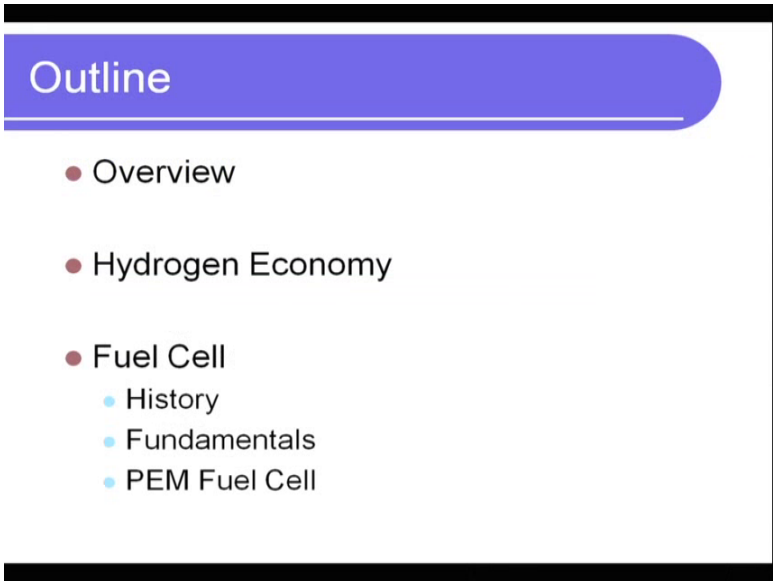
Energy Conservation and Waste Heat Recovery
Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 60
Hydrogen Economy

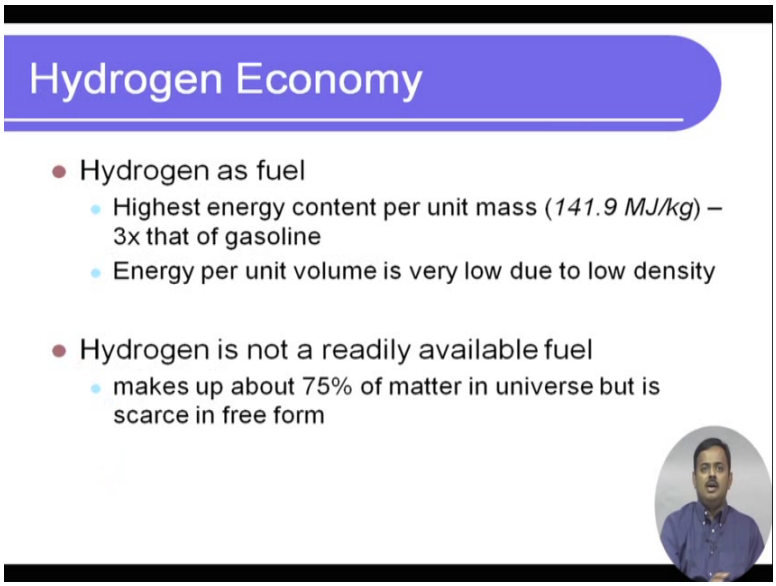
Welcome back and to the next lecture of energy conservation and waste heat recovery. So, today we will take up a completely new topic, and that is called hydrogen economy and fuel cells. So, hydrogen economy and fuel cells it is an important topic this the topic that has gained more and more attention over the last two decades I would say towards the late 90s is when they started really picking up. So, given compared to let say coal or natural gas etcetera hydrogen that ways is very new, it is very new topic. And there are still lots of which was a lots of different opinions about how good is hydrogen as an energy source and so on. So, let us talk about that, let us understand what hydrogen economy means what it is and also we are going to talk about fuel cells which is again and energy generating device that uses hydrogen as the fuel.

(Refer Slide Time: 01:24)



So, what is hydrogen. So, we are going to talk about hydrogen overview, then hydrogen economy and then about fuel cells a little bit.

