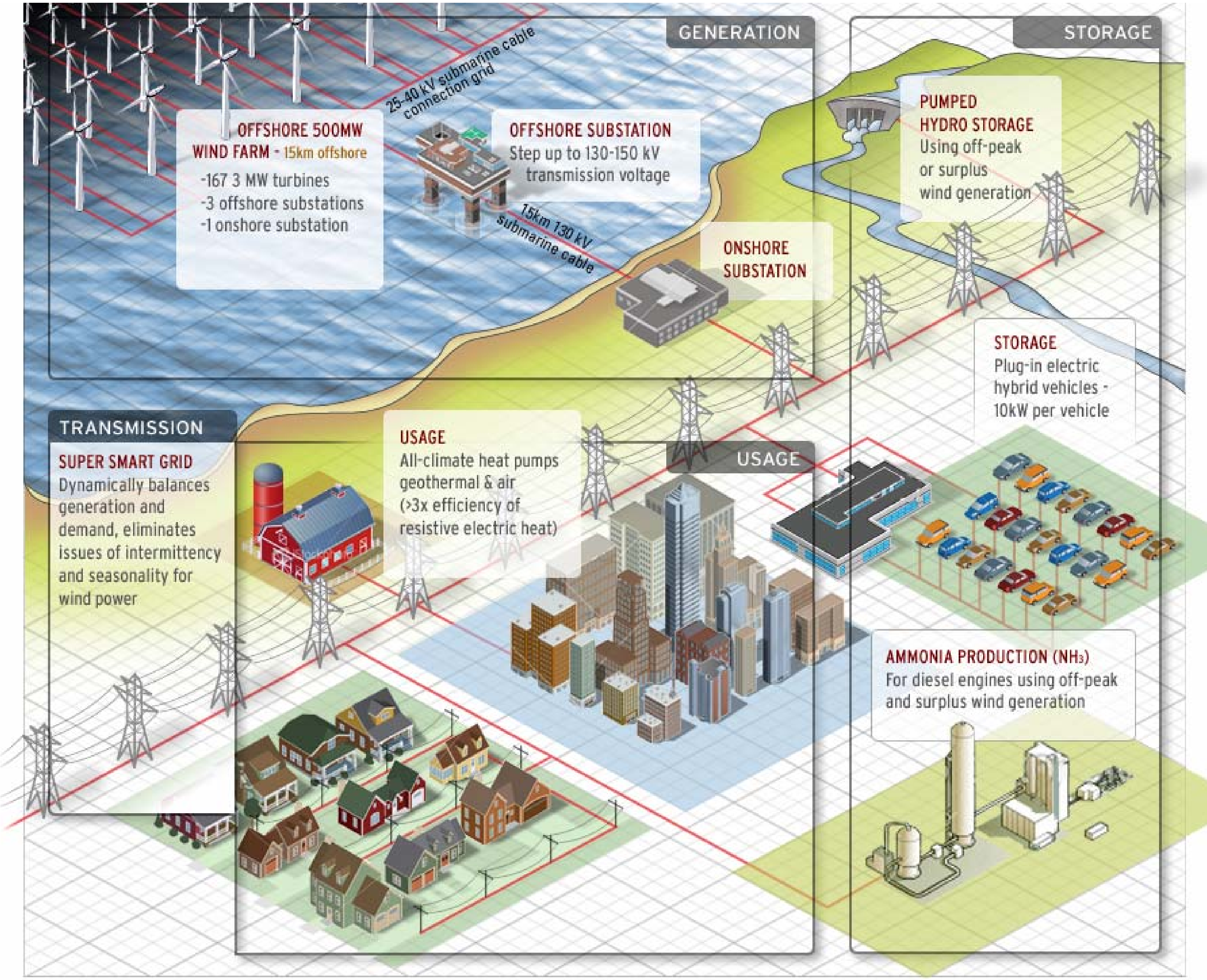
Hydrogen Production

- What we have
- What we want
- What is promising

A Green Energy Utopia?



