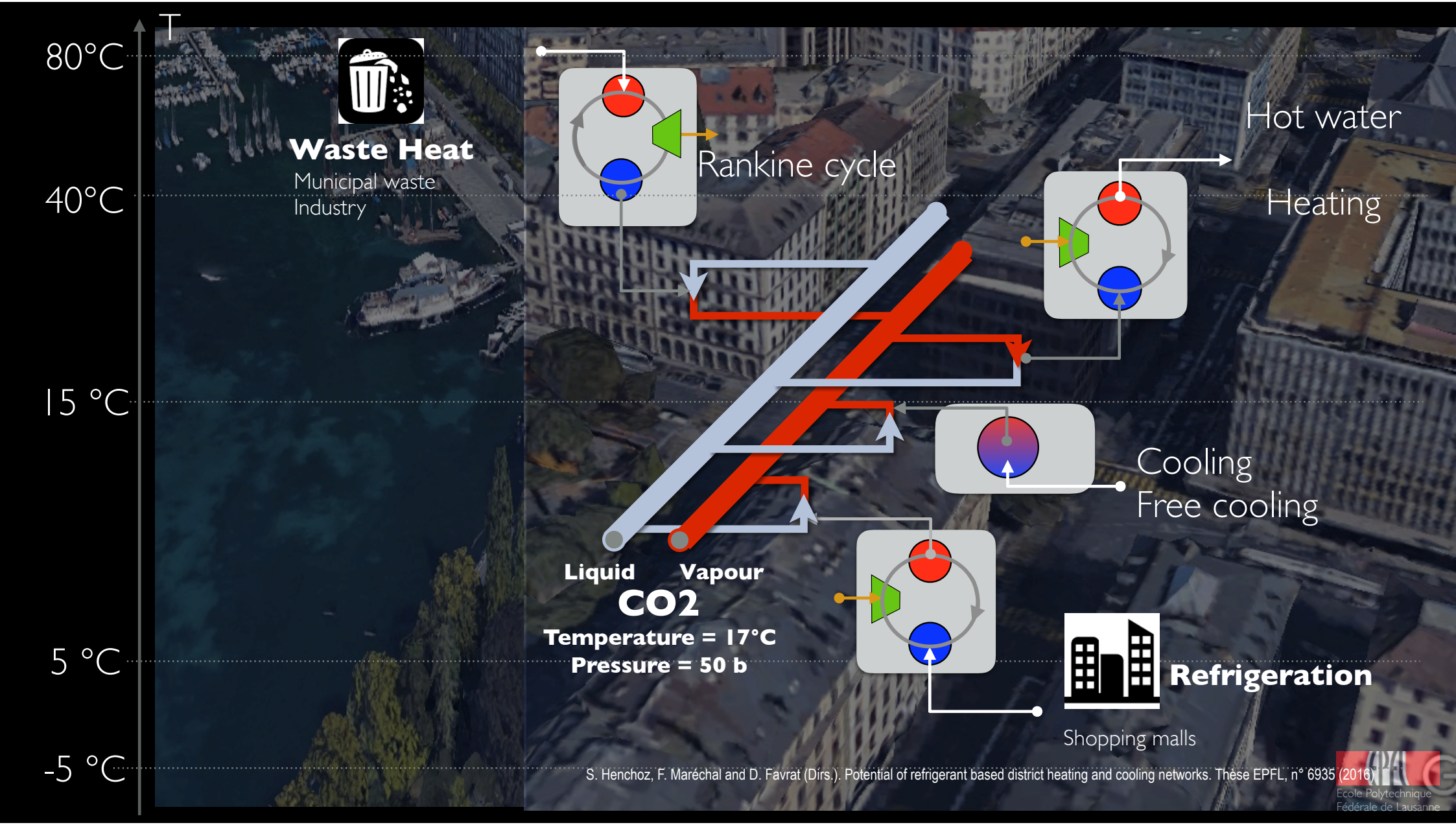

S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)

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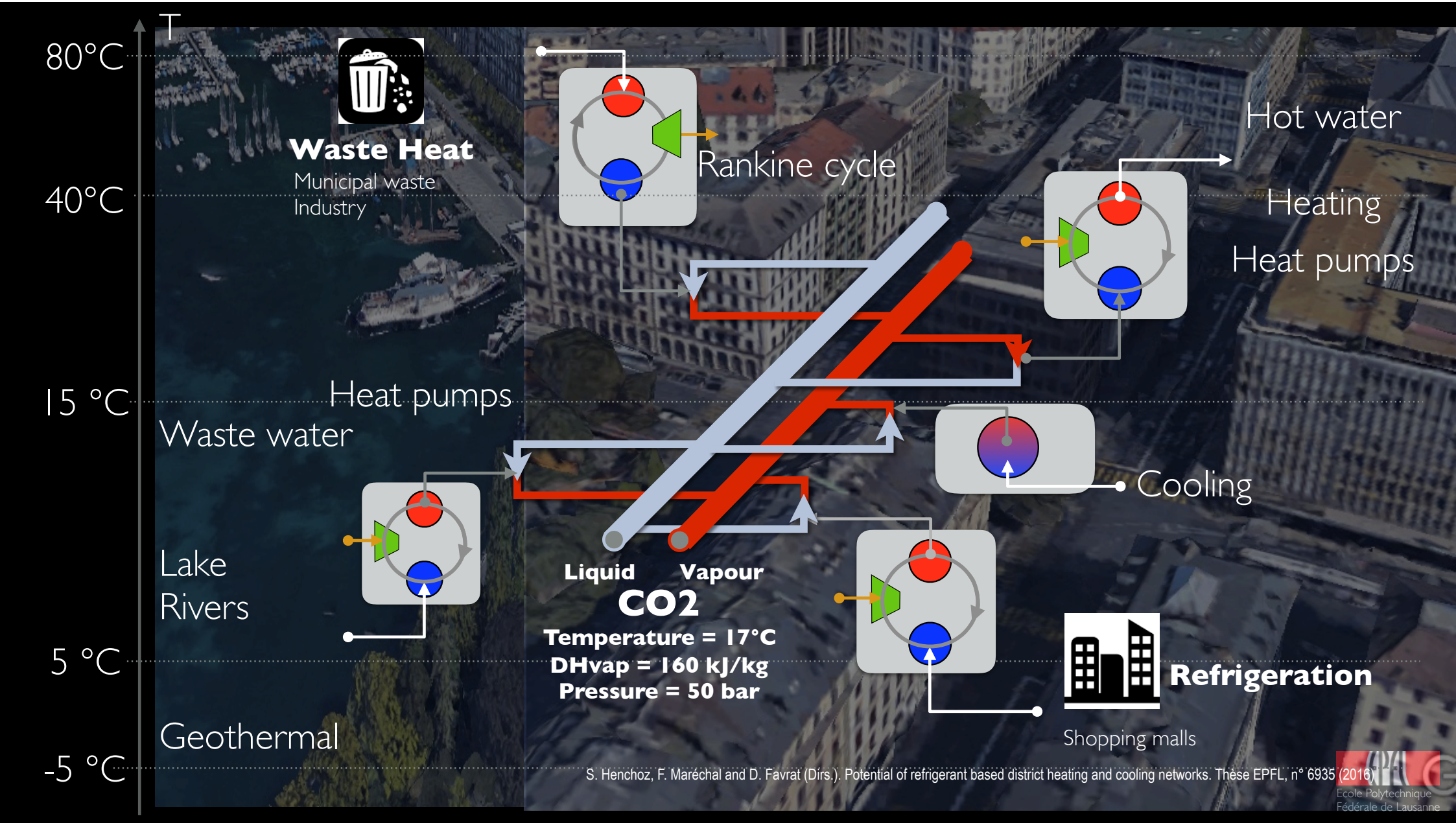
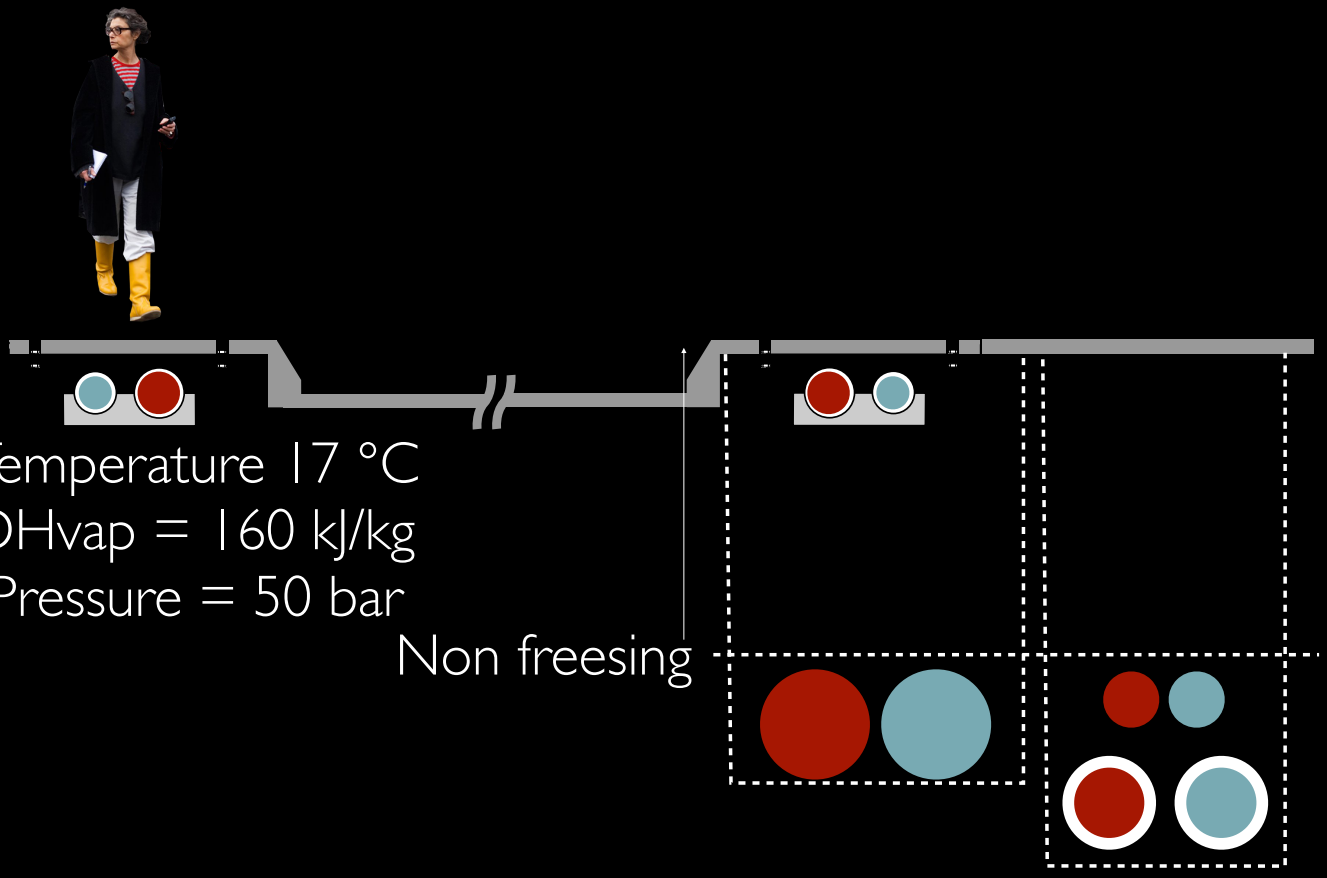
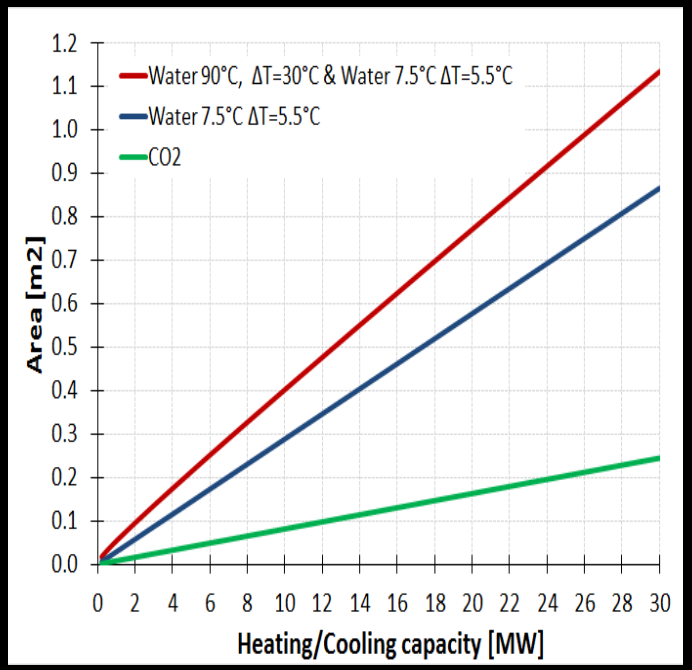


