The Energy Hub - A Powerful Concept for Future Energy Systems

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on behalf of the research team :

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Presentation outline

- Project background
- The hub concept
- Examples
- Concluding remarks

Visions of Future Energy Networks: Motivation

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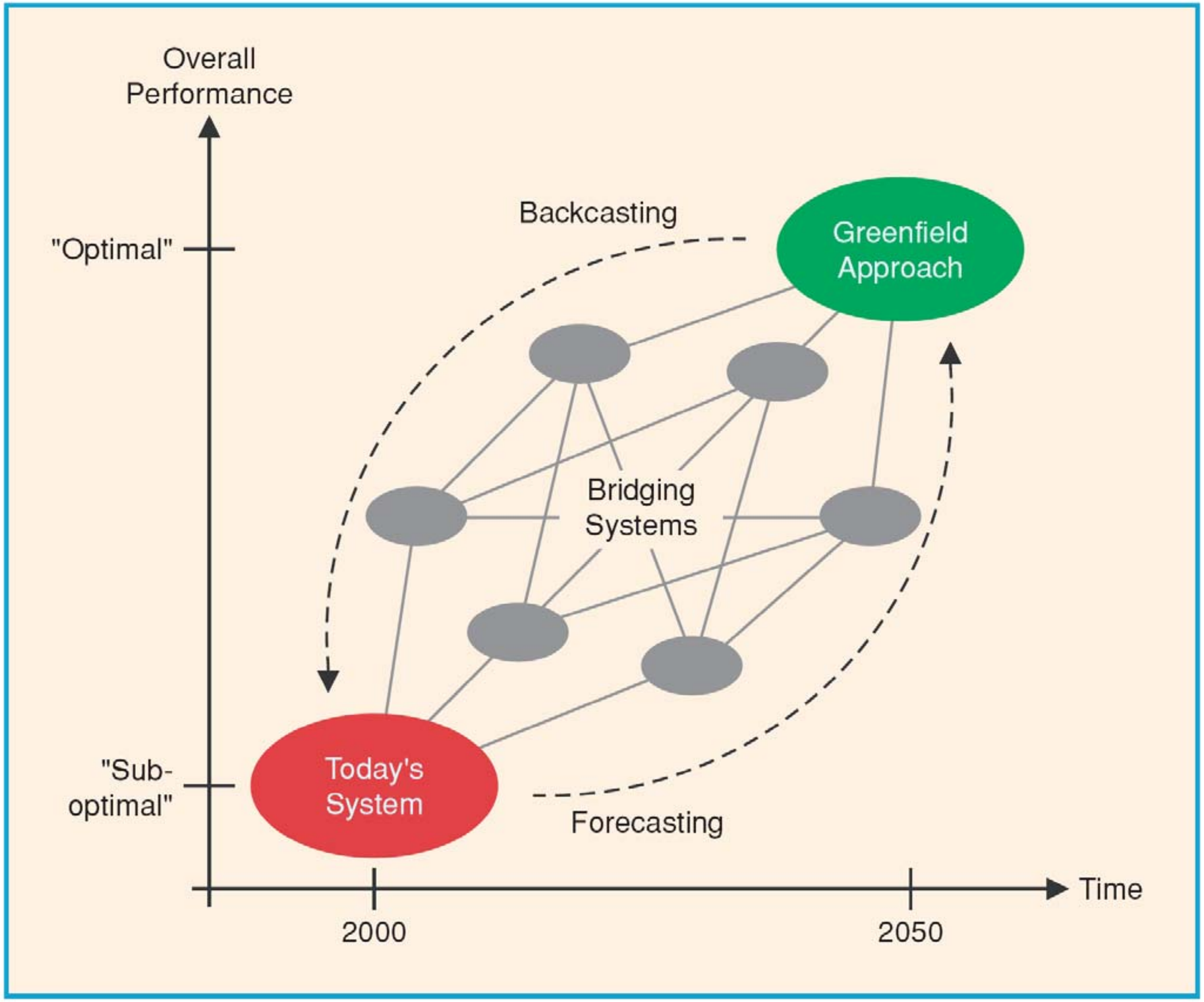
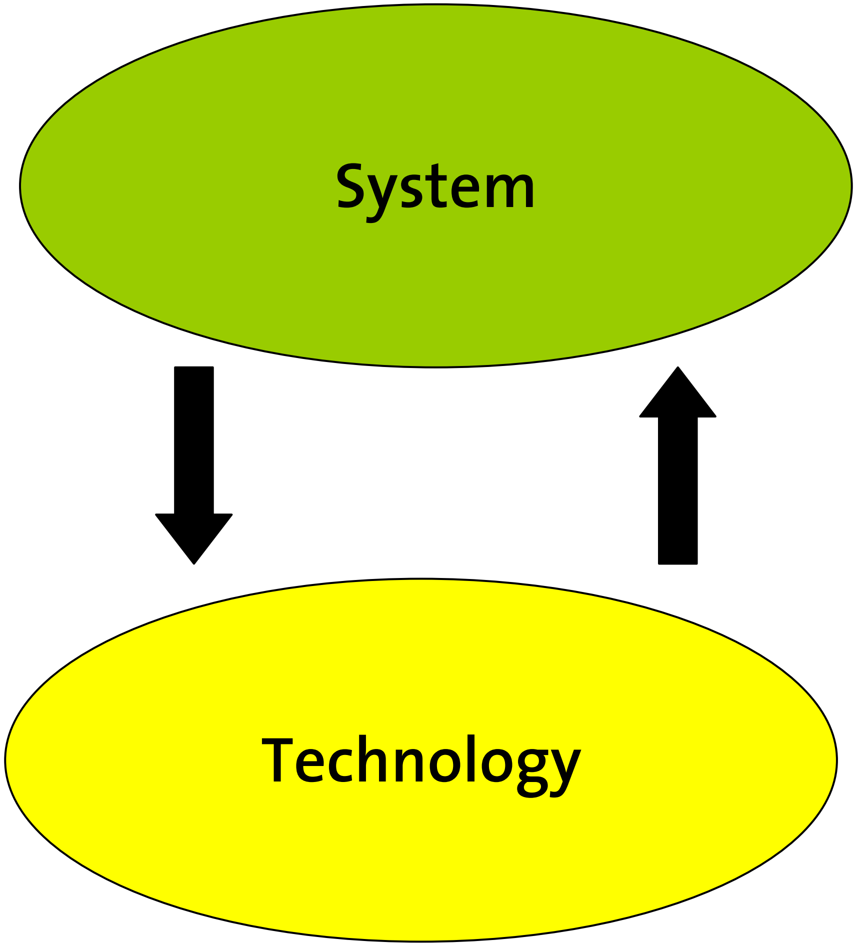
Swiss Federal Institute of Technology Zurich

- Today's system is necessarily not optimal to meet future requirements from customers and power producers
- New technologies are emerging both with regard to primary systems and secondary and enabling systems
- Environmental and regulatory requirements are changing

Greenfield Approach



Interaction System Requirements - Technology



Customer req.
Layout
Operation - Control
Optimisation
Regulation
...

Features
Costs
Requirements
...

