Carbon Materials and Manufacturing
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Lecture - 59
Supply Chain of Industrial Carbons

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Hello everyone.in this lecture we are going to discuss what is known as the Supply Chain and we are going to focus on some of the carbon materials; some representative examples we are going to take. Many of you might be aware of what is a supply chain; maybe those from engineering backgrounds definitely learnt about supply chain management and also operations research during their bachelor's degree, but anyway I am going to give a brief overview.

And sort of to remind you what do you need to do when you want to move from manufacturing to production. So, what is supply chain by definition? Supply chain basically involves all these steps starting from the production or the procurement of your raw materials, all the way to providing the final product to your customer and even customer service at times. So, this entire chain is known as the supply chain.

Although it is called a chain; it is actually not. When you think of chain, what do you think? So, in terms of carbon materials chain is carbyne but supply chain is not really as

simple as that; it is not really a chain; it is a network because everything is connected to everything. There, you do not have one individual company in the entire business network, often you have multiple companies, multiple producers and also multiple buyers; they are connected to each other.

These are the things that you need to think of again when you want to move from your scientific research to actually providing a product to the customer. And even if you are a researcher, often you will have some deliverables for the industries.

So, you basically need to make something that can be sold.in that case it is very important for you; maybe there is a certain scientific process and you are very happy about your process, but it is not scalable or it is not cost effective; maybe you can make some very excellent devices, but they are too expensive.

So, all of these things together, you need to think of and if you want to make whatever you are making for the general public, in that case supply chain becomes very important. This is kind of a set of all of these steps involved in the production of your material and not just the production, but getting the raw material from somewhere and supplying the final product to someone. So, this is your supply chain; what does it mean?

You know that there is a certain demand for some materials and when there is a demand, you supply that material. Sometimes there is more supply, sometimes there is more demand and this optimization of supply and demand is what is very important for anybody to have a successful business. Supply chain basically is the interface between supply and demand. So, you need to definitely understand the demand first.

So, if you want to start a business, first you need to understand which type of carbon material and why should you produce that? Maybe, there is no demand for that material or the demand is there, but only for research purposes. For example, you do not really need several kilograms of graphene.

Because even if you have 100 grams of graphene that can be used for a lot of purposes; if you are making devices and you are making devices with single or few flakes of graphene; in that case how many flakes do you need? Maybe, 100 grams of graphene will be sufficient for some research lab for a good few year. So, in that case, how much production is actually required, what are the quantities that are required?

and accordingly, what is the cost that is associated with it? If you want to make some other carbon material, let us say carbon black; yes the demand is very high because carbon black is required as a reinforcement material for tire industry. Demand is definitely high, but in that case; you may have to think that there are already a lot of companies who are making it; a lot of manufacturers. So, you do have various players in the market.

You may have to compete with really major players and you may not be able to compete with them; you may not because also when the production quantities increase, the overall cost generally decreases. So, if you are making something in smaller quantities; then you are going to probably have very high costs involved and that is why you may not be able to compete with the larger companies, who are producing several thousands of tons of carbon black.

These are the things that you need to think of and this is where you move from research to business. Supply chain is a network and supply chain involves multiple things. So, with the examples, it will become more clear, but let me tell you what are our goals.

So, minimize the production time and production cost that is something you understand because obviously, if you can produce something very fast that is good and if you can produce something at a low cost, especially lower cost than your competitors; in that case definitely you are at an advantage.

You also would like to have a good production efficiency and what you should also have, this is a very important factor in business is to ensure the quality of your product. If your product is of bad quality, maybe it is cheap and so initially a lot of people buy it, but you will only have this peak of your sales. But after that, once people realize that, although this carbon material is good, but it does not really perform the task.in that case you may not have a good sale, or your business will die out after some time.

So, ensuring the quality of a product is also very important; at the end, it is customer satisfaction. So, customer satisfaction something that we do not think of when we are making something especially when you move from science to business, it is very difficult. Because for us what is important is the quality of course, of what we make; it is also important that we use good manufacturing processes.

