Energy Conversion Technologies (Biomass and Coal)

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Lecture 30

Concept of integration of energy system

Good morning everyone.

Welcome to this lecture of module 8. In this lecture we will discuss about the integrated energy system. So, the term integrated energy system broadly refers to the system where the energy needs are satisfied by using different energy carriers that exploit the different available energy resources but in an optimal way. In an integrated energy system, the energy carriers and resources are considered as part of one large system where they work together as whole rather than as separate entities. By using an integrated energy approach, energy systems can be made more efficient, sustainable, flexible and reliable. Before we start discussing on integrated energy system, let us first discuss about the evaluation of energy resources and fuels.

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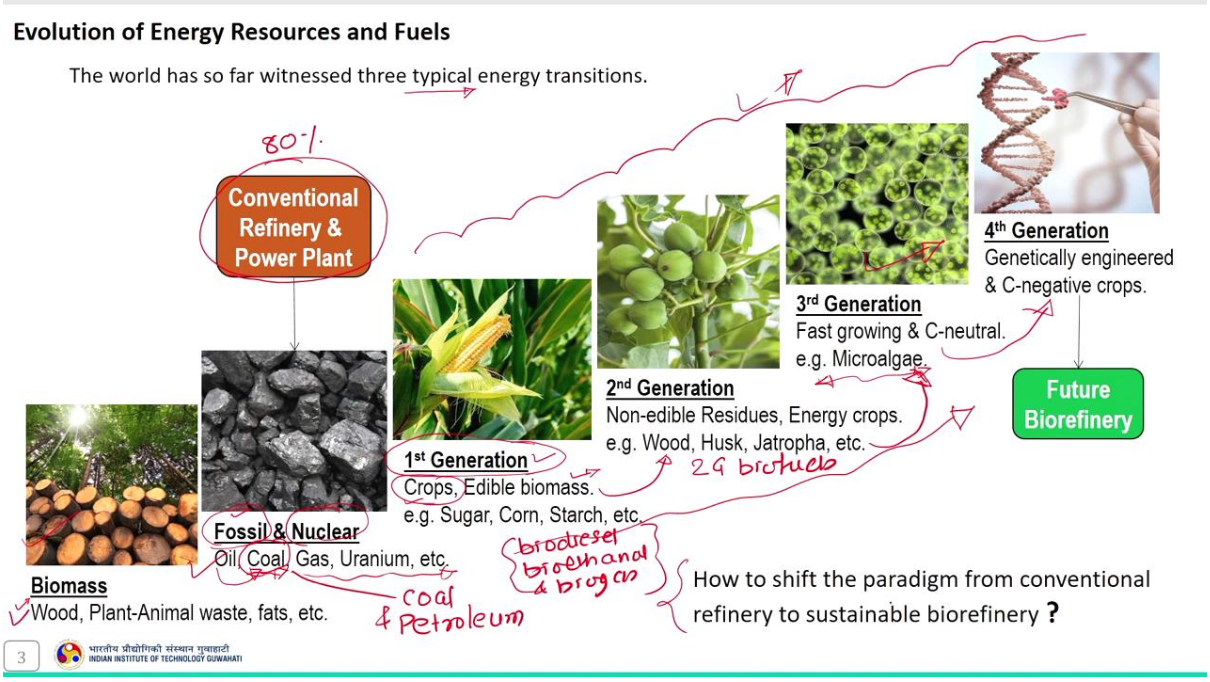

The world has so far witnessed three typical energy transitions. The first transition involved replacement of wood with coal as the main energy source that is fossil and nuclear. In the second transition which took place between the fossil sources, oil replaced coal as the dominant energy resource and in the third transition there is a global commitment to replace fossil fuels with renewable energy resources. In ancient times wood is the most preferred and common source of heat and still being considered as the preferred energy source in rural areas. The energy of flowing water and wind was also used for limited activities. The exploitation of coal as a source of energy made the industrial revolution possible. And this increasing industrialization has led to better quality of life all over the world.

And it has also caused the global demand for energy to grow at a tremendous rate. The growing demand for energy is largely made by this fossil fuel that is coal, and petroleum. And the conversion technologies because if you look at the current refinery infrastructure, so all these technologies are also developed using these energy sources that is the fossil sources mainly the coal and the petroleum. But these fields were formed many millions years ago and there are only limited reserves available. The fossil fuels are even non-renewable sources of energy.

So, we need to conserve these resources so that it can be used for longer run. If we continue using these resources at such alarming rates, we would soon run out of energy and in order to avoid this alternate sources of energy are explored that is the renewable energy sources. So, the first generation energy sources to produce biofuel include crops and edible biomass material and the biofuels which are produced from these sources includes biodiesel bioethanol, biogas which are used commercially. However, the first generation resources explicitly attempt to compete with the food crops. Because if you see the resources which are being used for the production of energy in the first generation energy resources are mostly edible in nature and these particular resources explicitly attempt to compete with the crops for feed.

And because of this concern there is a shift to second generation resources and this second generation resources address many of the issues related to the first generation resources or you can say the first generation biofuels. Although producing 2G biofuels is cost efficient, but there seems to be various technological challenges that need to be overcome before realizing their potential. As a result, algae are at the forefront of the production of third generation biofuel, but massive algae processing also faces technical and logistical challenges. High energy and cost intensive downstream processes remain the primary techno economic obstacles to full commercialization of microalgae based biofuel production. And now the trend of fourth generation biofuel processes that focuses on genetically engineered and carbon negative crops.

Although both problems of fossil fuels and the benefit of renewable energy have been known for decades. Our global consumption of energy has only increased and we continue to get roughly 80 percent of energy from these fossil resources. Thus using an integrated approach an energy system can be made more efficient, sustainable, flexible and reliable. Now, how to shift this paradigm from conventional refinery to sustainable biorefinery?

