Nuclear Hydrogen Production using the Copper-Chlorine Thermochemical Cycle

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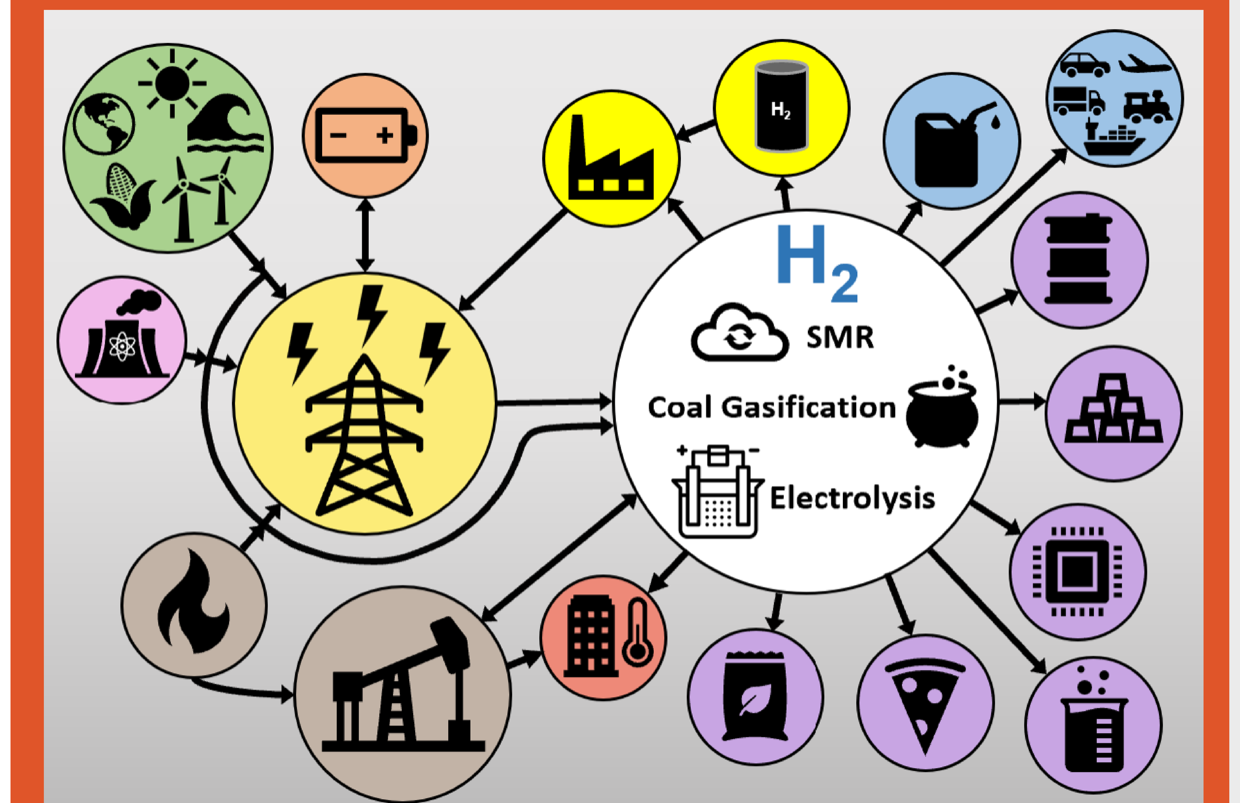
Background



H2@Scale. *U.S. DOE*. 2020
Path to hydrogen competitiveness: A cost perspective. Hydrogen Council. 2020
Hydrogen Strategy: Enabling a Low-Carbon Economy. U.S. DOE. 2020

Economics

- Major cost drivers: reactors, materials of construction, water usage, energy efficiencies

Renewable Energy Certificate (REC)	
Unit of measure	1 MWh of renewably sourced electricity generated with a low/zero emission energy source
Source	Generators of renewable electricity
Represent	Property rights to environmental & social benefits
Requirements	• No fossil fuels used • Generator must maintain RECs for renewability
Purpose & Benefits (Generator)	• Proof of electricity source renewability • Additional revenue stream • REC Arbitrage
Purpose & Benefits (Consumer)	• Claim direct/indirect use of renewable electricity from low/zero emission source • Reduce scope 2 (indirect) emissions • Expand electricity choices

