Advanced energetics

2024-2025

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Industrial Process and Energy Systems Engineering

IPESE - http://ipese.epfl.ch

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IPESE
Industrial Process and Energy Systems Engineering

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Génie Chimique …
Marié, 3 enfants

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

The team

- Professor François Maréchal
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  Industrie, 17, CH-1951 Sion
- Assistants
  - Dr. Daniel Flórez-Orrego, Yi Zhao, Dareen Dardor, Pullah Bhatnagar, Vibhu Baibhav

Schedule of Today

- Advanced energetics : application in the industry
  - Julie Dutoit Hitachi-Zosen-Inova
    - Example of application and possible student projects
- Advanced energetics
  - Organisation and course overview
- Advanced energetics
  - The energy bill and the energy audit

Advanced Energetics : Goals of the lecture

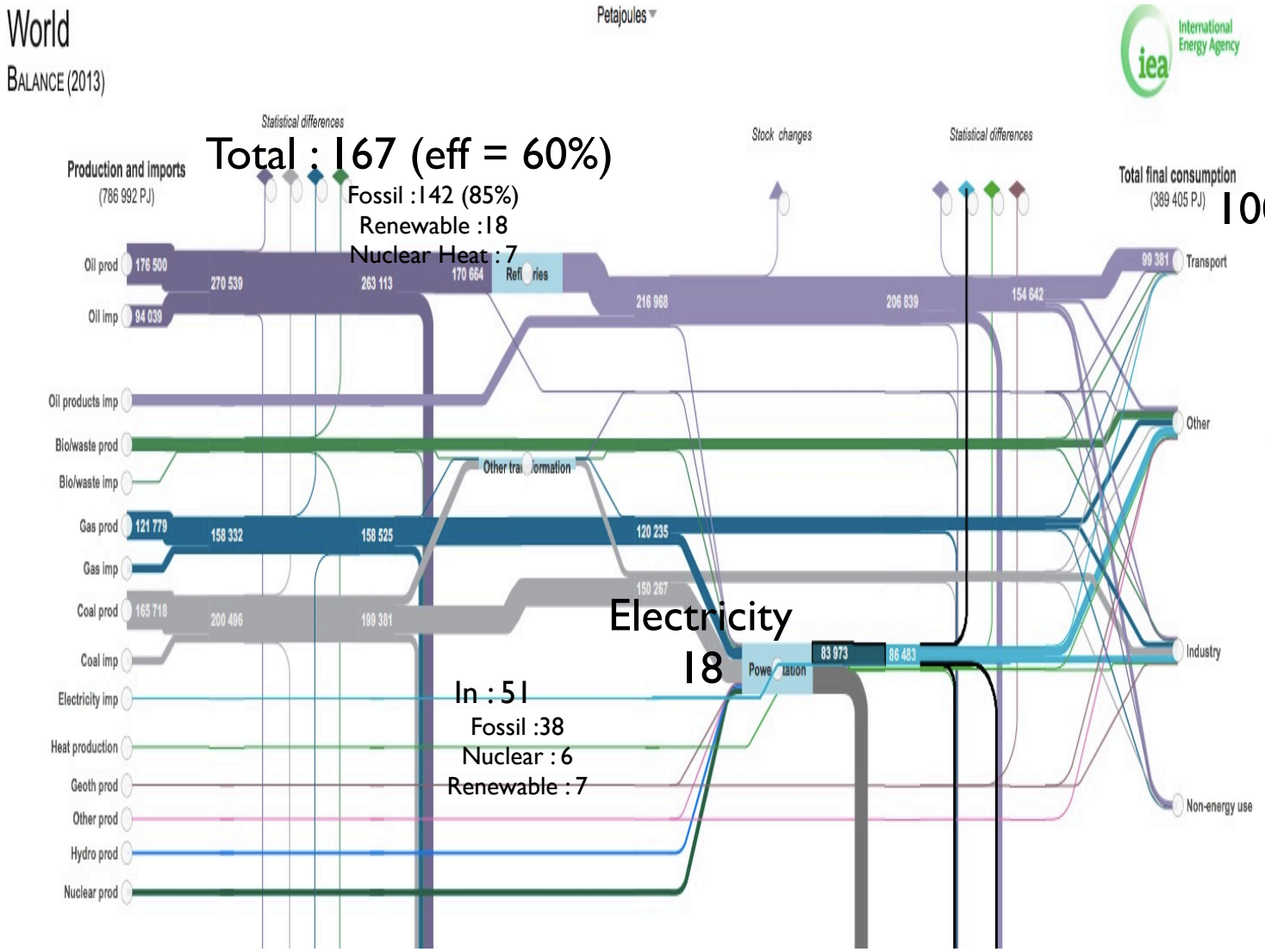
Energy analysis and synthesis of industrial and energy conversion processes