Some Facts about H2

- Darn hard to store and manage
- Do we have a hydrogen mine, anyone?
- It’s sort of an energy medium, not a source (if nuclear fusion is not considered)

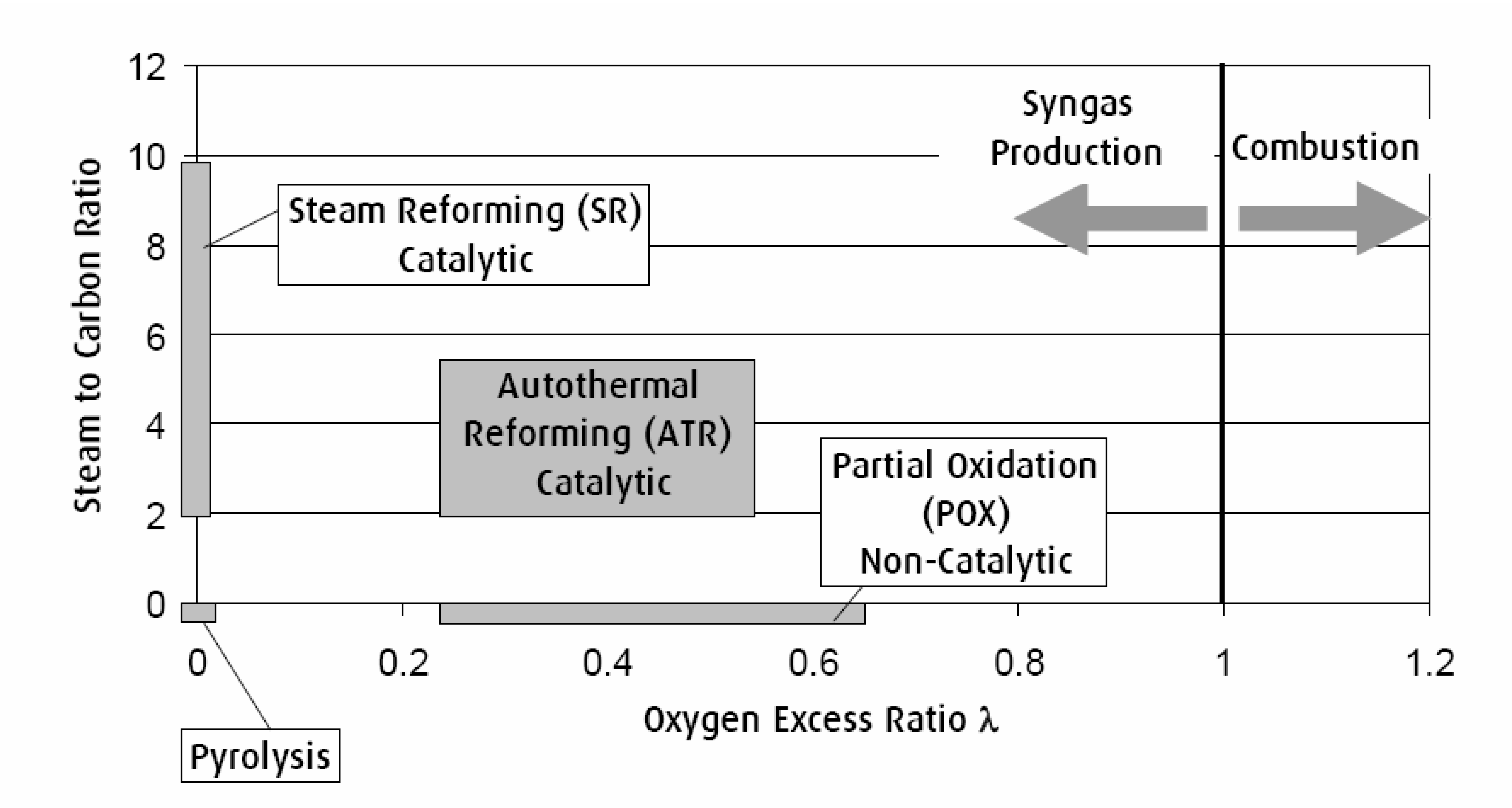
Where do we get H2 today?

