Hydrogen Economy in Champaign-Urbana, IL

ANS Annual meeting 2020

Roberto Fairhurst Agosta, Samuel G. Dotson, Kathryn D. Huff

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

June 10, 2020

ILLINOIS

Outline

Introduction

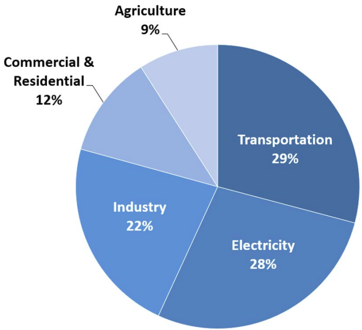

Figure: Total U.S. GHG Emissions by Economic Sector in 2017. Image reproduced from [5].

Illinois Climate Action Plan (iCAP) [10]:

- American College and University Presidents' Climate Commitment.
- Main goal: carbon neutrality by 2050.

Six target areas:

- Energy conservation.
- Energy generation, purchasing, and distribution.
- Transportation.
- Water and storm water.
- Waste and recycling.
- Agriculture, land use, and food.

Transportation

Fuel Cell Electric Vehicles (FCEV):

- Address global warming concerns.
- Limitation on fossil fuel supply.
- Examples:
  - Japan: Fuel cell vehicles, trucks, buses, forklifts.
  - California: 1000 refueling stations by 2030.
  - Champaign-Urbana: Expects 2 Hydrogen buses in 2020.

Figure: New Flyer fuel cell bus. Image reproduced from [6].

Energy generation

Obvious solution:

- More renewables.

New problem:

- Duck curve.
- Net demand ramps.
- Over-generation.

Consequences:

- Increase in dispatchable generation.
- Decrease in non-dispatchable generation.

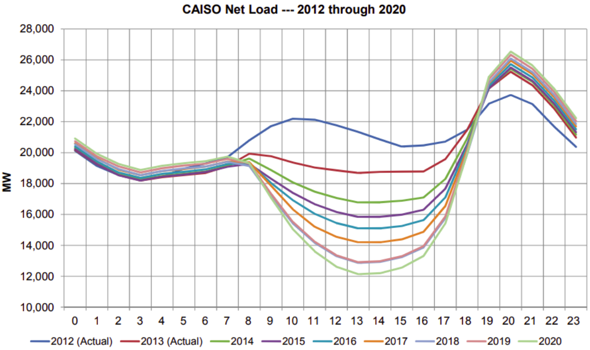

Figure: The duck curve. Image reproduced from [2].

A possible solution

Nuclear reactors and hydrogen:

- DOE and INL established the Next Generation Nuclear Plant (NGNP) [13].
- Office of Nuclear Energy (NE): H2@Scale initiative [16].
- Energy produced with no carbon emissions.
- Produce hydrogen as main/secondary product.
- Hydrogen as fuel for the FCEV.
- Hydrogen as electricity storage.

Approach consistent with our goal of reducing carbon emissions!!

Microreactors

- Several designs are under development in the US.
- Plug-and-play reactors.
- Remote commercial applications.
- Remote military bases.

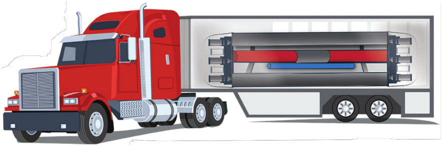

Figure: Microreactor design. Image reproduced from [17].

Features:

- Factory fabricated.
- Transportable.
- Self-regulating.

Objectives

1. Replace use of fossil fuels by CU MTD and UIUC fleets with hydrogen.
2. Supply the hydrogen with one or many microreactors.
3. Analyze the magnitude of the duck curve in UIUC grid.
4. Mitigate the negative effects of the duck curve.

Outline

Electrolysis

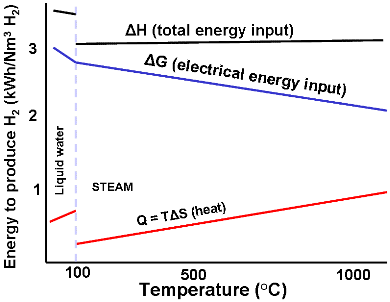

Figure: Energy consumption of an ideal electrolysis process. Image reproduced from [9].

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

- ΔG: Electrical energy.
- TΔS: Thermal energy.