By good, I mean that sometimes you try to use something innovative. You want to basically apply a lot of your skills, a lot of your thought process goes into whatever you are manufacturing. We often tend to not think of the customer; maybe the customer does not really want very high quality. Maybe the customer does not really care for 99.9 percent purity, but the customer probably wants a reasonable cost.

If the cost is increasing a lot, when you move from 96 percent purity to 99 percent purity; let us say those are the steps that require a lot of energy consumption. So, this often happens in the case of carbons because you see when you are making carbon fiber; you making anything that is graphitic; in that case the last steps of graphitization are the most expensive, most energy consuming steps because you need to go to temperatures as high as 3000 degrees.

And these processes are also relatively very slow; it may take several days to convert certain set of carbon fibers into graphitic carbon fibers. So, the question is do we need those kinds of carbon fibers? What applications require those kinds of carbon fibers? What is the fraction of those applications? Because and how many customers do you have? This is something that you need to understand because otherwise why should you make something that nobody is going to buy.

Even though, it is going to be a very good material; you are going to have a very high modulus of carbon fiber. But at the same time, you need to see how many people actually like to buy it, how many applications depend upon it? So, these are some of the aspects that you need to think of.

What are the primary components of supply chain? Again, the manufacturer is at the center and then there will be raw material suppliers and then on the other side you will have warehouses, which means storage facilities. Of course, to send your material to the warehouse, you will also have some transport companies involved. And these transport companies are also involved when you are getting your raw material to the manufacturing plant.

Then, you also have people who are involved in selling the material., for example, retailers or even sometimes wholesalers are involved. Nowadays, there are less and less wholesalers involved in businesses and a lot of things have also changed since we started doing online business. But for carbon materials not so much changed because your

carbon materials are often used in very large quantities, especially those carbons which we call industrial carbons.

For example, carbon fibers or free forms of carbon fibers; some of them you could actually buy online. But a lot of them are still shipped in several thousands of kilograms and that is why we still do not rely on online products, but for other some smaller products.

Some cosmetics; some small things, then a lot of things have changed in the supply chain, a lot of steps which used to be there are not there anymore. But these are some of the primary people involved; who are the people? So first is your marketing team and your market research team also.

When we say marketing that is about selling the product, but marketing research marketing team will do some market research which basically means the team will tell you whether or not you should make a certain carbon material. What are the demands and what is the predictive demand; they will do some forecasting, they will do some trend projections. And then they will tell you whether or not it is feasible to start the business; there is always definitely some risk involved.

But you would like to minimize that risk. All of these teams in fact, risk analysis team I have not written here. Risk analysis is also not just about thinking that this is risky or not; you actually do a proper mathematical analysis of the risk also.

And how do you do the mathematical analysis? All of these steps that I have mentioned here, you must be thinking that these are more general things right. You know it depends on whether or not you rely on someone whether or not you so, they you will be thinking that these are rather social aspects. Whether or not you can trust the person who selling you the or; not person, but a company selling you the raw material, but it is not just that; it is much more than that because you can actually assign mathematical values or numbers to everything that is important to you or unimportant to you.

So, for example, if there is something which is of very high importance to me. Let us say I want to start playing badminton from this weekend onwards. So, I have decided that I definitely want to play, I have not played for several months and now it is very important

for me. But I realize that I do not have badminton shoes; in that case, I would like to buy the shoes what is most important for me is the time of delivery.

I need the shoes now, the color of the shoes is not important to me, but maybe the quality is, but to some extent; what is more important now the quality or the time? So, you can actually assign numbers to all of these things and then based on these numbers, you can see there are maybe 3 or 4 shoe sellers and you can compare who fits better, who scores more and then you will accordingly buy something from there. So, this is valid; this is a very simple example.

But this kind of thing is valid also when you are dealing with several different companies, several different suppliers on both sides; procurement and also sending the finalized or finished product. So, these are the things that we can actually mathematically evaluate. A number of steps that are either a part of the supply chain or influencing the supply chain. And this entire field of study is actually what we call operations research.

