Hydrogen Energy: Production, Storage, Transportation and Safety
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Lecture - 30
Economics and Status of Various Hydrogen Production Routes

In the last class, we have seen technical comparison of the various Hydrogen Production Route. In this class, we will see the economics associated with the different hydrogen production methods and what is the global and Indian status. So, this is the last class on the hydrogen production and thereafter we will in the next class, we will start with the hydrogen storage methods.

Before we go on to the economics, we will quickly revise some of the definitions or terms which we use in energy economics. The foremost term that we use in energy economics is simple payback period. So, this is the number of years in which an investment pays itself. However, this term it does not use the time value of money or the life of any plant. So, in order to include that there are other terms which are used like the net present value or life cycle cost.

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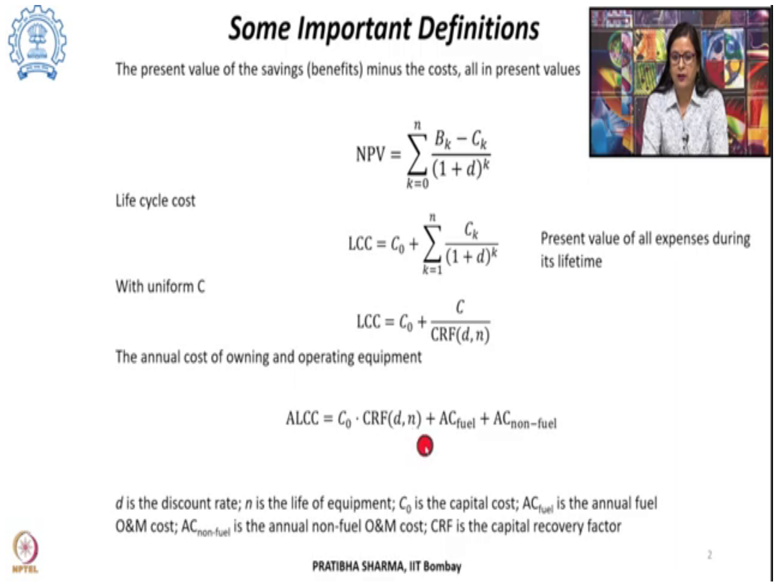

When it is net present value, it takes into account the savings and the cost. So, savings minus cost and then in the denominator is the discount rate; discount rate considers the time value of money. So, when some investment is done today what is the expected gain or what will be the worth of that money which is invested in future? So, that is considered by the discount rate and this is summed over the number of years.

So, for kth year, this is B_k the benefits minus the cost C_k in kth year divided by $(1+ d)^k$; d is discount rate, k is the year. Now, when we have to find the life cycle cost of a energy producing plant then that can be obtained by adding the initial investment and the present value of all the expenses summed up over its lifetime. So, this is the present value of all the expenses during its lifetime to that we have added the initial investment.

Now, if this expenses remain constant over years for this uniform C_k, we can write the life cycle cost by the initial investment plus expenses over capital recovery factor that depends upon both the discount rate and the years. Now, the annual cost associated with owing as well as operating an equipment can be obtained as annual life cycle cost which is the initial investment times the capital recovery factor plus the annual fuel associated operation and maintenance cost, non-fuel operation and maintenance cost.

So, this is how we can get the annual life cycle cost of an energy producing plant.

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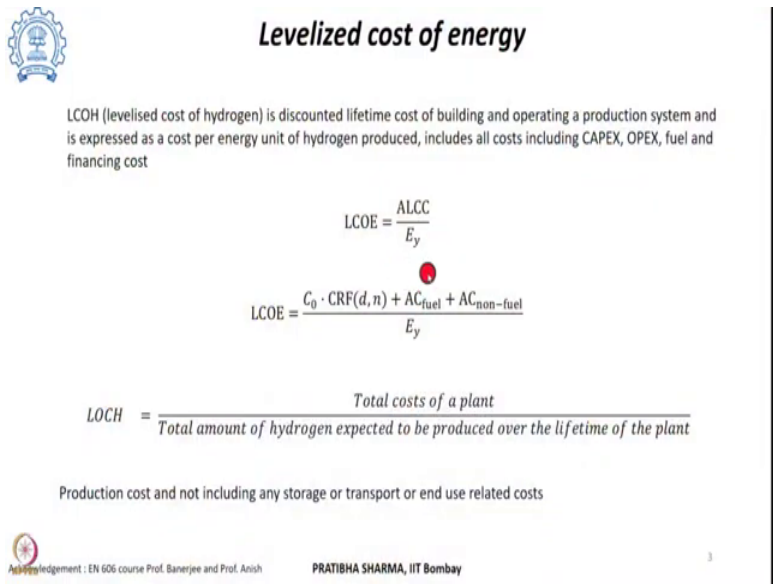

We can find out also the levelized cost of energy by dividing the annual life cycle cost by the amount of energy that plant is going to produce over its lifetime. So, the levelized cost of energy is given by annual life cycle cost which we have seen is the initial investment times the capital recovery factor. And, the expenses associated with the fuel related and non-fuel related operation and maintenance divided by the total energy being produced during the life cycle of the plant. So, that gives the levelized cost of energy.

On the same pattern, we can also calculate the levelized cost of hydrogen and that levelized cost of hydrogen is the discounted lifetime cost of building and operating a production system. And, it is expressed as the, total cost of the plant divided by the total amount of hydrogen which is being produced over the life time of the plant.

So, the total cost divided by the total amount of hydrogen that is expected to be produced by that plant over its entire lifetime. And, this is the only the production cost is included while calculating the levelized cost of hydrogen, not the storage or the transport or the end use cost.

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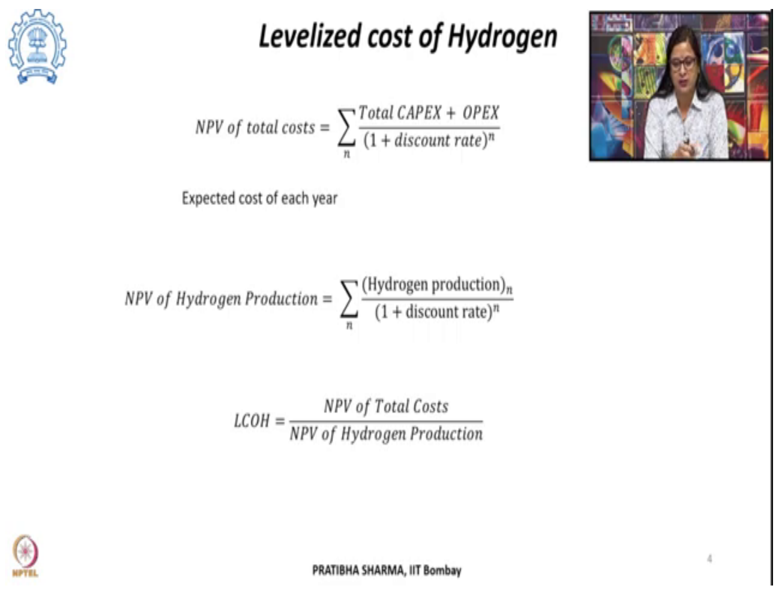

We can also find levelized cost of hydrogen as net present value of the total costs which includes both CAPEX and OPEX. So, it is the net present value of the total cost summed over the number of years for which the plant is operational, from commissioning to decommissioning divided by 1 plus discount rate to the power n.

