DE LA RECHERCHE À L'INDUSTRIE

PERFORMANCES AND ECONOMIC COMPETITIVENESS COMPARISON OF ADVANCED HYDROGEN PRODUCTION PROCESSES COUPLED TO A NUCLEAR REACTOR

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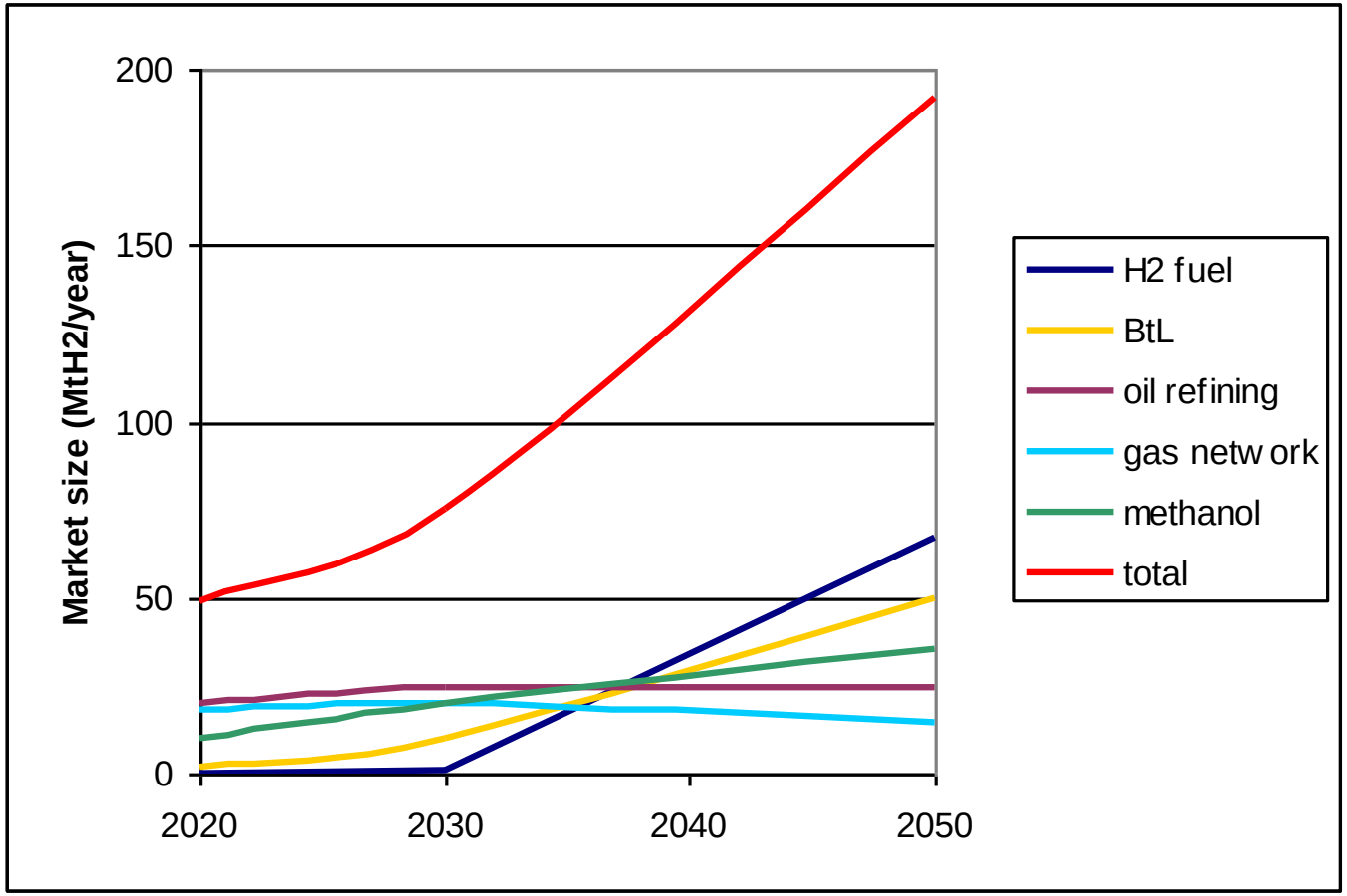
WORKSHOP ON ECONOMICS OF NUCLEAR COGENERATION – 4-5 APRIL 2013

