Micro-reactor evaluation for hydrogen economy

Roberto Fairhurst Agosta

Advanced Reactors and Fuel Cycles
University of Illinois at Urbana-Champaign

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ILLINOIS

Outline

Electricity and Hydrogen Generation

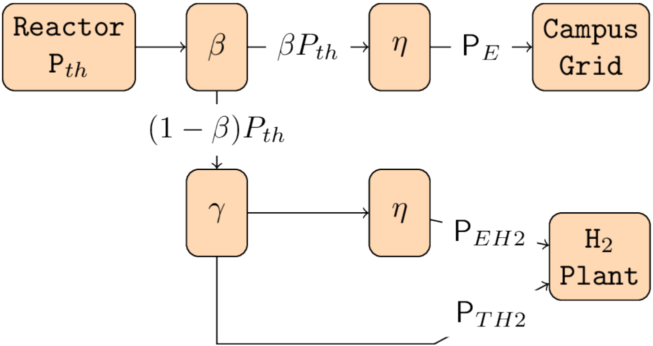

Figure: Diagram of a reactor coupled to a hydrogen plant.

Outline

Electrolysis

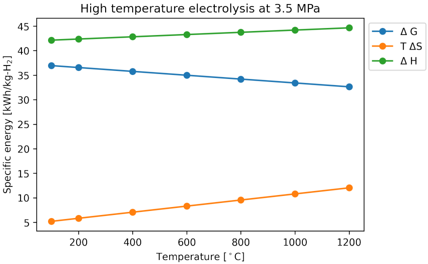

Figure: Energy required by HTE at 3.5 MPa.

$$\Delta H = \Delta G + T\Delta S$$

- ΔG: specific electrical energy $kWh \cdot kg_{H_2}^{-1}$
- TΔS: specific thermal energy $kWh \cdot kg_{H_2}^{-1}$.

- In low temperature electrolysis (LTE), electricity provides the thermal energy.
- In high temperature electrolysis (HTE), a heat source provides the thermal energy.
- HTE has the advantage of decreasing the electricity requirement.

Sulfur-Iodine

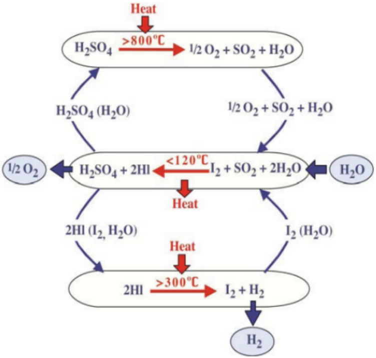

Figure: Diagram of the Sulfur-Iodine Thermochemical process.

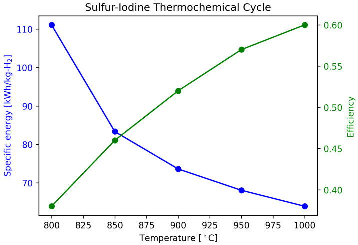

Figure: Energy required by the Sulfur-Iodine Thermochemical Cycle.

Co-generation

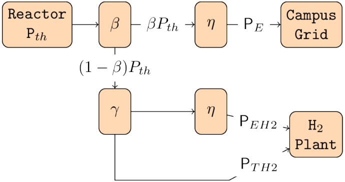

Figure: Diagram of a reactor coupled to a hydrogen plant.

Table: Energy requirements of the different H_2 production methods.

Method	γ	P_{EH2}	P_{TH2}
LTE	1	$\neq 0$	0
HTE	$0 < \gamma < 1$	$\neq 0$	$\neq 0$
SI	0	0	$\neq 0$

Outline

Fuel demand

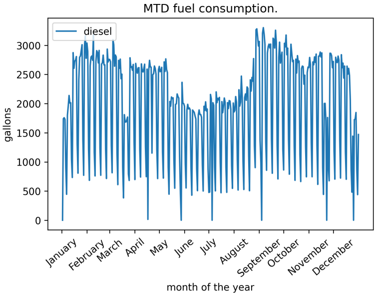

Figure: MTD fuel consumption. Data goes from July 1, 2018, until June 30, 2019 [6].

