Hydrogen Economy in Champaign-Urbana, IL

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1 INTRODUCTION

Climate change presents a threat that we should address swiftly. Decarbonizing the electric grid through variable renewable energy and nuclear power seems to be a remedy. Unfortunately, a carbon neutral electric grid will be insufficient to halt climate change because transportation contributes more to greenhouse gas (GHG) emissions than electricity. As seen in Figure 1, transportation produced the most GHGs in the US in 2017. Thus, decarbonizing transportation underpins global carbon reduction. Accordingly, the University of Illinois at Urbana-Champaign (UIUC) has committed to the Illinois Climate Action Plan (ICAP) which aims to attain carbon neutrality by 2050 [1].

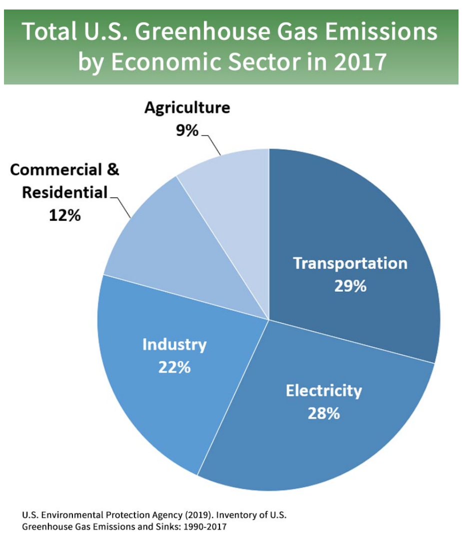

Fig. 1: Total U.S. GHG Emissions by Economic Sector in 2017 [2].

One possible solution to reduce carbon emissions, and even achieve a net zero carbon production, is to develop a hydrogen economy as the state of California is currently doing [3]. Although using hydrogen does not produce CO_2, any hydrogen production method is only as carbon-free as the source of energy it relies on (electric, heat, or both). Nuclear reactors present a clean energy option to produce H_2.

Micro-reactors are an innovative technology attractive for hydrogen production. Several micro-reactor designs are currently under development in the United States. These reactor concepts have three main features: they are factory fabricated, transportable, and self-regulating. All of the components are fully assembled in a factory and shipped out to the generation site, reducing capital costs and enabling rapid deployment. Simplified design concepts eliminate the need for many specialized operators and maintenance staff. Moreover, they utilize passive safety systems that prevent overheating or meltdown [4].

The purpose of this abstract is to review and evaluate methods of hydrogen production for a hydrogen economy on a campus similar to the UIUC campus. Section 2 presents several methods and Section 3 explains the methodology to calculate the mass of hydrogen required to fuel the Champaign-Urbana Mass Transit District (MTD) bus system and a portion of UIUC campus fleet service vehicles, as well as the mass of CO_2 produced by both fleets.

2 HYDROGEN PRODUCTION METHODS

Some hydrogen production processes are:

- Steam-Methane Reforming [5]
- Electrolysis [5]
- Iodine-Sulfur Thermochemical Cycle [6]
- Coal Gasification [7]
- Thermochemical Water Splitting [8]

The following subsections describe some of these methods.

2.1 Steam Reforming

Steam reforming (aka Natural Gas Reforming) is currently the least expensive way to produce hydrogen. This method separates hydrogen atoms from carbon atoms in methane (CH_4). This process results in carbon dioxide emissions. Steam reforming is a mature production process that uses high-temperature steam (700°C-1000°C) to produce hydrogen from a methane source. Methane reacts with steam under 3-25 bar pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and a small portion of carbon dioxide. The reaction is endothermic and requires the supply of heat to convert methane and water to carbon monoxide and hydrogen gas with the following balance equation [5],

$$CH_4 + H_2O + heat \rightarrow CO + 3H_2. \tag{1}$$

A secondary reaction known as water-gas shift reaction occurs given by the balance equation,

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{2}$$

producing CO_2 and more hydrogen.

2.2 Electrolysis

Electrolysis uses an electric current to split water into hydrogen and oxygen as shown in Figure 2. The reaction takes place in a unit called an electrolyzer. Electrolyzers consist of an anode and a cathode separated by an electrolyte. A few classes of electrolyzer technologies, distinguished by their materials and functionality, include polymer electrolyte membrane, alkaline, and solid oxide electrolyzers [5].

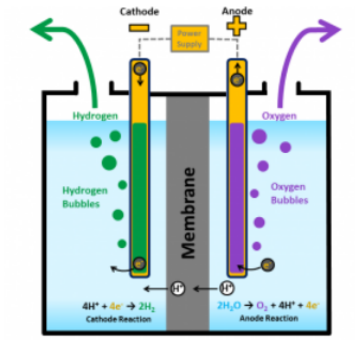

Fig. 2: Production of hydrogen by electrolysis [5].

Solid oxide electrolyzers must operate at temperatures high enough for the solid oxide membranes to function properly (about 700°-800°C). The use of heat at these elevated temperatures decreases the electricity needed to produce hydrogen from water. Thermal energy rather than electricity converts water to steam and then the electricity dissociates the water at the cathode to form hydrogen molecules [9].

2.3 Iodine-Sulfur Thermochemical Cycle

The most efficient methods operate at considerably high temperatures, typically above 900°C. Sulfur-based cycles (Figure 3) use a sulfuric acid dissociation reaction that only works above 870°C and whose efficiency increases with temperature [6]. The sulfur-iodine (SI) cycle results the best cycle for coupling to a high temperature reactor (HTR) due to its high efficiency. A General Atomics experiment has operated multiple times to produce hydrogen. The production was at a rate of 75 L/min. A scale-up of the process using a 50 MWth Nuclear Reactor could produce 12000 kg/day of hydrogen [10]. Another example of hydrogen production is by the Next Generation Nuclear Plant (NGNP) [11] which aims to produce 500 kg/h of H_2 by using 50 MWth [6].

