

# Techno-economic study of hydrogen production by High temperature Electrolysis coupled with and EPR, SFR or HTR – Water steam production and coupling possibilities

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## **Introduction**

**High Temperature Electrolysis (HTE - autothermal mode) coupled  
with Nuclear reactors**

**European Pressurised Reactor (EPR)**

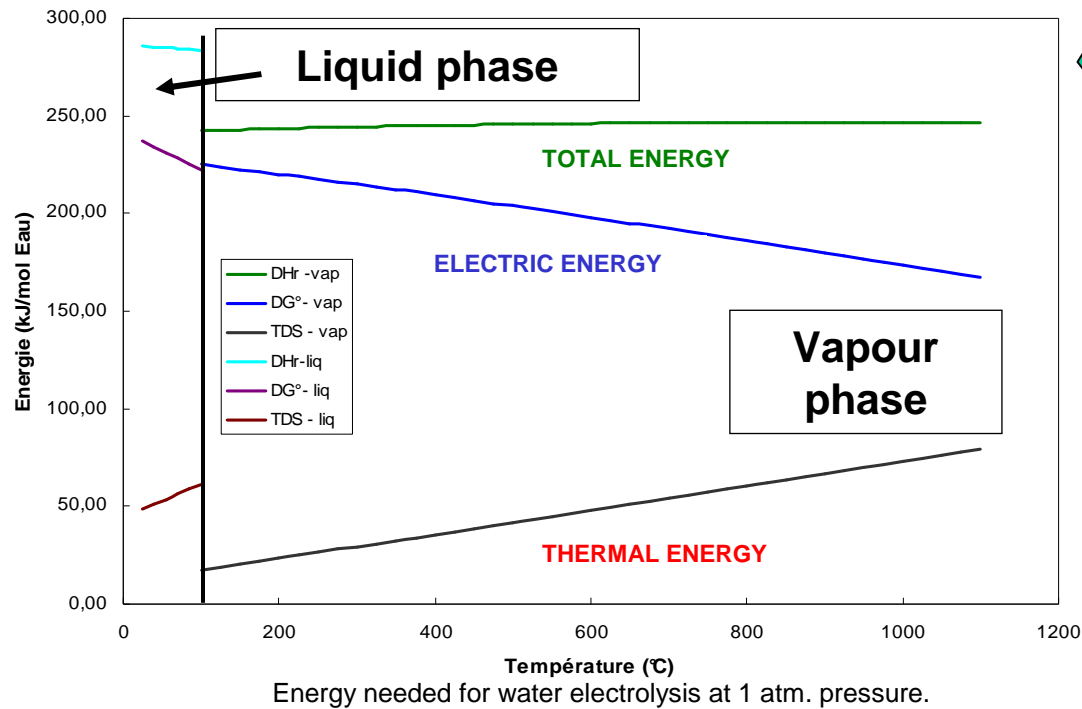
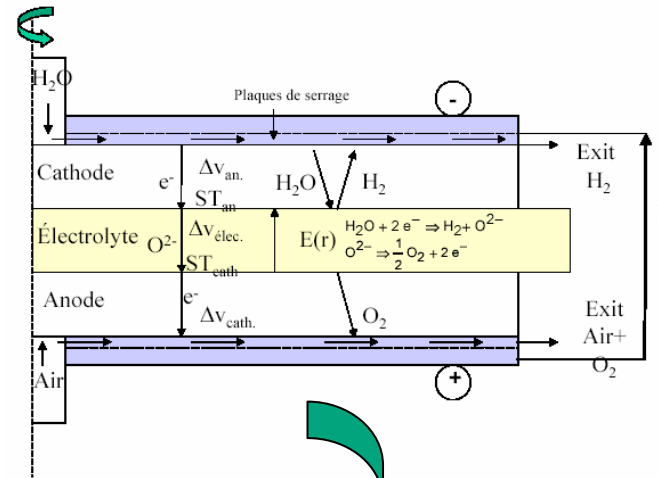
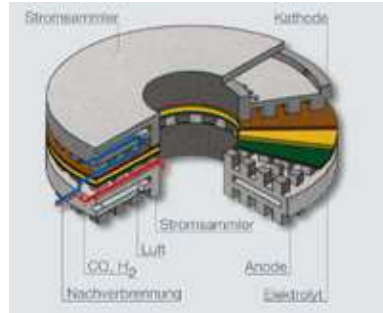
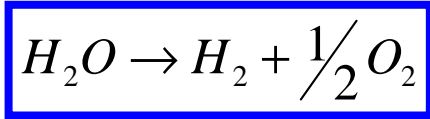
**Sodium Fast Reactor (SFR)**

