Hydrogen Production Progress Update

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22.033 Fall

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Presentation Outline

- **Objectives**
  - Hydrogen economy viable?
- **Options**
  - Steam Methane Reforming (SMR)
  - Westinghouse Sulfur Process (WSP)
  - Water Electrolysis (ES)
  - HT Steam Electrolysis (HTSE)
  - Sulfur-Iodine (S-I)
  - Br-Ca-Fe (UT-3)
  - Bacteria / Urine
- **Comparison**

Hydrogen economy viability?

Chemical Properties

- Difficult to contain in gaseous forms
- Parasitic energy losses
- Cryogenics required for best storage
- Safety concerns

Infrastructure Overhaul

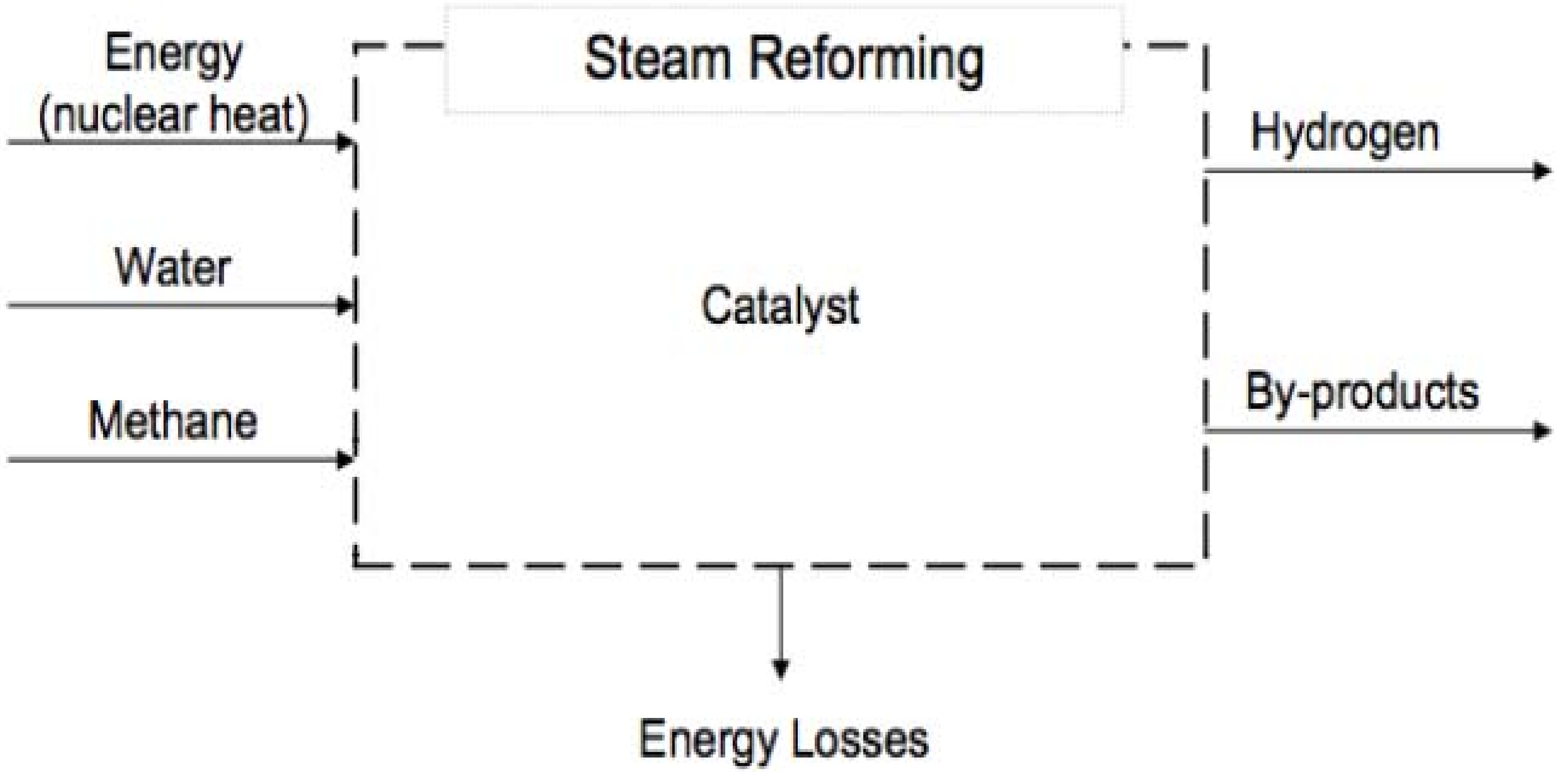
- Multi-billion dollar distribution framework required

Conclusion: A hydrogen economy is not technically or economically viable in the relatively near future.

