Dear Investors,

I am pleased to share our new note as part of our **'Knowledge Series'** initiative. The previous notes released by colleagues so far, covered some key quantitative and qualitative aspects of fundamental investing. In this note, I have attempted to help you understand the basics, application and the future of this emerging **alternate source of energy – Hydrogen**.

To make sure the building blocks are in place, the flow of this note has been structured as follows:

1. What is Hydrogen and where is it found
2. How is Hydrogen made
3. How can it be transported/used
4. How does it compare with other sources of fuel
5. Is it going to replace electric vehicles as a mode of transportation
6. Current applications and ways to invest in this space

1. What is Hydrogen and where is it found

Hydrogen is an element, usually in the form of a gas, that consists of one proton and one electron. **Hydrogen is the most abundant element in the universe**, accounting for about 75 percent of its normal matter, and was created in the Big Bang. Being a single electron, it is highly reactive and rarely exists as a free element in nature. It can be found it in every compound (water is H2O, methane is CH4, ethanol is C2H60). Due to this nature, **it is a stepwise process to unlink the hydrogen atoms and turn them in to gas in order to use them as a fuel.**

2. How is Hydrogen made

Hydrogen has to be separated from the compounds it is normally (and most abundantly) found in **which includes natural gas, water, ethanol, and biomass**. There are 5 major commercially viable ways to produce hydrogen

a. Natural Gas Reforming
b. Electrolysis
c. Renewable liquid Reforming
d. Fermentation
e. Gasification

Each of these processes has some advantages and some disadvantages attached to it but these are the most commonly used and thus commercially viable methods. There are some experimental methods under research but the viability of these methods remains untested and thus unreliable.

a. **Natural Gas Reforming**

Natural gas is reacted with high temperature steam to break it in to its components:
$Natural\ Gas + High\ Temperature\ Steam \rightarrow Hydrogen\ (H_2) + Carbon\ monoxide\ (CO) + Carbon\ dioxide\ (CO_2)$

This method of hydrogen production is the cheapest and most efficient and therefore most widely used in developed nations with large natural gas reserves. But it has significant pitfalls as well. In order to get hydrogen, we need natural gas and hot steam (energy needed to heat steam). So, the obvious question is to ask- why not just use natural gas instead of hydrogen? **This method also gives us some pollutants as bi products** (CO and CO2), thereby it's not a clean process.

b. **Electrolysis**

This method involves running electricity through water:$Water\ (H_2O) + Electricity \rightarrow Hydrogen\ (H_2) + Oxygen\ (O_2)$

If electricity is produced from a renewable/green source, then this method is the cleanest way to produce hydrogen with no emissions in the chain at all. The issues here are plenty as well. Efficiency of solar power is already 23% at most and then hydrogen production will never be 100% of that so there are losses in power as well.

The other problem is that salt water cannot be used in this process because of chlorine gas formation (from the salt (NaCl) in sea water) which means sea water first needs to be purified. This involves another step and more power consumption. **This method is being researched most since production of chlorine is toxic in uncontrolled environments.**

c. **Renewable Liquid Reforming**

This method uses ethanol to produce hydrogen

$Ethanol\ (C_2H_5OH) + High\ Temperature\ Steam \rightarrow Hydrogen\ (H_2) + Carbonmonoxidess\ (CO) + Methane\ (CH_4)$

This is an expensive method of hydrogen production and begs the question about using ethanol directly as a fuel since carbon monoxide is produced regardless.

d. Fermentation

In this method, **biomass is used along with sugar rich feed stock to create hydrogen and carbon monoxide.** This is a really slow process and takes longer for production and is harder to do in large quantities. It makes sense for applications where biogas and large quantities of feed stock are readily available.

e. Gasification

Coal or biomass are reacted with steam and oxygen under high pressure to produce a hydrogen rich gas which is reacted with high temperature steam to produce hydrogen and carbon monoxide. **This process is longer and therefore has lower efficiency and still produces CO as a pollutant.**

3. How can Hydrogen be transported

Like any other gas, hydrogen can be transported in its pure form or as a liquid. In its gaseous form it can be transported through pipelines or pressurized trailers. Both these methods have their pitfalls since pipelines involve high upfront expenditure but quicker evacuation while trucks and rail are slower and less predictable. It is also a highly reactive gas and its transportation can be tricky.

