Metal Additive Manufacturing
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Lecture 40
Sustainability in MAM (Part 3 of 3)

Hello everyone, this is the third part of the lecture on Sustainability in Metal Additive Manufacturing.

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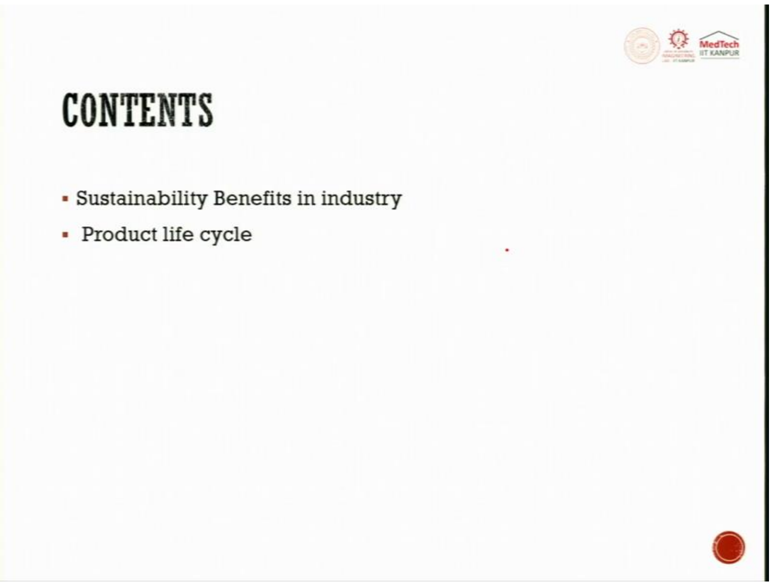

We have discussed about the circle economy and product lifecycle in the previous lectures. We will try to have an elaborated details of product lifecycle in this lecture.

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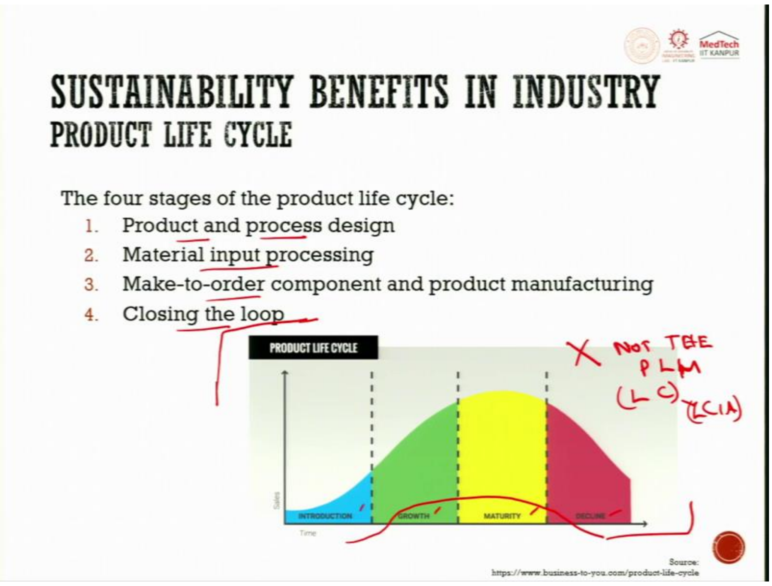

So, to understand product lifecycle, it has four different stages, product and process design, material input and processes, make-to-order and closing the loop. So, it is generally a cradle to grave approach. This product lifecycle is not to be confused, when the product lifecycle that we are talking about in the sustainability or lifecycle assessment viewpoint. This is a marketing product lifecycle in which the product is introduced to the market, then the growth of the sales go then maturity happens and the decline go and the profit is in such a way.

I have only put this graph because this confuses the people. So, this is not I would say cross not the PLM lifecycle. PLM is product lifecycle management or when we try to say lifecycle impact analysis. This is not that lifecycle. This is only the sales of the product.

