Hydrogen Economy in Champaign-Urbana, IL

ANS Annual meeting 2020

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

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Outline

Introduction

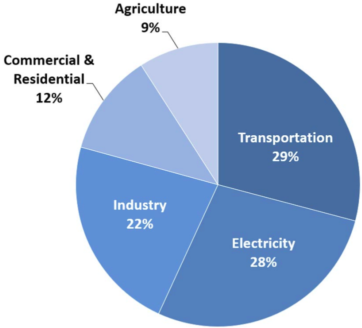

Figure: Total U.S. GHG Emissions by Economic Sector in 2017. Image reproduced from [5].

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.

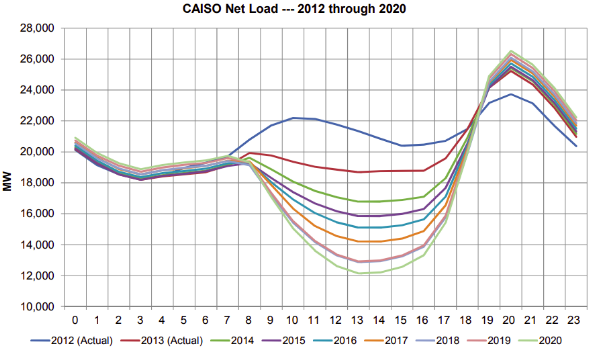

Figure: The duck curve. Image reproduced from [2].

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.

Features:

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

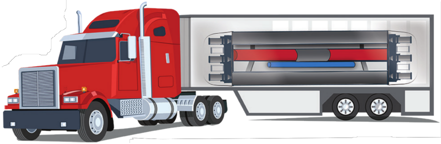

Figure: Microreactor design. Image reproduced from [17].

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

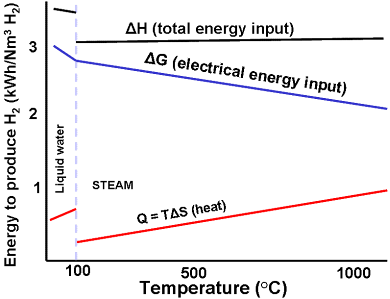

Figure: Energy consumption of an ideal electrolysis process. Image reproduced from [9].

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

- 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

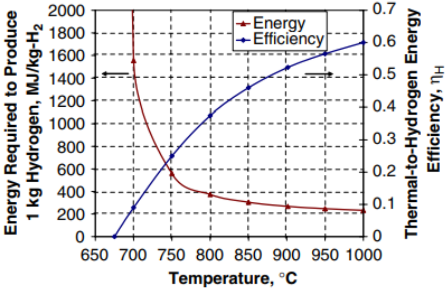

Figure: Sulfur-Iodine thermochemical cycle. Image reproduced from [12].

- 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

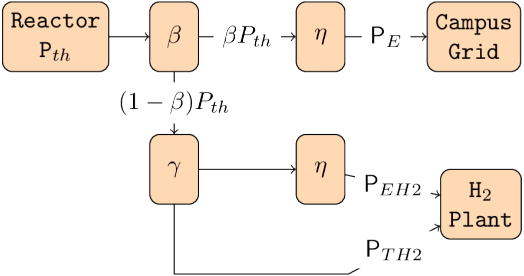

Figure: Diagram of a reactor coupled to hydrogen plant.

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

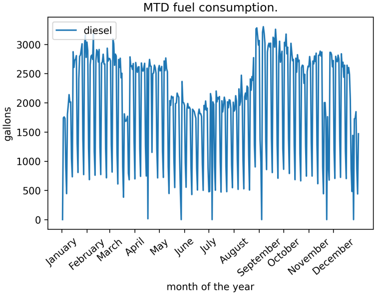

Figure: MTD fuel consumption. Data goes from July 1, 2018, until June 30, 2019 [11].