And, similarly we can find out the net present value of the hydrogen being produced and the ratio of the two net present value of the total cost to the net present value of the hydrogen production will give us the levelized cost of hydrogen. So, these are some of the terms we should know before we look at the cost analysis of the hydrogen which is being produced through different production routes.

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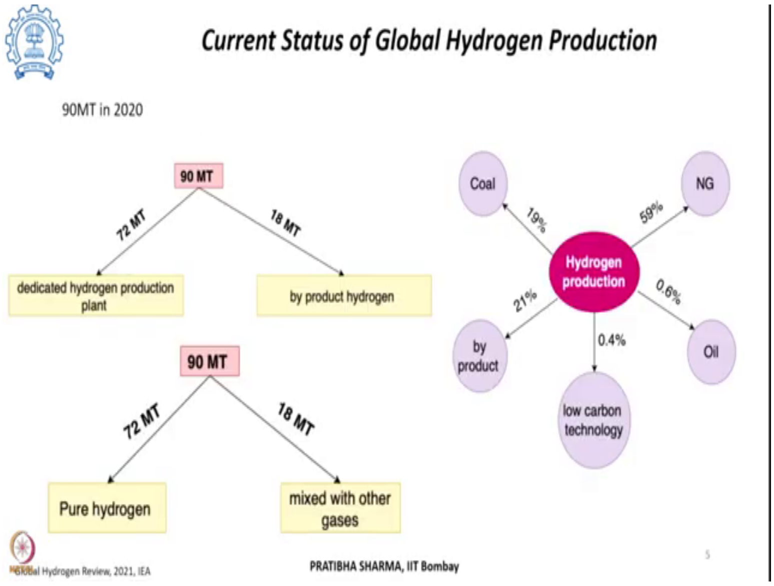

Now, if we look at the current global status in the year 2020, 90 million tons of hydrogen was produced globally. Out of that 90 million tons, 79 percent of it, 72 million tons was produced in dedicated hydrogen production plant. Another, 21 percent which is 18 million ton was produced as a byproduct hydrogen in refineries, primarily in refineries. Now, this 90 million tons out of that 72 million tons was used as pure hydrogen in ammonia synthesis and in the refineries. Another 18 million tons used as mixed gas with other gases.

Basically, for methanol production or for DRI for steel production. Now, in the various production routes, natural gas is the dominant fuel which is used for producing hydrogen and steam methane reforming is the dominant process for producing hydrogen. So, about 59 percent of the production of hydrogen was using natural gas. And, approximately 240 billion cubic meters of natural gas was used for producing hydrogen which is approximately 6 percent of the global natural gas consumption.

19 percent of hydrogen produced using coal and about 115 million tons of coal equivalent is used for producing hydrogen which is 2 percent of the global coal demand. 21 percent obtained as byproduct, 0.6 percent produced using oil and the remaining using low carbon technology which includes electrolysis, which includes fossil fuel plants which have carbon capture use and sequestration.

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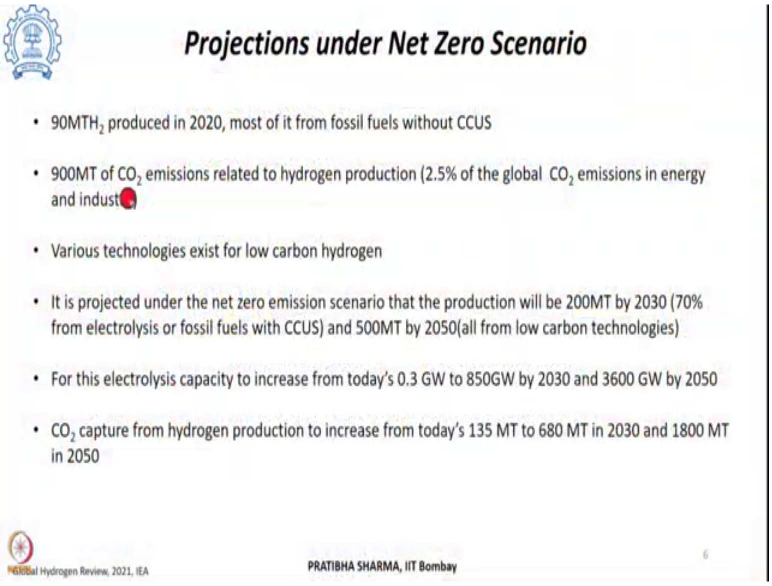

Now, out of this 90 million tons, we have seen most of it is being produced from fossil fuels and without CCUS. And, because of that there are 900 million tons of carbon dioxide emissions which are related to the hydrogen production, which corresponds to 2.5 percent of the global carbon dioxide emissions in the energy and industry.

Now, there are various technologies which exist for low carbon hydrogen production like production from water using either thermochemical cycles or from electrolysis or it can be produced from fossil fuel plants with CCUS or from biomass gasification.

But, the current status is only 30 kilotons of hydrogen is being produced from water electrolysis. And, there are about 16 fossil fuel plants which have carbon capture use and sequestration producing 0.7 million tons of hydrogen in these plants. However, it is expected that the scenario may change.

And, in the net zero scenario the production of hydrogen from the current 90 million tons will increase to 200 million tons by 2030. And, it is projected that out of that 200 million tons 70 percent should come from electrolysis and fossil fuel with carbon capture use and sequestration. Remaining will come from plants which are not integrated with CCUS. By 2050 this number will grow to 500 million tons and all this 500 million ton is expected to come from low carbon technologies.

