Energy Resources, Economics, and Sustainability

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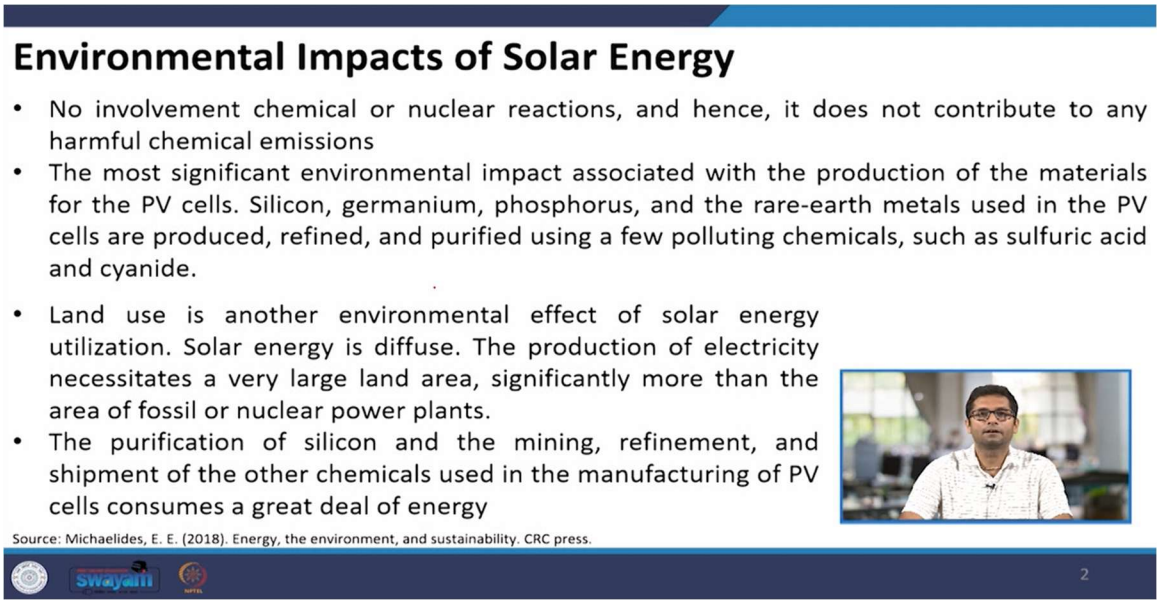
Week – 06

Lecture – 05

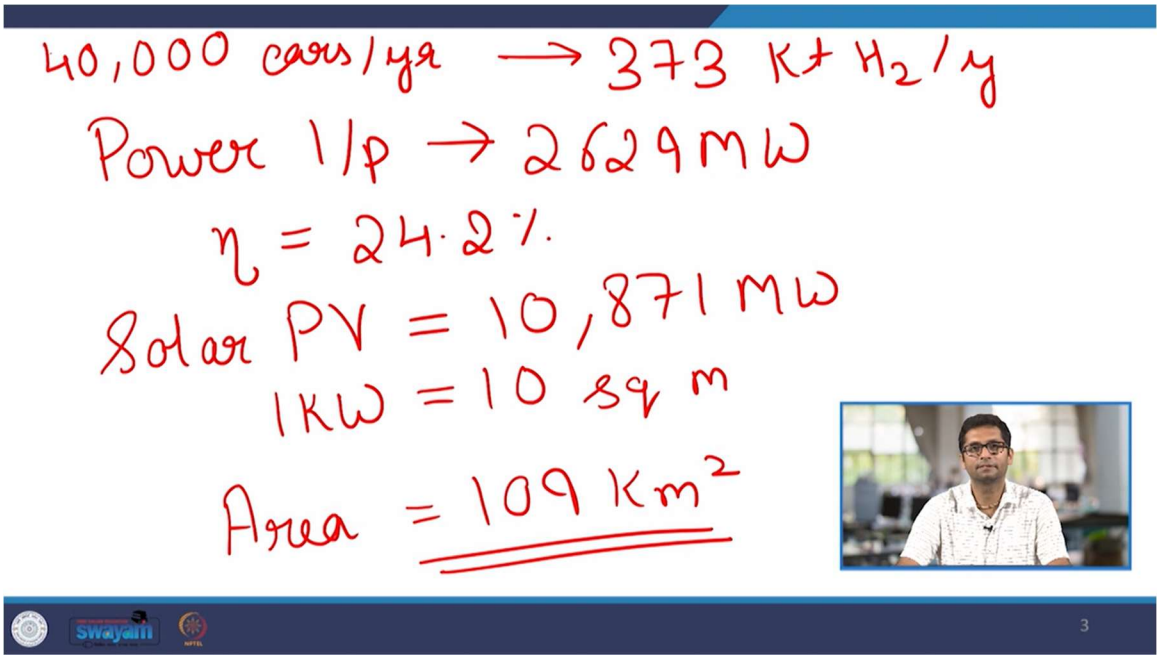
Lecture 31 - Environmental Impacts of Different Energy Pathways-II

Hello everyone, welcome to the course Energy Resources, Economics and Sustainability. In the past few classes, we have been discussing the different environmental impacts resulting from the different energy production pathways. We have tried to understand the problem of global climate change in detail and then we have tried to understand what could be the other problems coming from the conventional sources of energy. In today's class, we will focus on what could be the likely environmental impacts of the energy pathways that stem from the non-conventional or the renewable sources of energy. So, we will go by one by one on the different technologies and try to understand what could be the likely environmental impacts and also try to understand the relative advantages and disadvantages. So, if we talk about renewable sources of energy, one of the first things that comes to our mind is solar energy. So, solar energy because of its attribute of not involving any chemical reaction for the conversion or the production of energy seems to be quite clean. You do not have any CO2 molecules coming out of any solar PV plant or solar plant as such. There are no chemical conversion ways, the carbon is getting combusted or there are new radioactive materials which would be producing a good amount of heat as was the case with most of the fossil or nuclear based technologies. So, this per se is a great advantage with respect to solar energy.



But solar energy also consumes a good amount of rare earth metals which include silicon, germanium, phosphorous and other metals, the production, the mining, purification of which consumes a significant amount of energy. So, it has been proposed in the past that the energy that goes into the solar PV plants is quite high and that used to be the case almost 50 years back when the solar panels or the solar energy production was quite new. It almost needed almost 40 years of production of energy to recover the energy that went into the manufacturing of the different types of solar panels. But this time duration has now come to around 1 to 2 years. So, that is an advantage with respect to the technology development.