- 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

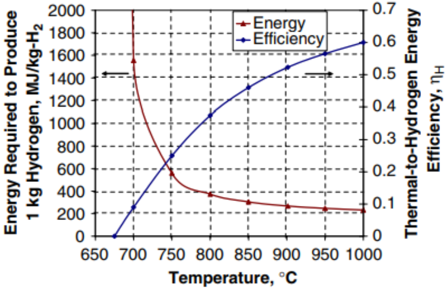

Figure: Sulfur-Iodine thermochemical cycle. Image reproduced from [12].

- 3 different reactions: sulfuric acid decomposition, Bunsen reaction, and hydrogen iodide decomposition.
- Input: H_2O.
- Output: H_2 & O_2.
- Does not require electricity.
- Needs a high temperature source.

Co-generation

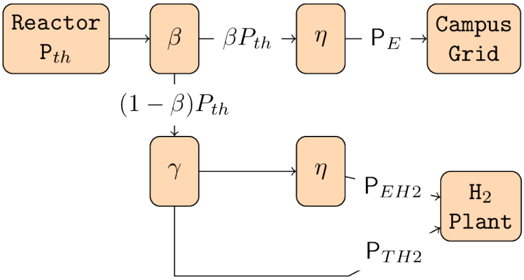

Figure: Diagram of a reactor coupled to hydrogen plant.

β: power fraction that is converted into electricity.
$\beta = 1$: no hydrogen produced.
$\beta = 0$: no electricity produced.

Low temperature electrolysis (LTE):

- γ=1. $P_{TH2} = 0$.

High temperature electrolysis (HTE):

- $0 < \gamma < 1$.

Sulfur-Iodine (SI):

- γ=0. $P_{EH2} = 0$.

Outline

Fuel demand

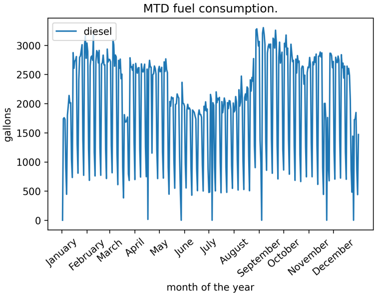

Figure: MTD fuel consumption. Data goes from July 1, 2018, until June 30, 2019 [11].

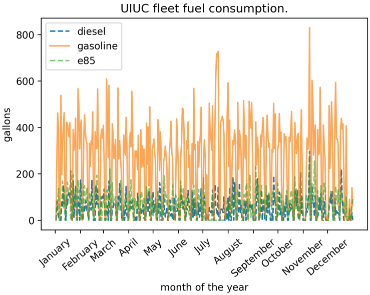

Figure: UIUC fleet fuel consumption. Data goes from January 1, 2019, until December 31, 2019 [19].

Hydrogen requirement

Table: GGE, DGE, and E85GE [15] [3].

	Hydrogen
GGE	1 kg
DGE	1.13 kg
E85GE	0.78 kg

Table: Hydrogen requirements.

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

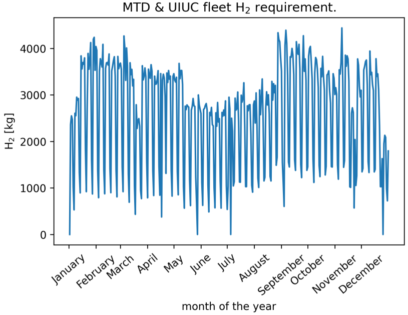

Figure: Hydrogen requirement for MTD and UIUC fleets.

Hydrogen production rate

Table: Microreactor designs.

Reactor	P[MW_{th}]	T_o[°C]
MMR [18]	15	640
eVinci [8]	5	650
ST-OTTO [7]	30	750
U-battery [4]	10	750
Starcore [14]	36	850

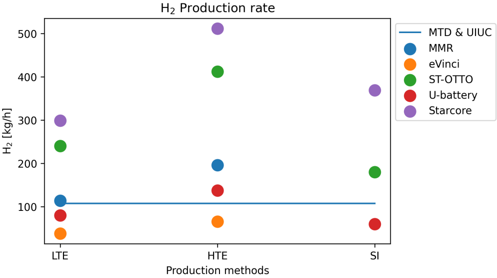

Figure: Hydrogen production rate by the different microreactor designs.

Net demand prediction

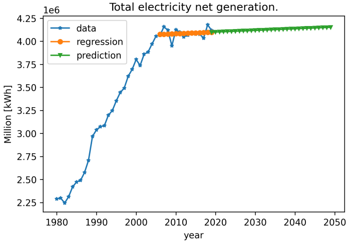

Figure: Prediction of the total electricity generation in the US for 2050. Data from [1].