**High Temperature Reactor (HTR)**

**Techno-economic optimisation of HTE – Nuclear couplings**

**Conclusion**

# Introduction : Water electrolysis (1/2)



**Autothermal mode:**  
**Energy needed in the electrolyser that keeps the outlet gas temperature at least as in the inlet stream.**

### Objectives:

- Evaluate the couplings of the HTE process with the nuclear reactors
- Evaluate the effect of the pressure and temperature on the hydrogen production cost
- Evaluate the effect of the energy costs on the hydrogen production cost

## Introduction

### High Temperature Electrolysis (autothermal mode) coupled with Nuclear reactors

European Pressurised Reactor

Sodium Fast Reactor

High Temperature Reactor

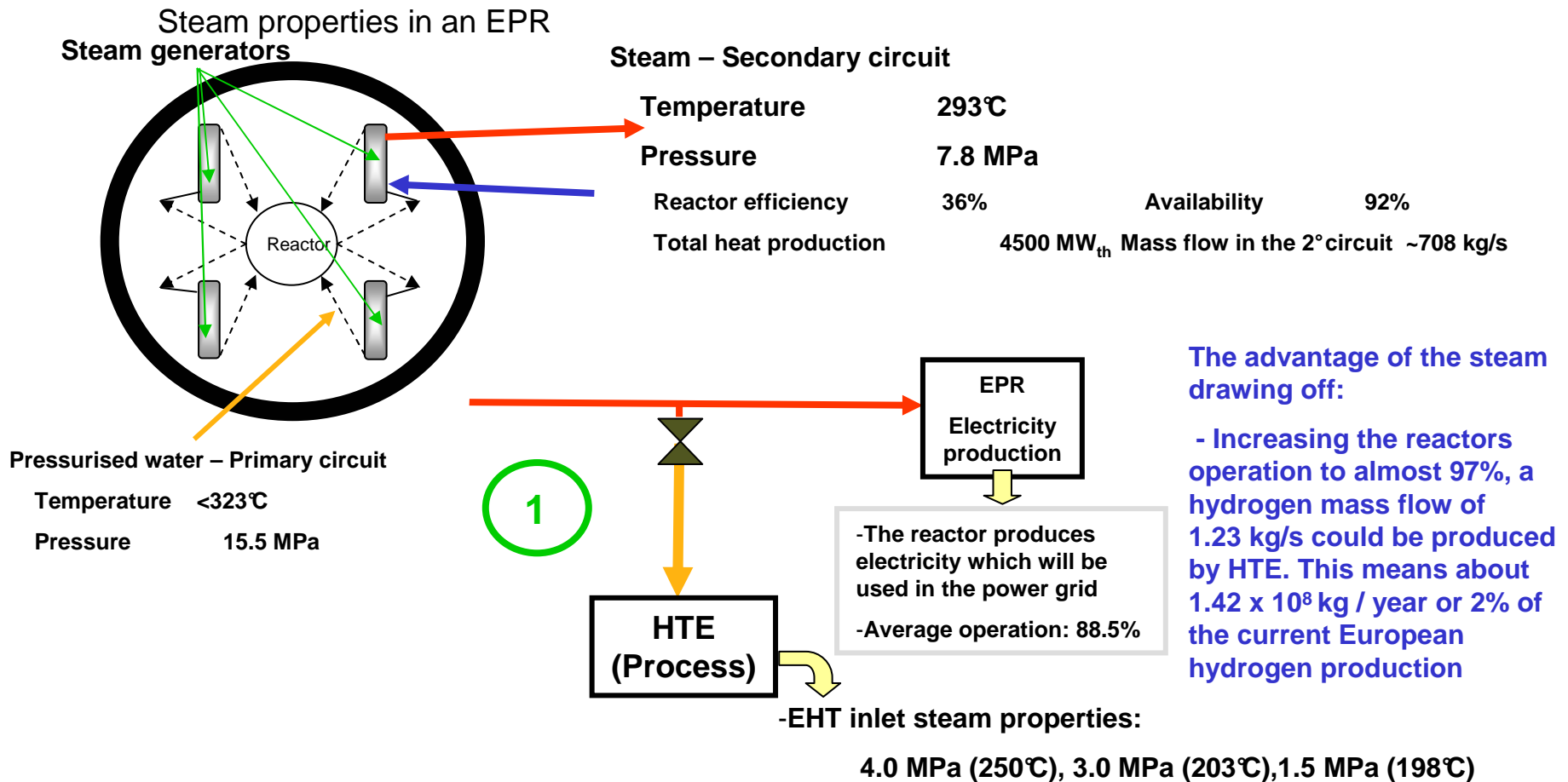
### Techno-economic optimisation of HTE – Nuclear couplings