INTRODUCTION (1/2)

- A context of increasing needs for hydrogen

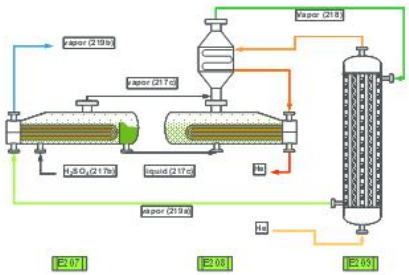


C. Mansilla, S. Avril, J. Imbach, A. Le Duigou. 2012. CO2-free Hydrogen as a substitute to fossil fuels: what are the targets? Prospective assessment of the hydrogen market attractiveness. International Journal of Hydrogen Energy 37(12) 9451-9458. Doi: 10.1016/j.ijhydene.2012.03.149

INTRODUCTION (2/2)

- Efficiency is commonly used to compare processes
- However, advanced processes often imply high investments
  ⇨ the energy consumption may not be the first cost item
- Even if the efficiency of a given process can give some insights about its performances
  ⇨ ultimately, decisions will be made on production cost grounds
- 3 processes are examined, with a view to identify the main cost drivers:
  - S/I cycle
  - HyS cycle
  - HTSE

METHODOLOGY

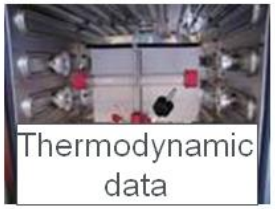


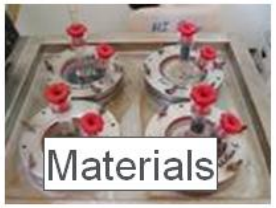
Technico-economic assumptions

Components

Plant design

Flowsheet





