System Design for Sustainability
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Week – 12
Lecture - 01
Design for Sustainability - Engineering Design Criteria and Guidelines

Hello, welcome to our today's lecture. So, this lecture will be on Engineering Design Criteria and Guidelines, where can you use the particular guidelines that I will be talking about today is in design of any kind of product. So, these while you are trying to design a product or when you are trying to analyse an existing product, you can use all these guidelines to determine the sustainability or to build in aspects of sustainability.

So, these guidelines have been taken from this book called as Design for Environmental Sustainability. If you are more interested in understanding and knowing more about this particular all the guidelines, then you can also go through this particular book, but it is not a mandatory read for this course.

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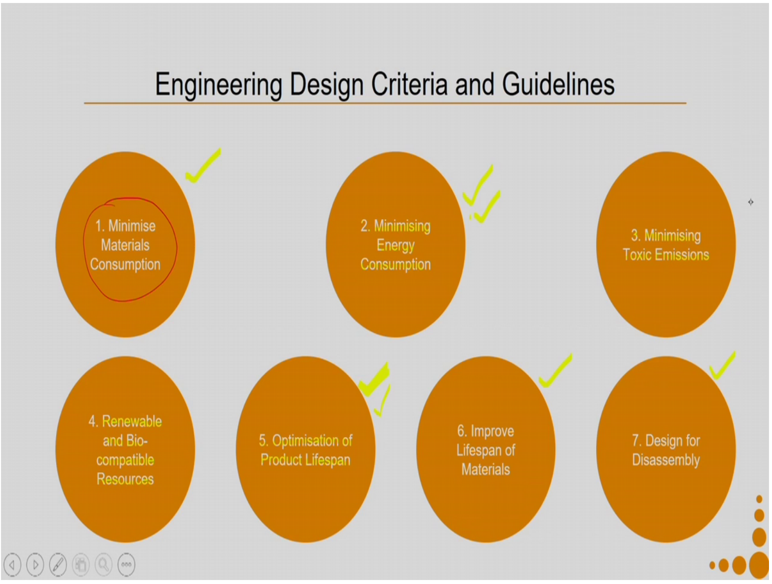

So, the engineering design criteria and guidelines goes like this. So, the first criteria is minimise material consumption. Second is minimise energy consumption, then minimise toxic emissions, renewable and biocompatible resource usage, optimisation of product lifespan, and improve lifespan of materials. Finally design for disassembly. So, why do we why are we supposed to go ahead with the first one that is minimise material consumption. So, the lesser amount of material that we use, higher is a environmental benefit, because we are causing less damage to the environment. We have less material which is being consumed by the in a product as well as less material when the product will reaches end of lifespan.

Then minimise energy consumption this energy consumption maybe in the use phase, maybe in the production phase, maybe in the design phase. So, first we have to understand where the energy consumption is the most impactful and then we have to give higher priority in minimising the energy consumption at that particular phase. And in general we have to try to optimise on the energy consumption.

Then minimising toxic emissions. So, you have to try as far as possible there should be no toxic emissions that is the most ideal case. In case it is unavoidable we have to see how can we minimize toxic emission from happening. Again the toxic emission can happen during the preproduction phase, during the production phase, during the usage phase or during end of life phase. So, we should identify the areas where the emissions they has the highest impact or highest volume leading to highest impact there we have to put in more effort. How do you come to know where the toxic emissions have the highest impact or where the volume is a highest? You can know this by doing a life cycle assessment.

Then using renewable and biocompatible resources this again helps in making reducing the footprint of the product or the service that you are designing. So, talking about optimisation of product lifespan our fifth criteria; so, we do not talk over here as a designing for a long life. Why we are not talking of designing for a long life, of course, we should design for as long life as possible, but what we are talking more in terms is optimisation of product lifespan. Why, because like if you remember when we were doing the life cycle assessment and design for products for environmental good performance, we were discussing about an air conditioner. So, an air conditioner if it is designed in the manner say it has a very very long life, very good because I am using minimum amount of material, because my consumer does not need to change the air conditioner every now and then.

But the drawback for that particular context is for an air conditioner, the highest impact is at the energy consumption level. Now, at the energy consumption level because every year I have more and more better performing more energy efficient in the air conditioner is coming. So, an extremely long life air conditioner which was built say 20 years back might not be performing very good on energy consumption aspect.

Hence we talk about designing, so that I can have an optimum product lifespan and I can design it in the manner. Say for example, I know certain components of the air conditioner if it is changed regularly in a say in a couple of years time span, my products lifespan will also increase, and at the same time my product will also work with efficient energy consumption.

So, in that case, maybe I can my optimisation idea in that particular case will be designing the AC in a manner that I can keep on changing those components which brings in the energy efficiency plus it minimises material consumption also. So, which means it gives the product a long life. So, many different techniques can be applied for bringing in optimisation of product lifespan.

Then comes improve lifespan of materials that is being used. So, how do I design the product in a manner that the product does not become redundant because say for example, one part in the product broke down because that part was under stress. So, say if you in the case of a refrigerator, because the cold environment inside and there are different types of materials used. Say because of the cold environment a part of the material cracked, because I did not design the material with a particular lifespan. So, then I will have to change the whole refrigerator just because that particular part cracked. So, we have to consider that how can I design my whole product in a manner that I can improve the lifespan of each and every material used, maybe by strengthening it or maybe by using the appropriate kind of materials and so on.

Finally, is the design for disassembly. So, a product in order to do an appropriate lifecycle treatment, say for example, a product is made up of layers of paper and plastic. In case if I can separate the paper and plastic, I can take the paper for composting or for recycling, whatever is applicable in that context and I can take the plastic for a different kind of recycling process.

But see in case it is not possible to disassemble them that is separate them out together, then I cannot do any recycling with them. The only thing that can be done with that kind of a combination is either through it into the landfill, I might not be even able to incinerate them properly. There are certain cases in which u can incinerate them in other cases you cannot incinerate them. So, I have to in order to the product each or every component to be either reused remanufactured, recycled or incinerated or to go for the landfill it is good that you design for disassembly.

Another thing which this helps you is if a certain part breaks down, I do not need to discard with the whole product or say a larger part of the product, because I can easily disassemble it and I can put a new part which had broken. So, let us see how do we go ahead with these engineering design criterion guidelines.

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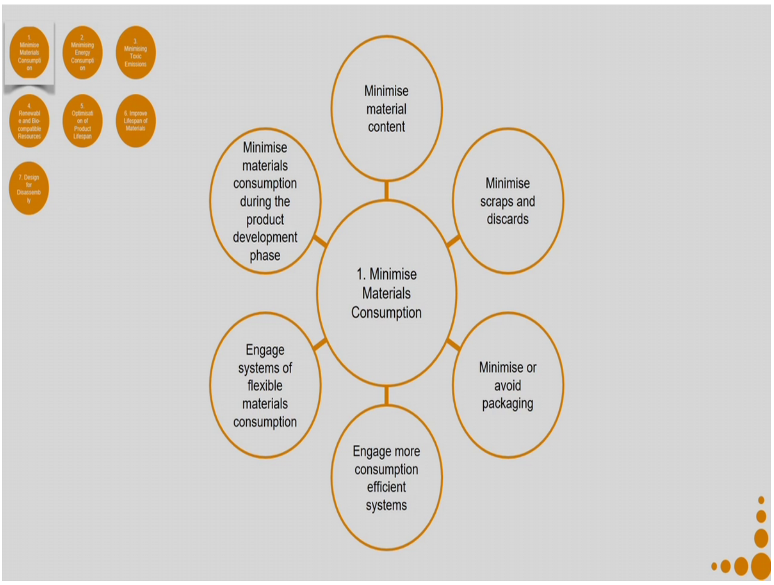

So, let us talk about minimising material consumption. So, the first step is I try to minimise material content, then I minimise scraps and discards. So, say for example, out of a sheet of paper, if you want to cut circles, and the circles will be used for certain secondary process. After all the circles are cut out what I get is a scrap. So, I have to also think and the scrap might be discarded or it can be reused for making another sheet, their time when it needs to be discarded.

Say for example, if it is composite that is made up of couple of layers of different materials, most likely it has to go for discarding or otherwise if say it is plastic product and it is one homogeneous plastic it can go as a scrap it can be recycled and it can be again used back. So, in any case I should try to minimise scraps and discards which happened during the manufacturing process.

Then minimise or avoid packaging. So, say for example, if I have a pen which is very fragile, because I designed it in that particular manner, I will have to have additional layers of packaging on top of it so that it does not get damaged during transportation or while it is being displayed in a shop. So, in case in this particular case I could have designed my pen in a manner that I might no longer required packaging or I might require a lesser volume of packaging. So, we should always think so, you are designing the product, but now you are also trying to think about how do you minimise or avoid packaging which is be coming into picture just because the way you have designed the product.

Then engage more consumption efficient systems. So, if we have more efficiency a built into the system, my consumption level will go down or I will have more optimal consumption of the material that I have used to make the product. Then engage systems of flexible material consumptions. And finally, minimise material consumption during the product development phase as well. So, when you are designing the product at that particular phase, let us go into depth of each of these aspects and see how all we can to them. All these are examples of doing it, do not limit yourself to do to the sub criterias. So, minimise material content.

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So, you can minimise material content by seeing can you miniaturise certain components or you can digitalise the product or some of its components in a manner that you can minimise the material content. Say can you reduce the thickness, but build in strength by building ribs, can you avoid extra components with little functionality. So, if a particular part has very little component is it really necessary in that particular product; avoid over sized dimensions just because you want to make it look big or you want to a make it feel big bigger means material. So, try to see how you can bring in the most optimal size.

But yes when you are trying to do this reducing the size of the product, you should also take into consideration that the how the product is going to be used. If I am supposed to hold a product in my hand and use it in a certain manner and the product becomes too tiny it becomes very difficult for me to hold that product. If I have to open something, I need a particular dimension to be to easily open up; if it is too small, I will not be able to put in that much of effort. So, under those considerations you try to avoid oversized dimension.

You can apply ribbed structures to increase the structural thickness. Also say for example, I want to have a smaller knob rather than a bigger knob because a smaller knob prevents or minimises material usage. I can also add ribs because that adds to the grip and I can apply more force than having a completely flat surface. You can dematerialize the product or some of its components, so that is remove material from there.