Further, another major disadvantage with respect to the solar energy is the amount of land that it consumes. So, by nature solar energy is diffuse, the electricity or the energy is produced at a very distributed form and this calls for a large use of area and which could be very high as compared to conventional fossil or nuclear power plants. Further, as we have understood the purification of different kinds of elements that go into the manufacturing of different PV modules call for the purification, refinement, mining, shipping, manufacturing of these panels and that has its own energy consumption. And this calls for a proper life cycle assessment for this technology to derive at the meaningful values. So, just trying to estimate like if I talk about the land use area of a solar PV panel which is one of the major disadvantages with respect to the use of solar panels, let us try to estimate with a simple example.



Suppose now everyone is talking about green hydrogen and it is expected to come from solar based electricity running electrolyzers producing hydrogen. So, let us envision a futuristic hydrogen filling station which would be used for filling around 40,000 cars per year. So, tentatively this kind of filling station would require almost the production of 373 kilotons of hydrogen production per year. So, this would be the likely consumption of or likely production of hydrogen that is needed. The power requirement in terms of running a conventional PEM based electrolyzer for such case would be around for the power input which goes into the electrolyzer would be of the order of around 2629 megawatt. And taking a typical efficiency for production of electricity using a PV panel, let us assume an efficiency of around 24.2% for a typical PV panel. The solar panels or the solar PV that needs to be installed would roughly be of the size or of the power rating of 10871 megawatt. Going by a normal rule of thumb that 1 kilowatt of panels requires almost 10 square meters of area. We can estimate the area that would be required for such a capacity of plant.

If we do this calculation, the area required for a typical hydrogen filling station which would be catering to around 40,000 cars a year which is rather typical would be almost 109 kilometers square which in itself seems to be a very high value. So, this is one of the problems with respect to solar PV plants that it occupies a lot of land.

Wind energy (Environmental concerns)

The materials that make the towers and the components of the engines are commonly used structural and engineering materials. Their production involves very limited environmental impacts:

- **Noise pollution:** A rotating engine always produces noise, and wind turbines are no exception. However, noise may have a significant effect on the wildlife of the area and force animals to migrate, thus disturbing the balance of the ecosystem.

- **Bird injuries and mortality:** Flying birds are often killed by the rotating blades. The motion of the blade and the local pressure reduction immediately upstream of the rotating blades detract the flight of birds and often kill them.

Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.

Going to the other sources of energy, we can also think the next major thing that comes to our mind is the wind energy. Now, wind energy as such in the towers or the blades that are made up of does not have like much of the rare earth elements and do not have very significant environmental impacts. The impacts could be seen in the form of the noise pollution. The rotating engines which would produce certain kinds of vibrations and noises could have detrimental effect on the people as well as the fauna and flora that happens to live in the vicinity. It might force the animals as well as the humans to migrate because the noise is quite consistent in nature and it also leads to some kind of imbalance in the ecosystem. Further, the birds that hit the moving turbines, the blades which are quite large in amount and leading to ultimately mortality or like the birds getting hit is another major concern that is associated with the wind energy plants. In many of the areas where which sees migratory birds coming in, wind energies are not encouraged much.

- **Aesthetic pollution:** The picturesque landscape of remote pristine areas is often disturbed by the placement of wind farms
- **Radio and TV signal interference:** Many wind turbines are located near the top or the sides of hills and mountains, and their operation interferes with the transmission of electromagnetic waves including signals from radio, television, and cellular telephones. Better location design and stronger signals will counteract this effect.

Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.
https://www.wind-watch.org/documents/blight-for-naught-wind-turbines-and-the-rationalized-desecration-of-nature/

5

Further, there is something called as the aesthetic pollution. Normally, the wind farms as can be seen in the picture are installed on tops of hills which are known for their picturesque beauty and which are known to be tourist destinations as well. So, given that the wind farms are going to not look so good in the future, people discourage installation of wind farms in the areas or in the countryside which might spoil the view of the countryside as well as might lead to their reduction in the tourist that happens here. Further, because these kinds of windmills are on top of hills, they can also create interference with the radio and the TV signals which is also not a very welcome step. And these are some of the minor environmental impacts that we face with respect to wind energy. Coming to another major source of energy which is biomass.

Environmental and Ecological Impacts of Biomass Use

- **Arable land use:** Arable land is a scarce resource on the planet.
- **Freshwater requirements:** A significant environmental effect of the growth of biomass for energy is the very high requirements of freshwater for irrigation and processing.
- **Use of fertilizers and pesticides:** Energy crops are very fast-growing plants and need the input of large amounts of fertilizers, pesticides, and insecticide chemicals. These chemicals contain phosphorus, sulfur, nitrates, arsenic, and trace metals such as zinc, lead, and manganese. Many of these elements are toxic to humans and harmful to the environment.

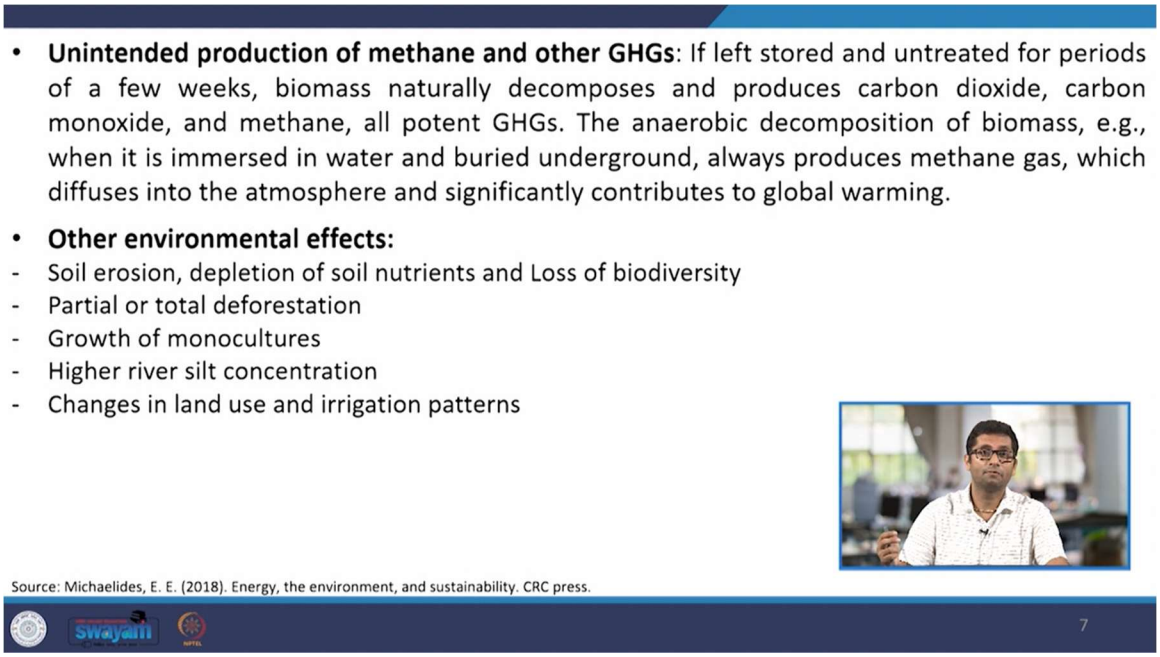
Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.