It is very important. There are also nowadays a lot of software that can perform this kind of analysis; especially when you are dealing with big data; so all of these things are important when you are starting a business or when you are in a business; even when you are joining a company. This is basically what I said that you can mathematically calculate number of things and market research will tell you what is the demand.

There are few methods; forecasting trend projections; I have told you already, but there are many small factors, you need to ensure before you do your market research. Now, supply chain is not really exactly the same for all types of products, especially when you are making carbon materials; you are often making the material and not the final product, but in some cases, you might also be making the final product.

What is very interesting about our carbon materials? Either you can make them in bulk. So, now, when I was talking about applications previously then I told you that there are few carbon materials that are used for making structures like graphite is; when you are manufacturing graphite, actually before making the graphite, you give a shape to the precursor itself. So, there your structure design, structure manufacturing as well as material manufacturing are pretty much the same, you do that in the same heat-treatment process. But on the other hand, there are also carbon materials that are rather sold as

powders or pellets like activated carbons; they are not really used for making structures, but still the material manufacturing is important to you.

So, there are all types of carbon materials; if you are making a small device, you are making a field-effect transistor using carbon nanotube that is also in a way some sort of manufacturing, you can call it fabrication; you can do it in the cleanroom, but it is some sort of manufacturing; making something.

And there the nature of your product is completely different; the cost of your product, the raw materials; everything is very different. The requirement of your raw material is also very different; I mean when I say requirement in terms of quantity. So, all of these things become important and that is why you cannot have the same type of supply chain for every product. Even for the same product; sometimes the supply chain may vary, depending upon what is your raw material.

Again, that is a very interesting thing when it comes to carbon materials. We do not always have the same type of raw material right, even for making say activated carbon. I am going to show you the example, you can make activated carbon using different types of raw materials.

So, again accordingly your supply chain will change and it is not always this one single type of supply chain that you need to study. So, various parts of the supply chain are of often assigned numbers; this is something I have already told you and this is the entire field is known as operations research.

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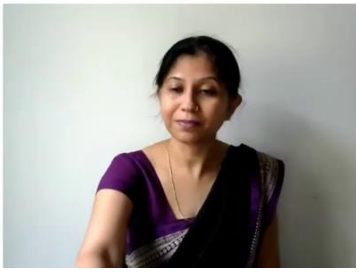
Demand of Industrial Carbons

- Global demand of carbon materials such as carbon fiber, CFRPs and some carbon nanomaterials has drastically increased in the past few years.
- Bulk industrial carbons also show an increased demand due to the increase in the number of processes that use carbon as raw material (e.g. carbon black as rubber reinforcement for tyre making)
- If the applications of carbon materials become more valuable, the demand increases
- For example, strict regulations on industrial waste water purification increase the demand of activated carbon
- Interests in research on graphene may influence the demand of graphene
- Whether you are a researcher or working in a company, knowledge of market and the economic potential of the material is essential.

Global and Indian market of some industrial carbons
(approximate values based on a quick internet search; data from 2018; b = billion, m = million)

Carbon material	Global market (in US$)	Indian market (in US$)	Import (in US$)	Export (in US$)
Carbon black	17.5 b	879.26 m	351.8 m	39.5 m
Carbon fiber	4.15 b	50 m	1.97 m	0.31 m
Activated carbon	4.72 b	20.2 m	11.4 m	36.7 m
Graphite	29.05 b	260 m	61.5 m	91.07 m



Now we come already to carbon materials; what is the demand for carbon materials? So, I told you that demand and supply are two important things and our supply chain is connecting the two. What is the demand for carbon materials? And carbon materials are so many different types.

For each one of them, the demand varies. So, what I have done here is; I have sort of made a table for some representative carbon materials based on a quick internet search. So, first of all, some carbon materials have lately become very important and one name that comes to your mind whenever you think of industrial carbons as carbon fiber. And not just carbon fibers, carbon fiber reinforced plastics.

They are used nowadays in the automobile industry extensively. They are also used for many other applications. So, anything that should be lightweight and strong; then you could replace metals with carbon fibers in principle. So, this is one material, lately its demand has really gone up in the last few years.