Hydrogen can also be cooled to turn it in to a liquid and then transported through trucks and pipelines which reduces effort of transporting (less reactive as a liquid). However, it is expensive to cool and liquify. At the destination point, hydrogen has to be stored in pressurised containers to prevent it from evaporating and reacting with other substances.

4. How does Hydrogen compare with other sources of fuel

Instead of measuring calorific value, (amount of energy in a fuel per gram) its more useful to look at well to wheel efficiency since it encapsulates the entire value chain. **Well to wheel efficiency means the output power as compared to the power required to mine or extract the fuel from its source**. A comparison of different fuels is shown below:

Efficiency	ICEV	Series HEV	Natural Gas Vehicle	FCV with Reformer	BEV	DHFCV
X	0.86	0.86	0.86	0.86	0.36	0.65
Y	0.16	0.27	0.27	0.32	0.80	0.47
(X x Y)	**0.137**	**0.232**	**0.232**	**0.275**	**0.280**	**0.305**

Source: Research report by Moghbelli, Hassan et al

X is the well to vehicle efficiency
Y is the vehicle to wheel efficiency
ICEV – Internal Combustion Vehicle
HEV- Hybrid Electric Vehicle
FCV – Fuel Cell Vehicle
BEV – Battery Electric Vehicle
DHFCV – Direct Hydrogen Fuel Cell Vehicle

5. Is Hydrogen going to replace electric vehicles as a mode of transportation

As evident from the table, the efficiency is highest for hydrogen by a large margin over internal combustion engines but only marginally over electric vehicles.
The added benefit of electric vehicles is of course the pre-existing infrastructure and support systems that hydrogen lacks. The trade between switching to hydrogen automobiles and power and costs of producing hydrogen just don't justify the investments that would have to be made on hydrogen.

6. Current applications and ways to invest in Hydrogen

Applications outside of Mobility

All of the above data points is not to say that hydrogen doesn't have a place in our ecosystem as a fuel. Fuel cells were first used commercially on NASAs moon mission for late-stage thrusters and have been used in passenger vehicles (Honda Clarity, Toyota Mirai etc) for over a decade.

Fuel cells make a lot of fiscal sense in situations with fixed infrastructure and to power industries but automobiles is unlikely. They are currently used as backup power for remote transmission towers for telecom operators and to provide uninterrupted power for critical uses like hospitals.

Ways to invest in this space

There are a lot of opportunities in the start-up space focussing on hydrogen as a fuel for automobiles and for industries. But in the listed space, there are a few investments as well in establishing a scale.

In India, the Adani group has committed to investing $20 billion in green energy of which a considerable amount will be diverted towards hydrogen production as well. Mukesh Ambani (Reliance Industries) has made a similar promise for hydrogen as well setting aside $10 billion for investments in the next few years.

Globally there a lot of investments being made in this space as well. Bosch is working with Nikola to develop hydrogen fuel cells with greater efficiencies and lower costs. Hyundai has set an internal target to convert all commercial vehicles to hydrogen by 2028 while BMW and Volkswagen are developing cheaper hydrogen powered cars.

There is a lot of buzz and excitement around this space and for good reason but all these needs to be considered in relation to the entire eco system so that a more comprehensive decision can be made. **Since the biproduct of using hydrogen is eventually water, it's a clean burning fuel but production is what poses a challenge.**

We hope you enjoyed reading our compilation as much as we enjoyed putting it together and look forward to hearing from you for your valuable feedback. We shall continue to take up interesting topics to help educate you further and in turn learning from you via your feedback.

Warm Regards,

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