(Refer Slide Time: 01:31)



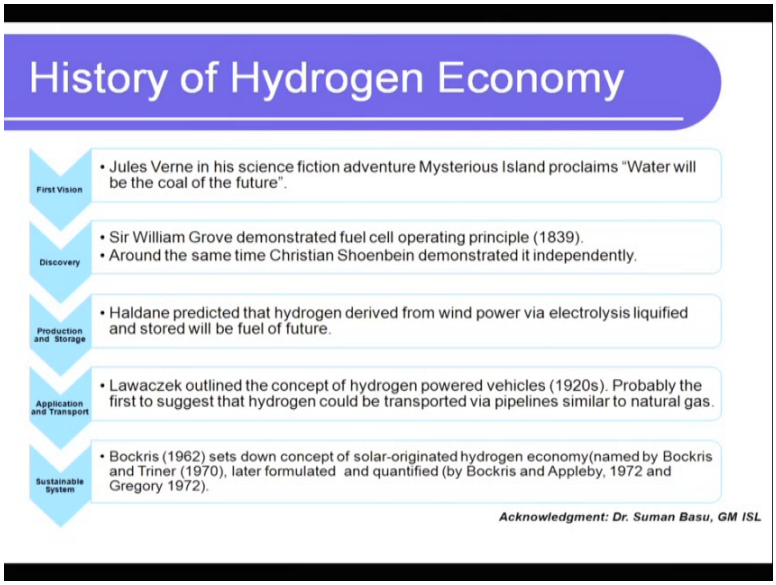
So, as I say hydrogen economy means we are looking at hydrogen gas or hydrogen as an element as a fuel. So, why is it fuel, why is it good as a fuel. So, if you look at hydrogen, the energy content per unit mass is very high 142 mega joules per kg. If you consider gasoline or petrol, which we put in our cars that is about a third of this, so per kg per unit mass hydrogen fuel is one of the highest energy sources, so that is the attractive part. And second attractive part is hydrogen is abundantly available in nature, which is also drawback by the way we will come to that. However, you also we should keep in mind that hydrogen is purely the lightest element, so since it is very light if you talk about energy per unit volume then that is very low, because its density is the lowest among all elements that we know. So, therefore, even though per unit mass the energy content is very high to store that unit mass to have a storage for that unit of for a for a given mass of hydrogen the volume required is humongous.

Now, next thing I said that hydrogen is readily available, is abundantly available in nature, but unfortunately it is not abundantly available in its atomic form. It makes up about 75 percent of the matter in universe, but in the free form as just hydrogen at the hydrogen gas or liquid, it is not available; it is mostly available as an element in water H 2 O. So, therefore, if you in order to use hydrogen, we have to first break down water into its constituent elements and separate out hydrogen and oxygen and then use the hydrogen. Or in other wherever it is available, we have to first break up that compound

and extract the hydrogen out as an element in the gaseous form or in the liquid form which form is available. So, this is about hydrogen.

If I if I talk about what is hydrogen, why is hydrogen human being looked as fuel it is because it has very high-energy content per unit mass, but the problem is it is not readily available. If you think of coal, fossil fuel, natural gas, there are reservoirs that are in which it is available today to us, yeah we have to mined we explore the natural gas out, we have to mine the coal. Even if you talk about biomass, yeah that is there; or if you look at the renewable sources – wind, solar, these are all energy sources are available to us in nature, but hydrogen is not available. So, we have to spend energy first to get hydrogen and then use it as an energy source clear.

(Refer Slide Time: 04:47)