6

Biomass has been used for energy production for quite a long history. In the initial few classes, we also understood that biomass is one of the sources of energy which was most abundantly used since the history. If we go 300 years back, biomass probably was the only source of energy that was being used. But what are the issues? Another big issue with biomass is the land that it occupies. Again something similar to the solar energy, biomass is also a decentralized source of energy quite scattered. The plants or the biomass feedstocks need their own area to grow and so the area that would be required for planting the required number of plant species to get a considerable amount of energy can be quite huge. We have already estimated the amount of, like the area that is required to sequester a certain amount of CO2 and we just estimated it could be quite huge. Further, the plants also tend to have a huge amount of freshwater requirement. So there is a debate between like should we be using water which is quite scanty, the freshwater, for growth of biomass. It is estimated that the volumetric ratio for production of biomass-based fuels, ethanol, consumes almost 1000 times the amount of water.

So 1 kg of ethanol, sorry 1 liter of ethanol would likely consume almost 1000 liters of water. So that needs to be answered if you should be encouraging a fuel which has a very high water footprint. Then the biomass is expected to be carbon neutral because the carbon that is eventually getting combusted in the form of biomass or biofuel is the carbon that was absorbed during the growth of the biomass. But what about the different types of fertilizers, pesticides or the machinery or the energy that is consumed by the machinery during the production of biomass? That tends to consume a lot of energy. Specifically, is the energy consumed by the different kinds of fertilizers and pesticides? In the developed world, a lot of emphasis is paid on production of energy by the growth of energy crops which means growing crops like eucalyptus, poplar, switchgrass, miscanthus which has a high biomass production rate but at the same time they do not have a food value. So the people want to avoid a food versus fuel conflict and therefore they want to go for crops which are quite fast to grow. But the crops like this also consume a lot of pesticides as well as fertilizers and a majority of these fertilizers are produced from fossil fuels sources. Further, there are also a lot of nutrients in these pesticides like phosphorus, sulfonitrates, arsenic which might end up into the water

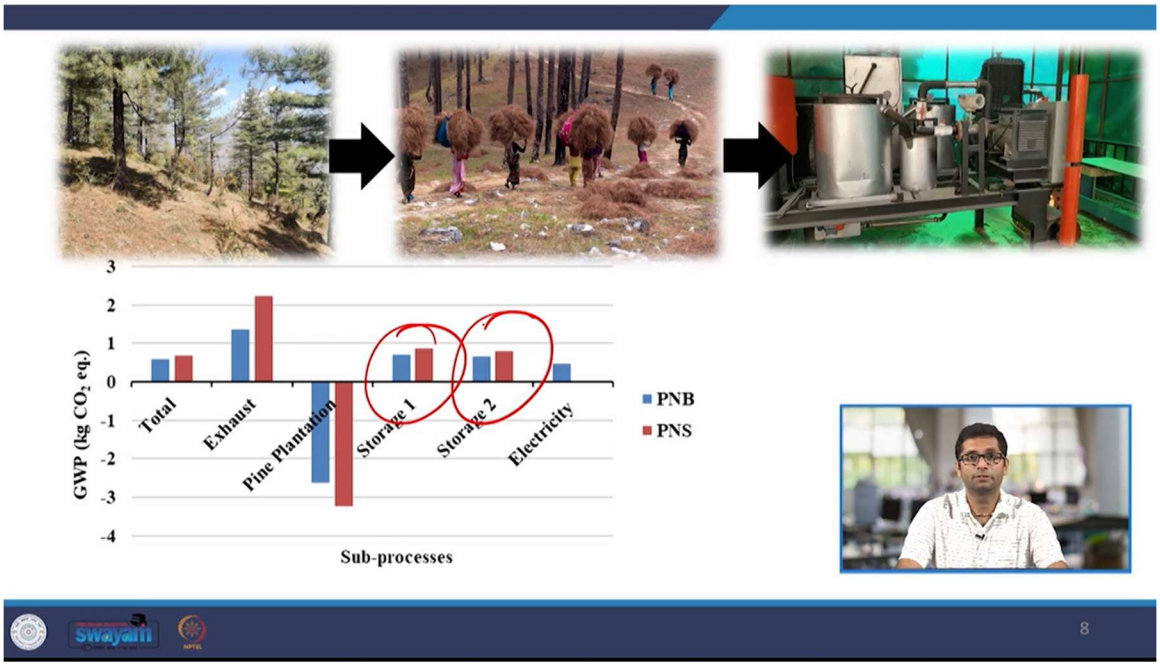
network, might end up into the water bodies and could have toxic effects and could be harmful to the environment in the long run.



Then there could also be an unintended production of methane and other GHGs. So biomass by its very virtue is available through certain times of the year whenever there is a harvest season. It is not that like you can harvest biomass day in and day out. And for the rest of the year it would need to be stored in some kind of storage medium. So when the biomass is stored it also tends to produce or degrade and produce different gases, methane being the most potent of that. And as we will understand in the future classes as well that one molecule of methane is more than 20 times more potent than a molecule of CO2. So the problems that could come from the degradation of biomass when it is left to stored is another big issue that is a source of worry for the people. Further we also need to understand whenever we are harvesting biomass the biomass which is in the ground remains there and it would decay as a normal process. So whenever the biomass is decaying under anaerobic conditions it will also lead to a good amount of production of methane which again has a global warming potential that is much larger than that of carbon dioxide. The storage of biomass as well as the inefficient extraction of biomass leaving the roots inside the soil could have serious consequences. Further some of the other environmental effects that have been noted is the soil erosion because of the