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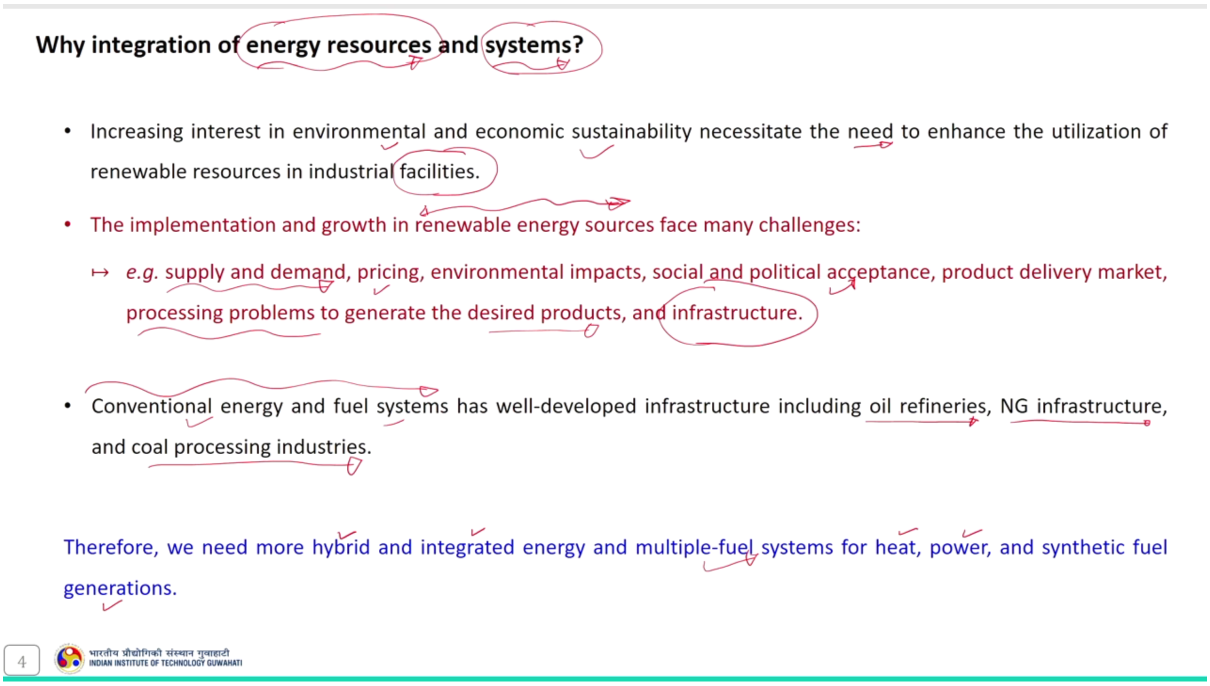

And why the integration of energy resources and systems are essential? Because of the increasing interest in environmental and the economic sustainability it necessitates the need to enhance the utilization of these renewable resources in industrial facilities. However, the implementation and growth in renewable energy sources face many challenges in the form of supply and demand, pricing, environmental impacts, social and the political acceptance, product delivery market, processing problems to generate the desired product and the required infrastructure. And these challenges can be overcome by integrating these renewable energy sources with conventional energy and fuel system. Because this conventional energy and the fuel system has well developed infrastructure including the oil refineries, natural gas infrastructure and coal processing industries. As a reason, it becomes very easy to integrate these renewable energy resources with already existing infrastructure. And therefore, we need more hybrid and the integrated energy and multiple fuel systems for heat, power and synthetic fuel generations. And that is why it is important to integrate the renewable energy resources with conventional energy and the fuel system.

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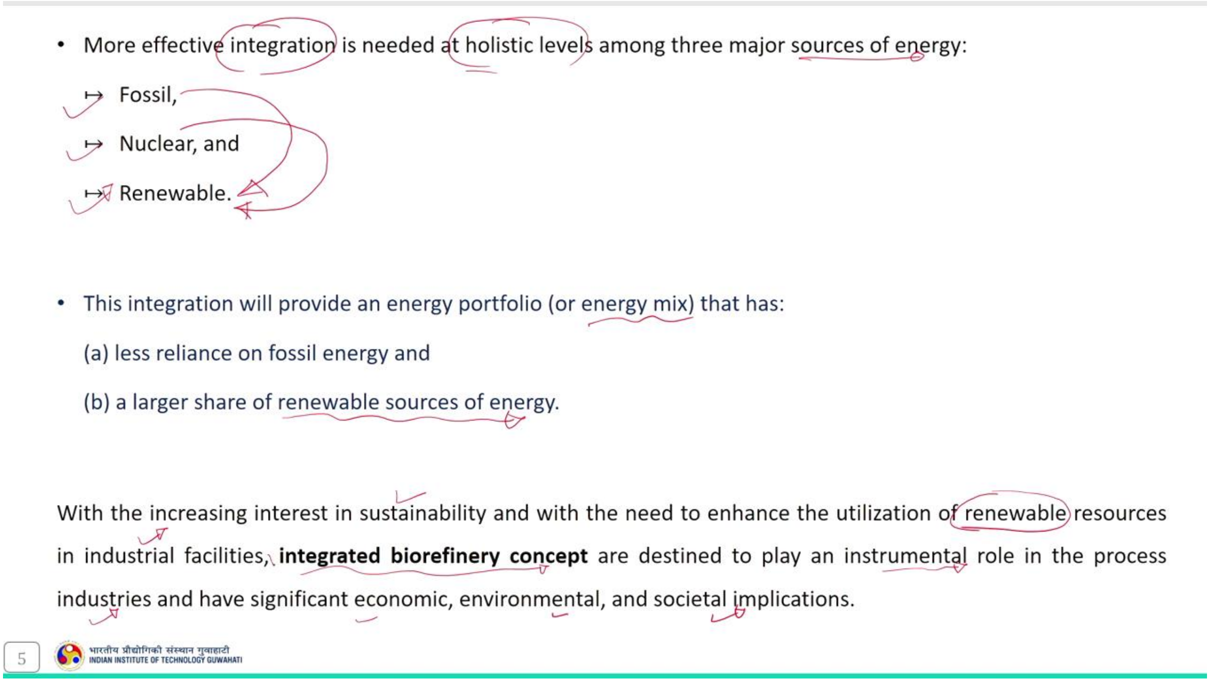

And the more effective integration is needed that is at the holistic level among the three major sources of energy that is fossil resources, nuclear and renewable energy resources. And this integration that is integration of fossil resources with renewable energy resources and the integration of the nuclear resources with the renewable energy resources will provide an energy portfolio. That is also termed as a energy mix that has less reliance on the fossil energy and that also has a larger share of renewable sources of energy. And with this increasing interest in sustainability with the need to enhance this utilization of renewable resources in existing industrial facilities, the integrated biorefinery concept are destined to play an instrumental or we can say a very important role in the process industries and have significant economic, environmental and the societal implications.