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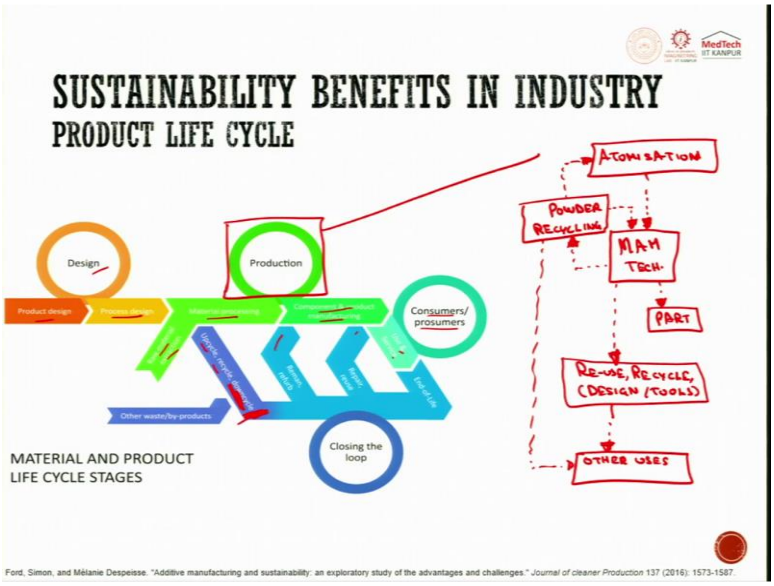

This is the lifecycle that we tend to talk about. Product design, process design is the first step. Then we have production, steel processing, raw material extraction also comes as one because it is cradle to grave from the birth of the child to the final disposal of the body of the child. So, raw material extraction is always there, material processing, component product manufacturing that is the part in the production.

Then we have the consumers or prosumers, which use and service the product, then end of life. And it is a closed loop, always repair and reuse through the consumer itself or the remanufacturing or refurbishment through the manufacture or sometimes the recycling that is the upscale recycle or down cycle the systems from the material processing itself.

So, in the production phase of this cycle, if I take an example of the additive manufacturing, suppose if I try to make this as larger like a bigger circle, the first step is automatization.

Automatization transports the material to the metal additive manufacturing technology or the system I would put technology here. So, it transfers the material.

So, I will just put a dotted line here. So, this technology produces the component I would say the part is produced here, which is taken from this technology. Now, what does the sustainable system or the lifecycle impact analysis suggests that recycling, repair, reuse has to happen that is from the manufacturing technology is as it went to the remanufacture recycle here and down cycle was here is a down cycle we have.

This could go from the technology to the powder recycling as well. I would put powder recycling, powder recycling could take inputs from the rapid manufacturing instruction technology only and this can further helps to provide input to the optimization process once again. These are all inputs.

Make sure that the arrow has the right pointing head. From here the metal additive manufacturing also would reuse, recycle, the design or tools both and this can go again as an input to the other industrial uses. I will put if the design is optimized for one process, the similar this optimized design could be used as an input to the other process. So, these other processes take inputs from reuse and redesign.

These can also take input from the powder recycling, the recycled powder could also be used in the other processes. And the recycle powder could also give inputs to the current technology, maybe the powder fusion process, but we are using. But this is a production process that while putting an example in the metal additive manufacturing, how does it help to get the technology from here.

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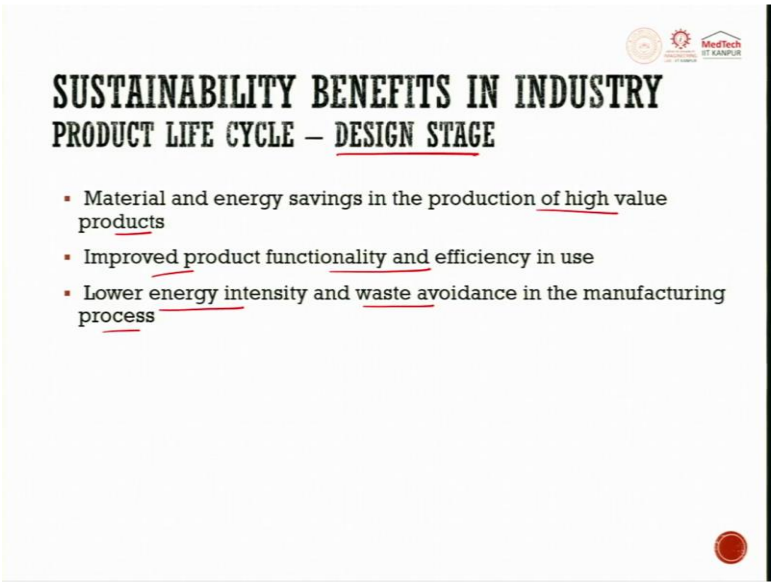