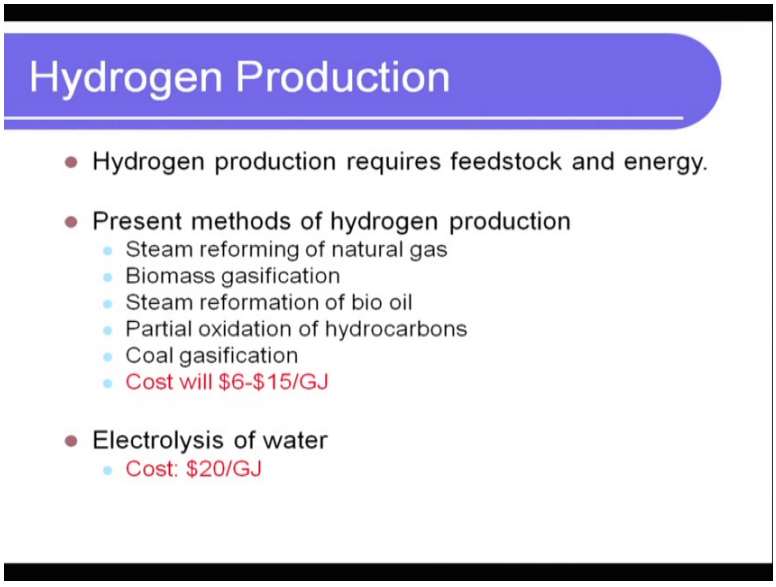
So, that introduction let us look at the history of hydrogen economy. So, the start with a first vision which is a little philosophical Jules Verne you know Jules Verne in a science fiction adventure called Mysterious Island, he says that water will be the coal of the future he writes that. So, if you talk about the first vision of looking at hydrogen probably that is embedded in this statement. And what Jules Verne thought about when he wrote about this, we do not know. But then the discovery this was just a vision that imagination that you had a science fiction right.

But discovery Sir William Grove first demonstrated fuel cell operating principle way back in 1839 and also independently around the same time Shoenbein he also showed

demonstrated it independently. So, remember 1839 very, very many, many years back. So, Haldane predicted the production and storage the Haldane predicted that hydrogen derived from wind power via electrolysis liquefied and stored will be the fuel of the future. So, you have to get hydrogen from wind power via electrolysis. So, you use wind power, the electricity generated in wind turbines that is used for electrolysis of water and then you liquefy the hydrogen, pressurizing it and then store it and that you then you can use it as a fuel.

What is the cost of generating that fuel because that probably is going to be high we will come to that. Application and transport - Lawaczek, he outlined the concept of hydrogen powered vehicles in 1920s. So, you can see this the this whatever the isolated inventions and discoveries and findings date back a long way back to the 1800, 1920 and so on. So, this is the first person to such that hydrogen could be transported via pipelines likes natural gas similar to natural gas. So, we said like just like we go to gasoline is vision was just like we go to a gas station or a petrol pump, where the petrol or diesel is either transported by pipelines or transported through trucks, he said that even hydrogen in future could be I mean could be transported via pipelines similar to natural gas. And then the sustainable system here are a few statements about that, so I am not going to you can just read it. So, this is this kind of your snap shot of hydrogen economy.

(Refer Slide Time: 07:41)