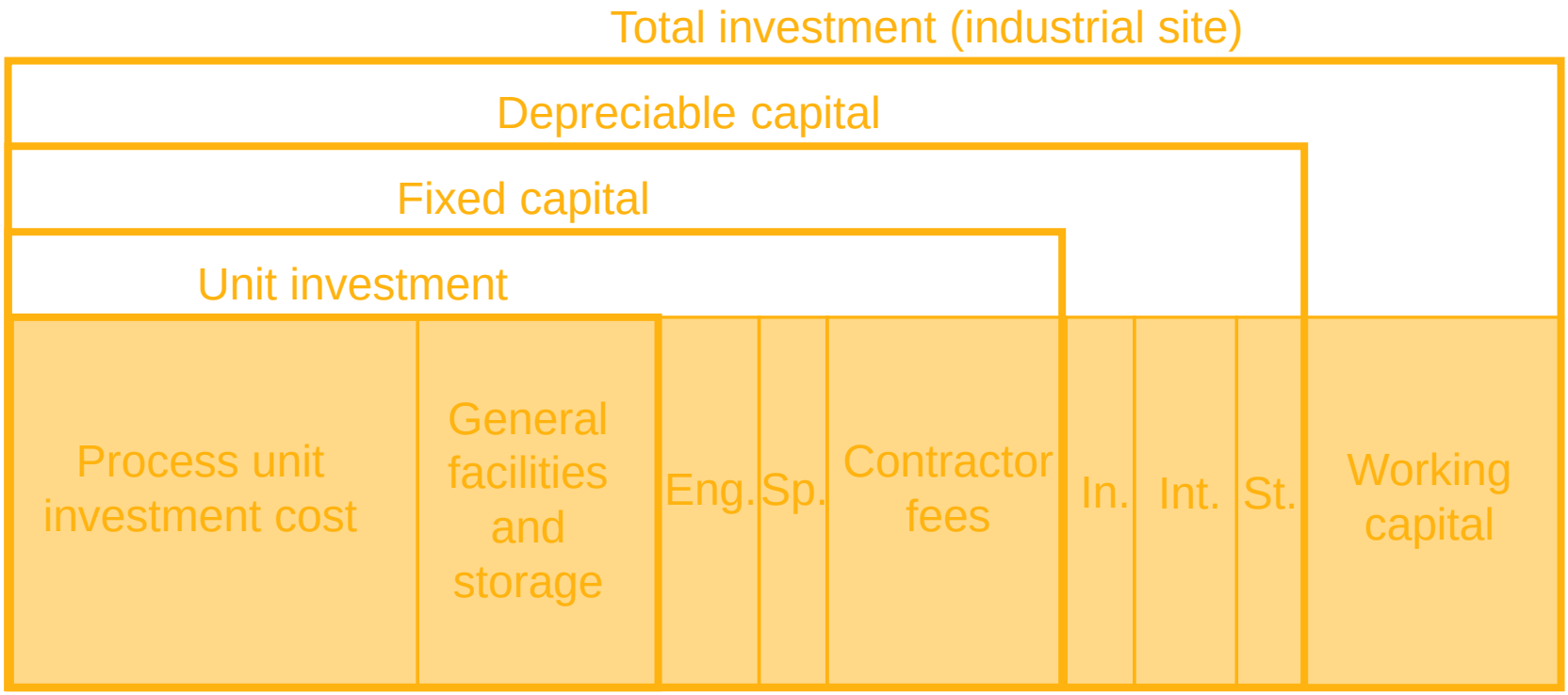
Investment cost

Other cost components

Energy consumption

Hydrogen Production cost

INVESTMENT COST: TOTAL INVESTMENT (INDUSTRIAL SITE)



The investment is not restricted to the equipment price.

OPERATING COST: MAIN ASSUMPTIONS *(2009 CONTEXT)*

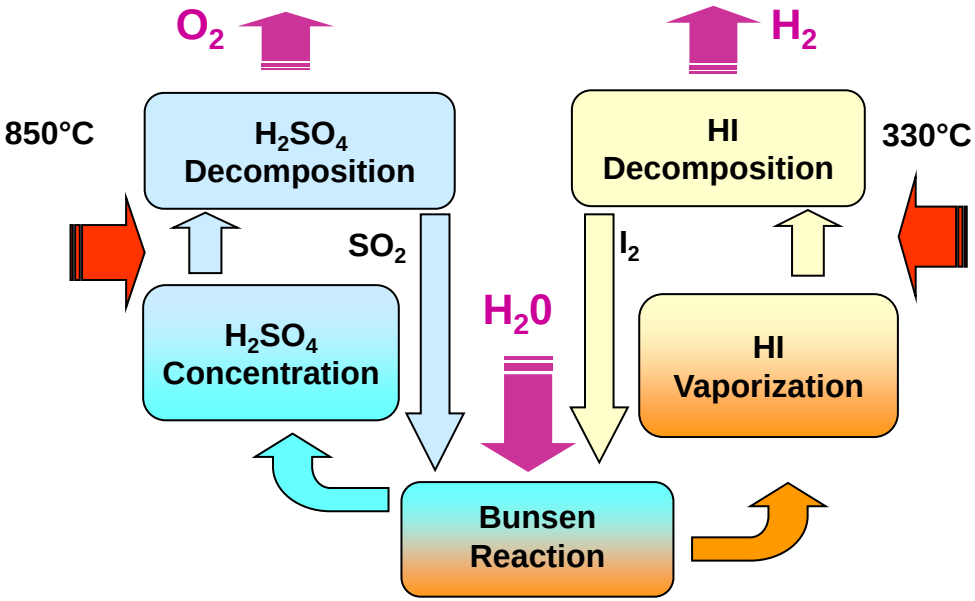
- Energy:
  - electricity: 40 €/MWh
  - heat: 20 €/MWh when supplied by a HTR
- Maintenance: 7%/year of the installed real equipment cost
- Other items:
  - Taxes and insurance
  - Plant overhead costs
  - Iodine losses when relevant
  - Platinum regeneration when relevant
  - Replacement of electrolysers (specific maintenance)

CALCULATION OF THE PRODUCTION COST

- Calculation of a levelized production cost

- Selected assumptions:
  - Construction period: 3 years
  - equally-distributed investment over the construction period
  - Plant life: 30 years with no replacement during the operation
  - Load factor: 80%
  - Discount rate: 8%

SULPHUR-IODINE CYCLE (S/I)



