Environmental Biotechnology
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Lecture – 48
Emerging Pollutants

Welcome to the 48th lecture of this course environmental biotechnology and in this particular lecture we are going to discuss about emerging pollutants. Especially I will also talk about plastics and microplastics and they are their bioremediation or interaction with microorganisms.

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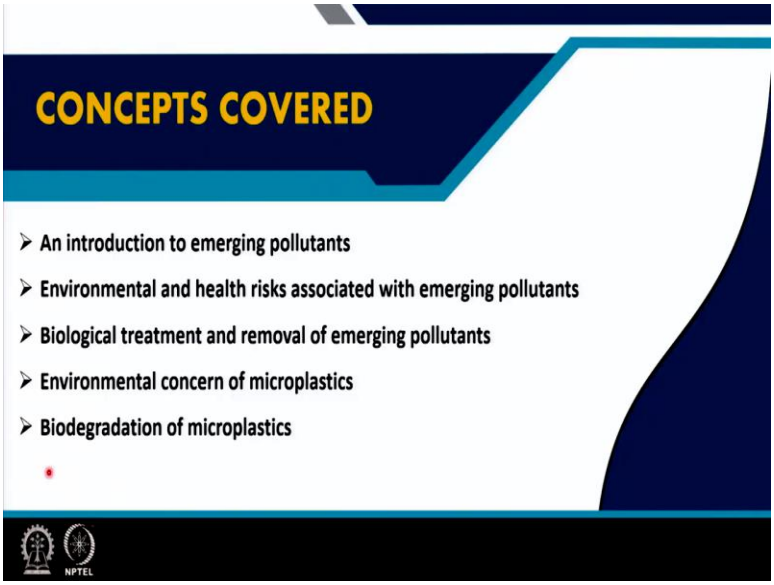

Now in this particular lecture these following topics will be covered. An introduction to emerging pollutants followed by environmental and health risk associated with the pollutants biological treatment and removal options for emerging pollutants, environmental concerns of plastics and micro plastics and the bio degradation opportunities for microplastic management.

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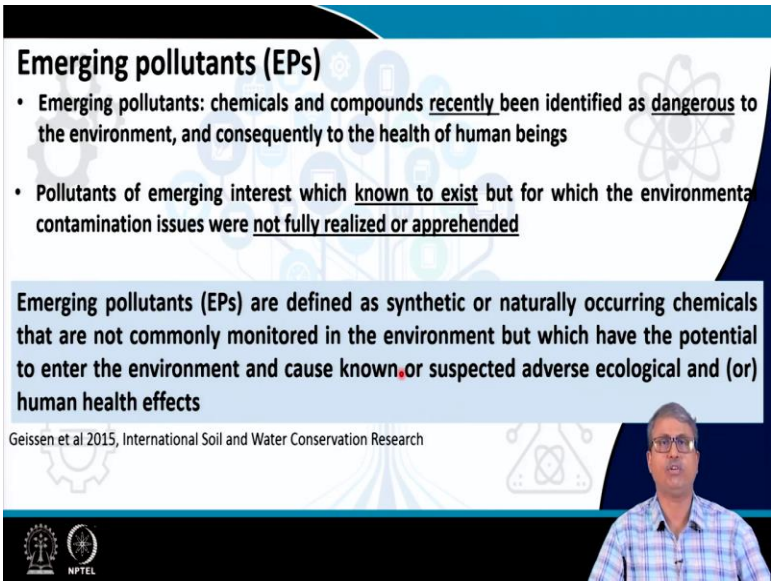

Now emerging pollutants or EPs, emerging pollutants are chemicals and compounds recently been identified as dangerous to the environment and consequently to the health of human beings and these are the pollutants of emerging interest which are known to exist but for which the environmental contamination issues were not fully realized or apprehended. Now it is defined as synthetic or naturally occurring chemicals that are not commonly monitored in the environment but which have the potential to enter the environment and cause known or suspected adverse ecological or human health effects.

So, as it describes that these are synthetic compound most of the time and these are either already existing or are already present in the environment but possibly we are not able to detect them because of the lack of analytical methods or these compounds could be newly synthesized newly introduced into the environment. And what is also true about this that the cause the kind of hazards they impose to the ecosystems are often not very clearly defined.

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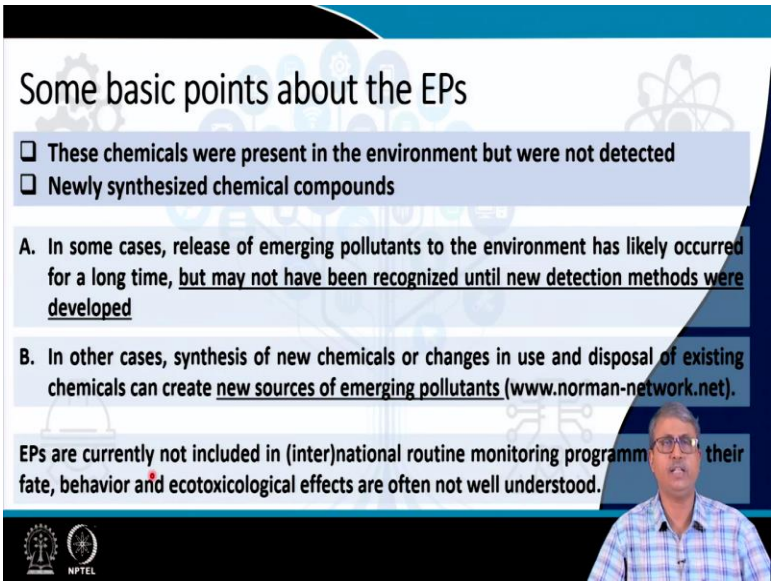

Now some basic points about these EPs: These chemicals were present in the environment but were not detected maybe as I mentioned possibly because of the lack of analytical instruments and many of them are also newly synthesized chemical compounds. Now in some cases the release of emerging pollutants to the environment has likely occurred for a long time but may not have been recognized until new detection methods were developed. In other cases synthesis of new chemicals or changes in use and disposal of existing chemicals can create a new source of emerging pollutants.

And EPs are currently not included in international or national routine monitoring programs with respect to environmental monitoring programs particularly and their fate behaviour and eco toxicological effects are often not very clearly understood.

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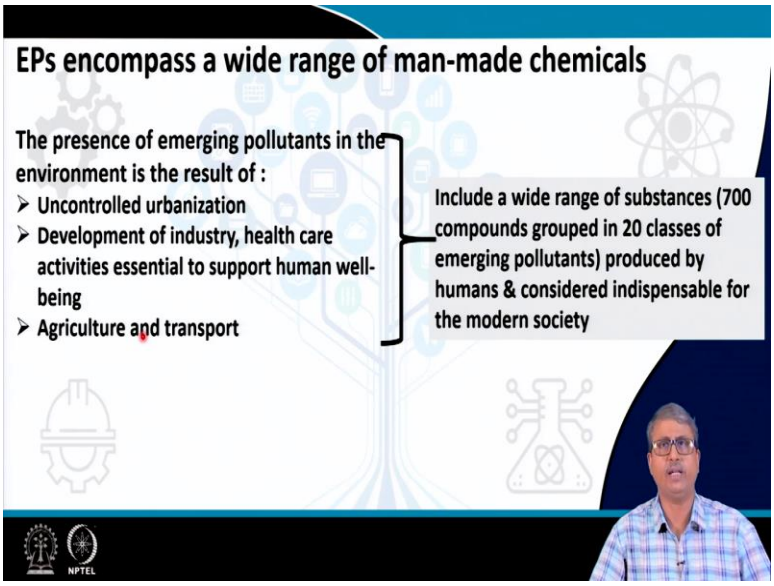

Now these EPs they encompass a wide range of manmade chemicals the presence of emerging pollutants in the environment is basically resulting due to fundamentally uncontrolled urbanization development of industry, health care activities, essential to support the human well-being as well as different agricultural and transport related activities and these emerging pollutants they actually represent a wide range of substances.

More than like 700 compounds grouped in 20 classes of emerging pollutants and produced by human and considered indispensable for the modern society.

