Energy Resources and Technology
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Lecture - 40
Hydrogen Economy

So far, we were talking about different types of energy sources and while we were discussing those different types of energy sources we discussed the fossil fuels as well as the renewables. Now, in doing so, you might have noticed that there are some of the sources, mainly the fossil fuels which are also a source of major concern today, because of the greenhouse effect, because of the global warming problem, the climate change problem and this problem has come to the notice of the scientific community approximately since the 80's, not before that.

So, before that we thought that the world big system can absorb. It may cause difficulties in a transient manner, but on a long run, a system can absorb the effects. But, since that time approximately we started to realize that no, that is not quite so. The amount of carbon dioxide that we are releasing into the atmosphere that is adding to the greenhouse effect. I suppose you know the mechanism of the greenhouse effect. Without the greenhouse effect, the Earth will not survive, because unless there is a greenhouse effect, we have already talked about the greenhouse effect when related to the solar thermal collector, so you are exposed to that.

Without the greenhouse effect, if the amount of solar radiation coming in, in totality it goes out, then the temperature would be far lower. So, because there is a certain amount of carbon dioxide and water vapor in the atmosphere, some amount of outgoing radiation is arrested. As a result, the temperature is relatively higher. After all, the equilibrium has to be reached. It is not that a larger amount of incoming solar radiation comes and a lesser amount goes out; no, that is not possible. The fact is that, because of the greenhouse effect the equilibrium is reached at a relatively higher temperature, which say, about 100 years back it was more or less an equilibrium temperature, a constant temperature that

was good for the survival of the human species and the other species. This does not mean that average temperature does not change. It does change and that is why there are ice ages and relatively hotter periods without the intervention of humans. These are natural, but here what we are talking about are caused by the human intervention, essentially by the introduction of the greenhouse gases into the atmosphere.

So, what are the greenhouse gases? In the main they are carbon dioxide, methane and water vapor. Out of all these, even though the water vapor is the maximum amount, but it is realized that water vapor is going, is being evaporated and precipitated, so it is a cycle. But, in case of carbon dioxide it is not quite so, because the carbon dioxide that is, that is going into the atmosphere it takes a very long time for that to be absorbed mainly by the green mass. So, the amount of carbon dioxide in the atmosphere has been increasing, because the amount of carbon that was available as negentropy stock in this planet has been depleted and that is been reacted with the oxygen and that is being distributed into the atmosphere and as you have already learnt, it took millions of years to store that amount of carbon, that amount of chemical energy and it took about 80 years to exhaust that. So, all that amount of carbon has been released into the atmosphere over a period of last 80 years.

Now, that has, that has raised a number of concerns, main important being that the average temperature will then go up and if it goes up by just 1 degree, then that itself can cause a lot of damage and one of the major damages that is already salient are the melting of the ice caps. This year a big island like mass of ice has broken off the Arctic Circle. Similarly, things are happening in the Antarctic also and if these things go on, obviously the average sea water level will go up and that has a very detrimental effect on many of the coastal cities. Apart from that you can easily see physically that there has been a change in the climate over the last few years and that is being blamed on this, this problem.

So, there was a concern and that was sort of nucleated by the United Nations meeting on climate change that was held in Rio de Janeiro in 1992 that sort of adopted a frame work,

so that all the nations together would now work towards combating this problem. But, that was the frame work in which the, that was a frame work in which all the countries and their leaders participated, but that has to be, you know, put forward in terms of very concrete palpable policy. That came out in through a meeting in Kyoto in 1997 I suppose, in which some very concrete recommendations were made and some 130 countries signed that; means they agreed to be, to be, those rules to be binding on them.

What were the rules? The rules said that a country is hence forth not allowed to release more than this amount of carbon into the atmosphere and for each country this was set. That was set basically dependent on the level of development, on the population and things like that. In some cases, the limit was above what was the current release level, remember that and there were some cases, where it was below the current level. For most of the European countries and the American countries it was below the currently, current level of release of the carbon into the atmosphere, so that they had to reduce, but also there were countries for which everybody agreed that they are now allowed to even increase. In what sense?

In the sense that those countries level of development was such that the per capita consumption of energy is so low that in order to develop the economies, there has to be some amount of increase, but there was another aspect to it. The aspect was that now carbon trading was allowed, meaning that the countries which are unable to reduce, even though it is binding on them to reduce, they can buy that carbon from other countries which can now increase. Suppose there is one country, England which is now supposed to release this amount and then there is some other country, say Bangladesh which is now allowed to increase. So, England can buy from Bangladesh that additional amount, so that overall the increase can be arrested. Is that idea clear?