Engineering Objectives

Hydrogen Production	0.1 kg/s at STP
Required Temperature	< 800 C
Power Consumption	< 150 MW
Environmental Impact	Zero Greenhouse Emissions

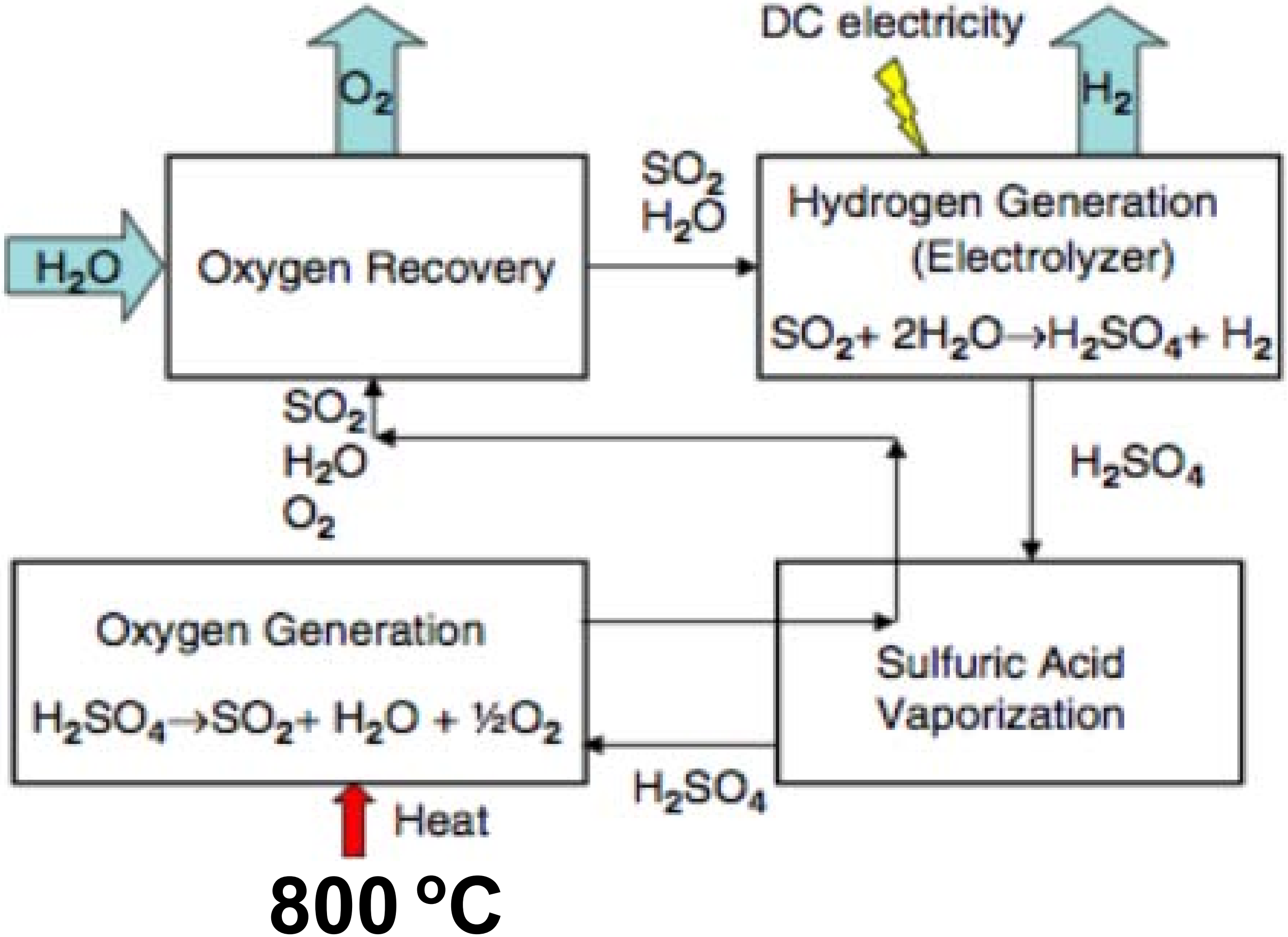
Options - Steam Methane Reforming



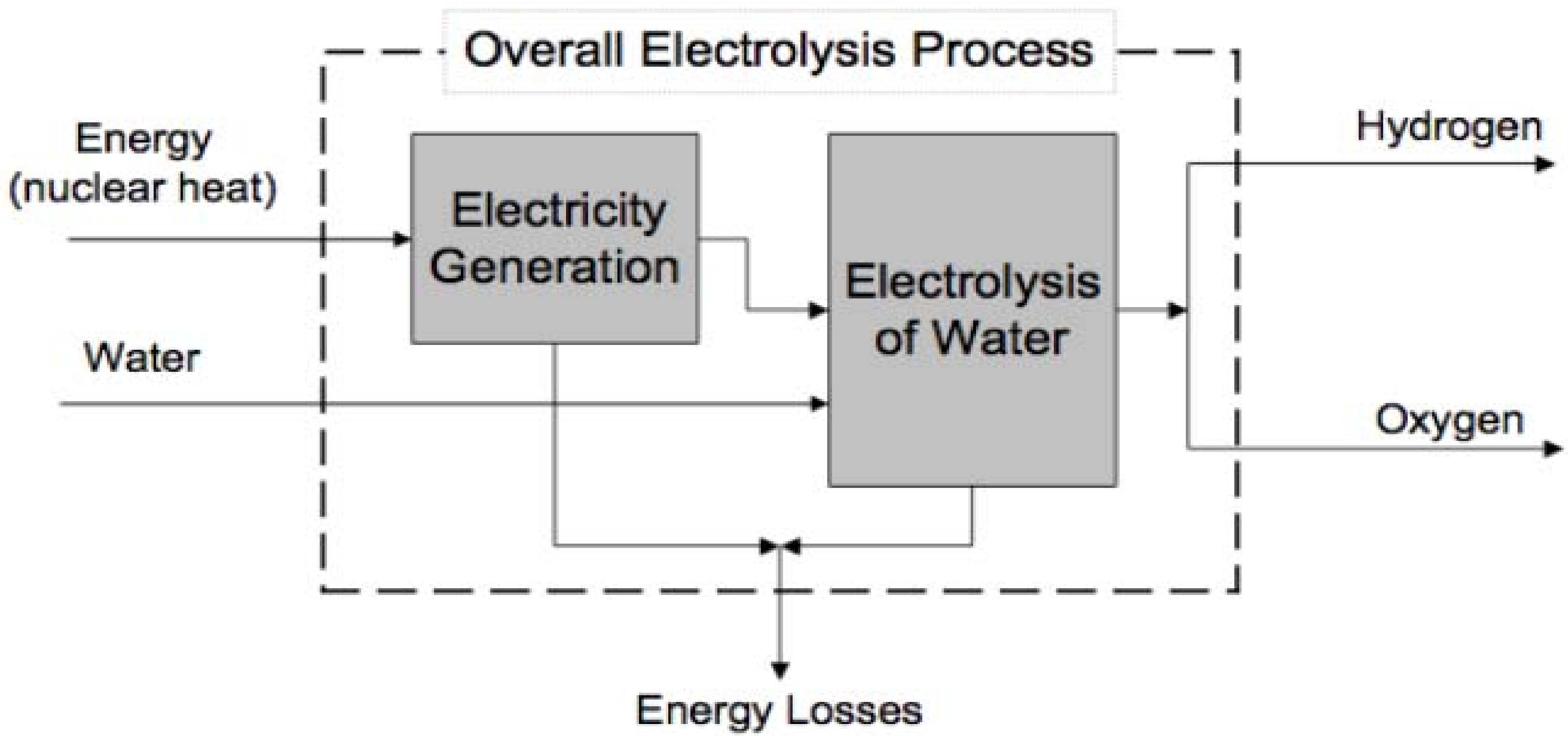
- Currently used commercially
- Input temperature: 700-800 C
- 70% efficient
- By-product: CO_2

Konopka, Alex J., and Gregory, Derek P. "Hydrogen Production by Electrolysis: Present and Future." Institute of Gas Technology, Chicago IL. IECEC 1975 Record.

Options - Westinghouse Sulfur Process (WSP)



Options - Water Electrolysis



Polymer Electrolyte Membrane	80 - 100 °C at P_{atm}
Alkaline Electrolyzers	100 - 150 °C at P_{atm}

Konopka, Alex J. and Gregory, Derek P. Hydrogen Production by Electrolysis: Present and Future. Institute of Gas Technology, Chicago, Illinois 60616. IECEC 1975 Record.