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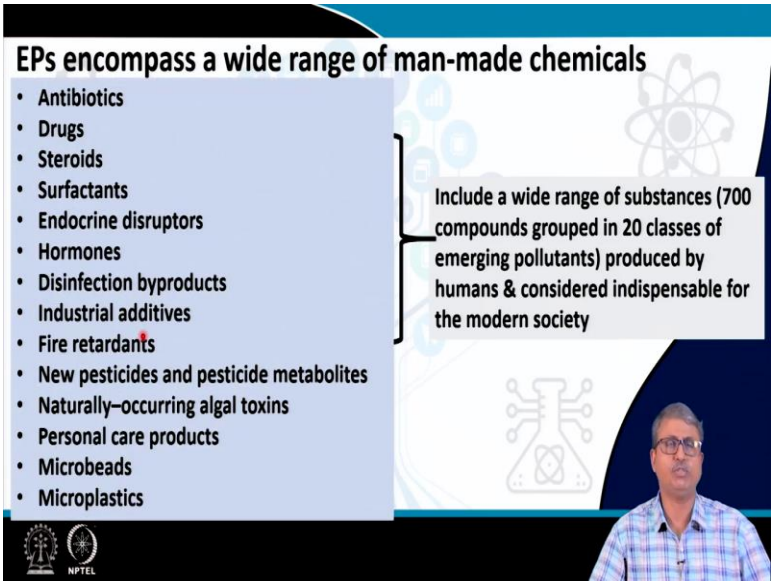

And these compounds if you look at the least will understand that why they are considered as

indispensable for the modern society. Because this they start from antibiotics drugs, steroids, starvations, endocrine disruptors, hormones disinfection, by products industrial additives, fire retardants, new pesticides and pesticide metabolites naturally occurring algal toxin personal care products, different type of microbeads and micro plastics.

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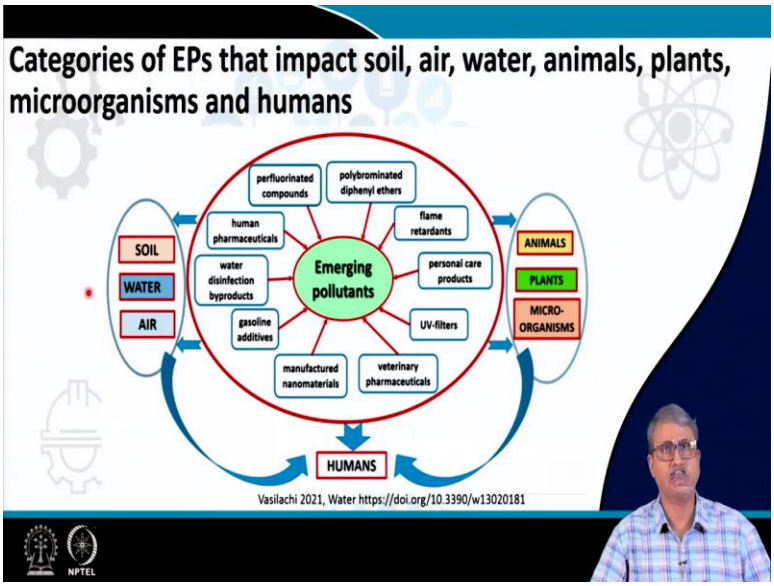

And as we as we can understand these are actually covering a broad which are categorized as 20 broad groups of molecules or compounds distributed across 700 types of total molec compounds. We can see that these are represented here is a broad array of the compounds. Now these compounds are mostly released from non point emission sources or sometimes from the point source emission as well like the some of the industries if they are releasing then it is it is considered to be a point source emission whereas many of them are human pharmaceuticals or personal care products.

So, in regular use in household use we are actually using those emerging pollutant containing molecules or compounds. These compounds are emerging pollutant molecules are essentially discharged into the environment through the different waste released into the environment and entering into the soil water and air systems. And when they are coming into the soil water and air systems essentially all animals plants microorganisms and human are going to be part of their system.

Where they are going to accumulate or will be are going to be affected by those compounds. Human on the on the other hand can be directly impacted because the human sometimes we consume the drinking water. For example can consume the milk the dairy product the agricultural residual agricultural products wherever we have the chances that they are possibly contaminated with these kind of emerging pollutants.

Human could be directly impacted or human could be indirectly impacted because if we are consuming the poultry products or if we are consuming the fish or meat or other agricultural residues then we would be indirectly impacted by consuming that.

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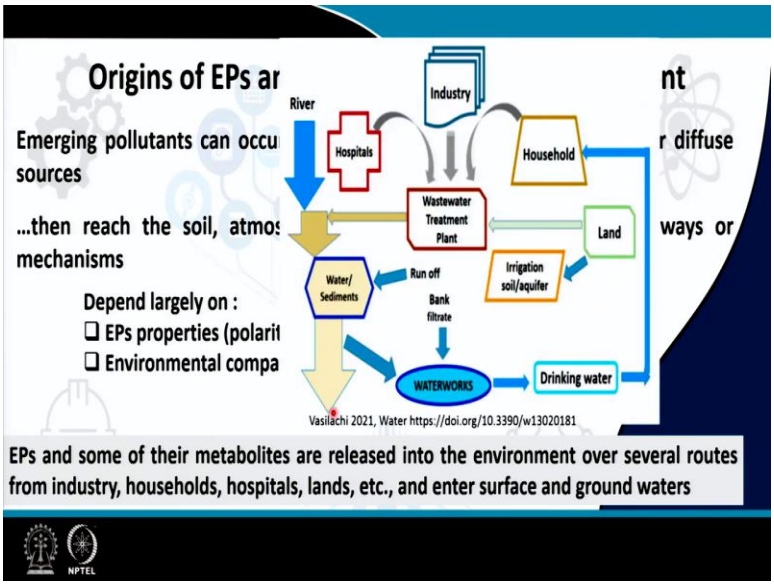

Now the origin of EPs and their roots in the environment: Emerging pollutants can occur in the environment from various point or diffuse sources. And then once they are released they reach to the soil atmosphere water bodies through several ways and mechanisms. And these mechanisms generally depend on their properties like their polarity volatility their environmental persistence as well as environmental compartments characteristics like where they are going to be entering into the system.

Whether it is a soil, it is a kind of water system aquifer what type of system where this emerging pollutants a particular type of pollutant is getting into the mixed into the environment. This emerging pollutants and some of their metabolites when they are when they are subjected to

some kind of or chemical alterations either purely chemically or biologically catalyzed this metabolites are released into the environment over several routes from the industry household hospitals etcetera.

And as you can see that a large array of facilities including hospitals industries household land etcetera they are all discharging these into the wastewater system and from there they might be coming into the other systems. And finally entering into the drinking water or even the soil etcetera.

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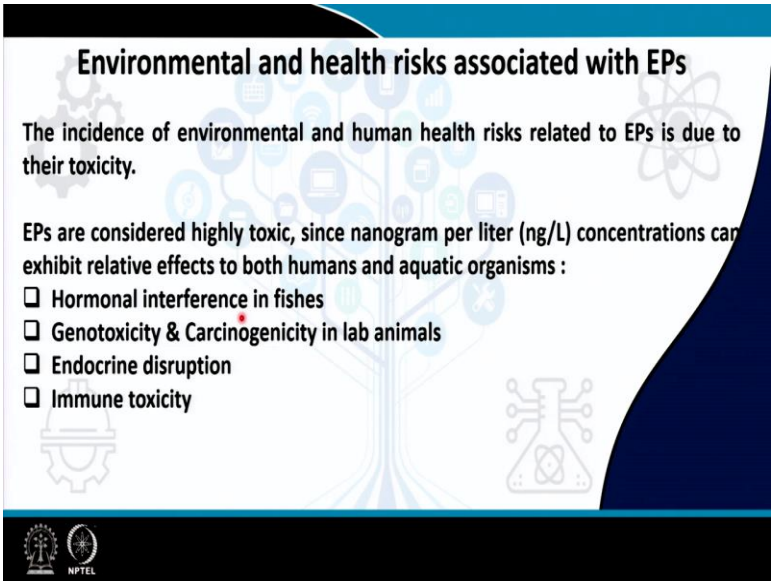

Now what are the environmental and health risks associated with this EPs. The incidence of environmental and health risk particularly human health risk related to EPs is due to their toxicity most of or almost all these compounds are toxic at some levels. EPs are considered to be highly toxic since nanogram per liter concentration can exhibit relative effects to both human and aquatic organisms including the hormonal interference or hormonal imbalances as has been observed in fishes. Genotoxicity, carcinogenicity in lab animals endocrine disruption and immune toxicity.

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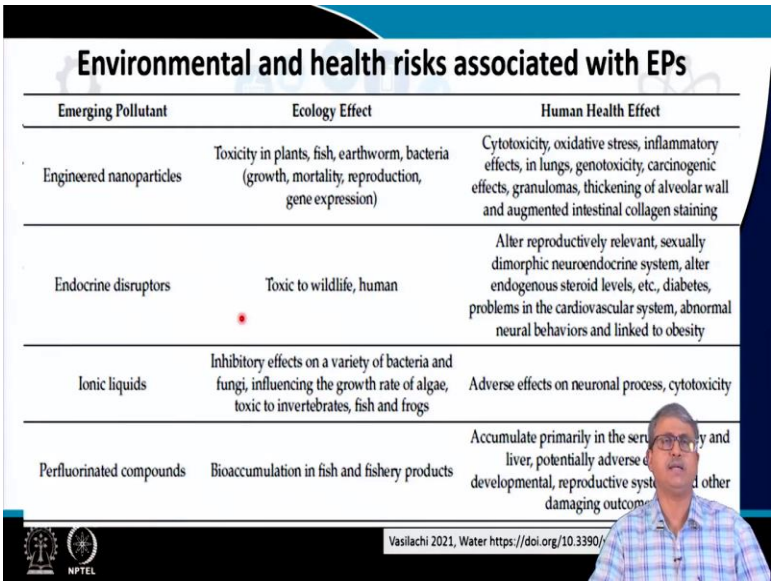

And this is the this table is basically presenting the different type of ecological effects of the broad categories of emerging pollutants and also their human health effect.