So, when we try to see the product lifecycle and we try to see the different stages of product lifecycle divided into three major stages. In the design stage, the material and energy savings in the production of high value products is the major contributor in having the sustainable products. Improved product functionality and efficiency in use is instituted during the design phase itself. Lower energy intensity in waste avoidance in the process is taken care of.

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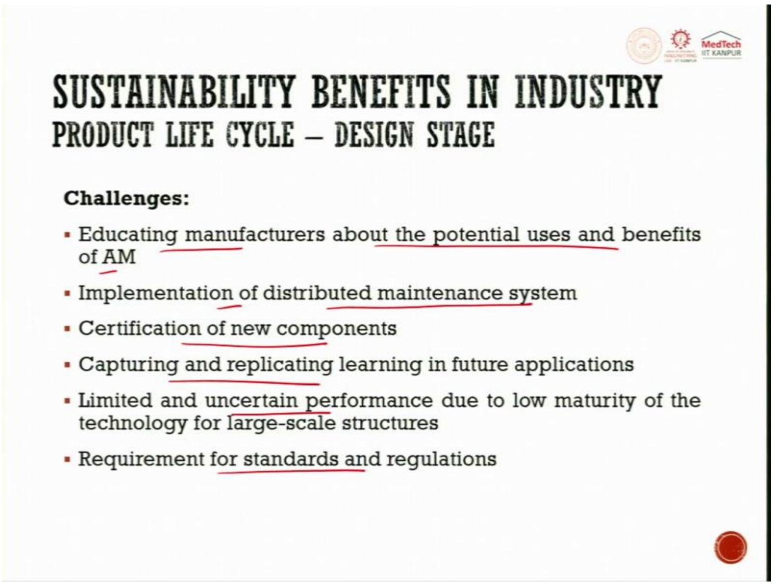

During the design phase itself, there are certain challenges like educating the manufacturers about the potential uses and benefits of additive manufacturing. Then we need to implement the distributed maintenance system and certification of new components. Then capturing and replicating learning in future applications.

Then limited and uncertain performance due to low maturity of technology for large scale structures, requirement of standards and regulations. So, in the design stage, we do not have the specific lead, design standards as they are anticipating restructuring diocese tenders are still missing major of the clauses which are very important to design the additive manufacturing component in a legitimate manner in a great manner.

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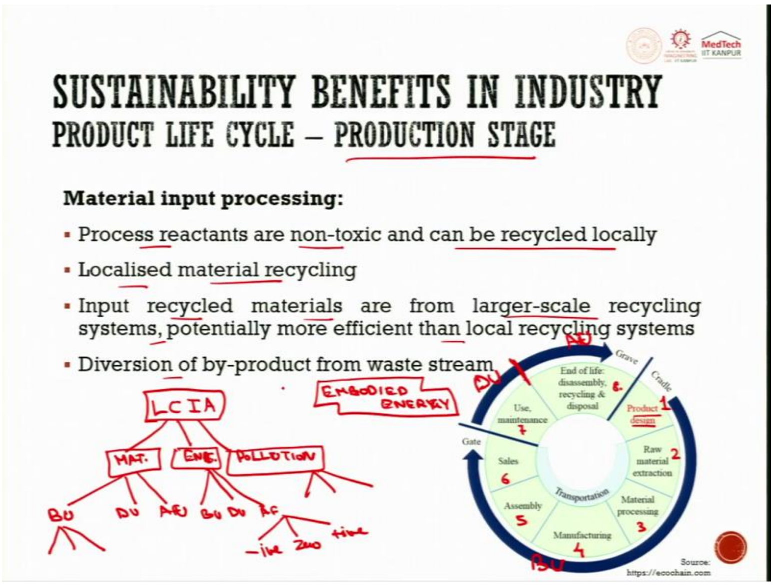

So, when I talk about the design stage, the next stage obviously is the production stage. You can see this graph in the cradle to grave starts from the product design to though it is a running system only, so this becomes step one. Then raw material extraction, the material processing, then manufacturing, then assembly, then sales. So, this is from cradle to gate, it has given 6 processes.