Options - Water Electrolysis

Efficiency

Process 75% ⇒ Overall 25-45% ⇐ Energy Generation 30%

Production Rate

Need: 0.1 kg/s ⇒ 8640 kg/day

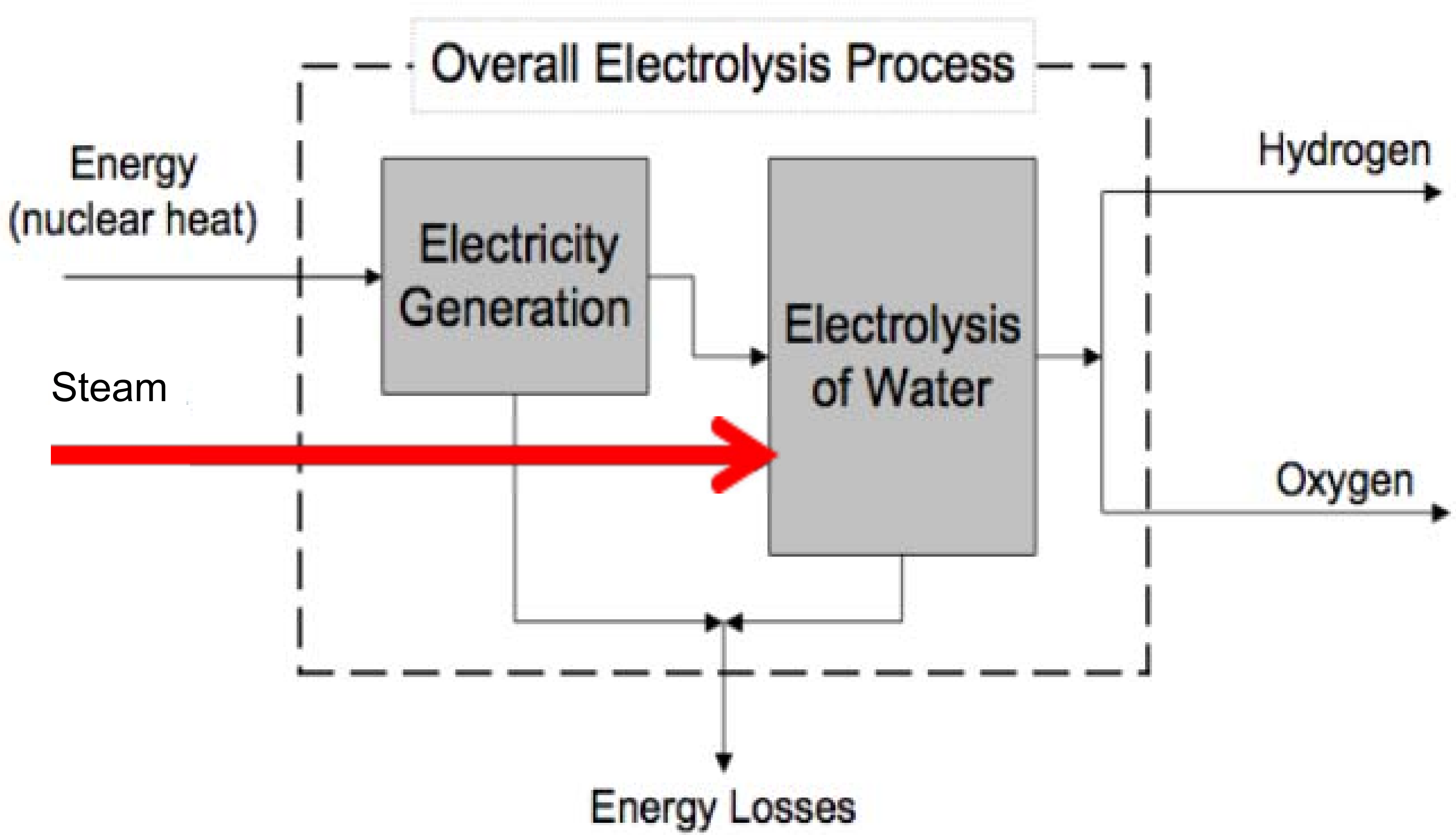
Best Option[2]:

$$\left(\frac{1046 \text{ kg/day} \quad 53.5 \text{ kW-hr/kg}}{2332 \text{ kW}} \right) \times 8.3$$

19.4 MW

Konopka, Alex J. and Gregory, Derek P. Hydrogen Production b Electrolysis: Present and Future. Institute of Gas Technology, Chicago, Illinois 60616. IECEC 1975 Record.

