Sustainable Transportation Systems
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Lecture 36
Material Flow Analysis (MFA)

Hello friends, today we will discuss about Material Flow Analysis. You have seen various techniques to assess the project's impacts or their environmental impacts like EIA, LCA. So, similarly, this one, very simple technique is material flow analysis.

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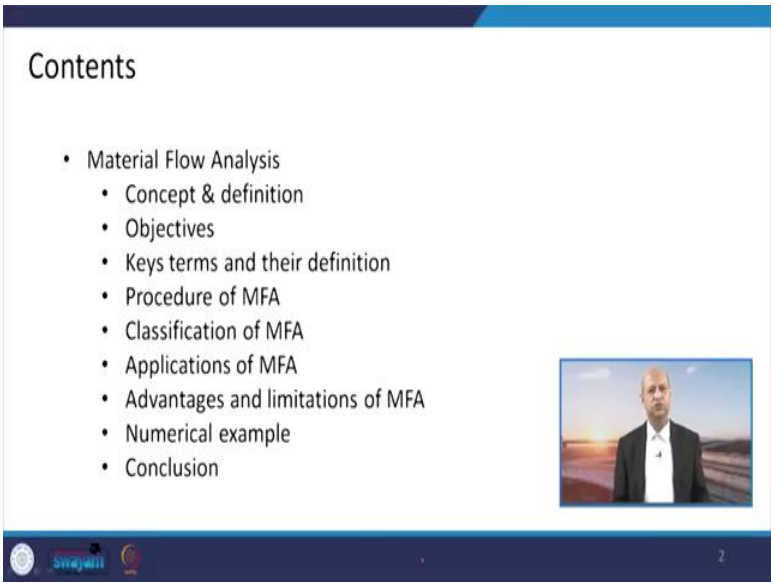

So, this will include like, we will understand the concept of the material flow analysis or MFA, and how do we define it then what are the objectives or purpose of MFA and some important terms, terminology and their definition, then procedure to carry out the MFA or material flow analysis. How do we classify for different situations MFA, then how do we apply it?

So, a very simple example of calculation will be there. Then we will discuss about advantages and limitations of material flow analysis and later on we will conclude it after the example and little bit like differences of EIA, LCA and MFA. So, that clarity can be developed regarding these three techniques, which sometimes look similar but they have different scope and in different settings they are more useful. So, that would also be discussed at the end.

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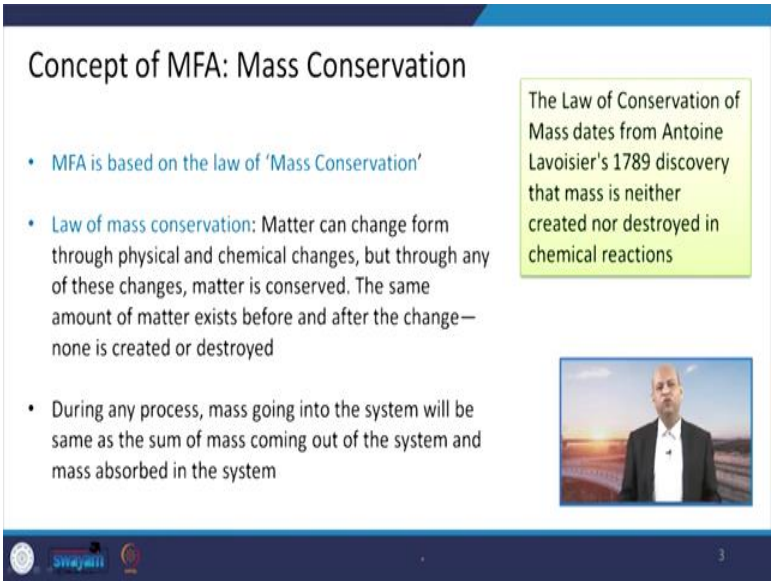

So, when we talk about this concept of MFA, that is the material flow analysis, basically this is based on mass conservation. You have, I am sure you might have heard mass conservation, energy conservation. So, these laws of mass conservation, as you know it has been, in 18th century it was decided by some experiments on the basis of the experiments it was given by one scientist and then it has been applied in different situations where a kind of physical and chemical changes are there, so that we can know that from one state to another how much conversion of mass in terms of another kind of product.

Again, the mass is there, so input, output kind of things. During some chemical reactions or some changes, for example if you are trying to see one particular activity, for example you are trying to convert one chemical in to another, so you have to see the total input and output, and in that process if like due to heat, the mass can be converted into energy also.

So, there is a loss of heat, etc., then that is known like stock, etc., and you can see total mass conservation can be defined in that way, because mass is neither created nor destroyed, but it transforms from one state to another.

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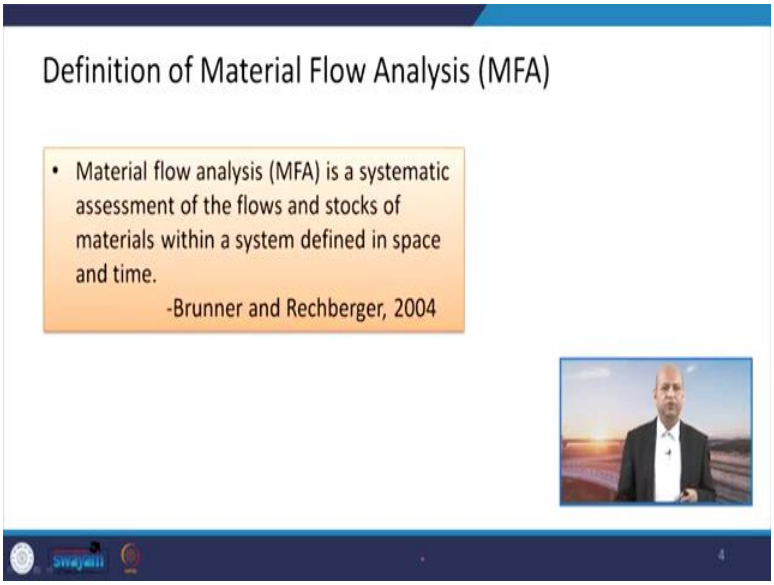

So, this is the basically this MFA and we use it as a kind of systematic assessment when we try to break the total system in to small subsystems or flows and processes. So, this is a systematic assessment of the flows and stocks. Stocks means whatever material is there which is left out or created within the system boundary and then input and output. So, total sum of those is basically the part of MFA.

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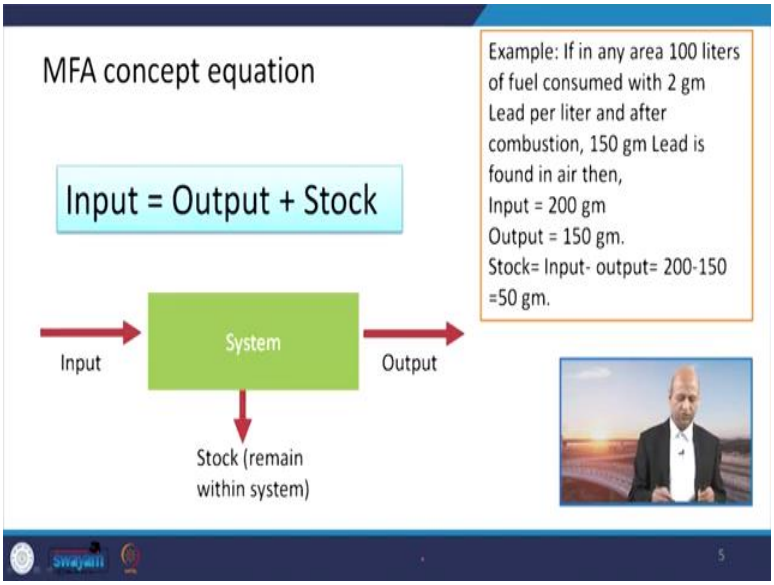

So, that is the simple equation you can see, like

$$Input = Output + Stock$$

So, stock means like within system something is there, it is being converted into some other kind of mass or service or product or heat or whatever. So, total sum is basically the conservation. It is same. So, for example if you know the input and if you know the stock related output can be easily calculated.

