Design for Quality, Manufacturing and Assembly
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Lecture – 25
Introduction to Sustainable Development and Sustainability Indicators

Good morning, I am Dr Sivakumar from the Department of Civil Engineering at IIT Madras. This presentation provides an overview of Sustainable Development and Indicators used for Measuring Sustainability.

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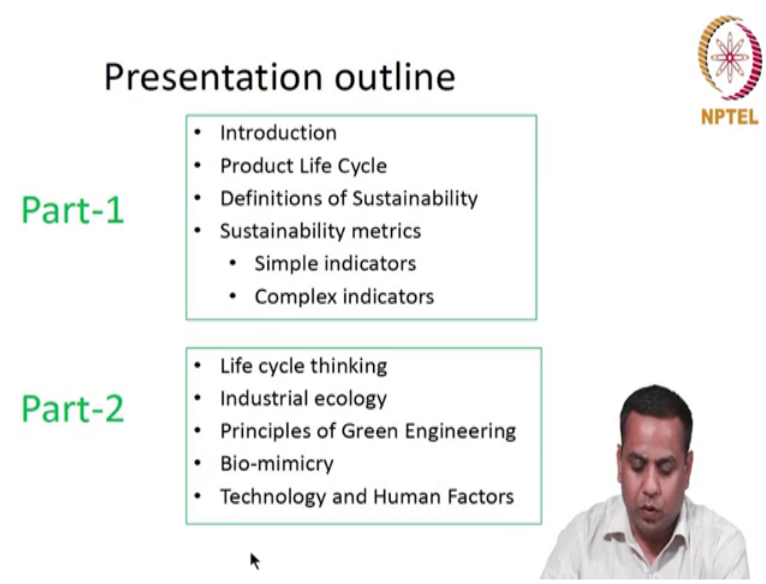

I have organized this presentation into two parts: part 1 focuses on Introduction, Life Cycle of a Product, different Definitions available for Sustainability, Indicators used for measuring Sustainability, for example; Simple indicators and Composite indicators. The part 2: focuses on Life Cycle Thinking, Industrial ecology, Principles of Green Engineering, Bio-mimicry and Technology and Human Factors.

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In today's context we use a number of terms like sustainability, sustainable development, sustainable manufacturing, sustainable construction, green materials, green buildings, green products, and of course zero defects and zero effects. That emphasizes the significance of integrating sustainability concepts into industry practice whether it is a construction sector or its manufacturing sector. There is lot of emphasis on greening the manufacturing and construction processes.

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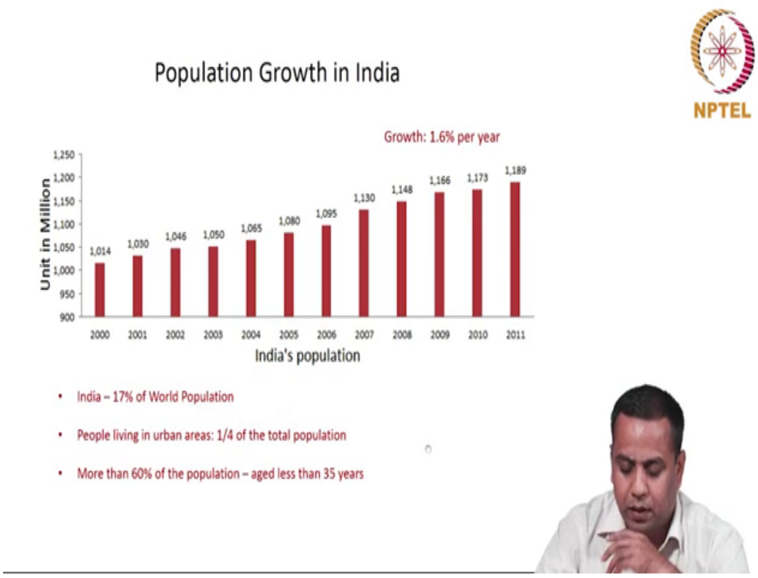

Before we get into the different definitions available for sustainability I would like to go through some brief statistics about India. For example, India's population grows at the rate of 1.6 percent per year, India represents about 17 percent of the world population and about 25 percent of the population lives in the urban areas. And one of the unique aspects of India is that, more than 60 percent of the population or age less than 35 years. So, we have more young work force in India compared to other countries.

Now, if we compare India with other countries in terms of population and land area. For example, let us compare USA and India.

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Population of India is 3 times bigger than US, whereas the land area in USA is 3 times bigger than India. So, that gives an indication of the population density in India and the constraints in terms of resource availability.

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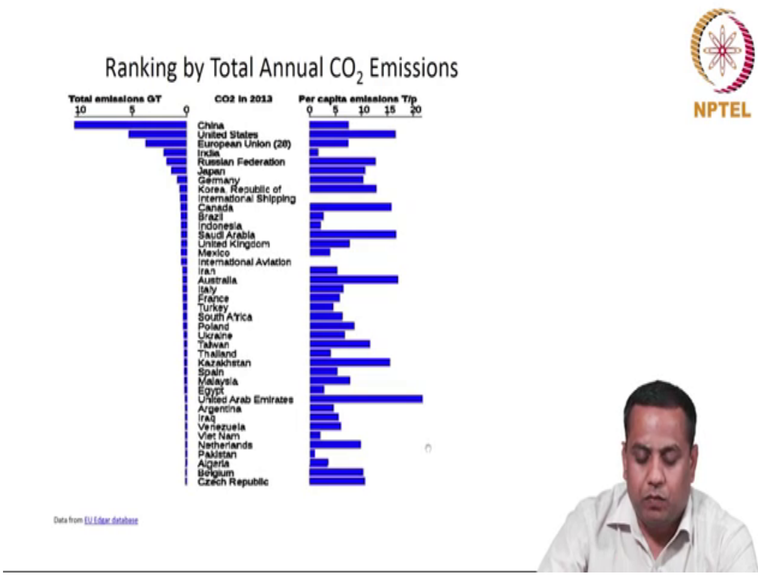

We are one of the top 5 countries in the world, in terms of energy use and emissions. Whereas, in terms of per capita CO 2 emissions India stands in the bottom of the list.

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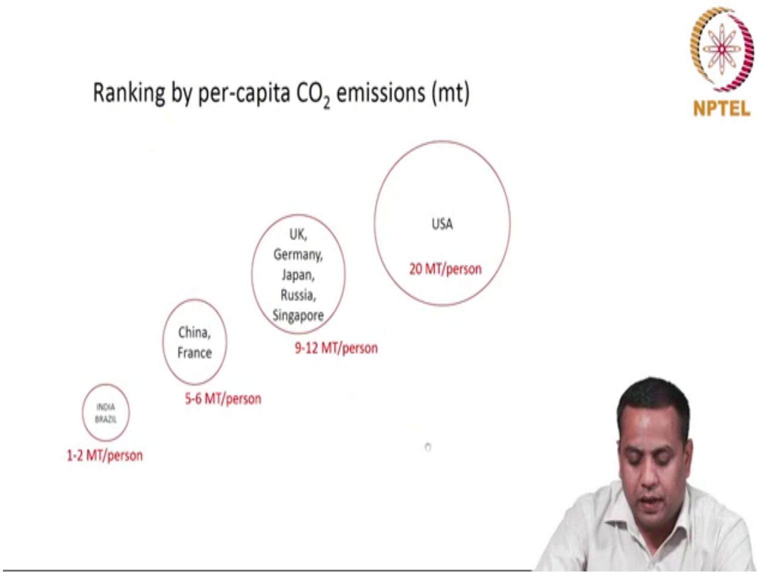

This slide graphically shows the comparison of per capita carbon footprint of different countries. So, we are comparing four areas USA, Europe, China, and France, and India.