- 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

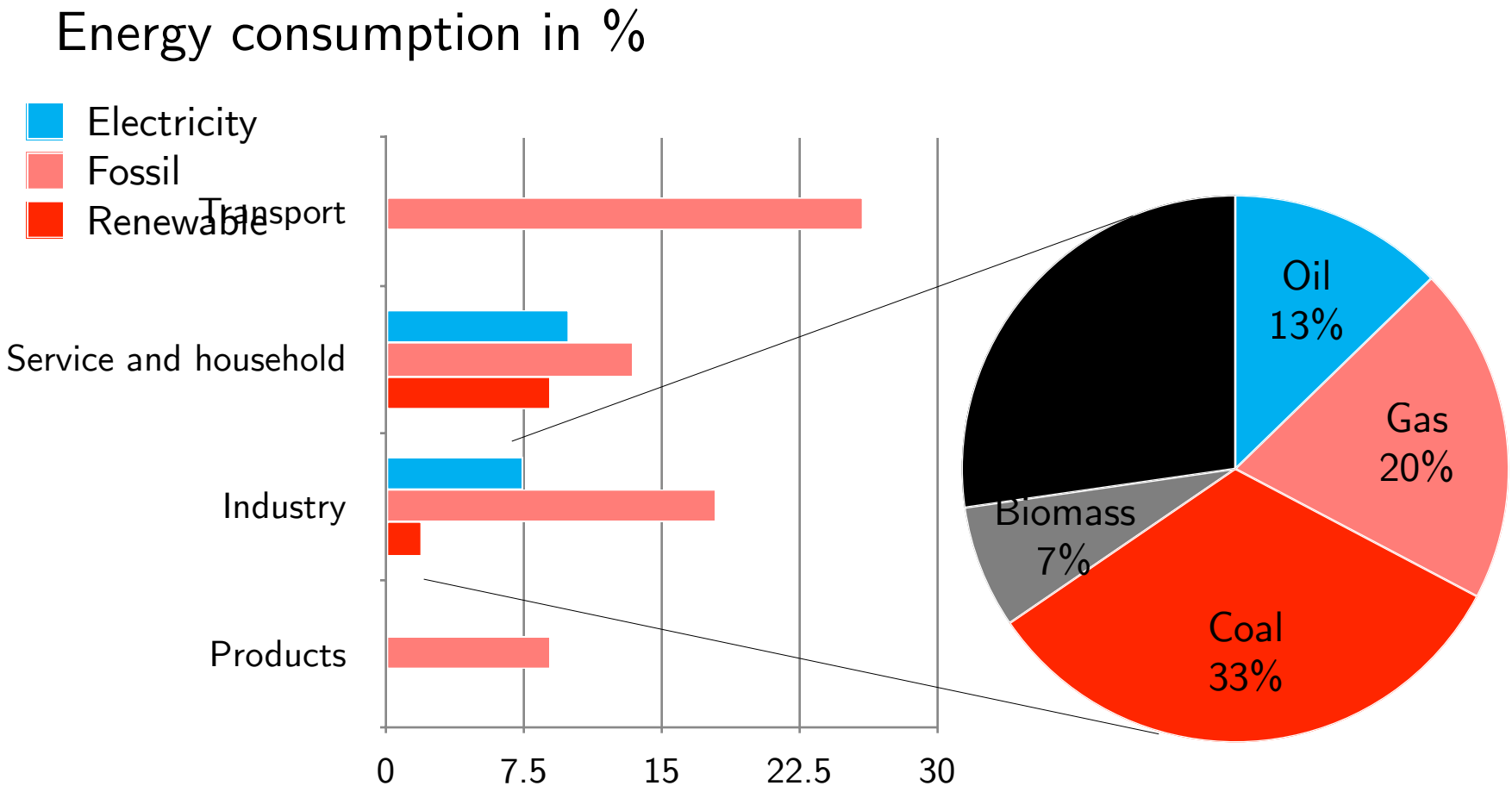
Industry 29
Oil : 3.5
Gas : 5.5
Elec : 7.5
Biom : 2
Coal : 9