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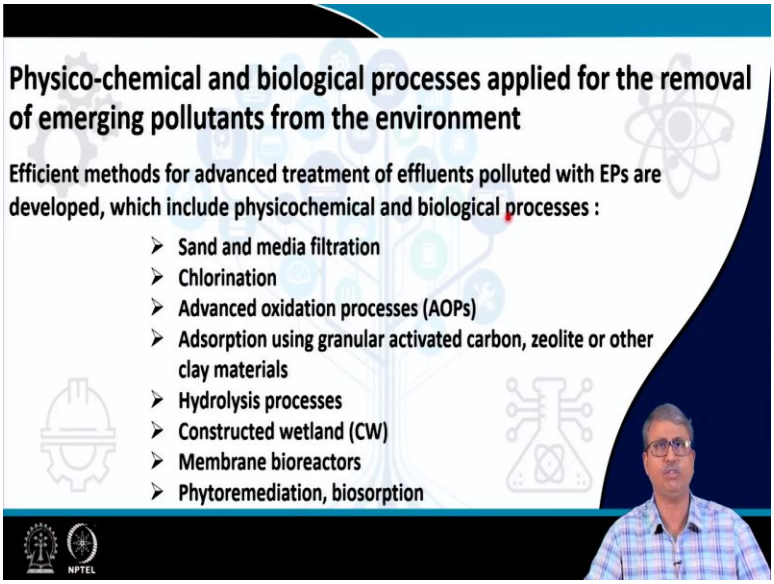

Now the physic-chemical and biological processes have been applied for the removal of emerging pollutants from the environment. As we understand that these are newly enlisted pollutants and listed in the sense at this we are discussing about them. But couple of years ago environmental engineers and environmental biotechnologist were not aware of or not having the scope to discuss about these emerging pollutants.

But with rising concentration rising threat the hazard imposed by emerging pollutants is making

a greater sense or posing greater stress on the environmental biotechnologist directly to develop different kind of tech techniques or process strategies through which we can actually manage these kind of waste materials. So, the efficient methods for the advanced treatment of effluents polluted with EPs are developed.

So, essentially normal wastewater treatment technologies or normal bioremediation technologies may not be able to do sufficiently sufficient catalytic job because these are present in a very low concentration first of all and often they are very poorly characterized also that how actually they can be removed or they can be treated with microorganisms or chemical processes are often not very clearly understood.

In the recent past we the scientists are doing lot of studies lot of research in order to identify that how these molecules these compounds can be effectively removed from different type of waste or soil or water or aquifer systems. It includes both the physiochemical and biological processes. And as you can see a number of strategies can be adopted sand media and media filtration to chlorination advanced oxidation process, adsorption hydrolysis constructed wetland membrane bioreactor and different type of phytoremediation and bias option technologies.

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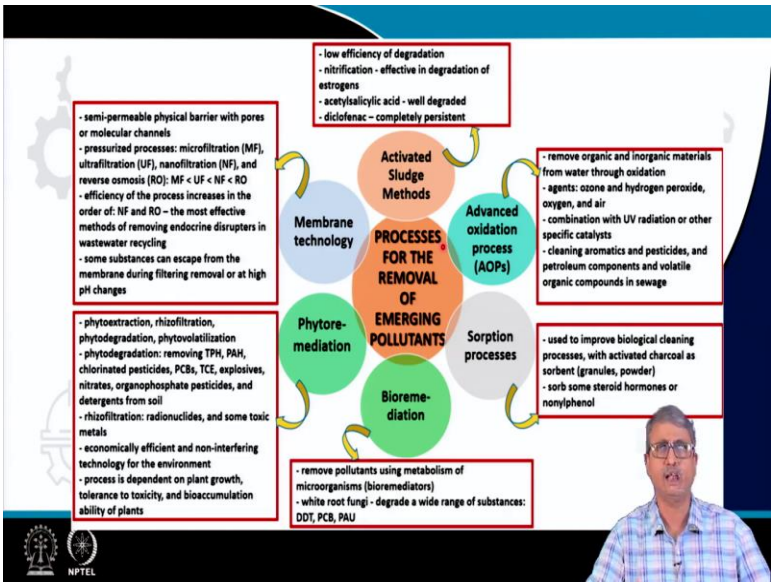

So, here we have a summary of the methods to remove the EPs from the environment and use. As you can see that in the center we have the processes for the removal of emerging pollutants

and on the side line you have the membrane technology for example which actually allows the use of semi permeable physical barrier through pores or molecular channels and it is a pressurized process through micro filtration, ultra filtration, nano filtration, reverse osmosis etcetera and obviously it is it is an expensive process.

The phyto remediation is relatively inexpensive easy to perform but relatively slower and often poorly understood. Phyto extraction, rhizo filtration, phyto degradation and phyto volatilization use of plants different type of plants are being used to remove different kind of compounds. And it is economically more affordable efficient and non interfering technology for the environment. So, we will talk about this that the hybrid processes are often developed including the phyto remediation as a part of that.

Activated sludge method which is a very conventional technique for wastewater treatment processing wastewater treatment methods. But for emerging pollutants we can we can understand that they could be low efficiency or of degradation of this compound but still some processes are being developed in order to use the activated sludge methods to remove this emerging pollutants.

Advanced oxidation process is found to be relatively more efficient because it removes the organic and inorganic materials from waste through oxidation and ozonization and hydrogen peroxide based treatments. And in combination with UV radiation other specific catalysis are often used and it is also using the cleaning aromatics and pesticides petroleum hydrocarbon volatile organic compounds in sewage are removed through this advanced oxidation process.

Absorption process used to improve the biological cleaning processes with activated charcoal etcetera to absorb some of the steroids and other emerging pollutants. And finally the different direct approaches of the bioremediation where the pollutants can be removed directly through the metabolism of microorganisms.

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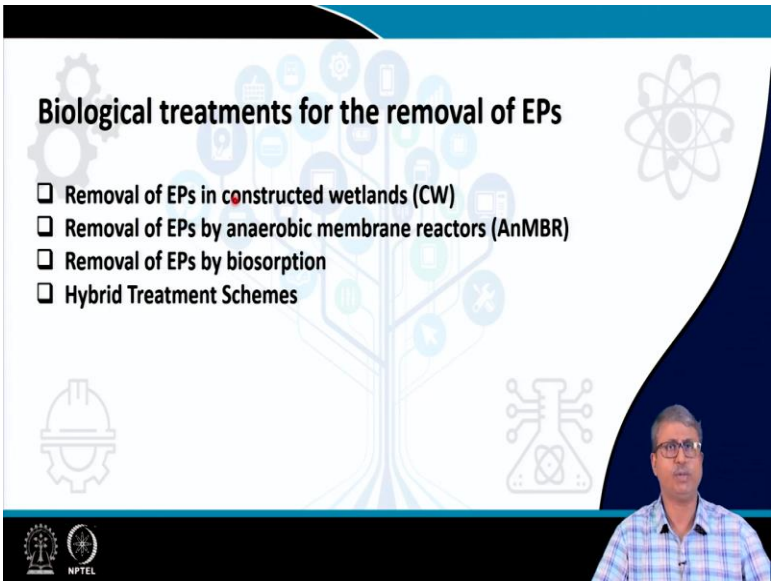

Now in today's class we will also discuss especially on the biological treatments of the removal of the EPs. Now removal of EPs can be done through constructed wetlands through anaerobic membrane reactors or by bios option and through implementing different hybrid treatment process.

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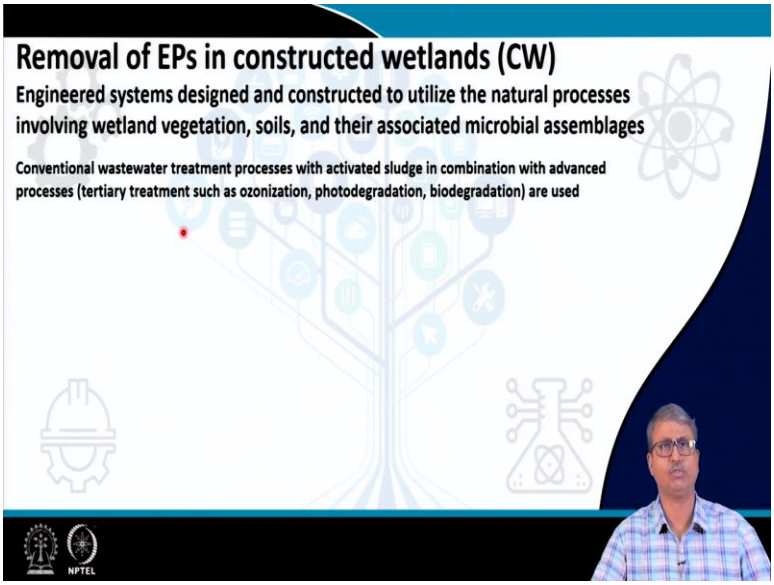

Now first we will discuss about the constructed waste wetlands. Now this is kind of an engineered system designed and constructed to utilize the natural process involving wetland vegetation, soil and the associated microbial assemblages. You can understand that the wetlands are being used for natural reclamation of the of the system or the natural treatment of the contaminated waste material waste water even.