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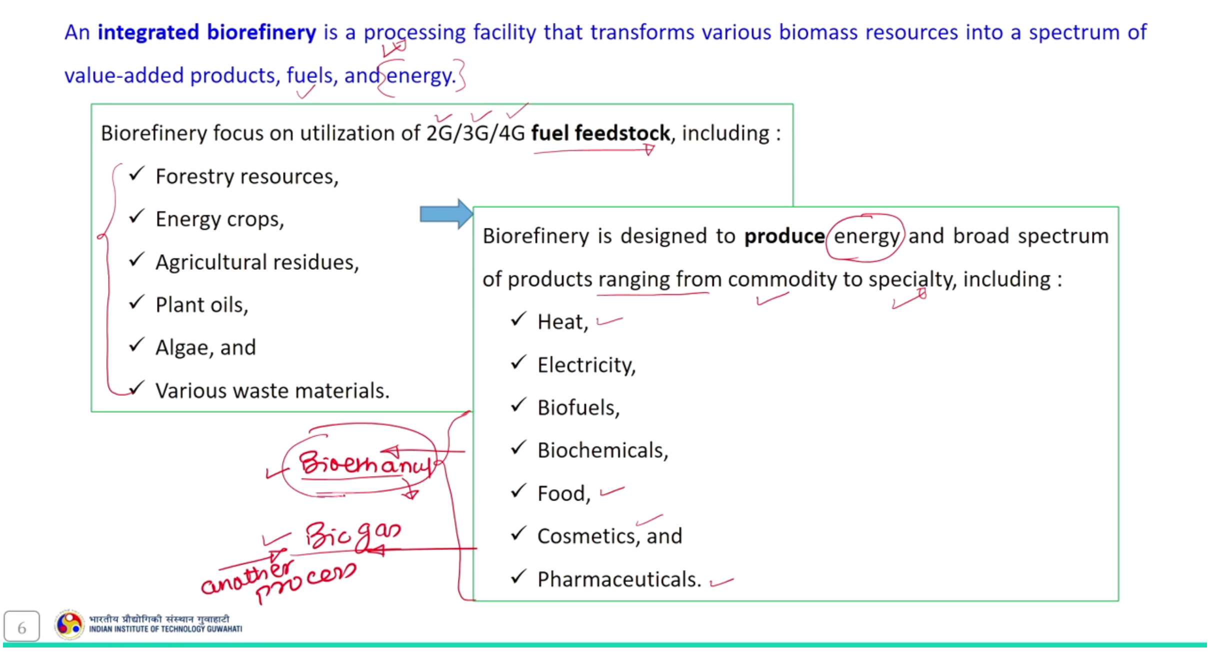

Now, what is the integrated biorefinery concept? An integrated biorefinery basically is a processing facility that transforms various biomass resources into spectrum of evaluated product, fuels and energy. This biorefinery basically is focused on utilization of 2G, 3G and 4G fuel feedstock including forestry residues, energy crops, agriculture residues, plant oils, algae and various waste materials. And this integrated biorefinery are designed to utilize these feedstock materials to produce energy and the broad spectrum of product ranging from commodity to specialty including heat, electricity, biofuels, biochemicals, food, cosmetics and pharmaceuticals. And if you recall our discussion in one of the lecture of module 5, we discuss about combined bioethanol and biogas production. The proper combination of both bioethanol and biogas production processes has been regarded as a suitable strategy to improve the competitiveness of fermentation plants by producing both bioethanol and biogas in a biorefinery concept.

And this is one of the examples of the integrated bio refinery concept and such strategy follows the combination of the material flows of different bio industries. So, that the residue from a bio industry becomes input of another process. That means the residue generated during the fermentation process can act as a feedstock material for another process that is a biogas production.

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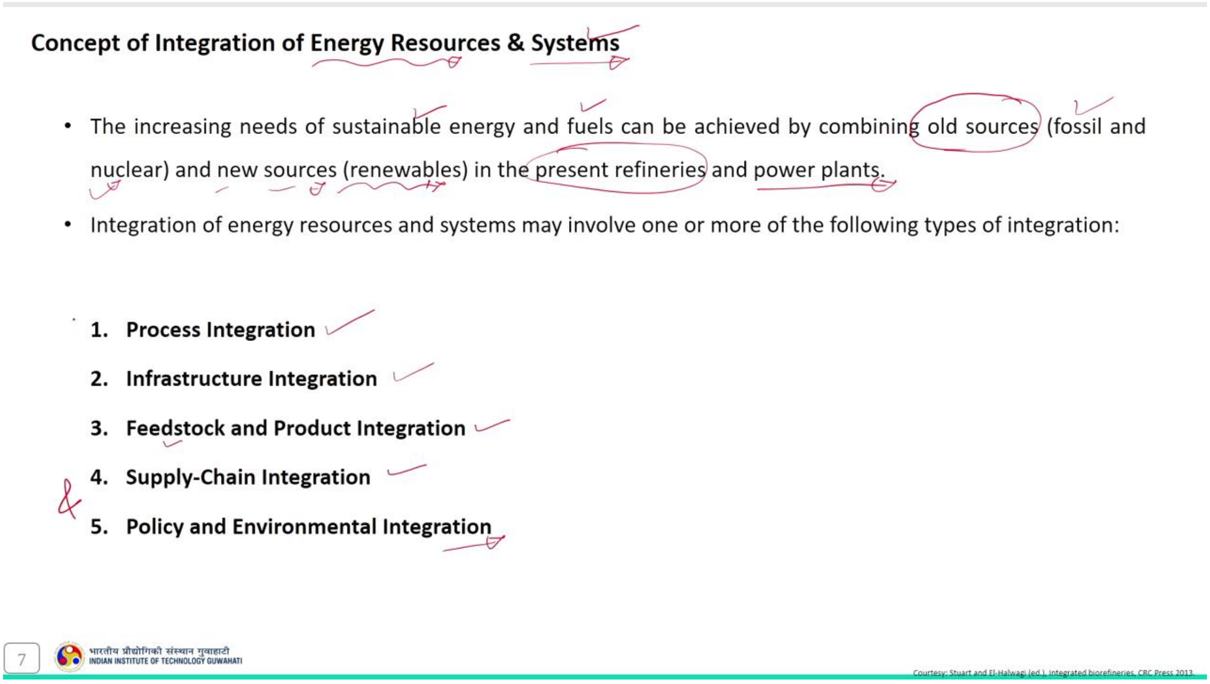

So, now let us discuss about this concept of integration of the energy resources and systems. So, considering the current trend of increasing needs of sustainable energy and fuels as well as considering the present trend of development of non-conventional that is renewable energy resources. It indicates that it has become more important to explore the possibilities to meet growing demand for energy by combining these old sources that is fossil sources and nuclear energy sources, and new sources that is renewable energy sources in the present refineries and power plants. And this integration of the energy resources and the systems may involve one or more of the following types of the integration. That may be at the process level that is termed as process integration, or it may be at the infrastructure level that is a infrastructure integration, even feedstock and the product integration, supply chain integration, and policy and the environmental integration. So, let us discuss about these types of integration one by one.

