Metal Additive Manufacturing
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Lecture 01
Introduction to Metal Additive Manufacturing

Welcome to the course on Introduction to Metal Additive Manufacturing.

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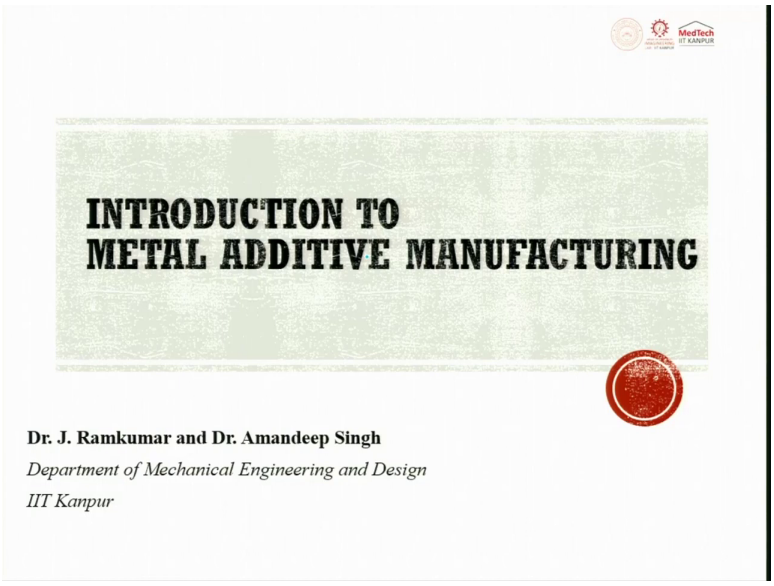

This course will be jointly done by me and Dr. Amandeep Singh. I am a professor with mechanical engineering department and design program at IIT, Kanpur.

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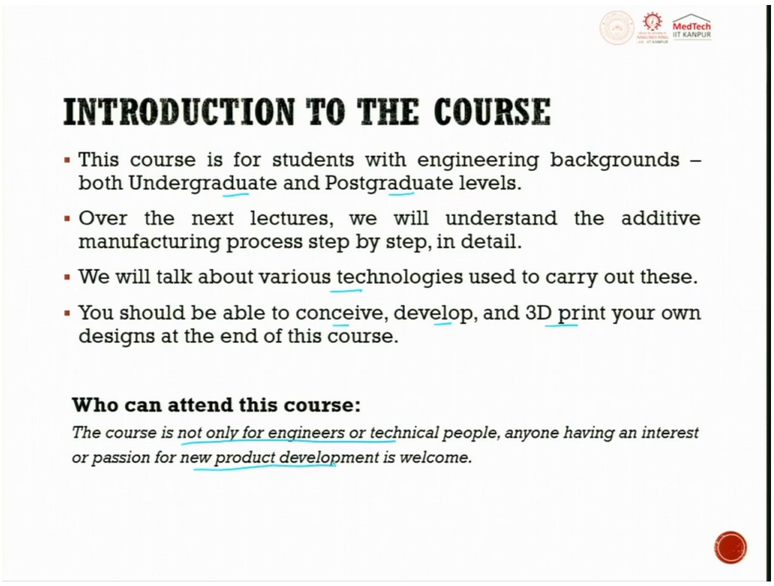

Introduction to the course: This course is for students with and without engineering background, both at undergraduate level and post graduate level. This course is also useful for practicing engineers who are in research organization, defense organization and industries. Our next lecture will be on understanding the additive manufacturing process step by step. We will talk about various technology and connect this technology with real time application. At the end of the course, you may be able to conceive, develop and 3D print your own design and develop new products.

This course is not only for engineering or technical people, anyone having an interest or passion in new product development are welcome to this course.

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Contents: First, we will see the need of this course. Then, we will try to see different manufacturing systems, subtractive manufacturing, then need for additive manufacturing, then introduction to additive manufacturing, then we will have classifications.

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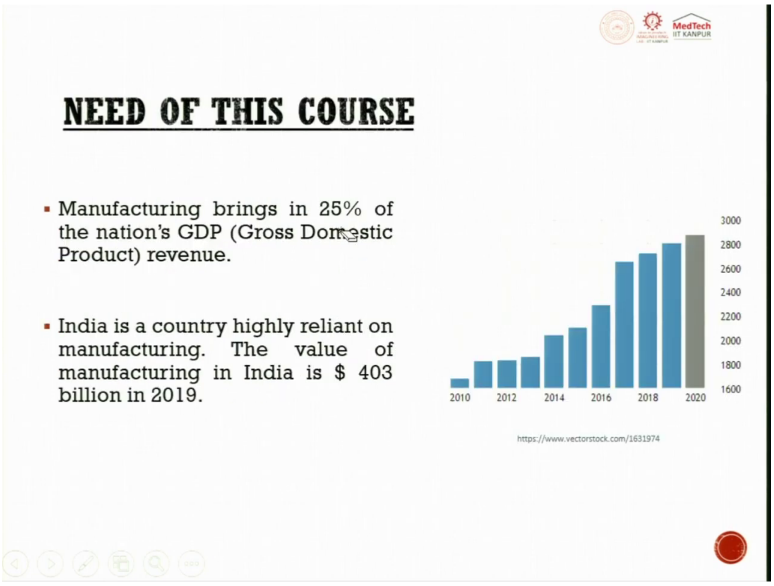

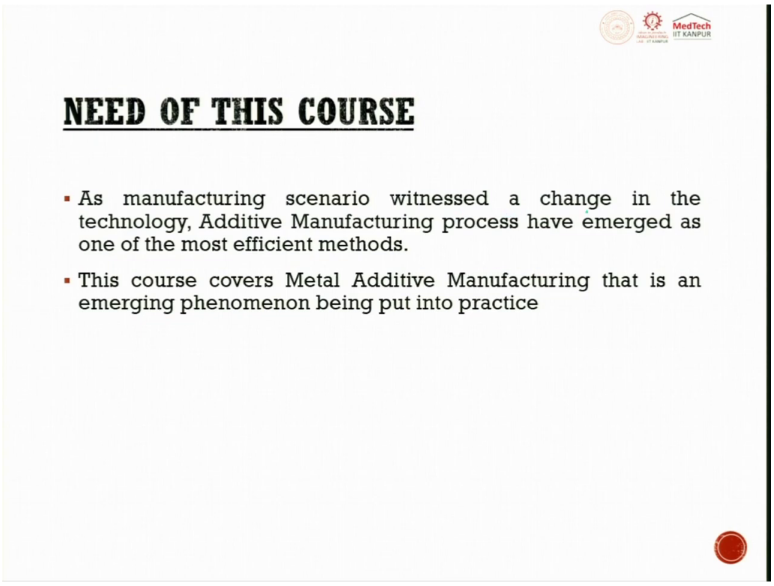

Need of this course: Manufacturing brings in 25 percent of the nation's GDP revenue. The other two big industries are service industry and agriculture. But, predominantly manufacturing industry plays a very important role. It tries to give a lot of job opportunities and it also brings revenue. India is a country highly reliant on manufacturing. The value of manufacturing in India is 403 billion dollars in 2019. You can see slowly; this is being exponentially increasing and going higher. As manufacturing scenario witnesses' year change in the technology, additive manufacturing processes have emerged as one of the most efficient methods. So, there are several manufacturing processes, we will see them in detail.

But additive which is a recent development is playing a very important role, which also tries to keep efficiency of producing a part as a prime importance. This course covers predominantly metal additive manufacturing that is emerging phenomena being put into practice today. As part of this course, we will try to have one or two demonstrations on a live metal additive manufacturing machine.