From the gate, it goes to the user then users uses and maintain. So, this becomes my seventh step, then end of life is the eighth step. So, when I put my material, there are certain again I will put the sustainable impact analysis. I would say I will just put impact analysis I am not putting life. I will put lifecycle impact analysis only. To have this the three dimensions are material, energy and pollution.

All these three stages are studied for during use, before us and after the use of material. Before use I would say before use, during use, after use. Before use means the material how is it extracted? During use means when you are producing it how is it being produced? After use means once we have used it after use, how is it is affecting the environment, whether the material is wasted or not that energy during use before use and after use.

Before use the energy, how is the material got, what is the machine manufacture of, what is an embodied energy in the machine. Embodied energy I will put it as a term, to manufacture each component, there is an energy that is consumed that is known as the imported energy of that product or part or component.

Similarly, for pollution, we have three nodes again. In these three nodes, it could be impact, impact could be positive, negative or zero, whether the impact is positive for example, in this if I put after use impact of energy, is it giving energy, is it zero, is it positive or is it negative? So, this is one of the ways when you try to see the before, during and after use. So, this is the use phase. So, this is the before use phase. This is during use phase.

All this is the before use phase from cradle to grave and end of life is after use phase that is how you will dispose it off, what is the energy that is being consumed. So, if suppose, coal is to be disposed of sometimes it is reused the energy becomes positive here. So, material input processing in the production stage, product process reactants are non-toxic and can be recycled locally. This is one of the important factors.

Localized materials recycling is taken care of. Input recycled materials are from larger scale recycling systems and potentially more efficient than local recycling systems. Diversion of a byproduct from waste stream is to be taken care of.

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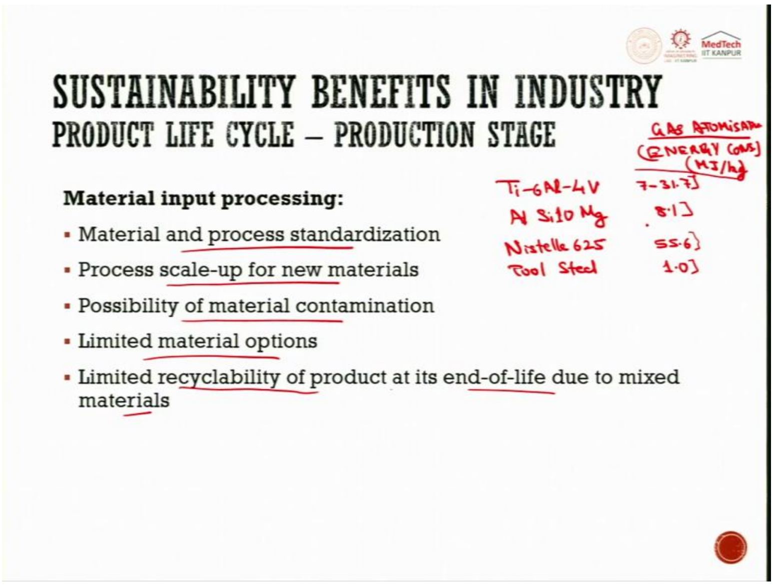

