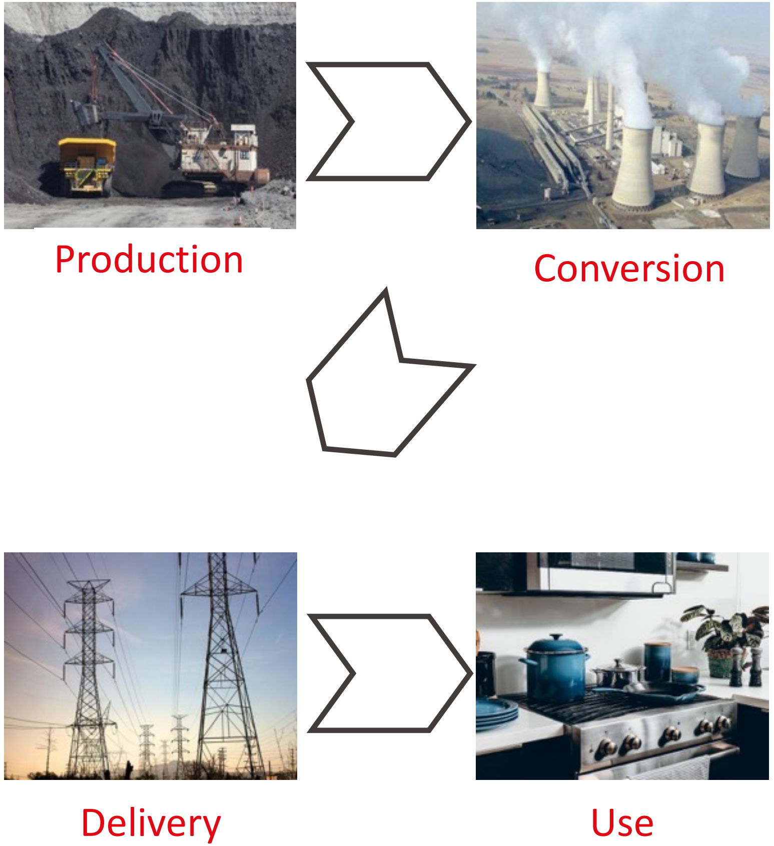
Course organization

François Maréchal

Tuong-Van Nguyen

Lausanne – 08/09/2025

École
polytechnique
fédérale
de Lausanne



Course organization

People

Schedule

Materials

Evaluation

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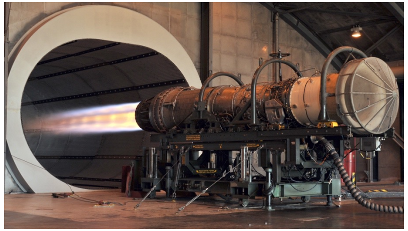
Learning objectives



- **Explain** the main principles of energy conversion & storage technologies
- **Compare** them in terms of efficiencies, costs and impacts
- **Select** and **size** them for given energy demands

Exercises

- **Describe the energy system of Switzerland as of today**
- **Explore** the interactions between renewables and storage technologies in the future
- **Apply** a system approach to our energy system

Project

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Lecturers

- Francois Maréchal (EPFL)

Sciences et Techniques de l'Ingénieur

- Jan van Herle (EPFL)

Sciences et Techniques de l'Ingénieur

- Tuong-Van Nguyen (PLANAIR/EPFL)

Sciences et Techniques de l'Ingénieur

- Gianfranco Guidati (ETHZ)

EPFL

Schedule

Week	Date	Topic	Lecturer
1	08/09	Introduction / What is an energy system?	FM / TVN
2	15/09	Energy performance / modelling	TVN
3	29/09	Rankine cycles	TVN
4	06/10	Combustion / Brayton cycles	FM
5	13/10	Coal / CCS	FM
6	20/10	Nuclear / Cogeneration	TVN

POWER CYCLES + FOSSIL FUELS

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Schedule

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3	29/09	Rankine cycles	TVN
4	06/10	Combustion / Brayton cycles	FM
5	13/10	Coal / CCS	FM
6	27/10	Nuclear / Cogeneration	TVN
7	03/11	Heat pumps / Geothermal	TVN
8	10/11	Solar	FM
9	17/11	Wind / Hydro	FM
10	24/11	Biomass	TVN
11	01/12	Storage	TVN
12	08/12	Fuel cells & Hydrogen	JVH

RENEWABLES

FM = Francois Maréchal, **TVN** = Tuong-Van Nguyen, **JVH** = Jan Van Herle, **GG** = Gianfranco Guidati

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Schedule

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5	13/10	Coal / CCS	FM
6	27/10	Nuclear / Cogeneration	TVN
7	03/11	Heat pumps / Geothermal	TVN
8	10/11	Solar	FM
9	17/11	Wind / Hydro	FM
10	24/11	Biomass	TVN
11	01/12	Storage	TVN
12	08/12	Fuel cells & Hydrogen	JVH
13	15/12	Energy strategy / Final wrap-up	GG / FM / TVN

ENERGY SYSTEM, MODELS, POLICIES

FM = Francois Maréchal, **TVN** = Tuong-Van Nguyen, **JVH** = Jan Van Herle, **GG** = Gianfranco Guidati

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Schedule

- **Timetable:**
  - From week 2 : 1h exercise (10h15) + 2h lecture (11h15) + 1h project (13h15)
  - **Exercises, Case studies & Projects** – solve them in class
- Expected **contribution** from your side:
  - 4 credits ≈ 4x30 hours = **120 hours**
  - 14x4 hours lecture/exercise → 120-56 = 64 hours homework over 13 weeks
    ≈ 5 hours/week for exos, project and exam

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Materials

▪ Moodle & Ed

- Course organization and slides on Moodle: https://moodle.epfl.ch/course/view.php?id=16284

If needed (for example, if you **cannot attend the class**)

- All course notes on: https://ipese-lectures.epfl.ch/energy-conversion-2019/
- Pre-recorded videos on: https://tube.switch.ch/channels/90cbb52f

- Announcements and Questions? → **Ed on Moodle :** https://edstem.org/eu/courses/825/discussion/

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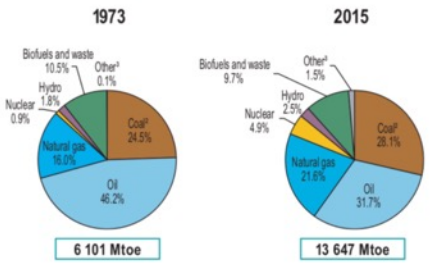
Materials

- Course compendium on the **course website (EPFL network/VPN)**

https://ipese-lectures.epfl.ch/energy-conversion-2019/l-energy-systems.html

1.1 Introduction

The world energy demand has increased significantly in the last decades and is at present dominated by the consumption of fossil fuels (**> 80%**) (International Energy Agency 2017a). Compared to 50 years ago, oil and coal represent a smaller share, and new sources of energy, such as nuclear and hydro, have emerged. This shift is even more marked when analysing the energy system before the industrial revolution, as biomass alone was satisfying more than **90%** of our primary energy needs.



1. World includes international aviation and international marine bunkers.
2. In these graphs, peat and oil shale are aggregated with coal.
3. Includes geothermal, solar, wind, tide/wave/ocean, heat and other.

Figure 1.1: Global primary energy consumption (International Energy Agency 2017a)

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Evaluation

- **Examination:**

  - 60% on **written exam** (theory + exercise): allowed 5 two-sided pages (10 p.) of summary
  - 40% on **project – scientific articles**

Fall 2019 - January 2020

Problem 1 - Energy Systems

Several paths can be followed to reduce CO_2 emissions in the European Union, and your *task* is to perform back-to-envelope calculations (levelized cost, CO_2-avoidance cost, marginal efficiency and energy savings) and to suggest relevant policies.

1. The concept of **levelised cost of electricity** is widely used to compare different energy technologies. What is the **LCOE** of this CCGT plant? (/5)
2. The levelized cost of electricity for CCGT power plants with CCS is 90 CHF/MWhe. These new plants achieve a 90%-reduction of the CO_2-emissions. What is the **CO_2-avoidance cost of CCGT-CCS plants, in CHF/tCO_2**? Assume a CO_2-emission factor of conventional CCGT power plants of 432 kg/MWhe. *If you have not been able to solve (a), assume a LCOE of 50 CHF/MWhe for them.* (/2)
3. Instead of using a natural gas boiler with an efficiency of 90% for heating and getting electricity from the grid with an efficiency of 38%, a cogeneration plant, with an electrical efficiency of 40% and a heat generation efficiency of 45%, can be implemented. What is the **marginal efficiency of electricity production**?

