SCIENTIFIC FORUM

NUCLEAR ENERGY FOR CLIMATE

Hydrogen Production by Nuclear Power

Practical Pathways for Gradual Realization

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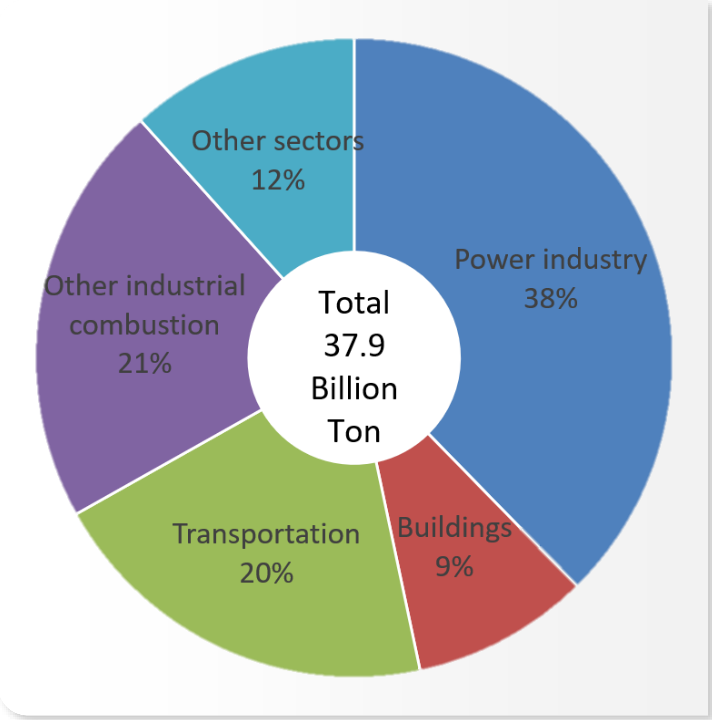
Need for Hydrogen in Non-Electricity Energy Sectors

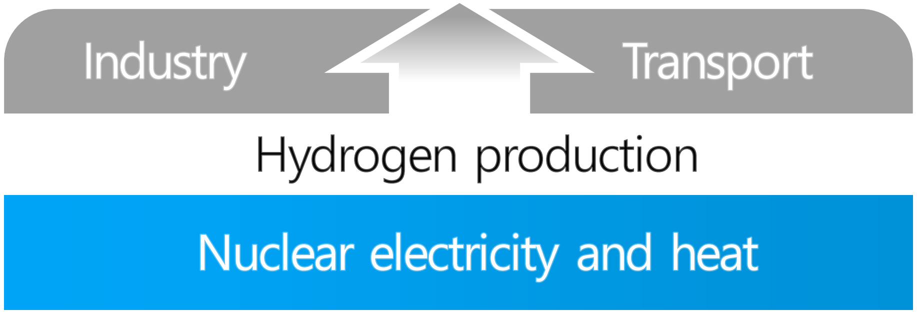
Global energy-related CO2 emission by sector



Source: Statistica.com (2021).

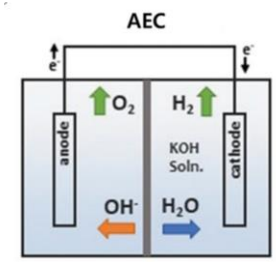
CO_2 emission reduction through the use of hydrogen in industrial and transportation sectors

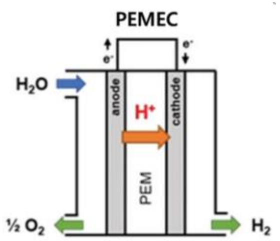
- Energy storage and feedstock synthetic fuels
- Fuel cells for heavy duty vehicles and building heating
- Steel production by hydrogen reduction and other uses