And if you extrapolate that curve, then you will realize that in the next few years also the demand is going to only increase. Because, see the demand for a certain material depends upon the related industries. Automobile industry is growing and also people have realized that if you have a lighter material; you require less fuel.

Also environmental concerns are pushing these kinds of lighter vehicles;. You also nowadays have hybrid vehicles and electric vehicles and for them, it is very beneficial to

have not just a lightweight car but also if you can utilize that car for some sort of energy storage; because our carbon materials are also electrically conductive, electrochemically active.

They could potentially also be used for the storage of some sort of energy. So, all of these things are actually supporting the carbon fiber industry and the demand is drastically increasing. So, this is the table that I was talking about; this is based on a quick internet search these are approximate numbers from 2018, I found some reports. So, do not hold me accountable if some number does not match.

But just to give you an idea; number one these are some of the industrial carbon materials and I have not included nano carbons because the demand and supply and even the production for nano carbons compared to our industrial carbons is still much low.

Here I have mentioned the market in India as well as the global markets and that is why all the costs are in US dollars. In India, there is little market compared to the rest of the carbon materials or carbon nanomaterials. Also, even when it comes to manufacturing; nanomaterials are still much less manufactured specially in India because we have environmental concerns related to these nanomaterials.

And this should definitely be addressed because any environmental factor is very important to us; if there is some nanomaterial that can cause cancer or its presence in the air is not good for us; in that case, definitely, we should think twice before manufacturing it. So, these are some of the carbon materials.

Now, other bulk industrial carbons; you can see from here also show an increase in demand. So, these are just the numbers of the current markets, but even if you project the demand for example, for graphite; it is not that once we have more advanced carbon materials like carbon fibers and nanomaterials that does not really mean that the graphite demand has gone low or it has even become saturated or stable. No, the demand for all carbon materials is increasing.

Let me give you an example of carbon black. It is also very strongly connected to the automobile industry because that is what we use for reinforcement of rubbers for more advanced tires, are also very important for all cars. So, these materials have also increased demand, they have seen increased demand in the past few years for sure. So,

this, you can see it for other carbon materials as well. So, the idea is that once the application becomes important. That increases your demand and that is how then automatically sort of supply increases. Also for example, if there are more regulations about the cleaning of the industrial wastewater. In that case, what will happen? Now, you will think that this industrial wastewater is not really related to the carbon industry, but it is very much related.

Activated carbons are the ones that are used for making water filtration columns. So, indirectly if there is a regulation that all the water from all the industries should be completely clean, purified; in that case, that is indirectly influencing or increasing the demand of activated carbons.

Similarly, even when there are a lot of research interests in a certain material; even that influences the demand. We take the examples of graphene and carbon nanotubes; so these carbon nanomaterials, the fact that there has been a lot of research or a lot of research interest at least, has actually increased the demand relatively; compared to bulk industry materials, still much lower. But, if we find an application that can be scaled up, but that can be commercialized.

For example, device application of graphene, in that case, the overall demand will suddenly increase. And if we are unable to do that, then maybe this demand will reach a saturation point; so everything is connected. The point is that whether you are a researcher or you are working for a company or you want to start a company; it is important for you to understand. Sometimes, even your research might be influenced by the market demand and supply, you do not even realize it.

In many countries, for example, research is more dependent on industrial funding because the governments are not providing enough funding. In that case, it is very important for them to understand the market, even when they are doing research. So, everything is connected.