Project sponsors:

ABB

AREVA TD

Siemens

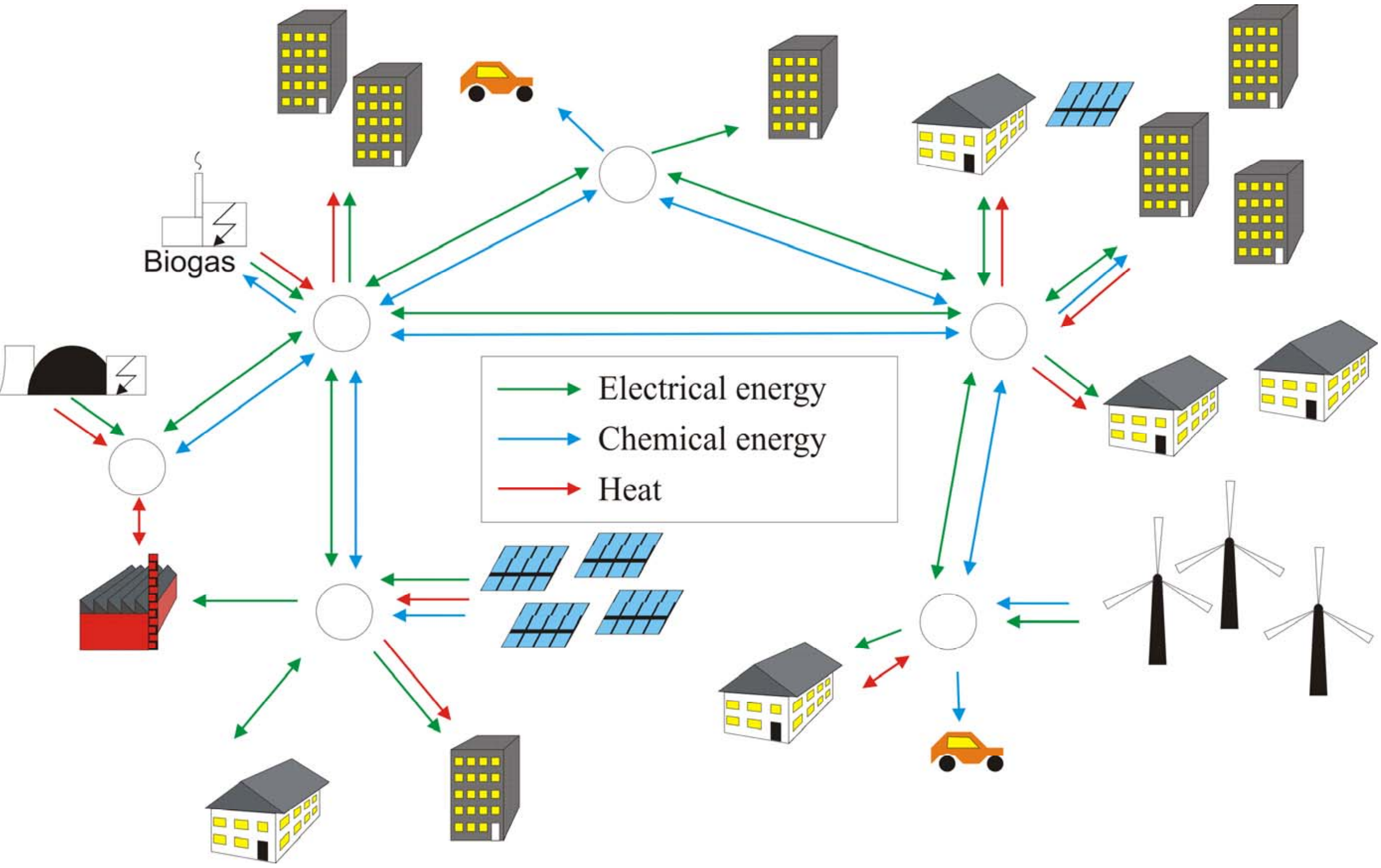
Bundesamt für Energie (CH)

SwissPower, Novatlantis, ...