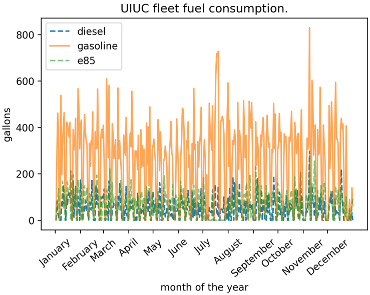

Figure: UIUC fleet fuel consumption. Data goes from January 1, 2019, until December 31, 2019 [10].

Hydrogen requirement

Table: GGE, DGE, and E85GE [8] [2].

	Hydrogen mass [kg]
GGE	1
DGE	1.13
E85GE	0.78

Table: Hydrogen requirements.

Total [tonnes/year]	943
Average [kg/day]	2584
Average [kg/h]	108
Maximum in one day	4440 kg

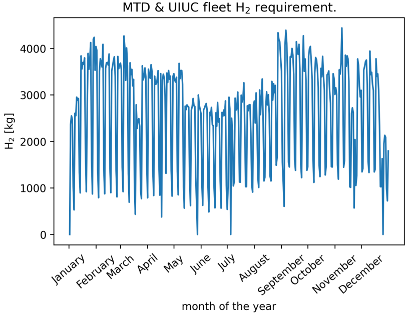

Figure: Hydrogen requirement for MTD and UIUC fleets.

Hydrogen production rate

Table: Microreactor designs.

Reactor	P[MW_{th}]	T_o[°C]
MMR [9]	15	640
eVinci [5]	5	650
ST-OTTO [4]	30	750
U-battery [3]	10	750
Starcore [7]	36	850

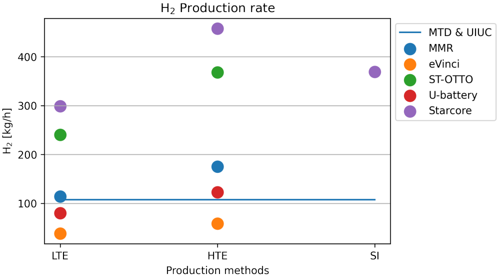

Figure: Hydrogen production rate by the different microreactor designs.

Net demand prediction

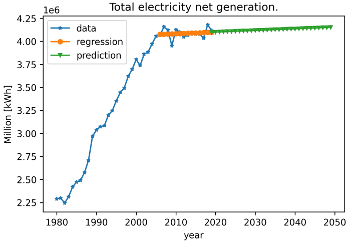

Figure: Prediction of the total electricity generation in the US for 2050. Data from [1].

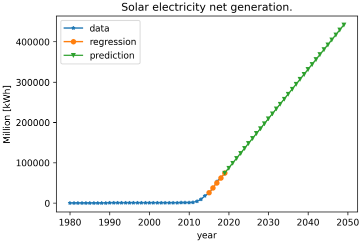

Figure: Prediction of the solar electricity generation in the US for 2050. Data from [1].

Duck curve

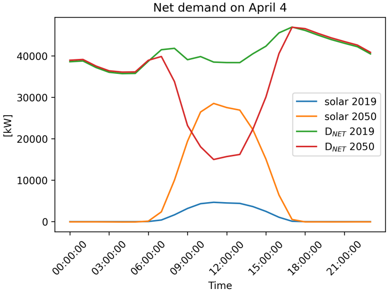

Figure: Prediction of UIUC's net demand for 2050.

- Spring: solar production is higher, total demand is low.
- Solar generation peaked on April 4, 2019.

D_{NET} = Total demand - Solar energy

- Peak demand: 46.9 MW at 5 P.M.
- Lowest demand: 15 MW at 11 A.M.
- Requires an installed capacity of 31.9 MW of dispatchable sources.

Over-generation

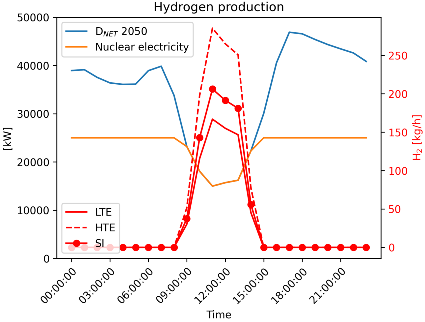

Figure: Hydrogen production with the excess of energy due to a net demand decrease.