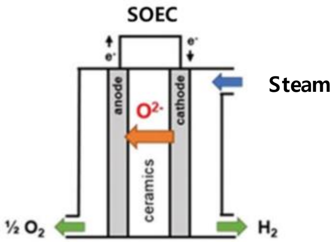


Hydrogen Production Methods

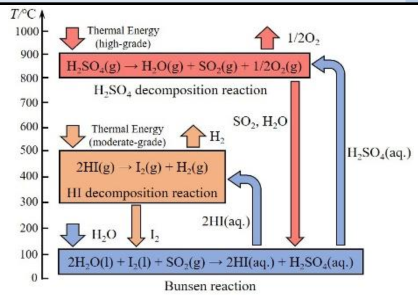
Water Electrolysis			Chemical Water Splitting	5. Steam Methane Reforming (SMR)
1. Alkaline Electrolysis (AE)	2. Proton Exchange Membrane (PEM)	3. Solid Oxide Electrolysis (SOE)	4. Sulfur-Iodine Cycle (S-I)	
Operating Temperature 60~90 ℃	50~90 ℃	**High Temperature Steam** Over 700 ℃	850 ℃	Over 700 ℃
Features ✓ Proven method ✓ Cost effective ✓ Cheap catalyst × Low pressure × Low flexibility × Low gas purity × Corrosive electrolyte	✓ High pressure ✓ High current density ✓ High gas purity ✓ Flexibility × Expensive catalyst × High cost	✓ Heat energy use ✓ High current density ✓ High gas purity ✓ High efficiency ✓ Cheap catalyst × Low pressure × First-mover-disadvantage	✓ Heat energy use ✓ High efficiency ✓ Closed system ✓ Continuous production × Corrosive environment × Expensive material × Not yet verified	✓ Proven technology × Highest CO_2 emission



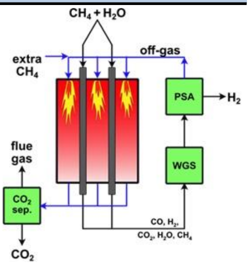




Source: Korea Institute Energy Research (2022).



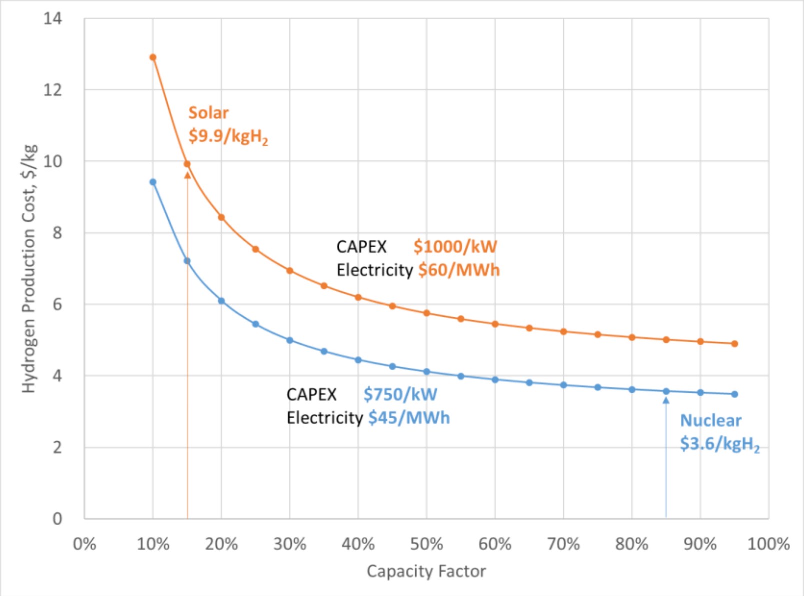
Source: T. Proll and A. Lyngnfelt (2022)Source: BASF (2019).



Source: Q. Wang (2022).