ETH

Academic partners: TU Delft, RWTH Aachen, NTNU Trondheim, CEPE ETHZ,

Principle network layout – multicarrier system



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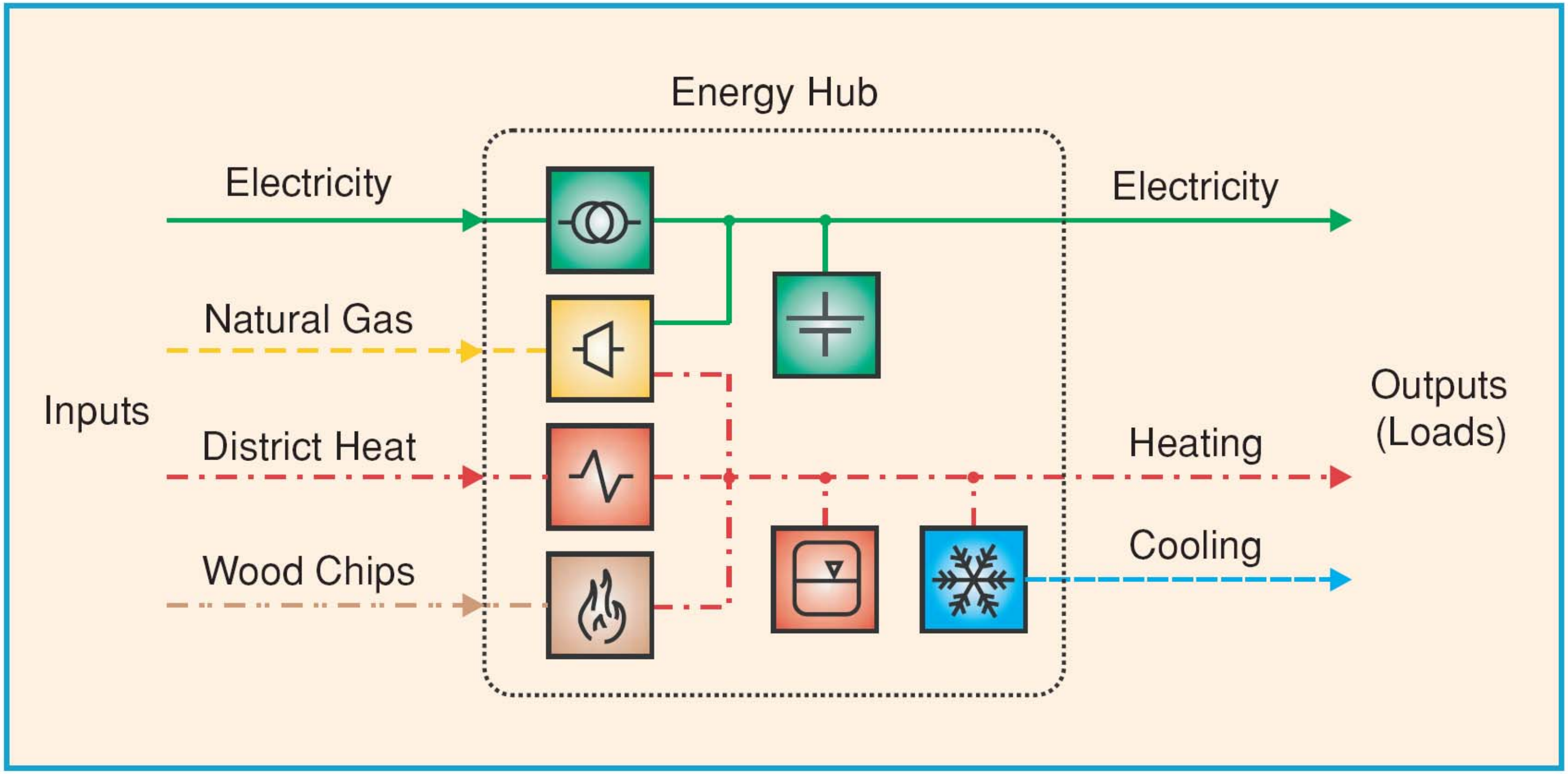
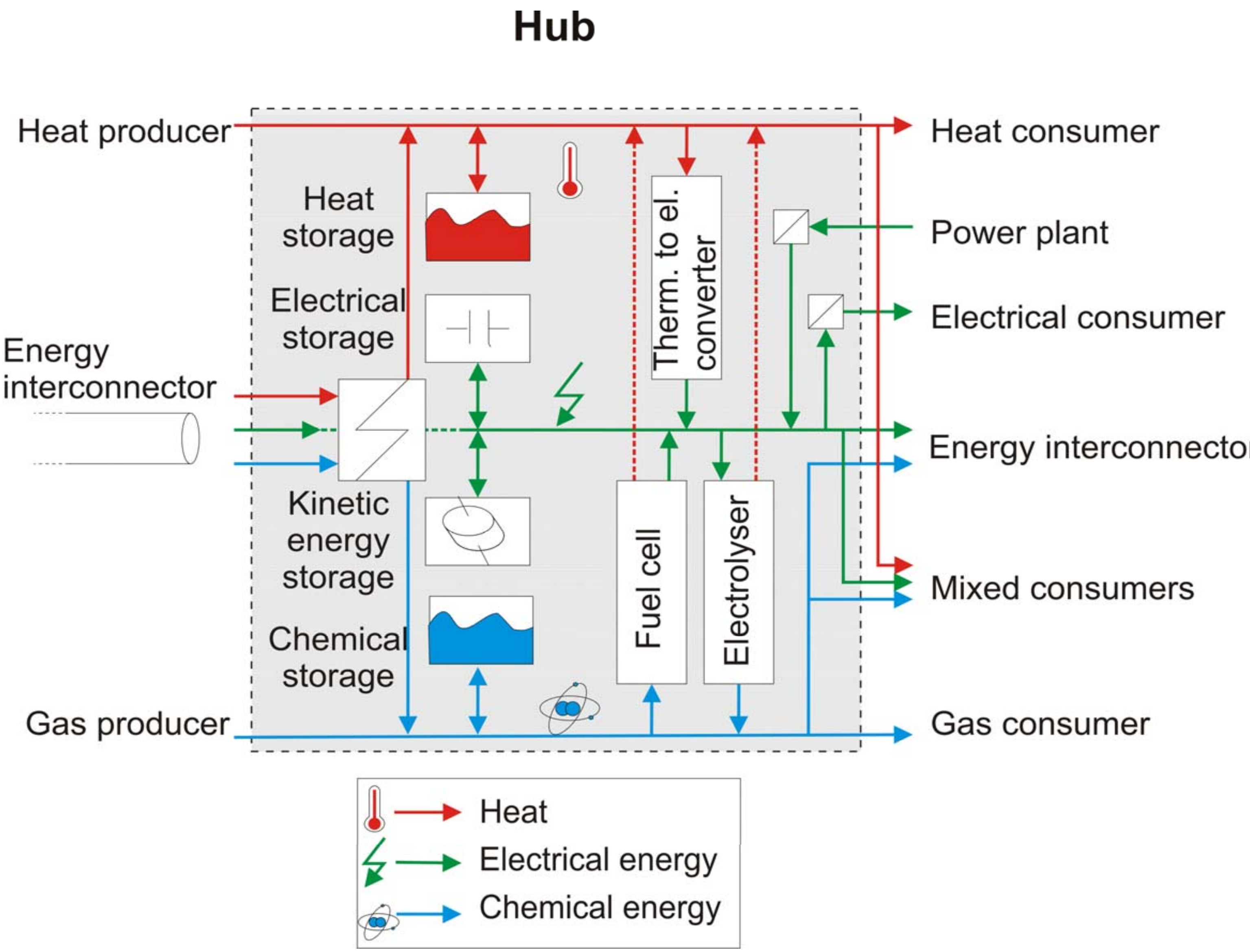
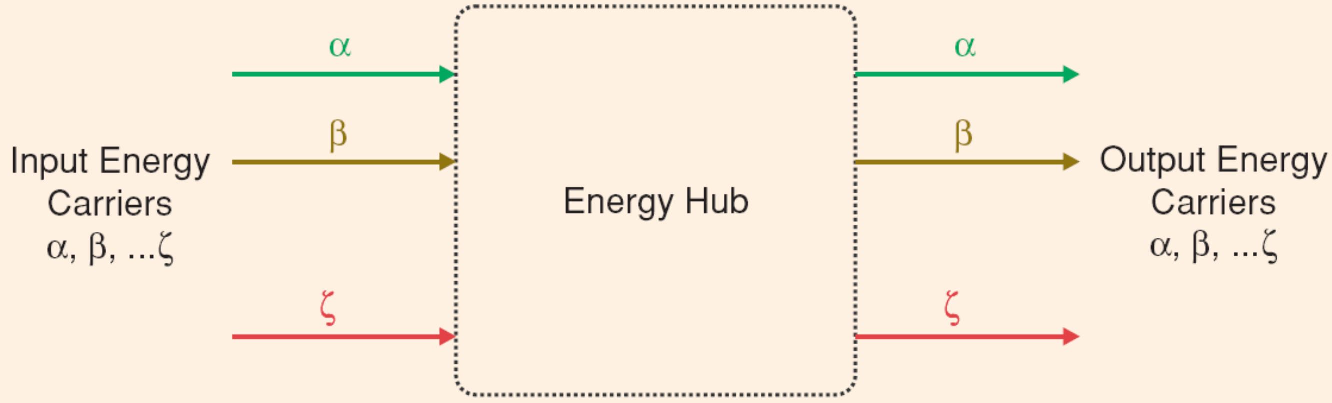
The Energy Hub – a key element