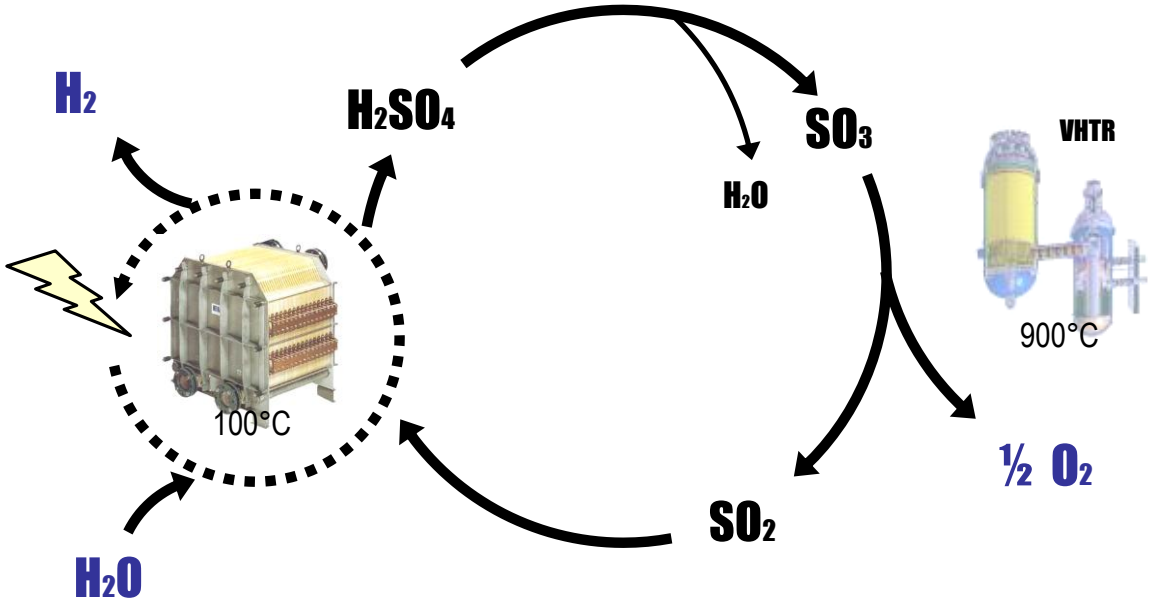
$$7\ I_2 + SO_2 + 15\ H_2O \rightarrow (2\ HI + 9\ H_2O + 6\ I_2) + (H_2SO_4 + 4\ H_2O)$$

3 step cycle

High temperature heat provided by a HTR

→ 600 MW_{th}, 66 MW_e to produce 2 kg_{H2}/s

HYBRID-SULPHUR CYCLE (HYS)



$SO_2 + 2\,H_2O \rightarrow H_2 + H_2SO_4$ 80-100°C : electrolysis

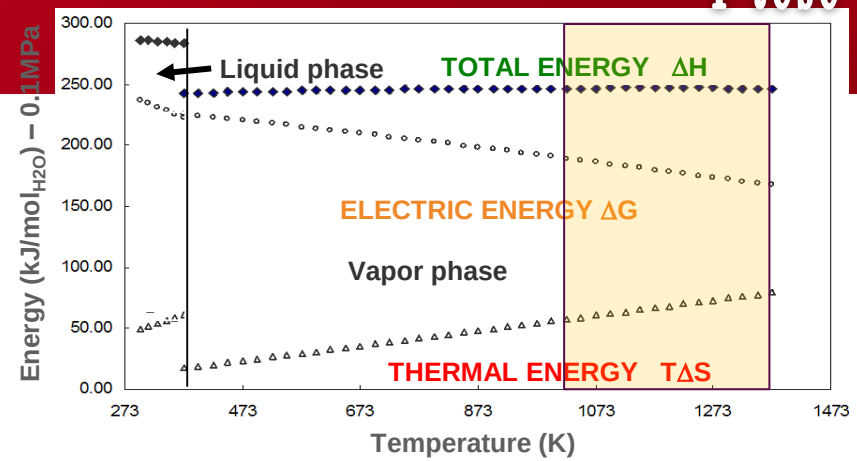
$H_2SO_4 \rightarrow H_2O + SO_2 + ½O_2$ 850°C