S. Henchoz, F. Maréchal and D. Favrat (Dirs.). Potential of refrigerant based district heating and cooling networks. Thèse EPFL, n° 6935 (2016)

ADD THE PIPES IN THE PEDESTRIAN WAYS





Instead of putting them underground

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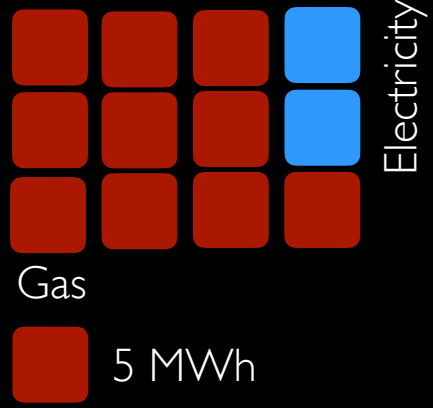
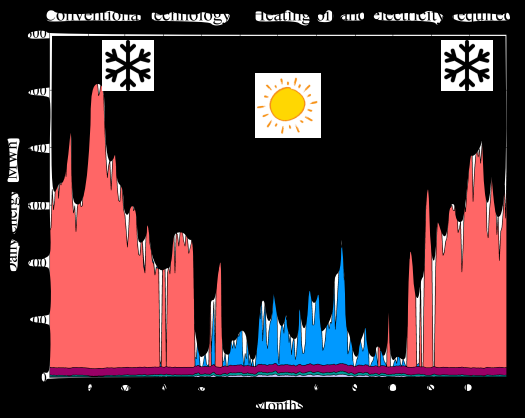
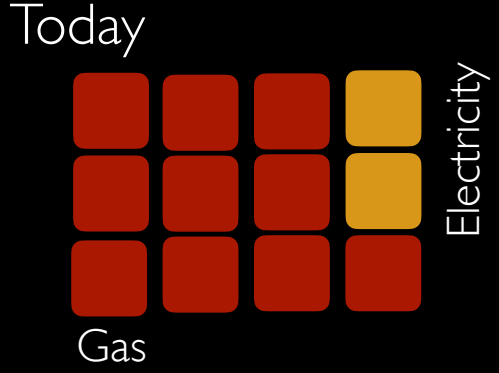
APPLICATION TO A DISTRICT