Products 9
Oil : 6
Gas: 2
Coal : 1

75 % of electricity is fossil based

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

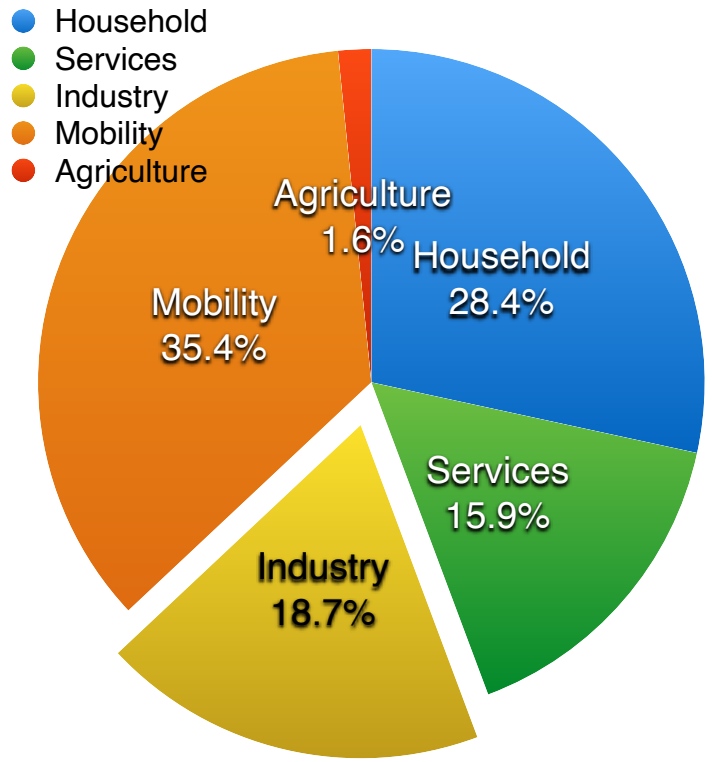
Energy usage in industry



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

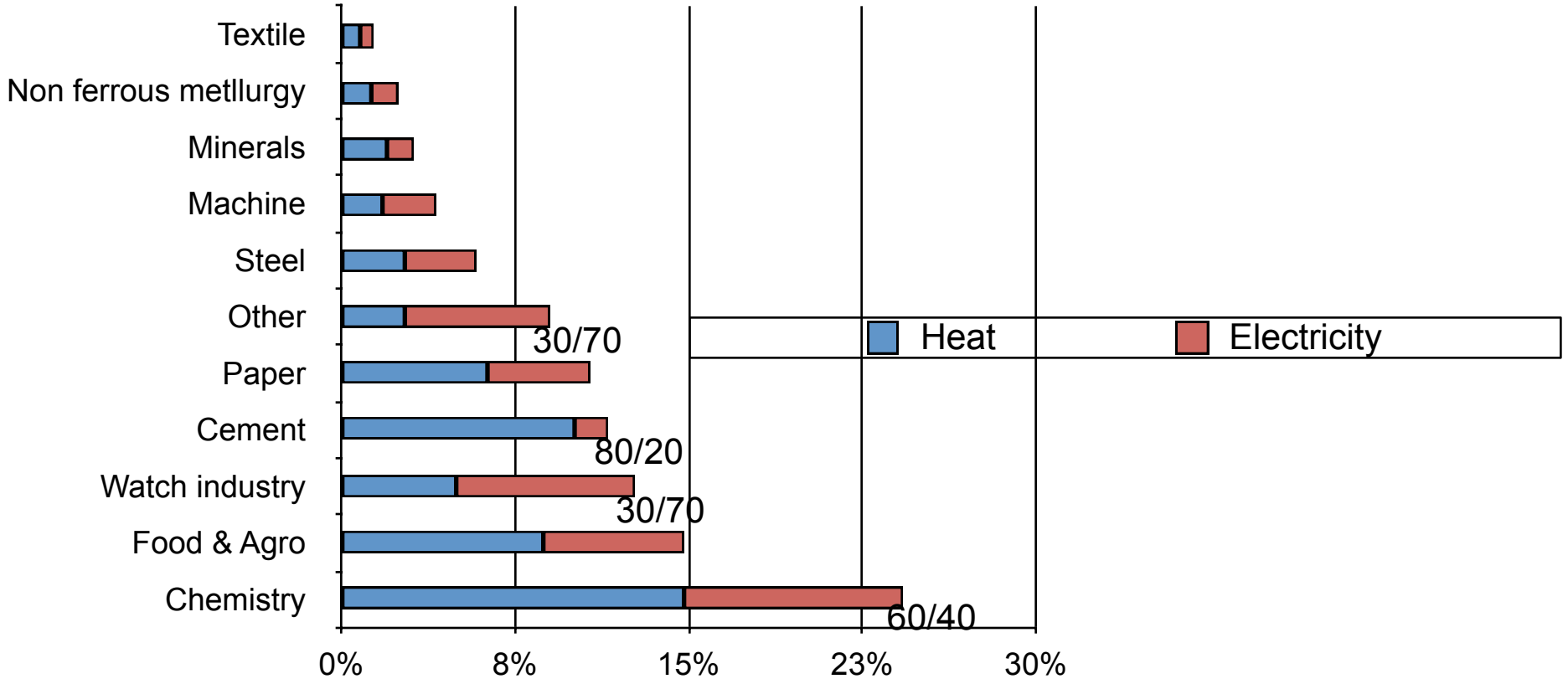


Example of industrial processes

- 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

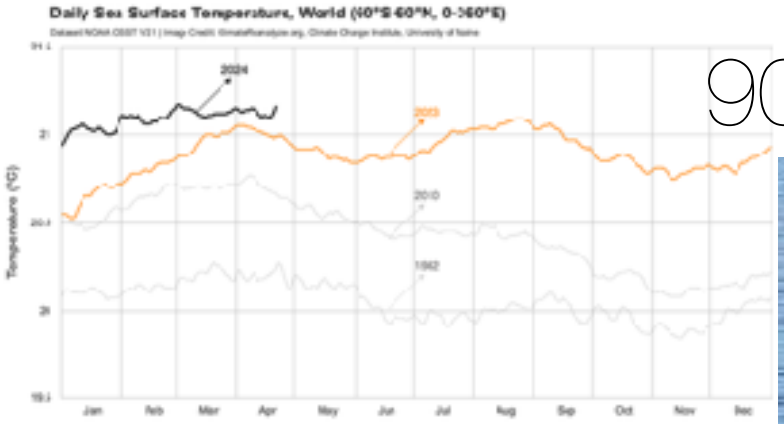
$CO2_e[kg_{CO_2}/kJ_e]$ = CO2 intensity of energy resource e