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1. Process Integration

Process integration refers to the systematic and holistic approach of optimizing the design, operation, and integration of various processes within a production system, focusing on the unity of the process.

It may involve mass and energy integration.

e.g.:

- ✓ Reactive distillation involve synthesis and separation steps in a single operation;
- ✓ Simultaneous Saccharification and Fermentation (SSF);
- ✓ Bioelectrochemical Systems (BES) integrate microbial catalysis with electrochemical reactions to produce electricity or valuable chemicals in the same system;
- ✓ Neste Corporation (Finnish renewable fuels company), uses integrated hydrotreatment technology to convert vegetable oils and animal fats, into green diesel, bio-naphtha, bio-jet fuel, and fertilizers.

So, the process integration here it refers to the systematic and the holistic approach that takes into account all the possible interaction between the various steps of a process and the exploitation of these interaction in order to achieve the minimization of the overall investment cost, higher product yields and efficient process design.

And it may involve the mass and the energy integration, for example, the reactive distillation. So, the reactive distillation basically it involves two different steps in the process that is synthesis that we term it as a reaction stage and the separation that we can term it as a distillation. So, these two steps are combined and converted into a single step operation and that is termed as a reactive distillation. And this reactive distillation is an attractive intensified process unit, because of its many advantages such as an improved chemical process that means it gives higher conversion and the selectivity.

Second is energy savings cost reduction and inherently safer design. So, another example includes simultaneous saccharification and fermentation process. In case of simultaneous saccharification and the fermentation, basically it is a process that combines enzymatic hydrolysis with fermentation, to obtain value added product in a single step. So, here in this case the enzymatic hydrolysis and the fermentation are basically two different steps in a process. And these two processes are combined to convert it into a single step operation.

And that is termed as simultaneous saccharification and the fermentation. Similarly, the bioelectrochemical systems are versatile electrochemical technologies that use microbial catalysts for simultaneously harvesting energy and treating waste water. The Finnish renewable fuels company uses integrated hydro-treatment technology to convert vegetable and animal fats into green diesel, bio naphtha, bio jet fuel and fertilizers. And this is one of the commercial level examples where the integrated hydro treatment technology is being used to convert the waste oils into green diesel, bio naphtha, bio jet fuel and fertilizers as product.

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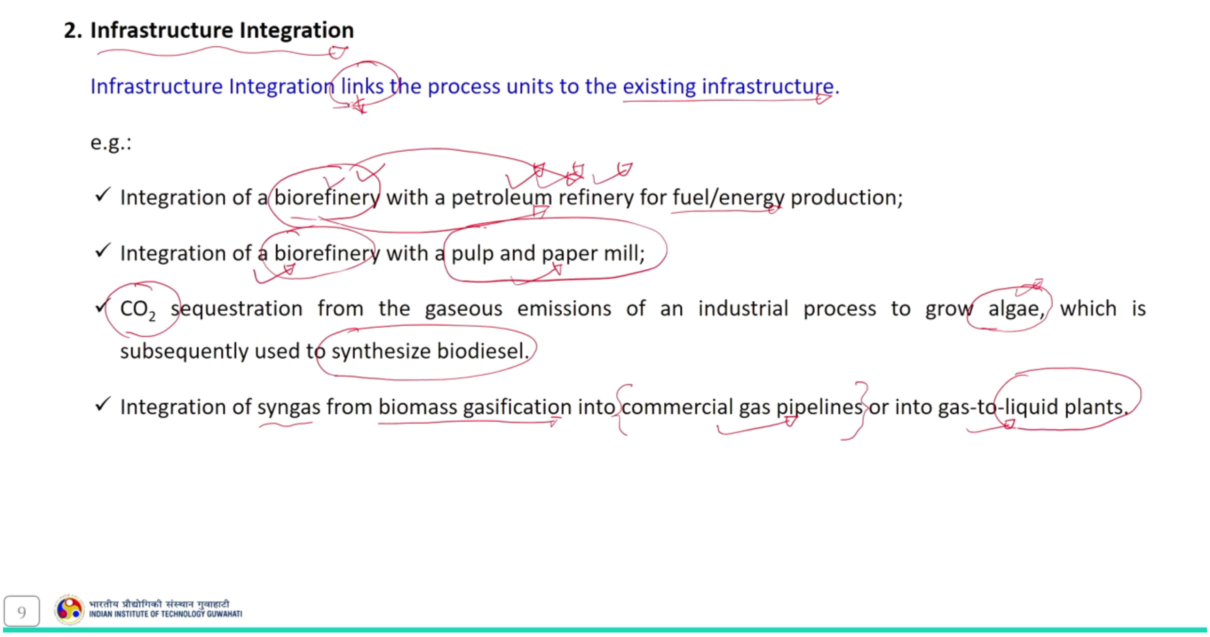

So, the next is the infrastructure integration. Infrastructure integration, it links the process units to the existing infrastructure and example integration of biorefinery with existing petroleum refinery for fuel and energy production. Since the bio-based feedstock is abundant and currently still low in utilization, the biorefinery facility to convert this bio-based feedstock into fuel and chemical is still lacking in competitiveness to petroleum refinery. An attractive solution that addresses both is the integration of this biorefinery with petroleum refineries and that is by linking the process units of biorefinery to the petroleum refineries. And that means the process steps of biorefinery which are not part of the conventional refinery system can be linked to the existing petroleum refineries excluding the common process steps. And that way the biorefinery can be integrated with the existing petroleum refinery system and that is termed as infrastructural integration.

Another example includes the integration of biorefinery with pulp and paper mill. And in the similar line the integration of biorefinery is also possible with pulp and paper mill. Another example of infrastructure integration includes the carbon dioxide sequestration from the gaseous emission of an industrial process to grow microalgae. and the produce microalgae can further be used to synthesize biodiesel. Similarly, the integration of the syngas from biomass gasification system into commercial gas pipelines and that is obviously after the gas cleaning operation or the produce syngas can be used to convert into the liquid product in the gas to liquid conversion system. Likewise, the infrastructure integration is possible by linking the process units of biorefinery to the existing infrastructure or existing refineries.