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

APPLICATION TO A CITY DISTRICT



COP =5.7

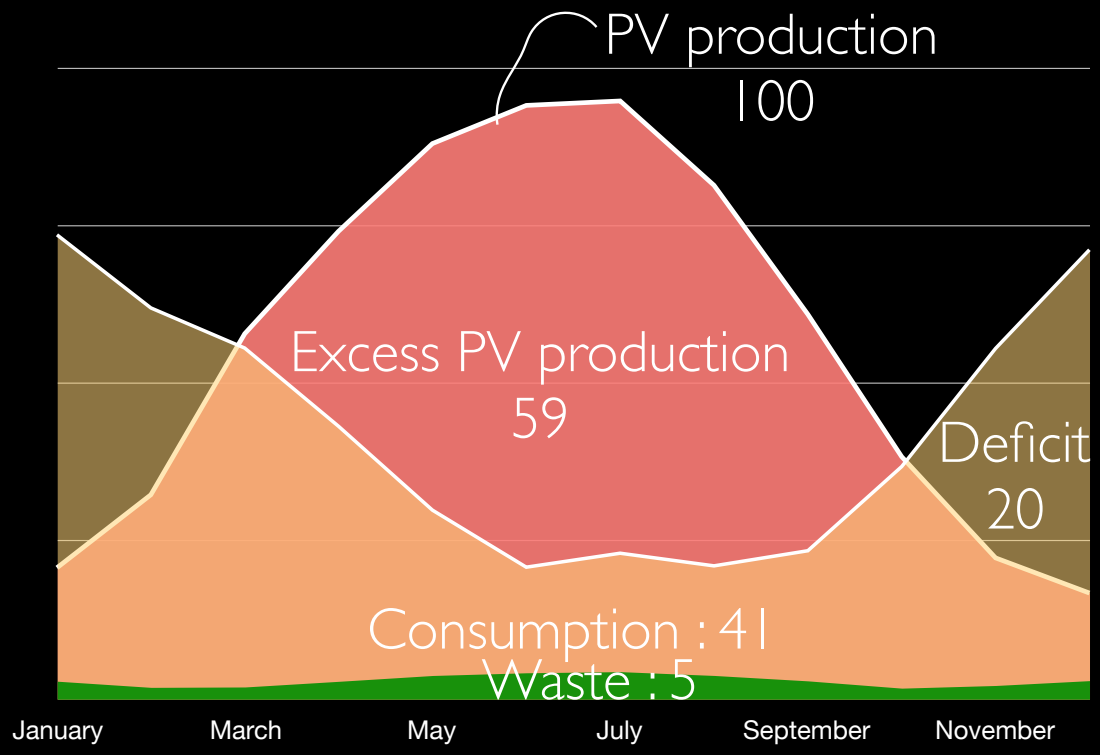
-84 %

No CO2 emissions

Pay back 6 years

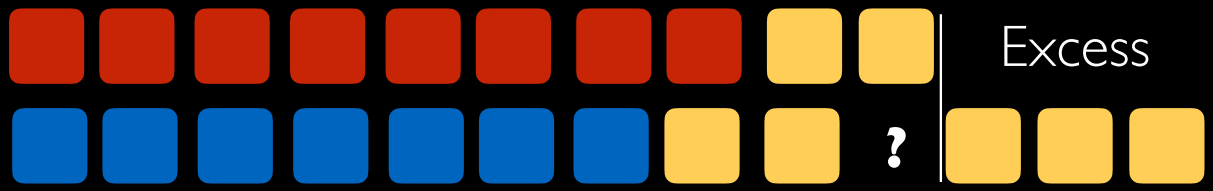
Investment : 10 k€/cap

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



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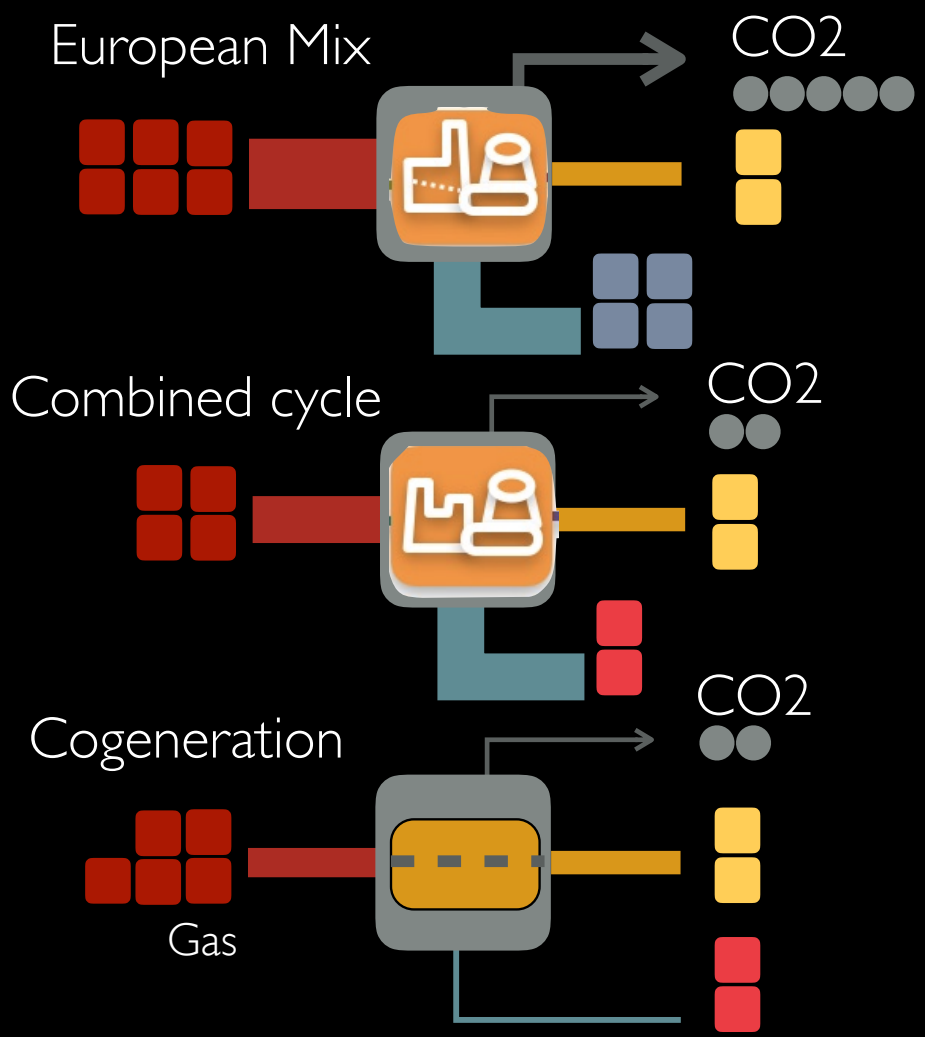
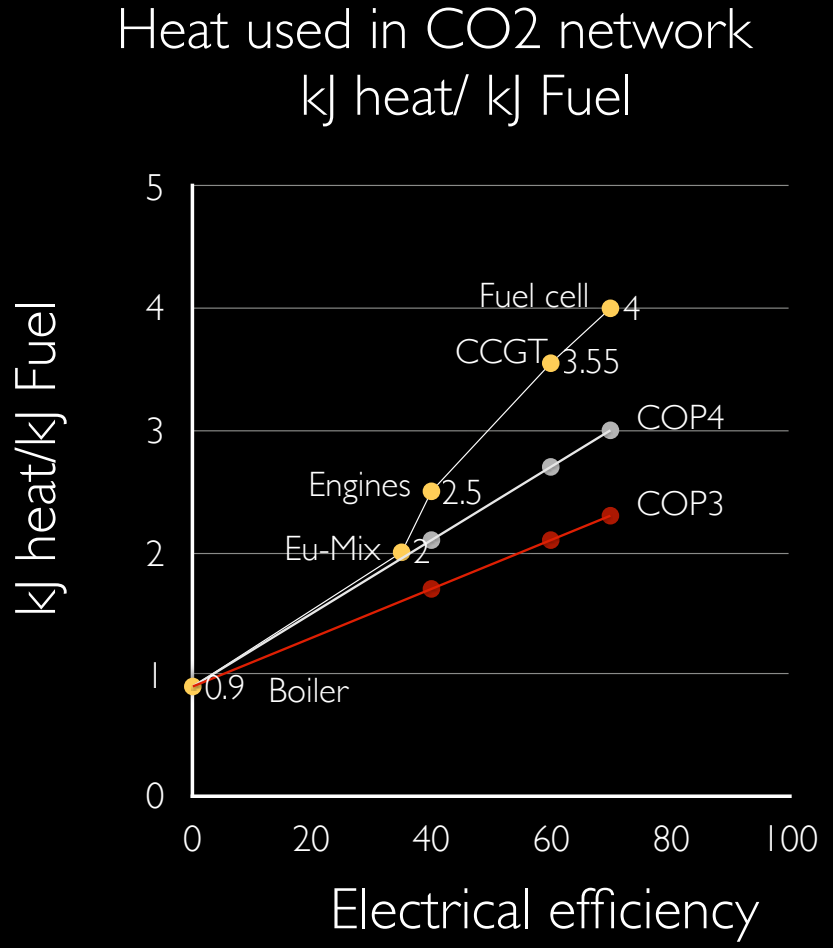
PRODUCING THE ELECTRICITY DEFICIT





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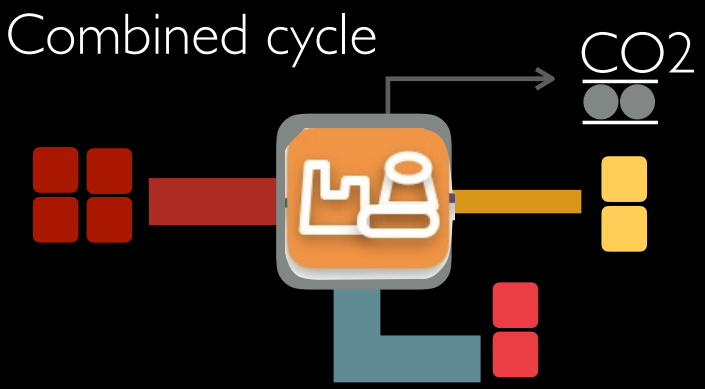
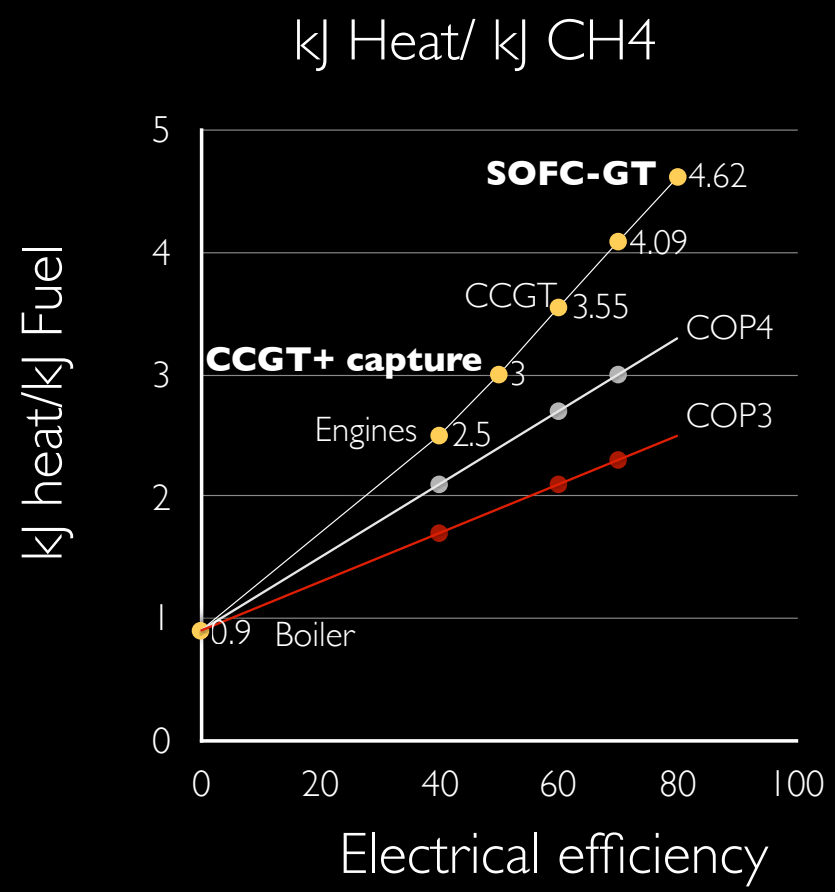
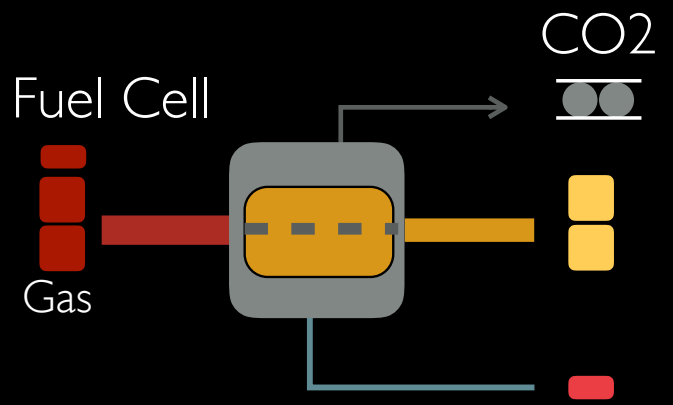
CO2 CAPTURE







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.*

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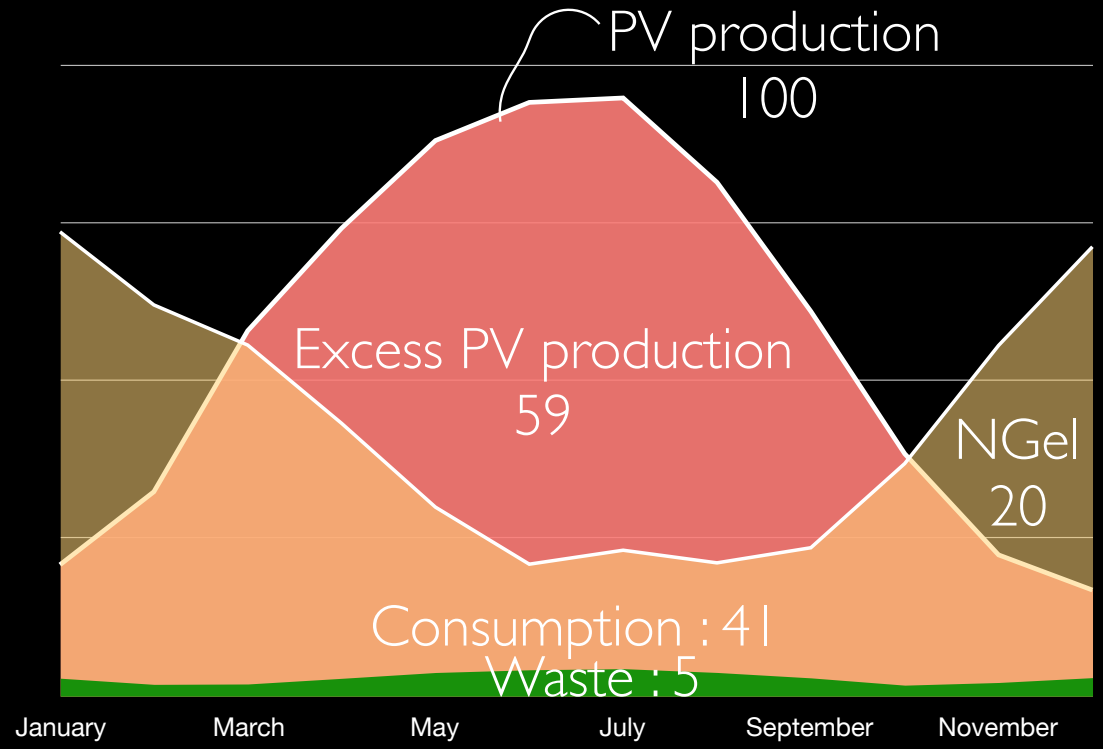
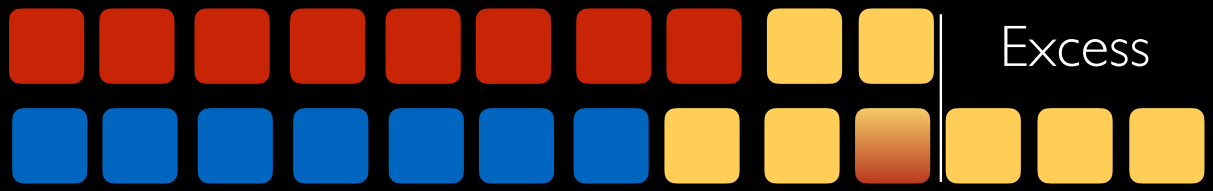
EXCESS OF ELECTRICITY ON THE ROOFS