the other problem … : CO2 emissions

NASA Computer model of the CO2 emissions

Climate change

90% heats the oceans



Global warming gases emissions

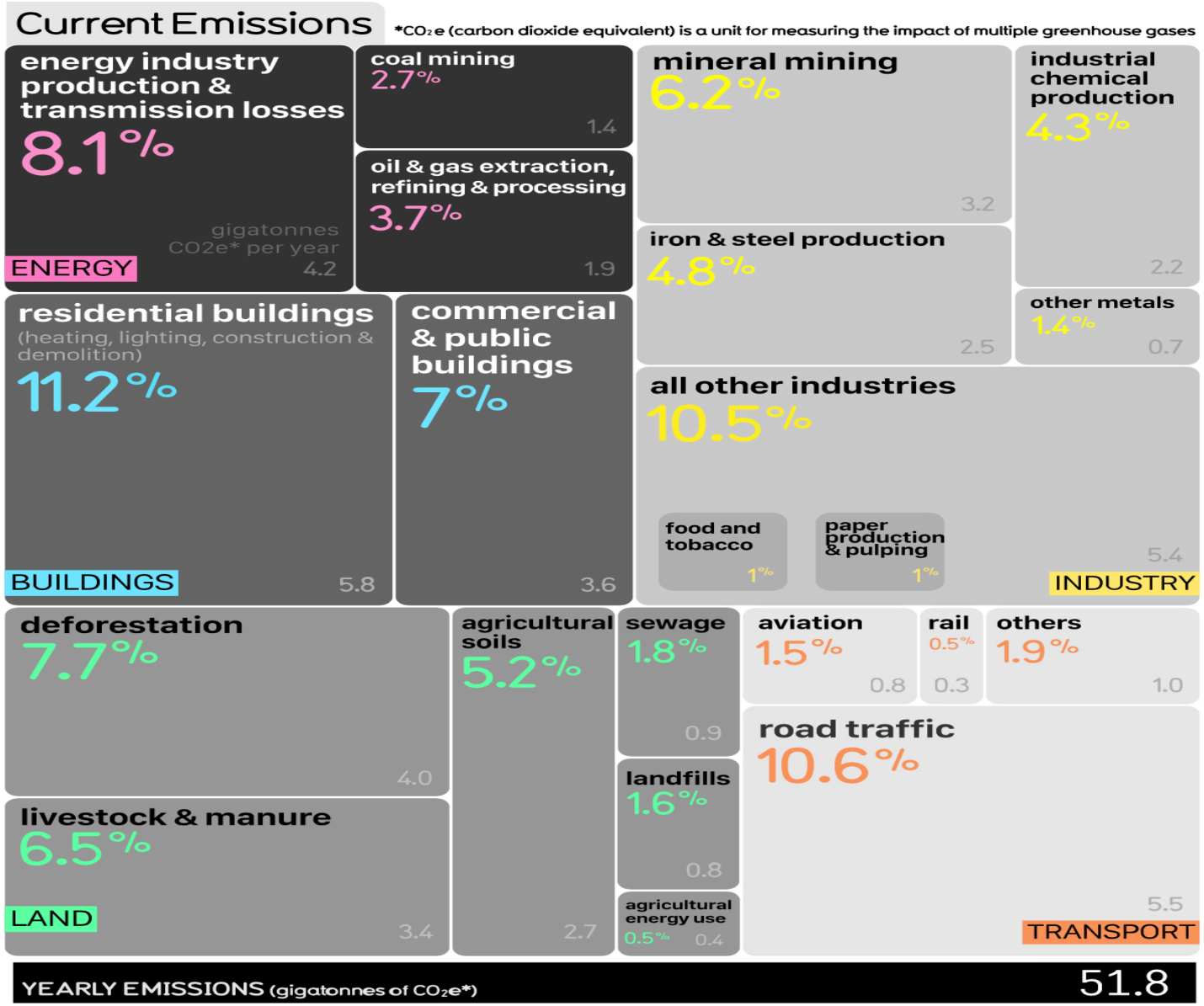
Human activities related

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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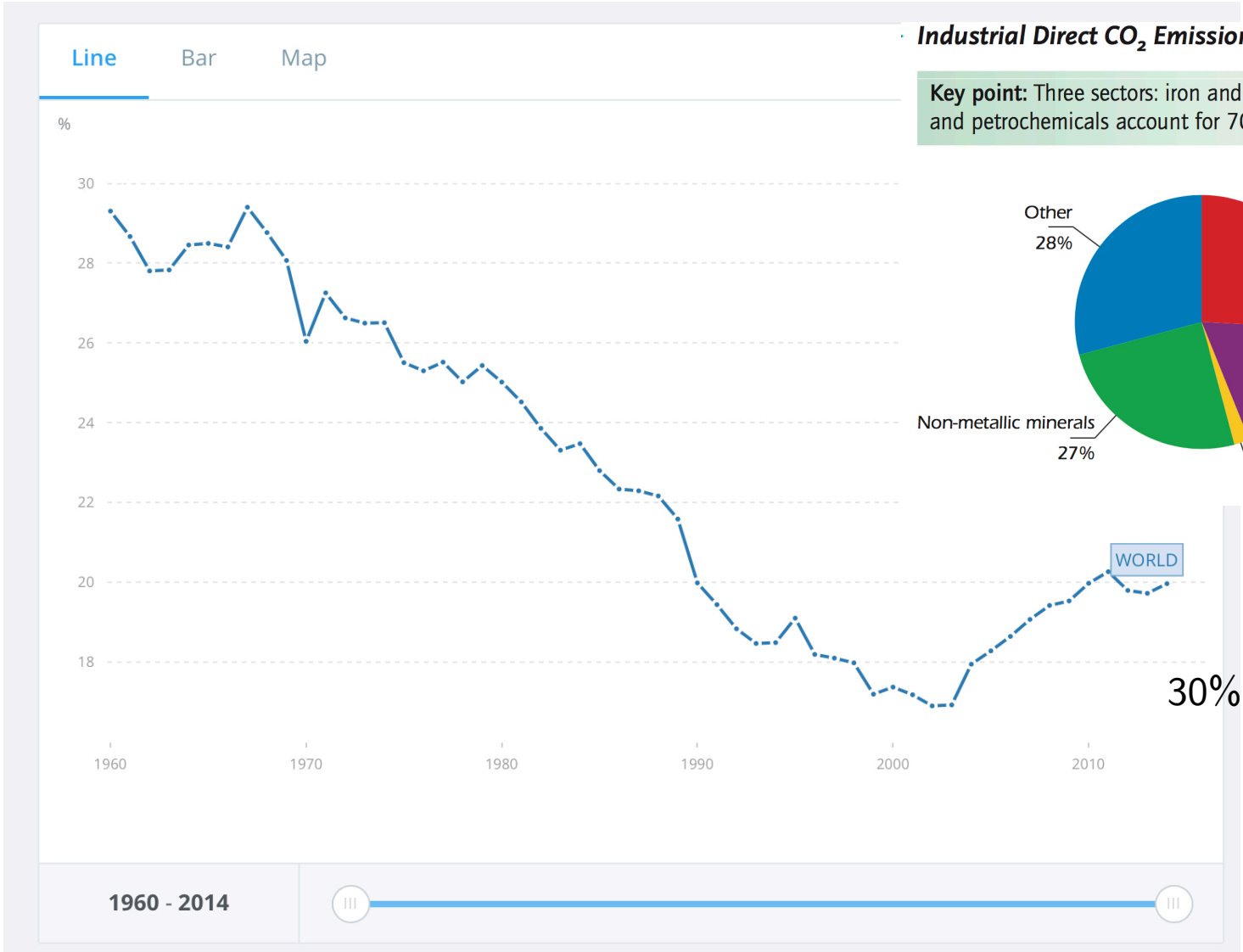
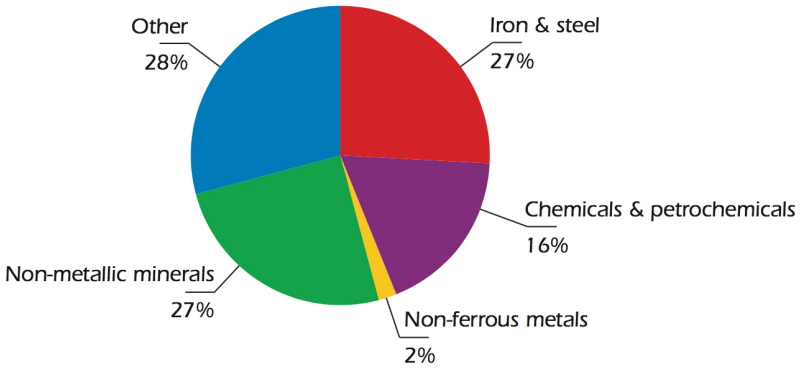
Share of the CO2 emissions of process industry



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.

