Advanced energetics

2025-2026

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Industrial Process and Energy Systems Engineering

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IPESE
Industrial Process and Energy Systems Engineering

Prof. François Marechal
Industrial Process and Energy Systems Engineering
EPFL Valais-Wallis, Energypolis, Sion

Chemical engineering …
Maried, 3 enfants

STI - Sciences et Techniques de l'Ingénieur
GM - Section Génie Mécanique
- Orientation Energie
- Minor Energie

The team

- Professor François Maréchal
  - http://people.epfl.ch/francois.marechal, @francoismarechal.bsky.social

  Industrial Process and Energy Systems Engineering
    - http://ipese.epfl.ch
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  Industrie, 17, CH-1951 Sion
- Assistants
  - Dr. Daniel Flórez-Orrego, Pullah Bhatnagar, Vibhu Baibhav

Schedule of Today

- Advanced energetics : introduction
- Advanced energetics
  - Organisation and course overview
- Advanced energetics
  - The energy bill and the energy audit

Advanced Energetics : Goals of the lecture

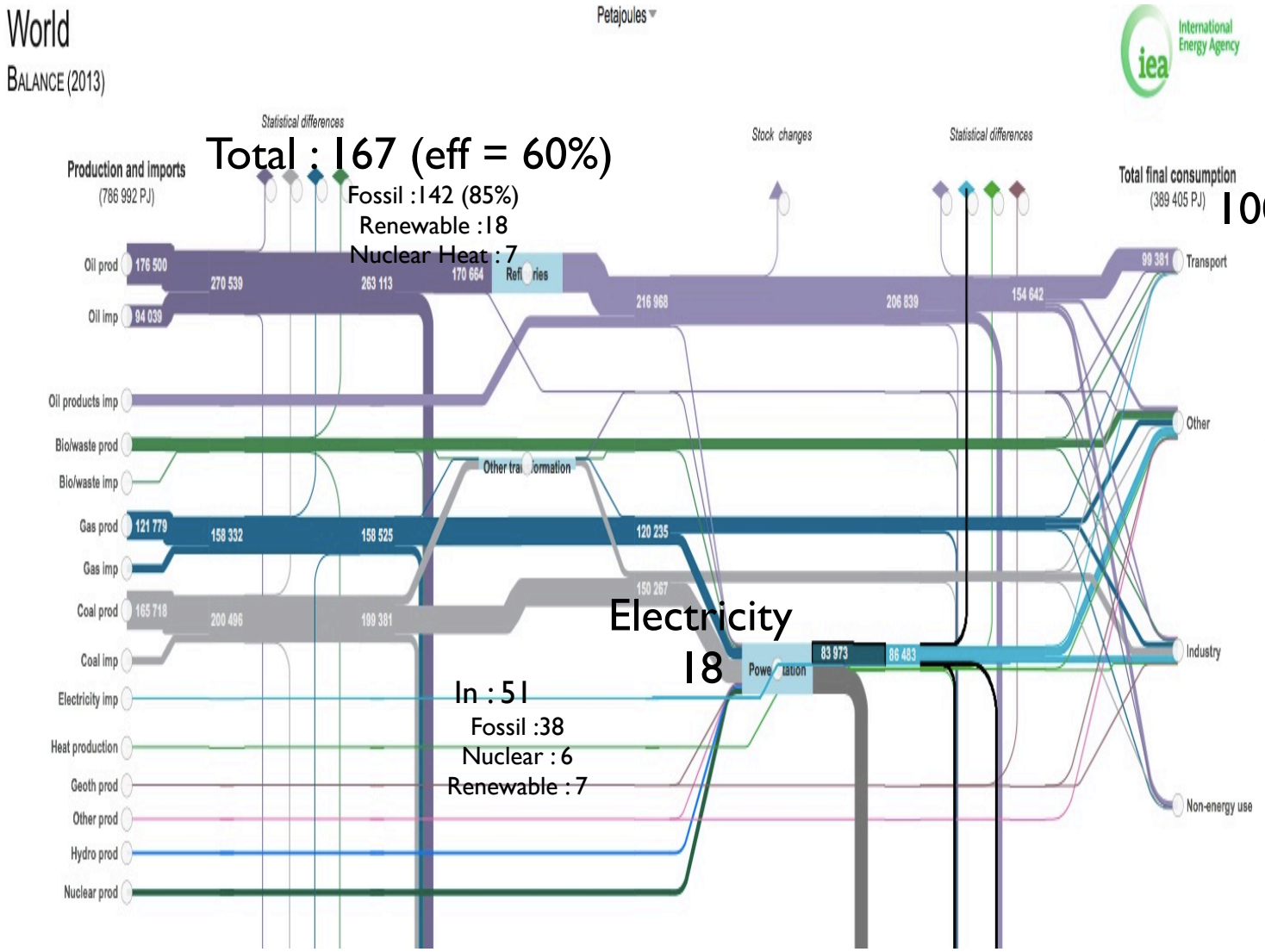
Energy analysis and synthesis of industrial and energy conversion processes

- To be able to propose decarbonisation options in industrial processes by
  - Analyzing the energy requirement of an Industrial process
  - Identifying and quantifying heat recovery options
  - Identifying the decarbonised ways to supply the process energy
  - Defining the associated investment
  - Defining the Economic & Environmental impact key performance indicators for the investment

The energy in the industry

- Why is it important ?

Industry is 29% of the World Energy Balance



Total : 167 (eff = 60%)
Fossil :142 (85%)
Renewable :18
Nuclear Heat : 7

Electricity
18
In : 51
Fossil :38
Nuclear : 6
Renewable : 7

100

Transport 28
Oil : 25
Gas : 1

Services & Household 35
Oil : 5
Gas : 7
Elec : 10
Biom : 9
Coal : 1.7

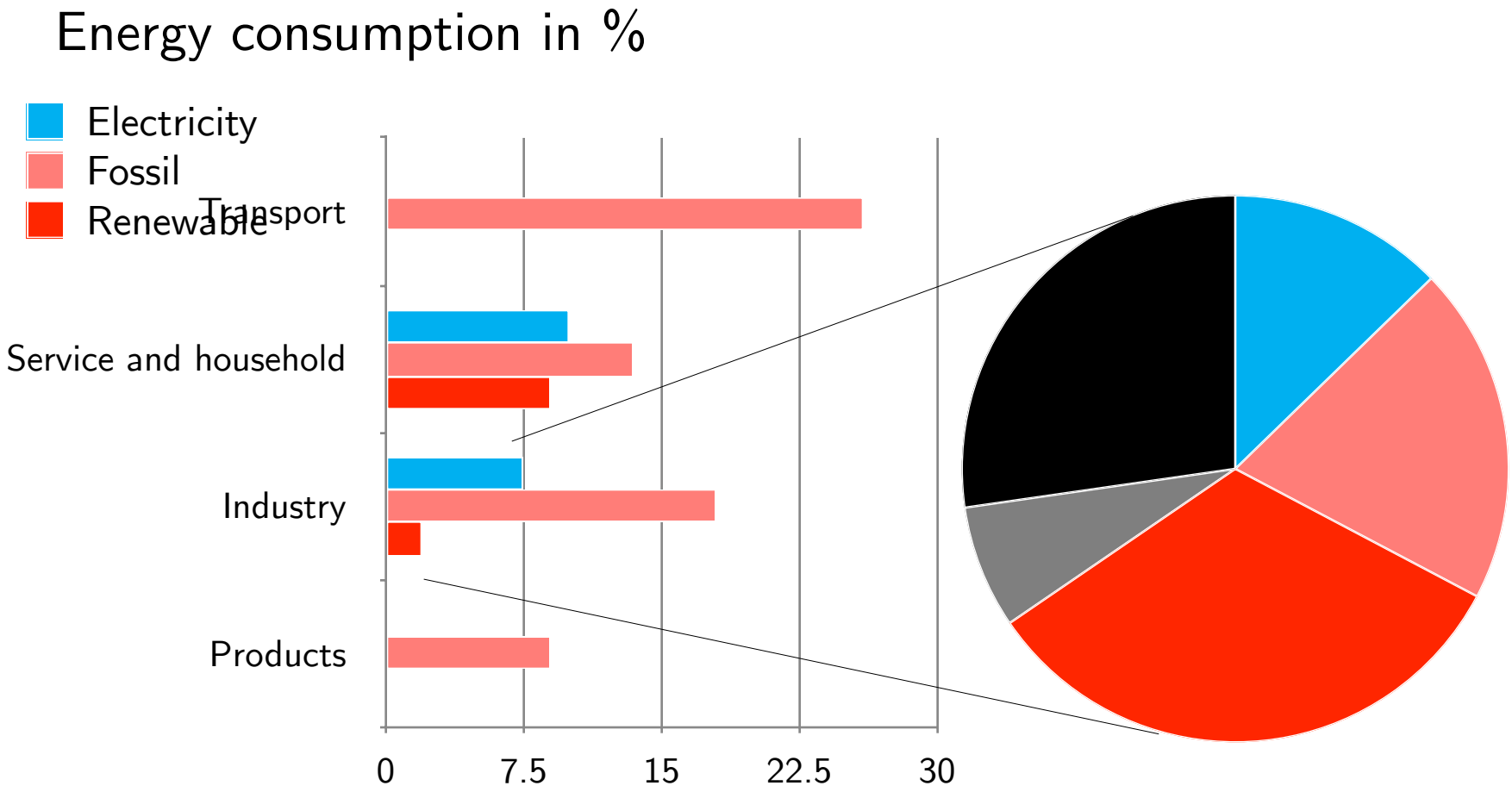
Industry 29
Oil : 3.5
Gas : 5.5
Elec : 7.5
Biom : 2
Coal : 9