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



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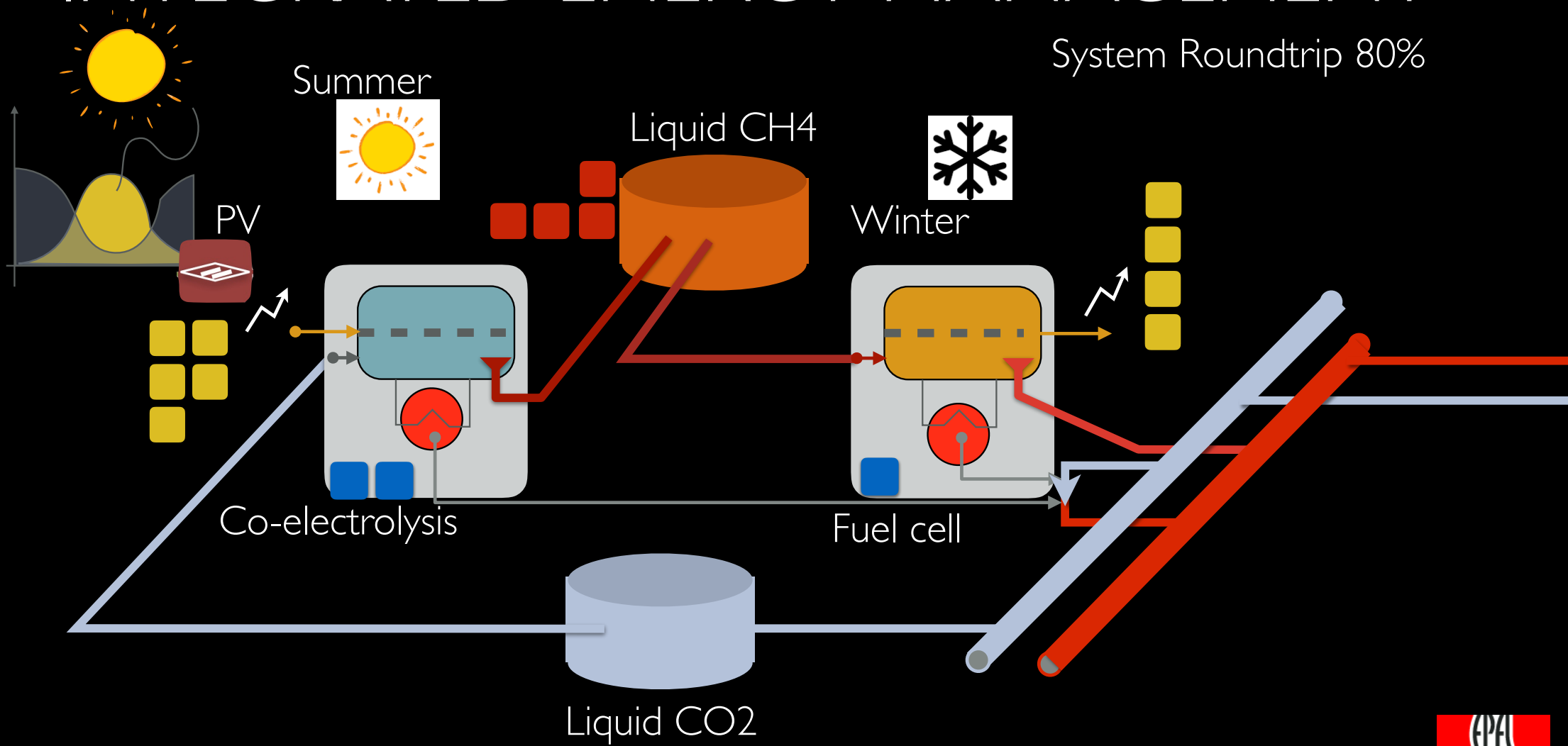
INTEGRATED ENERGY MANAGEMENT



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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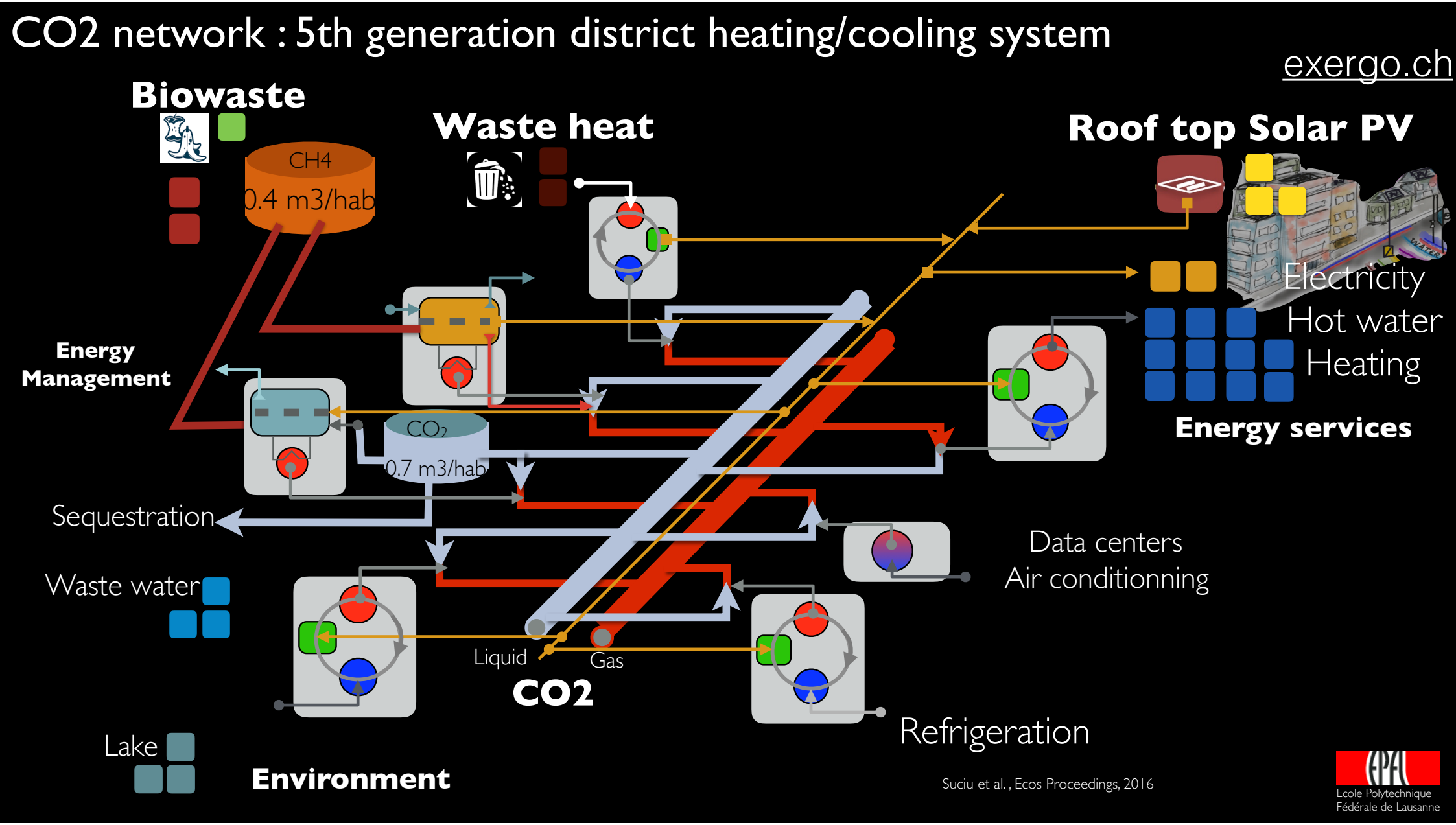
CO2 network : 5th generation district heating/cooling system