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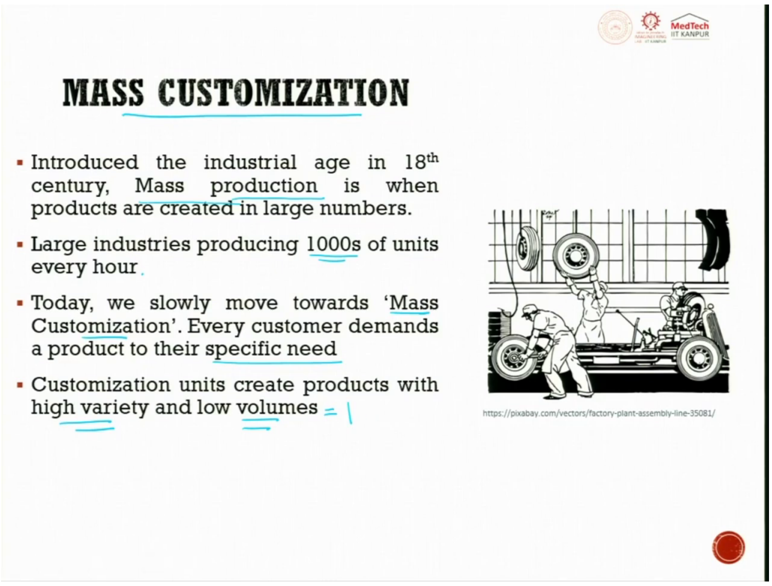

Metal additive manufacturing has come in a big way because it tries to give you the concept of mass customization. Initially, we were all more focused towards mass production. When we talk about mass production, we are trying to produce parts which are same or similar in a large quantity to meet to the demands of customer. And while we were doing so, we also integrated cost into it and we brought in automation. So, predominantly mass production was the need of the hour till very recent years. I am talking about 1990s. So, large industries produce thousands of units in an hour. Today, we are slowly moving towards mass customization from mass production. What is mass customization?

We are trying to customize every part or every product to meet the customer needs. So, no two products will be same, two products can be similar and there too, there will be some variation such that it gets customized to meet the needs of people. Every customer demands a product of their specific need. Customization units create products with high variants and low volume. Variants is high and volume is low. So, when we talk about low, we are talking about mass customization, the batch size of the volume whatever we talk about, in an idealistic case should be equal to 1.

So, no two products are same, they can be similar, this is a paradigm shift from mass production to mass customization.

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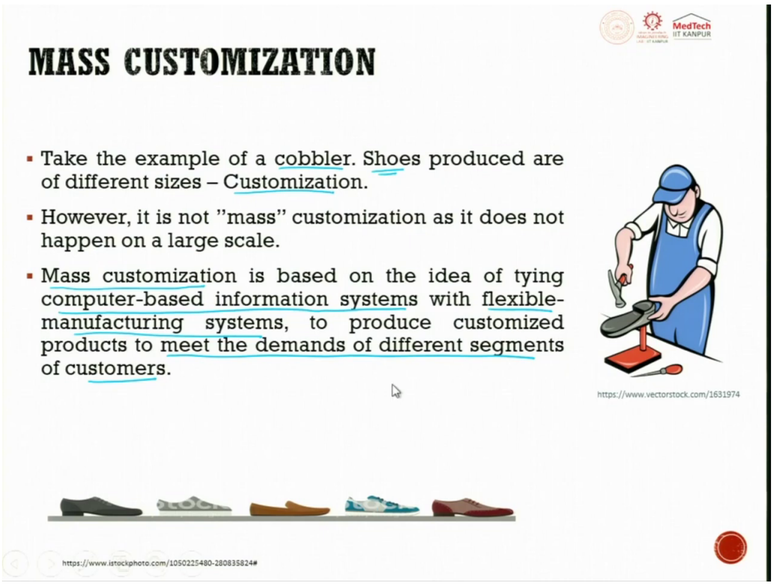

Let us take a simple example of mass customization. We always go to a cobbler give our foot design or we give or we show our foot, he tries to draw our foot. When he tries to develop it into a product from 2D to 3D, he tries to ask us like would you like to have this sole? Would you like to have a stretch like this? Would you like to have combination? Would you like to have a slipper or a lace attached? He asks a question about all these things, and he produces a shoe which is customized. It is not mass customization as it does not happen on a large scale, whatever cobbler does, it is customization.

When you try to produce in large quantity it is called as mass customization. A cobbler customizes the product. So, you should clearly understand the difference between mass production, mass customization, and customization. If the numbers are low, it is customization, if the numbers are large, then it is mass customization. Mass customization is based on the idea of trying computer-based information system with flexible manufacturing system to produce customized products to meet the demands of different segments of customers.

The key words are computer-based information system, flexible-manufacturing system to meet the demands of different segments of customers. So, you can see here for the shoes, the sole size will be same, but you can have a black shoe, you can have a party wear, or you can have a sportswear.

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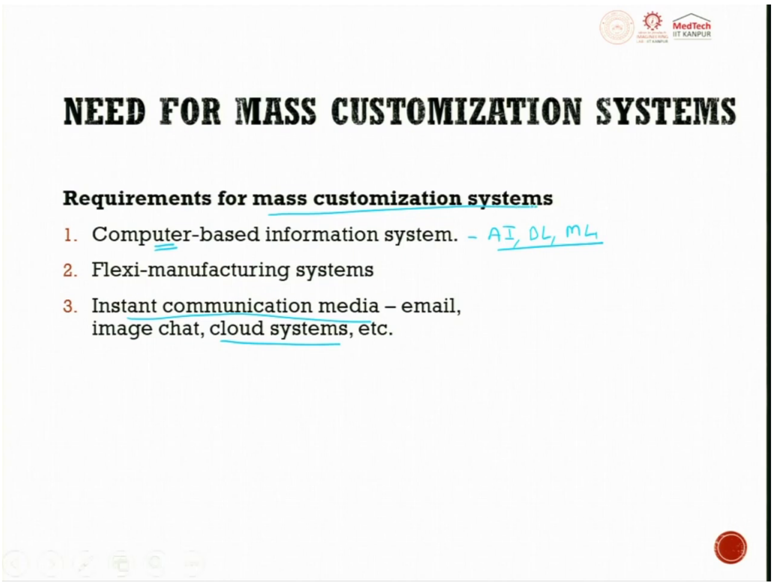

The need for mass customization of systems is increasing today, why because there are computers, which have come handy with maximum information. So, computer-based information systems have become economical and the software have become robust. So, lot of things are getting integrated today in the area of artificial intelligence, deep learning, machine learning, and all these things are able to be done with respect to product design today, because of computer-based information systems. Flexibility in manufacturing system is because of computer getting integrated into manufacturers system. So, that makes it flexible manufacturing system.

And today in this computer information system, we have instant communication media, where in which we use cloud systems for computing. So, all these variables lead you towards mass customization systems.

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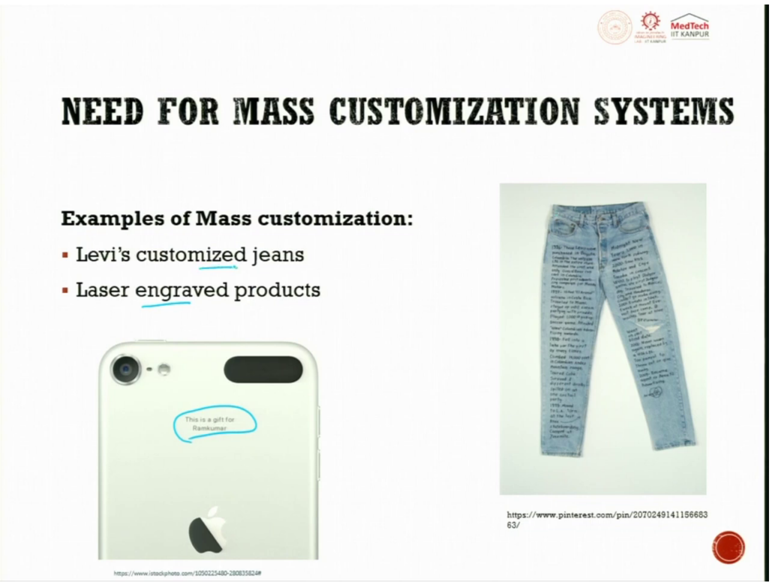

So, another example for mass customization you can see here is Levi's customized jeans. You can try to buy a blue-jeans and try to write your own story. Try to write your own name. Or you can try to buy an Apple phone and try to engrave- "This is a gift for Ram Kumar from Sonu". Okay, so this is customization of jean, or customization of a mobile phone. We use laser engraving for individuals or when you buy a jean, you try to cut down the jean to meet out your requirements or change or adjust the ways to meet out your requirement, that is also customization.

