

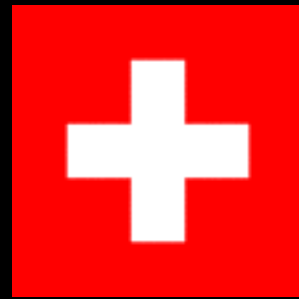
TOWARDS ZERO EMISSIONS : A SYSTEMS ENGINEERING PERSPECTIVE

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Industrial Process and Energy System Engineering, EPFL, Switzerland

Ecole Polytechnique Fédérale de Lausanne - Campus Energypolis EPFL Valais Wallis CH- SION

THE SWISS ENERGY SYSTEM



80
CHF/month/cap

15
kg CO2/day/cap



47%



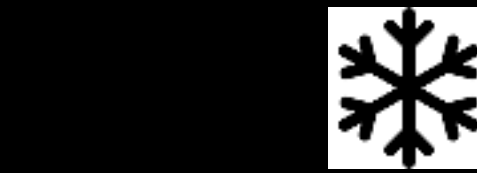
36%



products

17%

2%



80-140
CHF/month/cap

24
kg CO2/day/cap

 Import



Mix
50-90
gCO2/kWhe

 Export



Subsidies from our children

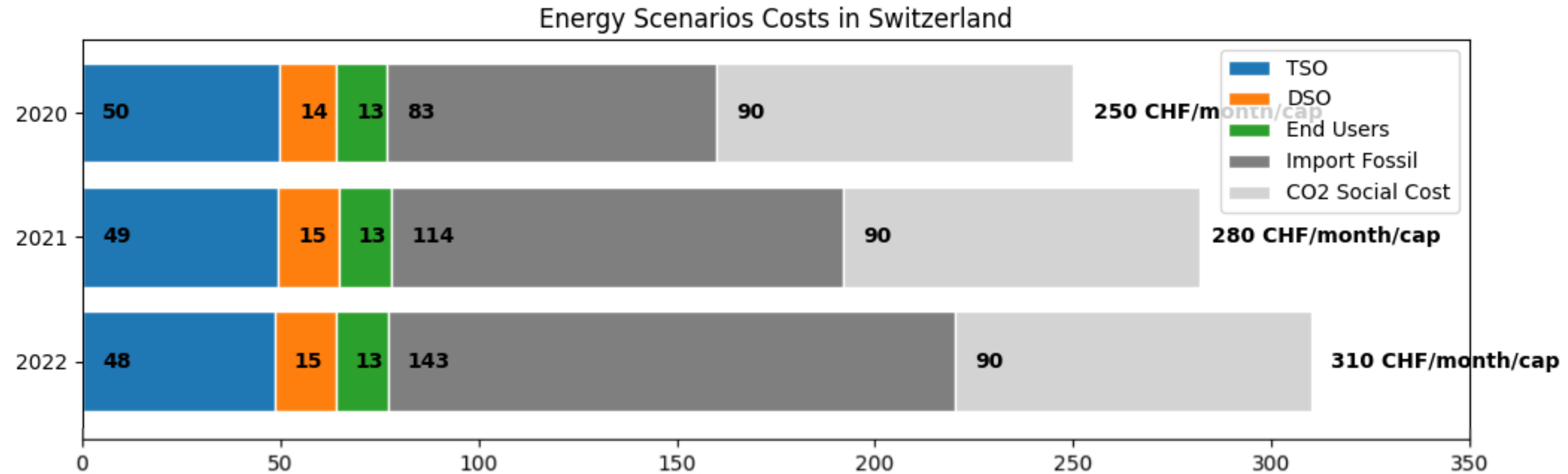
250
CHF/month/cap

Fossil fuel

1 unit = our food energy needs
100 l gasoline/year/hab

Electricity

Le système énergétique de la Suisse



Investment : 80 CHF/month/cap: infrastructure and conversion

Import : 80 - 140 CHF/month/cap: Energy imports, variations by V. Poutine

Russia receives 30 CHF/month/cap

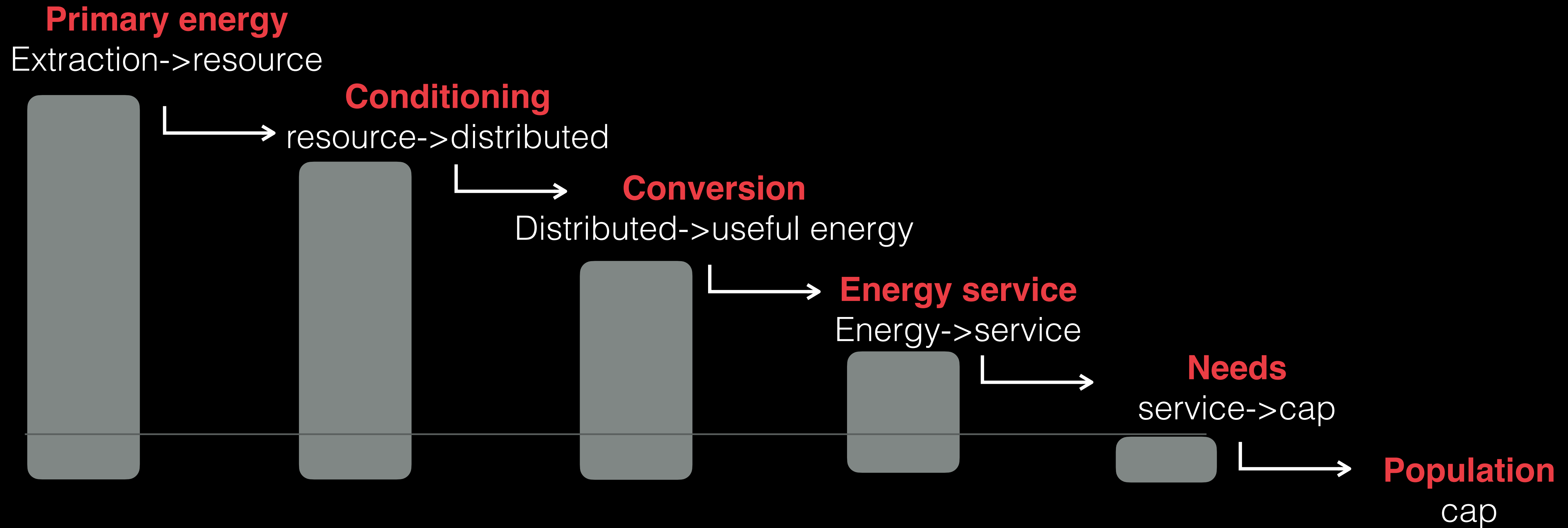
Social debt : 90 CHF/month/cap

-> Our children will have to pay to reparate

*10 CHF/mois/cap = 1 Milliard CHF/an

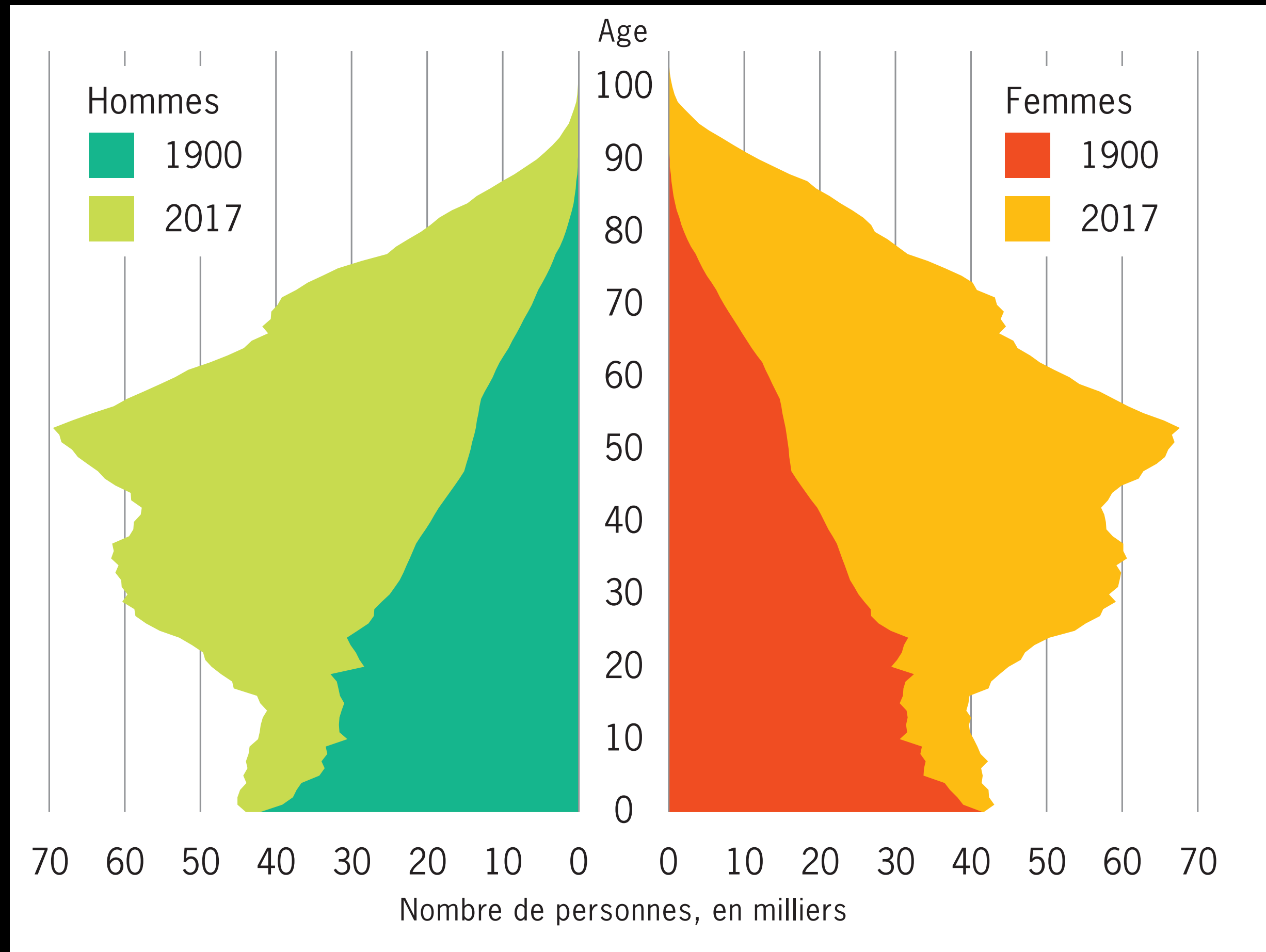
THE CHALLENGE OF THE COMPLETE CONVERSION CHAIN

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

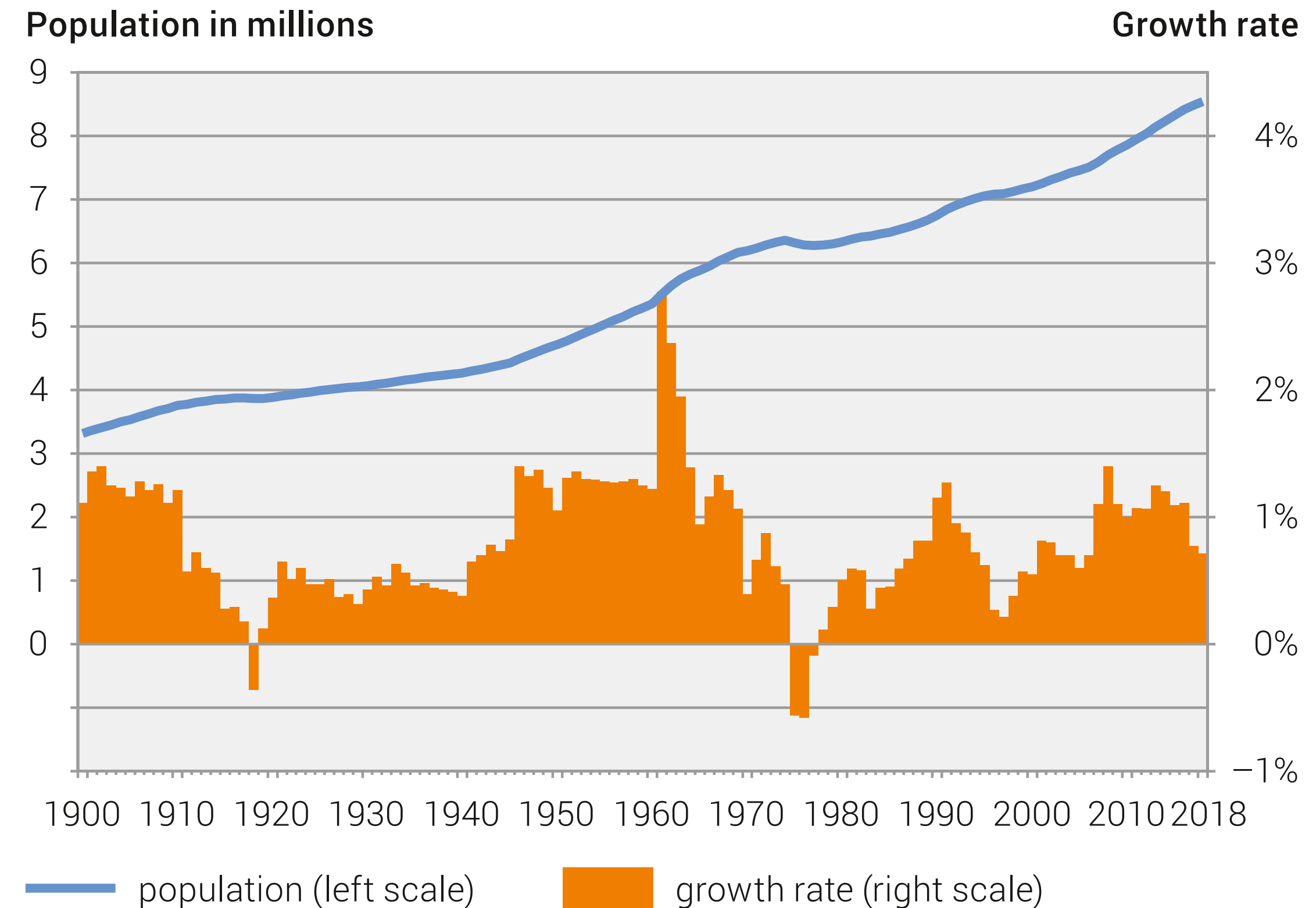


EVOLUTION OF POPULATION

Structure par âge de la population



Population growth and size

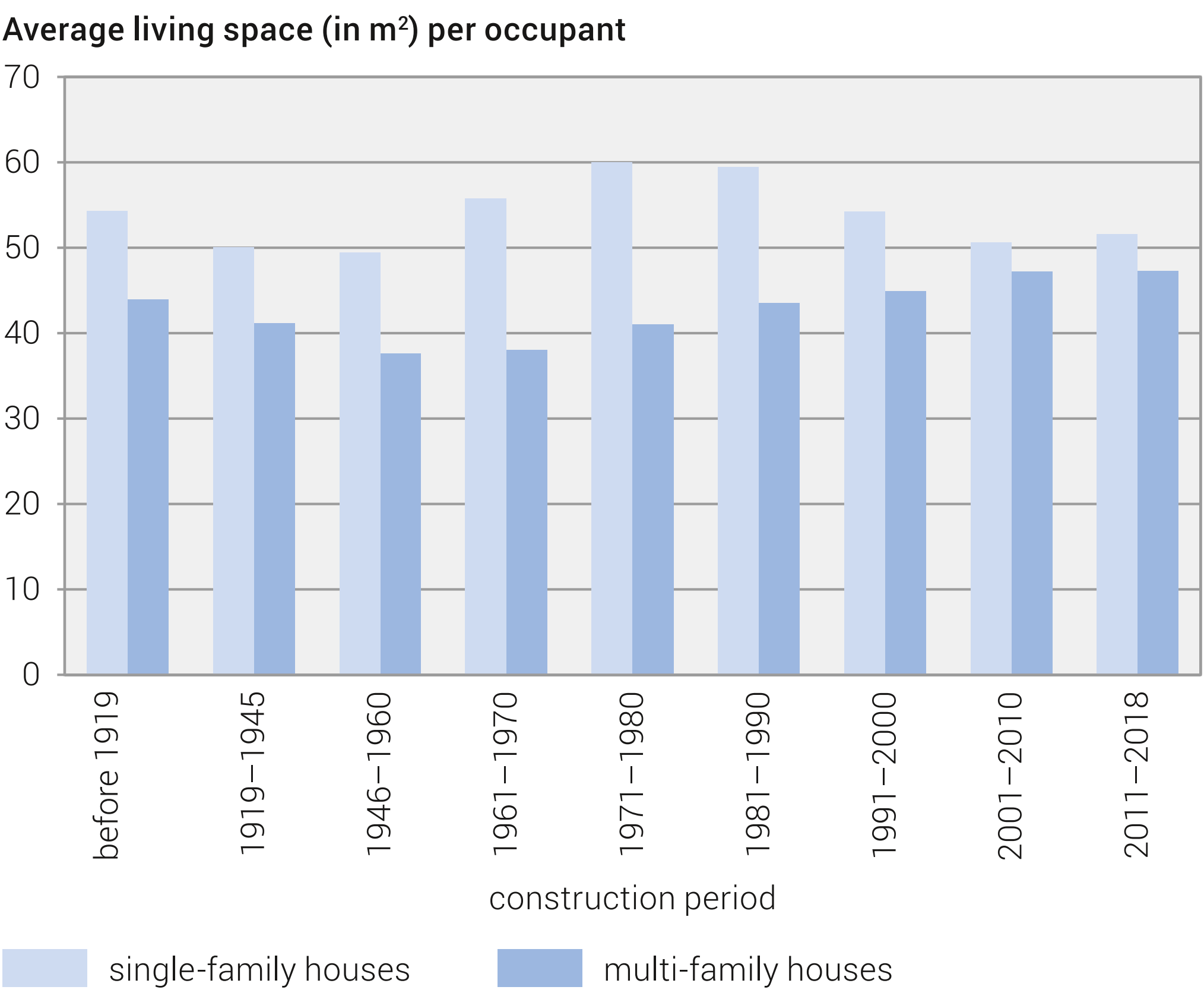


8'500'000 hab. (life time exp : 83 years)

Growth rate : 1.0 %/year

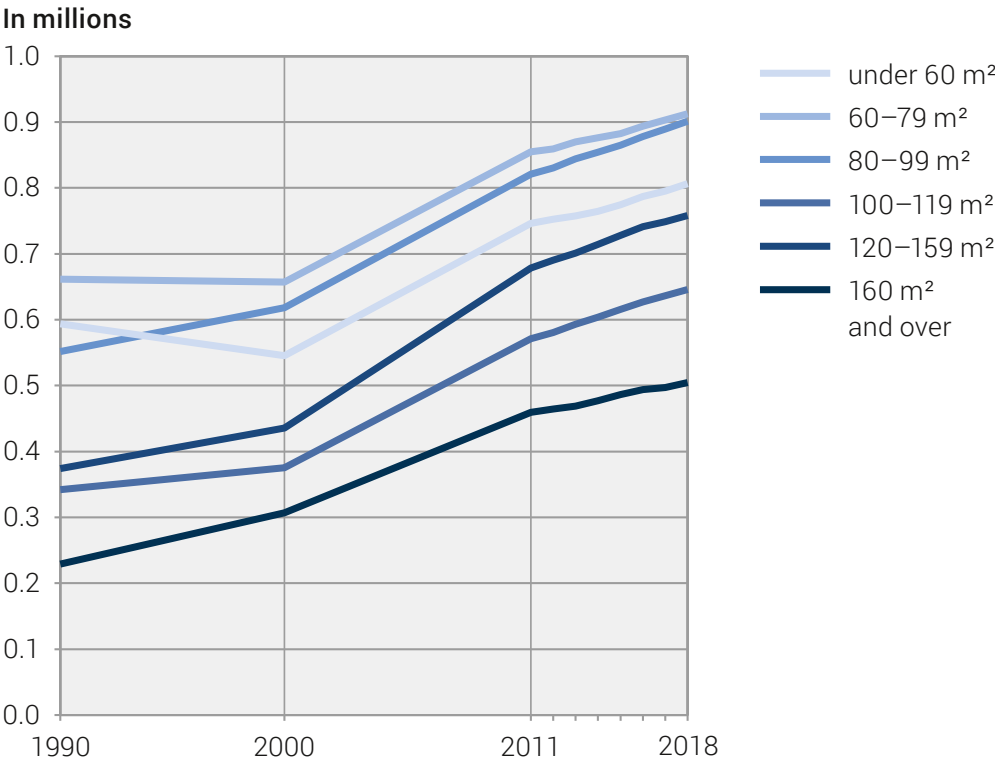
EVOLUTION OF THE NEEDS

Average living space per occupant by building category and period of construction, 2018



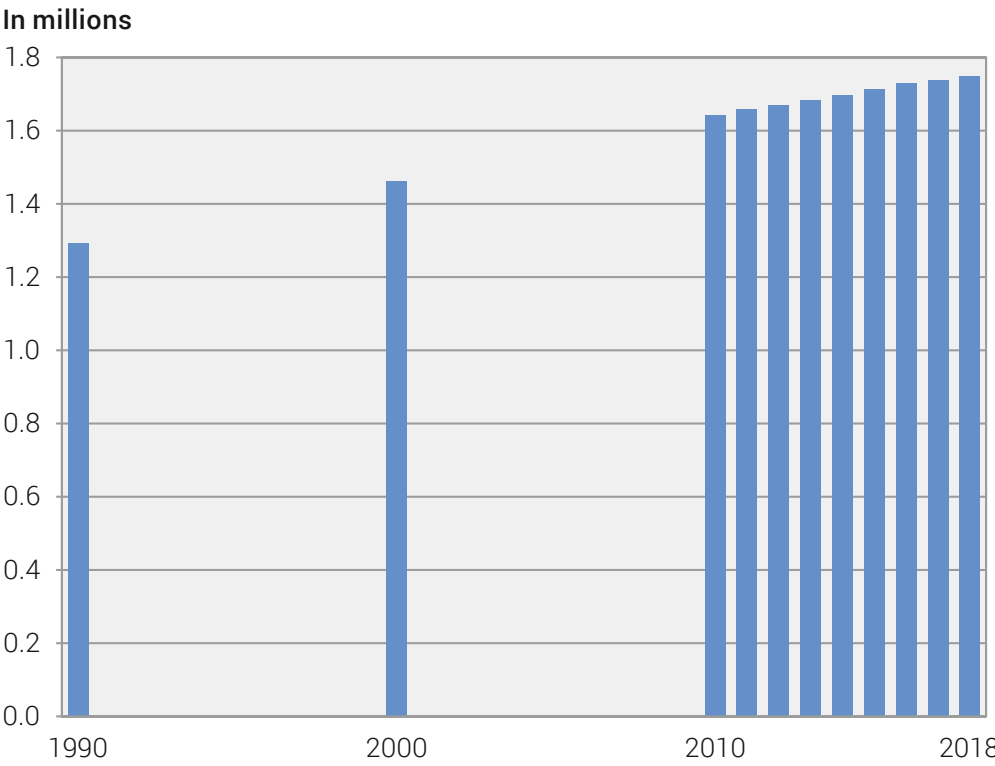
Source: FSO – Buildings and dwellings statistics © FSO 2019

Dwellings by size group



Sources: FSO – Federal population censuses, Buildings and dwellings statistics © FSO 2019

Residential buildings in Switzerland

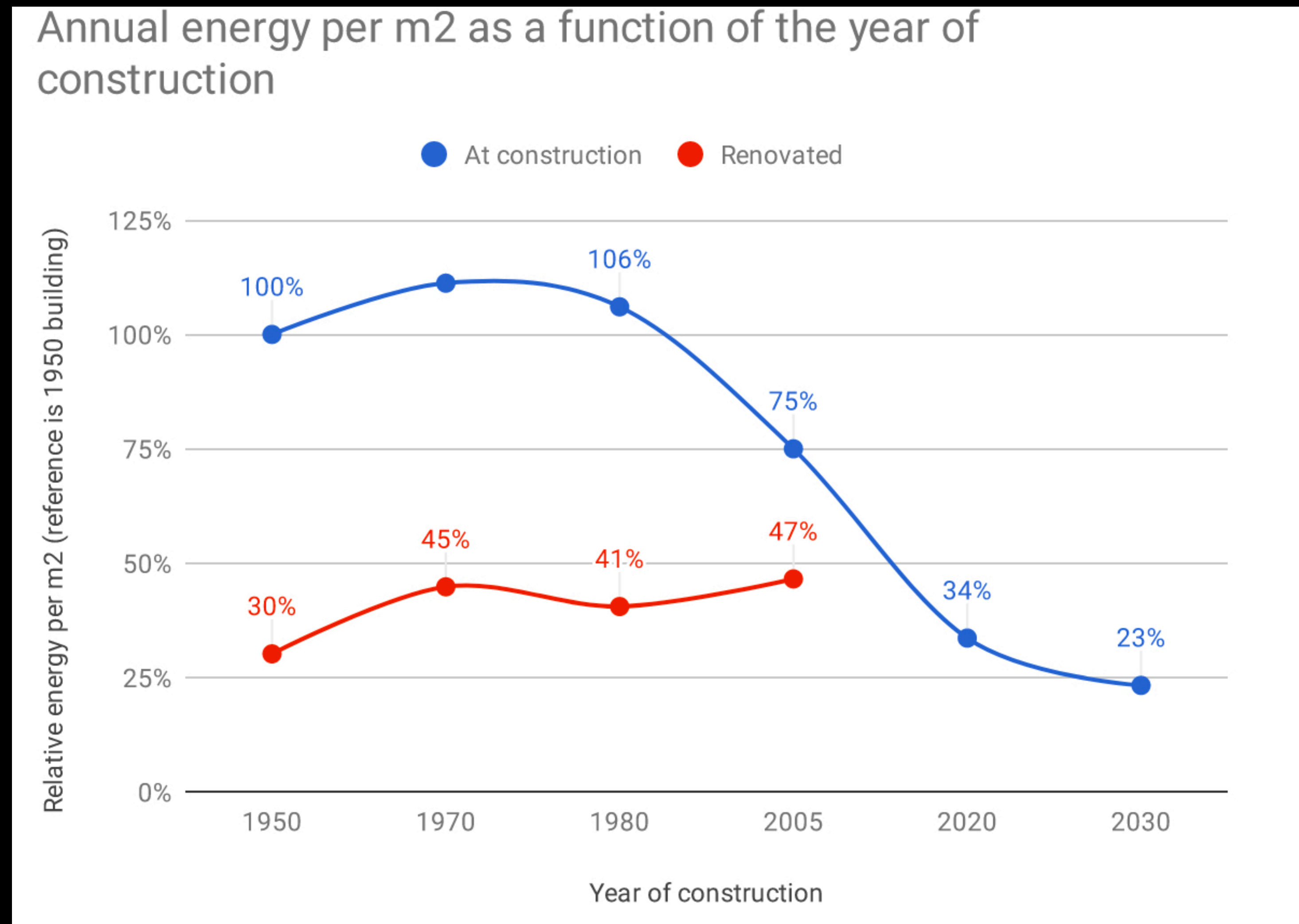


Sources: FSO – Federal population censuses, Buildings and dwellings statistics © FSO 2019

50-70 m²/hab

1,748,477
Buildings

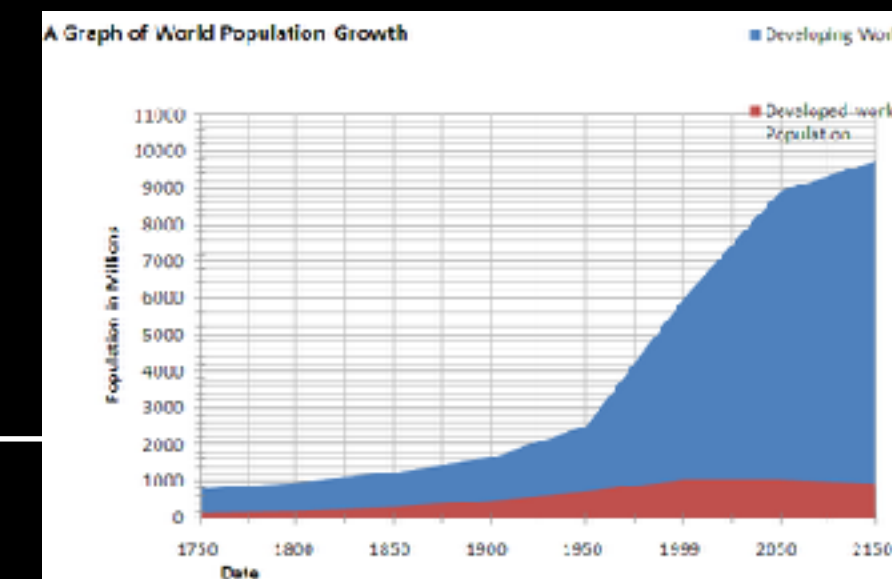
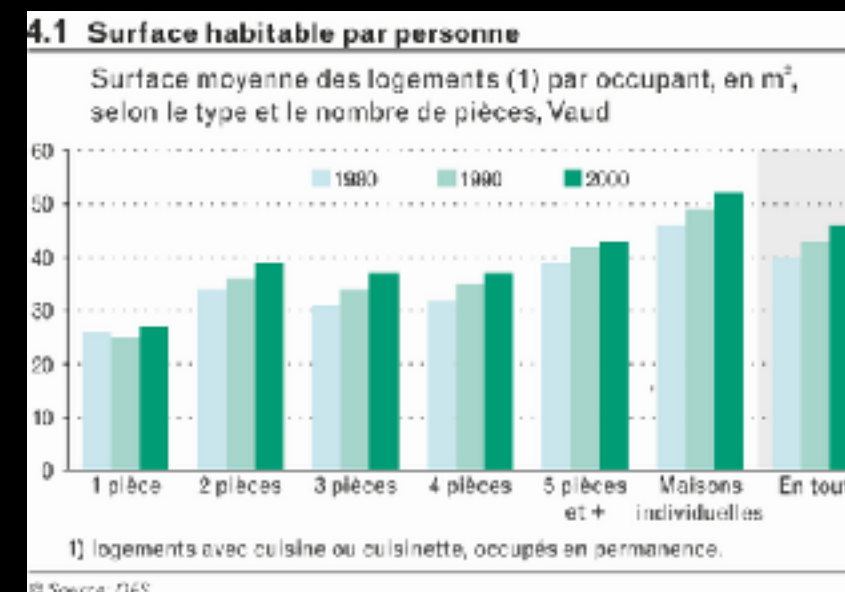
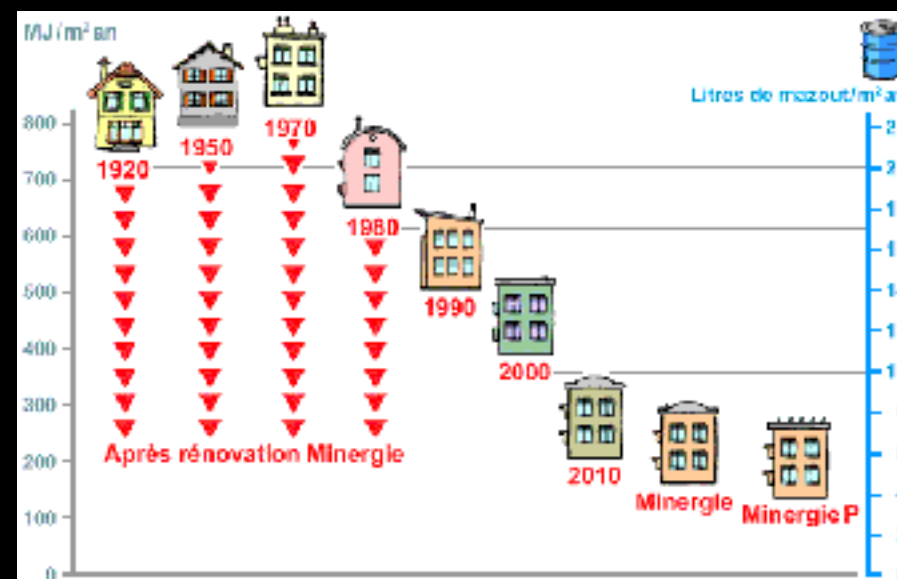
ENERGY EFFICIENCY OF HEATING HOUSES



Reference : 750 MJ/m²/an (1950)

THE NEEDS

$$\begin{array}{l} \text{Soberty} \\ \text{Energy} \rightarrow \text{m}^2 \text{ heated} \end{array} \times \begin{array}{l} \text{Comfort} \\ \text{m}^2 \rightarrow \text{hab} \end{array} \times \begin{array}{l} \text{Population} \\ \text{hab} \end{array} = \begin{array}{l} \text{Service} \\ \text{service/hab} \end{array}$$



Renovation

New buildinds

Population

2020

-

8.6 M hab

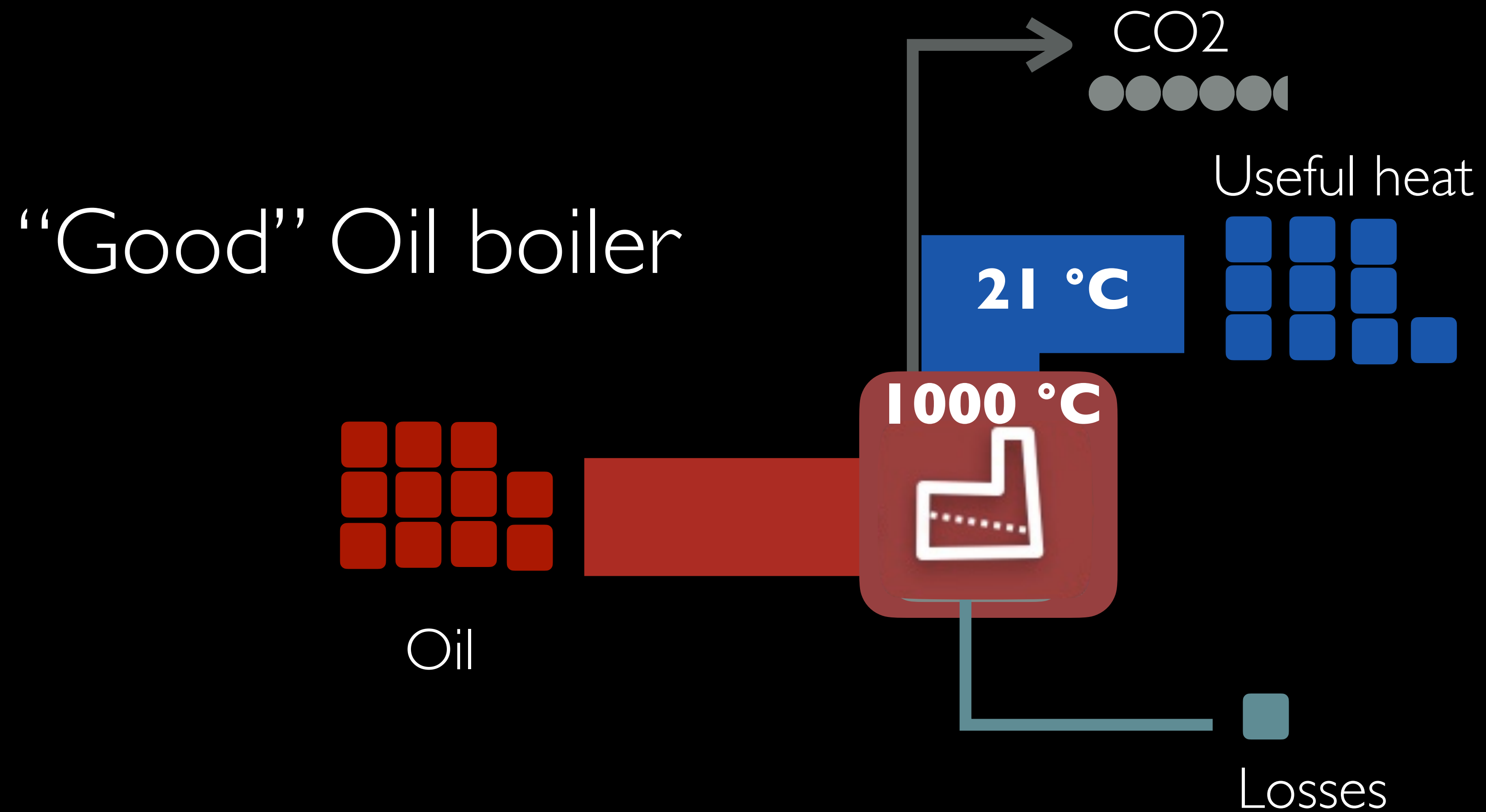
2050

30 %

+56 %

9.9 M hab

HOW DO WE SATISFY THE ENERGY NEEDS IN A BUILDING ?



HEATING BUILDING IS 50% OF COUNTRY ENERGY CONSUMPTION

120-190

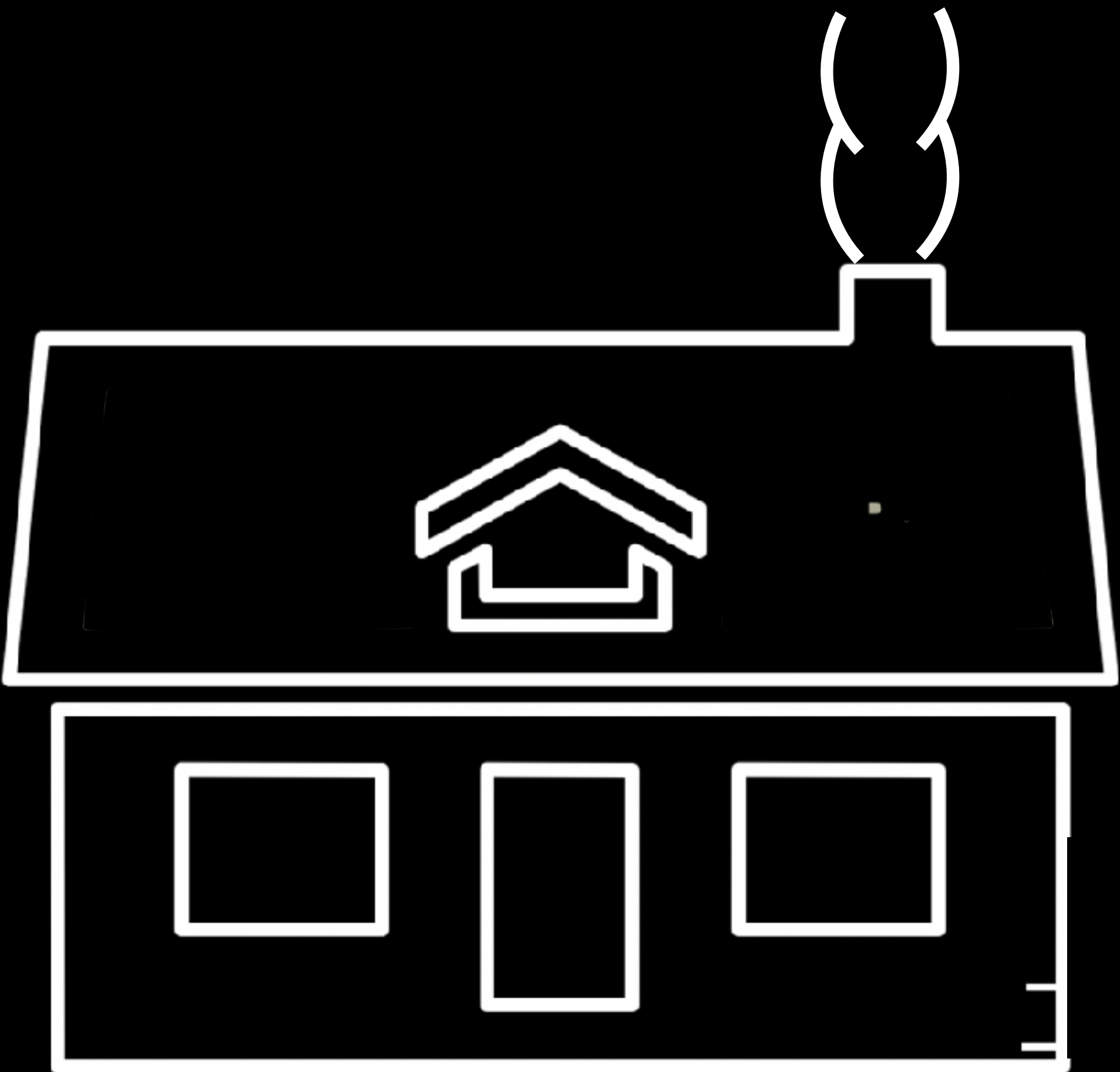
CHF/month/100 m²

Energy (Oil)

110-180 CHF/month/100 m²
in which 85-155 CHF/month/100 m²
import

Boiler

10 CHF/month/100 m²



3.78

tons **CO₂**/year/100 m²

63

CHF_{children}/month/100 m²



(1830) CARNOT : THE MAGIC FORMULA



Electricity

your sobriety

$$\dot{E}_{work} = \dot{Q}_{heating} \cdot \left(1 - \frac{T_{source}}{T_{heating}}\right)$$

Nicolas Léonard Sadi CARNOT (F)

1796 - 1832

Fraction of heat from the environment

(1830) CARNOT : THE MAGIC FORMULA APPLIED

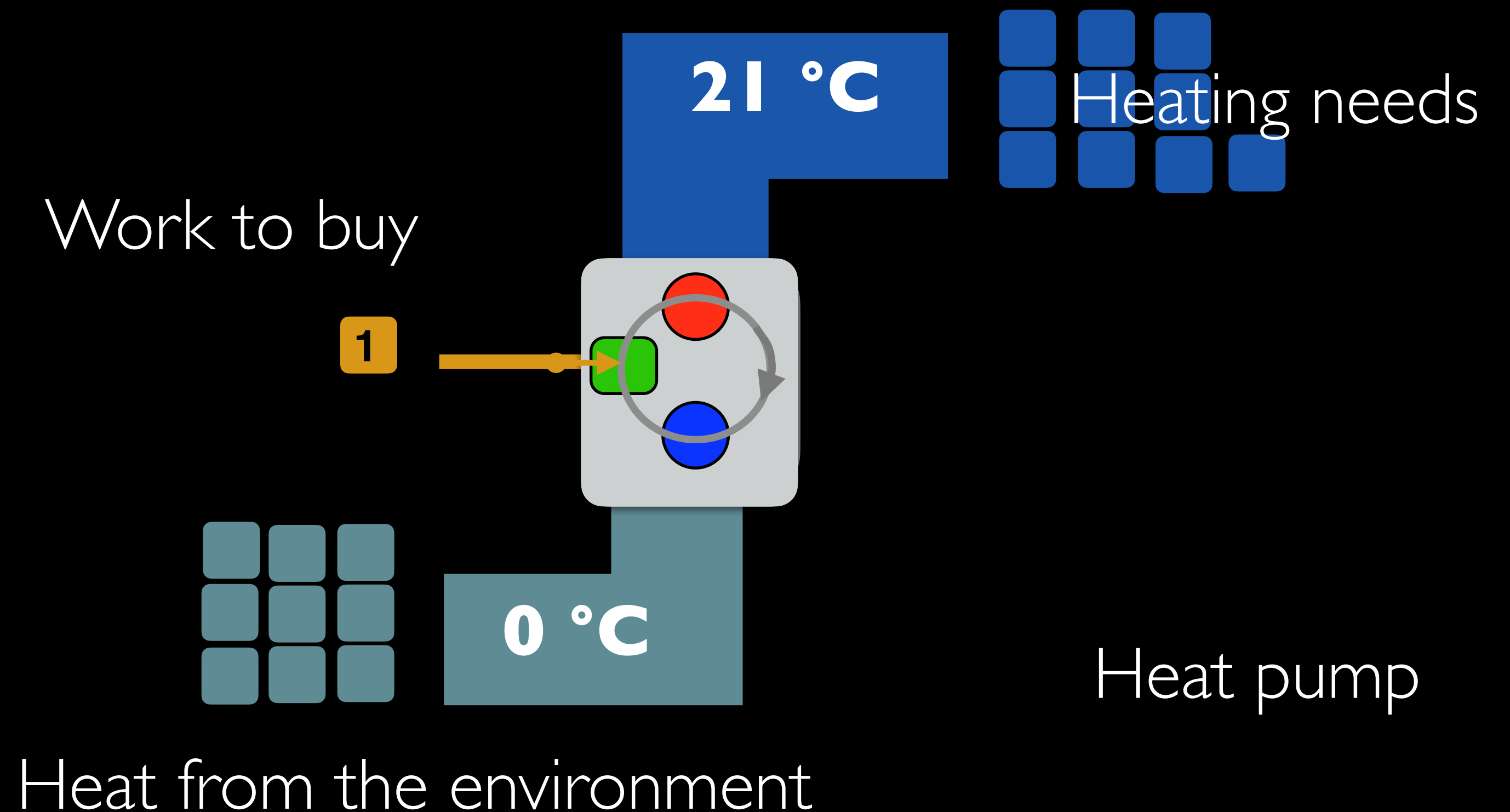
$$\dot{E} = \dot{Q}_{Heating} \cdot \left(1 - \frac{T_{source}}{T_{Heating}}\right)$$