Now, there is something known as a carbon trading which means that there is economic advantage of using less fossil fuel. So far, there was no economic advantage of using less fossil fuel. Now, you can reduce and then trade on it. I have reduced and therefore, I can sell you that, so that those countries which are, you know, defaulting countries they can

buy that and they can still continue to release that amount of carbon into the atmosphere. Most of the countries agreed to this protocol with one very notable exception that is America, United States of America and that is the largest releaser of carbon into the atmosphere.

So, the success, overall success of this protocol which is known as the Kyoto protocol is somewhat in doubt, because after all we are talking about the total planet and its carbon budget and if some country as strong as the USA does not agree to that, then there is a difficultly. But, it really happened. But still, there is now indication that the mechanism is working, because the overall level of carbon release into the atmosphere is not as high as was anticipated, say 10 years back and people are realizing the economic advantage of going for energy sources that are other than fossil fuels. So, now that this convention is in place, one has to look for other alternatives.

Now, some of the alternatives were already there. For example, we have already learnt about the renewables - the wind, solar, biomass, the tidal, all these, these are of course nonpolluting in the sense of carbon. I am not saying that they are nonpolluting in any way, they are. Every source of energy has some kind of environmental impact, you cannot help it, but in the sense of carbon release into the atmosphere, they are nonpolluting. Now, if that is so, then, then one of course has to go into this and that is why after this protocol there has been a renewed interest in the renewable energy sources. In India for example, over the last 5 years there has been a very large installed capacity of wind energy generation, mainly because of this advantage that there is now economic advantage of it. But then, apart from the source of the energy, for example the coal fired power, power stations, oh, by the way some countries have effected within the country this Kyoto protocol, in a rather clever way.

For example Sweden, for example Denmark, for example Holland, these countries have introduced a levy on the fossil fuels depending on the carbon content in it. For example, if anybody buys coal in Sweden, he will have to pay an extra tax, because coal contains carbon. If anybody buys petrol, he will have to pay a tax, because petrol contains carbon

and since coal contains more carbon than petrol, petrol contains more carbon than natural gas, so natural gas, CH 4 and petrol contains a more equitable distribution of carbon and hydrogen, so the natural gas is least taxed, but the taxation is on C. Get the point?

In our country also the fossil fuels are taxed, but not on this basis. They are heavily taxed. The price of fuel that you pay, about half of it goes as simply tax to the government, but that is not the carbon tax. Now, those countries use this carbon tax in order to pay for the carbon exchange. So, that is, that is one good thing to do, because in that case there is an inherent advantage of going for non-carbon based sources. Now, the major source of pollution in all these countries is basically the vehicular traffic, right, vehicles. Yes, coal is burnt in the power stations, yes natural gas in burnt in power station, but ultimately the major source of the pollution is the vehicle traffic. Now, in the vehicles notice that the primary source of energy is going with the vehicle, right, primary source of energy is going with the vehicle and that is why it has to contain the carbon and hydrogen which is burnt. In the mid 60's, there was an alternate idea. By then, none of these concerns were really voiced, but scientists proposed an alternate idea.

You might notice, what is electricity? Electricity is not really energy source, energy carrier, right. It is, it is being generated somewhere using some primary energy source. It is carrying the energy from the source to the user and the user is using electricity as a prime over, so it is essentially energy carrier. Electricity is, it is possible to use electricity as a media for vehicular traffic in the sense of the battery and hybrid vehicles. But these, its utilities are somewhat limited, because the hybrid vehicles are fine, but battery driven vehicles have rather limited range. So, when people want to drive long distances, batteries are not really good for the purpose. Hybrid vehicles are okay, which I have talked about in this class, last class or so. Have I? Hybrid vehicles, yes? But then, still it burns, ultimately it burns carbon, right, carbon based fuels.

The alternate idea was to use something else as the energy carrier – hydrogen.

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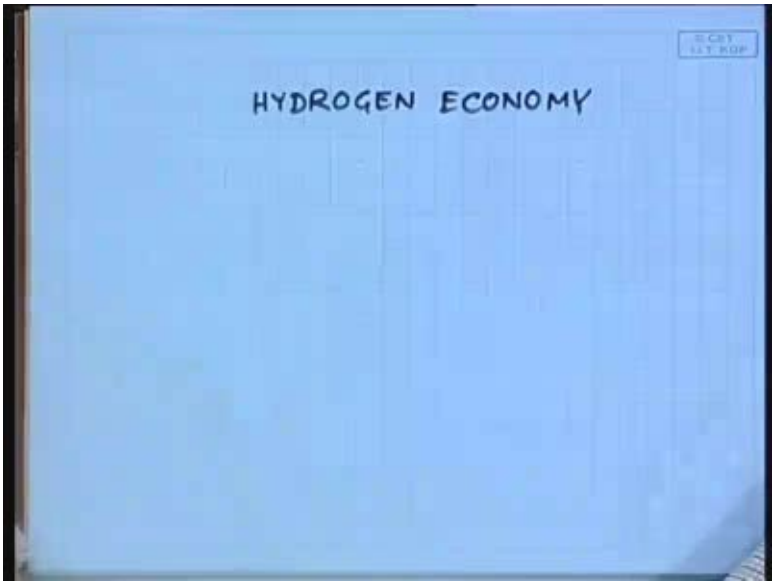