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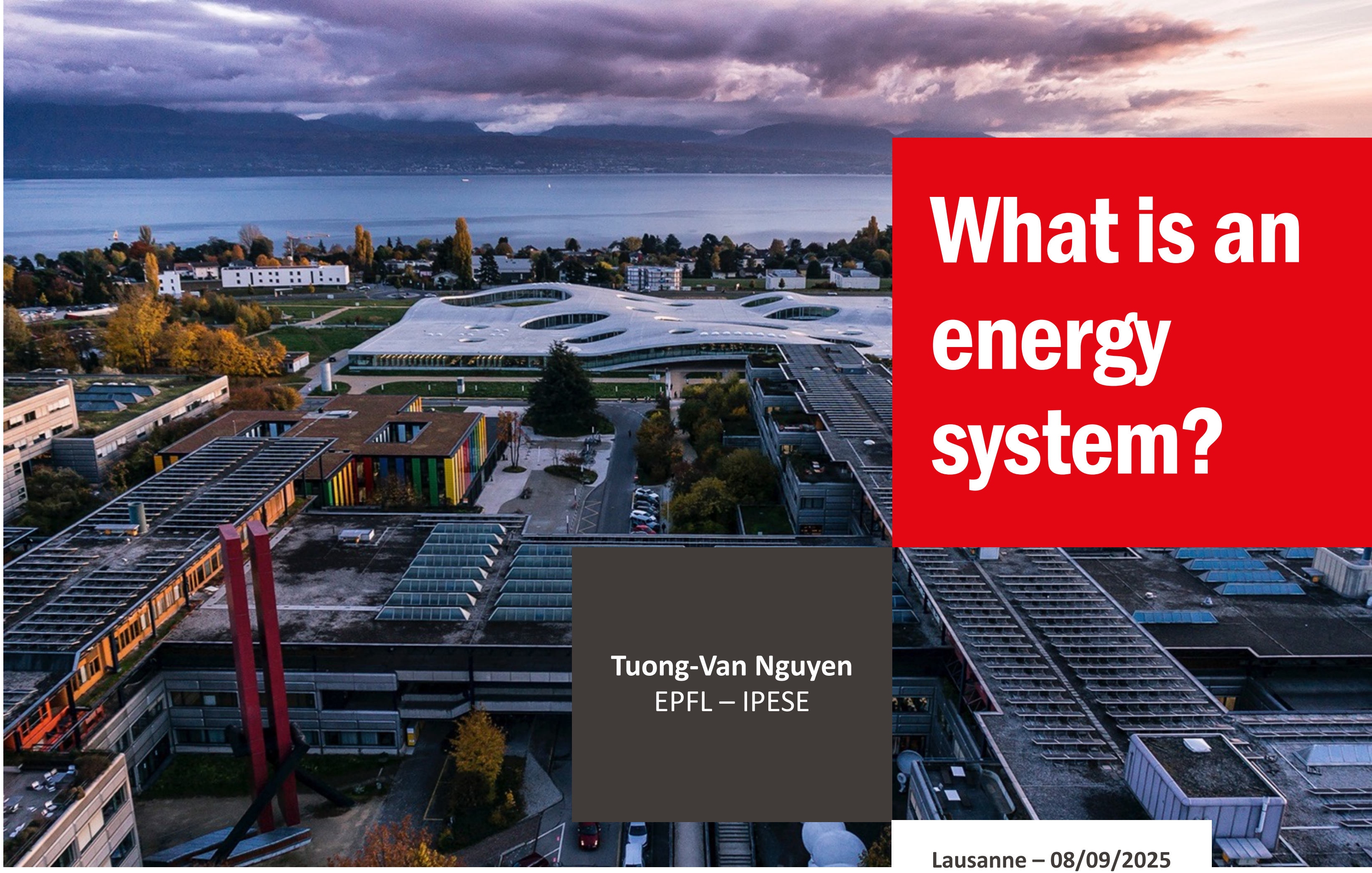


What is an energy system?

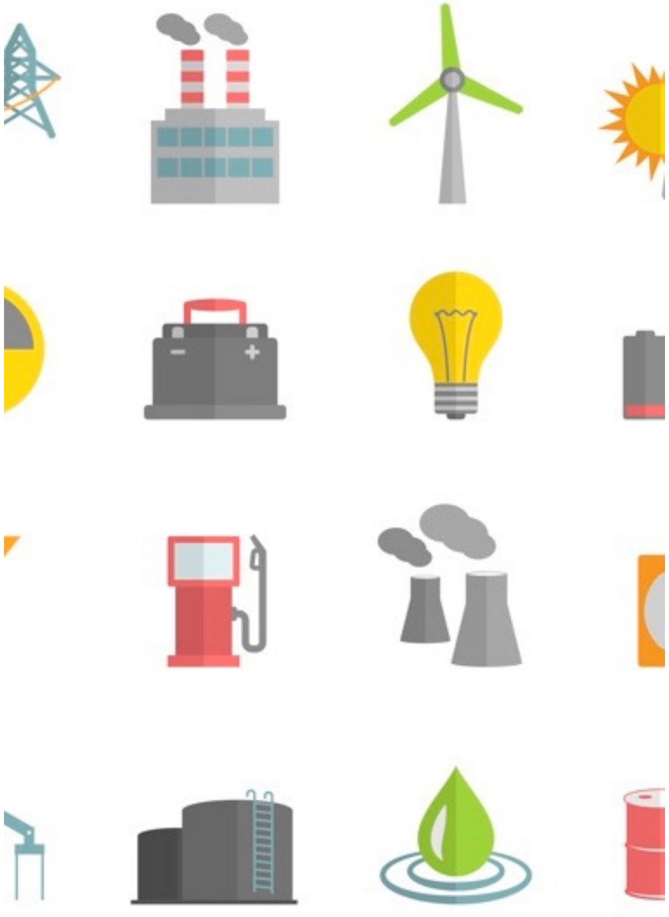
Tuong-Van Nguyen
EPFL – IPESE

Lausanne – 08/09/2025

École polytechnique fédérale de Lausanne

Learning objectives

- ***Describe*** what is an energy system and how it is illustrated (Sankey)
- ***Identify*** *primary*, *final* and *end-use* energy demands
- ***Apply*** a basic system approach to compare conversion technologies



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Production

Conversion

Delivery

Use

Introduction

Energy Systems

Energy Flows

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QUESTION

What is the share of electricity in our final energy use (CH)?

- ~ 25%
- ~ 50%
- ~ 75%
- ~ 90%

Energy service =

why we use energy

Cooking

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Energy service =

why we use energy

Useful energy =

the energy form at the very end

Cooking

Heat

Demand

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EPFL

Energy service =

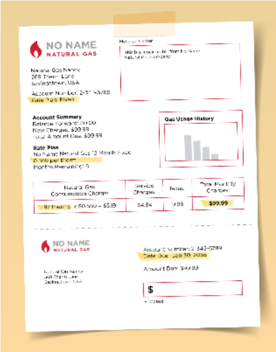
why we use energy

Useful energy =

the energy form at the very end

Final energy =

what you see on your bill, as a consumer



Cooking → **Heat** → **Light oil, gas, …**

Demand

EPFL

Energy service =

why we use energy

Cooking

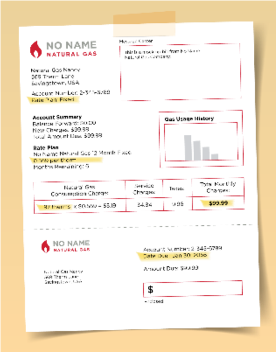
Useful energy =

the energy form at the very end

Heat

Final energy =

what you see on your bill, as a consumer



Light oil, gas, …

Distribution =

how it comes to your place

Trucks, grids, ships, etc.

Demand

Conversion (& transmission)

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Distribution =

how it comes to your place

Trucks, grids, ships, pipelines, etc.

Secondary energy =

what is available before you transport it

LPG

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Distribution =

how it comes to your place

Trucks, grids, ships, pipelines, etc.

Secondary energy =

what is available before you transport it

LPG

Conversion =

how it becomes something directly usable

Refineries

Conversion (& transmission)

Conversion =

how it becomes something directly usable

Primary energy =

what was harvested at the very beginning

Refineries

Raw oil/gas - before the refinery… from the wells

Conversion (& transmission)

Resource

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Introduction
– Definitions of an energy system

- "The energy system comprises all components related to the **production, conversion, delivery, and use of energy**."

