

Hydrogen Economy in Champaign-Urbana, IL

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

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Outline

① Introduction

Motivation

Finding a solution

Objectives

② Hydrogen Production

Hydrogen production methods

Nuclear energy-based hydrogen

③ Results

Transportation

Energy generation

④ Conclusion

Introduction

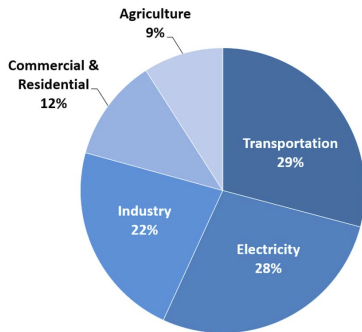


Figure: Total U.S. GHG Emissions by Economic Sector in 2017. Image reproduced from [5].

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.

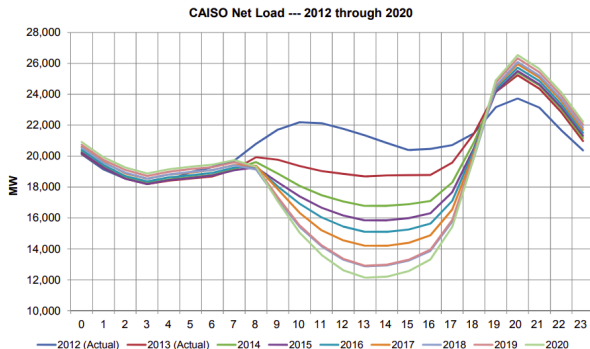


Figure: The duck curve. Image reproduced from [2].



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.



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① Introduction

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Electrolysis

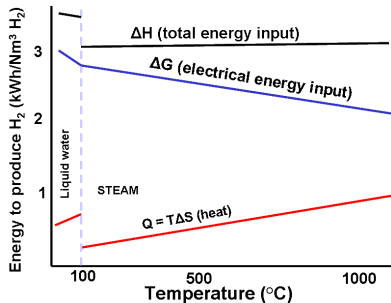


Figure: Energy consumption of an ideal electrolysis process. Image reproduced from [9].

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

- ΔG : Electrical energy.
- $T\Delta S$: 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

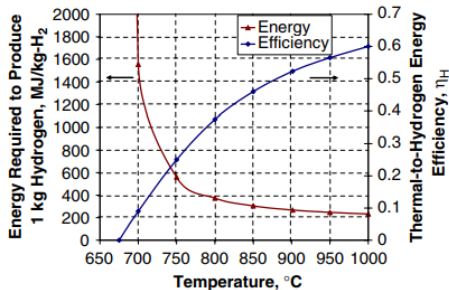


Figure: Sulfur-Iodine thermochemical cycle. Image reproduced from [12].

- 3 different reactions: sulfuric acid decomposition, Bunsen reaction, and hydrogen iodide decomposition.
- Input: H₂O.
- Output: H₂ & O₂.
- Does not require electricity.
- Needs a high temperature source.

Co-generation

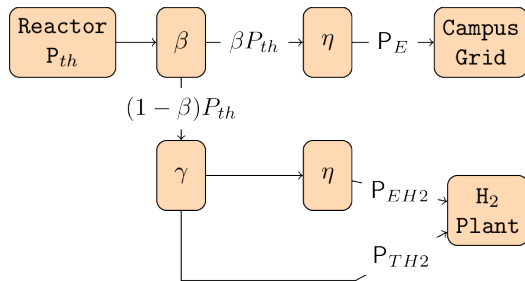


Figure: Diagram of a reactor coupled to hydrogen plant.

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

Low temperature electrolysis (LTE):

- $\gamma=1$. $P_{TH2} = 0$.

High temperature electrolysis (HTE):

- $0 < \gamma < 1$.

Sulfur-Iodine (SI):

- $\gamma=0$. $P_{EH2} = 0$.



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③ Results

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Energy generation

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Fuel demand

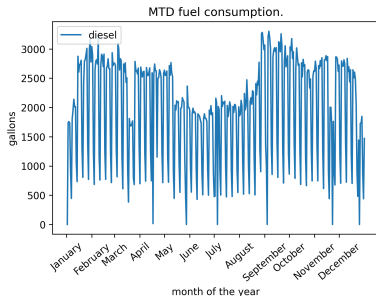


Figure: MTD fuel consumption. Data goes from July 1, 2018, until June 30, 2019 [11].

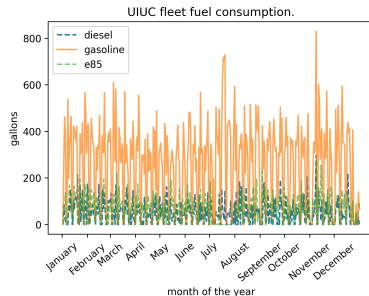


Figure: UIUC fleet fuel consumption. Data goes from January 1, 2019, until December 31, 2019 [19].