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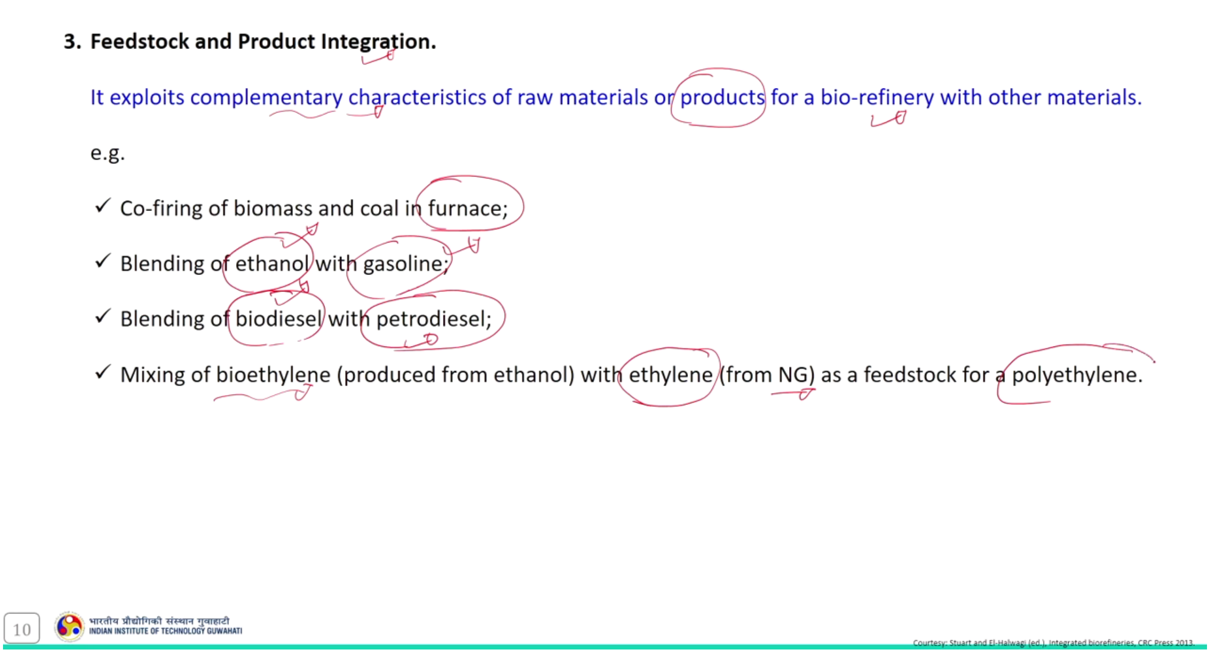

And the next is the feedstock and the product integration. It basically exploits the complementary characteristics of raw material or product for biorefinery with other materials. And example includes the co-firing of biomass and coal in furnace. Another example includes the blending of ethanol with gasoline. Because of the complementary characteristics of the ethanol, it can be blended easily with the gasoline. Similarly, the blending of biodiesel with petrodiesel is also possible, because of the complementary characteristics of the produced biodiesel with petrodiesel. Mixing of bioethylene produced from the ethanol with ethylene from natural gas as a feedstock for the polyethylene. So, this is an integration based on the feedstock and product.

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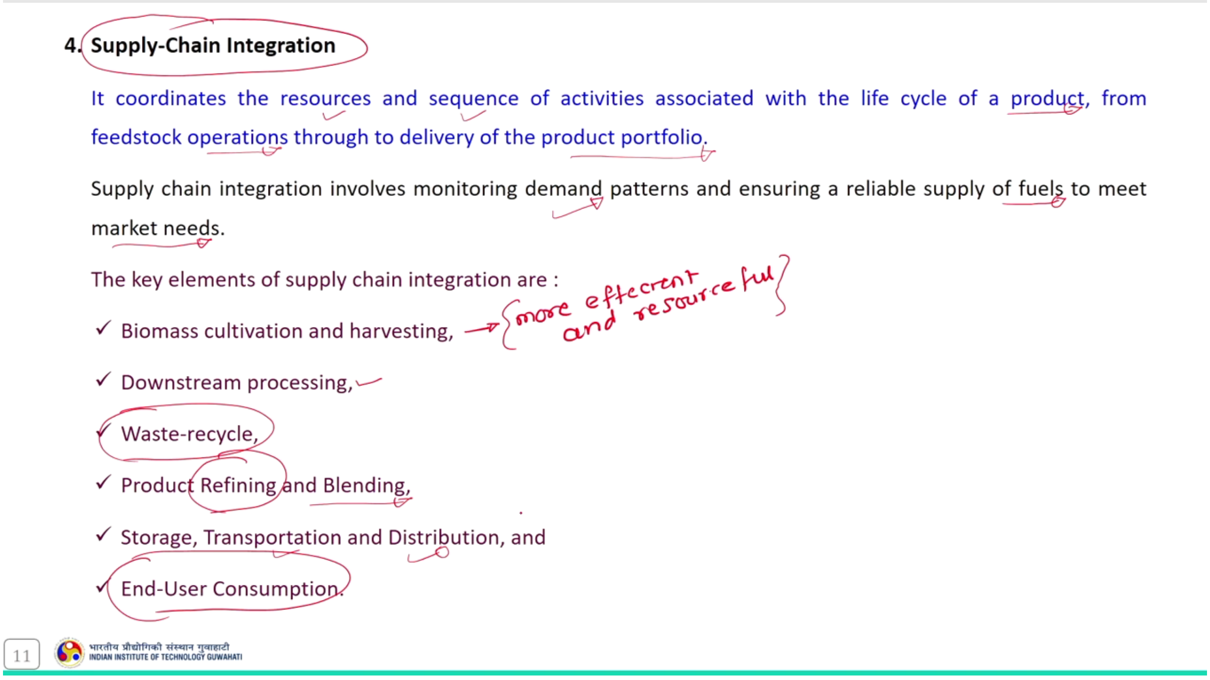

And the next possible integration is the supply chain integration. It basically coordinates the resources and sequence of the activities which are associated with the life cycle of product from feedstock operation to delivery of the product portfolio. And this supply chain integration it involves monitoring demand patterns and ensuring a reliable supply of fuels to market needs. And the key elements of these supply chain integrations are biomass cultivation and harvesting. So, in this case more efficient and resourceful feedstock material need to be cultivated and harvested on regular basis to ensure continuous supply of raw materials.

Next is the downstream processing, waste recycle. So, during the direct process integration these waste streams are recycled or reused or can be used as an input material for another process to generate the useful product. And the key element of the supply chain integration includes the product refining and blending followed by the storage, transportation and distribution. And at the end use to meet the market needs.