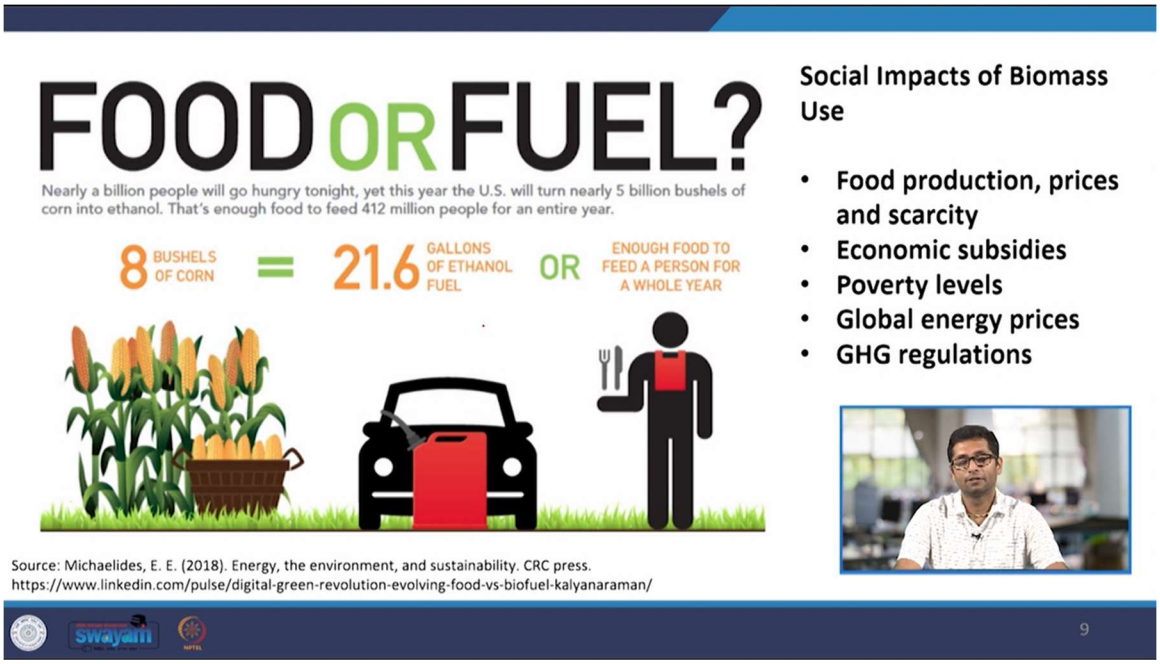
continuous growth of biomass and the cutting of biomass. It could also lead to partial or total deforestation.

Given the recent incentives on different production of biofuels people have been cutting down the forest so that they could have much more land for the production of biomass eventually to be turned into biofuels. Then it also encourages the growth of monocultures. People would want to plant only the species which gives maximum amount of biomass. They are no more concerned about the recycling of the different nutrients. It can also lead to serious land use changes and the irrigation problems because of the water requirement. These are some of the technical problems that might be arising because of the use of biomass. One of the major ones is the release of methane and other gases when the biomass is stored.



Just for an example, we did a small analysis for the use of pine needles that is available in the state of Uttarakhand in plenty. And These kinds of pine needles are one of the pathways that is suggested. It could be collected by foot transfer as you can see in the figure and could be used in a small gasifier for the production of electricity which you can see on the figure on the right. So, we tried to analyze what would be the global warming potential of such a system and we came to this conclusion that the storage of the

biomass which would happen in two places, one at the collection point and then the other at the distribution point could have significant amount of CO2 emissions which could be quite high in number and needs to be accounted for. And this storage is something that should be accounted whenever we are dealing with a biomass-based supply chain.



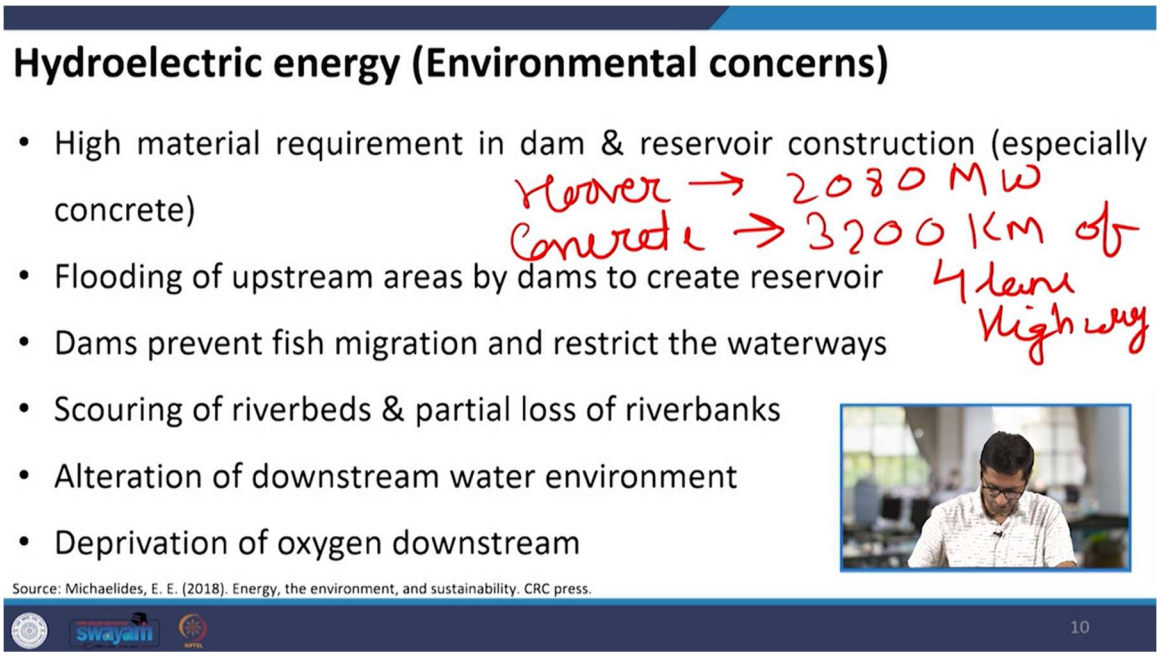
Further, some other social impacts that are associated with the use of biomass tends to be the food versus fuel conflict. Now, biomass or the different biofuels have been encouraged in much of the developed countries for the past two to three decades and there have been a lot of biodiesel or biothenol production specifically in the countries like US or Brazil. There have been a lot of incentives going on. But these kinds of production have also led to other kinds of changes. Say, like in the past 20 years there was a huge lobby that wanted to go towards corn-based bioethanol production and with that, like lots of farmers which were earlier producing corn for food wanted to shift towards the production of bioethanol. The result was that the prices of corn went up in the society and given that the Americas have a significant population of Mexican people who love to eat corn-based foods like tortillas, the staple diet increased in price and that led to consequences where the companies or the countries had to take up policies so as to stabilize the price of the corn. Because the corn which was earlier forming the staple diet was now being routed towards production of different kinds of fuel, in this case,

bioethanol. Further, this also led to a debate whether the different kinds of economic subsidies that goes to the farming community should be continued or not.

