Systeem Thinking, Systeem Integration 'Multi Source Multi Product' Systems.

Kas Hemmes

KNAW-VCE lezing 7 november 2006, Amsterdam

Sustainable development Brundtland

- *. . development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*
- *. . . sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs.*
- **Energy is only part of the problem.**

System Thinking (Amory Lovins)

Systems Thinking: Optimizing Not Just Parts, But Entire Systems

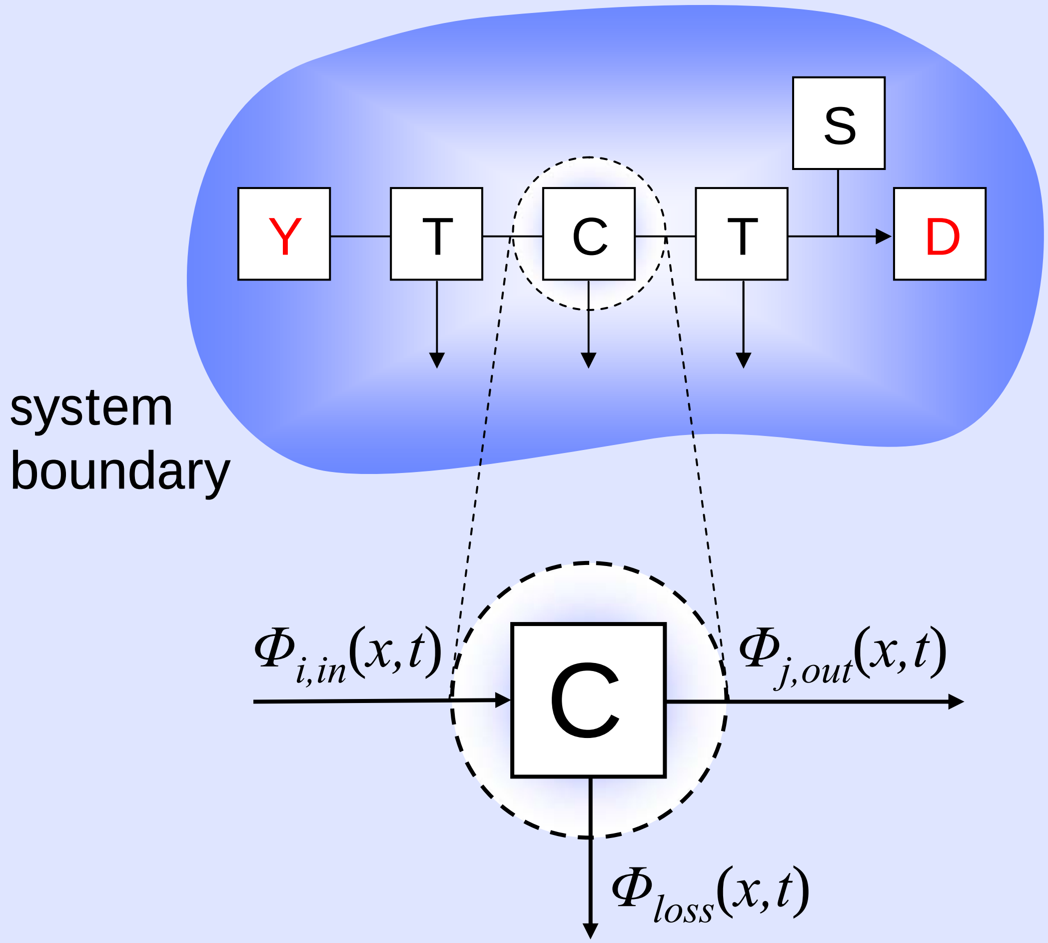
- *Designers and decision-makers too often define problems narrowly, without identifying their causes or connections. This merely shifts or multiplies problems.*
- ***Systems thinking*** *—the opposite of that dis-integrated approach—typically reveals lasting, elegantly frugal solutions with multiple benefits, which enable us to transcend ideological battles and unite all parties around shared goals.*
- *… systems thinking also reveals interconnections between problems, which often permits one solution to be leveraged to create many more.*

- **Its about a different way of thinking!!**
- **That is the goal of this lecture**
- **The (energy) examples are just an illustration**

What is Systems Integration?

1. Integration of components into systems
2. Integration of different energy sources (multi source multi product systems)
3. Integration of new and existing technologies
4. Integration of sectors
5. Integration of functions

1. Integration of components to form an energy system

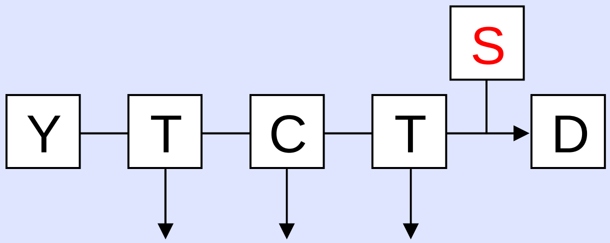


Y = Yield; supply
T = Transport
C = Conversion
S = Storage
D = Demand

Mismatch in place and time

Yield & Demand

$Y(x,t)$ $D(x,t)$

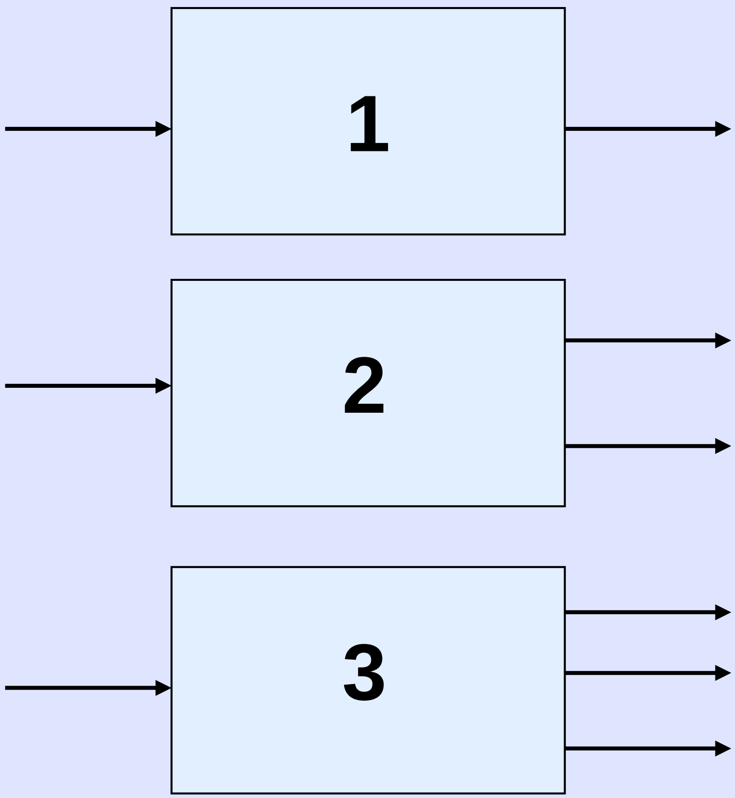


Solution: transport and storage

But…

Systems thinking!

Classification of energy system

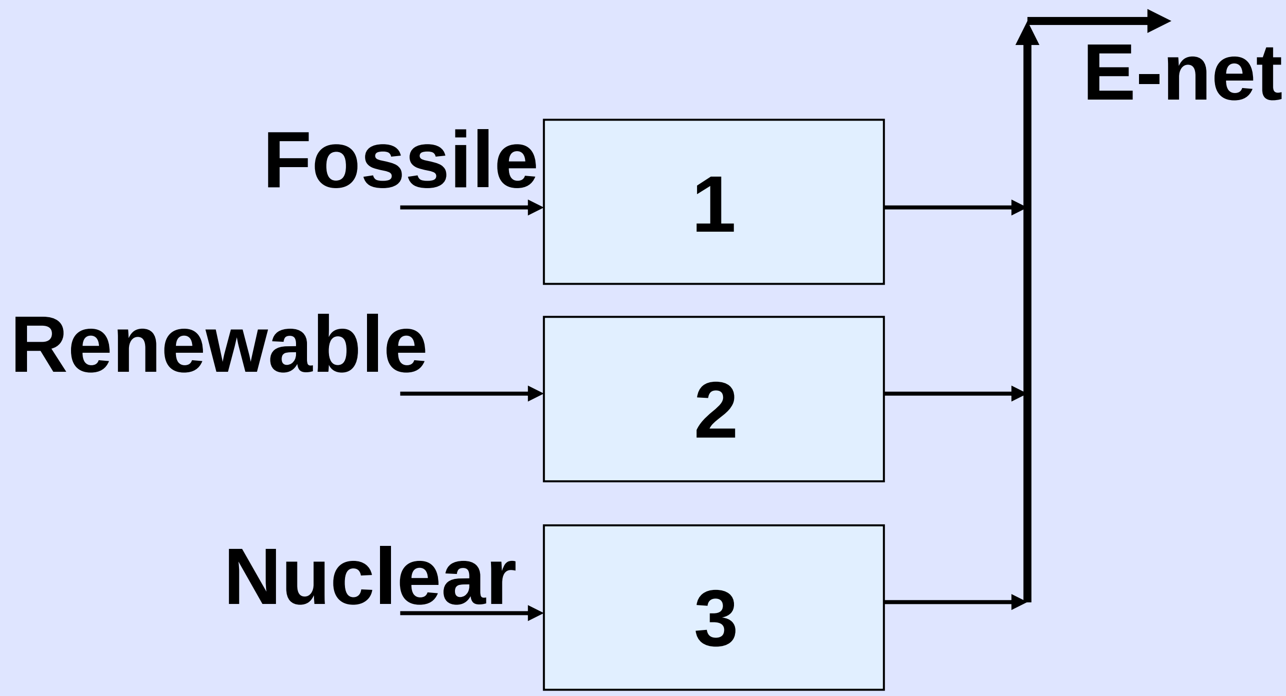


Linear energy system

Co-generation system

Tri-generation system

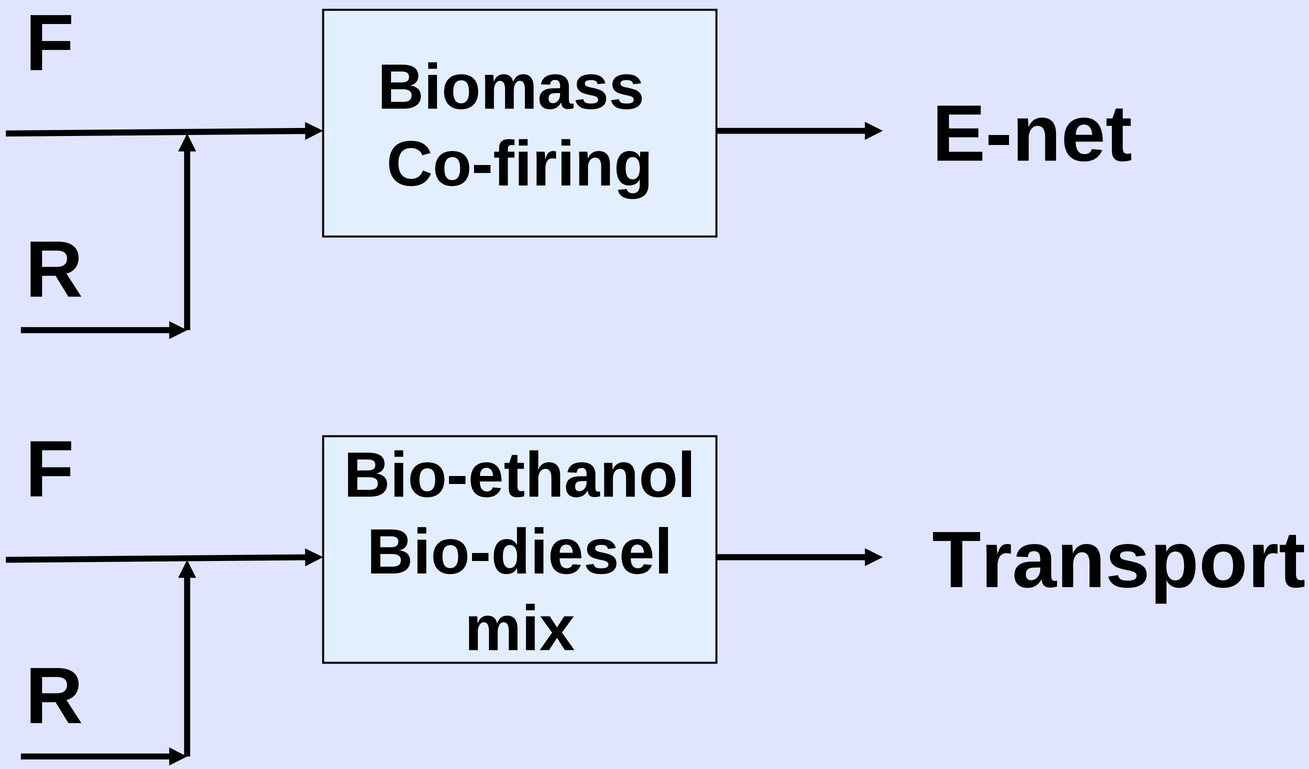
Niet really integrated, but linked linear energy system



