Similar Systems

# Hydrogen Generation

From the last two and a half weeks, ERH2 has conducted on and off research on ways to generate hydrogen (H2) gas for our capstone demonstration.

## Microbial Biomass Conversion

Microbial Biomass Conversion (MBC) uses fermentation processes with either bacteria or fungal spores that break down hydrocarbons to produce H2 gas. The US Department of Energy has been conducting experiments on MBC systems for both renewable generation and for waste management options. One current application has been in sewage and wastewater treatment plants. The MBC bacteria have been employed to break down the “wastewater slurry” into products such as methane gas. With the gases free, plants can feed the gas into a Brayton cycle natural gas turbine system to produce power. This does still emit carbon dioxide into the atmosphere, however unlike unfiltered coal burning, the system will not produce sulfuric oxide (SOx) and nitrous oxide (NOx) as biproducts. Currently MBC is not used for H2 gas production directly, but there are plans to use two or more bacteria strains or fungal spores to convert the methane gas into H2 gas.

One reason why ERH2 investigated MBC was the “easiness” to have bacteria passively break down wastewater into H2 gas. One benefit from MBC is the lack of complexity for the breakdown process, however it brings its own challenges in collecting the hydrogen from the bacteria. During a fermentation process, the bacteria typically consume some of the elements such as the hydrogen we are trying to get. This leads to a “race” to collect the H2 gas before the bacteria can consume it. As it currently stands, there is no way to collect all the H2 gas generated from this process. Because of this, the net efficiency of MBC systems is low and vary heavily from the strains of bacteria chosen. Another issue with MBC systems is the production rates of H2 gas in each period. Some data of MBC production rates have shown that at best a MBC system can produce 1.6 liters of H2 over a 10-day period. Insert reference number for Wang et al. When talking to Dr. Eaton about using the MBC system for H2 gas generation, one major part ERH2 would need to employ is a bioreactor. A bioreactor is an apparatus that is employed to conduct artificial biological reactions. Embry-Riddle does not have one of these systems on hand and would require one that is certified for lab use, to apply it to ERH2s planned design. With the complexity in design for a bioreactor ERH2 could not build a unit in a semester timeframe. This would also limit the system to remain indoors, since bioreactors do not work in an outdoor condition.

## Photobiological

Similar to MBC, photobiological systems (PBS) uses bacteria that breaks down water into H2 gas. Instead of fermentation, PBS uses microorganisms such as microalgae or cyanobacteria, that take in sunlight and split water into oxygen (O2) and H2 gas. PBS faces similar issues to MBC, with the only difference is that PBS can be outside since it uses sunlight to function. Because of this, PBS also produces hydrogen very slowly and can only produce when sunlight is available.

### The Shared Issues with Biology

With the biology route there are several shared benefits and issues. With that in mind, this paragraph will explain them. To begin with production rates, both routes in fermentation (MBC) and photobiology (PBS), are known for being slow. Not just slow like a liter an hour, but slow in a liter in several days. This would be an issue for demonstration purposes, since ERH2 will not show the capstone over a week in length. The next issue with biology can be deciding on the strain to use. The Earth houses one trillion types of bacteria and with that comes a challenge on deciding on the used bacteria. As it stands, there is no one appointed strain that is commercially selected as the “best”. Instead, biologists are still trying to find and/ or create the most “optimal” strain. From the multitude of possible strains of bacteria to choose from, along with adding the difficultly of obtaining the bacteria, this would lead to another issue for ERH2. Another issue that Dr. Eaton listed with a biology route, is a waste filtration system for the bacteria. After the bacteria has completed its cycle, there will be some-amount of waste that if left untreated, it will kill the bacteria. The bacteria will also need a properly regulated environment, meaning that the housing system will need to be thermally controlled to the nearest degree. These are some of the main reasons why ERH2 is not using biology to produce the hydrogen gas.

## Electrolysis

Electrolysis has been employed for H2 gas generation for several decades. Electrolysis uses an electrical current to apply a charge to a water molecule. Now charged with an added electron, the water molecule separates into H2 gas and O2 gas. All electrolysis systems have three main components: the electrolyte, the anode, and the cathode. As of now, there are three main types of electrolysis systems they are the following: polymer electrolyte membrane (PEM), alkaline, and solid oxide.

# Hydrogen Storage

From the last two and a half weeks, ERH2 has conducted on and off research on ways to store H2 gas for our capstone demonstration.

## Physical Based

One possible way ERH2 investigated storing H2 gas is through physical storage. Physical storage consists of compressed gas, cold/cryo, and liquid H2. Even though physical storage works well for most gases, such as propane, oxygen, and refrigerants, however for hydrogen physical storage is hard. H2 is the smallest atomic bond in the known universe, this makes storing it difficult since compressing a very small amount of it takes a lot of energy. The other way to store hydrogen in a physical state is through extreme temperature control. To achieve liquid hydrogen, a temperature of -253° C and for solid state a temperature of -259°C. This all lead to several issues for ERH2 when designing a storage system within an effective cost range. Since compressors are expensive and the university does not have the ability to cool down the H2 gas to almost absolute zero conditions, ERH2 will have to look elsewhere for storage.