For 10 units of heat, 9 come from the environment and 1 as electricity

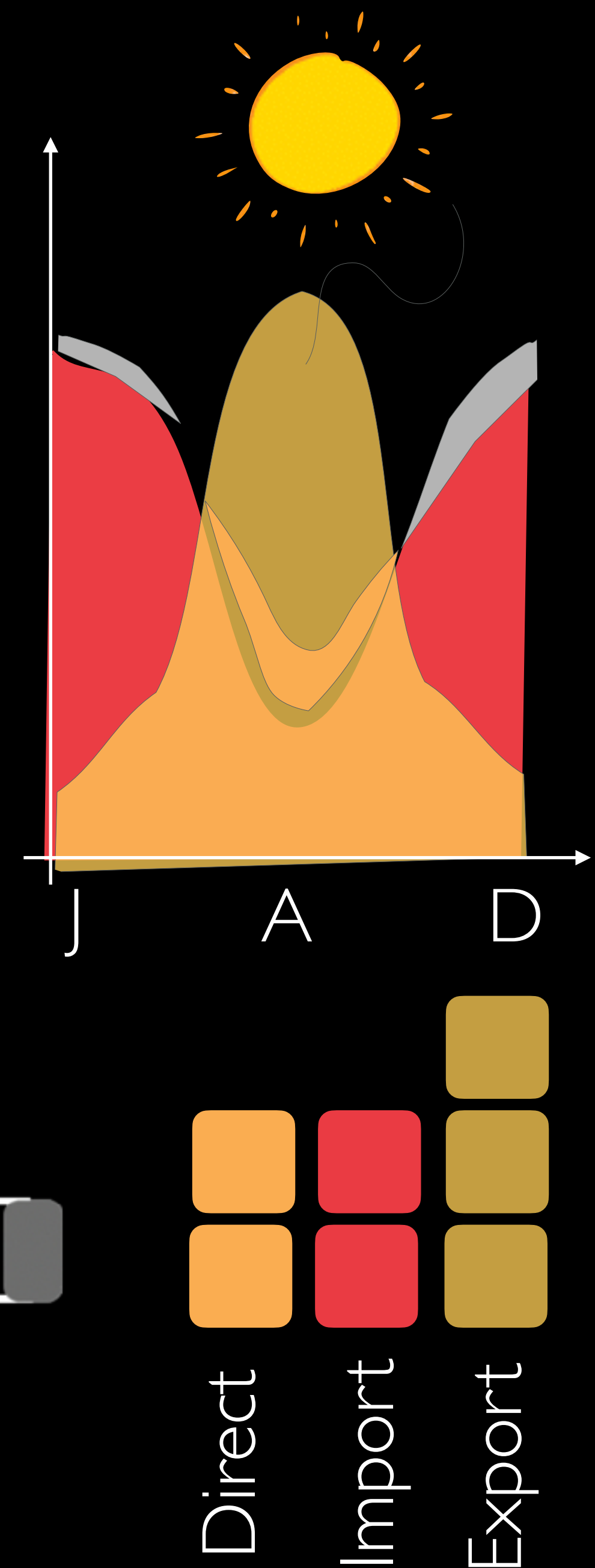
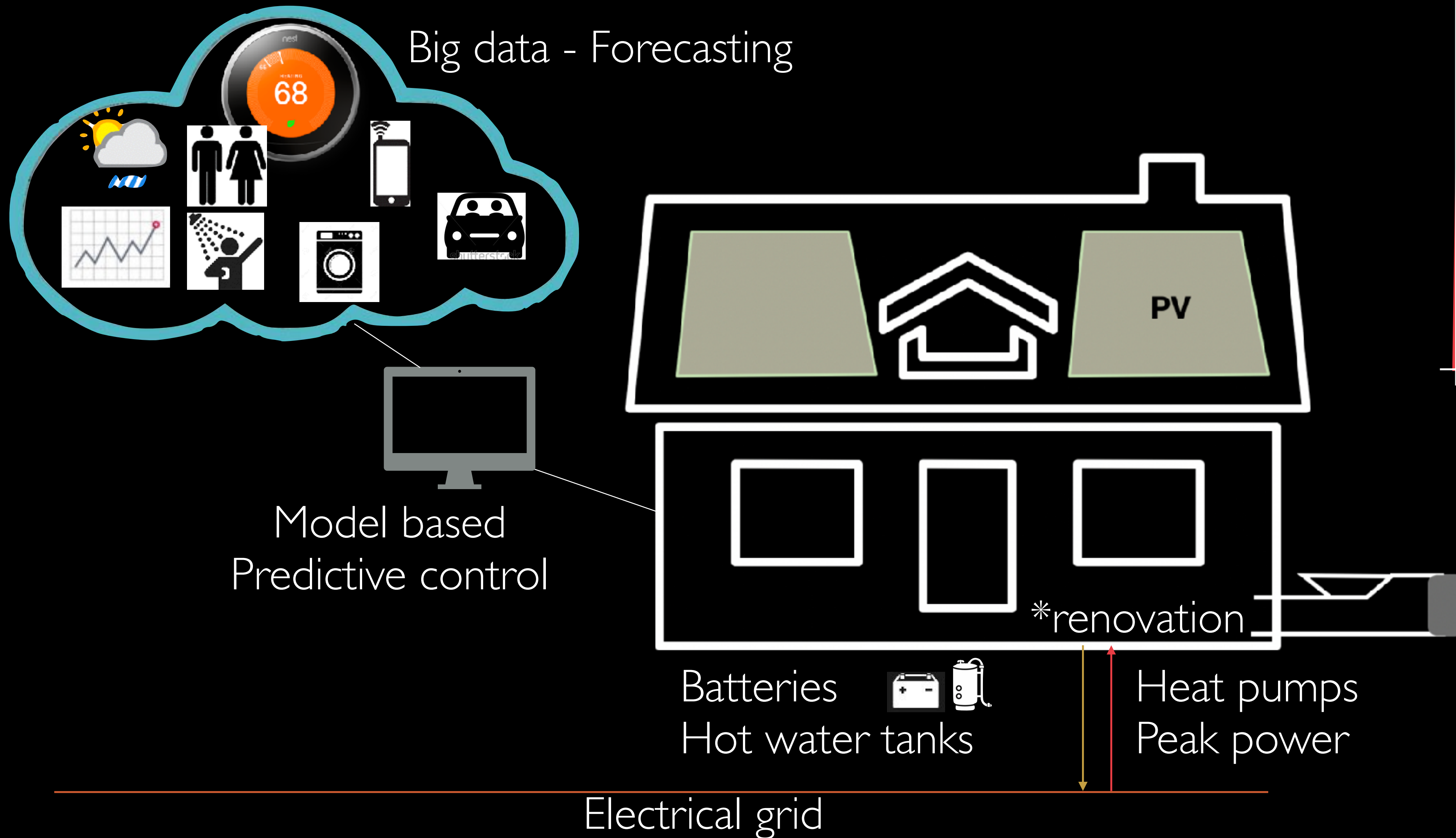


Nicolas Léonard Sadi CARNOT (F)

1796 - 1832

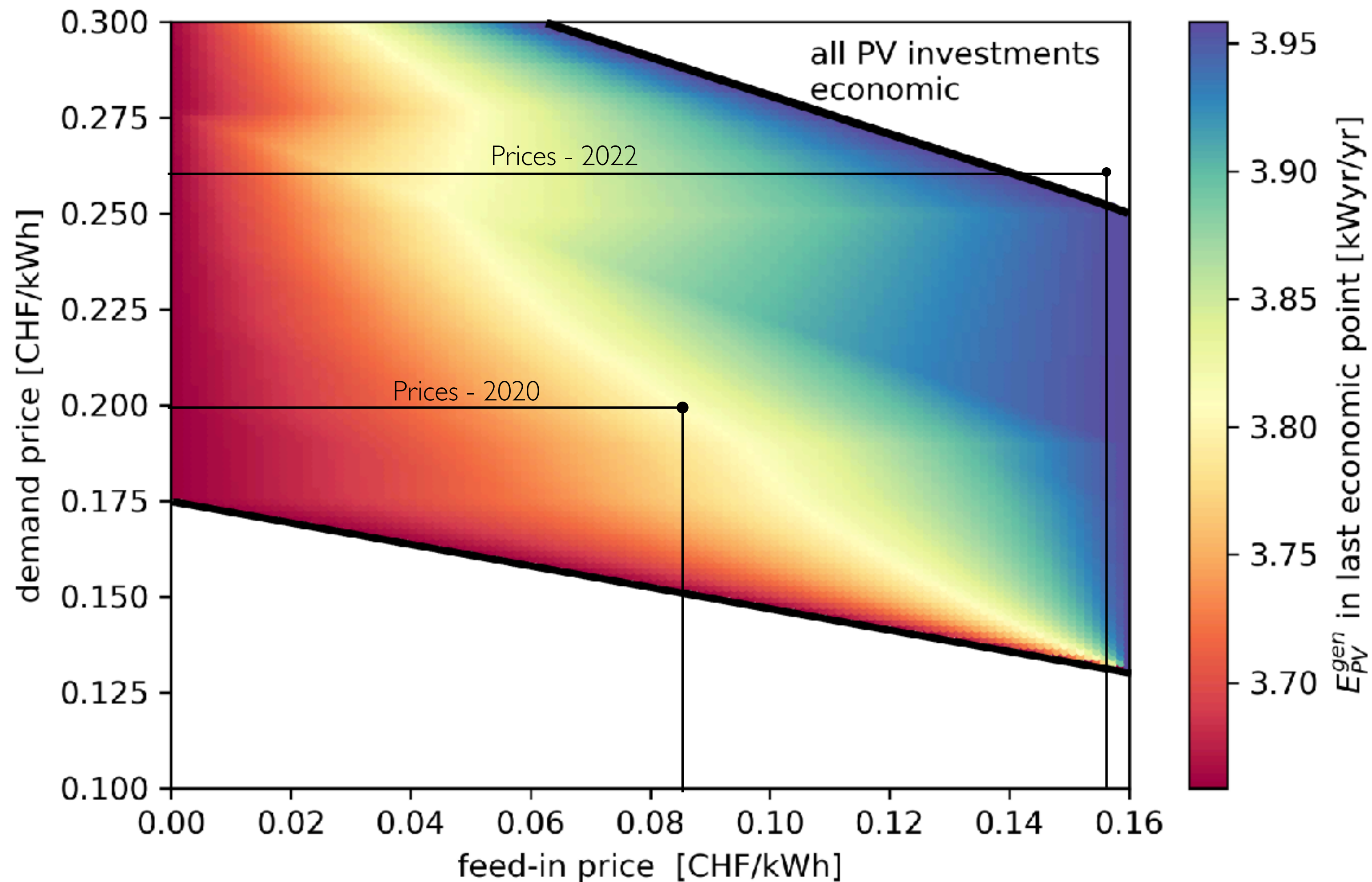


RENEWABLE ENERGY HUB



RENEWABLE ENERGY HUB

FEED-IN AND ELECTRICITY PRICES DECIDES THE INVESTMENT



Multi-owners dwelling (880m²) - 1980
22 residents - 6 electrical vehicles

Electricity:
feed-in 0.083 CHF/kWh
retail 0.20 CHF/kWh

Fuel
heating oil: 0.9 CHF/L, or 0.09 CHF/kWh
gasoline: 2 CHF/L, or 0.20 CHF/kWh

CO₂ emissions
electricity: 0.17 kgCO₂/kWh
heating oil: 0.28 kgCO₂/kWh
gasoline: 0.28 kgCO₂/kWh

YOU HAVE ALSO A FREE BATTERY FOR THE ENERGY SYSTEM

Model predictive strategic operation via $c_{b,r,t}^+$ signals

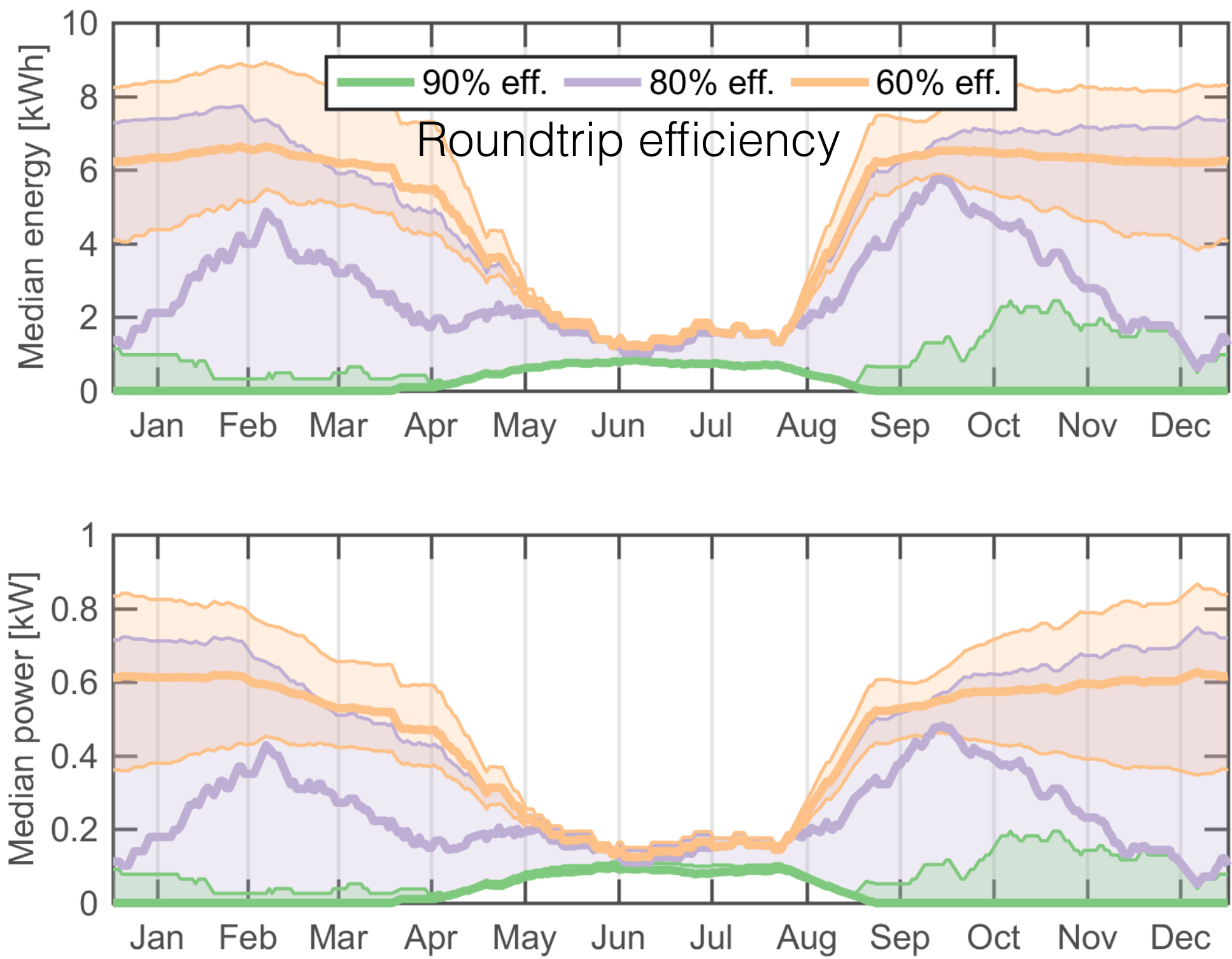
Offered stored energy and power by the system

Building performance (solution I)

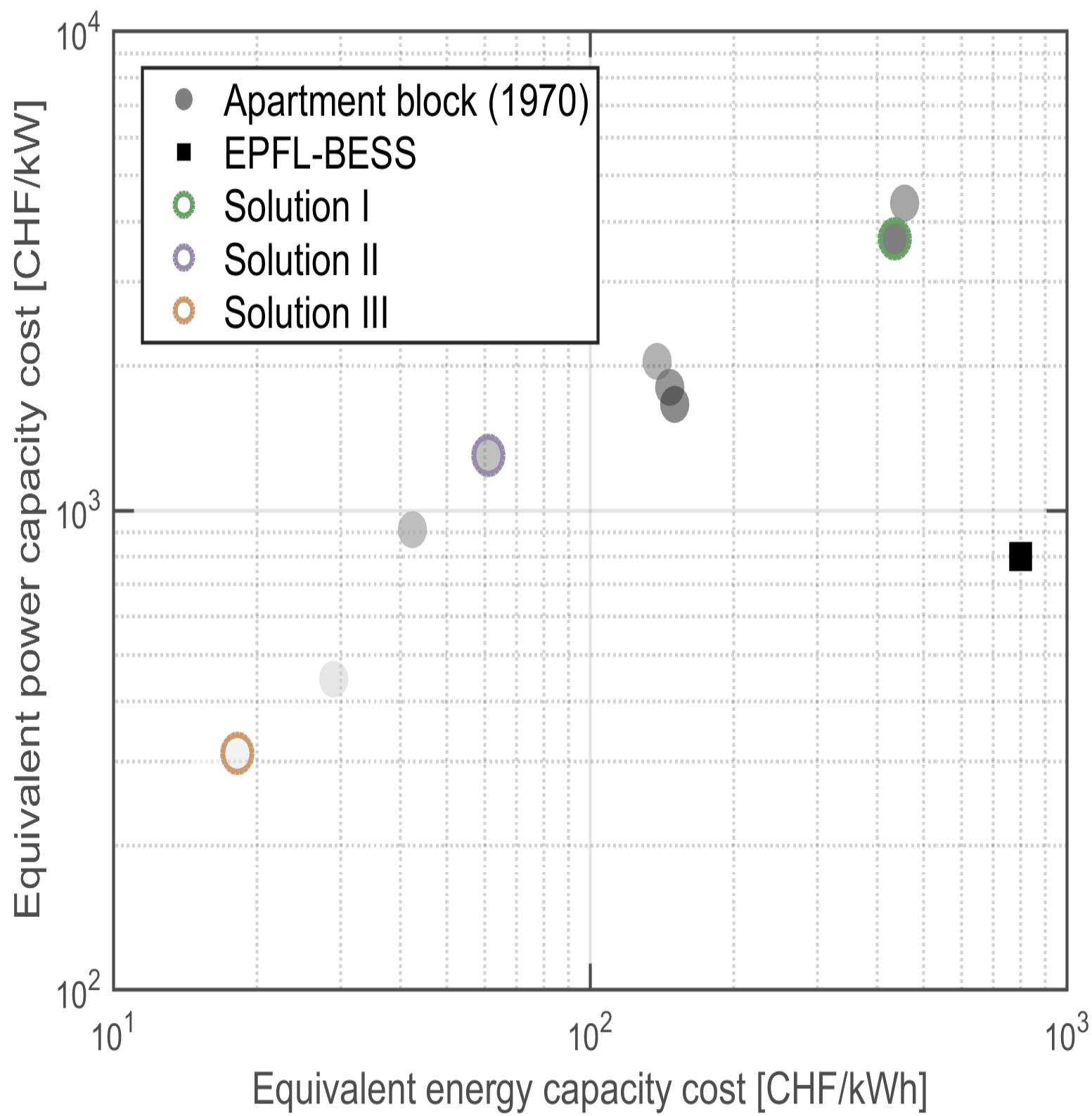
Ind.	Value (imp/exp/gen)		
E [MWh]	34.8	00.0	00.0
H [MWh]	00.0	00.0	00.0
COP [-]	3.00		

Building energy system design (solution I)

Unit	Size	
Heat pump	7.0	kW _e
Battery	0	kWh _e
Boiler	0	kW _{th}
Water tank	0.22	m ³
Electric heater	14	kW _e
Heat tank	1.0	m ³
Photovoltaics	0	kW _p
Solar thermal	0	m ²
SOFC-CHP	0	kW _e



Annual equivalent battery performance

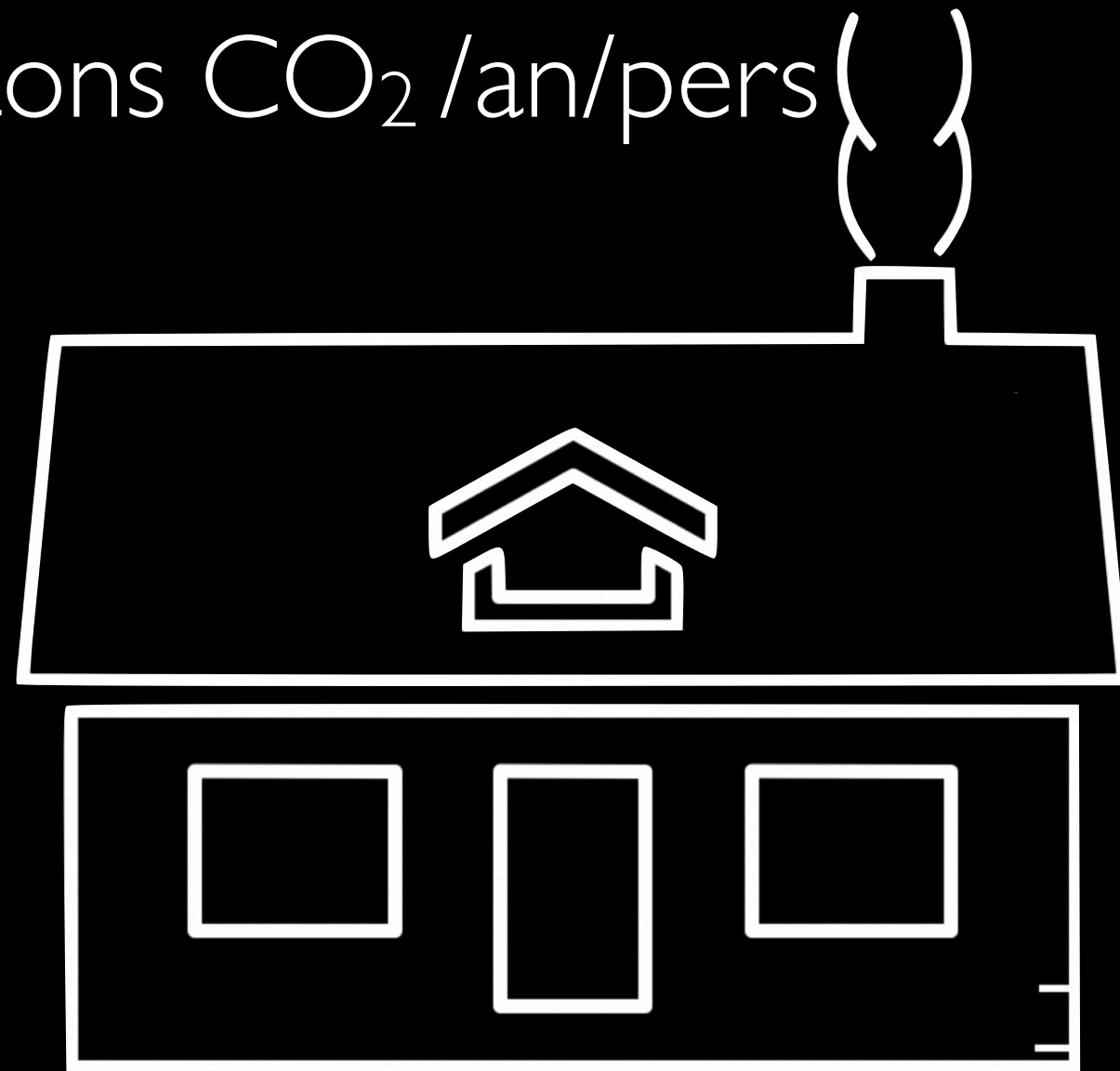
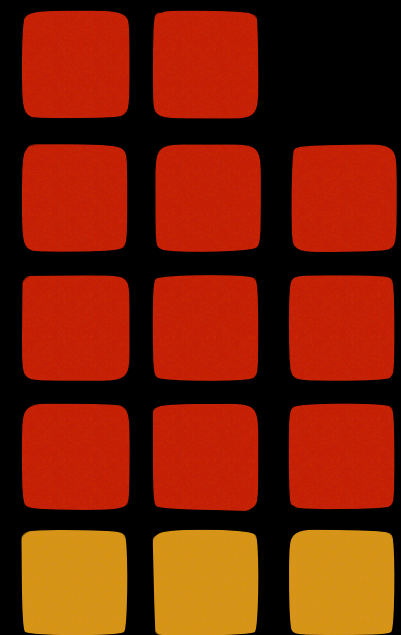


BUILDINGS : RENEWABLE ENERGY HUB

90+ % CO₂ EMISSIONS REDUCTION

2.20

tons CO₂ /an/pers { }



Oil: 6 cts/kWh
Electricity: 18 cts/kWh

572

CHF/y/cap

542 CHF/y/cap

30 CHF/y/cap

Energy :
Investment :



2021

0.25 - 0.04

tons CO₂ /y/cap

15.5

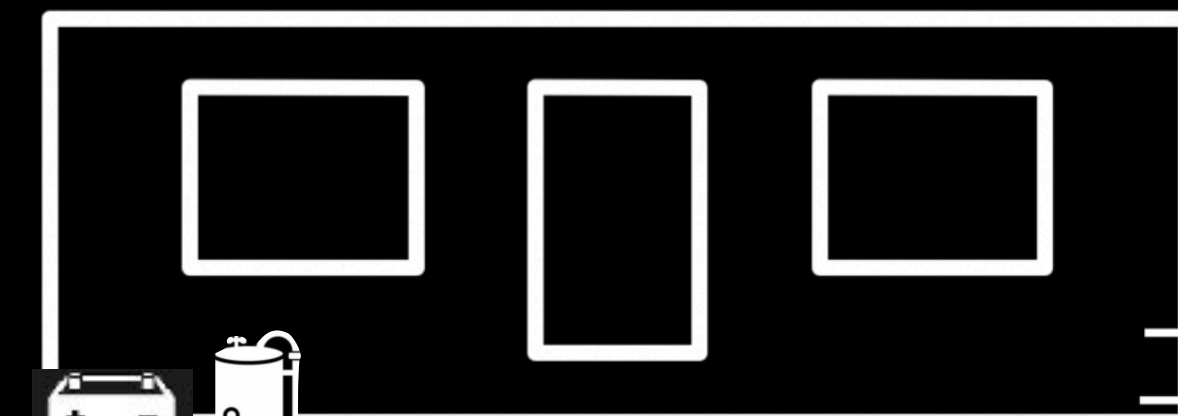
m²PV/cap



Direct

Achat

Vente



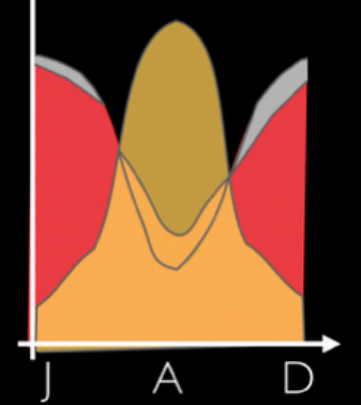
Feed-in: 8 cts/kWh

Electricity: 18 cts/kWh



Internet

Contrôle prédictif



209

CHF/y/cap

PV feed-in :

-139 CHF/y/cap

Energy :

118 CHF/y/cap

Investment :

230 CHF/y/cap

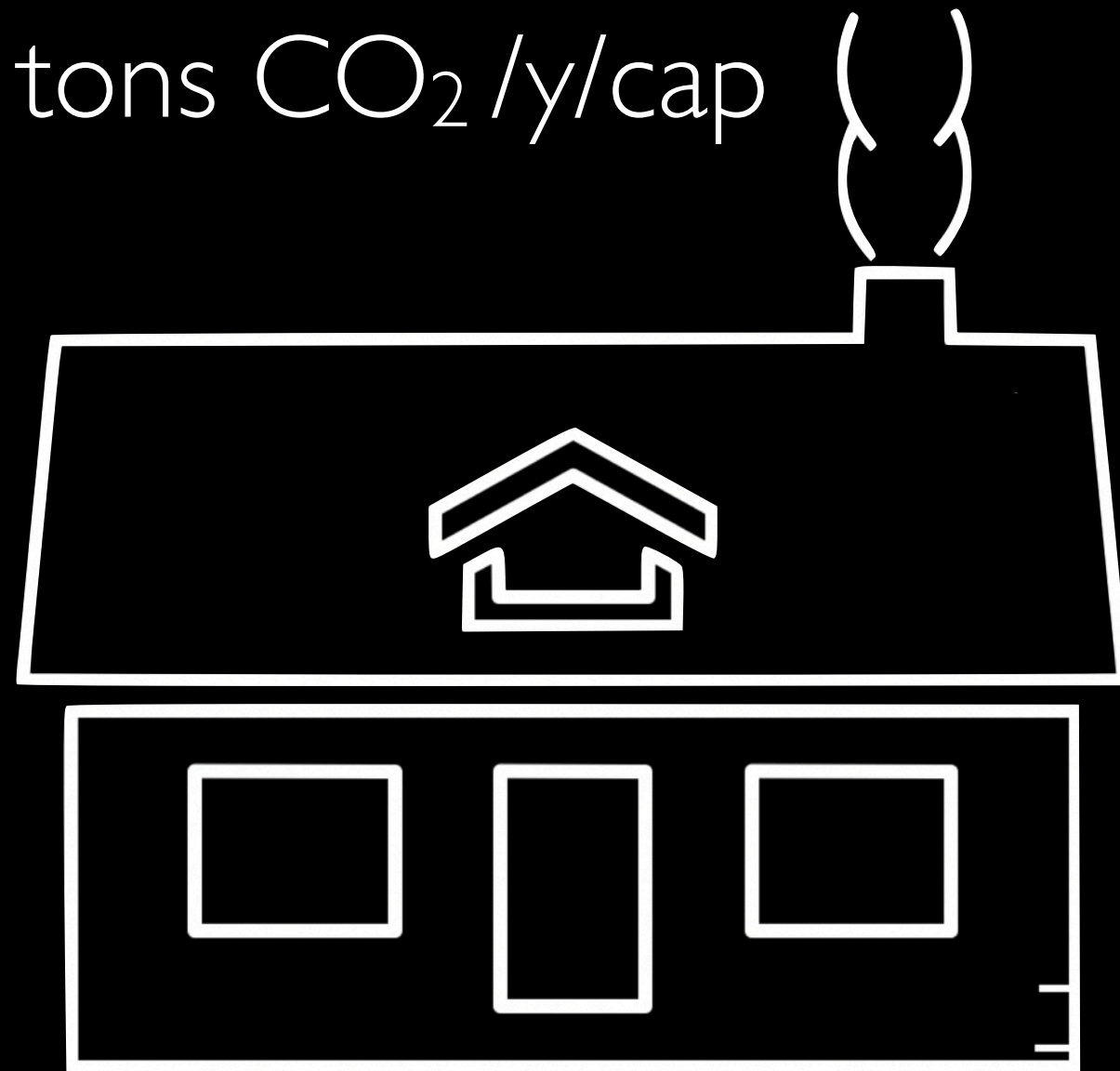
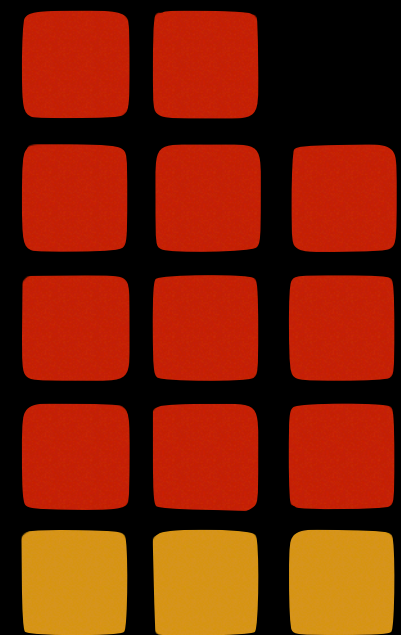


BUILDINGS : RENEWABLE ENERGY HUB

90+ % CO₂ EMISSIONS REDUCTION

2.20

tons CO₂/y/cap



Oil: 11 cts/kWh
Electricity: 28 cts/kWh

1132

CHF/y/cap

1102 CHF/y/cap

30 CHF/y/cap

Energy :
Investment :



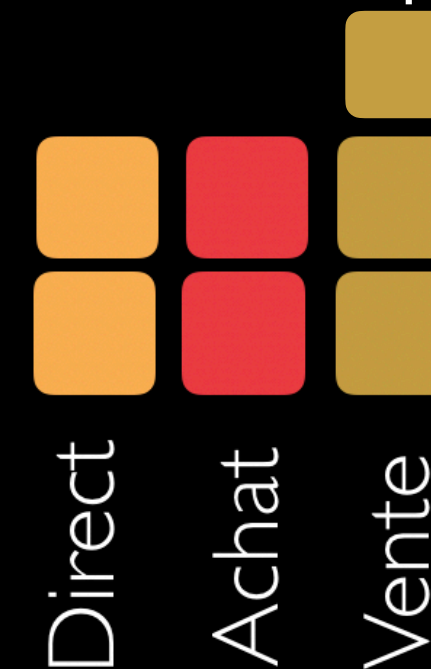
2023

0.25 - 0.04

tons CO₂/y/cap

15.5

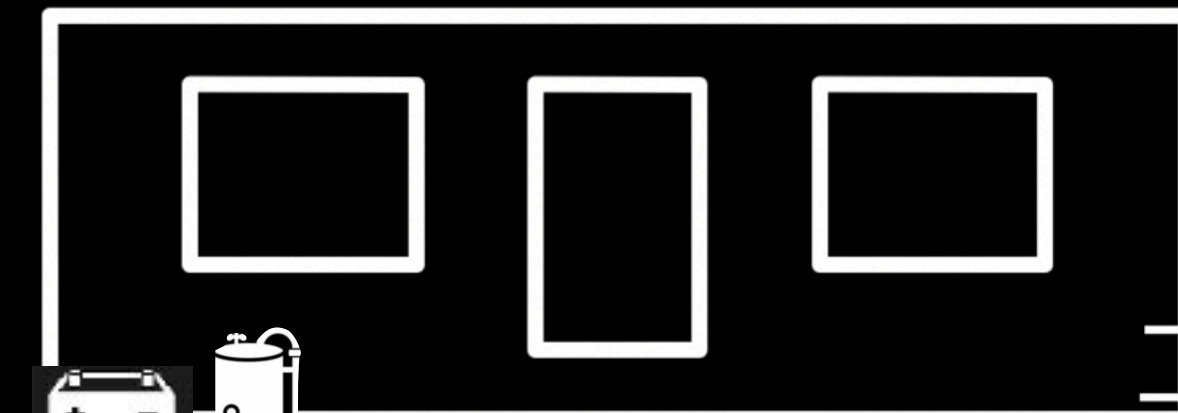
m²PV/cap



Direct

Achat

Vente

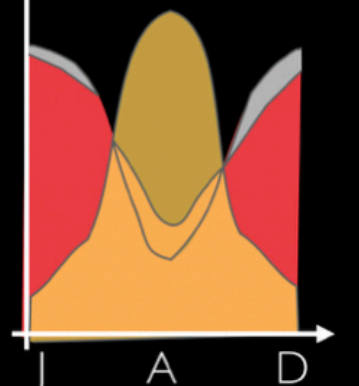


Feed-in: 16 cts/kWh

Electricity: 28 cts/kWh



Contrôle prédictif



138

CHF/y/cap

PV feed-in :

-278 CHF/y/cap

Energy :

184 CHF/y/cap

Investment :

230 CHF/y/cap



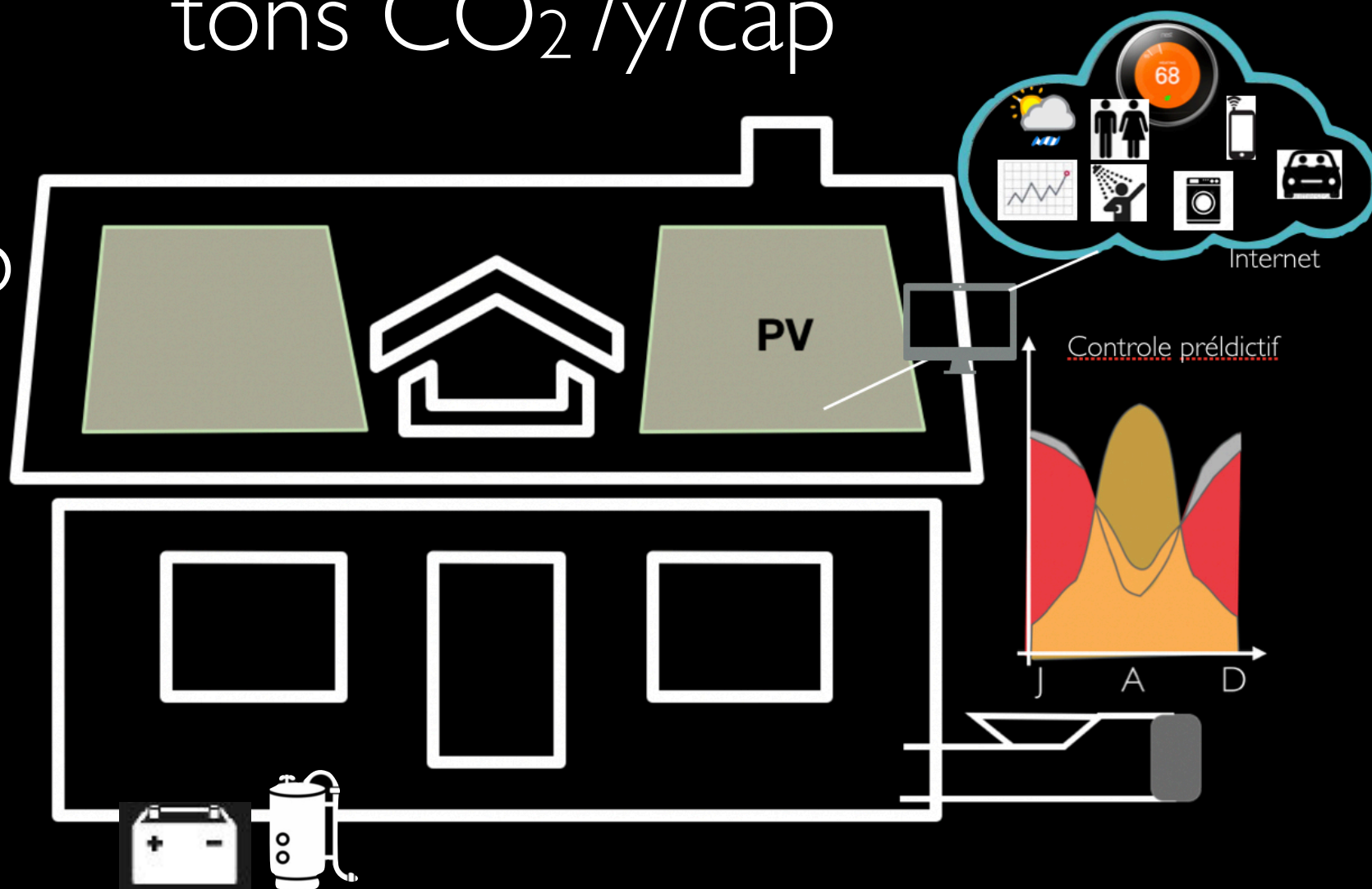
RENEWABLE ENERGY HUB AND E-VEHICLES

2.00 (0.25 + 1.74)

tons CO₂ /y/cap

15.5
m²PV/cap

Direct
Achat
Vente



1109 (138 + 881)

CHF/y/cap

PV feed-in : **-278** CHF/y/cap
Energy : **184** CHF/y/cap
Investment : **230** CHF/y/cap
Building



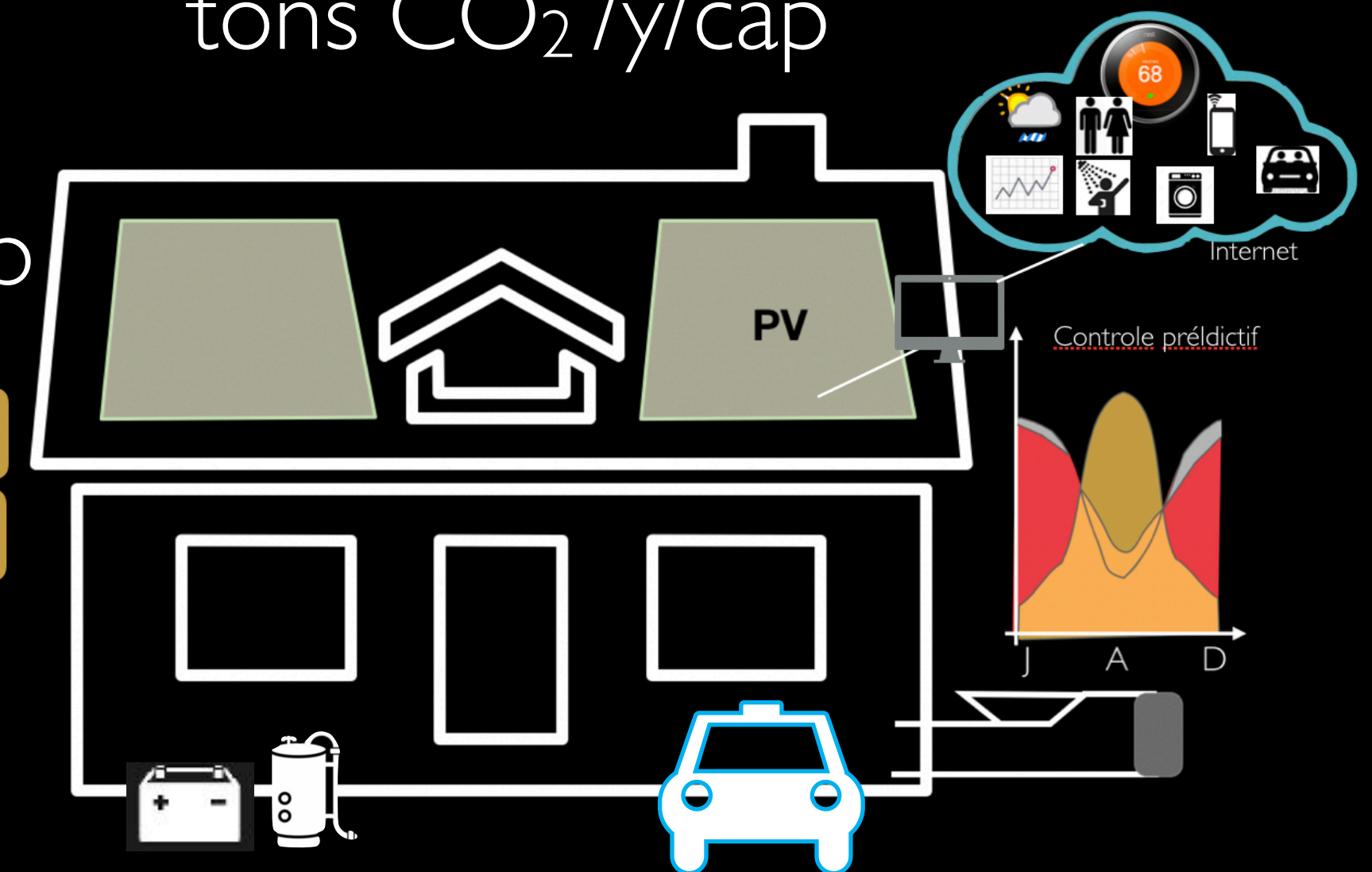
Gasoline car

0.32 (-83%)

tons CO₂ /y/cap

15.5
m²PV/cap

Direct
Achat
Vente



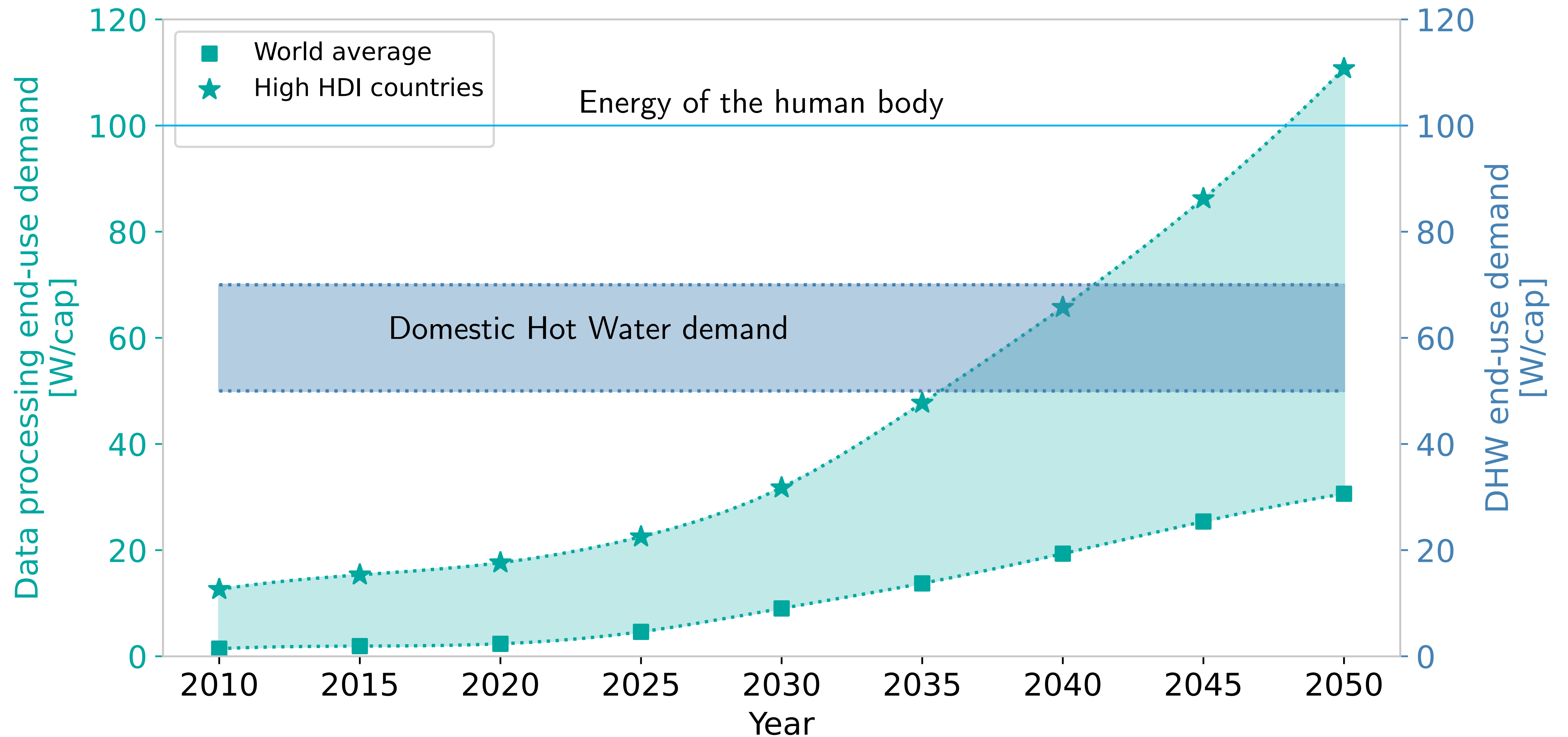
208 (-79%)

CHF/y/cap

PV feed-in : **-226** CHF/y/cap
Energy : **204** CHF/y/cap
Investment : **230** CHF/y/cap