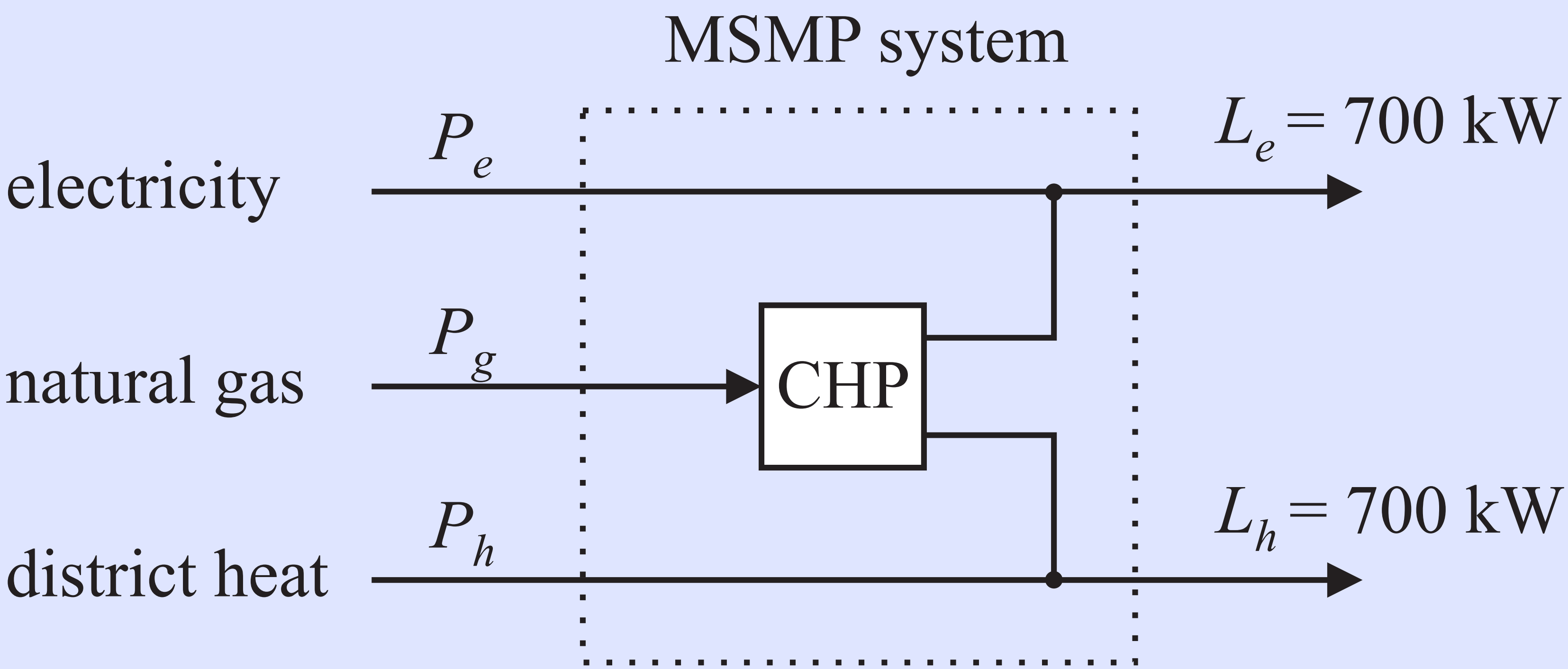
Compare to communicating vats!!

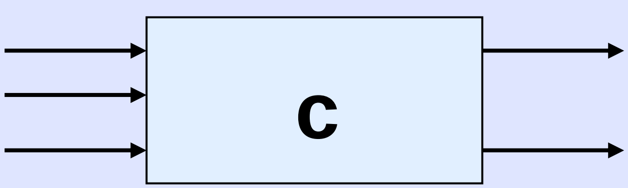
1 Joule wind/solar saves 2,5 Joules of fossil fuels

Consequent integration: co-firing / mix

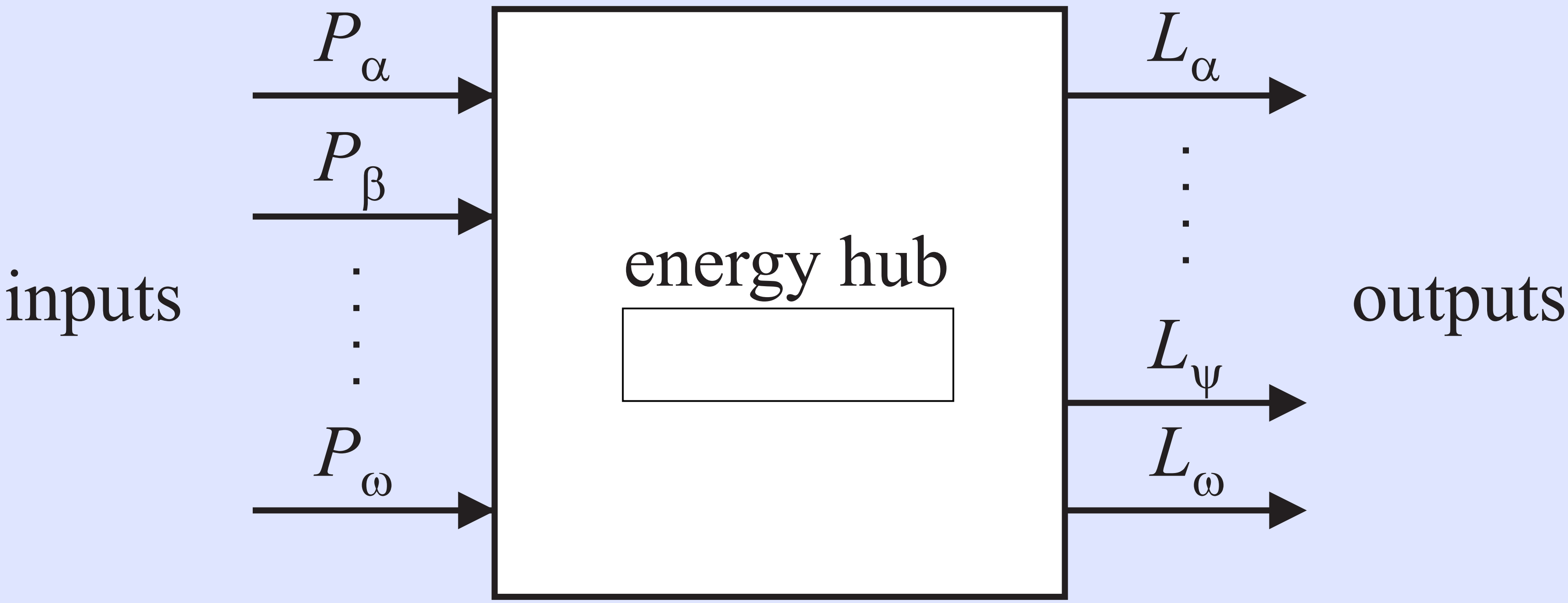


Example : simple CHP MSMP





Multisource-multiproduct systemen (MSMP)

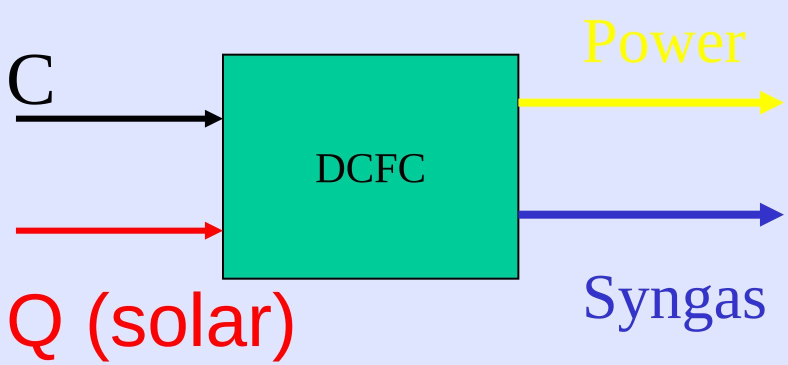


Use degrees of freedom to optimise

- How much of which input is needed to optimally meet demand?
- Welke limiting conditions?
- Which optimalisation criteria??
- **Economical optimalisation ≠ Energy optimalisation**

A Fuel Cell that produces hydrogen and converts heat into power ?

$$C + \frac{1}{2}O_2 = CO$$

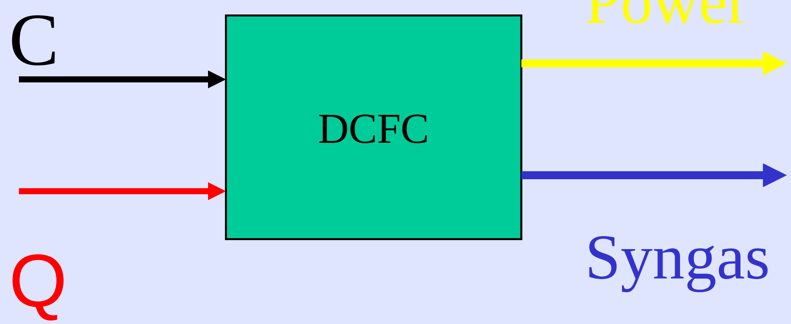


$$CO + H_2O \Longrightarrow H_2 + CO_2$$

Electrochemical gasification in a Direct Carbon Fuel Cell

$$2C + O_2 \Longrightarrow 2CO \qquad \Delta S > 0 \qquad \Delta H < 0$$

$$\eta_{fc} = 1 - \frac{T\Delta S}{\Delta H} > 100\%$$



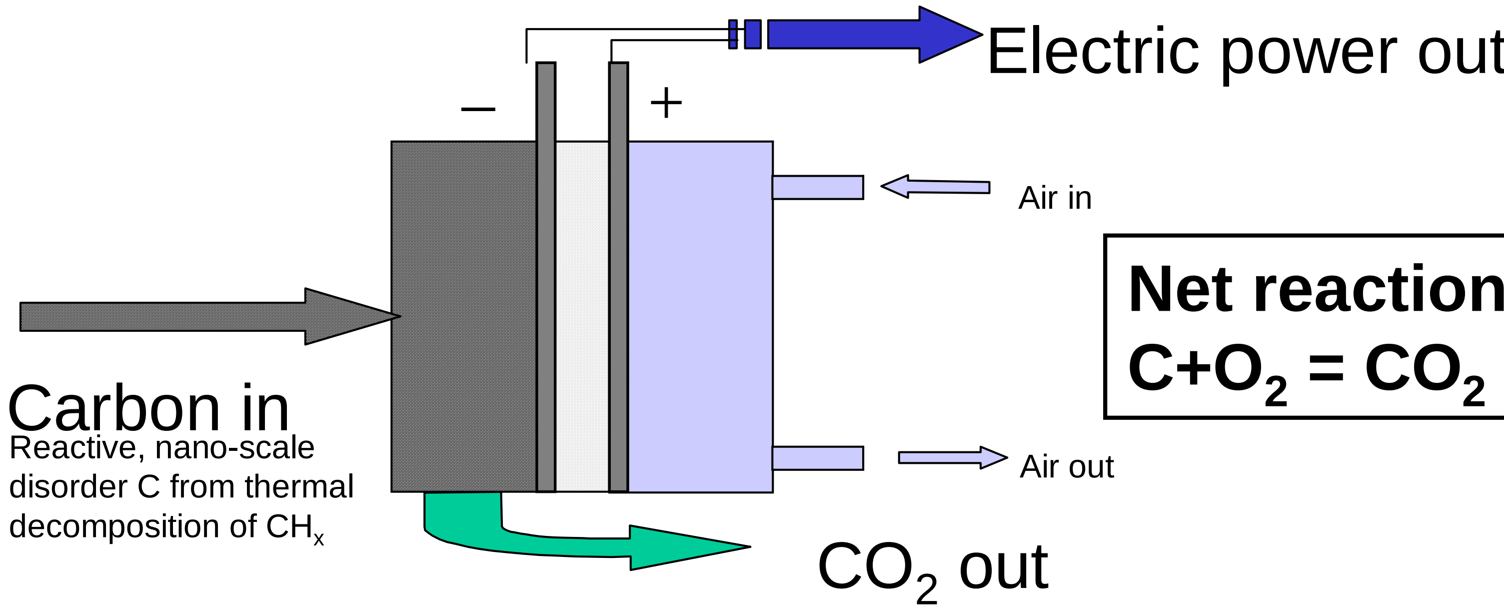
- (Solar) Heat can be converted into power with an efficiency higher than the Carnot efficiency!
- Self regulating process

