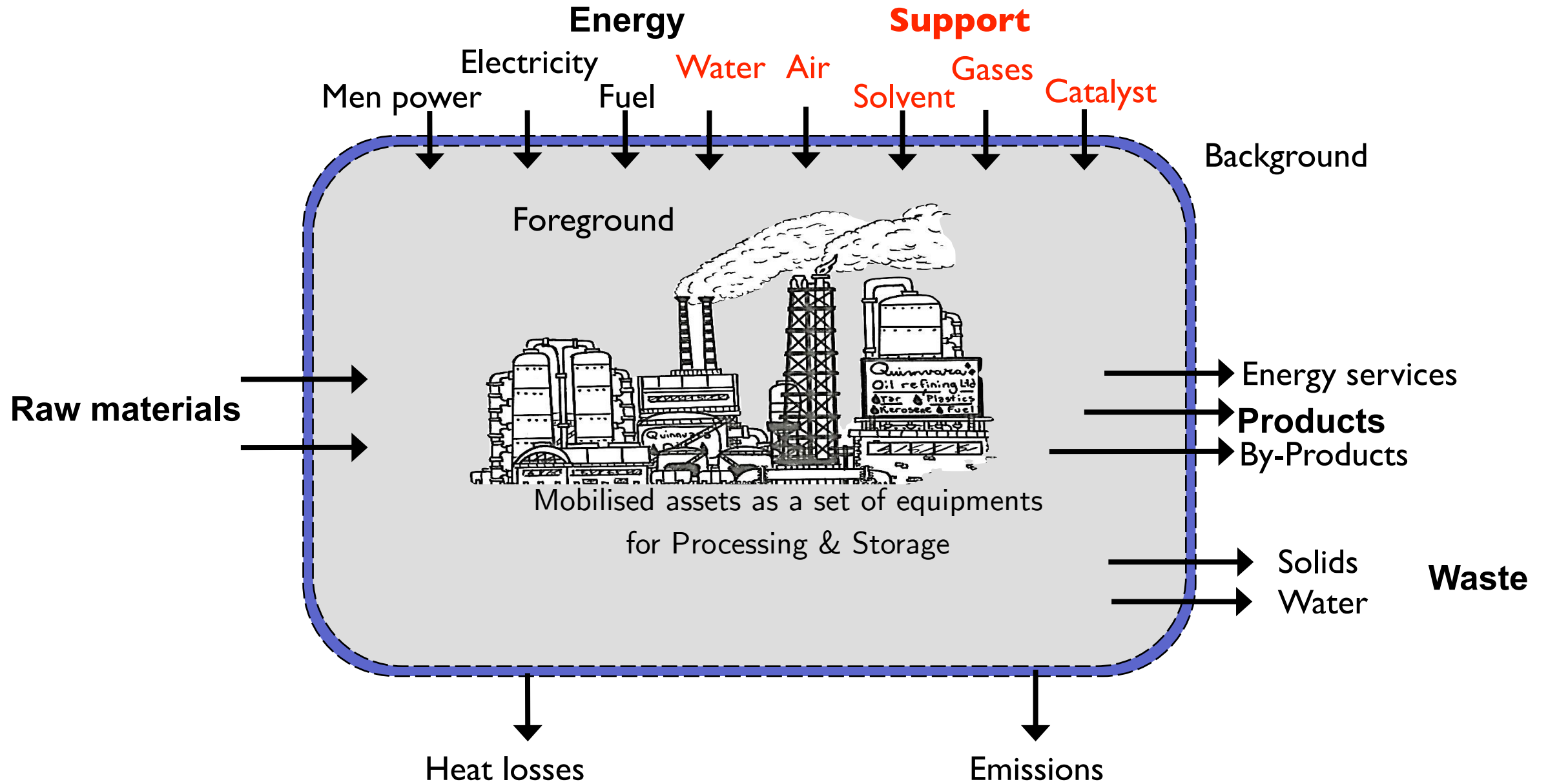


Process performances

EPFL Key performance indicators of an industrial process



EPFL Thermodynamic performances of a process

- Sources of inefficiencies (explain $\dot{Q}_{T_a}^-$)
- Material and Energy Efficiency
- Specific consumptions
 - Materials
 - Energy
- Targeting-monitoring procedures
- Influencing factors

- Atom economy : $\forall a \in \{atoms\}$

$$\frac{\text{a in products}}{\text{a in feed streams}} = \frac{\int_{t_0}^{t_{period}} \sum_p^{products} \dot{M}_p^- \cdot x_{c,p} \cdot \nu_{a,c}}{\int_{t_0}^{t_{period}} \sum_f^{inputs} \dot{M}_f^+ \cdot x_{c,f} \cdot \nu_{a,c}}$$

- Energy efficiency:

$$\frac{\Delta \text{energy products}}{\text{energy consumed}} = \frac{\int_{t_0}^{t_{period}} \left(\sum_p^{products} \dot{M}_p^- \cdot h_p - \sum_f^{inputs} \dot{M}_f^+ \cdot h_f \right) dt}{\int_{t_0}^{t_{period}} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot LHV_f + E^+ - E^- \right) dt}$$

$$\frac{\text{Heat release}}{\text{Energy process balance}} = \frac{\int_{t_0}^{t_{period}} \dot{Q}_{T_a}^- dt}{\int_{t_0}^{t_{period}} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot LHV_f + E^+ - E^- \right) dt}$$

EPFL Thermodynamic efficiency : specific consumptions

- **Specific Cost of energy (CHF/kg products):**

$$\frac{\int_{t_0}^{t_f} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot v_f^+ + E^+ \cdot v_e^+ - E^- \cdot v_e^- \right) dt}{\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \right) dt}$$