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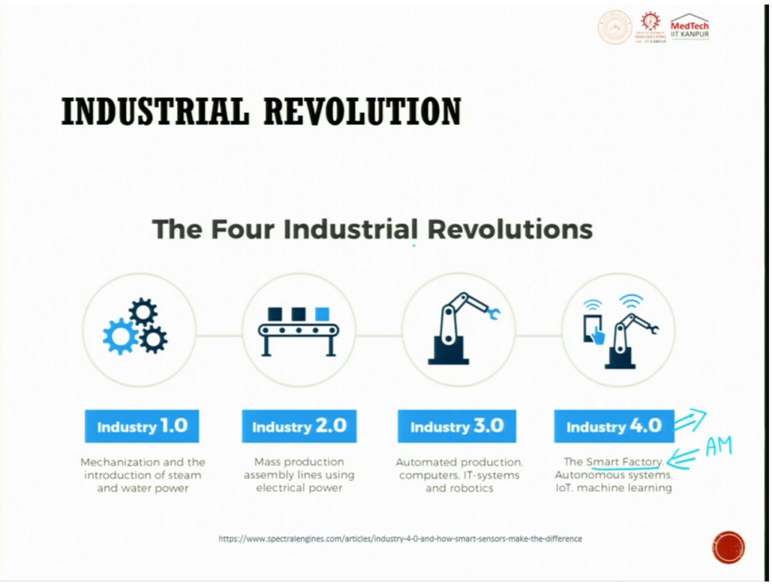

Today, the most popular word which is very much talked about is industry 4.0. So, before appreciating industry 4.0, I thought it is a good idea to start from industry 1.0 and move on to

4.0 and understand at every level, what was the amount of addition of technology happened in the industry. When we were talking about industry 1.0, we were more focused towards mechanization and introduction of steam and water power. When we went to 2.0, we are focused more towards mass production, assembly line use and electric power. So, this is typically nineteenth century beginning.

Then third, industry 3.0 is automated production, computers, IT systems and robotics. This is somewhere between 1950s to 1970s or 80s, we were just going around it and people also say up to 1990s. Then industry 4.0 started after 2000 where in which we started talking about smart factories, autonomous systems, IOT, machine learning, etc. All these things are part of industry 4.0.

When we are talking about additive manufacturing, they all get into smart factories. So, additive manufacturing as part of smart factory, are playing a very important role in industry 4.0. This is the fourth industrial revolution which has happened.

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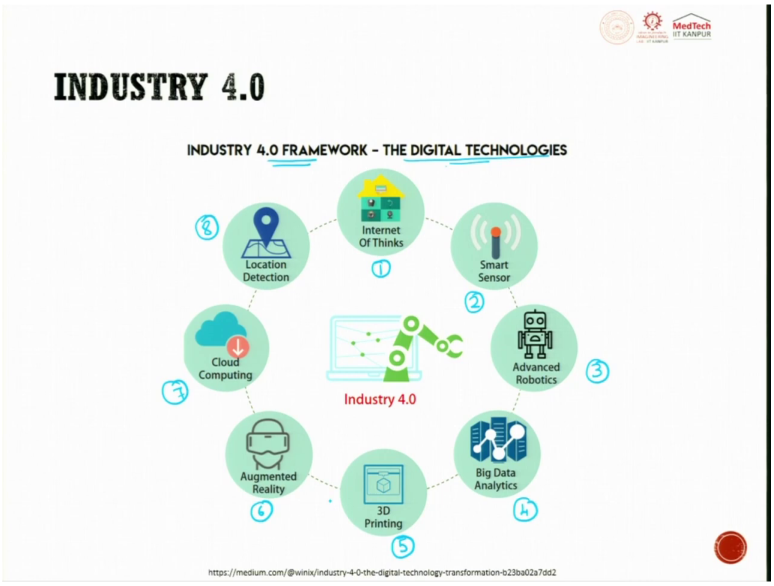

So, to get more insight, industry 4.0 framework is more focused towards the digital technologies. So, I will start from Internet of Things, Smart Sensors, Advanced Robotics, Digital Data Analytics, 3D Printing (3D printing, additive manufacturing, freeform manufacturing, digital printing, all these things fall here), Augmented Reality, Cloud Computing and Location Deduction. All these things are part of the digital technologies, which is a framework of industry 4.0. You see out of these eight, 3D printing plays a significant role.

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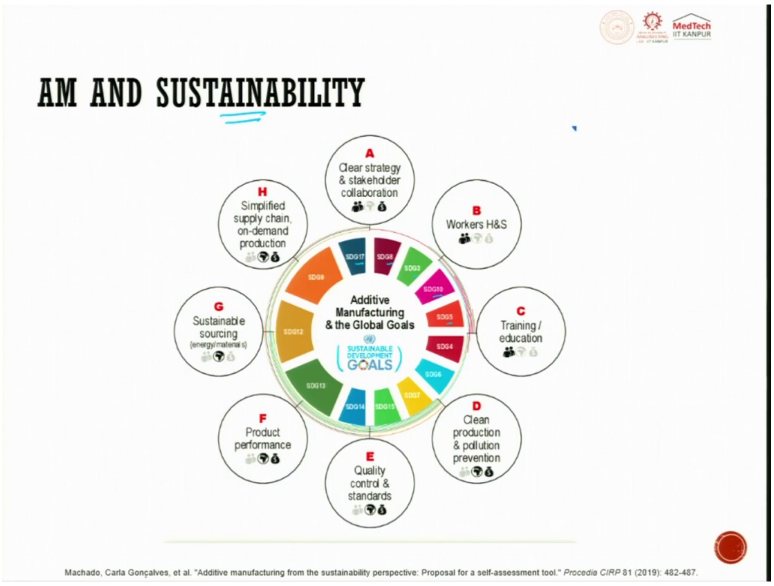

Not only 3D printing plays a significant role in industry 4.0, 3D printing or additive manufacturing is also part of sustainability. So, the sustainable development goals were declared. There were 17 goals, in which additive manufacturing plays a very important role in the concept of sustainability. The goals include clear strategy and stakeholders' collaboration, worker and H S, then you have training education, clean production and pollution prevention, quality control and standards, product performance, sustainable sourcing and simplified supply chain, on-demand production.

So, for all these things if you see, additive manufacturing is in the core. So, additive manufacturing is now integral part of the SDGs.

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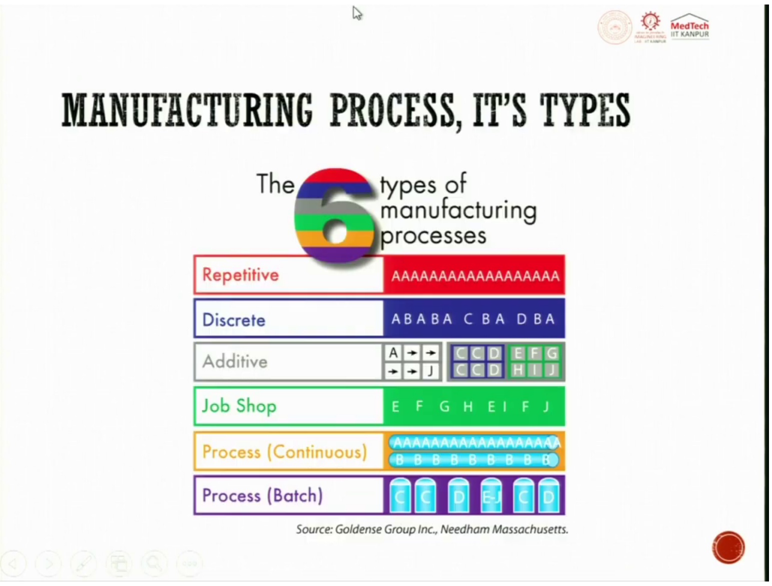

When we talk about manufacturing, there are six different types of manufacturing. The first one is repetitive manufacturing, wherein which, we keep on producing only A type material. In this course, we are more focused towards discrete part or product manufacturing. We are not discussing about process industry or process manufacturing. We are only looking at discrete part manufacturing. So, there are six types, one is repetitive, you keep on reproducing a discrete part AAAAAAA, when I say discrete, it is ABABA CBA DBA. So, it is all discretized, it is not only AAAA you are trying to produce, as and when you get the demand from the customer, you produce as per the needs.