- Steam reforming of methane (Dominating technology) or other hydrocarbons, alcohols
- The Syn-Gas process
- Electrolysis

Feedstocks

Light Hydrocarbons	Heavy Hydrocarbons
▪ Refinery Gases ▪ LPG (Propane, Butane) ▪ Natural Gas (48 %) ▪ Naphtha	▪ Fuel Oil (30 %) ▪ Vacuum Tar ▪ Asphalt ▪ Petroleum Coke ▪ Coal (18 %)
Process	**Process**
▪ Steam Reforming ▪ Partial Oxidation	▪ Partial Oxidation

Various reforming processes



Various reforming reactions

Non Oxygen Consuming:

- Steam Methane Reforming (SMR)
  $CH_4 + H_2O \rightarrow CO + 3\ H_2$ endothermal
- Carbon Monoxide Conversion (CO-Shift)
  $CO + H_2O \rightarrow CO_2 + H_2$ exothermal

Steam Reforming

Oxygen Consuming

- Hydrocarbon Conversion
  $C_nH_m + n/2\ O_2 \rightarrow nCO + m/2\ H_2$ exothermal
- H_2 Oxidation
  $2\ H_2 + O_2 \rightarrow 2\ H_2O$ exothermal
- Carbon Monoxide Oxidation
  $2\ CO + O_2 \rightarrow 2\ CO_2$ exothermal

Partial Oxidation, Autothermal Reforming

- **Synthesis Gas contains H_2, CO, H_2O, CO_2, unreacted Hydrocarbons, Impurities**
- **Requested Products are H_2, CO, CO+H_2**
- **H_2 Separation + Purification required**

Issues for reforming

- New bottle, old wine
- Non sustainable fossil fuels
- Hydrogen purification
- Its not really a cyclic hydrogen production; more like a mining and leaching of H2