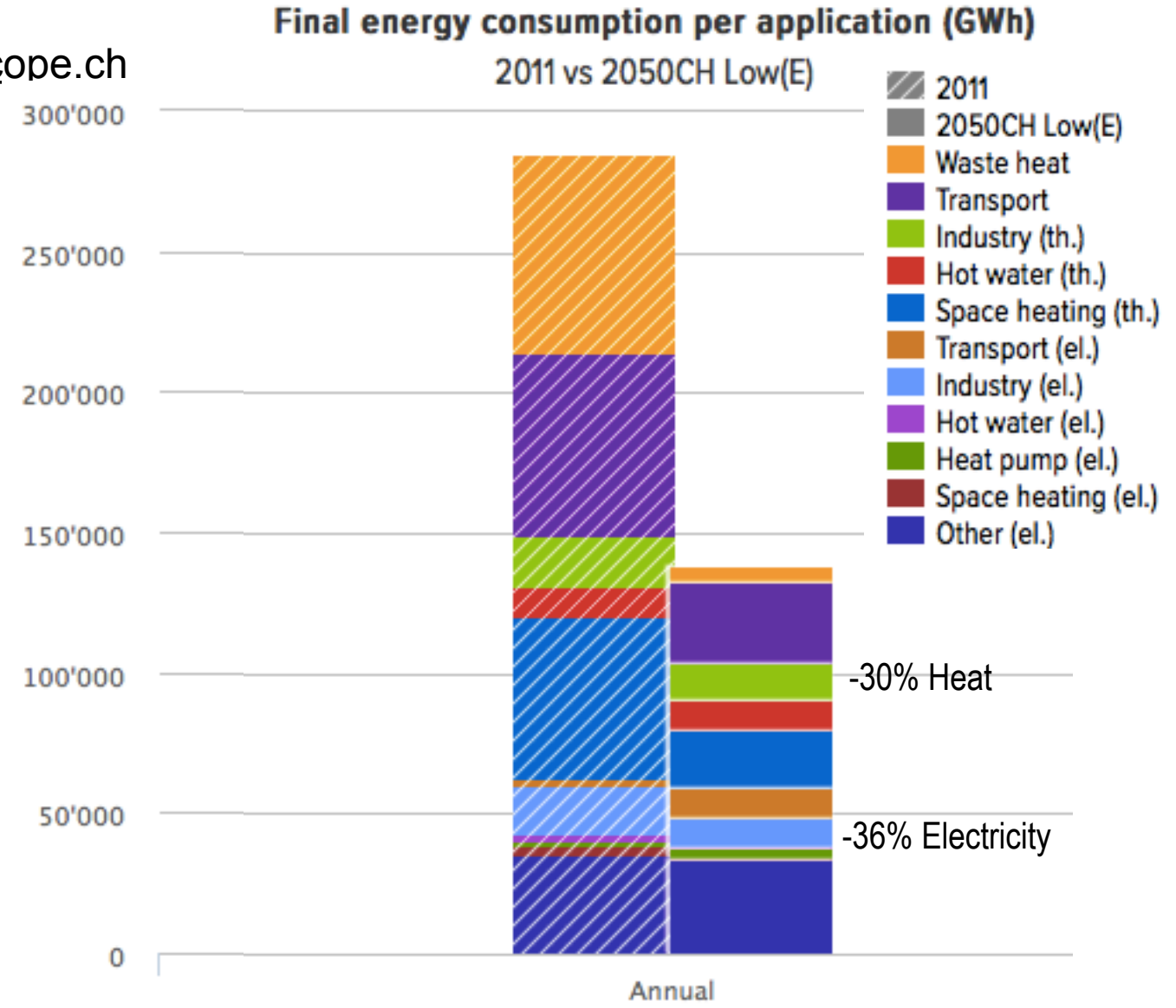


30% -> 20%

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

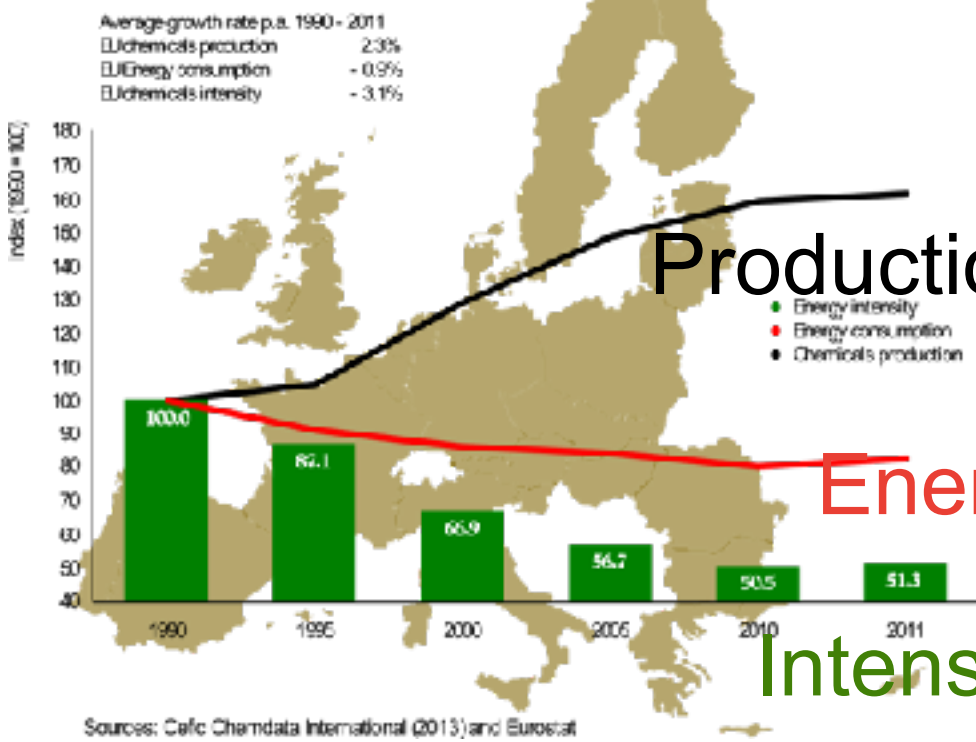
Industry and the energy transition

- www.energyscope.ch



The problem of the industry

Revenue [CHF/y]



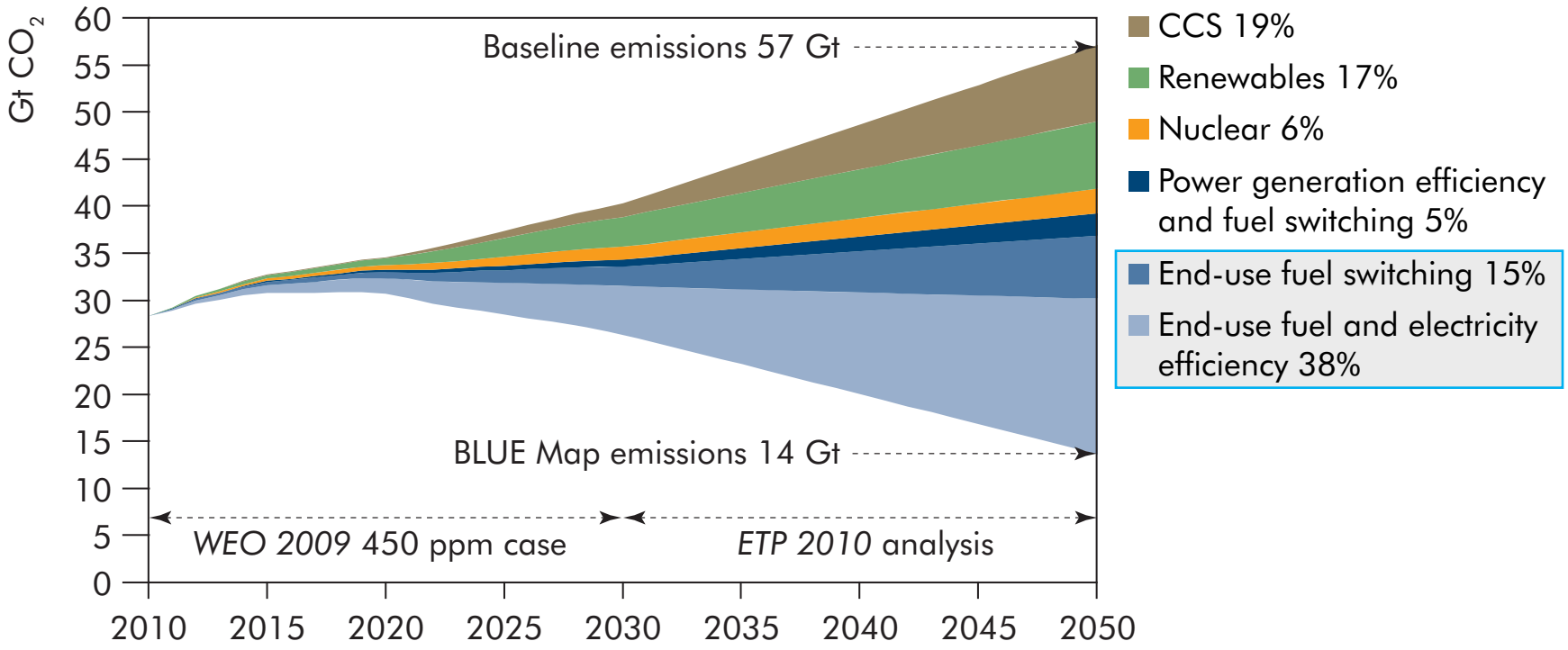
Production [kg/y]