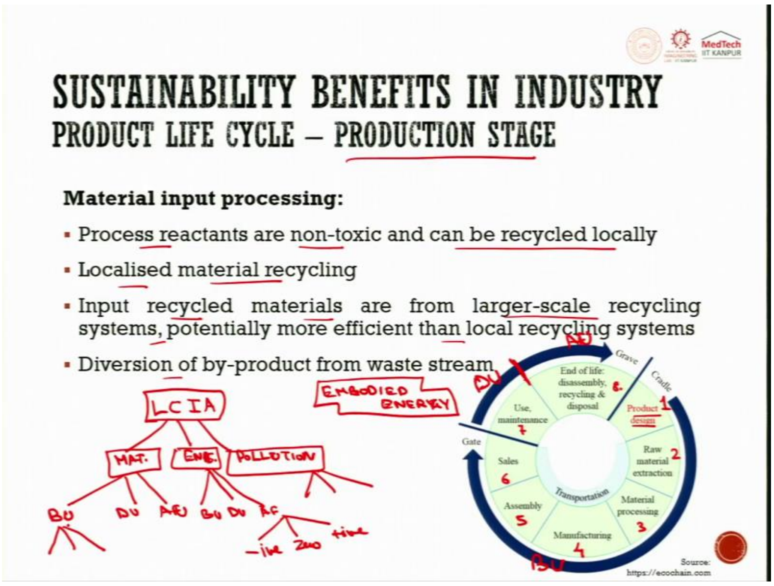

So, material input processing, material and process standardization, process scale-up on your materials, possibility of material contamination, limited material options, limited recyclability of product at its end of life due to mixed materials. When I talk about material input processing, again the data given by the same paper or the same publications by Liu et al.

They say for the different material like Ti-6 Al-4V and an aluminium alloy Al Si 10 Mg. Then there is a turbine blade alloy Nistelle 625 and tools steel. They have given the energy consumption at the gas automatization stage only at gas automatization stage the energy consumption. So, it is given that the energy consumption for titanium is around 7 to 31.7 of mega joules of energy per kg of the metal powder production.

So, it depends upon the process parameters, here 7 to 31 kg it is given a range. Then for the aluminum alloy, it has given 8.1 mega joules per kg. For this turbine blades alloy it has given 55.6 and for the tool steel it is given 1.0. So, this energy becomes our energy input here before use. Before use energy material input in energy here the second part here, I will put 1, 2, 3 in the second part energy before us that is even when it is not used to produce the powder only. So, this is having the maximum energy this alloy. This is an input to the impact analysis.

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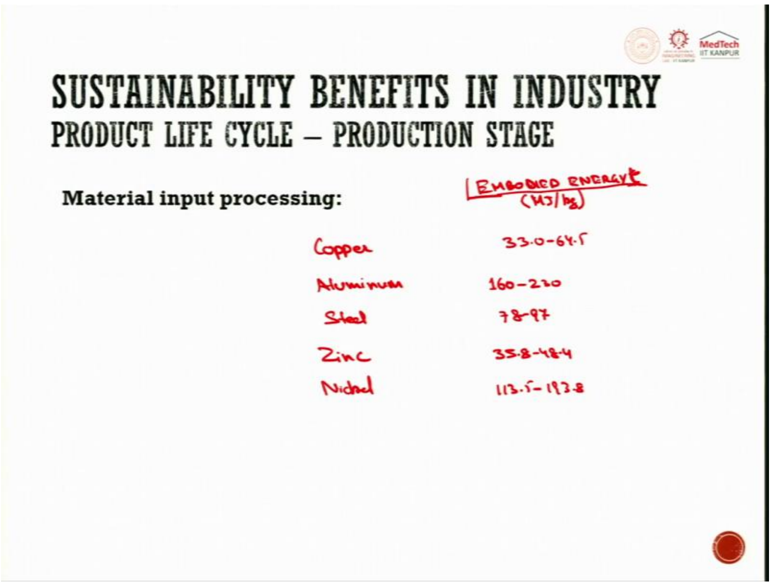

So, in the material input processing another data set that is provided in the same publication, they have given the embodied energy in metal powder materials. For example, the materials that have given are copper, aluminum, steel and zinc along with nickel. So, it is given the energy that is embodied energy in mega joules per kg. This energy is maximum for aluminum, which is in the range of 160 to 230 mega joules per kg.

It depends upon the material, how the material is extracted, how the material is then processed, extraction of the ore, the ore extraction process, then the treatment of the ore all these processes contribute. And the minimum energy that is given for is copper 33.0 to 64.5 mega joules per kg in between the zinc is there 35.8 to 48.4 mega joules per kg. We have steel that varies from 78 to 97 of the units and the nickel varying from 113.5 to 190 3.8 mega joules per kg.