So, the per capita CO 2 emissions per year in India is much less compared to other countries. In case of China and France it is 5 to 6 times higher than India. In terms UK

Germany, Japan there about 10 times higher than India. And USA about 20 times higher than India. Now we will go through different phases of a product life cycle.

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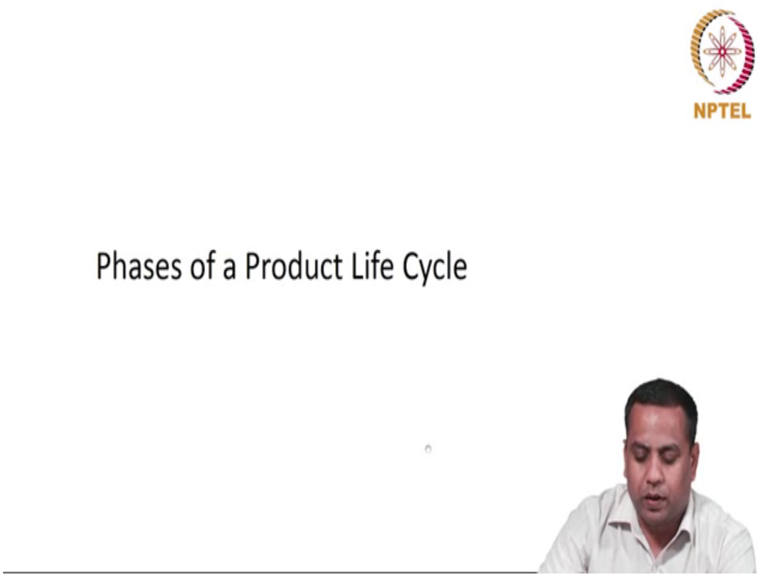

The inputs to the product life cycle are.

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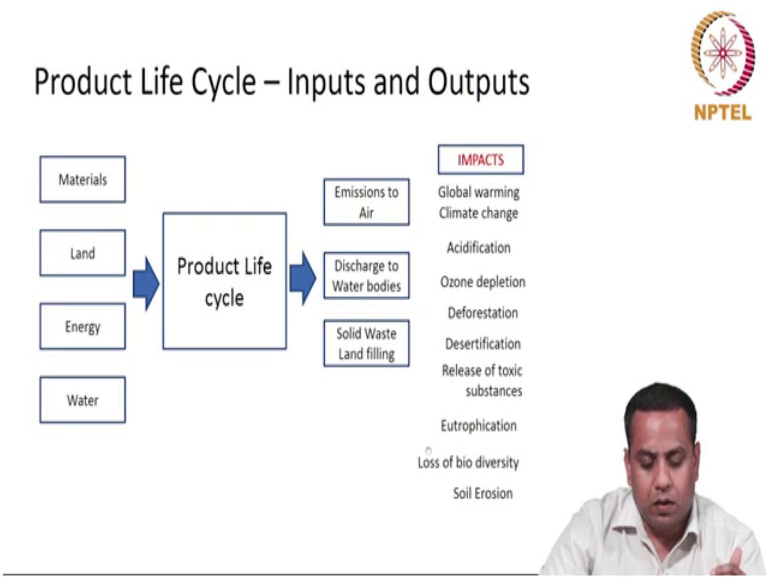

Materials, land use, energy use, and water. And output from the product life cycle as emissions to air, water, and land. And this generates a number of impacts in the environment like global warming, climate change, acidification, ozone depletion, deforestation, desertification, release of toxic substances, eutrophication, and loss of biodiversity, and soil erosion, and a number of problems are related to environment.

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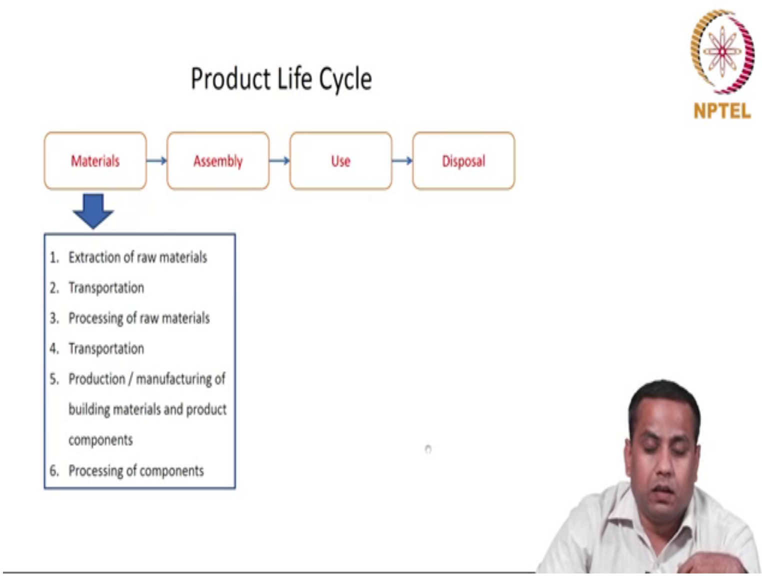

Now, the product life cycle has four major components as shown in this figure first manufacturing of materials used for a product, second assembly of the product, third the use of the product, and finally the disposal of the product after the service life is completed. In the first phase manufacturing of materials required for a product we have a number of activities like extraction of raw materials, transportation of raw materials, processing of raw materials, transport of process raw materials, and manufacturing of materials, and then packaging, and then transport, and delivery to suppliers.

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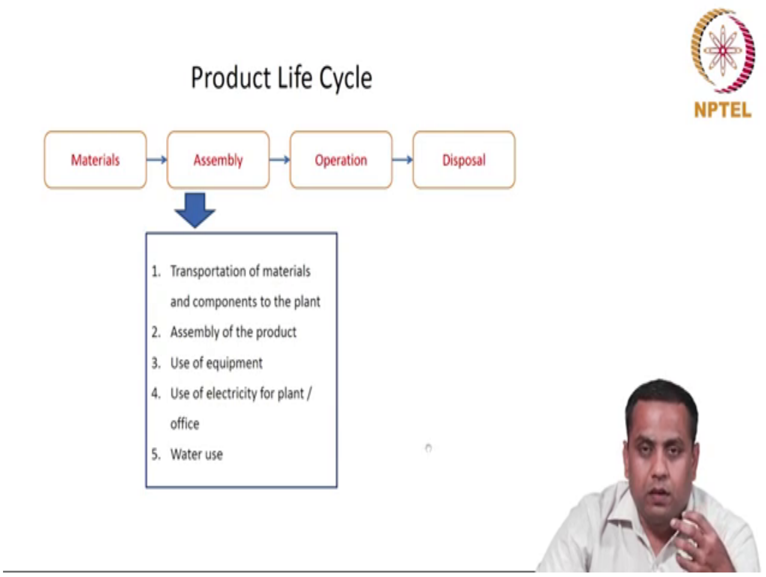

The second part, the assembly of the product involves transportation of manpower, machineries, materials, to the factory where the product is manufactured; use of equipment at the factory, use of electricity, use of fuel, use of consumables in the factory, and of course, water used in the factory. So, these resources are required for assembling the product in the factory.