Options - HT Steam Electrolysis



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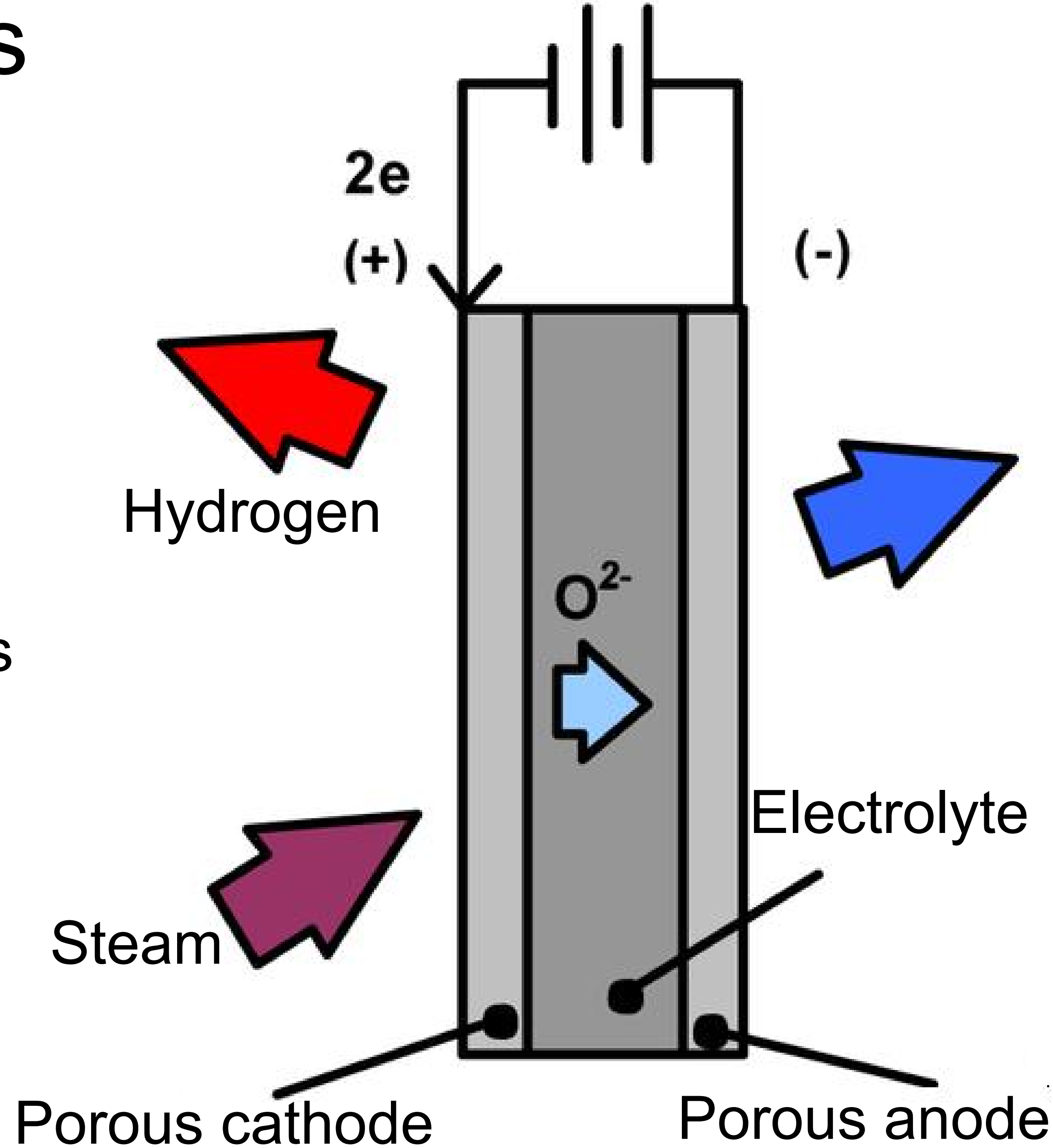
HTSE Process