Energy [MJ/y]

Intensity [MJ/y]

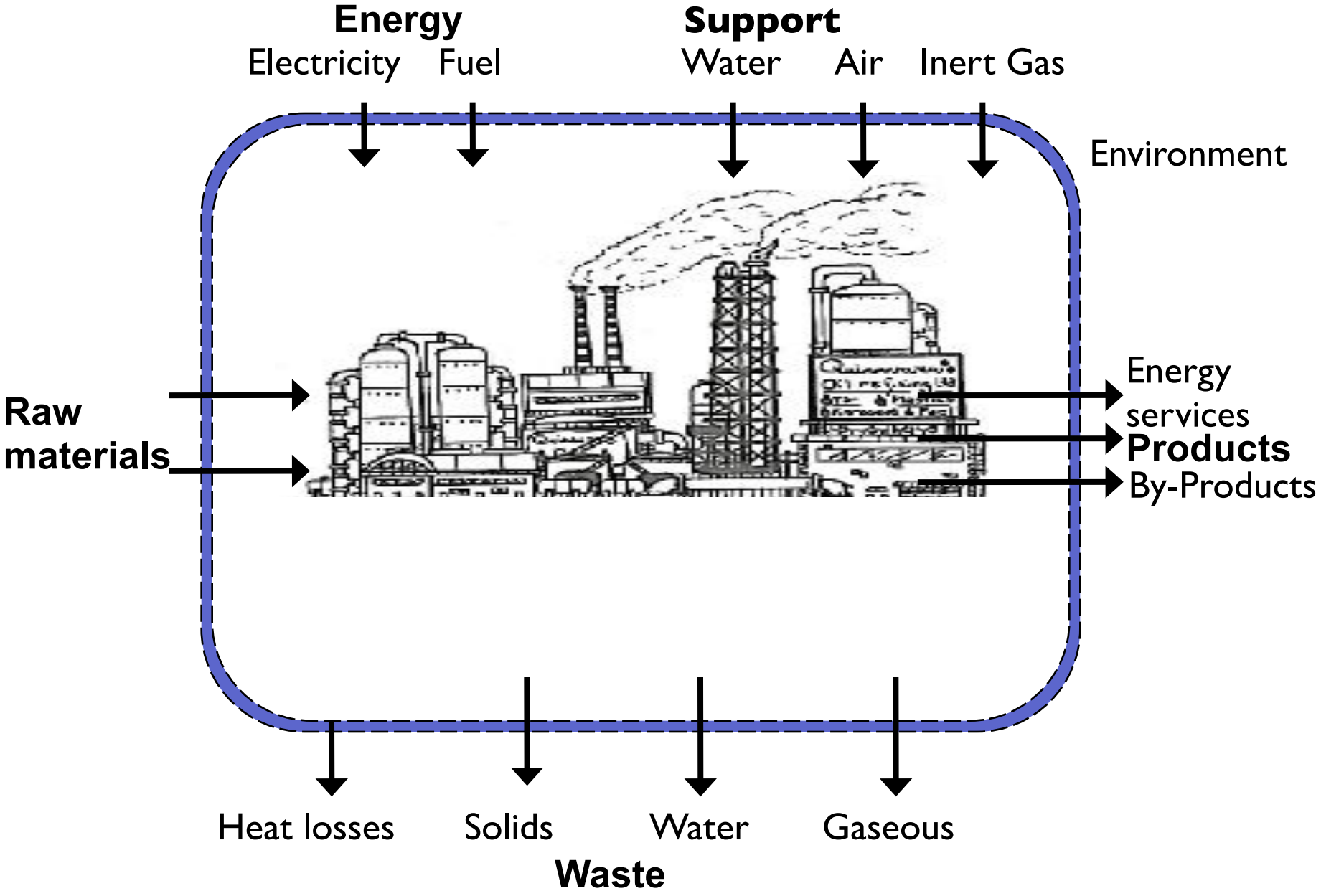
Impact of Energy system engineering

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



Energy Technology Perspective 2010, International Energy Agency , 2010

How to reduce the emissions of an industrial Process ?