Products 9
Oil : 6
Gas: 2
Coal : 1

75 % of electricity is fossil based

http://www.iea.org/Sankey/

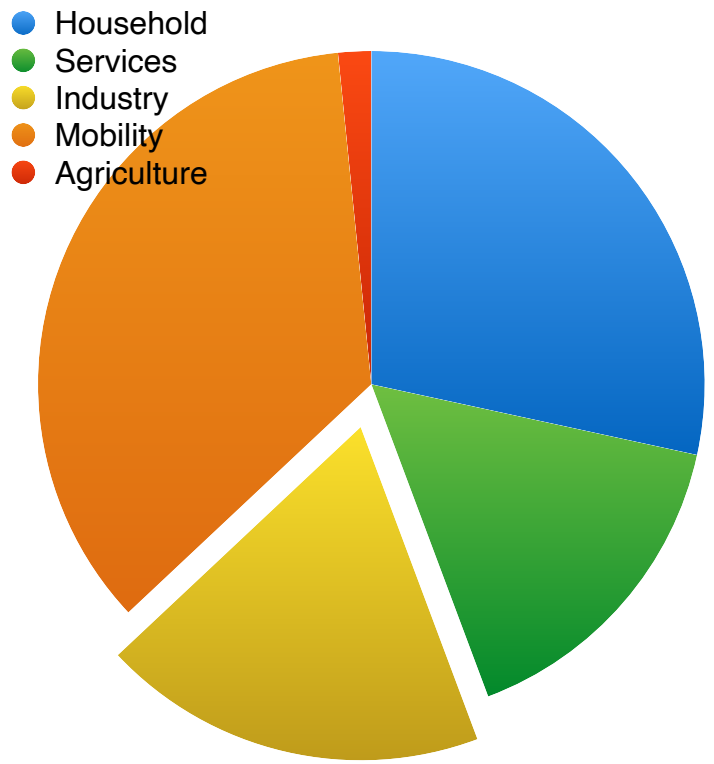
Energy usage in industry



Final Consumption of Energy (CH)

Switzerland Industry 2011 : 507 Wyear/cap

- 18.7% Final Energy consumption
- 56% Heat
  - in which 50 % in Natural Gas
- 44% Electricity

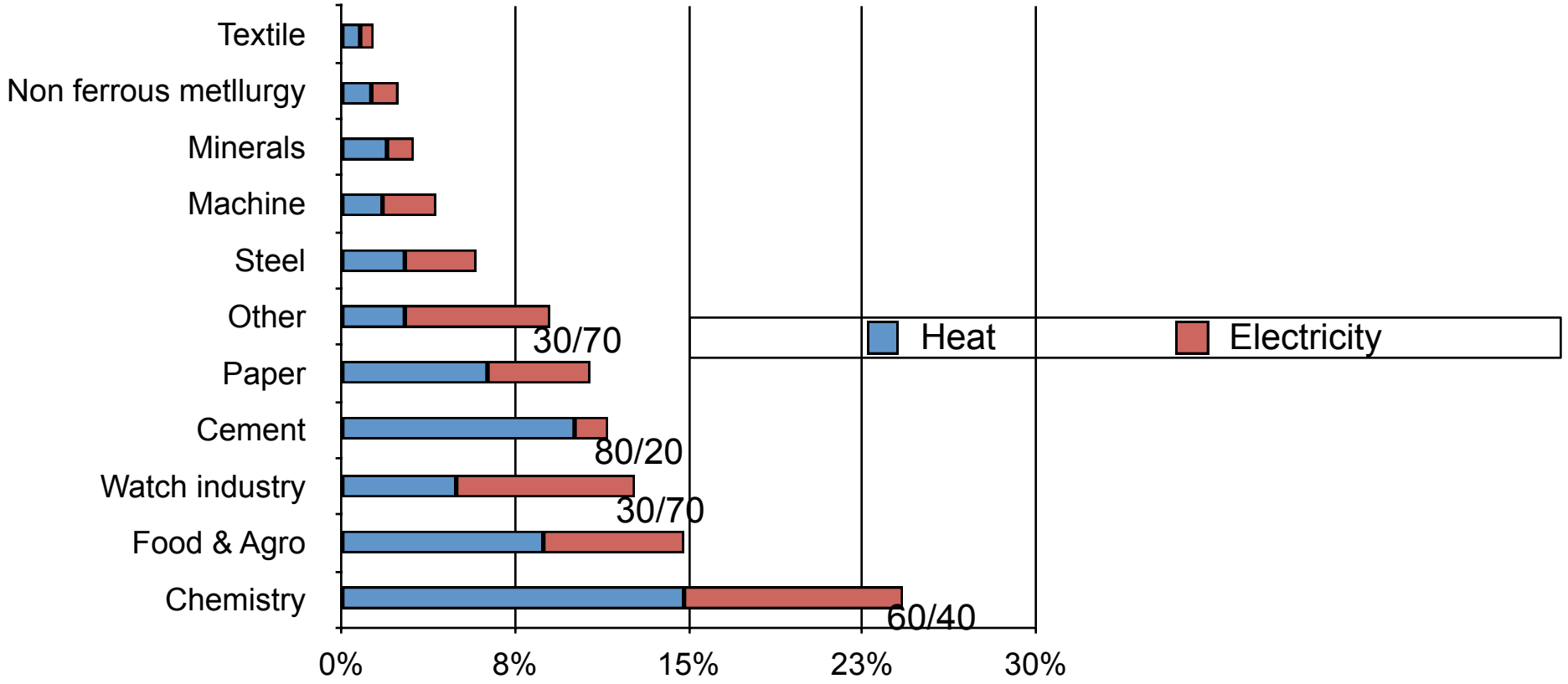


Example of industrial processes

- Chemical industry
  - e.g. fertilizers, fine chemicals, additives,…
- Pharmaceutical industry
  - drugs, clean rooms,…
- Cement industry
- Petrochemical + refining
  - gasoline, diesel, kerosene, plastics,…
- Steel & Aluminum industry + metals
- Food & Agro industry
- Car manufacturers
- Power production
- Waste management
  - sorting, recycling, incineration
- Urban systems
  - Services : heating-cooling

Different industrial sectors profiles

- From the Swiss Industry : share to the total primary energy use in industry



Prognose 2012

CO2 emissions is the Key Issue

$$CO_{2p}[kg_{CO_2}/year] = \dot{m}_p[kg/y] \cdot \sum_e (e_p[kJ_e/kg_p] \cdot CO2_e[kg_{CO_2}/kJ_e])$$

$CO_{2p}[kg_{CO_2}/year]$ = CO2 intensity of product p

$\dot{m}_p[kg/y]$ = production of product p

e = Energy resources used

$e_p[kJ_e/kg_p]$ = Energy intensity of energy ressource e in product p

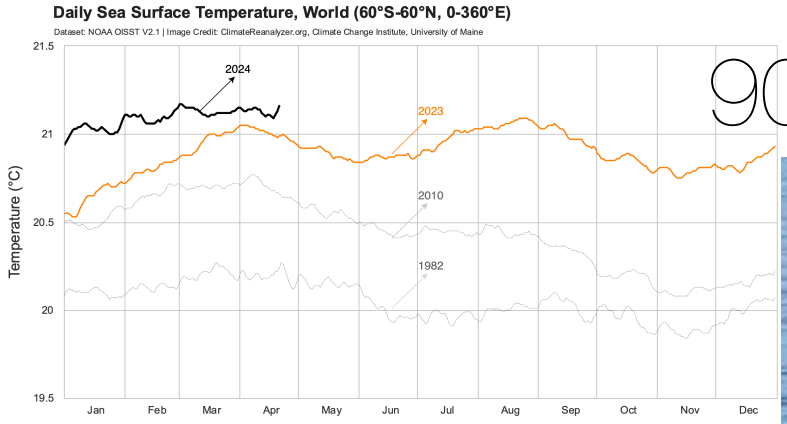
$CO2_e[kg_{CO_2}/kJ_e]$ = CO2 intensity of energy resource e