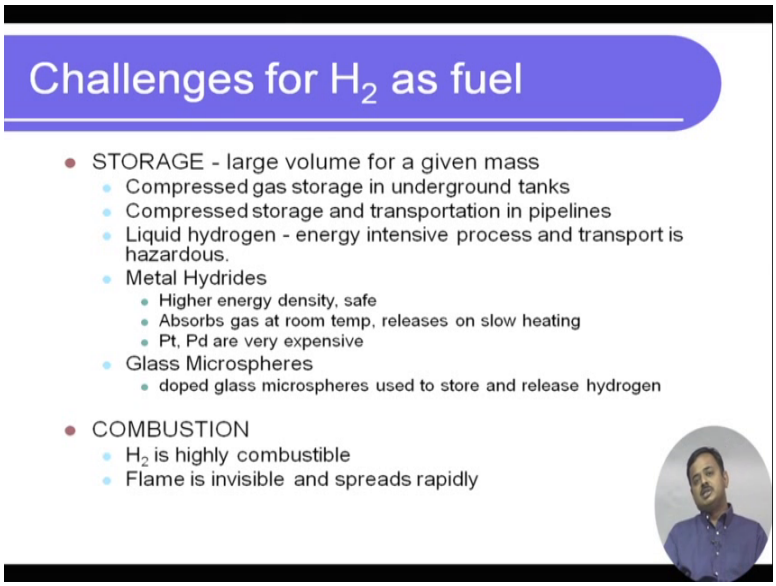


So, hydrogen production how do we look at hydrogen production how do you produce hydrogen as we see that hydrogen is not available we have to produce it first. So, present methods of hydrogen production are few, steam reforming of natural gas, so reformation reaction we looked at chemical energy storage. For from methane, we were able to get hydrogen as a product. So, methylation and reformation which is the same thing steam reformation of natural gas all right. Biomass gasification, so all these have hydrogen as an element right. Steam reformation of bio oil clear; then partial oxidation of hydrocarbons to get the hydrogen out; hydrogen carbon monoxide carbon dioxide water vapor maybe the products. Coal gasification these are the ones that that are used today, but if you look at the cost of producing hydrogen as a source of energy using any of these methods it is pretty high.

We see for 1 gigajoule, which is not a very high number. For 1 gigajoule the cost is 6 dollars to 15 dollars using any of these and these values be change a little bit these values change as any of this processes are also changing with time this values can change the cost can change. But what I am trying to say supposed to say that this is pretty high, 1 gigajoule is actually less than 11 megawatt hour. So, just this is a cost of producing that source of energy and then you are going to use this hydrogen as a fuel to generate energy which again will have its cost. And again remember that the cost of mining coal cost of exploring or you know I mean digging into the reservoirs getting natural gas out there not very high, I am the much, much lower compared to this

And imaging the electrolysis of water which is actually using electrical energy to produce hydrogen which again we will see we are saying that we are going to use hydrogen to eventually produce electrical energy. So, this kind of a you know roundabout situation the electricity is being used to produce electricity and of course, there will be losses in the processes. So, the cost there is almost 20 dollars per gigajoule. So, definitely it is a very costly today and compared to the other sources of energy that we have today.

(Refer Slide Time: 10:25)



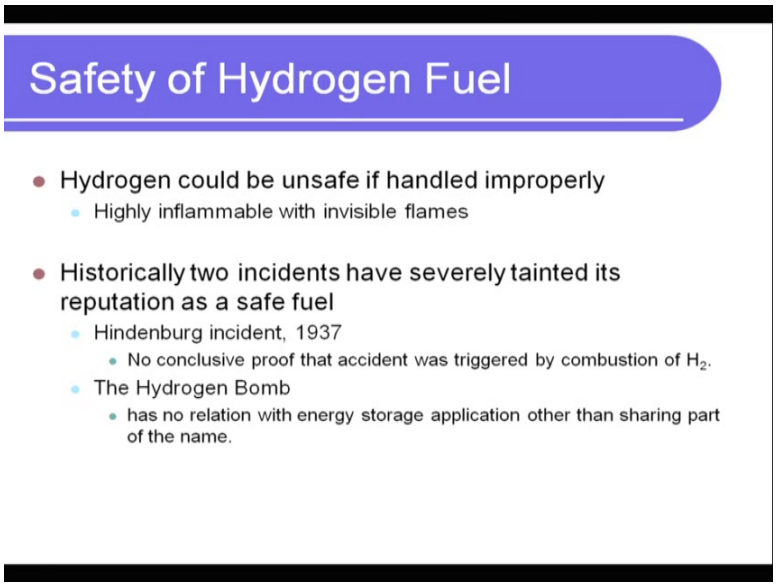
So, the challenges for hydrogen as fuel of course, generation is definitely one; the second one is storage because it is a large volume for a given mass. So, these are some of the methods that are being thought of compressed gas storage in underground tanks. Remember when we talked about compressed air energy storage, we said that compressed air storage is competing with storage of hydrogen liquid, liquefied hydrogen or compressed hydrogen as gas. So, we are told that it is completing with hydrogen compressed hydrogen also as well as LNG which is liquefied natural gas. Compressed storage and transportation in pipelines and that typically is in the gaseous compressed gas or liquid form. Liquid hydrogen, so this is an energy intensive process and transport is hazardous because hydrogen again keep in mind as we will talk later is a highly combustible fuel.