DATA PRODUCTION AND ENERGY SYSTEM

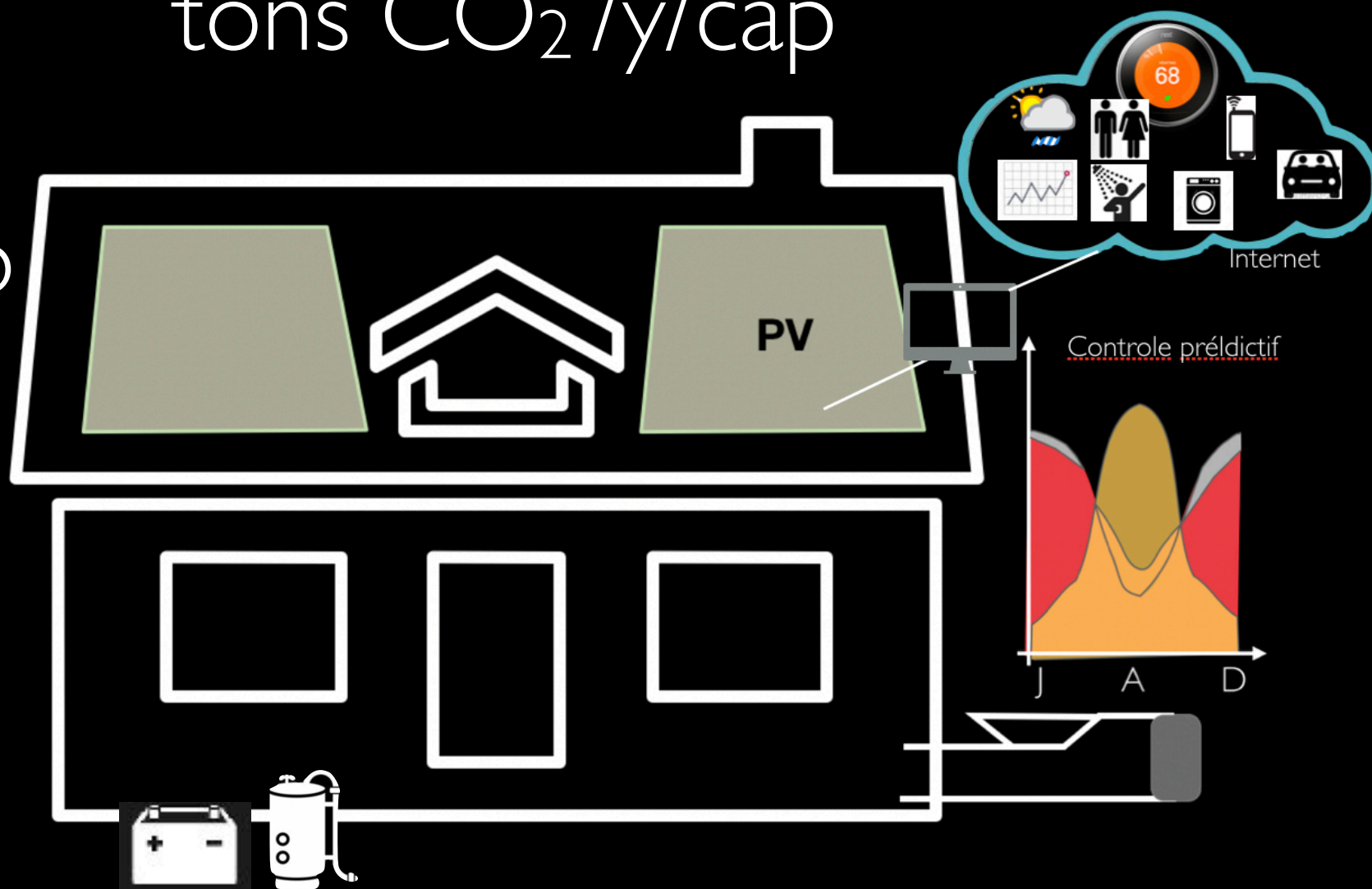


RENEWABLE ENERGY HUB AND DATA PRODUCTION

0.25 + 0.24

tons CO₂ /y/cap

3.8
m²PV/cap



493

CHF/y/cap

43 CHF/y/cap

450 CHF/y/cap

Building

+

476

CHF/y/cap

290 CHF/y/cap

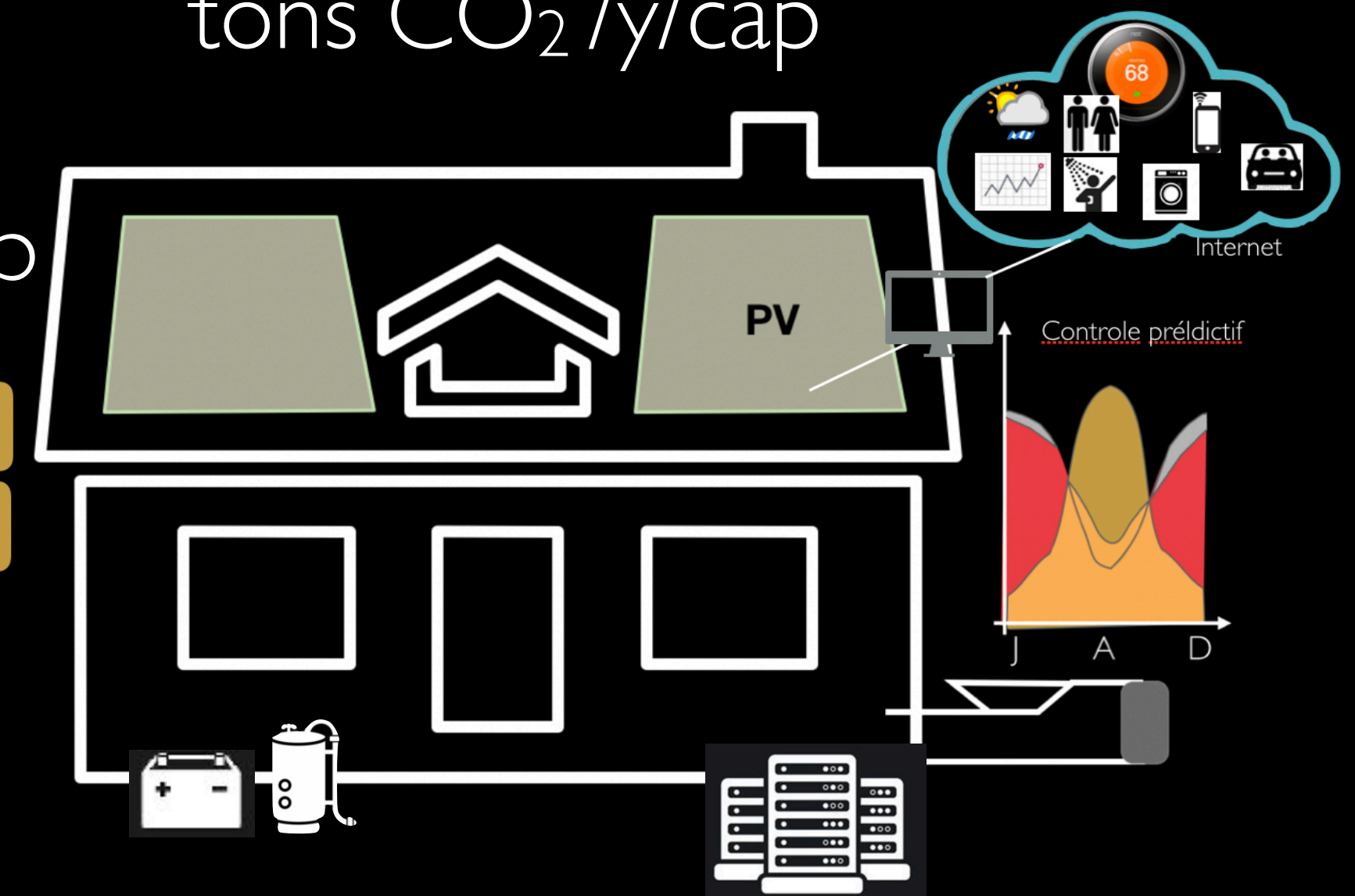
186 CHF/y/cap

Data center

0.32 (-34%)

tons CO₂ /y/cap

4.5
m²PV/cap



855 (-12%)

CHF/y/cap

115 CHF/y/cap

450 CHF/y/cap

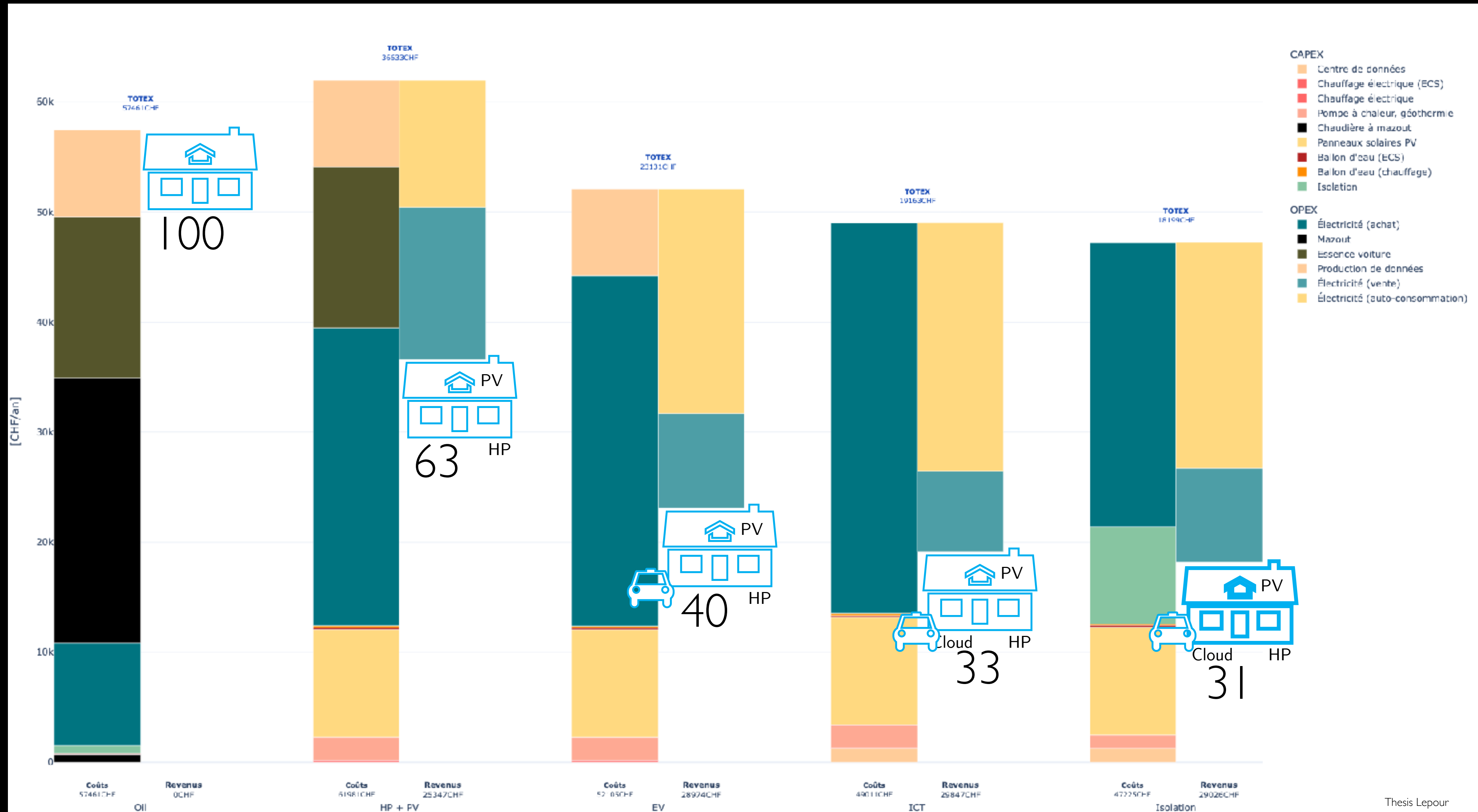
Energy :

Investment :

Bits heater :

290 CHF/y/cap

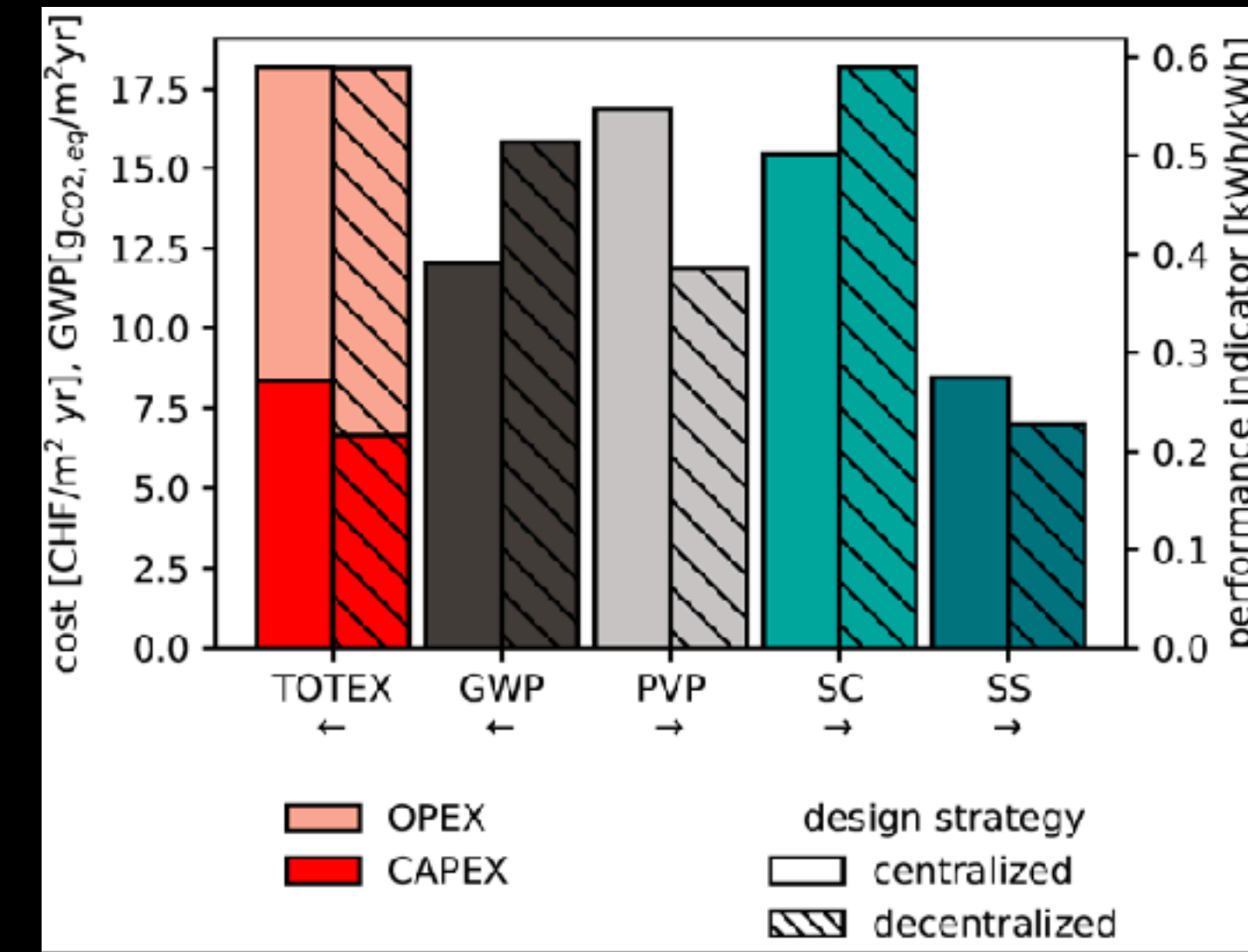
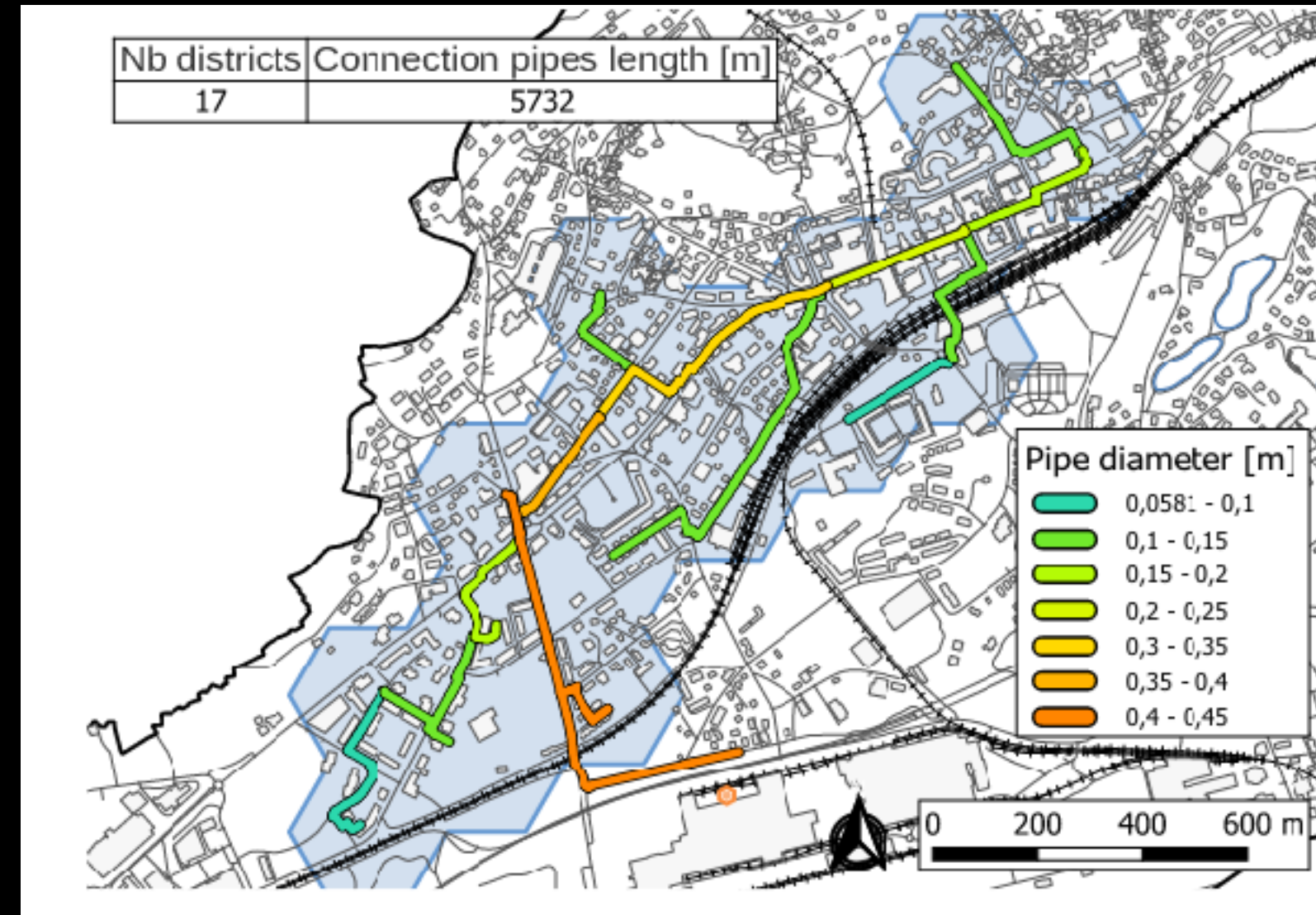
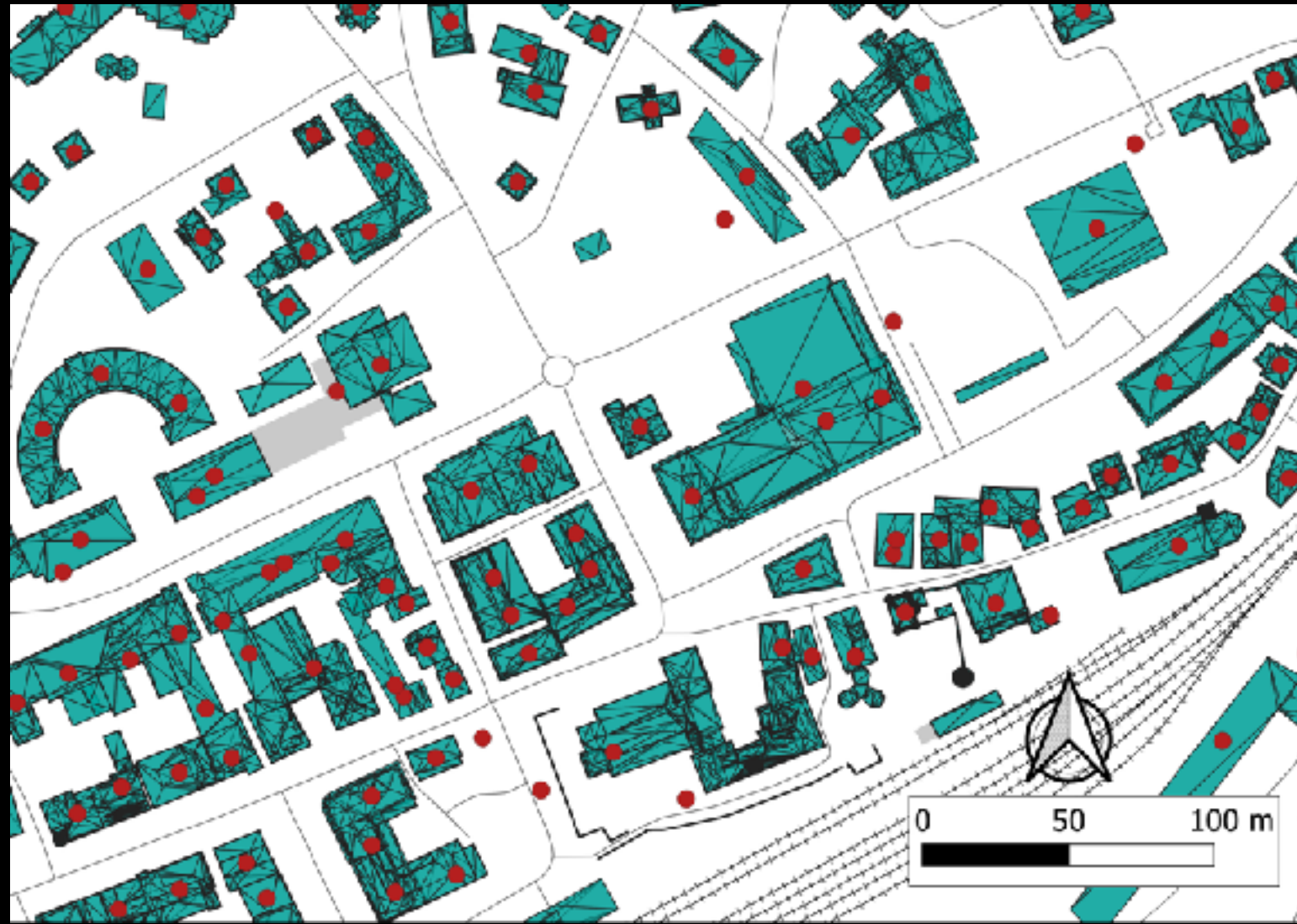
PV - HEAT PUMP - ELECTRIC CARS - DATA - RENOVATION



INTEGRATING RENEWABLE ENERGY HUBS : SYSTEMS IN SYSTEMS

- District scale => interactions between buildings

building vs community



For the same feed-in/feed-out prices

- PV + 40%
- Prosumer Invest + 30%
- - 20% GWP
- facade from 16 to 40%

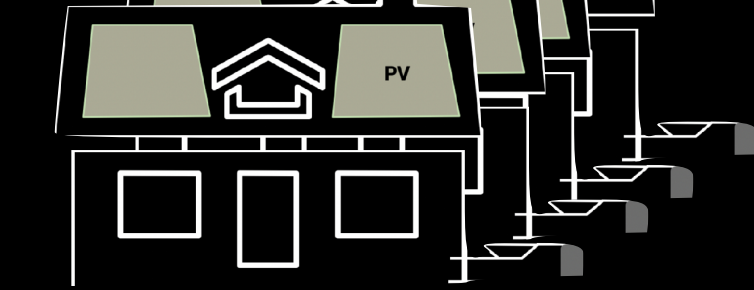
- Operating costs: -9%
- Self-consumption: +34%

CHASING HEAT SOURCES IN THE CITY

Heat sources (T_{source})

Users ($T_{heating}$)

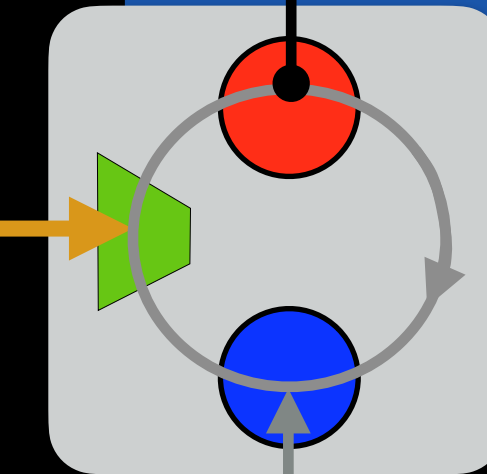
Heating



30 °C

$$\dot{E}^- = \dot{Q}_{Heating}^- \cdot \left(1 - \frac{T_{distrib}}{T_{heating}}\right) \cdot \frac{1}{\eta_c}$$

COP=8



17°C

CO2 $\frac{L}{V}$

Distribution

Data center : **30°C**
WWTP : **17-22 °C**

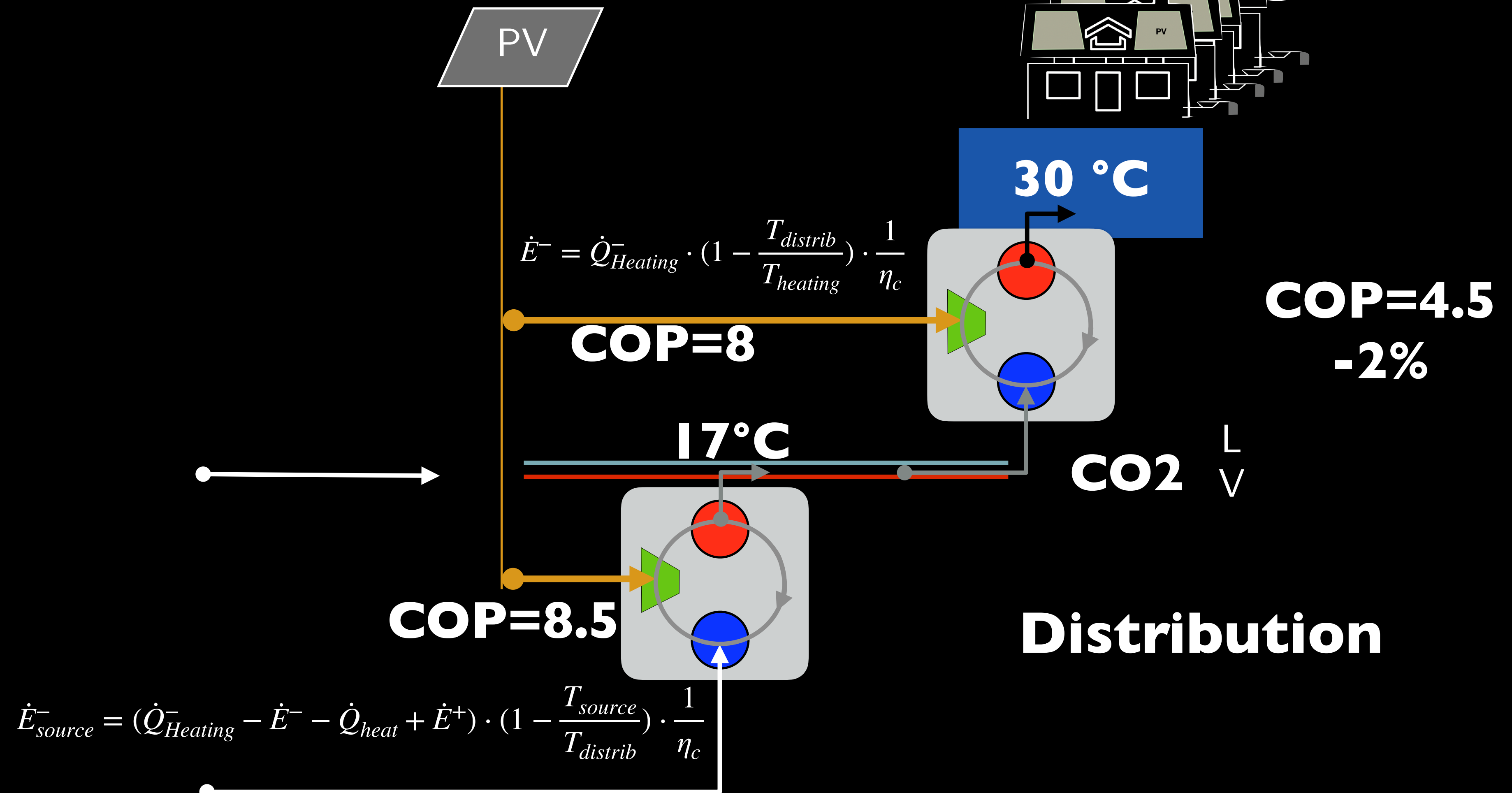
HEAT SOURCES IN THE CITY

Heat sources (T_{source})

Users ($T_{heating}$)
Heating

Data center : **30°C**
STEPS : **13-20 °C**

Aquifers : **10 °C**
Rivers/Lakes : **7°C**
Geothermy : **>10 °C**
Refrigeration : **< 0°C**



APPLYING THE MAGIC FORMULA IN THE CITY

Heat sources (T_{source})

**Users ($T_{heating}$)
Heating and Cooling**

Industry: **>80°C**

$$\dot{E}^+ = \dot{Q}_{Heat}^+ \cdot \left(1 - \frac{T_{source}}{T_{distrib}}\right) \cdot \eta_h$$

Data center : **30°C**

Waste Water : **13-20 °C**

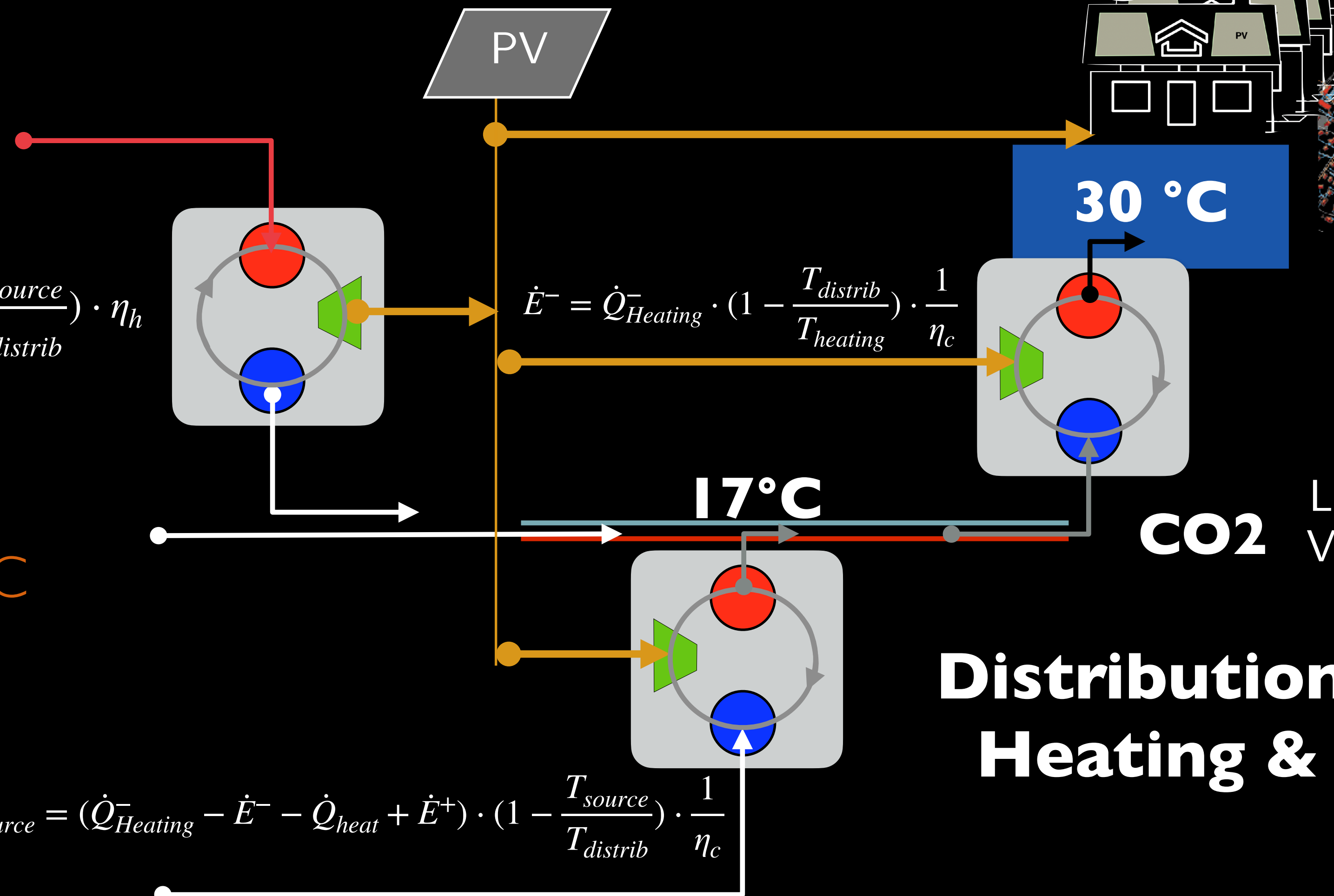
Aquifers : **10 °C**

Rivers/Lake : **7°C**

Geothermal : **>10 °C**

Refrigeration : **< 0°C**

$$\dot{E}_{source}^- = (\dot{Q}_{Heating}^- - \dot{E}^- - \dot{Q}_{heat} + \dot{E}^+) \cdot \left(1 - \frac{T_{source}}{T_{distrib}}\right) \cdot \frac{1}{\eta_c}$$

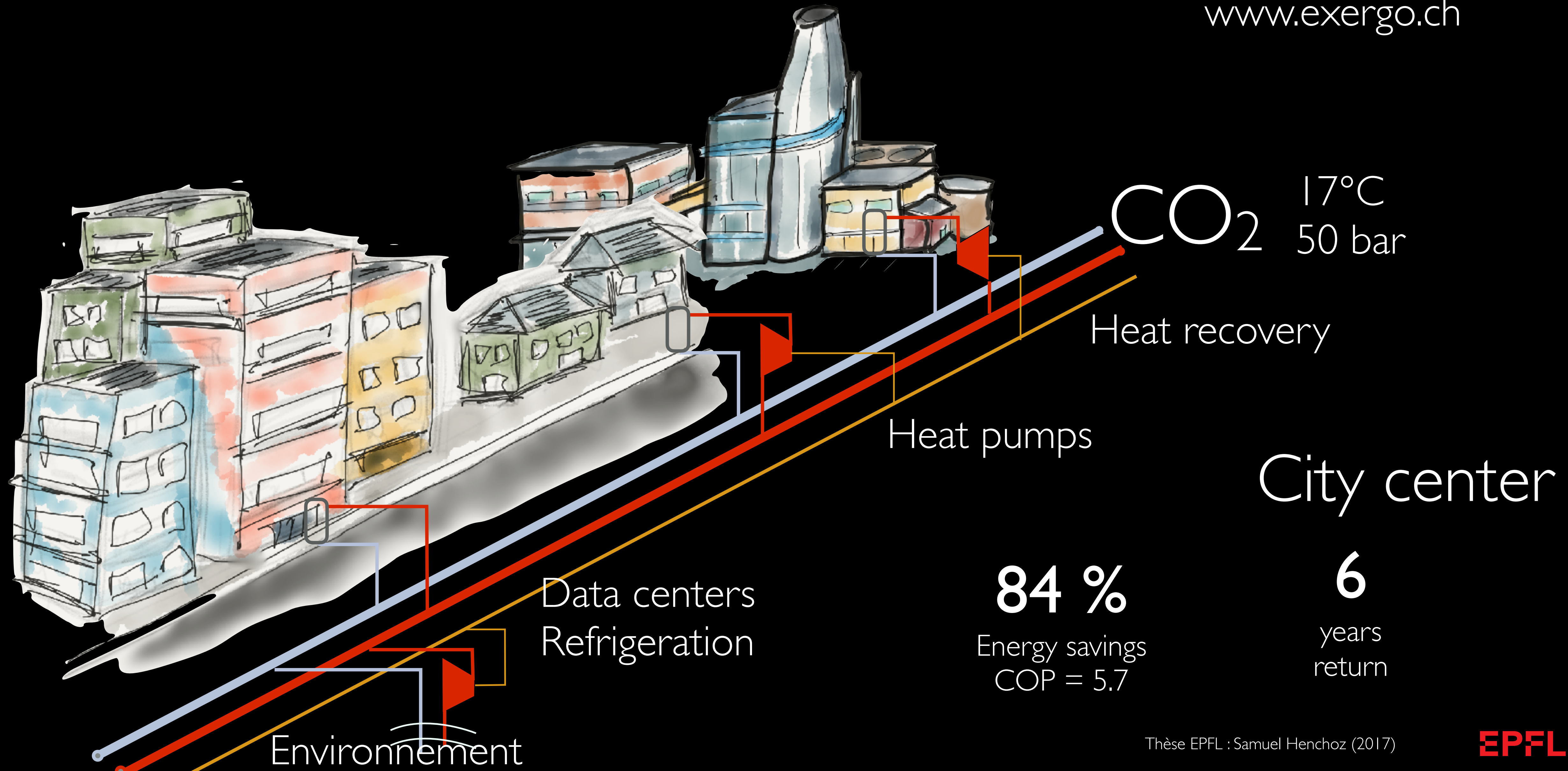


**Distribution : anergy
Heating & Cooling**

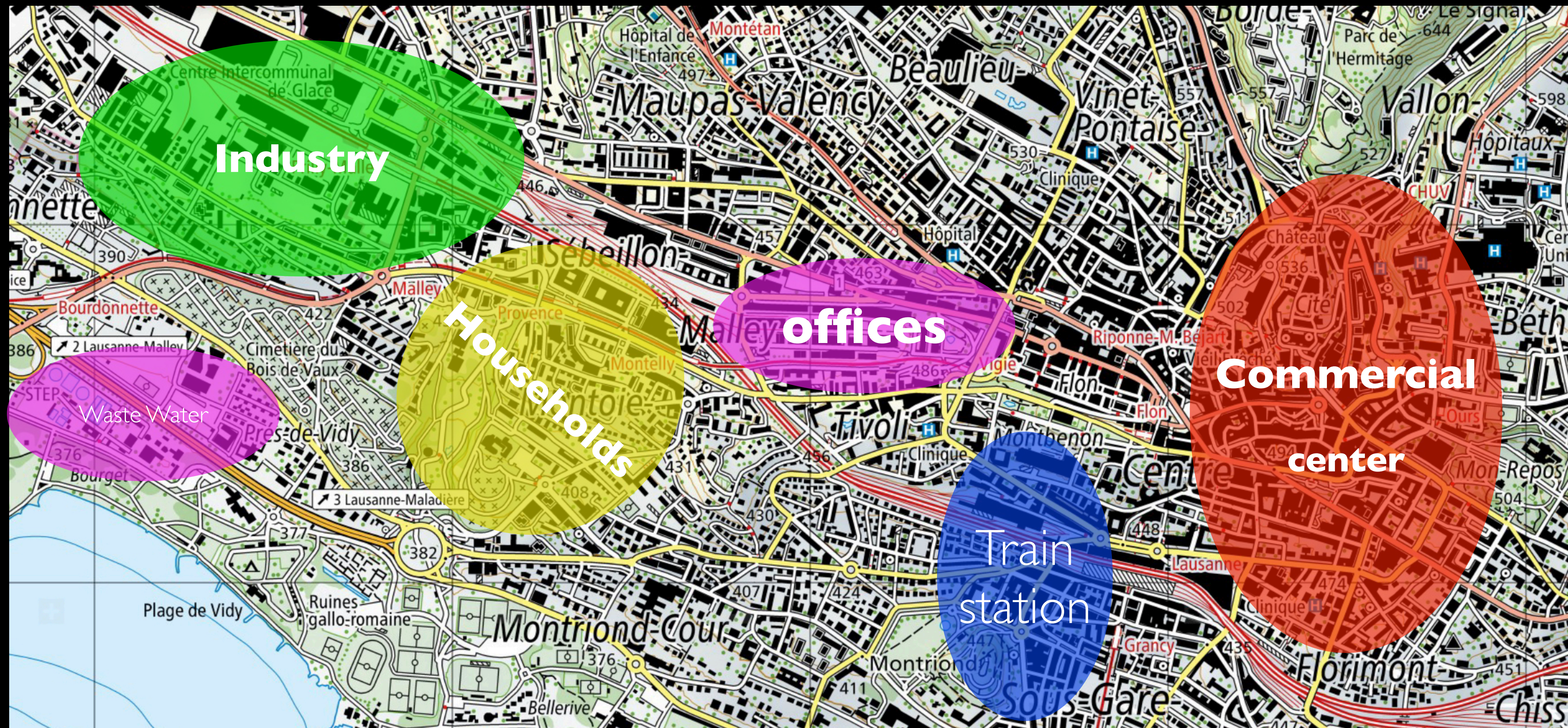
URBAN SYSTEMS



www.exergo.ch



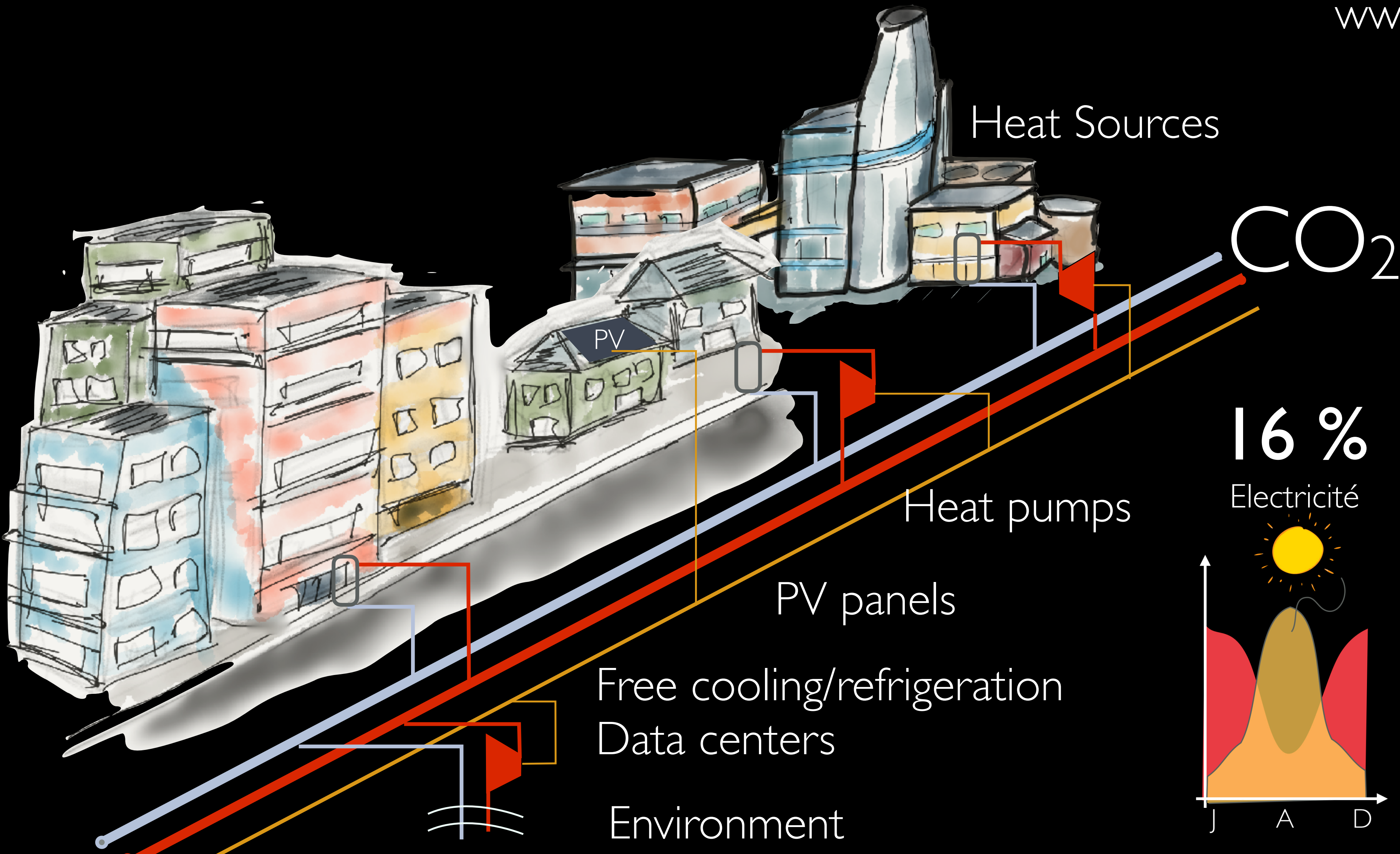
DISTRICT ENERGY HUBS



<http://urb.io> : decision support for urban development

DISTRICT RENEWABLE ENERGY HUBS

www.exergo.ch



16 %

Electricité

6 %

direct

10 %

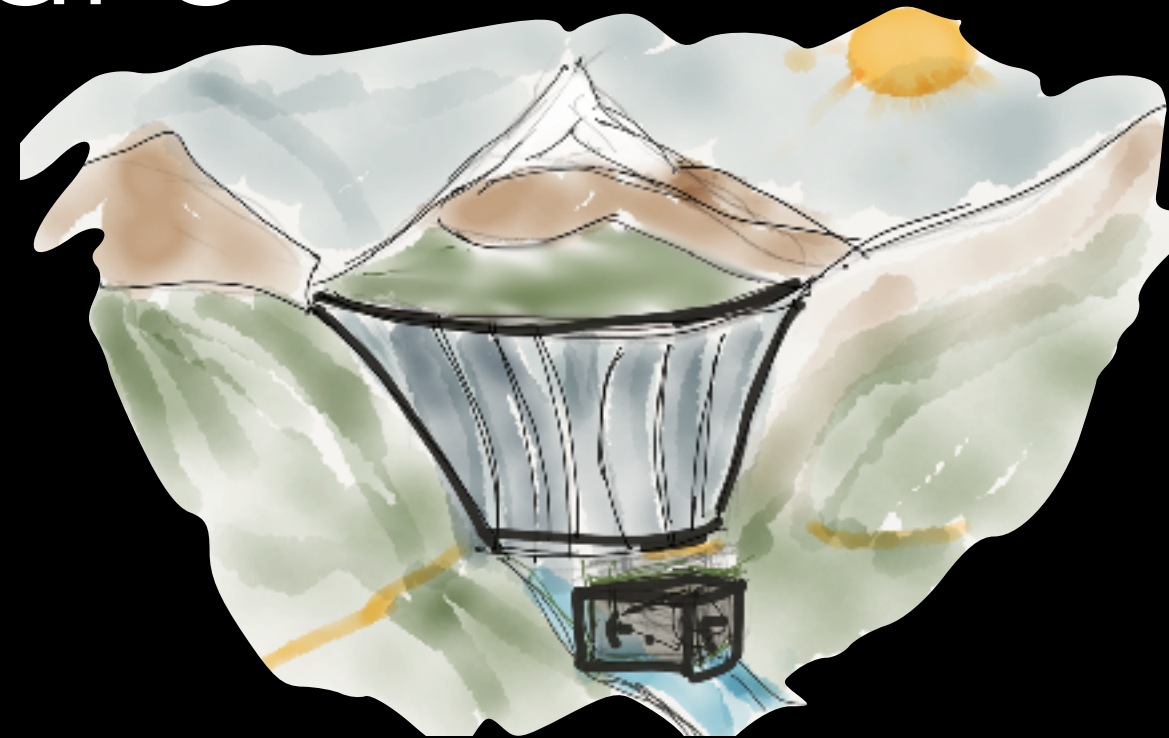
import

12 %

export

HOW TO PRODUCE THE IMPORT ?