the other problem … : CO2 emissions

NASA Computer model of the CO2 emissions

Climate change

90% heats the oceans



Global warming gases emissions

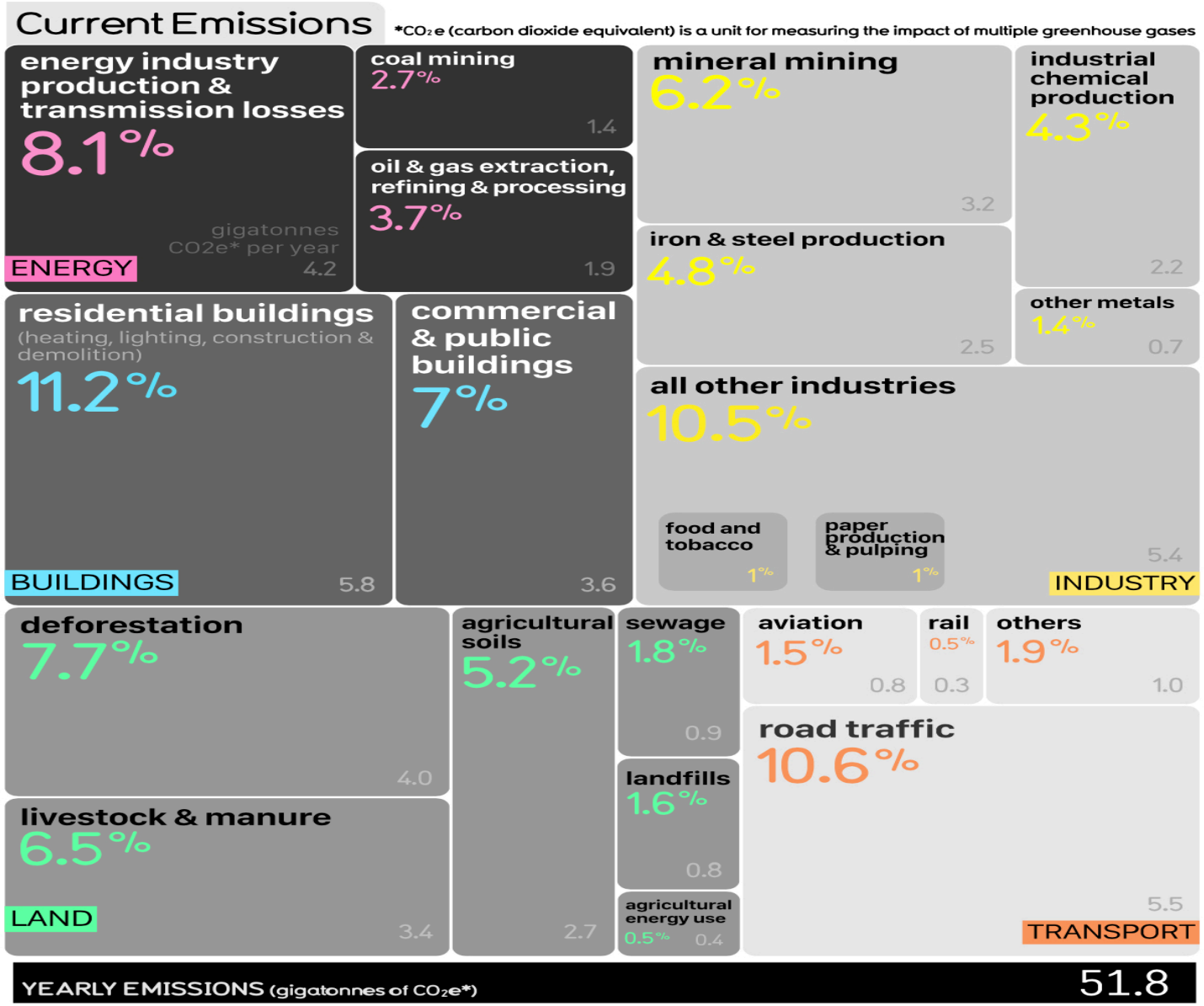
Human activities related

36.5

GT CO2/y

48%

remains in the atmosphere



https://informationisbeautiful.net/visualizations/how-to-reduce-the-worlds-carbon-footprint-by-2050/

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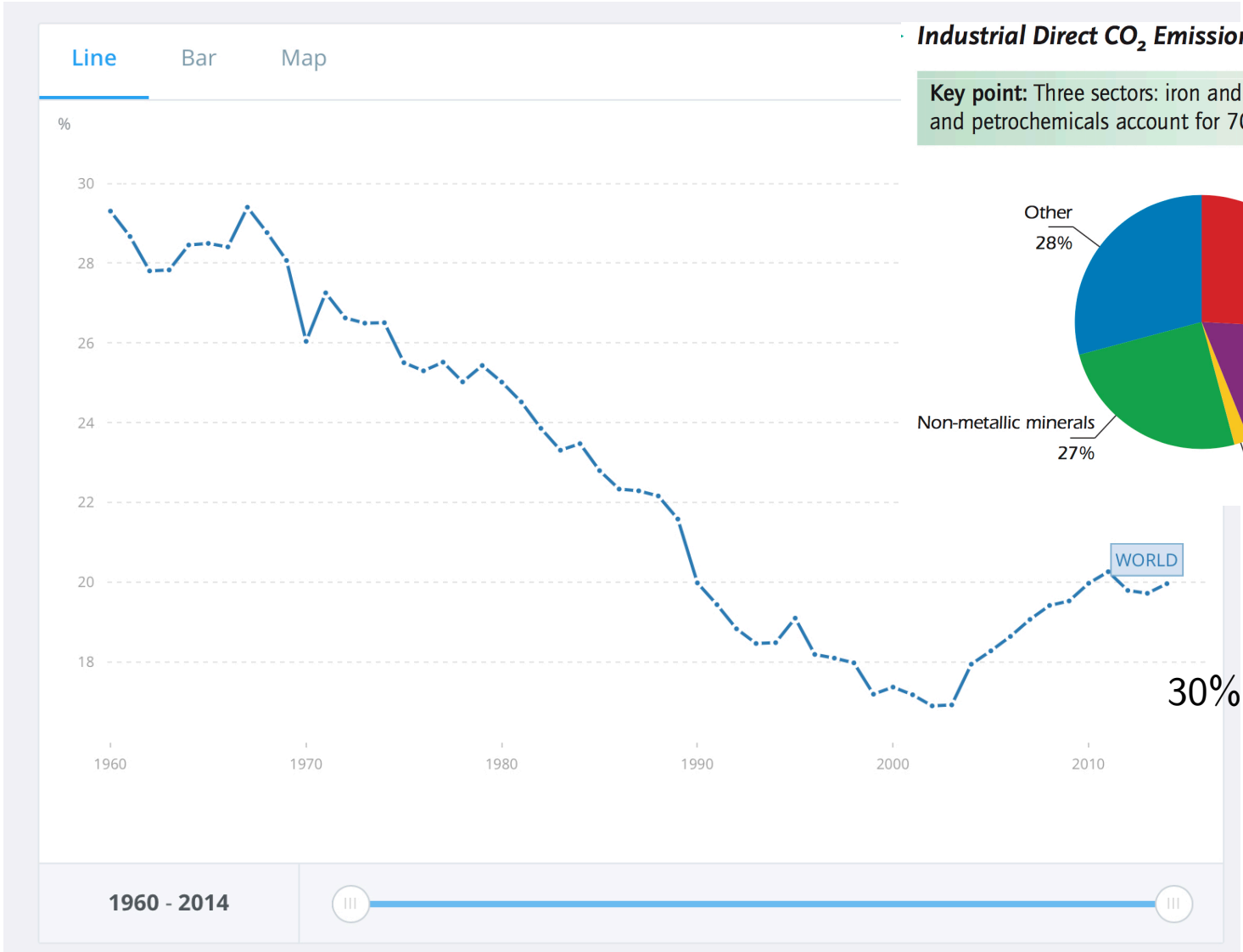
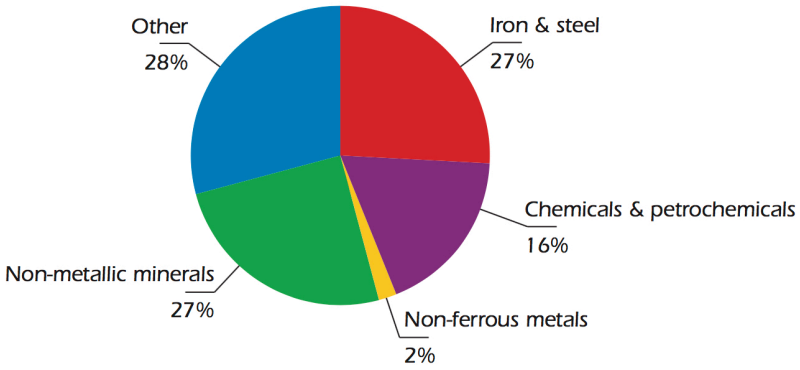
Share of the CO2 emissions of process industry



Industrial Direct CO_2 Emissions by Sector, 2004

Key point: Three sectors: iron and steel, non-metallic minerals, and chemicals and petrochemicals account for 70% of industrial CO_2 emissions.

