Basics of Mechanical Engineering-2

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Week 12

Lecture 48

Introduction to Sustainable Manufacturing

Welcome to the last week of the course, Basics of Mechanical Engineering II. We are discussing manufacturing processes in this course. In this last week, we are focusing on sustainability or sustainable manufacturing. This week is titled Introduction to Sustainable Manufacturing. I am Dr. Amandeep Singh Oberoi from the Indian Institute of Technology, Kanpur.

The contents of this lecture will flow as follows. We will introduce sustainability. What does the term sustainability imply, and how is it related to green manufacturing? And

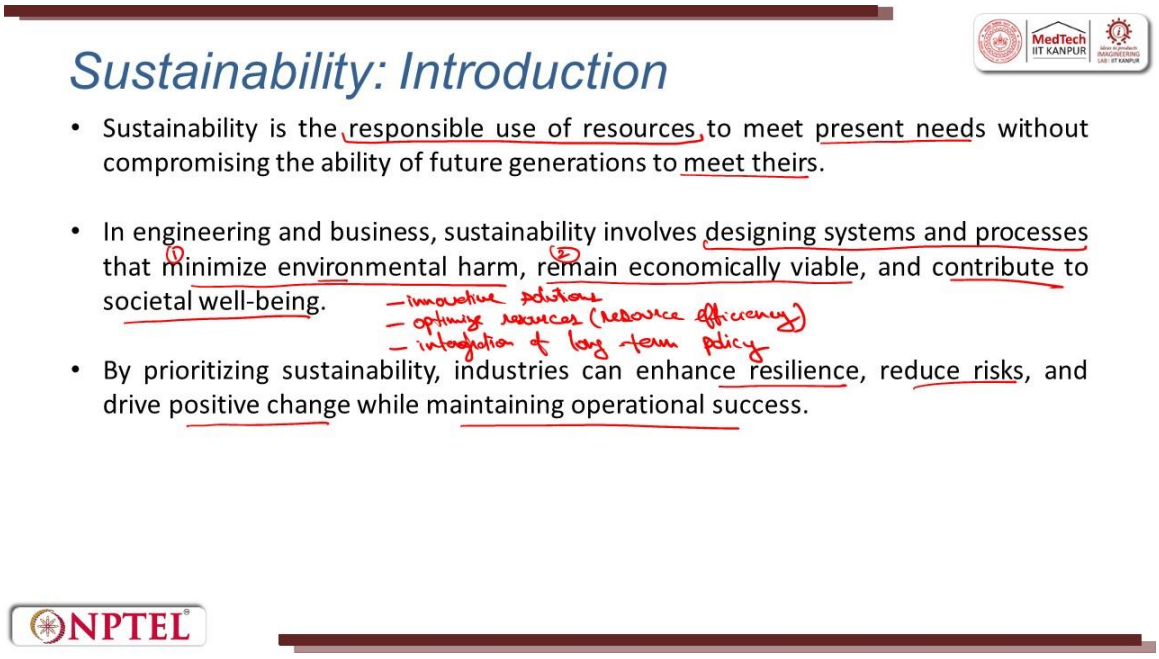
what exactly is green manufacturing? That, too, we will discuss. Then, the triple bottom line of sustainability.

What are the three major pillars on which sustainability stands? The components of the triple bottom line, benefits, and challenges in implementing them. Then, elements of sustainable manufacturing. What are certain elements at the elemental level? We start from the introductory level and see how far we need to go. We'll talk about sustainability.

When we talk about sustainability in engineering, in the coming lectures. We'll talk about green machining, green manufacturing systems from the systems. You find when we talk about manufacturing from the systems. It talks about the complete supply chain, complete ERP, enterprise resource planning. But from there, from the complete factory to the production line, to the specific unit process.

In unit process, green machining will more focus upon here. Then some regulation and policies that I will discuss in this lecture only. Because when we talk about sustainability, when we talk about green manufacturing. When we talk about ecological manufacturing systems. This is all aligned to the SDGs that is sustainable development goals.

In those what are regulation and policies, generic policies. Which are there in India that we will talk about. This will be just introduction to the sustainability in the first lecture. Then we will talk about specifically sustainable manufacturing in the forthcoming lectures in this video.



Sustainability is the responsible use of resources to meet the present needs. Without compromising the ability of future generations to meet theirs. Which means the resources nowadays of future generations 100 years. From now should also be able to enjoy the same. Which means the way we are resourcing the resources, resources could be anything. It could be water, it could be land, it could be anything that is manufactured.