One example is given like this. You can see in 100 liters of a fuel, let us say 2 gram lead per liter is kind of present so in 100 liter it will be 200 gram, and if we measure and we find that 150 gram is in air, so where 50 has gone basically. So, that is basically stock. That has been converted into some other thing. So, that way very simple calculations can be made.

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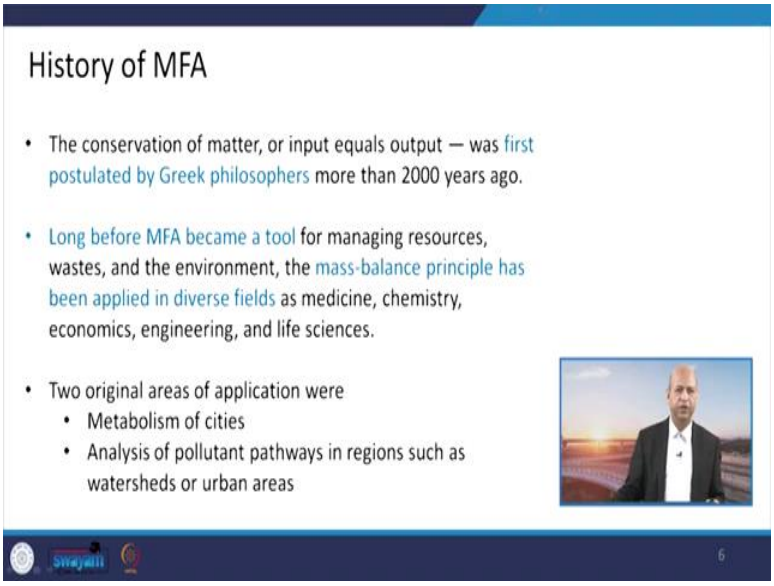

Historically, basically it dates back to 2000 years before, when Greek philosophers also thought about this, like transformation of mass from one state to another, one form to another. So, those kind things have been seen, and it has been applied in several fields like medicines, chemistry, economics, engineering or life sciences and the areas which is like metabolism of cities and analysis of pollutants, pathways in particular region such as watersheds or urban area shed.

So, some pollution stream is coming and then it is going to transform in another kind of compound so through this mass flow analysis you can easily trace and you can also see that how much of that

pollutant will be part of let us say some watershed or some stream, and how much will be converted into some other compounds or products.

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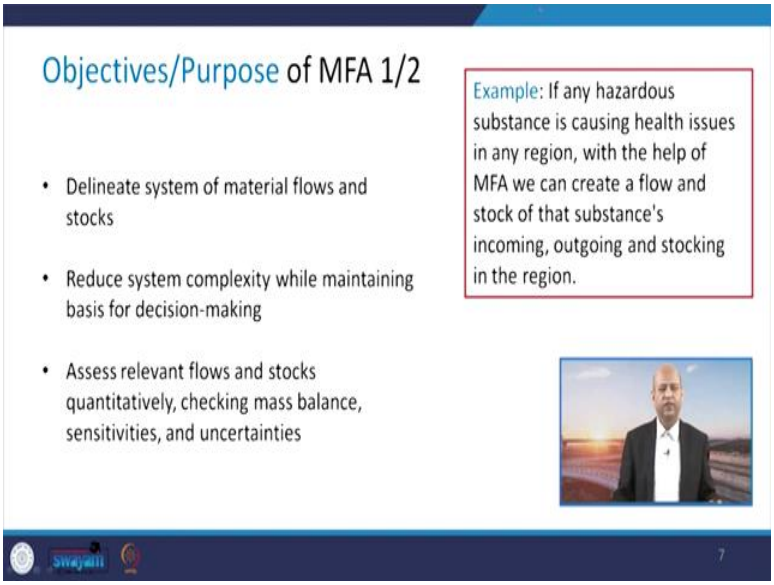

So, the objectives and purpose of MFA you can see like you can have like description of the systems analysis, based on the material flow and the stock's values, and it also reduces the system's complexity rather it take it in a simplified way, and maintaining all decision making processes. So, that way simplified version of the complex system through MFA can be broken into very simple kind of parts and then you can see where some particular thing is going on. So, accordingly, the judgment can be made.

And like one example, for example hazardous substances are there, so health issues may be there related to hazardous substances. So, if you know the pathways we can pinpoint that okay this much hazardous material is coming from a particular source, there may be two or three sources, but because of this material flow analysis you can pinpoint which source is basically giving more hazardous material and then you can deal with that.

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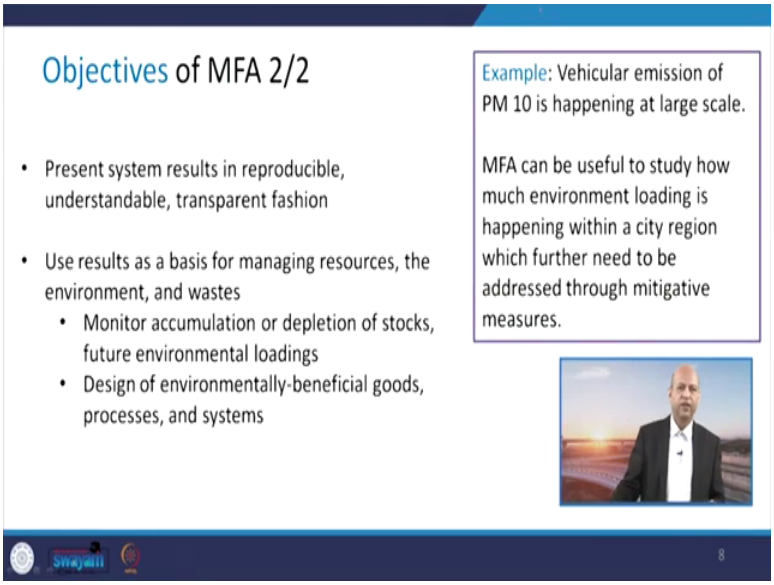

Then also like present systems which reproducible and it can be understandable because it is based on some quantities, so measurable things always help engineers and scientists to make good decisions. It is also useful for monitoring of like depletion of stocks or resources, environmental loadings, pollution loading and design of environmentally beneficial goods, processes.

Because through material flow, we can learn that which kind of process is better. Product is the same and due to process you can save the resources material. So, less resource intensive it can be. So, that way you can easily use it for several purposes.