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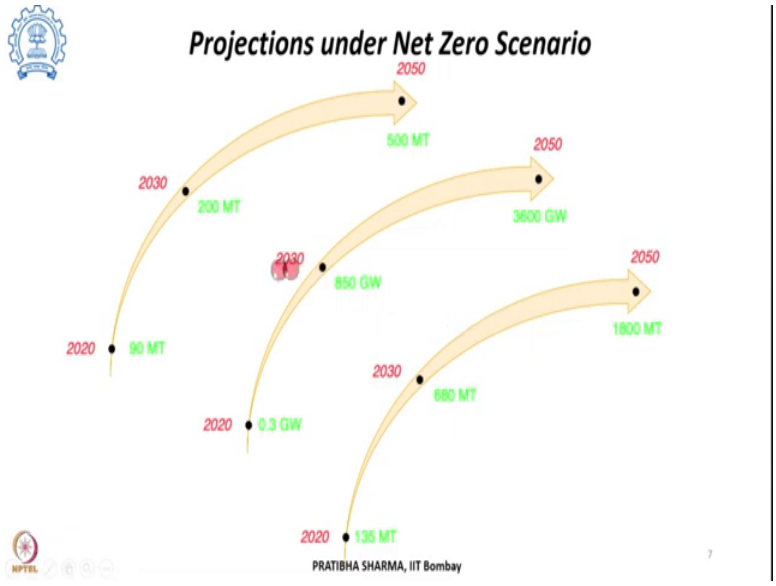

Now, if this is the forecast for providing that much amount of hydrogen as we move in the net zero scenario, the requirement of electrolyser capacity which is currently 0.3 gigawatts installed capacity will grow to 850 gigawatt by 2030 and it will be 3600 gigawatt by 2050. So, this is the requirement in terms of the electrolyser capacity. At the same time when it is net zero scenario, the fossil fuel plants needs to be integrated with CCUS.

So, carbon dioxide capture will be required. Currently, the status is 135 million tons of CO2 is abated with using CCUS at the production plant site which will grow in 2030 to 680 million tons. And, in 2050 it should grow to 1.8 gigatons or 1800 million tons of carbon dioxide per year. When these renewable methods or water electrolysis or plants integrated with CCUS, these all will be used for hydrogen production or in the net zero scenario. The water that will be required for these technologies will also grow.

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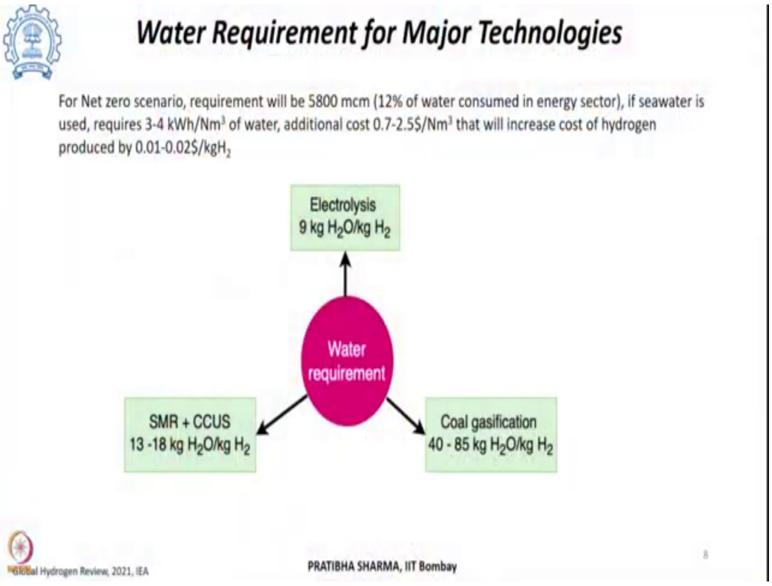

Now, currently if we see if the hydrogen is being produced from electrolysis, roughly we require 9 kg of water per kg of hydrogen being produced. When it is steam methane reforming integrated with CCUS, there is a requirement of 13 to 18 kg of water per kg of hydrogen being produced. In coal gasification depending upon the mining method, it varies from 40 to 85 kg of steam requirement per kg of hydrogen.

However, this requirement will be in net zero scenario of 5800 million cubic meters of water which is 12 percent of the water being consumed in the energy sector. It is also possible to use sea water, because most of the places which are water deficient may not be able to supply or meet this much requirement of water. So, in that case seawater can be used through reverse osmosis desalination method which will require 3 to 4 kilowatt hour per normal meter cube of water.

And, that could add an expense of 0.7 to 2.5 dollars per normal meter cube and there will be a marginal increase in the cost of hydrogen being produced. So, in that case the cost of hydrogen will increase by 0.01 or 0.02 dollars per kg of hydrogen.

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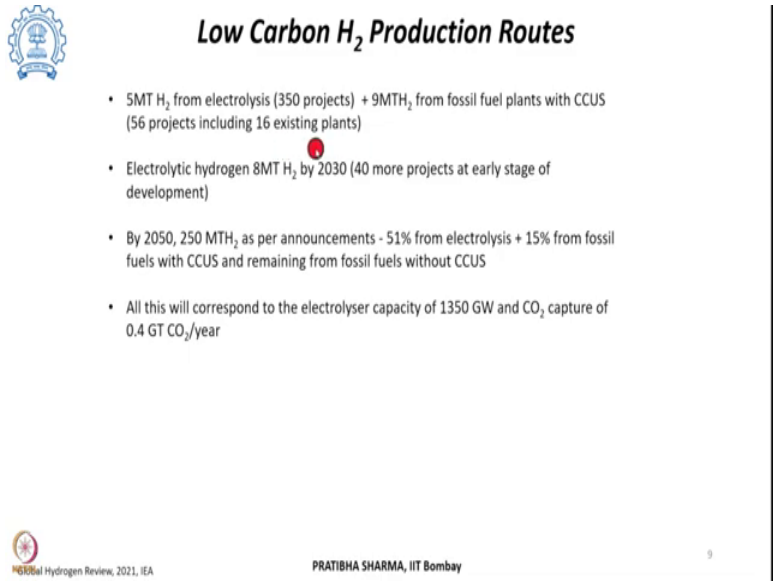

Now, if we look at the plants which are coming up, the plants which are being already under construction or at later stage of planning for commercialization, development. Then, roughly about 350 such projects of electrolysis are there which could account for 5 million tons of hydrogen, being produced through electrolytic route. There are currently 16 fossil fuel based plant with CCUS and total that will account for 56 such projects, where the production of hydrogen from fossil fuels integrated with CCUS will account for 9 million tons of hydrogen being produced by 2030.