Existing issues with electrolysis

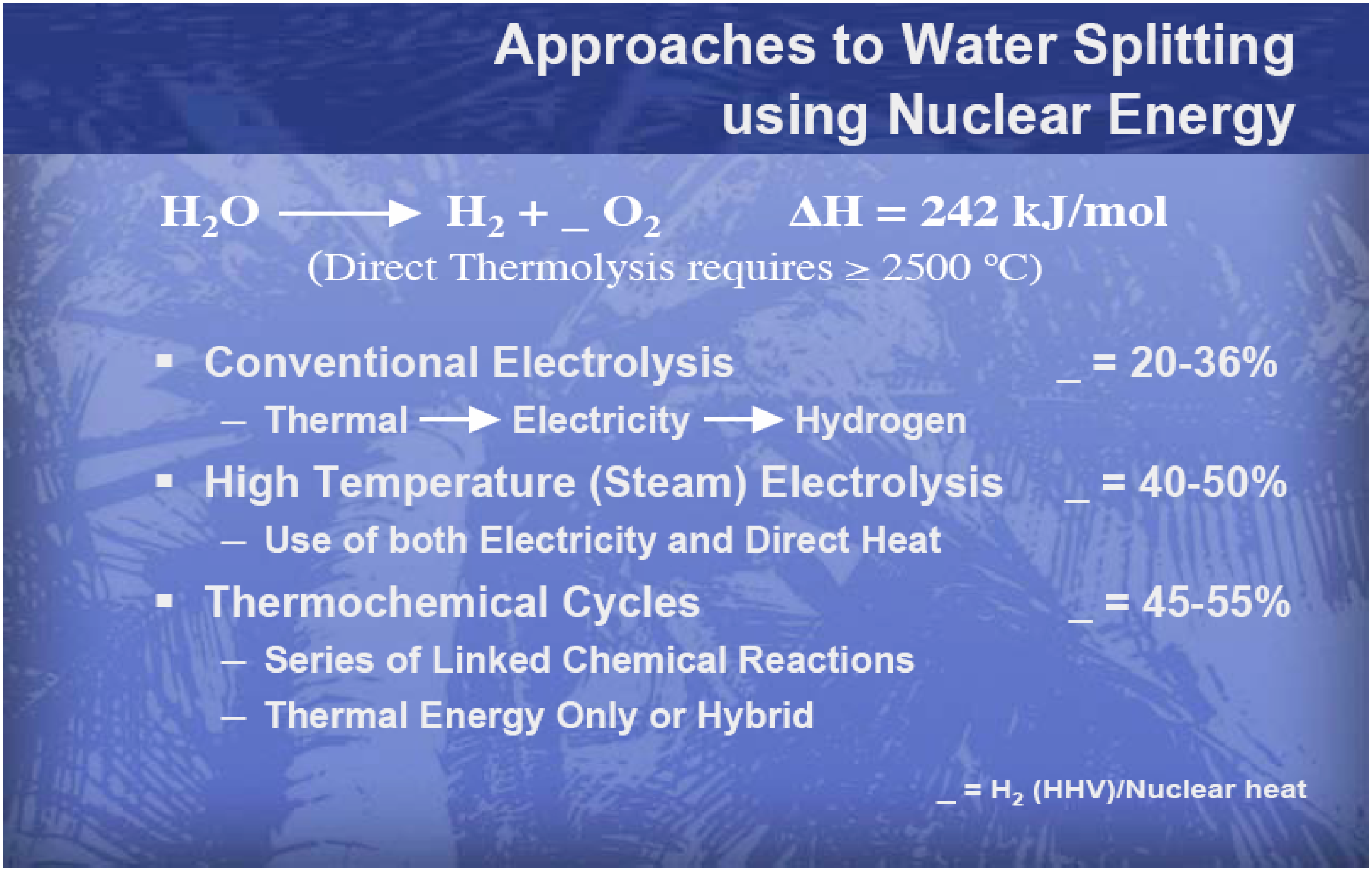
- Energy intensive
- Using high quality energy (electricity)
- Electrolyzers are costly (corrosion, noble metals, PEM, etc.)

What hurts electrolysis

- Overpotential in the hydrogen evolution reaction (HER)
- Stability of electrodes in a certain pH range