Next one is metal hydrides, so this actually is good. What is happening is this a some metals, which sort of absorbed this gas at room temperature and release it on slow heating. When you elevate the temperature little bit the hydrogen will be released, but the issue is those elements are platinum, palladium, which are extremely expensive. Right now some rare earth metals and some rare earth other rare earth elements are being also looked upon for you know for observing hydrogen at room temperature and releasing on heating, so that is also known that is that is one topic under research. And finally, glass microspheres this is also very attractive and very nice technology that is again under

evaluation. So, glass microspheres these are doped glass microspheres, which are used to store and release hydrogen.

So, these are some options of storage that we have today that are being looked into and that have probably been proven if may not be at a very large scale, but have been proven to be good candidates for storage of hydrogen as fuel, but this is a challenge. And the other challenge is combustion, because hydrogen is highly combustible fuel. And the other issue is the flame when it burns the flame is invisible and it spreads rapidly because this is very light right the density is so low that it will spread, so that is a problem. So, we need to keep it in mind I mean nothing we just because something is hazardous, if it is combusted should not stop us from looking at it as a is a good source of energy, but we have to be careful with any fuel, so that is what I come to in the next slide.

(Refer Slide Time: 13:12)



The safety of hydrogen fuel the hydrogen could be unsafe if handle improperly because it is a highly inflammable with invisible flames which is what we are talking about, but that is true for any gas even when we or even for any other energy source, when petrol and diesel we see those trucks we see that highly inflammable. So, we have to take good care and we have to be careful. The problem is there are historically two incidents that are severely tainted the reputation of hydrogen as a safe fuel. The first one is called it is a very tragic accident called Hindenburg incident in 1937. So, Hindenburg in those days I mean right now we see this jet planes; in those days are also these things called air ships.

So, air ships there was one called Zeppelin. So, air ships typically used to have this compressed hydrogen tanks inside and then there was a large metal frame and then there was a fabric around it, so that use to be the aircraft plane. And of course, it did not fly at very high speeds like the jet planes of today, but you could use it I mean that that was pretty regularly used for flights.

The Hindenburg incident where the airship the Zeppelin caught fire and that lead to loss of 36 lives, it is very landmark incident because it forever changed the face of the aviation industry. After this incident air ships were never used again and we went on to the jet planes that we used for flying today. However, that being said there are several theories that go around the Hindenburg incident as to why the explosion took place, why the plane caught fire. And there is no conclusive proof that the accident happened because of hydrogen because of combustion of hydrogen and that was a trigger. There are lots of theory this was you know this was that the plane belong to Germany. So, there were there are several conspiracy theories sabotage theory etcetera, etcetera. So, and I do not want to get into that what I will show you slice video because this is a very historic incident. So, we should know about it.

The other thing is the hydrogen bomb. Now, let me very clear, apart from just you know sharing part of the name, hydrogen bomb and hydrogen as an energy source has nothing in common. Hydrogen bomb has nothing to do with hydrogen as energy source. It is just like saying that and be we know that atomic bomb, nuclear bomb of course there, but does it mean that anything else anything related to nuclear energy is bad, no. It is like any other fuel also I mean coal can be used or a natural gas can be used to generate electricity petrol and diesel can be used to move our cars or trains of a transport to move moving vehicles, but both of these can be used for arson. So, if you misuse anything of course, that is there. So, hydrogen bomb and hydrogen as energy source is nothing in common.