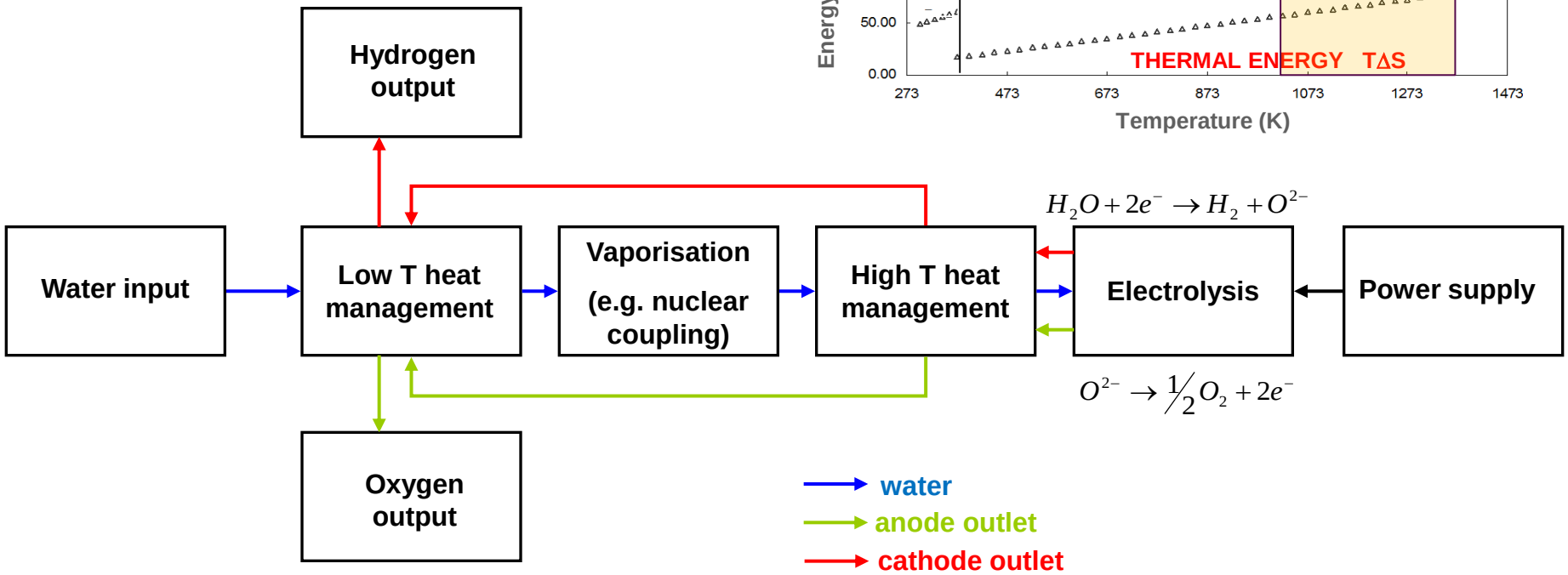
2 step cycle

High temperature heat provided by a HTR

→ 410 MW_{th}, 118 MW_e to produce 2 kg_{H2}/s

HIGH TEMPERATURE STEAM ELECTROLYSIS (HTSE)





Steam electrolysis + high temperature → reduction of the energy need

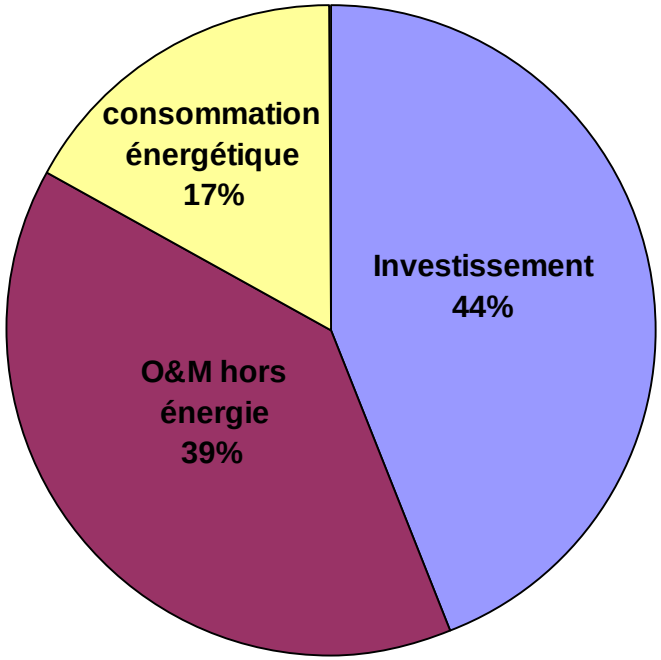
Heat supply for the vaporisation step: high T reactor is not mandatory