So, the concept came as a proposition of a completely different type of economical idea that is hydrogen economy in which hydrogen would play a major part in the generation and distribution of energy. What was the idea like? The idea was essentially that wherever you have a primary energy source, be it the coal, be it nuclear, be it wind, be it tidal or whatever, using that energy, well, generate electricity when you need to use that electricity, but electricity cannot be so stored. So, whenever you have surplus, especially during the night you have surplus, especially due to the variability of many of these renewable energy sources, it cannot be directly used, right. Because, in that case the demand would be that whenever there is wind you switch on your light, whenever there is no wind switch off your light. Of course, you cannot do that.

So, this variability is taken care of by generating hydrogen by electrolysis, using that somewhat unpredictability or surplus electricity during the night time. So, generate hydrogen, use that hydrogen in the vehicle you are traveling, but there are difficulties in that. Let me, let me point them out. Is hydrogen manufactured presently? Are there companies that manufacture hydrogen? Yes, there are. Why? Because, hydrogen is the major source of ammonia and ammonia is input for fertilizer industry. So, that is one major way in which hydrogen is presently used.

The other area in which hydrogen is presently used is cracking of the hydrocarbons. Cracking, you understand, means the heavier components of the hydrocarbons, those things are cracked by using hydrogen, so that using the very heavy part of the hydrocarbon like naphtha you generate a relatively lighter part that can be used in ……. So, these are the two ways in which hydrogen is used at present and at present out of the whole generation, major amount of generation is using natural gas. Presently it uses natural gas, presently it uses coal by water gas generation technique, but very little out of the world's production of hydrogen, about 4% only is used in electrolysis. Why? Because, this concept of hydrogen economy has not really taken root. But, there is one country which has initiated it.

You can easily see that the difficulty is that in one place energy is generated, the hydrogen has to be transmitted. Presently electricity is transmitted, then the hydrogen will have to be transmitted. Now, that hydrogen transmission is not an easy job. Why? Because, in that case you have to build pipelines and in the pipelines, the difficulty with the hydrogen is that what is the pipeline made of? Made of steel; hydrogen being a very, very tiny molecule that, you know, goes through any material, so it goes into the steel. Through the steel that can look out, leak out through the steel and as a result, the steel becomes brittle after sometime. So, there is a, there is a practical difficulty in transmitting hydrogen over long distances by means of steel pipes.

There are other difficulties also, but then what the country like Iceland has done? The other difficultly is that you have to have, presently you have petrol pumps, then you have to have hydrogen pumps or the hydrogen distribution network has to be in place which is an extremely expensive proposition. Why? Because, you have to have a completely different, completely new infrastructure for the distribution. Presently it is petrol based or diesel based, now it will be gaseous fuel based. Now, Iceland has the advantage of having a large geothermal energy resource and also a large wind energy source, right and the countries consumption in electricity is not as that much. So, it is exporter of energy. It exports energy. How can it export energy? It is after all island.

So, what it does is it generates hydrogen. Now, if it generates hydrogen, why not use it in the country itself? So, Iceland was the first country that started hydrogen distribution points and that started running buses by hydrogen. So, city buses in Reykjavik, the capital of Iceland, run on hydrogen, many buses. Nowadays, there are other cities in Europe also in which buses run by hydrogen. But in that case, the distribution are not in different places. They are in the specific, you know, terminus points where they can get the current. But, the idea that is now being proposed is that you generate electricity, whatever, wherever it is available, either in a concentrated way, for example, in very large coal fired power plants or nuclear power plants you might argue that in that case of course there is a burning of coal, yes, there is, but if it, if the coal is burnt in a very concentrated manner, then you can install all sorts of matters in which it becomes very, very efficient way of doing it. There can be nuclear power plants also, there can be distributed generation of electricity by means of the renewables. But wherever it is, if it is connected, connectable to the grid, transmit that electricity to the places where the hydrogen is to be used.

