

Hydrogen Economy in Champaign-Urbana, IL

ANS Annual meeting 2020

Roberto Fairhurst Agosta

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

June 10, 2020



ILLINOIS

Outline



① Introduction

② Hydrogen Production

③ Results

④ Conclusion

Introduction

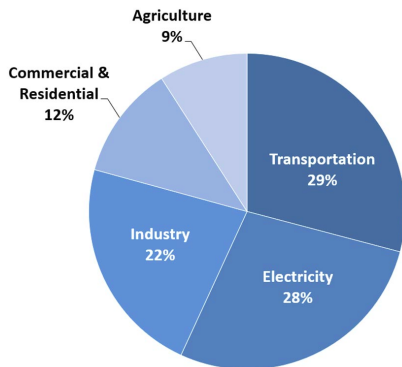


Figure: Total U.S. GHG Emissions by Economic Sector in 2017 [1].

Illinois Climate Action Plan (iCAP):

- 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.
- Japan, Germany, and California.
- Champaign-Urbana.



Figure: New Flyer fuel cell bus.

Energy generation



Obvious solution:

- More renewables.

New problem:

- Duck curve.
- Demand ramps.
- Over-generation.

Consequences:

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

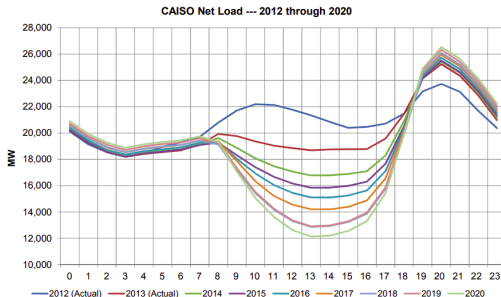


Figure: The duck curve.

A possible solution

Nuclear reactors and hydrogen:

- 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.

Features:

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

Objectives



- ① Replace use fossil fuels by CU MTD and UIUC fleets with hydrogen.
- ② Supply the hydrogen with a or a series of microreactors.
- ③ Analyze the likelihood of the duck curve in Champaign-Urbana.
- ④ Mitigate the duck curve negative effects.

Outline

- ① Introduction
- ② Hydrogen Production
- ③ Results
- ④ Conclusion

Electrolysis

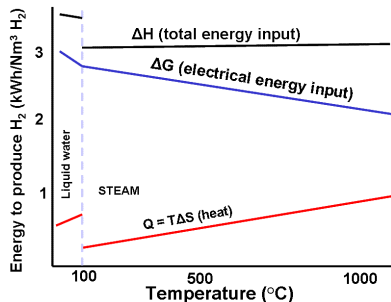


Figure: Energy consumption of an ideal electrolysis process [2].

ΔH : Required energy.
 ΔG : Electrical energy.
 $T\Delta S$: Thermal energy.

In low temperature electrolysis (LTE), electricity provides the thermal energy.

In high temperature electrolysis (HTE), heat source provides the thermal energy.

HTE has the advantage of decreasing the electricity requirement.

Sulfur-Iodine

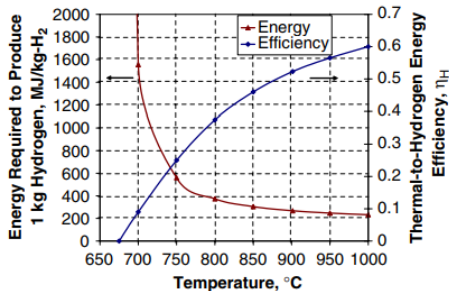
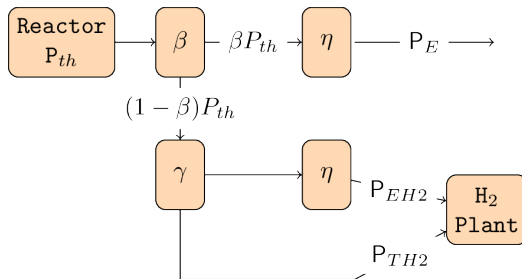


Figure: Sulfur-Iodine thermochemical cycle.

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

Co-generation



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

LTE:

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

SI:

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

Figure: Reactor coupled to hydrogen plant diagram.

Outline

- 1 Introduction
- 2 Hydrogen Production
- 3 Results**
- 4 Conclusion

Transportation: fuel demand

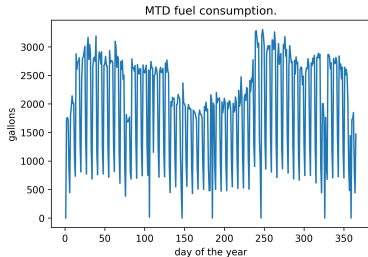


Figure: MTD fuel consumption.

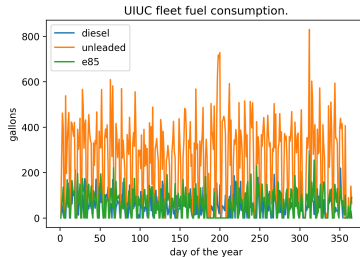


Figure: UIUC fleet fuel consumption.