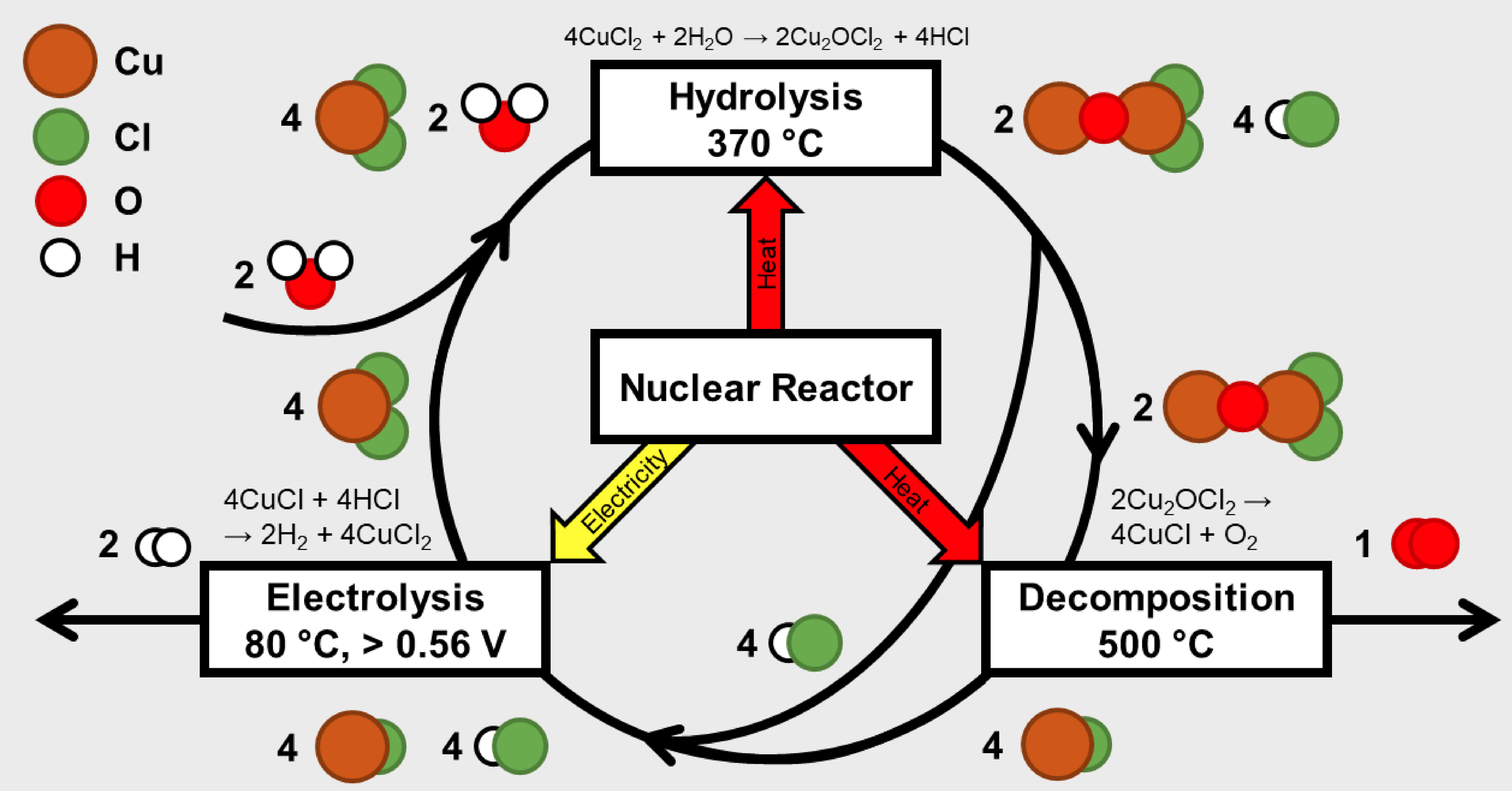
Offset	
Unit of measure	1 MT CO_2-equivalent emissions
Source	Activities meant to reduce or avoid GHG emissions
Represent	Verified GHG emission reductions
Requirements	• Additionality • Rigorous verification • Stated reduction time frame
Purpose & Benefits (Generator)	• Funding source • Verify emission reductions • Lower costs of mitigation
Purpose & Benefits (Consumer)	• Subtract from net emissions to meet voluntary reduction goals • Claim to reduce/avoid GHG emissions

Green Power Partnership. *Offsets and RECs: What's the Difference?* EPA. 2018.
Part 260 - Guides for the use of environmental marketing claims. U.S. FTC. 2012.
Green Power Partnership. *Renewable Energy Certificate (REC) Arbitrage*. EPA. 2017.