And a group of organisms group of plants have been identified very well characterized very well to deal with the different type of pollutants. So, instead of advanced wetlands systems are being developed to take care of the emerging pollutants. Now the conventional wastewater treatment process with activated sludge for example in combination with advanced processes like tertiary treatment such as ozonization, photo degradation, bio degradation can also be used.

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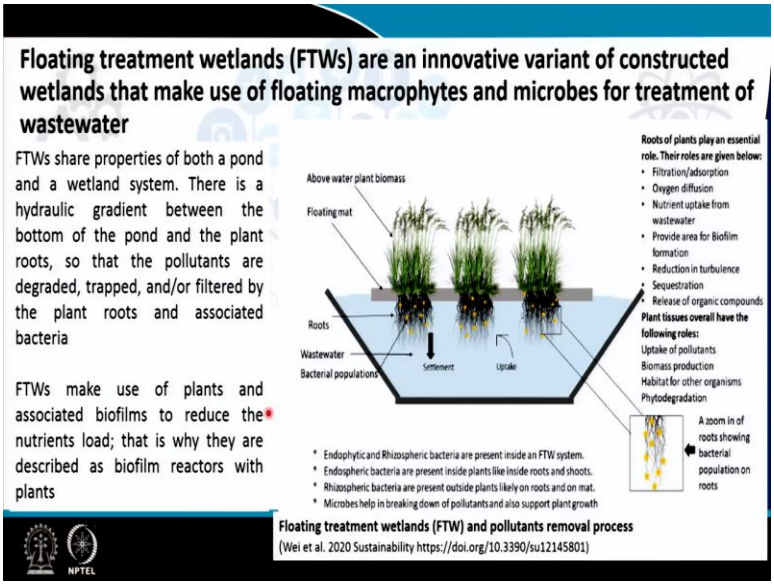

One of the most suitable technique is found to be the floating treatment wetlands are is kind of an innovative variant of constructed wetland that is making use and getting popularity. Because it is using the floating macrophytes and microbes in the water for treatment of the emerging pollutants present in the wastewater. So, as you can see here this is the water in which some mess is there and over this mess the plants are actually floating into that.

And the roots are emerged into the water and this is waste water and within which the bacterial populations are also thriving. So, you can see that if you zoom into this root zone we can see numerous microbial populations which are isospheric populations living in these root zones. So, it provides kind of an unique opportunity because it allows the diffusion of oxygen nutrient uptake provide area for biofilm formation reduction of the turbulence sequestration release of organic compounds which encourage the the growth of the microorganisms.

And the plant tissues overall have different roles into that like they can uptake the pollutants, they can produce the biomass, they could be the habitats for the organisms and they also allow the phyto degradation of the different pollutants. Because for a long period of time we have seen that plant cells are also capable of producing different enzymes and other methods through each which like the bacterial cells they interact with toxic metals and organic compounds the plant cells are also capable of interacting with them.

So, that property is utilized through this floating treatment technologies. Now to go into the detail, so, actually the mats float on the water surface we put a mat on that, that is the floating mat and plants are grown on these mats in such a way that the these are called halophytic grasses. The roots are actually completely submerged into the water and the aerial part is above the water. Now vegetation is supported by the buoyant mats which is floating and which make these mats easy to retrofit in any water body where they need to be used.

So, it is a kind of a modular system. So, based on the shape and size of the water bodies we can actually design this or take these floating mats and then use them and this floating treatment wetlands they share the properties of both the pond and the wetland system. So, there is a hydraulic gradient between the bottom of the pond and the plant root. So, that the pollutants are degraded trapped and filtered by the plant root and associated bacteria and they you make use of plants and associated biofilms which are growing over here and also the planktonic cells we are which are growing into the free water.

And thereby creating opportunities for different microbial processes towards the degradation and the removal of the pollutant as well.

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The plants generally used in this process are listed over here as you can see the many of them are very, very common plants used for wetland processes. Along with some microorganisms which are again very well known like pseudomonas, dichloromonas, bacillus hydrobacter, geobacter rotococcus etcetera. And the commonly targeted EPs are different kind of drugs and other emerging pollutants.

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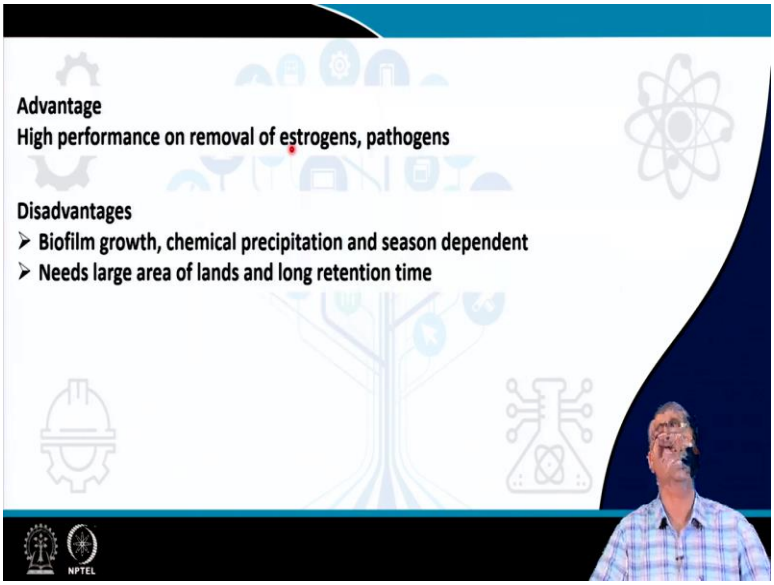

The advantage of this process is high performance on removal of the particularly what is observed for estrogen and different type of pathogens. The disadvantages are the biofilm growth chemical precipitation and season dependency needs large area of lands and long retention time.

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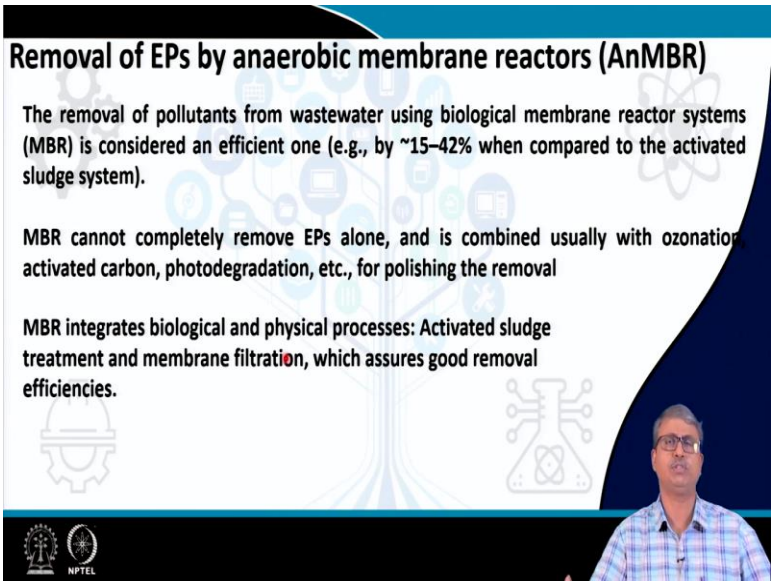

The second procedure of the biological treatment of this emerging pollutant is the anaerobic membrane reactor. Now the removal of the pollutant from wastewater using biological membrane reactor is considered to be a very efficient option. Now this normal MBR or Membrane Reactor System or a biological membrane reactor cannot completely remove the EPs alone and is combined usually with other chemical physical process like ozonization activated carbon based process photo degradation for polishing the removable processes.

And the MBR integrates biological and physical process activated sludge treatment membrane filtration which assures good removal efficiency. So, a couple of things are mixed or added together in this anaerobic membrane reactor system.