Hydro



Also stores energy

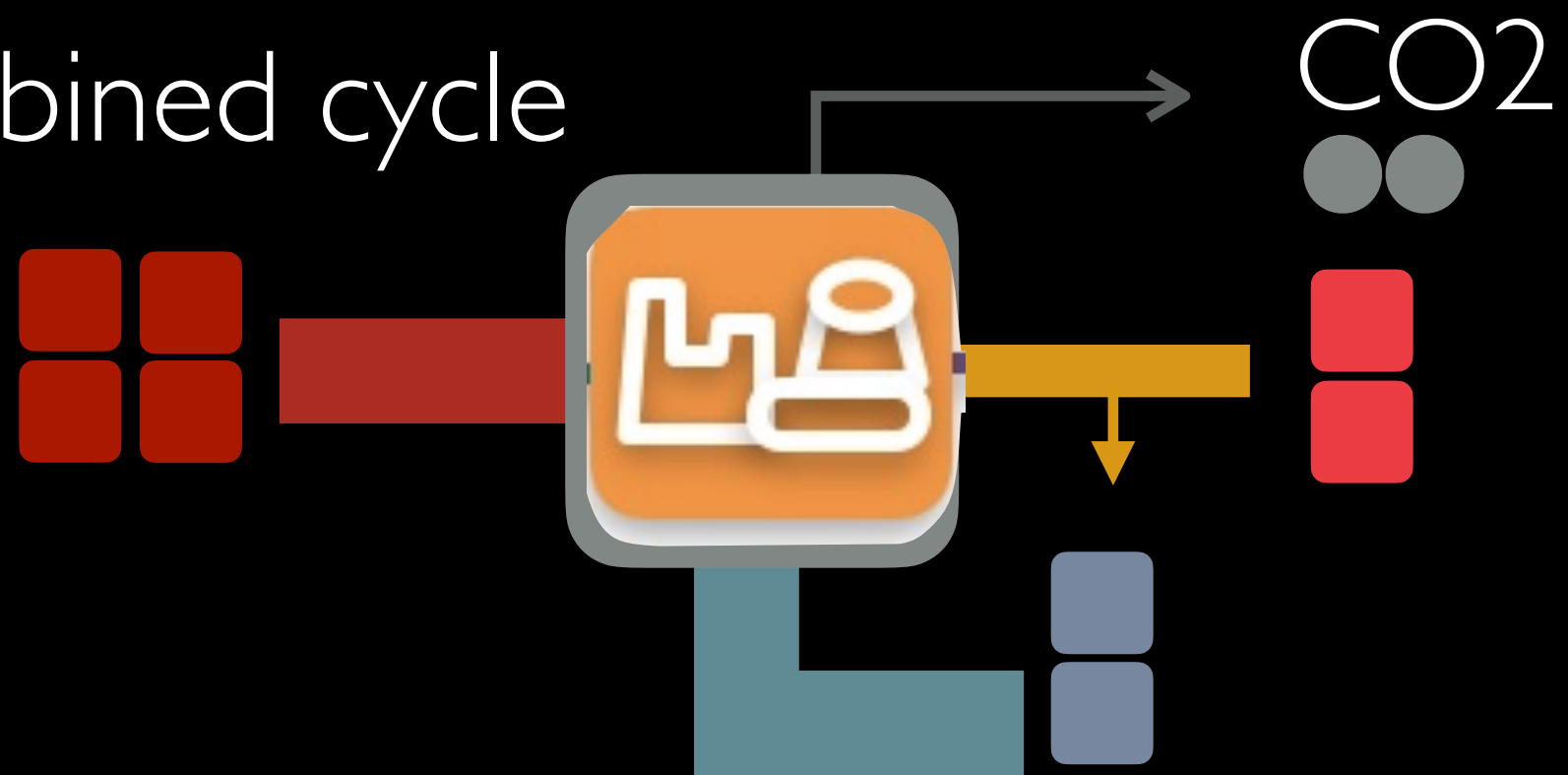
Wind



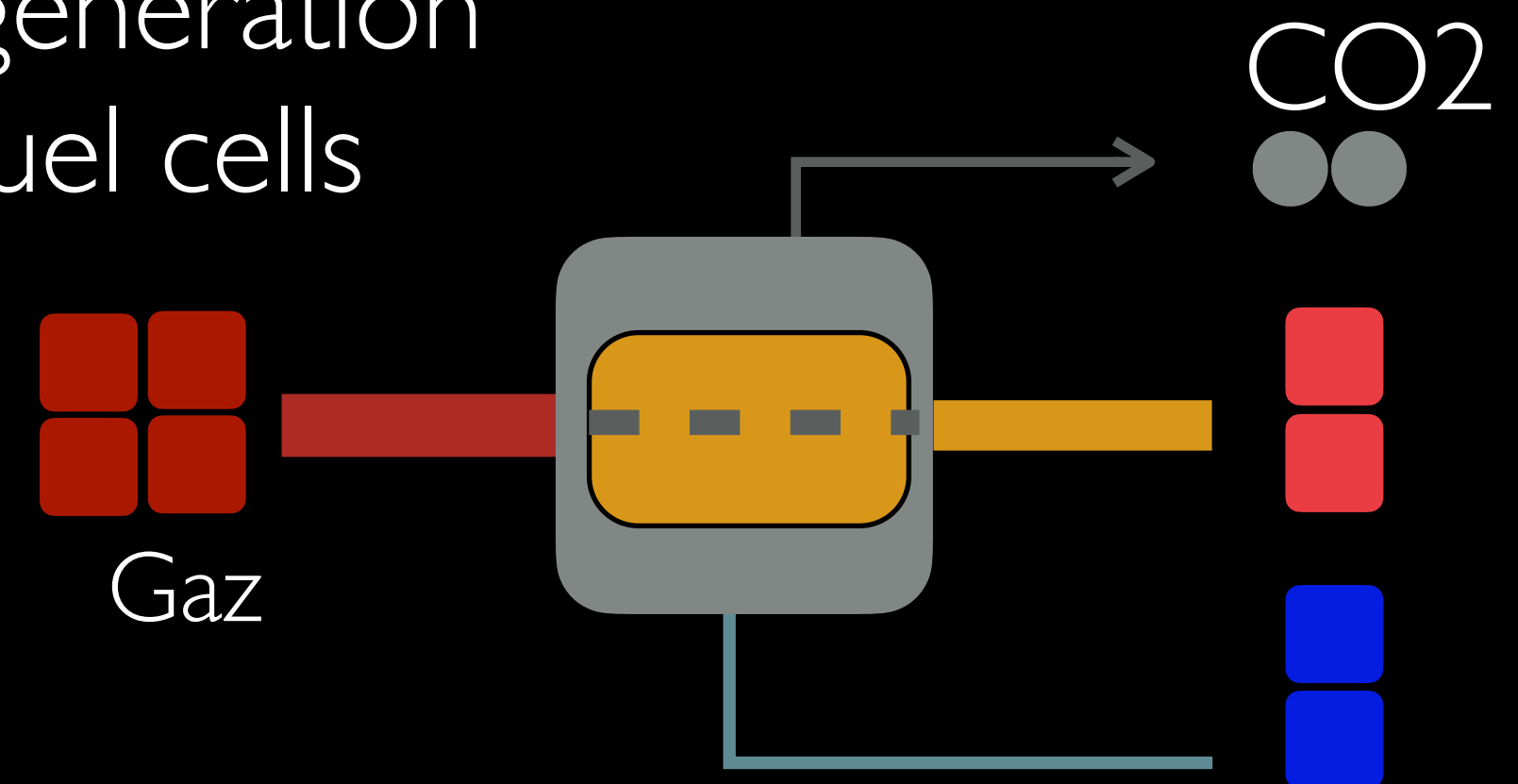
Intermittent !

Gas

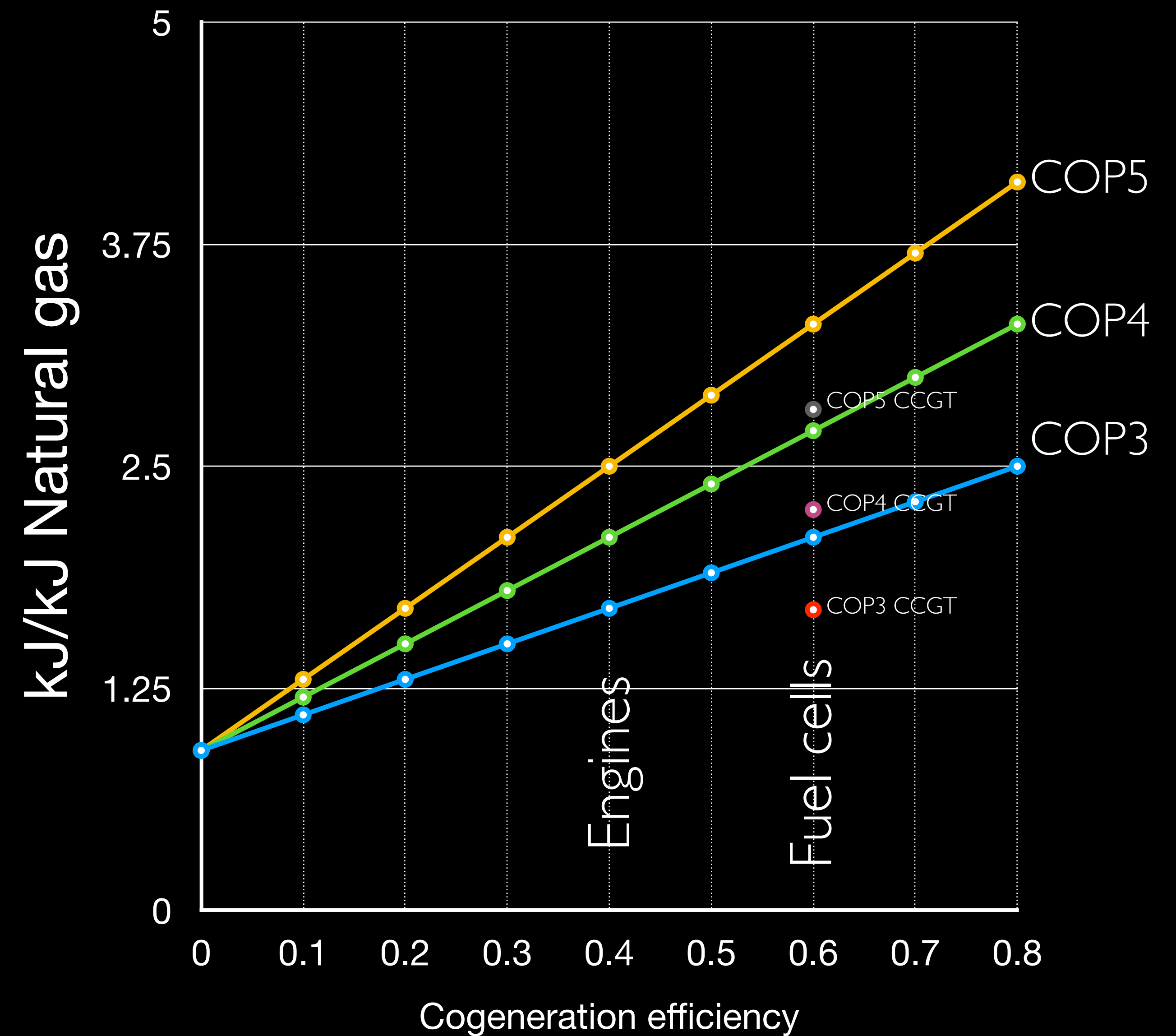
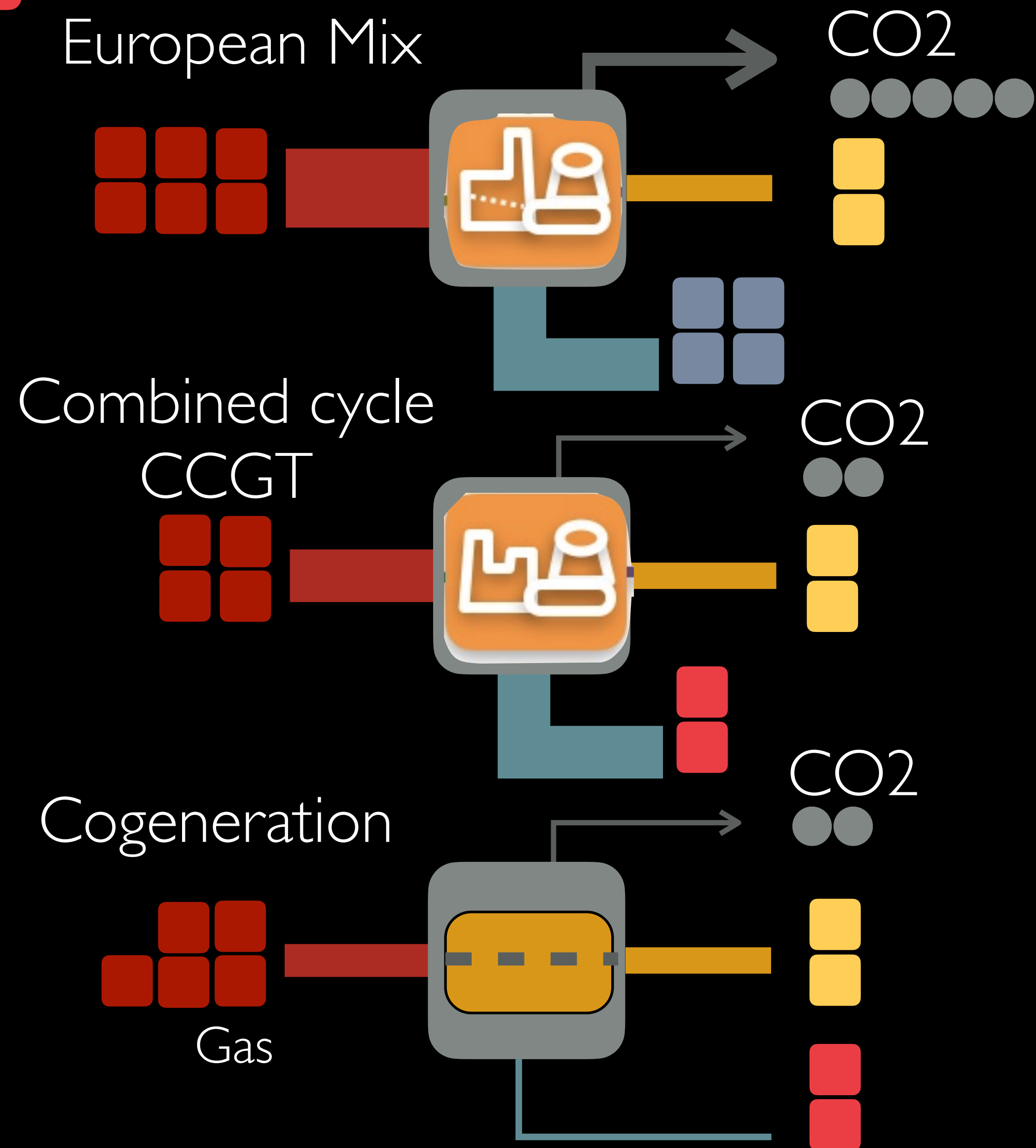
Combined cycle



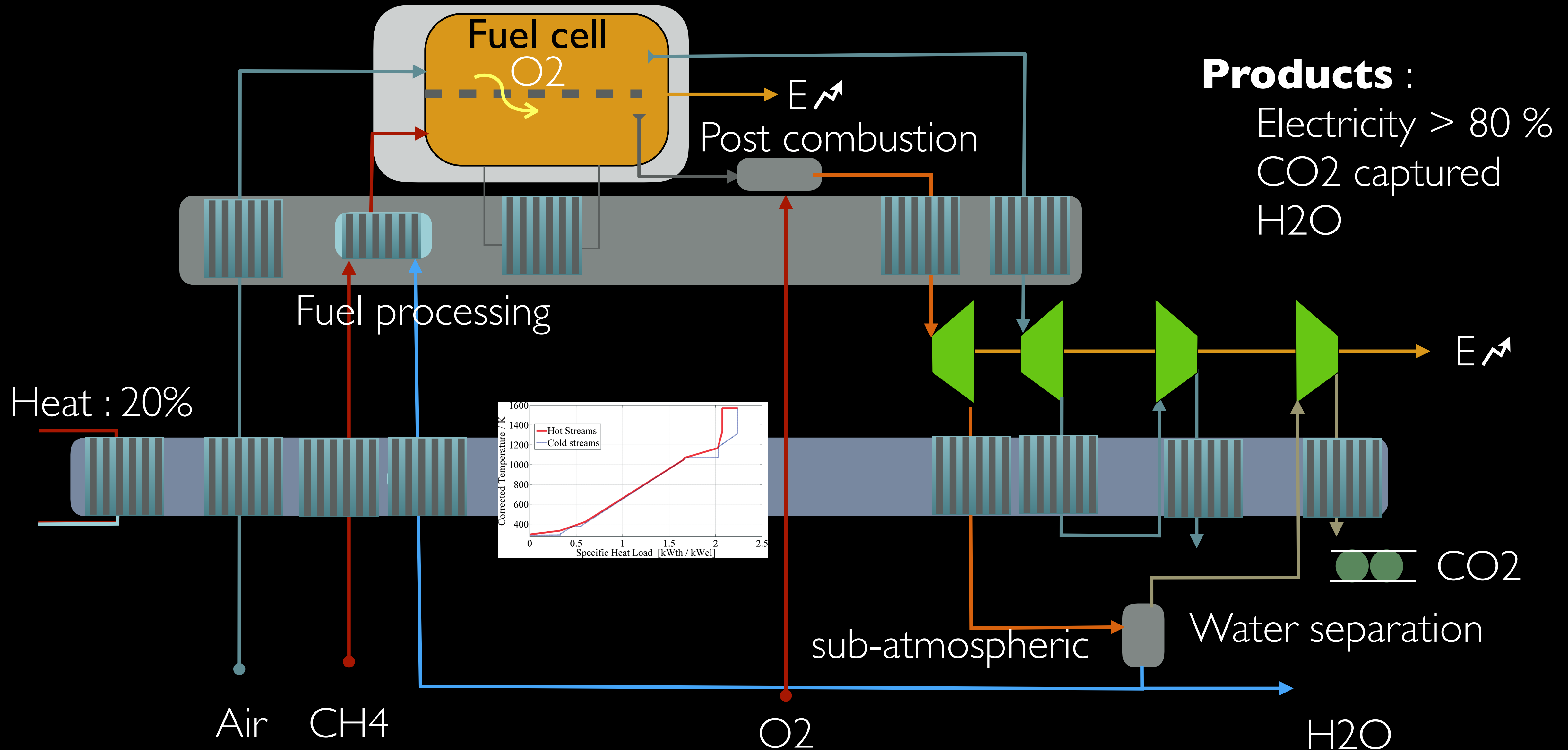
Cogeneration
Fuel cells



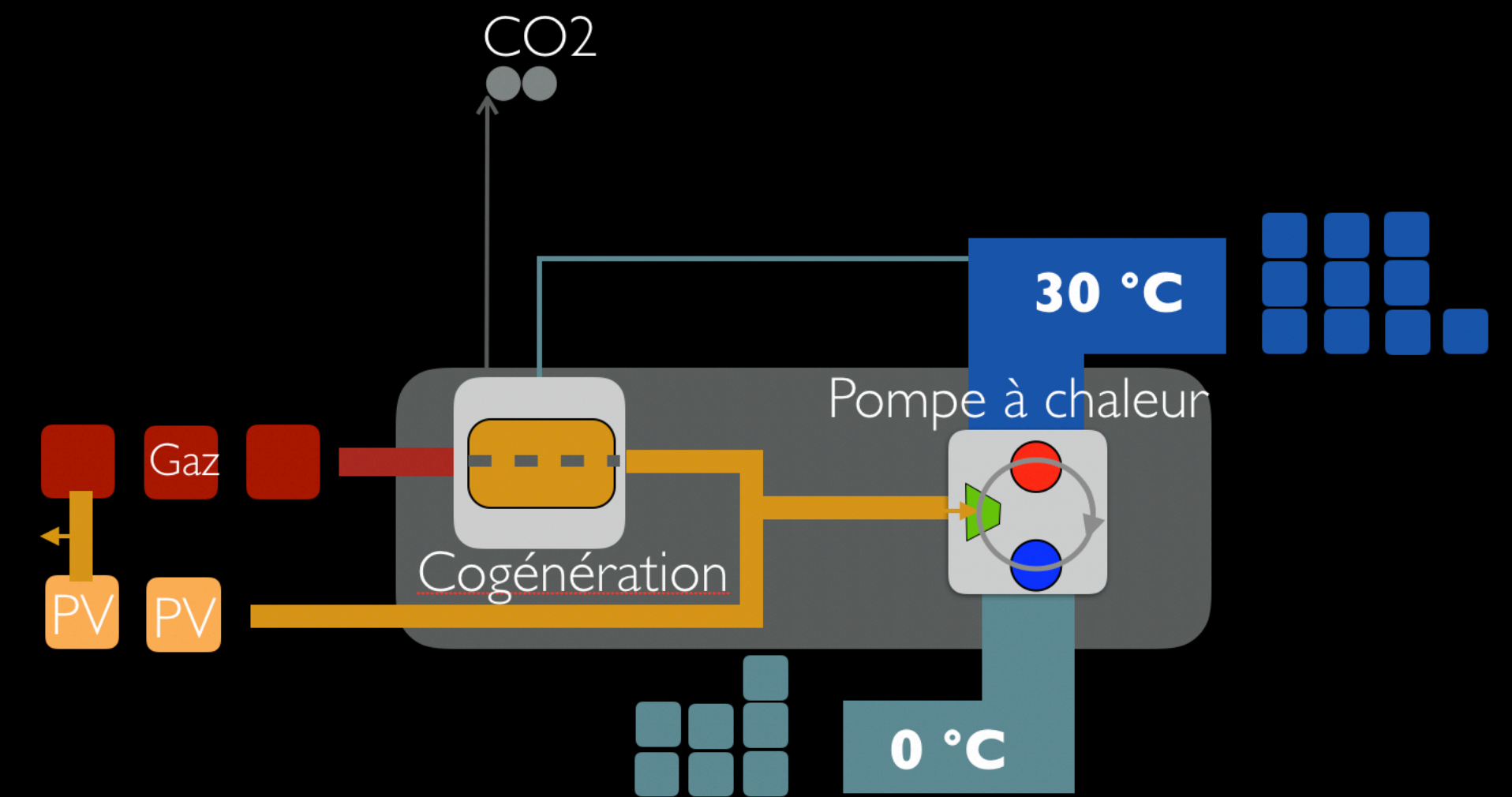
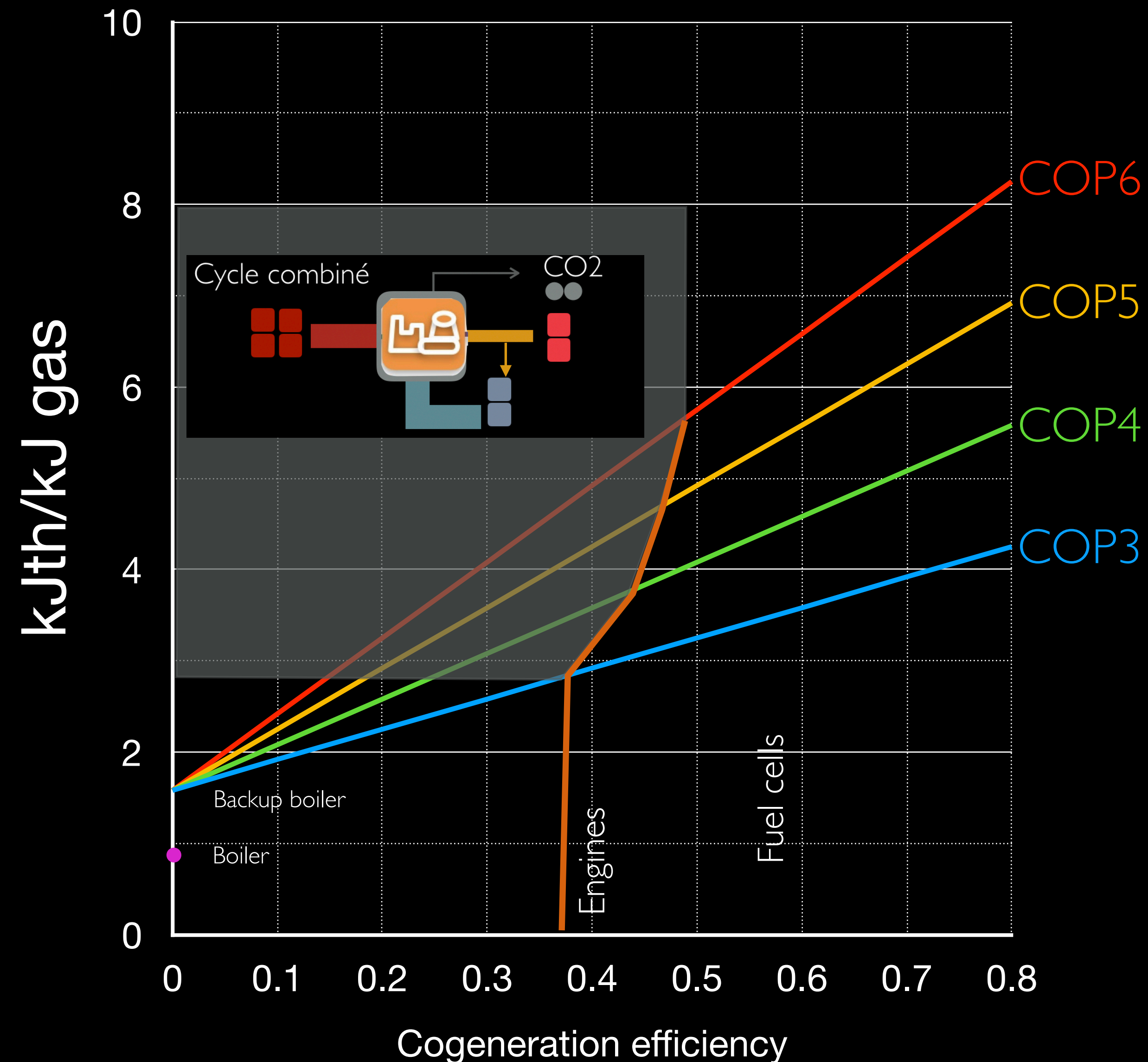
PRODUCING THE ELECTRICITY DEFICIT



PRODUCING ELECTRICITY WITH ADVANCED FUEL CELL SYSTEM



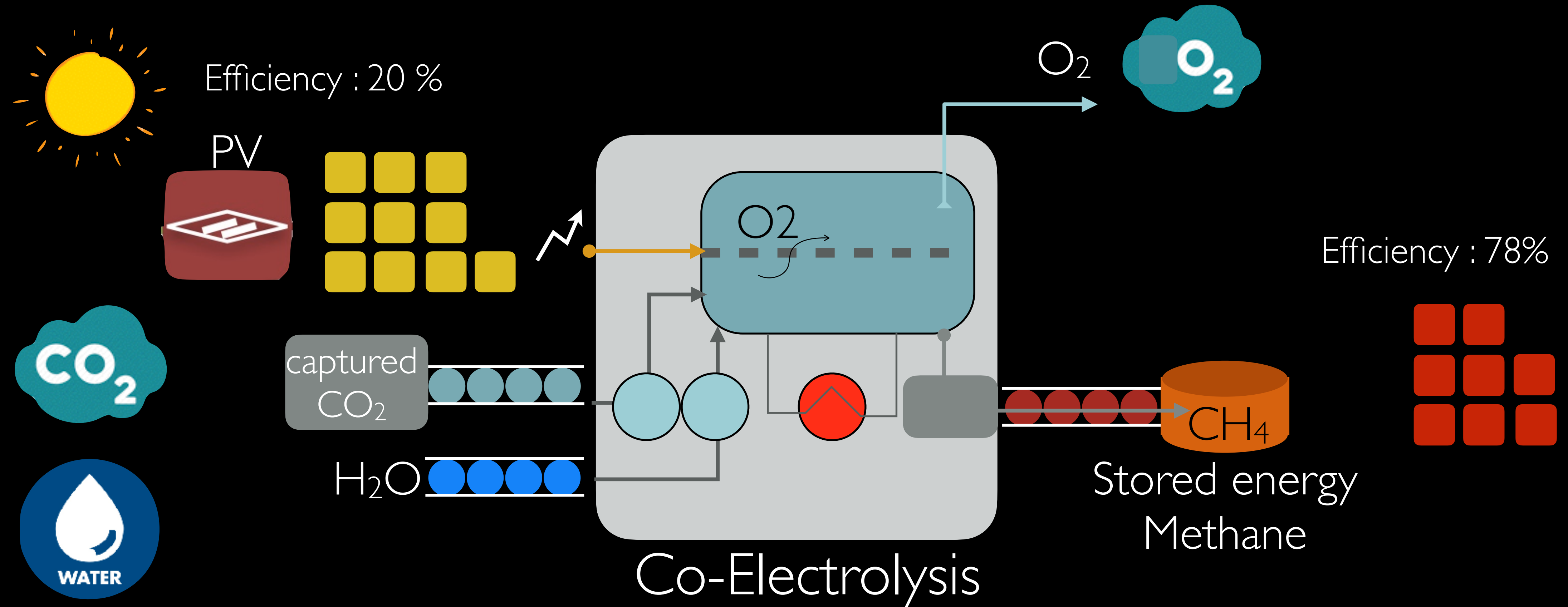
EFFICIENT USE OF NATURAL GAS



Decentralized solution

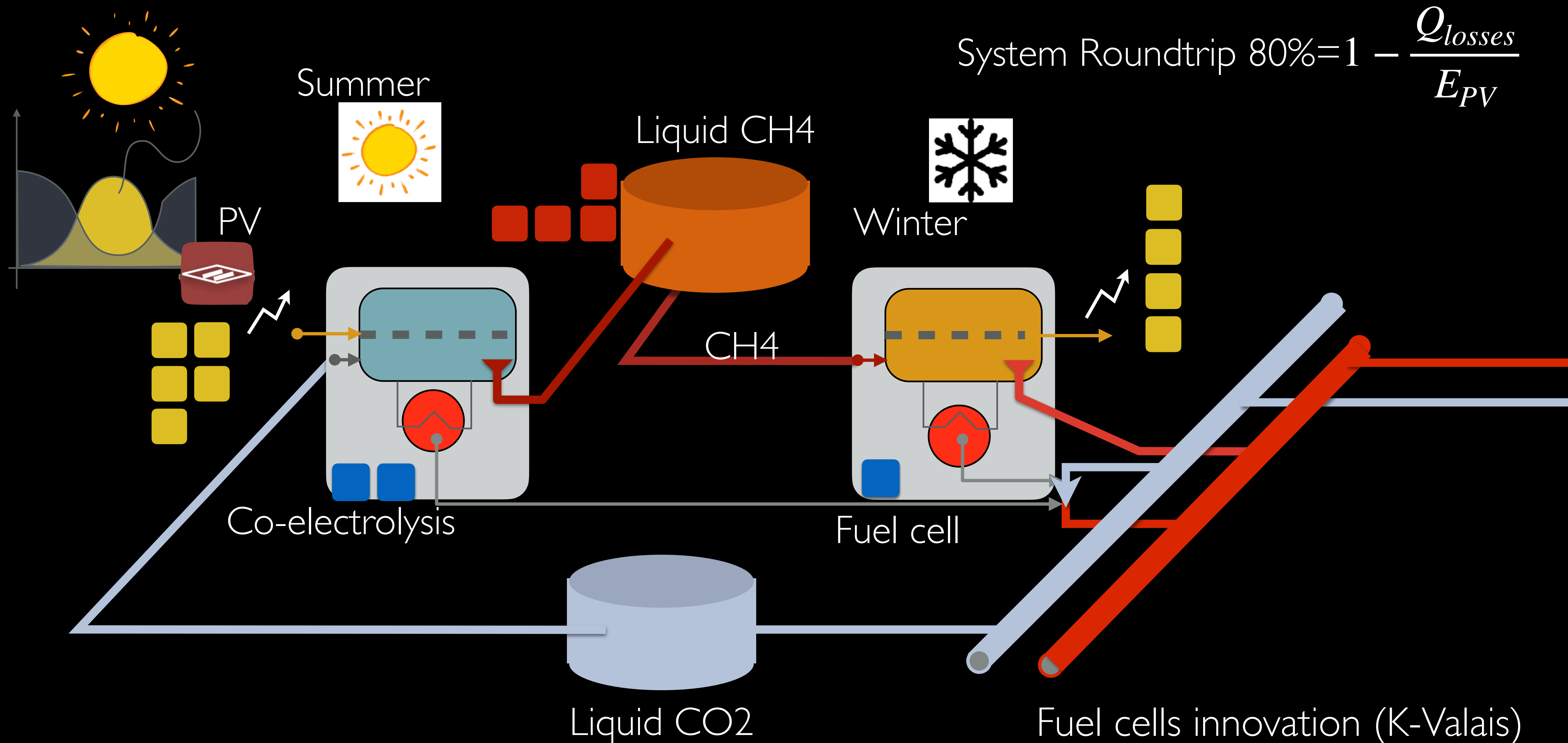
+20% per unit of gas

STORING EXCESS OF ELECTRICITY



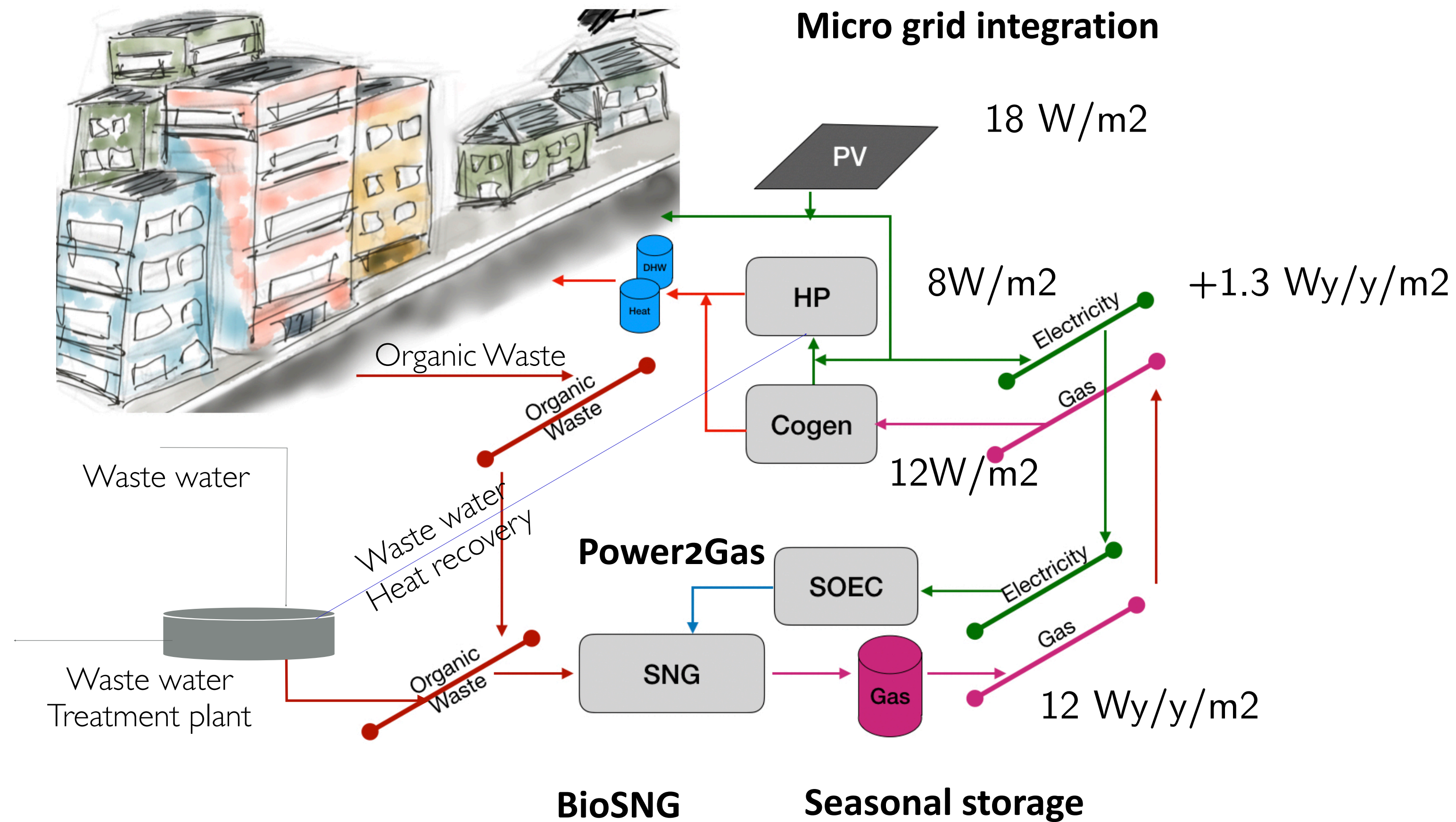
Artificial photosynthesis : 13-16 % Solar efficiency

INTEGRATED ENERGY MANAGEMENT



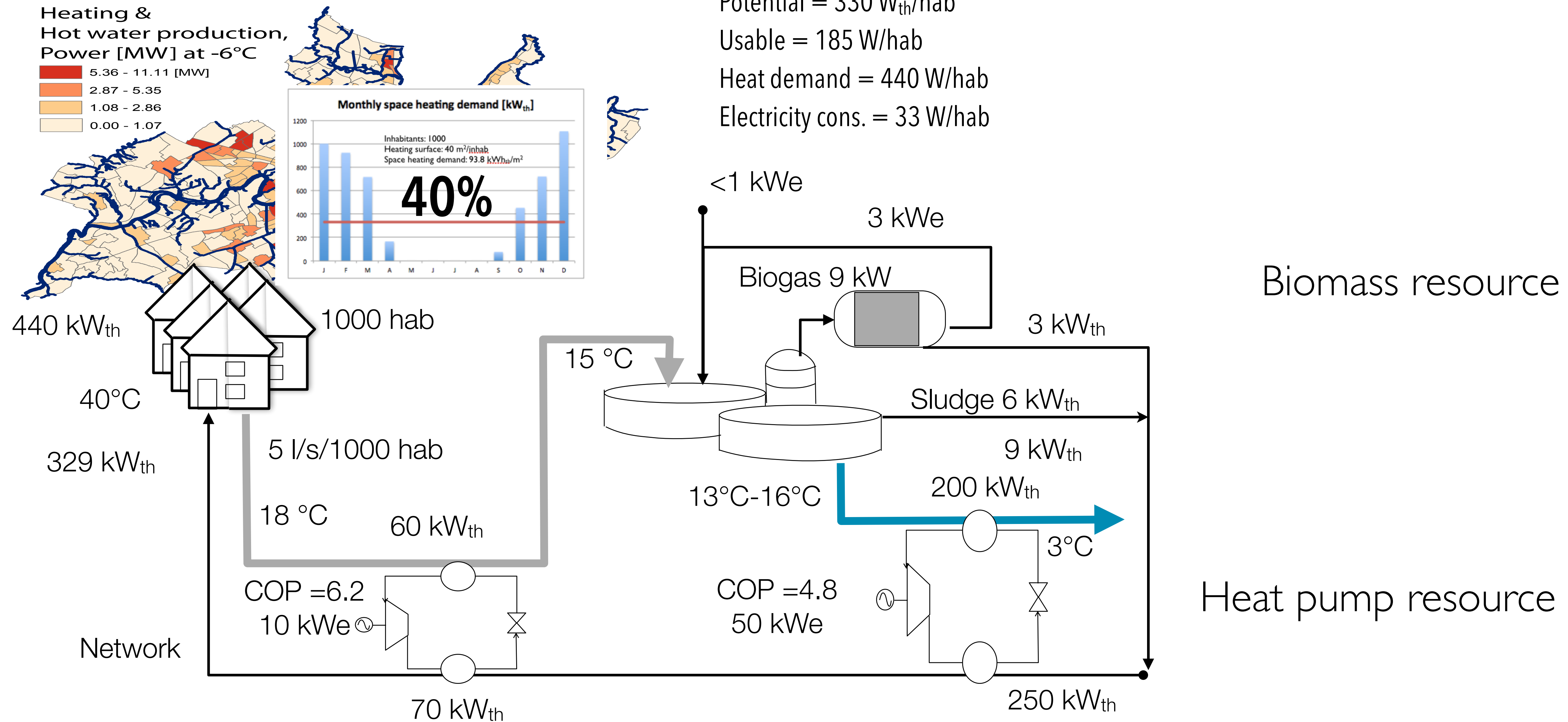
$$\text{System Roundtrip } 80\% = 1 - \frac{Q_{\text{losses}}}{E_{\text{PV}}}$$