Limitation of Renewables Due to Low Capacity Factors

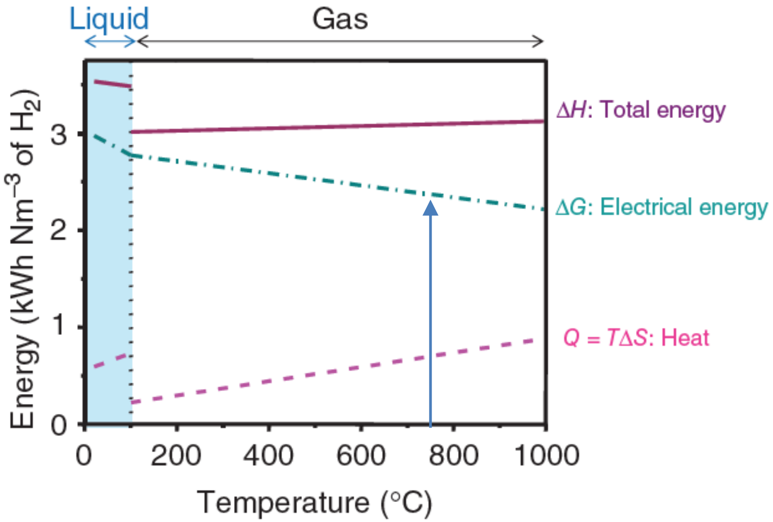
Korea Case



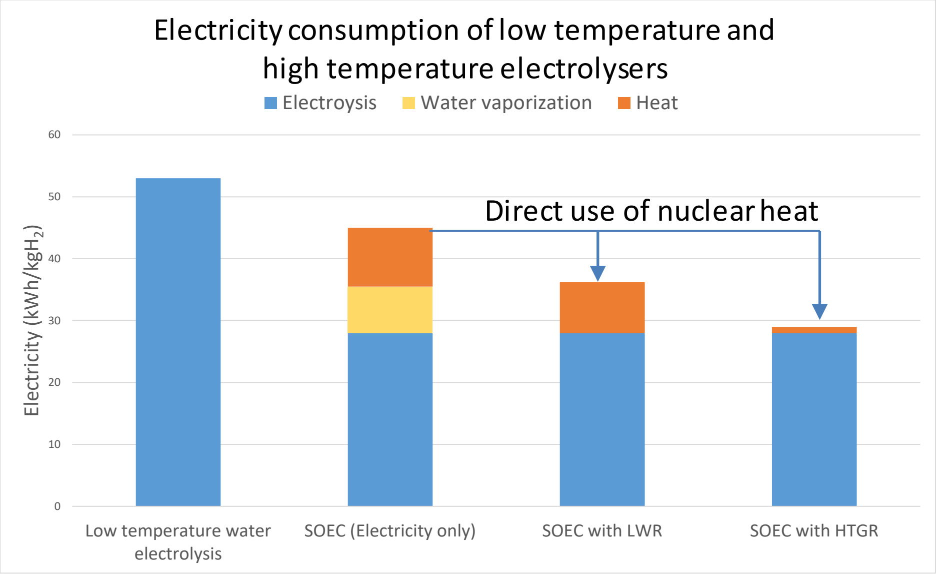
- Intermittent and variable electricity input causes instability in electrolyzer
- Low capacity factor leads to higher electricity cost and electrolyzer cost

* Internal calculation by KAERI based on two assumed values of CAPEX and electricity price.

Advantage of High Temperature Steam Electrolysis with Nuclear Power



Energy demand as a function of temperature for electrolysis



SOEC:	Solid Oxide Electrolysis
LWR:	Light Water Reactor
HTGR:	High Temperature Gas Cooled Reactor

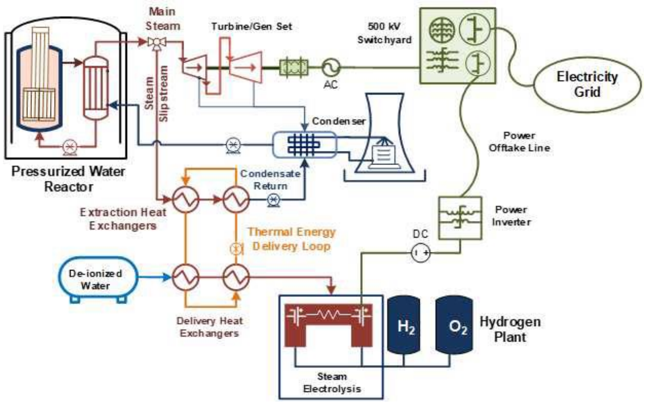
Status of High Temperature Steam Electrolysis with Nuclear Power

USA

- 100 kW Bloom energy HTSE system is being operated at INL
- Xcel Energy will install a 100+ kW HTSE system at an NPP in the Minneapolis/St. Paul region
- APS is evaluating the integration of a HTSE system at its Palo Verde Nuclear Generating Station