Steps in decarbonisation

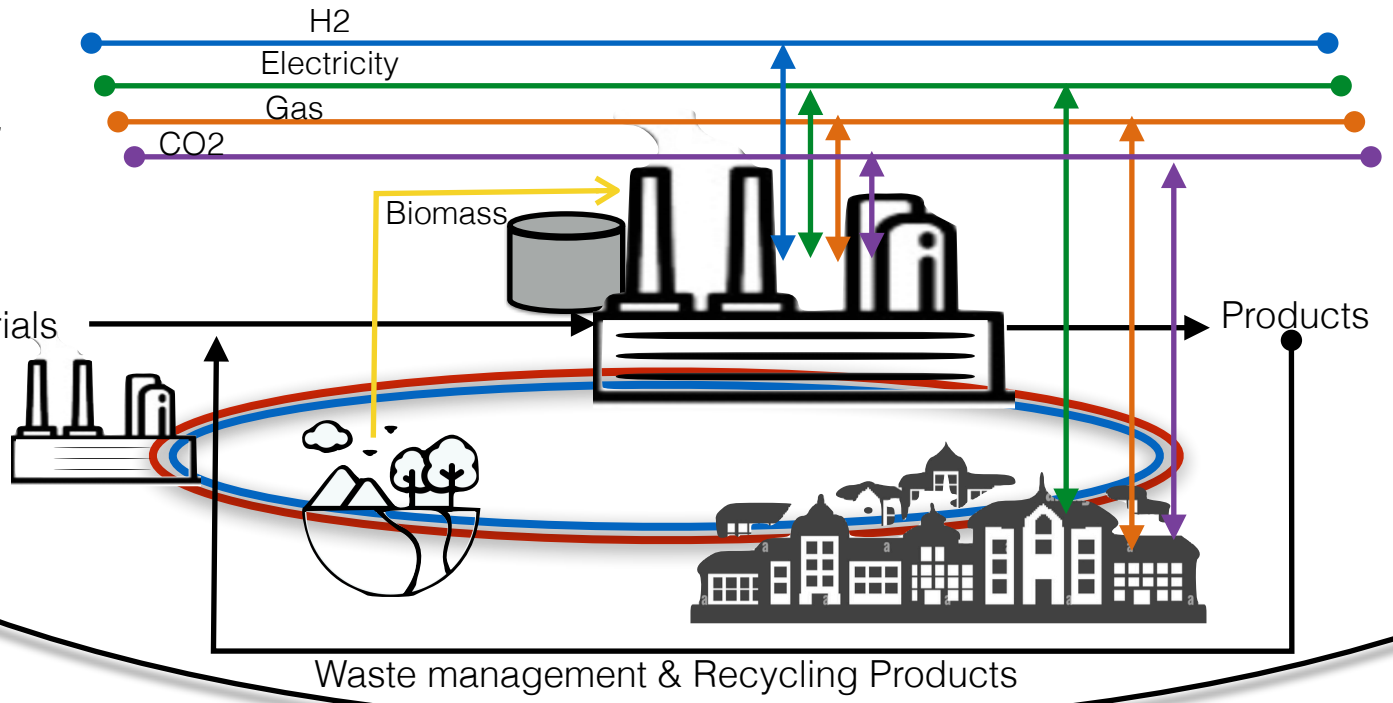
Heat valorisation
Heat pumping
Waste heat to electricity

Energy conversion
Renewable energy sources
Combined Heat and Power
Combined Heat and Fuel

Efficiency
Materials recovery
Heat recovery

Technology efficiency
Optimal operation
Technology improvement
Technology innovation

CO2
Capture, reuse, sequestrate



Energy system integration
Energy grids
Heat and electricity storage
Hydrogen
Power2Tanks2Power

Energy Audits
Energy Drivers
Efficiency KPI
Monitoring

System expansion
District heating/cooling
Industrial symbiosis
Waste-water-energy
Circular economy

Sustainability metrics
CO2 footprint
Resources usage
Environmental impact

Economic metrics
CAPEX-OPEX
Technology Readiness
Retrofit and pay-back

Thermodynamic metrics
Energy Efficiency
Mass balances
Exergy

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

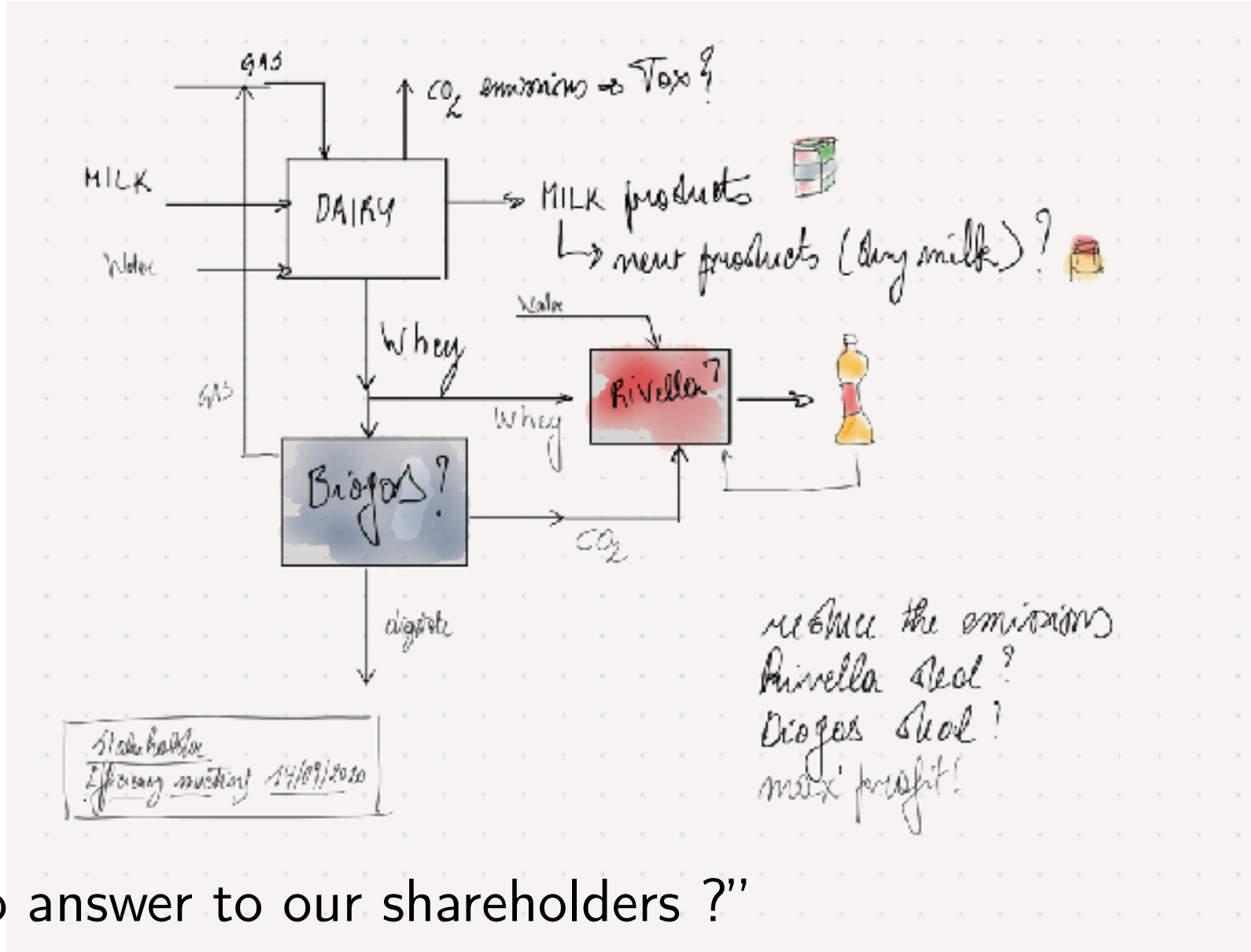
- **Project-oriented**: you are supposed to realise a guided industrial process energy efficiency analysis project. This project covers the whole duration of this course, and will help you better understand the theory concepts.
- **Theory - Application - Flip class** : Theory is first presented and put 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.
  - **Flip Class** : Typical questions of the exam prepared and illustrated by students on Miro boards : “ The theory and how it was applied in your project “ + feed-back discussion by professor.