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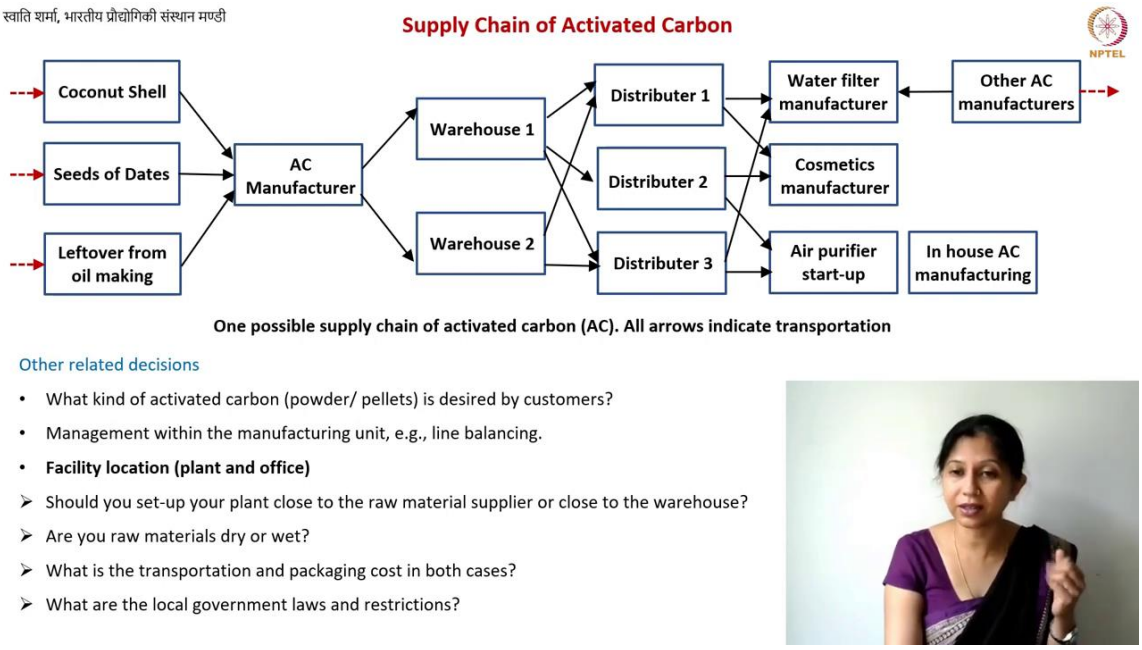

Now let us take some examples; this is the first example; you are the activated carbon manufacturer. So, I assume that now from this course you have learned how to manufacture it; you even learnt about different types of furnaces and you learnt how to make your activated carbon, you also know that this can be actually made from waste materials.

So, you are the manufacturer; what are you going to do? What are you going to first think of? I want to start a company or I have a small company already and I am making activated carbon, how do I get my raw materials? Coconut shell which is one of the most common precursors in India especially for making activated carbon because of the fact that it gives you a very high quality activated carbon and we also have it available in India.

Coconut shells, I get from some supplier; then I also get the seeds of some fruits let us say dates or khajoor. So, I get the seeds because these are also very good precursors for making activated carbon. So, I decide that I will not just use one type of precursor, but I will make different grades of activated carbon, from different precursors; maybe also different types like I make pellets and I also make powder.

So, for different types of activated carbons, I need different raw materials say there is some raw material that also comes out as the waste from some oil making company.

Because a lot of oils, let us say even this ground nut oil when you make, then after that you have a lot of leftovers.

Once you extract all the oil from something, then what do you have? You have the basic cellulosic skeleton left over. So, those cellulosic materials can definitely be converted into a porous activated carbons and so on. So, let us say these three are our suppliers of raw materials.

Now, I do the manufacturing; I am not going to go into the details of manufacturing, that you already have learned so much in this course. Now, I have some storage facilities; let us say two of them and then supply it to some distributors let us say I have 3 different distributors.

They may be supplying the material or sending the material to more than one distributor. So, let us say the first warehouse is sending it to all three distributors and the second one let us say to two distributors. Now, remember all of these arrows; they indicate transport of the material, bringing the raw material and sending the finalized products product. You actually strongly depend on your transport companies and the network of roads and trains.

So, this is also very very important for you. Often, this is the most important optimization problem; when we want to optimize the transportation because transportation has two things involved in it. One is the time of transportations, very important; especially when you are when you require something which for example, is very sensitive or when you are selling something that is very sensitive.