- District scale => Exploring options

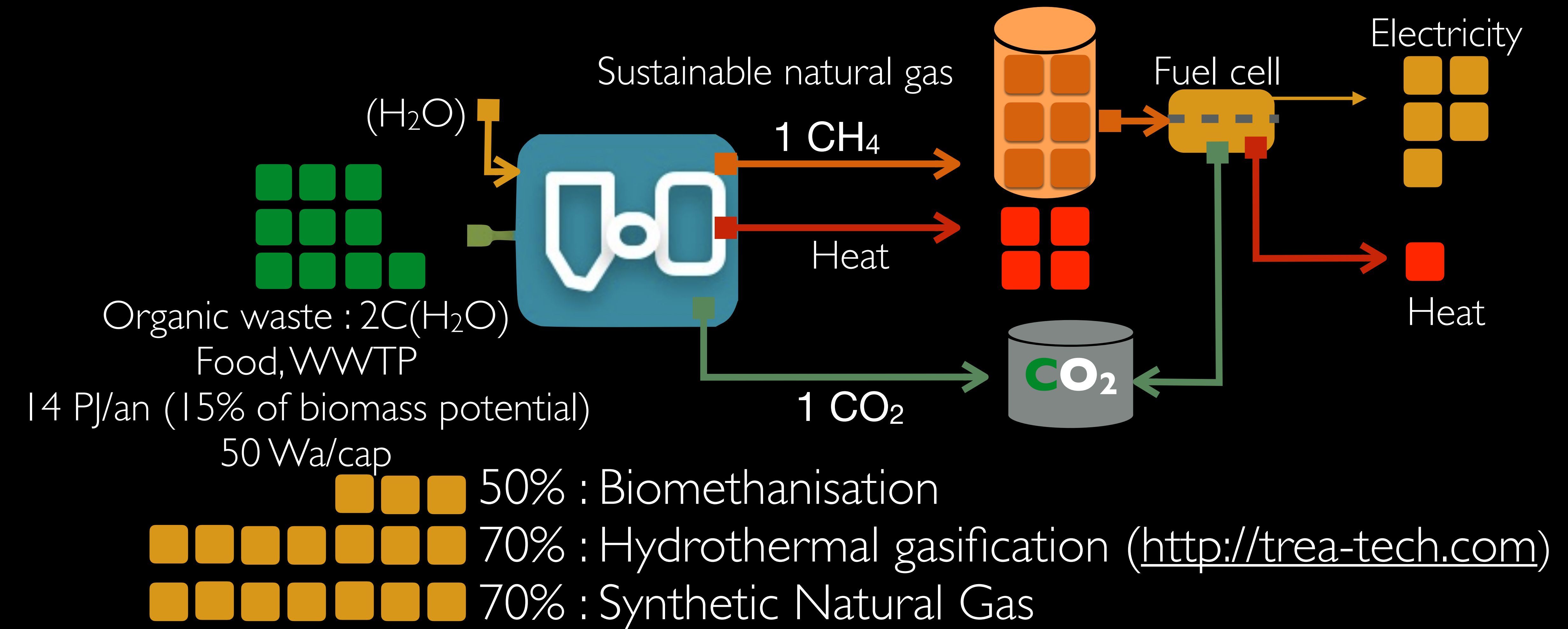


m² = heated surface

Waste water management : chase the heat sources

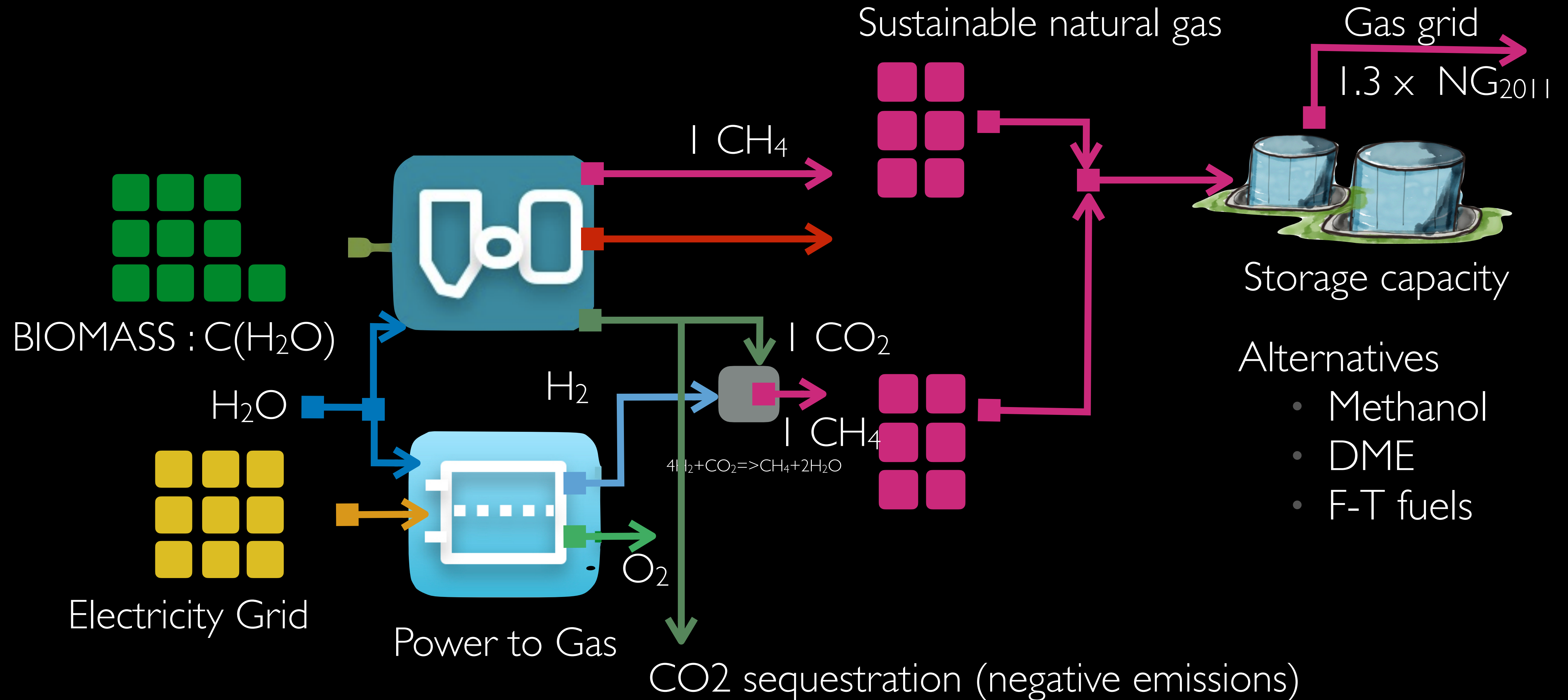


ORGANIC WASTE TO CLOSE THE ENERGY BALANCE

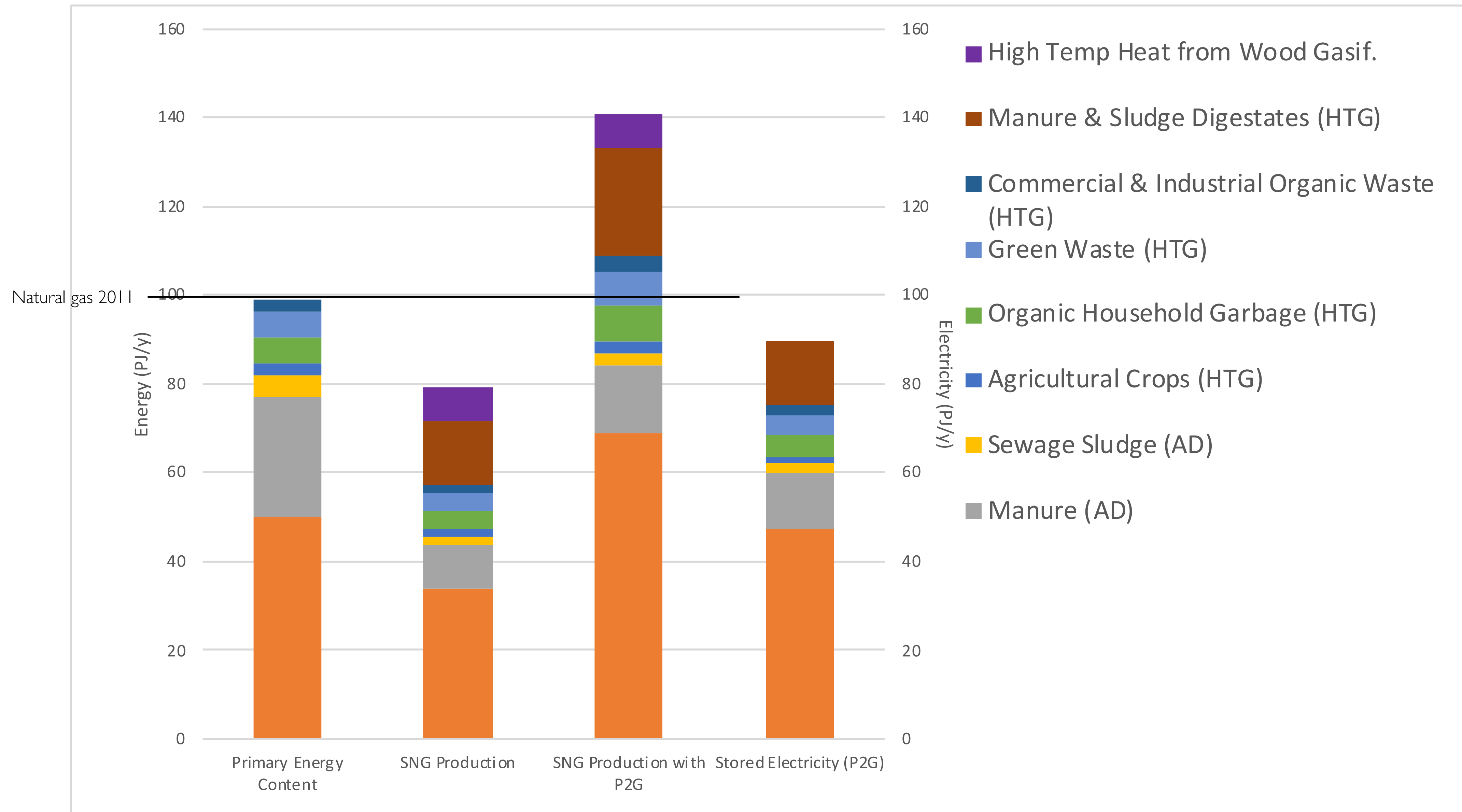




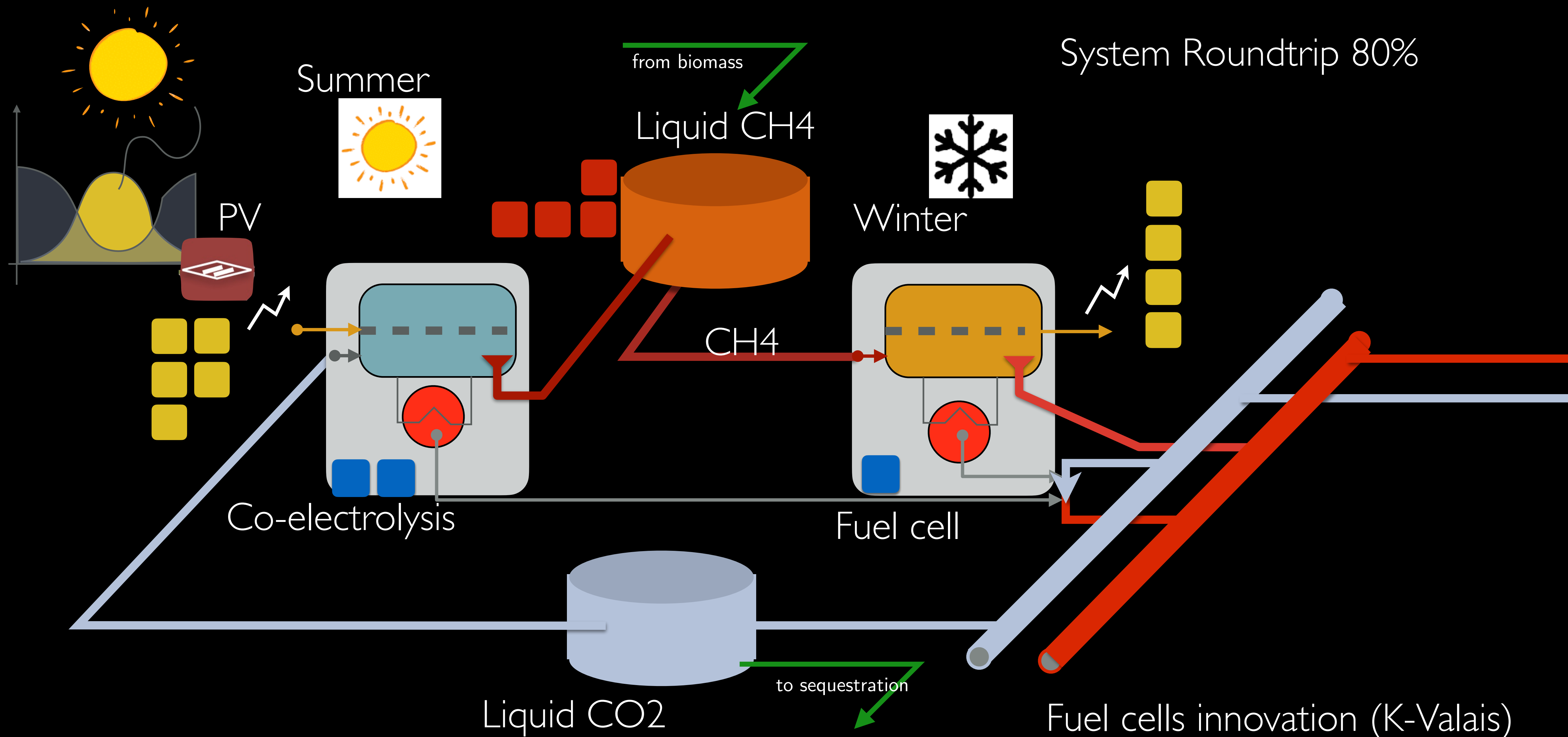
COMBINING BIOMASS CONVERSION AND ELECTROLYSIS



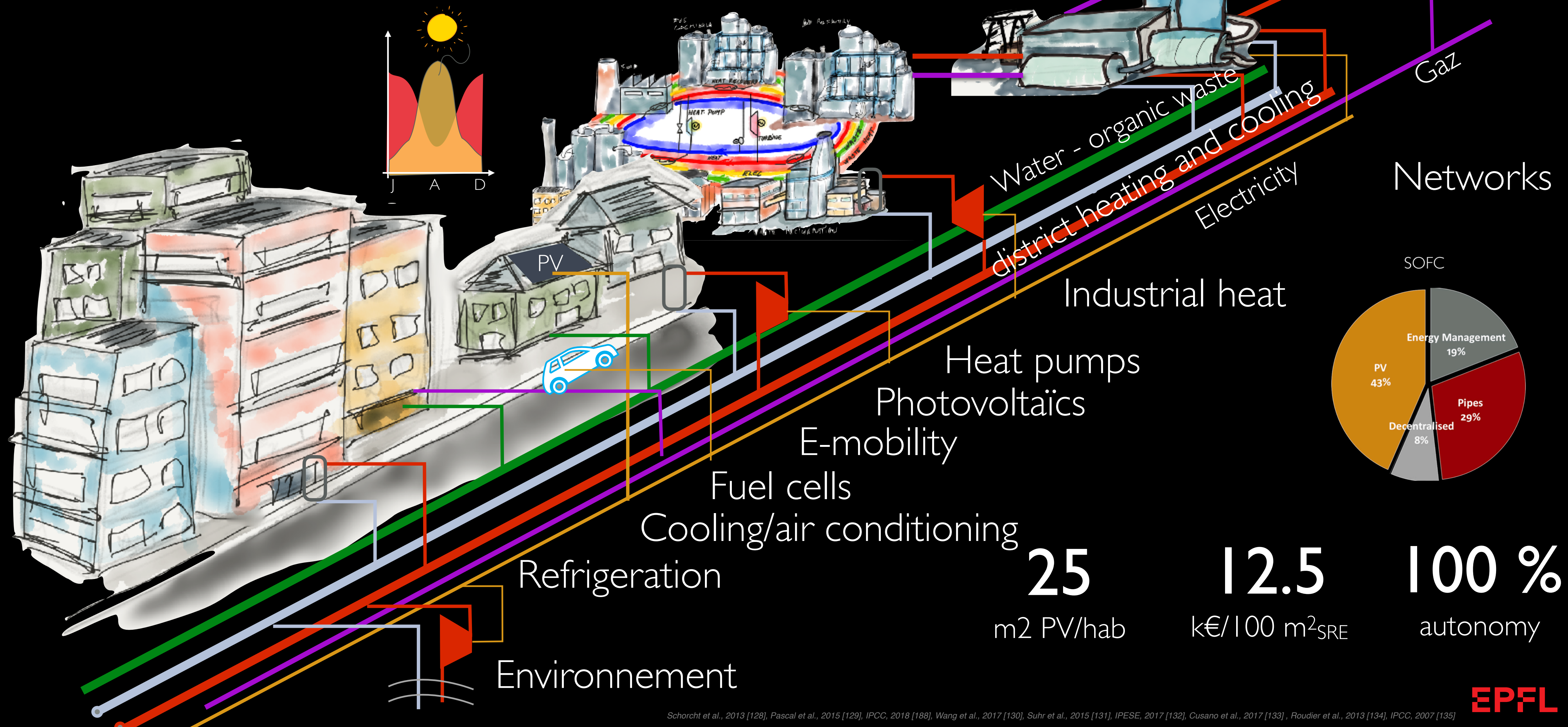
SNG from biomass potential in Switzerland



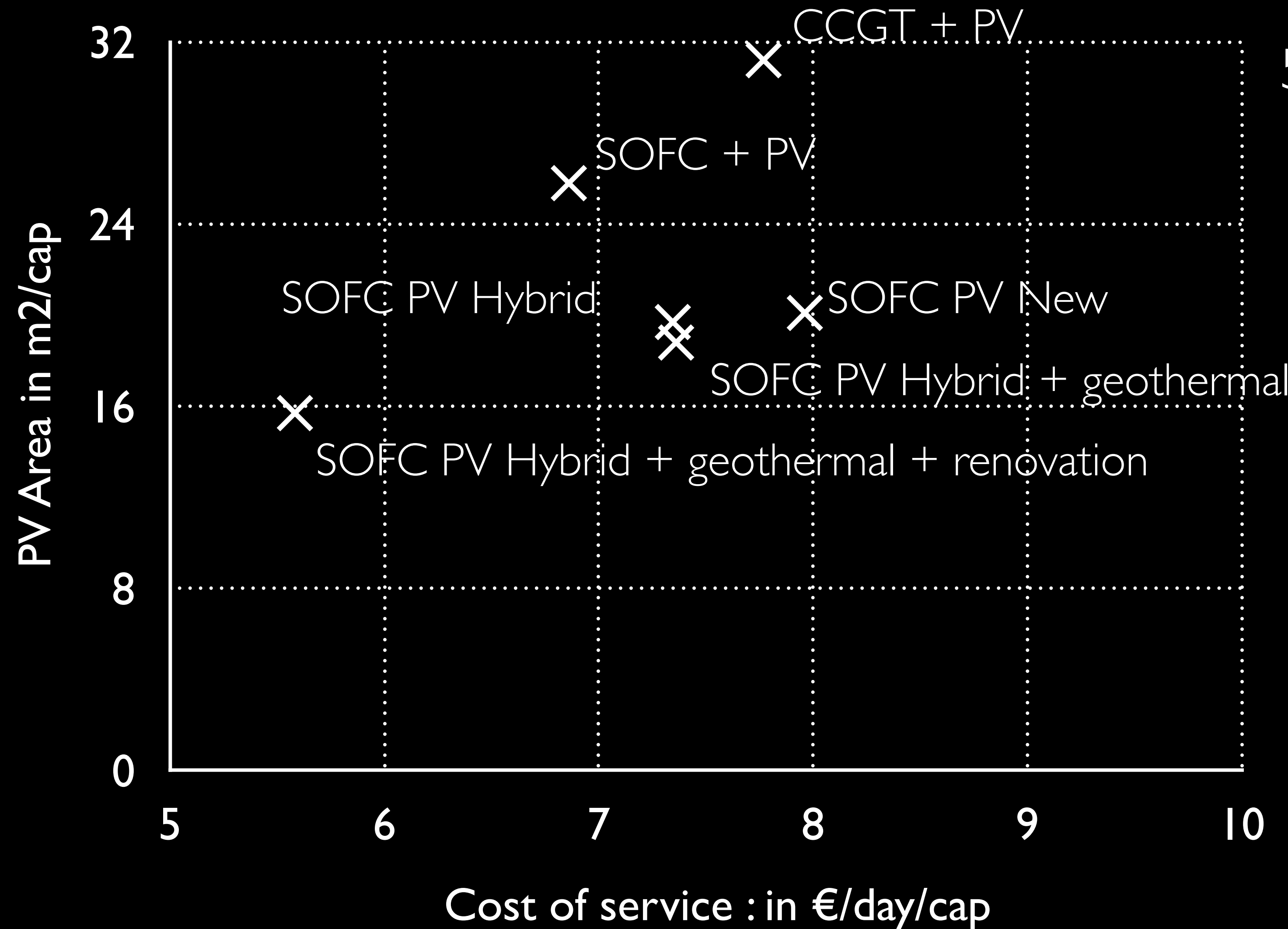
NEGATIVE EMISSION CITIES



AUTONOMOUS CITIES



EFFICIENCY VS COSTS

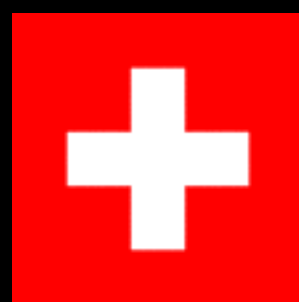


5.5 - 8 €/day/cap

16 - 32 m2 PV/cap

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

THE ENERGY SYSTEM



47%

Solar PV



Bio



Waste



Export



Waste water

Environment

?



36%



products

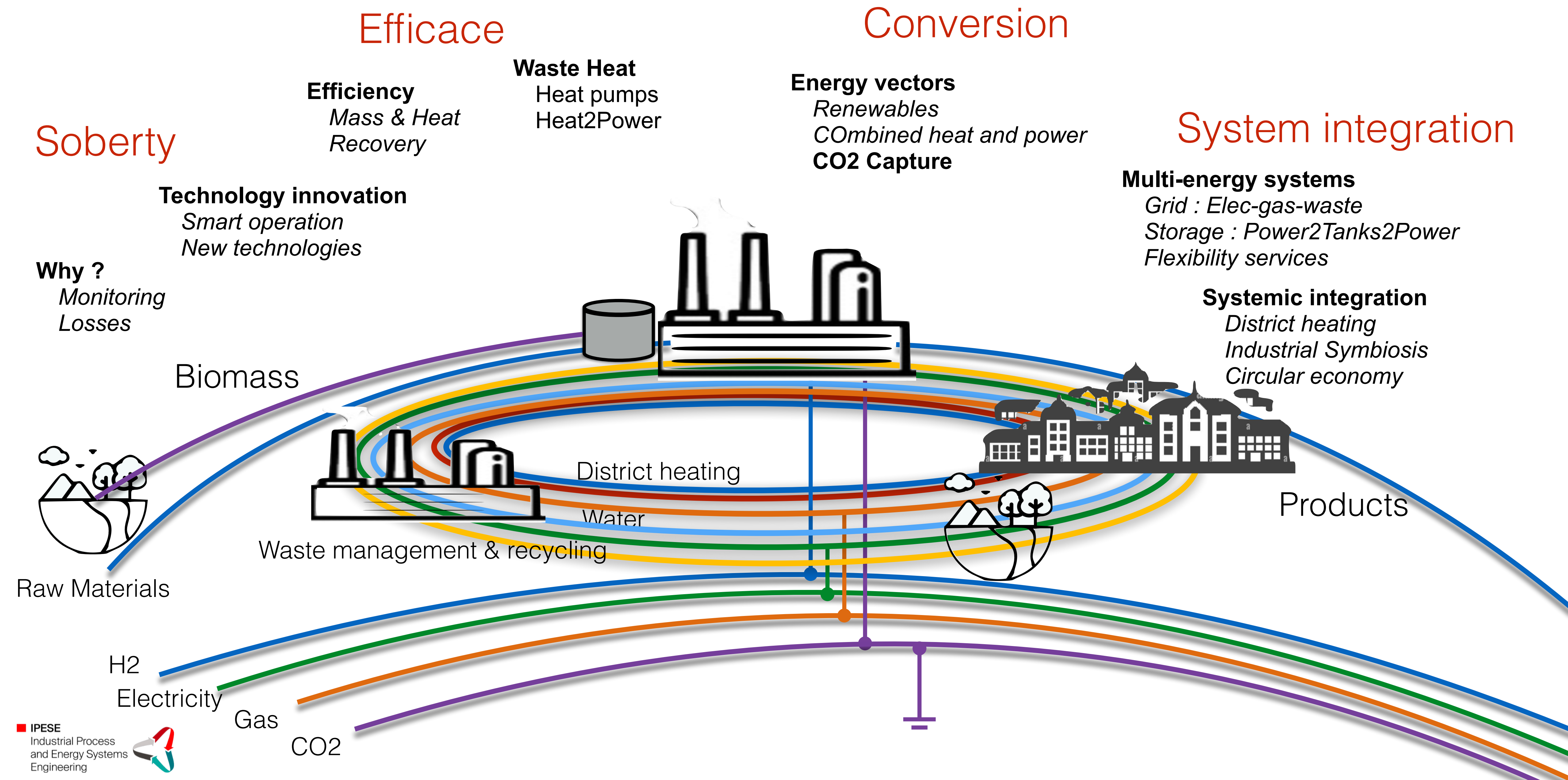
17%

2%



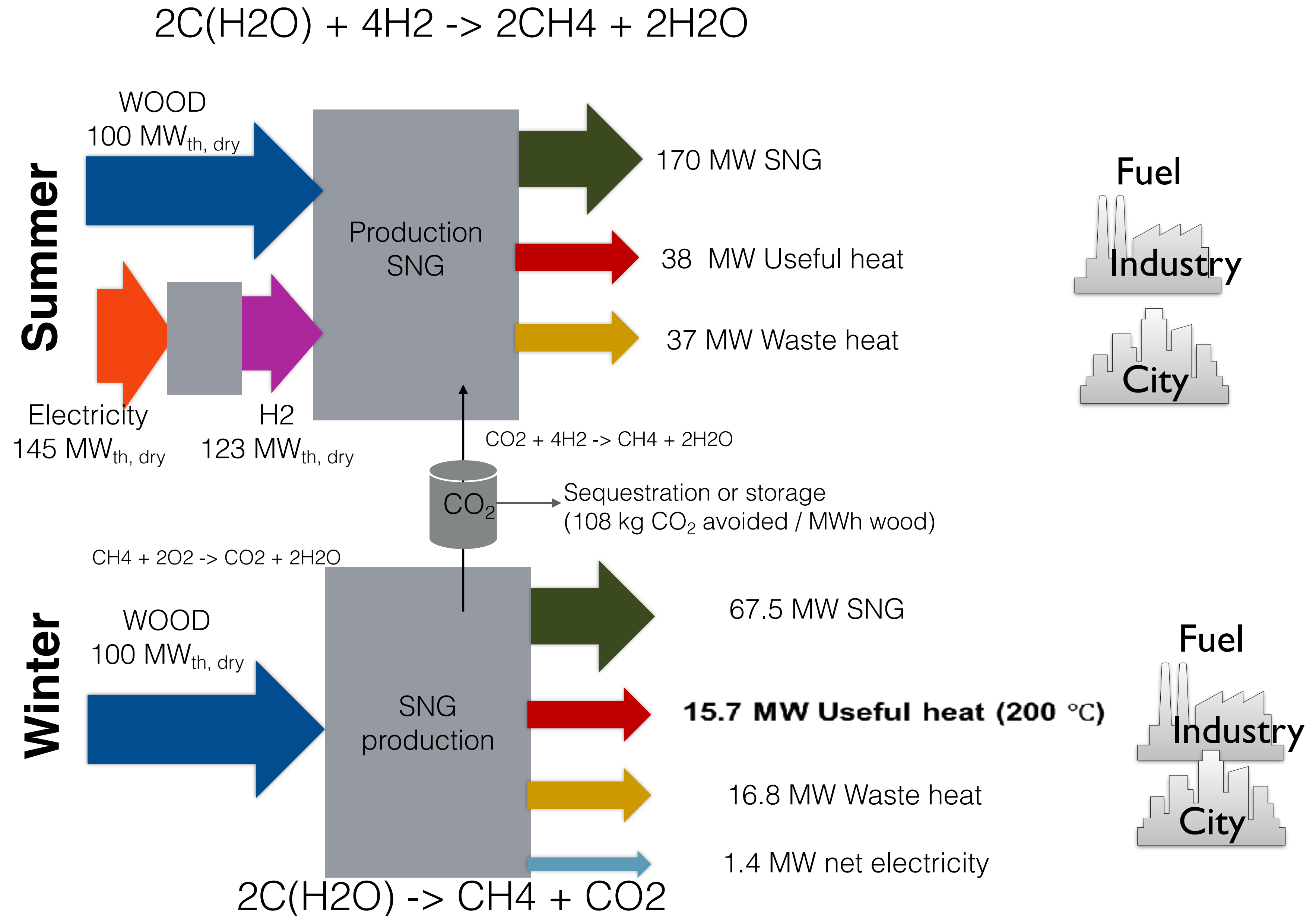
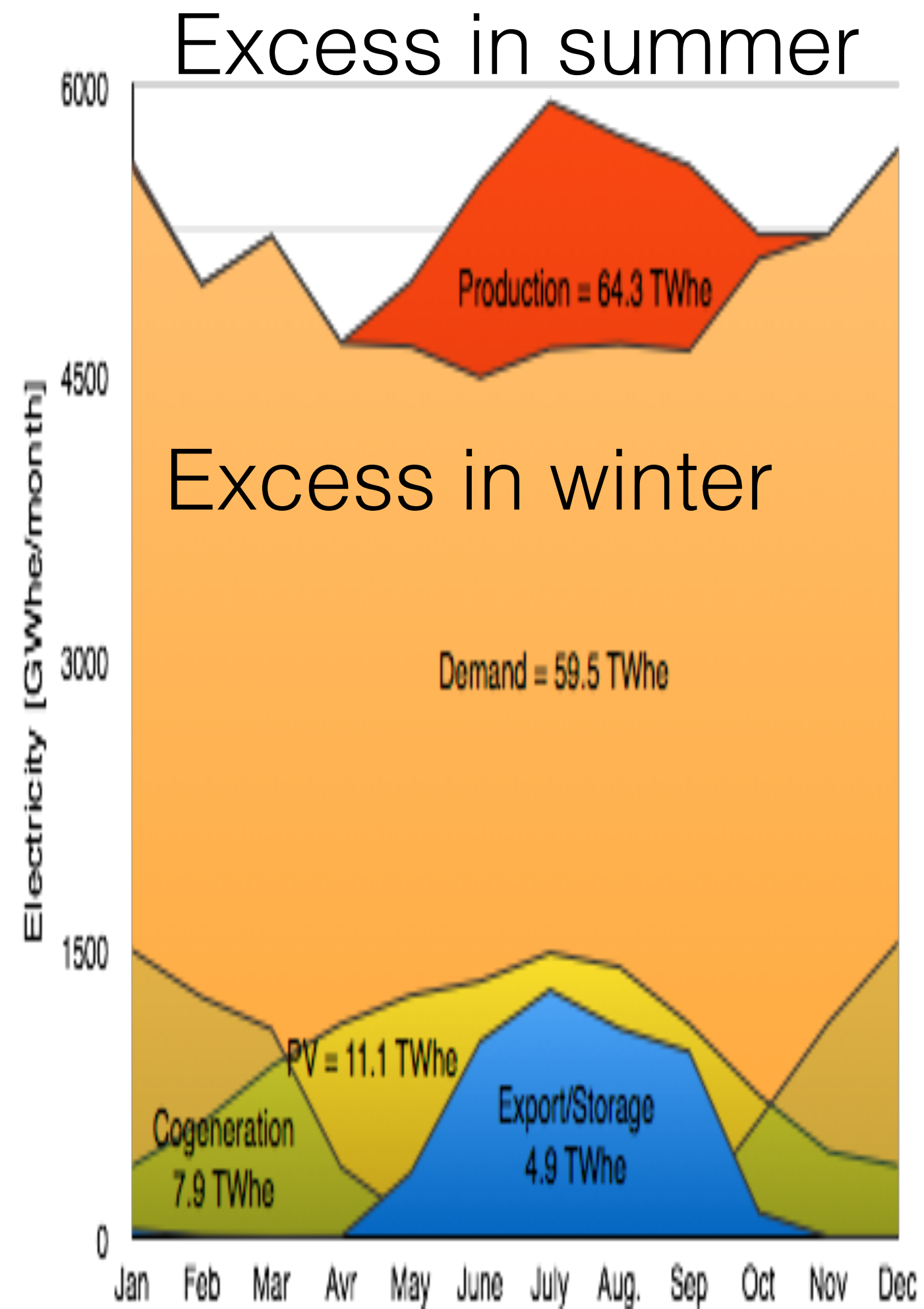
100 l gasoline/hab/year Electricity

EPFL Industrial clusters : industry in the territory



Swiss Energy System

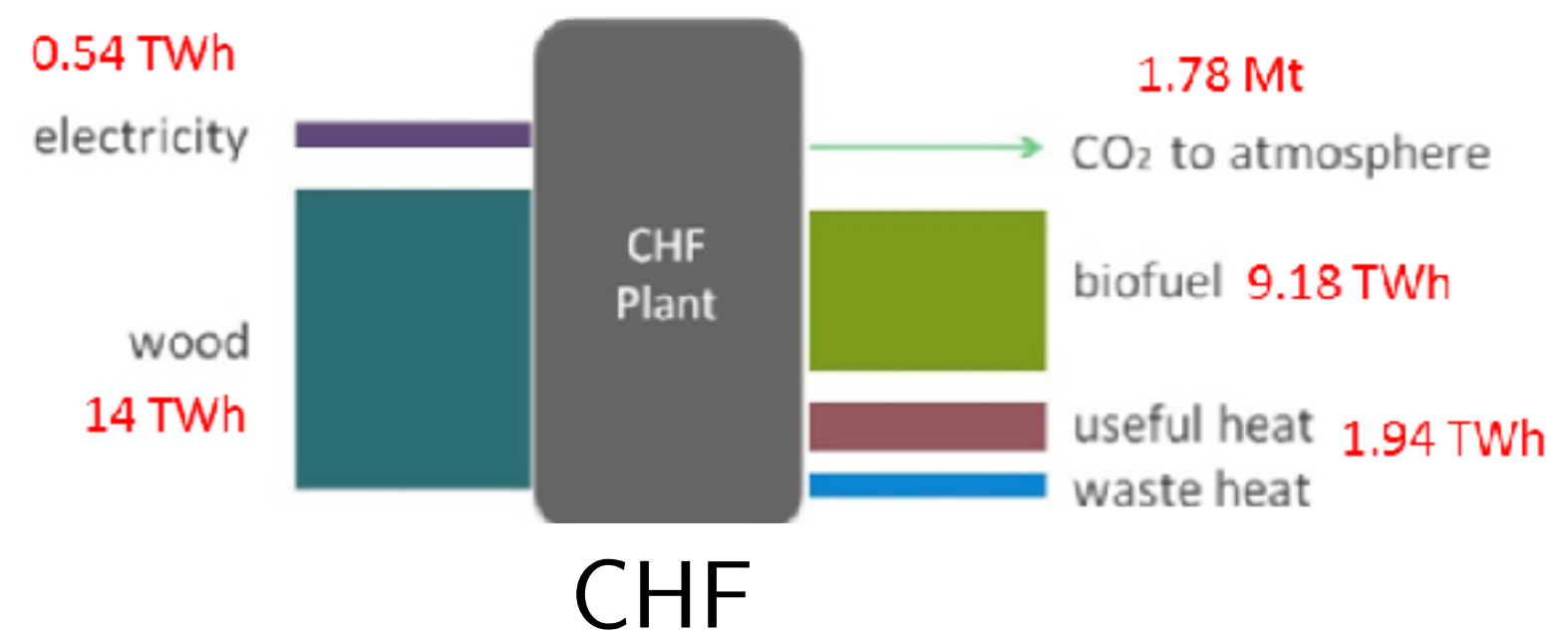
Storage Cogeneration Photovoltaic Demand Total Production



Combined Heat and Fuel (CHF) production

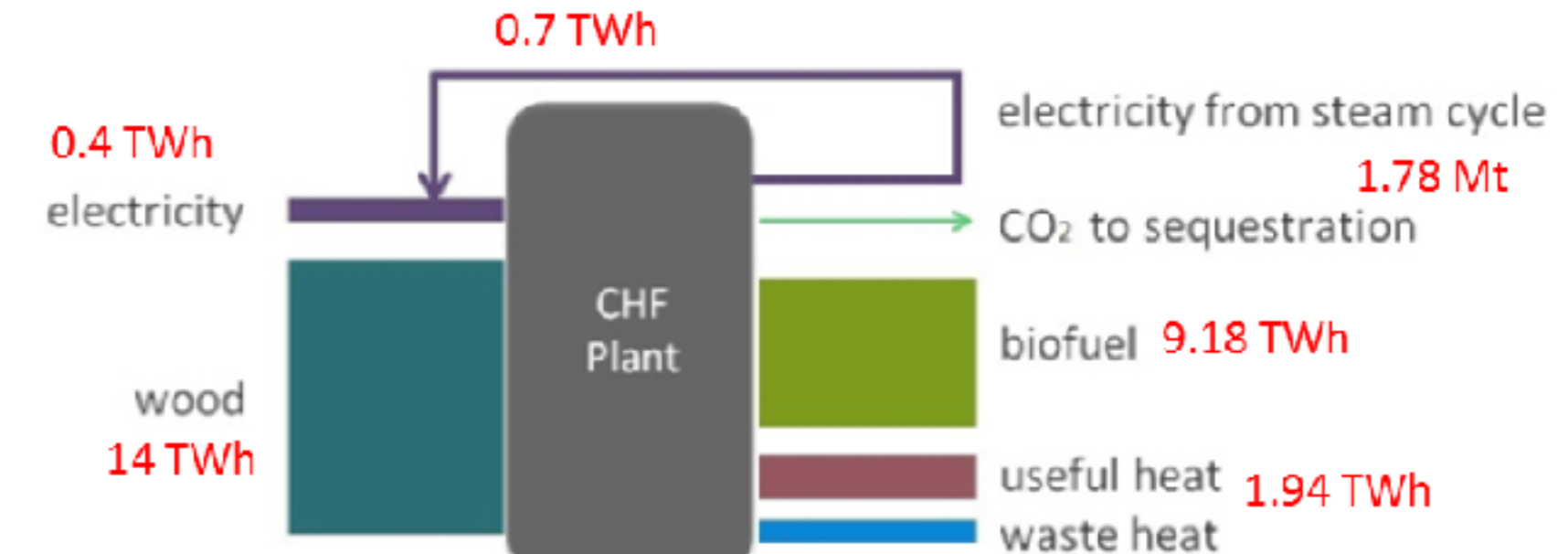
Substituted fossil carbon per unit of biogenic carbon in wood

1.6
wood boiler



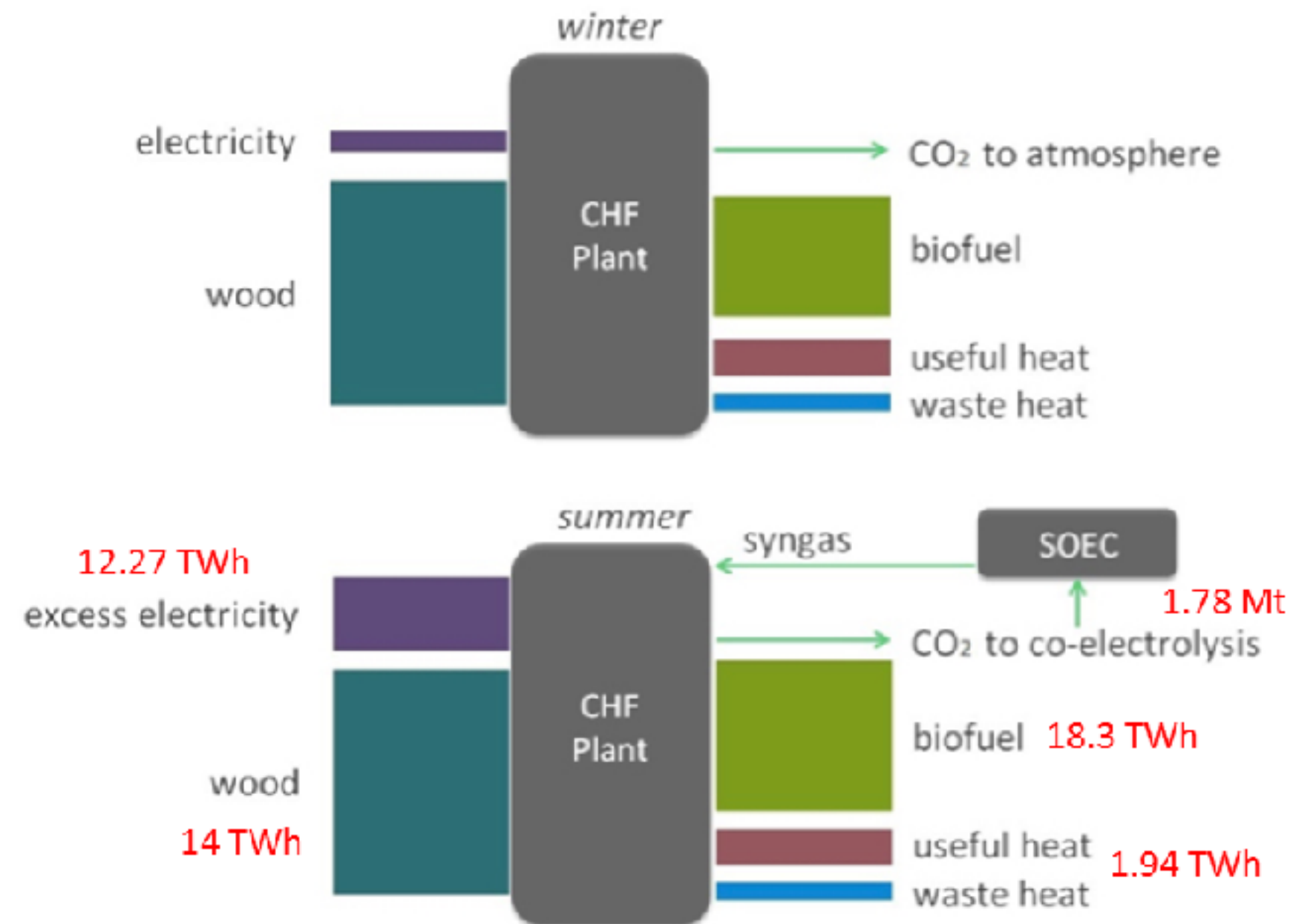
CHF

2.8
wood boiler



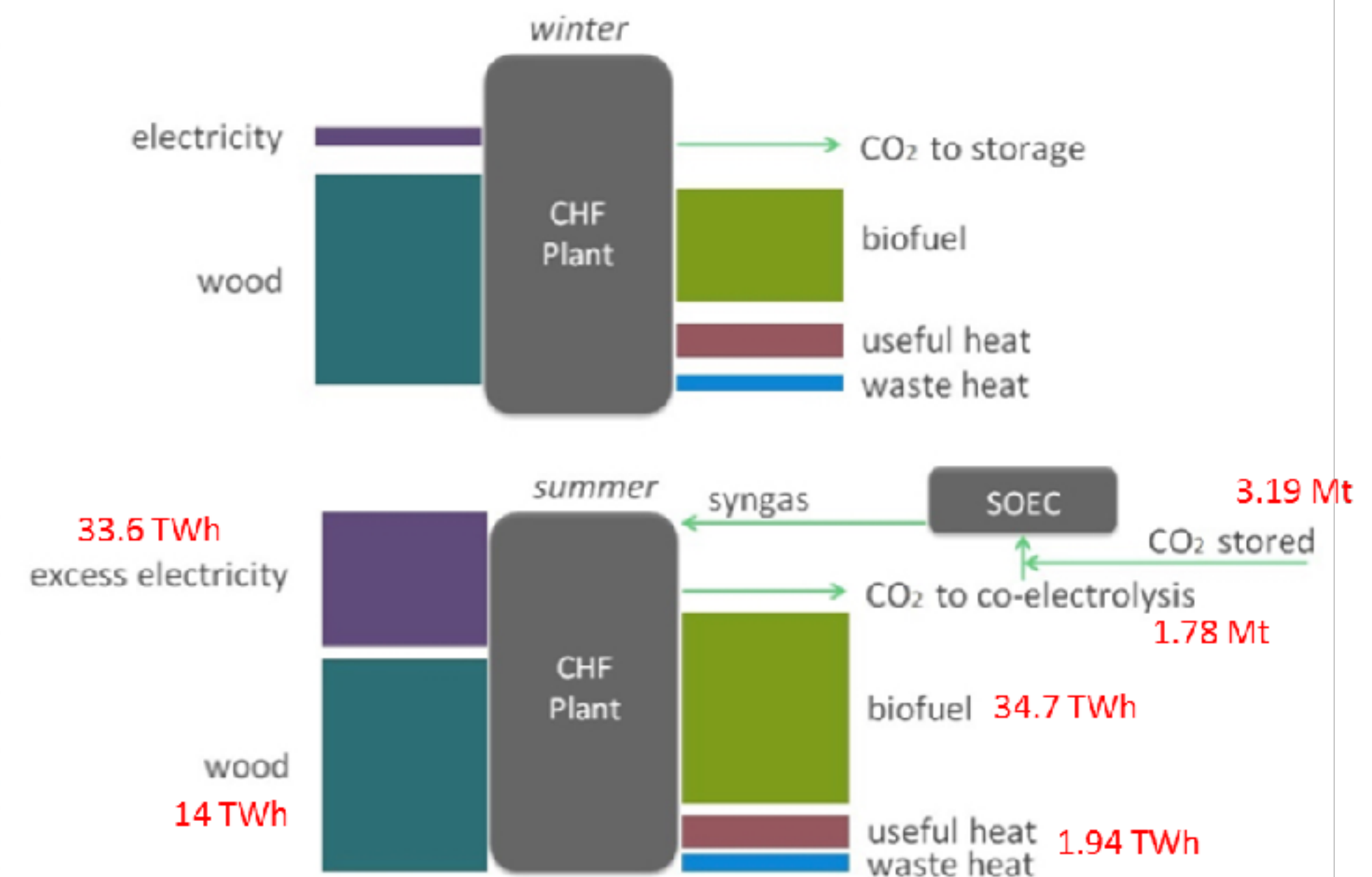
CHF + Carbon sequestration

2.1
wood boiler



CHF + P2G without CO₂ storage

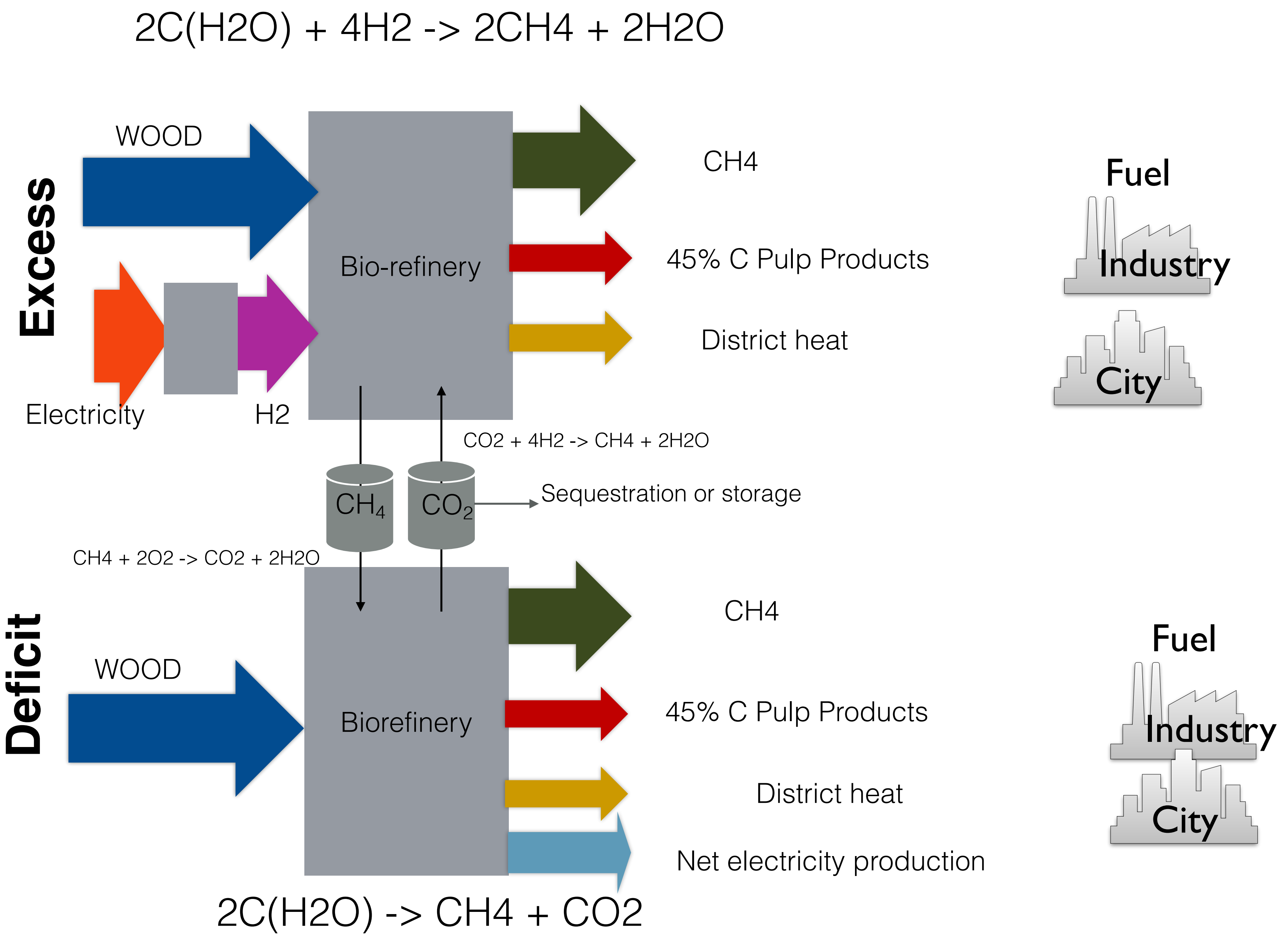
3.0
wood boiler



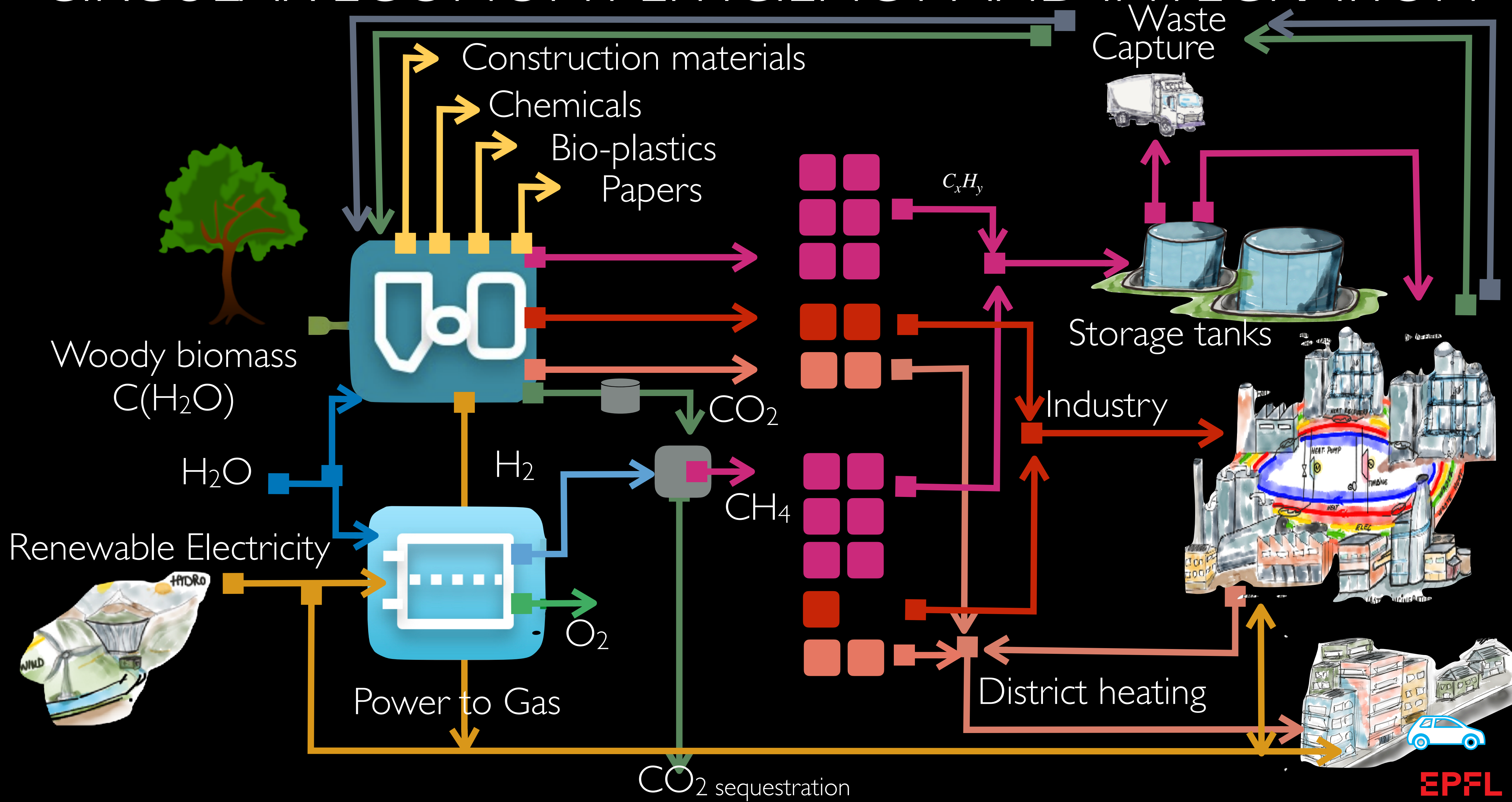
CHF + P2G with CO₂ storage

For wood boiler (WB) 0.3 kg of fossil carbon are substituted per kg of biogenic carbon

