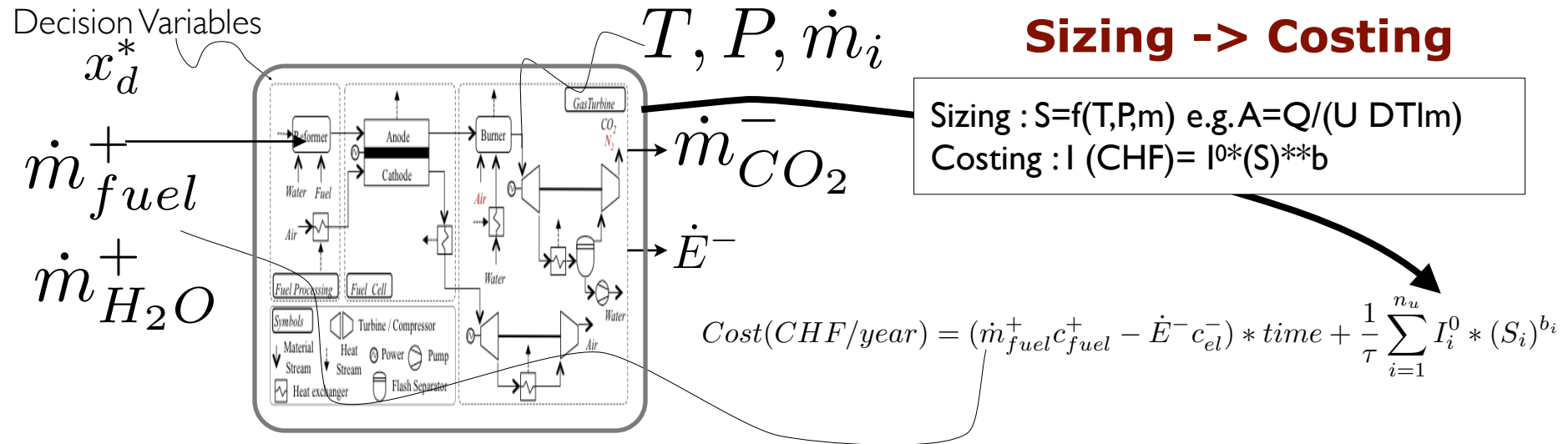


Key performance indicators

Prof François Marechal

- Cost of operation : give values to flows
- Cost of the investment
 - Estimate the size of each equipment
 - Estimate its cost



$f(x) = 0$ Process simulation

$x_d - x_d^* = 0$ **THERMO=> flows**

ECONOMIC=flow*price

- Sizing function may be complex and heuristics
 - Describe the transfer phenomena
 - Residence time => sizes

$$Size_u(x, \pi_u^*)$$

where $x \in \{x_u^+, x_u^-, \pi_u\}$: problem state variable

x_u^+ Streams entering the unit u

x_u^- Streams leaving the unit u

π_u Parameters of the unit u

π_u^* sizing model parameters the unit u

Ulrich, K.T., and S.D. Eppinger, others. *Product design and development*. Vol. 384. McGraw-Hill New York, 1995.

see also : http://www.mech.utah.edu/senior_design/07/uploads/Main/Lect12-ConceptSelection.pdf.

General formula of the KPI in KPI unit/lifetime

$$KPI = \int_{t=0}^{LifeTime} \left(\sum_{r=1}^{n_r} \dot{m}_r^+(t) v_{r,p}^{+,KPI}(t) + \dot{E}^+(t) v_e^{+,KPI}(t) - \dot{E}^-(t) v_e^{-,KPI}(t) + \sum_{u=1}^{n_u} f_u(t) v_{m,u}^{KPI} \right) dt + \sum_{u=1}^{n_u} v_u^{KPI}(I_u(S_u))$$

KPI [KPI unit/lifetime] for n_p conditions of operation over the lifetime of the system

$$KPI = \sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}_{r,p}^+ v_{r,p}^{+,KPI} + \dot{E}_p^+ v_{e,p}^{+,KPI} - \dot{E}_p^- v_{e,p}^{-,KPI} + \sum_{u=1}^{n_u} f_{u,p} v_{m,u}^{KPI} \right) d_p + \sum_{u=1}^{n_u} v_u^{KPI}(I_u(S_u))$$

$\dot{m}_{r,p}^+, \dot{E}_p^+, \dot{E}_p^-$ [kg/s, kW] : flows calculated in the system configuration during conditions p

d_p [s/lifetime] : probability of appearance of conditions p during the life time of the system

$v_{r,p}^{+,KPI}$ [KPI/kg] : value given to flows or investment to characterize the system configuration during conditions p

$v_{e,p}^{+,KPI}$ [KPI/kJ] : value given to Electricity to characterize the system configuration during conditions p

$v_{m,u}^{KPI}$ [KPI/use of u] : value of the maintenance cost of unit during the conditions p

v_u^{KPI} [KPI/\$ invested] : value given to the investment of unit u in the system (typically in $\frac{\$^{2020}}{year} \frac{1}{\$_{invested}}$)