Now, biomass for all practical purposes is a farm product and we understand that different countries around the world would like to subsidize the farmers so as to enable them to have profit from the growth of different types of crops. This involves subsidy in the price of electricity or the price of produce or the biomass or the different kinds of crops that they produce. Even in India, we have a lot of incentives that are provided to the farmers in the sort of free electricity, subsidized prices, subsidized fertilizers, subsidized insecticides and these are provided around the world. So the debate is that like these subsidies or the incentives that are provided to farmers to be able to produce food in a more economical way should they also be provided to the production of crops that are used for biofuels? Now given that the source remains the same, they are using the same kind of farmland, how do you distinguish between the two? And in case something like this is happening, we are artificially subsidizing the production of biofuels which might not bring out their true economic cost. Further, a majority of these incentives or subsidies are aimed at bringing the farmers above their poverty levels because farmers around the world are not very affluent parts of the society and they need certain kinds of incentives. But whereas when you come talk about biofuels, the land is owned by big big corporates and they would not need this incentive but if they are still getting this incentive that brings in like should they be really be getting incentives. So as you can see in this figure like should we be using the corn for production of like if we produce 8 bushels of corn which is a measurement of production of corn, it is equivalent to around 21.6 gallons of ethanol or it could help feed a person for the complete year. So again like should we be looking at rising poverty or feeding hunger or we should be looking at fueling the cars.

So that is a big debate that is around the biofuels market. Further, there needs to be regulations with respect to the GHG accounting because biomass as such have a very complex supply chain. So should we be taking into account the land that is cleared? A typical example is taken for the country of Brazil which is one of the leaders in biofuel production. So in the advent of producing more and more biofuels, a lot of land that was earlier occupied by Amazon forest was cleared and this led to the land use changes. The

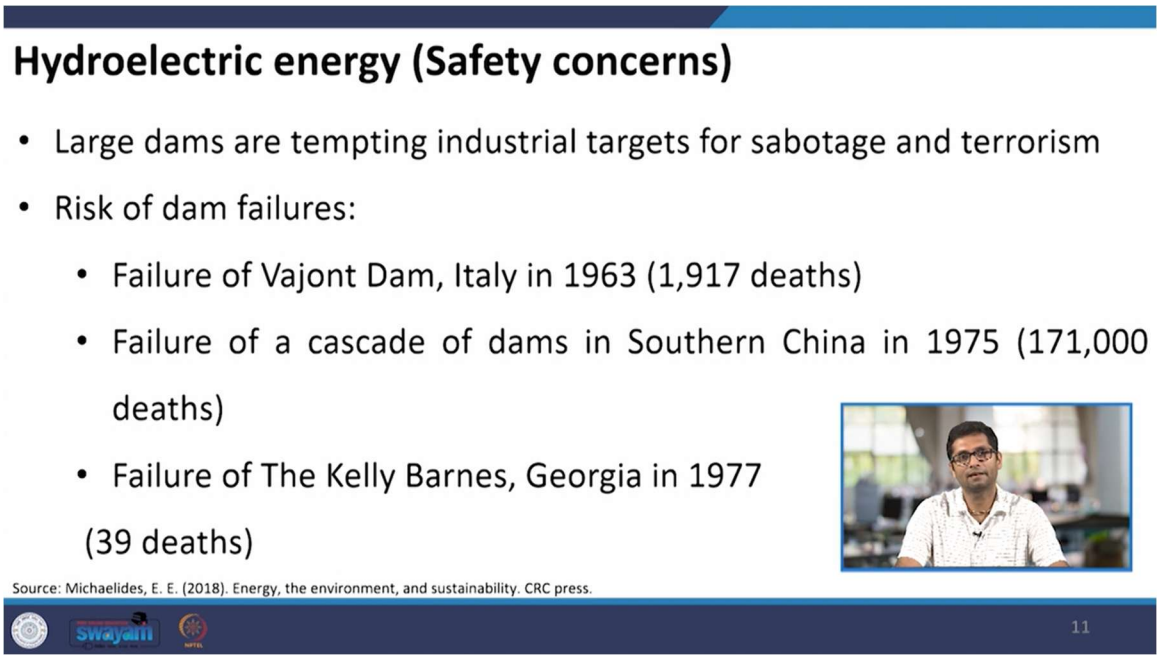
earlier carbon sinks that was there in the form of the Amazon forest or the carbon that was captured in the soil was released because of this land use change and it eventually led to production of more carbon because this land use change where the forest was converted for a biofuel production. Then the advantages that could be derived from the biofuel production itself. So again it is a very big debate like how should the GHGs that are coming out from the different supply chains from biomass be regulated.



Then comes another major source of energy which is the hydroelectric energy or the hydropower. So we all understand that like the hydropower calls for building of big big dams. If I talk about one of the largest dams which is the Hoover Dam in the US. So the Hoover Dam and that particular dam produces almost 2080 megawatt of electricity and if I talk about the concrete that was used for that for the building of this particular dam it was good enough for building around 3200 kilometer of a four-lane highway. So the amount of construction material that goes into the construction of this dams is quite high. Further this also the construction also leads to flooding of the upstream areas because the dams require a big amount of reservoir and we have been discussing that like the typical Teheri Dam that we have in India led to a displacement of a good amount of families. Something similar is expected for the Three Gorges Dam in China which is expected to

have displaced lakhs of people because of the sheer amount of reservoir that was created by the dam. Further the dams also prohibit the fish migration during the different seasons.