Production

Conversion

Delivery

Use

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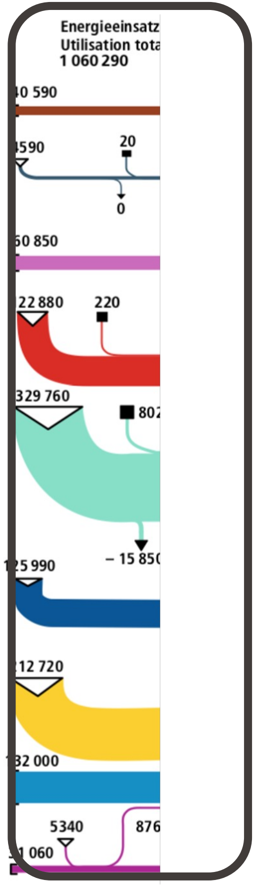
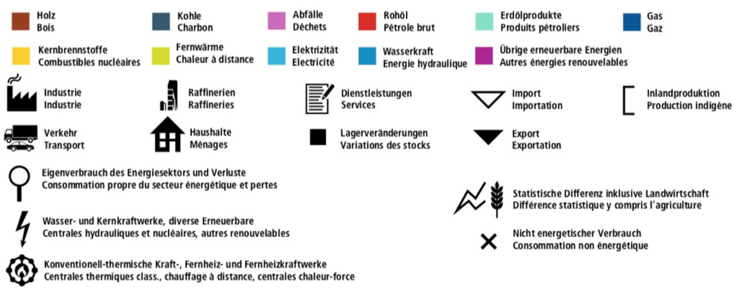
Introduction

– An "energy-flow" diagram (Sankey)



(1) **RESOURCES:**

- **Fossil**: oil, natural gas, coal, uranium
- **Renewables**: wind, solar, geothermal



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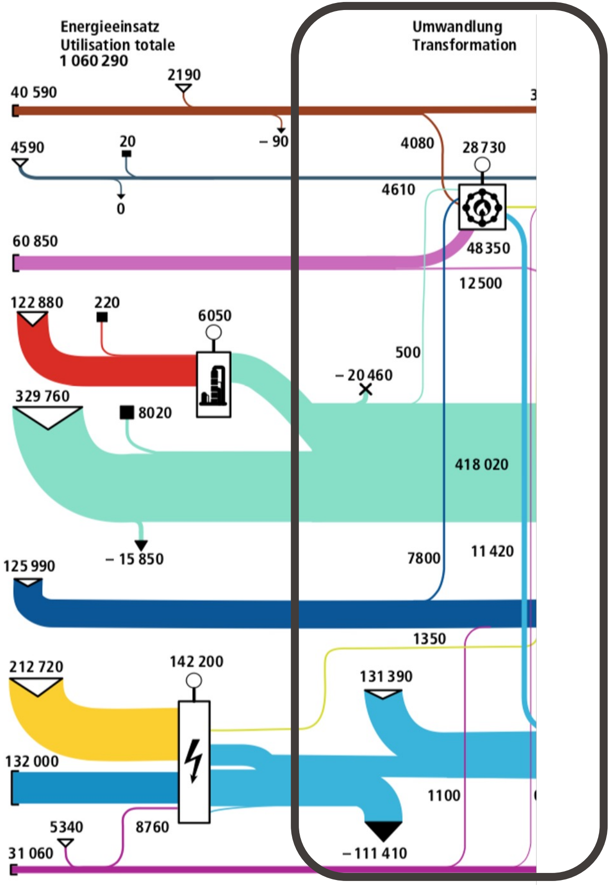
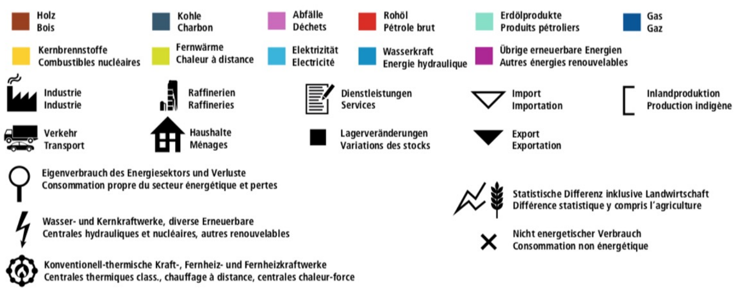
Introduction

– An "energy-flow" diagram (Sankey)



(2) CONVERSION TECHNOLOGIES:

- Power plants
- Hydroelectric dams
- …



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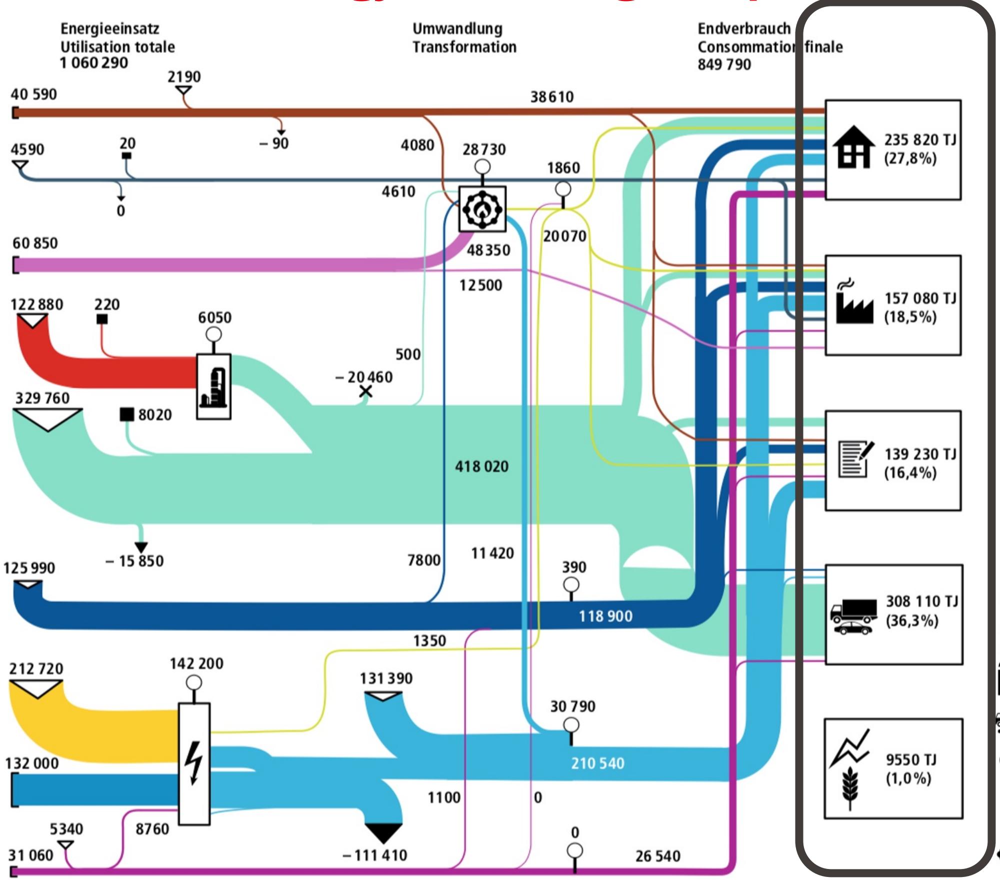
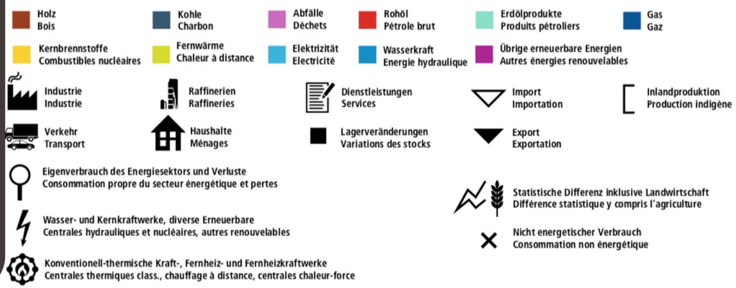
Introduction

– An ”energy-flow” diagram (Sankey)



(3) DEMANDS:

- Per **sector**:
  - Households
  - Industry
  - Services
  - Transport



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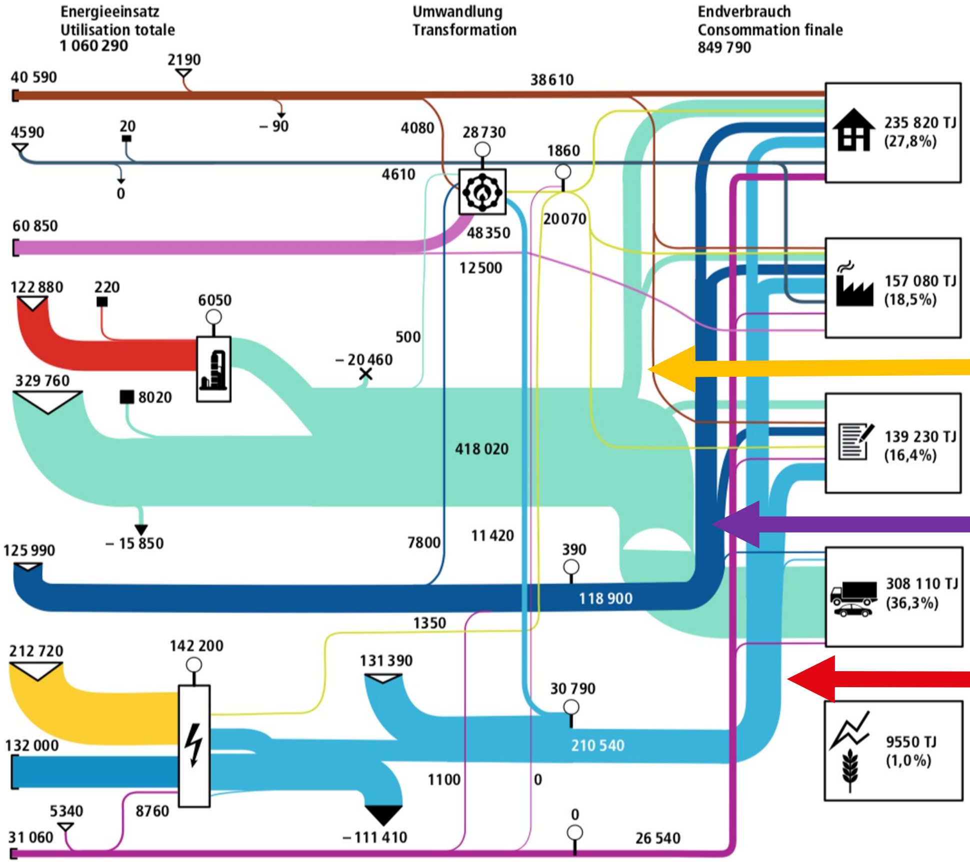
EPFL

Introduction

– The current situation: fears of natural gas and electricity shortages



Pressure on oil-derived products : about **420'000 TJ per year** (105 TWh/year)

Natural gas : about **33 TWh/year**

Electricity : about **54 TWh/year**

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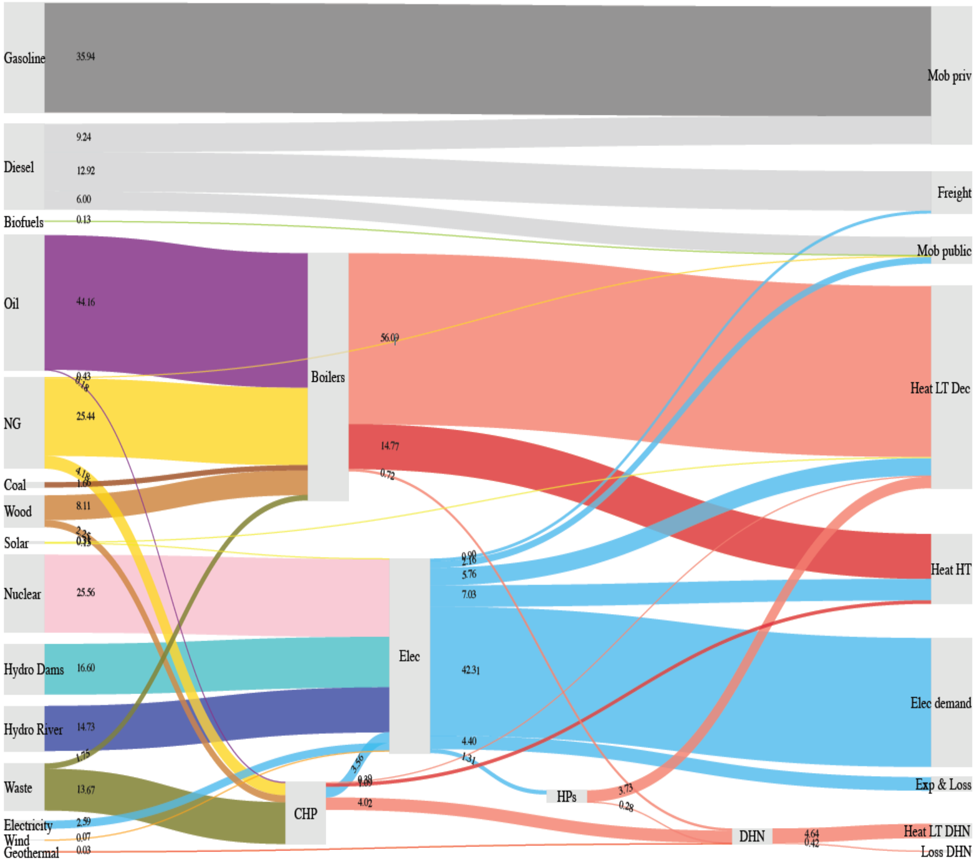
Introduction

– An alternative "energy-flow" diagram (Sankey)



- Per **type of end-use demand:**

Mobility

Heating

Electricity

~ 25% of the final energy use

Energy is not only electricity!

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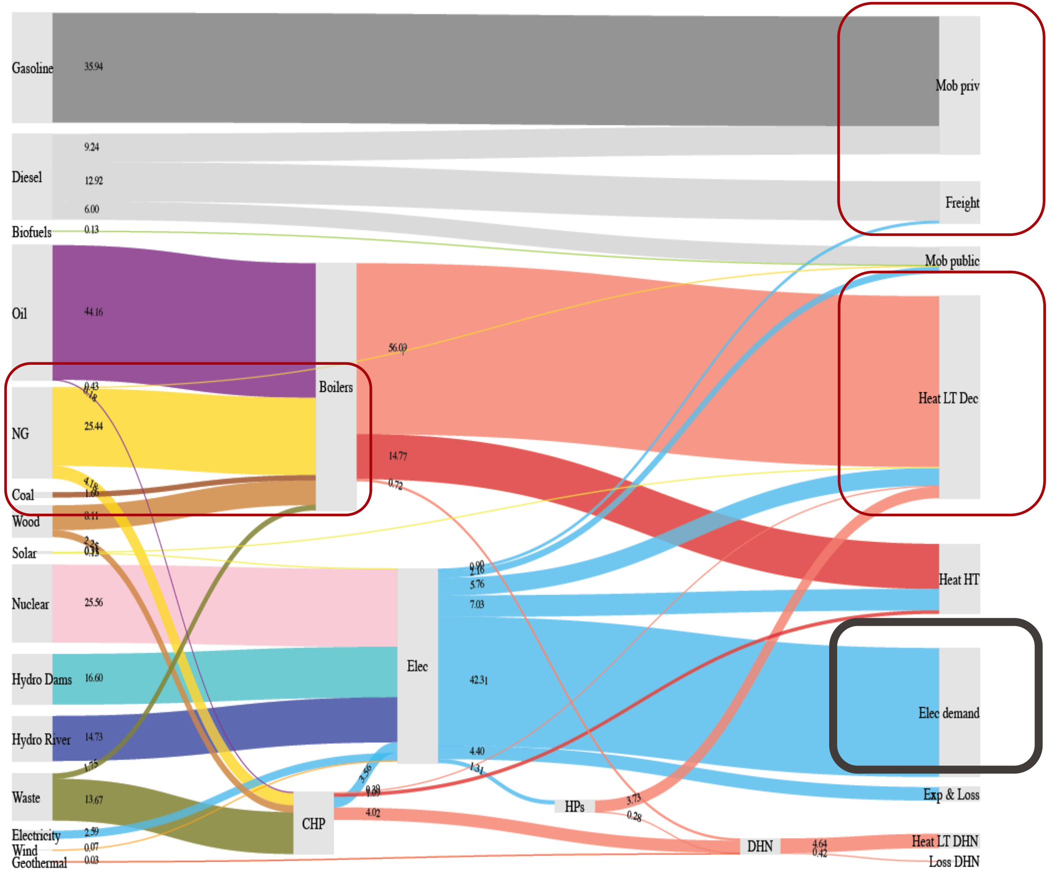
Introduction

– The current situation: fears of natural gas and electricity shortages



Mobility

Private, public and freight

Low-temperature heating (cooking…)

Residential, services and industry

Specific electricity demand (lightning…)

Residential, services and industry

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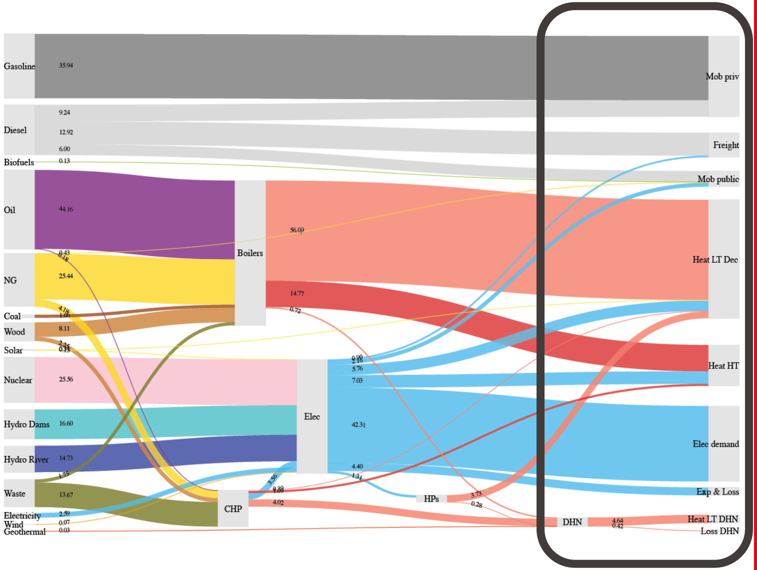
QUESTION

Is the share of electricity in our final energy demand expected to **increase** or **decrease** in the future ?