Now, there can be like petrol pumps, there can be hydrogen pumps in which the electricity comes through the transmission lines and right there electrolysis is done, so that the hydrogen does not have to be carried over long distances and that hydrogen is then put into the cars and buses. So, that is how in fact Iceland is doing it. They have those kumties in which the electrolysis is taking place and from there, there is similar, have you seen those gas pumps in Delhi? Because, Delhi has natural gas distribution, so natural gas means that is also a gaseous thing. So, similar way, but the difference is that in Reykjavik all the gumties have no roof. Do you know why? Because, if there is a hydrogen leakage, it is very dangerous and if there is a hydrogen leakage, if there is no roof it simply goes off. It is very, very light, immediately it goes off, so there is no burning. In fact, it is very difficult to sustain hydrogen flame, because it goes up so early, so fast, so you have this kind of economical ideas.

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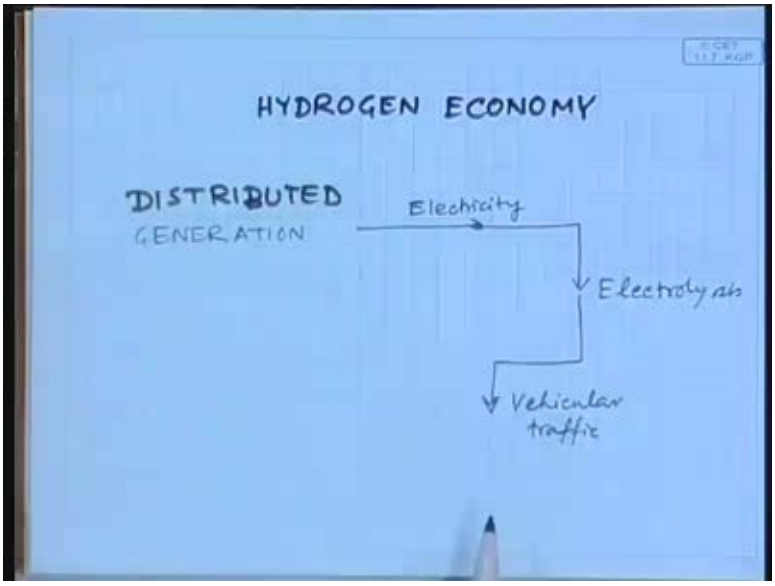

Ultimately the idea is that you will have generation, distributed generation, transmission through electricity, then conversion into hydrogen by electrolysis and then using. So, that was the channel we talked of. You might easily realize that there are also, when we talked about different energy sources, we also talked about wave energy, we also talked about ocean thermal energy conversion; those things are often done offshore in pretty distant locations. From there it is very difficult to transmit electricity to the shore. So, right there, generate the hydrogen and then transmit. Now, that brings the question of how to transmit hydrogen. As I told you, it is difficult to transmit hydrogen through simply pipelines.

There are two ideas. One, compress it, compress it and then transmit it. Two, liquefy it and then transmit. Both have the difficulties that if you compress it, in compression, because hydrogen is such a light gas, in compression there will be a large amount of energy spent. So, the energy that you have generated, a part of it will have to be spent on compression. In case of liquefaction also it is the same thing. You have to first compress it and then you have to take away the heat. So, that way you essentially spend a lot of money. The problem with hydrogen as compared to all these sources, the reason that hydrogen economy is not yet in place, is that the energy density of hydrogen is so low, energy density.

In case of petrol, it is very high, because it is naturally a liquid, it is very high. So, by a unit amount of say, 1 litre of petrol, the amount of energy that you can get by similar amount of hydrogen you can get far, far less amount. So, the mass that you have to store is large and that is exactly why so long as petrol is available in even, you know, minute quantity, still people will prefer that. But you know, in the first part of this …. like this, we have also understood that within your lifetime you are coming, you are going to see a time when petrol will no longer be available, petroleum products will no longer be available. Then, what I am now talking about the hydrogen economy will be the right thing. But, in that case, you will still have to overcome the problem of compression, because in the case of the, in the city buses in Delhi, it is the compressed natural gas CNG that is used and the amount of compression that is used is not very large, so that they have a reasonable working length and then it has to be refilled.

A similar thing can be done, so that you do not spend much energy in the compression. But then, you have to sacrifice the range, which is pretty all right in case of city traffic, especially in case of public transport it is pretty all right, because the bus will go from one point to other point. So long as it can go from that point to this point, it is fine and that is why the total hydrogen economy then sort of rests on the availability of cheap and very efficient public transport system, not private transport system. For the private transport, nobody will really prefer it, because of this problem. But still, cars have been manufactured. GM has manufactured cars that run on hydrogen, Toyota has manufactured cars that run on hydrogen; there are many companies. Especially buses have been made in large number, because many of the cities in Europe are going for hydrogen based transport.