Typically, the automobile industry is doing it. If you buy a pizza also, you see that the first one can be a rigid vegetarian piece or next one can be non-vegetarian or it can be something else, so that all falls in discrete part. Additive means, you get things added to produce the required output. Again, you have `Job Shop'. Job Shop means you are not producing it in bulk, you are producing it in ones, twos, threes, or discrete small numbers, but produce it. So, typically here in Job Shop what happens is, the product is fixed and all the machines go around in typical Job Shop.

Process industry is continuously producing. So, you will have a plant layout which is done for producing continuous process and process batch is another category.

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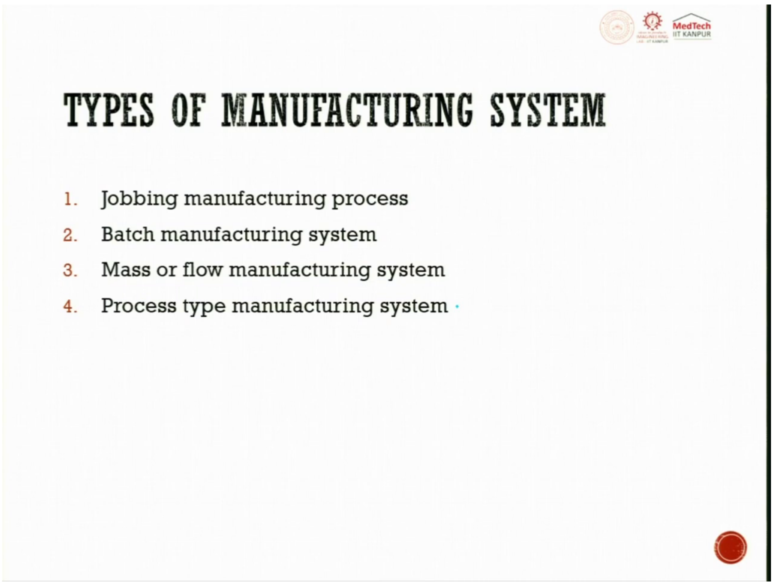

Types of manufacturing system- you have jobbing manufacturing process, batch manufacturing system, mass or flow manufacturing system then last one is the process type manufacturing system.

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This is a job manufacturing process, Job Shop production- this is part of job manufacturing processes. Job Shop production and varieties of products are produced in a small amount. It can be a paint shop or it can be machine tool shop. These are examples. For example, shipbuilding industry is a job manufacturing process, construction of flat is a job manufacturing, construction of big rocket is Job Shop manufacturing.

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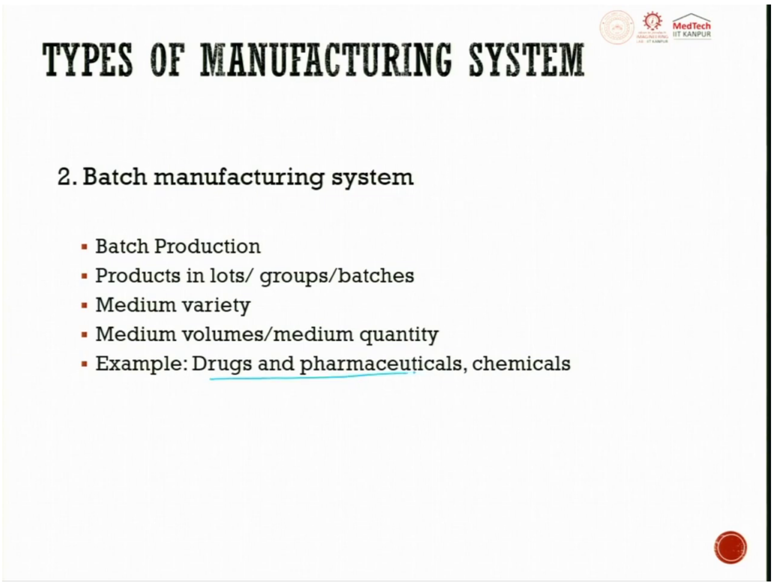

Batch manufacturing system produce the objects in batches, products in lots and groups or batches, medium variety, it has medium volume or medium quantity. Examples are drugs, pharmaceutical and chemicals. They are all batches.

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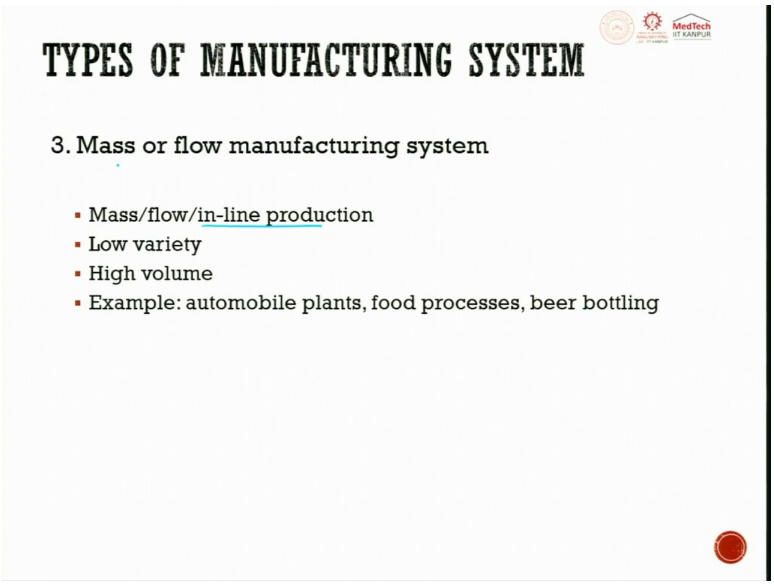

Mass or flow manufacturing system is that which talks about inline production, low variety, high volume. The automobile plants, food processing plant, beer bottling plant all these things falls under the category of mass production.

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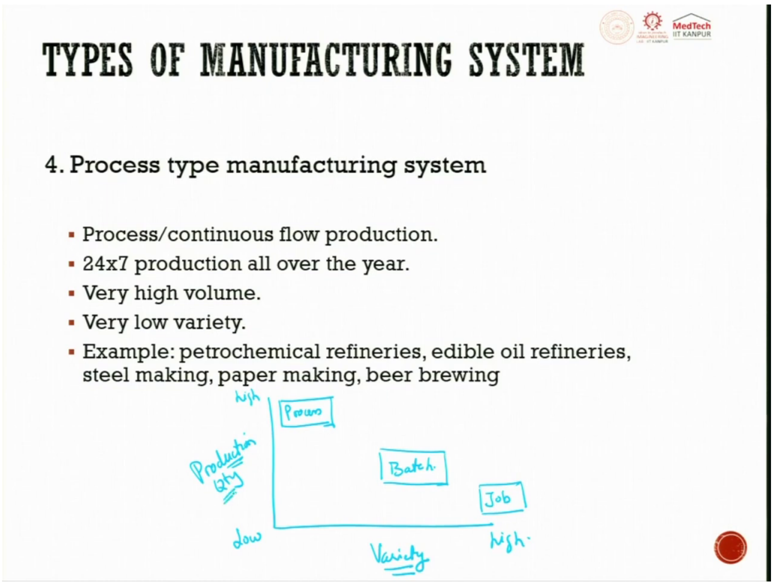

In process type manufacturing system, you will have continuous flow production, 24 x 7 production all over the year, high volume, and low variety. For example, petrochemical refinery, edible oil refinery, steel making, paper making, beer brewing. So, if you look at it, if I plot this in terms of low, high, production quantity and variety, the Job Shop falls where quantity is low variety is large. For process industry, you have quantity very high and the variety very low. So, in between you will have the other two cases. So, if you want to have mass flow you can have this and so batch production will fall somewhere in the middle.