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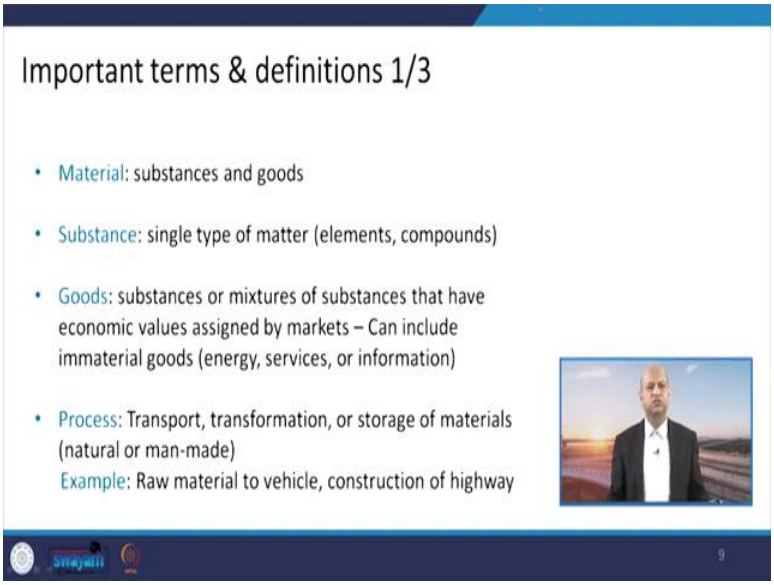

There are certain terminologies like materials, substances, goods, processes. So, they are defined here, substances are like, substances or goods are basically materials and then if we talk about only the substances then this is like single type of matter or elements or compounds.

Goods have several kinds of substances in that and also processes like services or energy, that is also known as goods. Goods and services tax you might have heard, GST. Then process, like transportation or transformation or storage and then whether in a natural environment, where, for example water is converting in to vapor, then clouds, then again rain, those kind of cycles.

So, at a particular thing, at a particular situation you can use this material flow analysis and see how much water will be flowing in the city area or that watershed area. So, that way you can use for designing like storm water related discharging facilities. So, those kind of things may be there.

And then processes also like raw materials in vehicle manufacturing or construction of highways, so that way also with the help of MFA we can learn, we can save certain materials by designing efficient processes.

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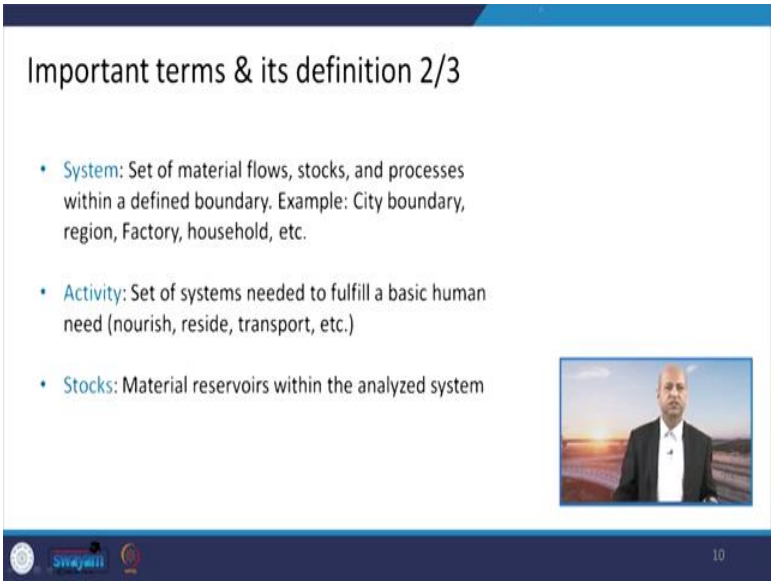

Systems when we talk about so like city, then we design city, city boundary so something is coming, something is going like nutrient values or vegetables or food supplies are there, they are incoming kind of input parameters into the city. Metabolism, then waste is discharged, so it goes to landfill area. So, those kind of boundary systems can be defined and then input-output and the stock related material flow can let us know how much waste material is being generated.

So, that way we can also look into what kind of facility we need for dealing with that waste, activities, like transportation or residence related activities, stocks that is again the material reservoirs and within the system, those kind of things.

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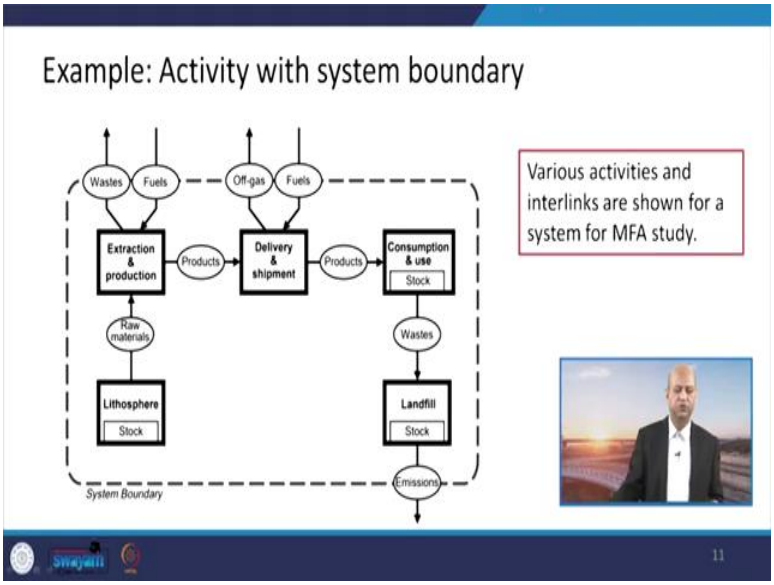

So, this is one system boundary you can see where raw materials are there, then extraction or production, so waste will be generated and fuel will be used for extraction or using, some product will be there. So, product will go, it will be delivered and shipping will be there, so again transport related activities will be there. Some gaseous pollutants will be there, fuel will be consumed, another product is going, it will be consumed or used.

And some stock, means after usage some waste material may be created so that waste will go to landfill. So, that way every stage, at every stage if you do this MFA, you can easily calculate how much waste will be generated, so that landfill design can be optimum in that way.

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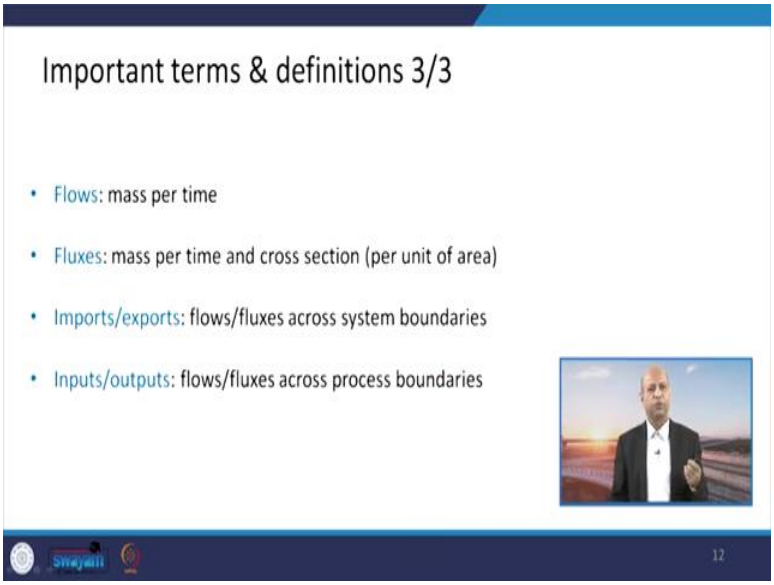

Then flows like mass per time or fluxes for example, mass per unit of time and cross section area. So, per unit of area, you can say. Similarly import, exports within the system boundary. Something is coming and something is going out. Input-output, that is basically process related flows and fluxes in the boundary and then going into the outer system or outer boundary kind of a flow.