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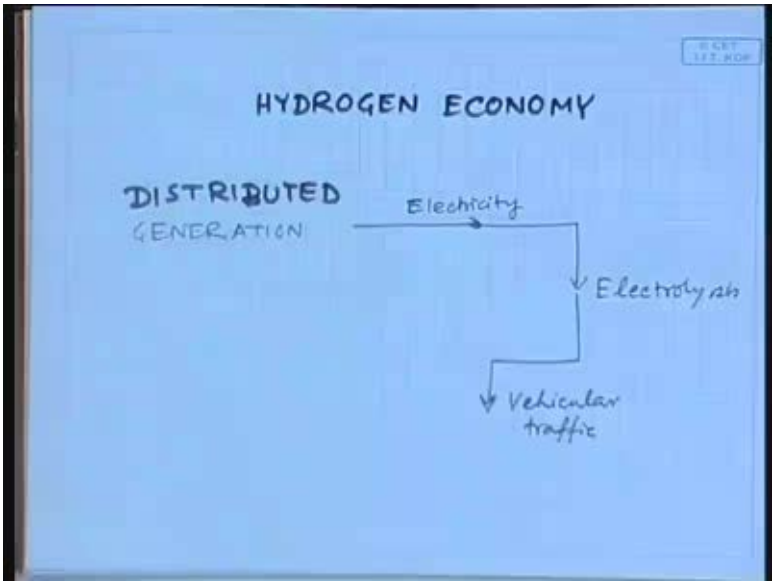

The other aspect of hydrogen economy is that one thing is to generate which I told that it has to generate, it has to be generated through electrolysis, but then how to use it? Now, obviously it can be used in two ways. The way many of these companies, Toyota, GM and companies like that, they are proceeding both the ways. One way is to use internal combustion engines that run on hydrogen in place of the other fuels. Obviously, this will necessitate only a bit of change in the fuel to air ratio that is all. Not much, not much change, a bit of change in the design that is all. But then, what is the efficiency of the internal combustion engines? That is after all limited by the Carnot efficiency, the average efficiency, 25 to 30%, nothing more. So, 25 to 30% is the efficiency of a normal car and those cars will also be about that efficient.

The alternative way is to have a direct conversion of hydrogen into electricity on site and then run a motor with it and the way to do that conversion is known as the fuel cells. You may have heard of these names, fuel cells.

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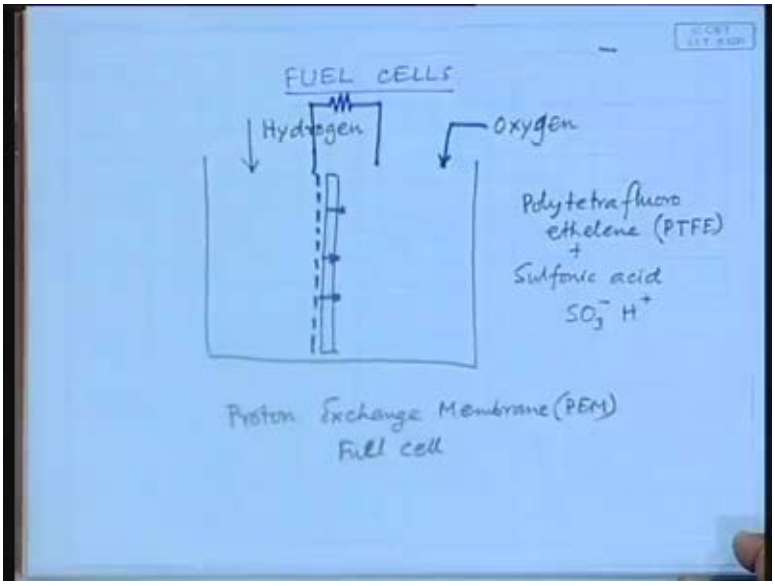

The development of fuel cells has been going on for a quite long time, for quite a long time. Fuel cells were discovered in the early 19th century, very long time, but then they were not used, because there were abundant amount of fossil fuels so far available, but now there is a renewed interest in the fuel cells. There are many types of fuel cell, but let us, let me describe only one type that is that uses hydrogen, because we are now discussing hydrogen economy mainly. In this kind of fuel cell, the key element is a membrane, say I am drawing this membrane, a membrane that separates the cell into two parts and that membrane has a specific property that it allows protons through, but it is insulator, so it does not allow electrons through. Is the property clear?

The property is that it is an insulator. Insulator means it does not allow electrons to pass through, but it is porous to the extent of being able to allow protons to pass through; protons means H plus. So, if from hydrogen you strip off the electron, what remains is a proton that can pass through. So, what is done is, in this part hydrogen is introduced which comes in contact with a catalyst here in this side. That catalyst is mostly platinum, platinum catalyst but there could be other things also. In contact with that, hydrogen ionizes meaning that the proton and the electrons are separated out. If they are separated

out, then the protons would pass through, right, protons would pass through, but the electrons will not be able to. Those electrons are collected from here.