Now, if we also include 40 more projects which are currently globally at an early stage of development, then the electrolytic hydrogen production capacity can increase from 5 million tons to 8 million tons by 2030. By 2050 as per the pledges, the strategies, the road maps which various countries globally are coming up, the different announcements that they are making, the pledges which are coming up in the clean hydrogen production scenario. By 2050, it is expected that 250 million tons of hydrogen will be produced.

And, out of that 250 million tons 51 percent will come from electrolysis and 15 percent will come from fossil fuels plants which are integrated with CCUS. The rest is going to come from plants which are not integrated with carbon capture use and sequestration. Now, if this is the scenario, then this 51 percent of hydrogen which is coming from electrolysis will account for increasing the electrolyser capacity to 1350 gigawatt. And, the carbon capture that needs to be integrated with the fossil fuels has to increase to 0.4 gigatons of carbon dioxide capture per year.

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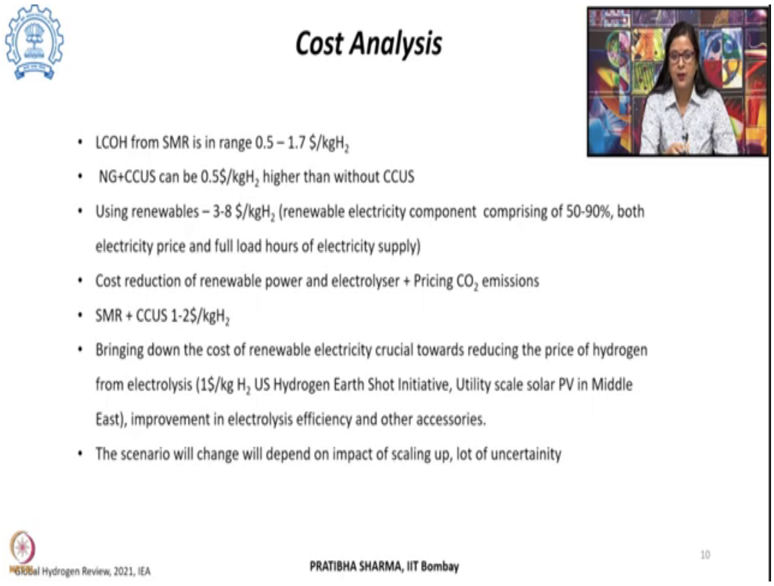

When it comes to cost analysis, we know that the fuel which is used widely we have seen is natural gas for hydrogen production and the method is steam methane reforming. This is the most cost effective method. So, the levelized cost of hydrogen which is produced using steam methane reforming, it lies in the range of 0.5 to 1.7 dollars per kg. Now, there is a huge variation in the cost. The reason is regional variation in the cost of the feedstock, natural gas.

However, this is without any carbon capture use and sequestration. If it is integrated, the plant is integrated with CCUS then there is an additional increment in the cost of hydrogen produced, levelized cost of hydrogen produced by 0.5 dollars per kg of hydrogen. And this is higher than the without the CCUS, but this price is still much lower than the cost of hydrogen which can be produced from renewables. So, if it is produced from renewables, the cost lies in the range of 3 to 8 dollars per kg of hydrogen being produced.

And, in this cost range the major component is of the electricity which is being used for electrolysis. So, the renewable power cost accounts for 50 to 90 percent of the total cost of hydrogen being produced. And that depends on both, what is the electricity price at which we are getting that power and the full load hours of electricity supply. For how long we can use that surplus electricity for producing hydrogen or for how many hours is the electrolyser running on the supply of that electricity.

Now, there is a requirement of reducing this cost from 3 to 8 dollars; so, that it can become compatible or comparable with the fossil fuel based hydrogen production. This cost reduction can come only when the price of the renewable power or the cost of electrolyser comes down. And, it is expected that with economies of scale, with more deployment of renewable; the renewable power cost will come down.

And, this gap between the cost of hydrogen being produced from reforming and from renewables will decrease with the reduction in the cost of renewable power as well as the decrease in the cost of electrolyser, the CAPEX cost of the electrolyser. There is another way in which we can see that the cost gap between the two methods will reduce which will be when the carbon dioxide emissions are priced. So, price associated with the carbon dioxide emissions will also reduce this gap between the fossil fuel based production and renewable based production.

For example, if 100 dollars per ton of carbon dioxide cost has added for the carbon dioxide released in the environment, then the cost of production from natural gas will increase by 0.9 dollars per kg. So, this is one more method by which the bridge, the gap between the two prices can be reduced or shrinked. Now, when it comes to production from steam methane reforming and carbon capture use and sequestration, the price typically lies in the range of 1 to 2 dollars per kg.

So, important is to produce hydrogen in a sustainable manner from renewables, for that the cost of renewable electricity should come down and that will be crucial towards reducing the price of hydrogen from electrolysis. And, there has been several initiatives globally to bring down that cost. Like one of the initiative is US Hydrogen Earth Shot Initiative wherein, they are considering to bring down that cost by 2030 to 1 dollar per kg of hydrogen being produced.

And, it is expected that the cost of renewable electricity, when it is considered like 20 dollars per megawatt hour, then it can come down to 1 dollar per kg of hydrogen being produced. That was 20 dollar per megawatt hour was without including CAPEX and OPEX; now, if it has to further come down, if that also needs to be included. Now, this price of renewable electricity can come down at places, where there is more of deployment, where there are more number of sunshine hours.

Like Middle East, like in country like India where we have ample amount of renewable source which is available. We have ample sunshine hours, solar insulation available. Similar, to that a project, a Utility scale solar PV project, that tendering has been done in Middle East. And, the bit that has been done in 2019, 2020 has even shown prices as low as 14 to 17 dollars per megawatt hour of renewable based electricity price.

So, all these will be crucial towards bringing down the cost of renewable electricity. At the same time requirement is that there should be improvement in the efficiency of electrolyser and the other balance of plant. So, it is expected that in long run the scenario will change. There will be reduction in the renewable price, there will be economies of scale bringing down the cost of electrolyser.

And, we will have a learning experience with these scaling up, that will further lead to better understanding. But, currently there is lot of uncertainty associated with the how the price and the deployment will take place in future.