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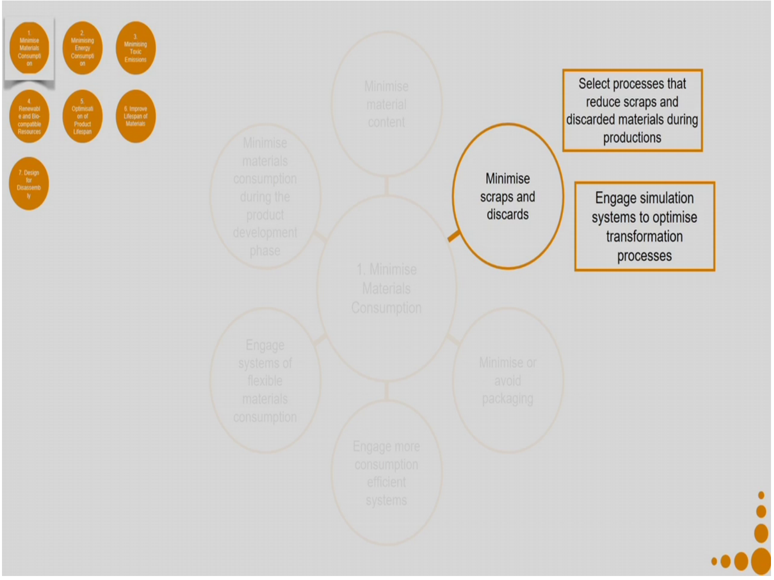

Coming to minimise scraps and discards, say select processes that reduce scraps and discards materials during production, so that you can manufacture your particular product by using two different manufacturing processes. One manufacturing process generates more scraps, the other generates less scraps. So, go for the process which generates less scraps or go for the process where the discarded material during production process is minimum. Engage simulation systems to optimise transformation processes. So, when we use simulation, we can optimise onto the scraps and discards produce in a big manner.

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Minimise or avoid packaging. So, apply materials only where absolutely necessary. Design the package to be part or become a part of the product that can be another strategy in which the package is not supposed to be discarded, but the package can be used for storing the product or for any other purpose or maybe say the package gets turned into a tray and you can keep on using that particular tray. Best possible situation is avoid packaging completely, but yes of course, it is always not possible to do that.

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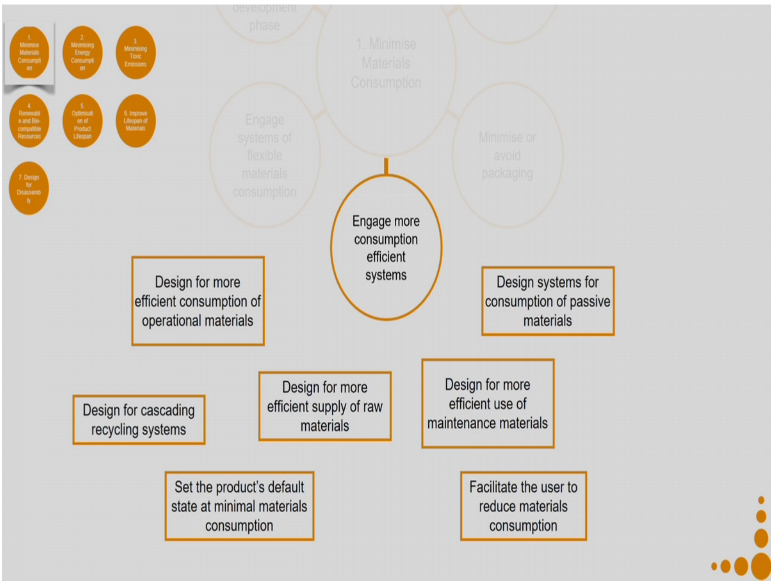

Now, how do we engage more consumption efficient systems? So, design for more efficient consumption of operational materials. So, all those materials that are required during the operation of the product you should consider them and how can you make their consumption more efficient. Say for example, if you are making a printer and you realise that that particular printer, a waste lot of paper because there is lot of misprinting happening or every time you want to you put in a cartridge, you need to put in couple of pages to do the alignment. So, in that is where it is the operational material is consumed in a big way and it is a waste material you cannot use those prints after that. So, you can see how can you make that consumption more efficient.

Design for more efficient supply of raw materials. So, when you are making your product, all the raw materials which are to be supplied for making a product. See how can you come up with a more efficient supply of raw materials. Design for more efficient use of maintenance materials. So, all those things which are required for maintaining your product, how can you build an efficiency in that particular context.

Say for example, from our fresh example, the filter is a particular product which needs to be continuously changed that is a maintenance material. And we can see how can we bring in more efficiency there. Design systems for consumption of passive materials. So, materials which do not have much impact on the environment, then design for cascading recycling systems so that I can recycle them.

Set the products default state at minimal materials consumption. So, say for example, in case of a printer, if you set the default at the best printing, then you might be consuming more ink. But in case if you would have set the default to more optimal printing say a medium level of printing, the user will change as per their requirement, but if the user still continues to use the default settings this because the user is not trained enough in that particular domain, you are still using the ink in a more optimal fashion. Facilitate the user to reduce material consumption, so maybe train your user or inform your user or design your product in a manner that the user can reduce the material consumption.

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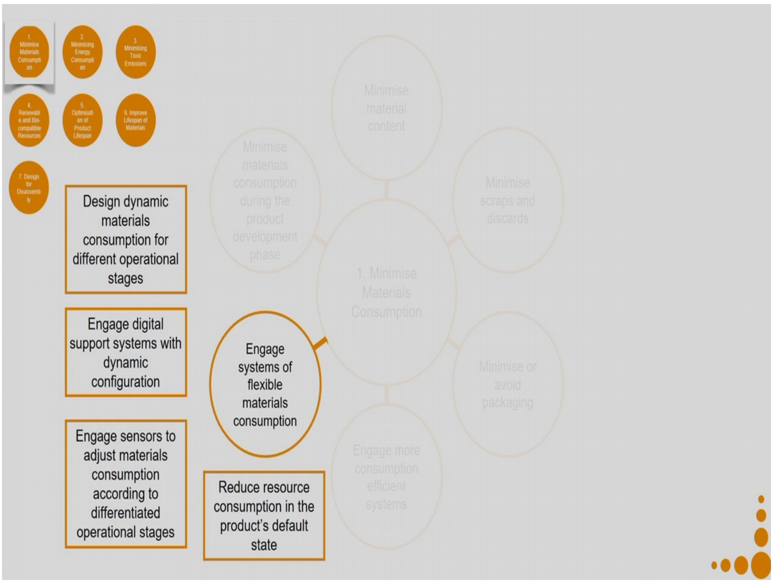

Engage systems of flexible material consumption. So, like design dynamic material consumption for different operations stages. Say for example, our context when we were talking about different quality of clean water for drinking, washing utensils, washing clothes and bathing. So, this can be an example of that that depending on what consumption I am doing, I am optimising my product delivery accordingly.

Engage digital support systems with dynamic configuration, rather than having manual settings or having mechanical settings, maybe digital settings can be used in case they are helping you in minimising material consumption.

Engage sensors to adjust materials consumption according to differentiated operational stages, because human beings might not be very good at doing this particular task. So, sensors might workout more better in this particular context. Say for example, you can also use sensors in a building. So, when people move out of that particular space, you can lower down the air conditioning or you can switch off the lights. Reduce resource consumption in the products default state.

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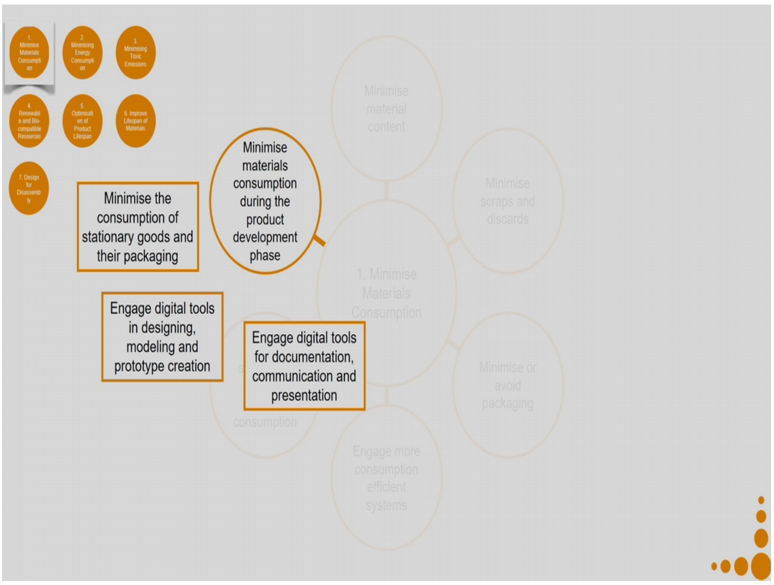

Now, coming to the last one which is minimise material consumption during the product development phase. Minimise the consumption of stationery goods and their packaging. The product development phase might have lower impact as compared to when you are the product is actually in production or in use. Hence, this might not be the most important phase to concentrate on, but this is also an important area where you can focus on. So, you can minimise consumption or stationery goods and their packaging, engage digital tools and designing modelling and prototype creation. In case you are not using digital tools you might have to make too many physical prototypes, which is a waste of material.

Engage digital tools for documentation, communication and presentation, rather than printer documentation. So, when I talk about all these different strategies for minimise material consumption, they are just guidelines given to you. You can try to minimise the material consumption in many other manner. So, when you take up a particular product, you can come up with more and more ways or in which you can minimise material consumption.

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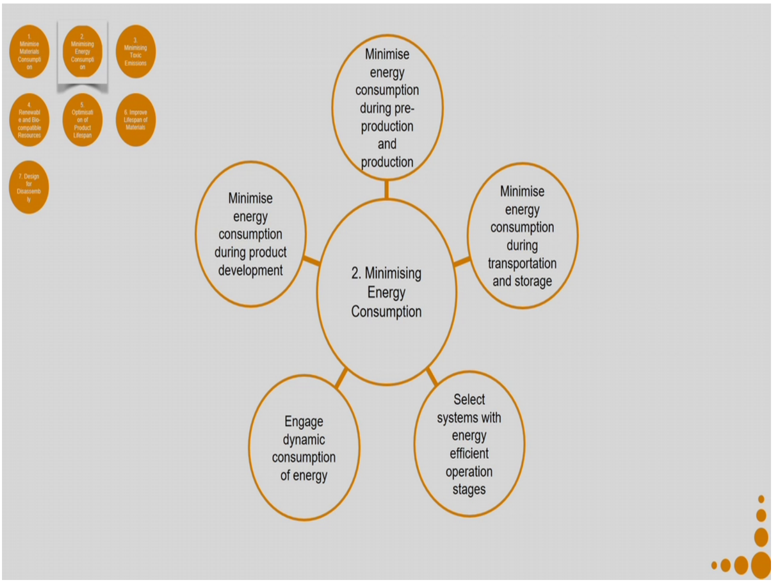

Now, minimising energy consumption. So, minimise energy consumption during pre production and production, minimise energy consumption during transportation and storage, select systems with energy efficient operation stages, engage dynamic consumption of energy, minimise energy consumption during product development.