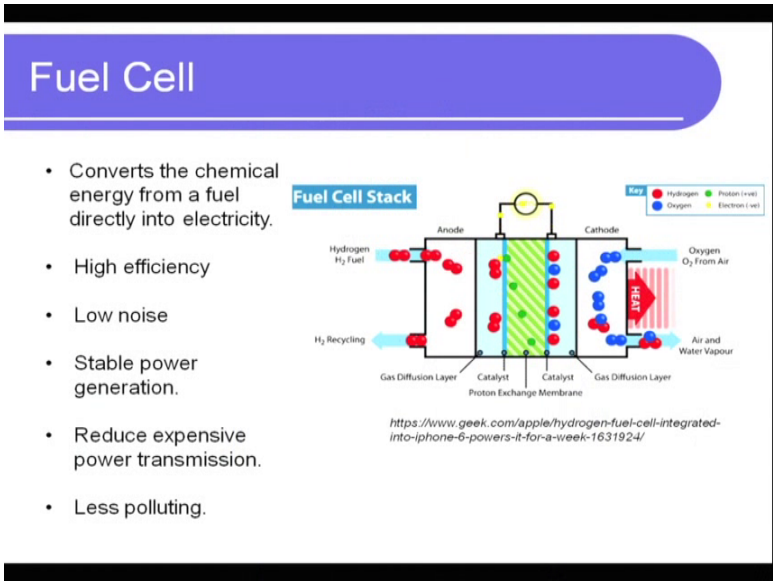
(Refer Slide Time: 16:46)

What I will doing I will just deviate a little bit now and show you a small video, which is the very tragic incident of Hindenburg. It is the short video. This is a Zeppelin aircraft. Nearing my fate land of (Refer Time: 17:00) landing (Refer Time: 17:01) the season, the Hindenburg approaches the modern masters (Refer Time: 17:04). Twenty-one is (Refer Time: 17:06), the world's biggest legible has made. Since I play (Refer Time: 17:10) the experimental services become a matter of routine. Scarcely a 100 feet about run the (Refer Time: 17:16) shape with her frame casing seven million cubic feet inflammable gas is being (Refer Time: 17:20). When suddenly in (Refer Time: 17:30) falling tragedy a matter of second. It seems all incredible with anyone to do scare. (Refer Time: 18:04) hundred and one disaster west in the history of aviation.

So, very tragic incident as you see it was it happened just moments before it was landing in New Jersey. So, within minutes 36 lives were lost of passengers and crew together, but that being said the also there is a positive part of it is I think more than two-thirds of the lives were saved of course, thirty six loss of lives is tragic, but many people were also saved. And one of the reason was hydrogen fuel being light actually moved up, so anyways. So, Hindenburg incident that was a little detour, but I wanted to show you as to what happened actually thus when jet plane caught fire. And it is the landmark incident even another respect is because as I said it forever changed the face of aviation industry because this air ships hydrogen powered air ships were never used again. And we went to gas turbine power jet engines.

So, what we will do next is after this brief discussion on hydrogen economy and hydrogen as fuel, we will move into fuel cell. And fuel cell actually uses hydrogen as a fuel to generate electricity. Keep in mind this is also an electrochemical device like battery, where chemical energy is converted to electrical energy directly, but battery can be used to store energy. Whereas, fuel cell is direct conversion real time, there is no storage involved, as long as you supply fuel you are going to get energy generation. Unlike battery where it will supply energy during the discharging cycle, but then it is beyond the point it will discharge and then we will have to either throw it away if it is a single use like in our torches or in our clocks or in our remote controls. Or we will recharge it like we do for our cell phones, for laptops etcetera.

(Refer Slide Time: 20:27)



So, what you will do is you will now move onto fuel cell. So, what is the fuel cell. So, fuel cell actually uses hydrogen as I said as an energy source. So, fuel cell consists of electrodes and a catalyst. So, any fuel cell will have like a battery has two electrodes and then electrolyte. So, as we will see later there is one form of fuel cell which is called a proton exchange membrane fuel cell. And what it does is it allows protons to flow through and while sort of stopping the movement of electrons. So, what happens is this electrodes have a is a catalyst where the hydrogen when it reaches there, it dissociates into electron and proton.

So, if you take a mono atomic hydrogen if you remove the electrons then what we are just left with one proton that proton moves through this proton exchange membrane to the other side of the electrode where what comes in is air which as oxygen. So, this protons actually then in the presence of the catalyst react with the oxygen molecules. Now, what happens to the electrons? So, when the electrons are separated at this electrode we attach an external circuit. So, this electron actually flows to that external circuit and it comes to the other electrode where it recombines with the proton to produce hydrogen which then combines with the oxygen to produce water and what comes out therefore, is the air minus some oxygen and water vapor. And it is an exothermic reaction. So, therefore, you are going to generate heat clear.