Demands



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Demands

– How can we reduce them?

ÉNERGIE

La Confédération et les cantons se préparent à des scénarios extrêmes en cas de pénurie d’électricité

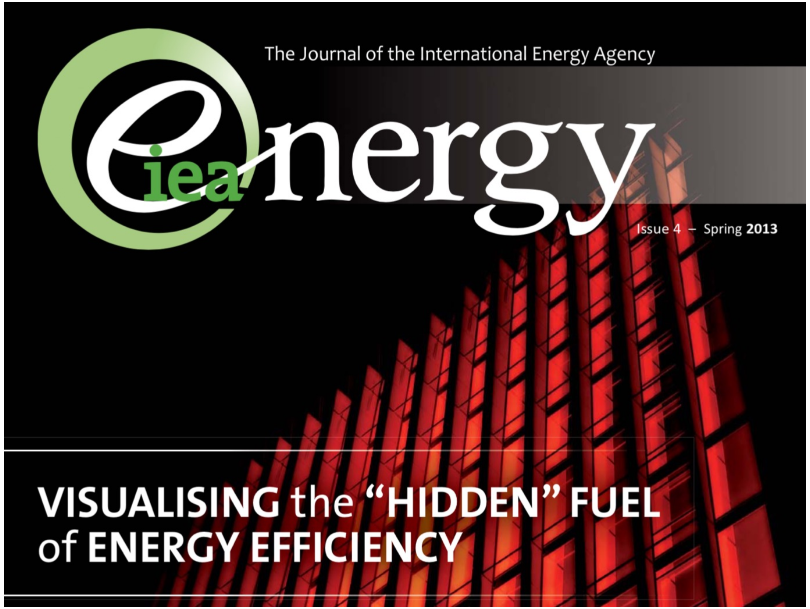
Black-outs, rébellions, pillages: même si de tels scénarios restent improbables, la Suisse doit se préparer au pire, explique dans une interview au «Blick» Fredy Fässler, président de la Conférence des directrices et directeurs des départements cantonaux de justice et police

Des pylones électriques à Collonges, en Valais, fin mai 2022. — © JEAN-CHRISTOPHE BOTT / KEYSTONE

Source: https://www.letemps.ch/suisse/confederation-cantons-se-preparent-scenarios-extremes-cas-penurie-delectricite

Demands
– How can we reduce them?

- Energy efficiency ("deliver the same service with less input") to conversion AND to demand side!




private lending and technology research, development demonstration and deployment.
5. Enforce, evaluate and regularly update efficiency policies and measures in all sectors.
BUILDINGS
6. Apply energy codes and minimum energy performance standards (MEPS) to all new buildings and those undergoing renovation.
7. Support construction and marketing of buildings with net-zero energy consumption.
8. Improve existing buildings' efficiency, emphasising building envelopes and systems during renovations.
9. Require building energy performance labels or certificates.
10. Establish policies to improve the performance of critical building components, such as windows and heating, ventilating and cooling systems.
APPLIANCES AND EQUIPMENT
11. Adopt and regularly tighten mandatory MEPS and labels across the full spectrum of appliances and equipment.
12. Regularly update product test standards and measurement protocols.
13. Use incentives and other measures to support the introduction and uptake of new technologies and high-efficiency machinery.
LIGHTING
14. Phase out inefficient lighting products.
15. Require and promote improved lighting systems design and management.
TRANSPORT
16. Adopt and regularly update fuel-efficiency standards for road vehicles.

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EPFL

Demands
– Example of house heating

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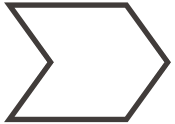
- **Energy demand [J]** = [J/m2] * [#m2] = **[J/ca]** * [ca/m2] * [#m2]

Step I
Energy service
Comfort temperature?

Demands
– Example of house heating

- **Energy demand [J] = [J/m²]** * [#m²] = [J/ca] * [ca/m²] * [#m²]



Step II
End-use energy demand
Thermal insulation?
Low-T floor heating?

Step I
Energy service
Comfort temperature?

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Demands
– Example of house heating

- **Energy demand [J]** = [J/m^2] * [#m^2] = [J/ca] * [ca/m^2] * [#m^2]

Heat demand

Step III
Energy conversion
Technologies & resources?

Step II
End-use energy demand
Thermal insulation?
Low-T floor heating?

Step I
Energy service
Comfort temperature?

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Demands
– Example of house heating

Demand-side actions

Do not forget about them!

Heat demand

Step III
Energy conversion
Technologies & resources?

Step II
End-use energy demand
Thermal insulation?
Low-T floor heating?

Step I
Energy service
Comfort temperature?

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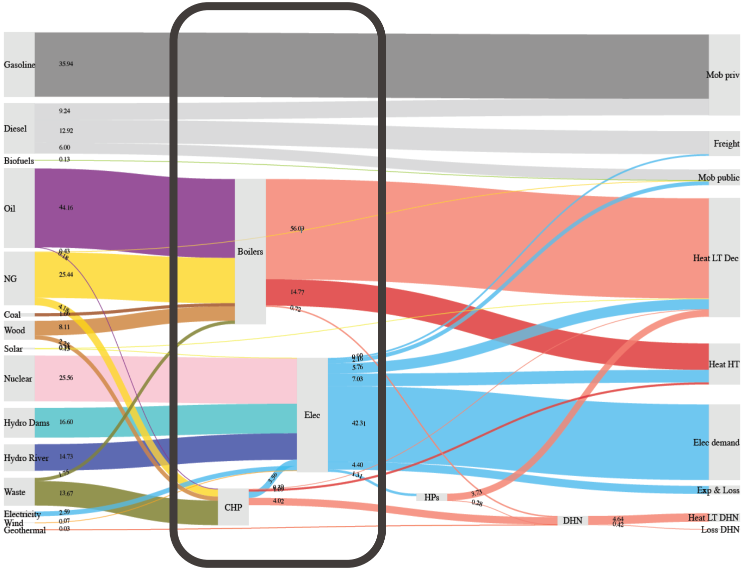

Conversion

Technologies

System approach

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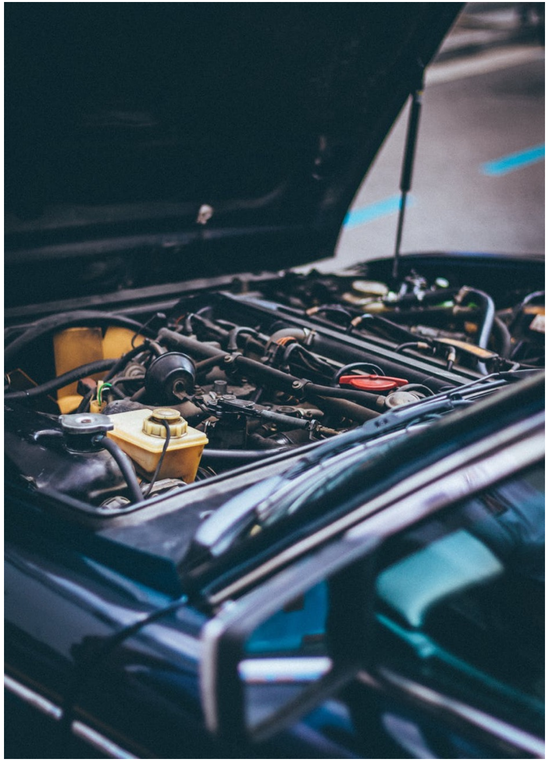
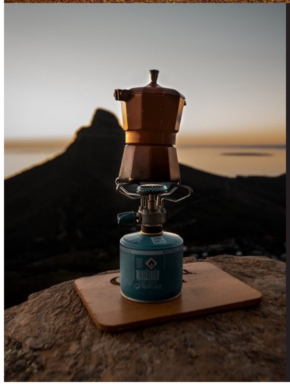
Conversion

