CO2 AND RENEWABLE ENERGY FOR AUTONOMOUS CITIES

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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
MOTHER NATURE WAS A PROCESS ENGINEER

Stochastic summer energy

Photosynthesis

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{C(H}_2\text{O}) + \text{O}_2 \]

Biomass

1961 Nobel Prize in Chemistry

Calvin cycle, Calvin-Benson-Bassham (CBB) cycle

ATP: Adenosine-5'-triphosphate

NADPH: Nicotinamide adenine dinucleotide phosphate

www.sheppardsoftware.com

www.thesimplehomeschool.com
CIRCULAR ECONOMY ...
CIRCULAR ECONOMY OR NOT?

- **Geological storage**: 40 MJ/kg
- **Biosphere storage**: 20 MJ/kg
- **Stochastic**: 1-100 years

**Plant matter**

- CH₂O
- CO₂ + H₂O
- Fuel CₓHᵧ

**Partial decomposition under high temperature and pressures**

- 5% of 1 year of sun
- 100 millions years

**Solar Energy**

- +Solar Energy
- +Energy

**Geological storage**

- +O₂
- CO₂ + H₂O

**Biosphere storage**

- -O₂
- Stochastic

**Stored Energy**
OUR ENERGY NEEDS

Food: 0.25 l/day

Oil: 5.5 l/day

Waste: 2 kg/day

BioWaste: 0.7 kg/day

CO2: 14 kg/day
Can someone turn the heating system off?
ENERGY NEEDS

47% 100 l gasoline/hab/year
36% Electricity
17%
CITIES = 75% OF THE POPULATION

Genève

- Population: 200,000 hab
- Area: 16 km²
- 16 km² Heated
- 3.5 km² Built
- Water usage: 260 Million litres/year
- CO₂ emissions: 1 Million Tonnes/year
- Waste: 100,000 Tonnes/year
- Oil equiv. consumption: 40,000 Tonnes/year
- Water usage: 620 Million litres/year
IS IT POSSIBLE TO MAKE THE CITY AUTONOMOUS?

• without CO2 emissions

• without importing energy

• without reconstructing the whole city

• without loosing money
HEATING A BUILDING

Natural gas boiler
90% efficiency

Useful heat
21 °C

Waste heat

CO₂

CH₄

1000 °C
WHAT ARE THE NEEDS?
HEATING BUILDINGS

Thermodynamic minimum

\[
\dot{E} = \dot{Q}(1 - \frac{T_{\text{cold}}}{T_{\text{hot}}})
\]

Nicolas Léonard Sadi CARNOT (F)
1796 - 1832

Energy to buy

Useful heat

Energy from the environment
WHAT IS WRONG?
WHY DO WE BUY 10X MORE?

FUEL

CO2
HEAT PUMP IS THE SOLUTION

Electricity

Heat from the environment

30 °C

Useful heat

0 °C

\[ \dot{E} = \frac{1}{\eta_{Carnot}} \cdot \dot{Q} \cdot \left(1 - \frac{T_{cold}}{T_{hot}}\right) \]

\[ \eta_{Carnot} = 0.55 \]
REACH THE GOOD RESOURCES
SUPPLY WHAT IS NEEDED

Electricity
75%

Electricity
25%

Heat from the environment

CO₂

CO₂ based district energy system, U.S. Patent 2010018668

D. Favrat, C. Weber
CO2
Temperature = 17°C
DHvap = 257 kJ/kg
Pression = 50 bar
Source: earth.google.ch

Hot water

Heating

Cooling

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

CO2

Liquide

Vapeur

ADD THE PIPES IN THE PEDESTRIAN WAYS

Instead of putting them underground

Temperature 17 °C
DHvap = 257 kJ/kg
Pressure = 50 bar
APPLICATION TO A DISTRICT
APPLICATION TO THE DISTRICT

-84 %
No boilers

CO2 network - Electricity required

Electricity annual: 11.0 GWh
APPLICATION TO THE DISTRICT

-84 %
No boilers

PRODUCING ELECTRICITY IN THE WINTER?