Exergy

- Coal and biomass are increasingly important!!
- Use the complete exergy of solid fuels
- Plane gasification of coals and biomass is a waste of exergy

Concept

Direct Carbon Conversion (DCC): electric power from electrochemical reaction of C and O_2



Net reaction:
$C+O_2 = CO_2$

- **Total efficiency ~ 80% of ΔH_{std}**
- **Pure CO_2 product for reuse/sequestration**
- **Use highly reactive carbons from CH_x pyrolysis**
- **Inherent simplicity**

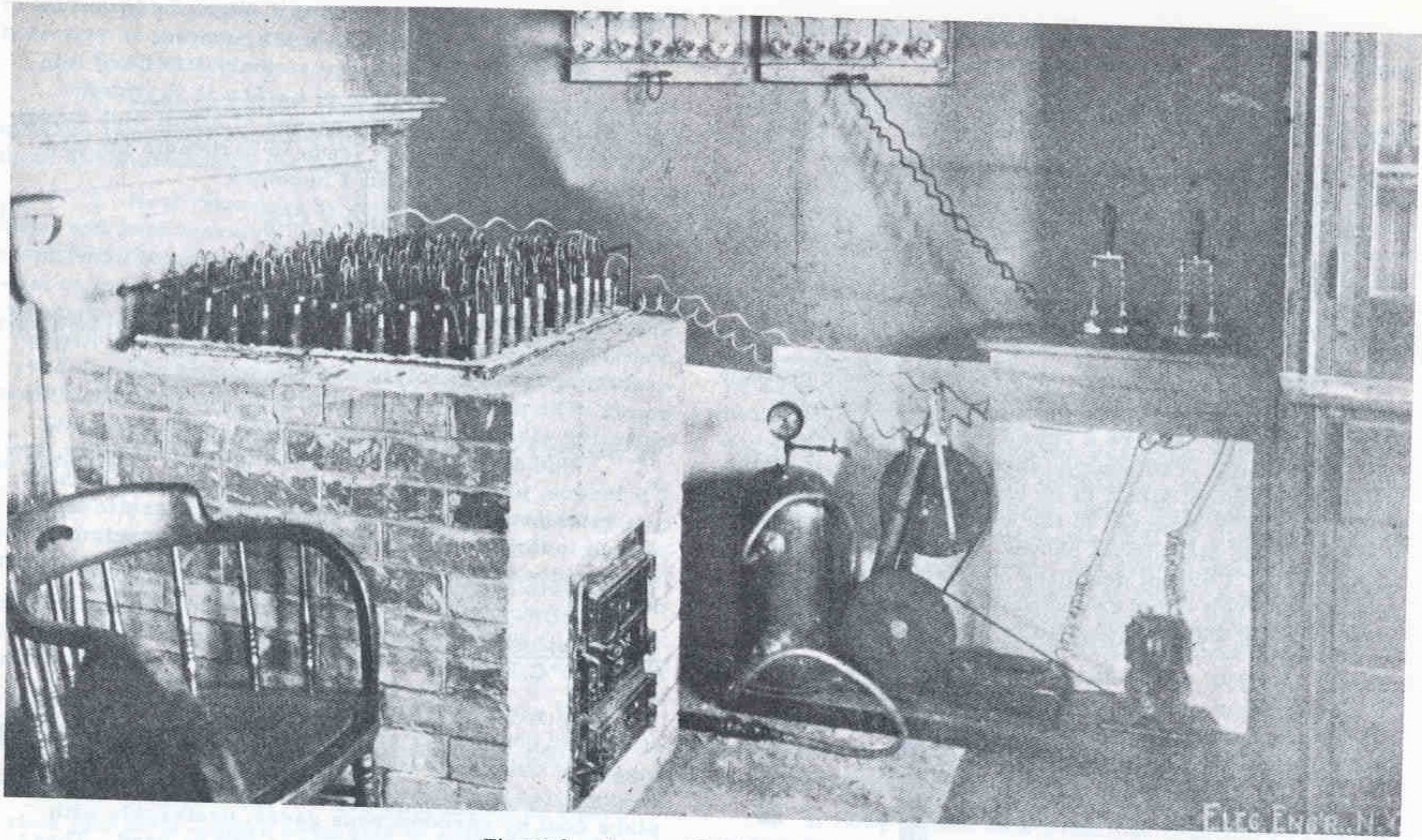


Figure 3. Jacques' 1.5 KW coal battery.

Objectives

Evaluate processes for fossil conversion to electric power at efficiencies > 70 %

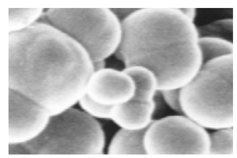
Electrochemical conversion

- Coal, lignite
- Natural gas
- Petroleum
- Petr. coke
- Biomass

H-pyrolysis or pyrolysis

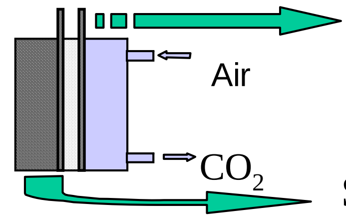
Δ

C & H_2



C

H_2



Electric power

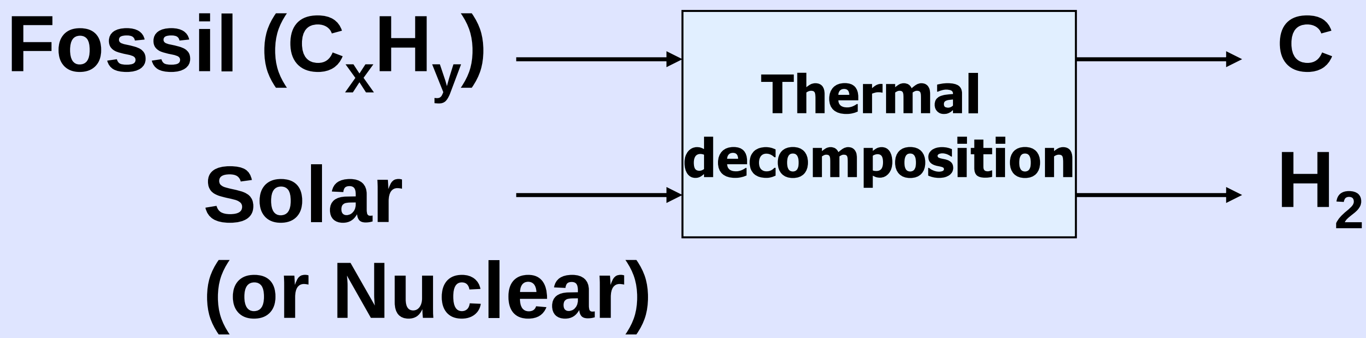
Sequester or reuse

Fuel cells, turbines, refinery, etc.

Target: 70 – 80 % efficiency

- **The pyrolysis of CH_x => C + (x/2)H_2 consumes 3-8% of fuel value; no ash**

Integration of solar & fossil in a MSMP system



Apply in Northern Africa/ Algeria??

Thermodynamic advantages of direct electrochemical carbon conversion

Fuel	η_{fc}	$\eta_{Nernst\ loss}$	η_{irr}	η_{tot}
C	1.0	1.0	0.8	0.8
H_2	0.7	0.8	0.8	0.45
CH_4	0.89	0.8	0.8	0.57

Table 3 Order of magnitude comparison between the electrochemical conversion efficiencies of C, H_2 and CH_4 at 700 ^oC (Cooper, J. F. et al 2000)

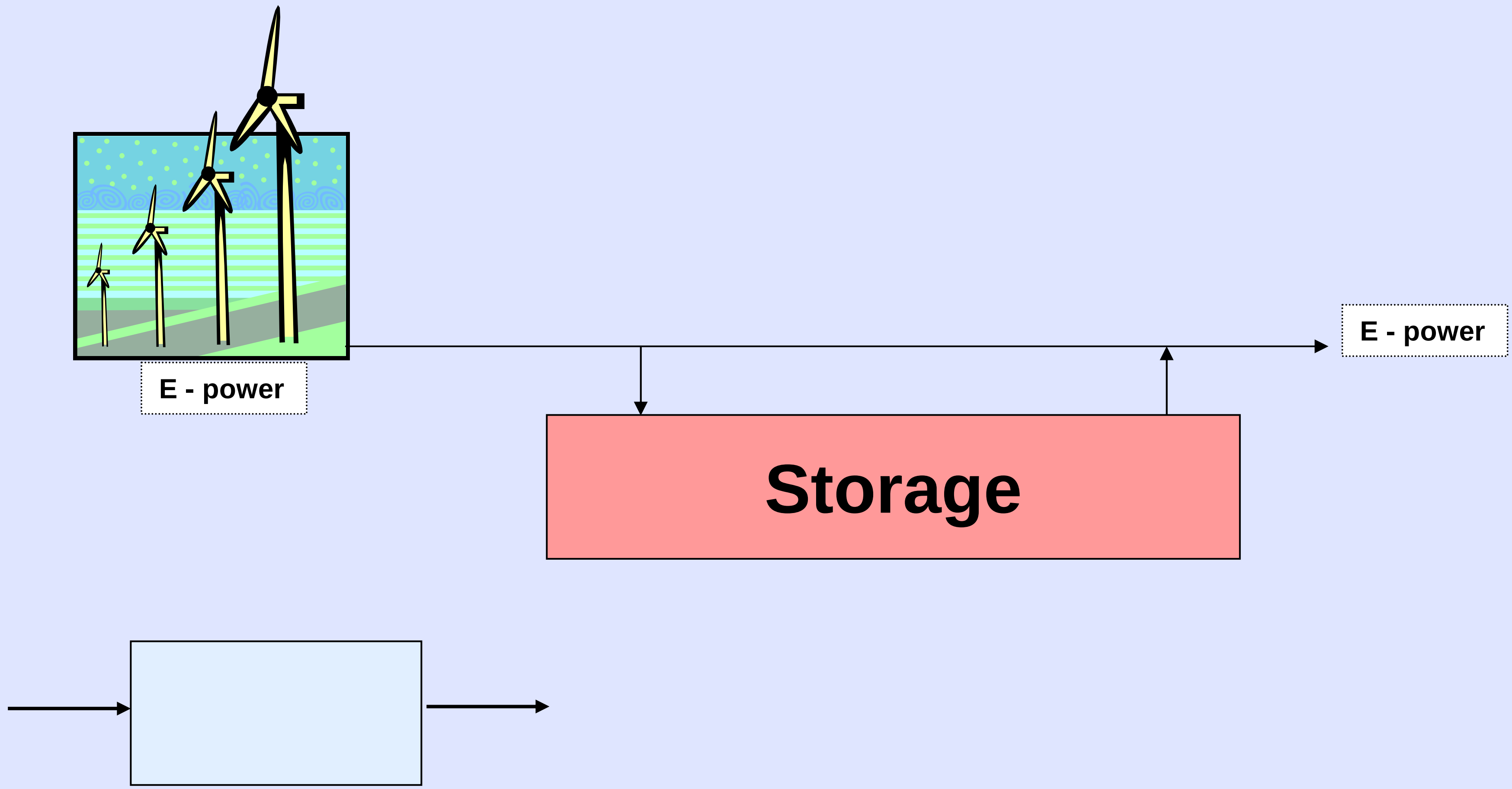
Countries with large potential for Solar and Biomass can become the energy producing countries of the future.