H2O+2e->H2+O

Chemically stable electrolyte

Hydrogen and Oxygen released through porous material

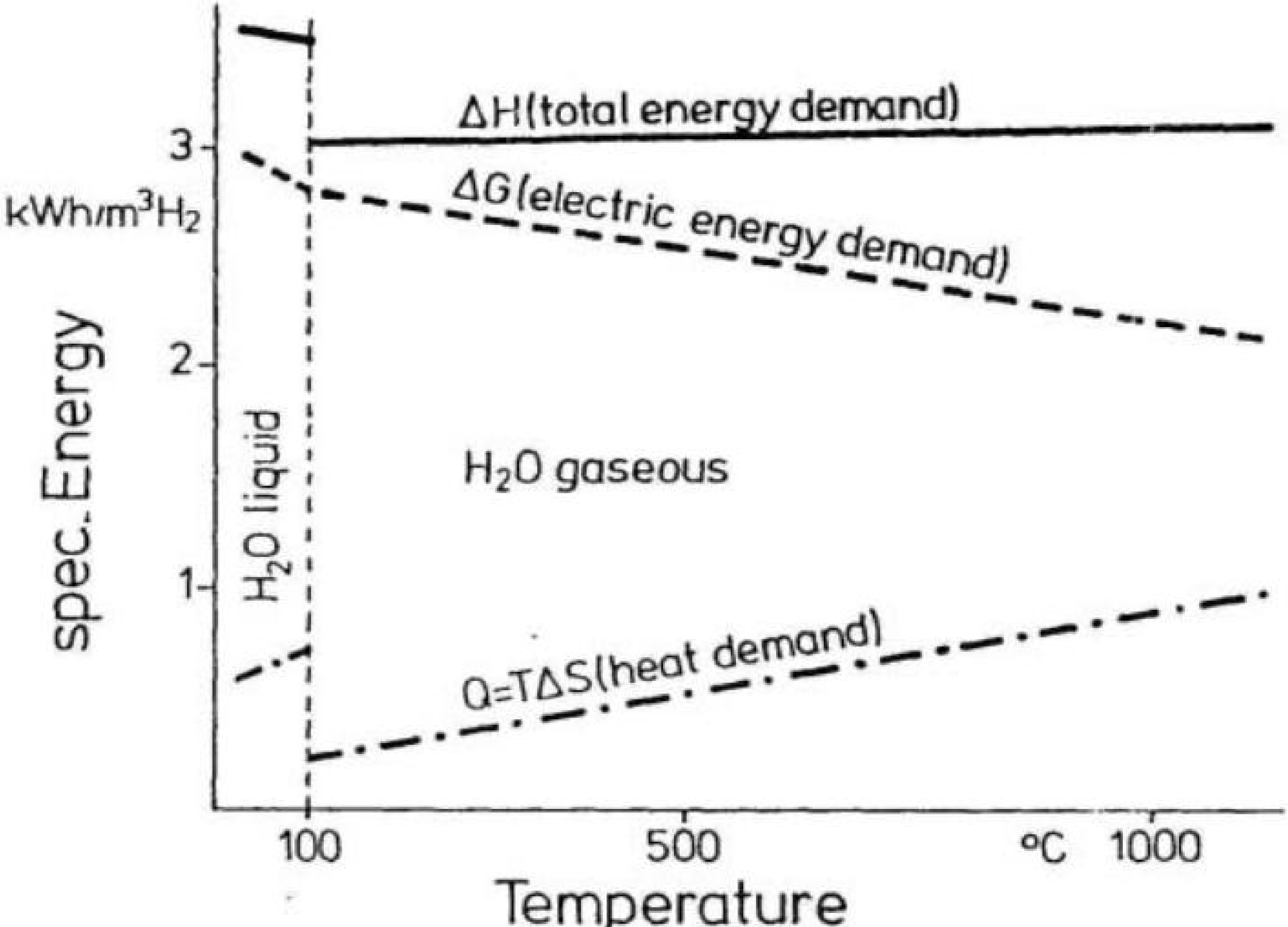


U.S. DOE factsheet for high-temperature electrolysis