$I_u(S_u)$ [\$ invested/Size of u] : investment in the equipment of the system

$$TotalCost[CHF/year] = OPEX + CAPEX + Tax$$

$$OPEX = \sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}_{r,p}^+ c_{r,p}^+ + \dot{E}_p^+ c_{e,p}^+ - \dot{E}_p^- c_{e,p}^- + \sum_{u=1}^{n_u} f_{u,p} c_{m_u} \right) d_p$$

$$CAPEX = \sum_{u=1}^{n_u} \frac{1}{\tau(n_{y,u}, i)} (I1_u y_u + I2_u f_u^{max})$$

$$Tax = CO_2^+ \gamma^{CO_2^+}$$

$$CO_2^+ = \sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}_{r,p}^+ \epsilon_r^{CO_2} + \dot{E}_p^+ \epsilon_{e,p}^{CO_2^+} - \dot{E}_p^- \epsilon_{e,p}^{CO_2^-} \right) d_p$$

$$Impact = \zeta^{CO_2^+} (CO_2^+ + \sum_{u=1}^{n_u} \frac{1}{n_{y,u}} (\xi_{c_u}^{CO_2} + \xi_{d_u}^{CO_2}) f_u^{max})$$

$$RES = \sum_{p=1}^{n_p} \left(\sum_{r_{res}=1}^{n_{r_{res}}} \dot{m}_{r_{res},p}^+ + \sum_{u=1}^{n_u} f_{u,p} e_{u,p}^{res+} \right) d_p$$

$$\dot{E}_p^+ + \dot{E}_p^- + \sum_{u=1}^{n_u} f_{u,p} (e_{u,p}^{res+} - e_{u,p}^-) = 0 \quad \forall p = 1..n_p$$

$$OPEX[CHF/year] = \sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}_{r,p}^+ c_{r,p}^+ + \dot{E}_p^+ c_{e,p}^+ - \dot{E}_p^- c_{e,p}^- + \sum_{u=1}^{n_u} f_{u,p} c m_u \right) d_p$$

with

$\dot{m}_{r,p}^+[kg/h]$ flow of resource r in period p

$c_{r,p}^+[CHF/kg]$ specific price of resource r in period p

$\dot{E}_p^+[kW]$ Electricity import in period p

$c_{e,p}^+[CHF/kWh]$ Electricity price at import in period p

$\dot{E}_p^-[kW]$ Electricity export in period p

$c_{e,p}^-[CHF/kWh]$ Electricity price at export in period p

$n_u[-]$ number of units

$f_{u,p}[-]$ level of use of unit u in period p

$c m_u[CHF/h]$ specific maintenance cost of unit u

$d_p[h/year]$ duration of period p

We assume that the specific prices are valid for the whole life time : 25 years !!!!

Capital Expenditure is the amount of money needed to buy the equipment, it is expressed on an annual basis

$$CAPEX[CHF/year] = \sum_{u=1}^{n_u} \frac{1}{\tau(n_{y,u}, i)} (I1_u y_u + I2_u f_u^{max})$$

$\frac{1}{\tau(n_{y,u}, i)}$	$[\frac{1}{year}]$	annualisation factor of unit u
$n_{y,u}$	$[year]$	expected life time of unit u
$I1_u$	$[CHF]$	fixed investment of unit u
y_u	$[-]$	existence unit u
$I2_u$	$[CHF]$	proportional investment cost of unit u
f_u^{max}	$[-]$	size of unit u

- Measures the amount of CO2 emissions associated to the operation of the system during the n_p operating conditions p.

$$CO_2^+ [kgCO_2/year] = \sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}_{r,p}^+ \epsilon_r^{CO_2} + \dot{E}_p^+ \epsilon_{e,p}^{CO_2^+} - \dot{E}_p^- \epsilon_{e,p}^{CO_2^-} \right) d_p$$

$\epsilon_r^{CO_2} [kgCO_2/kg_r]$	kg CO2 emitted per unit of resource r burnt (local emissions)	-> SCOPE 1
$\epsilon_{e,p}^{CO_2^+} [kgCO_2/kWh_e]$	kg CO2 emitted per kWh of electricity consumed	
$\epsilon_{e,p}^{CO_2^-} [kgCO_2/kWh_e]$	kg CO2 avoided per kWh of electricity exported (substituted in the grid)	-> SCOPE 2

$$Tax [CHF/year] = CO_2^+ \gamma^{CO_2^+}$$

$$\gamma^{CO_2^+} [CHF/kgCO_2] \quad \text{CO2 tax per kg CO2 emitted}$$

SCOPE 1 emissions : directly emitted on site

SCOPE 2 emissions : indirectly emitted (i.e. emitted at the time of the production of the electricity or for the supply of the resource)

$$Impact[ImpactUnit/year] = \zeta^{CO_2^+} (CO_2^+ + \sum_{u=1}^{n_u} \frac{1}{n_{y,u}} (\xi_{c_u}^{CO_2} + \xi_{d_u}^{CO_2}) f_u^{max})$$

$\zeta^{CO_2^+} [ImpactUnit/kg_{CO_2}]$ Impact of CO2 emissions per kg of CO2 emitted
 $\xi_{c_u}^{CO_2} [kg_{CO_2}]$ life cycle CO2 emissions during the construction of unit u
 $\xi_{d_u}^{CO_2} [kg_{CO_2}]$ life cycle CO2 emissions during the dismantling of unit u

An impact value is given to an emission. It concerns SCOPE1, SCOPE 2 or SCOPE 3 (considering the life cycle)
 The impact is typically measured by life cycle impact assessment indicators.