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

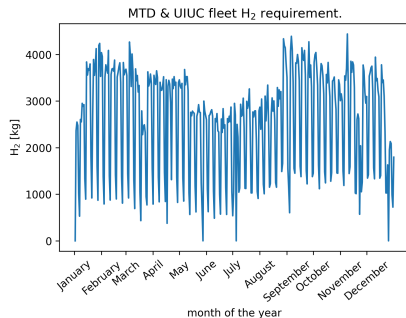


Figure: Hydrogen requirement for MTD and UIUC fleets.

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

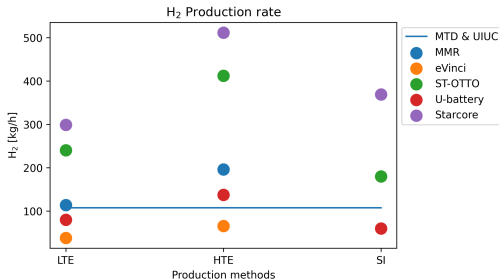


Figure: Hydrogen production rate by the different microreactor designs.

Net demand prediction

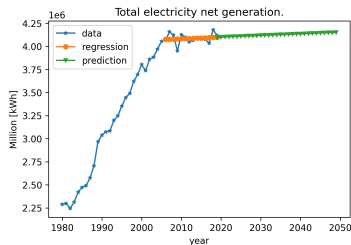


Figure: Prediction of the total electricity generation in the US for 2050. Data from [1].

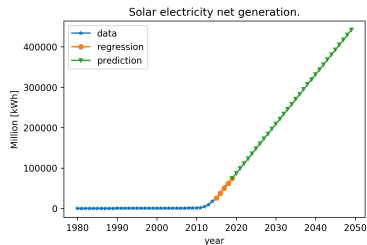
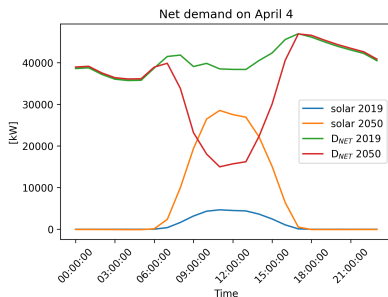


Figure: Prediction of the solar electricity generation in the US for 2050. Data from [1].



Duck curve



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

$$D_{NET} = \text{Total demand} - \text{Solar energy}$$

- 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.

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

Over-generation

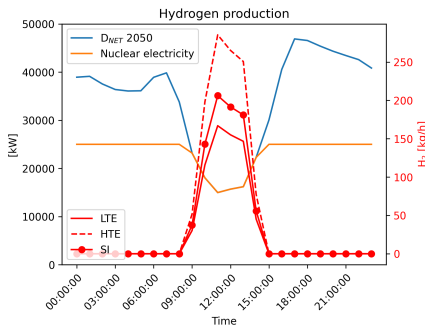


Figure: Hydrogen production with the excess of energy due to a net demand decrease.

25 MWe reactor

Low temperature electrolysis (LTE):

- $\eta = 33\%$.
- Cumulative H₂: 660 kg.

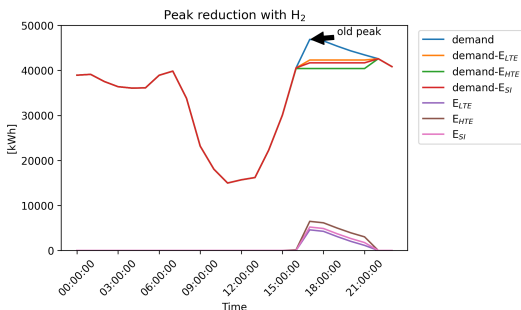
High temperature electrolysis (HTE):

- HTGR.
- $T_o = 850^\circ\text{C}$.
- $\eta = 49.8\%$
- Cumulative H₂: 1129 kg.

Sulfur-Iodine (SI):

- HTGR.
- $T_o = 850^\circ\text{C}$.
- $\eta = 49.8\%$
- Cumulative H₂: 815 kg.

Hydrogen for energy storage



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

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④ Conclusion

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.
- An excessive integration of PV to UIUC grid will make the duck curve phenomenon likely to occur.
- Nuclear energy and hydrogen production present an approach to mitigate the negative implications of the duck curve.
- Hydrogen introduces a way to store energy that reduces the reliance on dispatchable sources.

Acknowledgement

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I would like to thank Beth Brunk (MTD), and Pete Varney (UIUC) for their contributions to the development of this project.

**Thank you.
Questions?**

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