3 METHODOLOGY

A gasoline gallon equivalent (GGE) is the amount of fuel that can generate equivalent energy to a gallon of gasoline. One kilogram of hydrogen is equivalent to one gallon of gasoline [5]. Burning a gallon of gasoline produces 19.64 lbs of CO_2 [12]. Similarly, a diesel gallon equivalent (DGE) has the same amount of energy as a gallon of diesel. Approximately, a DGE is 113% of a GGE [13], then 1.13 kg of hydrogen is equivalent to one gallon of diesel. A gallon of diesel produces 22.38 lbs of CO_2 [12]. Table I summarizes this information.

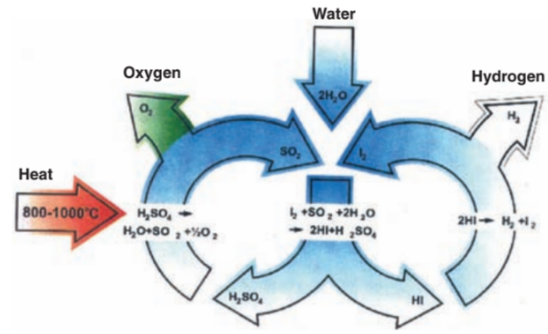

Fig. 3: Production of hydrogen by iodine-sulfur thermochemical cycle [6].

	Hydrogen	Gasoline	Diesel
GGE	1 kg	1 gallon	0.88 gallon
DGE	1.13 kg	1.13 gallon	1 gallon
CO_2 produced	-	19.64 lbs	22.38 lbs

TABLE I: GGE, DGE, and CO_2 produced.

4 RESULTS

Figure 4 shows the gallons of diesel purchased every day by MTD in a year. The data go from July 1st of 2018 to June 30th of 2019 [14]. The calculations assume that MTD consumed the purchased fuel on the same day. Table II lists the mass of hydrogen required to supply the MTD fleet. Average gallons per day refers to the total amount of fuel consumed in a year averaged in 365 days.

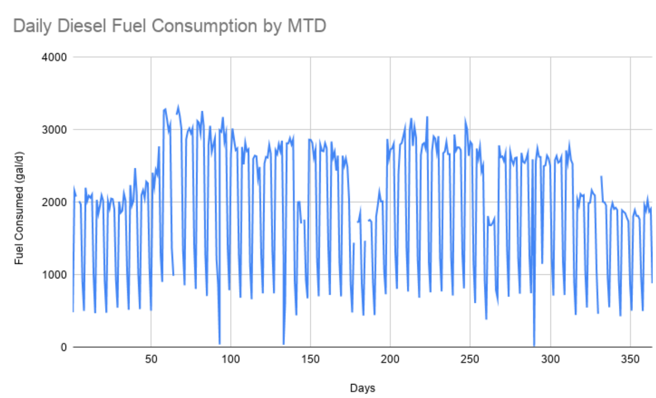

Fig. 4: Diesel gallons consumed each day by MTD from July 1, 2018 to June 30, 2019 [14].

The UIUC fleet includes both passenger and service vehicles [15]. The calculations consider only the portion of the fleet that operates in town and consumes gasoline [16]. Figure 5 presents the daily consumption of unleaded gasoline by the UIUC fleet in a year. The data go from January 1st of 2019 to December 31st of 2019. The fleet also uses diesel and ethanol but in smaller proportions that future analysis will take into account. Table II summarizes the hydrogen required to supply the UIUC fleet based on this accounting.

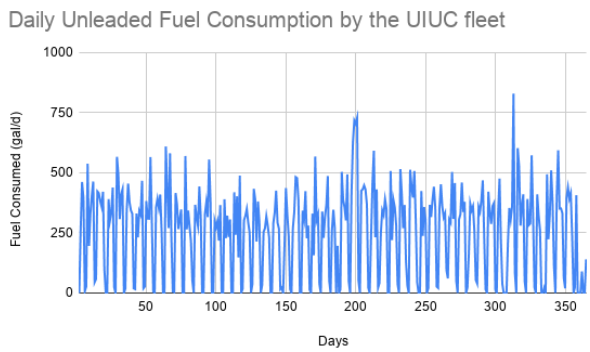

Fig. 5: Gasoline gallons consumed each day by the UIUC fleet from January 1, 2019 to December 31, 2019 [16].

	MTD (Diesel)	UIUC (Gasoline)
Average gal/day	1,971.8	251.8
kg of H_2/day	2,228.2	251.8
CO_2 (lbs/day)	44,129.5	4,945.3
gal/year	719,717.6	91,925.1
kg of H_2/year	813,280.9	91,925.1
CO_2 (lbs/year)	16,107,279.9	1,805,408.9

TABLE II: Hydrogen required and CO_2 produced by MTD and UIUC fleets.

Table II also shows the CO_2 emitted by MTD and UIUC fleets. Combined, these fleets would consume 2480 kg/day of H_2.

5 CONCLUSION

MTD and UIUC fleets combined emit around 9 thousand tons of CO_2 per year in Champaign-Urbana. This has negative effects on the environment and intensifies climate change. The University of Illinois is leading by example and actively working to reduce GHG emissions on its campus. Switching to a hydrogen economy could be the answer to reducing CO_2 from transportation.

Nuclear energy could contribute as well. Some energy sources are not entirely emissions free. A 10 MWth micro-reactor would ease the CO_2 emissions on campus by generating energy for H_2 production regardless of weather conditions (in contrast with renewables). Additionally, the most efficient hydrogen production methods run at high temperatures, another reason nuclear is appealing.

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