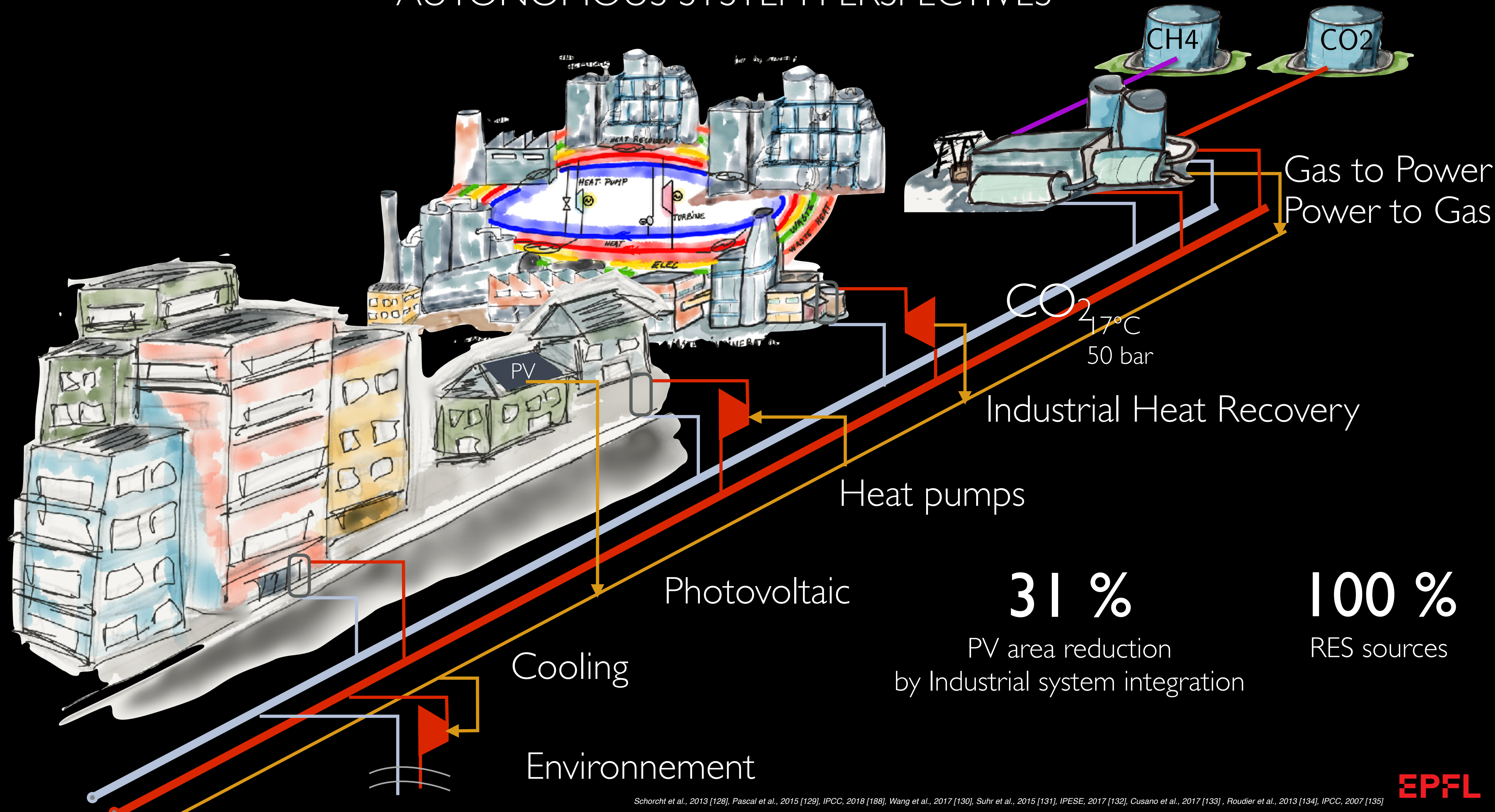
Swiss Energy System



CIRCULAR ECONOMY-EFFICIENCY AND INTEGRATION



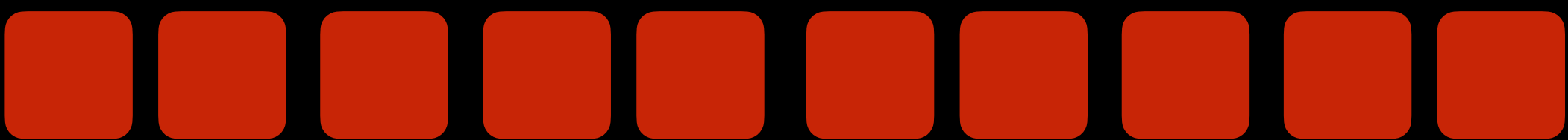
AUTONOMOUS SYSTEM PERSPECTIVES



MOBILITY



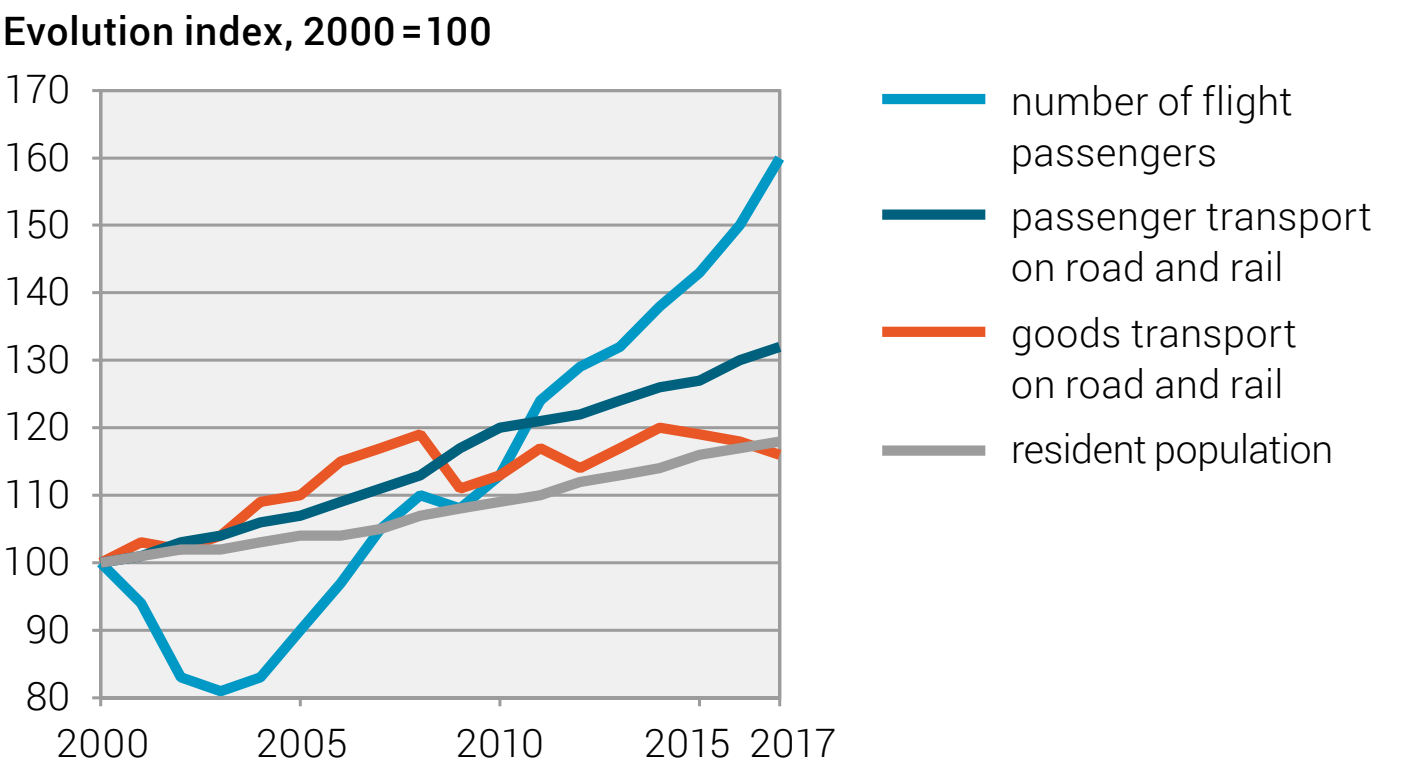
36%



Key figures on mobility and transport

	Value	Year	Change from 2000
Total costs ¹ of transport	CHF 89.7 billion	2016	...
National road network length	1 859 km	2018	+13%
Stock of passenger cars	4 602 688	2018	+30%
Average daily distance per person ²	36.8 km	2015	+5%
Passenger transport performance ³	134.6 billion person-km	2017	+32%
Public transport share	19%	2017	+3 pp
Goods transport performance ⁴	27.9 billion tonnes-km	2018	+19%
Rail share	37%	2018	−5 pp
Persons killed in road traffic	233	2018	−61%
Transport's ⁵ share of CO2 emissions	39%	2017	+3 pp

Passenger transport is growing faster than the population



Note: base passenger transport=person-km, base goods transport=tonne-km

- 1) Road, rail and air transport, without human-powered mobility (on foot, by bike). Including non-material costs due to damage to environment and health as well as accidents
 - 2) Distances inside Switzerland
 - 3) Rail and road incl. human-powered mobility
 - 4) Rail and road. In combined transport calculated without the tare weight of the loaded road vehicles, containers and swap bodies (i.e. for rail: net tonne-kilometres)
 - 5) Excl. international aviation
- pp = percentage points
- Sources: FSO – Goods transport statistics (GTS), Costs and funding of transport (CFT), Passenger transport performance (PV-L); FSO, ARE – Mobility and transport microcensus (MTMC); FSO, FEDRO – Stock of road motor vehicles (MFZ); FEDRO, FSO – Road accidents (SVU); FEDRO – Length of Swiss motorway network; FOEN – Greenhouse gas inventory

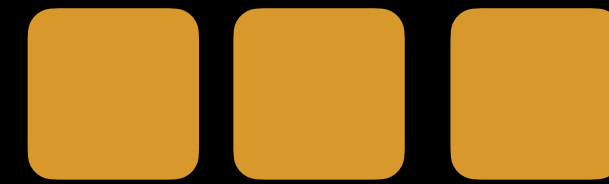
100 l gasoline/hab/year

MOBILITY



36%

Efficacité



Soft Mobility

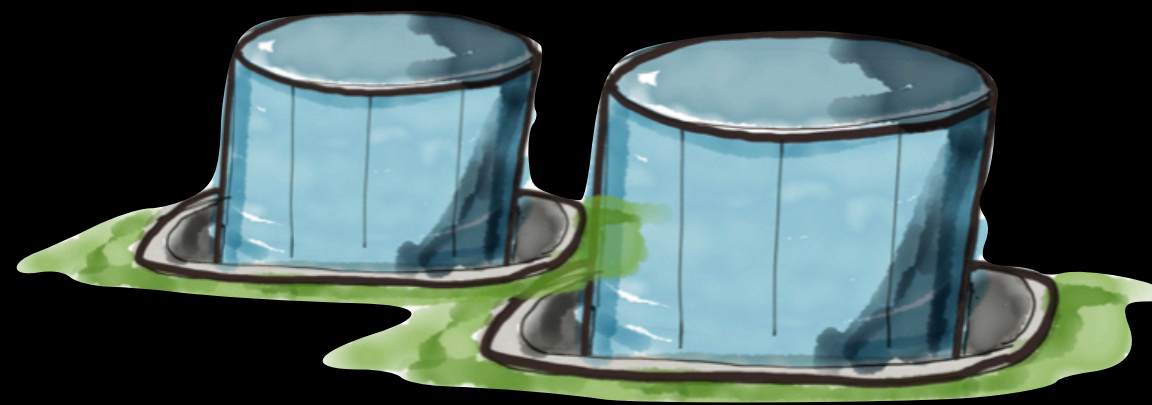
Public transport : électric/hybrid (mobilitylab.ch)

Electric vehicles : 400 km

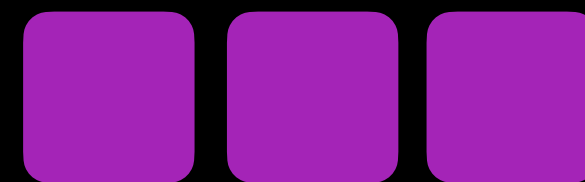
Fast charge (WattAnyWhere)

Range extenders vehicules (H2, CH4)

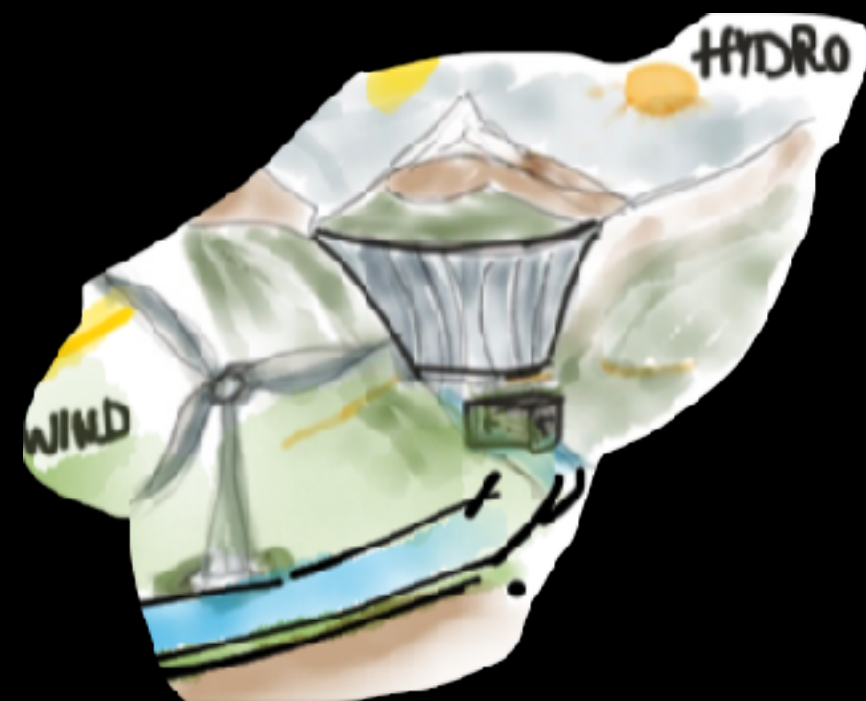
CO2 capture on board



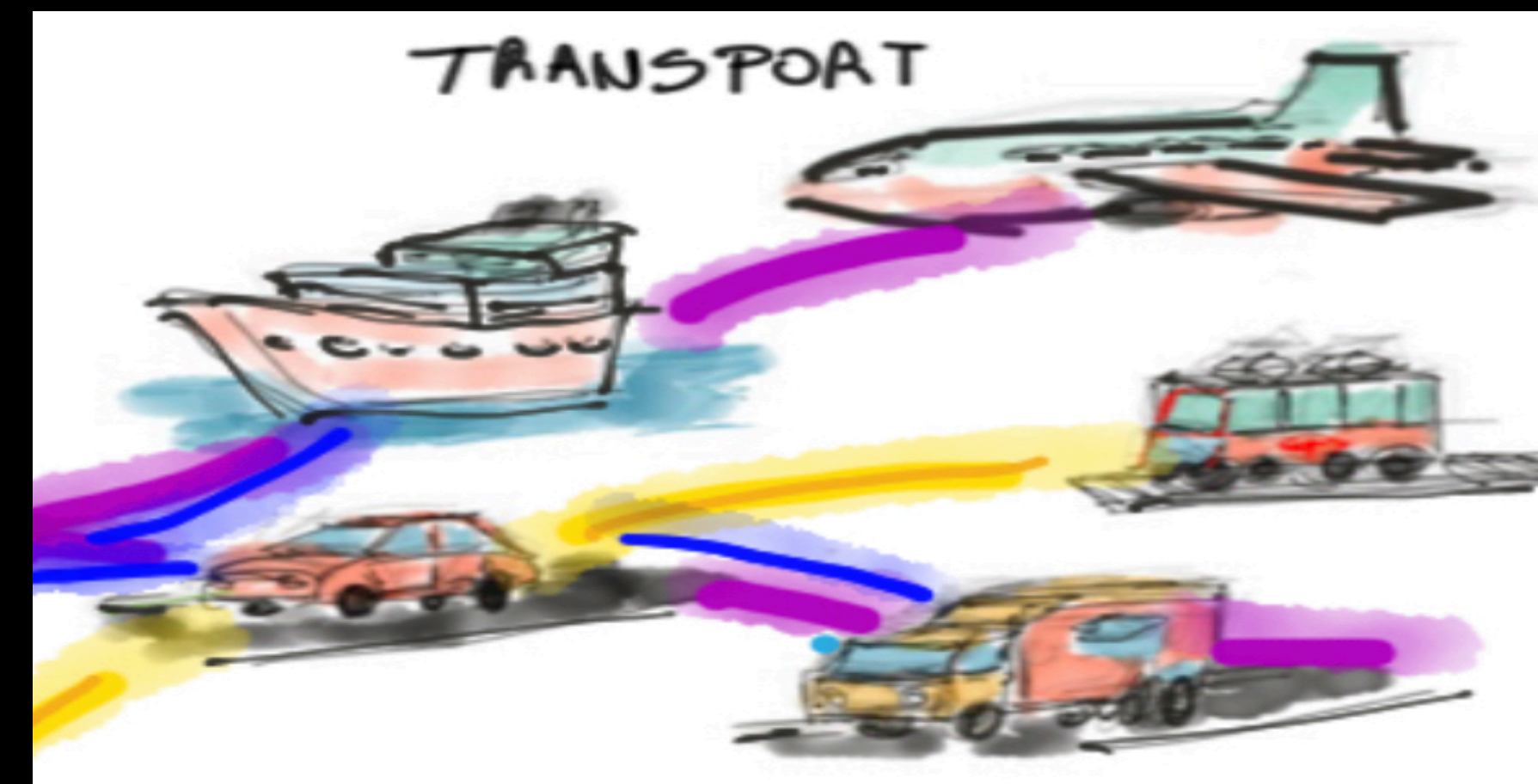
Bio-Fuel



Wind and Hydro



100 l gasoline/hab/year



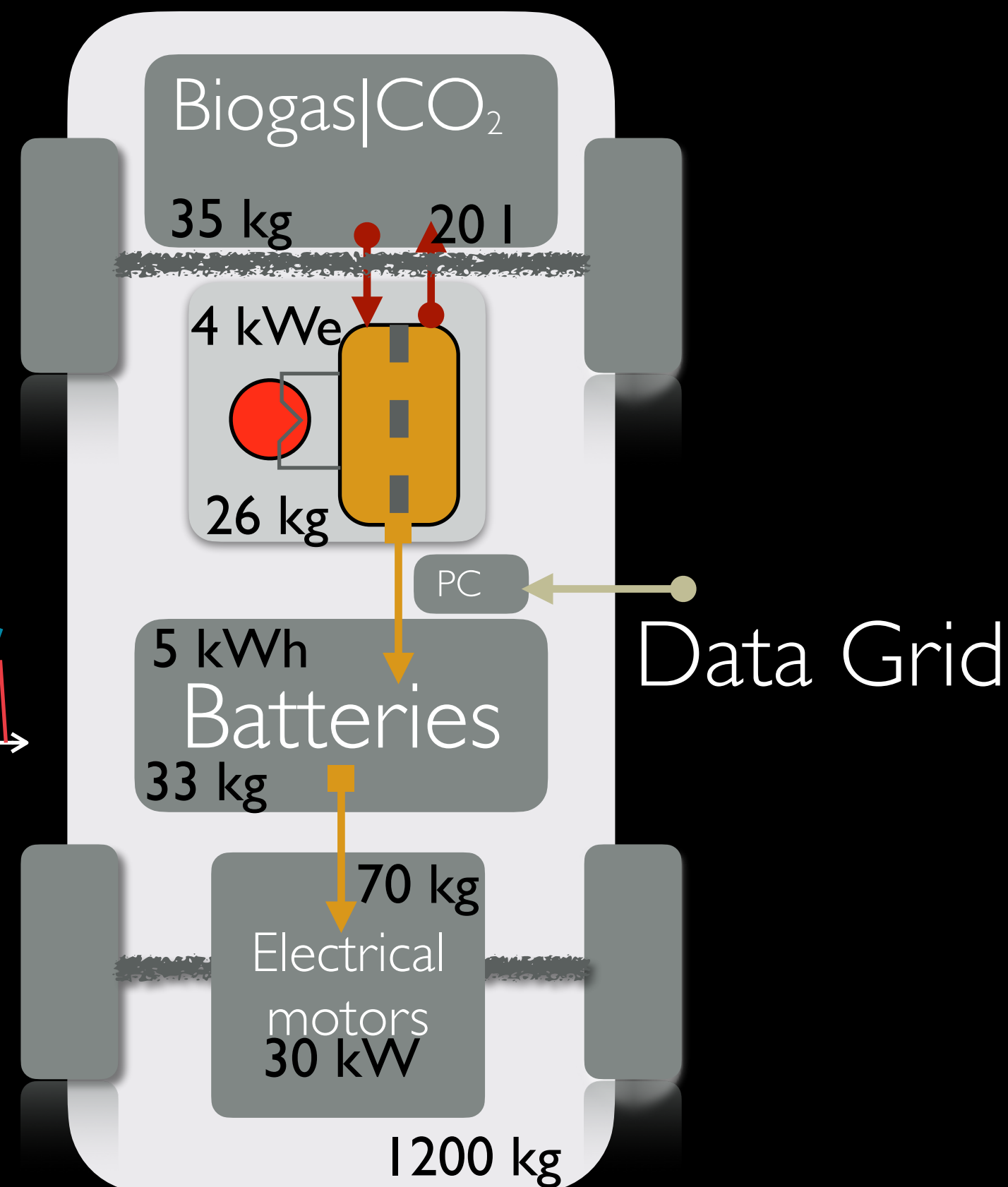
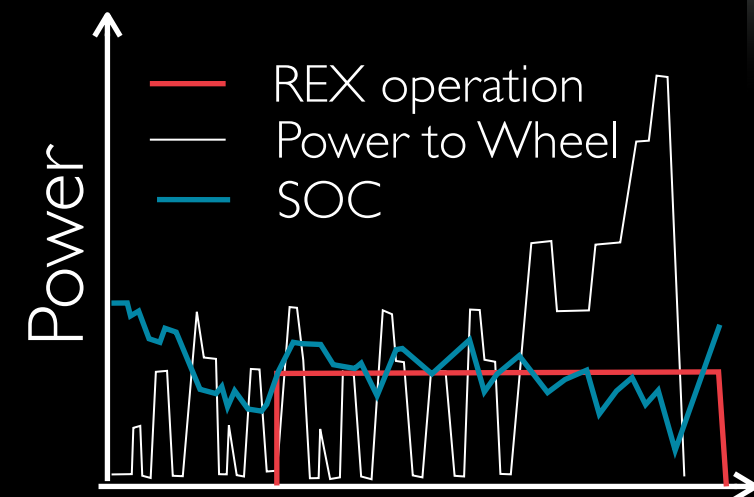
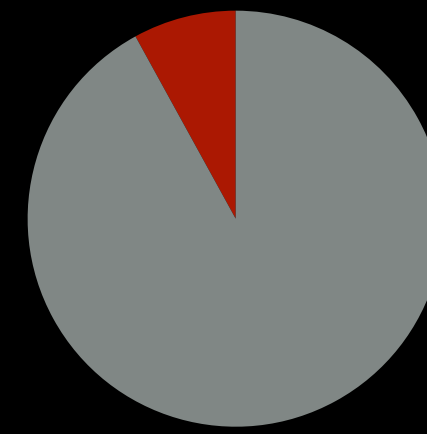
“RANGE EXTENDERS” VEHICLES

Driving mode

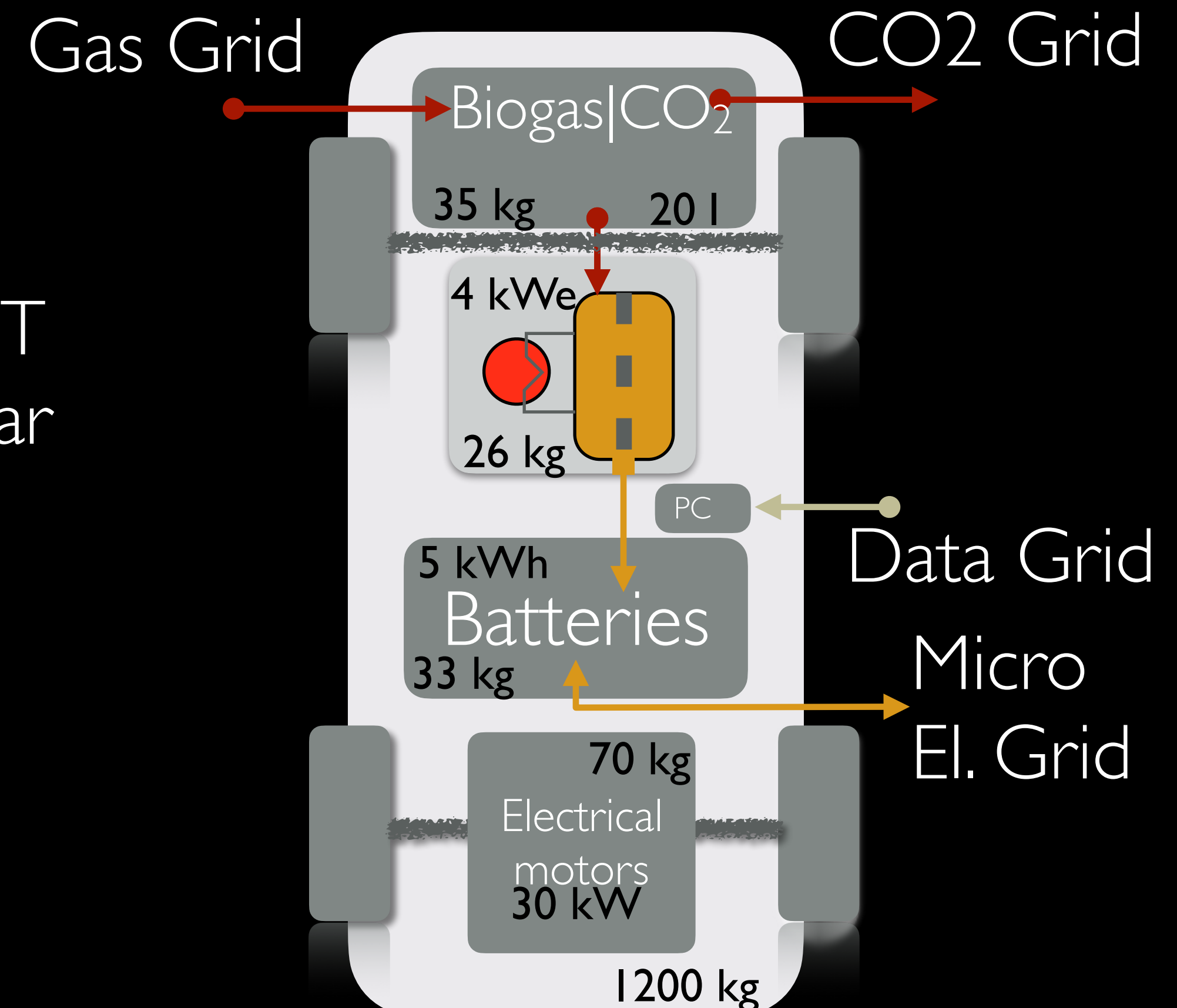
Autonomy : 950 km
Cons : 1.1 l/100 km

Parking mode

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



SOFC-GT
Hybrid car

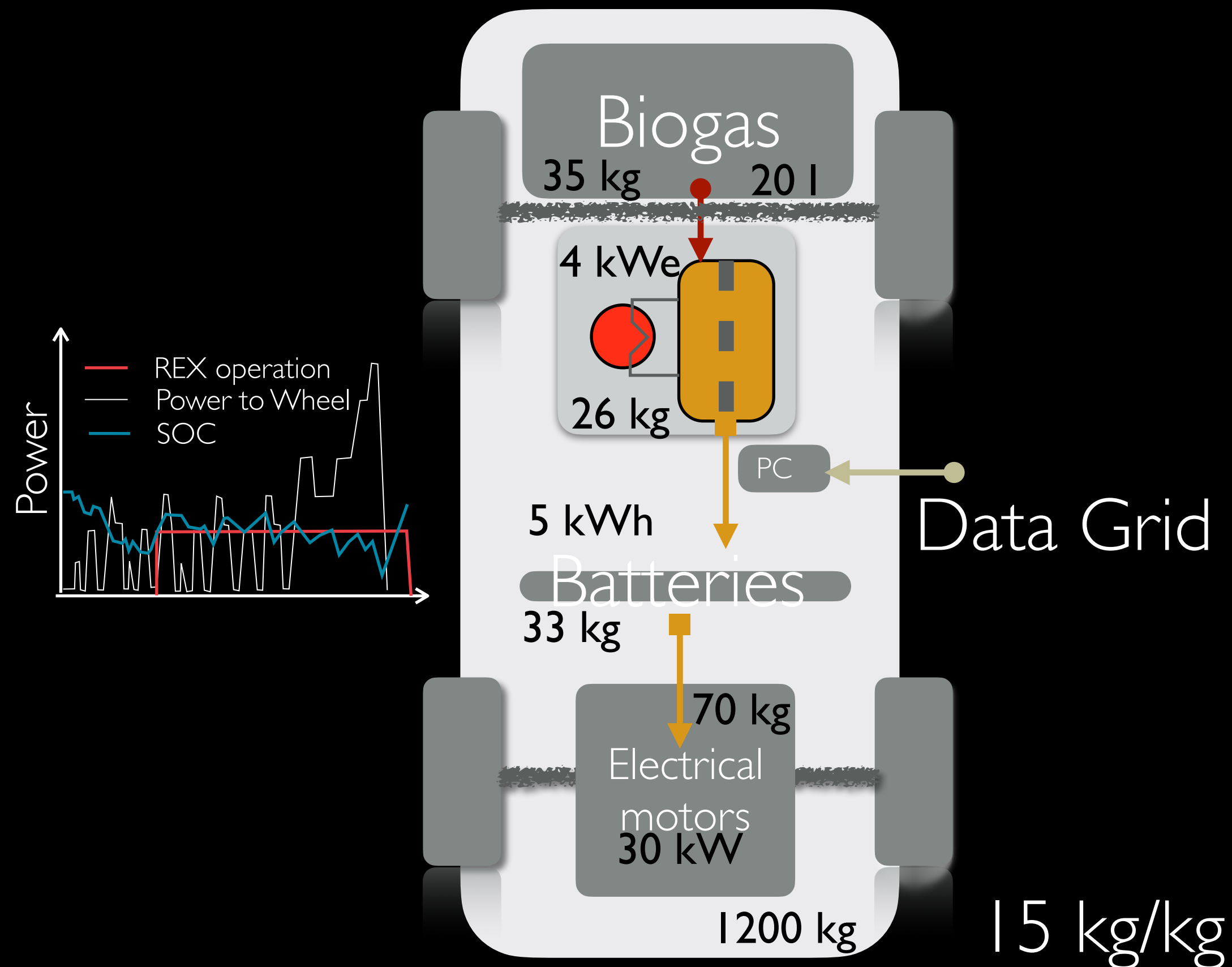


SMART CARS

12 m² PV/car (hybrid SOFC-GT)

Autonomy : 950 km

Cons : 1.1 l/100 km

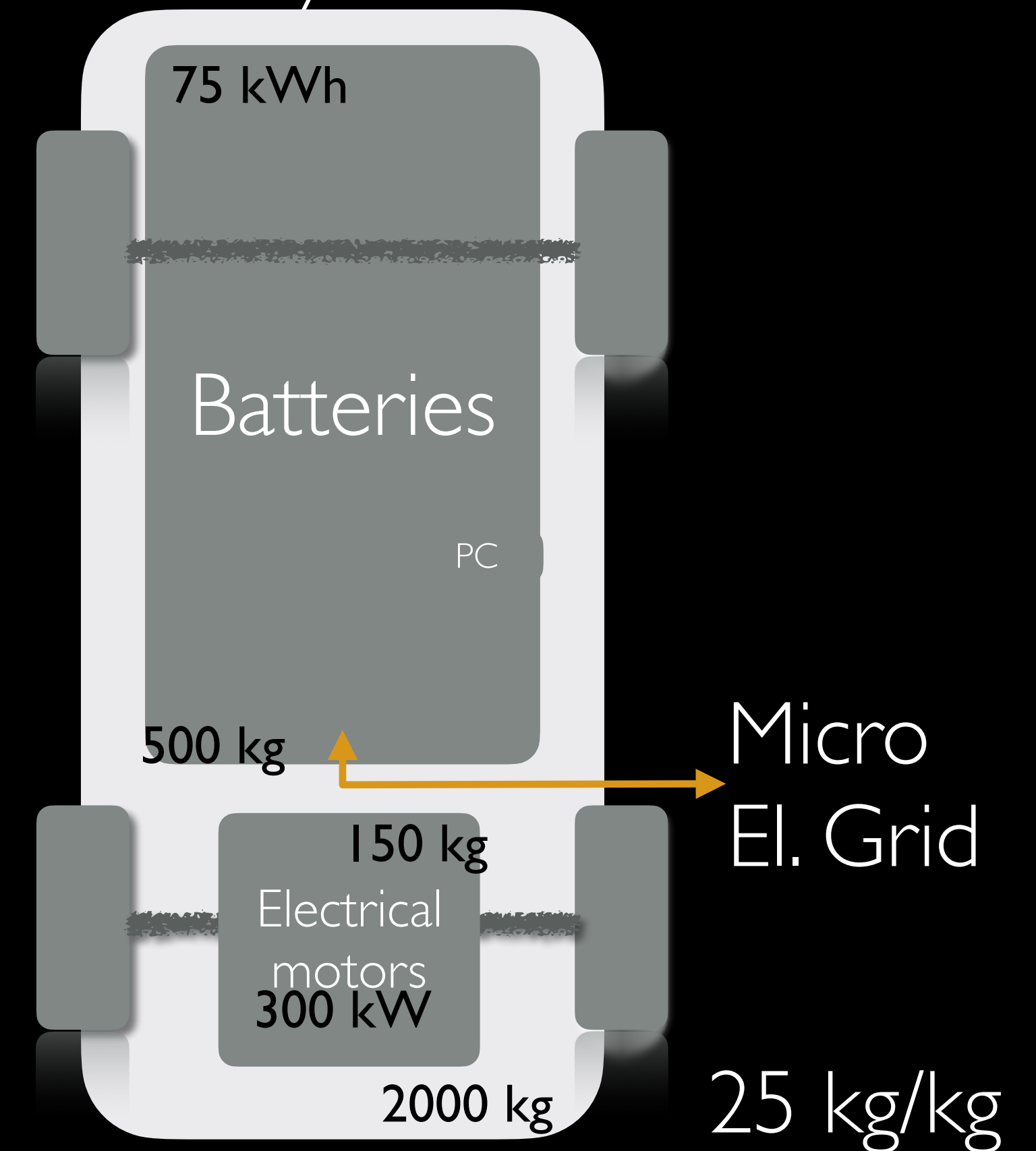


24m² PV/car (Tesla)