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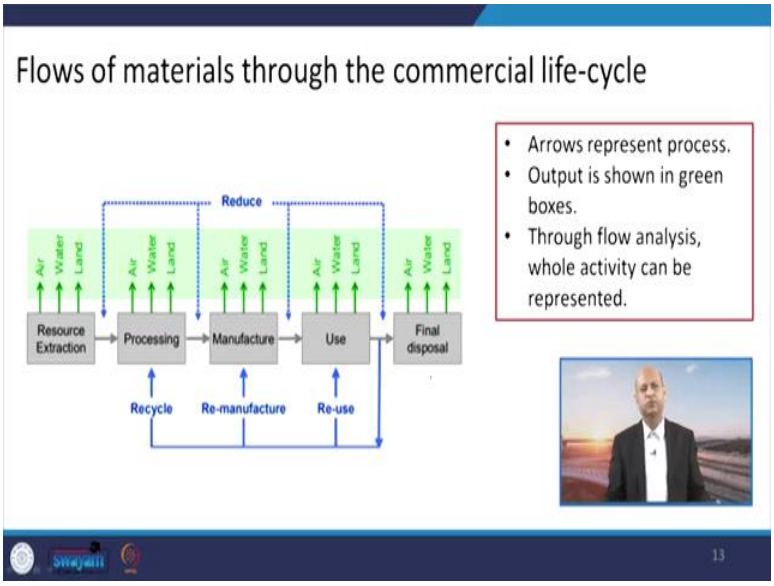

Then we also see like flows of materials through commercial life cycle. So, like resources extraction then processing, manufacturing, just we discussed earlier, uses and final disposal, so all these basically, they also have impact like reduction related some system or methodology is there,

then it will reduce the consumption of material then recycling may be there, remanufacturing, reuse, all these things will be part of that grand MFA.

And ultimately, we know that something is going into air, water and on the land in terms of waste or something, so those things also be taken into account otherwise the calculations will not be proper.

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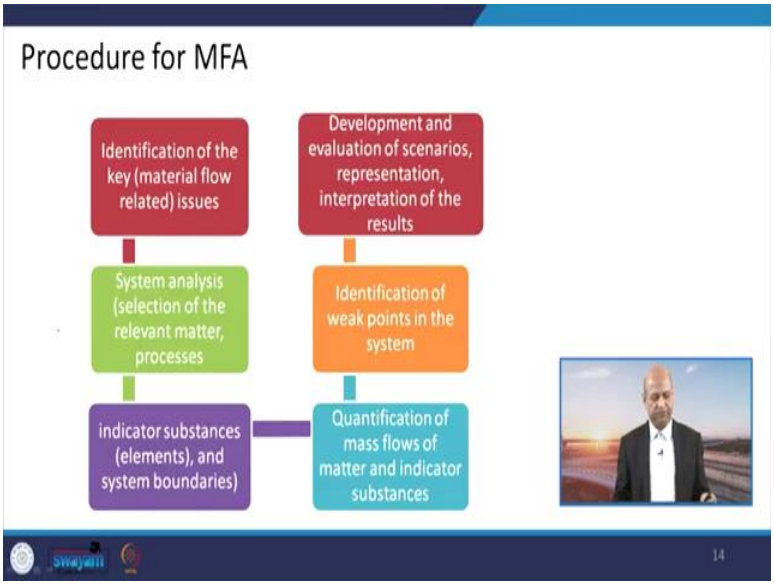

So, the procedure which we carry out for example, you have seen in terms of EIEA or LCA also. So, for example first of all we identify the key material flow related issues. What are important issues, which are related to material flow. So, we have to first identify that, like problem definition we do in certain case.

Then we analyze the system. The selection of relevant matter and the processes of that particular system and the indicators like some elements or some waste material or those kind of things, system boundaries we have to see that. Only this much system boundary we will consider that, otherwise it can be a non-ending process.

Then we quantify those mass flows of matter and indicator substances whether it is pollutant or whether it is other thing. Then we identify the weak points in the systems, because there may be something which is kind of losses, those kind of things are there, which is difficult to catch but we

have to see and we have to consider them, and ultimately we develop that strategy and evaluate different scenarios, because for each scenario you have to do MFA.

Only then we will be able to decide which scenario is better. Then representation and interpretation of those results properly, tabulated form or graphical form, so that analysis becomes quite easy and it is easy to convey also.

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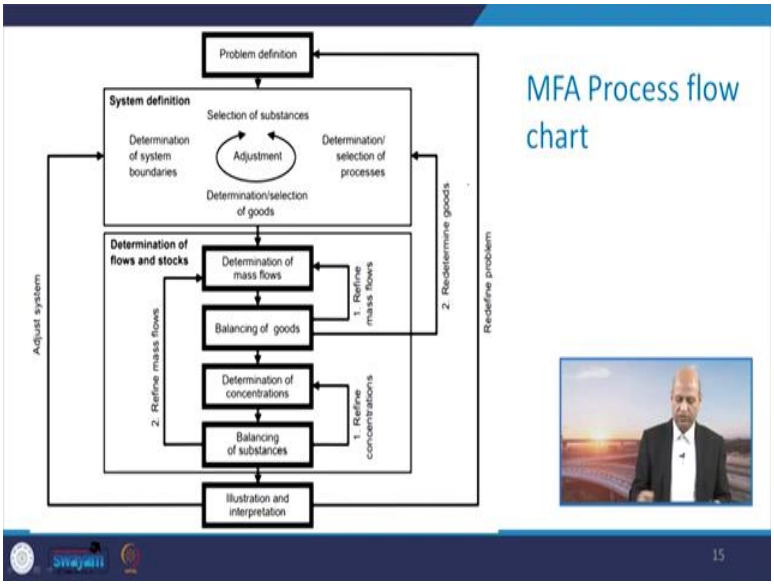

So, in this flow chart basically this MFA process has been shown for different activities, here selection of the problem definition first of all and this is also coming, at the last we will see why this feedback is there, which was in EIA also if you remember. Selection of the substances and determining the system boundaries and also determine the processes.

Then the selection of the goods where material will be calculated, then determination of the mass flow and balancing of the goods, determination of the concentrations when it is being converted into some substances or compounds, balancing of substances again, then illustration of the interpretation of the results.

So, there will be some gap, because some losses may not be easy to capture in early stage. So, then we will stage it, we will adjust it at that particular stage. Similarly, this feedback will go, this redefine the problem, because maybe, because of certain uncertainties we are not able to address

a particular issue. So, we have to redefine the problem to leave that issue otherwise we will not be able to achieve the targeted outcome.

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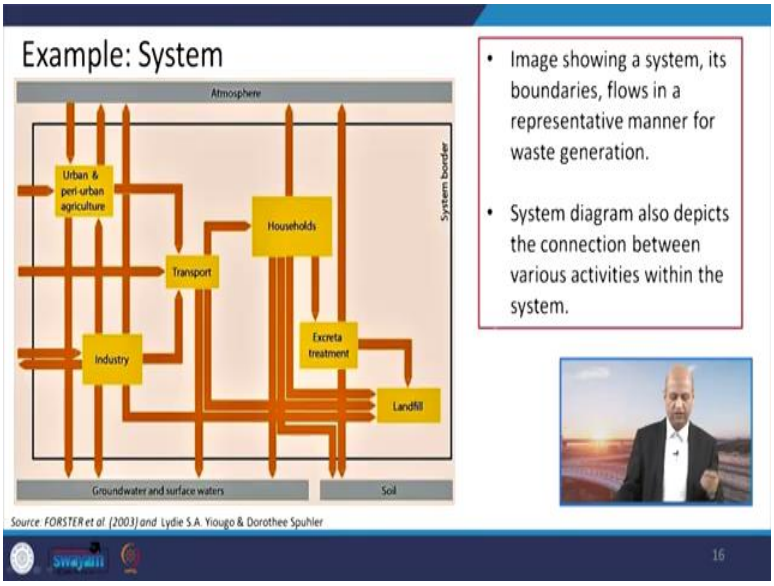

The system example is there for, you can see like urban and peri-urban agriculture system may be there, industry is there. From industry some products will be going to agriculture area like fertilizers, etc. Then agriculture products will be transported, and industrial products will also be transported. It will go to the household where it will be used and then some waste will be released and that waste will go to landfill and from landfill there are other issues like leachate or methane emissions or those kind of things.