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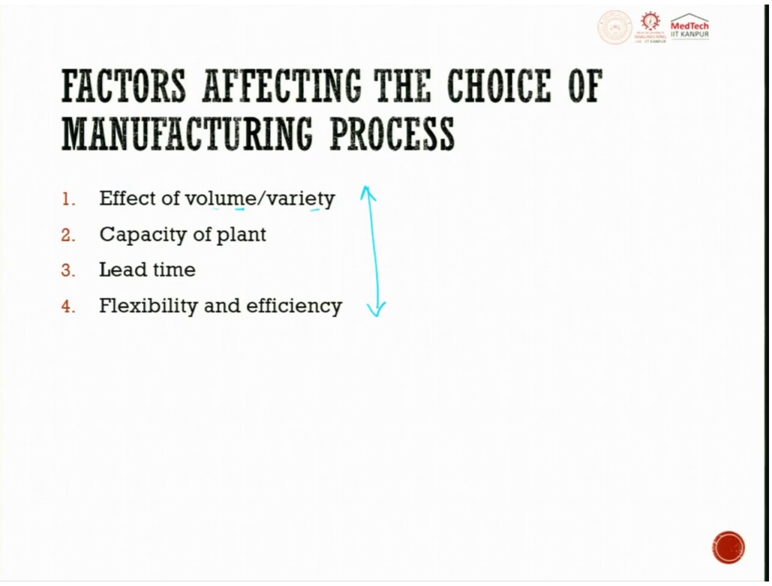

So, the factors affecting the choice of manufacturing process are the effect of volume or variety, the capacity of the plant, lead time, flexibility and efficiency. All these things affects the choice. These are all the factors which affects the choice or choosing of the manufacturing process, volume/variety, capacity, lead time and flexibility efficiency.

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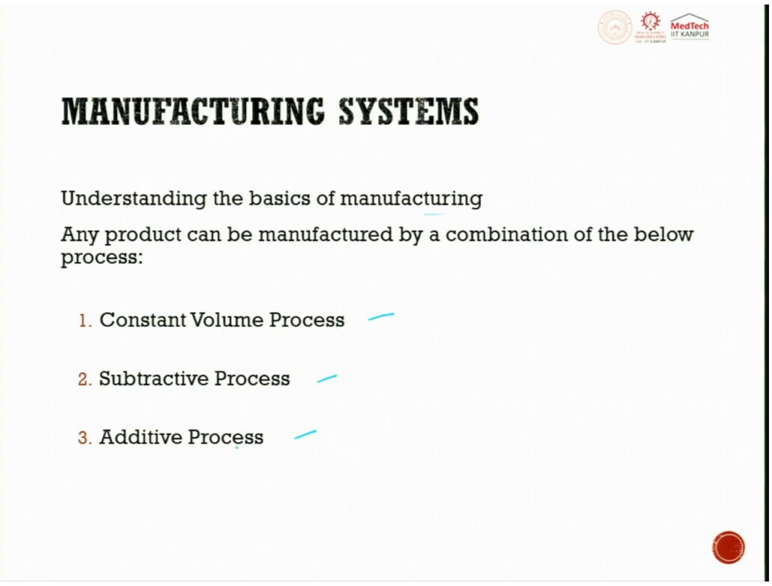

When you talk about manufacturing system, we first will try to understand the basics of manufacturing. Any product can be manufactured by a combination of the below processes, constant volume process, subtractive process and additive process. So, it can be one process, it can be one and two or it can be all the three together.

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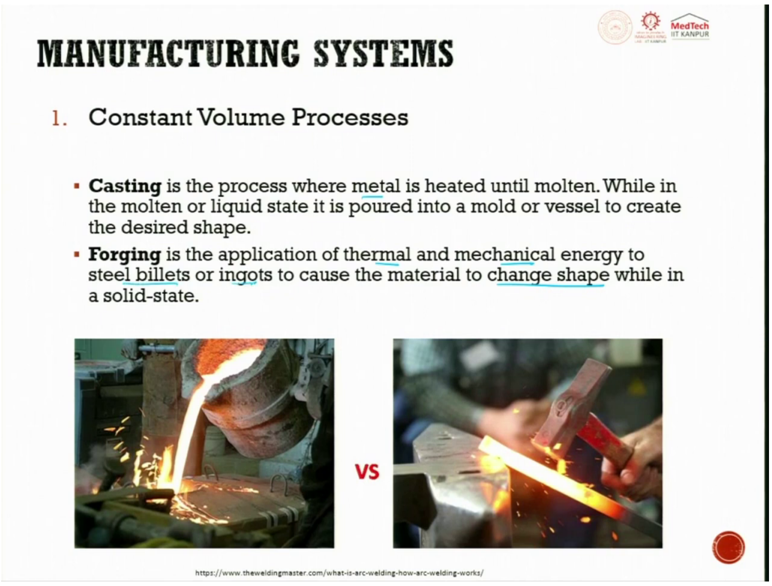

What is constant volume process? In a constant volume process, the starting material and the ending material will be almost the same in terms of quantity. Volume wise it will be almost the same. The two major dominating processes are casting and forging. In casting, metal is heated until molten. While in the molten or in the liquid state it is poured into a mold or a vessel to create the desired shape. This is a very primitive definition.

Forging is an application of either thermal and mechanical or only mechanical to produce a steel billets or ingots to cause the material to change the shape while in the solid state itself. This is again a very primitive definition.

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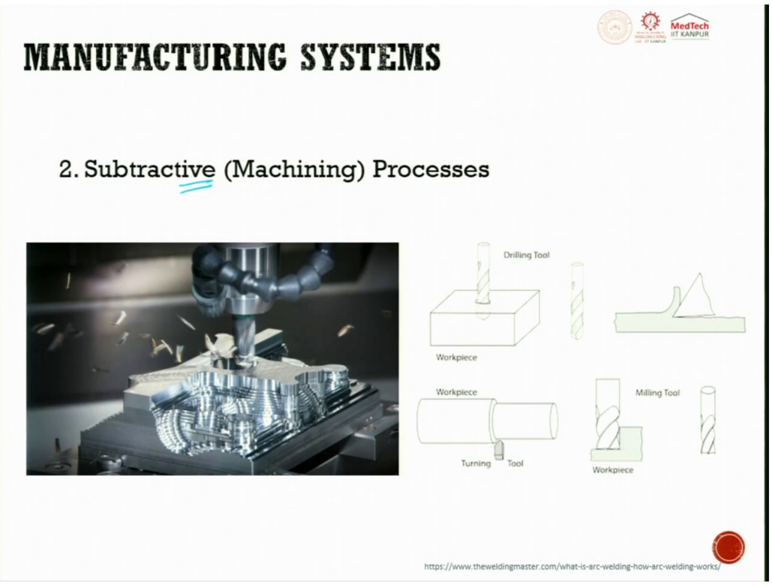

Subtractive process is very much used today, because the part geometries have become complex, the production rate has come down in the sense. There is not a mass production process here in which you can try to have variation between one part and the other part. So, subtractive tries to always give you a freedom of producing complex job to the highest accuracy. Subtractive process can be done and the production volume is lower than that of the constant volume process as we go for subtractive. Depending upon the geometry of the tool and the workpiece, you can try to generate profiles, whatever you want.

So, you can have drilling, turning, milling and grinding, and all these operations are part of subtractive process.

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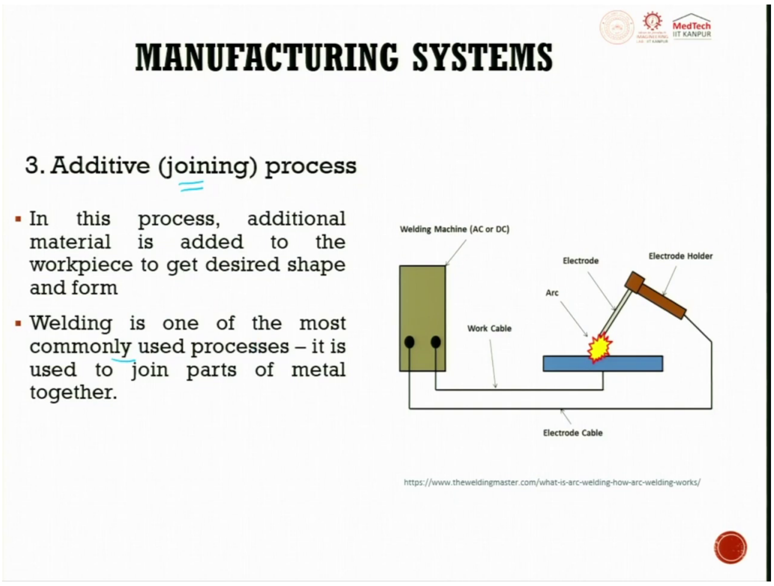

Predominantly additive process, what is known to the manufacturing community is more of joining in the early stage. In this process, additional material is added to the workpiece to get the desired shape and form. Welding is one of the most commonly used process. It is used to join or to fill metal in the given space. This gave the seed idea to additive manufacturing of metal parts.