## Material Based

H2 can also be stored inside other compounds either through adsorption or absorption. Using a series of compounds, H2 gas can be stored and easily used without needing compression and low temperature systems. This is a highly sought-after approach; however, it requires a magnitude of research dedicated in chemical research. ERH2 is looking into a material storage approach using urea and granulated sugar to act as the binding material. When H2 is exposed to the urea-sugar combination, the H2 will become “trapped” inside the compound “powder”. Once stored, the H2 gas can be accessed by heating the compound powder to 300°C.

Trade Studies

# Electrolysis

Electrolysis is the process of using electrical current to “rip apart” a water molecule (H2O) and split it into 2 H+ and a O. Electrolysis has been used to split water molecules since 1800, however large-scale hydrogen production, such as through electrolysis, has been slowly growing in todays (2022) market. Electolyzers can be built via several different ways; Proton Exchange Membrane (PEM), Alkaline, and Solid Oxide. The following paragraphs will go further into detail on how the listed systems work and the associated challenges with them.

# Alkaline

The conventional alkaline is the most common type of electrolyzer and has had several decades of research associated with the improvement of efficiency, production rates, and safety. The classic alkaline is a unipolar design often using iron or nickel as the electrode and an aqueous electrolyte solution like potassium hydroxide (KOH) flowing over the electrode. Once the electrode is powered by direct current (DC), water can flow through the anode while contacting the powered electrolyte. When the water contacts the electrolyte, the water molecule will split, sending positively charged hydrogen (H+) to the cathode side. The H+ ions will bond in pairs becoming H2 and leave the cathode. Issues with the conventional alkaline can be from the total system efficiency and low production rates of hydrogen gas. On average conventional alkaline systems can have a net efficiency of 70% while taking around 55 kWh to produce 1 kg of H2.

# PEM

Unlike conventional alkaline, PEM electrolysis uses a solid polymer membrane usually made from Nafion. This leads to a higher efficiency at H2 production at 84% round trip and using on average 50 kWh of energy. One of the major disadvantages of PEM is the cost. A PEM electrolyzer can cost anywhere from double to almost triple the amount as an alkaline electrolyzer. Most of this increase in cost can be associated in the Nafion itself, this leads to the overall price of a PEM electrolyzer dependent on the size of the membrane. ERH2 is planning on using a PEM membrane for the electrolysis sub-system. The currently planned membrane will be a Nafion 10 X 10 cm MEA 3 layer, at $472.00 (not including shipping and taxes).

# Solid Oxide

Solid Oxide electrolysis requires the ceramic electrolyte to be at a temperature range of 700°C - 800°C. There is a fair amount of research in solid oxide electrolysis for laboratory purposes, however for a capstone demonstration, solid oxide would prove to be more challenging to implement compared to a PEM or alkaline system. One such issue would be achieving the needed temperature range and maintaining it long enough for demonstration.

# Material Storage

Hydrogen material storage is a method of storing hydrogen in within solid materials. This process is highly efficient since the material absorbs the H2 and then can be stored at ambient conditions until release is necessary. The absorption and extraction process are different for every material, and along with the H2 weight percentage capacity and cost of material, determine the value of each material and how we decided which material would be the best for our application.

## Metal Hydrides

Metal hydrides utilize a host metal to chemically bond hydrogen to for storage. Elemental metal hydrides most promising for hydrogen storage are magnesium and aluminum hydrides with capacities of 7.6% (wt) and 10.1% (wt) respectively. Magnesium hydride displays sluggish kinetics during both hydrogenation and dehydrogenation, requiring temperatures exceeding 300℃ to achieve a reasonable charge amd discharge rate. Aluminum hydride creates weaker bonds than magnesium resulting in much lower temperatures (100℃) for reasonable discharge. However, aluminum hydride requires extreme pressures and temperatures for formation (1450ksi and 600℃) making their use unreasonable.

## Intermetallic hydrides

The proposed idea behind the use of intermetallic hydrides is that an element that binds hydrogen strongly and an element that binds hydrogen weakly are both included in an alloy. The alloys storage abilities vary based of the choice of the two elements in addition to the ratio of the two elements. Unfortunately, most intermetallic hydrides have hydrogen storage capacities of less than 2% (wt). In addition to the low storage capacity, these materials are often very expensive, such as TiFe costing more than $367/kg. Although they have been successfully used in industry, intermetallic hydrides are very costly and lack sufficient storage capacity making them unreasonable for our application.

## Chemical Hydrides

Chemical hydrides are similar to the metal hydrides since they also chemically bond to the hydrogen, but they are often liquids at standard conditions. This simplifies their storage and transportation. In addition, many of the chemicals that can store hydrogen already have the required production and infrastructure built around them, such as methanol and ammonia. Methanol and Ammonia both have high hydrogen storage capacities of 12.5% (wt) and 17.7% (wt), respectively. But both of these chemicals need high temperature and pressure in order to absorb and bond with the hydrogen. This makes them impractical when compared to other materials that bond with hydrogen at ambient conditions and only require high temperature when extracting.

## Graphitic Carbon Nitride

Cheap and good.