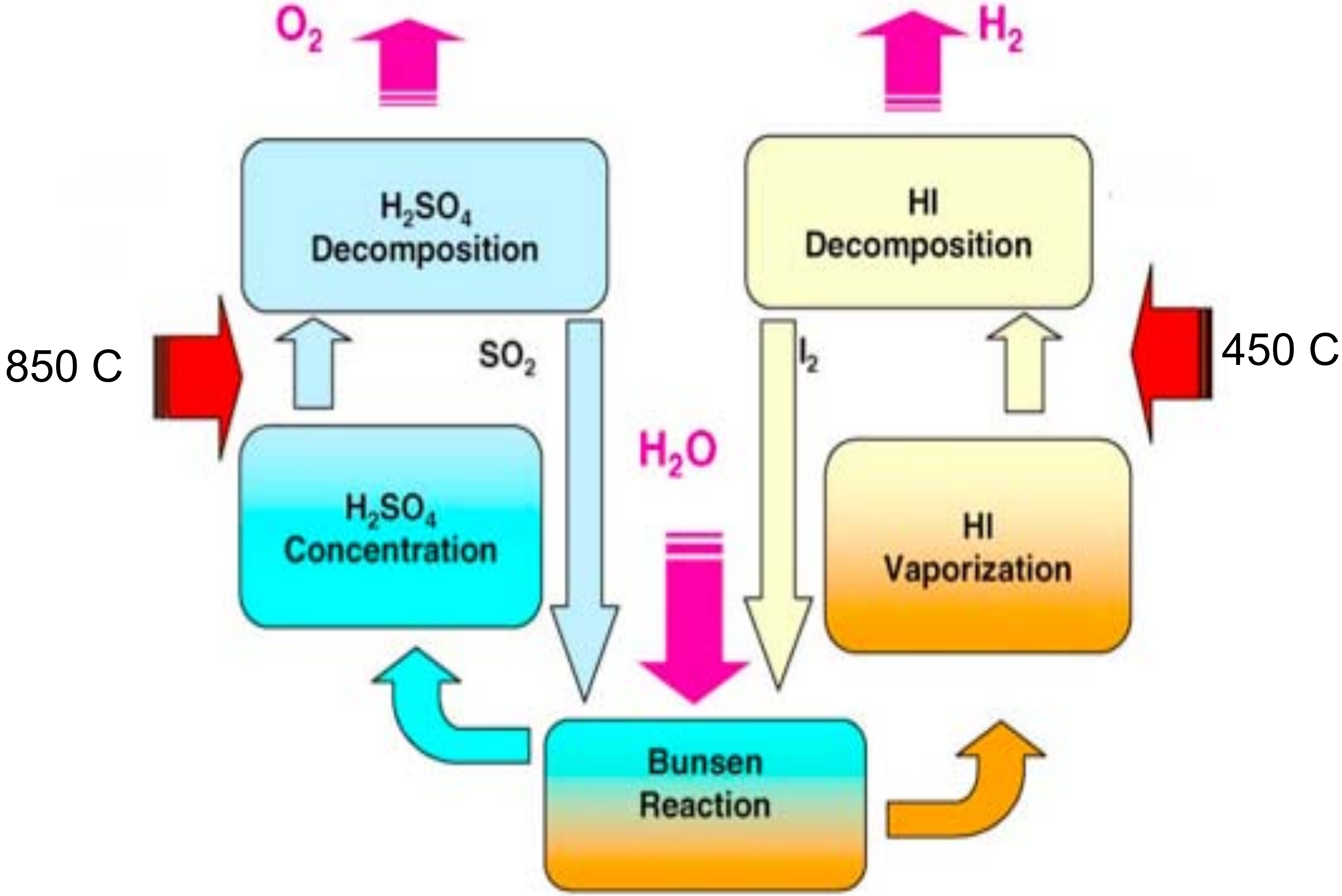
HTSE Advantages

- High efficiency (enthalpy of steam vs water)
- No pollutants
- Uses reactor heat
- Simple chemistry
- Improvement with temperature