So, that way this whole, it will also go into atmosphere. Something will go the ground water, surface water and then to the soil. So, all environmental components are related to release of gaseous or solid waste kind of things. So, that is the system boundary you can see where material flow analysis can take place and you can easily calculate from one stage to another, how much, means one stage's output can be input of another stage. Here you can see the output of transport will be input of the household, then output of this will be input of landfill, like that.

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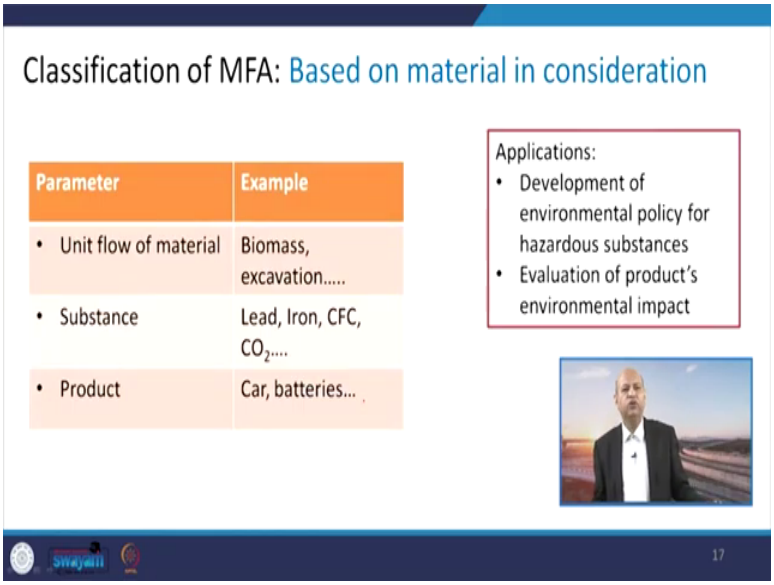

When we want to classify this material flow analysis then there are different ways of basis for that. Like if you are talking about unit flow material, for example in terms of biomass or evaporation of substances like lead or iron or CFCs or greenhouse gases, products like cars or batteries, so that way some parameters will give that line of action.

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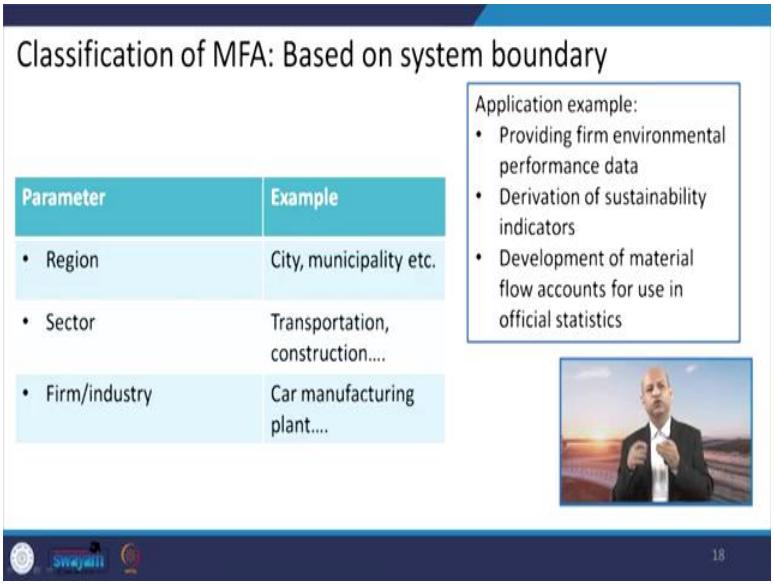

At regional scale city municipality can be considered, from sector point of view you can consider transportation or construction activities. If a firm or industry has to be considered then car manufacturing plant or fertilizer manufacturing plant or refineries, those kind of things may be

there. So, in those all kind of activities we can apply this MFA. So, accordingly, some classification may be as per their activities, intensity and so on.

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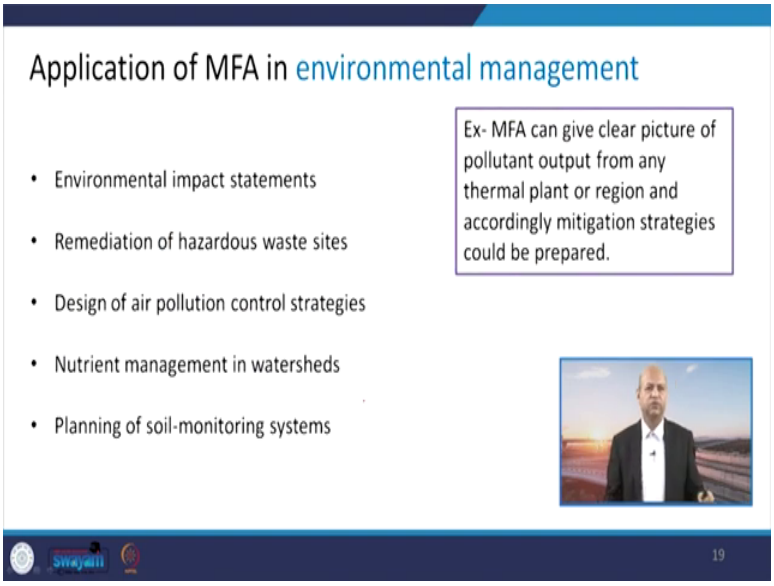

Then we also, when talk about application for environmental management, then naturally we talk about environmental impact statements or remediation of hazardous waste sites, design of air pollution control strategies. So, again, all these MFA can really help in achieving these things like nutrient management in watersheds or planning and monitoring of some systems. So, MFA really is helpful for those pollutant stream classification and analysis and then pinpointing some pollutants which may be problematic.

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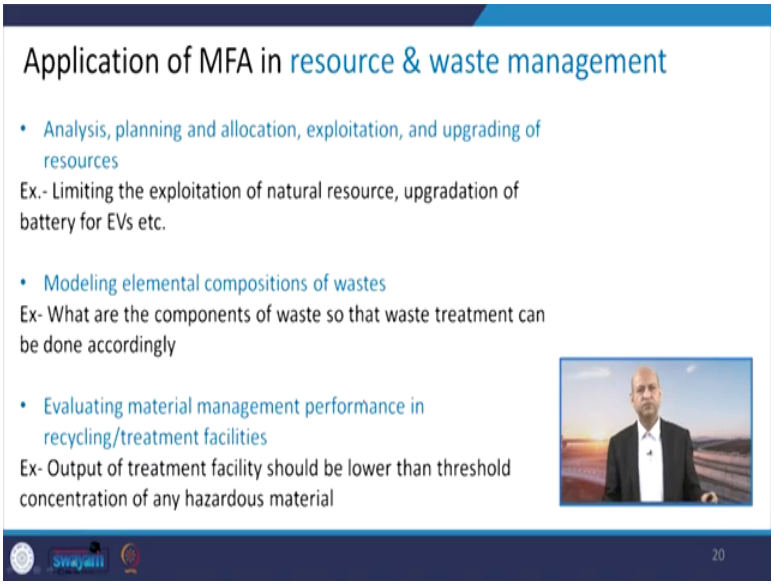

Similarly, for resource and waste management also as we have seen the examples of landfill related issues, so limiting of exploitation of natural resources or upgradation of like battery for EV, so MFA will let us know that in this particular technology this battery is consuming less resources. This MFA will easily help us to, in a tabulated form, we can know that these kind of methodology is giving us efficient battery where less resources are required and we can have same power, like that.