exergo.ch



Suciu et al., Ecos Proceedings, 2016

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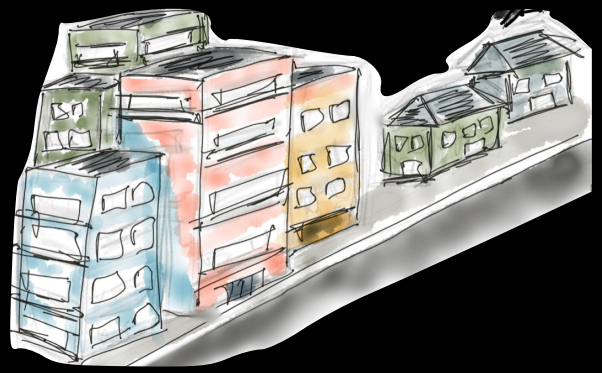
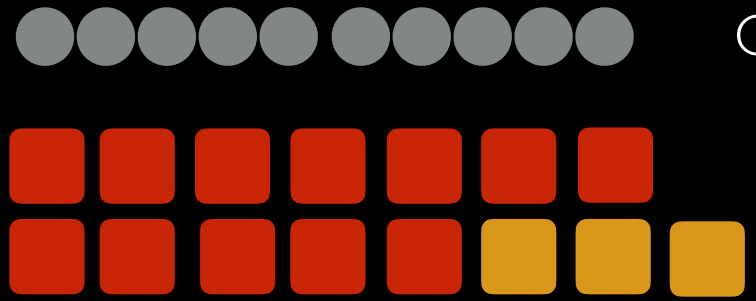
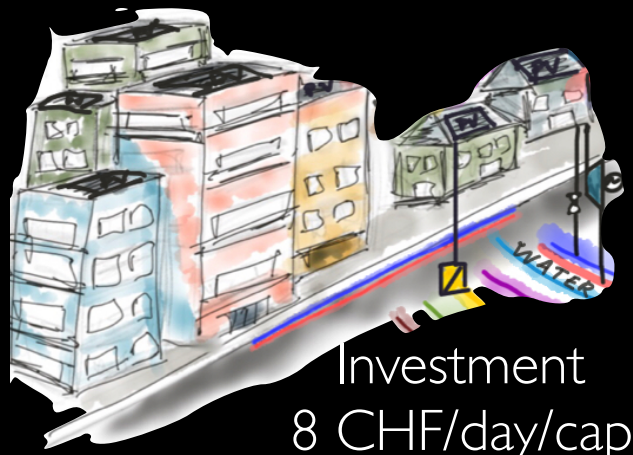
A CITY 100% RENEWABLES AND CO2 NEUTRAL BY 5 G DHC

Before





After



Investment $

8 CHF/day/cap

25 m2 PV/cap 1 m pipe/cap 12 kg CO2/cap

Storage : 1 m3/cap

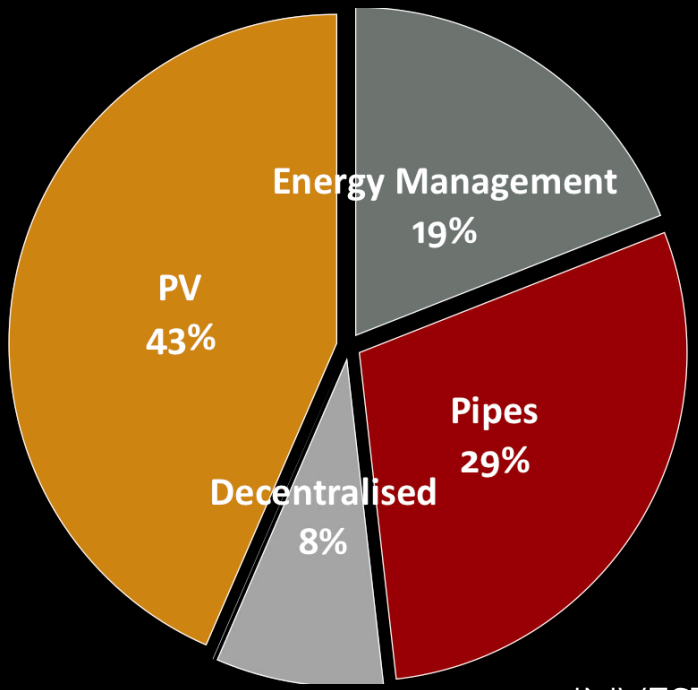
100 l gasoline/hab/year

Electricity

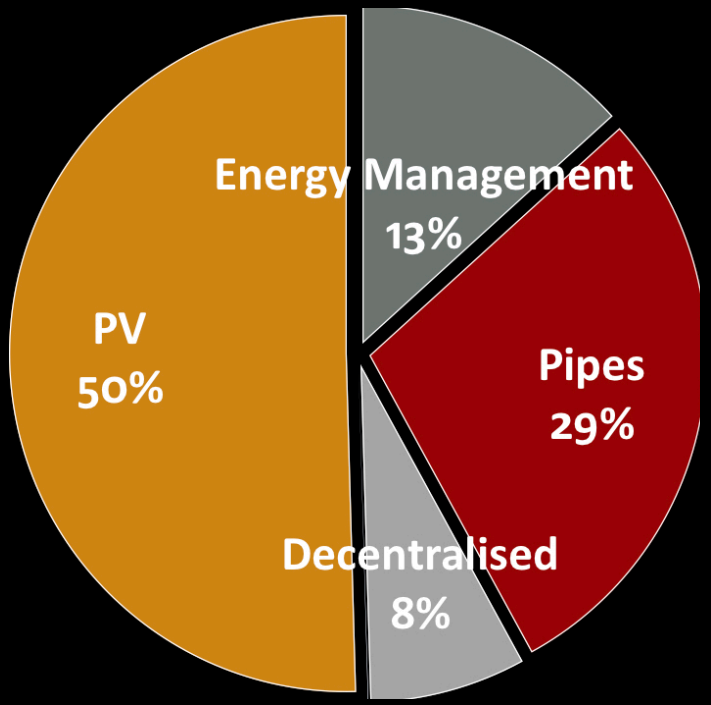
R. Suciu et al., Energy integration of CO_2 networks and Power to Gas for emerging energy autonomous cities in Europe, ECOS 2017 Proceedings

INVESTMENT : 330-440 CHF/M^2

SOFC



CCGT

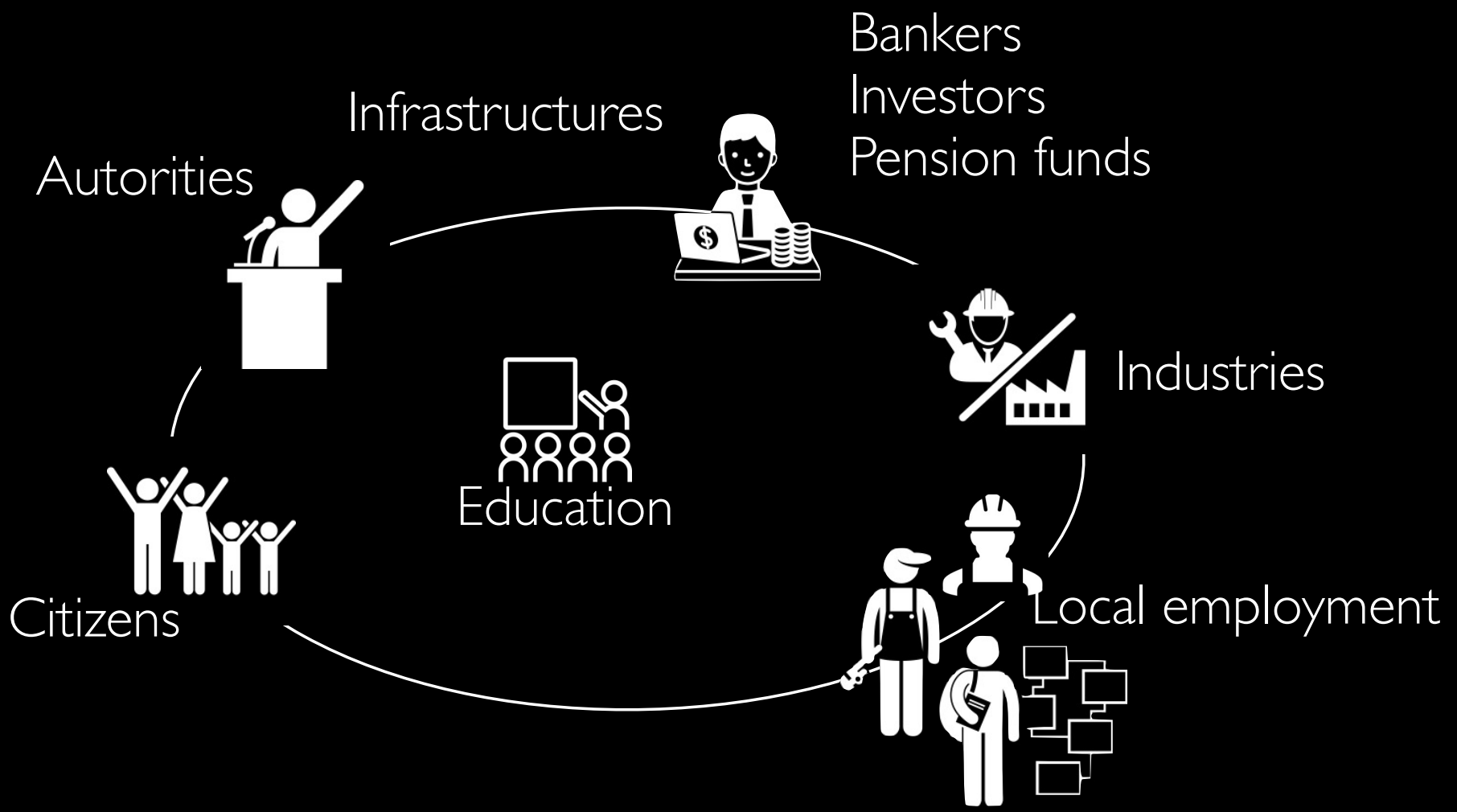


INVESTMENT 330-440 CHF/M^2

10% of the real estate value

50% private
50% Infrastructure and opération

A SOLUTION BASED ONLY ON LOCAL RESOURCES



THE ENERGY SYSTEM

47%

Solar PV

Bio

Waste

Export

Waste water

Environment

?