Oregon State University

Project Statement

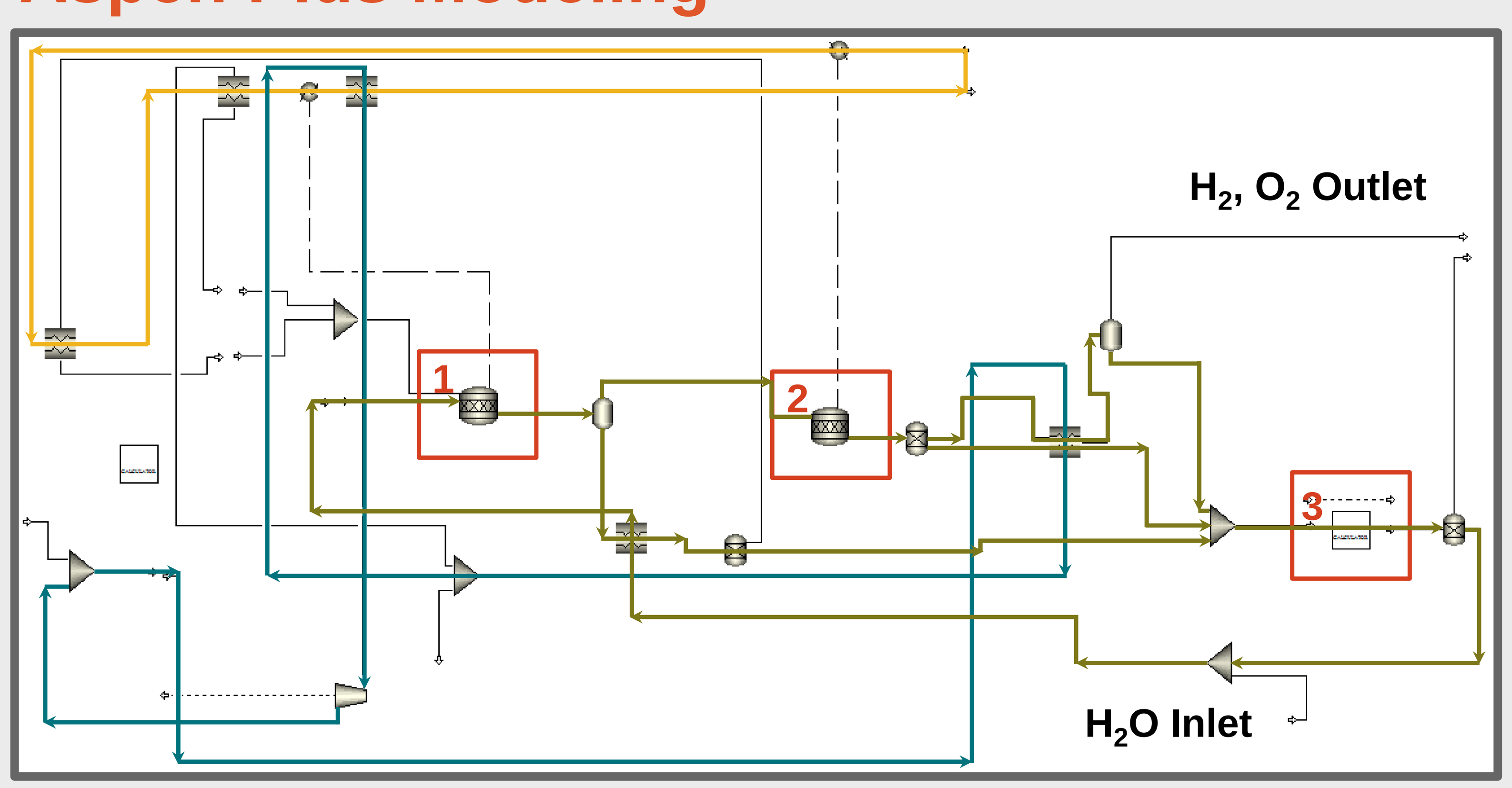
Develop a preliminary design of a nuclear hydrogen plant with a production capacity of 170 metric tons of hydrogen (H_2) per day via the copper-chlorine thermochemical cycle



Copper-Chlorine (Cu-Cl) Thermochemical Cycle

- **Overall $2H_2O \rightarrow 2H_2 + O_2$**
- Highest total sustainability score of all hydrogen technologies, desirable over current standard coal gasification and steam methane reformation technologies
  - NUCET, 2022, 54(4), 1288-1294
- Highly desirable due to increased efficiency (30-40%) over alternative technologies such as wind (20-40%) and solar photovoltaic (4-6%)
  - Int. J. Hydrog. Energy, 2012, 37(21) 16266-16286

Aspen Plus Modeling



Overview

- Key reactors
  1. Hydrolysis
  2. Decomposition
  3. Electrolysis
- Supercritical water thermal energy from nuclear reactor
- Superheated steam loop for waste heat recovery
- Cu-Cl loop