That we are using nowadays, the way we are enjoying it, 100 years from now. Our future generation should also be able to enjoy at the same level. That means the purity of water, the soil that has to be maintained with all nutrients. The purity of air, everything has to be maintained. Maintained means this is what sustainable system has to be there.

Now in engineering and business sustainability involves designing systems. And processes that minimize environmental harm. This is first point. Second point is remain economically viable and contribute to societal well-being. Societal well-being when we say sustainable designs and in such a way.

So that social and economic and environmental, all the factors are taken care about. So this needs a certain initiative such as we need to have innovative solutions. Then existing resources, whatever we have, we have to use that in an optimized way. Optimized resources or I will call it resource efficiency as well. This all is to be done with the integration of long term policy. By prioritizing sustainability, industries can enhance resilience, reduce risk and drive positive change while maintaining operational success.

Sustainability: Introduction

- Sustainability in manufacturing is an essential approach that focuses on reducing environmental impact, optimizing resource usage, and ensuring long-term economic and social benefits.

- The rapid industrialization and increasing environmental concerns have pushed companies to adopt sustainable practices.

Carbon Credit trading
Carbon Accounting Systems

- In this document, we explore various aspects of sustainability in manufacturing, including key principles, regulations, case studies, future trends, advantages, limitations, and real-world applications.

https://www.nist.gov/blogs/taking-measure/sustainable-manufacturing-smart-manufacturing

In manufacturing, when we talk about sustainability in manufacturing, it is an essential approach that focuses on reducing environmental impact, optimizing resource usage. And ensuring long-term economic and societal benefits. This is the same thing.

The rapid industrialization and increasing environmental concerns have pushed companies to adopt sustainable practices. When we talk about sustainable practices, nowadays, you know, carbon credits. Carbon credit trading carbon credit trading you develop carbon credits. That is while working you develop something. So that you are saving something for the environment or in the environment those credits.

You can convert into the economic terms as well like you grow number of trees. You try to develop the system so that you purify water those systems could be then converted into carbon credits. These credits are sold to the companies who would purchase them and give you something in return. This all is required to have a carbon accounting system.

Carbon accounting system. So there are companies specifically focusing on the carbon accounting itself. For example uh chanel electric they are developing their own software systems. Where we put in the data the way your logistics are running the way your supply chain system is running the energy. That is consumed by your machines so those are all taken as input by this company.

And this company gives you a carbon accounting that what is the green or carbon rating of your system or the product or the production line that you are using. So, in this lecture, we will explore various aspects of sustainability manufacturing. Including key principles, regulations, case studies, future trends, advantages, limitations and real world applications.