ENERGY CONSUMPTION AND COST COMPARISON

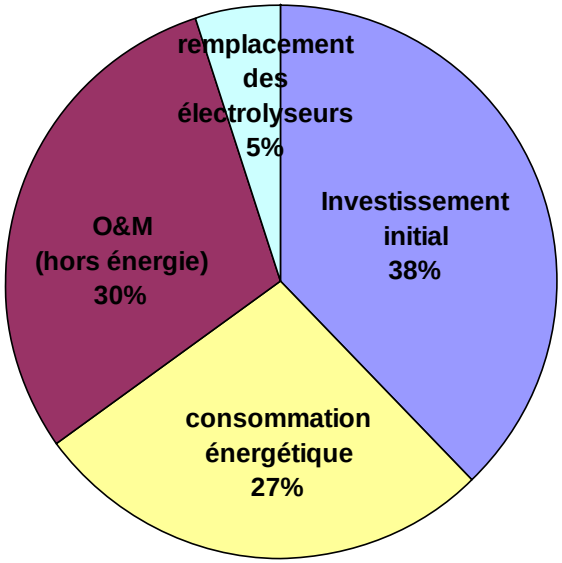
S/I cycle	HyS cycle	HTSE
600 MWth 66 MWe	410 MWth 118 MWe	79 MWth 255 MWe
2.0 €/kg_{H2}	1.8 €/kg_{H2}	1.6 €/kg_{H2} *with degradation of the electrolyser performances* 1.8 €/kg_{H2}