*Arizona Public Services

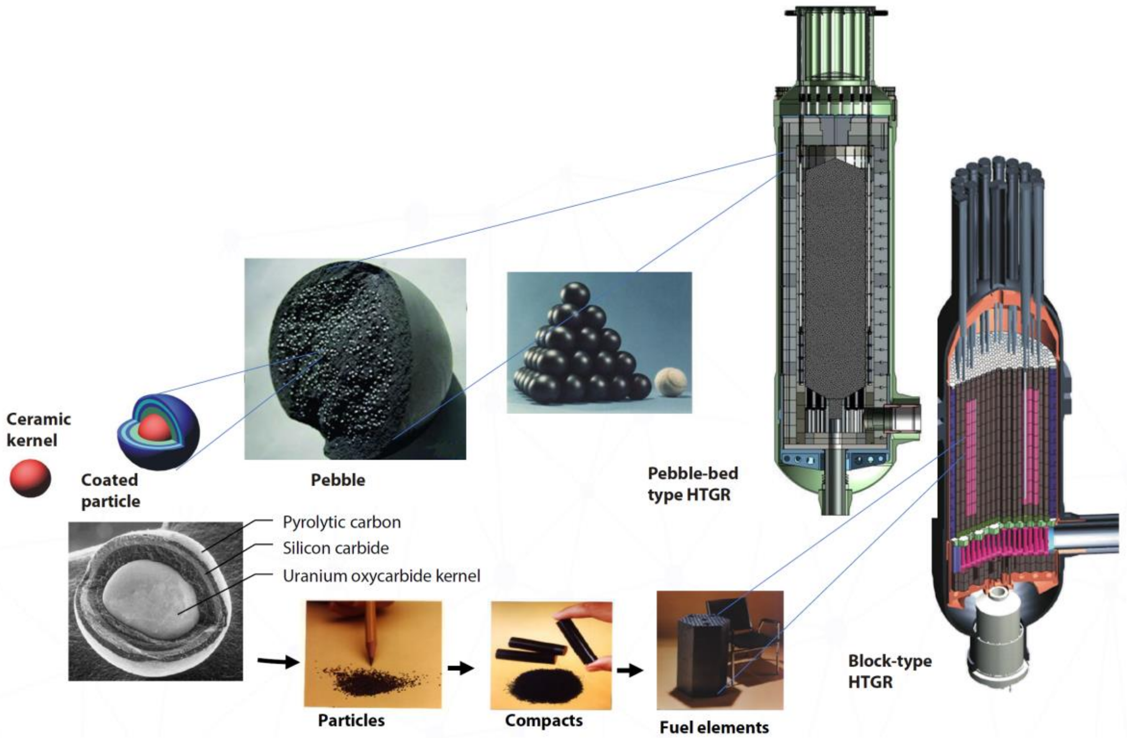
Bloom prototype 100 kW HTE system at INL
Source: INL, 2022



Overview of HTSE integrated with an NPP
Source: INL, 2022

The Prairie Island nuclear power plant
(Photo: Xcel Energy)

High Temperature Gas Reactors



Source: Gougar, H.D., INL, 2019

Technical characteristics

- Heat supply capability (550~ 900℃)
- Safety features (TRISO coated fuel)
- Technical maturity
- Nuclear non-proliferation and security

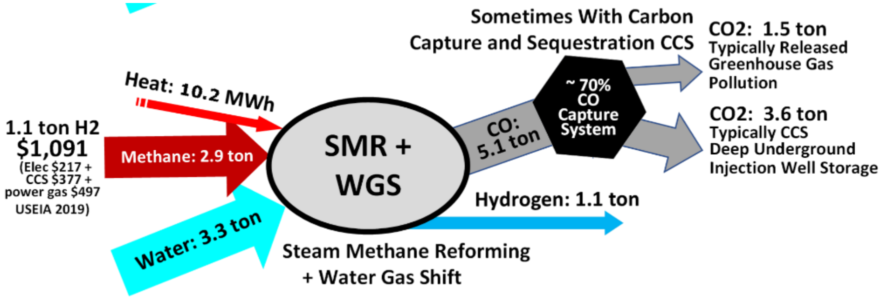
Potential benefits

- Low carbon energy source
- High-temperature heat supply
- Reliability and flexibility

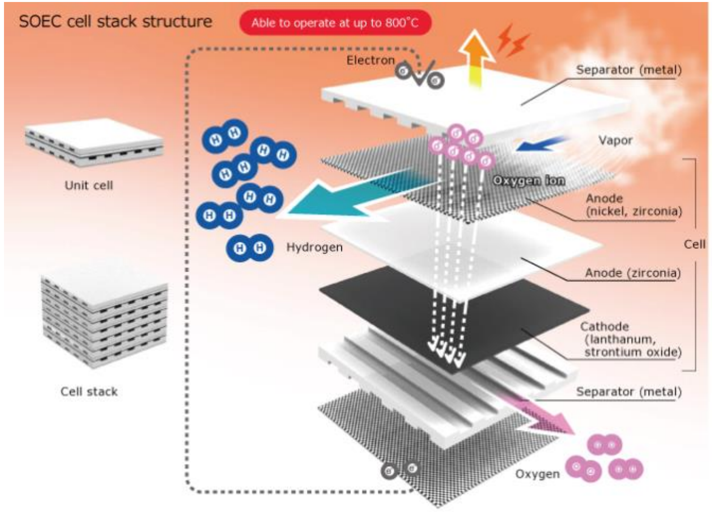
Better Possibilities with High Temperature Gas Reactors