Fuel cell technology

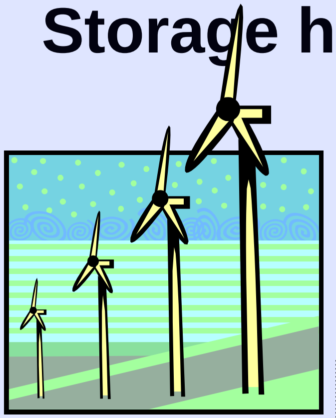
Solar

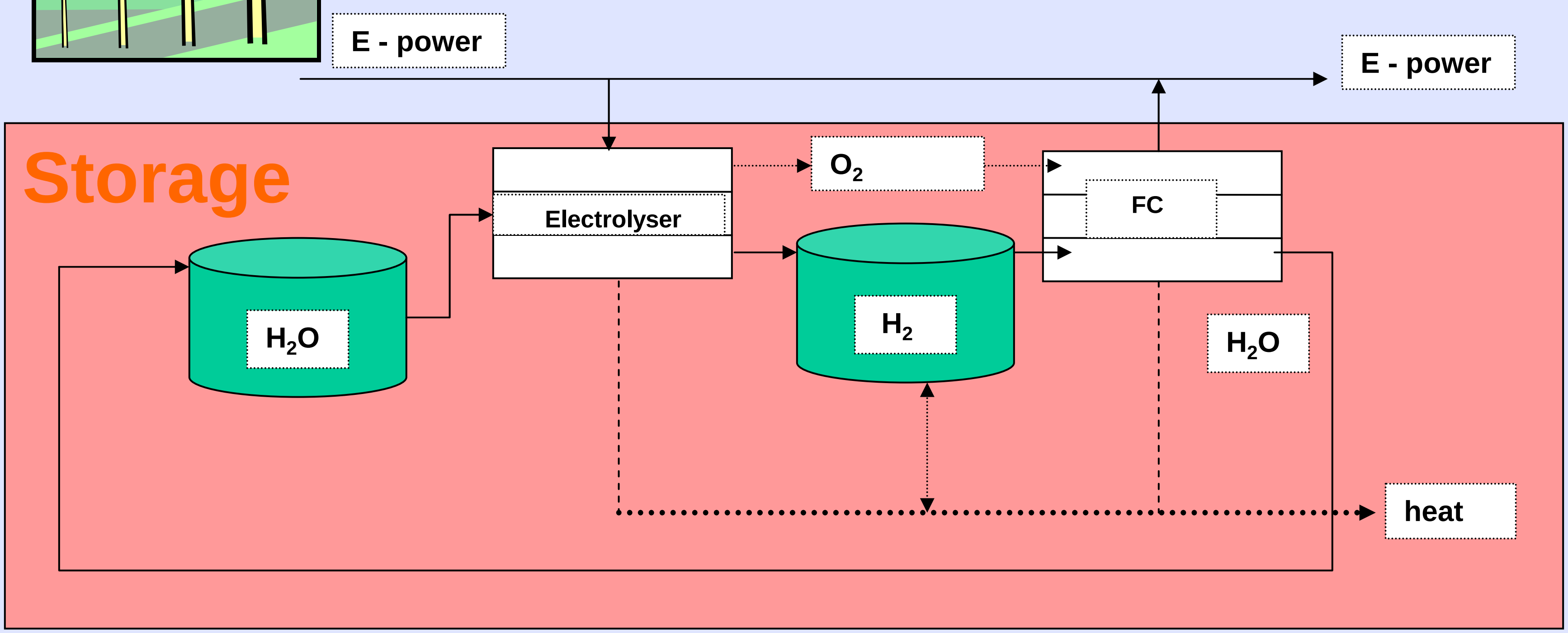
Biomass

Conventional Solution for dealing with fluctuating renewable energy sources essentially is a complex storage device *in a linear energy system*.