- **Specific Energy (kJ/kg products):**

$$\frac{\int_{t_0}^{t_f} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot lhv_f^+ + E^+ - E^- \right) dt}{\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \right) dt}$$

- **Cost (CHF energy/ CHF products)**

$$\frac{\int_{t_0}^{t_f} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot v_f^+ + E^+ \cdot v_e^+ - E^- \cdot v_e^- \right) dt}{\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \cdot v_p^- \right) dt}$$

EPFL Thermodynamic efficiency : specific emissions

- Specific impact of production (emission/kg products):

$$\int_{t_0}^{t_f} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot i_{ef_{f+}} + E^+ \cdot i_{ef_{e+}} - E^- \cdot i_{ef_{e-}} \right) dt$$

$$\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \right) dt$$

$i_{ef_{f+}}$ environmental impact factor of emission ef of fuel f at import

$i_{ef_{e+}}$ environmental impact factor of emission ef of electricity import e^+

$i_{ef_{e-}}$ environmental impact factor of emission ef of electricity export e^-

- Specific cost of environmental impact (CHF/kg products)

$$\int_{t_0}^{t_f} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot i_{ef_{f+}} \cdot v_{i_{ef_{f+}}}^- + E^+ \cdot i_{ef_{e+}} \cdot v_{i_{ef_{e+}}}^- - E^- \cdot i_{ef_{e-}} \cdot v_{i_{ef_{e-}}}^- \right) dt$$

$$\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \right) dt$$

EPFL Thermodynamic efficiency : specific consumptions per type

- **Specific Electricity (kJe/kg products):**

$$\frac{\int_{t_0}^{t_f} (E^+ - E^-) dt}{\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \right) dt}$$

- **Specific fuel consumption (kJ fuel/kg products)**

$$\frac{\int_{t_0}^{t_f} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot lhv_f^+ \right) dt}{\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \right) dt}$$

- **Exergy efficiency:**

$$\frac{\text{Exergy delivered}}{\text{Exergy input}} = \frac{\int_{t_0}^{t_{\text{period}}} \left(\sum_p^{\text{products}} \dot{M}_p^- \cdot h_p + E^- \right) dt}{\int_{t_0}^{t_{\text{period}}} \left(\sum_f^{\text{fuels}} \dot{M}_f^+ \cdot k_f + E^+ + \sum_f^{\text{inputs}} \dot{M}_f^+ \cdot k_f \right) dt}$$

- **Specific Exergy (kJe net / kg of products):**

$$\frac{\int_{t_0}^{t_{\text{period}}} \left(\sum_f^{\text{inputs}} \dot{M}_f^+ \cdot k_f - \sum_p^{\text{products}} \dot{M}_p^- \cdot k_p + \sum_f^{\text{fuels}} \dot{M}_f^+ \cdot k_f + E^+ - E^- \right) dt}{\int_{t_0}^{t_f} \left(\sum_{P=1}^{n_P} \dot{M}_{\bar{P}} \right) dt}$$

- **Specific Exergy (kJe net / kJe of products):**

$$\frac{\int_{t_0}^{t_{\text{period}}} \left(\sum_f^{\text{inputs}} \dot{M}_f^+ \cdot k_f - \sum_p^{\text{products}} \dot{M}_p^- \cdot k_p + \sum_f^{\text{fuels}} \dot{M}_f^+ \cdot k_f + E^+ - E^- \right) dt}{\int_{t_0}^{t_f} \left(\sum_{P=1}^{n_P} \dot{M}_{\bar{P}} \cdot k_p \right) dt}$$

EPFL Comparing different forms of energy

■ Electricity

- kJ_e vs kJ_{fuel} ?
- **Energy mix from the background**
 - Primary energy required in the background to produce the electricity (efficiency, emissions)
 - Natural combined cycle (60% , 0.376 kg CO₂/kWh)
 - Coal power plant (46%, 0.828 kg CO₂/kWh)
 - Hydro power plant (85%, 0.00534 kg CO₂/kWh)
 - PV via LCA (16%, utilisation rate 13% , 0.0625 kg CO₂/ kWh)
 - Wind (utilisation rate : 23%, 0.0161 kg CO₂/kWh)
- Availability / Substitution
 - Annual energy vs instantaneous power

EPFL Allocation when multiple products

- Overall energy consumption per unit of product

- MJ/kg of product p^*

$$K_{p^*} = \frac{\int_{t_0}^{t_f} \left(\sum_f^{fuels} \dot{M}_f^+ \cdot lhv_f^+ + E^+ - E^- \right) dt}{\int_{t_0}^{t_f} \left(\sum_p^{products} \dot{M}_p^- \right) dt}$$

- Allocation by

- Mass : $K_{p^*} = \frac{\int_{t_0}^{t_{period}} \dot{M}_{p^*} \cdot dt}{\int_{t_0}^{t_{period}} \left(\sum_k^{Products} \dot{M}_k \right) \cdot dt}$

Market value of product p^*

- Market Value: $K_{p^*} = \frac{\int_{t_0}^{t_{period}} \dot{M}_{p^*} \cdot v_{p^*}^- \cdot dt}{\int_{t_0}^{t_{period}} \left(\sum_k^{Products} \dot{M}_k \cdot v_k^- \right) \cdot dt}$

- Exergy Value: $K_{p^*} = \frac{\int_{t_0}^{t_{period}} \dot{M}_{p^*} \cdot k_{p^*} \cdot dt}{\int_{t_0}^{t_{period}} \left(\sum_k^{Products} \dot{M}_k \cdot k_k \right) \cdot dt}$

EPFL Conclusions

- Associating values to flows allows to define Key performance indicators
- Specific consumptions
- Efficiency
- Various allocations