Now, after the electrons are collected that means in this, from this part there would be electrons surplus and those things are collected from here, they are allowed to flow through external circuit because they cannot pass through this. Now, protons are passing through, electrons are passing through the external circuit, but finally when it comes here they are allowed to recombine along with input of oxygen. So, in this part hydrogen is introduced, in this part oxygen is introduced. So, what will be the result? Water. Not only hydrogen, here the protons are coming, protons are coming, recombining with the electrons and being mixed with the oxygen will produce water. So, ultimately the whole product of the system is nothing but water, the cleanest possible motor drive system.

So, if you store hydrogen and allow it to be converted into electricity by means of such a fuel cell, this is called a proton exchange membrane, PEM fuel cell. There are many other types of fuel cells, but only one I am describing here. So, you have got a container in which the key element is this membrane that allows the protons through, but does not allow the electrons through. So, the protons go through and electrons go through an external circuit and finally, they recombine with oxygen to produce water. That is essential idea. Now, this kind of cells normally produce something like, each cell will produce something like 0.5 to 0.7 volts. So, in order to produce a large voltage, you have to stalk such cells in series and then you get, in a way similar to photovoltaics you get, a voltage out of it and with that voltage you can run a normal motor to run the car.

Now, these fuel cell cars are in the market now; the fuel cell cars are in the market now, hydrogen that, the fuel cell cars that take hydrogen, but they are expensive, more expensive because the fuel cells are right now expensive. It is anticipated that with mass production, the fuel cell prices will go down and then if hydrogen is available, the whole car price will be lower than the normal car prices but that has not happened yet. But, the direction in which things are happening, in a span of about 5 years you can expect this to happen. So, the fuel cells, by the way, what is this, this membrane? This membrane is a

plastic material, is a plastic material, polymer material. It is, it is made of polytetrafluoroethylene. It is, its name is called PTFE. This is a plastic material, a polymer material.

Now, that is reacted with sulfonic acid that is SO 3 minus and H plus. Now, when you react it with sulphonic acid, this thing go into that polymer material. Now, when this is there in the polymer material, this one, H plus is mobile, but this is right there. So, the H plus, the protons move from one side to the other. As a result, it can move, so that is how the whole thing happens that the protons can move, while the electrons cannot, because it is a polymer material, it is an insulator. Probably you have seen in National Geographic or such TV channel programs that this thing, these cars are now very much in the market. There have been program on this and in IEEE magazines like Spectrum, you will find a good number of issues have been devoted to the development of fuel cells.

So, with the development of fuel cells as the consumer, with the development of electrolysis as the generator and there is only one point that remains, how to transport that. Transportation, as I told you, is a problem and when it comes to vehicular traffic also, then there also the transportation is the problem, because ultimately the hydrogen has to be transported. Notice, the primary fuel has to go with the vehicle, in case of the fossil fuels. That means petrol is the primary fuel and that has to go with the vehicle. But in this case, the primary fuel is something else, secondary fuel is generated and that has to go, but that has to somehow be accumulated. A reasonable amount of energy has to be somehow accumulated within the car.

Now, as I told you, there is a possibility of compressing it. There is a possibility of liquefying it, but liquefaction is not really considered, because of the expenses. The other thing that is considered are known as the metal hydrides.

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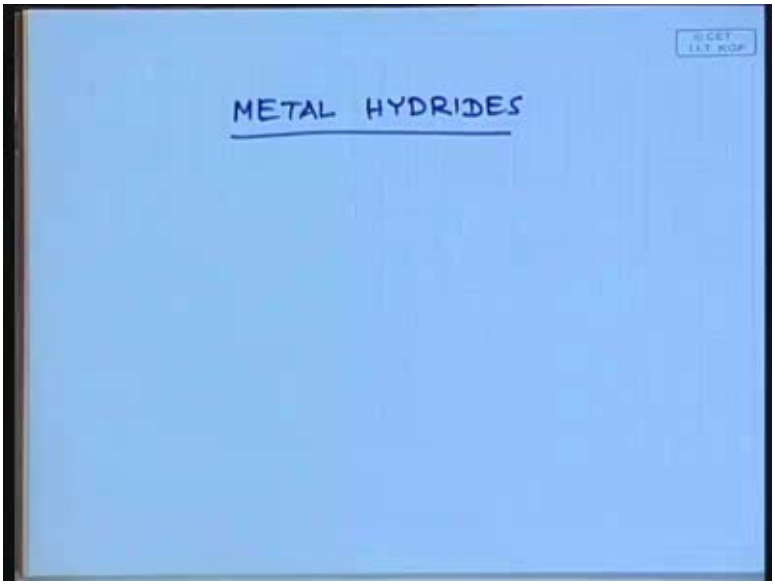

There are some hydrides, there are some metals which absorb hydrogen at certain temperature and at certain other temperature they give out that hydrogen. So, it sort of becomes a matrix of metal hydrides, metal in different locations of that matrix with hydrogen attaching to each of them and as you heat it, those hydrogens are again released. So, these metal hydrides can be used as sort of carrier of the hydrogen. That means in the hydrogen pump you absorb the hydrogen in the metal hydrides and later when you, when you run, you simply heat it to extract the hydrogen and then with that you run.