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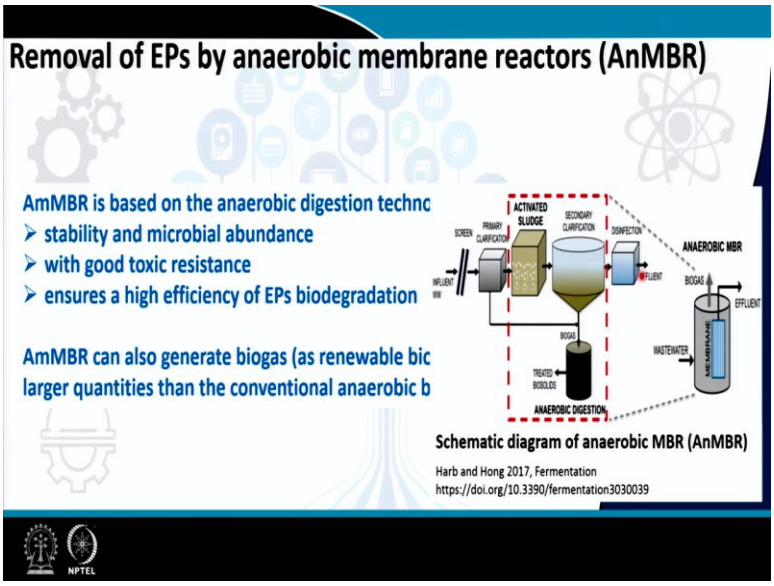

So, anaerobic membrane reactor system is based on the anaerobic digestion technology and is characterized by stability and microbial abundance, good toxic resistance and ensure high efficiency of the epibiotic gradation and it can also generate bio gas under anaerobic condition which is considered to be a renewable bio resource and it is in significantly larger quantities than the conventional anaerobic bio degradation system.

So, here is the picture of this system actually the system looks like this and if we enlarge it will have the primary clarifier followed by the activated sludge tank. Then the secondary clarifier and then the disinfection and the finally the fluid is going out of it.

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These are the organisms generally involved a number of bacterial strains are engaged into that and the the commonly targeted pollutants are different drugs and extra diols antibiotics etcetera.

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The advantage of this process is effective removal of the recalcitrant EPs and a very small footprint. Disadvantages include the high energy consumption and high cost pharmaceutical pollutants have low efficiencies for this.

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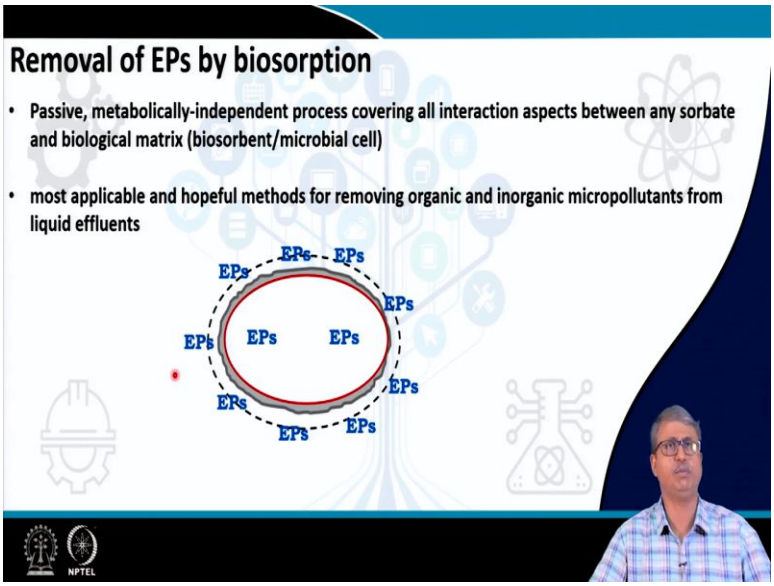

The third one is the removal of EPs by bioabsorption is a passive metabolically independent process covering all interaction aspect between any adsorbent and biological matrix like what we have learned in case of microbial interaction most applicable and helpful method for removing

organic and inorganic micro pollutant from liquid influence.

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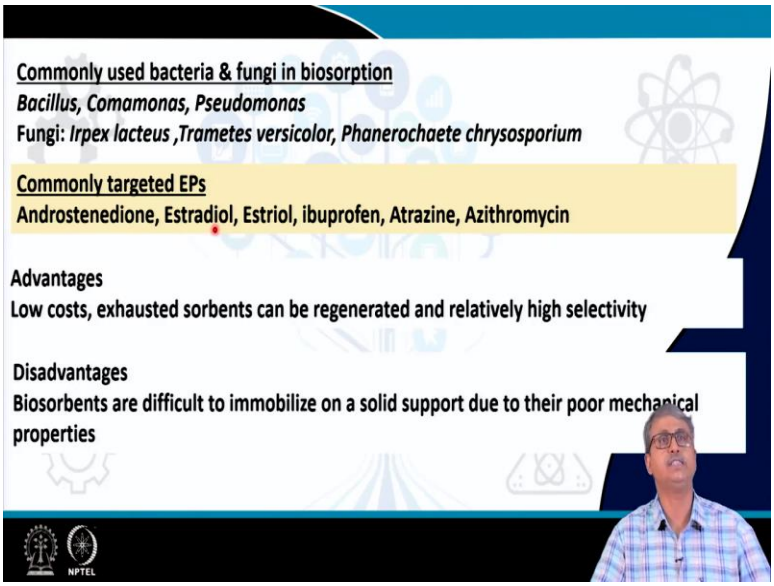

And a number of bacterial strains and fungal strains are used for this purpose and the commonly targeted EPs are again some of these compounds like extradiol, drugs Atrazine and antibiotics like azithromycin etcetera. And advantages include the low cost exhausted solvents can be regenerated and relatively with high selectivity. So, reusability of the solvent is always there. However it has the disadvantage of that biosolvents are difficult to immobilize on a solid support due to their poor mechanical properties.

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Now we will move on to the plastic part and see how the plastics are getting more importance in

environmental bio technology in particular. So, plastics and micro plastic is considered to be a critical material in the modern world due to its low cost and easy production. Without plastic I think the modern life is impossible. So, inadequate management and open disposal of the plastic and the products of the plastic including the micro plastic consider to be a major obstacle to achieving the sustainable developmental goals.

They cannot be recycled properly if they are not degraded nor recycled discarded close to the water resources in urban drainage system often it is observed. It flows into the river and ends up in the ocean in various forms such as the micro plastic. And it is considered to be the plastic waste have become a malevolent symbol of our wasteful society as we will see. Because a number of compounds which are basically considered as the synthetic plastics or the chemical plastics these are fundamental to every part of every aspect of our of our life.

Including the polyethylene, polystyrene, polypropylene, polyvinyl chloride, polyurethane polyethylene tetraphthalate etcetera. Now the global yield of plastic reached around 350 million tons in 2018. And countries like china and the European union accounts for 29 almost like 30% and 20% ranking first and second in the world of the all world plastic use respectively. And concomitant to the growing consumption of plastic it is inevitable that a large amount of plastic waste is being produced and dumped.

It is predicted that up to 26 billion tons of plastic waste will be produced by 2050 and more than half will be thrown away into landfill and finally enter into the ecosphere or the biosphere such as the ocean lakes and leading to the serious environmental problem.

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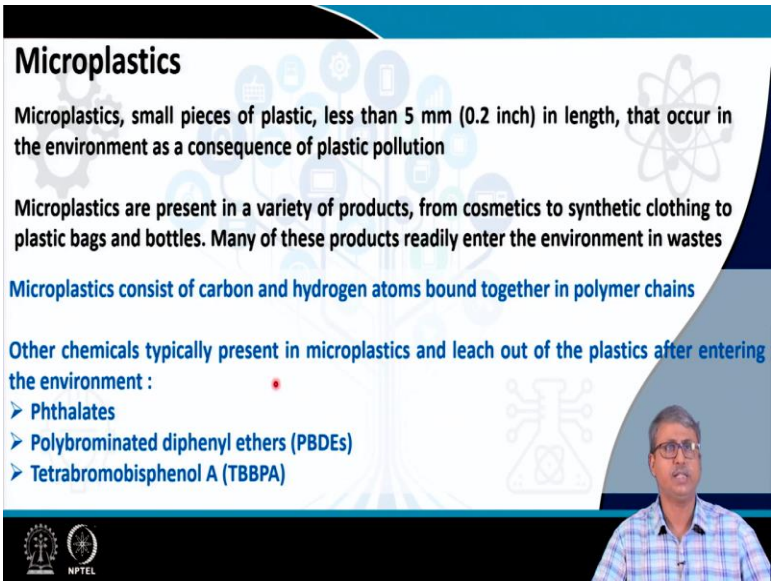

Now here is some statistics about the world production in terms of million tons of plastics per year and plastic distribution in different areas of our daily life. Now what is micro plastics? Micro plastics are basically small pieces of plastic less than 5 millimeter zero point or 0.2 inches in length that occur in the environment as a consequence of plastic pollution. Micro plastics are present in a variety of products from cosmetics to synthetic clothing to plastic bags and bottles.

And many of these products readily enter into the environment in west for example you can see here a nice picture of some amount of micro plastic on a fingertip. Now microplastics consist of carbon hydrogen atoms bound together with polymer chain. And they are often coupled with a number of chemical compounds which are also considered to be very hazardous and these chemical compounds along with the microplastic itself can leach out into the into the environment.

Once the microplastics are released into the environment and that includes phthalates polybrominated diphenyl ethers and tetra bromo bisphenol a type of compounds.