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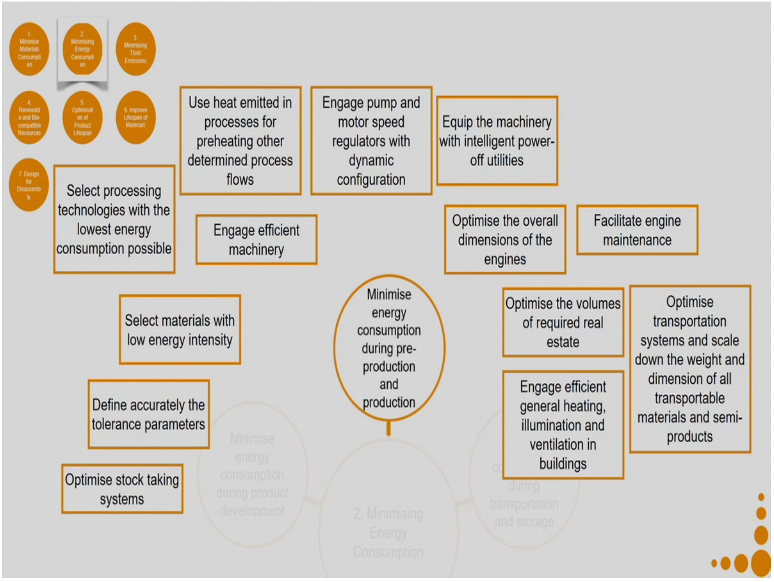

So, let us see some examples on how can we minimise energy consumption during pre production and production. So, engage pump and motor speed regulators with dynamic configuration, use heat emitted in processes for preheating other determined process flows. Engage efficient machinery, equip the machinery with intelligent power of utilities, select processing technologies with the lowest energy consumption possible, optimise the overall dimensions of the engines, facilitate engine maintenance, select materials with low energy intensity. Optimise the volumes of required real estate, define accurately the tolerance parameters, optimise transportation systems and scale down the weight and dimension of all transportable materials and semi products, optimise stock taking systems, engage efficient general heating elimination and ventilation in buildings.

So, here you can see it is not only about the product, but it is about the entire pre production and production stage. So, you as a designer might not be involved in doing all these activities, but your team is involved in all these activity. So, your entire team can look up into all the pre production and production stages and these can be some of the examples in which one can optimise onto the energy consumption during preproduction and production.

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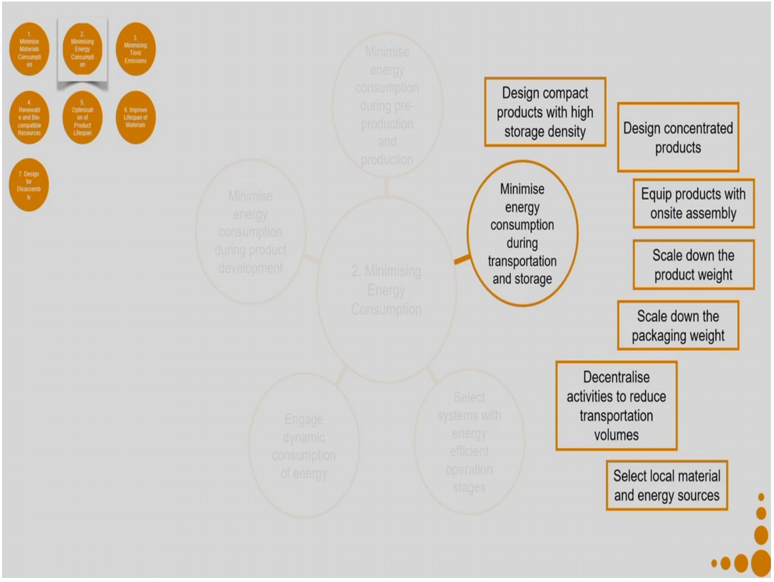

Now, minimise energy consumption during transportation and storage. So, design compact products with high storage density. So, in case you are person who is designing the product, this is completely related to your work, design compact products with high storage density. Design concentrated products. So, say for example, rather than having very low concentration cleaning product, you can sell it as a concentrate, and ask the buyer to make certain amount of water to it or any other solvent, which reduces the concentration before using it.

Equip products with onsite assembly, so that when you are transporting it the volume trance volume of transportation reduces. Scale down the product weight as far as possible, scale down the packaging weight as far as possible, decentralized activities to reduce transportation volumes. So, say for example, in a very big country, if I have a manufacturing unit located say somewhere in central India, then almost whole of India is equidistant in terms of transportation.

Say I have this particular manufacturing unit located somewhere in one extreme corner, so there is huge transportation requirement. Can I split this factory into two different location, so that I can minimise on the transportation or say for example, can I many have many more locations or can I have my things manufactured in certain location were assembled in another location, which is closer to the consumer. So you can check out what can be an appropriate strategy for your product to minimise the energy consumption. Then select local material and energy sources.

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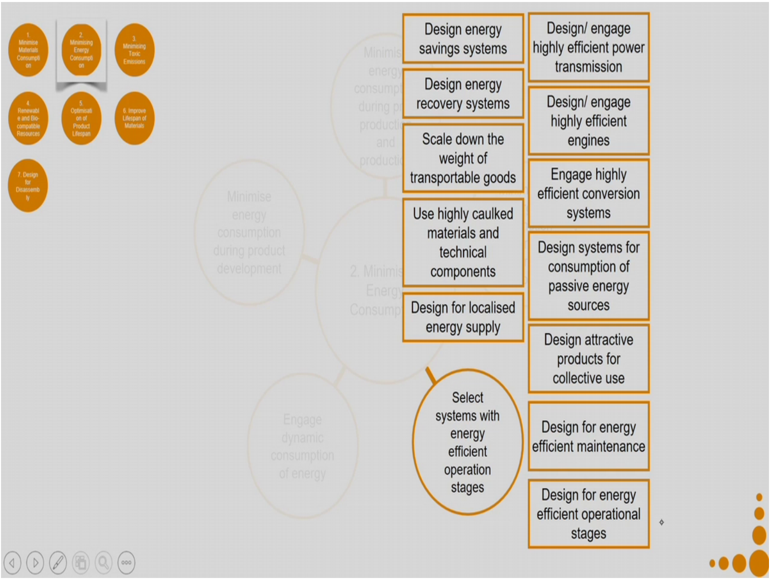

Now, coming to select systems with energy efficient operation stages. So, design for localised energy supply, use highly caulked materials and technical components scale down the weight of transportable goods, design energy recovery systems. Design energy savings systems, design or engage highly efficient power transmission, design or engage highly efficient engines, engage highly efficient conversion systems. Design systems for consumption of passive energy sources. Design attractive products for collective use. Design for energy efficient maintenance. Design for energy efficient operational stages. Not necessarily you have to do all of these, you can apply some of these whichever is applicable and any other strategy which you think can be applicable for your context.

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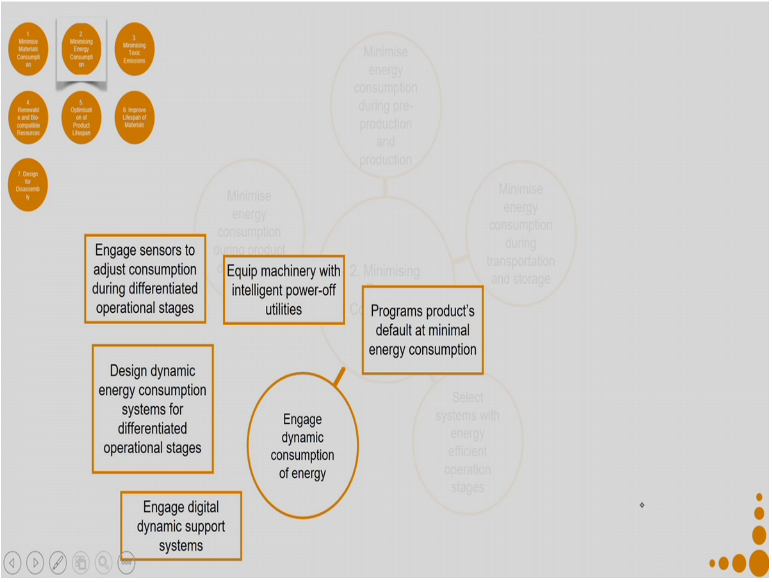

Engage dynamic consumption of energy. So, engage digital dynamic support systems, which helps you to do that. Design dynamic energy consumption systems for differentiated operational stages. Engage sensors to adjust consumption during differentiated operational stages, equip machinery with intelligent power of utilities program product's default at minimal energy consumption.

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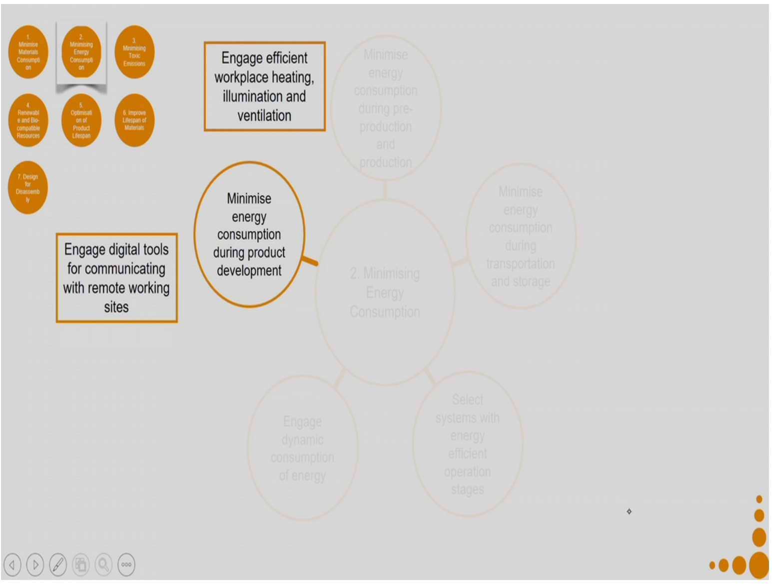

Then coming to the last one, which is minimise energy consumption during product development. So, engage efficient workplace heating, illumination and ventilation. Engage digital tools for communicating with remote working sites.