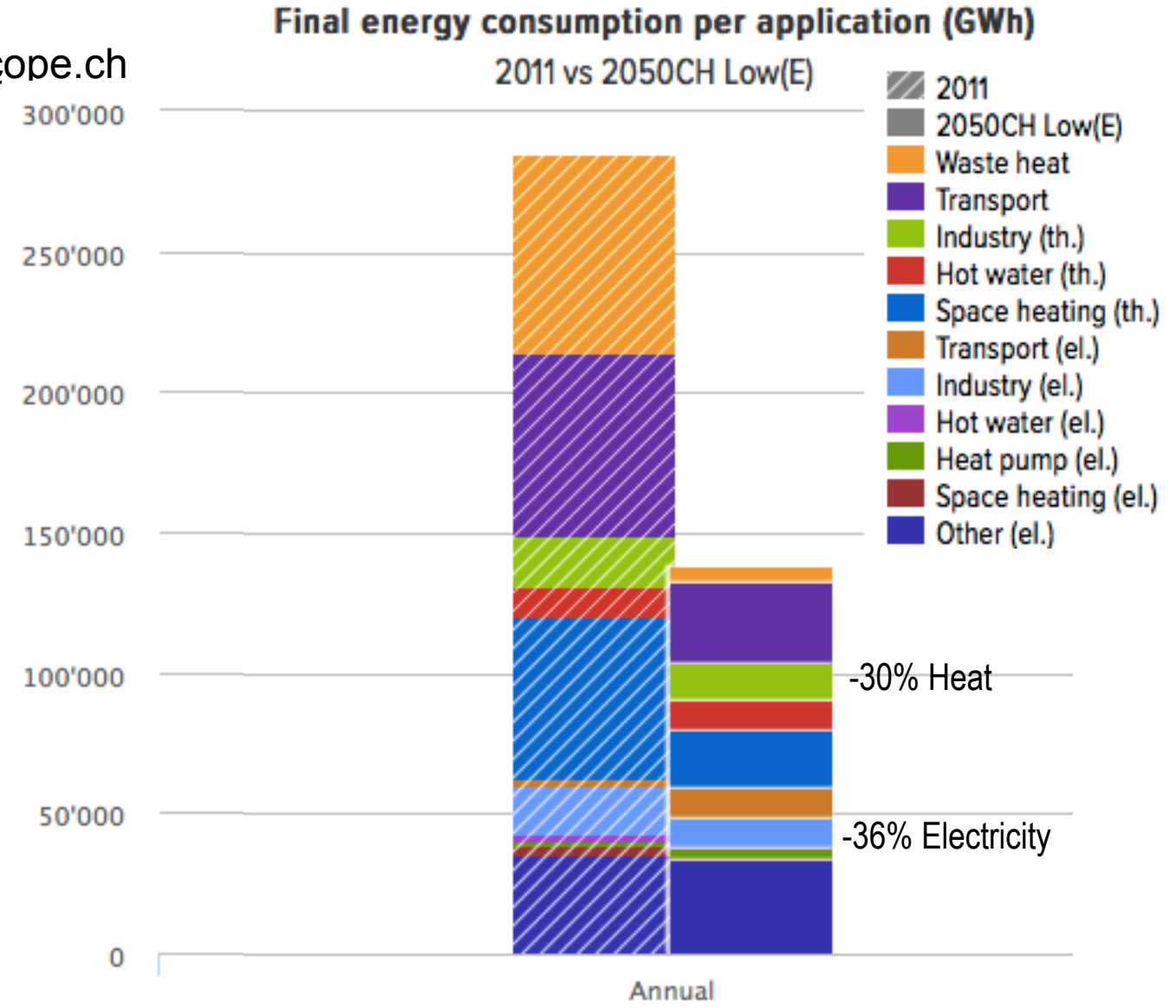


30% -> 20%

https://data.worldbank.org/indicator/EN.CO2.MANF.ZS?end=2014&start=1960&view=cha

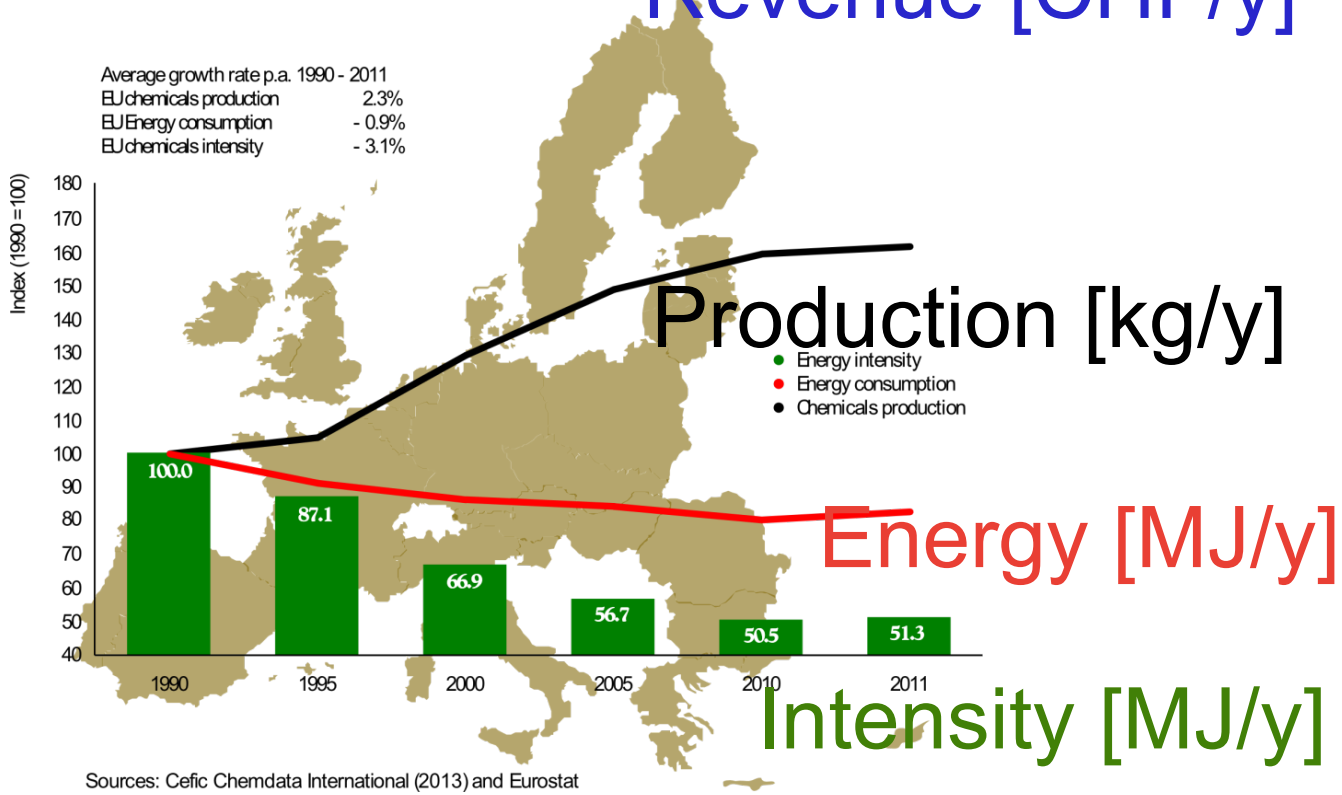
Industry and the energy transition

- www.energyscope.ch



The problem of the industry

Revenue [CHF/y]