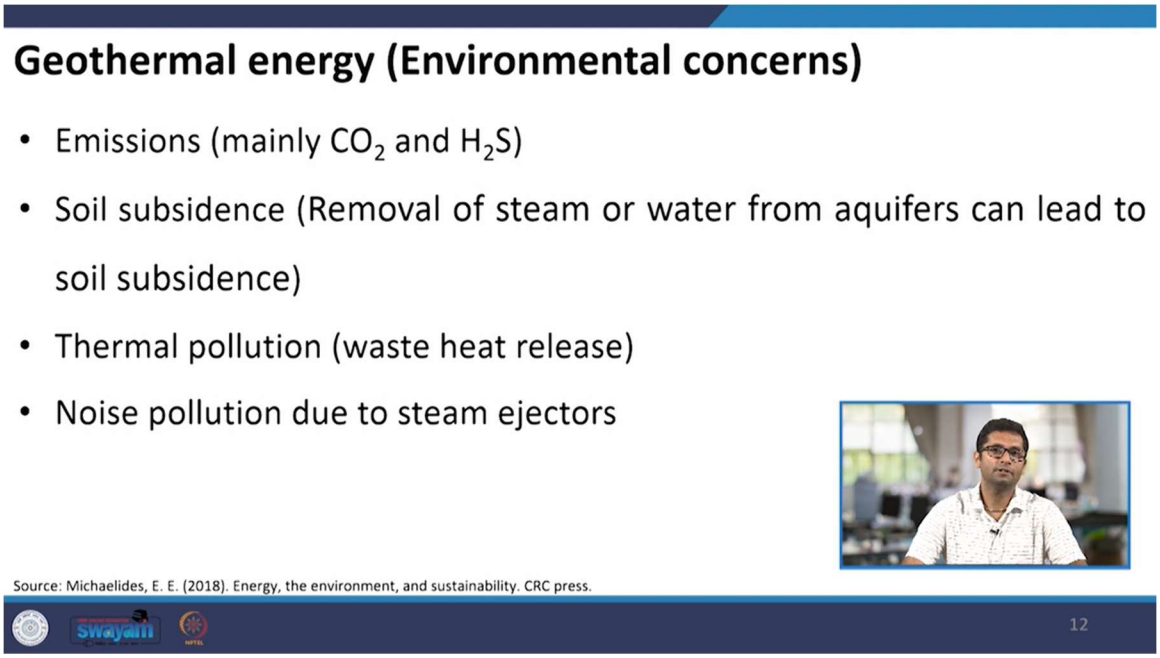
This kind of problem can normally be solved with the help of the fish banks or the fish pathways that are created. Then another problem that is faced is the scouring of the riverbeds because the turbines before the water enters the turbines there are a lot of sieves. So the sediments that are coming from upstream might not be able to travel downstream and this basically is not good for the riverbeds in the long run. Further it also spoils the downstream water environment. Also it is noticed that because of the pressure difference that is exhibited during the different areas of the power production and the dissolved oxygen that is there in the water is reduced and this further disturbs the ecology in the downstream areas. So these are some of the major issues that are associated with hydroelectric power production.



And we also understand that these dams are also attempting targets for like in the case of wars or terrorism because an attack of any of these targets could lead to huge scale destruction in the downstream areas. So this is again a major security concern as far as the dams are concerned. Also we have had experience of major dam failures which have happened in the past. An example would be the Vijon Dam in Italy which had a major failure in the year 1963 leading to deaths of around 2000 people. Something similar

happened in southern China in 1975 and which caused a drastic number of deaths amounting to more than 1,71,000.

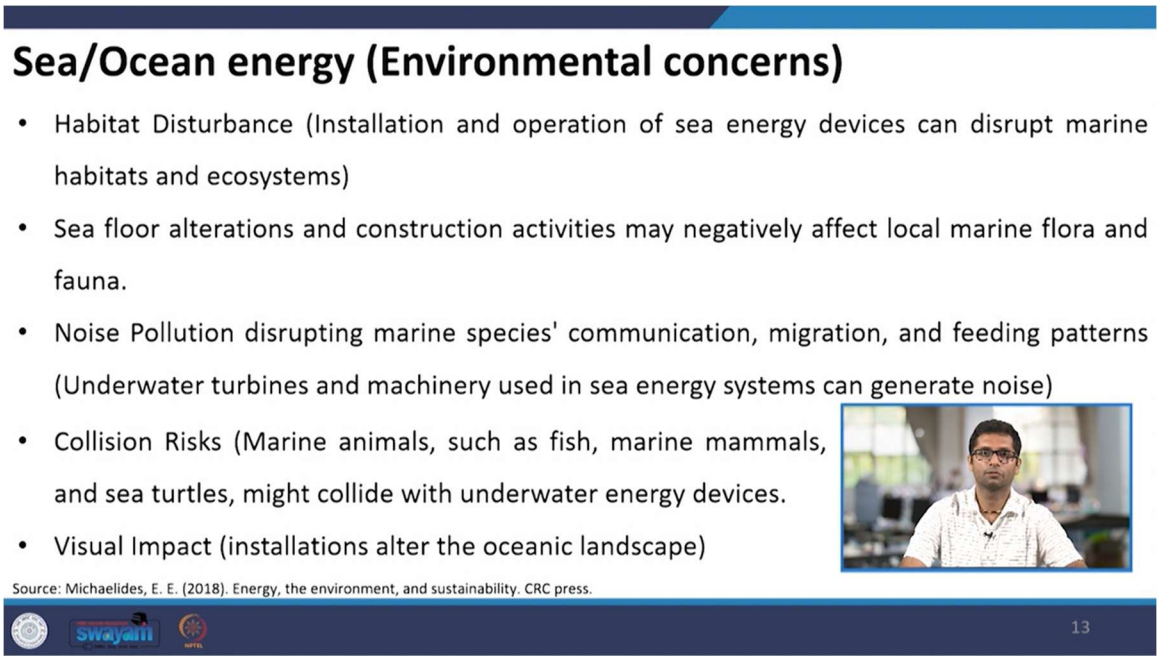
And it is normally expected that the smaller dams would be much more beneficial or much more safe as compared to larger dams. Well it's not always the case, there is a typical case of the Kelly Barnes in the state of Georgia in the US which was supposedly a small scale dam or a small SHP dam and it failed in the year 1977 leading to around 40 deaths. So like any problem that happens in the dam could lead, could have serious consequences in the villages that lie near the reservoir or near the river bank in the downstream areas.



Another major source of energy is the geothermal energy which basically takes into account the energy produced from the hot water springs that we have in different parts of the globe. And So when we are producing or using this type of energy for the production of electricity it is also accompanied by the emissions of CO2 and H2S.