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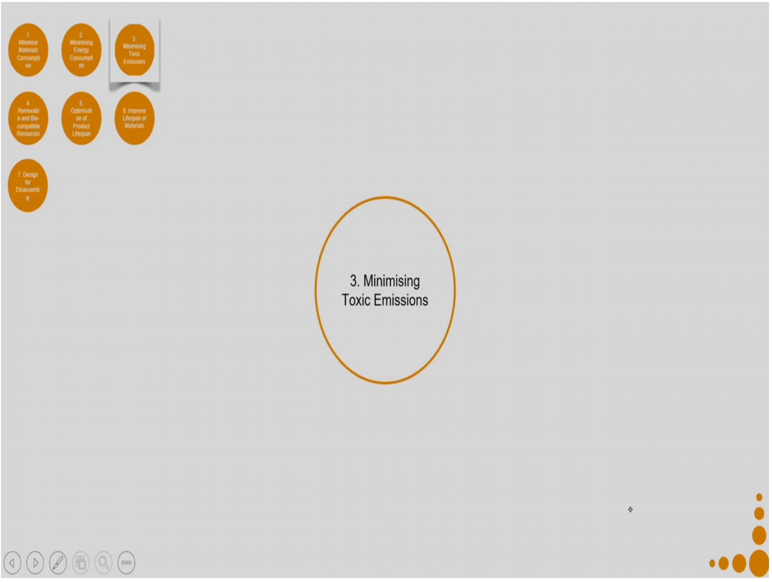

Now, let us come to the third criteria which is called as minimising toxic emissions. As far as possible, you should avoid toxic emissions. In case not, then see how can you minimise the toxic emissions.

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So, select non-toxic and harmless materials and select non-toxic and harmless energy resources. So, for a non-toxic and harmless energy resources you can select energy resources that reduce dangerous residues and toxic and harmful waste.

Say for example, thermal power generation, there is lot of your burning coal, so that is having lot of toxic emission happening or lot of greenhouse gases are emitted as a result; or say for example, you are generating power through nuclear sources, there again chances of toxic emissions or toxic waste.

But, say you generate your electricity using solar power or wind power or tidal energy, there is no chances of residue or toxic and harmful waste. Select energy resources that reduce dangerous emissions during pre-production distribution as well as usage.

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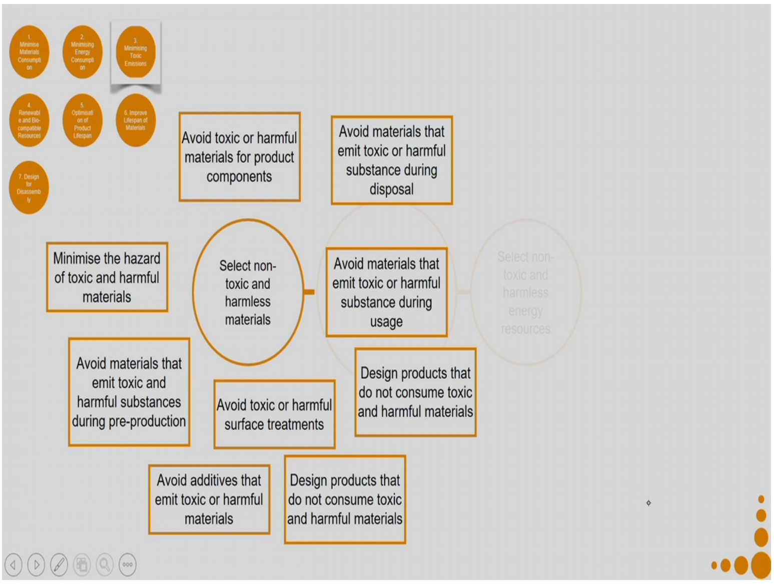

Now, selecting non-toxic and harmless materials; so, you avoid toxic or harmful materials for product components. Minimise the hazard of toxic and harmful materials, avoid materials that emit toxic and harmful substances during pre-production. Avoid additives that emit toxic or harmful materials. Say for example, many of the paints that is used in our interior on our interior walls or on our interior products, they do have a tendency to emit certain toxic elements so, avoidance of all using such kind of additive such kind of paints.

Avoid toxic or harmful surface treatments. Design products that do not consuming toxic and harmful materials. Design products that do not consume toxic and harmful materials. Avoid materials that emit toxic or harmful substances during usage. Avoid materials that emit toxic or harmful substances during disposal. So, you consider the entire life cycle of the product from pre-production up to disposal, and there should be minimization on all these different stages and in different components up till the surface finishing level.

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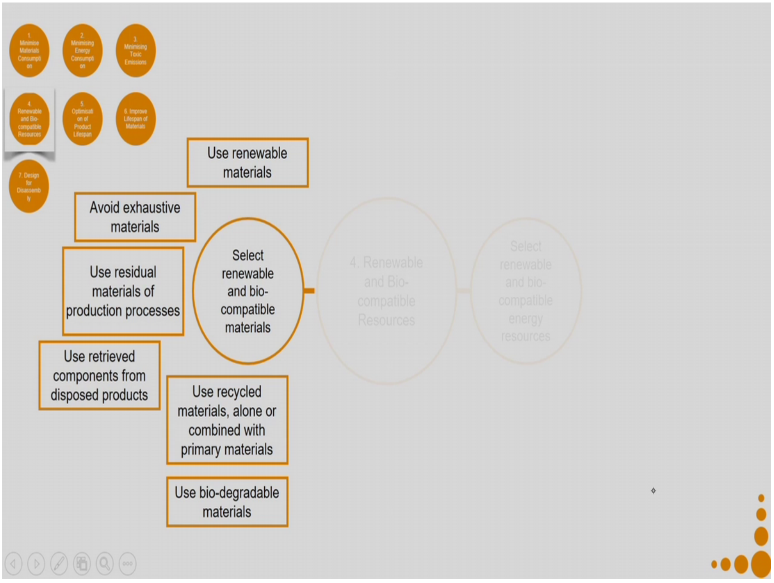

The fourth part is how do we bring in the usage of renewable and biocompatible resources. So, select renewable and bio-compatible materials and energy resources. So, for materials what we can do is, we can use renewable materials. Say for example, metals, they can be again in a recycled and used back without much degradation in their properties. Avoid exhaustive materials, materials which tend to get exhausted soon. Use residual materials of production processes. Use retrieved components from disposed products. Use recycled materials alone or combined with primary materials. Use bio-degradable materials.

If in case when you use bio-degradable materials, you have to also consider under what circumstances do they bio-degrade. Say for example, those build bio-degrade only when I put them under right composting situations, then you might have to also create the a way in which all those bio-degradable materials can be collected back from the consumer and composed it. If that does not happen, then the whole purpose of using bio-degradable material will fail.

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Then coming select renewable and bio-compatible energy resources. So, you can use renewable energy resources, you can engage the cascade approach. You select energy resources with high second order efficiency.

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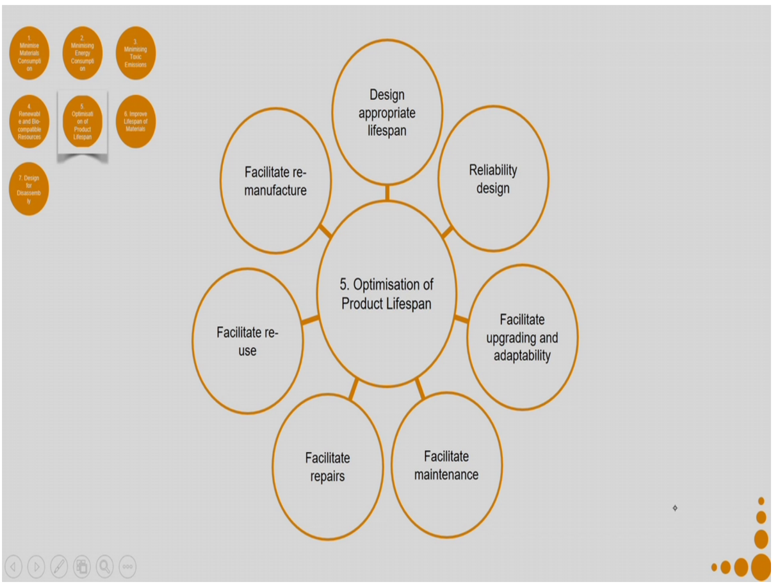

Next, coming to optimisation of product lifespan. So, you can design for appropriate lifespan. So, again we are not talking about long lifespan, but we are talking about appropriate lifespan. So, for each and every product, each and every component and then in that product, the definition of appropriate lifespan will vary. Also, it will vary from product to products.

So, say if it is a lifestyle product, the products lifespan is anyways very small, because it is a lifestyle product. People would discard it after a certain amount of time, when it does not fit into their lifestyle anymore then design for reliability. Facilitate upgradation and adaptability, so that the person can use the product for very much more longer time. Facilitate maintenance, facilitate repairs, facilitate reuse and facilitate remanufacture.

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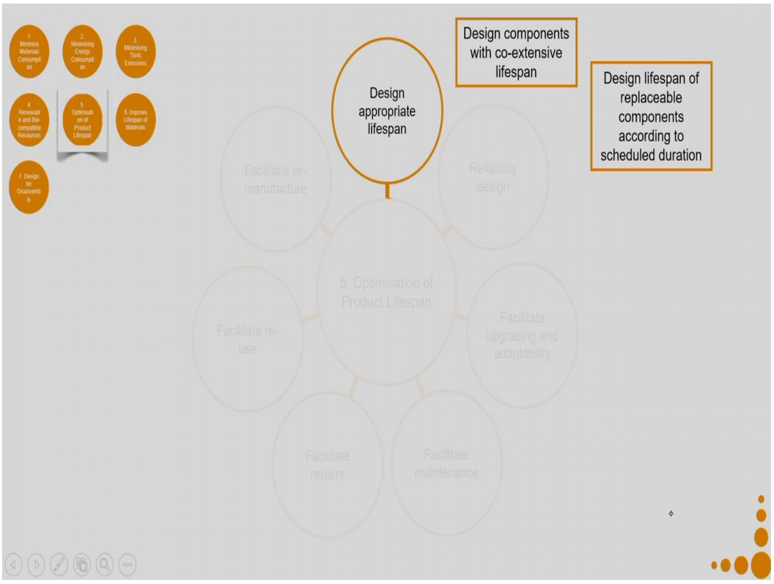

So, design appropriate lifespan. What all can be do here, some examples. Design components with co-extensive lifespan. So, I know that a particular products lifespan is say 20 years, so I will try to design different components into it, which might also have a long lifespan. Say if I know that my whole product only has a 5 years lifespan, but I have a component in it, which has 20 years of lifespan.