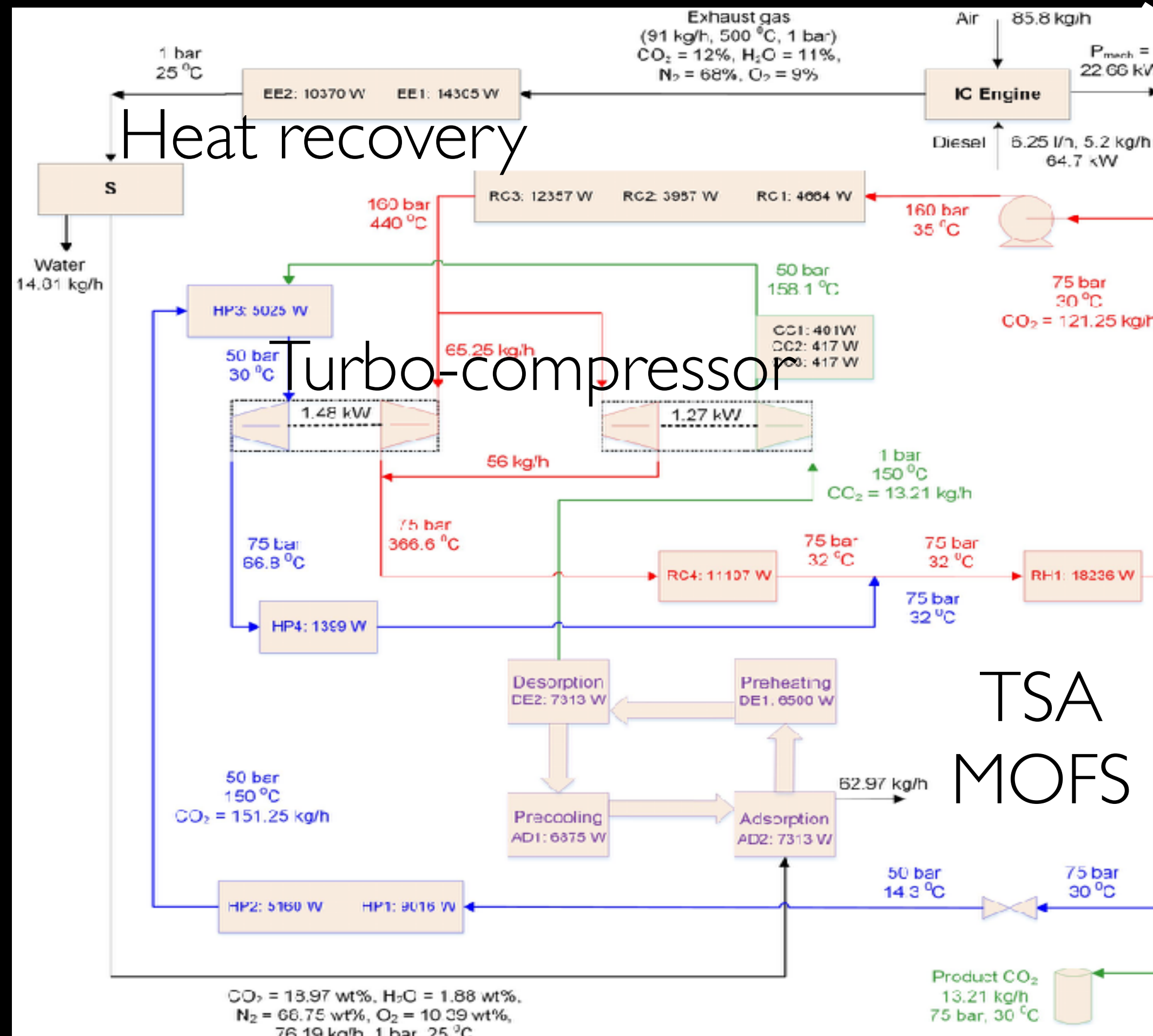
Autonomy : 800 km

Cons : 2.0 l/100 km

Battery : 75 kWh



CAPTURING CO2 FROM TRUCKS



90% CO₂ capture



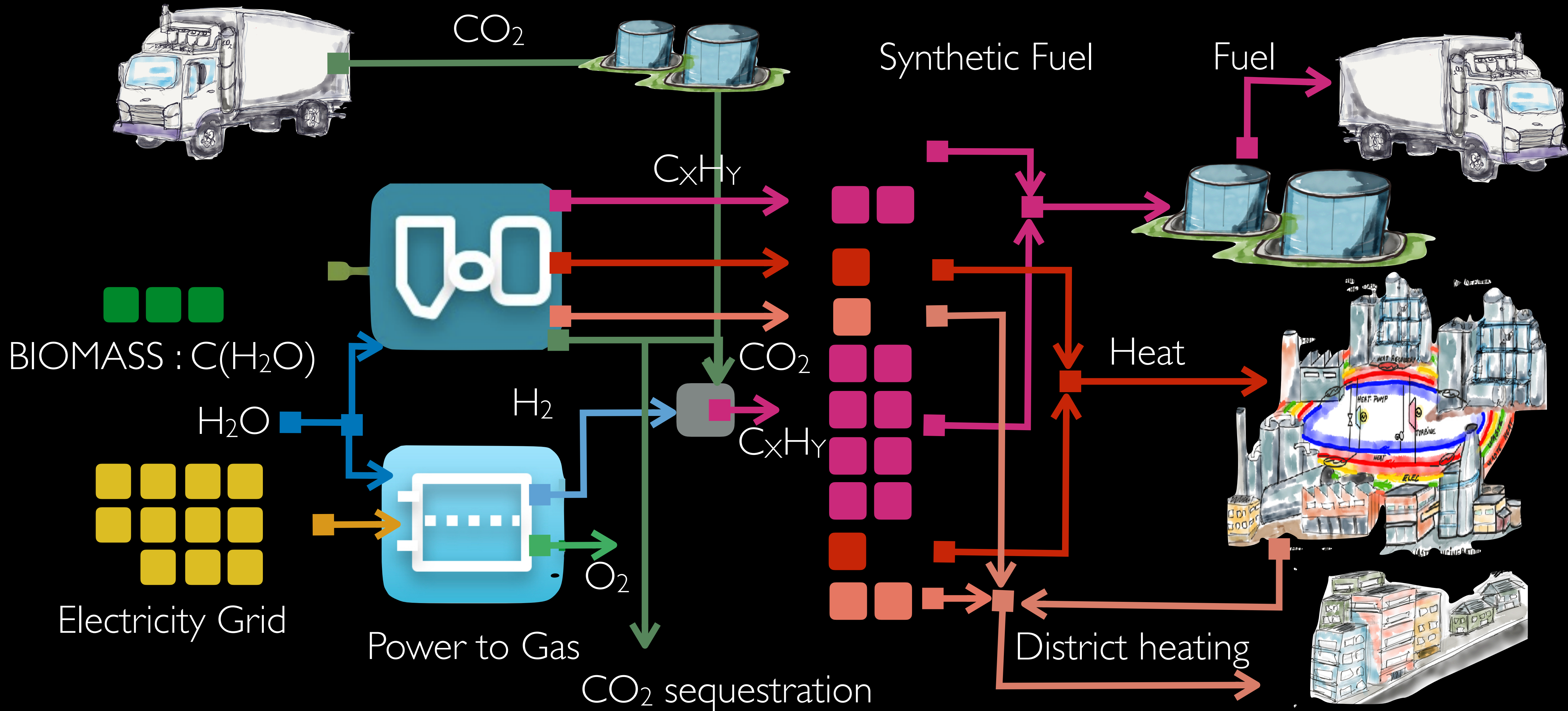
3

liter CO₂/liter fuel

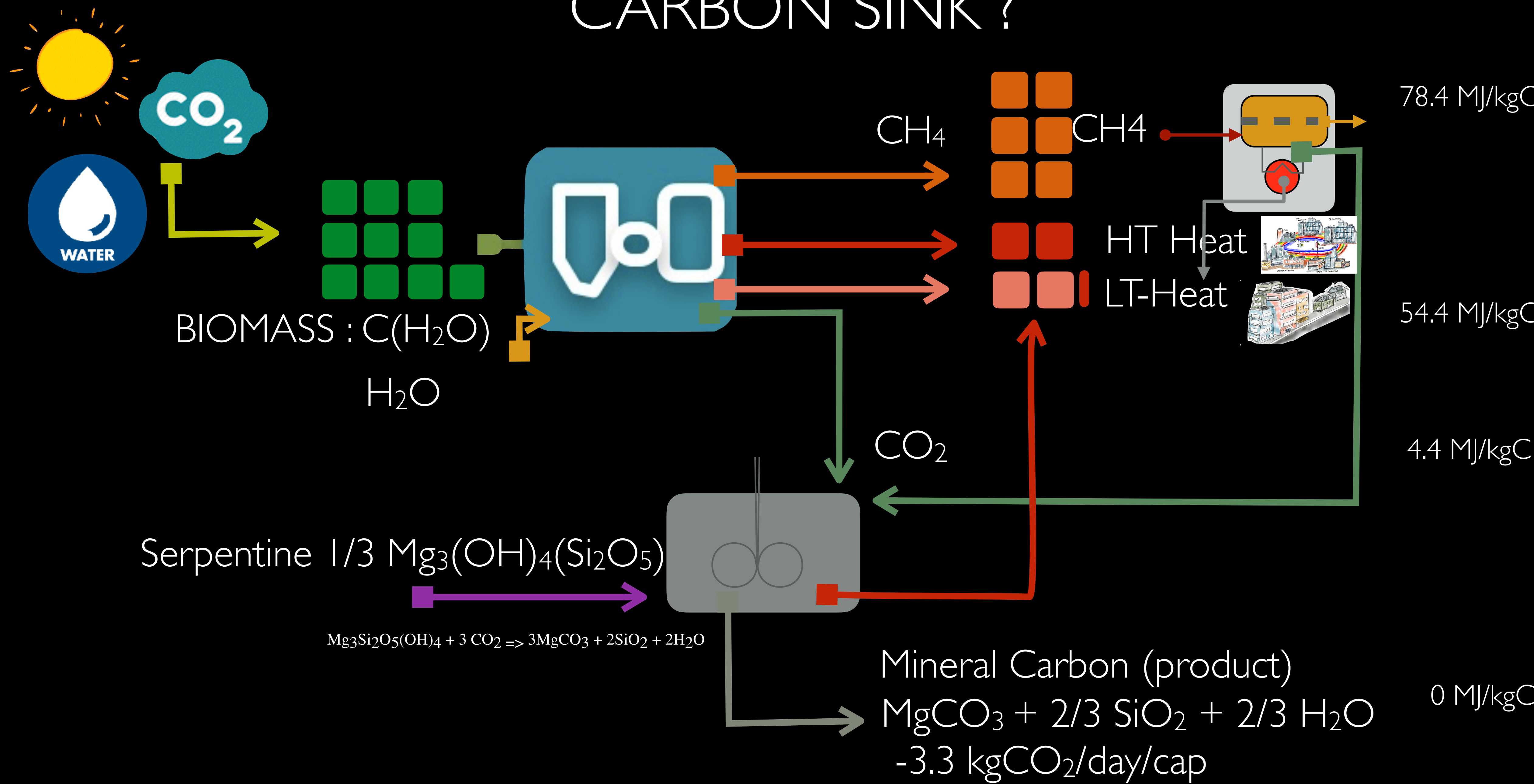
0.05 - 0.1

kg CO₂/kg payload

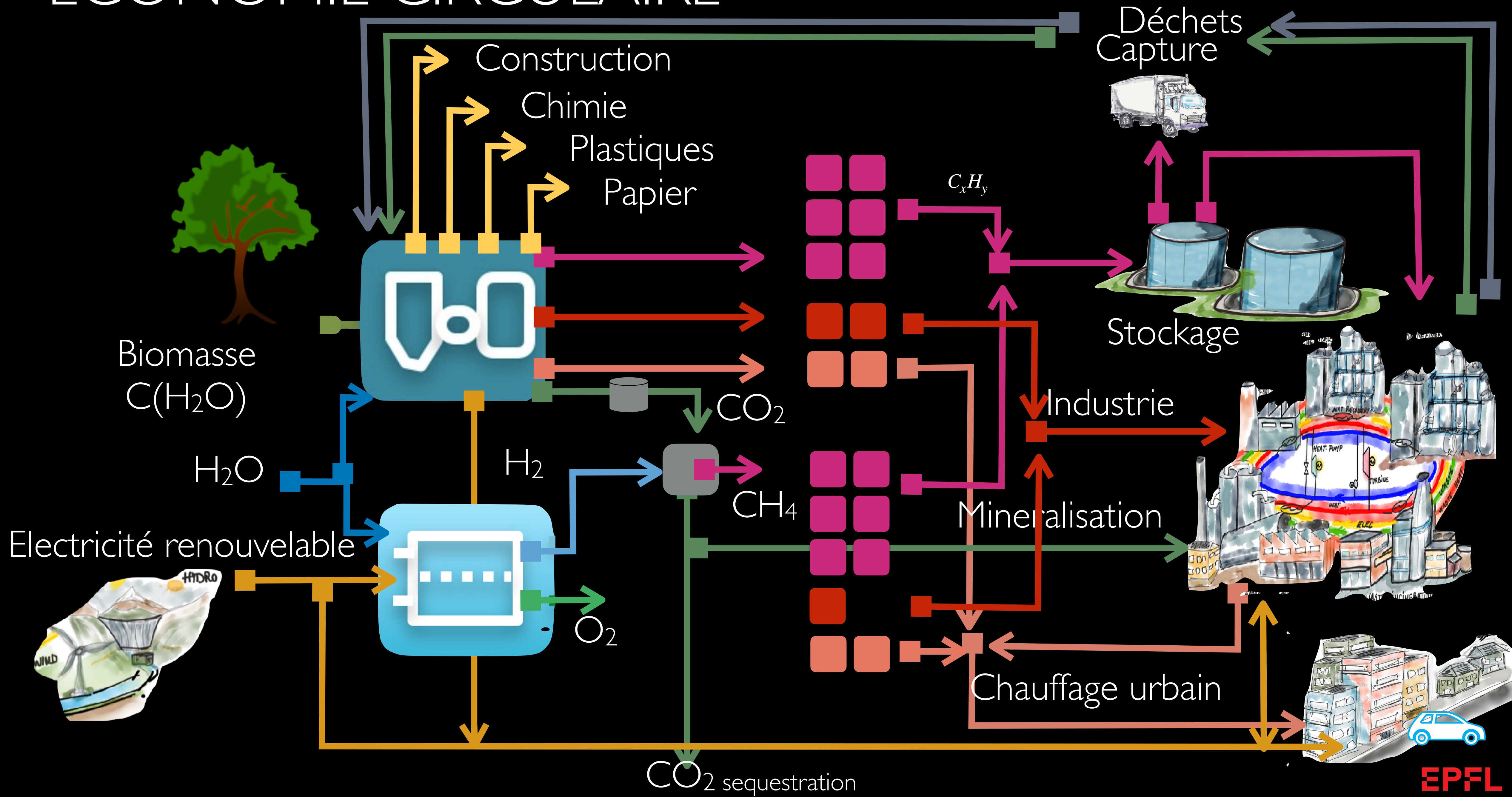
CARBON NEUTRAL TRANSPORTATION SYSTEM



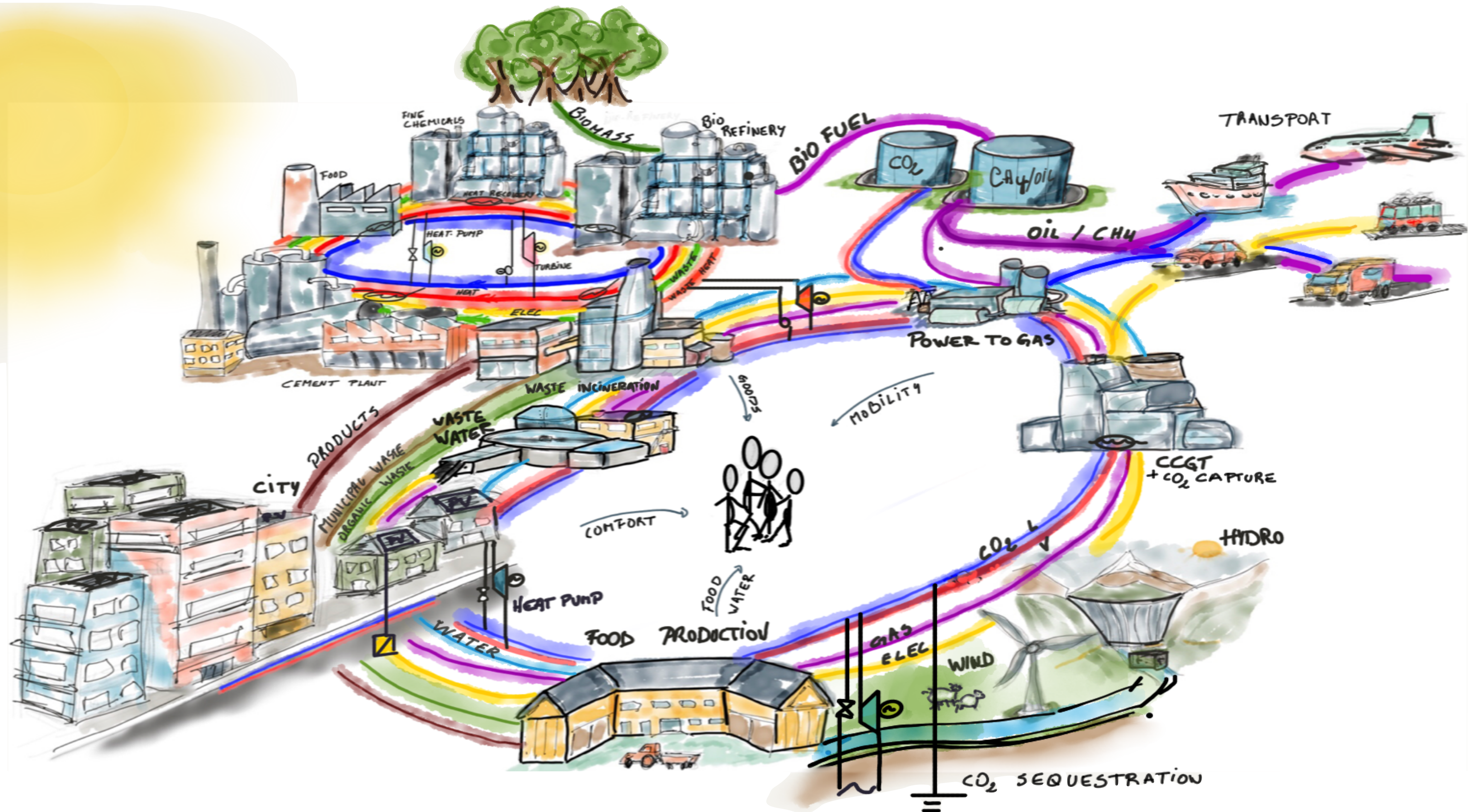
CARBON SINK ?



ECONOMIE CIRCULAIRE



ENERGY SYSTEM INTEGRATION



EPFL Intégrer l'innovation

Air



Refroidissement
Climat
Qualité

Eau



Potable
Usée
Irrigation
Refroidissement
Inondation

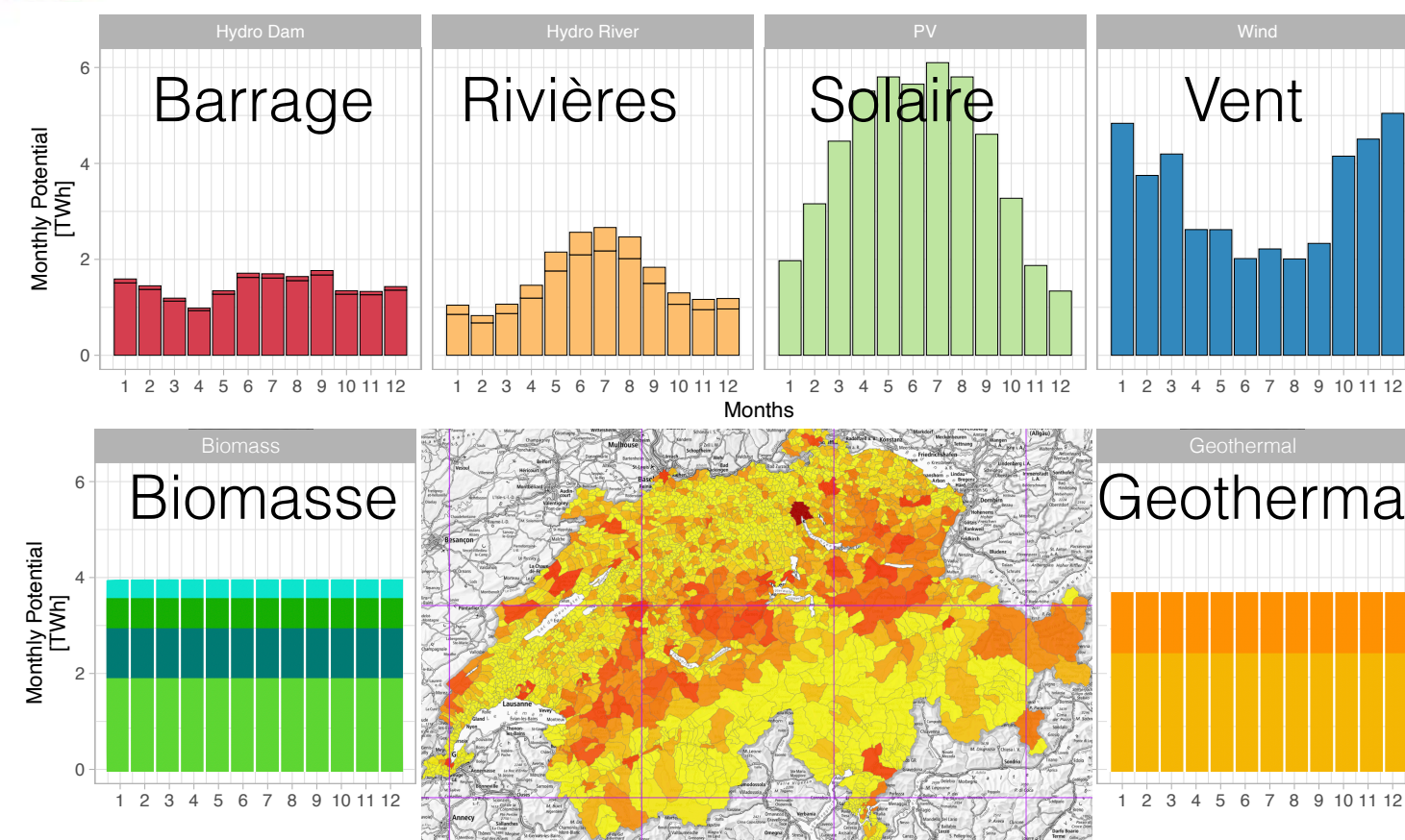
Terre



Urbanisme
Nourriture
Forêt
Paysage
Faune et flore



Feu : ressources

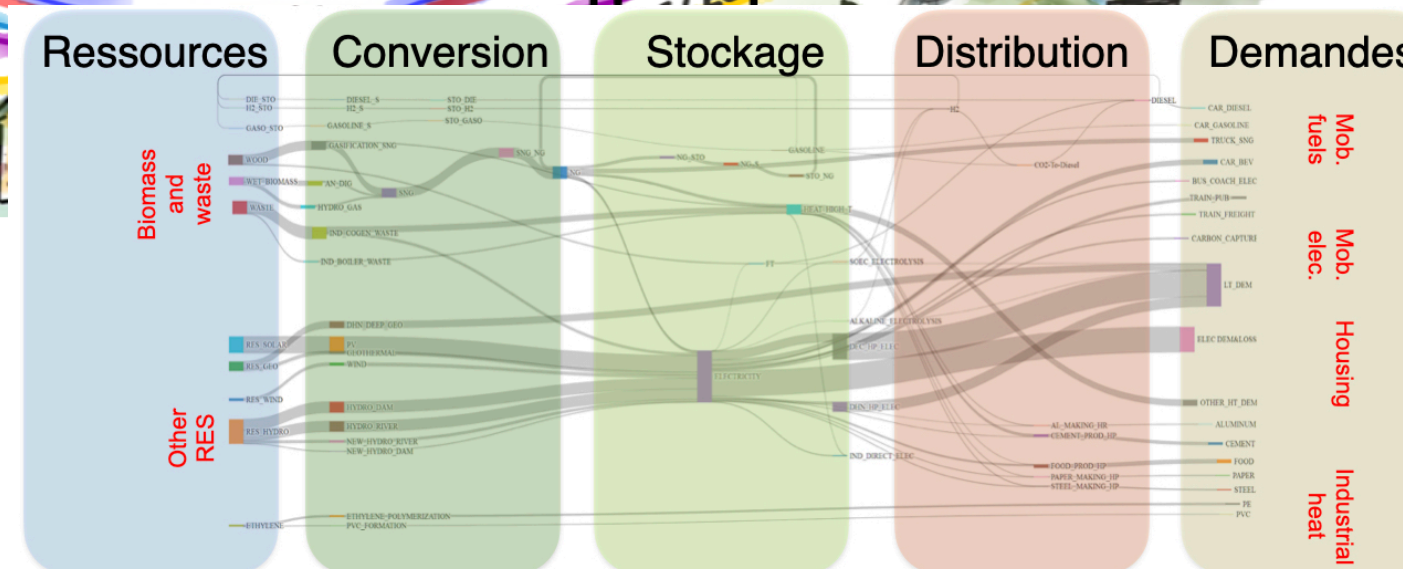
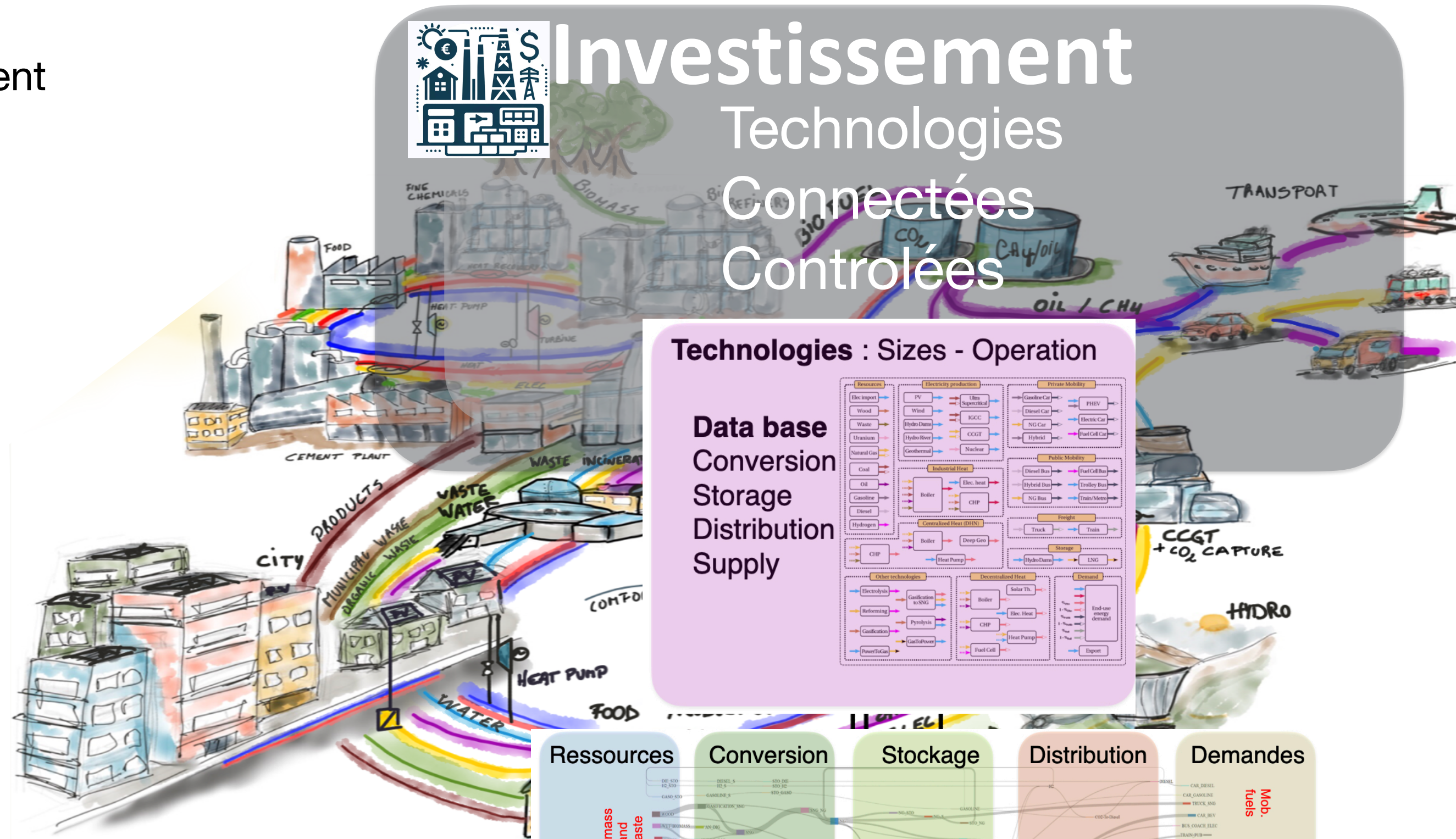


Investissement

Technologies

Connectées

Contrôlées



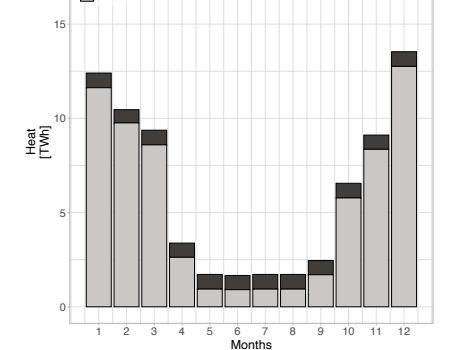
Mes besoins

... maintenant

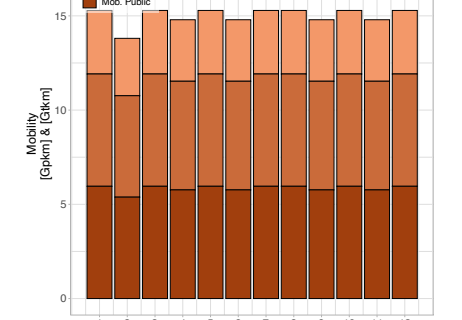
- Produits
- Services
- Confort
- Nourriture
- Données
- Mobilité
- Sécurité



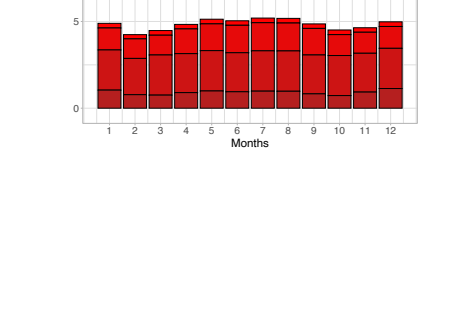
Chauffage



Mobilité



Electricité



Mes Déchets

Recycler
Valoriser
Resource

Impact ESG*

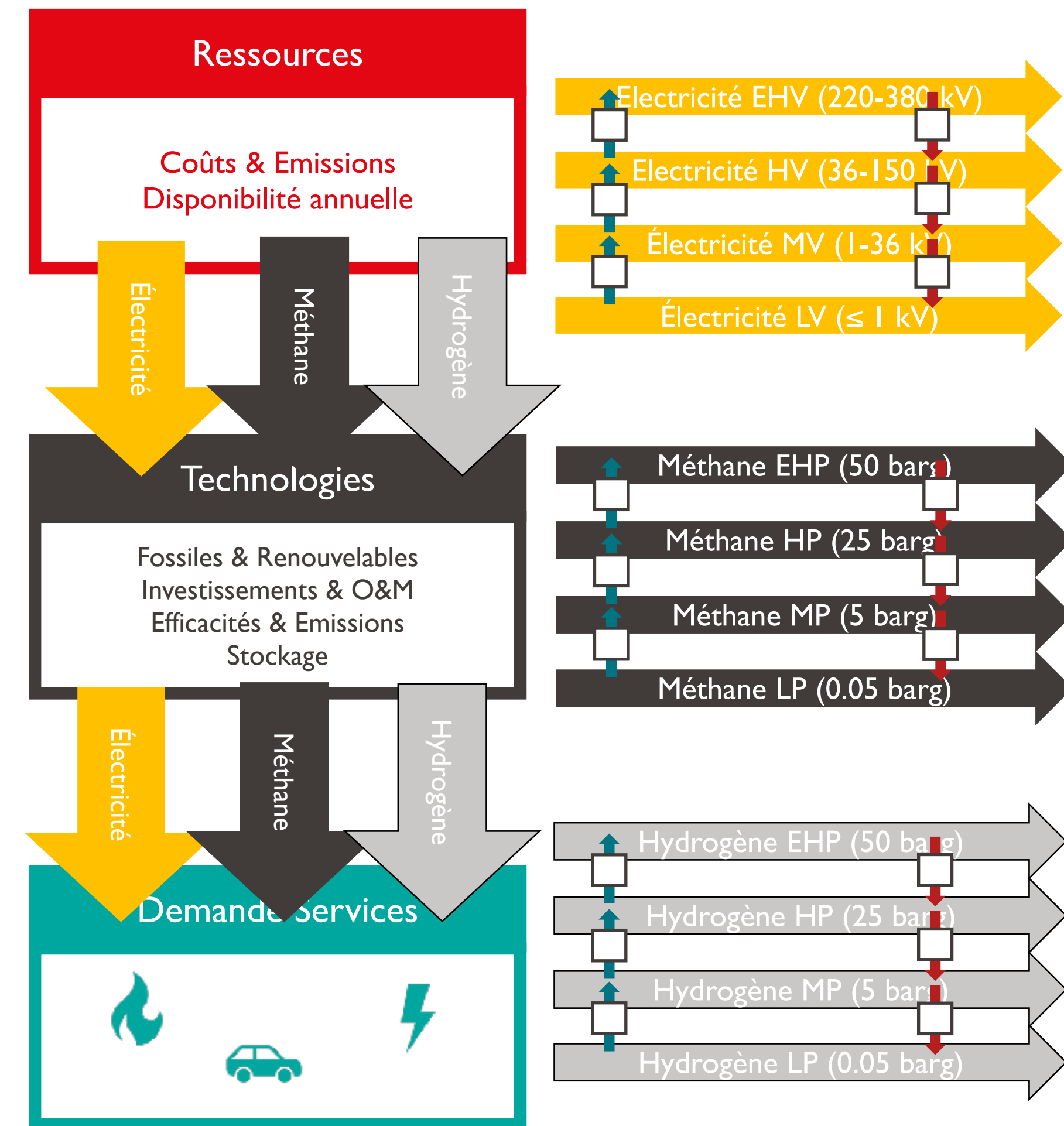
Generation futures

Bien-être

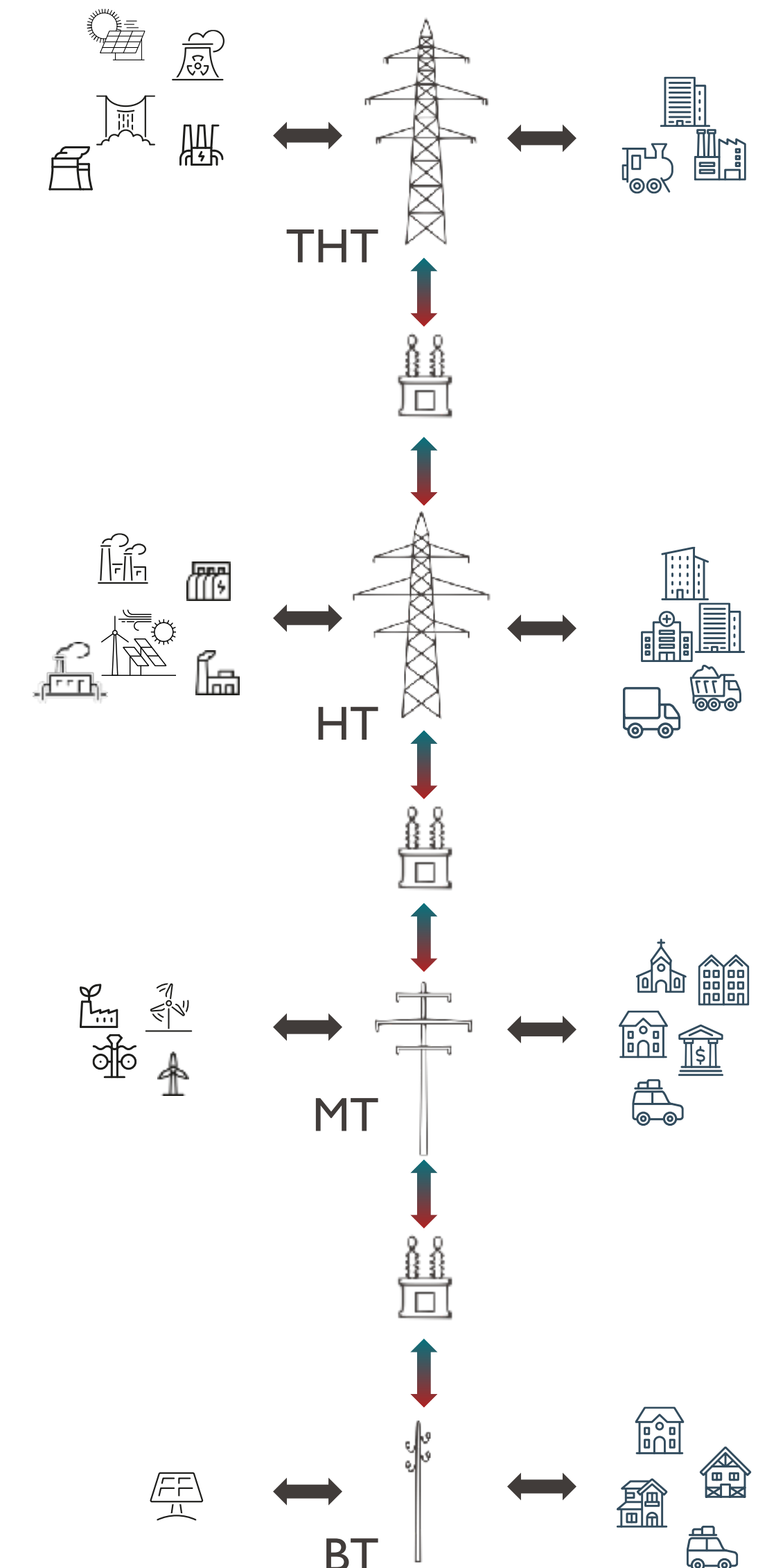
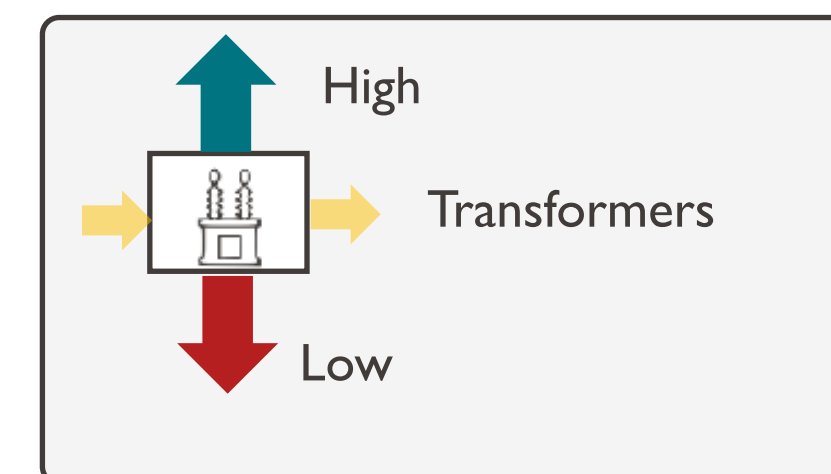


*ESG : Environment - Social - Gouvernance : règles des PFI

Infrastructure models

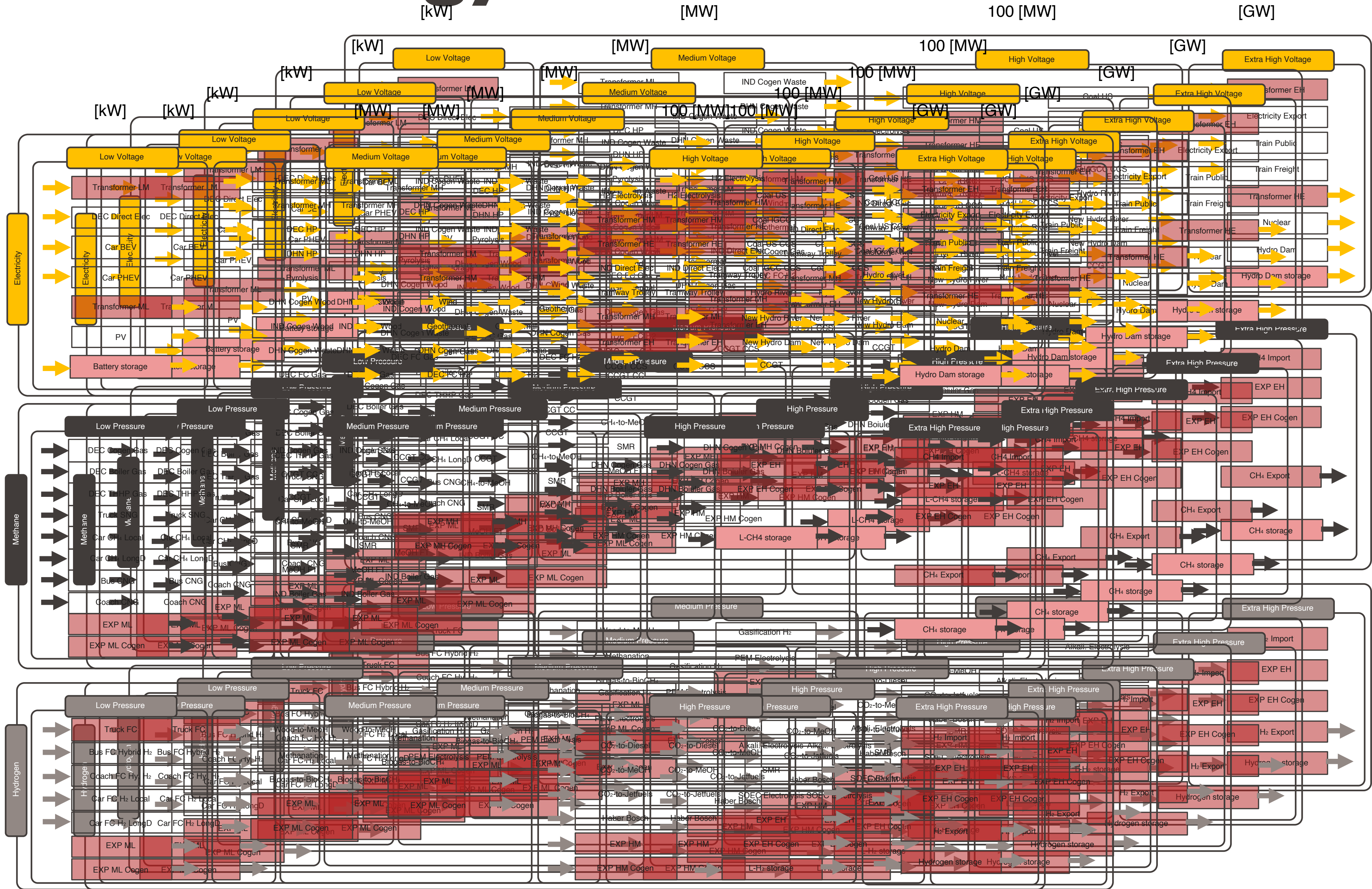


- Energy vectors
 - Electricity
 - Methan
 - Hydrogen
- Transmission-Distribution
 - Electricity: BT, MT, HT, THT
 - Gas: BP, MP, HP, THP
 - Losses
- Transformers



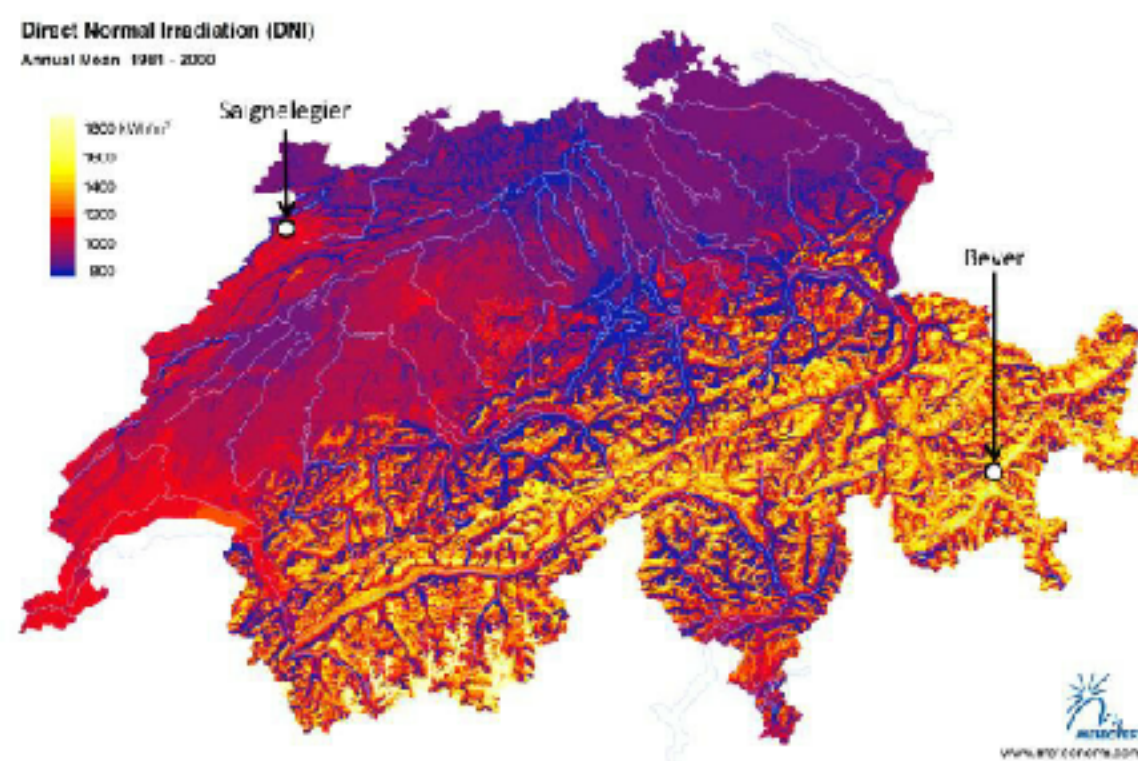
Schematic illustration of the grid level power separation

2050: Technology innovation

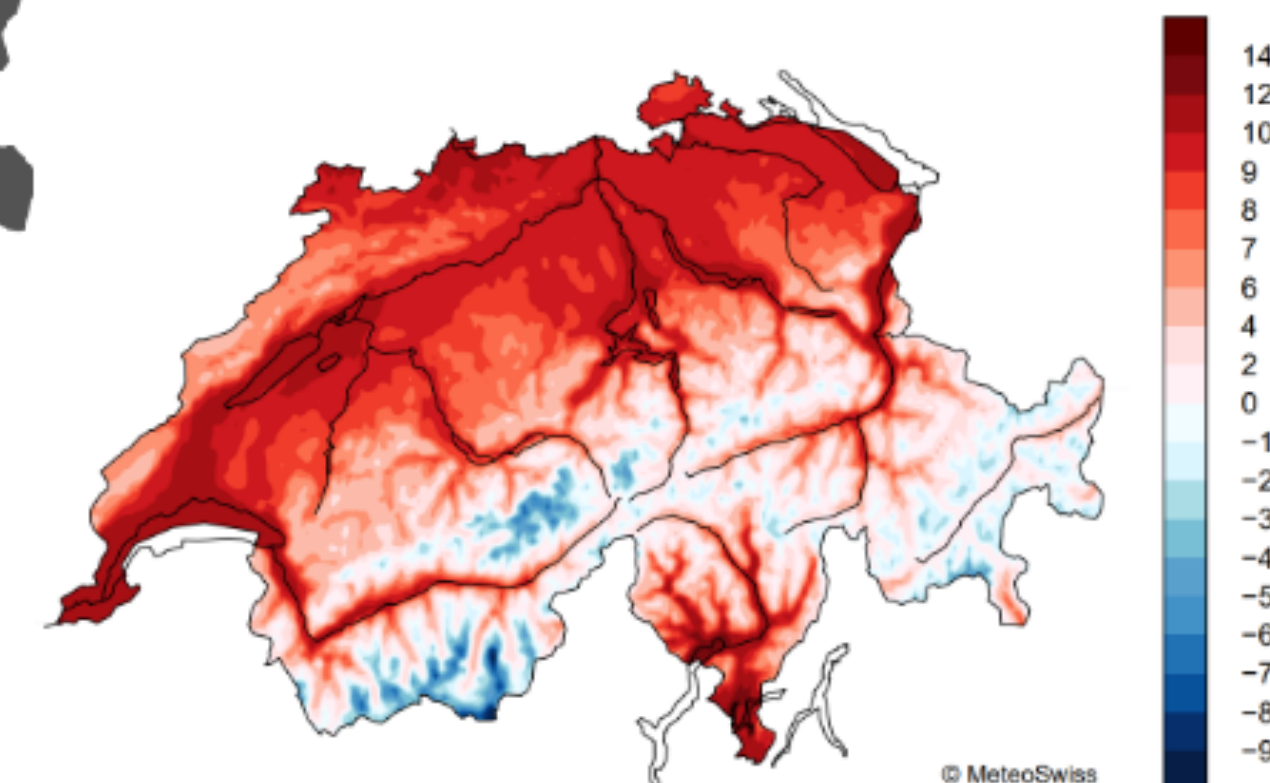


2050: Territorial integration

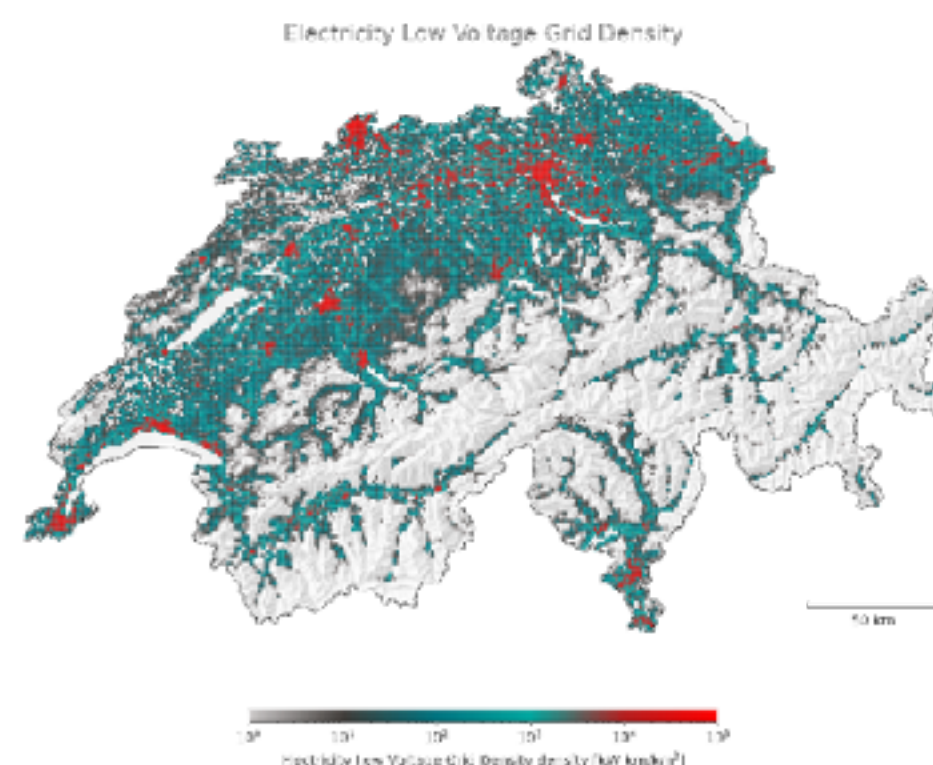
Solar irradiation



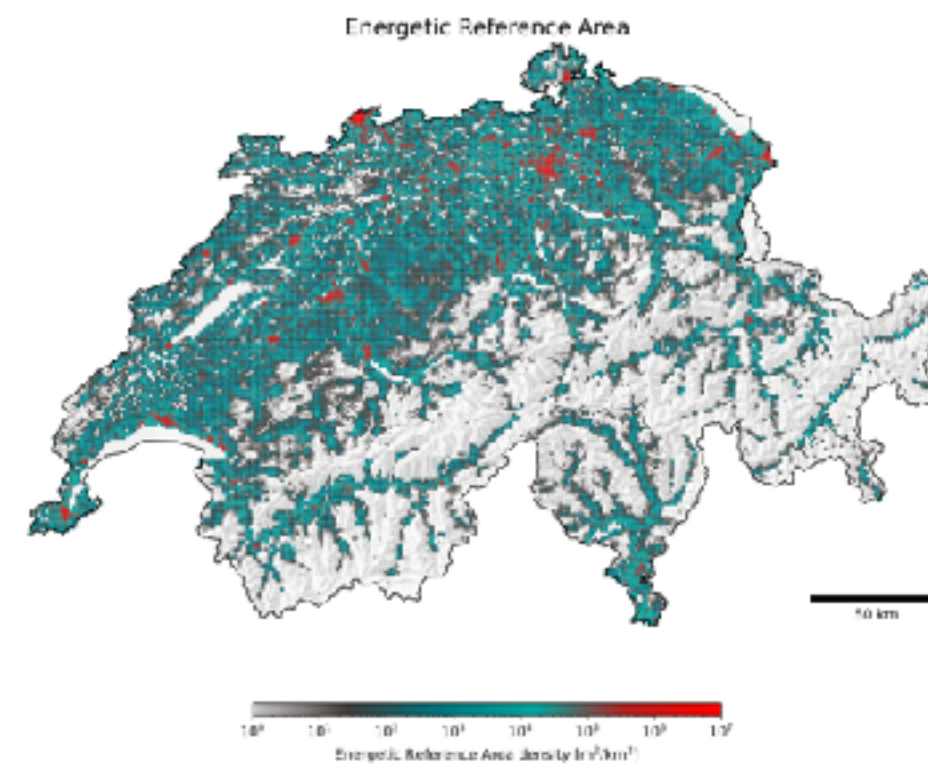
Temperature



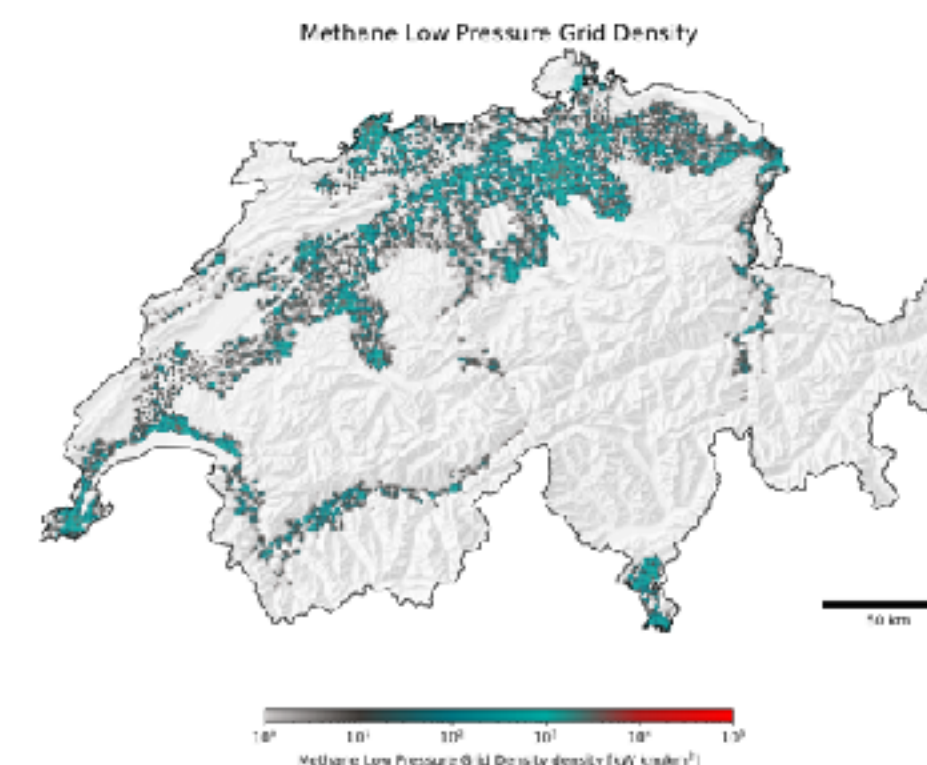
Electrical grids



Heat demand

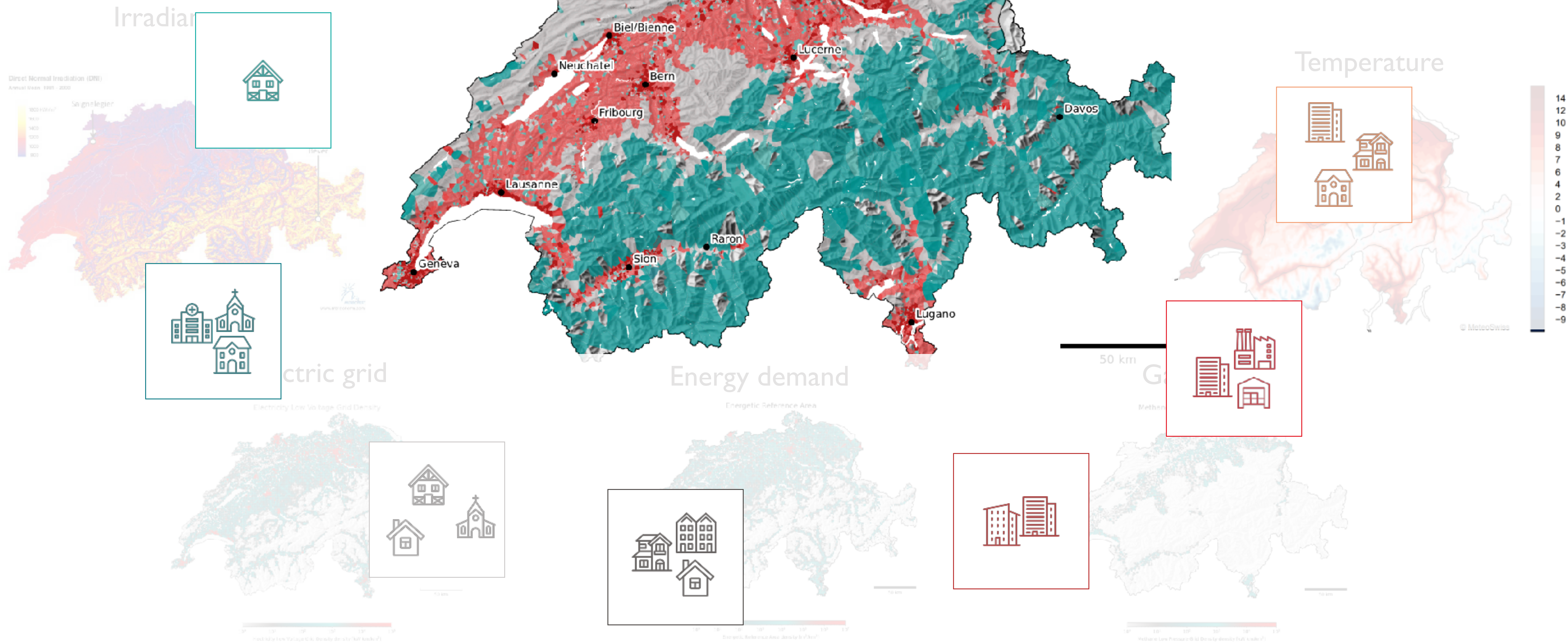


Gas



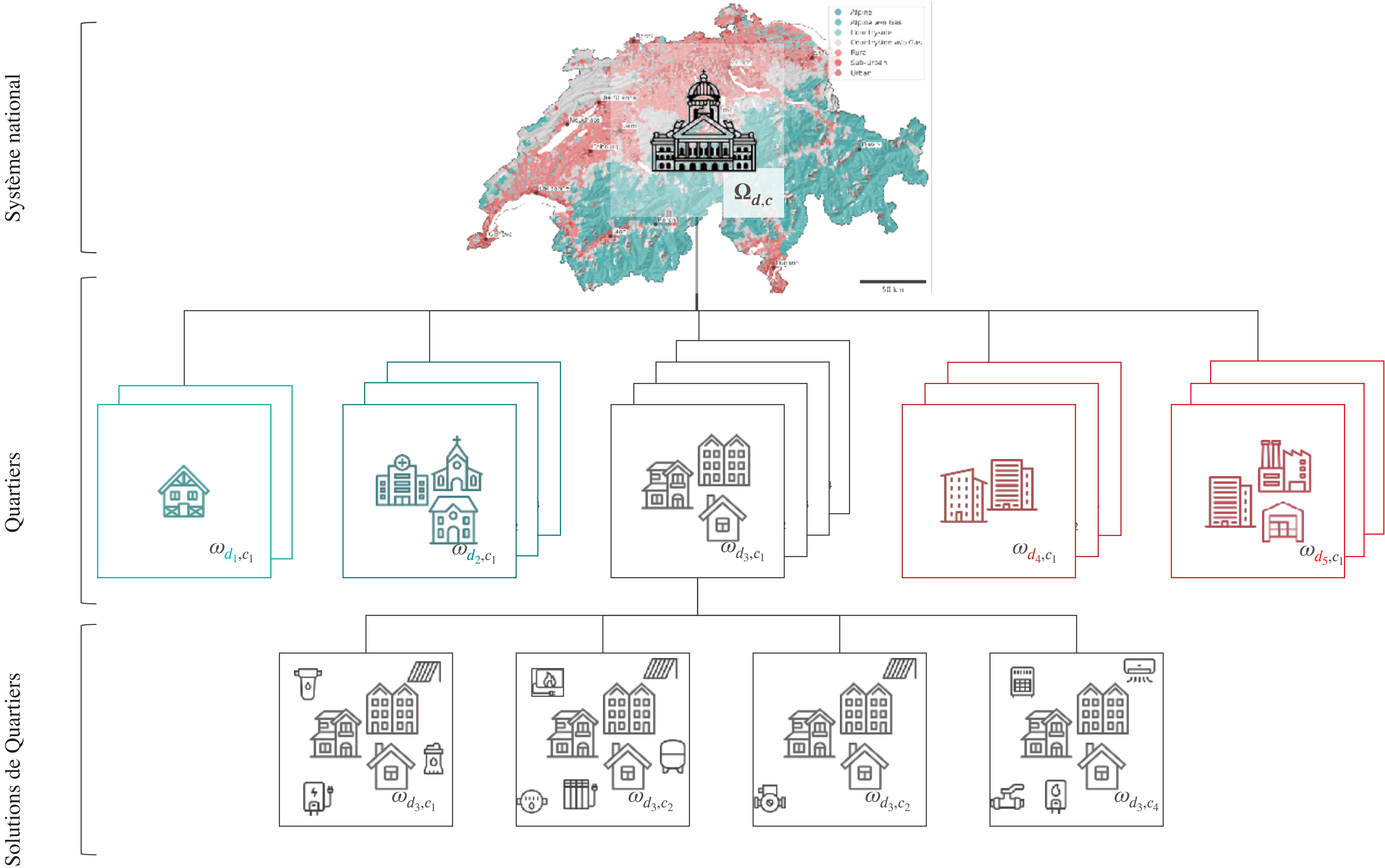
Et le caractère bien sûr...