The Energy Hub – an example



Energy Hub Model

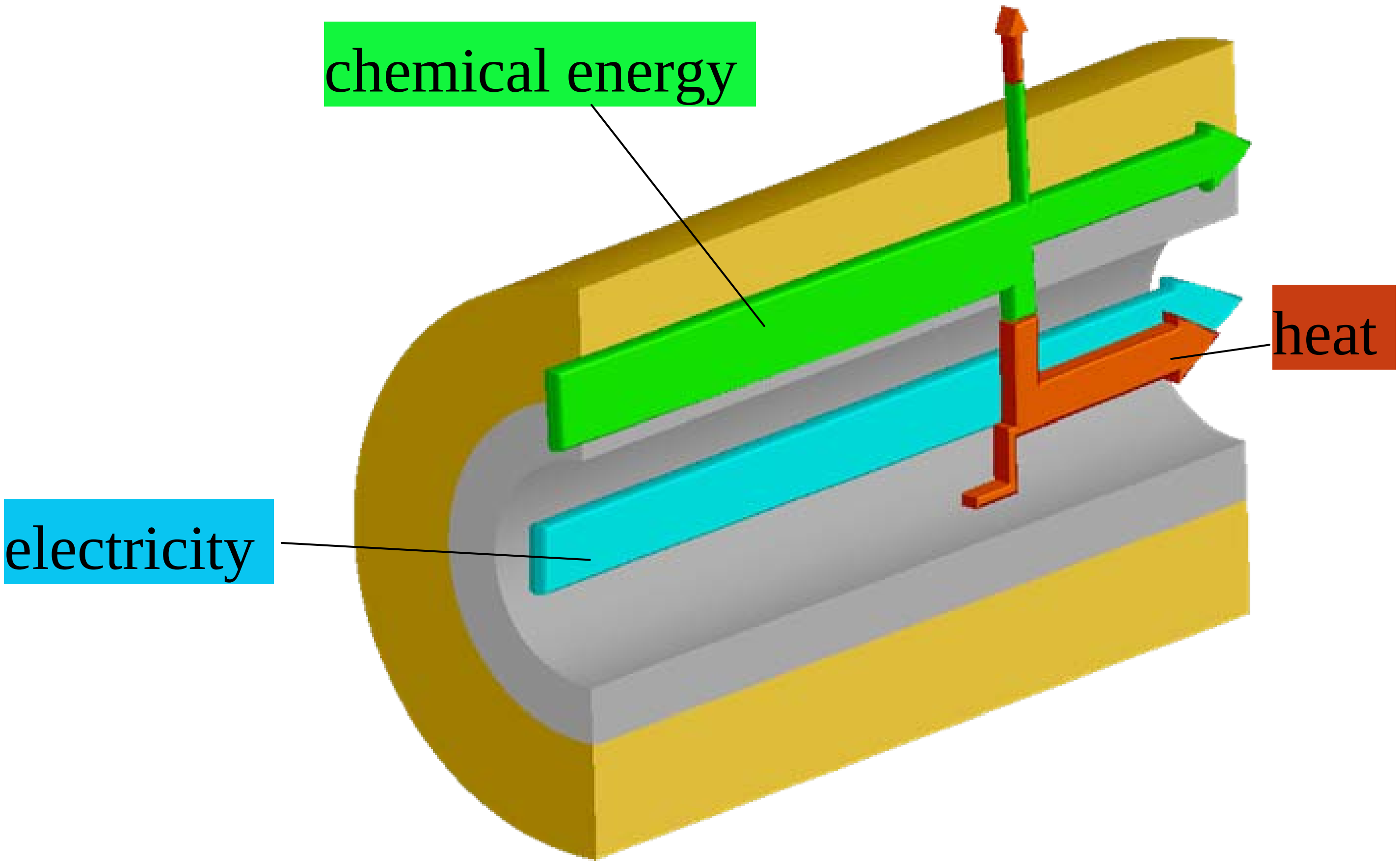


$$\begin{bmatrix} P_{out}^{\alpha} \\ P_{out}^{\beta} \\ \vdots \\ P_{out}^{\zeta} \end{bmatrix} = \begin{bmatrix} C_{\alpha\alpha} & C_{\beta\alpha} & \cdots & C_{\zeta\alpha} \\ C_{\alpha\beta} & C_{\beta\beta} & \cdots & C_{\zeta\beta} \\ \vdots & \vdots & \ddots & \vdots \\ C_{\alpha\zeta} & C_{\beta\zeta} & \cdots & C_{\zeta\zeta} \end{bmatrix} \begin{bmatrix} P_{in}^{\alpha} \\ P_{in}^{\beta} \\ \vdots \\ P_{in}^{\zeta} \end{bmatrix}$$