To produce 2 kg_{H2}/s

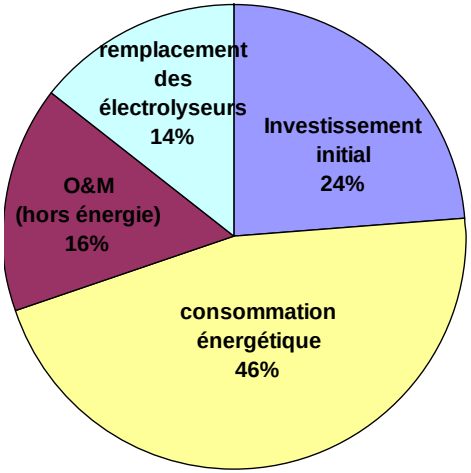
ECONOMIC COMPETITIVENESS COMPARISON



S/I 12 €/kg



HyS 6.6 €/kg

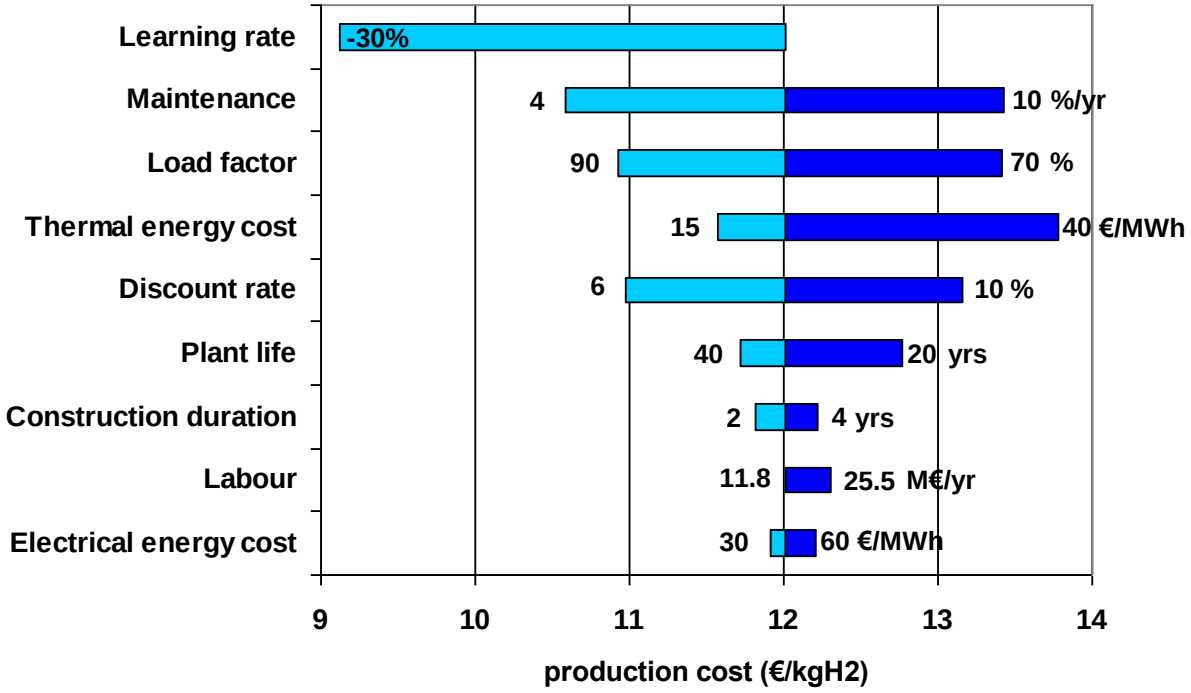


HTSE 3.6 €/kg

HTSE demonstrates a higher competitiveness

→ CEA's choice in 2009

S/I CYCLE COST DRIVERS



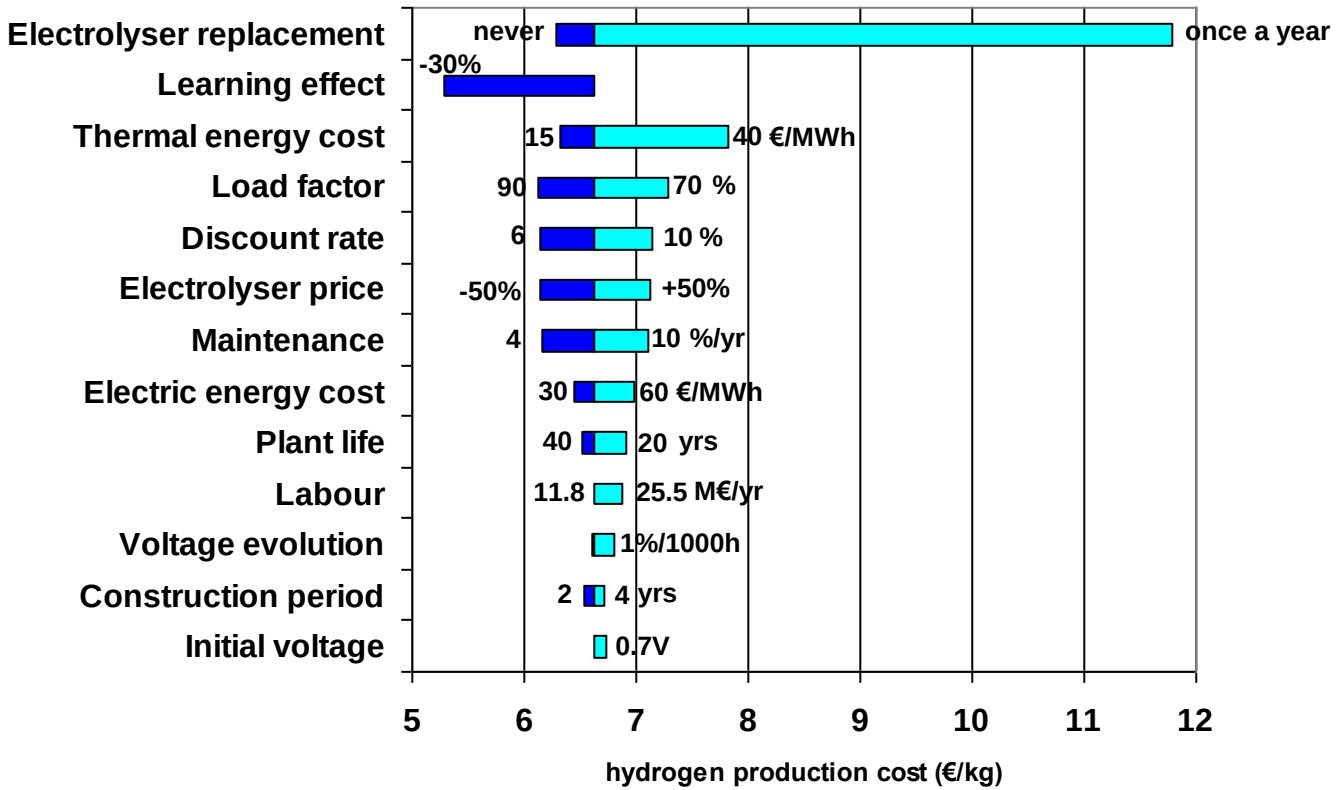
High investment

→ impact of learning, maintenance, load factor, discount rate

High temperature process

→ impact of thermal energy cost

HYS CYCLE COST DRIVERS



Impact of the electrolyser

→ uncertainty about its cost

→ potential high impact of its life expectancy

High temperature process

→ impact of thermal energy cost

HTSE COST DRIVERS

Electrolysis process

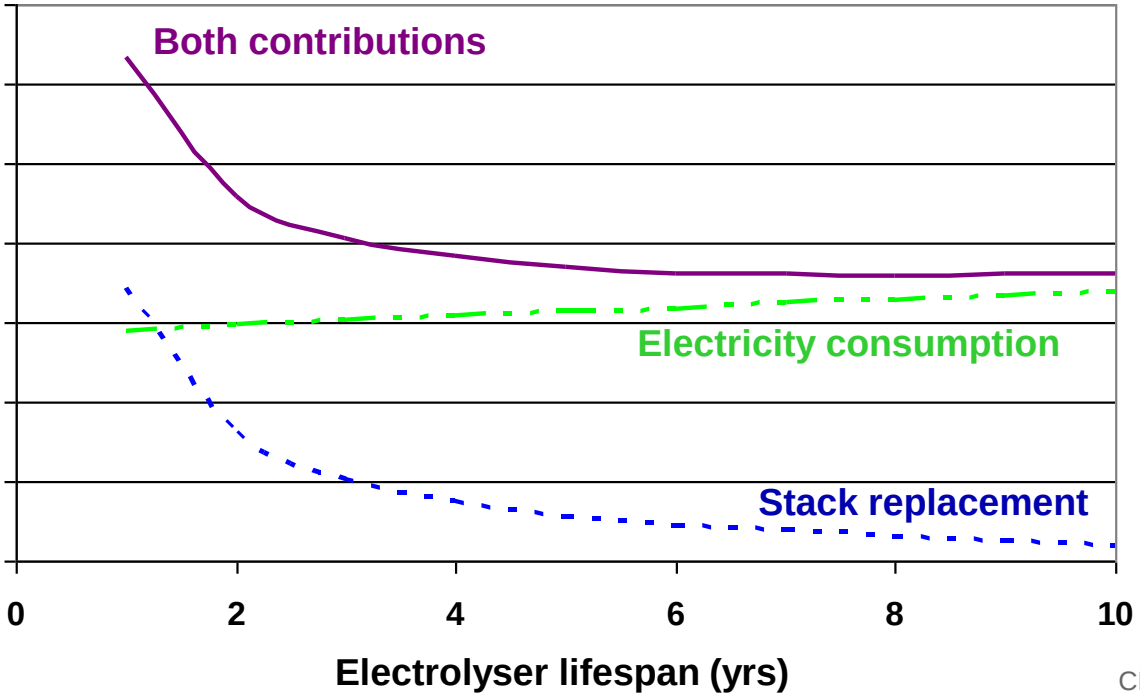
→ high impact of electricity consumption

(1.4 €/kg_{H2} without performance degradation)

High temperature electrolysis

→ electrolyser lifespan

(*e.g.* 1000 €/m² - 3yrs # 0.4 €/kg_{H2})



CONCLUSION (1/2)

- Very different specificities and cost drivers:
  - S/I: high investment
  - HyS: electrolyser performance and lifespan
  - HTSE: electrolyser performance and durability
- Beware of the cost assumptions and uncertainties when comparing economic competitiveness of several processes
- Technological breakthroughs to come?

CONCLUSION (2/2)

- The assessment that was carried out by the CEA in 2009 led to promote HTSE as the most competitive advanced process
- Major challenger in a CO_2 mitigation context: alkaline electrolysis (~ 3 €/kg_{H2} based on similar assumptions)
- R&D is still needed
- 2009 – 2013 studies focused on HTSE durability, cell performance, system integration
  → a production cost < 3 €/kg_{H2} seems achievable based on recent studies
- In an increasing electricity price context: the relative advantage is stronger for HTSE

Thank you for your attention

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