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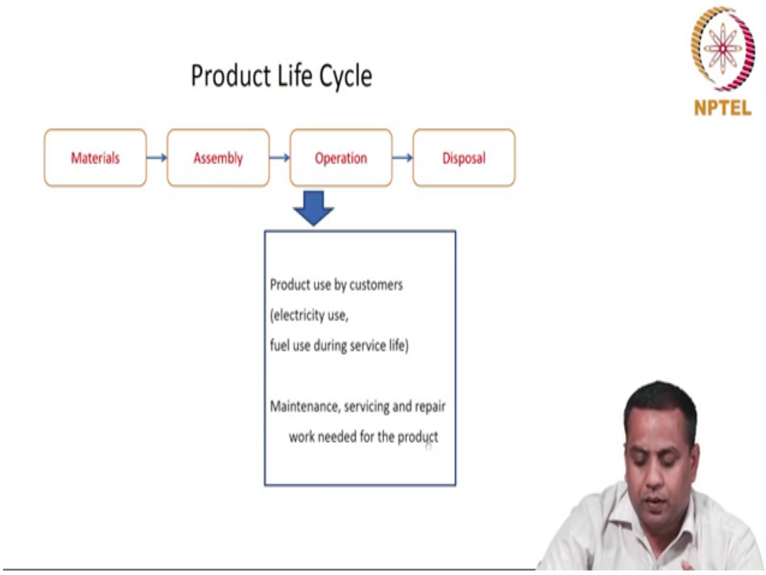

The third phase the use of the product for a number of years requires the use of electricity fuel during, the service life. For example, if you have a computer we use electricity for operating the computer and if we use two wheeler we need fuel for running the two wheeler. And then another major part of the operational phases that the maintenance and repair work associated with the product the periodical maintenance, servicing, and repair work, required for keeping the product in good condition. That also requires substantial amount of resources such as energy and materials depending upon the life of the product, depending upon the life of the components.

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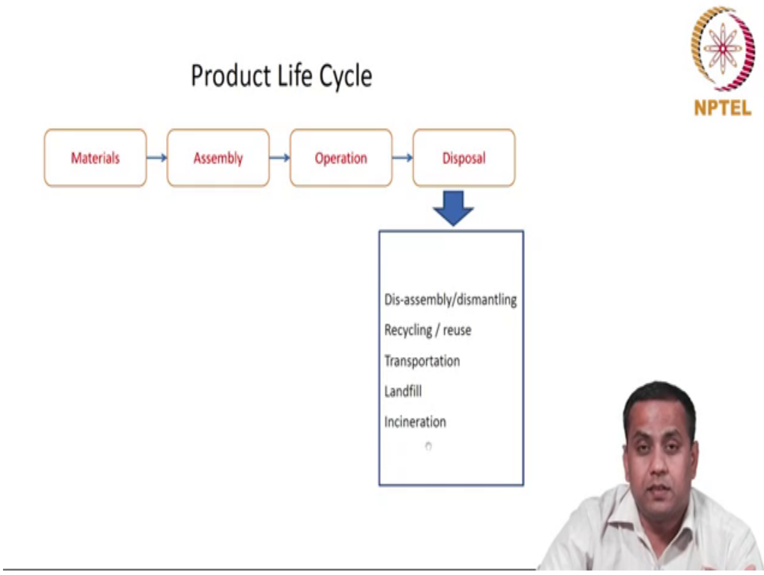

The last phase of the product is the disposal of the product after the service life is completed. This involves disassembly or dismantling of the product, reusing the food product if it is in good condition, transporting the waste, land filling, or incineration of the waste.

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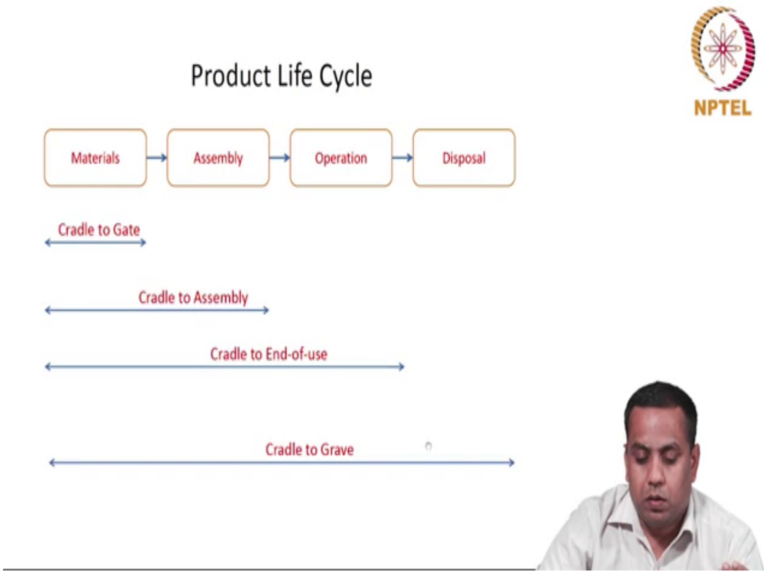

Now, the scope of any sustainability study can belong to one of the four terms shown in this presentation. Even we would like to assess the sustainability aspects of materials the scope is limited to cradle to gate.

In other words for example, if I would like to assess the energy footprint of 1 ton of cement; the scope of the study is from mining of raw materials to packaging of cement in the factor. The second term cradle to assembly if I want to study the energy footprint of one finished product for example, refrigerator or computer the scope of the study is from cradle to assembly. That means, from mining of raw materials to assembling the product in the factory.

Third the scope of the study can be from cradle to end of use till the service life, forth cradle to grave till the disposal phase of the product. So, the sustainability study conducted to assess the energy footprint or carbon footprint of a product can belong to one of these four scenarios.

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Now we will look into how the construction and manufacturing practices evolved over a period of time for example

Let us look into this temple

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You know many of the historic temples in Tamil Nadu or in other state, they were built 1000 years ago they are still in good condition.

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Whereas, if you look into the modern construction practices; for example, high rise residential buildings, how do we compare these two construction practices, ok. How the construction and manufacturing practices have evolved over a period of 100 or 1000 years using these two examples.