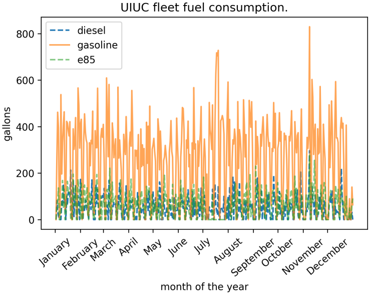

Figure: UIUC fleet fuel consumption. Data goes from January 1, 2019, until December 31, 2019 [19].

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

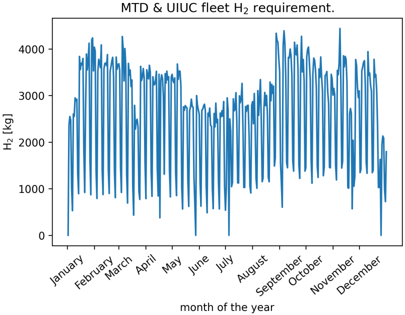

Figure: Hydrogen requirement for MTD and UIUC fleets.

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

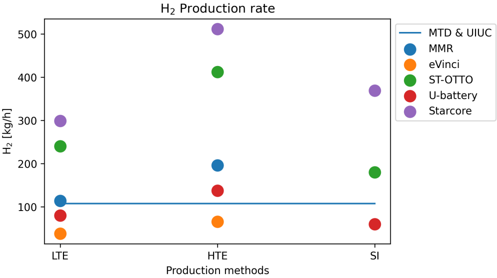

Figure: Hydrogen production rate by the different microreactor designs.

Net demand prediction

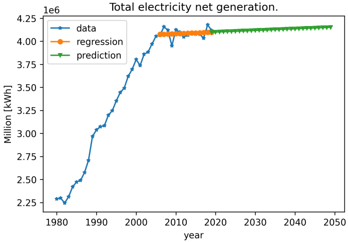

Figure: Prediction of the total electricity generation in the US for 2050. Data from [1].

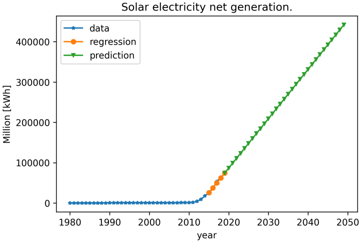

Figure: Prediction of the solar electricity generation in the US for 2050. Data from [1].

Duck curve

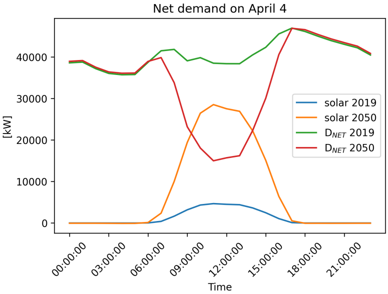

Figure: Prediction of UIUC's net demand for 2050.

- 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

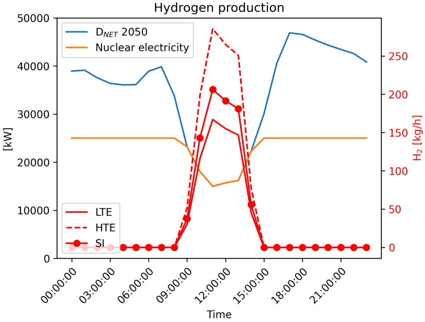

Figure: Hydrogen production with the excess of energy due to a net demand decrease.

25 MWe reactor

Low temperature electrolysis (LTE):

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

High temperature electrolysis (HTE):

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

Sulfur-Iodine (SI):

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

Hydrogen for energy storage

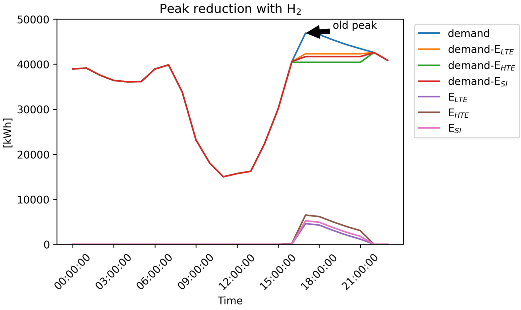

Figure: Peak reduction by using the produced H_2.

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

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Thank you.

Questions?

This presentation has been pre-recorded.

Questions can be directed to:

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