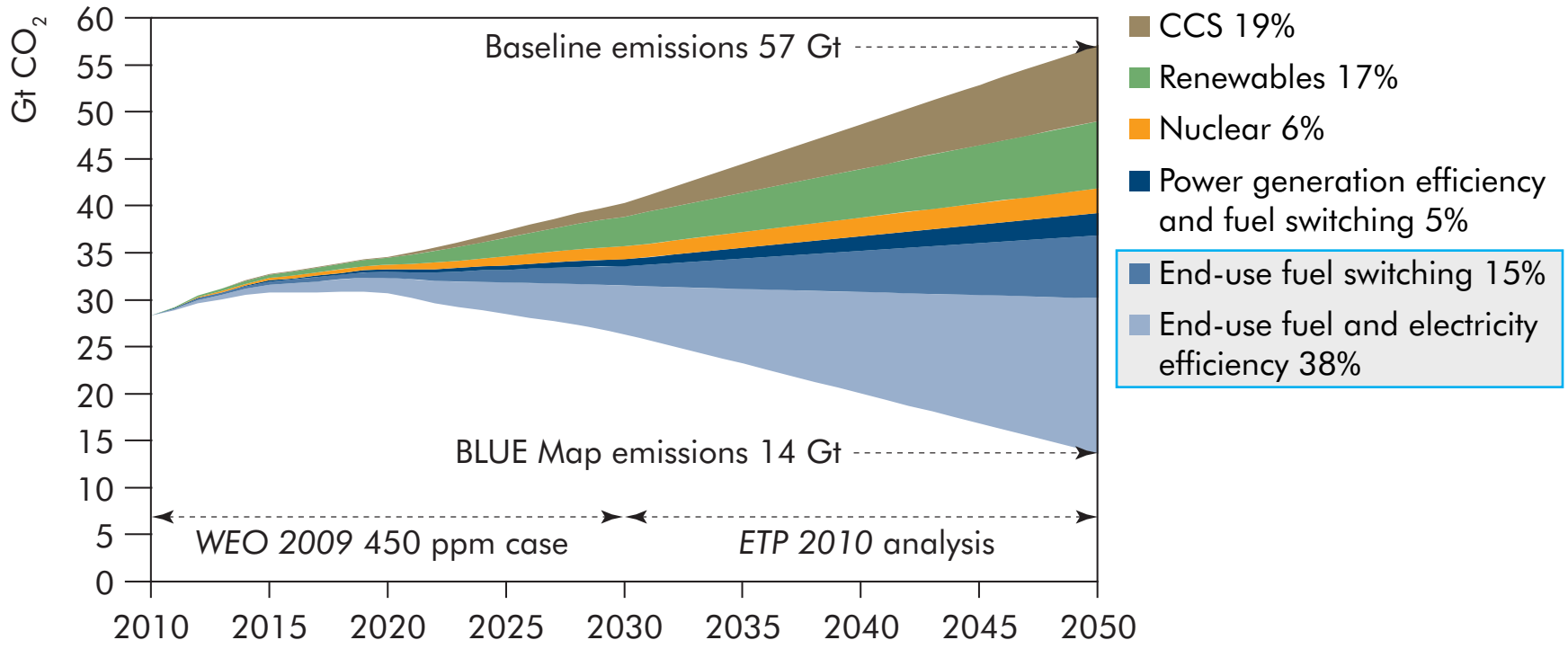
Production [kg/y]

Energy [MJ/y]

Intensity [MJ/y]

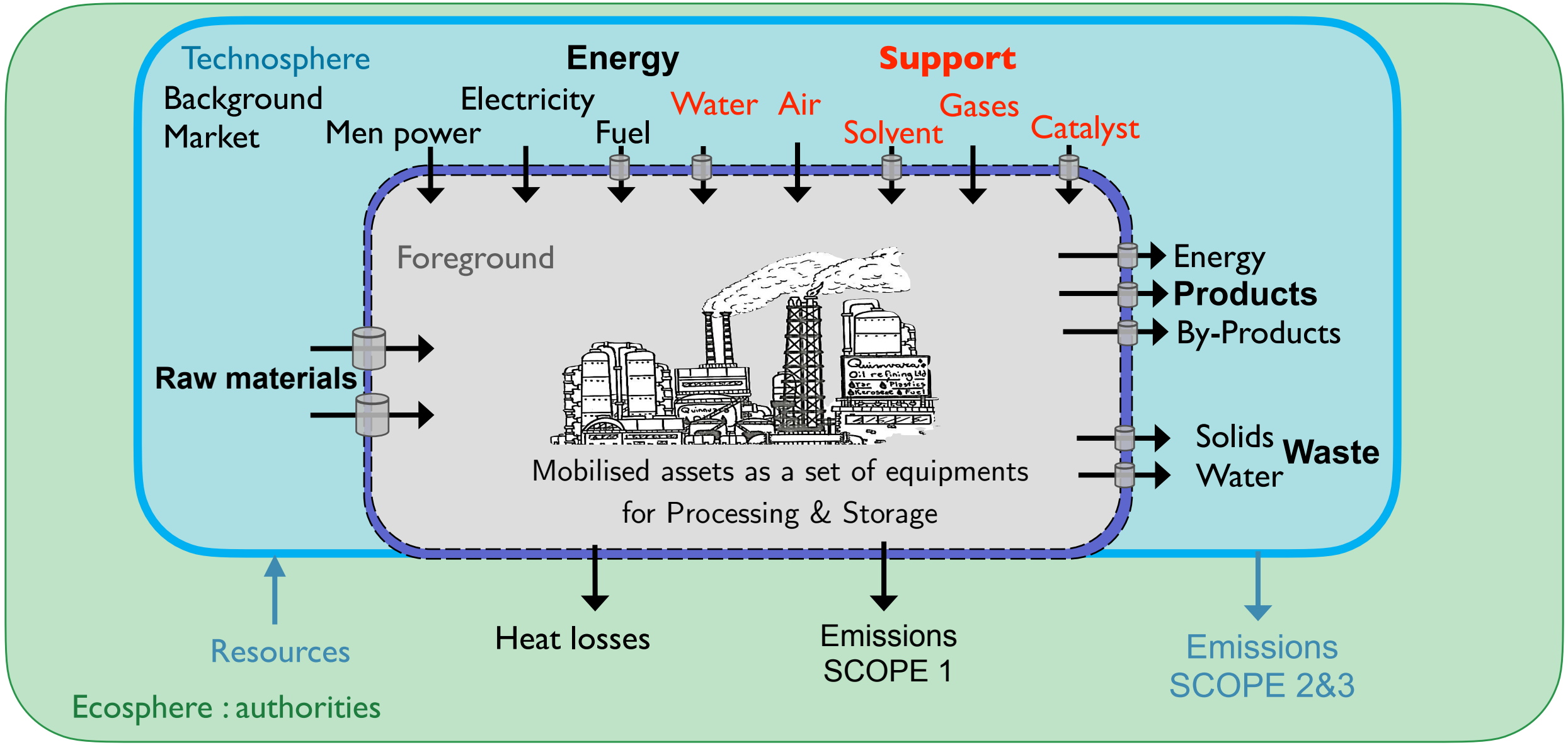
Impact of Energy system engineering

Figure ES.1 ▶ *Key technologies for reducing CO_2 emissions under the BLUE Map scenario*



Energy Technology Perspective 2010, International Energy Agency , 2010

Challenge: System boundaries : Flows of industrial processes



EPFL Challenge: Industry decarbonisation engineering

Efficiency & Conversion

Efficiency
Mass & Heat Recovery

Waste Heat
Heat pumps
Heat2Power

Energy vectors
Renewables
Combined Heat and Power
CO2 Capture

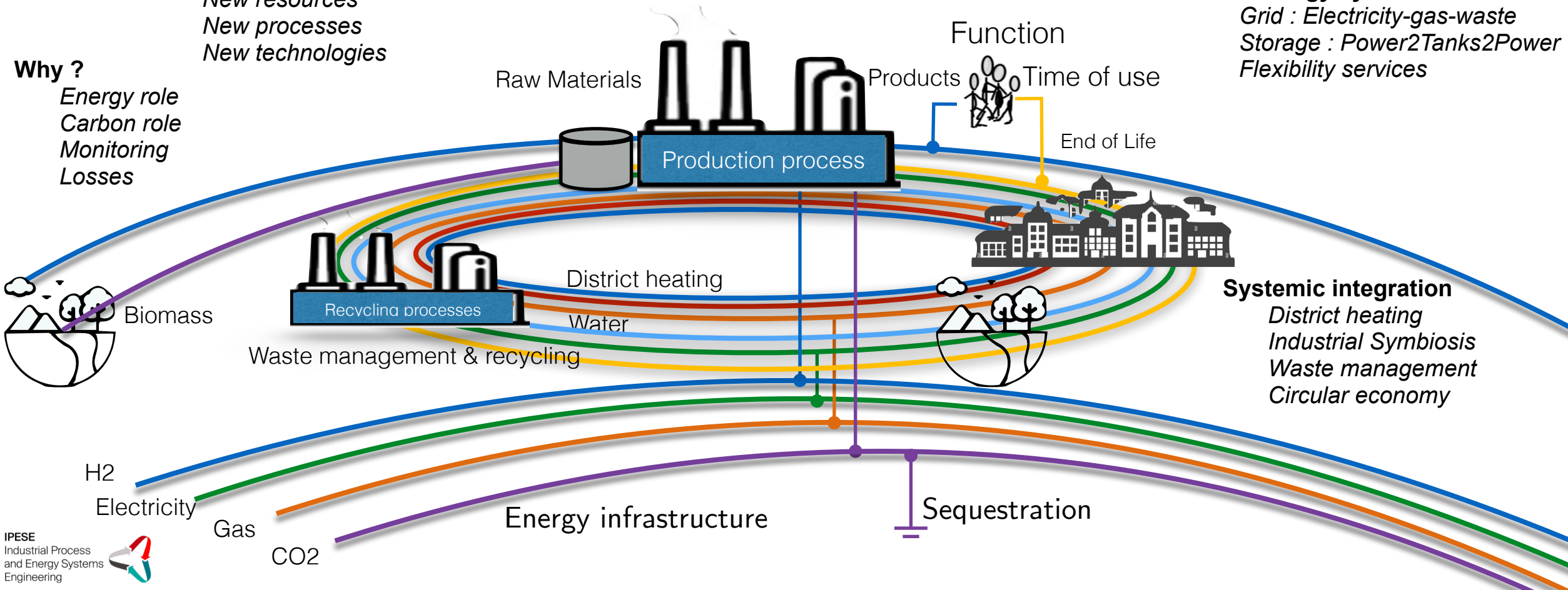
Energy Audit

Innovation
Smart operation
New resources
New processes
New technologies

Why ?
Energy role
Carbon role
Monitoring
Losses

System integration

Multi-energy systems
Grid : Electricity-gas-waste
Storage : Power2Tanks2Power
Flexibility services