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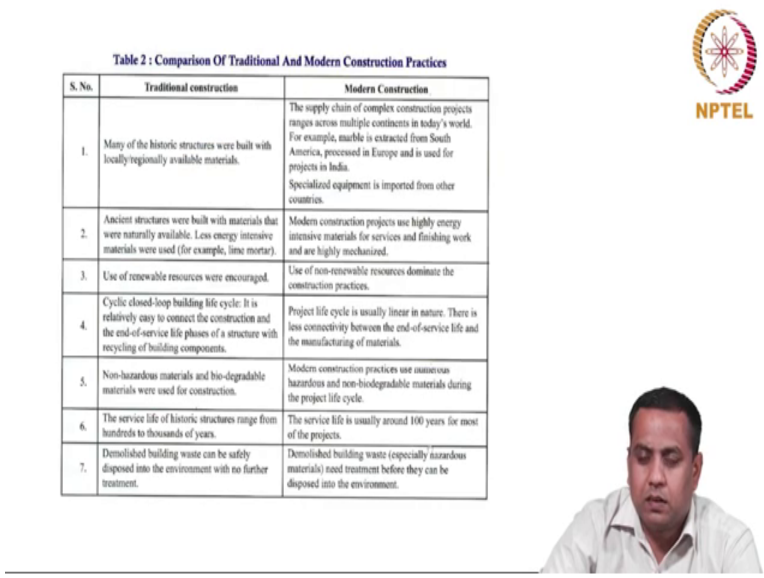

Table 2 : Comparison Of Traditional And Modern Construction Practices

S. No.	Traditional construction	Modern Construction
1.	Many of the historic structures were built with locally/regionally available materials.	The supply chain of complex construction projects ranges across multiple continents in today's world. For example, marble is extracted from South America, processed in Europe and is used for projects in India. Specialized equipment is imported from other countries.
2.	Ancient structures were built with materials that were naturally available. Less energy intensive materials were used (for example, lime mortar).	Modern construction projects use highly energy intensive materials for services and finishing work and are highly mechanized.
3.	Use of renewable resources were encouraged.	Use of non-renewable resources dominate the construction practices.
4.	Cyclic closed-loop building life cycle: It is relatively easy to connect the construction and the end-of-service life phases of a structure with recycling of building components.	Project life cycle is usually linear in nature. There is less connectivity between the end-of-service life and the manufacturing of materials.
5.	Non-hazardous materials and bio-degradable materials were used for construction.	Modern construction practices use numerous hazardous and non-biodegradable materials during the project life cycle.
6.	The service life of historic structures range from hundreds to thousands of years.	The service life is usually around 100 years for most of the projects.
7.	Demolished building waste can be safely disposed into the environment with no further treatment.	Demolished building waste (especially hazardous materials) need treatment before they can be disposed into the environment.

So, in case of modern construction practices the supply chain processes span across multiple countries multiple continents in the world for example, a marble used in a building project in Chennai is source from Brazil processed in Europe and used in India.

Similarly, many of the advanced mechanical electrical equipments used in India, are imported from Europe or other countries. So, the supply chain processes in modern industry practices have become global in nature they are all transported from other countries not necessarily local within India. Second we do use a number of highly energy intensive materials in construction and manufacturing sector.

Also there is a high degree of automation and mechanization in construction industry as well as in manufacturing industry. We use the number of non renewable materials in product and the product life cycle is more of a linear in nature. When I say linear there is less connectivity between the end of life phase of a product and manufacturing phase of the product. In other words, we are mining raw materials from one side of the planet and dumping the waste to landfills on the other side of the planet.

So, there is this connectivity between mining and disposal of waste in modern practices and that creates tremendous pressure on the planet. Forth in modern practices, we do use a number of hazardous non biodegradable substances in processes and the service life of the product; of course it varies from product to product. If we compare the service life of a consumer product with a building product of course, a buildings stands for hundreds of years whereas, the life of a consumer product is relatively less you know it varies from few years to few decades.

And then the disposal of the waste also is a very important given the fact that we use a number of hazardous materials. That means the waste generated from the product disposal need to be treated before they are disposed into the environment. So, this gives an overview of how the manufacturing practices and construction practices have evolved over period of time.

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Now we will go through different definitions of sustainability.

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The first definition is one of the most widely used definitions by united nations sustainable development is defined as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

That means we want to use resources in a more responsible manner. So, that you know we preserve the planet for future generations.

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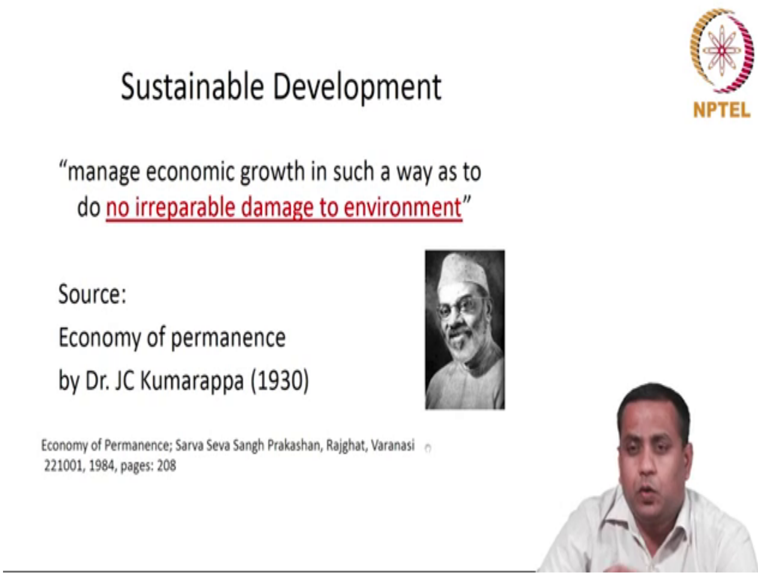

The second definition of sustainable develop is by Dr. JC Kumarappa from India, he defined sustainability as manage economic growth in such a way as to do we irreparable damage to environment. So, when we develop in such a way that there is no irreparable damage to environment we follow sustainability concepts.

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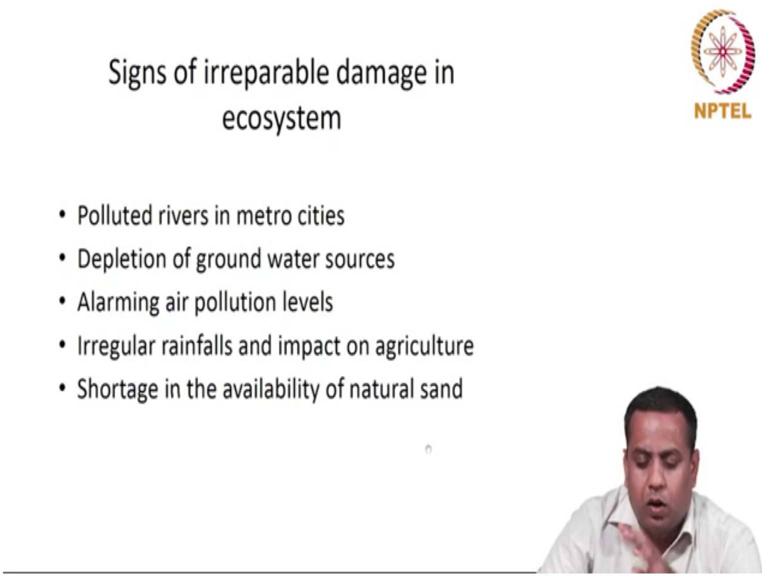

Now you can ask the question yourself are we in the elastic state of the ecosystem of plastic state of the ecosystem.

So, I use the term elastic state to represent a scenario, where the ecosystem has the ability to go back to the initial state. That means, there is no permanent damage in the ecosystem. I use a term plastic state to represent a scenario where the ecosystem does not have the ability to go back to the initial state there is a permanent damage to environment. So, if you ask the question are we in the elastic state or plastic state of the ecosystem? The answer is obviously, you know there are irreparable damage in the ecosystem we have a number of science of that for example, polluted rivers in the metro cities depletion of groundwater table.