Storage has become a problem rather than a solution

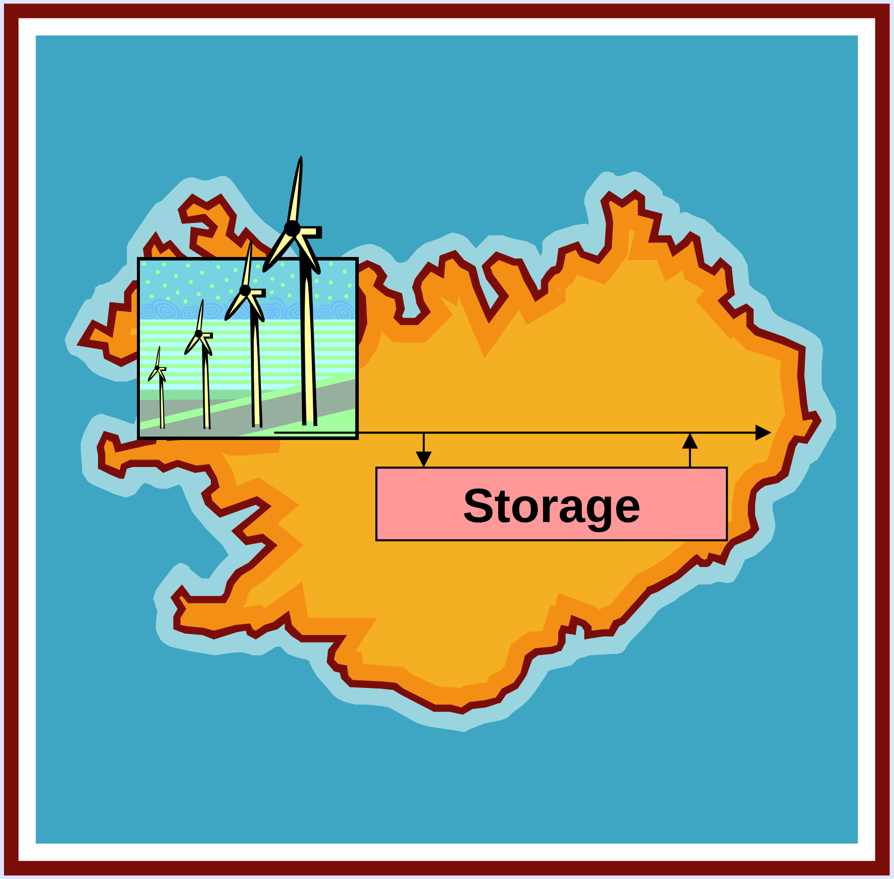




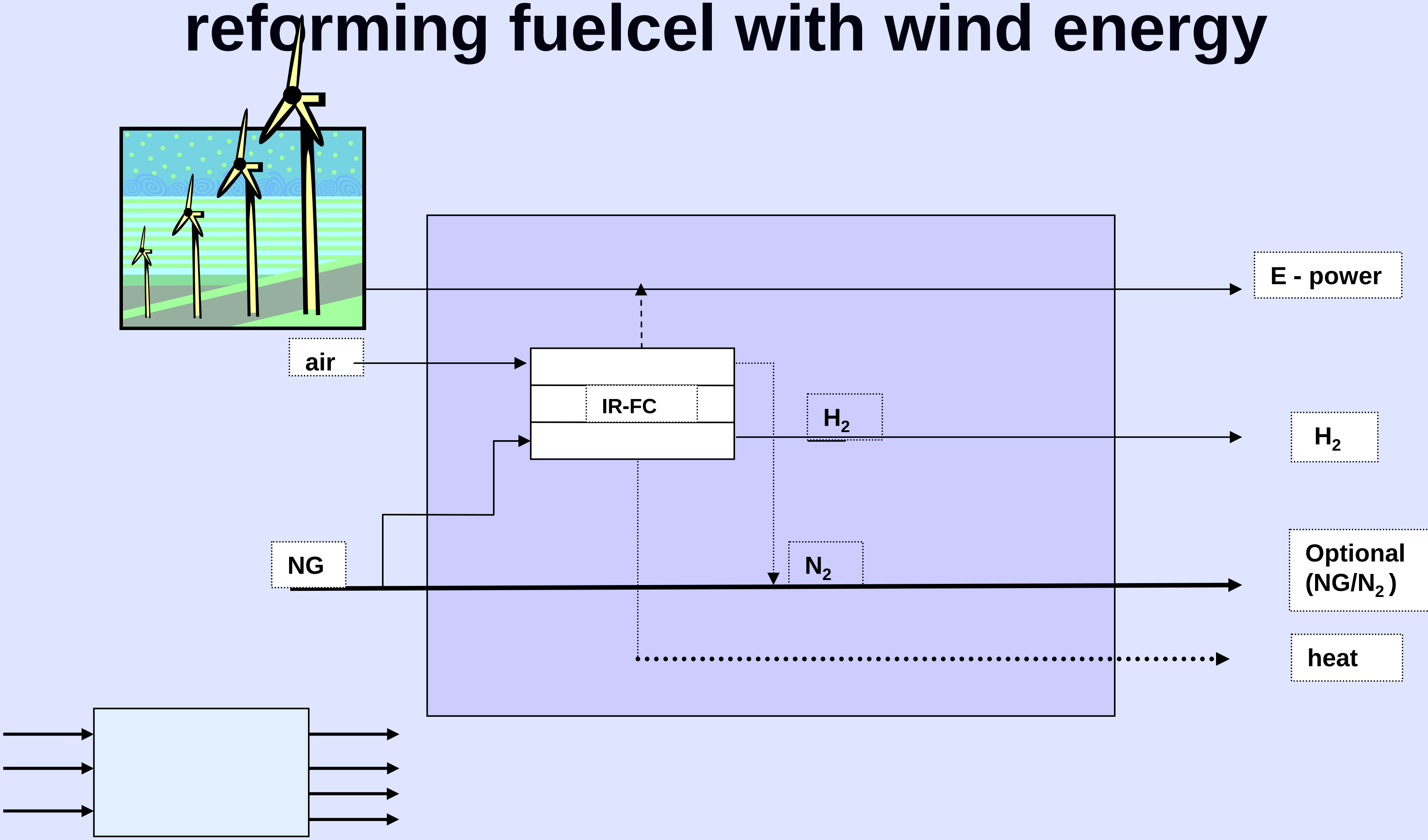
SECTIE ENERGIE EN INDUSTRIE
FACULTEIT TECHNIEK, BESTUUR EN MANAGEMENT

TU Delft

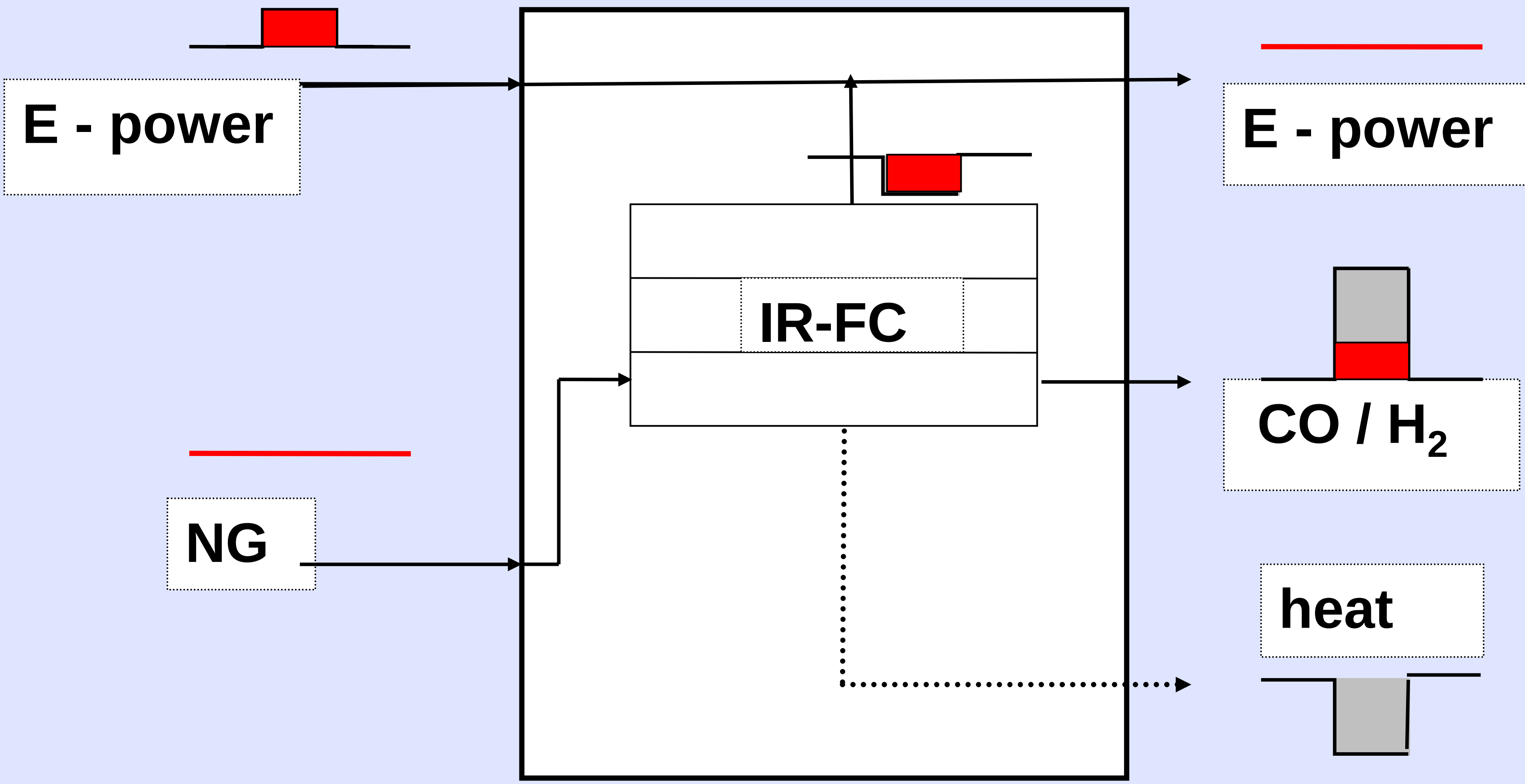
Conventional Solution is ‘Island Thinking’ not ‘System Thinking’



MSMP voorbeeld: integration of an internal reforming fuelcel with wind energy



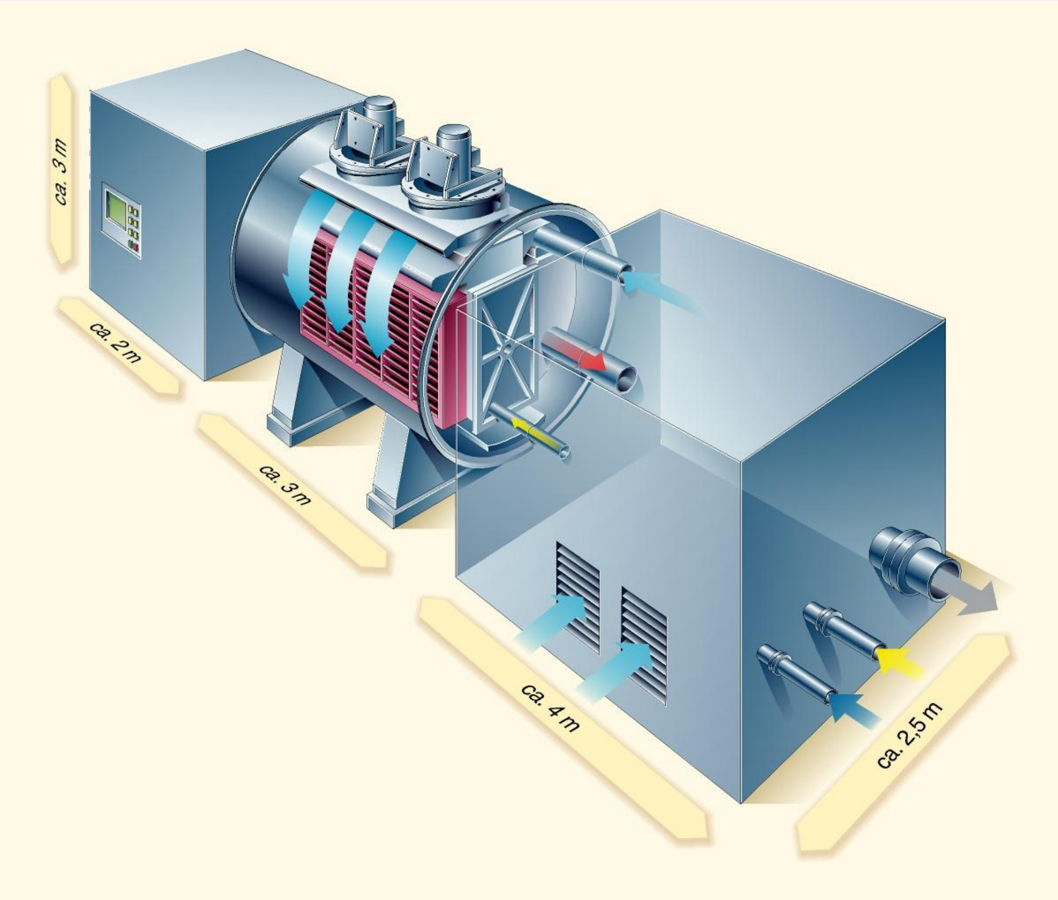
MSMP



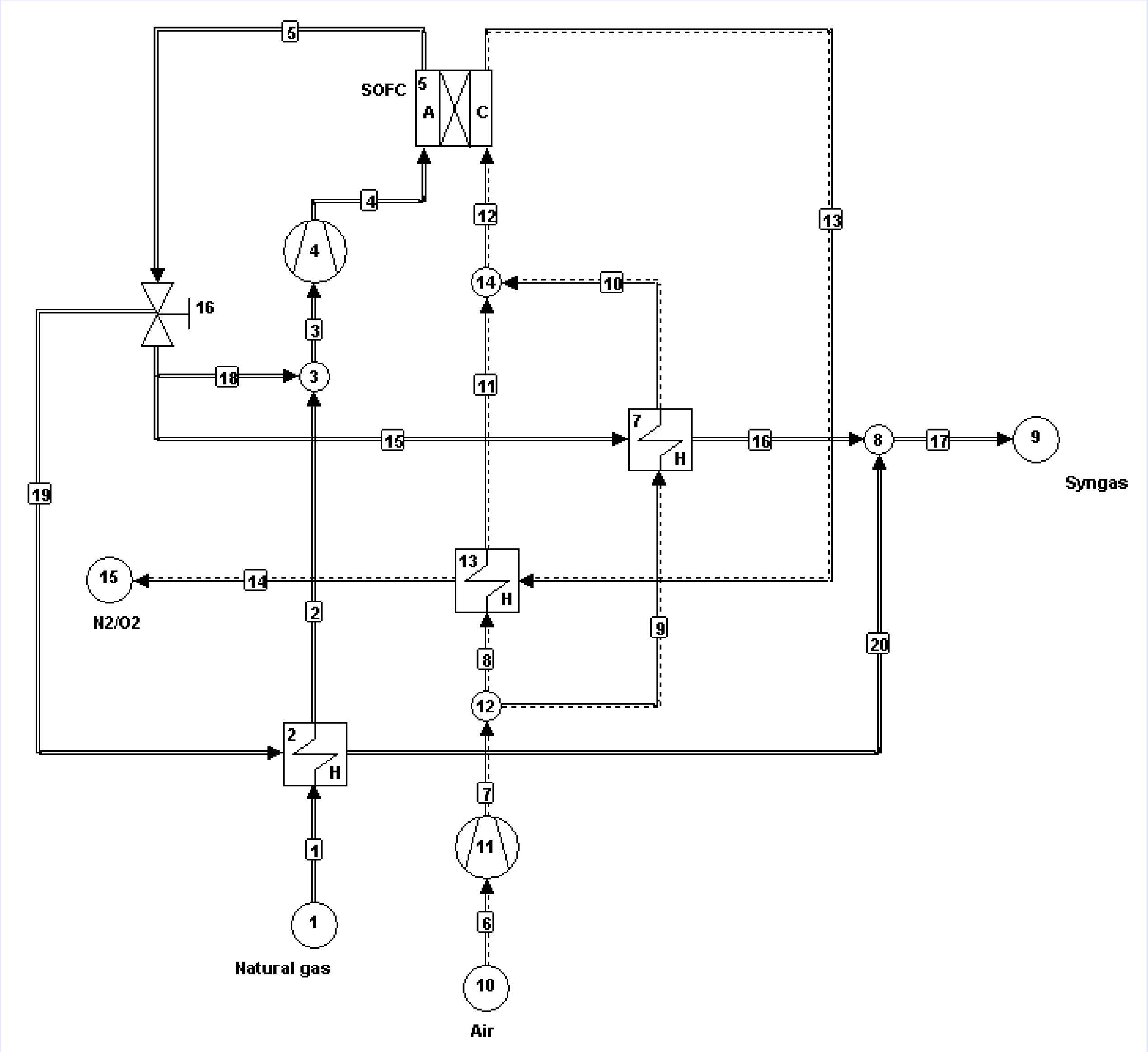
Co-productie

- Co-productie of hydrogen and electricity in an internal reforming fuelcel
- The fuelcel can operate with 95% natural gas (standard) and 60% (hydrogen and carbonmonoxide co-production)

MCFC Hot Module



Internal Reforming - SOFC system flowsheet

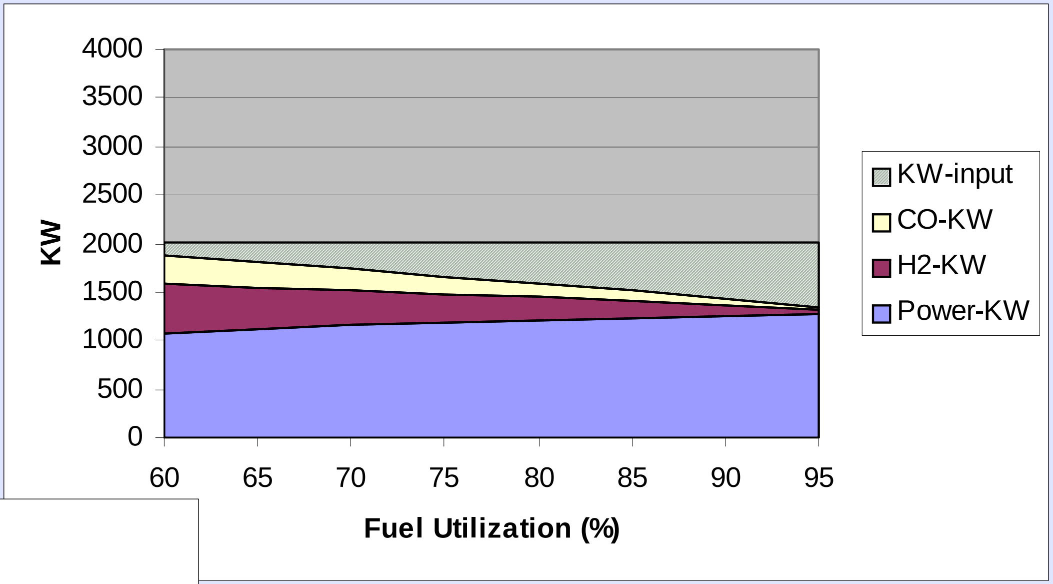


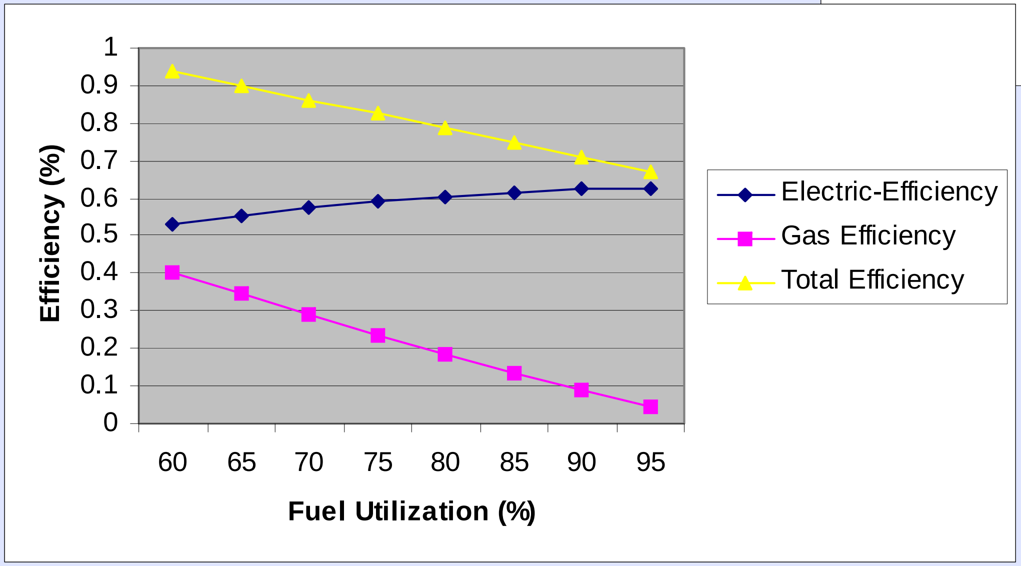
Mode 1 – High efficiency mode

- **Input flow rate of NG is kept constant at 2000 kW.**
- **The fuel utilization is decreased by decreasing the current density.**