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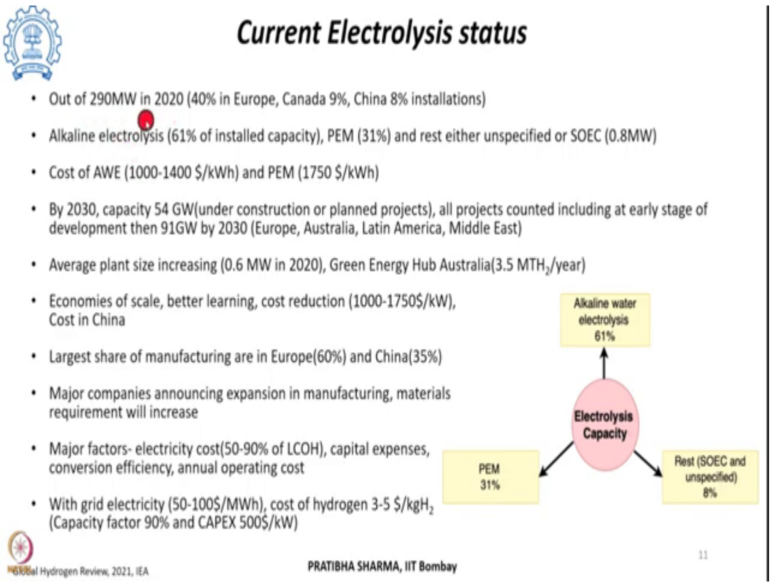

If you look at the current electrolysis status around 0.03 percent of the global hydrogen is being produced using water electrolysis. So, out of the 290 megawatt which was produced using water electrolysis in 2020, 40 percent of it was in Europe. The installed capacity of 290 megawatt global, out of that 40 percent in Europe, 9 percent in Canada and 8 percent installations were in China.

And, out of this 290 megawatt, if we see the different technologies which we have already studied in this course; alkaline water electrolysis accounted for 61 percent of the total hydrogen production using the electrolytic route. PEM electrolyser 31 percent and rest are either unspecified or SOEC solid oxide electrolytic units. The cost of alkaline water electrolysis lies in the range of 1000 to 1400 dollars per kilowatt hour. For PEM it is around 1750 dollars per kilowatt hour.

It is expected that by 2030 this capacity will increase, considering whatever plants which are under construction or plants which are projects which are planned, this capacity will grow to 54 gigawatts. Now, if we also consider all the projects which are in their early stage of drafting or development, then this capacity can even grow to 91 gigawatt by 2030. So, the two major contributors will be in Europe about 22 gigawatt, Australia 21 gigawatt, Latin America 5 gigawatt and Middle East 3 gigawatt and remaining from the rest of the world.

It has also been seen that the average plant size over a period of time will increase. So, currently if we see the average plant size of an electrolyser lies in like is roughly about 0.6 megawatt in 2020. But, now there are projects which are coming up which have plant size of 100 megawatt. There are plants which are even planned which will have capacity of 1 gigawatt.

Like a plant in Australia which is under the Green Energy Hub, it has 50 gigawatts of solar PV and wind installation, that will be used for hydrogen production. And, that will have a capability of producing 3.5 million tons of hydrogen per year. So, what is expected is that there will be economies of scale. As the deployment will increase, we will have a better learning that will further lead to cost reduction from current which is say 1000 to 1750 dollars per kilowatt.

But, there are certain installations in China where they have reported this cost range to be something between from 750 to 1300 dollars per kilowatt. Even there are reports wherein they say the CAPEX can be as low as 500 dollar per kilowatt. And, all these will make a difference in terms of the electrolysis price. Now, out of the major manufacturing which is going on globally, the largest manufacturer being Europe with 60 percent of the manufacturing capacity. China being the second with 35 percent manufacturing capacity.

And, now there are several major companies which are entering into expanding towards their manufacturing capacity of electrolysers, like the Thiessen Group, ITM, Cummins, Hydrogen

Nel. So, there are several other companies which are expanding. But, then when the capacity of manufacturing will increase, the requirement of materials will also increase. But, we expect that in future with more technological advancement the amount of material, precious materials that will be used will also reduce.

Now, the major factors which contribute towards the total cost includes the electricity cost which is the major component 50 to 90 percent of the levelized cost of hydrogen, the capital expenses, conversion efficiency and the annual operating cost. We know that with the grid electricity considering that the electricity price being 50 to 100 dollars per megawatt hour. This may not reduce the cost of hydrogen and the cost of hydrogen will be roughly lying between 3 to 5 dollars per kg of hydrogen being produced, considering the capacity factor of 90 percent and CAPEX as low as say 500 dollars per kilowatt.

So, the cost will reduce, if it is being produced from renewables. And, let us say if it is being produced at a 0 cost and considering an operating hour of 750 hours per year; still the cost will be 3 dollars per kg. So, it is expected that using the renewable power say solar or wind power, the cost should further go down as the economies of scale work well.

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Projections on Electrolysis status

In places with high solar insolation available, offshore wind

Year	Cost of renewable electricity ($/MWh)	Cost of H2 produced ($/kgH$_2$)	Capacity factor (%)	CAPEX ($/kW)
Solar PV				
2020	20	3	32	1000
2030	17	<1.5		320
2050	12	1		250
Wind				
2020	60	4.5	50	
2030	30	2	57	
2050	25	1.5	60	

NG + CCUS

NG w/o CCUS

Global Hydrogen Review, 2021, IEA

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Now, at places where there is larger sunshine hours, there is high solar insulation available like Middle East, like country like India. The cost will go down in the 0 emission scenario. Now, considering the current status say 2020, where the cost of renewable electricity is like in Middle East, it is taken as 20 dollars per megawatt hour. The cost is 3 dollars per kg of hydrogen being produced with a capacity factor of the plant 32 percent, considering a CAPEX of electrolyser being 1000 dollars per kilowatt.

Now, it is expected that in 2030 the cost of renewable electricity price if it reduces to 70 dollars per megawatt hour. The cost of hydrogen will go down to 1.5 dollars per kg, considering CAPEX also will come down to 320 dollars per kilowatt. And, then it will become equivalent to the hydrogen which is being produced from natural gas integrated with CCUS.

Further, price down of the renewable electricity to 12 dollars per megawatt hour will bring down the cost of hydrogen being produced to 1 dollar per kg. And, then it will become equivalent to natural gas based hydrogen production without CCUS. In Europe, the hydrogen production could be from offshore wind and then from there it could be taken through pipelines. And, that will reduce the cost of transmission and distribution which could be anyone the losses associated with that.

Considering, that if the current price is associated with the wind power; the cost of renewable electricity currently are higher 60 dollars per megawatt hour and that is responsible for 4.5 dollars per kg, a higher cost of hydrogen being produced; considering a capacity factor of 50 percent. But, it is expected that by 2030 the cost of renewable electricity from wind will come down to 30 dollars per megawatt hour. And, then the hydrogen production cost will be 2 dollars per kg, considering the capacity factor of 57 percent, considering wind turbines which are larger in size.