This is the important energy this is the material input that is there. So, this should come in the initial phase even before the production when we get the material. If we try to see the lifecycle impact analysis, the energy of the material that is taken into account and bonded energy, how the materials in itself have their energy that becomes an input to the lifecycle impact analysis.

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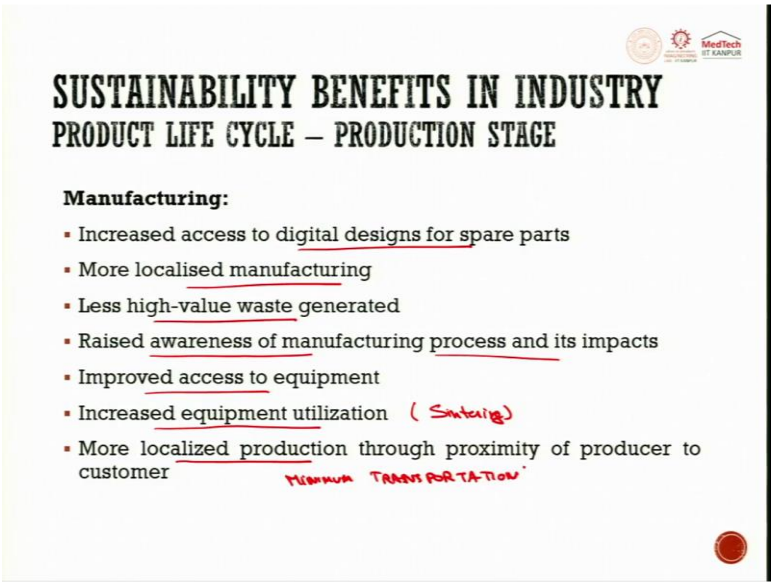

Now, in manufacturing increased access to digital designs for spare parts is more important, more localized manufacturing, less high value waste generated, raised awareness of manufacturing process and its impacts, improved access to equipment, increased equipment utilization. Equipment utilization, the example that we quoted was the sintering. More localized production, so, that minimum transportation.

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Now, in manufacturing if we try to compare the different steps in manufacturing. For example, the four steps how do they draw and time shared in the fabrication stages. So, let me say the first step is preheating, same researchers give the comparison or the study of the power consumed and the time shared, it has taken in the power.

The laser scanning, then powder spreading and cooling down and cleaning. It is given that power in kilowatt hour for the cooling down system is minimum that is 0.7 kilowatts, then we have the pre-heating system that is 2.25 kilowatts. Then we have the laser scanning that is 3.25 and then is the 3.45 that is for the powder spreading.

The timeshare for the stages that how long these stages took the time. So, laser scanning took the maximum time that is 68 percent of the time I will put it timeshare, preheating took 12 percent, powder spreading took 5 percent and cooling down took 15 percent of the time. This is in metal additive manufacturing how the things change putting a specific case here we have taken the data and try to see that how do we put the indicators or different parameters, while calculating the impact analysis.

There are certain models that could give us the impact analysis like we have given life cycle practice analysis equivalent to the lifecycle costing, plus lifecycle analysis plus sustainable life cycle analysis. It is further divided into certain equations. It could also be seen if you wish to study, we will provide those in the references.

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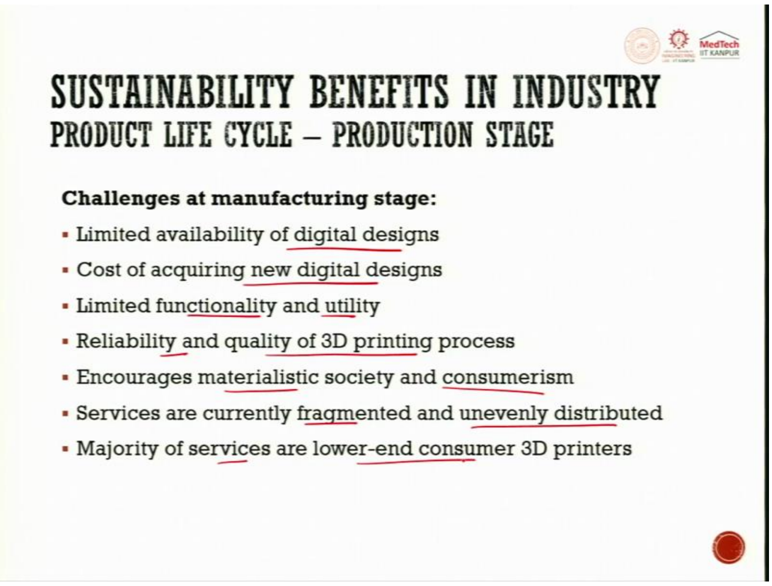