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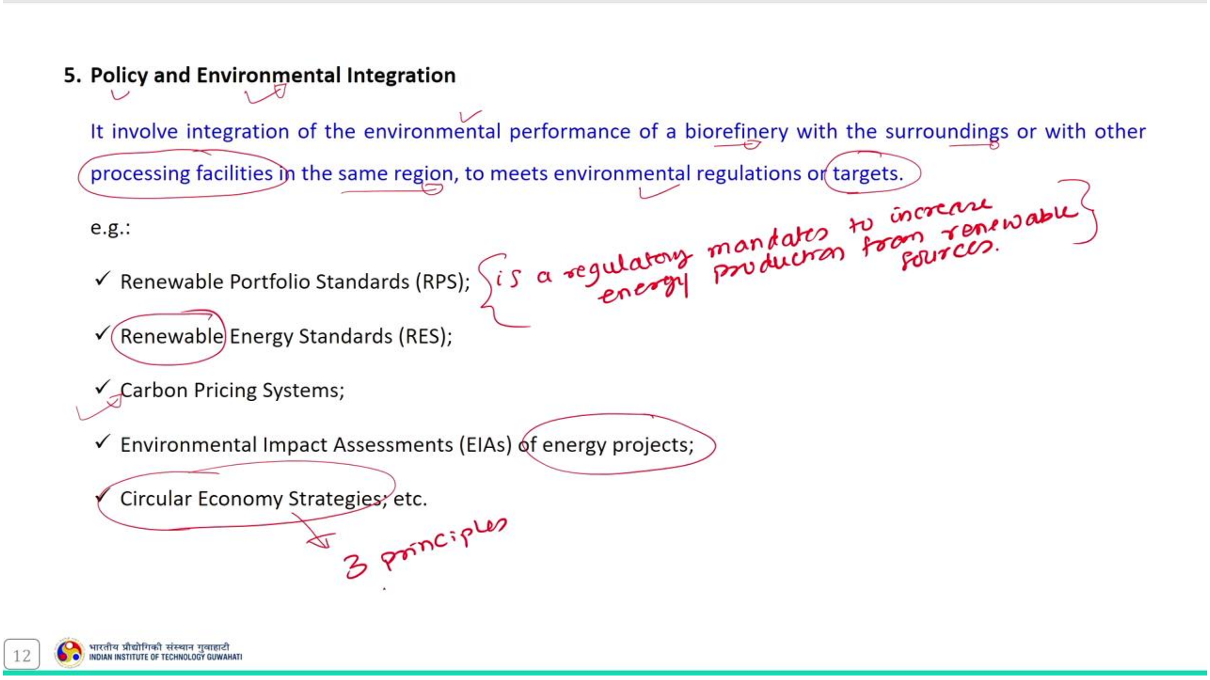

And the next important integration is policy and the environmental integration. And it involves the integration of the environmental performance of biorefinery with the surroundings or with other processing facilities in the same region to meet environmental regulation or targets. An example includes the renewable portfolio standards is a regulatory mandates to increase energy production from renewable sources other than the fossil fuels and nuclear energy. And the standard is also known as renewable electricity standard. So, another example includes the renewable energy standards and in its most basic form is a policy that requires the increased generation of energy from the renewable resources. Carbon pricing system is another example of the policy and the environmental integration, environmental impact assessment of energy projects, and circular economy strategies.

Here the circular economy strategy is a framework of three principles that is the elimination of waste and pollution starting from the design of the product and the services. That means the process should be design in such a way that it will not generate any waste or pollution. Another is the materials and the product to remain in use over time and third is the regeneration of the natural ecosystem.

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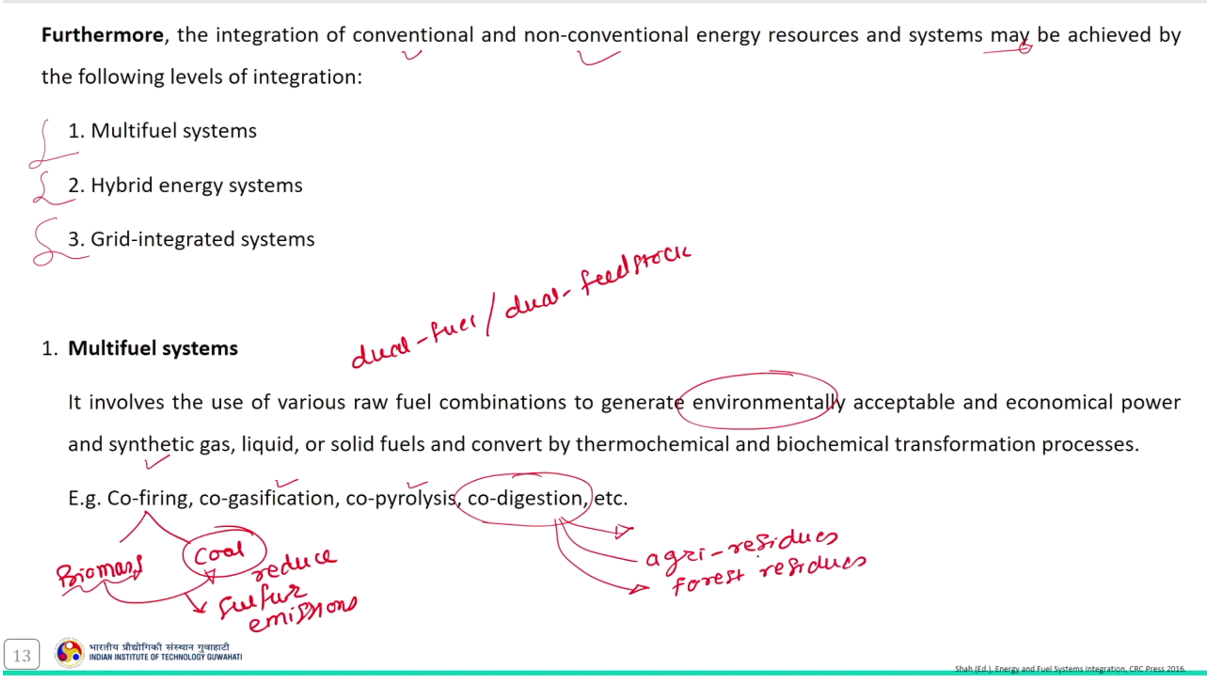

And apart from this, this integration of the conventional and the non-conventional energy resources and the system it may be achieved by using the following integrations that is multi fuel system, hybrid energy systems and grid integrated energy systems. The multi fuel system this is basically approach is often characterized as dual fuel or dual feedstock approach to power and synthetic fuel generation.

With right fuel combination, power and the synthetic fuel can be generated on a large and the sustainable scale with minimum impact on environment, for example, the co-firing. This co-firing it involves using biomass as a supplementary energy source in high efficiency coal boilers. Co-firing of coal in the existing boilers is the lowest cost biopower and the existing coal fired power plants can significantly reduce sulphur emission by involving the biopower technology because biomass has low sulphur content compared to that of the fossil fuel that is coal. As a result co-firing biomass with coal can significantly reduce the sulphur emission. Another example includes the co-gasification, co-paralysis, and co-digestion.