Systemic integration
District heating
Industrial Symbiosis
Waste management
Circular economy

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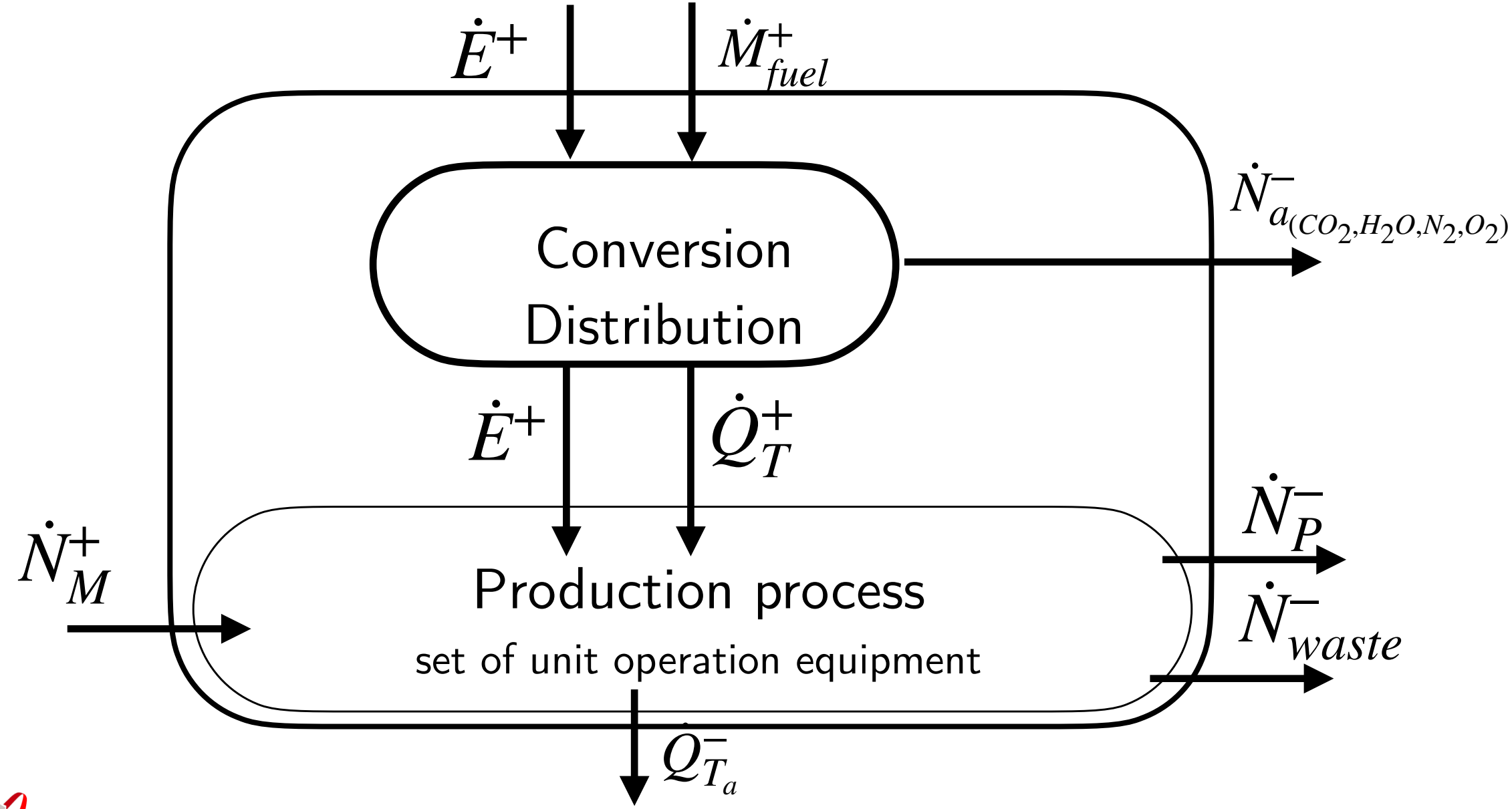
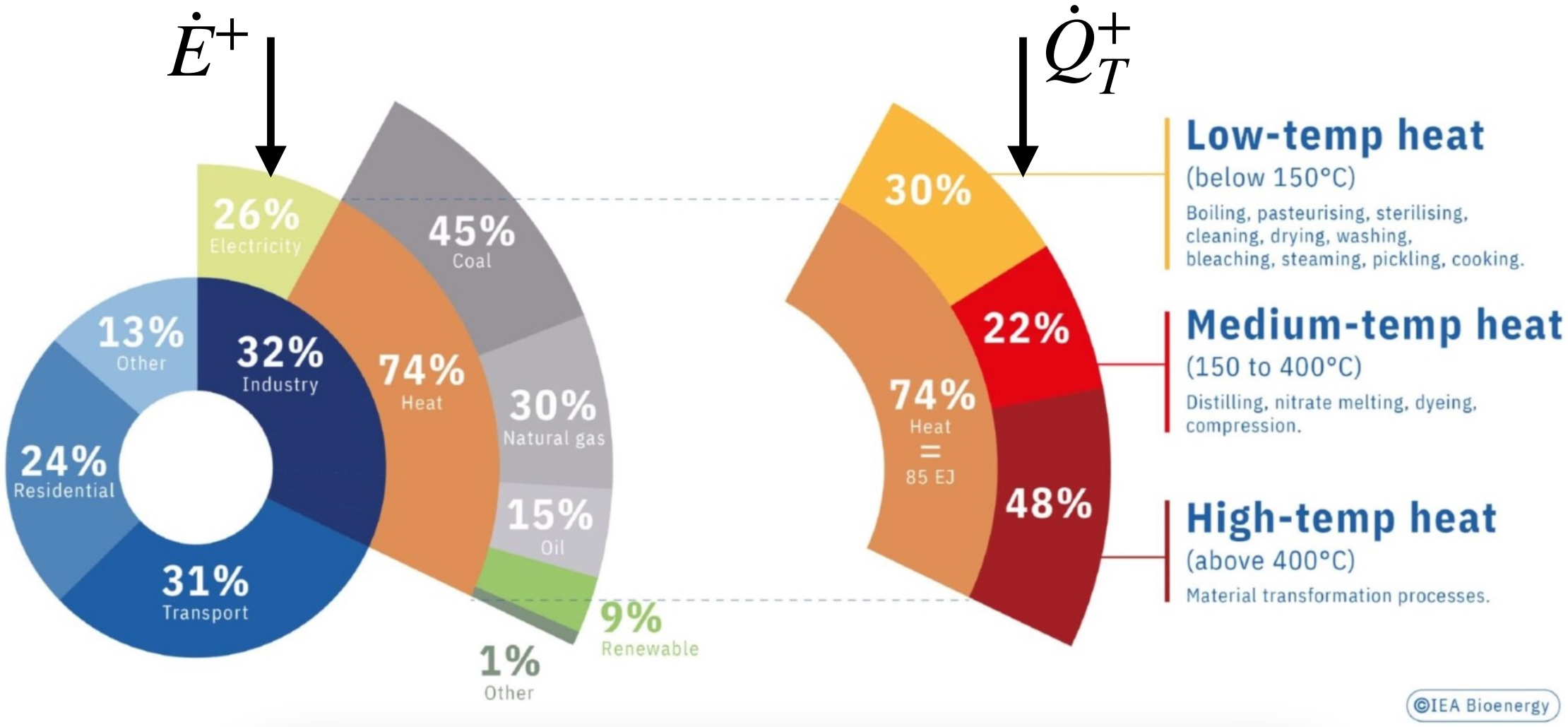
Process system engineering