Similarly modeling of elemental components or compositions of the waste so that can also be done by MFA. Similarly, evaluating materials management performance recycling treatment, whatever activity which deals with the material and conversion or transportation or transformation of the material from one stage to another, one form to another, their MFA can be used.

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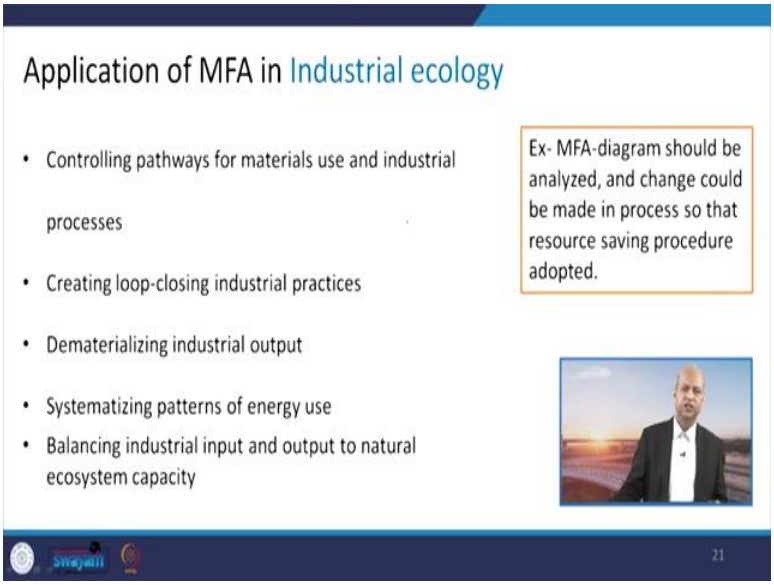

In industrial ecology also, like something is coming and which is like raw material then production will be there, some waste material will be there. That can be raw material for another industry. So, those kind of circular economy or industrial ecology, that also can be supported by MFA. So, that we can easily design the right kind of industrial ecology or circular economy related facilities.

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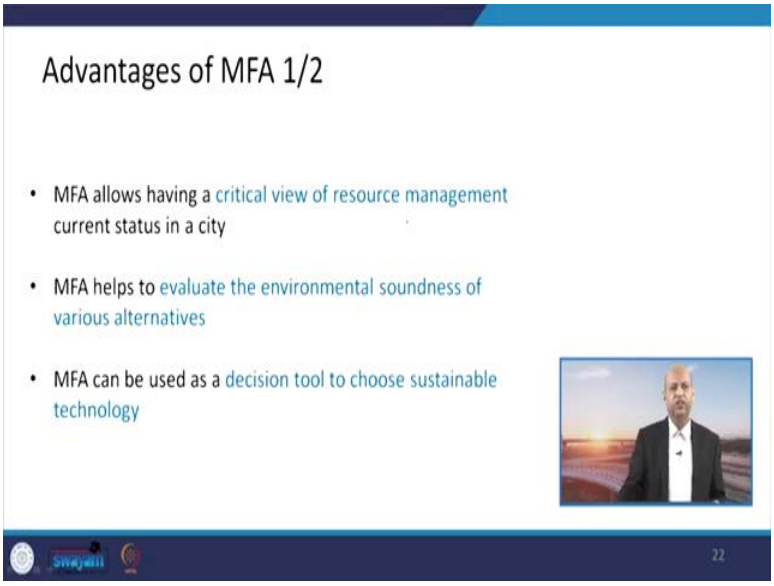

Then we talk about advantages and limitations, then advantages are like the complex thing can be divided into simplistic way, and this is very easy to implement MFA, input, output, stock, those values and calculations.

And it can also help in environmental soundness of various alternatives. So, it is not necessary that you go for lengthy EIA, which is time consuming resource consuming or LCA, which is very detailed exercise. With the help of MFA, you can do some sort of screening, some sort of over the envelop calculation kind of a thing, which can help you to make decisions at the very early stage. So, that is one very advantageous situation with the MFA.

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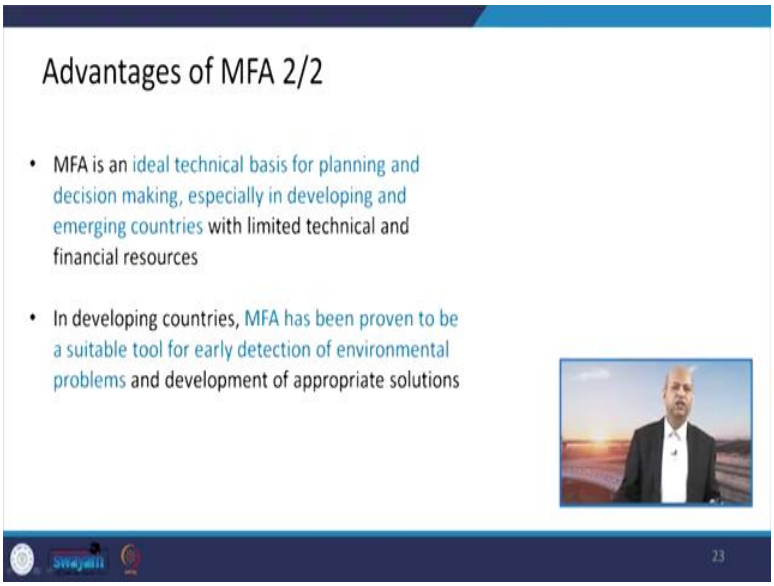

Then also it helps in like technological basis for planning and decision making for developing in emerging countries because developing and emerging countries always struggle with the resources, money and other things. So, these are the simple tools which can help them to make better decision, better decision process is helped by MFA. So, in developing countries many people or many organizations use this particular tool for, like detection of environmental problems in some activities, in some industry or those kind of things.

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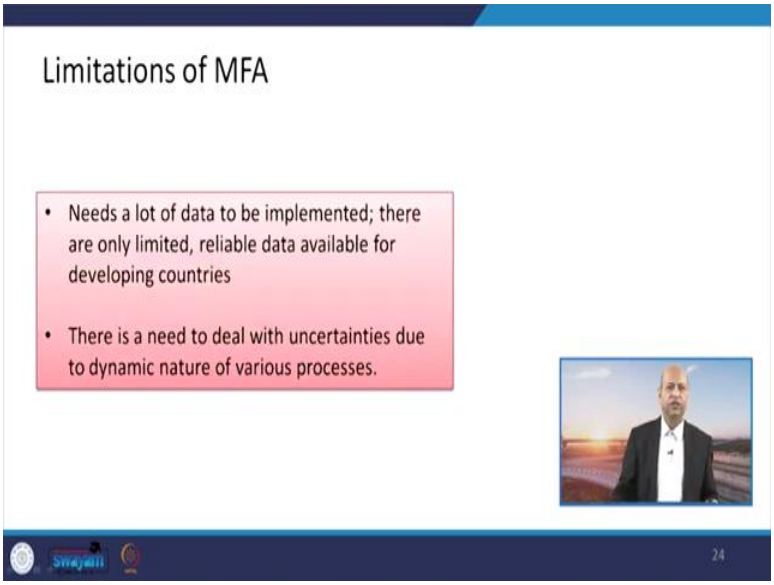

When you talk about the limitations then of course like it needs data, input, output, those kind of, for data you can say, if data is not available then there may be a little bit problem when you have to do a kind of survey and get the data, otherwise secondary resources, so uncertainties may be there. So, uncertainty can be addressed by some other techniques also, but at least to be begin with MFA, is good thing.