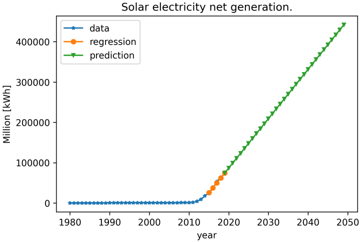

Figure: Prediction of the solar electricity generation in the US for 2050. Data from [1].

Duck curve

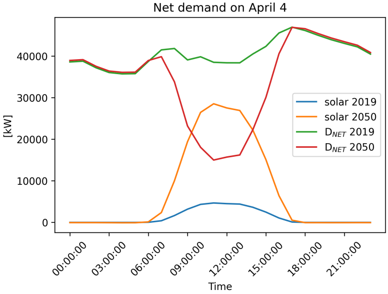

Figure: Prediction of UIUC's net demand for 2050.

- 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

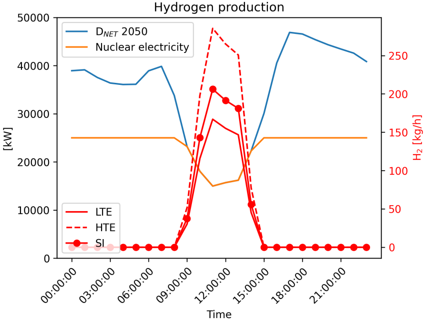

Figure: Hydrogen production with the excess of energy due to a net demand decrease.

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.

Hydrogen for energy storage

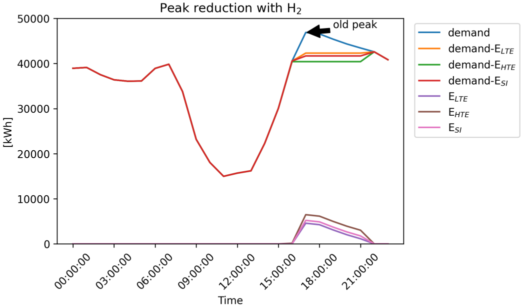

Figure: Peak reduction by using the produced H_2.

Low temperature electrolysis (LTE):

- Electricity produced: 15.9 MWh
- New peak: 41.9 MW
- Peak reduction: 5 MW

High temperature electrolysis (HTE):

- Electricity produced: 27.1 MWh
- New peak: 40.0 MW
- Peak reduction: 6.9 MW

Sulfur-Iodine (SI):

- Electricity produced: 19.6 MWh
- New peak: 41.3 MW
- Peak reduction: 5.6 MW

Outline

Conclusions

- The University of Illinois is actively working to reduce GHG emissions on its campus.
- A few microreactor designs would be able to produce enough hydrogen to meet MTD and UIUC fleet fuel demand.
- Increased solar penetration worsens the duck curve.
- Hydrogen introduces a way to store energy that reduces the reliance on dispatchable sources.
- Nuclear energy and hydrogen production present an approach to mitigate the negative implications of the duck curve.

Acknowledgement

This work is supported the NRC Faculty Development Program.
I would like to thank Beth Brunk (MTD), and Pete Varney (UIUC) for their contributions to the development of this project.

Thank you.
Questions?

References I

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

[2] Brad Bouillon.
Prepared Statement of Brad Bouillon on behalf of the California Independent System Operator Corporation, June 2014.

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

[4] 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.

[5] US EPA.
Sources of Greenhouse Gas Emissions, January 2020.

[6] New Flyer.
xcelsior charge H2, March 2020.

References II

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

[8] 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.

[9] Hi2H2.
Highly Efficient, High Temperature, Hydrogen Production by Water Electrolysis, January 2007.

[10] iSEE.
Illinois Climate Action Plan (iCAP).
Full Report 2015, University of Illinois at Urbana-Champaign, Urbana, IL, 2015.

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

[12] Mikihiro Nomura and Ikenoya Kazuhiko.
Efficient hydrogen production through the thermochemical IS process using membrane technologies, 2004.

References III

[13] US NRC.
Next Generation Nuclear Plant (NGNP), March 2017.

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

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

[16] Office of Nuclear Energy.
Could Hydrogen Help Save Nuclear?, November 2018.

[17] US-DOE.
The Ultimate Fast Facts Guide to Nuclear Energy.
Fact Sheet DOE/NE-0150, Department of Energy Office of Nuclear Energy, Washington D.C., January 2019.
https://www.energy.gov/ne/downloads/ultimate-fast-facts-guide-nuclear-energy.

[18] USNC.
MMR - USNC, 2019.

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