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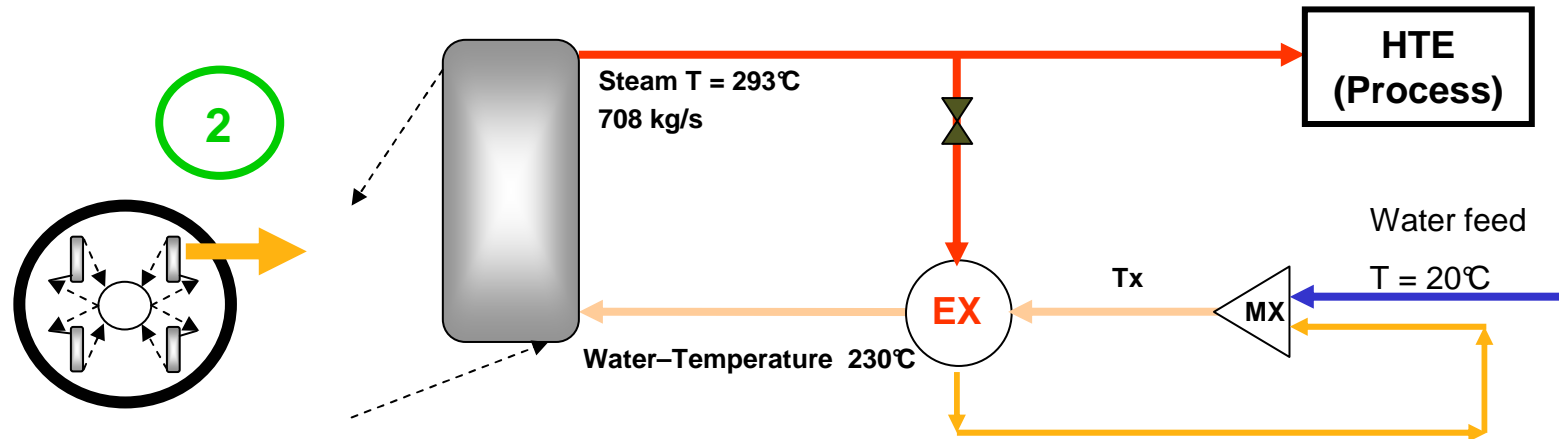
## European Pressurised Reactor (1/2)