3 outputs vs Fuel Utilization

- Electric Power
- H_2 & CO
- (Waste) heat





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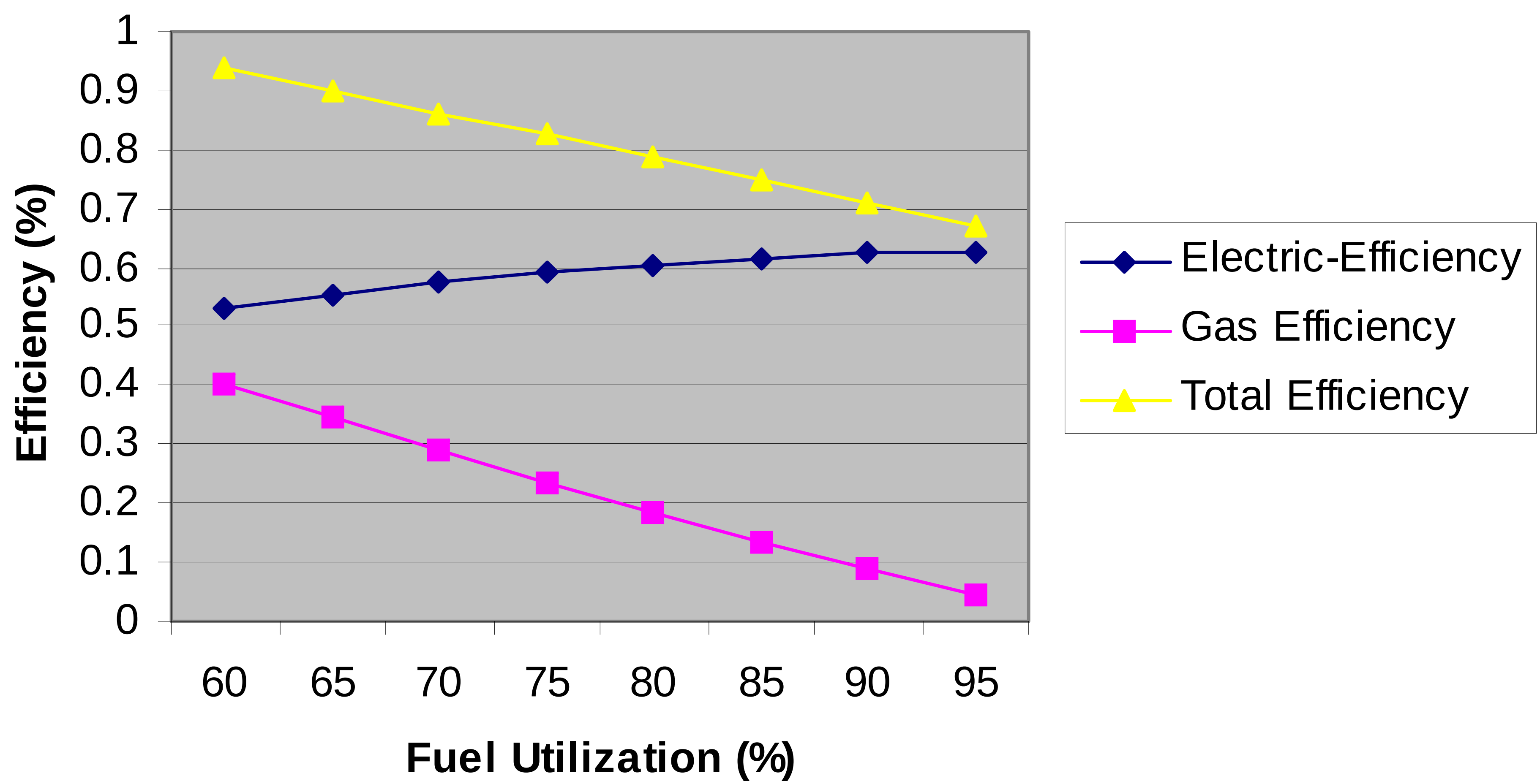


Analysis 'Gasfired Windenergy' (1)

- **Use the specific charactersitics of a component (fuel cel)**

$$V_{cell} \approx OCV - \frac{1}{2}\alpha.u_f - i\ .r$$

OCV = Open Cell Voltage
α *= 100 – 220 mV*
u_f *= fuel utilisation*
i = current density
r = specific resistance

Analyse 'Gasgestookte Windenergie' (2)

- No hydrogen storage
- Use naturally present storage of natural gas
- Offshore gas and wind available(North sea).
- What's the problem and for who?
- Large scale implementation of windenergy or fines on promised kWh targets that aren't met?

3. Integration of new technologies in existing technologies

- Developing new technologies takes time
- Existing technologies are not always very efficient
- Exisiting technologies are not always written off already.
- Needs to be implemted in existing knowledge structure.

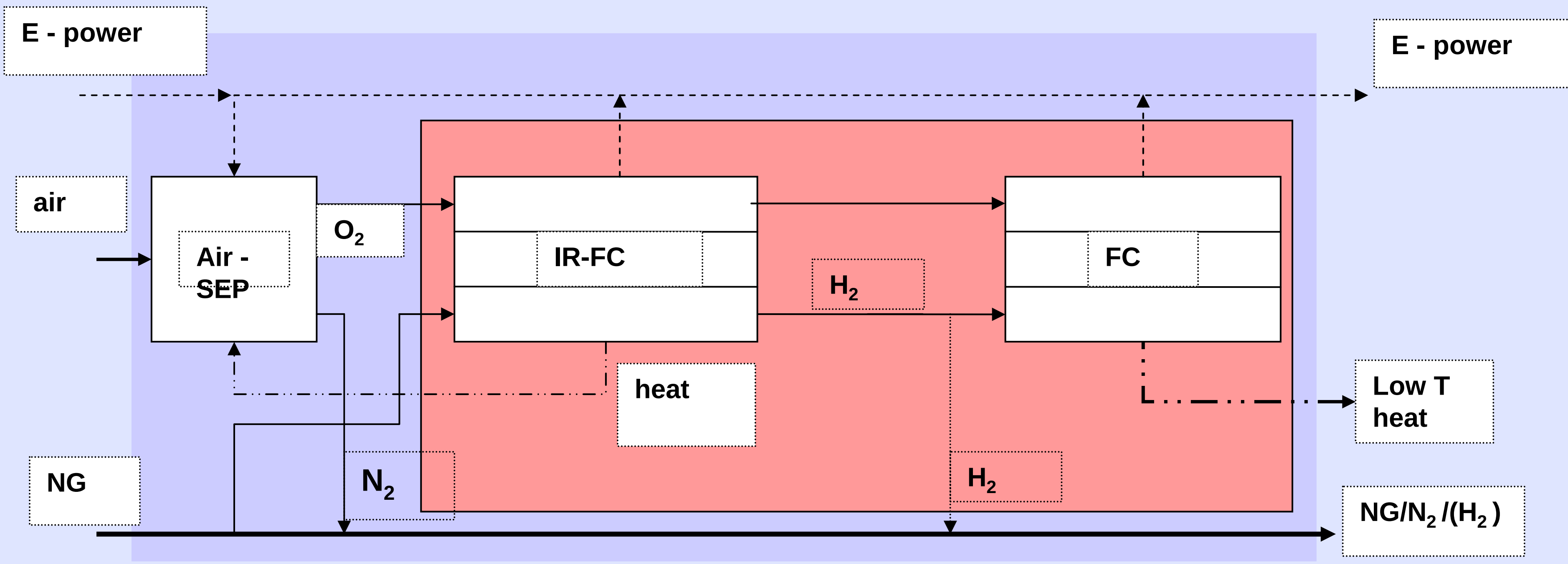
Examples :

3.1 Fuelcels in a natural gas mixing plant

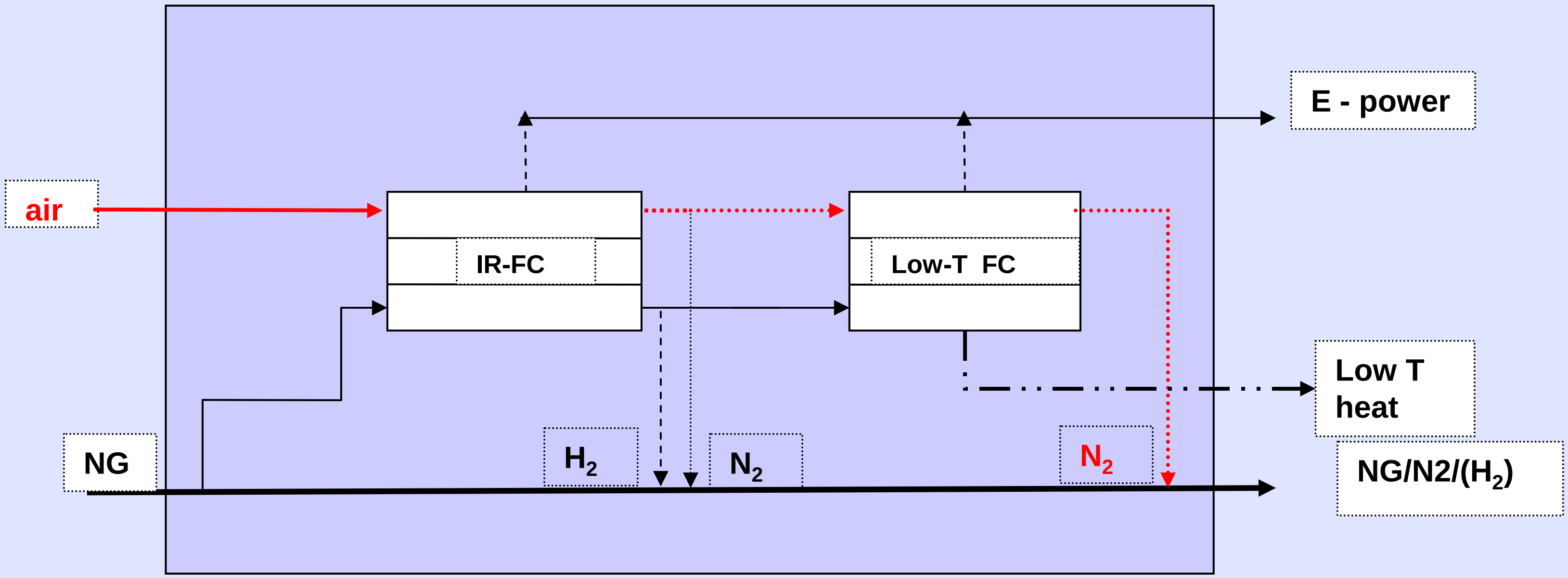
3.2 MCFC or DCFC throught the concentration of CO2 from off-gas of a coal power plant (BP)