Output Power Vector — Coupling Matrix — Input Power Vector

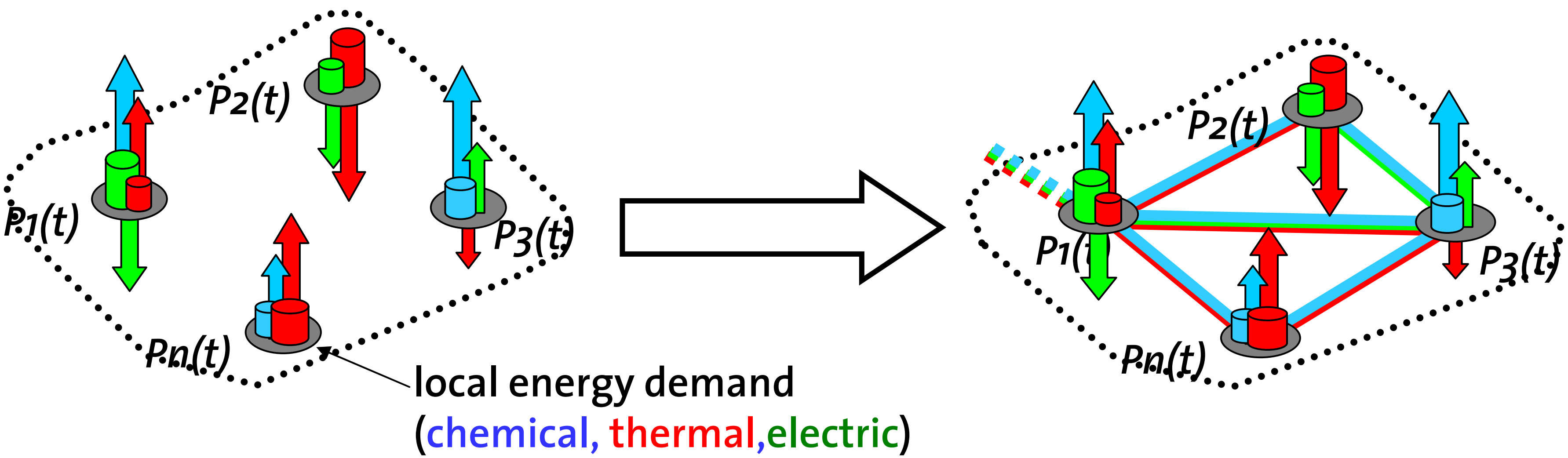
The energy interconnector

Approach: Common transmission device for several energy carriers



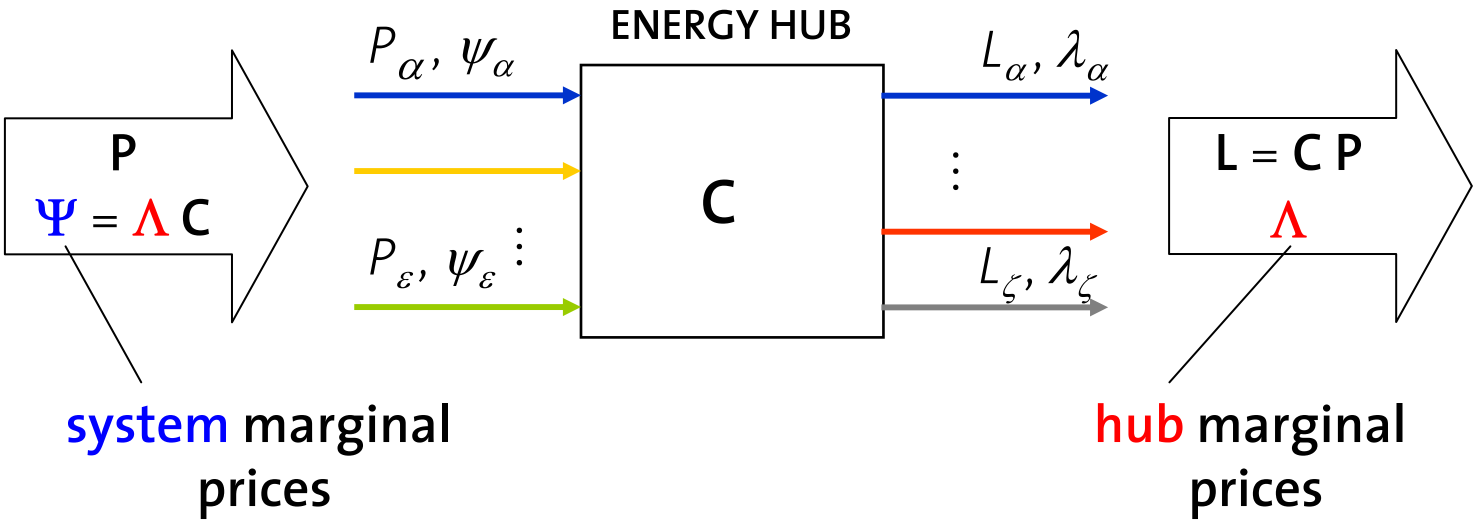
Three step procedure

requirements of the (future) grid participants	→	identification of necessary technology	→	modelling, optimisation, analysis
extrapolation, scenarios		databases, eco-balancing, techn. forecasts		implementation proposals



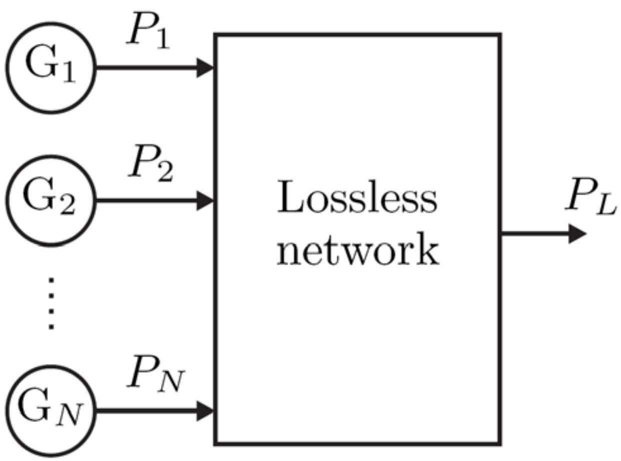
General Results

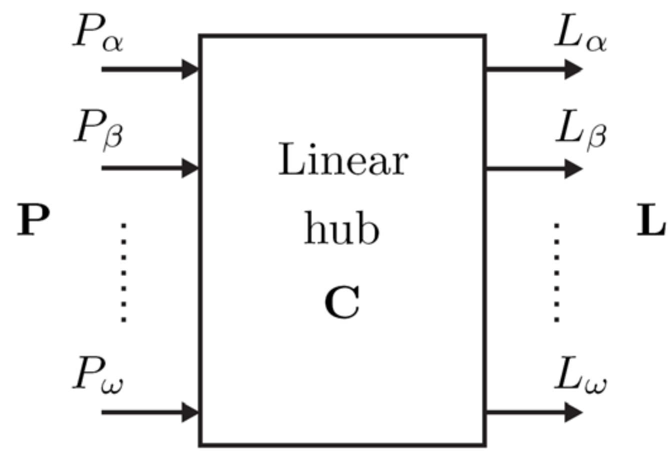
- Power conversion ⇔ price conversion



Comparison with classical case

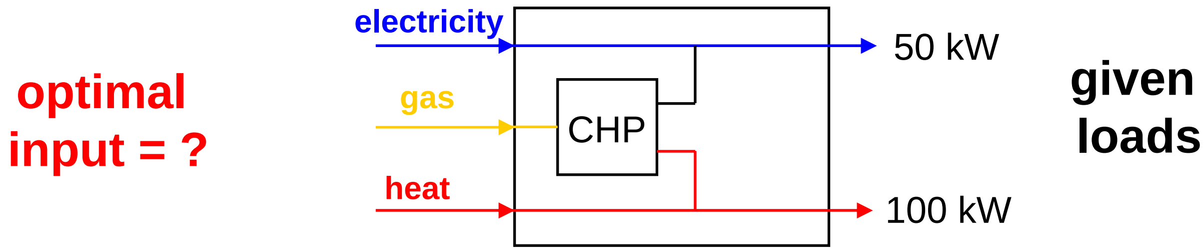
Electricity optimal dispatch	Multi-carrier optimal dispatch
Constraint: $$P_1 + P_2 + \ldots + P_N = P_L$$	Constraint: $$\mathbf{L} = \mathbf{C}\,\mathbf{P}$$
Optimality condition: $$\lambda_1 = \lambda_2 = \ldots = \lambda_N = \lambda_L$$	Optimality condition: $$\mathbf{\Psi} = \mathbf{\Lambda}\mathbf{C}$$





Example for hub evaluation

- Goal: optimal operation of an energy hub



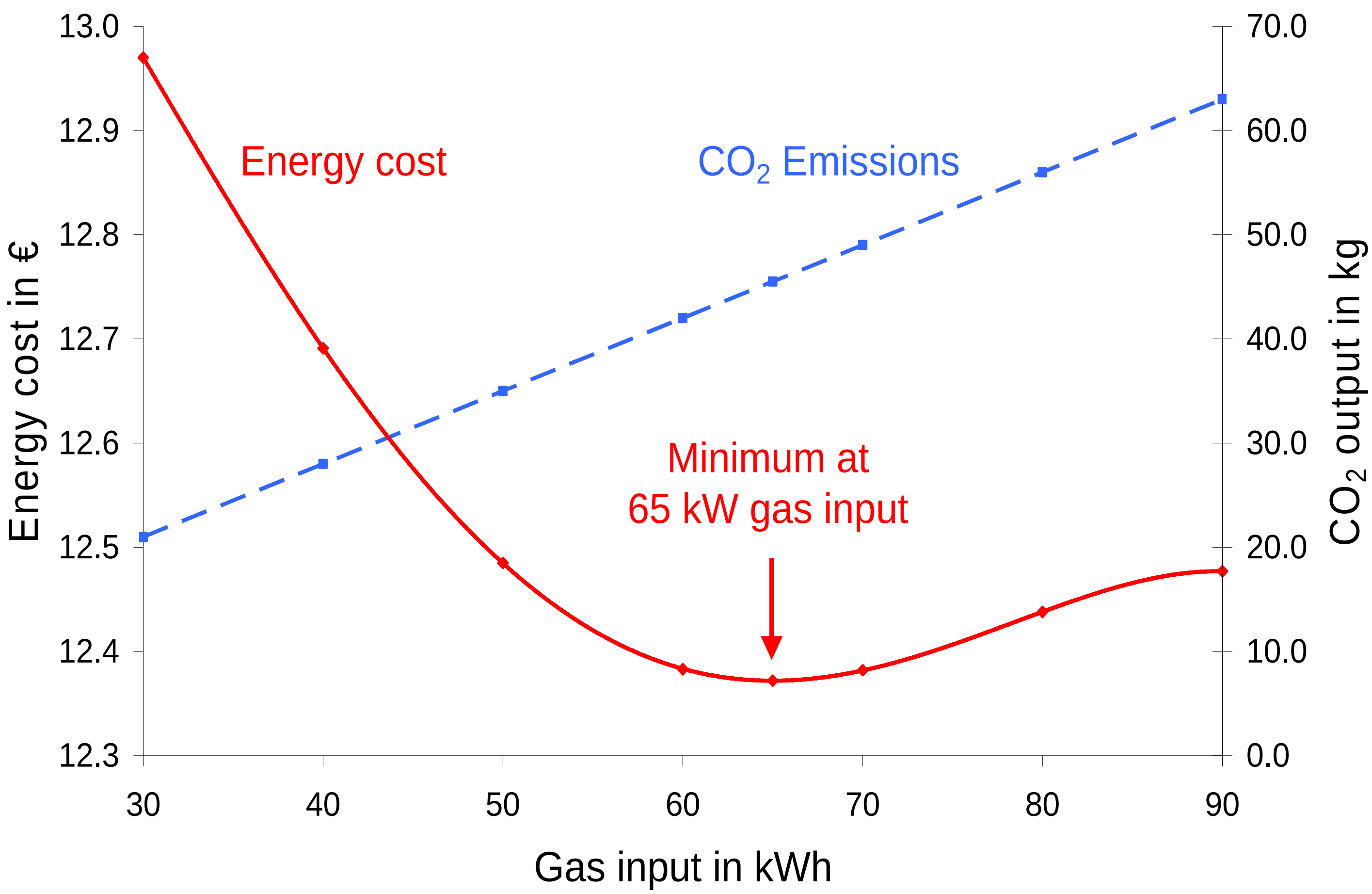
- Given
  - Energy cost (electr. = 0.1 €/kWh, gas, heat = 0.05 €/kWh)
  - Hub characteristics