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All the above manufacturing process deal only in 2D or 2.5D. To obtain a 3D part, a combination of process is very much required. Today, we look at shortening the lead time and expediting the product life cycle. So, the necessity of 3D printing grew due to the need for smaller lead time and making the product also very fast by using the combination of the process. The most important thing which evolved due to this is rapid prototyping.

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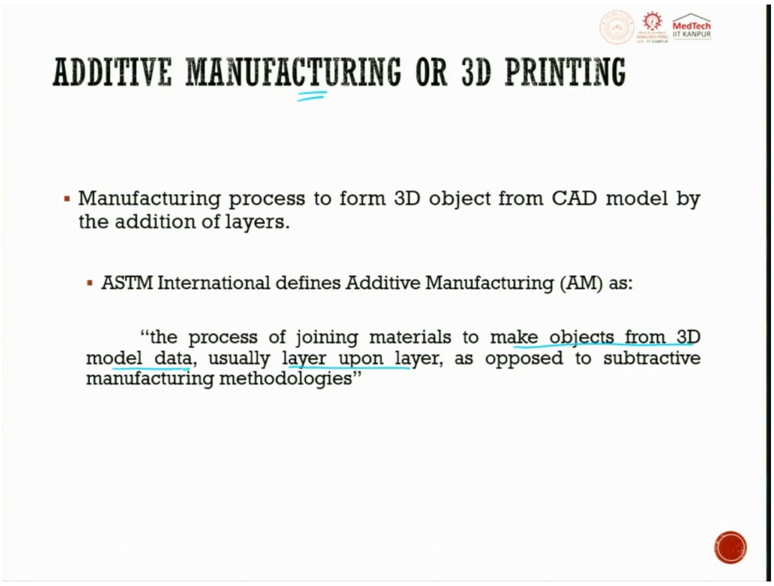

The rapid prototyping and additive manufacturing are almost the same. So, manufacturing process to form 3D objects from CAD model by adding material layer by layer is nothing, but additive manufacturing. The ASTM definition for additive manufacturing is the process of joining material to make objects from 3D model data, usually layer upon layer as opposed to subtractive manufacturing methodologies. So, layer by layer making of objects form 3D model.

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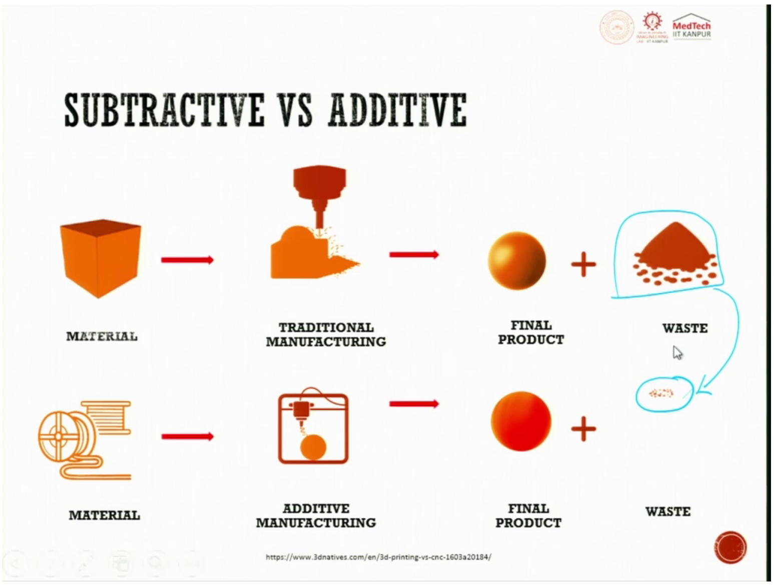

This is a schematic representation of a subtractive process and additive process comparison. In subtractive process, you start with a huge chunk of material, then you do a lot of machining operation. And finally, you get an object done. When you get this object done, you also generate so much of waste, scrap or chip. So, now for producing this output, you used so much of material in the start and then finally, after making the object this is scrap for which initially you spend so much of energy to build up this part. Finally, you scoop away and remove whatever is unnecessary things and you say it is scrap. So, this process is no way energy efficient as compared to that of additive manufacturing.

In additive manufacturing, we try to use the starting material and try to do various processes and convert the raw material into a finished part. We try to lay down our raw material at the required space alone. By doing so, we try to reduce the scrap or the waste from bigger amount to smaller amount. The material can be a powder, a wire, or a sheet. From there, we try to build the object and add material at the required space to produce the output. The wastage is reduced and it is energy efficient. This is the comparison between subtractive process and additive process.

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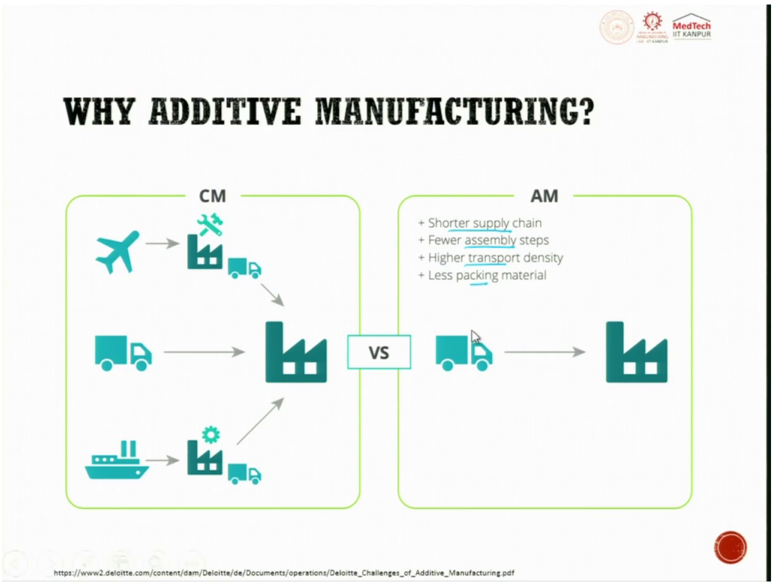

In continuous manufacturing, we need planes and then trucks to ship these material/products to the industry, hence so much of logistics are involved. But in additive manufacturing, it tries to shorter the supply chain. It has fewer assembly steps, and has higher transportation density. That means to say the number of parts which could be moved are very high and it has less packing material. So, all these things are the advantages of additive manufacturing.

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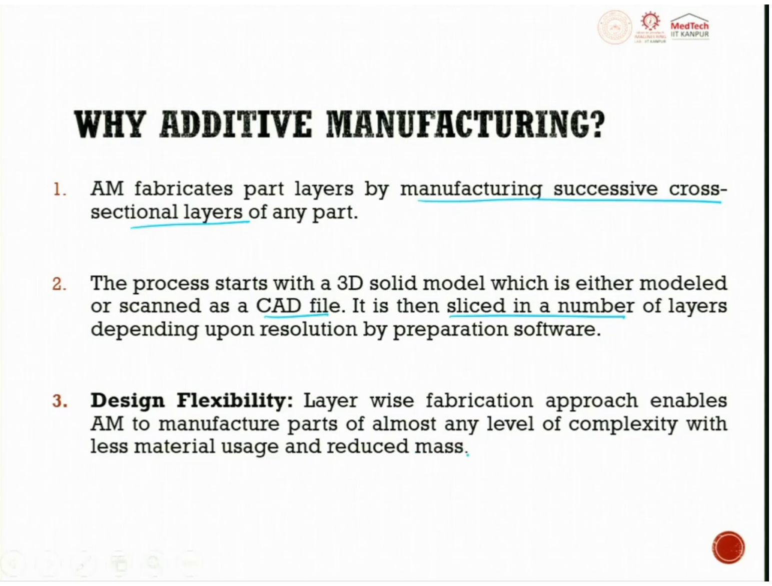