Then I should have some mechanism in which I can collect this component, which has 20 years of lifespan, after the product is no longer useful. Otherwise, I am wasting that particular the material consumed, the energy consumed in that creation of that component.

Design lifespan of replaceable components according to scheduled duration. So, say for example, if I am designing a water purifier in which there are three components, which needs to be replaced every 1 year, but there is one component, which needs to be replaced every 1 month, so my service engineer will have to be constantly going and visiting them to replace that component every 1 month.

So, can I design the machine in a particular manner, which I know that there are these certain five components, which need to be constantly replaced, but I design it in a manner that they can be replaced together. Select durable materials according to the product performance and lifespan. Avoid selecting durable materials for temporary products or components very important.

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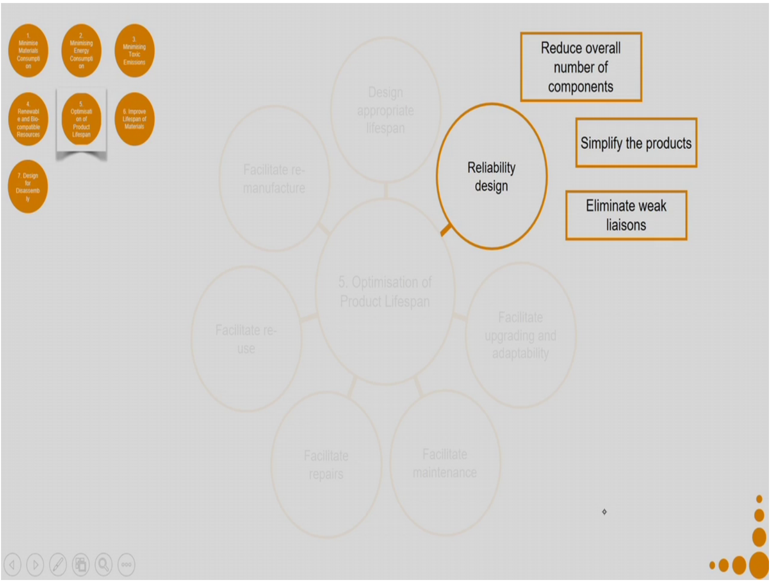

Then reliability design. Reduce overall number of components; more the number of components the chances of some component breaks down is very high. Simplify the products, eliminate weak liaisons.

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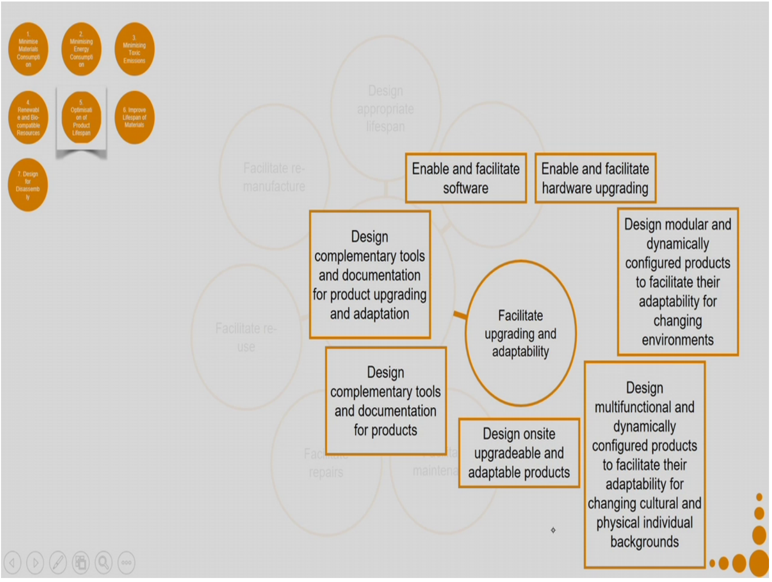

Then coming to facilitate upgrading and adaptability. So, enable and facilitate software, enable and facilitate hardware upgrading. Design modular and dynamically configured products to facilitate their adaptability for changing environments. Design multifunctional and dynamically configured products to facilitate their adaptability for changing cultural and physical individual backgrounds. Design onsite upgradable and adaptable products, design complementary tools and documentation for products, design complementary tools and documentation for product upgrading and adaptation.

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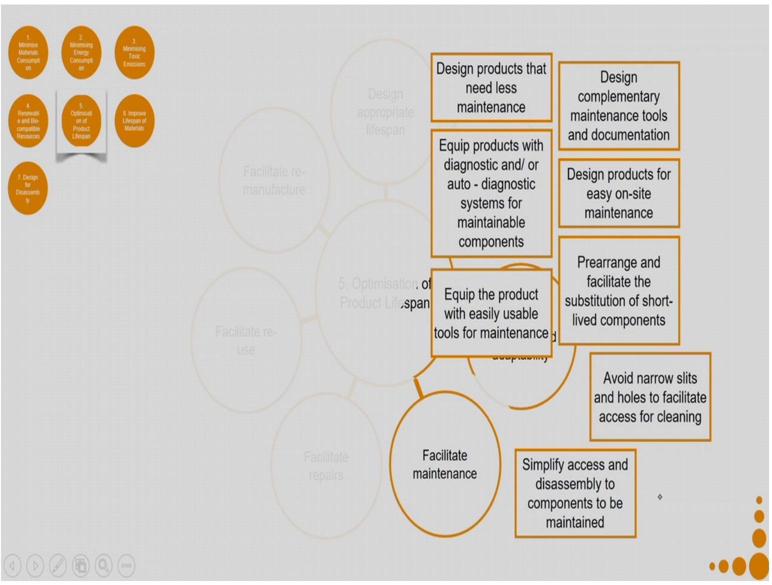

Then coming to facilitate maintenance so, simplify access and disassembly to components to be maintained. If you do not have access, you cannot disassemble them the components. Avoid narrow slits and holes to facilitate access for cleaning. Prearrange and facilitate the substitution of short-lived components. Maybe you can place all the short-lived components in one particular panel, so I just remove that panel and I can get rid of all the short-lived or I can have an access to all the short-lived components.

Equip the product with easily usable tools for maintenance. So, when if you know a particular panel needs to be removed to do some maintenance, it should be removable by easily available tools, and not like a very special tool, very expensive tool. Equip products with diagnostic and or auto-diagnostic systems for maintainable components.

Say for example, many digital components say many say for example, induction heater, when there is an error into it, it displays an error code. So, if you have a booklet with all the error codes, you can read that booklet and you can understand what kind of error is happening. Same with washing machine, it display and error code, so that you know what diagnosis; so you know exactly what diagnosis you can give it.

Design products for easy onsite maintenance, so that I do not have to carry the product from site all the way up to the factory or to the shop floor or to the showroom. Design complementary maintenance tools and documentation. Design products that need less maintenance.

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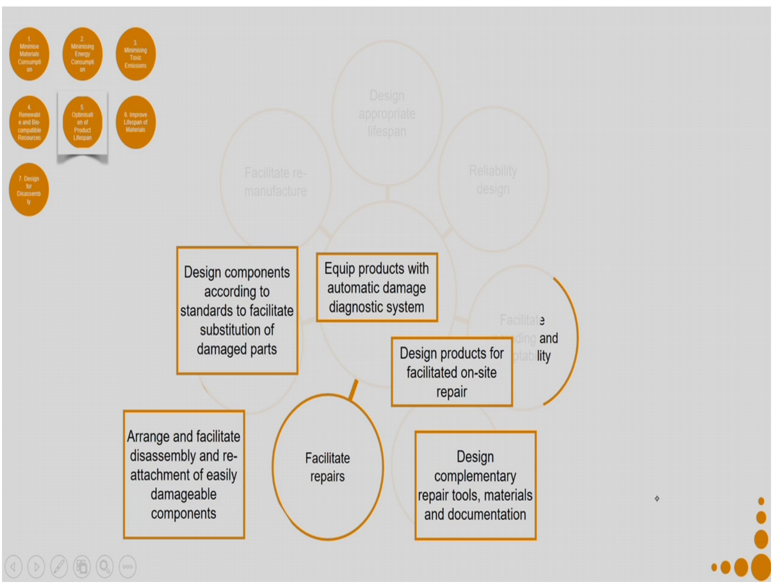

Then coming to facilitate repairs. So, arrange and facilitate disassembly and reattachment of easily damageable components. Design components according to standards to facilitate substitution of damage parts. Say for example, some of your components are very generic components, they can be bought of the shelf from any particular any shop say any hardware shop, so in such cases it is better that we design as per standards, so that substitution of damage parts can happen more easily. Equip products with automatic damage diagnostic systems. Design products for facilitated onsite repair. Design complementary repair tools materials and documentation.

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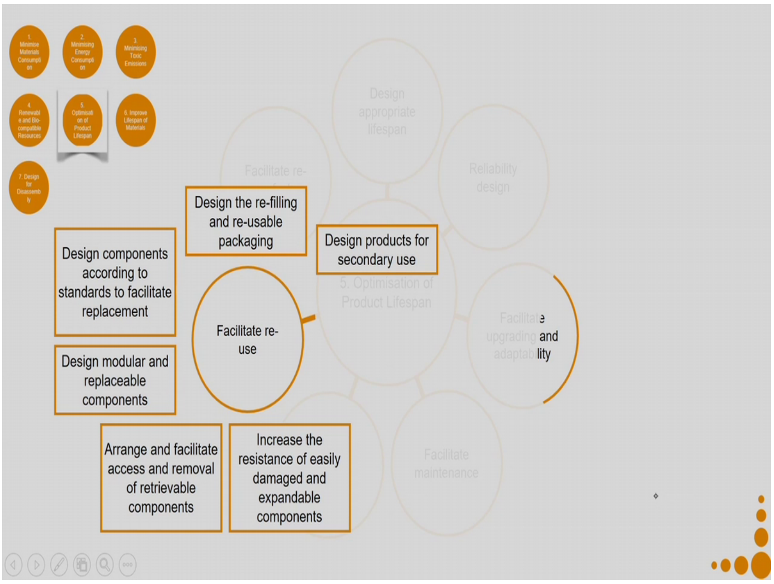

Then coming to facilitate reuse; so, increase the resistance of easily damaged and expandable components. Arrange and facilitate access and removal of retrievable components. Design modular and replaceable components. Design components according to standards to facilitate replacement, design the re-filling and reusable packaging. Say for example hand wash, you can also by the hand wash in a bottle, and the bottle does not get damage so often. So, after that bottle is finished, you can also buy refill pouches. Design prototypes for secondary use.