We studied two different couplings between the HTE and the EPR :

- 1) The steam drawing off of the secondary circuit
- 2) An EPR completely used for steam production to be electrolyzed -->hydrogen



EPR... 2) An EPR completely used for steam (hydrogen) production (2/2)



$$T_x = \frac{\dot{m}_{phst} C_{p_{water}} (T_1 - T_{ref}) - L_{vap} \dot{m}_{phst}}{\dot{m}_{steam2} C_{p_{water}}} + T_{ref}$$

$$T_x = \frac{(T_{fw} - T_{ref}) C_{p_{vap}} (\dot{m}_{steam2} - \dot{m}_{phst}) + (T_{cs} - T_{ref}) C_{p_{water}} \dot{m}_{phst}}{\dot{m}_{steam2} C_{p_{water}}} + T_{ref}$$

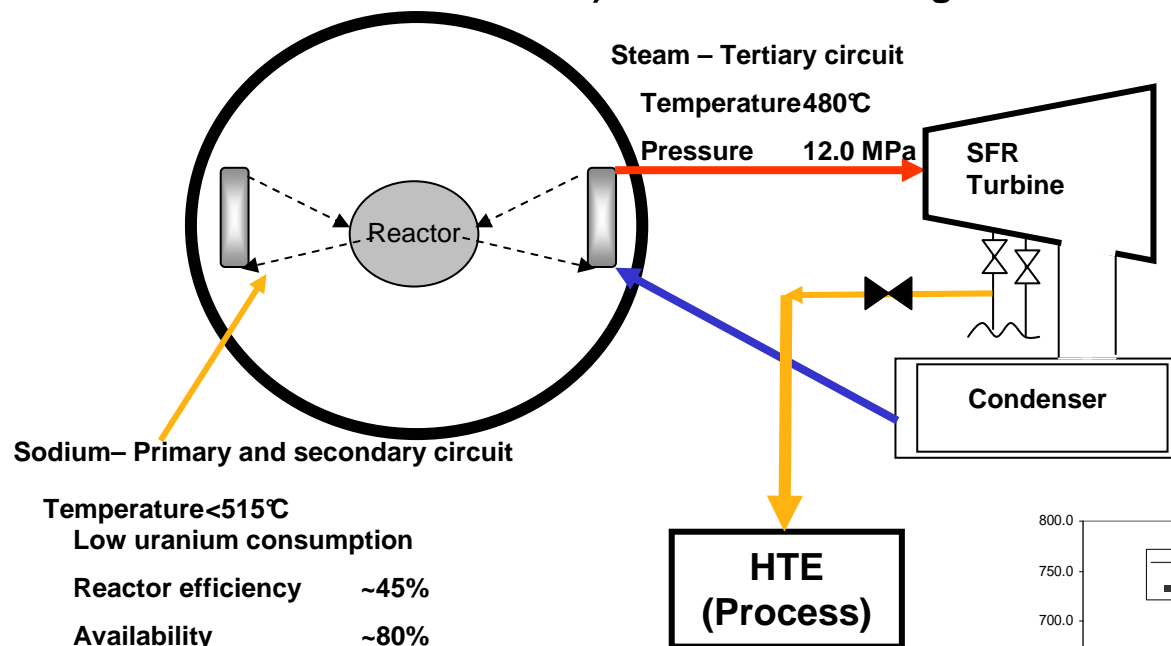
The advantage of an EPR used for steam production:

- the HTE hydrogen production could reach 200 kg/s using the 4 secondary circuits of the reactor. If the reactor operation is at 100% of its capacity, around  $5.8 \times 10^9$  kg / year could be produce = ~72% of the current European production.