- How to improve?
- High temperature electrolysis

Thermochemical H2 production



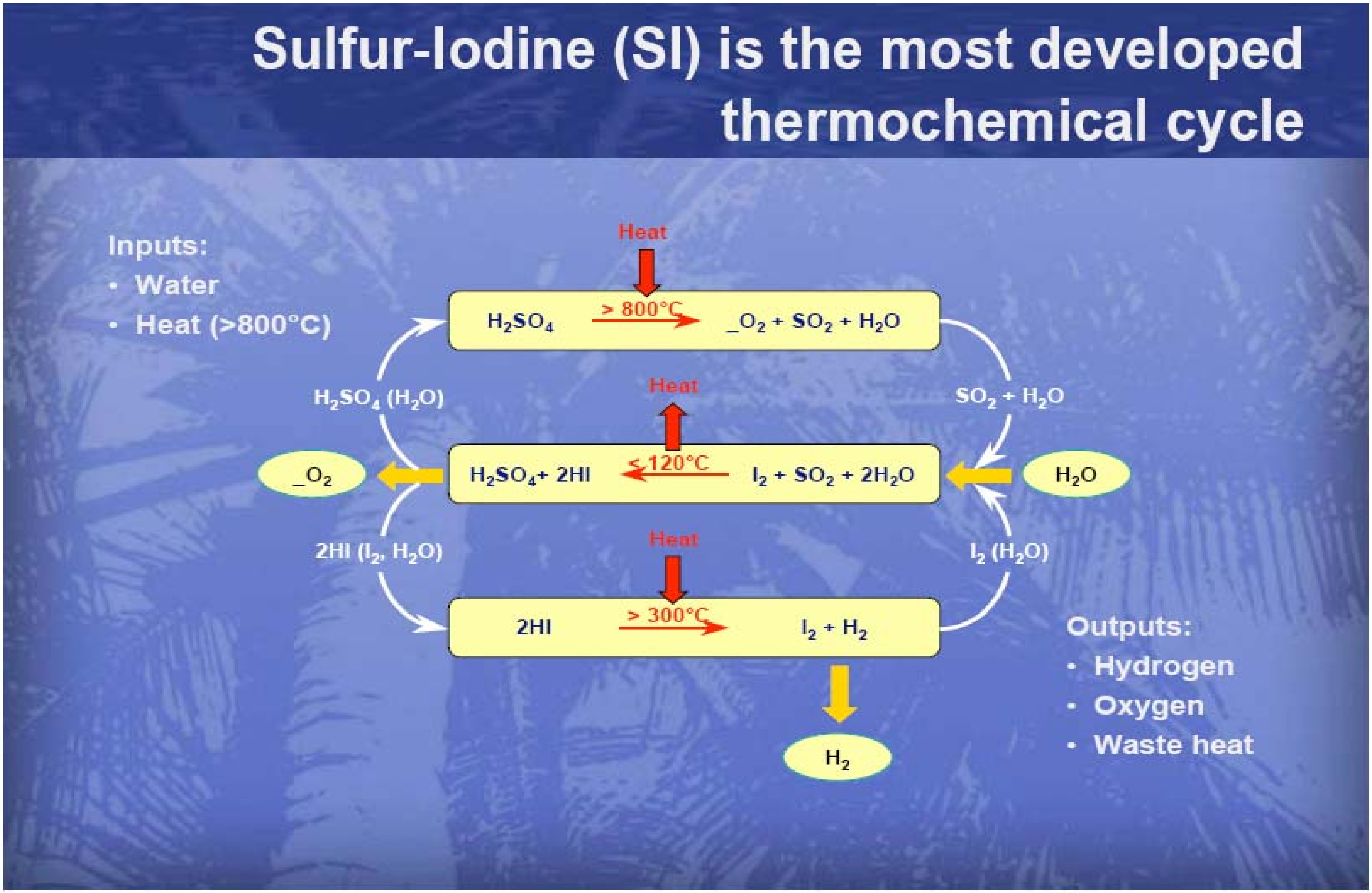
Thermochemical H2 production

- Potentially the highest cycle efficiency
- Negligible electrochemical corrosion
- Bulk reaction instead of an interfacial one (as in electrolysis) -> higher yield

Thermochemical H2 production Wish List

- All reactants in fluid phases
- Proper phase separation of some reaction intermediates
- Good isolation and purification of the products