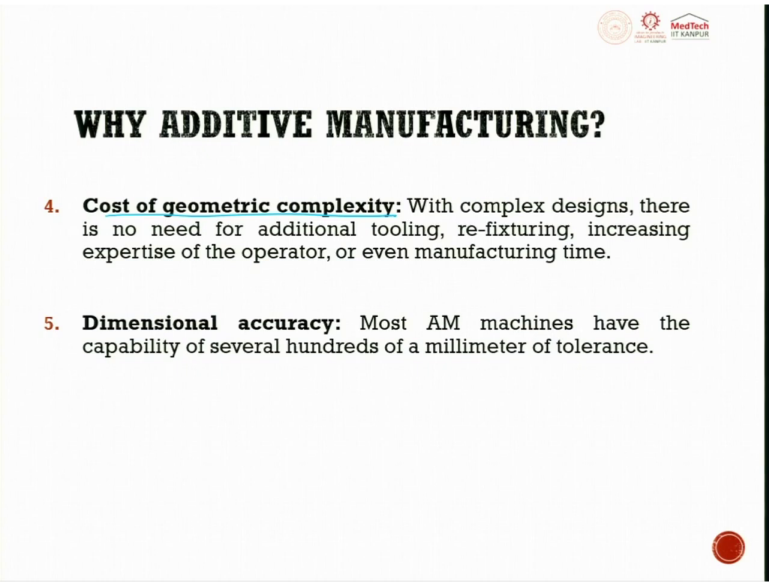

Additive manufacturing fabricates parts layer by layer by manufacturing successive cross section layers of any part. The process starts with a 3D solid model which is either modeled or scanned as a CAD file. It is then sliced in a number of layers depending upon the resolution by preparation software. The additive manufacturing gives lot of design flexibility, and layer wise fabrication approach enables additive manufacturing to manufacture parts of almost any level of complexity with less material usage and reduced mass.

With complex design, there is no need for additional tooling, re-fixturing, increasing expertise of the operator or even manufacturing time. So, due to all these things, the cost of geometry complexity is very low for additive manufacturing. The dimensional accuracies are very high as compared to that of subtractive process when we do complex jobs. Most additive machines have the capability of several hundreds of a millimeter of tolerance.

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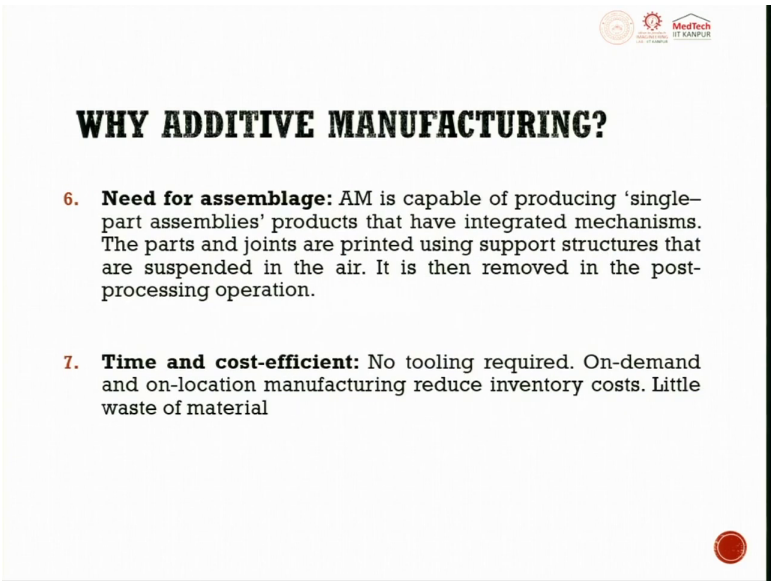

The need for assembly is reduced. AM is capable of producing single part assemblies, and products that have integrated mechanisms. The parts and the joints are printed using support structures that are suspended in the air. It is then removed in the post processing operation. AM is time and cost-efficient. No tooling required on demand and on location manufacturing reduces vendor cost and material wastage is less. So, these are the six or seven advantages of additive manufacturing.

Here, you build up layer by layer from a CAD file and hence design flexibility is there, cost of geometric complexity is very less, dimensional accuracies are very high, need for assemblages are reduced, and time and cost are efficiently maintained.

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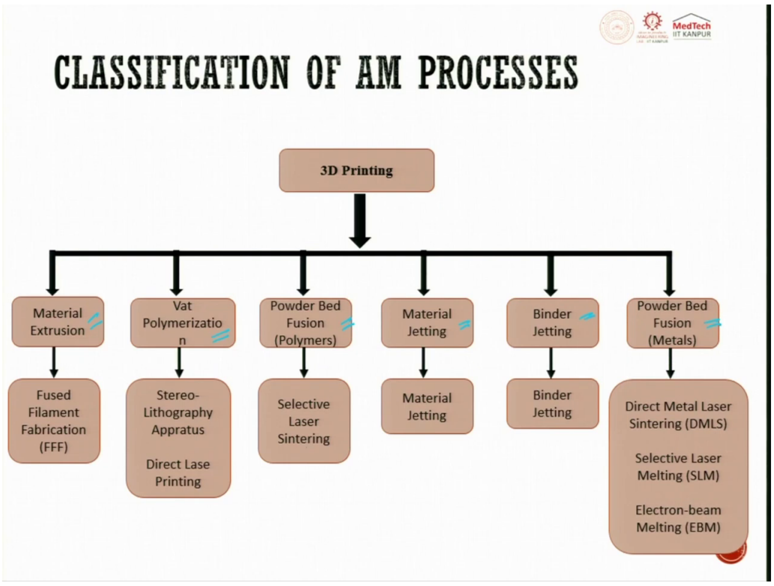

The additive manufacturing can be classified based on the material form whatever we use, so, material can be in the extruded form, material can be in the vat polymerization, powder bed fusion, metal jetting, binder jetting, and the powder fusion bed. So, here the technology is same for polymer and metal. So, you can have materially extruded, you can have vat, liquid polymer which is used. So, you get a very high accuracy of the part, powder bed fusion of polymers, powder bed fusion of metals, then material is jetted and then drop is made into droplets and next one is binder is put into droplets and then we try to get this part. We will see these processes in the due course of time.

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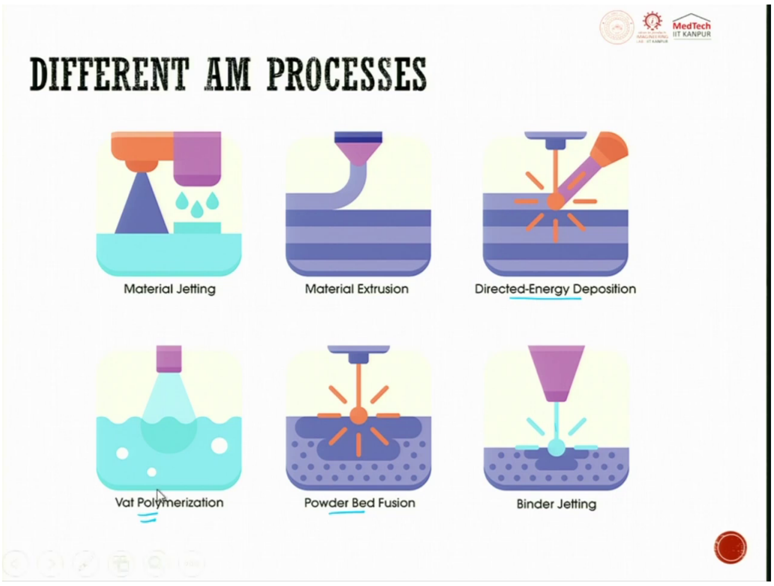

The material deposition can be done through extrusion, through material jetting, or through binder jetting. The difference between material jetting and binder jetting is binder is dropped, one after the other and the powder is agglomerated and then it tries to produce a layer. So, when we talk about material jetting, material in the jet form is dropped, so, that you try to get it. For example, wax.