So, what is the input in a fuel cell, input in a fuel cell is hydrogen mainly because that is the fuel and oxygen which is available I thinks quiet in significant amounts in air. And what comes out of the fuel cell apart from electricity that is generated, the byproducts is heat definitely, because it is an exothermic reaction and then its water vapor, and of course, unused air clear. So, this is conversion of chemical energy from a fuel directly into electricity. As we will see it has high efficiency. Why it has very high efficiency, it is extremely high efficiency, we will talk about that. It has low noise actually there is no moving parts that we are apart from you know having some kind of a pump or some kind of a driving force to have the hydrogen and air flow through, you do not have compressors and turbines are pumps I mean may be a small amount of pump that is about it. So, it is low noise that way. It is a stable power generation as long as the fuel supply is stable and it is less polluting.

So, what is an ideal application for such a fuel cell. An ideal application for such a fuel cell is actually cars; one of the ideal applications. It depends on I mean it depends on the temperature etcetera, but in cars you can think of a especially when we talk about electric cars right, we can use fuel cell as a source of electrical energy or even hybrid vehicles the electrical part we can use as fuel cells. But of course, the challenges, so most of the electric vehicles and hybrid vehicles that are available today in the market commercially is being driven by batteries, but fuel cell is an equally strong contender if we can bring the cost down if you can bring the size down make it compact and so on. So, this is how in nutshell what is a fuel cell and an application of generation of electricity using hydrogen as a fuel.

So, with that small introduction what we will do is we will stop today or stop this lecture and we will continue in the next lecture with further description of fuel cell. So, let us kind of recap what we discussed in this lecture. We started by saying that hydrogen is an attractive source of is an attractive candidate to be used as fuel. Why, because its energy content per unit mass remember calorific value or heating value that is very high three times that of gasoline that we use in cars so very attractive, but of course, it is a very light element. So, the volume required for a given mass is much larger compare to any of the other fuels that we used regularly.

But one of the big drawbacks is hydrogen is not abound is not available freely in nature it is available it is available only 75 percent of matter in the universe contains hydrogen, the biggest source is water, the water is H 2 O. So, hydrogen is available. Natural gases hydrogen, any of the hydrocarbons has hydrogen, coal has hydrogen, but the thing is you have to extract the hydrogen from all these matters or from all these sources and for that we need to use electricity. And the cost of electricity of course, the energy cost involved to just generate hydrogen is quite high, so that is a problem. So, generally we have to see that we have we incurring additional cost to generate hydrogen. So, I will going to get the returns because for a given mass, I get a lot more energy.

The other thing that we said is storage of hydrogen is a challenge because its light element. So, it requires large volumes. So, we have to think of compressing it and storing it or liquefying it and storing it. And the two other things that we talked about is storage in that form of metal hydride, storage in the form of glass microspheres. The other thing we said was hydrogen is a highly combustible gas and the flames are invisible and it spreads very rapidly because it is light. So, that way there is a little bit of safety hazard using hydrogen, but then honestly every fuel has some safety hazard. So, as long as we are careful we should not be too worried about it we should be conscious, we should be aware of the dangers involved and take adequate precautions, so that it does not lead to any safety hazards or any accidents.

So, with that we also said that you also took a little diversion, I talked about the Hindenburg incident, where this airships which are hydrogen powered the jet plane which was the last air ship crashed in 1937. It was a very tragic fire accident, but whether that accident happened because of combustion of hydrogen the jury is still out there are several theories that do the rounds including sabotage including using an inflammable

material on the outer surface and so on. So, we do not know, so it is not conclusively proven that the accident happen due to hide use of hydrogen as fuel. So, with that brief discussion at hydrogen as fuel we moved onto and we introduce the concept of fuel cells where hydrogen which is a device that converts the energy trapped in hydrogen directly into electricity. So, what you will do is we will pick up from here, and in the next class we will continue with our discussion on fuel cells.

Thank you very much.