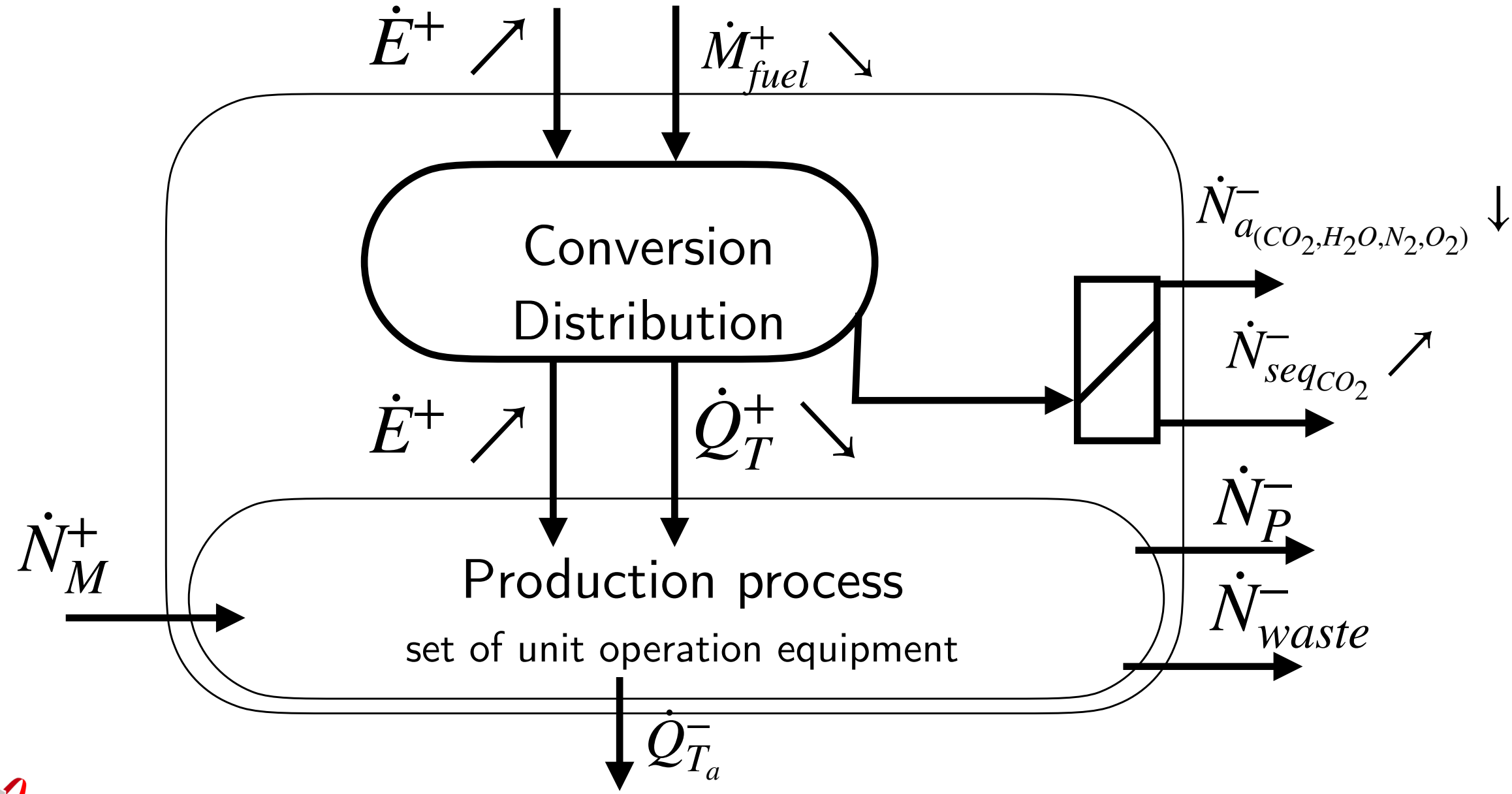


$\dot{Q}_T^+$: Industry Decarbonisation Challenge



IEA Bioenergy (2022). Reaping the multiple benefits of bioenergy. https://www.ieabioenergyreview.org/reaping-the-multiple-benefits-of-bioenergy/

Reducing emissions by efficiency and electrification



Advanced Energetics : Goals of the lecture

Energy analysis and synthesis of industrial and energy conversion processes

- Be able to propose energy efficiency improvement in industrial systems by
  - Analyzing the energy requirement of an Industrial system
  - Identifying heat recovery options
  - Defining the investment for the heat recovery
  - Analyzing and integrating the energy conversion system
    - energy resources to useful process energy
  - Making a thermo-economic and environmental evaluation of the solutions

Teaching concept

- **Project-oriented**: you are supposed to realise a guided industrial process energy efficiency analysis project. This project covers the whole duration of this course, and will help you better understand the theory concepts.
- **Theory - Application**: Theory is first presented and put in perpsective of the project realisation.
  - **Lectures** by professor : **in class** + slides + lecture notes + videos
  - **Application** by applying theory in the project : a project report template with suggestions on how to solve the problems and FAQ is made available to support the project realisation.

Project based learning

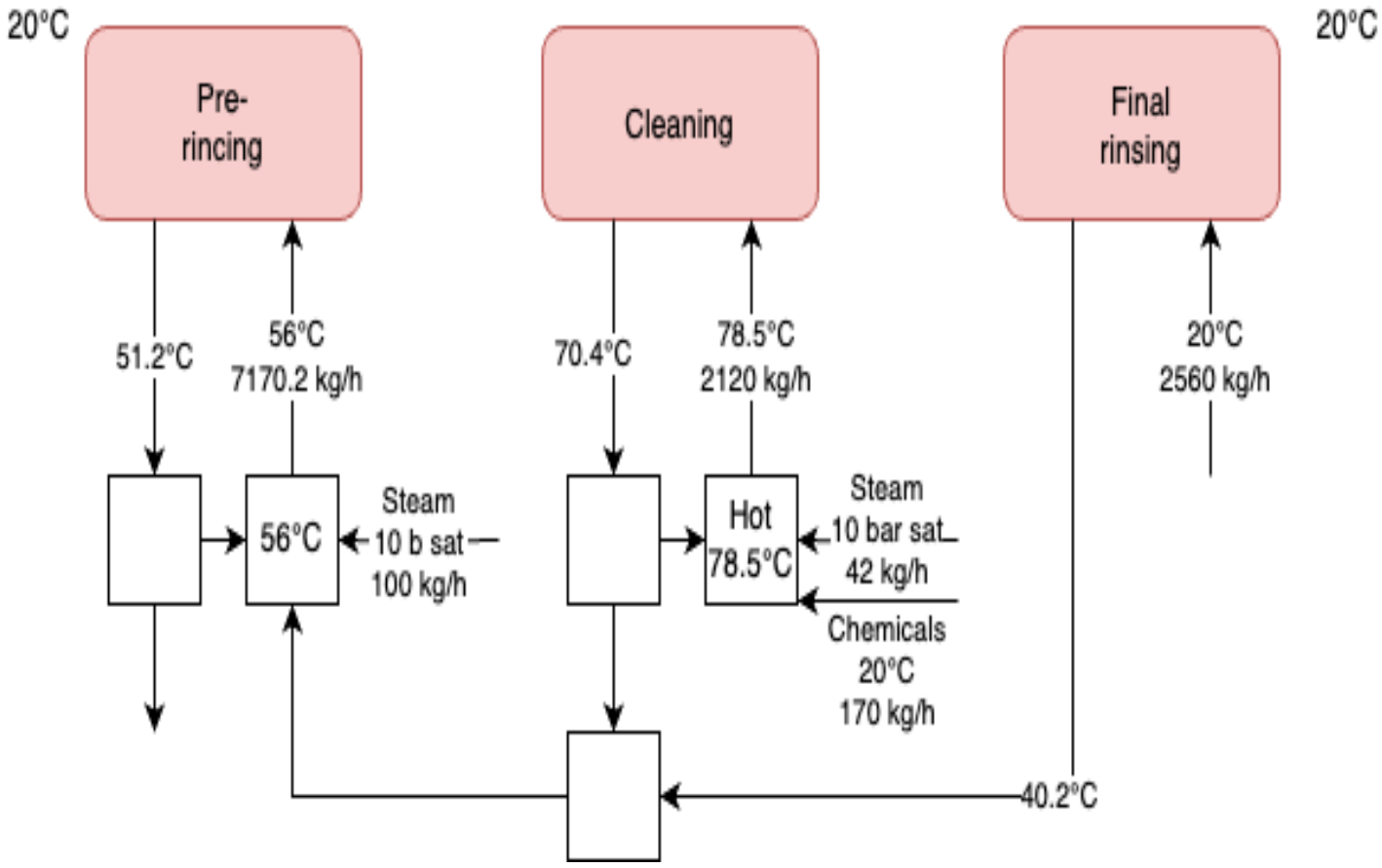
- Forget about…
  - listening religiously to your professor
  - take the exercice &… the correction and go home
  - Reproduce
- You are entering the Active learning world !
  - Theory is given on how to solve the problems => structure your reasoning
  - The project scenario is built to learn & apply the theory
    - A-G-I-R
  - Project steps are used to guide/inspire your reasoning
  - Problem solving : facing problems by solving problems
  - Example are given as an inspiration and to speed-up the application
- Computational thinking
  - Computer Aided Engineering
  - Professional tools : MS word and excel should not be the tools for your professional life

A project based teaching concept

- You are an engineer in a dairy…
  - and your boss comes with a request :

"please find solutions to reduce the consumption of the cleaning in place system"

If successful you will have to study the full dairy process energy efficiency



- and tells you

"I need to show decarbonisation options to answer to our shareholders ?"