$$\mathbf{C} = \begin{bmatrix} 1 & \eta_{ge}(P_g) & 0 \\ 0 & \eta_{gt}(P_g) & 1 \end{bmatrix} \qquad E_{CO_2} = 0.7\ \mathrm{kg/kWh_{gas}}$$

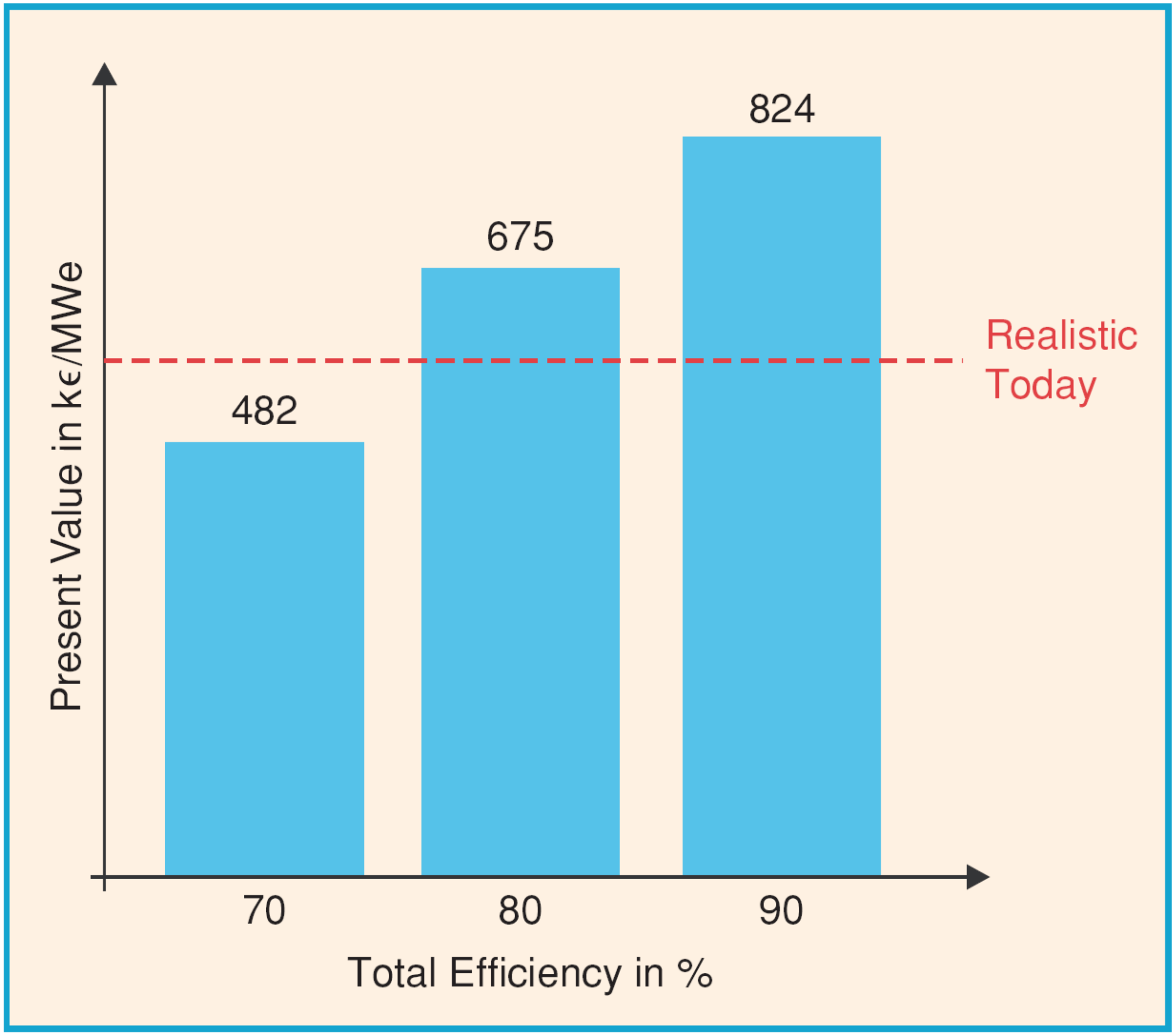
- Wanted: optimal hub inputs due to minimal energy cost