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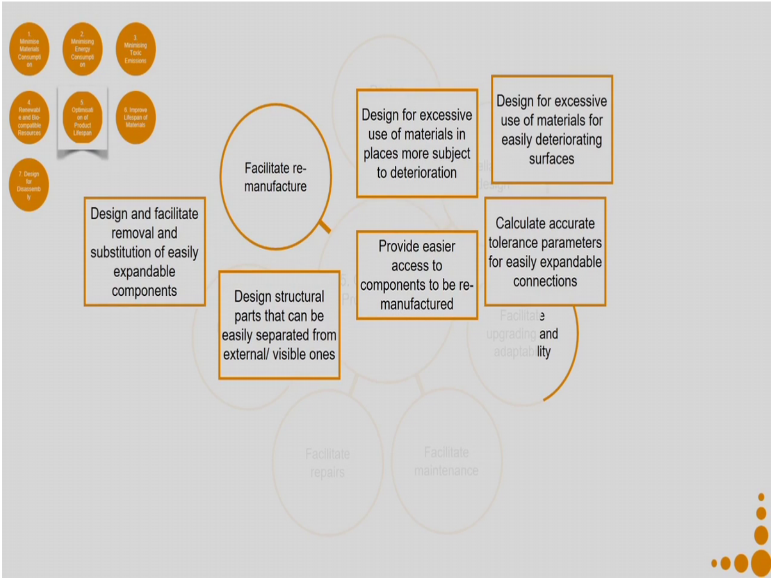

Then coming to facilitate re-manufacture. So, design and facilitate removal and substitution of easily expandable components. Design structural parts that can be easily separated from external or visible once. Provide easier access to components to be re-manufactured. Calculate accurate tolerance parameters for easily expandable connections. Design for excessive use of materials in places more subject deterioration. So, here you can see, we are talking about use of excessive material. Just, because we expect that the part might deteriorate more often. Design for excessive use of materials for easily deteriorating surfaces.

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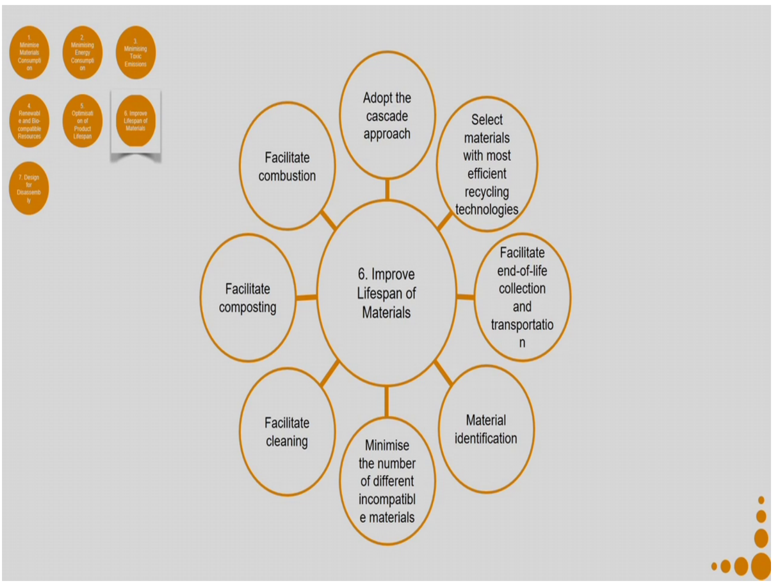

Now, coming to the 6th aspect, which is improve lifespan of materials. So, under this category, we can have adopt the cascading approach. We can select materials with most efficient recycling technologies. Facilitate end of life collection and transportation. Material identification should be possible. So, if I do not know what this material is, I do not know how to do end of proper end of life for it.

Minimise the number of different compatible materials. So, if there are too many incompatible material say paper joined to plastic joined to aluminium foil, they are incompatible materials, when it comes to end of life. So, we have to try to avoid having different incompatible materials. Facilitate cleaning, facilitate composting, facilitate combustion.

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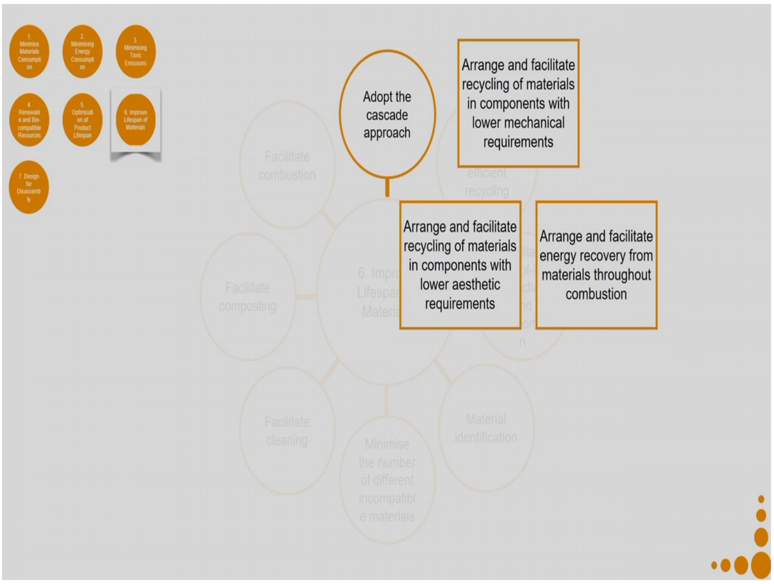

So, adopt the cascade approach. So, arrange and facilitate recycling of materials in components with lower mechanical requirements. Arrange and facilitate recycling of materials in components with lower aesthetic requirements. Arrange and facilitate energy recovery from materials throughout combustion.

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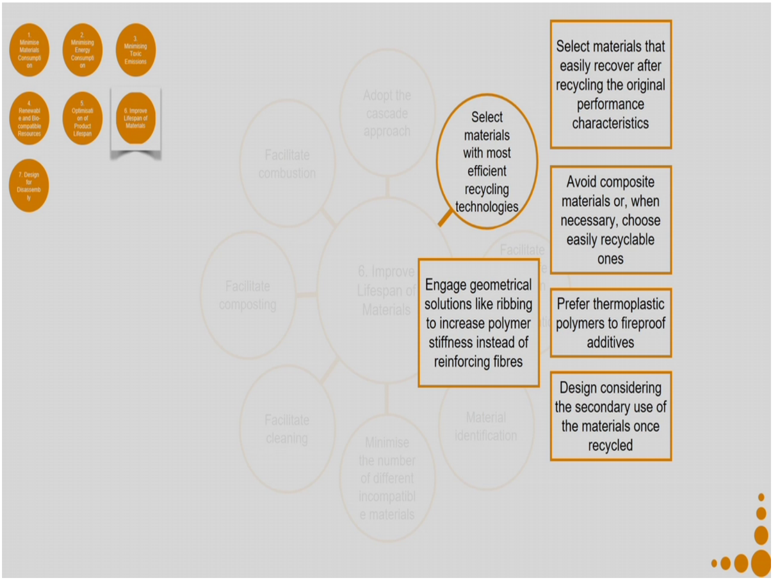

Select materials with most efficient recycling technologies. Select material that easily recover after recycling the original performance characteristics. In case of plastics, it is really difficult to achieve. But, in case of metal, it is easily more easily achieved. Avoid composite materials or when necessary choose easily recyclable ones. Engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibres.

Because, when you use reinforcing, fibre because is a combination of plastic and fibre, so it goes into the composite category is no longer recyclable. Prefer thermoplastic polymers to fireproof additives. But, again when you are using this particular plastic in a context, where you know that fire can happen, then it is very much better that you go with the fireproof additives. These are just like criteria, which you have to take a conscious decision, whether in my particular context is applicable or not, whether it can be used or not.

Design considering the secondary use of the material once recycled. In most product design situations, you do design for recycling, in case you do design for recycling, you do not think of what that recycled material can be used for, so that becomes a problem, so you know it can be recycled, but you do not know, what it can be recycled into. And then many a times the whole purpose of recycling does not succeed properly.

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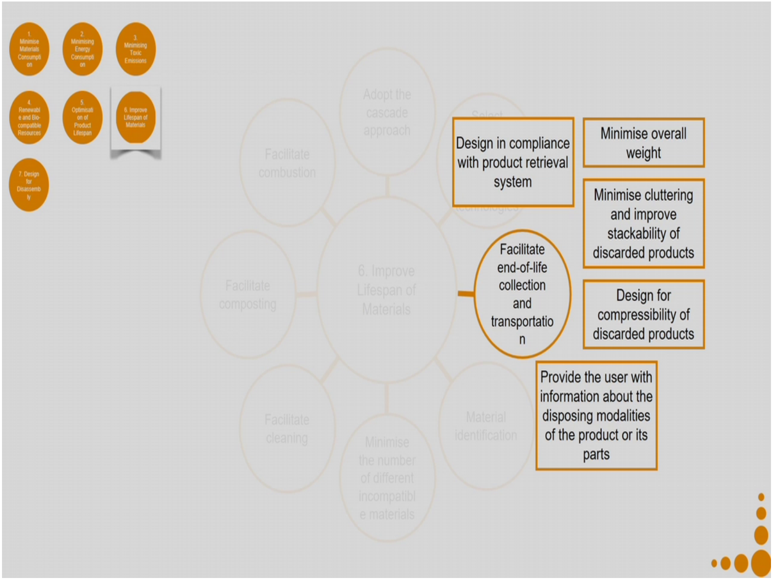

Then facilitate end-of-life collection and transportation. So, design in compliance with product retrieval system. Minimise overall weight. Minimise cluttering and improve stackability of discarded products. Design for compressibility of discarded products. Provide the user with information about the disposing modalities of the product or its parts.

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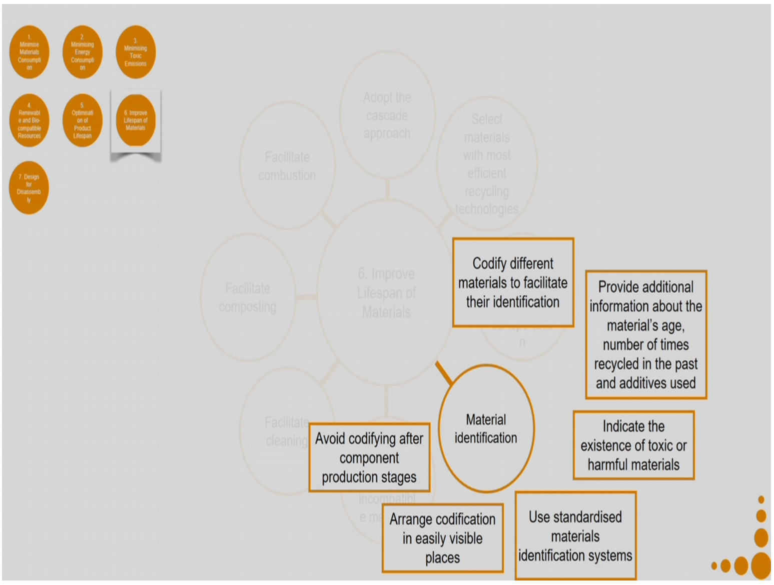

Now, coming to material identification so, codify different materials to facilitate their identification. For plastic such codes are already available, so you identify what kind of plastic. You have used in your product, and you can apply appropriate codes. It is always better that the code is built into the products. So, say for example if it is a plastic product, so I build inside the mould itself the code, so that the code does not get erased away.