3.3. Fuelcel top-cycle in existing plants(N. Lior)

Example 3.1: Fuelcels in a natural gas mixing plant

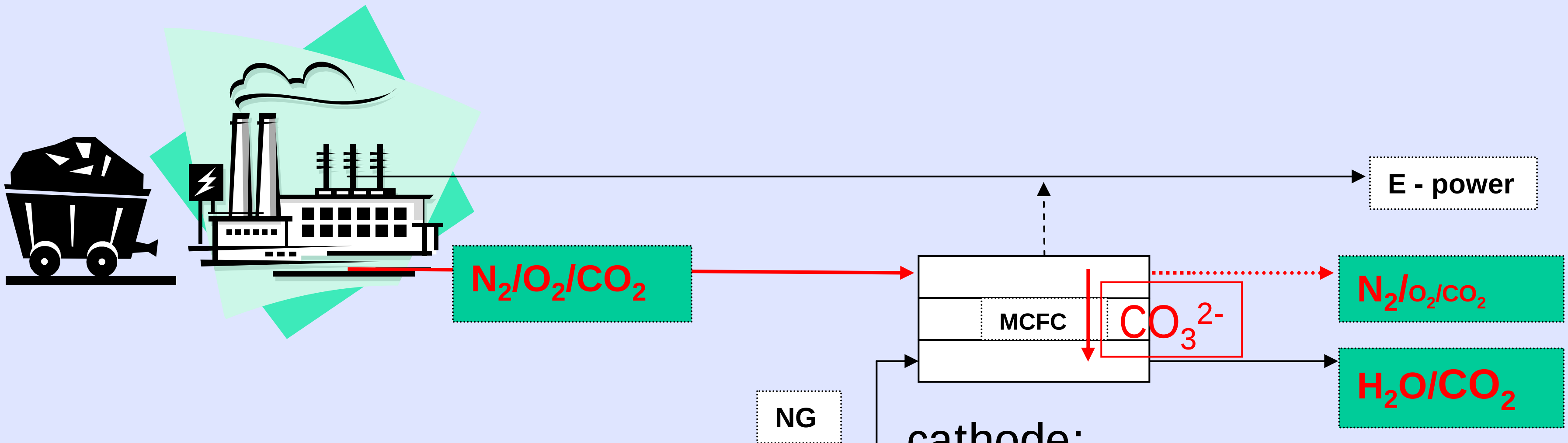


Replacing airdivider in a mixing station by a fuelcel



The system produces electricity instead of using it!! (Order of magnitude of tens of MW)

voorbeeld 3.2: MCFC or DCFC throught the concentration of CO2 from off-gas of a coal power plant (BP)



cathode:

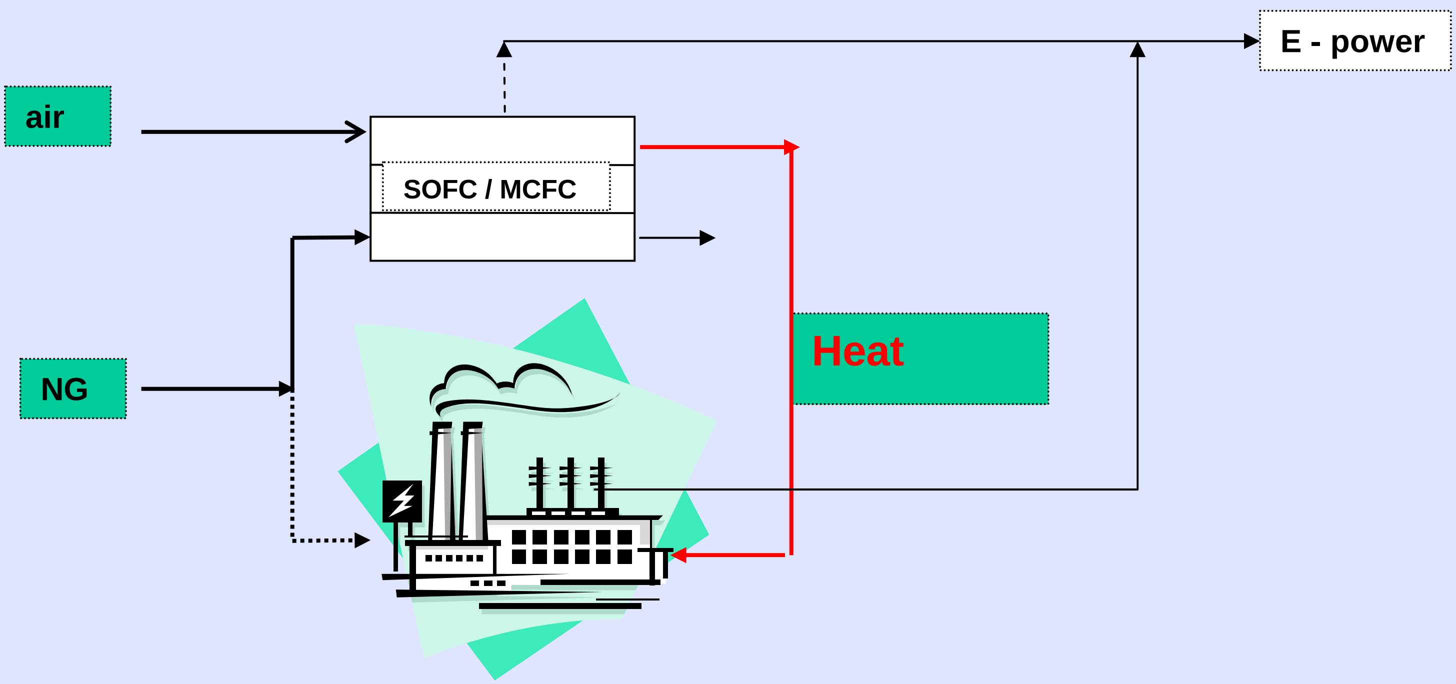
$1/2\ O_2 + CO_2 + 2e^- = CO_3^{2-}$

anode:

$H_2 + CO_3^{2-} = H_2O + CO_2 + 2e^-$

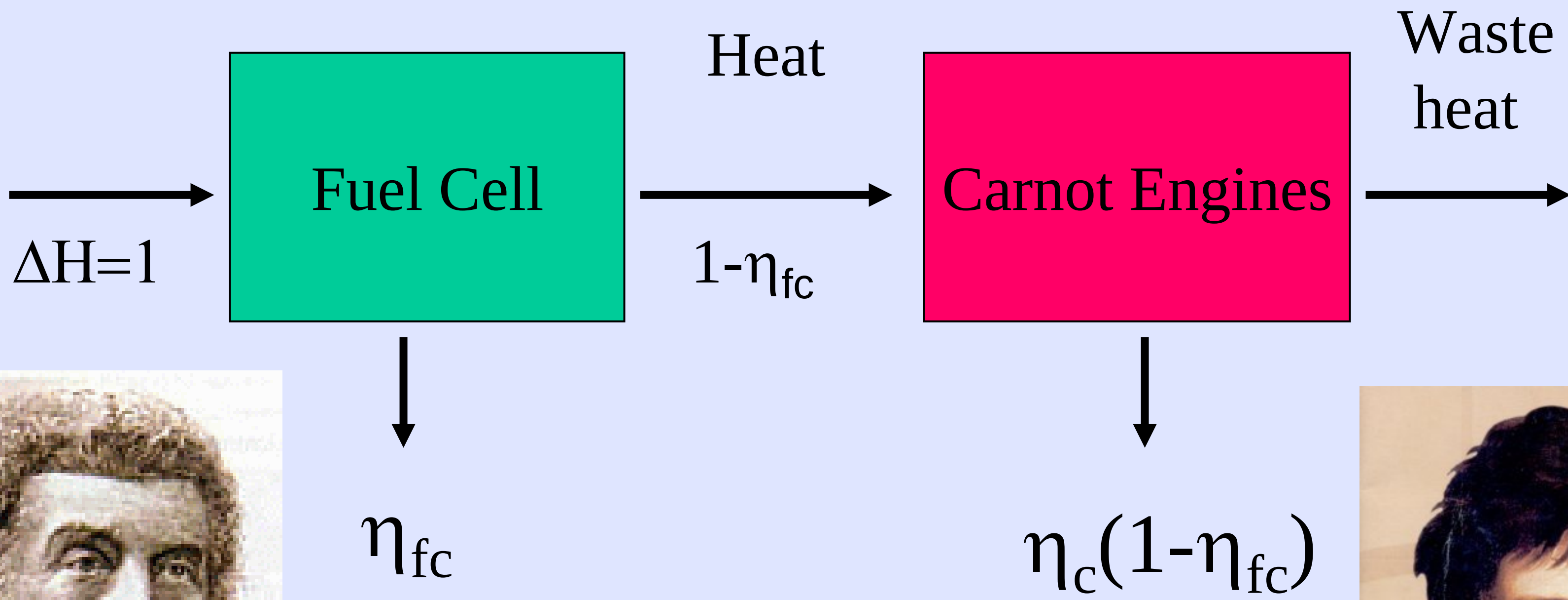
The CO2 system produces electricity instead of using it (about 10 - 100 MW)

voorbeeld 3.3:
Fuelcel top-cycle in existing plants(N. Lior)



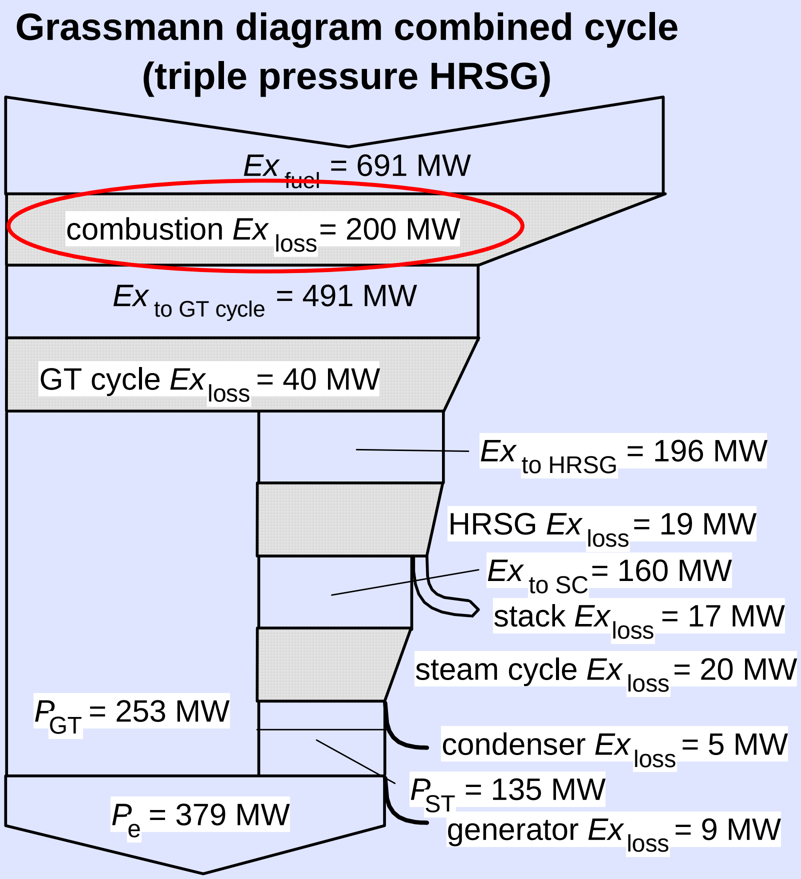
NG

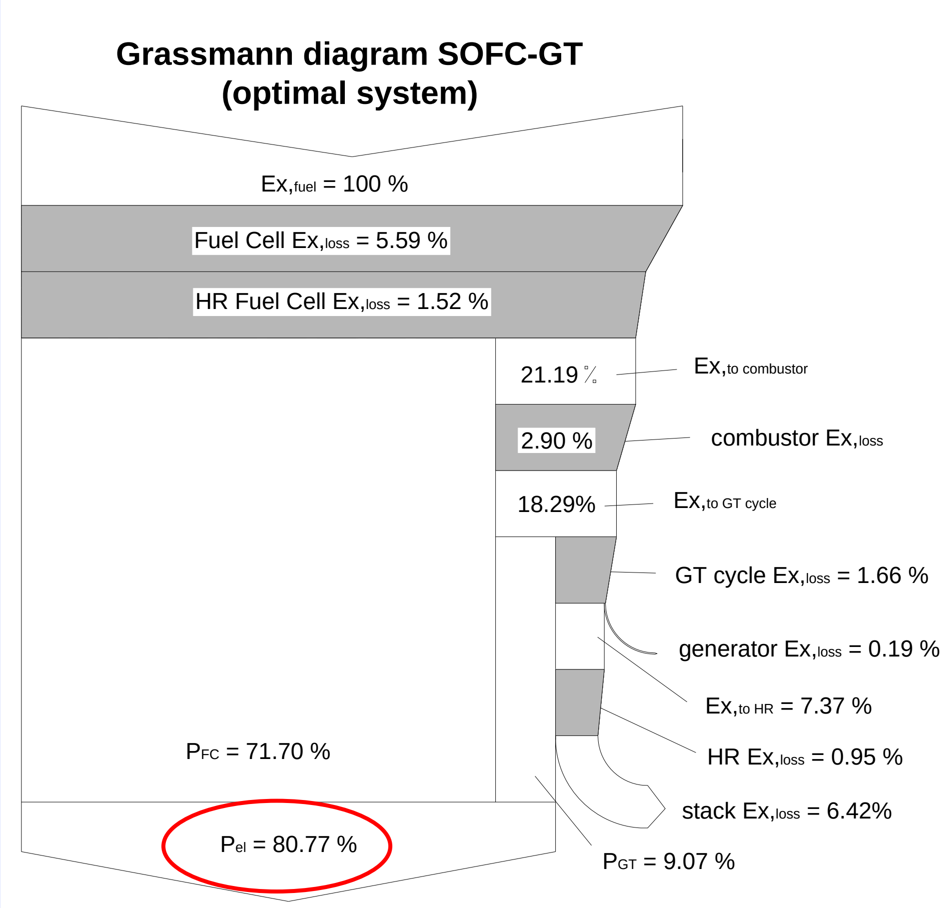
If you can't beat them; join them!