Operational Optimization

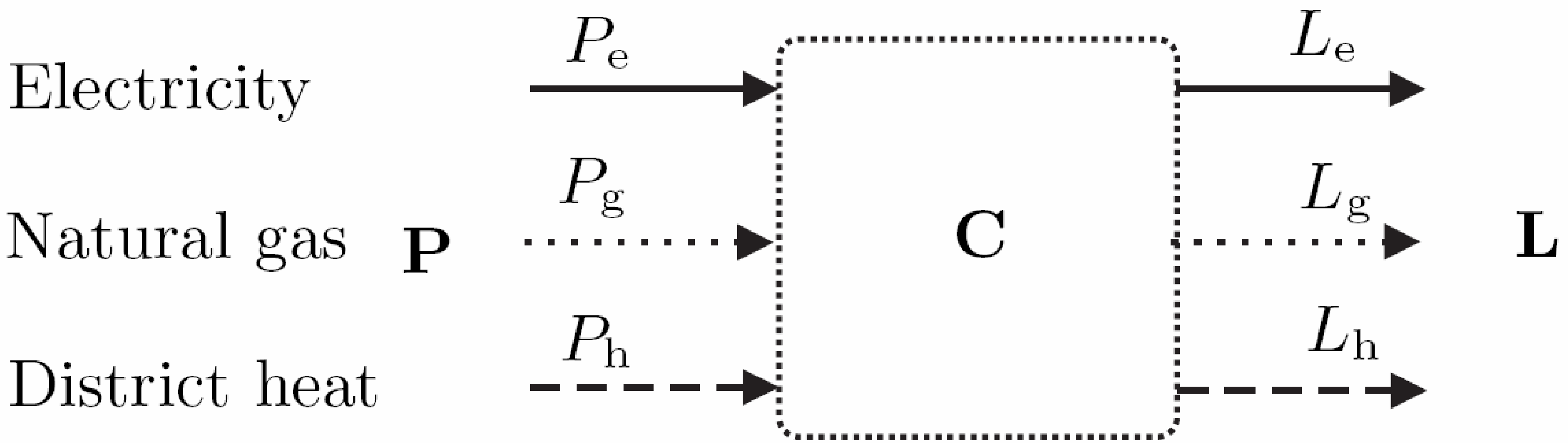
- Result



Investment evaluation



Optimal Hub Coupling

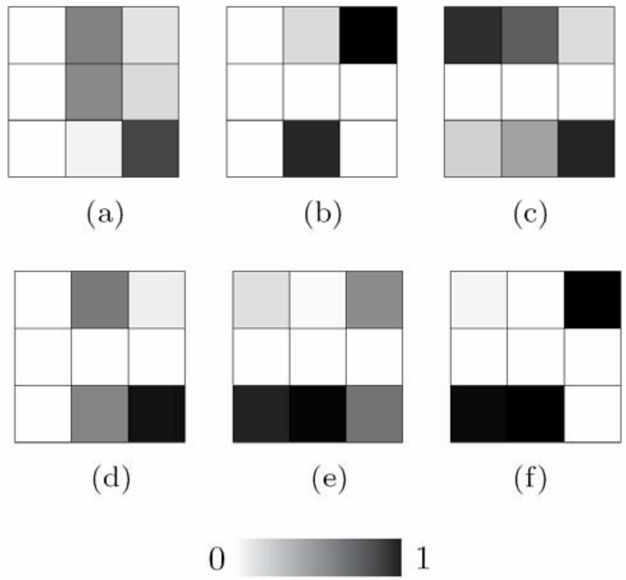


C = ?

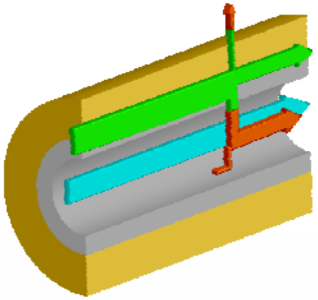
Optimal Hub Coupling

Table 5.10: Optimal Inputs for Different Loads.

Case	Required $\mathbf{L}^{\mathrm{T}}$ in pu	Optimal $\mathbf{P}^{\mathrm{T}}$ in pu
(a)	[1 1 1]	[0.00 1.76 1.24]
(b)	[1 0 1]	[0.00 1.17 0.83]
(c)	[2 0 2]	[0.77 1.89 1.34]
(d)	[1 0 2]	[0.00 1.76 1.24]
(e)	[1 0 5]	[2.51 2.04 1.45]
(f)	[2 0 10]	[7.84 2.44 1.72]



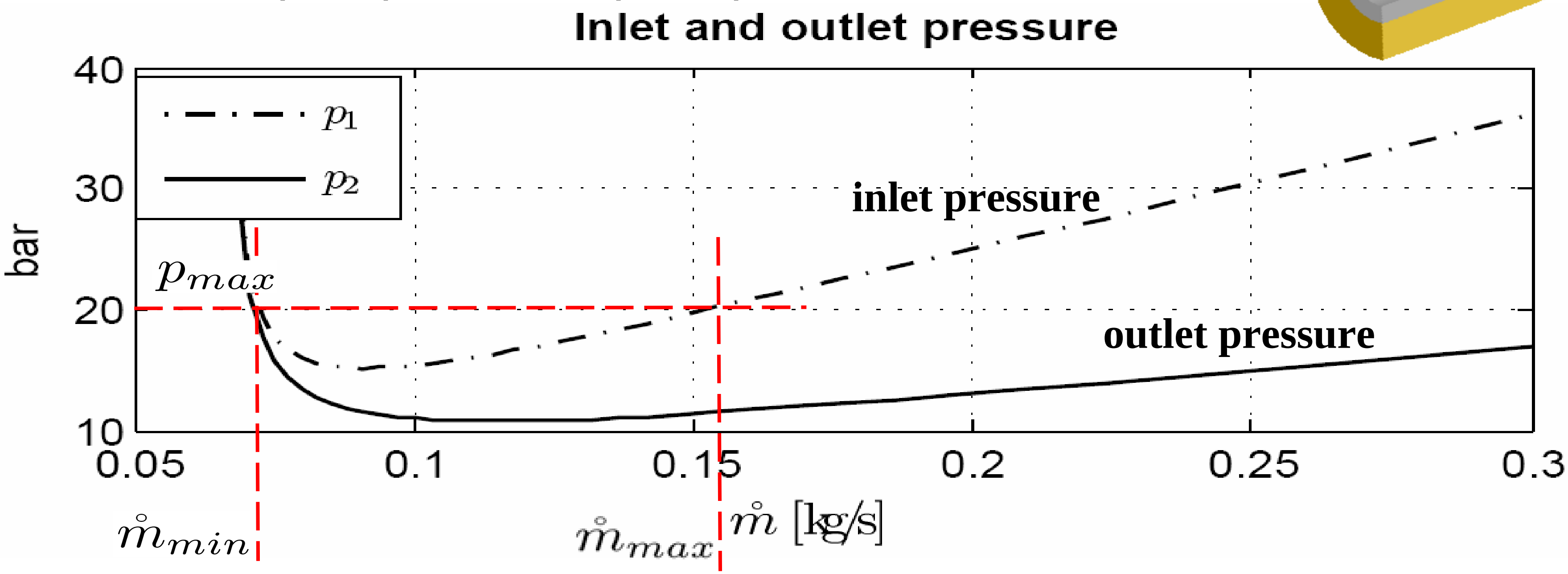
Example: coupling of electrical and gaseous chemical power



Assumptions:

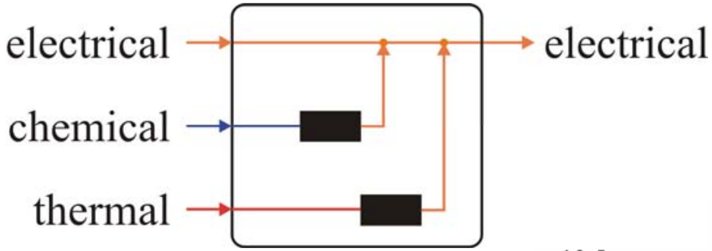
electrical input power constant

inlet (20 °C) and outlet (120 °C)