So, in this case the material such as annual manuals can be co-digested with agri-residues or can be co-digested with the forest residues, to improve the process efficiency. So, these are example of the multifuel system.

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2. **Hybrid energy systems**

It involves the use of two or more energy systems in a hybrid combination with or without cogeneration of heat and power to produce one or more products.

e.g. Hybrid nuclear power–biofuel system; → heat, power and synthetic fuel

Hybrid wind power–hydrogen system; etc.

3. **Grid-integrated systems**

It involves the use of a grid approach to holistically integrate the generation and demand of gas, heat, and electricity.

e.g. Integrated hydrogen–natural gas grid;

Power-to-Gas (P2G) Systems (surplus electricity used to produce hydrogen through electrolysis);

Grid-Integrated Energy Storage Systems (such as batteries and pumped hydro storage); etc.

The next is the hybrid energy systems. It involves the use of two or more energy systems in a hybrid combination with or without cogeneration of heat and power to produce one or more products. And example includes hybrid nuclear power biofuel system. In this case the nuclear and or renewable energy systems are combined in a hybrid manner to produce stable, sustainable, large scale, economical and environment friendly operation to generate heat, power and synthetic fuel. Another example includes the hybrid wind power hydrogen system. Next is the grid integrated system.

To some extent the fuel, heat and electrical networks are connected and interdependent and the energy storage also plays an important role on the reliable and the efficient grid operation. In recent years significant advances on the development of natural gas and the electricity grid have been made and recent expansion of the shale gas and other unconventional gases such as biogas, synthetic gas and the hydrogen production have led to further development of the natural gas grid. The old electric grid has been transformed into smart grid which dynamically controls the supply and demand of electricity by highly optimized and centrally controlled operation.

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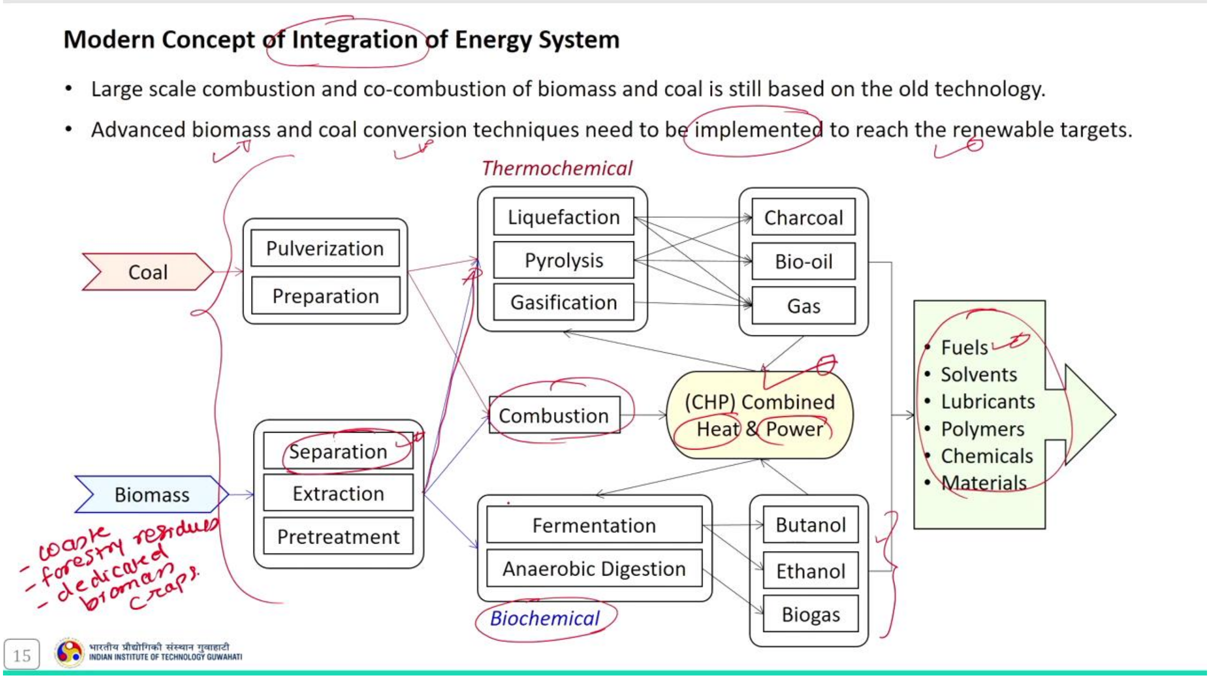

And now this modern concept of integration of energy system include advanced biomass and coal conversion techniques that need to be implemented to reach the renewable energy targets. So, the regional feedstock is supplied to the refinery and it is composed of waste that is a biodegradable waste, forestry residue and dedicated biomass crops. So, after separation into different groups an appropriate method of processing is selected for each biomass and easily fermentable material undergo the biochemical conversion processes while the more resistant material are subjected to thermochemical conversion, or we can say for the combustion operation. As a result of this, an array of the evaluated products such as biofuels or platform chemicals can be obtained and the rest of the feedstock is transformed into heat and power by this combined heat power unit.

And even these produced biofuels and the platform chemicals can further be transformed into useful products such as polymers, the lubricants, chemicals, solvents and fuels. And this schematic here it provides the modern concept of integration of the energy system that is the conventional energy system with non-conventional energy system that is renewable energy sources.