And, then in 2050 this renewable electricity price may go down to 25 dollars per megawatt hour; resulting into the cost of hydrogen being produced to 1.5 dollars per kg of hydrogen, considering a capacity factor of 60 percent.

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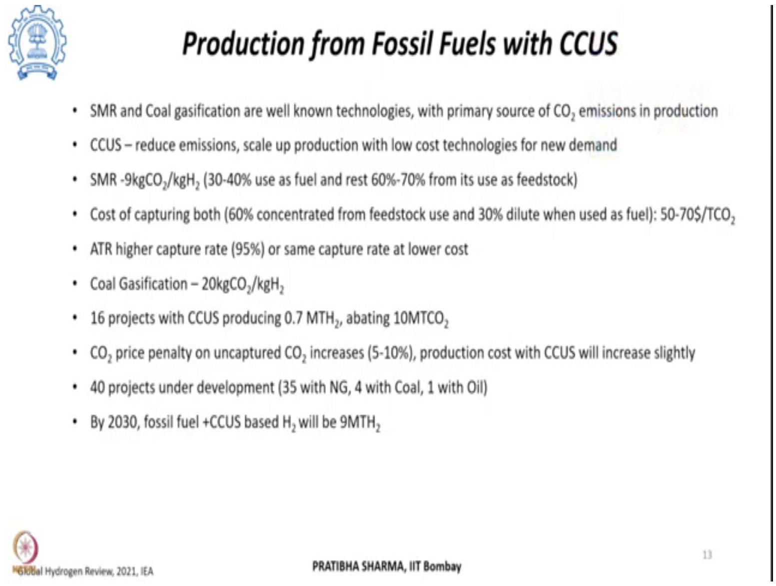

So, this is how the scenario will change. Now, we know that the other possibility could be for a sustainable hydrogen production that we can produce from the fossil fuels and then integrate CCUS along with it. So, steam methane reforming and coal gasification we know that these are very well-known technology. But, then they are the major polluters also which will release carbon dioxide emissions during the process of hydrogen production.

So, it is essential that CCUS should be integrated. It is not only to reduce the emissions associated with the hydrogen production. But, at the same time when CCUS is integrated, we can still use these low-cost technologies, we can scale them up and meet the growing demand of hydrogen. When CCUS is being integrated, then the cost of hydrogen being produced increases; roughly about 0.5 dollars per kg of hydrogen.

With steam methane reforming, if we consider the emissions then it is 9 kg of carbon dioxide is released per kg of hydrogen being produced. We have seen in detail that the emissions are taking place on both the end, when it is used as fuel burning in the burners and providing the reaction heat. So, 30 to 40 percent of these emissions occur when it is being used as fuel, rest of the emission 60 to 70 percent comes when it is used as feedstock.

So, in the product gas stream that is more concentrated. So, if we capture both at the fuel end as well as at the product side, 90 percent of that capture is possible. And, for that the cost will be 50 to 70 dollars per ton of carbon dioxide being captured. Another method which we have seen was auto thermal reforming. We can achieve higher capture rate because, in auto thermal reformer the entire carbon dioxide which is being produced is concentrated and the same reactor, the fuel is burnt and the product stream is obtained.

So, we can get concentrated carbon dioxide. So, if we capture that; so, we can increase that capture rate from 90 percent to 95 percent or we can have the same capture rate, but at a relatively lower cost. In case of coal gasification, the amount of carbon dioxide emission is 20 kg of carbon dioxide per kg of hydrogen being produced.

Now, the current situation is there are 16 projects with carbon capture use and sequestration integrated with the fossil fuel production plants producing 0.7 million tons of hydrogen and abating 10 million tons of carbon dioxide which is produced in the process.

Now, if we consider that there will be a carbon dioxide price penalty that will be levied in the future on the uncaptured carbon dioxide and that will be about say 5 to 10 percent, then the production cost with CCUS will slightly increase. Now, these 16 projects are existing. There are 40 more projects under development.

These are 35 integrated with natural gas based production, 4 with coal, 1 with oil. It is expected that by 2030 when fossil fuel plants, these plants will be operational with CCUS. Then, we will be able to produce 9 million tons of hydrogen from these plants, where carbon capture will be considered.

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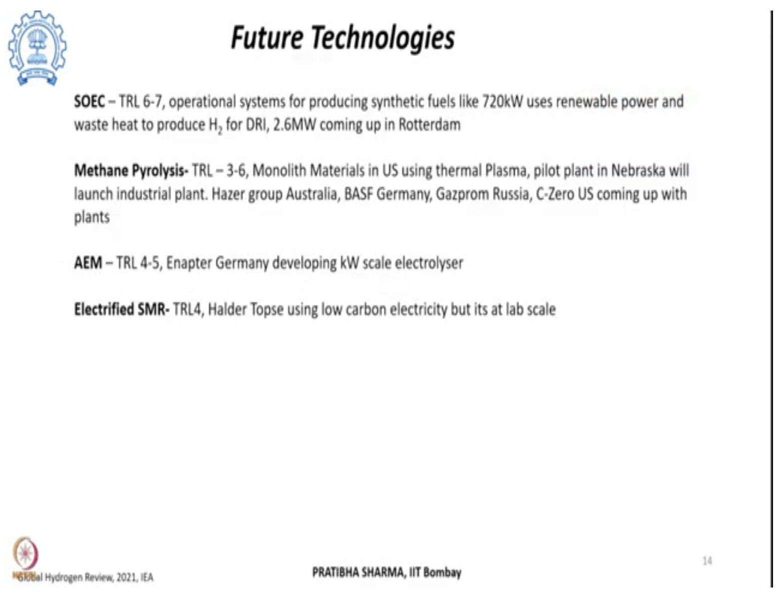

Now, there are certain future technologies which are at not at commercial scale, at a higher Technology Readiness Level (TRL) level. Like solid oxide electrolysis which we have seen. This is the high temperature electrolysis or steam electrolysis. Currently, this is at a TRL level of 6 to 7. This is for producing synthetic fuels, like it is used with renewable power and of capacity 720 kilowatt wherein, even the waste heat is used for producing hydrogen for DRI, in steel production.

There is one more plant which is coming up of capacity 2.6 megawatt in Rotterdam. Methane pyrolysis is another technique which is a future technology having a TRL level of 3 to 6. So, there are plants like monolith materials in US, they are using thermal plasma for the cracking of methane. There was a pilot plant in Nebraska and now they are planning for an industrial scale plant. There are several plants which are coming up in Australia, Germany, and Russia, US.