Thermochemical H2 production

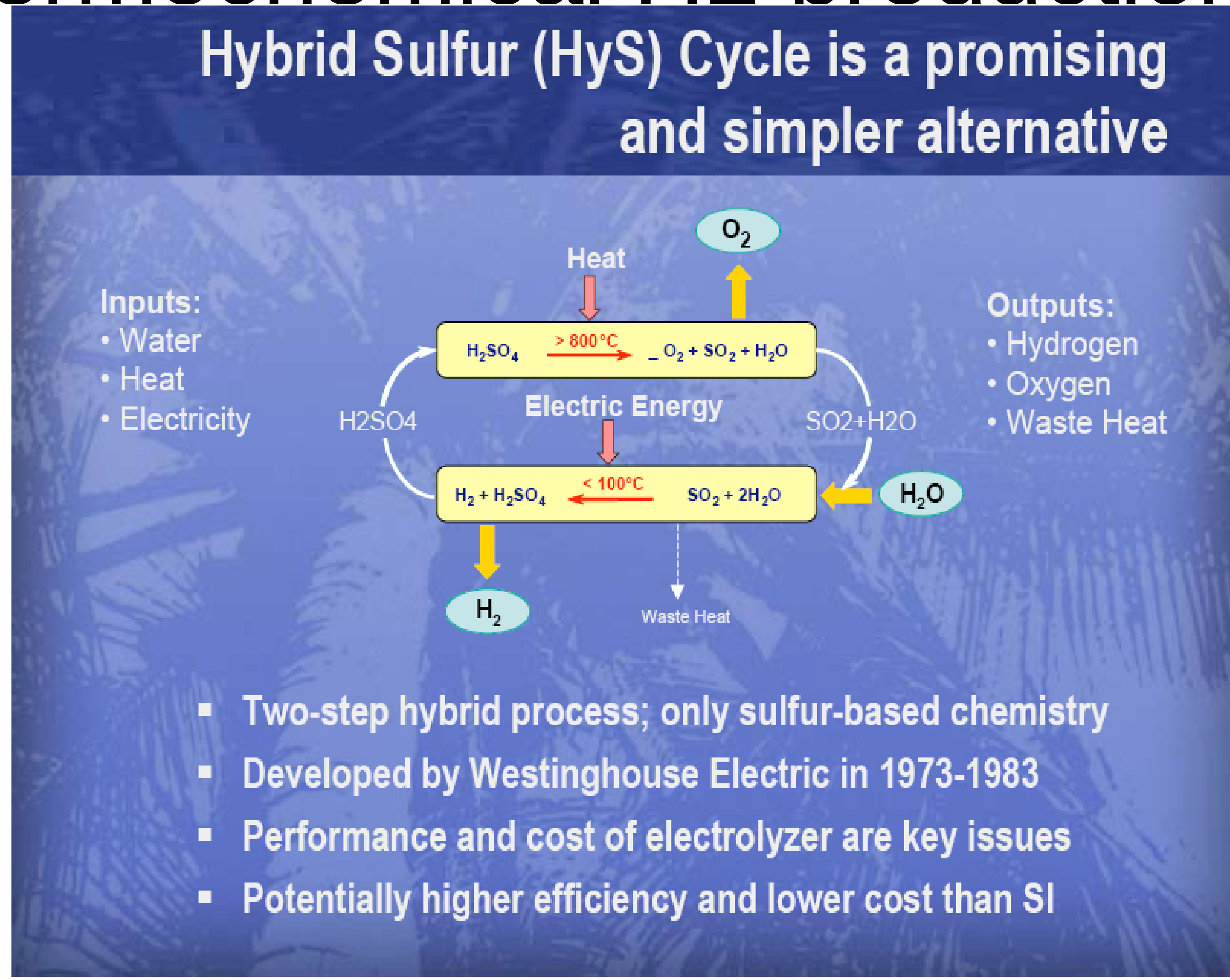


Neat features of the S-I process

- Sulfur-Iodine
- All reactants can be a fluid if the cycle temperature is properly chosen
- A natural phase separation exist in the intermediate HI and H_2SO_4
- Thermo-only process.

Thermochemical H2 production

Some Variations



Neat features of the S-I process

- In comparison, the Sulfur-Bromine process needs an electrolysis to split HBr

$2HBr \rightarrow H_2 + I_2 \quad \sim 1.066V$

Neat features of the S-I process

- Issues
- The first step is exothermic, and is preferably carried out at a T lower than 120 C.
- Iodine is relatively not very abundant and so the cost could be high.

Any idea on improving the S-I?

- Think about your suggestions/improvements
- No need to demo in labs yet, but at least the concept please.
- This could be one problem for the HW#2