Next, there are certain challenges in the production stage, that is limited availability of digital designs are there. The cost of acquiring new designs is always a challenge, limited functionality and utility, reliability and quality of 3D printing processes. This also encourages the materialistic society and consumerism.

Because the more and more we could produce more and more new and new designs come to consumers, keep on trying to get newer new designs, people like to have their customized mobile cover. People would like to have their specific redesigned components or the key rings for them for example. Then services are currently fragmented and unevenly distributed. Majority of the services are lower end consumer 3D printers only.

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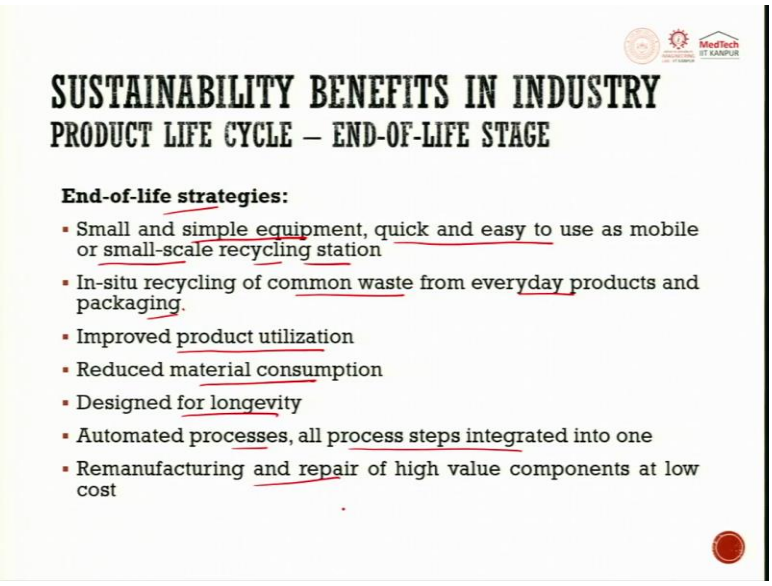

In the end of the life strategies, small and simple equipment, quick and easy to use as mobile or small scale recycling stations. Recycling stations are always suggested. In-situ recycling of the common waste for example, the powder, the support material, if that could be recycled once again. Everyday products and packaging, everyday means the routine products in the metal additive manufacturing.

Improved product utilization, produced material consumption, designed for longevity. Automated processes - All process steps integrated into one. Remanufacturing and repair of high value components at low cost.

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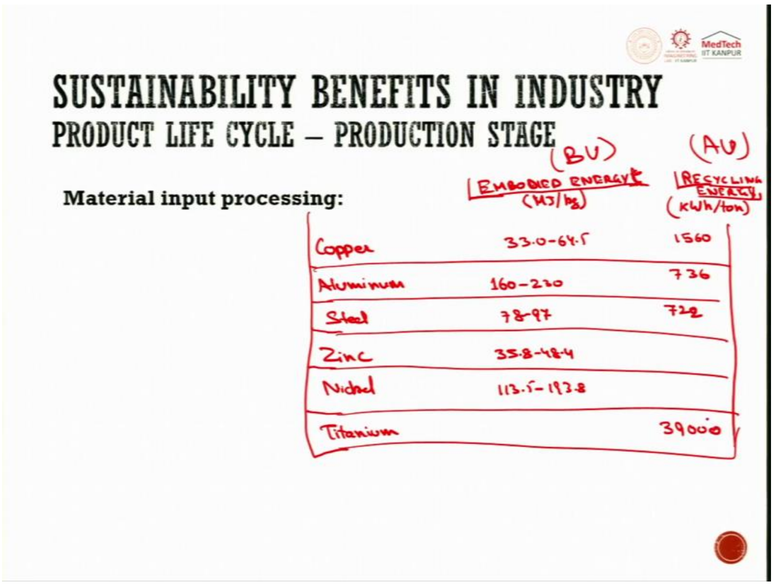

There are certain challenges like limits on recyclability of material due to quality loss, educating consumers about recycling of 3D printing materials, about recycling of the treatment materials, I will have to put the data on the same table, where the material is where they are and the embodied energy is there this is before use, let us put something that is after us.