36%

products

17%

2%

100 l gasoline/hab/year

Electricity

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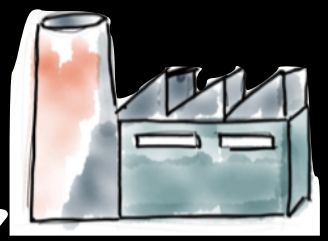
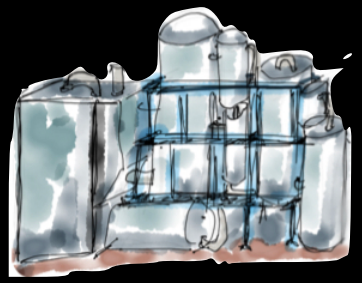
THE INDUSTRY

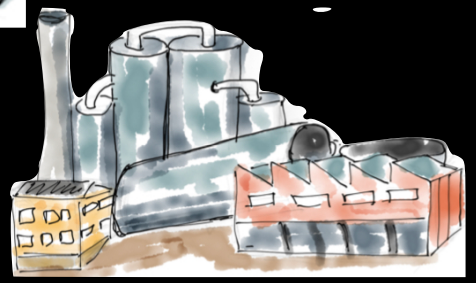
products **2%**

Industry **17%**

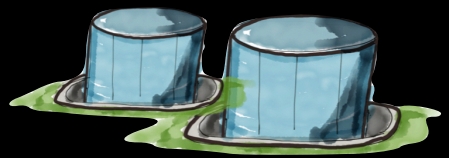


Oil

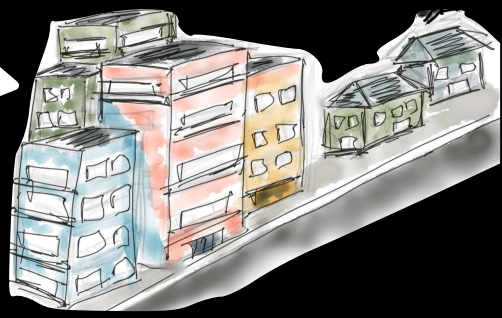




fuels



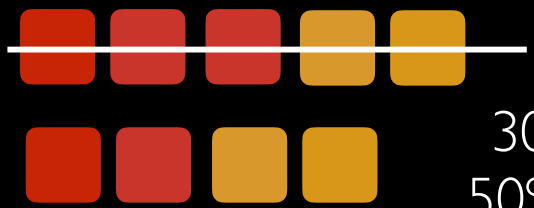
products



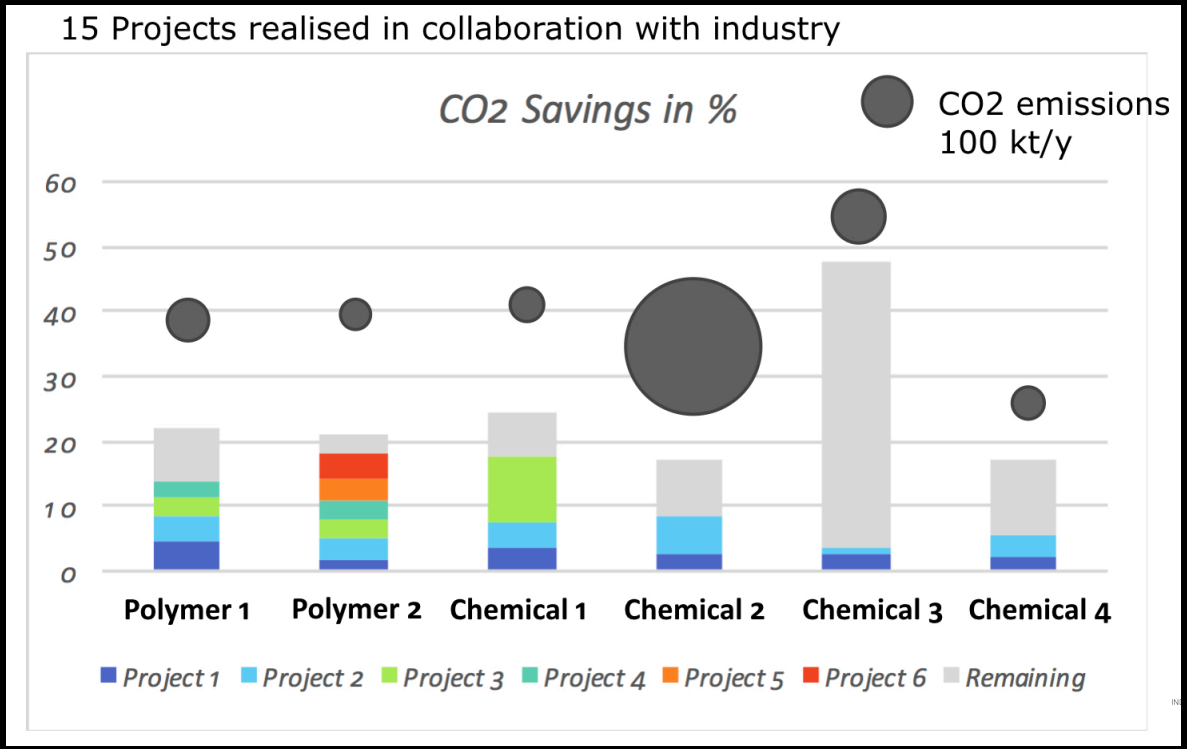
ENERGY EFFICIENCY

17%

Efficiency



30 % heat by Heat recovery
50% by heat pump integration



Energy audits
Process efficiency
Energy targets
Heat recovery
Heat pump integration

SCCER EFFICIENCY OF INDUSTRIAL PROCESSES

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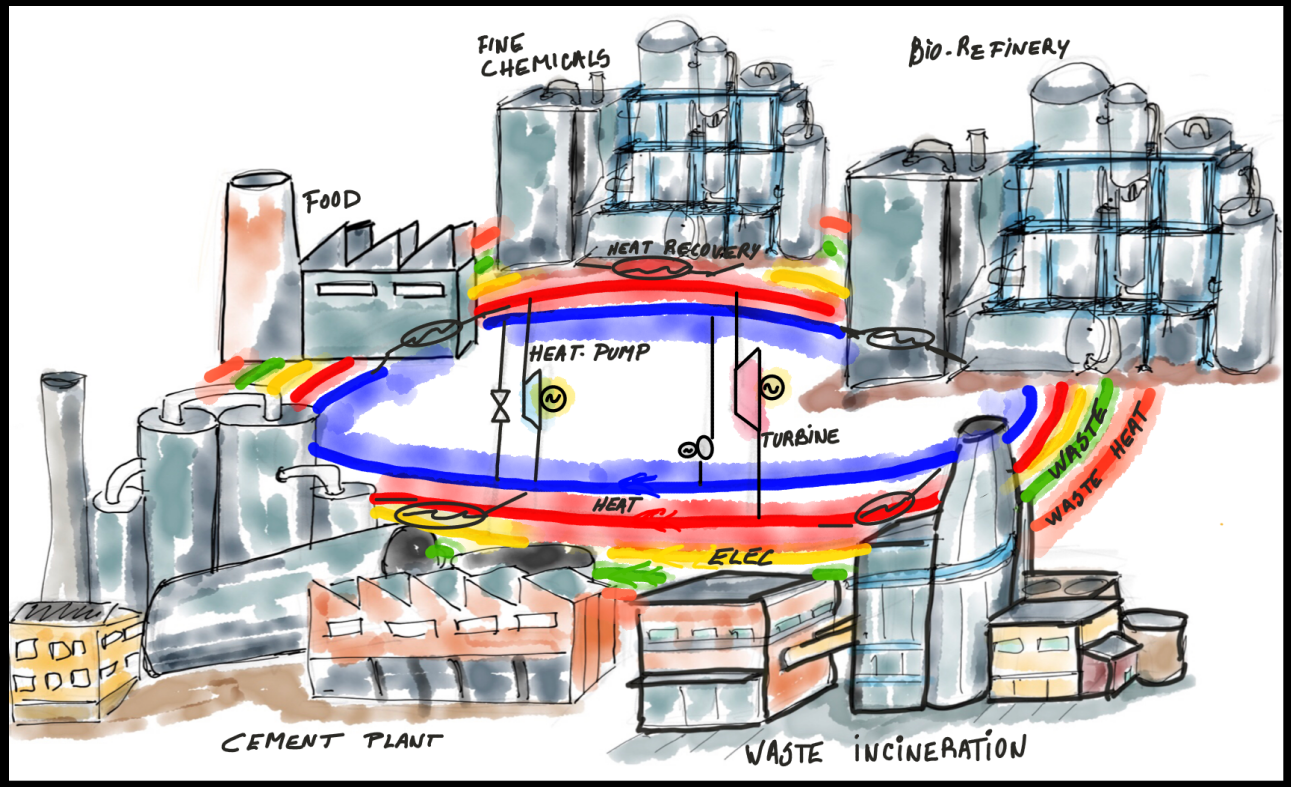
INDUSTRIAL SYMBIOSIS

products **2%**

17%

Heat and mass (waste) exchanges



- Heat recovery
- Heat pumping
- ORC and steam Rankine cycle
- Energy and water integration
- Waste management
- Resource efficiency
- Industrial Symbiosis
- Combined fuel and heat