So, the metal hydrides, there are a few different metals that on which researches are going on. Metal hydride has not yet come into the large scale consumer market, but it will come because the research is in very, undergoing in a very strong way. So, the point that I am trying to make is that there is an alternate proposal. Presently, the model of energy generation and consumption is that you generate energy through fossil fuels, convert into electricity and take that electricity to the consumer end and run whatever you want with that electricity. That is the present model and in case of the vehicular transport, the present model is that you take a part of the primary fuel into the vehicle and run it.

Now, the way the things are changing especially because of the climate change concern and the Kyoto protocol is that, now things are moving towards generating the electricity and wherever possible run the vehicular transport directly with electricity, like electric trains, like trams and things like that. That is why in many of the western cities where which abolished trams in the 70's, they have brought back trams, because that is how the trend is going. That is most radical, rational thing to do.

The other thing is going towards hydrogen. But as I told you, the difficultly of the hydrogen are some technical difficulties. We have to increase the efficiency of the fuel cells, we have to bring down the price of the fuel cells, we have to bring down, we have to find some solution of transportation of the hydrogen which is, as I as I told you is the problem right now. So, because of these issues, the hydrogen economy is not in place in most places. But, some countries are going very strongly at it, like Belgium, Denmark, Iceland, as I told you, some countries are going very strongly at it.

Now, let us come to India's situation. Since today is the last class, let us talk of where India stands in terms of the total energy availability and the total energy consumption. At present, a bulk of India's generation is from coal fired power plants and India has a large stockpile of coal, it has; not a very good quality, but still it has. When I say not a very good quality, I do not mean in the sense of the sulphur content, I mean in the sense of ash content. Indian coal, especially the ones that are available in the Eastern part, they are low in sulphur. So, the ash content essentially means that you have to, if here is a coal mine and there is a power plant, then you have to carry it and when what you are carrying it costs, it incurs expense and half the thing that you are carrying is ash, so obviously that is not preferred and now, naturally the trend is towards pit head power plant. That means wherever the mines are, very close to that there should be power plant, large power plants and that is how the NTPC, National Thermal Power Corporation, they are installing large power plants, very large power plants of the order of 2000 megawatts each, in places which has very easy access to the primary fuel and or water falls.

That apart, India has a large amount of hydroelectric power generation capacity, but not equally distributed into states. The southern states have reasonably larger amount of hydroelectric power capacity, the middle states do not have much, the northern states have again a large amount. That is why when it comes to generation mix between the thermal and the hydro, the southern states are better off, the middle states are very badly off, because they do not have much of hydro power generation, but the northern states do not have much of thermal power generation. So, there is a difficulty there.

For example, the ones, the states that are in the Himalayas, they have a large amount of hydroelectric potential, but that is mostly small rivulets coming down at a very large head, but the amount of water available in each is rather small. So, each one would be able to produce a small amount of electricity, all right, but there is an overall generation capacity that is pretty large. For example, in the state of Sikkim, in the state of Arunachal Pradesh, the NHPC has planned very large total generation capacity, but each one would have relatively small generation capacity, but these are still the conventional power generation.

In the hilly ranges, the logical thing to do would be the run off the river hydroelectric plants. I have told you that run off the river means where there is very little storage capacity. The storage capacity is not meant for storing the water for use at a time when there is no water. It is basically, the amount of storage is only meant to level the loads during the peak hour and the off peak hour. Water is coming at the same rate, but the electricity is needed during the evening time and daytime and the other time it is not needed, so that amount of water only to be stored. Unfortunately, some of these plants in the hilly regions have been planned with a larger capacity and that may later cause problems of ecology, but essentially the way to go is to have run off the river hydro plants.

If you have run off the river hydro plants, there is very little planning that is possible. In the sense that you cannot really plan to generate electricity when there is no water. India, as I told you, has a reasonably large coast line and India has a reasonably large number of

spots in which there is high wind speed. Which are the places, which are the places in India? Mainly the Western Ghats, not the Eastern Ghats; mainly the Western Ghats. So, when the wind comes and if in the Western Ghat there is some kind of a, you know, channel like structure, the wind has to pass through that at high speed. So, those are the places where very high wind speeds are encountered and some of these places are in TamilNadu. That is why TamilNadu right now has a very large, in fact the maximum wind generating capacity in India. The next is Gujarat.