So, the material extrusion is in the form of a wire, which is getting extruded through a nozzle and then you are trying to deposit. Direct energy deposition is done through the laser for sintering the powder into a pot. The difference between direct energy deposition and powder bed fusion is that you have a powder which is getting fed and the laser hits here on the powder. So, at one place, feeding is done through a nozzle, while at the other place, it is done on a bed. So, these two are different.

So, direct energy deposition, fused bed deposition, binder jetting, material jetting, and material extrusion are generally used for polymers. These are the six different principles which are used for producing parts in the additive manufacturing process.

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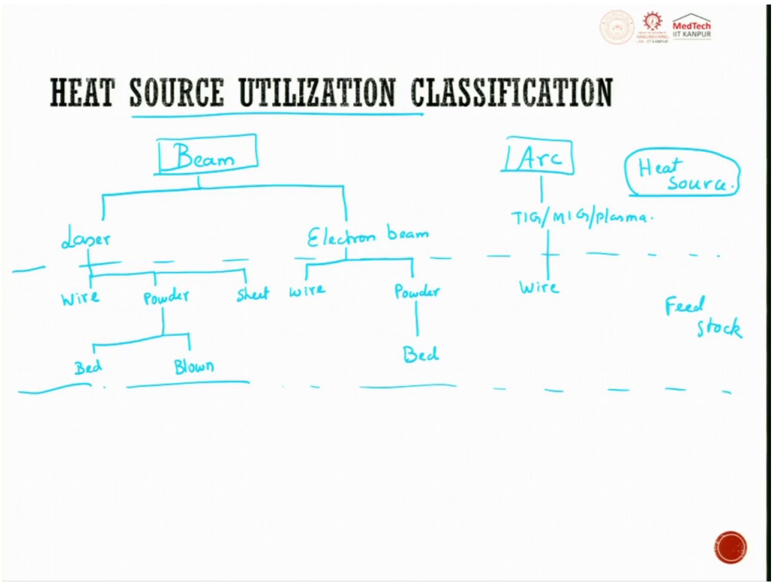

When we talk about different heat source utilization, we will try to classify them into two parts, one you can have a beam, the other one is you can have an arc. These are the heat sources which is required for polymer as well as metal. Our course is more focused towards metal. So, we are looking at beam and arc. Again, in beam for metal you will have two classifications, one is using laser as a beam, the other one is using electron beam or electron gun. The arcing is nothing but we try to use inert gas arc. So, it can be TIG, arcing and sparking between two electrodes, when you apply a potential.

In arcing we have TIG, MIG and then we have also plasma. So, these are the heat sources. Now, these heat sources will try to interact with the feedstock. So, with laser you can have wire and then you can have powder. With electron beam also, you can have wire and powder. Then with TIG MIG and all you will have only wire.

Now, when we try to use this powder there are two types, one is called as bed type, the other one is called as blown. In electron beam, it is predominantly bed and here it is wire. So, the heat source which is generally used for additive manufacturing depends on the beam or arc. So, the beam is further classified into laser and electron beam. The material form can be in wire form or it can be powder form.

We will try to stick to three different types of sheets and then we use laser for this process. So, laser can also have sheet. Generally, we do not try to use a sheet in electron beam.

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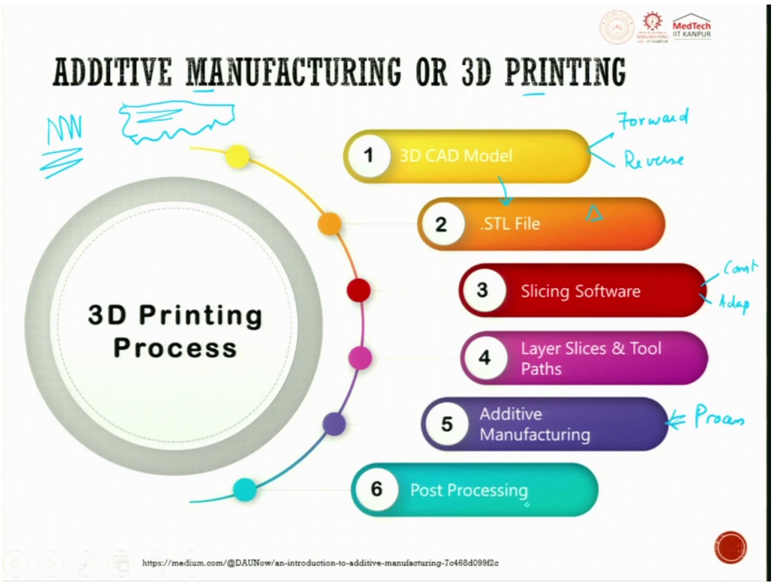

So, we have been talking about additive manufacturing or 3D printing. These are the steps which are involved in additive manufacturing. First you will always try to generate a CAD. So, here you have two things, one is called as forward the other one is called as reverse. Reverse means you have an object, from the object you use a scanner, you scan it and then try to get data points, from the data points you try to convert CAD. The other one is start from points then you try to draw an object and then make a CAD. So, watertight CAD model is used here.

Next, this CAD model is converted into STL file. What does STL file means? STL file makes the surface area into several small faces, and then this surface can be mathematically represented very easily. Then after this STL file is done, we try to slice the object into various layers. Again, here you can make the layer constant, and make the layer adaptive. So, same layer thickness throughout the object or varying layer thickness throughout the object, and slicing softwares are used. Then the layer sliced and the tool path are next generated such that this can be fed into the machine.

Let us assume this one layer of information of layer, slice and tool path. So, in this layer, you have to tell me whether I should move the tool in the serpentine pattern, or whether I should move in the vertical pattern, or should I move it in the zigzag pattern. The tool path is the nozzle moving path or the laser moving path. The next process is called as additive manufacturing or 3D printing. Once the process is done, there is always a need to do post processing such that it meets to the customer needs.

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To recap, in this lecture, what all we have studied is why do we need to learn additive manufacturing? What is mass customization? Difference between mass production, customization and mass customization. How is current industrial revolution working wherein which we covered industry 1.0 to industry 4.0. In industry 4.0, what are all the elements in the digital framework, what are the manufacturing systems, constant volume, subtractive and additive. Then we saw what is the need for additive manufacturing and a very small introduction to additive manufacturing, wherein which we store different steps which are used in additive manufacturing.

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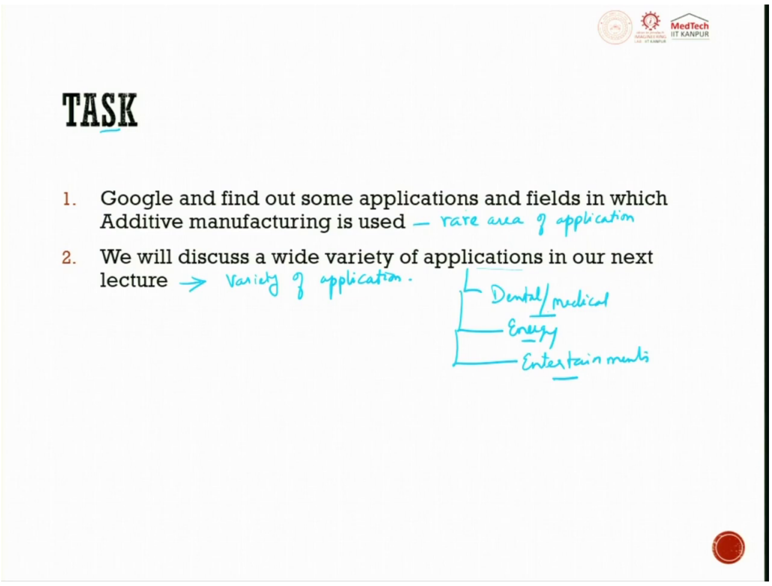

Before we close, I would like to give you a small task and this task is do it for yourself so that you will start appreciating this course more. Try to do Google and find out some application and fields in which additive manufacturing is used. Let it be a rare area of application. So, do not say an automobile, or rocket, look at something which is very rare and additive manufactured part. So, first you have to find out the product and then in which field it is used.

Then we will discuss a wide variety of application in our next coming lectures. This is used in dental field exhaustively, medical field exhaustively, in energy, in entertainment industry, etc. So, you have to just go through Google and find out what are these applications and how are they used. Thank you so much.