Let us say, you are selling fresh vegetables and you want to get them from different farmers in different parts of the country. What is most important for you, more than even the cost, what is more important for you is the time. So, if the vegetables reach you after 3 days; then they are not fresh anymore and you are known for selling fresh vegetables. Something like that will not happen to carbon materials.

You can keep it for several days and it is still good; most of the carbon materials at least. So, in general we strongly depend on transportation people. Now, what do these distributors do now? They send it to some other companies who are your final customers

in this particular case. So, let us say there is a water filtration manufacturing company and they definitely require activated carbon and they buy it from you.

Maybe distributer 1 and distributer 3 are selling it; why not distributer 2? Maybe because of the location of the warehouse, maybe because of the location of the water filter manufacturer. So, maybe for some reasons it is these two distributors, they send it to your manufacturer.

Maybe, not just to one company; you are now selling it to have multiple customers. So, your other customer is some cosmetics company, they add activated carbon into some soap or something; so that is they probably do not require as much quantity but they are also your good customers. So, maybe there are also some of the distributors that are sending it to this cosmetics company and the third one is a startup started by some ambitious students because they thought that this is easy, all I need is coconut shells. So, I can just make activated carbons. Let us say this is a group of three ambitious students from some IIT or anywhere, for that matter. And then these students have started this small company; again they do not require very high quantities, but they are also your valued customers. So, now again you see there is a network and again you depend a lot on the transporters.

Now, this is where your supply chain sort of ends; once you reach your customer; as long as you can satisfy all the demands and you can keep your customers happy, you are supply chain has such end. But now for if you want to make a supply chain for this water filter guy, they also will have some other suppliers. Maybe, they are not just buying the activated carbon from you, but from other manufacturers as well.

Also maybe the group of students are also probably making their own activated carbon. In fact, that is what they thought, they are going to do, but they thought that why do not we just also make the air purifiers.

And then they realized that suddenly the demand has increased so much that they do not have sufficient supply and they do not have the resources to make enough activated carbon, but they do have a lot of demand for their final product. So, in that case, they also then started buying it from other companies. The point is that the chain does not really or the network or supply chain does not really end at one point, it is just a part of a one big large supply chain.

That is why I have made this red arrow here; now these other manufacturers may also supply their activated carbon to some other companies; so it continues. Similarly, when you see that you have these coconut shell suppliers; who is your coconut shell supplier? You are not going door to door and collecting coconuts. You probably have some organization or some company that is collecting coconut shells or other types of waste materials and segregating the waste.

And then probably cleaning it up, making some right size pallets of an optimum size and that is how they are selling it; you do not just take individual coconuts. There is also somebody involved. They are also connected in that company, may also be connected to people in some way.

Similarly, your oil making company has its own supply chain; this is basically what you think of and every supply chain is a part of much larger network. Now, you will have other related decisions; some related decisions some of them we already discussed.

For example, assigning values to things based on the importance but what you can now when you are a manufacturer, you will also have to take some other decisions. For example, do you want to make powdered activated carbon, do you want to make pellets? For which type of carbon, you have more customers; sometimes you probably want to make just powder but you have more customers who would like to buy pallets.

In that case, you should be open to a little bit of change in your manufacturing as well. A little bit of flexibility, you should have. Now, I have not discussed is what is known as line balancing because that is a part of the manufacturing itself.

So, line balancing also something that is another related factor and you need to think of the decision line. Basically, your production line or assembly line describes different steps of manufacturing.

For example, cleaning the coconut shell and then optimizing their weights and then placing them in a certain type of furnace. And then you have to also think which type of furnace is good for you; do you want fluidized bed or do you want rotary kiln and that will depend on your application.

So, again the furnace and then you do the packaging of that product and what kind of packaging you require? So, this entire is known as production line and assembly line. So, these are the things also you will need to pay attention to.

Where should your facility be located? We are talking about both manufacturing plant and we are also talking about your offices, where you would be dealing with the financial matters and so on. You will often see that several manufacturers. They do not have their head office at the same place where they have the manufacturing unit. Because of various environmental regulations and also because how close do they want to be to their raw material supplier or whether they want to be close to the raw material supplier or they want to be close to the warehouse or they want to be close to the final customer; that would depend again upon various factors.