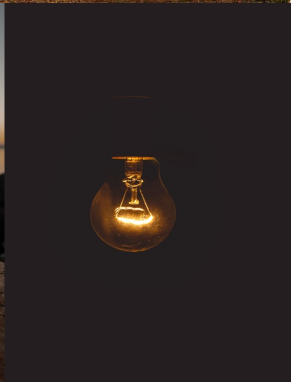
– Examples of conversion technologies



Car engines

Power plants





Gas boilers

…

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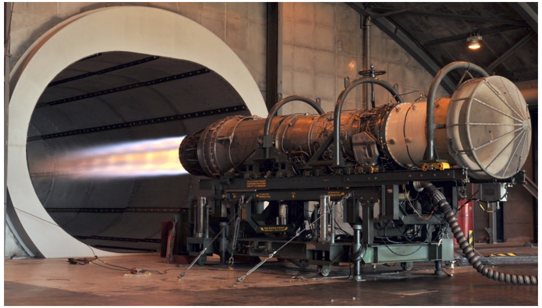
Conversion
– Examples of conversion technologies

- The concept of **energy efficiency** : what you want / what you consume
- Example of a **power plant** :
  - What we want = power, electricity
  - What we consume = nuclear fuel, coal, natural gas
- Example of a **heating system** :
  - What we want = heat
  - What we consume = wood, gas, oil



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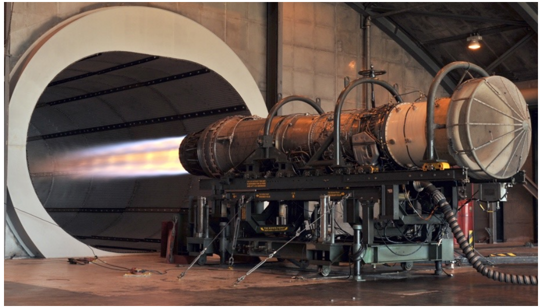
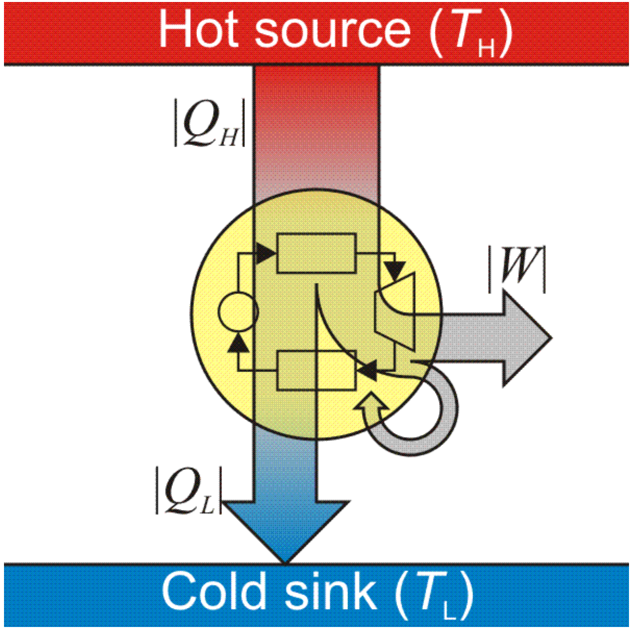
Conversion

– Case of heat engines

- A **heat engine** = **heat/chemical** energy to mechanical





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EPFL

QUESTION :

Which technologies do you know for producing space heating, and with which energy efficiency ?

100 J

Conversion
– A system approach on the EPFL heating system

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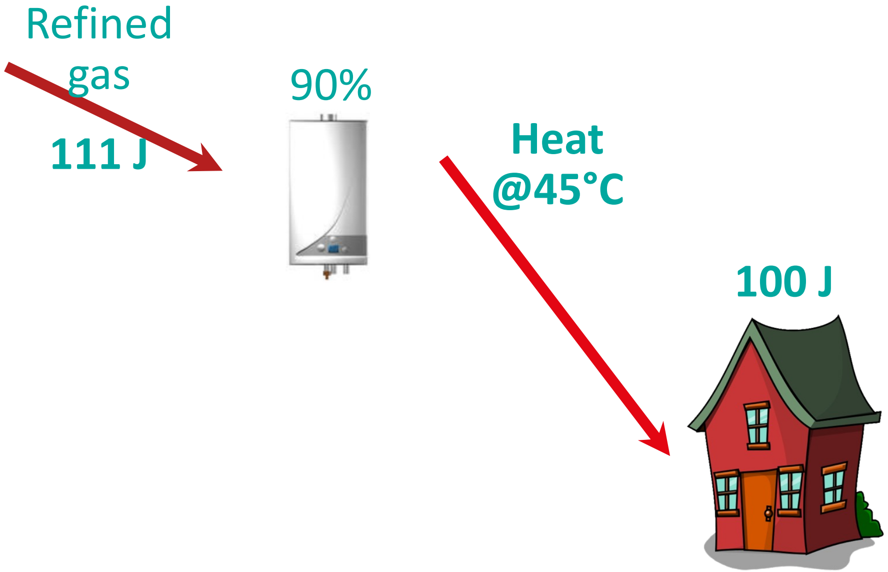
100 J

Conversion

– A system approach on the EPFL heating system



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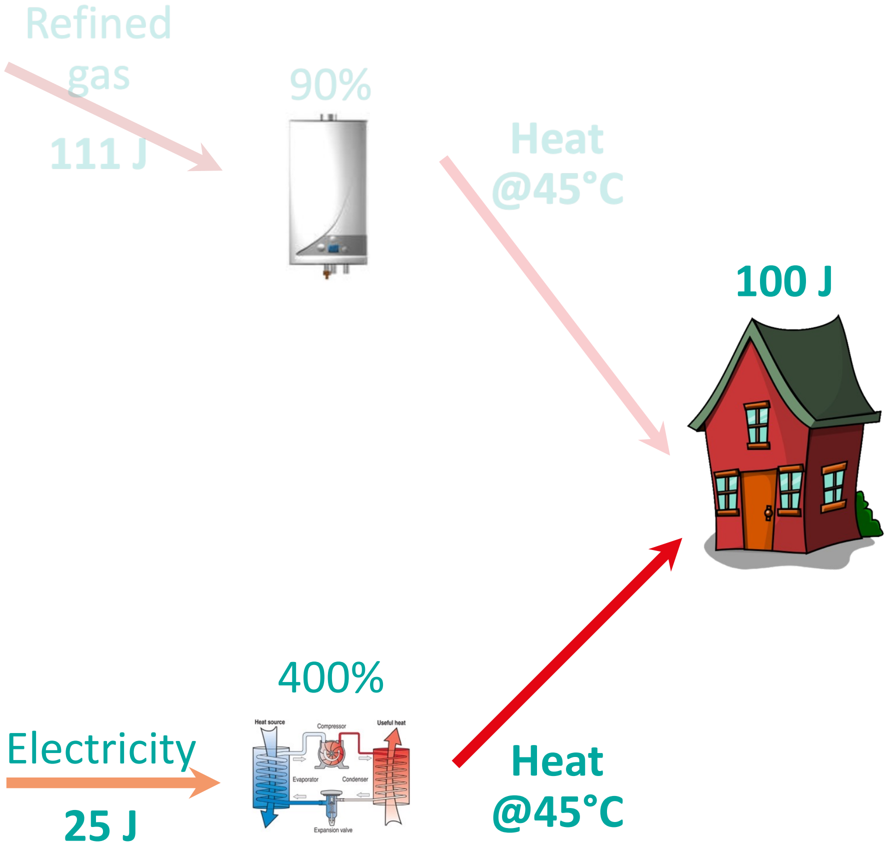
Conversion