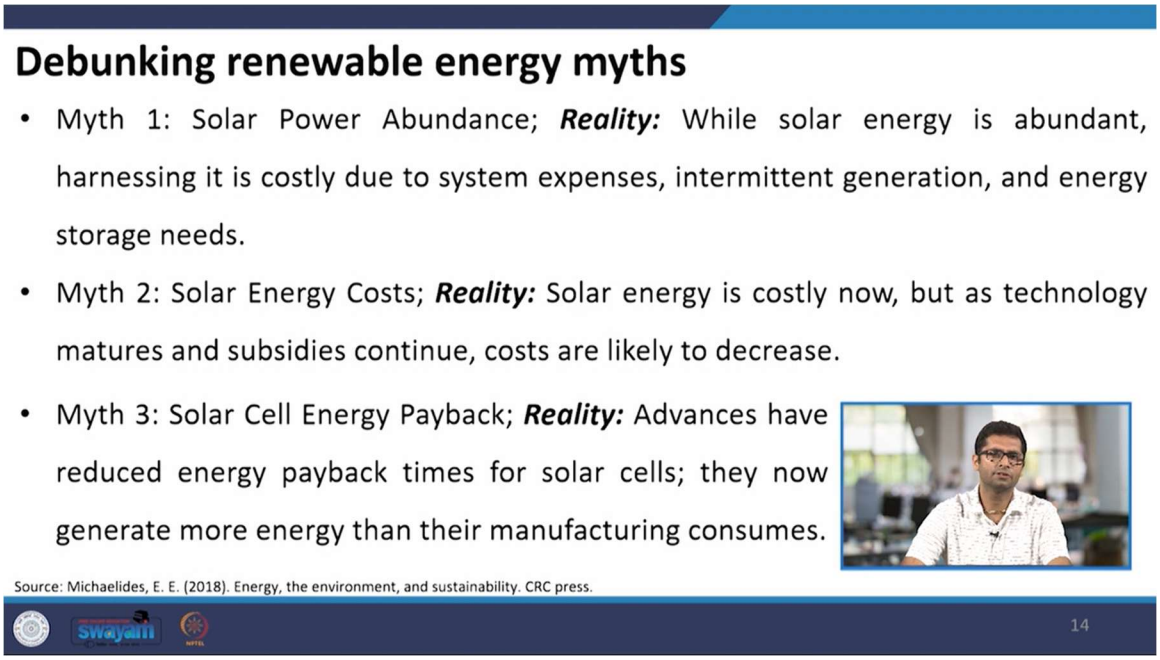
This is particularly from this carbon dioxide or the hydrogen sulphide which is dissolved inside the water or the steam that is recovered. So again the level of the CO2 or the hydrogen sulphide is many orders of magnitude lesser than what you would encounter in a fossil fuel based power plant but there are somewhat emissions. Another major problem

that is expected is the subsidence of soil because we are removing steam and water from the aquifers. The thermal pollution as we have discussed in the earlier cases is also an issue because these kinds of plants would normally run at a lower temperature and at a lower efficiency. So the thermal pollution that results from a geothermal plant is expected to be somewhat larger as compared to a similar capacity of fossil fuel based power plant. And further we use steam injectors which are rotating equipment and they would be creating noise. So this noise pollution is something that is also encountered in the case of geothermal energy.



Another source of energy that is normally utilized is based upon the sea or ocean energy which basically makes use of the movement of the water bodies in terms of tides or other ways. So one major issue is the habitat disturbance in terms of like you would be installing and operating sea energy devices which would basically disrupt the marine habitats and ecosystems. Then there could be sea floor alternations and construction activities could lead to could have bad effects on the local flora and fauna. Further the noise pollution that would be created by the moving equipment might not be taken well by the marine ecosystems. There are also expected collision risks that the marine animals might collide with some of them and cause harm to them. Further as in

the case of wind energy there could be the visual impact which causes disruption in the oceanic landscape.



So with this we have discussed some of the major problems or major environmental impacts apart from the emissions of CO2 that might be resulting from the different kinds of renewable sources of energy. Let us also spend the remaining part of the class in debunking some of the renewable energy myths which have been doing rounds. So one of the first myths that you are going to come around is like solar power is available in more capacity than we can need. We can rely just on solar energy for meeting all our energy needs for the coming future for years. Well we need to be sure that the solar energy that we are producing presently is quite distributed and it might be coming out to be quite comparable with respect to the fossil fuels on just a day basis but if we take throughout or the 24-7 availability of energy we need storage and this storage comes out to be very costly. Further the transportation of energy because not all areas on the planet have equally abundant solar energies we might not be able to utilize solar energy as as being propagated by a few organizations. Further another myth that we come across is solar energy cost like solar energy might be costly now but as the technology matures as the efficiency of the PV panels becomes better it is going to reduce.

Well which is likely like the solar energy has been decreasing its cost quite significantly since its discovery a few decades back so the costs have come down substantially and this downward trend is expected to be followed in the coming few years as well. We keep on hearing new and new announcements with respect to the efficiency improvement and with the following efficiency improvement it is expected that the solar energy costs are not going to be always higher than the conventional energy they are expected to reduce in the future. Then another myth is about the solar energy solar cell energy payback a lot of energy goes into the production of the solar PV panels and if you talk about around 60 or 70 years back the type of energy that went into manufacturing one solar PV panel it would take around 40 years of functioning of that solar cell to recover that energy. That used to be the case in the past but if we talk about today the efficiency of solar PV panels is quite high and the energy payback has been reported of the years of 1 to 2 years. So the energy payback has been reduced greatly and we need not worry about the solar energy payback anymore.

Debunking renewable energy myths

- Myth 4: Wind Energy Potential; ***Reality:*** Although wind power potential is vast, practical constraints limit its widespread utilization and require costly energy storage solutions.
- Myth 5: Geothermal Energy Substitution; ***Reality:*** Geothermal energy's feasibility varies by location; smaller countries with lower electricity needs have a greater proportion of geothermal resources.
- Myth 6: Ethanol as a Solution; ***Reality:*** Ethanol production is costly, inefficient, and requires significant water use.

Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.

A similar kind of myth is that we have enough amount of wind energy that is available and we should be able to meet the globe's requirement for energy just by wind energy. Well we agree that there is a lot amount of wind power available but a lot of wind or a substantial part of this power that is available is in the oceanic regions or it is in the

region which cannot be reached quite easily. So this basically puts a cap on the type of places that we can put the wind farms in. So of course there is a lot amount of wind power available but again the sites at which we can profitably encash this energy is quite limited. Further something similar to the solar energy we would need significant amount of storage for making use of this wind energy.

Then what about geothermal energy? We keep on hearing about countries like Ireland or Iceland or Costa Rica which have been using geothermal energy for meeting more than 50% of their energy needs. Well these are small countries and the energy need as such is quite small and given that the majority of the world is not endowed with these kinds of natural resources so the application of geothermal energy is quite limited. It might be coming quite handy in a few countries like Iceland which produce a lot of its electricity and energy needs through the use of geothermal energy but that might not be the case with bigger countries like India or the US. Then people see a lot of potential in ethanol or biothanol as a solution. We have seen different countries running fuel like gasohol which is nothing but gasoline or petrol mixed with 10% ethanol.