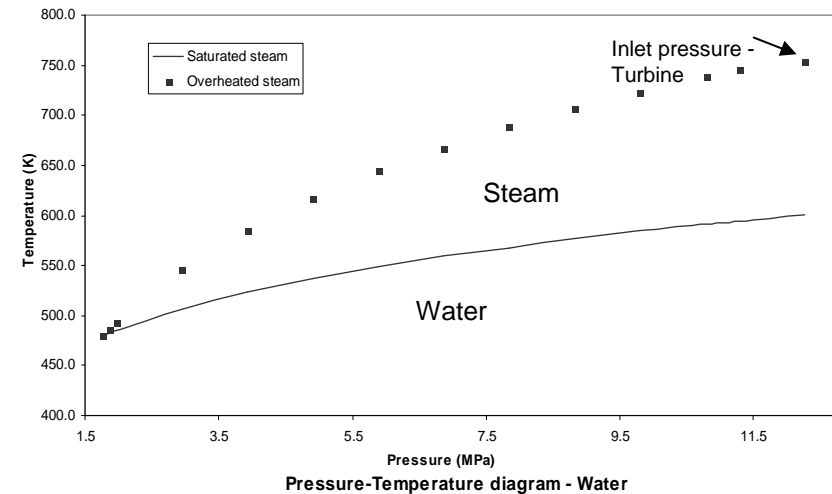
## Sodium Fast Reactor

A coupling with the HTE process by:

### 1) The steam drawing off from the turbine



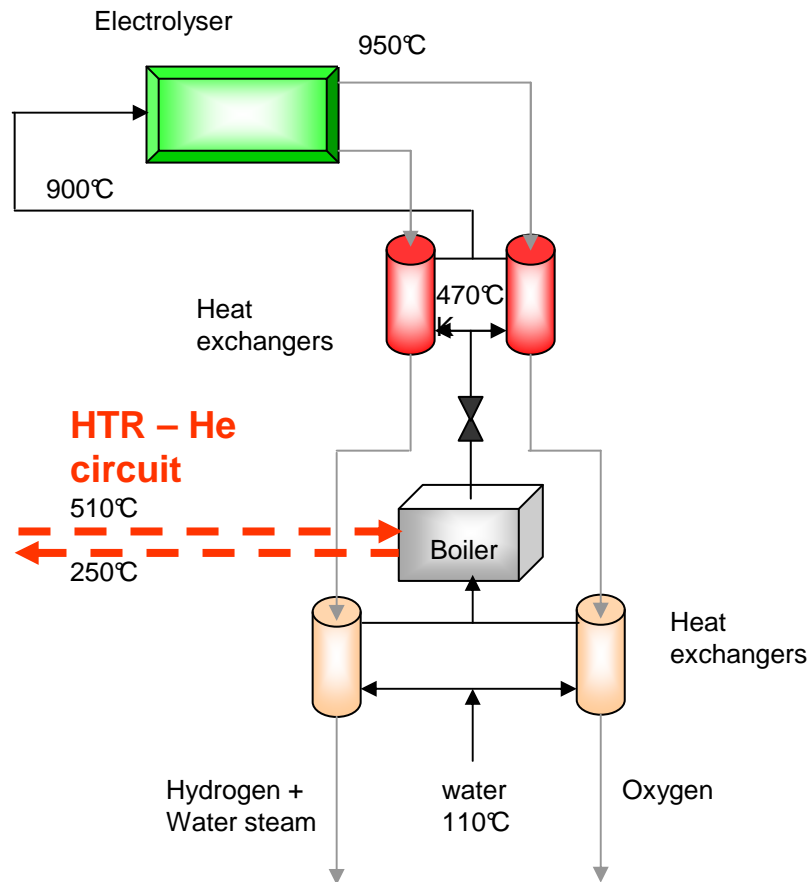
DRAWING OFF	
Drawing off pressure	2.0 MPa
Temperature	210°C
Steam mass flow	0.19 kg/s
or 1% of total flow (at 100%)	



Taking into account a sodium reactor, as a BN-1800 (Russia), and a steam drawing off of 1% of the total mass flow (100% capacity), a hydrogen production of  $5 \times 10^7$  kg/year could be reached (around ~1% of the current European production).