This is before use I would say and after use that is the energy consumption for recycling energy. This is also given in the energy per unit weight, but the units here are kilowatt hour of energy per ton. So, for the copper the energy that is given is 1560 kilowatt hours per ton. For the steel it is only 722 because steel is easy to recycle it gets rust easily.

So, it is easy to convert into a new shape. Then for aluminum it is given as 736. One data point is also given for titanium. For titanium as we all know the melting pot is quite high. So, the energy for recycling of titanium, the machining, the production of titanium powders, it is very high. The energy for recycling here is 39,000 units. So, this is how the things differentiate.

Titanium has its own application in medical devices, in aerospace and because of the high strength to weight ratio, it is used for the critical components and it is having the bio friendly nature as well. So, it is a biomaterial, it can be used for the implants of the body, but see how heavy the energy consumption is there. So, this is what is being mentioned here about the recycling of the 3D printing material, what is energy consumption.

And replication of business model to other sectors is also important. Limited integration of additive manufacturing with other techniques in design and production and required mindset shift for designers and engineers. With this my lecture series on sustainability in metallurgical fracturing finishes.

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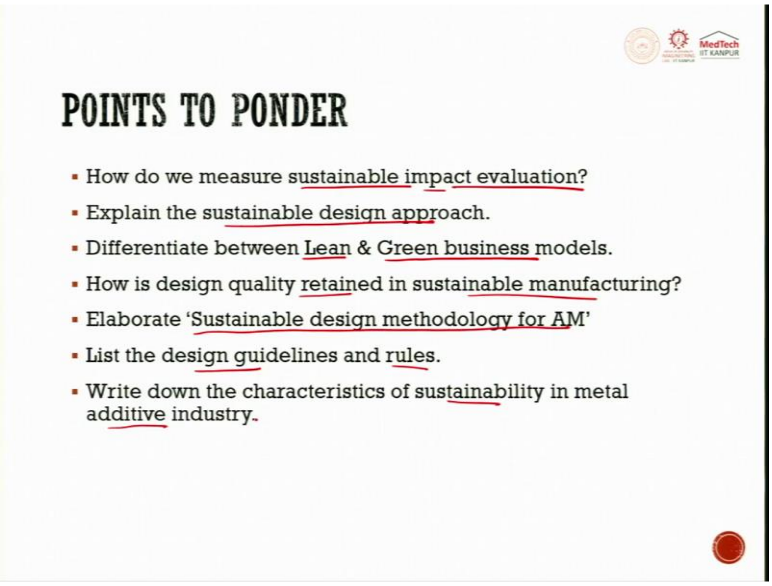

The major things that we have discussed and that you should find out the points on are how do we measure the sustainable impact evaluation? Try to see. Explain the sustainable design approach, differentiate between the Lean and Green business models, what is a synergy between both of them, how do they go hand in hand, what is environmental value streaming, how is designed quality retained in sustainable manufacturing.

Elaborate sustainable design methodology for additive manufacturing. The design guidelines and rules, try to look at them once and list them. Write on the characteristics of sustainability in metal remanufacturing. One example that is quoted, that could also be taken. So, you can take your own time and try to understand the lifecycle impact analysis.

This was a brief introduction to sustainability, green manufacturing, it means the concepts of lean manufacturing, green manufacturing, circular economy, lifecycle assessment, lifecycle impact analysis were studied. In this the major concepts of the lifecycle impact analysis, the design for green manufacturing, then the various steps in the lifecycle assessment, then consumer economy. All these concepts were studied. So, let us meet in the next week. We will have further discussion on the metal additive manufacturing. Thank you.