But after all, the wind generation capacity, wind generation itself is unpredictable. You cannot predict it, you cannot plan it; whenever it comes it is there. What about tidal energy? How much source do we have? We have basically, as yet we have nothing installed, but we have basically one place where a large tidal energy generation can be possible. That is in the Gulf of Cambay. The other place is in the Sunderbans which is very ecologically fragile and it is not desirable to install such a big thing there. So, in that place if we install a power generation capacity, we will have more than 2000 to 3000 megawatts of generation, but that generation, if you have listened to the lectures on tidal energy, you would notice that it is not really continuous. It is also discontinuous, depends on the time of the day and motion of the moon, which is not really synchronized with the solar day. So, it moves. So, that is also somewhat a discontinuous kind of generation, where it can, you cannot really plan in the same way.

India has a large, reasonably a good amount of nuclear power generation capacity, but that is not really a good proportion to the whole, because it is something like 5%. No, it is right now I suppose 3% and they are planning to raise it by 6% or 7% later. So, it is not a very large fraction of the total. So, how would you picture India meeting the future demand? Mainly out of wind energy, mainly out of tidal energy, mainly out of, well, ocean has completely been untapped so far, but India has a large, every country that has ocean has a large possibility of generating ocean thermal energy, wave energy. So, in future, one looks for the generation of a bulk amount of energy from these sources, but as I, as you easily understand that these are all unpredictable sources. When it is there you generate, when it is not there you do not. But, the economy has to run somewhat

predictably. You have to go to the office and have to, have to get electricity there, you have to go to the college and you do have to get electricity there. So, obviously the consumption must be predictable, but the generation is not predictable. How to meet that gap?

Presently, the only way to meet that gap is hydel generation. That means when there is no generation, you can use the hydel generation, presently. The coal fired power plants are not able to vary so fast, as I told you. So, coal fired power plants, the smaller ones are able to vary, but not much; bigger ones are not able to vary their power generation very fast. So, there is a problem there and that is why in future, going in a big way for hydrogen based economy would be an option for India also and possibly within your lifetime you will see that, India going in a big way for a hydrogen based economy.

So, what would be your views of a time, not much later, 10 to 15 years later, when the petroleum becomes so expensive that you cannot really run your cars with it, how will you do that? How will you do that? Presently you run your bicycles, right, mostly. But, some of you run your motor cycles. How do you run the motor cycles, how do you run the motor cycles then at that time? Well, motor cycles, scooters and things like that, even bicycles can be run with electricity itself and I do not know why this development has not happened in India. Probably because, people are hooked to, you know, the motor cycle kind of psychology. But in China for example, there is no petrol driven motor cycle. A big country, but hardly you will, you will see any. All these are electricity driven, battery, battery vehicles.

So, all that is necessary is for that particular type of construction of the motor, that particular type of construction of the vehicle, that particular specific construction of the, of the batteries, those things somebody has to take up as the entrepreneurship venture. In India, nobody has. Only a few days back, I saw one electricity driven bicycle, but they have not come to the market in a big way. But, that is the direction in which it should go. That means if you are planning to buy something in the future, do not buy a petrol driven

vehicle, because it is not going to last. What about the city transport? What is, what would be your suggestion there, city transport?

Recently, the city transport, in most of the Indian cities, are in the main private, private cars, private buses. In a country like even United States most of the city transport is

Students: Private.

No, that is the anomaly that people do not understand. City transport is ….., either metro or buses. So, mostly buses there or you have also the or you also have the, what are known as the trolley buses. All these are essentially ….. mode of transport. In a, in a city like New York or London people do not prefer to own cars. You know why? You do not park them. There is no parking, so India is also going in that direction. Obviously, there is no point in buying cars. But, the point is that in that case there has to be extremely strong public transport system, so that you feel as comfortable in the public transport system as you would in a car, right.

You want to reach any place, you have to, you will, you will be able to reach that using public transport system. That is the proper energy efficient economy, because a public transport system like a, like a train or a tram that can carry a very large number of people in one vehicle and as a result, the overall efficiency is very large. So, as energy engineers, you should really recommend that public transport system, not private transport system. Only in United States, you will find in the rural areas or not the big cities, you will find it is, it is practically all private transport. Everybody has to have; if there are three people in the family three cars, so because they have made their economy that way and that is exactly why they cannot sign the Kyoto protocol, because they have made their economy so very inefficient that there is no way to go back and that is why the planet is suffering, because some people are leading very lavish life.

Now, it is time for us to realize that we have to cut down, we have to tighten our belt and we have to cut down our energy expenditure. We have to cut down our carbon

expenditure. So, with that I suppose this is the end of the, not only the class, but also the course.

Thank you.