## High Temperature Reactor

### 1) Heat exchange with an helium circuit



- Normally, this heat exchange happens after the turbine outlet. The hot helium heats the water steam coming from another steam generation system

- The overheated steam pressure is supposed to be 3.0 MPa in the electrolyser inlet

- This kind of coupling has been studied by Rodriguez-Pinteaux (EHEC 2003), Mansilla et al. (Energy 2007), Sigurvinsson et al. (Energy Conv. & Man. 2006), Paul-Joseph et al. (HYSYSDAYS 2007)

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## Hypotheses concerning the heat sources --- Water steam

Nuclear reactors	Cost of kWh <sub>electric</sub>	Cost of kWh <sub>th</sub>
EPR	0.033 €	0.0119 €
SFR (Zrodnikov – Nuc. Eng. & Des. 2006)	0.023 €	0.0102 €
HTR	0.040 €	0.0192 €

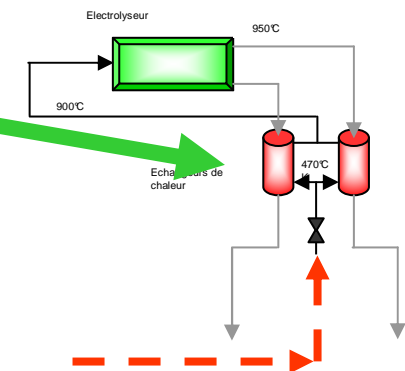
Sensibility study : The cost of the electric kWh evaluated → 1.5 times the original value

$$\frac{\text{€}}{\text{kWh}_{th}} = \frac{\text{€}}{\text{kWh}_{electric}} \times \eta_{reactor}$$

### The COUPLING

The steam is introduced in two heat exchanger series with three heat exchangers each. They are Classified according to their temperature operation range in :

Low Temperature	<650°C	400€/m <sup>2</sup>
Medium Temperature	650°C – 850°C	800 €/m <sup>2</sup>
High Temperature	>850°C	4000€/m <sup>2</sup>