For example, you know 20 years ago we used have ground water at 100 feet from the ground level in my native area. Now the same place we have to have a bore well of 300 feet depth to have water. So, there is a rapid depletion of groundwater resources in different areas, alarming air pollution levels in metro cities irregular rainfall, and impact on the agriculture, and livelihoods of people, and the shortage in the availability of natural materials like sand ok.

These are some science of you know permanent damage cause to the ecosystem and this have to be corrected in appropriate ways.

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Now the third definition for sustainable construction as "Creation and operation of a healthy built environment using sound ecological principles" this is from the International Council for Research in Building Construction.

Now, when we use a term sound ecological principles, how do we define that? What are the ecological principles we can adapt in the construction or manufacturing sector to promote sustainability. So, I have given some examples here.

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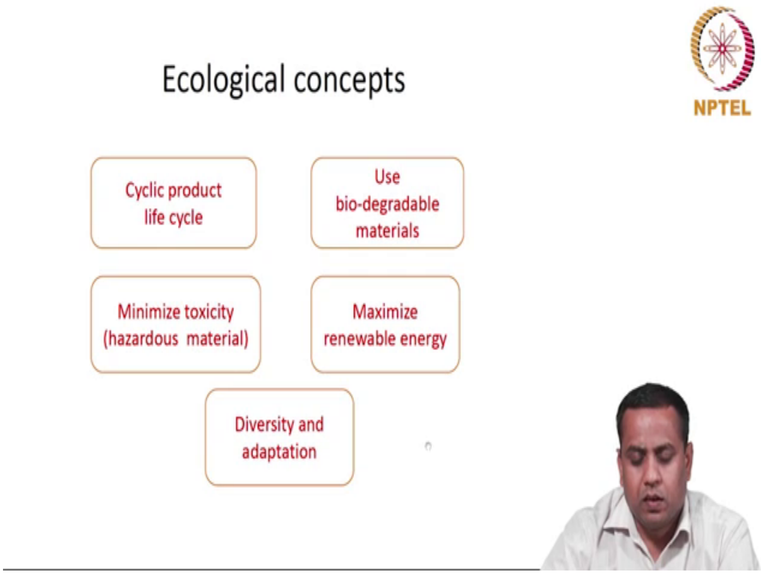

The first is we move from a linear economy to the circular economy. For example: instead of having a linear product life cycle we connect the end of life phase of a product life cycle back to the manufacturing phase, so that we enable the use of waste generated from one system as a useful resource input for another system. Second we have to promote the use of biodegradable materials, avoid the use of hazardous materials, maximize the use of renewable energy, and promote diversity, and adaptation in nature in the industry practices.

When we follow these concepts we move towards sustainable development.

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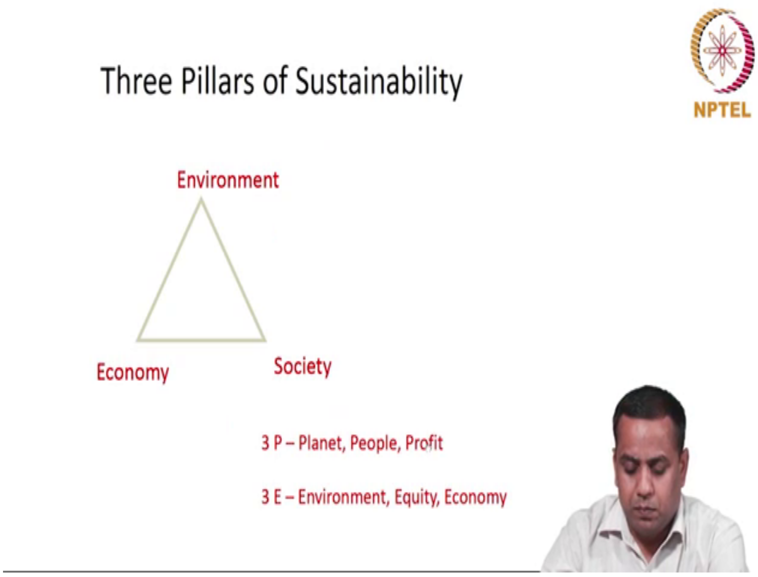

Now, sustainability indicators are broadly classified into three categories environmental aspects, economic aspects, and social aspects. This is often called 3P; that is planet, people, profit or 3E's environment, equity, and economy.

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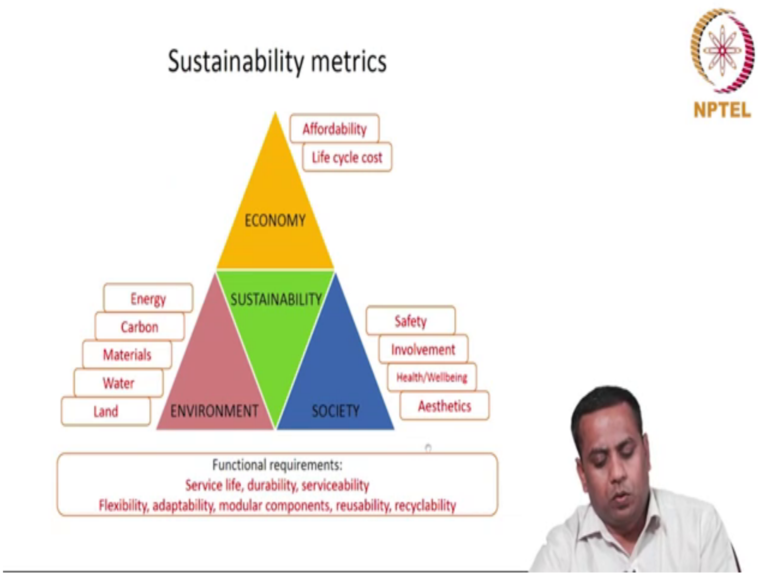

Now we will briefly look into the metrics

Now we will briefly look into the metrics that belong to each pillar of sustainability under environmental category we have indicators like energy carbon materials water and land use.

Under economic category, we consider the affordability of the product, life cycle cost of the product. Under social aspects, we consider metrics like safety, involvement of all the stakeholders, health, and well being of work force involved in the processes, and aesthetics beauty of the product. In addition to the three pillars of sustainability we also consider products specific features like service life, durability, serviceability flexibility, adaptability, modular components, modularity of the product, reusability, and recyclability and so on.

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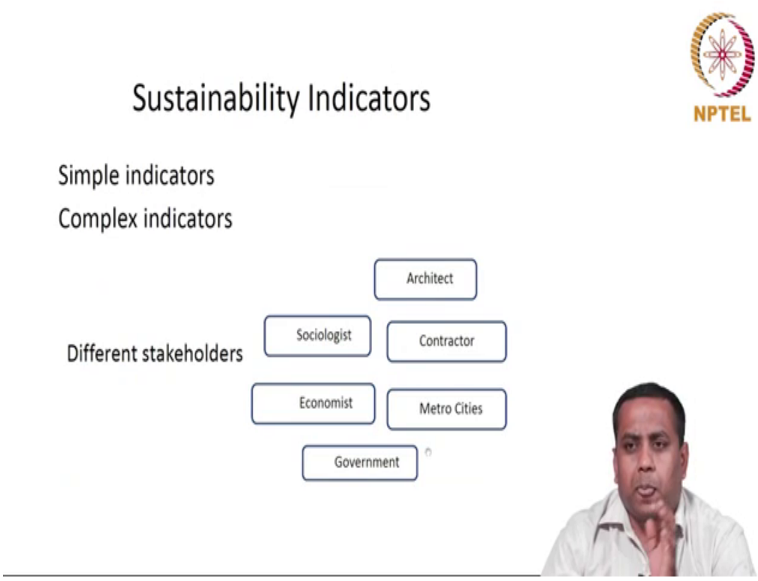

Sustainability indicators can be broadly classified into two categories simple indicators complex indicators. And the definition of sustainability vary from one scenario to another scenario. For example; we have a number of stakeholders with respect to construction projects; for example an architect, sociologist, contractor, economist, city corporations, and government. The definitions of sustainability vary based on the lens through which each stakeholder see the project. So, the definition of sustainability vary from one stakeholder to another stakeholder sustainability for an architect, is different from sustainability for a contractor.