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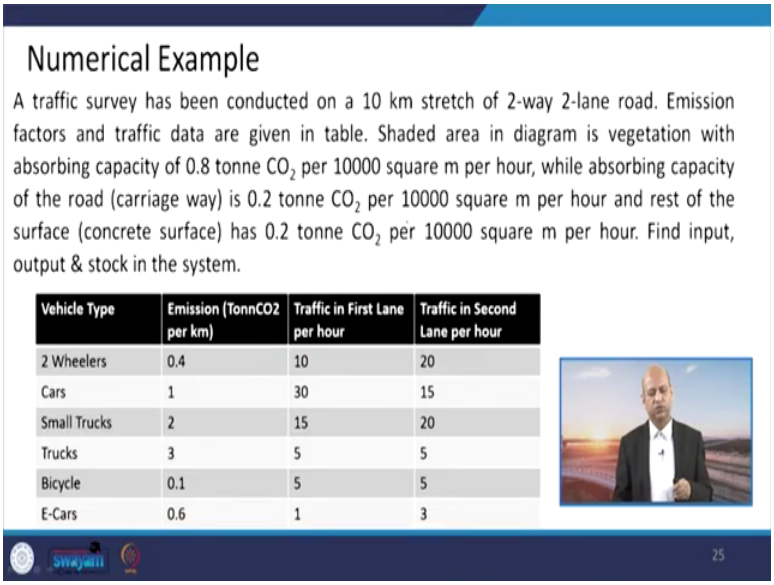

One numerical example is given here to explain how MFA is implemented so this is basically related to like 10 kilometer stretch of 2-way, 2-lane road. And then vehicle types and their numbers

or emissions from each vehicle is given. So, we have to find out input and output and stock of this particular system.

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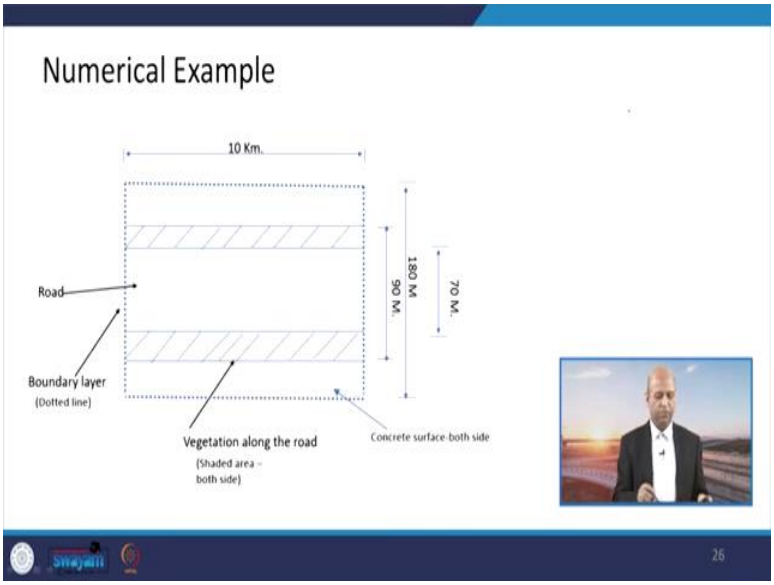

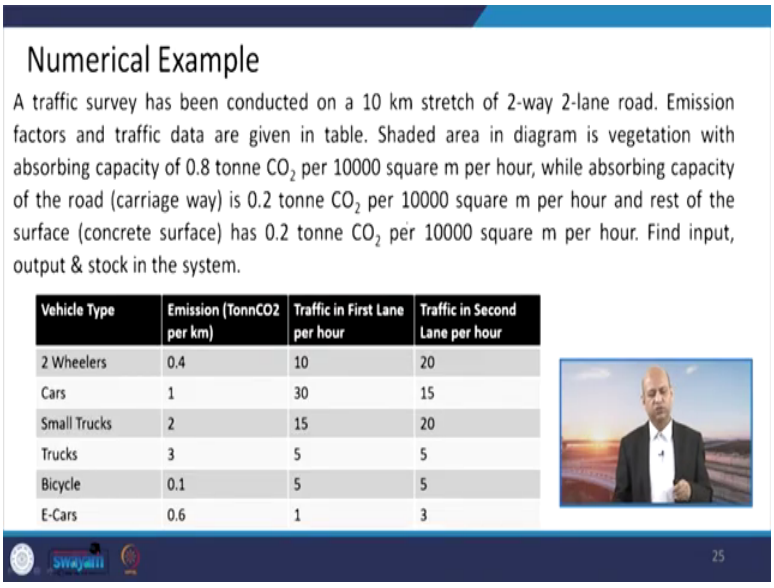

Vehicle Type	Emission (TonnCO2 per km)	Traffic in First Lane per hour	Traffic in Second Lane per hour
2 Wheelers	0.4	10	20
Cars	1	30	15
Small Trucks	2	15	20
Trucks	3	5	5
Bicycle	0.1	5	5
E-Cars	0.6	1	3

So, very simple, you can first design this stretch and there is gray area, where vegetation is also there and rates of absorption of different like CO2 is given. For example, road carriage way, 0.2 tonne CO2 per 10,000 square meter per hour. That is the absorbing capacity. Rest of the surface like concrete surface is also 0.2 tonnes, similar kind of values are given. 0.8 for this vegetation. So, in this 0.8, other is 0.2. So, those kind of values are given and dimensions are also given.

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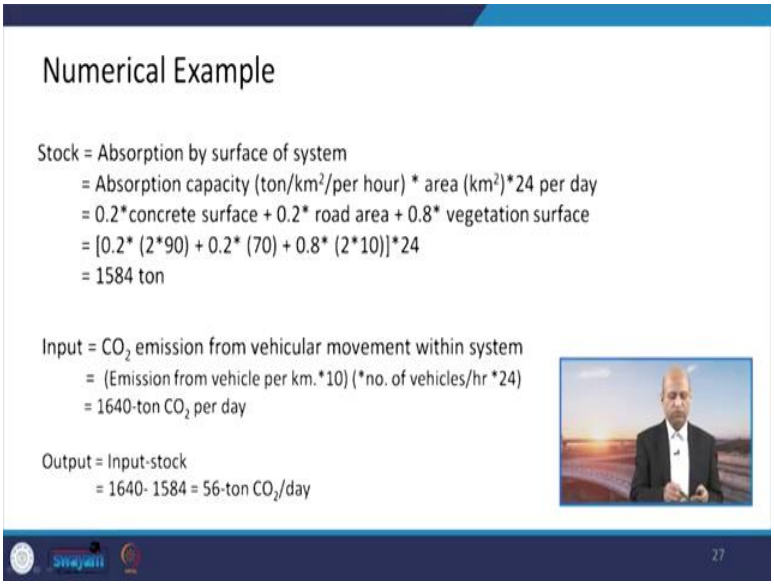

So, simple arithmetic kind of calculations, plus, minus, multiplication, those kind of things are used. You can easily see it. So, those values have been used to calculate how much input is there like 1640 tonne CO2 per day.

$$Input = CO2\ emission\ from\ vehiclular\ movemen\ within\ \ system$$
$$= 1640\ tonne\ CO2\ per\ day$$

$$Stock = Absorption\ by\ surface\ of\ system = 1584\ ton$$

$$Output = Input - Stock = 56\ ton\ CO2\ per\ day$$

So, that is the very simple way of calculating those values.