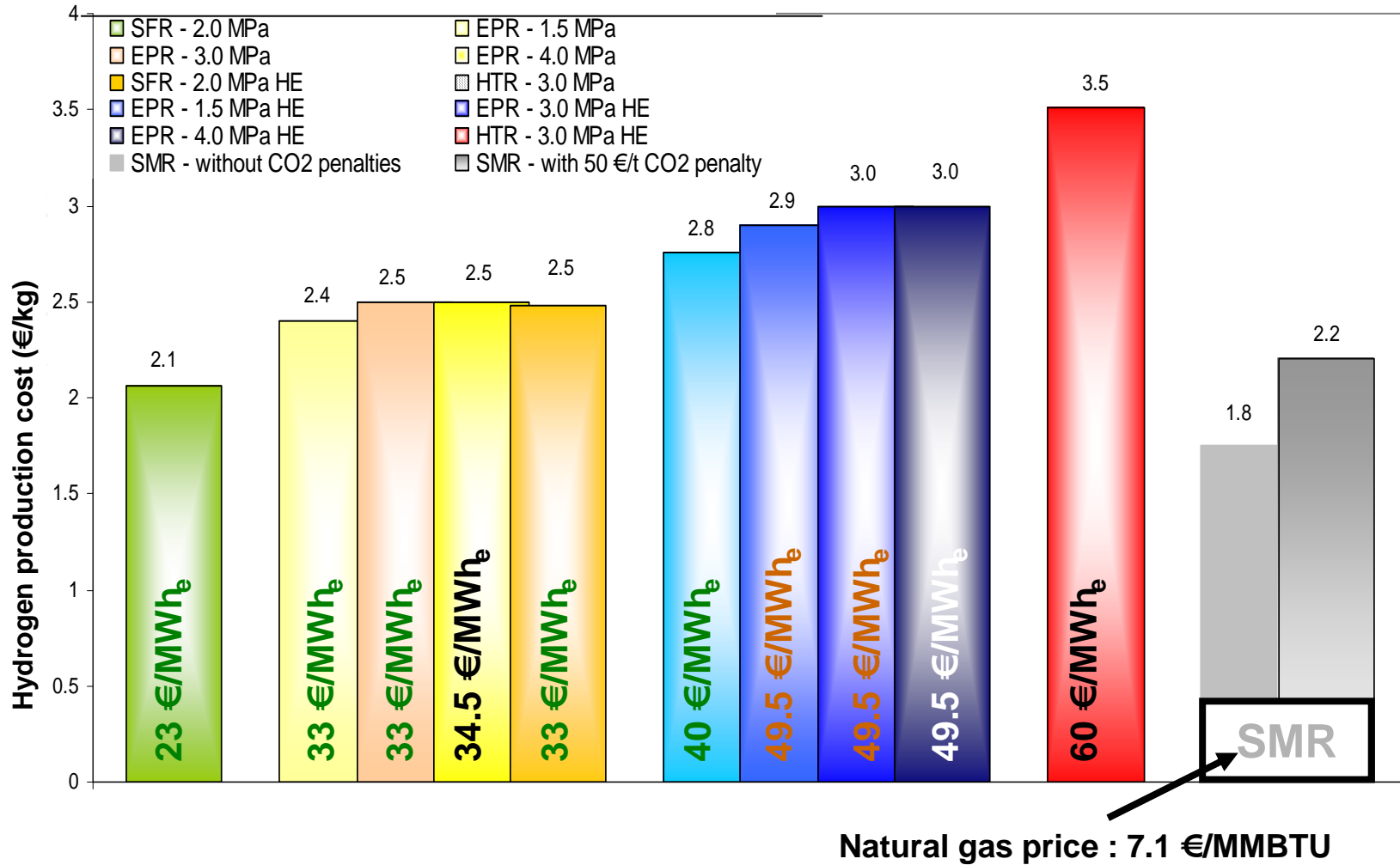
### Hypotheses concerning the High Temperature Electrolysis:

- The investment depends directly from electrolyser surface
- The minimum operation lifespan is assumed to be 5 years
- The electrolyser cell cost is 2000 €/kW at a current density of 0.5 A/cm<sup>2</sup>
- An electrolyser of 200 kW would be evaluated for each heat source
- The security distance between the HTE unit and the nuclear reactors are not considered in this work.
- The HTE operation lifespan would be of 30 years with a discount rate of 6%

$$CTA = \frac{\sum_{t=1}^{T_i+T_e} [(C_{i,exch})_t + (C_{i,elec})_t + (C_{o,th})_t + (C_{o,elec})_t] (1+\tau)^{-t}}{\sum_{t=1}^{T_i+T_e} [H_t (1+\tau)^{-t}]}$$

$C_{i,exch}$	<b>Heat exchangers investment</b>
$C_{i,elec}$	<b>Electrolyser investment</b>
$C_{o,th}$	<b>Operation cost – thermal energy consumption used in the water steam generation</b>
$C_{o,elec}$	<b>Operation cost – electrical energy consumption used in the electrolyser, pumping system and electrical overheaters</b>

## Results



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## **Conclusion**

- The steam temperature at the heat exchangers inlet does not strongly influence the total hydrogen production cost.
- By the other side, the electricity cost has an important role in the hydrogen production cost
- The increasing competitiveness of these couplings are not so far from the hydrogen production cost by SMR but....



**Highlights in HTE physical and economical modeling have to be studied so as the security distances between the HTE unit and the heat sources, especially the Nuclear reactors**