Transportation: fuel demand

Table: GGE, DGE, and E85GE.

	Hydrogen
GGE	1 kg
DGE	1.13 kg
E85GE	0.78 kg

Table: Hydrogen requirements.

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

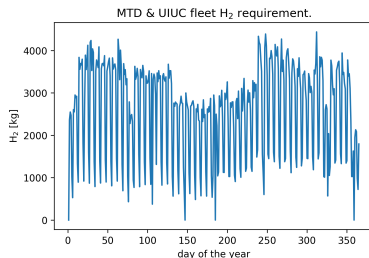


Figure: MTD and UIUC fleets hydrogen requirement.

Transportation: fuel demand

Table: Microreactor designs.

Reactor	$P[\text{MW}_{th}]$	$T_o[^\circ\text{C}]$
MMR	15	640
eVinci	5	650
ST-OTTO	30	750
U-battery	10	750
Starcore	36	850

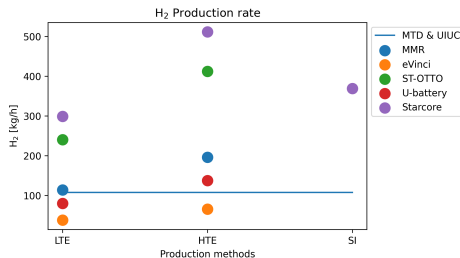


Figure: Hydrogen production rate by different microreactor designs.

Energy generation

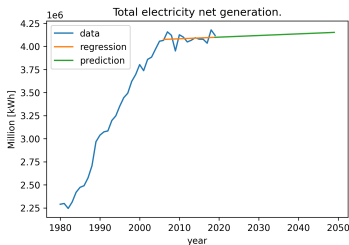


Figure: Prediction on the total electricity generation in the US for 2050.

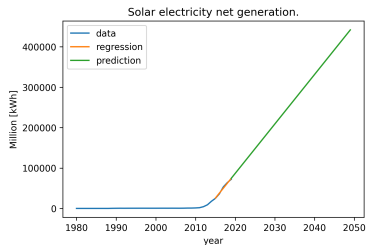


Figure: Prediction on the solar electricity generation in the US for 2050.

Duck curve

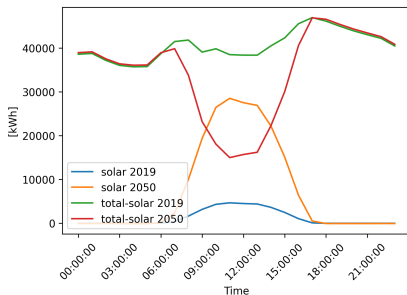


Figure: Prediction on UIUC's demand for 2050.

- Spring: solar production is higher, total demand is low.
- Solar generation peaked on April 4, 2019.
- Peak demand is 46.9 MWh at 5 P.M.
- Lowest demand is 15 MWh at 11 A.M.
- Requires an installed capacity of 31.9 MW of dispatchable sources.

Duck curve

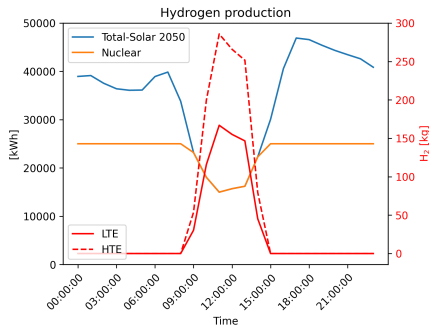


Figure: Hydrogen production with the excess of energy.

25 MWe reactor.

LTE:

- $\eta=33\%$.
- 660 kg-H₂.

HTE:

- HTGR.
- $T_o = 850^\circ\text{C}$.
- $\eta=49.8\%$
- 1136 kg-H₂.

Hydrogen for energy storage

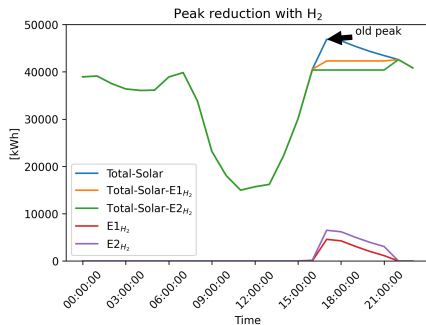


Figure: Peak reduction by using the produced H_2 .

LTE:

- 15.9 MWh.
- New peak: 41.9 MWh
- Peak reduction: 5 MWh

HTE:

- 27.3 MWh.
- New peak: 40.0 MWh
- Peak reduction: 6.9 MWh

Outline

- ① Introduction
- ② Hydrogen Production
- ③ Results
- 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 make the duck curve phenomenon likely to occur.
- Nuclear energy and hydrogen production proposes 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

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

References I

[1] US EPA.

Sources of Greenhouse Gas Emissions, January 2020.

[2] Hi2H2.

Highly Efficient, High Temperature, Hydrogen Production by Water Electrolysis, January 2007.