25 MWe reactor

Low temperature electrolysis (LTE):

- $\eta = 33\%$.
- Cumulative H_2: 660 kg.

High temperature electrolysis (HTE):

- HTGR.
- $T_o = 850°C$.
- $\eta = 49.8\%$
- Cumulative H_2: 1129 kg.

Sulfur-Iodine (SI):

- HTGR.
- $T_o = 850°C$.
- $\eta = 49.8\%$
- Cumulative H_2: 815 kg.

Outline

HTE with Steam Temperature Boosting System

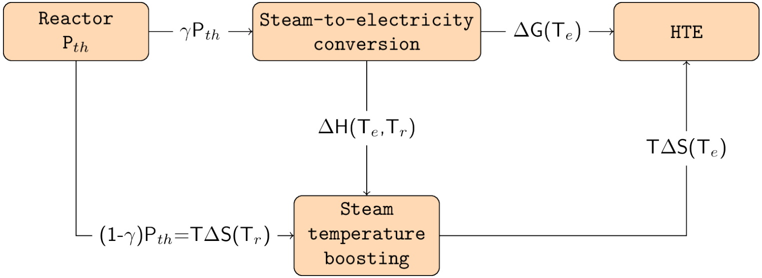

Figure: Diagram of a reactor coupled to a hydrogen plant via HTE with steam temperature boosting system.

Natural Gas Reforming

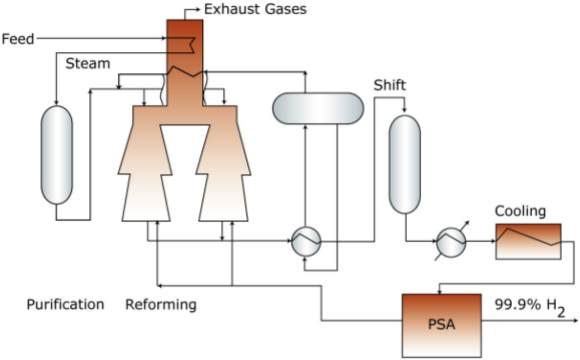

Figure: Steam methane reforming technology.

Addition of Hydrogen in Transportation to TEMOA's Model

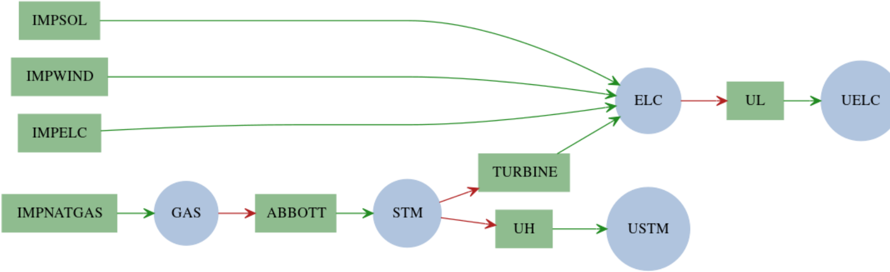

Figure: UIUC's grid model in TEMOA.

References I

[1] US Energy Information Administration.
Electric Power Monthly with data for February 2020.
page 273, April 2020.

[2] Alternative Fuels Data Center.
Fuel Properties Comparison, October 2014.

[3] Ming Ding, J. L. Kloosterman, Theo Kooijman, and Rik Linssen.
Design of a U-Battery.
Technical Report PNR-131-2011-014, Urenco, and Koopman and Witteveen, November 2011.

[4] Bowers Harlan.
X-energy Xe-100 Reactor initial NRC meeting, September 2018.

[5] Richard Hernandez, Michael Todosow, and Nicholas R. Brown.
Micro heat pipe nuclear reactor concepts: Analysis of fuel cycle performance and environmental impacts.
Annals of Nuclear Energy, 126:419–426, April 2019.

[6] MTD.
MTD Public Records, December 2019.

References II

[7] Star Core Nuclear.
Star Core Spec Sheet, December 2015.

[8] DOE Office of Energy Efficiency and Renewable Energy.
Hydrogen Production, January 2020.

[9] USNC.
MMR - USNC, 2019.

[10] Pete Varney.
Personal Communication, January 2020.