$$\eta_s = 1 - T_0 \frac{\Delta S}{\Delta H} = 1 - \frac{T_0}{T_{\Delta G=0}} \approx 0.94$$

Example 3.3: Exergy losses combined cycle vs Brandstofcel top-cycle (N. Woudstra)





4. Integration of sectors

- Expand system boundaries
- Solve multiple problems in one go

Voorbeelden:

4.1 combustion of waste

4.2 combi-boiler (warm tap water + heating rooms)

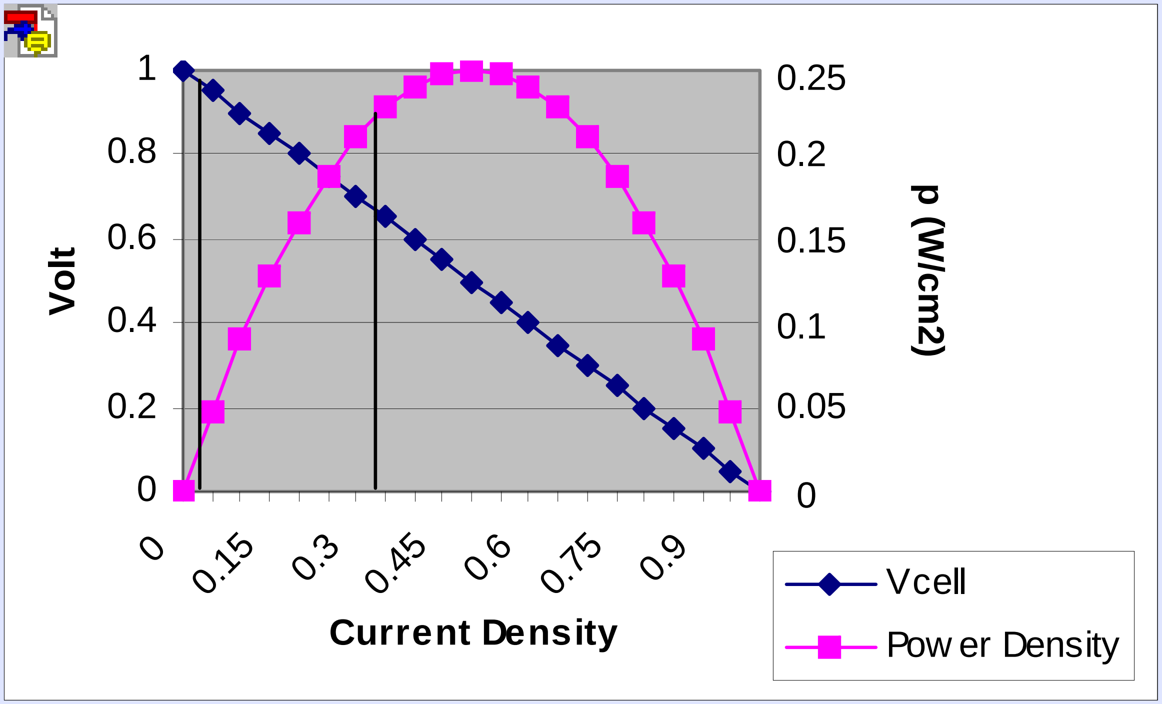
4.3. **V2G (vehicle to grid)**

Voorbeeld 4.3: V2G (vehicle to grid)

- NL: 6.000.000 cars à 50 kW = 300 GW.
- This is more than 10 x the available power
- Only 10% of the cars are needed
- or ... ??

..or... al cars at 10%of the maximum power

- A fuel cell at 10% of the maximum power is very efficient



Nedstack

NedStack PEM FC price development

Rapid price reduction of PEM fuel cell stacks

Annual reduction with more than 50% !!!!

Year	everage sales price
– 2000	€ 45.000 /kW
– 2002	€ 10.000 /kW
– 2004	€ 2.000 /kW
– 2005	€ 1.000 /kW
– 2006	€ 500 /kW
– 2007	€ 250 /kW
– 2008	€ 125 /kW
– 2010	€ 45 /kW

1/1000 !!!!

Nedstack fuel cell technology BV

analysis V2G (vehicle to grid)

Two steps to think about:

1. The current system is inefficient (cars are just parked al day)
2. Transport and energy sectors are combined

And...

- Overcapcity is used to approach the thermodynamic limit
- Batteries provide< 6. 10^6 kWh=6 GWh MW (1 hour of al power in the Netherlands)

5. Integratie van functies

- industrial designers apply this all the time

Examples:

5.1 solar panels instead of tiles on roofs

5.2 wind energy in the built environment

There are many opportunities in this area

Conclusion

Sustainable development demands

- A broad scope,
- Another way of thinking
- Systems integration in different ways and at different levels
- Creativity, lateral thining, ‘2 photon processes’.
- And, to sum it up…

" A look at KNAW-VCE possibilities"

1. Can you link to Rein Willems' energytransmition paths?
2. Is it possible to say something about consequences of multisource-multiproduct for out committee to selectideas?
3. Is there a direct link between sustainability and integration thinking?
4. Can we solve problems if we do not use sub-optimal parts of systems or technologies?
5. Do sub optimal solutions not even ' buy time', or do they?

PS: I'm curious to see your presentation!!!

Can you link to Rein Willems' energytransmition paths?

- *There is a growing demand for energy innovations.* ***(OK)***
- *Its split up in 6 themes* ***(too little attention for integration)***

1. *Sustainable resources*
2. *Sustainable mobility*
3. *System efficiency; (linear systems thinking)*
4. *New gas, clean fossil fuels*
5. *Sustainable electricity*
6. *Built environment*

Is it possible to say something about consequences of multisource-multiproduct for our committee to select ideas?

1. The number options (e.g. MSMP) is large, but unknown. The committee should not only select, but also provide guidelines.

Is there a direct link between sustainability and integration thinking?

There are similarities:

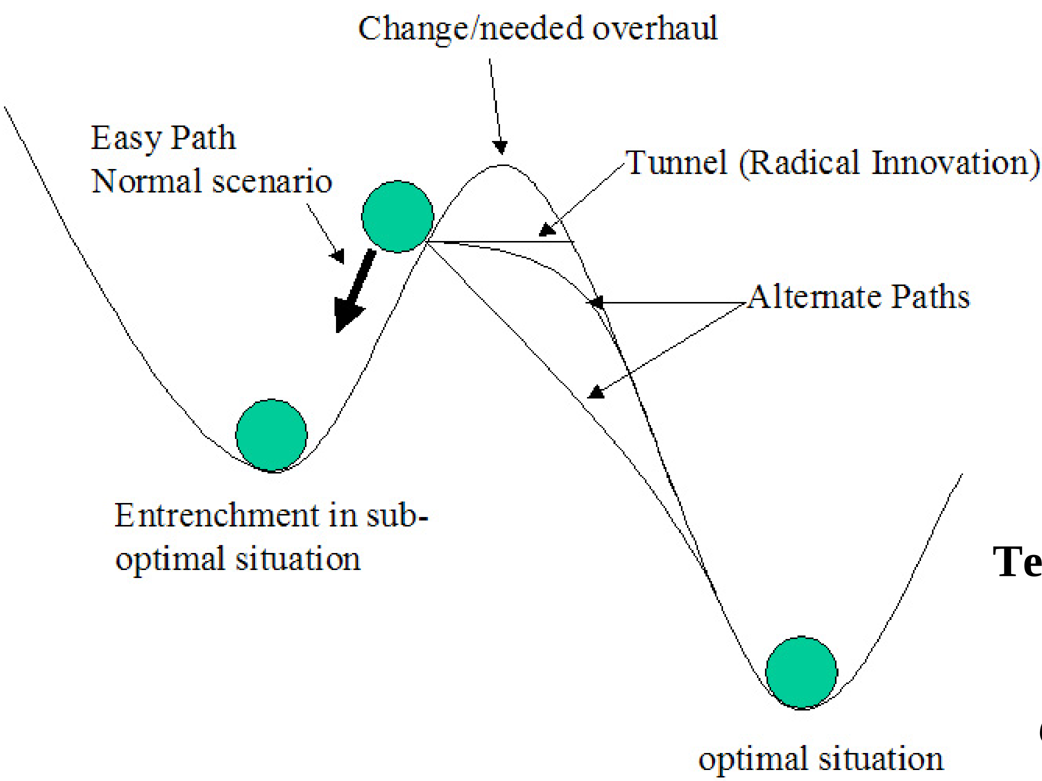
1. Broad system boundaries
2. Solving multiple problems at the same time
3. Goals are ambitious, abstract, far in the future, but clear. (don’t define secondary goals too soon)

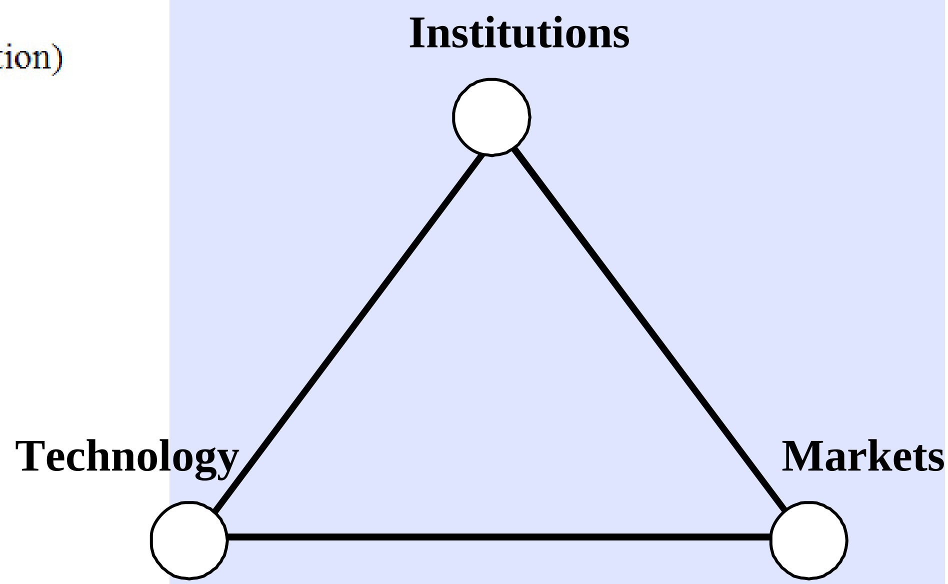
Can we solve problems if we do not use sub-optimal parts of systems or technologies?

Yes, although improvements of subsystems will always be carried out

Do sub optimal solutions not even ` buy time', or do they?

Danger for lock-in: coal and biomassgasification!!





Operational Elements of an Energy System