So in India we already have around 12 to 13% of mixing of biothanol with petrol and it is expected to be 20% in the future. We also need to understand that ethanol production currently is quite costly and it is not very efficient. The types of materials or the energy that goes into the production of ethanol is quite high. So and plus the water requirement tends to be very high. As we have discussed earlier for 1 liter of ethanol production almost 1000 liter of water is required and it needs to be made sure that this ethanol that is produced does not have a food value.

We need to be sure about the food versus fuel conflict. It should not happen that in the case of producing ethanol we are not looking at the need of the people who are in need for food and in India we have mass poverty and we have a huge population to feed. So such kind of decisions need to be taken by seeing the larger perspective.

Debunking renewable energy myths

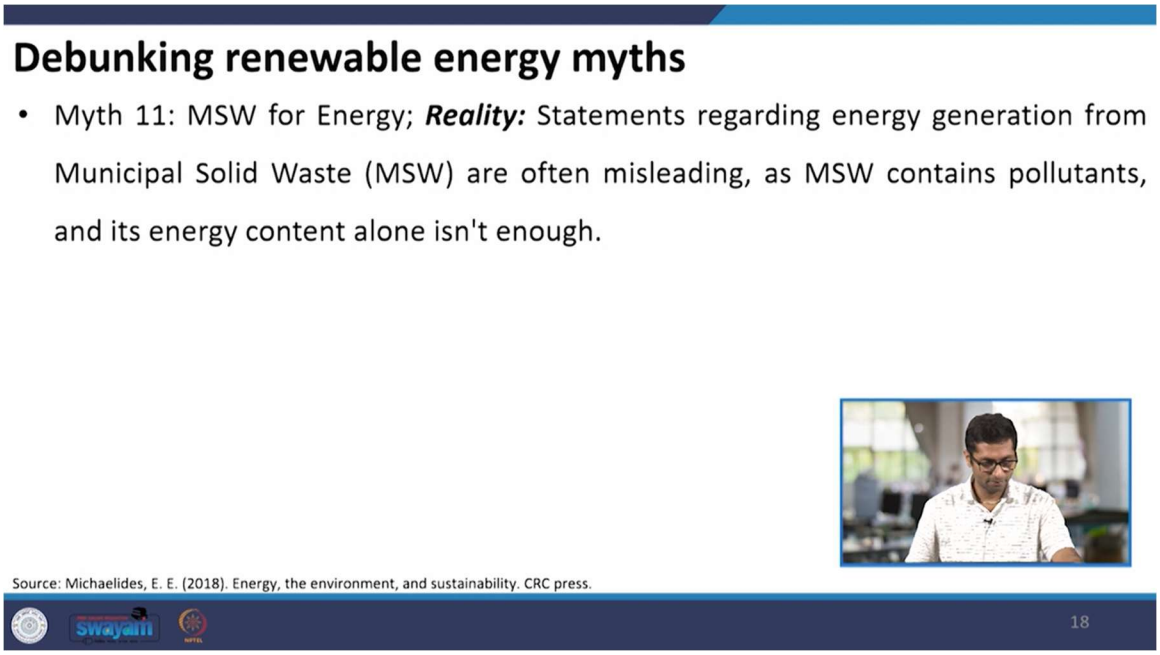
- Myth 7: Ethanol's Clean Image; ***Reality:*** Ethanol production involves substantial energy and material inputs, contributing to its carbon footprint.
- Myth 8: Kitchen Oil Waste for Fuel; ***Reality:*** Kitchen oil waste, while suitable for biofuel, cannot make a significant impact on petroleum consumption.
- Myth 9: Tree Planting for Carbon Offset; ***Reality:*** Planting trees to offset carbon is unsustainable due to limited land availability.
- Myth 10: Burning Wood as a Fuel; ***Reality:*** Burning wood for heating consumes vast quantities of trees and produces pollution.

16

Again something similar about the ethanol's clean image like when or like is it ethanol really renewable? Well that depends upon the complete supply chain and that is why a concrete life cycle assessment needs to be carried out and try to understand the different types of energy and the material inputs that go throughout the life cycle of production of ethanol. Further there is also a growing lobby towards using kitchen oil for the production of fuels like biodiesel. The waste kitchen oil which is used for cooking might be collected and could be used through the normal trans-esterification process for the production of biofuel. Well it is an important kind of mechanism that could be undertaken but the amount of kitchen waste oil that is available in any society or in any country would be very minuscule as compared to the total amount of fuel that that particular country would be using. Take the example of US. Now US is one of the countries which has a lot of wasting propensity so it is also like normally called the wasting society. So if I talk about a country like the US which is known for its like wasting lifestyle they waste a lot of resources so that particular country has almost 13 million kg of cooking oil waste. Whereas if I talk about the petroleum product that US uses this is of the tune of around 400 billion kgs.

So there is an order of magnitude difference. So of course it is good if we can recycle the used cooking oil but again the type of impact that it is going to have the overall economy

is not going to be very large. We already discussed that like people have been saying that tree plantation could be used as a carbon offset. Well there is a limitation to the amount of carbon that one single tree can absorb and further the area that is required by a typical plant is quite high. So given that huge amount of areas would be required for to sequester a significant amount of CO2. Well people have also been advocating like why should we be producing heat by using coal or other fossil fuels cannot we use just wood as we have been using in the prehistoric areas. Well burning wood is a good area but it is not very efficient and further this would also entail good amount of trees production which needs to be transported over large distances and this transportation would again consume a lot of fuels. So if you are transporting these fuels over long distances this does not make economic as well as environmental sense.



And finally we also have the case of municipal solid waste. So waste to energy plants are also gaining a lot of insights like cannot we use the energy that is produced from the different municipal solid waste plants. Well we need to understand the typical energy that is coming from the plants or the waste is not very high and compared to the fuels like biomass or coal it could be quite less.

Further it is also mentioned that many of these municipal solid waste have certain pollutants which would be released to the environment and not good for the public at

large. Of course like such an incentive should be encouraged but we also need to understand that this is not going to be a very big solution because the energy that could be derived from such municipal solid plants could be capped because the energy that is encapped in those kinds of waste is not very high. With this we have tried to understand some of the major pathways of energy production in terms of renewable energy and we also tried to understand the likely environmental impacts just to give an equal weightage in terms of the impacts that are caused by the different fossil fuels as well. So we have tried to get an understanding that no single source of energy could be said to be purely clean, green or sustainable. All of them have some likely environmental impacts and we really need to do a lot of analysis to see or to say that this particular fuel is sustainable for the future.

And this is what will be the topic of the next few classes where we are going to jump into the topic of sustainability and we will try to quantify or try to understand how do we quantify sustainability as far as the energy production pathways are concerned. With this we end today's class. Thank you.