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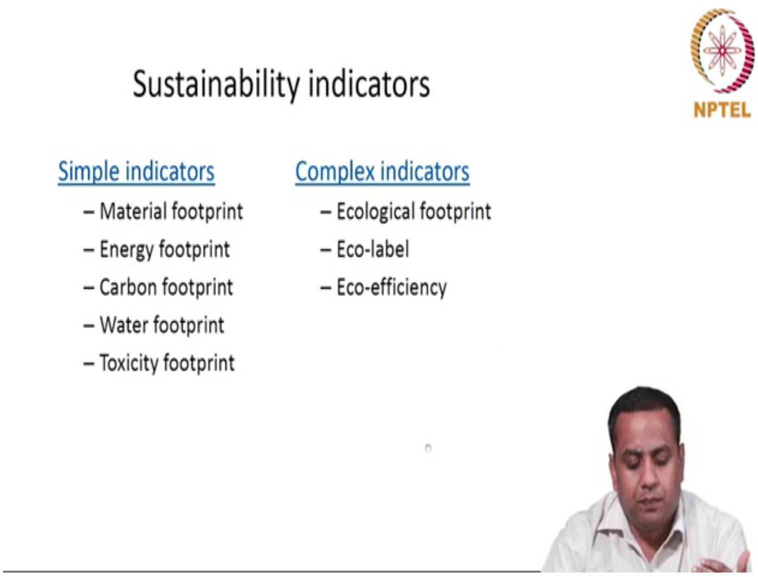

Now the under simple indicators; we have metrics like material footprint, energy foot print, carbon foot print, water footprint, and toxicity footprint. Under complex indicators we have ecological footprint, eco-label, and eco-efficiency.

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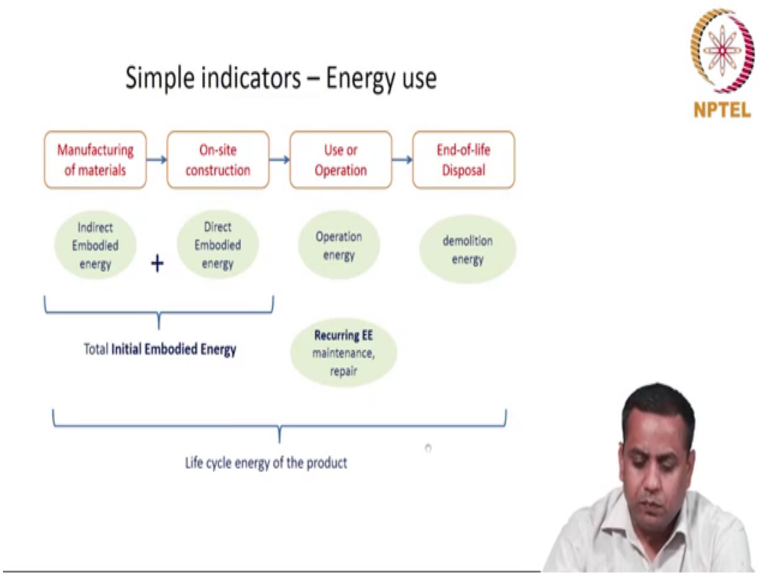

We will go through the simple indicators first, considering the product life the indicators belong to each phase of the product. Second the direct embodied energy associated with assembling the product the sum of both is called as total initial embodied energy, second the energy use associated with the use of the product operation energy. And then the energy use associated with maintenance and repair work of the product recurring energy, and then the final phases the end of life phase, the energy used for demolish of the product is called as Demolition Energy.

And the sum of the energy used in all these phases is called as the life cycle energy associated with the product. Now the energy used for manufacturing a product or manufacturing a material depends on a number of factors. For example, the location of mines, quality of raw materials, choice of methods used for transportation, choice of production technologies, time of data collection and so on. So, there are a number of parameters related to supply chain and production processes that affect the energy footprint of a product. Now we will go through the definitions of each indicator one by one.

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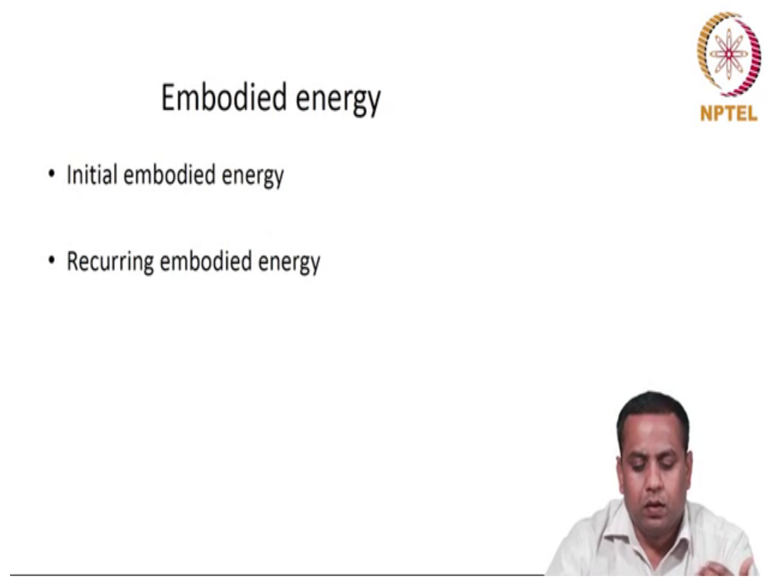

The embodied energy has two components initial embodied energy and recurring embodied energy.

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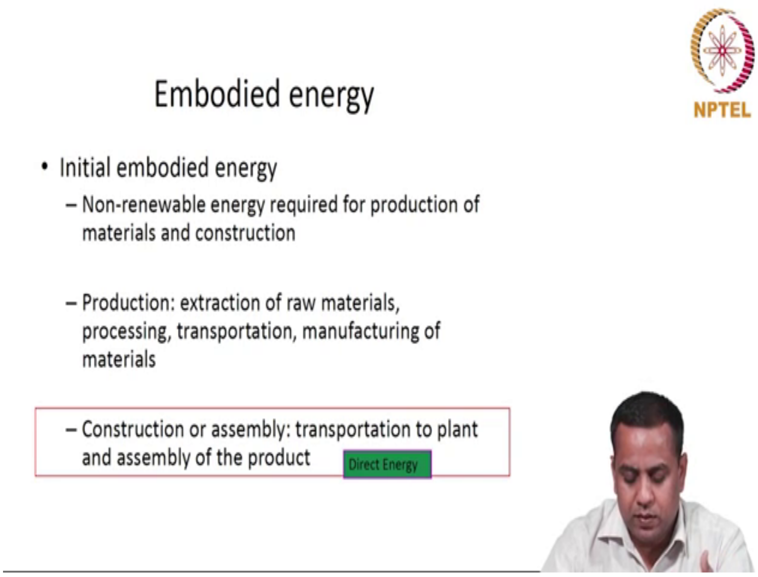

The initial embodied energy is a non renewable energy used for manufacturing materials and assembling the product this has two sub components. The first is the direct embodied energy used for assembling the product in the factory, and then the indirect embodied energy used for manufacturing materials in the supply chain.