Steam Methane Reforming with Carbon Capture and Sequestration

$CH_4+H_2O \rightarrow CO+3H_2$ (206 kJ/mol)
$CO+H_2O \rightarrow CO_2+H_2O$

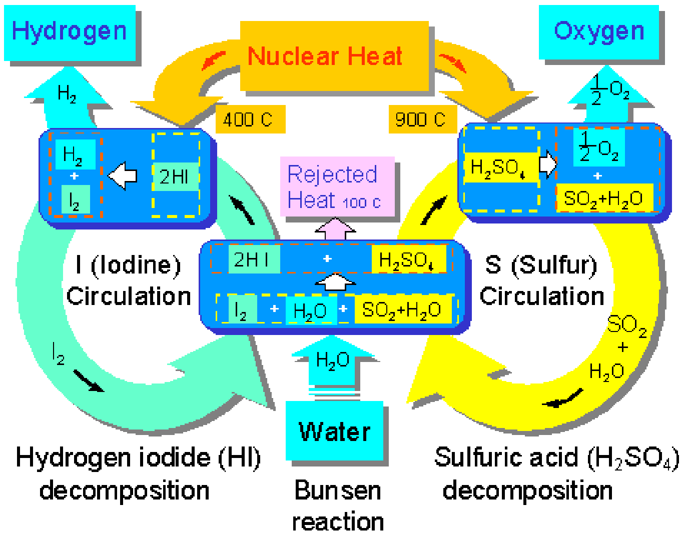


High Temperature Steam Electrolysis with SOEC



https://www.toshiba-energy.com/en/hydrogen/rd/

Challenges in Sulfur-Iodine Chemical Cycle even with the Availability of High Temperature Heat

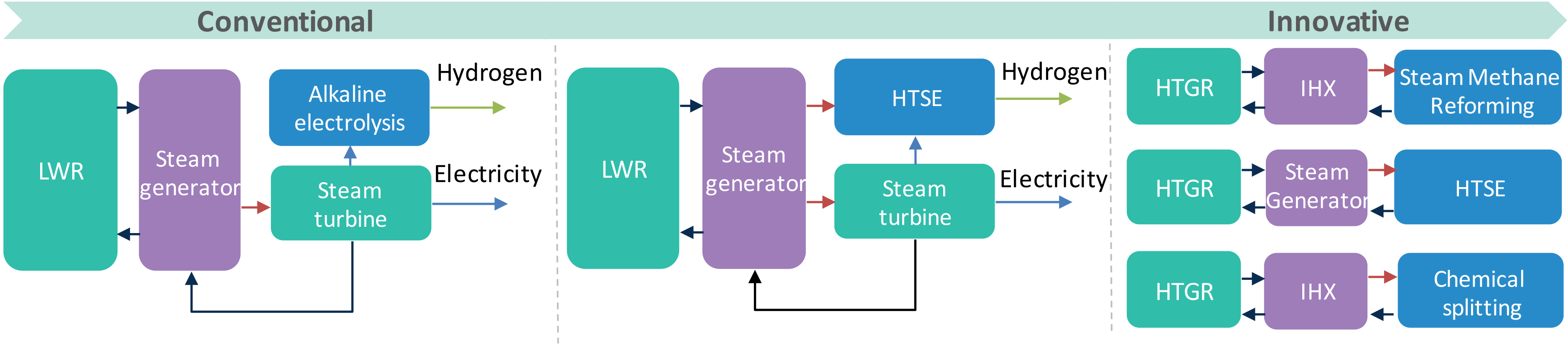


Critical point regarding both energy and efficiency

- HI_x Section (a mixture of iodine and iodides)
- A **large thermal burden** (decrease of the global efficiency) due to
  - Azeotropic composition in the HI/H_2O system (at about 57% w/w)
  - Excess of water and iodine from Bunsen reaction
- Electrodialysis (ED) was proposed to concentrate HI aqueous solutions.
- The ED system is still having a **high electricity consumption**.

Practical Pathways for Nuclear Hydrogen Production

- Alkaline Electrolysis with Operating Nuclear Reactors
- **H**igh **T**emperature **S**team **E**lectrolysis with Operating and Newly Built Reactors
- Steam Methane Reforming with **H**igh **T**emperature **G**as **R**eactors
- HTSE with HTGR
- Chemical Splitting with HTGR



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Thank You

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