So, the technology will grow in future. Anion exchange membrane based electrolysis which is at TRL level 4 to 5 and then kilowatt scale electrolysers are being developed by Enapter, Germany. It can be also electrified steam methane reforming which is at TRL level 4, Halder Topse they are using this technology. But, that it is still at a lab scale using the low carbon electricity, steam methane reforming is being performed.

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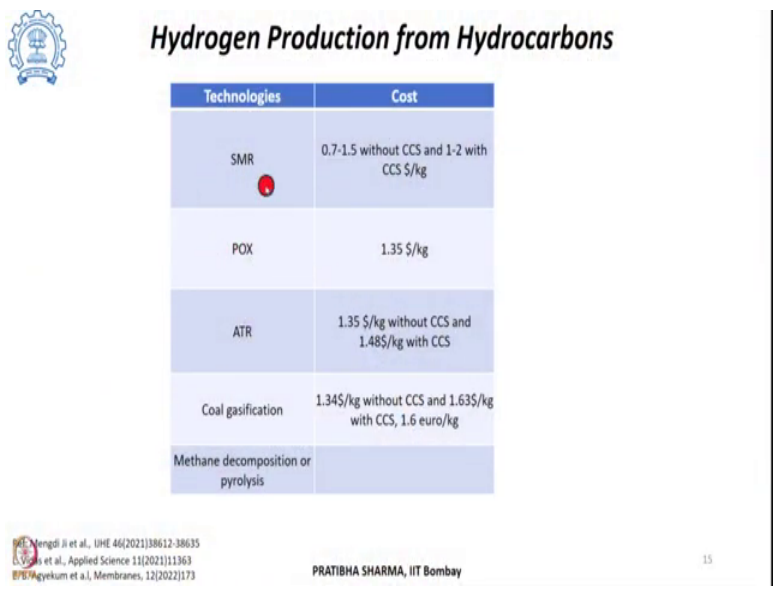
Hydrogen Production from Hydrocarbons

Technologies	Cost
SMR	0.7-1.5 without CCS and 1-2 with CCS $/kg
POX	1.35 $/kg
ATR	1.35 $/kg without CCS and 1.48$/kg with CCS
Coal gasification	1.34$/kg without CCS and 1.63$/kg with CCS, 1.6 euro/kg
Methane decomposition or pyrolysis	

Now, if we quickly look at the cost of hydrogen production from the different routes which we have seen in this course. The cost of hydrogen production from SMR, we have already seen 0.7 to 1.5 dollars per kg without CCS. If it is with CCS 1 to 2 dollars per kg. Partial oxidation 1.35 dollars per kg. Auto thermal reforming 1.3 dollars per kg without CCS, with CCS 1.48 dollars per kg. If it is coal gasification 1.34 dollars per kg without CCS and that increases to 1.63 dollars per kg with CCS. Methane decomposition still it has not been commercialized.

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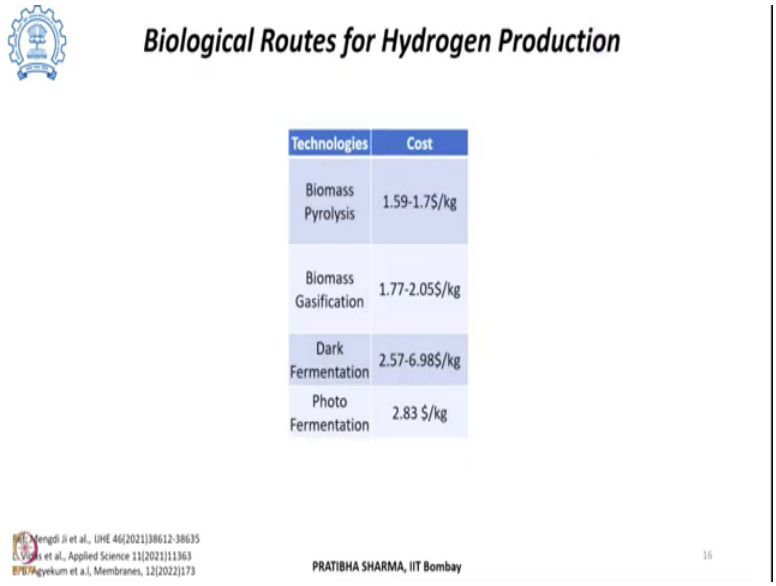

With biomass pyrolysis the cost lies in the range of 1.59 to 1.7 dollars per kg. With biomass gasification 1.77 to 2.05 dollars per kg. Dark fermentation 2.57 to 6.9 dollars per kg. Photo fermentation 2.83 dollars per kg.

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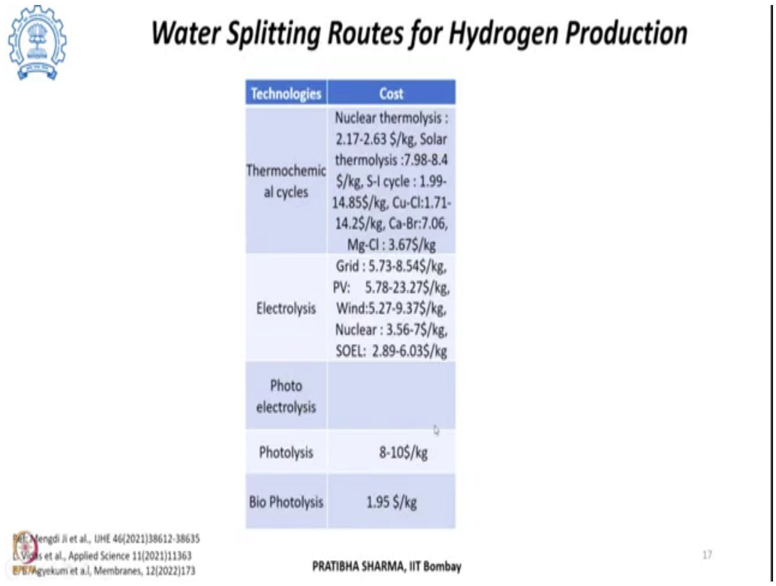

Water Splitting Routes for Hydrogen Production

Technologies	Cost
Thermochemical cycles	Nuclear thermolysis : 2.17-2.63 $/kg, Solar thermolysis :7.98-8.4 $/kg, S-I cycle : 1.99-14.85$/kg, Cu-Cl:1.71-14.2$/kg, Ca-Br:7.06, Mg-Cl : 3.67$/kg
Electrolysis	Grid : 5.73-8.54$/kg, PV: 5.78-23.27$/kg, Wind:5.27-9.37$/kg, Nuclear : 3.56-7$/kg, SOEL: 2.89-6.03$/kg
Photo electrolysis	
Photolysis	8-10$/kg
Bio Photolysis	1.95 $/kg

Ref: Mengdi Ji et al., IJHE 46(2021)38612-38635
L. Vidas et al., Applied Science 11(2021)11363
EPB.Agyekum et a.l, Membranes, 12(2022)173

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Thermochemical cycles based on whether the energy required for high temperature cycle for providing the heat for the high temperature cycle is by means of nuclear, then it is 2.17 to 2.63 dollars per kg. If it is from solar 7.98 to 8.4 dollars per kg and the different cycle costs.