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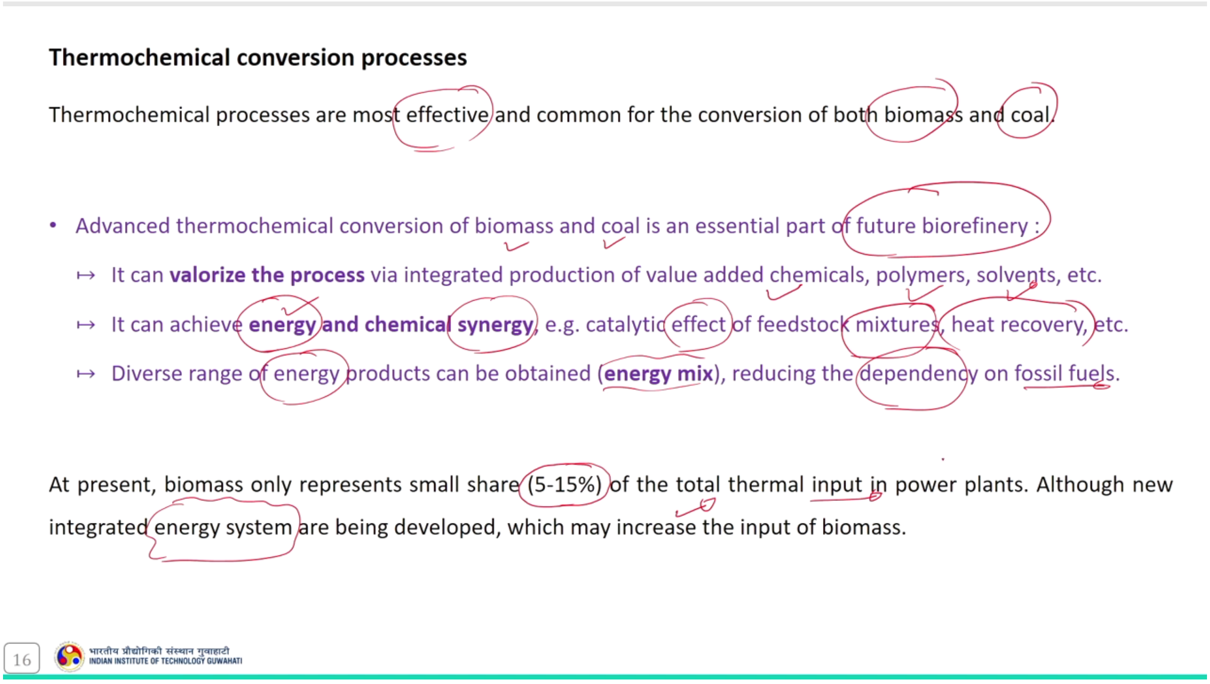

In that this thermochemical processes are most effective. And common for the conversion of both biomass and coal and that is the advantage of integrating the conventional resources with non-conventional resources for production of the energy. An advanced thermochemical conversion of biomass and coal is an essential part of the future biorefinery as well, because it can valorize the process via integrated production of valued chemicals, polymers and solvent.

It can also achieve energy and chemical synergy and example is like the catalytic effect of the feedstock mixtures as well as the heat recovery is the example of achieving energy and chemical synergy in the process. Diverse range of energy products can be obtained that is termed as energy mix reducing the dependence on the fossil fuels. And at present biomass only represent small share that is 5 to 15 percent of the total input in the power plant although the new integrated energy systems are being developed which may increase the input of biomass in the power plants.

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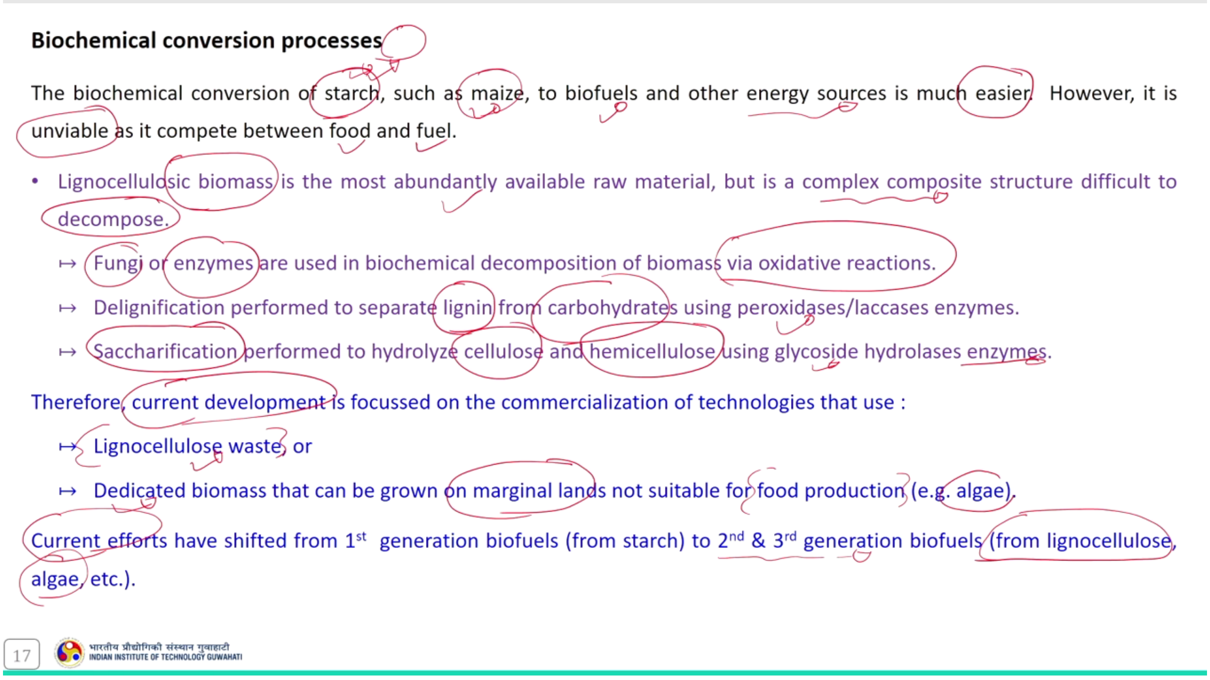

While in biochemical conversion processes that is the conversion of starch such as maize to biofuels and other energy sources is much easier. However, it is unviable as it competes between the food and fuel. And therefore, there is a shift towards the lignocellulosic biomass, which is the most abundantly available raw material, but is complex composite structure and difficult to decompose. And due to which the fungi or enzymes are used in biochemical decomposition processes for the decomposition of biomass via oxidative reaction. Similarly, the delignification operation is also performed to remove lignin. Or we can say separate out lignin from this complex composite structure that is from the carbohydrate using peroxidase or the lypages enzymes. And as we discussed earlier, the saccharification operation can be performed to hydrolyze this cellulose and the hemicellulose fraction present in the complex composite structure using glycoside hydrolysis enzymes.

And because of this reason, current development is focused on the commercialization of technologies that uses lignocellulosic waste or dedicated biomass that can be grown on marginal lands and not suitable for the food production and the example is microalgae. And because of this reason the current efforts have shifted from first generation biofuel, as we discussed here that is example the conversion of starch, to second and third generation biofuel that is utilization of the lignocellulosic waste or microalgae as a raw material for the production of energy.

This is all about the integrated energy sources and system. With this, we will end our module here as well as this is the last lecture of this particular course.

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For the reference purpose, I suggest you to refer the books which are displayed here on the screen. And if you have any doubt regarding this lecture as well as the lectures covered in the previous module, feel free to contact me at vvgood@iitg.ac.in.

Thank you.