– A system approach on the EPFL heating system



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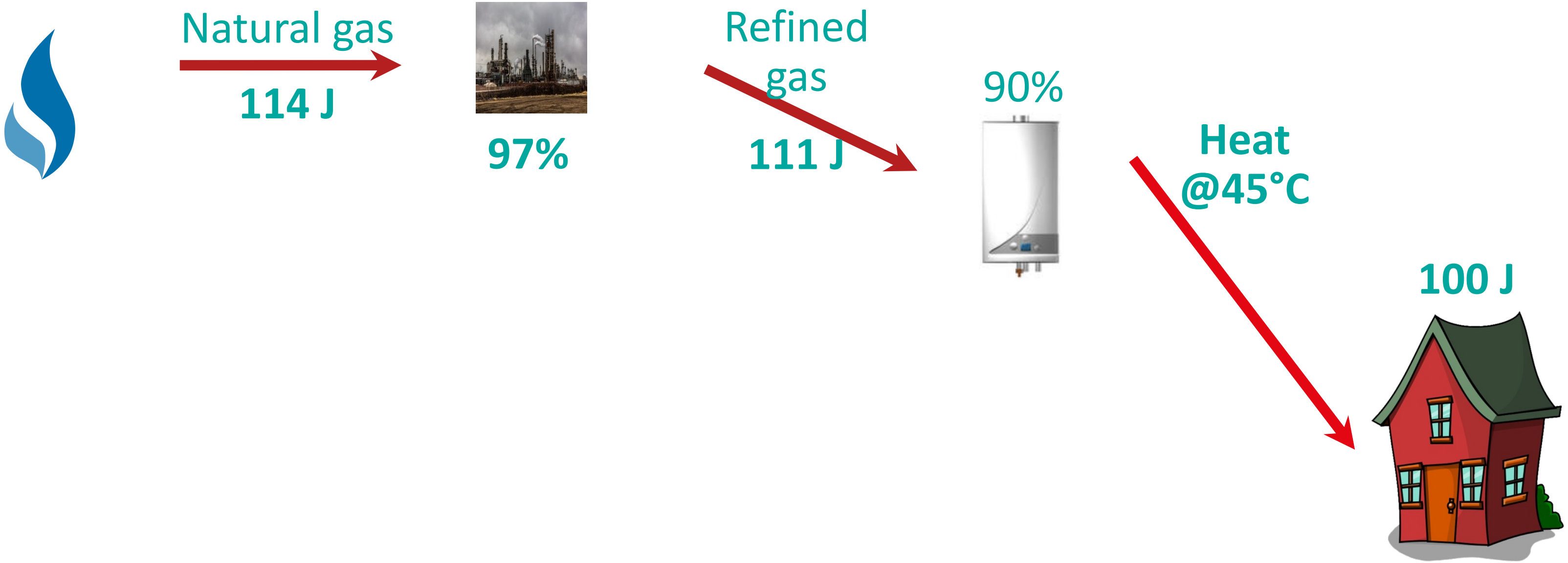
Conversion

– A system approach on the EPFL heating system



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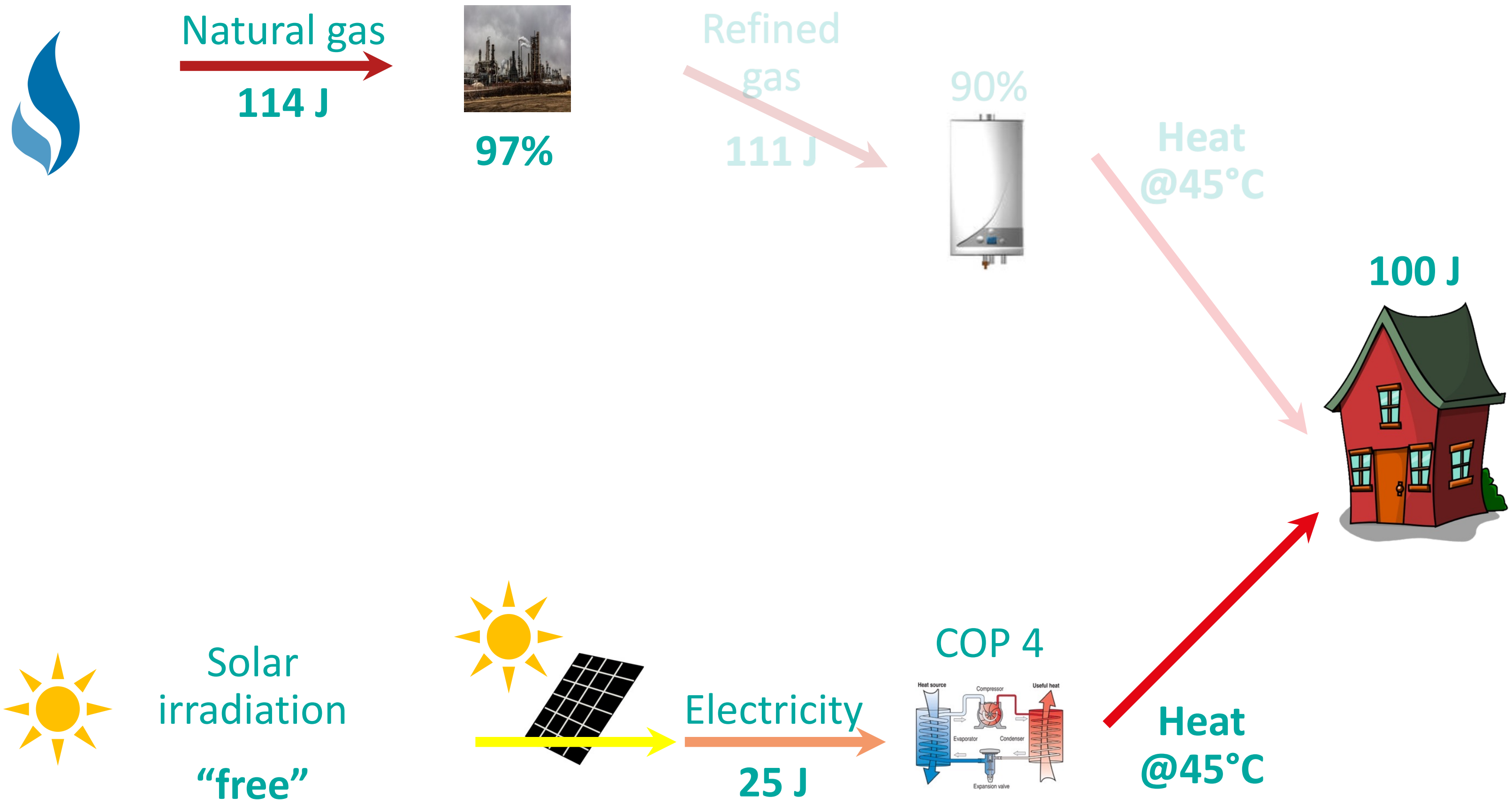
Conversion

– A system approach on the EPFL heating system



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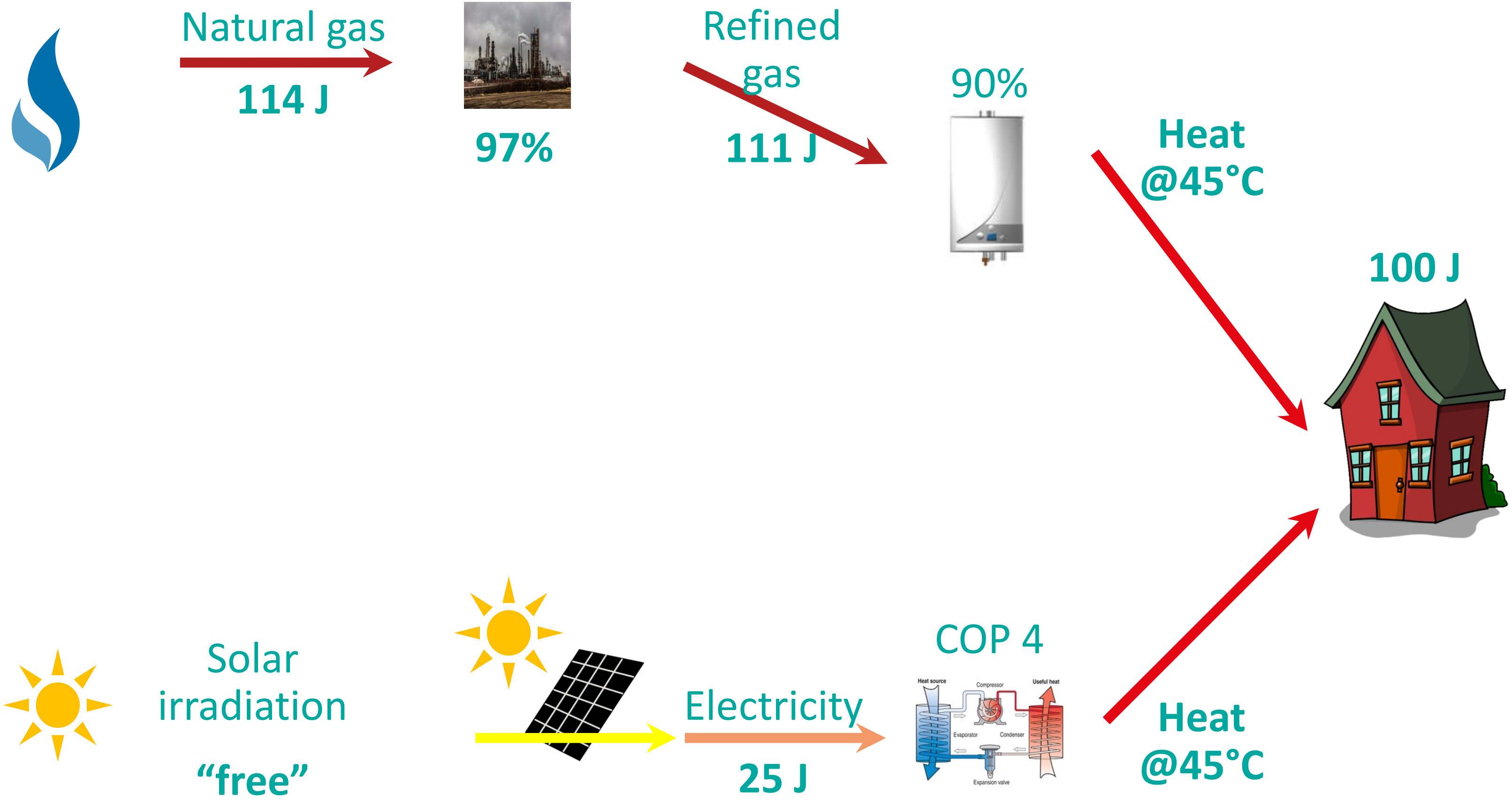
EPFL