When electrolysis is from grid electricity then 5.73 to 8.54 dollars per kg, from PV 5.78 to 23.27 dollars per kg. From wind 5.27 to 9.37 dollars per kg. Photolysis 8 to 10 dollars per kg. Bio photolysis 1.95 dollars per kg. So, these are roughly the costs of hydrogen production through all the routes which we have studied in this course.

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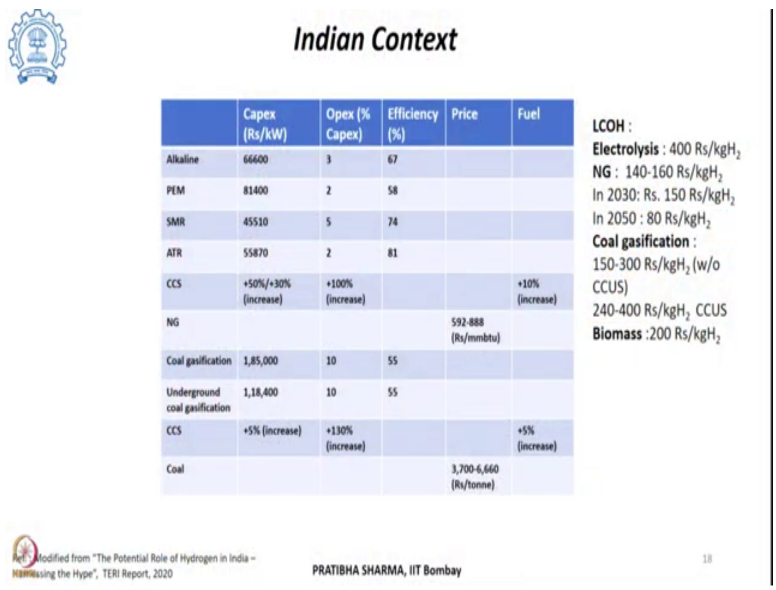

Indian Context

	Capex (Rs/kW)	Opex (% Capex)	Efficiency (%)	Price	Fuel
Alkaline	66600	3	67		
PEM	81400	2	58		
SMR	45510	5	74		
ATR	55870	2	81		
CCS	+50%/+30% (increase)	+100% (increase)			+10% (increase)
NG				592-888 (Rs/mmbtu)	
Coal gasification	1,85,000	10	55		
Underground coal gasification	1,18,400	10	55		
CCS	+5% (increase)	+130% (increase)			+5% (increase)
Coal				3,700-6,660 (Rs/tonne)	

LCOH :
Electrolysis : 400 Rs/kgH_2
NG : 140-160 Rs/kgH_2
In 2030: Rs. 150 Rs/kgH_2
In 2050 : 80 Rs/kgH_2
Coal gasification :
150-300 Rs/kgH_2 (w/o CCUS)
240-400 Rs/kgH_2 CCUS
Biomass :200 Rs/kgH_2

Ref: Modified from "The Potential Role of Hydrogen in India – Harnessing the Hype", TERI Report, 2020

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Now, I will quickly look at the Indian context. In India, 6 million tons of hydrogen is being produced annually, 3.2 million tons for ammonia production, 2.6 million tons for refineries, 0.2 million ton is obtained as a byproduct hydrogen from chloralkali plant.

So, if we see the levelized cost of hydrogen; from electrolysis this cost is higher, 400 rupees per kg of hydrogen being produced. From natural gas this lies in the range of 140 to 160 rupees per kg of hydrogen. This variation is because of the varying natural gas prices. And, it is expected that by 2030 this will be 150 rupees per kg of hydrogen, by 2050 it will be 80 rupees per kg of hydrogen.

Using coal gasification, the price is in between 150 to 300 rupees per kg without CCUS. However, if we integrate CCUC then the price goes up to 240 to 400 rupees per kg. Coal gasification is promising in the Indian context, because we have huge reserves of coal, but the problem is we have a high ash coal. So, either the technology should be developed so, as to use the Indian coal or then we will depend on the imports for low ash coal. From biomass, the price is 200 rupees per kg of hydrogen being reduced.

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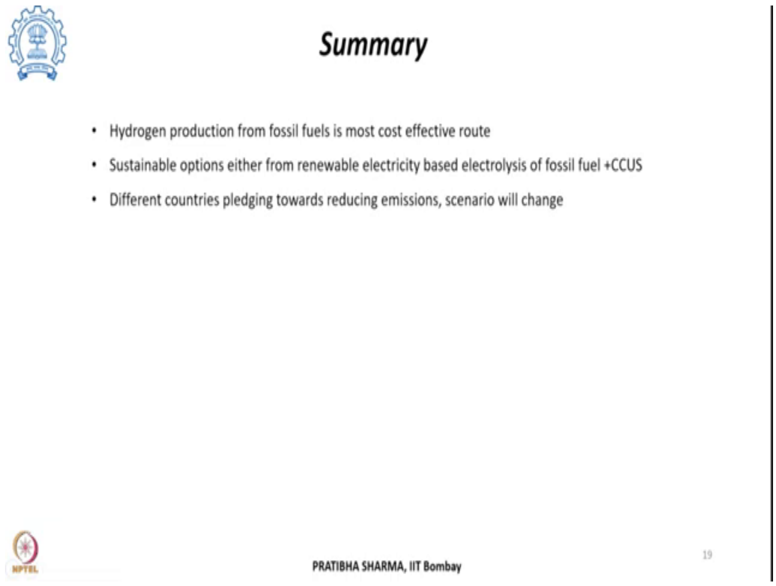

Now, to summarize this part, we have seen that hydrogen production from fossil fuel is the most cost effective route for hydrogen production economical, but then it is not a sustainable method. For sustainable hydrogen production, it should either come from the energy which is required for producing hydrogen should come from renewables or it should be produced from fossil fuel with CCUS.

Now, there are several advancements going on globally. There are different countries which are coming up with their road maps, their strategy documents. They are pledging towards reducing the emissions and it is expected that the scenario will change in future.

Thank you.