HTSE Thermodynamics



Options - Sulfur-Iodine Cycle



Options - Sulfur-Iodine Cycle

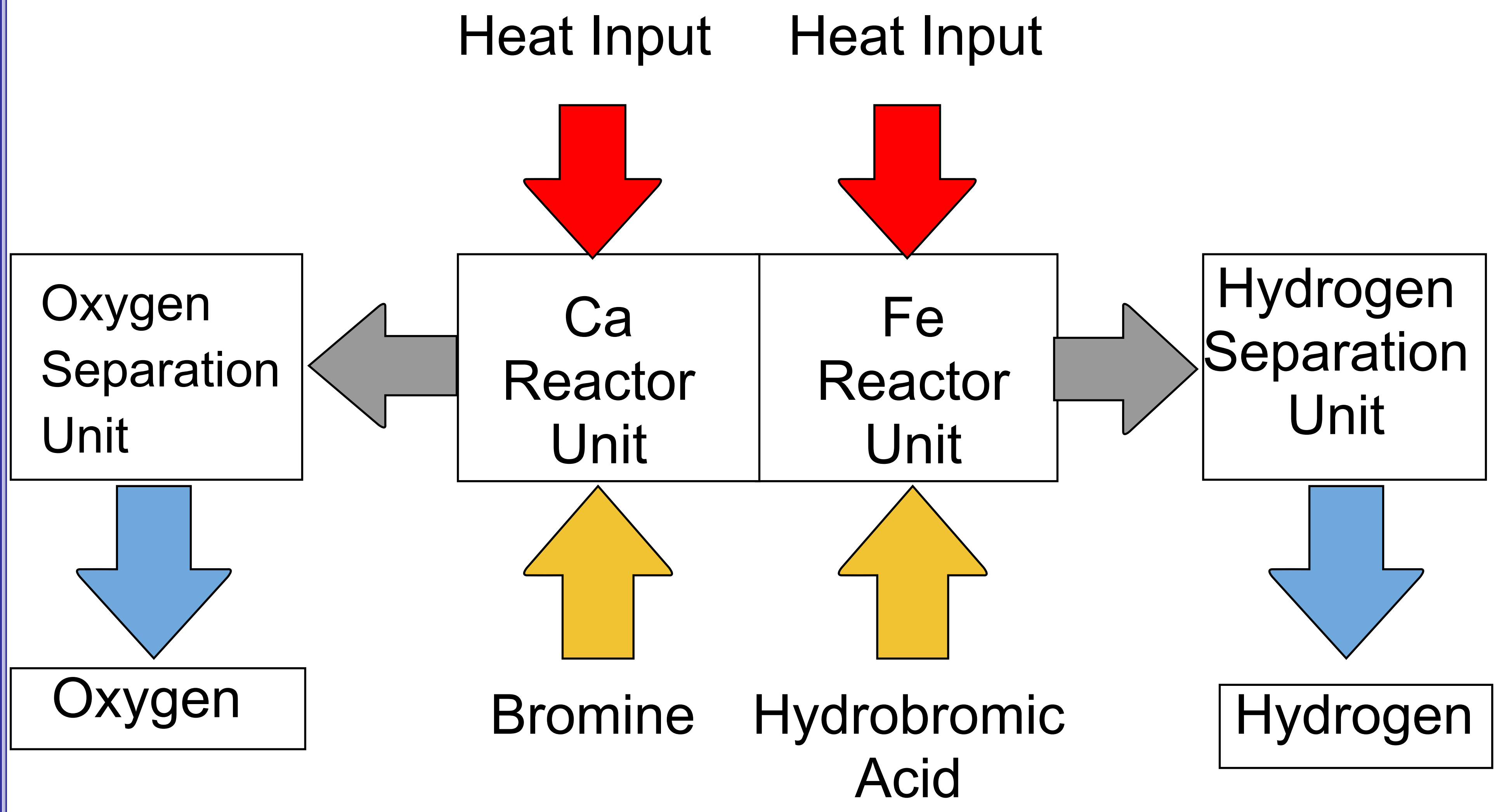
Advantages

- Commercial scalability
- No greenhouse emissions
- Cheap reactants

Disadvantages

- Very high temperatures required (850 C +)
- Material concerns due to aggressive chemistry
- Heat exchanger design limitations at high temperatures
- Process efficiency limited to roughly 34-37%

Options - Br-Ca-Fe (UT-3) Process



A. Aochi et al., Economical and technical evaluation of UT-3 thermochemical hydrogen production process for an industrial scale plant. *Int. J. Hydrogen Energy*, 14(7):421–429, 1989.

Options - Br-Ca-Fe (UT-3)

Advantages

- Can occur at a lower temperature than the sulfur-iodine process
- Commercially scalable method of hydrogen production
- No greenhouse gases produced

Disadvantages

- Efficiency limited to ~ 40%, but a soft limit
- Material concerns, though not as prominent as SI
- Higher temperature than core output is required

Options - Bacteria

- Dark fermentation is most commercially viable approach of bacterial hydrogen production.

Advantages

- Low temperatures required
- Limited material concerns

Disadvantages

- Uncertainty on scalability due to limited research
- Expensive strains required
- Contamination concerns
- Large volume of bacteria mixture required

Options - Urine

- Breaking down urea into hydrogen
- Storage and transport of human waste
- Hydrolyzes over time-->fast process needed
- Large volume of waste needed

Comparison of Processes

Process	**Materials**	**Temp [°C]**	**Pressure [atm]**	**Efficiency [%]**	**Feasibility**
ES	Water, Electrolytes, Anode/Cathode	~100	1	25-45	drastic scaling needed
HTSE	Ceramics	500+	1	90+	only small scale
SI	Ceramics	850+	1-10	34-37	commercially viable, but too high temp
SMR	Nickel catalyst	700-800	1-3	70	commercially viable, but polluting
UT-3	Ceramics	760	1	40+	commercially viable

Final Decision: UT-3 Process

- Well demonstrated over three decades
- Minor material concerns
- Commercially viable
- Reasonable temperatures required
- No greenhouse emissions
- Relatively cheap reactants

Next Steps

- Scale/capacity
- Hydrogen storage/reserves
- Material concerns
- Transportation to biofuels

22.033 / 22.33 Nuclear Systems Design Project
Fall 2011