Conversion

– A system approach on the EPFL heating system



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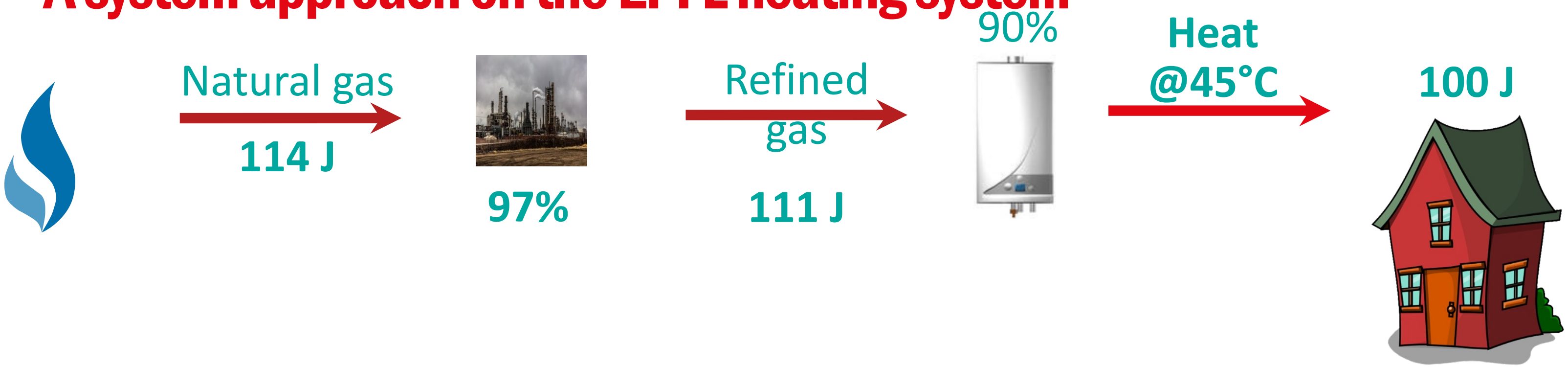
Conversion
– A system approach on the EPFL heating system



- **Natural gas** boiler

  + standard solution
  + low energy use (primary and final)
  - CO_2 emissions
  - NG price

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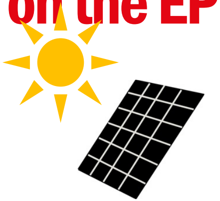
Conversion

– A system approach on the EPFL heating system

Solar irradiation

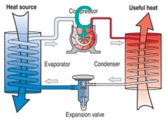
“free”



Electricity

25 J

COP 4



Heat @45°C

100 J

- PV panel + heat pump

  + more efficient
  + renewable sources
  - high investment costs
  - storage issues

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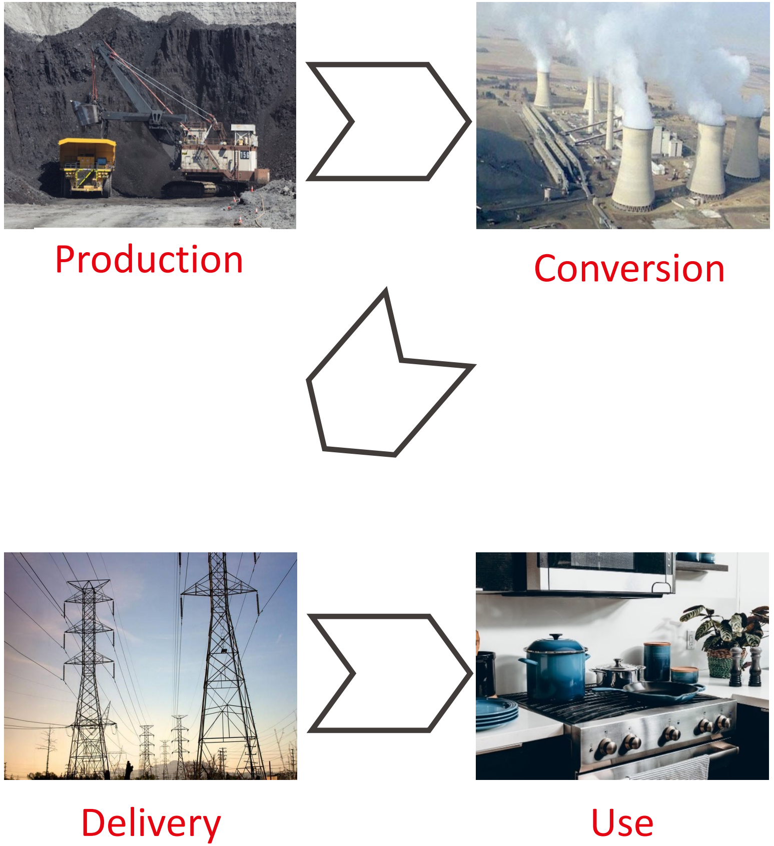

Conclusion

Take-home message

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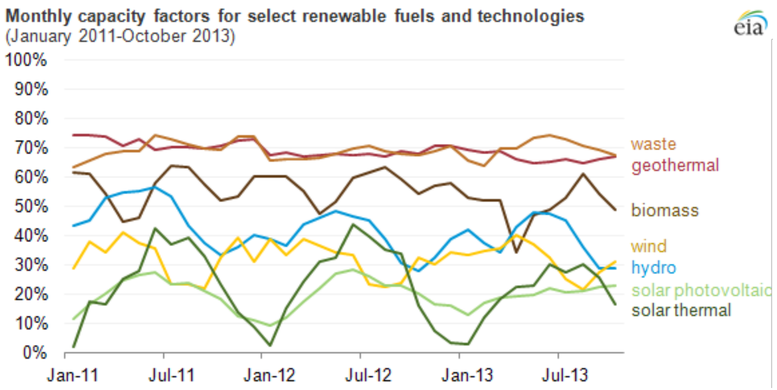
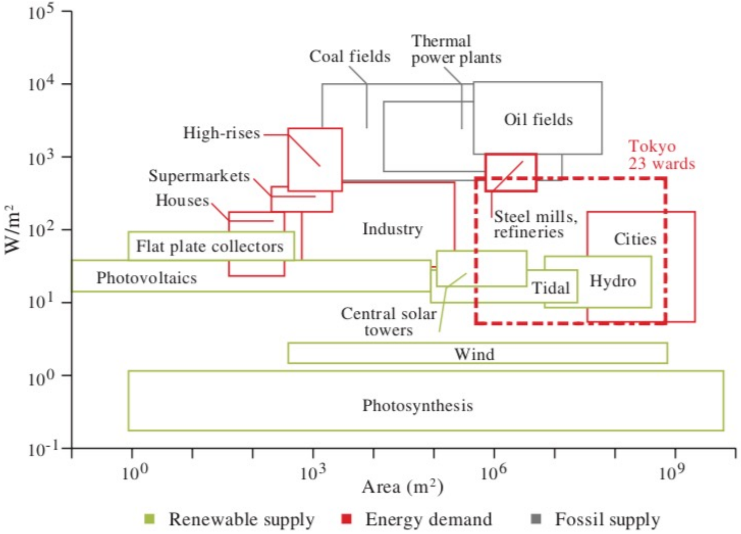
Take-home message

- Energy system >> power system → not only electricity!
- **Three main components:**
  - Resources, demands, **energy conversion technologies**
- **Energy conversion technologies:**
  - There are many alternatives → Need of a system approach





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Important concepts & formulas

- **Concepts:**
  - Primary, secondary, final and end-use energy
  - Energy-flow diagrams (Sankey)
  - Energy efficiency
  - System approach

- **Formulas:**
  - Energy efficiency : what we want/what we consume
  - System efficiency : the product of all efficiencies in the conversion chain

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EPFL

Questions?

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