- European Mix
- Combined cycle
- Renewable energy

**Products:**
- Electricity: 80%
- Heat: 20%
- CO2 captured
- H2O

FUEL CELL SYSTEM

Products:
Electricity: 80% CO2 captured
H2O

Fuel processing

Fuel cell

O2

Post combustion

Heat: 20%

Air

CH4

Sub-atmospheric

Water separation

CO2

H2O

ON THE USE OF WASTE HEAT

Heat from waste incineration
- Waste Incineration
- Industry

Electricity

Seasonal storage
- Heat from environment

Heat pump
- Heat from waste

Summer

Winter

2.6 x more heat supplied
THE GIFTS OF MOTHER NATURE

- Wind
- Hydro
- Renewable energy
- Fossil reserve
- Biomass
- Solar
- Bank accounts

Treasure
SYNTHETIC NATURAL GAS PRODUCTION

Biomethanisation
Hydrothermal gasification
Synthetic Natural Gas processes

BIOMASS : C(H2O)

Synthetic Natural Gas
Heat
CO2

=> FUEL CELL

=> CO2 network

SOLAR ENERGY

CH_NEp 2050 scenario
Electricity balance

Excess: 44% of PV cells production

www.energyscope.ch
SEASONAL STORAGE BY MOTHER NATURE

Photosynthesis

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{C(H}_2\text{O)} + \text{O}_2 \]

Biomass

1961 Nobel Prize in Chemistry
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Photosynthesis: 1-2% Solar efficiency

Stochastic summer energy

Stored energy

CO\(_2\)

\(\text{H}_2\text{O}\)

N, P, K

\(\text{O}_2\)
Artificial photosynthesis: 13-16% Solar efficiency

Efficiency: 78%

Heat: 20%

O2

H2O

CO2

PV

Co-Electrolysis

Stored energy
Liquid Methane

INTEGRATED ENERGY MANAGEMENT

Co-electrolysis

Fuel cell

Liquid CH4

Liquid CO₂

PV

Summer

Winter

80°C

40°C

15°C

5°C

-5°C

Ecole Polytechnique Fédérale de Lausanne

Waste incineration

Roof top Solar PV

Export

Hot water

Heating

Data centers

Air conditioning

Waste water

CH4

1 m³/hab

Biowaste

Lake

Liquid

Gas

CO2

Electricity

Refrigeration

Suici et al., Ecos Proceedings, 2016

80°C

1.3 m³/hab

1 m³/hab
AN AUTONOMOUS CITY IS POSSIBLE

Before

After

100 l gasoline/hab/year

Electricity

Solar PV

Bio

Waste

Waste water

Environment

Export

Gas

Electricity

CO₂

R. Suciu et al., Energy integration of CO₂ networks and Power to Gas for emerging energy autonomous cities in Europe, ECOS 2017 Proceedings
THE ENERGY SYSTEM

- Solar PV: 47%
- Bio: 36%
- Waste water: 17%
- Environment:?
- Export:?

100 l gasoline/hab/year
Electricity
MOBILITY

36%
**SMART CARS**

**Driving mode**
- Autonomy: 950 km
- Cons: 1.1 l/100 km

**Parking mode**
- Power plant: 3.5 kWe (eff. >70%)
- Battery: 5 kWh

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**Power plant:** 3.5 kWe (eff. >70%)

**Battery:** 5 kWh

**Driving mode**

- **Biogas**
  - 35 kg
  - 20 l

- **Batteries**
  - 5 kWh
  - 33 kg

- **Electrical motors**
  - 30 kW

- **1200 kg**

**Parking mode**

- **Biogas**
  - 35 kg
  - 20 l

- **Batteries**
  - 5 kWh
  - 33 kg

- **Electrical motors**
  - 30 kW

- **1200 kg**

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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
INDUSTRY

17% Efficiency by Heat integration
SYNTHETIC NATURAL GAS COGENERATION

BIOMASS : C(H₂O)

H₂O

Electricity

H₂

CO₂

CH₄

Synthetic Natural Gas

HT-Heat

LT-Heat

Power to Gas

HT-Heat

LT-Heat

4H₂ + CO₂ → CH₄ + 2H₂O

EFFICIENCY IS THE 1rst RESOURCES!

Biomass

- SNG production
- Cogeneration
- Other sources

Efficiency 17%

by Heat integration
LES RESSOURCES RENOUVELABLES

Biomass
Synthetic natural gas
HT heat
SNG
Seasonal storage by SNG
Industrial cogeneration

Wind and hydro

Needs (53%)

100 l gasoline/hab/year
SWITZERLAND CAN BE AUTONOMOUS

47% Waste water
36% Biomass
17% Wind and Hydro

and a net exporter of biogas

100 l gasoline/hab/year
Electricity
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!
Thank You!