The one very important factor is the weight of your raw material or the final product. Do you have wet raw materials or dry raw material? Because, if you have wet material; that means, it carries a lot of weight; that means, you are going to spend a lot on the transportation.

So, you would rather stay close to the guy who is selling you the wet raw material then because your final product is dry. And it is also not important how long will it take during the transport; if your activated carbon reaches the customer or the warehouse in two weeks. But the raw material, if it is sensitive or if it is wet in that case. So, these are the decisions that you need to take accordingly and optimize these things.

And of course, the cost of transportation and the availability of transportation; these are the things that become important. And at the end the restrictions or the regulations of the local government. You know that different states within India or different countries in the world have different regulations for businesses.

They can be financial regulations for example, related to tax payments or they can be regulations, related to the environmental policies. So, all of these things you need to factor in and then you should start your business. So, now, let us quickly also see one more example.

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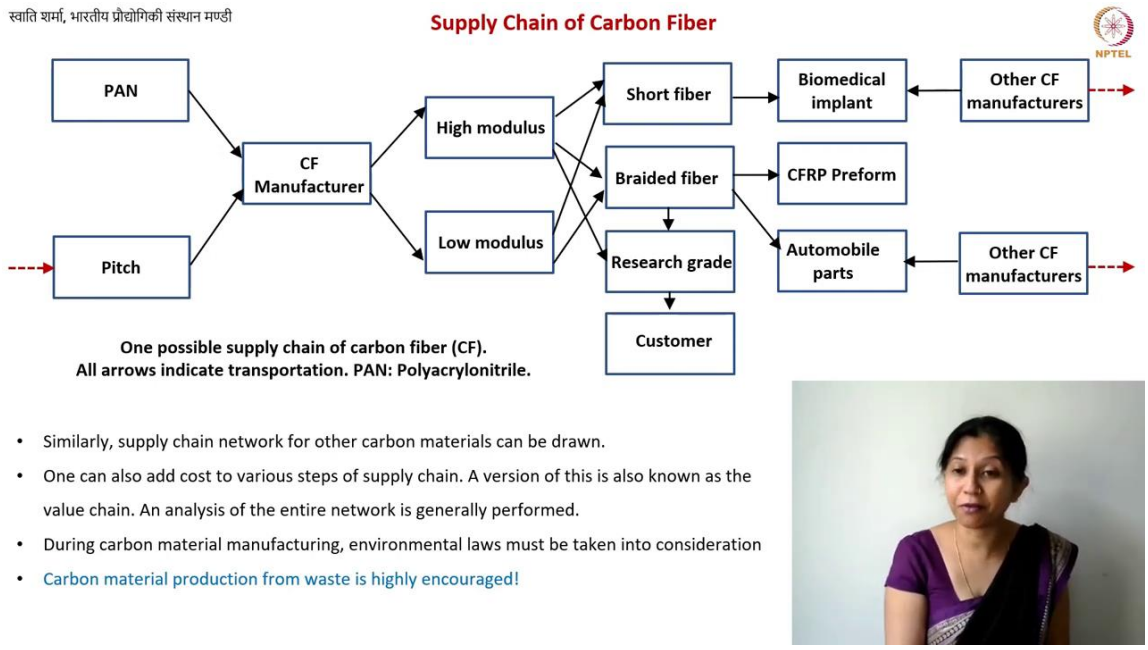

This example, I included because carbon fibers are very important nowadays. Here we will just quickly go over it. You are the carbon fiber manufacturer. Now, you have learned 2 or 3 techniques of making carbon fibers. Let us say you are not making vapor-grown fibers; you are not doing CVD because you want very large-scale production. So, CVD grown fibers are then more expensive in that case and also, they are not very long, so it is difficult to make preforms and so on.

You rather decide that I will just do electrospinning and melt spinning but then what precursors do you use? You know that different precursors will give you different types of different modulus of your carbon fiber. You decide that you will use both; you will use PAN polyacrylonitrile because that gives you nice and flexible fibers with good tensile strength. And you also decide that some of the customers want graphitic fibers, high modulus fibers.