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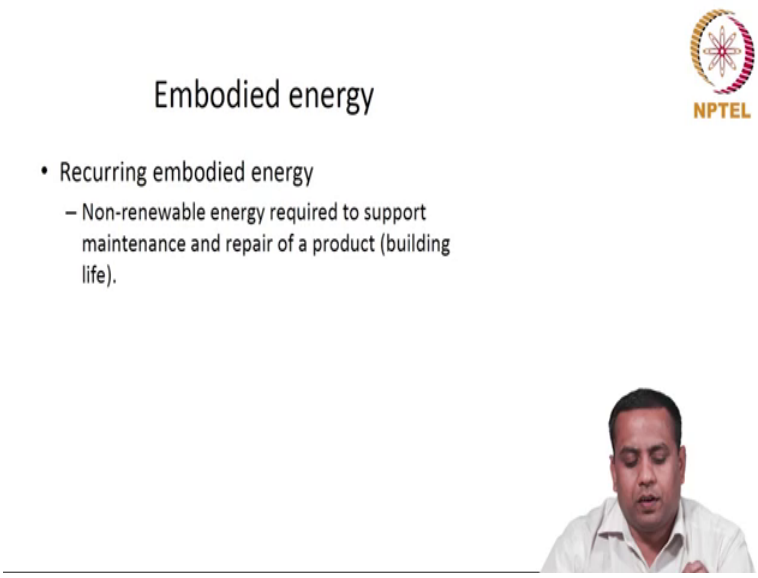

The second type of embodied energy is, the energy used for repair work maintenance and major rehabilitation of the product during the service life. This is a non renewable energy used for maintenance and repair during the service life.

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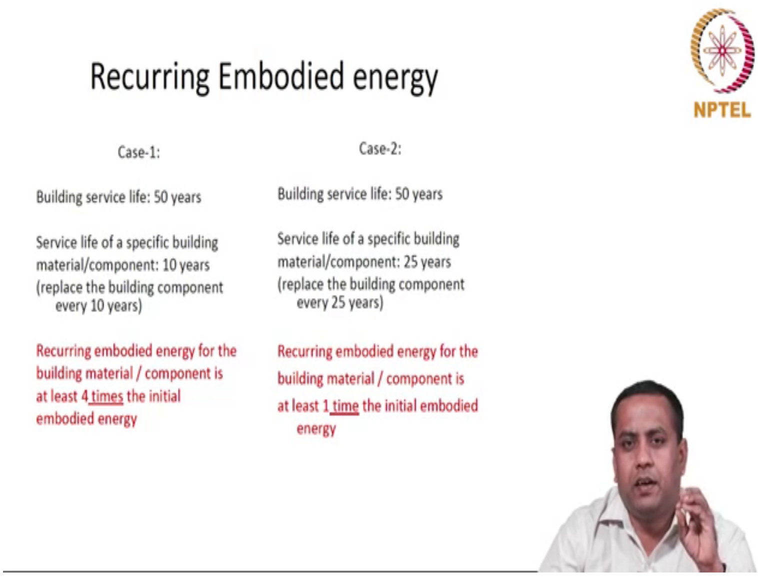

Now, the recurring energy or the recurring embodied energy used for maintenance and repair work depends on a number of factors for example, the life of the spare part, how often it is replaced during the service life? Life of the product, the amount of materials used in a part, the energy intensity of materials used in manufacturing a component, influence, the total recurring embodied energy for a product. For example, let us consider two scenarios case one, case two. In case one the life of the building is 50 years, the life of the component is 10 years; that means, I replace a component every 10 years.

So, in this case the recurring embodied energy of the component is 4 times the initial embodied energy of the component. In other words recurring energy is 4 times more than the initial energy of the component. Whereas in the second case the life of the building is 50 years the life of the component is 25 years; that means, I replace the component once in 25 years. The recurring energy is equal to the initial embodied energy in the second case. So, the relation between the recurring energy and the initial energy depends on a number of factors associated with the component and the product.

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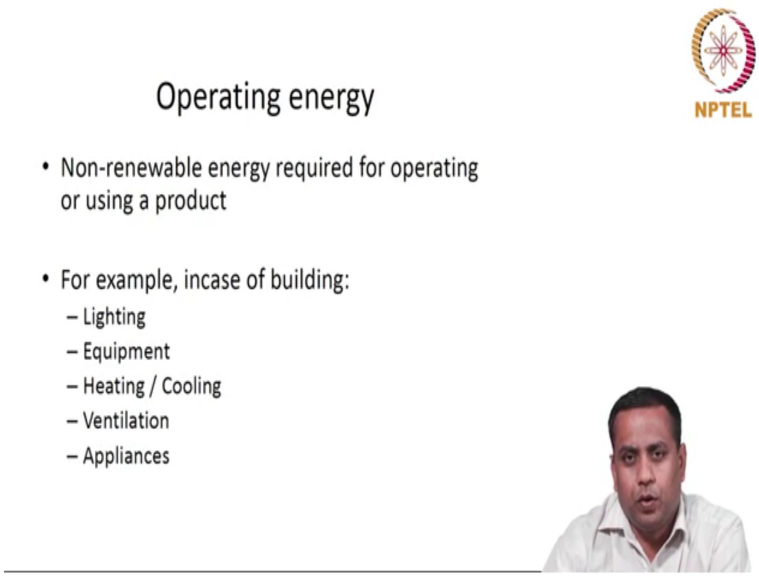

Now, another indicator for sustainability is the energy used during the operation of the product or the use of the product. For example, in case of a building we use energy for lighting, energy for ventilation, energy for equipment, heating, cooling, appliances, and number of other factors.

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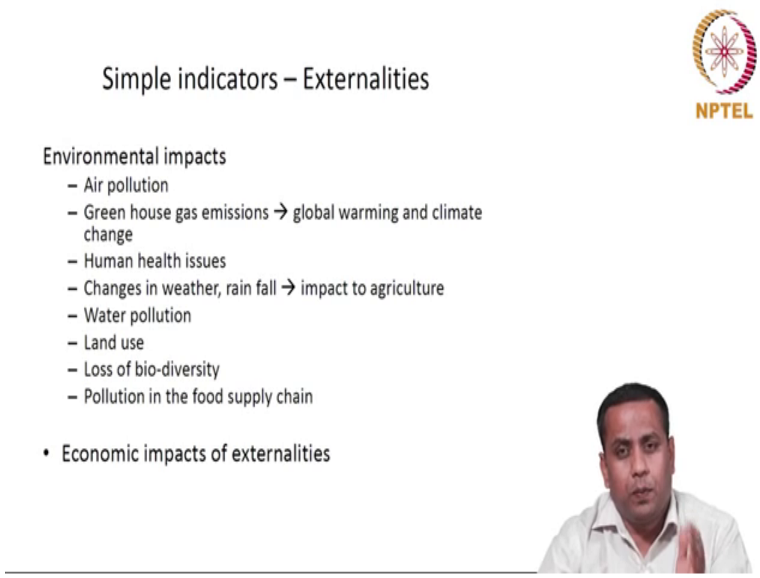

We do have several environmental indicators related to sustainability for example; pollution level, greenhouse gas emissions, human health issues, irregular rainfall, pollution in water bodies, land use, loss of biodiversity, pollution in the food supply chain.