So, if you put the code by sticking a sticker, it is quite likely that the sticker goes away, and then the code is lost. So, it is better that the code is imprinted on to the product in a manner that, it cannot go out. Provide additional information about the materials age, number of times recycled in the in the past, and additives used.

They again help in material identification and identifying, which recycling process it can go, and after recycling what secondary life it can go for. Indicate the existence of toxic or harmful materials. Use standardised material identification systems. Arrange codification in easily visible places not that you hide that. Avoid codifying after component production stages. So, like I told you not like when you have you put a sticker, and then that sticker contains the identification, because it is very easy to looks. So, try to build in the codifying system at the production stage itself.

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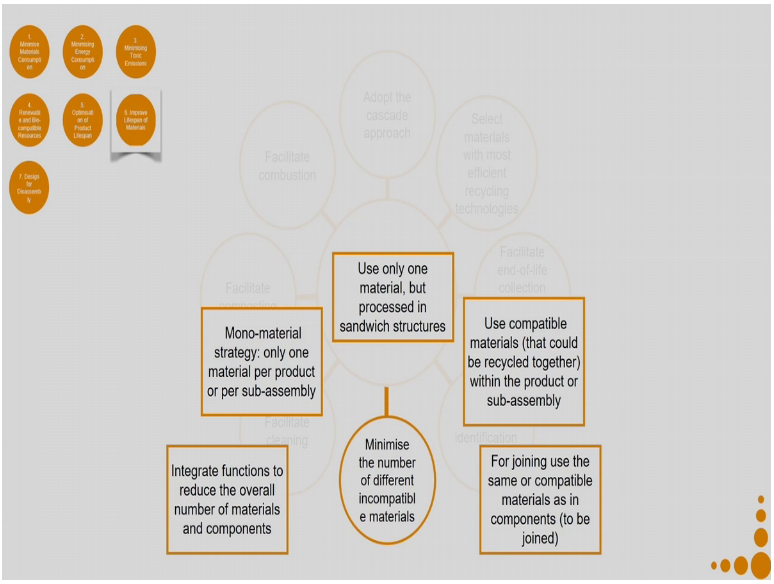

Then minimise number of different incompatible materials. So, integrate functions to reduce the overall number of materials and components. Mono-material strategy; only one material per product or per assembly is a very good strategy, but of course not always possible. Use only one material, but processed in sandwich structures that can give you a better structural integrity, in cases where it is required. Use compatible materials that could be recycled together within the product or sub-assembly. For joining use the same or compatible materials as in components to be joined.

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Then facilitate cleaning. So, avoid unnecessary coating procedures. Avoid irremovable coating materials. Facilitate removal of coating materials. Use coating procedure compliant with coating materials. Avoid adhesives or choose ones that comply with materials to be recycled. Prefer the dyeing of internal polymers, rather than surface painting. Avoid using additional materials for marking or codification, mark and codify materials during moulding. Codify polymers using laser.

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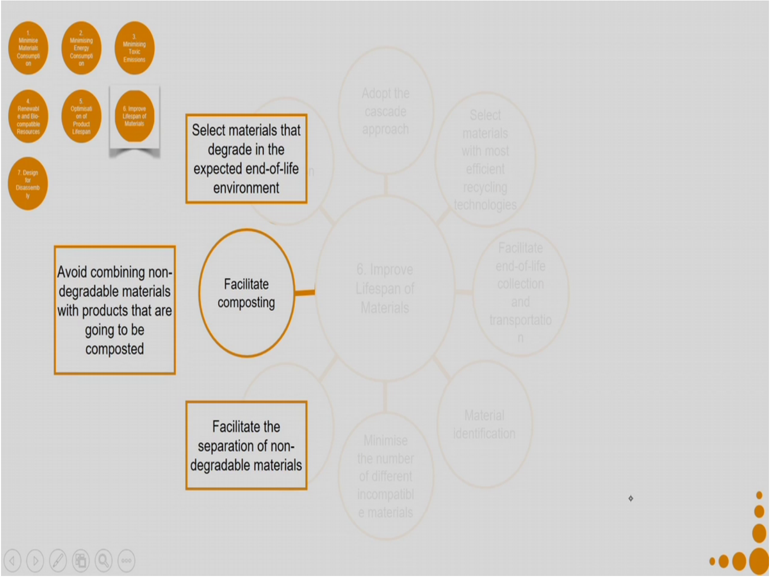

Then facilitate composting. So, select materials that degrade in the expected end-of-life environment. Avoid combining non-degradable materials with products that are going to be composted. Say for example, paper can be composed it, but if there are staples on the paper, you cannot compose that paper. You have to have some method of removing those staples. Now, assume you have a truck load of stapled paper, who is going to remove the staples. Facilitate the separation of non-degradable materials.

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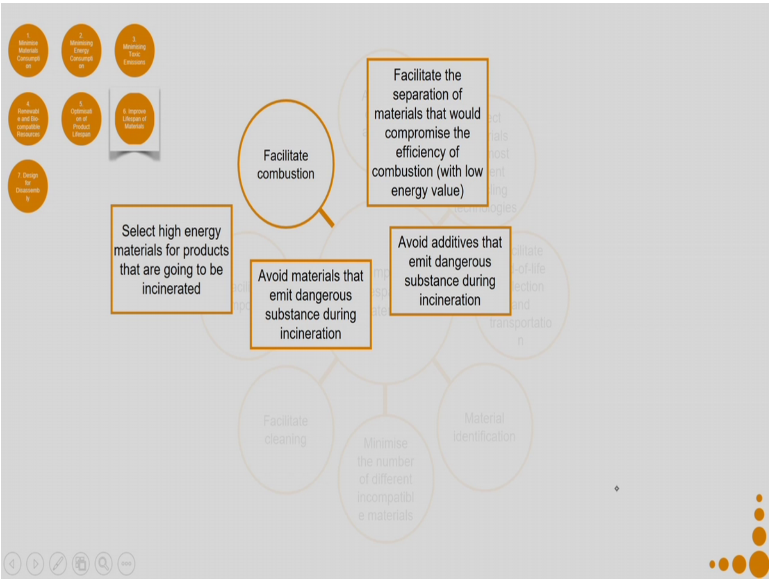

Then facilitate combustion, these are all end-of-life processes. Select high energy materials for products that are going to be incinerated. Avoid materials that emit dangerous substance during incineration. Avoid additives that emit dangerous substances during incineration. Facilitate the separation of materials that would comprise the efficiency that would compromise the efficiency of combustion with low energy value.

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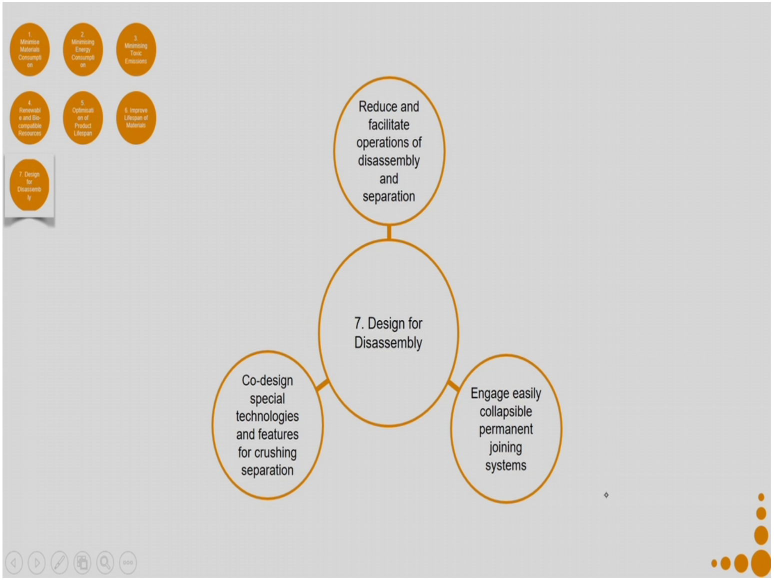

Now, the finals criteria is design for disassembly. So, reduce and facilitate operations of disassembly and separation. Engage easily collapsible permanent joining systems. Co-design special technologies and features for crushing separation. So, now you do not design the product thinking of the product itself, but you co-design it with a party who is going to also handle end-of-life. So, you design the product in a manner that end-of-life is easy.

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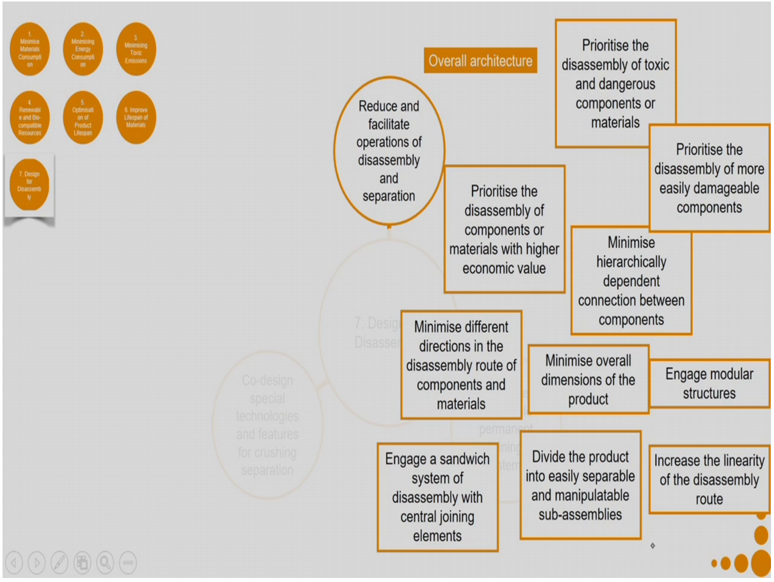

So, when we are talking about reduce and facilitate operations of disassembly and separation, it can be at the overall architecture level of the product. So, prioritise the disassembly of toxic and dangerous components of the materials first. Prioritise is the disassembly of more easily manageable component, sorry damageable components. Prioritise the disassembly of components or materials with higher economic value. Minimise hierarchically dependent connection between components.