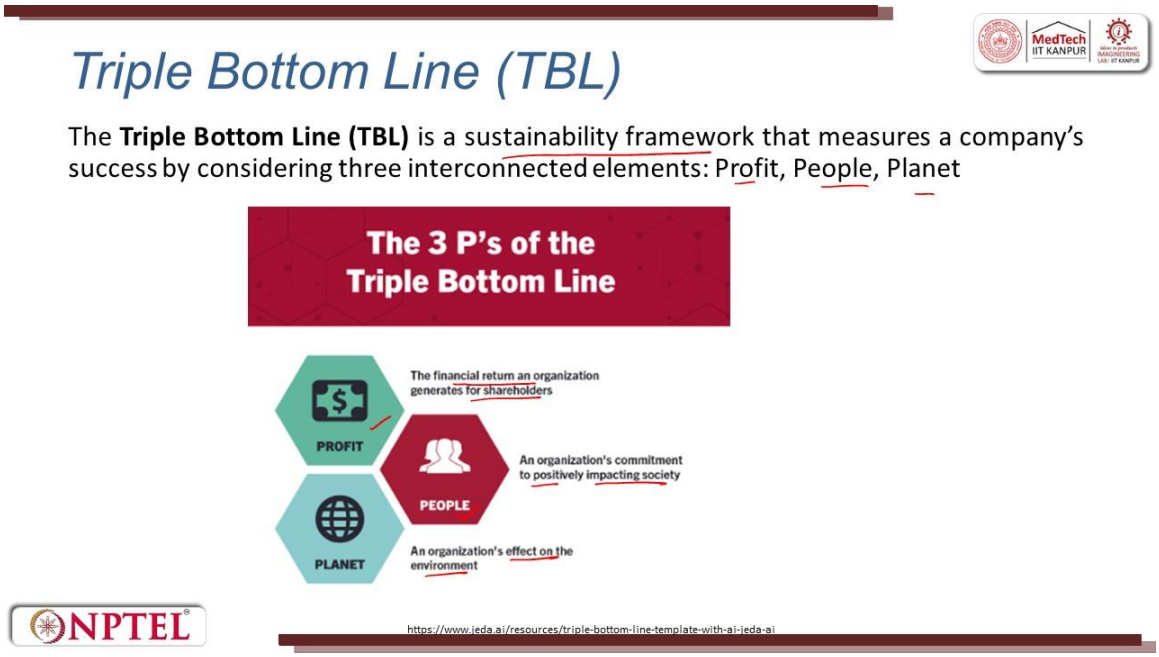
Triple Bottom Line (TBL): Introduction

- In today's business landscape, sustainability is a critical factor influencing corporate strategies and decision-making. The Triple Bottom Line (TBL) framework, introduced by **John Elkington** in 1994, provides a comprehensive approach to evaluating business performance beyond financial profits.
- By incorporating three fundamental dimensions— people, planet, and profit.
- TBL encourages organizations to achieve a balance between economic success, environmental responsibility, and social well-being.
- This approach is gaining widespread recognition among businesses, policymakers, and researchers as a pathway to sustainable development and long-term profitability.

When we talk about sustainability, Triple bottom line is the basic criteria that is being talked about. In today's business landscape, sustainability is a critical factor influencing corporate strategies and decision making. The triple bottom line framework introduced by John Linton in 1994. Provides a comprehensive approach to evaluate business performance beyond financial profits. By incorporating three fundamental dimensions that is people, planet profit. I'll talk about this in detail in the coming slides.

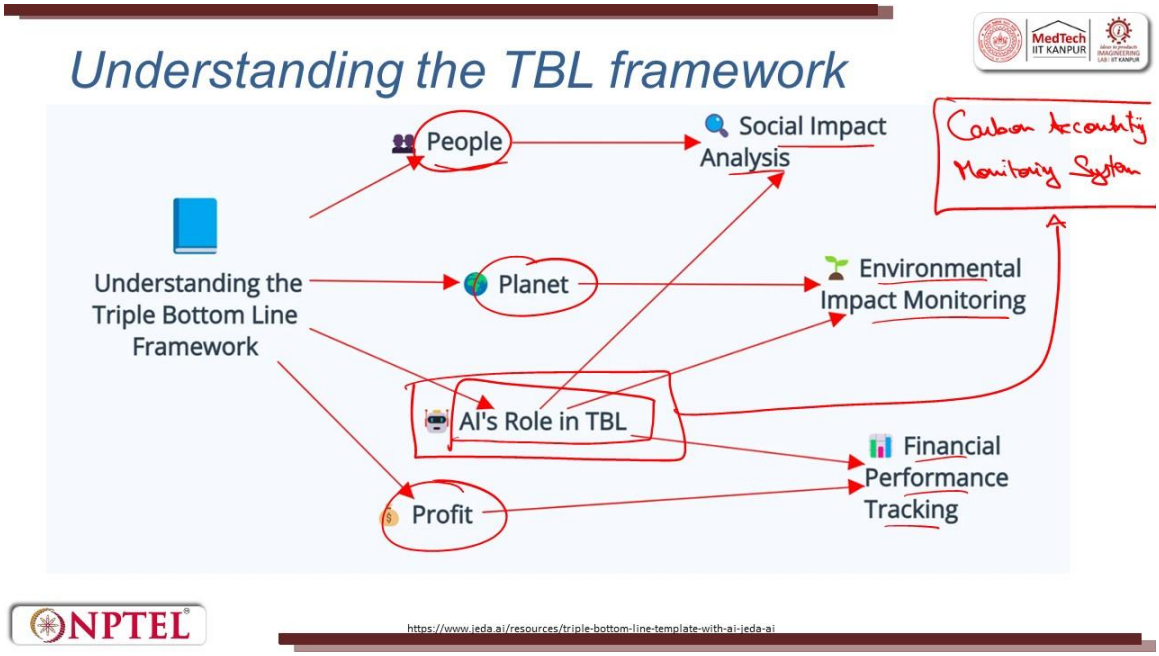
When we talk about people, we are talking about society. When we talk about the planet, we are talking about the environment. When talking about profit, that encompasses the economic aspects of the business.

The triple bottom line encourages organizations to achieve a balance between economic, environmental, and social well-being. These three words are here. This approach is gaining widespread recognition among businesses, policymakers, and researchers as a pathway to sustainable development and long-term profitability.



The triple bottom line is a sustainability framework that measures a company's success by considering three interconnected elements: profit, people, and planet. In profit, financial return. An organization generates for shareholders is discussed in people and an organization's commitment to positively impacting society. That may include generating more employment or developing the system.