Methodology

- Used lab-scale experimental reactor performance to develop scaled models
  1. Hydrolysis: Int. J. Hydrog. Energy, 2010, 35(3), 992-1000
  2. Decomposition: Int. J. Hydrog. Energy, 2012, 37(21), 16557-16569
  3. Electrolysis: Orhan MF, UOIT, 2011
- Peng-Robinson method used for gas modeling
- Electrolyte non-random two liquid method used for electrolyte modeling
- Henry's law used for dilute solution modeling

Results

- Cu-Cl cycle efficiency and plant power output is tunable via nuclear reactor output and steam flow rates
- At reactor thermal output of 1500 MW and steam flow rate of 350 kg/s: energy efficiency = 30%, net power out = 181 MW

Materials of Construction

Hazards	Stainless Steel 316	Hastelloy C-276	Diamalloy 4006 (coating)	YSZ (coating)
25 MPa pressure	✔	✔		
625 °C temperature		✔		
Hydrogen gas		✔	✔	✔
Hydrochloric acid		✔	✔	✔
Molten salts			✔	
Cost	$	$$$	$$$$	$$$$$

Int. J. Hydrog. Energy, 2017, 42(24), 15708-15723

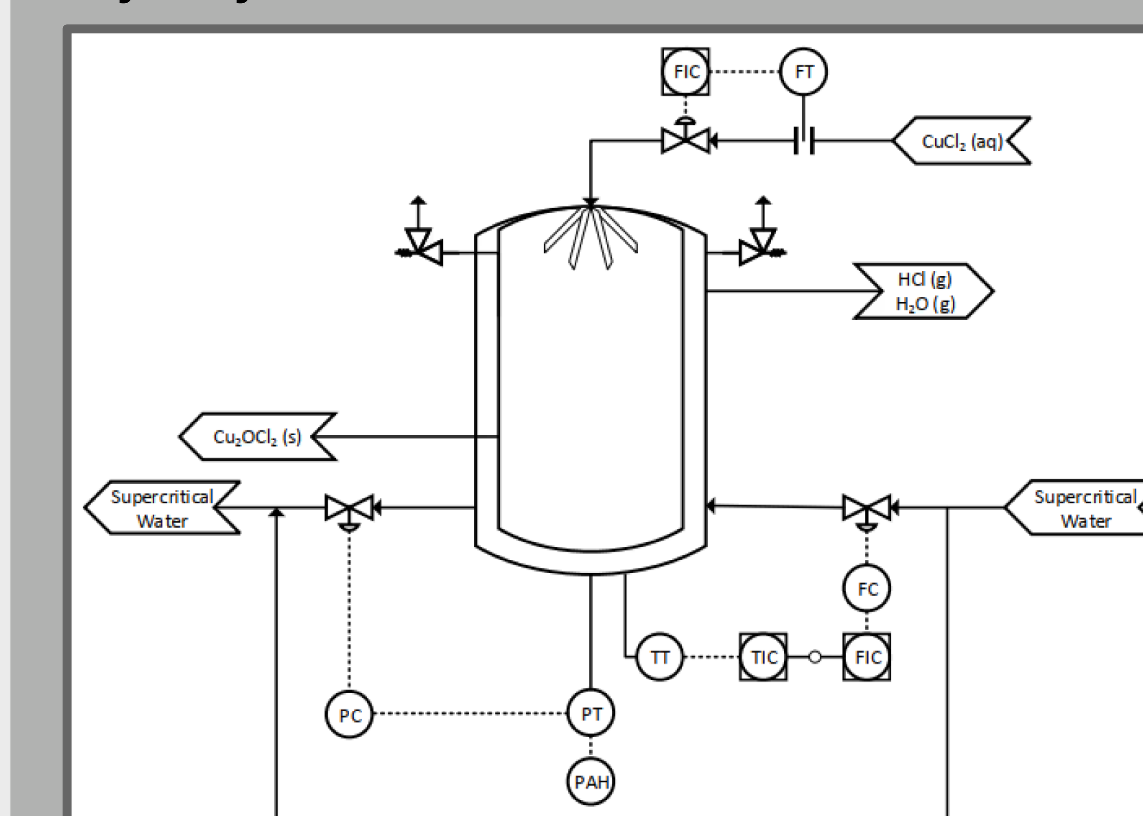
Extremely harsh conditions necessitate the use of Hastelloy C-276 with a Diamalloy 4006 layer deposited by high velocity oxy-fuel coating in the hydrolysis and decomposition reactors

Hastelloy C-276 is sufficient in the electrolyzer

Stainless steel 316 is sufficient for auxiliary equipment

Safe Operation (P&ID)

Hydrolysis Reactor



Decomposition Reactor