Minimise different directions in the disassembly route of components and materials. So, first you disassemble in this direction, then in this direction, then in this direction, it is a troublesome process, so if you can minimise on the different directions that will be helpful. Minimise overall dimensions of the product. Engage modular structures. Divide the product into easily separable and manipulatable sub-assemblies. Increase the linearity of the disassembly route, engage a sandwich system to disassembly; sandwich system of disassembly with central joining elements. So, say for example, I open one particular screw, and it helps me to open up the whole component layer by layer.

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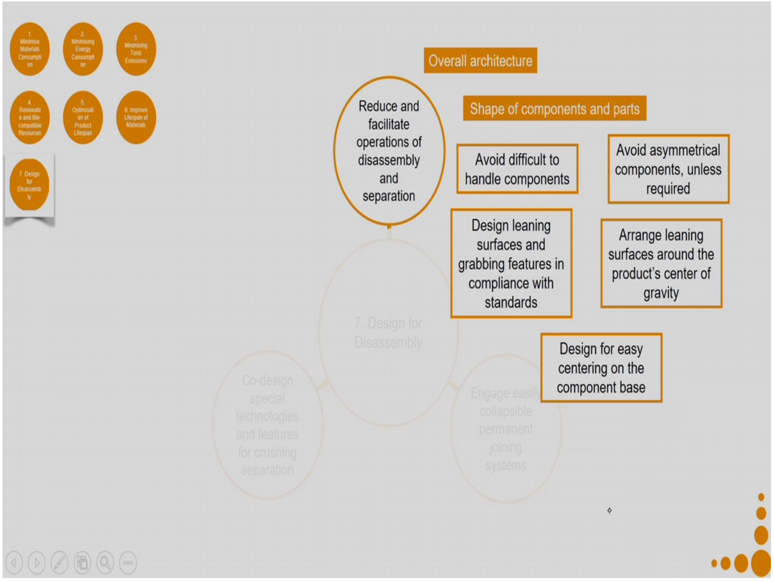

Then in we can also reduce and facilitate operations of disassembly and separation at the shape of components and parts level. So, avoid difficult to handle components. Avoid asymmetrical components, unless required. Design leaning surfaces and grabbing features in compliance with standards, where I might need to grab something and disassemble it. Arrange leaning surfaces around the products centre of gravity. Design for easy centering on the component base.

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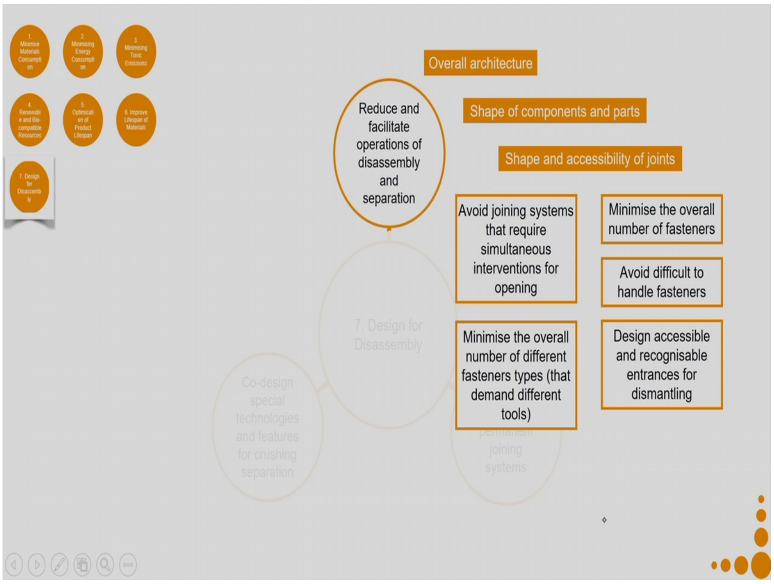

Then at the shape and accessibility of joints level, avoid joining systems that require simultaneous interventions for opening, it makes it difficult. Minimise the overall number of fasteners. Minimise overall number of different fastener types that demand different tools. Avoid difficult to handle fasteners. Design accessible and recognisable entrances for dismantling.

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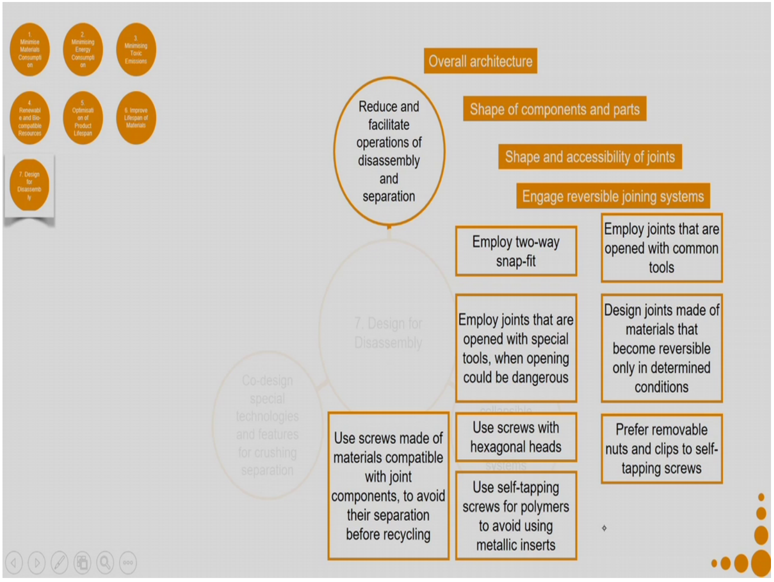

Then at engage reversible joining systems level. So, employ two-way snap fit. Say for example, or employ joints that are opened with tools or employ joints that are opened with special tools, when opening could be dangerous. Design joints made of materials that become reversible only in determined conditions. Use screws with hexagonal heads. Prefer removable nuts and clips to self-tapping screws. Use screws made of materials compatible with the joining components to avoid their separation before recycling. Use self-tapping screws for polymers to avoid using metallic inserts.

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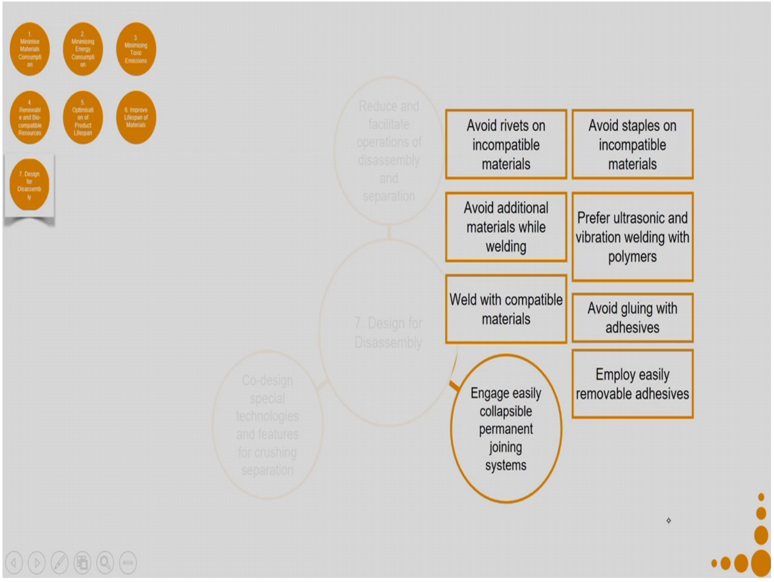

Now, let us come to the engage easily collapsible permanent joining systems. So, avoid rivets on incompatible material, avoid staples on incompatible materials, avoid additional materials while welding, weld with compatible materials only, prefer ultrasonic and vibration welding with polymers. Maybe you do not understand some of these concepts over here. Say you, if you do not know what is ultrasonic welding or vibration welding or say you do not know what are rivets. You can look up on the internet because this course we cannot cover all those different aspects. And say when you are designing a particular product, you need to know about all these different technical processes or technical components. So, in case you do not know them, you can look up on the internet for them. Avoid gluing with adhesives, employ easily removable adhesives

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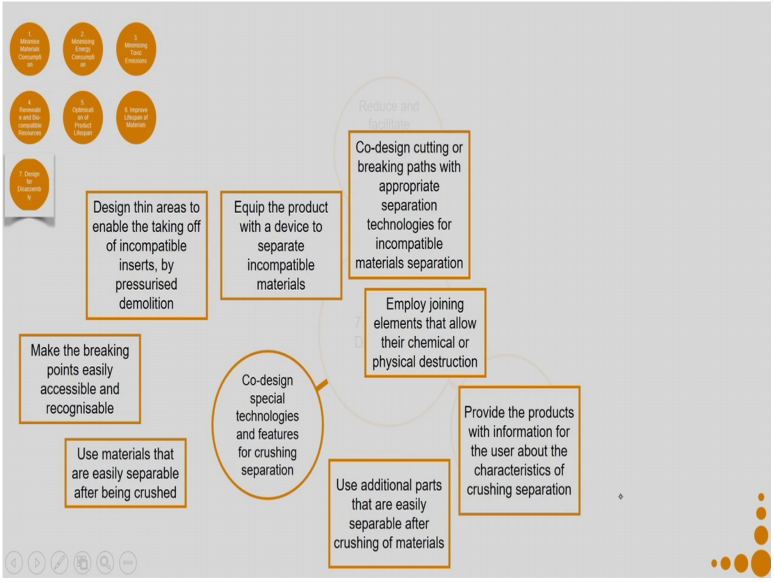

Now, coming to co-design special technologies and features for crushing separation. So, design thin areas to enable the taking of incompatible inserts by pressurize demolition. Equip the product with a device to separate incompatible materials. Co-design cutting or breaking paths with appropriate separation technologies for the incompatible material separation. Make the breaking points easily accessible and recognisable. Employ joining elements that allow their chemical or physical destruction. Provide the products with information for the user about the characteristics of crushing separation, use materials that are easily separable after being crushed. Use additional parts that are easily separable after crushing of materials.

Say for example, you have used two different types of materials and both of them have different kinds of density. So, you can crush them, and then you through a flotation tank you can separate those materials, these just examples of doing this whole process. You can identify for your particular project for the kind of materials that you are using what is an appropriate process if this process is applicable to you.

So, in order to, so these are the basic guidelines and criteria that can be used in order to help you in assessing an existing product and in designing. We can use something called as an ICS toolkit. So, you can download this toolkit. And in the next lecture, we will together explore on how to use this particular toolkit. This toolkit is very useful when you want to design a product with all these engineering design guidelines and criteria that we discussed today.

Thank you.