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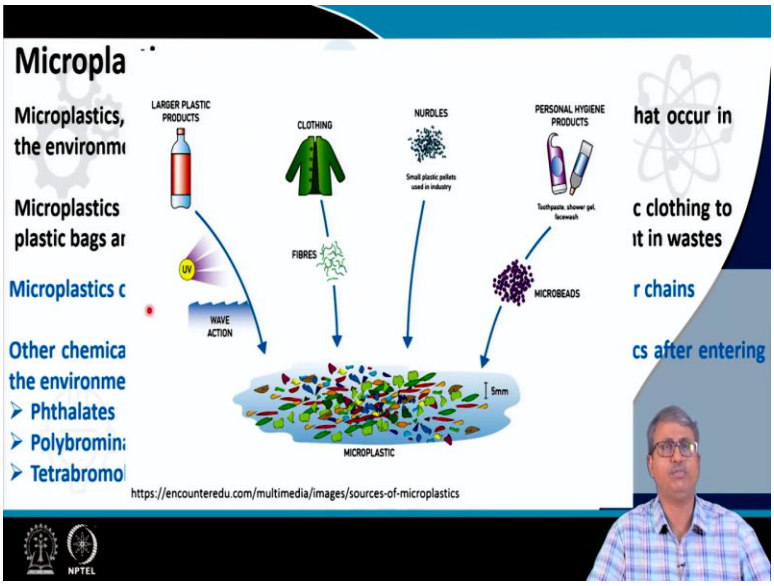

So, here is again epic cartoon to represent that how different sources like plastic bottles to clothing to different industrial grade plastic pellets and personal hygiene products. Every day we are using different types of these materials and we are if you are not managing them properly you are just discarding them abruptly then we are actually leading to the production of a large amount of micro microplastics.

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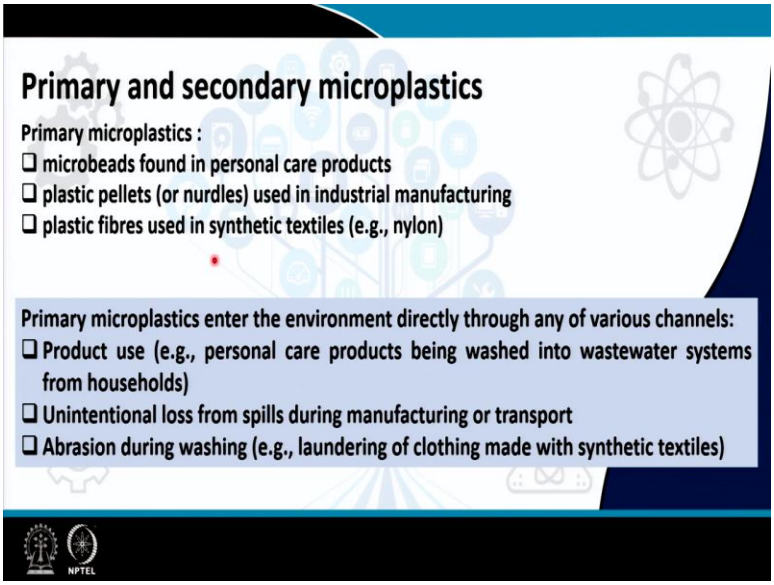

Now there could be two types of microplastics one is the primary type and the secondary type the primary microplastics are micro beads found in the personal care products. Plastic pellets used in industrial manufacturing and plastic fibers which are used in synthetic textile like nylons. These primary micro plastics enter the environment directly through the through any of the

various channels like product use.

For example personal care products being washed into a waste water system from the household unintentional loss from the spill during manufacturing or transport and abrasion during washing for example laundering of the clothes made from synthetic textile. So, a large amount of this plastic fibers plastic pellets or micro beads from the personal care products are being released into the environment.

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On the other hand the secondary micro plastics which are basically produced from the breakdown of the larger plastic. For example the plastic bottles plastic sheets etcetera. And typically happens when a large plastic undergo weathering through exposure to different kind of environmental or natural processes like wave action wind abrasion and ultraviolet radiation from the sunlight.

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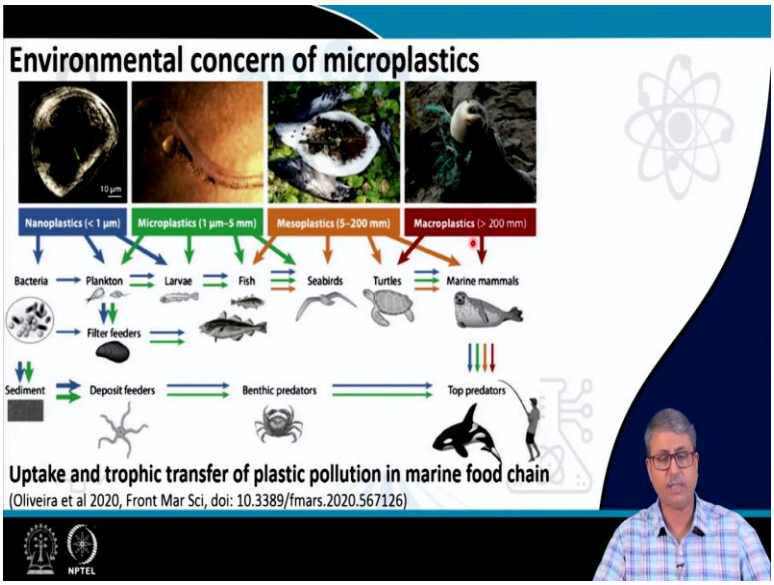

So, now what happens to this microplastic. So, one the plus micro plastics are released into the environment they are taken up by at different shapes like nano plastics to macro plastics are depicted over here. So you can see they can be taken up by the by the natural flora and fauna particularly the animals are found to be including bacteria also the plant towns the different larvae, fish, sea birds, turtles marine element mammals present in the sea they are all capable of accumulating the these micro plastics and they accumulate within themselves.

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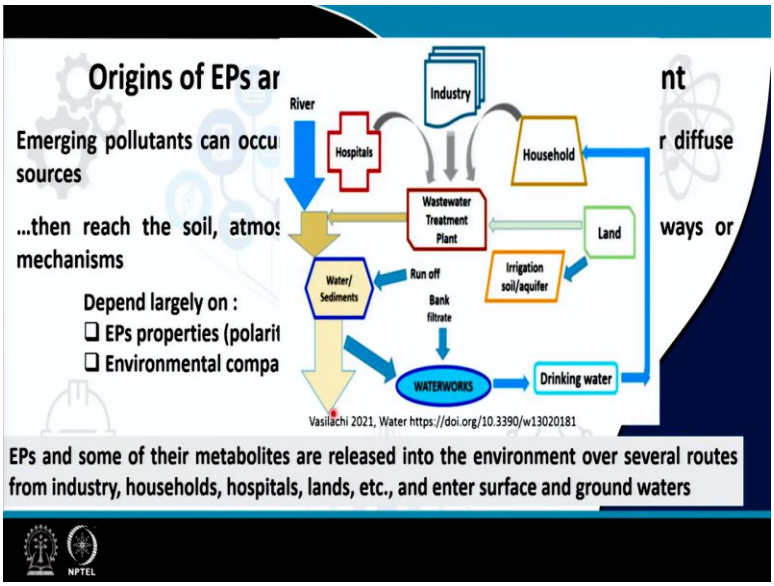

Because these plastics are easily ingested by marine animals because the sea water or the marine environment is reconsidered to be the ultimate sink for all these plastic materials. Because everything every material we dispose of it goes to the rivers and the rivers are taking them

eventually into the ocean. So, they are there moving into the kind of a global food chain. And for example recent statistics are showing that 99% of the sea birds have ingested microplastic and more than 600 marine species almost 15% are exposed to be threatened by microplastic injection or by entanglement in microplastic marine liter by 2050.

Severe, impact on human health intentional blockage, stomach ulcer etcetera because of the consumption of materials contaminated by this microplastic.

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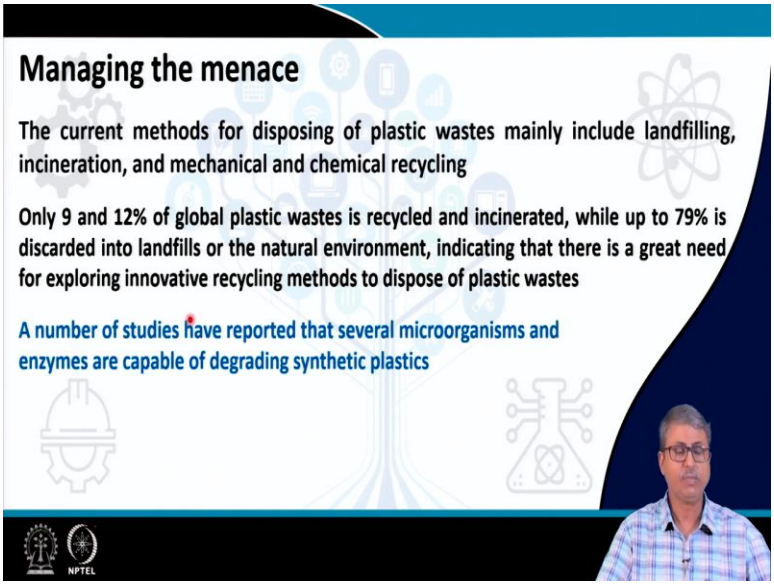

Now how do we control these minerals? Now the current methods for disposing of plastic waste mainly include the land filling incineration mechanical and chemical cycling. However all this physic-chemical process like land filling for example requires a huge land mass and also it allows the compounds to be degraded naturally and then they start leaching and then contaminating the groundwater.