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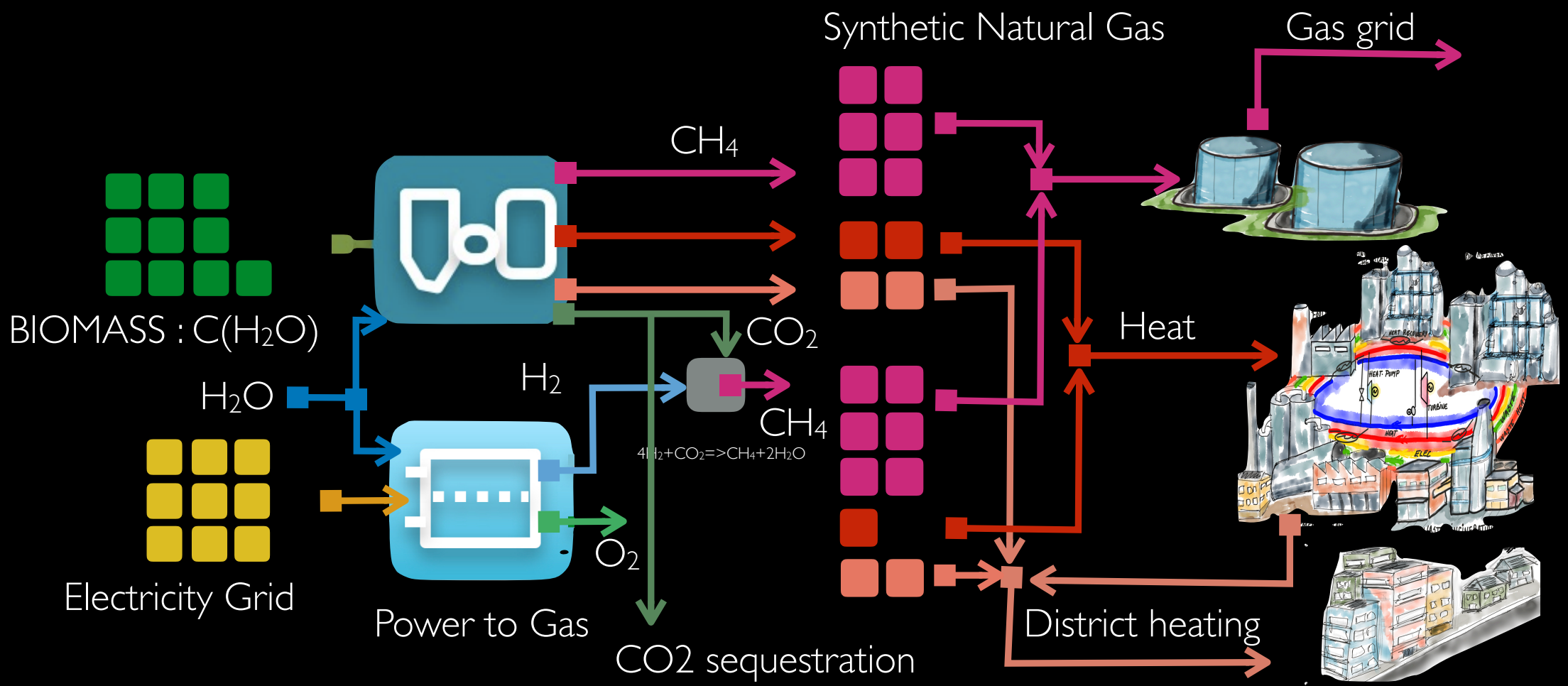
ON THE USE OF THE BIOMASS AS AN ENERGY SOURCE



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.