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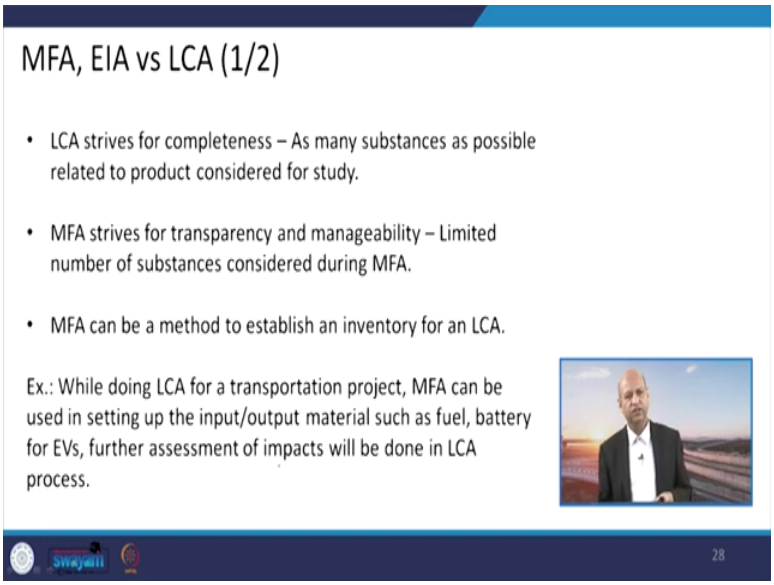

Then if you want to compare like having better clarity about MFA, EIA and LCA then we can see that like LCA is more of completeness, it is a holistic kind of a thing, MFA only part of things, look in to it, for complete system it may be difficult. So, LCA strives for completeness, like substances or products, et cetera, which are there.

MFA strives for simplistic way, transparency and manageability. It does not go to very lengthy kind of thing. So, limited numbers of substances are considered in MFA. So, the boundary system may be narrower or those kind of things, and it can also be a helpful inventory for an LCA. That means it can be used for LCA. It may be a subtool, similarly in EIA also we will see that in EIA we can use this tool.

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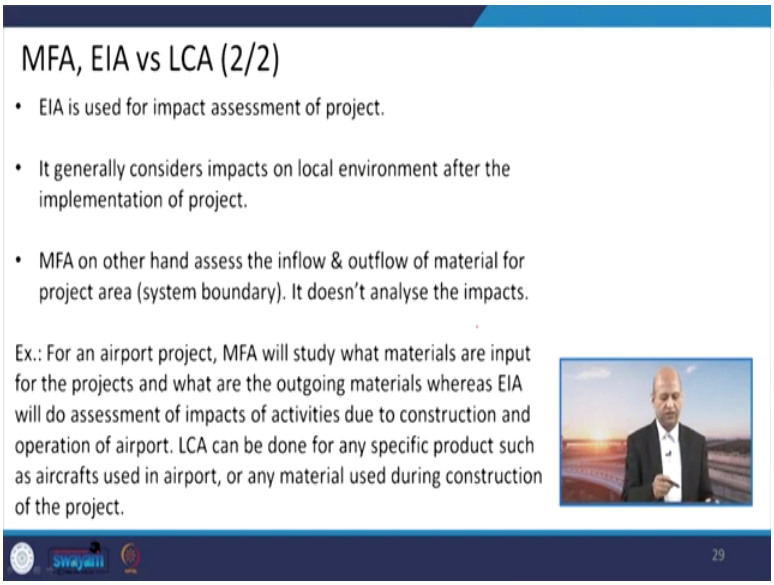

Because EIA is impact assessment of the complete project, whereas this MFA can go for inflow, outflow kind of material for a particular activity. So, in that way also again it can be one tool which can support into EIA kind of exercise. So, that way there is a difference of scale of application of these tools, and also their complexities and resource intensiveness because MFA is the least resource required kind of thing. If you have data, it is very easy to do MFA.

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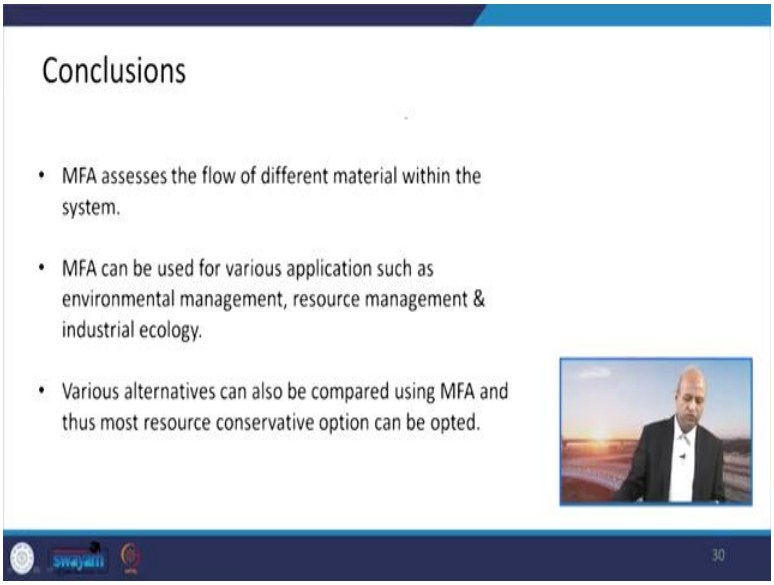

So, in conclusion we can say that it is a very simple system and not very highly skilled person is needed for that. Simple calculations are done for MFA input, output, stock kind of calculations, and it can give us a kind of information which helps to make decisions at early stages. Kind of screening stage or those kind of things, and if there are various alternatives, if we do the MFA for different kind of alternatives then also we can easily assess that which alternatives would be better in terms of least resources or least material consumption, so that MFA can give.

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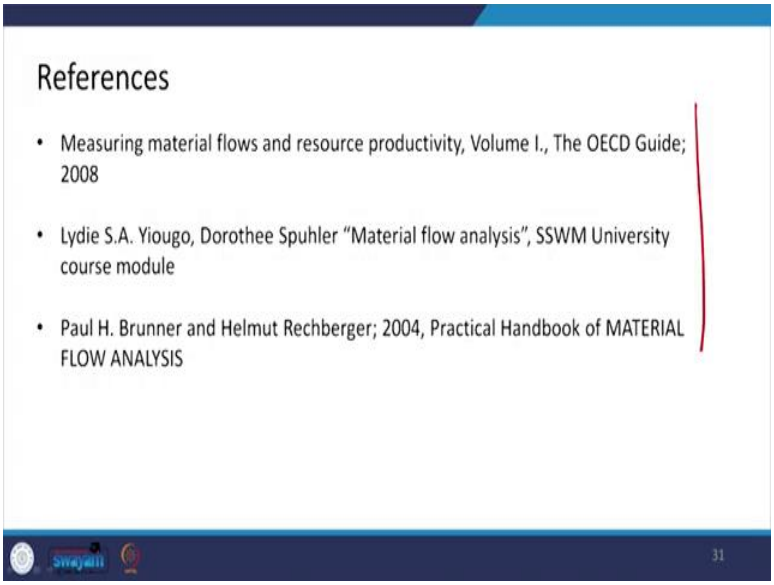

These are the references based on which we have prepared this presentation. So, thank you for your kind attention and we will continue about MFA next time we will see the case study of MFA. So, see you again with the same topic but application part. Thanks again.