Incineration could produce actually huge amount of the gaseous contaminants and the mechanical and chemical recyclings are also there but they they do have their own and different type of disadvantages. What we observe that only 9 and 12% of the global plastic waste is recycled and incinerated. While up to 79 or 80% is discarded into the landfills or the natural environment indicating that there is a great need for exploring innovative recycling methods to dispose the plastic waste properly.

In last decade if you see a number of studies have reported that several microorganisms and their enzymes are capable of degrading the synthetic plastics.

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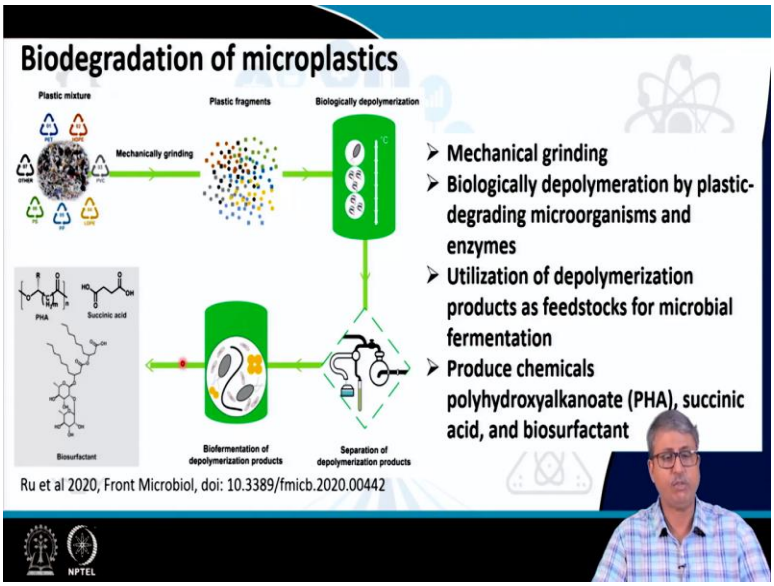

And particularly the bio degradation of micro plastic have been found to be a suitable option because of through this kind of a work flow like mechanical grinding followed by biological depolymerization by plastic degrading microorganisms which can be done under some reactor condition. And then utilization of the depolymerized products as feedstock for microbial fermentation and then produce chemicals like polyhydroxylkanoids like the bioplastic succinic acid and biosurfactant molecules which are having high industrial requirement.

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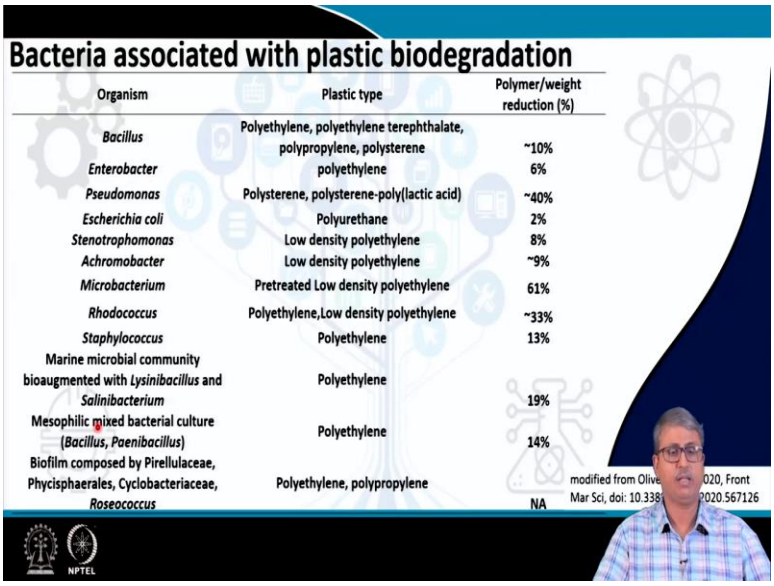

Now these are the well known some of the bacterial strain associated with plastic biodegradation or reported to be efficient or harboring different enzymes capable of degrading the plastics and micro plastics.

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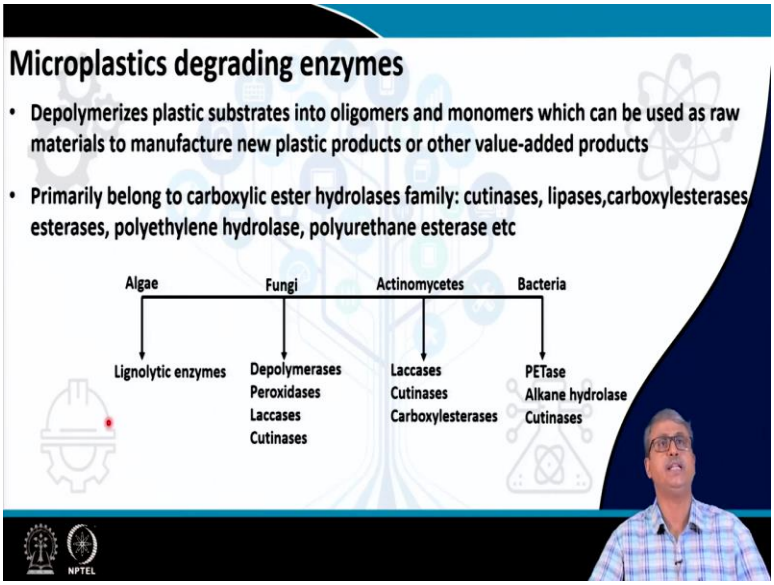

Now these microplastic degrading enzymes basically depolymerizes the plastic substance into oligomer and monomer which can be used as a raw material to manufacture new plastic also. So, it is going towards a kind of a circular economy where we can produce the value added materials. The primarily this enzymes belong to carboxylic ester hydrox hydrolysis family like cutenesses lipases carboxyl esterizes esterizes poly ethylene hydrolase polyurethane esters etcetera.

So, you can see from algae to bacteria the scientists they have found different kind of enzymes which are which are identified to be potent candidate for plastic and micro plastic degradation.

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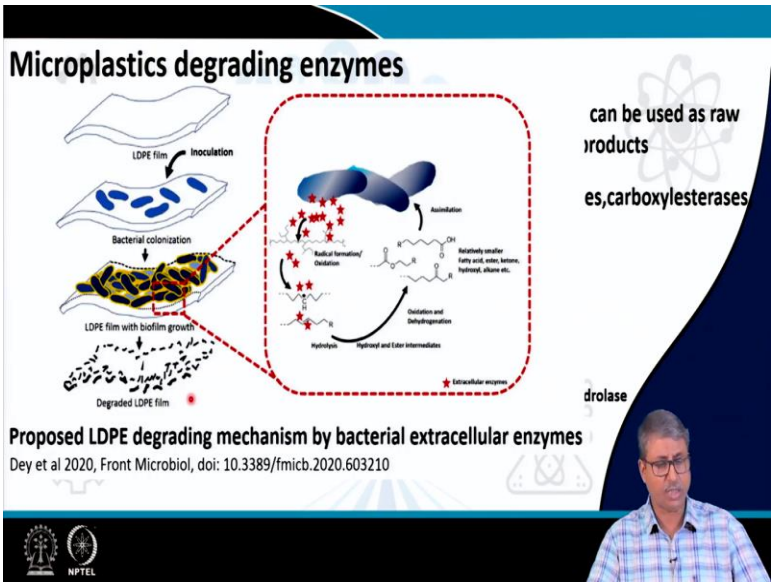

In one of our own studies we have found that the soil and other natural environments might have the bacterial strains which are capable of degrading like LDP biofilm can be or a film can be degraded using the the organisms which present in a natural environment.