CIRCULAR ECONOMY : WASTE MANAGEMENT

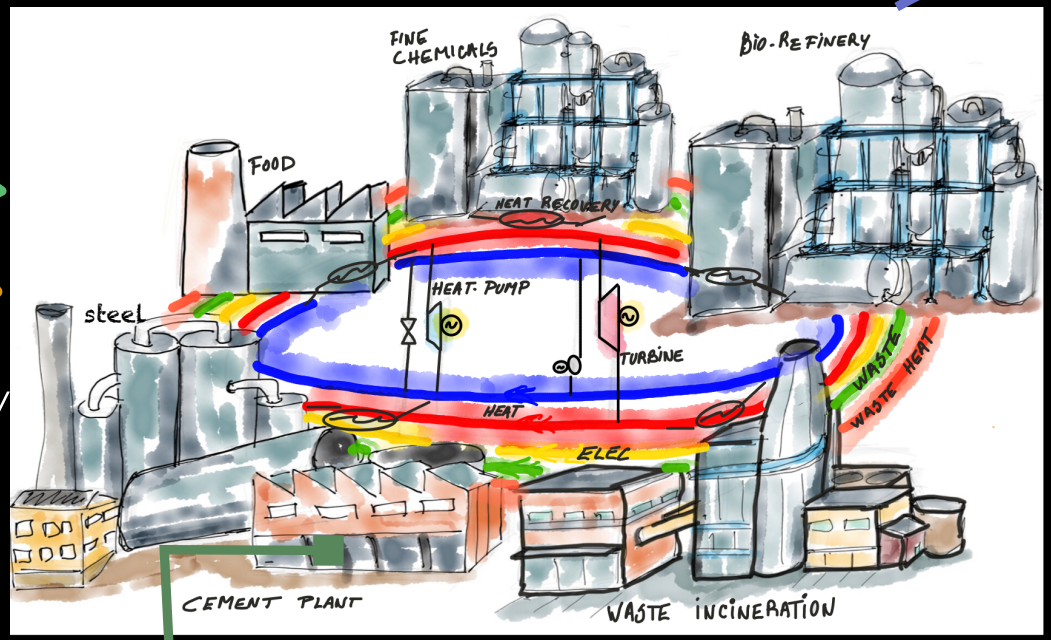
products **2%**

17%

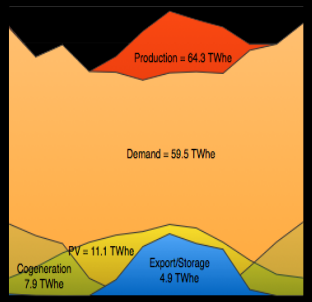
Biomass

Combined heat and fuel

Natural Gas



excess electricity



Products

Heat

Waste

CO_2

SATISFYING THE SWISS ENERGY NEEDS

products **2%**

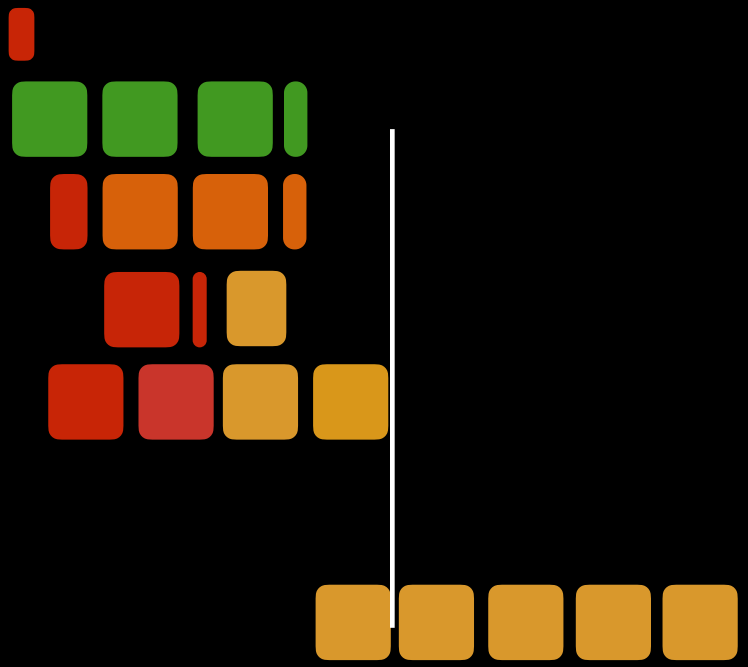
Biomass

Natural gas

Cogeneration

Industrial needs

Wind and hydro



100 l gasoline/hab/year

data : www.energyscope.ch

ELECTRIFYING MOBILITY

36%

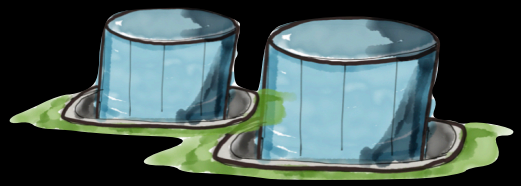
Efficiency

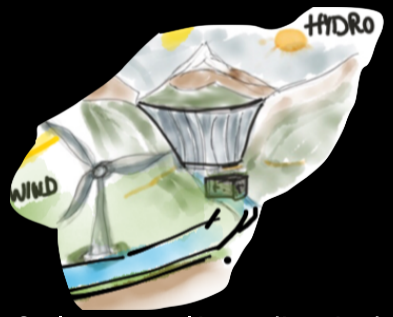
Electric vehicles

Hybrid and range extenders vehicles

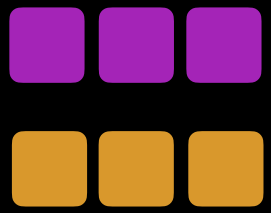
CO2 capturing in fuel powered vehicles

Public transport : electric/hybrid

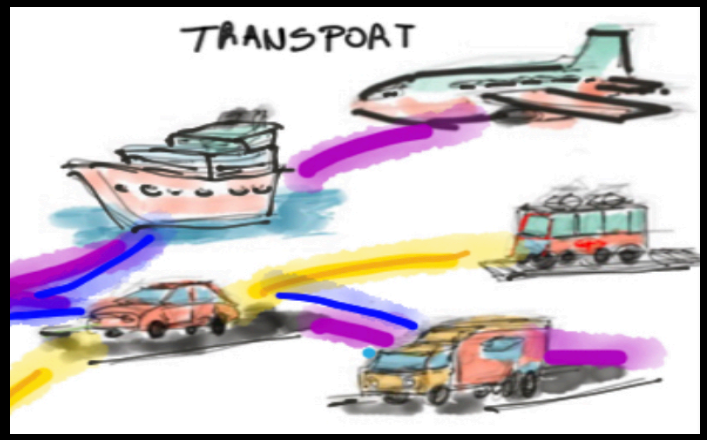




Bio-Fuel



Available electricity

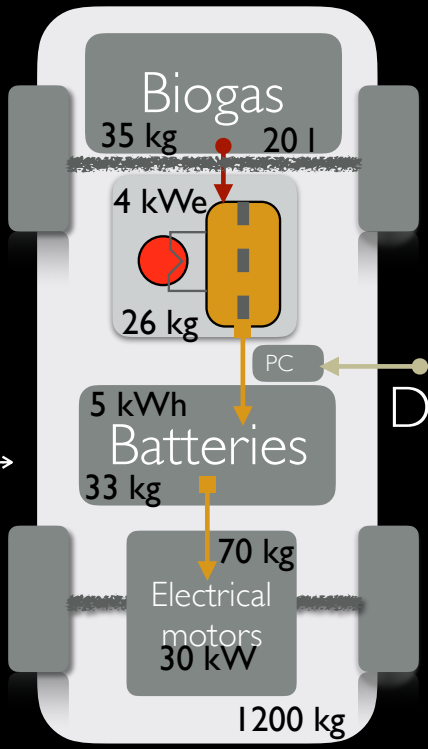


100 l gasoline/hab/year

RANGE EXTANDERS VEHICULES

Driving mode

Autonomy : 950 km
Cons : 1.1l/100 km

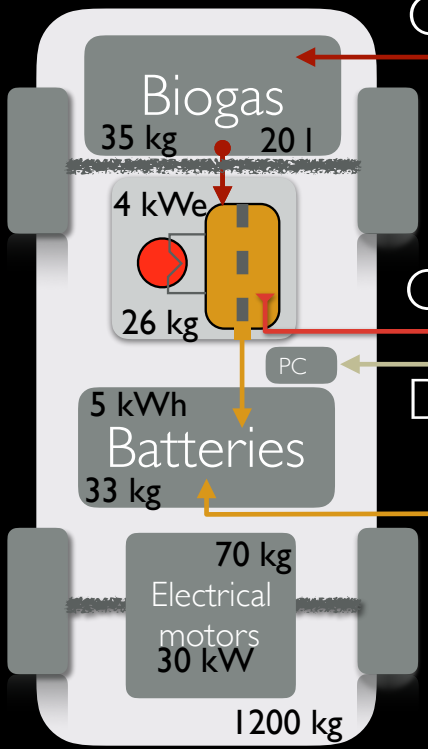


Data Grid

SOFC-GT
Hybrid car

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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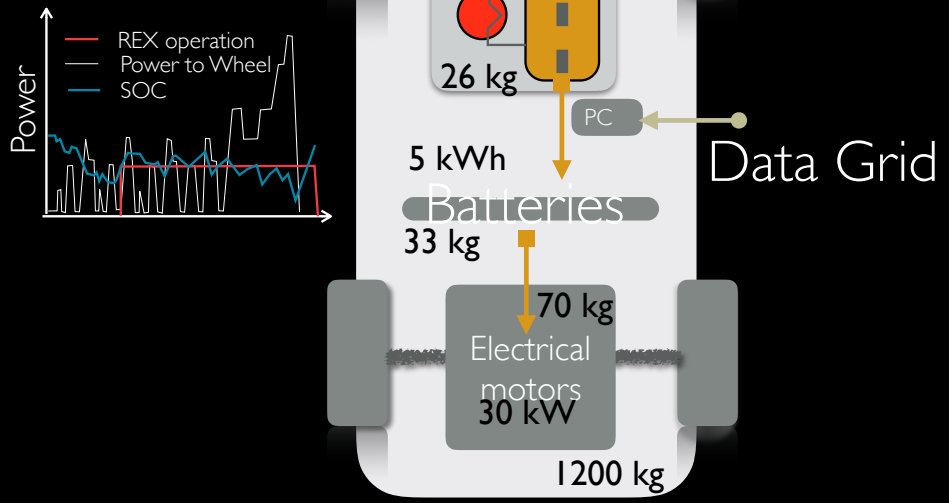
SMART CARS

12 m2 PV/car

Autonomy : 950 km
Cons : 1.1l/100 km

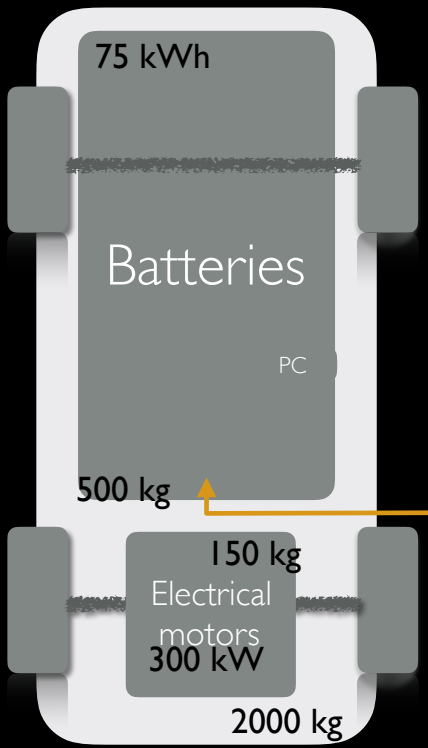


SOFC-GT
Hybrid car

Data Grid

24m2 PV/car

Power plant : 3.5 kWe (eff. >70%)
Battery :75 kWh



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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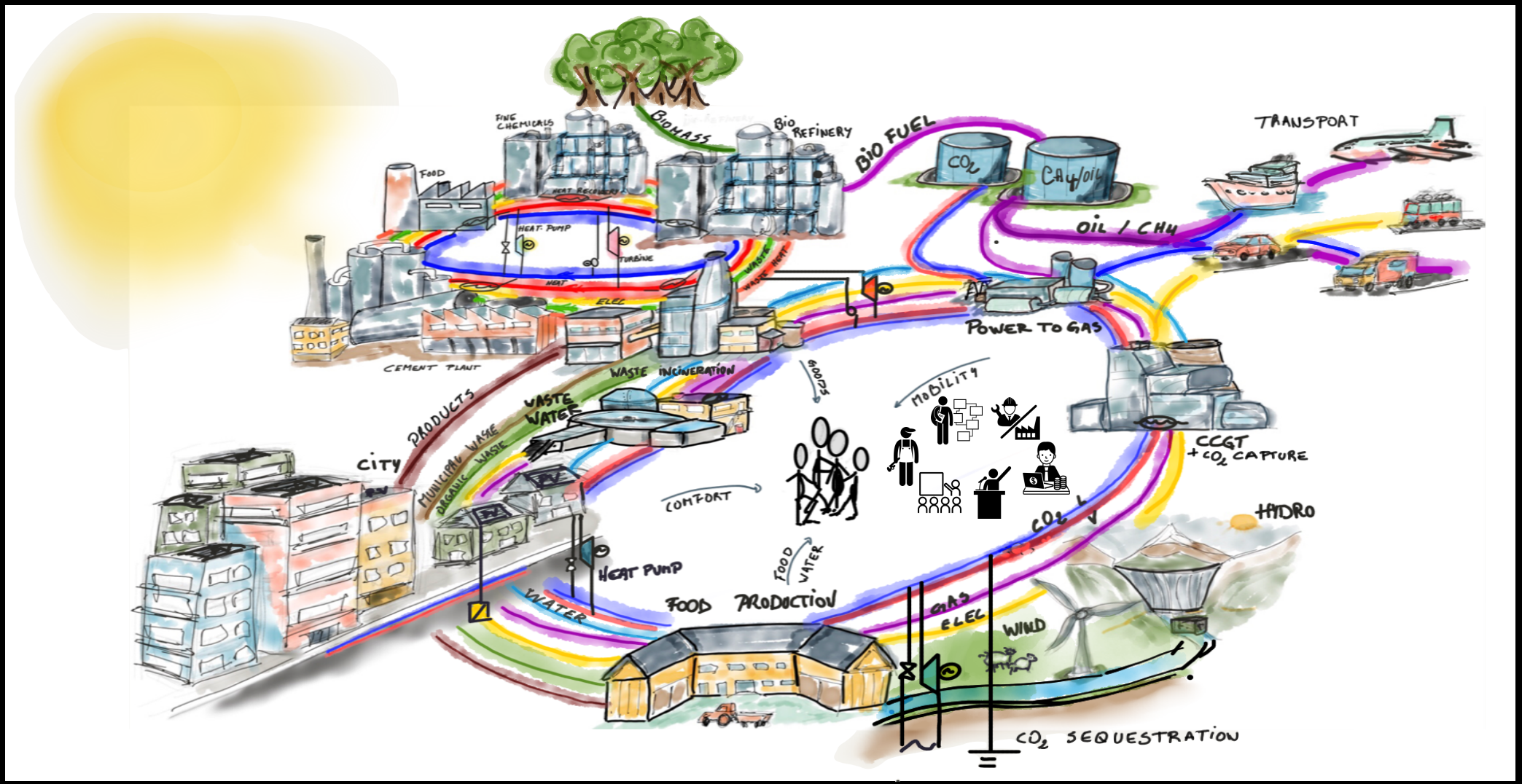
ENERGY SYSTEM INTEGRATION



100 % RENEWABLE COUNTRY

47%

PV

Bio

Waste

Waste water

Environment

Export

36%

Biomass

Wind and Hydro

products

17%

2%

Storage capacity

100 l gasoline/hab/year

Electricity

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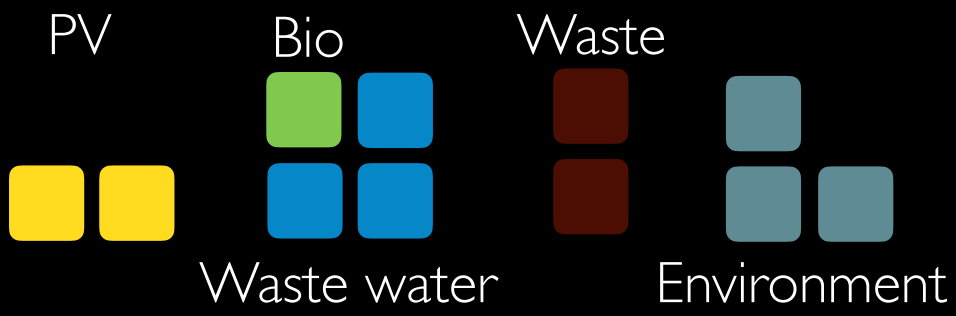
100 % RENEWABLE AND INDEPENDENT

47%

36%

products **17%**
2%



100 l gasoline/hab/year

Electricity

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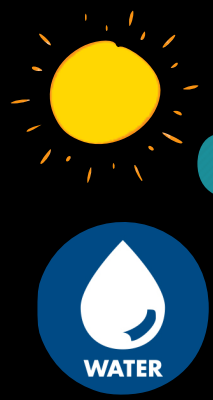
CARBON SINK ?



BIOMASS : $C(H_2O)$

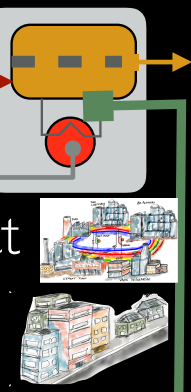
H_2O

CH_4

CH4

HT Heat

LT-Heat



78.4 MJ/kgC

54.4 MJ/kgC

CO_2

4.4 MJ/kgC

Serpentine $Mg_3(OH)_4(Si_2O_5)$

$Mg_3Si_2O_5(OH)_4 + 3\ CO_2 \Rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O$

Mineral Carbon

$MgCO_3 + SiO_2$

-3.3 $kgCO_2$/day/cap

0 MJ/kgC

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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 education system and the infrastructure
- **(Finance)** : to ethically use (our) money for the right goals

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE | VALAIS WALLIS

Thank **You** !

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