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 this …
  -



- and tells you

"what do I have 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. 09.Sep - 13.Sep	• Presentation by Hitachi-Sozen-Innova • Introduction to the course	• Tools set up (Quarto, Git, Mattermost, Virtual machine....) • Group Formation	
2. 16.Sep - 20.Sep **(Break)**			
3. 23.Sep - 27. Sep	• Mass and energy balance • Energy bill calculation	• Task 1 in the project description	
4. 30.Sep - 04.Oct	• Exergy analysis	• Task 2 and Task 3	• **Quiz 1** - Mass and Energy balance, energy bill
5. 07.Oct - 11.Oct	• ~~No lectures~~	• Wrap-up for task 1, 2 and 3.	• **Quiz 2** - Exergy analysis
6. 14.Oct - 18.Oct	• Delta T minimum	• Taks 4 (to be updated in the project description)	
7. 21.Oct - 25.Oct **(Break)**			
8. 28.Oct - 01.Nov	• Composite curve	• Task 5 (example to be changed)	**Milestone 1** for your report • Mass and energy balance • Energy bill • Exergy analysis • Composite curve
9. 04.Nov - 08.Nov	• HEN design	• Task 6 and task 7	• **Quiz 3** - Maximum heat recovery
10. 11.Nov - 15.Nov	• ~~No lectures~~	• Wrap-up of task 5, 6, and 7	• **Quiz 4** - Heat exchanger network design
11. 18.Nov - 22.Nov	• Heat pump introduction	• Report writing and organization	
12. 25.Nov - 29.Nov	• Utility integration	• Task 8	**Milestone 2** for your report • Minimum energy requirement solution • Heat exchanger network design Intermediate report submission
13. 02.Dec - 06.Dec	• ~~No lecture~~	• Task 8	• **Quiz 5** - Utility integration
14. 09.Dec - 13.Dec	• ~~No lecture~~	• Task 9	Intermediate report review submission
15. 16.Dec - 20.Dec	• Dry-run for the oral exam • Discussion with Prof. Maréchal by Group	• Finalize your project report	**Milestone 3** for your report • Utility integration

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 (**6** students)
  - sub groups of 2 students to realise tasks
- Weekly meeting with supervisor
  - Monday 16h-19h (+ office hours Thursday @14h)
- Preliminary report after module 3
  - individual review report (10 points)
- Final report after winter holidays 10 days before exam (20 points)
  - A validated report is a condition to present the exam
- Final presentation for exam poster
  - Dry-run preparation : prof feedback and recommendations
- Exam
  - Poster on how the theory has been applied in the case study
  - Oral exam

Groups for project based learning

- Group
  - 5 students
  - 1 TA + 1 Backup

- Interactive time
  - Monday at time of the course
  - Thursday : office hours 12:00-14:00 upon request

Computer aided engineering methodology : AGIR

A for Analyse and Activate

Analyse consist in defining what are the expected results. Although most of the time intuitive, it is important to exchange on what you expect, defining the values your are looking for and the physical units associated. When using programming, it is also useful to use names and create your own project specific vocabulary, especially for acronyms abbreviation

A stands also for **Activation** as you have to decide the knowledge and the tools you need to activate (put in your toolbox) to realise the tasks. It is not forbidden to refresh knowledge or to acquire new knowledge to realize the task.

G for Generate

You are going to use different tools to generate results. It typically requires the

- formulation of the problem
- the definition of assumptions
- the collection of information (from knowledge data base)
- the definition of the degrees of freedom (decisions you need to make)
- the choice and the programming of a solving method
- the calculation realisation
- the extraction of the numerical results

I for interpretation

Interpretation is the action of converting numerical results into meaningful information for the mission. This means:

- verifying the validity of the numerical results obtained
- the consistency with what was expected as defined in the Analyse phase
- verifying the validity and testing the sensitivity of the assumptions or of the data uncertainty
- testing the importance of the decision variables

R for reporting

Reporting of the results is the way to communicate not only the outcome of the mission but what you have learned. The report and the associated visual representation are targeting your teammates and classmates when you have realized a task or a broader audience (like your colleagues) so that if someone has the same task as yours, you will save their time. To validate the report, a critical review will be realised.

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)

Deliverables

- Quizz : be ready for the tasks (**5 points in the final grade**)
- Intermediate report : end week 10
  - Groups deliver preliminary report after 60% of the work
- Individual review report
  - Student deliver individual review of the report of one other group
  - Reviews are graded (**10 points to the final grade**)
  - Groups are supposed to integrate the comments in the final version of the report
- Final presentation
  - A dry run (individual meeting with prof. and assistant) is used to prepare the final presentation at the exam.
- Final report (**25 points to the final grade**) to be delivered 10 days before the exam

The exam (20 points)

- Oral exam (20 min/person)
- Poster presentation (individual) : 3 min
  - Summary of the case study
    - Methodology applied
    - Major results obtained
- Mastering the skills
  - Explain the theory and its application in the case study
- My own exam:
  - Detailed evaluation before leaving the exam room

Exam Grading

- Individual grading
  - Defines how you master the subject
    - theory and its application
  - Defines how you master the project realisation
  - Weight to the project (30/60)
    - case study is used a teaching support
    - you are responsible of part the report but you sign the whole report

Questions of the exam

- Document : Objectives (on moodle)
- each question will be treated during the year by your presentation.

4 Detailed specific goals of the course

The following tables should help you assessing your progress. By filling the bullets you should be able to follow your progress during the lecture.

4.1 Minimum Energy requirement

	Goals
ooooo	Compute the energy bill of an industrial system
ooooo	Explain what is the meaning of the $\Delta Tmin$ and what are the major parameters that define its value
ooooo	Define hot and cold streams for a process integration analysis
ooooo	Compute the energy balance of an industrial system including the application of First Law balances to verify the coherency of the data set.
ooooo	Explain the construction of the hot and cold composite curves
ooooo	Explain the construction and the use of the grand composite curve
ooooo	Compute the maximum energy recovery in an industrial process and compute its minimum energy requirement
ooooo	Explain the major assumptions and how these can be assessed or overcome
ooooo	Estimate the heat recovery heat exchanger network cost and compute the optimal $\Delta Tmin$ value of the plant.
ooooo	Identify and quantify pinch violations in a process
ooooo	Explain the More-in More-out principle
ooooo	Explain the plus-minus principle
ooooo	Identify ways to improve the minimum energy requirement from the analysis of the composite curves

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

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  - 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 for your bright future !