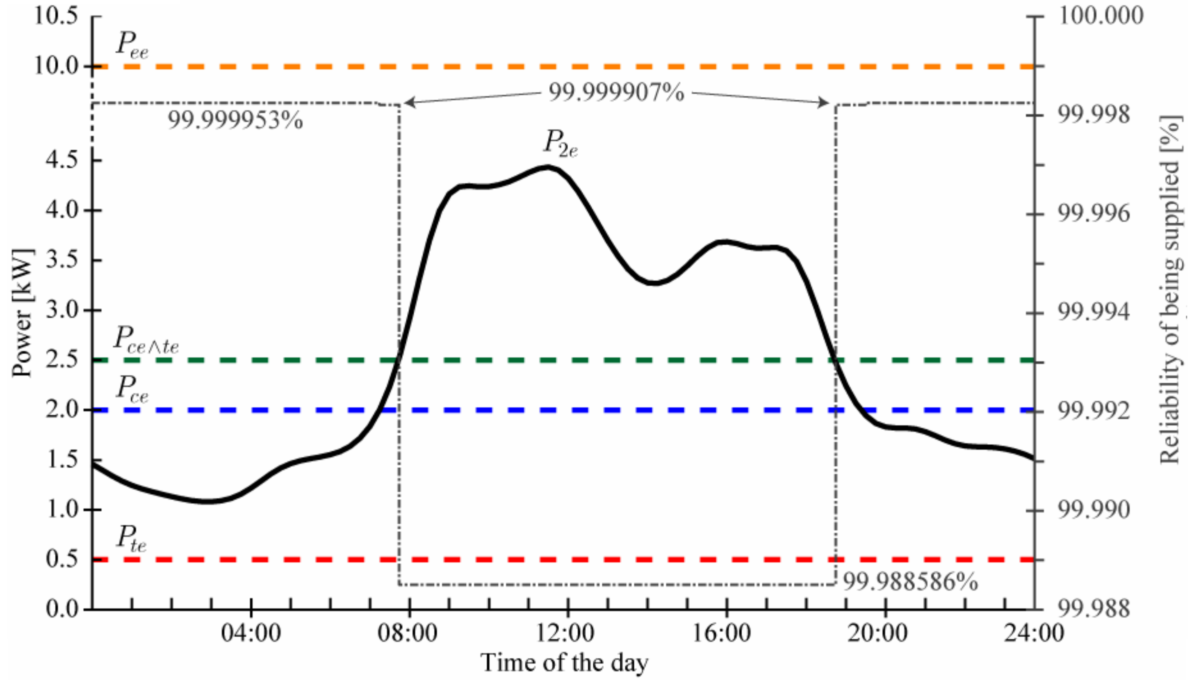


Conclusion: For given electrical losses economical chemical throughput is limited within the range: $\mathring{m}_{min} < \mathring{m} < \mathring{m}_{max}$

Reliability of an Energy Hub



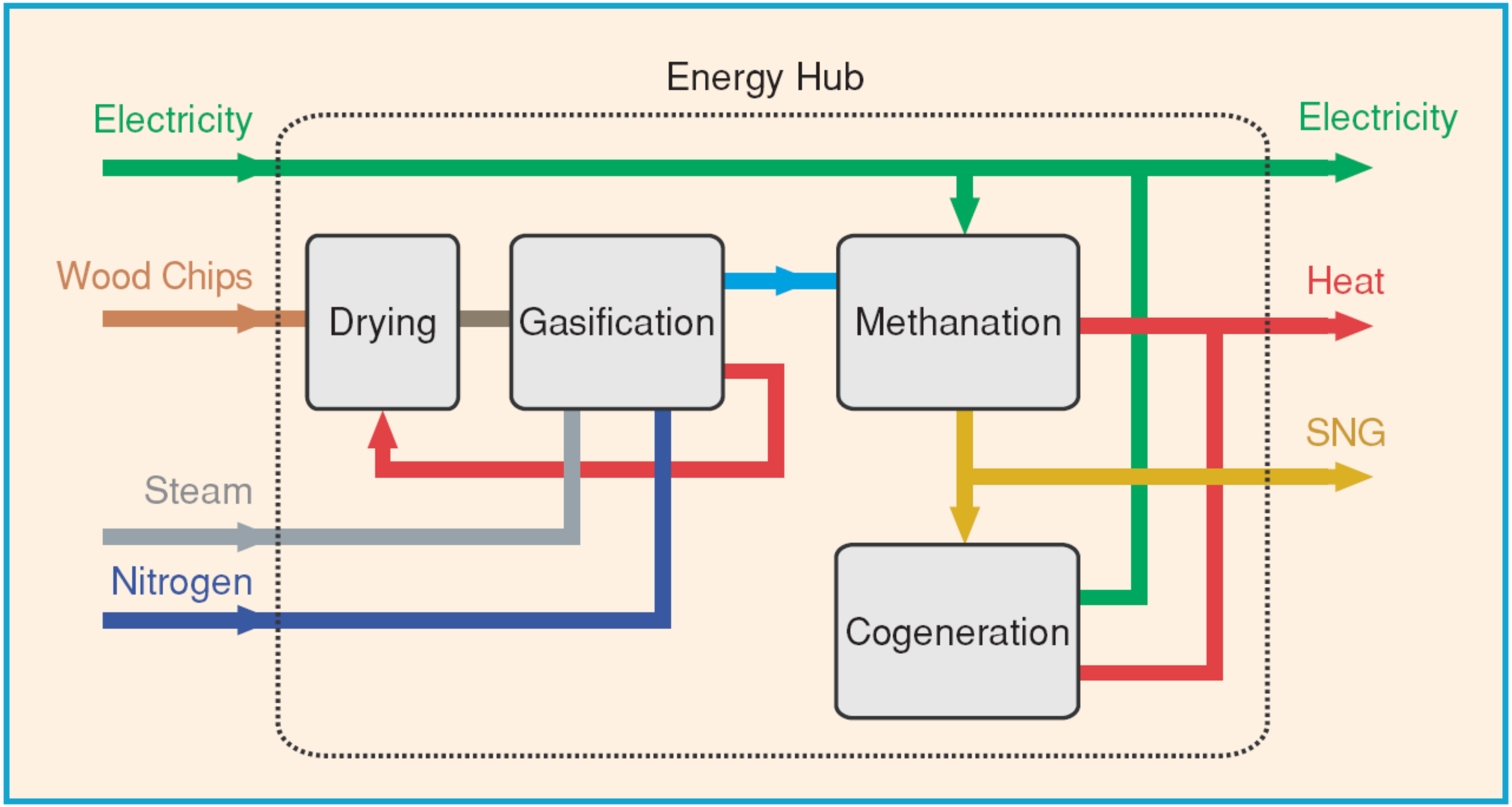
Exptected Energy Not Supplied:
1h/a → 27.6 Min/a



thermal

Connection	Capacity	Failure rate [f/y]	Mean repair time [h]	Repair rate [r/y]
electrical	$P_{ee} = 10\,kW$	$\lambda_{ee} = 0.5$	$MRT_{ee} = 2h$	$\mu_{ee} = 4380$
chemical-electrical	$P_{ce} = 2.0\,kW$	$\lambda_{ce} = 1.5$	$MRT_{ce} = 24h$	$\mu_{ce} = 365$
thermal-electrical	$P_{te} = 0.5\,kW$	$\lambda_{te} = 1.5$	$MRT_{te} = 24h$	$\mu_{te} = 365$

Practical Case: Regionalwerke Baden



Other results

- Detailed reliability modeling and analysis
- Optimal sizing and use of storage devices
- Modeling of stochastic (non-dispatchable) power sources

Future homework

- Expand models from steady state to dynamic, develop control strategies
- Develop investment strategies (bridging systems)
- Identify and evaluate necessary technology
- Apply the hub idea to a Swiss city (Baden, Swiss Power)
- Integrate coupling with mobility
- *Develop Road Maps for the European system*

Conclusions

- Sources, load and network are strongly interactive
- Systems and technology aspects are strongly interactive as well

➔ **research approach has to consider all these interactions**

- The hybrid network is closer to reality than it looks in a first view

More information

http://www.eeh.ee.ethz.ch/psl/research/vofen.html