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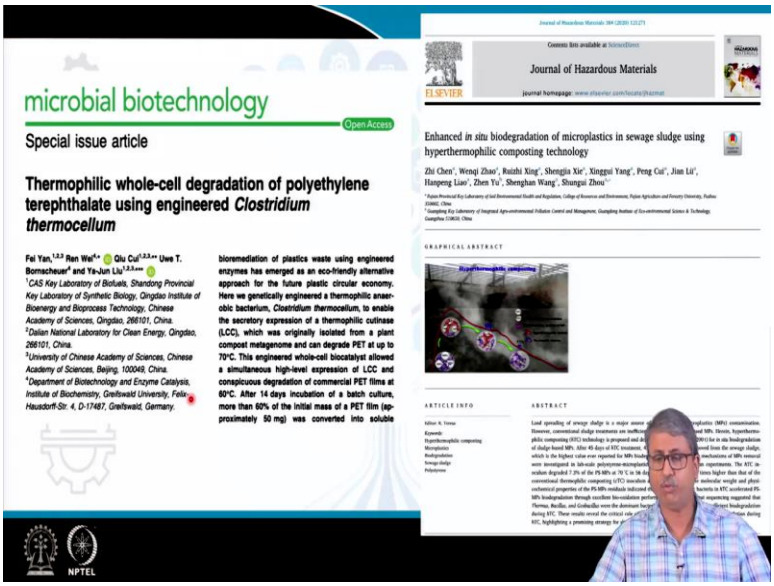

And in recent time while we see that lot of interest is being paid on thermophilic bacteria. Like in this case paper is dealing with thermophiliphinic whole cell degradation of polyethylene

tetratherate using engineered clostridium strain and also the enhanced in situ bio degradation of micro plastic in sewage sludge using hyper thermophilic composting technology.

So, the role of this microorganisms which are naturally able to tolerate high temperature and then also catalyze the required transformation reactions for the plastic and micro plastics are getting popularity both as in situ treatment as well as ex situ the processes.

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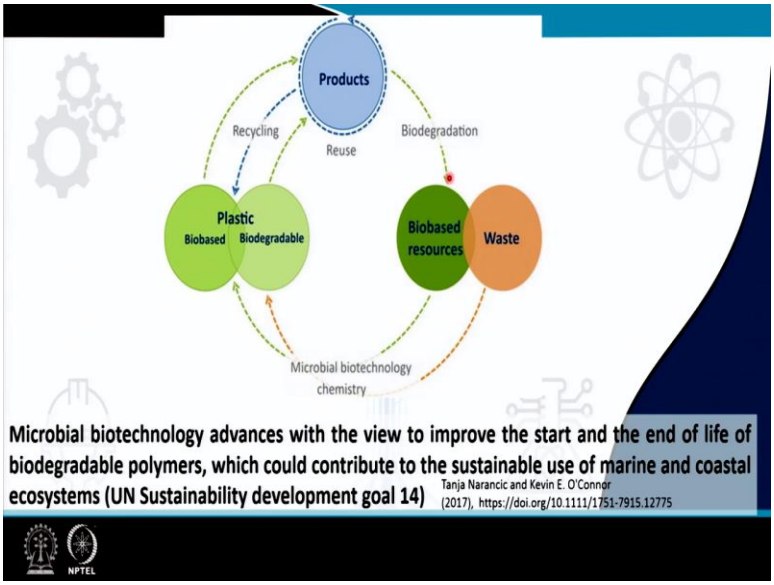

And also we see growing interest on with the environmental biotechnology point of view that to improve the start and the end of life of biodegradable polymers. So, one way this microbial biotechnology is helping us to produce the bio based or bio degradable plastics and towards the products or they can be using the products and producing these molecules which can be further used by the industry.

And on the other hand the products can be only degraded and then some bio based resource can be produced and then the bio is based resource can be utilized for other industries. So, there is a growing interest on this kind of circular economy around the plastic. So, both the plastic management existing petroleum or chemical plastic or synthetic plastic management as well as producing bio degradable or or bio plastic type of compounds as well.

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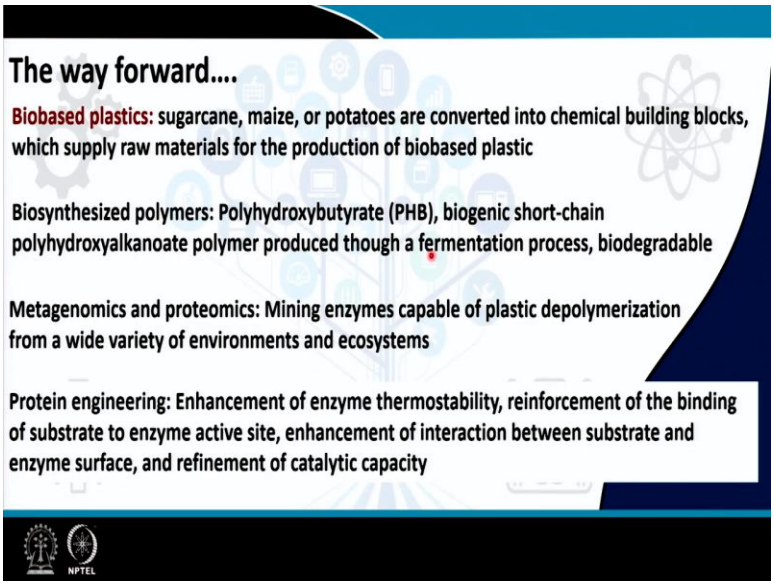

So, the way forward is one aspect is the bio based plastic the other is the biosynthesized polymers like the polyhydroxybutyrate biogenic short chain polyhydroxy alkanoid polymer etcetera meta genomic and proteomic studies particularly. So, helping us to mine different identify different enzymes and genes capable of plastic depolymerization to plastic degradation protein engineering is helping us to enhance the enzyme thermostability reinforcement of the binding of substrate to enzyme active sites enhancement of interaction between substrate and enzyme surface refinement of a catalytic capacity etcetera.

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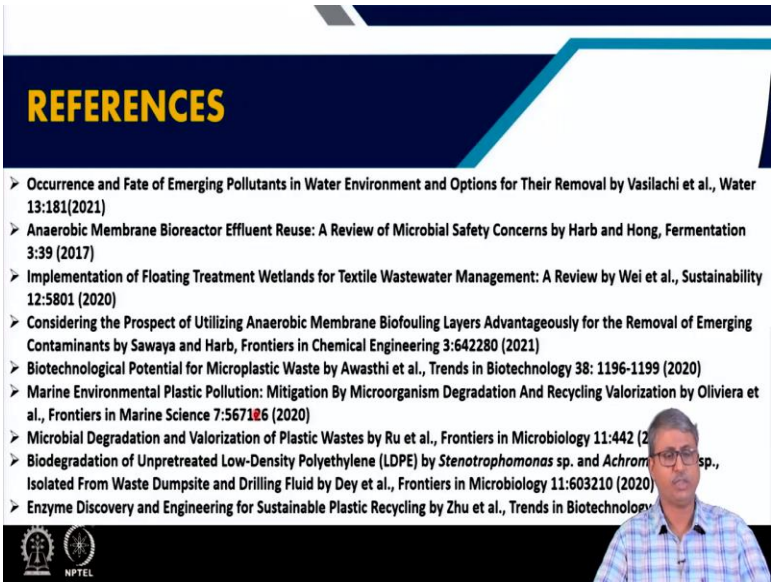

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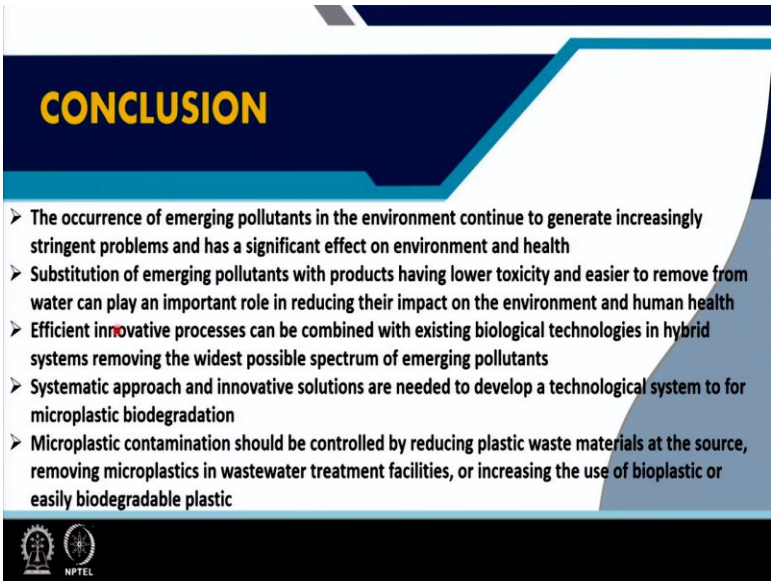

So, for this particular lecture these are the references which can be utilized and I found to be useful and in conclusion the occurrence of emerging pollutants in the environment continue to generate increasingly stringent problem. And it is it is gradually becoming very severe and has a significant effect on the overall well-being of the environment and the health substitution of the emerging pollutants with products having lower toxicity and easy to remove option is found to be a very important or alternative choice efficient innovative processes can be combined with existing.

Biological technologies in hybrid system removing the widest possible spectrum of pollutants emerging pollutants systematic approach and innovative solutions are needed to develop a technological system for micro plastic bio degradation in particular. Micro plastic contamination should be controlled by reducing plastic wet materials at the source removing micro plastic in wastewater treatment facilities or increasing the use of bio plastic or easily biodegradable plastics, thank you.