So, then we are also going to use mesophase pitch for that purpose. You may use just mesophase pitch or both isotropic and mesophase pitch. These are your 2 suppliers of raw materials. Maybe PAN, you are buying for the company for the chemical plant that is producing it.

So, maybe you are directly buying it from there, but maybe that pitch is coming from some other petrochemical refinery; these intermediate people and then you from them you buy your pitches. Now, what do you have? You have 2 types of fibers. You have

high modulus fiber, low modulus fiber; you can also call them general-purpose fibers. So, you now make 2 different types of fibers, but once you make these two different types of fibers.

This is in terms of the modulus we were talking about, now you also decide that I want to have short fibers as well as long fibers. So, short fibers and say braided fibers. Again because short fibers are also used for certain applications; you know certain types of composites require short fibers rather.

So, you make both; you also make braided ones and then there is a third type that you are also providing is what you call a research grade carbon fiber for a lot of research purposes. What you require is a very high quality of carbon fiber. Quality could be in terms of modulus mechanical strength, microstructure and also in terms of purity.

And for many research applications, you need to provide exactly what you are saying. In the sense that even there are very small tolerances when it comes to research grade materials. So, you decide that you are also capable of making some research grade fiber.

They will have a high cost; they will be more expensive, but at the same time the quantities are going to be relatively low; relatively small. Again, you have this network of who gets which high modulus fiber, you are making research grade as well and braided as well and then you see these arrows here.

And here you can see that this may or may not require transportation; that depends on whether or not you are in within your facility and able to perform the certain process of making short fibers. Now who buys it? There is some company who is making biomedical and they definitely require short fibers; so that they are your customers, only one customer you have.

But for braided fibers, you have more than one customer. Let us say there is some automobile company, they require the preforms and there is one company that probably only makes the performs. So, you have these CFRP companies making companies as well as the automobile industry; they are your customers.

And you also decide that you can sell even braided fibers for research purposes if the quality is good enough; so, some of it also goes into your research grade. Now, the

research grade things are directly sold to the customers; that is maybe it is done online; so that is directly sold to the customer.

This is also one of your strategies. These biomedical company, the implant people, they are also buying the different types, different sizes of carbon fibers may be also from different manufacturers. Again, as you saw in the previous example that the supply chain; thinks that this chain itself is not independent.

And you could actually potentially draw a supply chain for also this automobile part company, for example, they will have their own supply chain which is connected to yours. So, this is basically is the supply chain of carbon fibers and here these red arrows are showing that it is connected to other companies and so on. Now, you can draw a supply chain network for various carbon manufacturing companies on your own.

You can do that as an exercise for yourself and you can also then do further analysis for example, for each step; the arrows I said show the transportation, you can actually also mention the cost at every step. When you have also cost associated with the supply chain; you call it a value chain. Sometimes, you can also do this kind of analysis, you can do what is known as the entire network analysis which will tell you everything about the time and cost.

And as I mentioned a lot of these things nowadays are done using certain software but you should know the fundamentals, how it is done. One thing that I personally recommend that you should always take care of the environmental regulations; carbon materials do cause some pollution when we are manufacturing them. But at the same time, it is also not very difficult to ensure that you are not allowing those pollutants to go into the environment.

You can actually have a lot of filtration devices to catch those carbon particles that are unburnt and then reprocess them, similarly, for few gases; so you have these exhaust gases which contain maybe some tar. But you can actually also collect them and then you can reuse that tar or even you can even use that kind of tar or collection of that pyrolysis oil.

For example, for making a lot of for making carbon black. So, using it as a raw material for another industry that can even become your products; one of the byproducts of your

company. So, the only thing is that you need to think about it and you need to make sure this should be something that you should be aware of and then this may even help you increase your profitability.

So, utilize the waste and also when it comes to making carbon materials because a lot of cellulosic waste can yield good carbons especially the char type of carbons. So, in that case, that is something which is highly encouraged, and I hope that there is a good market for waste-derived carbon in the future.