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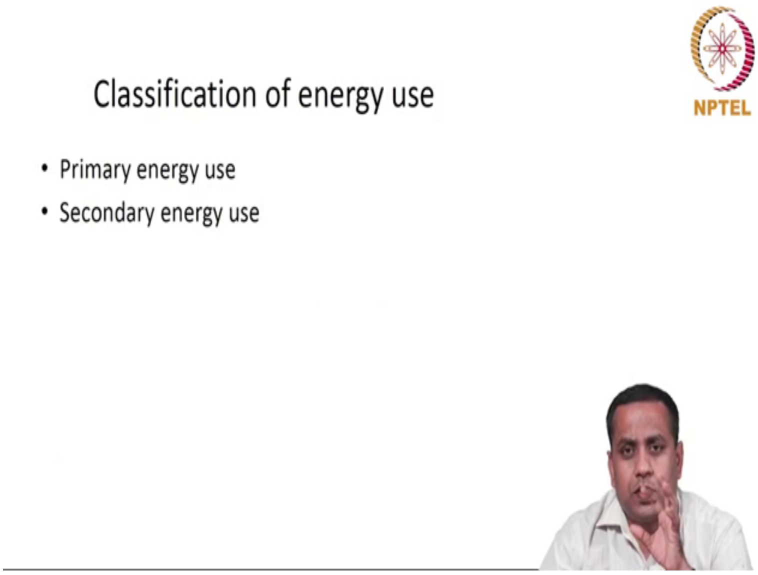

Now, the energy use associated with a product can be classified into two types one is the primary energy and the secondary energy.

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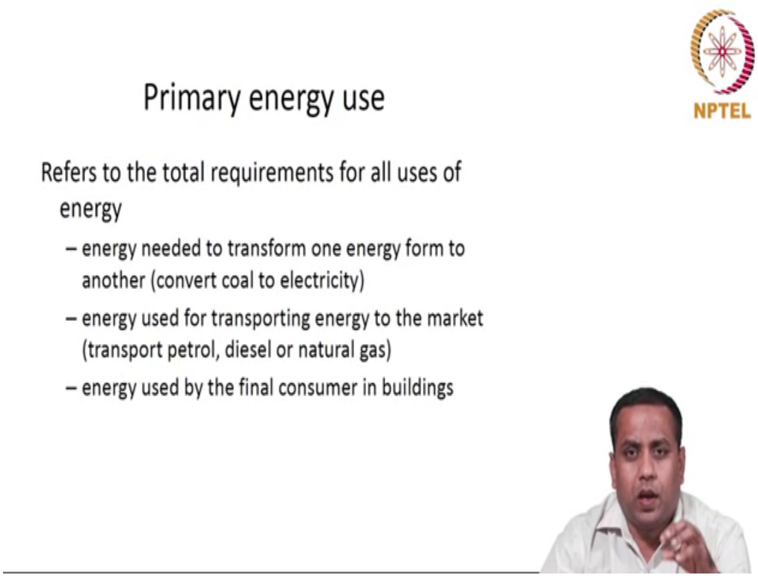

Primary energy includes the total energy requirements for the product whereas, the secondary energy represents.

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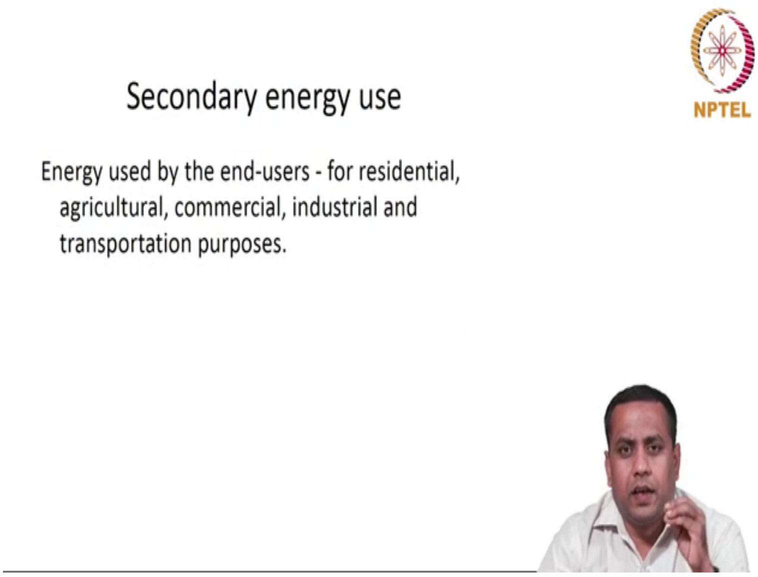

The energy used by the n customer associated with the product for example, in my residential building apartment, the number of units of electricity used per month is termed as secondary energy use. Energy use associated with producing the electricity transporting the electricity to the n customer in addition to the end user electricity is called as a Primary energy use. So in other words, in calculating the primary energy we also consider the energy for transforming one form to another energy for transporting the energy to the customers, and then the final energy used by the customers.

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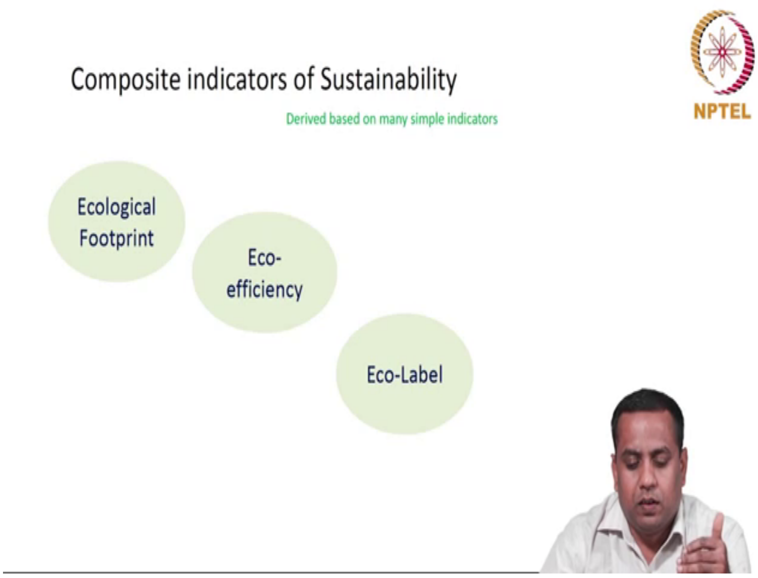

The second part of the indicators is the composite indicators of sustainability. We have three types of composites indicators: one is ecological footprint, second is eco efficiency, third is eco-label. We will go to the definitions one by one.