Typical districts



Et le caractère bien sûr...

Decentralised energy systems in districts



Who is deciding ?

- Who decides
 - Swiss Citizens
- Constraints
 - Security of supply
 - Independence
 - CO2 Neutrality
- Goals :
 - Lowest estimated costs
- Criteria
 - Environment impact
 - Economy
 - Social cost

Constitution fédérale de la Confédération suisse

du 18 avril 1999 (État le 3 mars 2024)

Préambule

Au nom de Dieu Tout-Puissant!

Le peuple et les cantons suisses,

conscients de leur responsabilité envers la Création,

résolus à renouveler leur alliance

pour renforcer la liberté, la démocratie, l'indépendance et la paix dans un esprit de solidarité et d'ouverture au monde,

déterminés à vivre ensemble leurs diversités

dans le respect de l'autre et l'équité,

conscients des acquis communs et de leur devoir d'assumer leurs responsabilités envers les générations futures,

sachant que seul est libre qui use de sa liberté et que la force de la communauté se mesure au bien-être du plus

faible de ses membres,

arrêtent la Constitution¹ que voici:

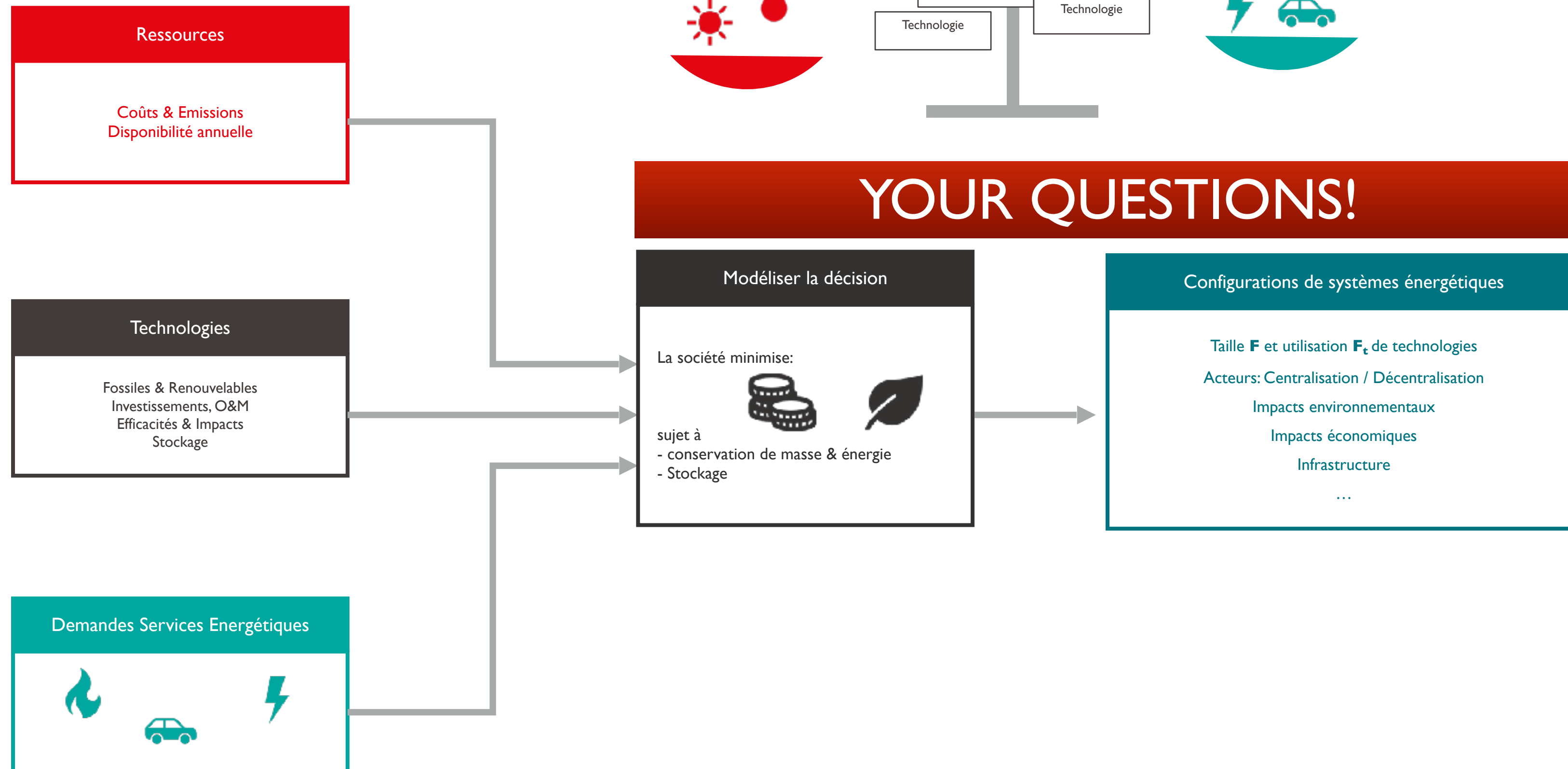
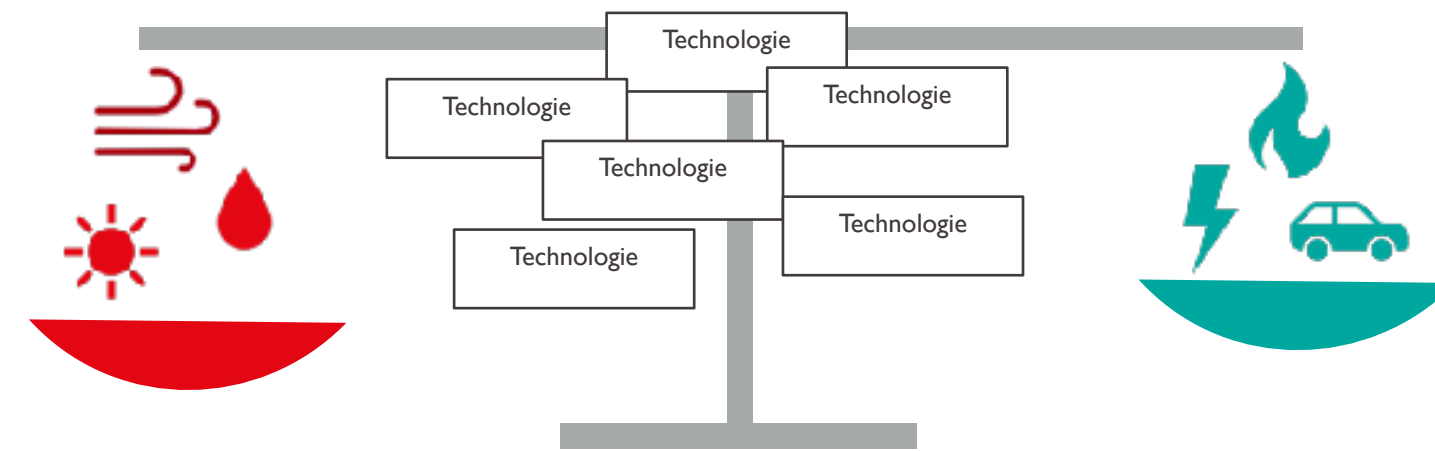
¹ Accepté en [votation populaire du 18 avr. 1999](#), en vigueur depuis le 1^{er} janv. 2000 (AF du 18 déc. 1998, ACF du 11 août 1999; [RO 1999 2556](#); [FF 1997 I 1, 1999 176 5306](#)).



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

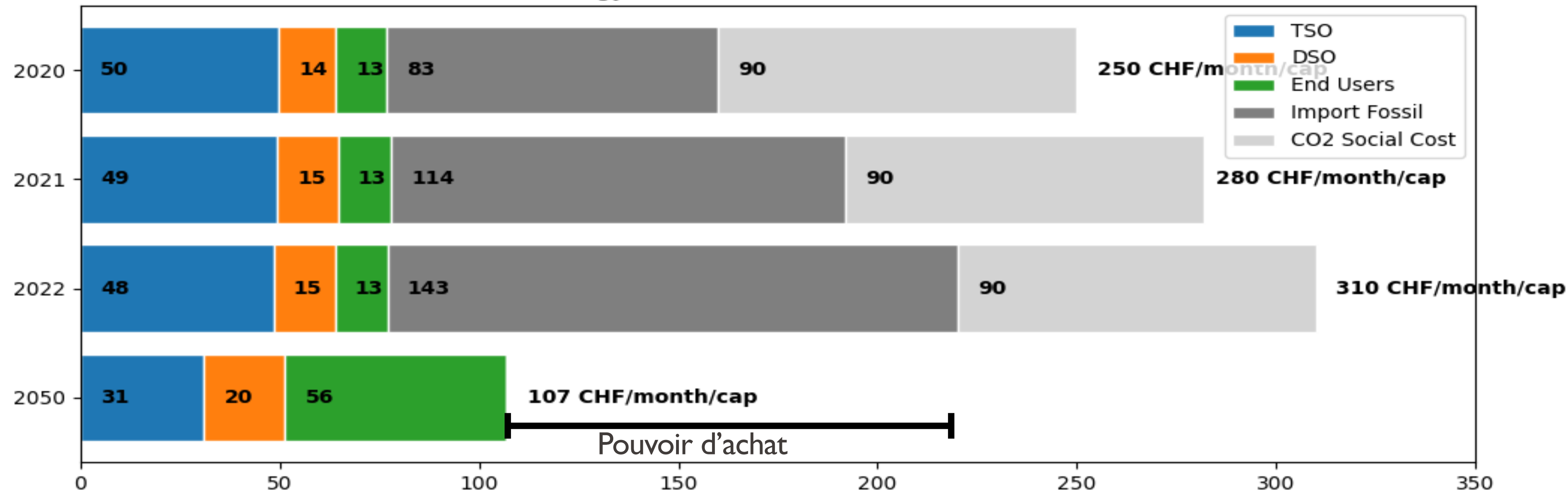
Energyscope

A digital twin to answer your questions



- Wind or PV
- Nuclear?
- Expected Costs ?
- import/exports?
- Hydrogen - Methane?
- Solar alpine ?

Economic impact assessment of the transition



x 5 : District Investment (communautés d'énergie locales)

uses **66%** of **today's fossil fuel cost**

x 1.8 : investment increase by **DSO** : decentralised energy management

-40% : Reduced investment in **TSO**

+ 33% to 50% : purchasing power

Public debt regulation: Social cost of **CO2 emissions**

Price stability and **security of supply** (indépendance)

Predict in an uncertain world

Biomass : 290 - 340 [W/cap]
Waste : 180 - 230 [W/cap]

Industry Elec: 110 - 140 [W/cap]
Industry heat: 210 - 250 [W/cap]

Building Elec: 270 - 320 [W/cap]
Building heat : 630 - 740 [W/cap]

Chemical storage
Liquid fuel : 15 - 88 [W/cap]
CH₄ : 140 - 170 [W/cap]

Transport Air : 240 - 290 [W/cap]

Freight : 70 - 90 [W/cap]

Public: 60 - 90 [W/cap]

Private: 100 - 140 [W/cap]

PV : 230 - 1800 [W/cap]

Wind : 20 - 80 [W/cap]

Hydro : 380 - 500 [W/cap]

HP : 460 - 680 [W/cap] (21 - 34 %)
DHN : 340 - 460 [W/cap] (48 - 72 %)
Other : 110 - 170 [W/cap] (19 - 33 %)

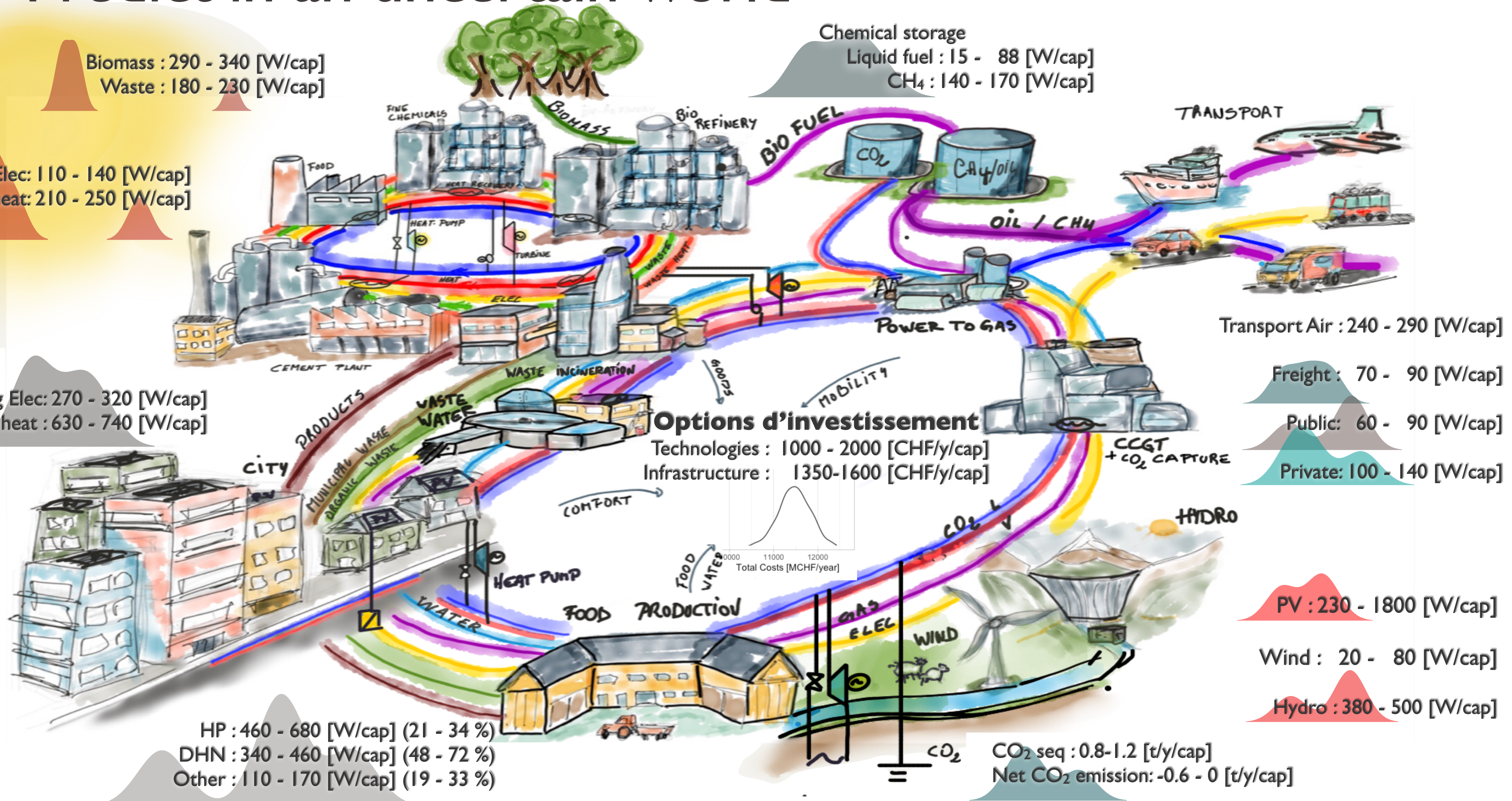
Options d'investissement

Technologies : 1000 - 2000 [CHF/y/cap]

Infrastructure : 1350-1600 [CHF/y/cap]

Total Costs [MCHF/year]

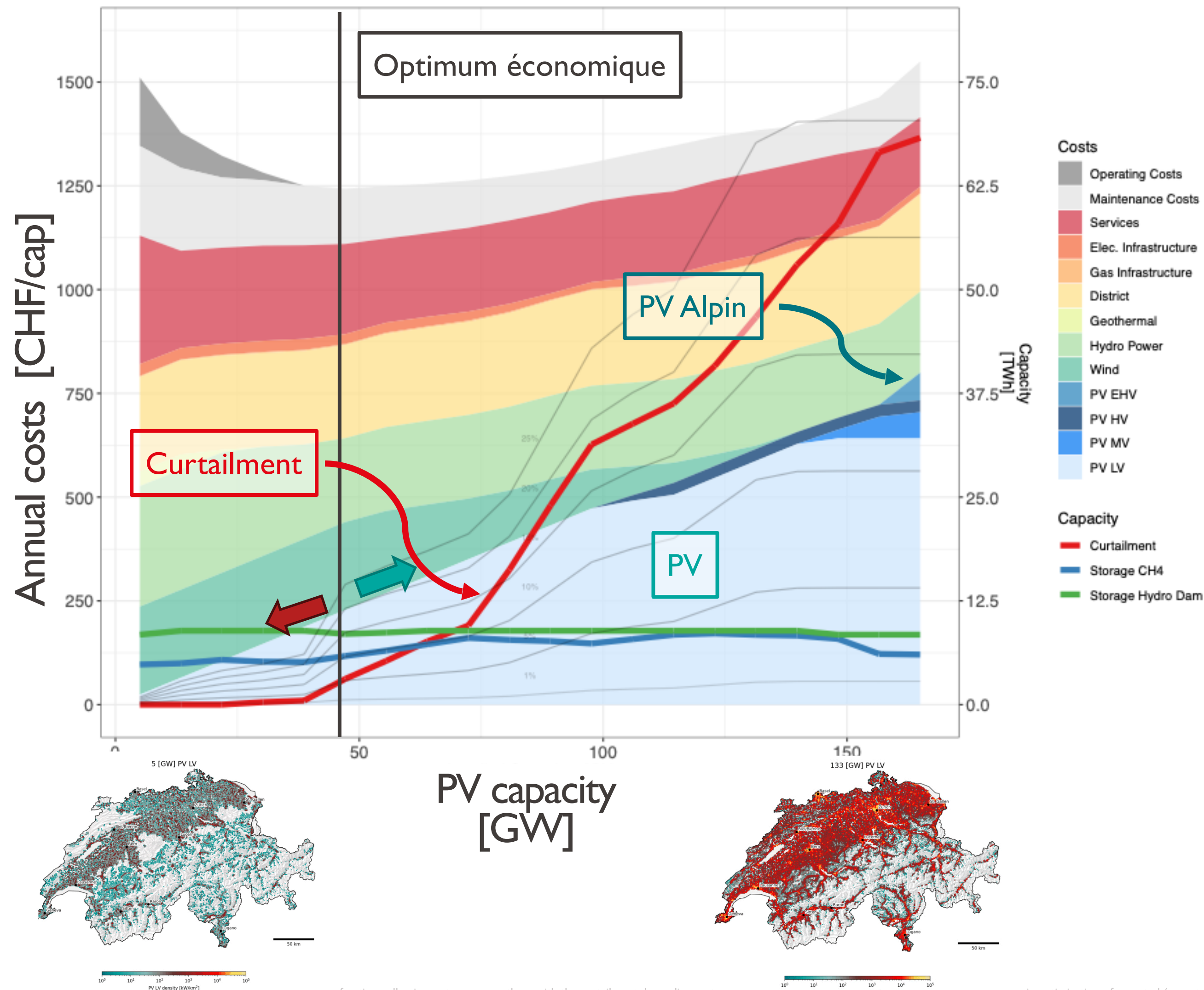
CO₂ seq : 0.8-1.2 [t/y/cap]
Net CO₂ emission: -0.6 - 0 [t/y/cap]



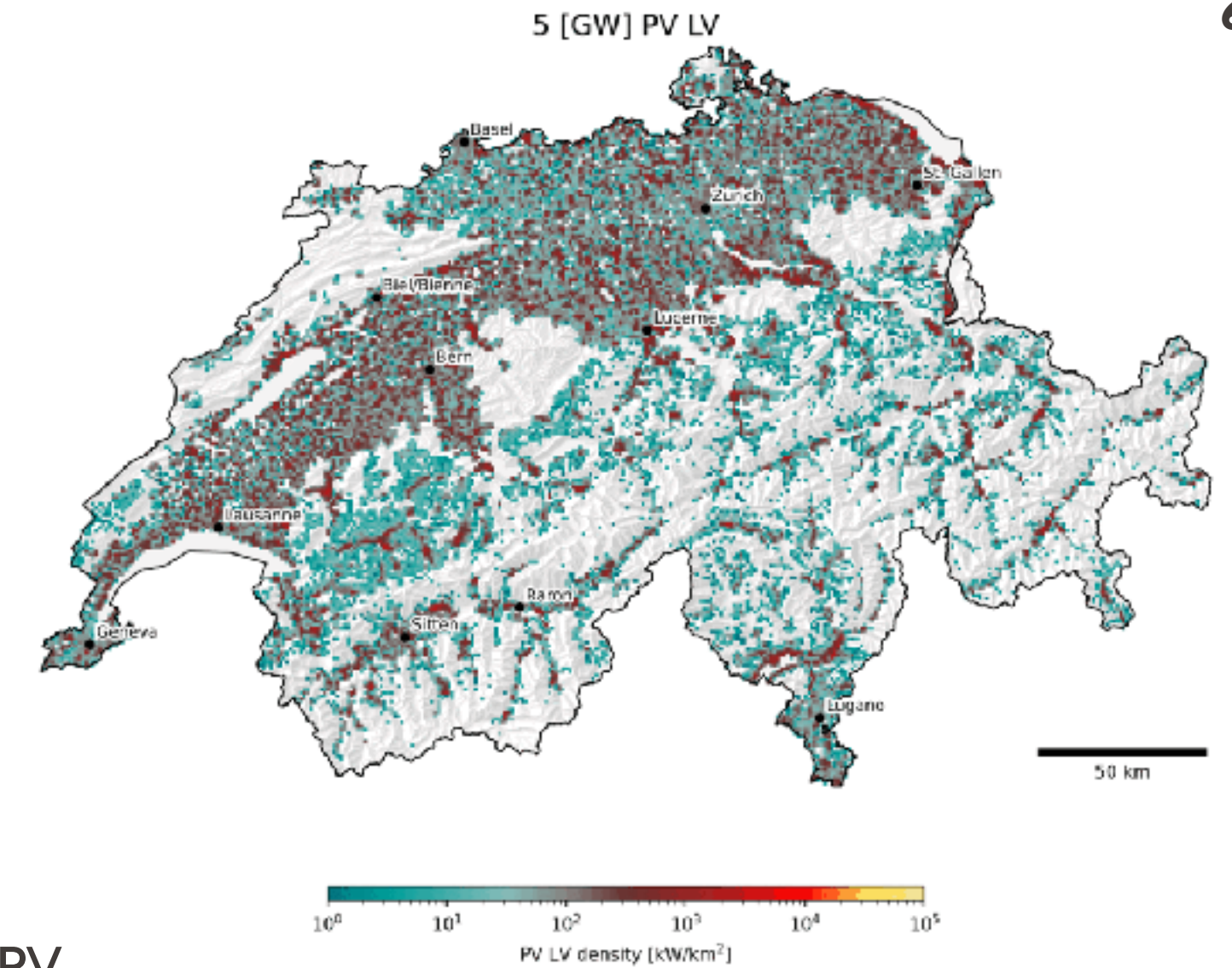
Your Question: Wind vs Photovoltaic ?

Min PV = +20%

Min Eolien = +22 %



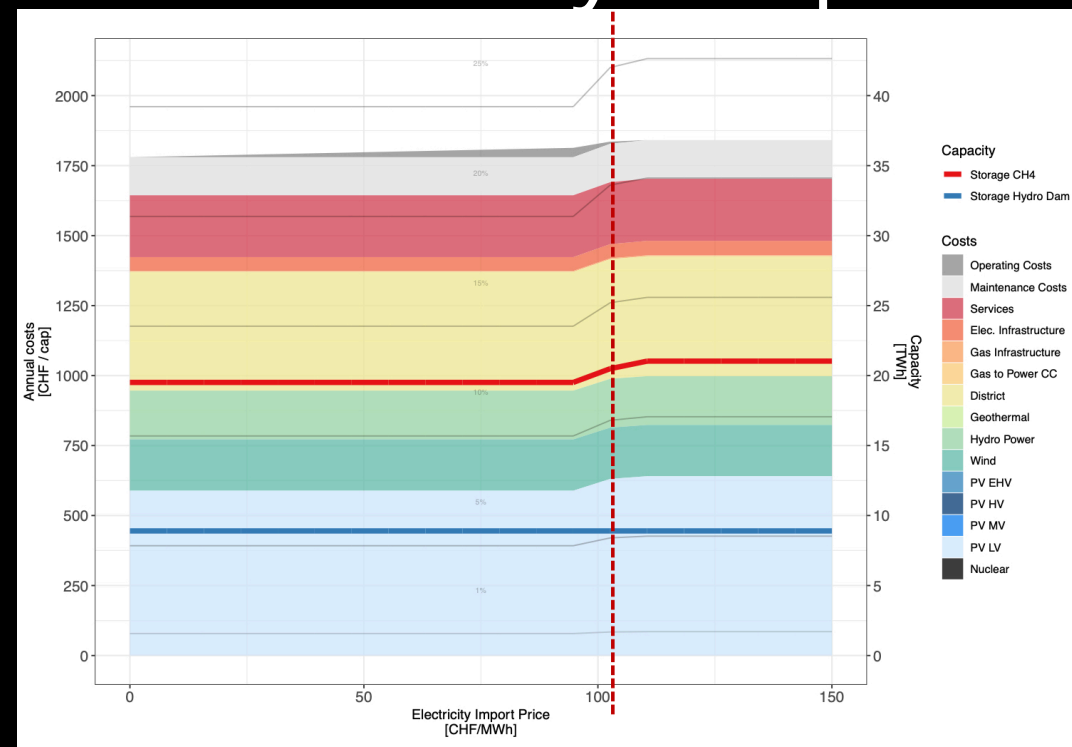
Animation of the geographic PV installation Evolution density



- **Best mix**
20 GW Wind & **37** GW PV
- PV: LT grid limits
- Max potential of wind
- PV 
- Wind to maximum
- Biomass compensates 0-15% biomass potential
- Power2tank2Power via biogenic methane (4.3 → 6.1 TWh)
- PV 
- Wind is reduced
- more seasonal storage
- Power2tank2Power via biogenic methane (6.1 → 8.8 TWh)

SMART TRANSITION ?

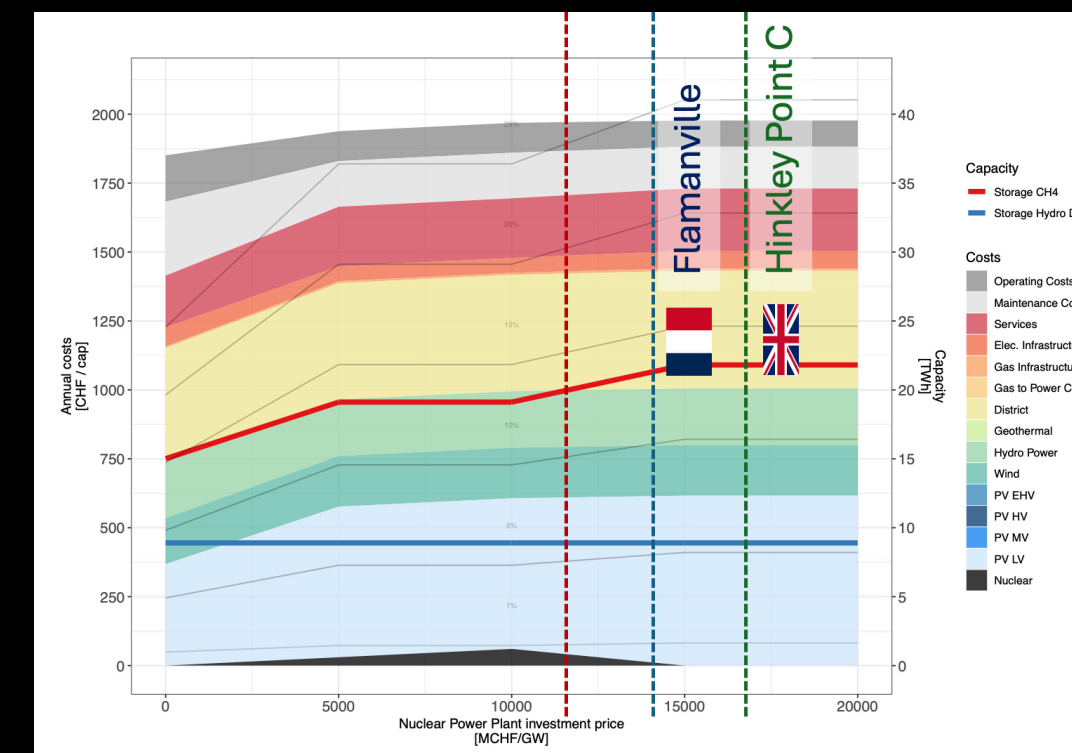
Electricity import



Flexibility services
New markets rules

if < 105 CHF/MWh

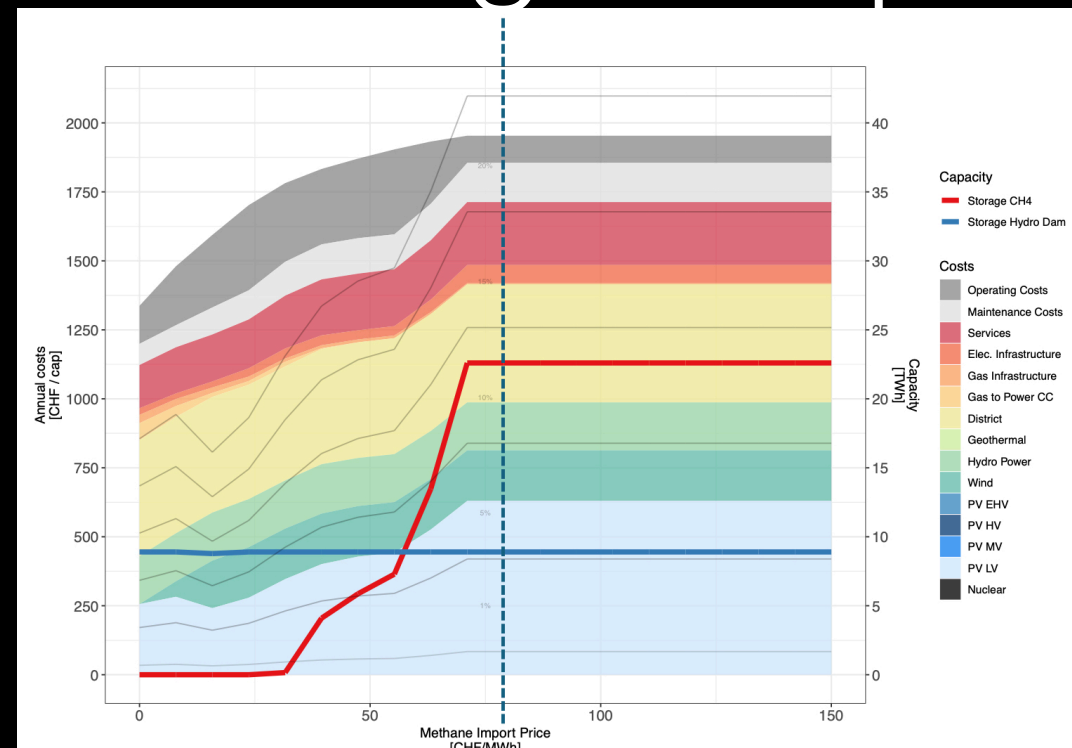
Nuclear



Construction time
> 15 ans
CO2 budget in the meantime ?
Substitutes PV
not wind

if investment + waste < 12000 MCHF/GW

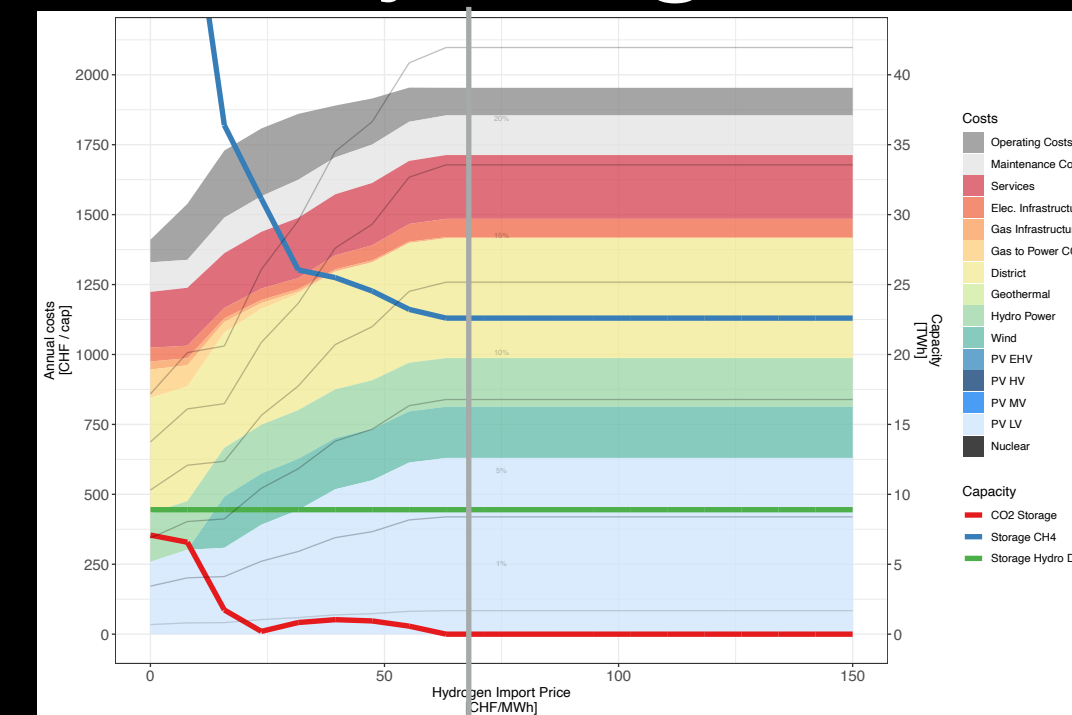
Natural gas import



Scope 2
CO2 Emissions
to compensate

if < 75 CHF/MWh

Hydrogen



New infrastructure
No need of H2 molecules

if < 60 CHF/MWh => elec < 4 cts/kWh !

CONCLUSION

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

Primary energy

Extraction->resource



Conditioning

resource->distributed



Conversion

Distributed->useful energy



Energy service

Energy->service

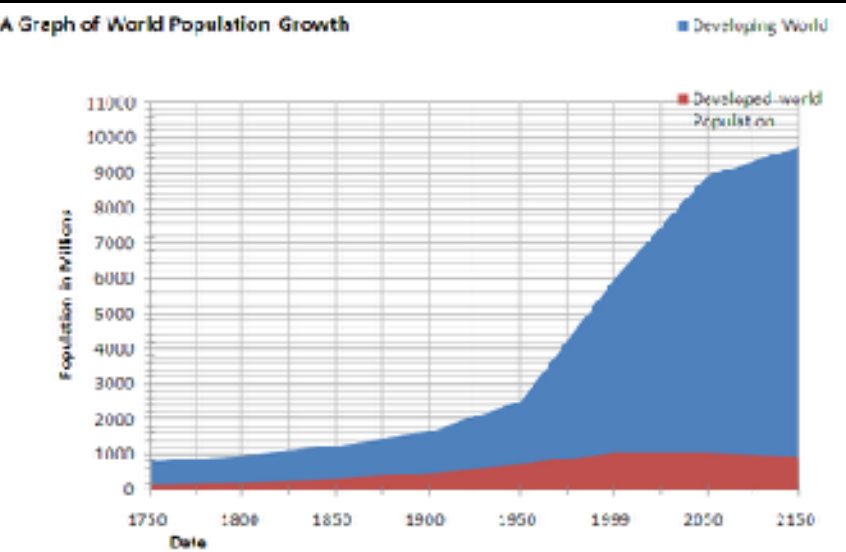
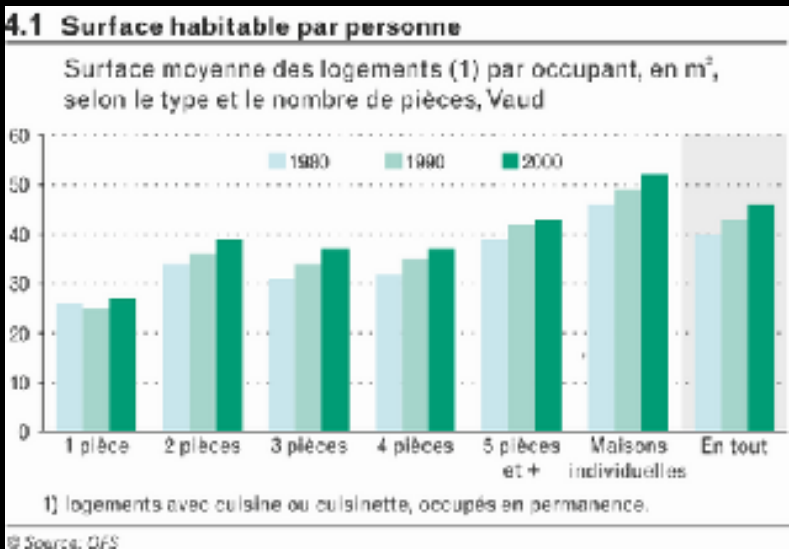
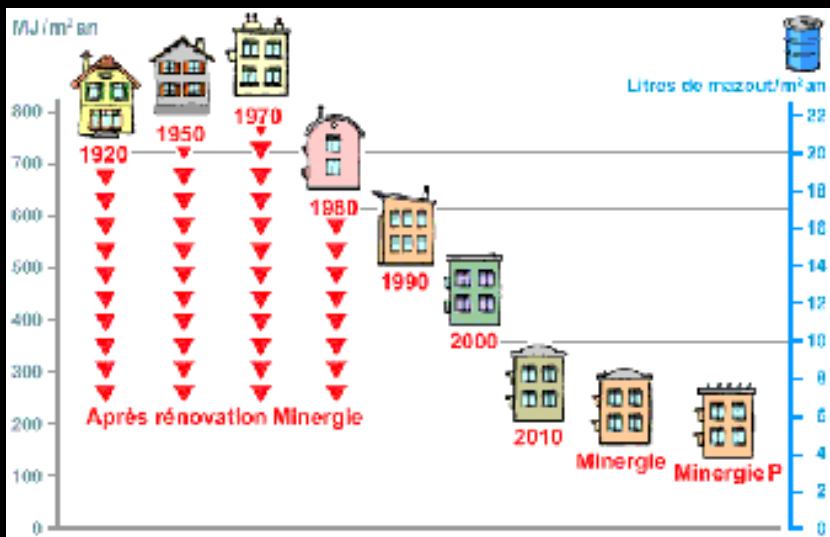
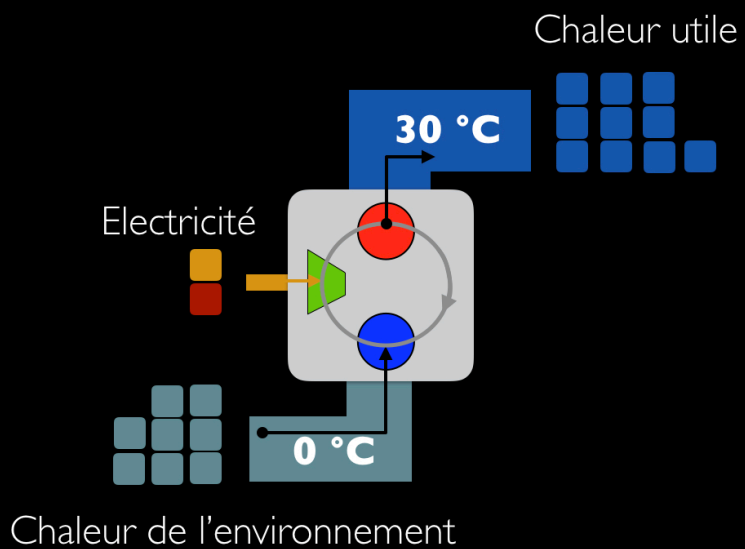
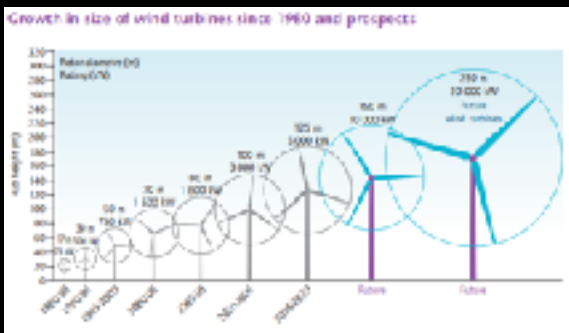


Needs

service->cap



Population cap



ACKNOWLEDGMENTS

- **Sun** : for the energy supply
- **Mother Nature** : to show us the way to store energy
- **Citizen** : to adopt responsible ways to consume
- **Carnot** : to show us the importance of ambiance and efficiency
- **Research** : to develop the methods and the knowledge to develop new technologies
- **Engineers** : to assemble and use the technologies in the right way at the right time
- **Industry** : to give us the technologies and develop circular economy
- **Authorities** : to develop education system and the infrastructure
- **Finance** : to ethically use (our) money for the right goals
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