Competences needed ?

- **Task 1 :** What is the energy usage ? => **energy audits**
  - energy bill $[CHF/kg_{product}]$ and $[CHF/year]$?
  - CO2 emissions and sensitivity to market ?
  - How good are we ? => benchmark
  - How good are we thermodynamically ? => exergy analysis
  - What are the energy requirement of the process ?
- **Task 2 :** What are the **heat recovery** options ?
  - What are the heating and the cooling needs ?
  - Can we recover heat ?
  - What are the heat recovery exchangers to buy
- **Task 3** : How to **supply at best the energy** to the process ?
  - What are the (renewable) energy resources to be used to close the energy balance
  - What are the best energy conversion technologies
  - Can we convert our waste into products or energy ? e.g. biogas
- **Task 4 :** Can we **expand the system boundaries** ?
  - Convert waste into product (Integration of Rivella production ? => look for synergies)
  - Capture and sequestrate CO2 ?

Course organisation

https://moodle.epfl.ch/course/view.php?id=141

Week	Planning for Lecture	Planning for Projects	Milestone/Quiz
1. 08.Sep - 12.Sep	• Introduction of course • Mass and energy balance • Energy bill calculation	• Tools set up (Quarto, Git, Virtual machine....) • Group Formation • Read about Git, Gitlab, Zotero, Quarto, Coolprop, and Python.	• Read the project description • Build the Quarto book with your CV and CO2 footprint.
2. 15.Sep - 19.Sep	• Investment estimation • Delta T minimum	• Exercise of DTmin	**Milestone 1** for your report: • Finish the energy Bill **Quiz 1** - Coolprop, Quarto, Mass and Energy balance
3. 22.Sep - 26. Sep **(Break)**			
4. 29.Sep - 03.Oct	• Composite curve • ROSMOSE tutorial	• Generate CC of the CIP process	
5. 06.Oct - 10.Oct	• HEN design	• Wrap-up for DTmin and CC part. • Identify the penalising heat exchanger • DWSIM tutorial	**Milestone 2** for your report: • Finish the MER and identify the pinch point **Quiz 2** - Energy bill
6. 13.Oct - 17.Oct	• Plus-Minus • Heat pump introduction	• Finish the HEN design part • Identify heat pumping opportunities	**Quiz 3** - Maximum heat recovery
7. 21.Oct - 25.Oct **(Break)**			
8. 27.Oct - 31.Oct	• Utility integration	• Integrate heat pumps in ROSMOSE • Integrate cogeneration in ROSMOSE	**Quiz 4** - Heat exchanger network design
9. 03.Nov - 07.Nov	• MILP and Exergy analysis	• Exergy analysis of CIP part	**Milestone 3** for your report: • Finish the HEN design and close the energy balance of CIP process
10. 10.Nov - 14.Nov	• No lectures	• Get familiar with Diary process and explore symbiosis with CIP	
11. 17.Nov - 21.Nov	• No lectures	• Identify hot and cold streams from the Diary and valorize waste heat	**Quiz 5** - Utility integration
12. 24.Nov - 28.Nov	• No lectures	• Work on Dairy process • Use DWSim models	
13. 01.Dec - 05.Dec	• No lecture	• Finish the dairy process analysis • List the whey valorization options	**Milestone 4** for your report • Benefits of CIP and Dairy process symbiosis
14. 08.Dec - 12.Dec	• Discussion with Prof. Maréchal by Group	• Work on the envrio-economic benefits of Whey valorization	
15. 15.Dec - 19.Dec	• No lecture	• Finalize your project report	**Milestone 5** for your report • Integrate whey valorization options

Organisation : Theory 3 ECTS + project 2 ECTS

- Lectures (50 %) + Project (50 %)
  - moodle.epfl.ch for the detailed schedule
- Lecture notes
  - available on moodle.epfl.ch
- Computational thinking tools

  we use Quarto : reproducible science & open source

  use Jupyter / Python or R scripting language
- Slides
  - available on moodle.epfl.ch
  - may be more slides than the one presented
  - ! just on time preparation
- Video of lectures
  - moodle.epfl.ch

Theory in the course

For realising those tasks, you will activate knowledge and theory and apply the concepts to your project.

1. The **theory** will be delivered as in class lectures that explain the theoretical background of the tools and methods to be applied. The list of topics is given below with associated lectures and support materials.
2. A discussion **forum** is proposed for the theory topics.
   Questions will be discussed in an interactive session with the professor.
3. Team of two students will be asked to prepare an illustration of the **application of the theory** to realise the task. The following discussion will be the occasion of experimenting the oral exam.
4. The **teaching assistants** have prepared the supporting materials and the necessary data to realise the tasks.
5. They will also present examples on how they have solved the different tasks in other projects.

At the end of the semester, you will have to deliver a **final report** and **present** your results.

Transversal skills from the guided project

- Apply the theory on a real industrial example
  - real numbers & validity of the solutions
  - use of professional tools
- Team work
  - Organise your work
  - Share tasks and information
- Write a report (transversal skills)
  - Clear - Concise
  - Uses QUARTO (open and reproducible science)
- Presents the results (transversal skills)
  - defend your assumptions
  - explain how you have solved the problem
  - what are the most important conclusions
- Serves as a support for the exam
  - Individual poster for the exam
  - Support the discussion of the exam

Case study organisation

- Case study based on one industrial application (Dairy project) description on moodle
- A project solving web site is available
  - Description of the tasks, hints and tricks, FAQ, theory questions
- A full example on an other industrial project is given
- Group work (**3** students)
- TA will be present to help
  - Monday 16h-19h (+ office hours Thursday @14h)
- Final report on 19.12.2025
- Individual reviews on 11.01.2026
- Written exam

Groups for project based learning

- Group
  - 3 students

- Interactive time
  - Monday at time of the course, use the moodle forum to ask questions
  - Thursday : office hours 12:00-14:00 upon request via the moodle forum

Computational thinking

Computational thinking

- Using computer softwares to solve problems
  - Finding and accessing data
    - search, find and cite your data sources
  - Programming calculations and reports
    - Variables with an engineering meaning
      - Variable = name + description + value + [physical units]
      - e,g, TempFlow1=25 #[C] temperature of the flow 1
    - Reproducible science
  - Using Professional tools
    - Developed by others but used by you
  - Reporting
    - Extracting data
    - Presenting data (graphs, tables)
    - Programmed reports
  - Project notebook
    - Documenting the calculations
    - Reviewing (do I understand what I'm writing)

Grading

- Group Project report (50%), weighting by auto evaluation by group members
- Individual Report review (15%). you are required to review the report of one other group and write a peer review on how they can improve their work.You will receive the group's report at the end of Semester (W4 Dec'25) and will have to submit your review file before the start of exam session (W2-W3 Jan'26)
- Quizzes (10%). Comments:5 distributed across the semester.
- Written exam (25%) : explain how you will answer the comments of the reviewers of your report (i.e. 3 student reviews + a TA review)

Comments on the course organisation

- **My slides**
  - are not lecture notes but a support to my talk (do not complain if the printed slides are messy !)
  - Just in time updates possible
  - Lecture notes and previous years lectures are are available on video (see on moodle.epfl.ch)
- **The lecture**
  - Do not hesitate to ask questions
  - Ask questions wrt project (read the projects objectives and ask questions)
- **Project based learning using a case study**
  - Theory is associated with the tasks to be realised : the project template report includes a lot of hints concerning the structure of the work to be done. Do not hesitate to read the template again : this is a nice synthesis exercice.
  - Learning by doing => you will struggle with numerical problems or software problems : does not always converge : this is real life !
  - Discussions => I will come and discuss with you during the project, do not hesitate to ask questions.
  - Report => visible part of your work (not only in this lecture) !
    - pay attention to reports, tables, graphs…
    - You sign the report, you are supposed to sign what is in the report

Comments on the projet organisation

- **Assistants**
  - They are available to help
  - They will do their best to coach and organise the project
  - They have a limited time available
    - “they are allowed to not answer if they consider that you can find the answer by yourself”.
    - Office hour on Thursday 12:00- 14:00 : reserve your time slots and prepare the discussion
- **Case study formulation and group work**
  - The case study is like a real problem
    - Distribute the work among yourself
    - Thinks might be missing : Make assumptions
    - Justify and report (journal)
    - Decide (negociation in the group)
    - http://te.epfl.ch (group organisation)
- **You will have to state the problems for each step**
    - Analyse => literature search, assumptions, level of detail requested, expected results, …
    - Generate => generate numerical solutions
    - Interpret => translate numbers into engineering decisions
    - Report => transfer your knowledge to the rest of the world

Contacts

- Prof. François Marechal
  - mailto:francois.marechal@epfl.ch
  - Office ME-A2-465 (Monday only !)
  - Office : Industrie 17 (Sion)
  - Please take appointment on mattermost
- Q&A via mattermost

Hope that we will have a lot of fun !

Not easy
Not relaxing

But cool and
useful for your future !