So those are clear for the societies which are living around, then planet and an organization's effect on the environment. It is minimizing the production or generation of waste in the triple bottom line.



When you talk about people, planet, profit nowadays in 2025. AI's role in the triple bottom line is very critical. That is understanding the triple bottom line framework.

There are tools which try to integrate societal impact analysis. The environmental impact monitoring and financial performance ranking. And developing AI tools, as I talked about carbon accounting. Monitoring system to develop the system in a way. So that it understands the way you are working. This is developed using AI.

I am not going to discuss this reaction because it will be a different tangent to the course. I will focus more on manufacturing only, so that part. I will focus more. This lecture is only an introduction. That is why I am trying to introduce what TBL is.

Triple Bottom Line (TBL)

1. People (Social Sustainability)

This dimension of TBL focuses on the impact of business operations on employees, customers, and communities. Organizations committed to social sustainability aim to:

- Ensure fair labor practices and worker rights.
- Promote diversity, equity, and inclusion in the workplace.
- Engage in corporate social responsibility (CSR) initiatives, such as community development and philanthropy.
- Provide safe and ethical working conditions.

By prioritizing social responsibility, businesses can build a positive reputation and enhance stakeholder trust.

And what are the other components of sustainable manufacturing, such as social sustainability. This dimension of TBL focuses on the impact of business operations on employees, customers, and communities. Organizations committed to social sustainability aim to ensure fair labor practices and worker rights.

Promote diversity, equity, and inclusion in the workspace, engage in corporate social responsibility. That is CSR initiatives such as community development and philanthropy. And provide safe and ethical working conditions. By prioritizing responsibility, businesses can build a positive reputation and enhance stakeholder trust.

Triple Bottom Line (TBL)

2. Planet (Environmental Sustainability)

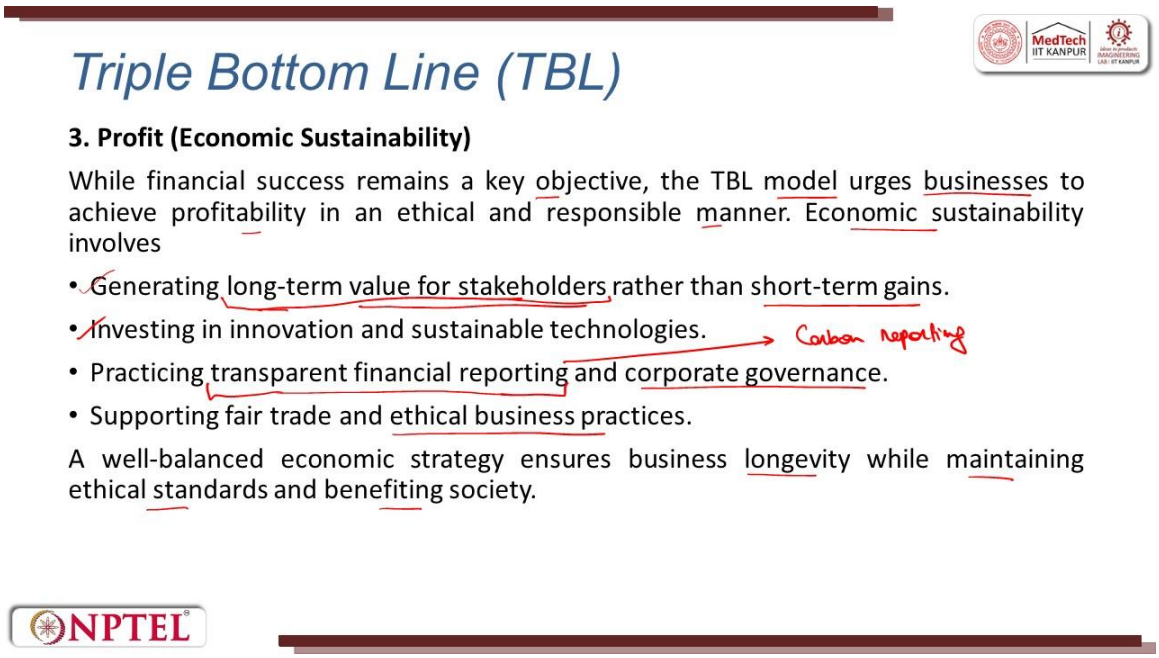
Environmental sustainability emphasizes minimizing negative environmental impacts. Companies focusing on this aspect strive to:

- Reduce carbon footprints and greenhouse gas emissions.
- Implement energy-efficient and renewable energy solutions.
- Adopt sustainable resource management and waste reduction practices.
- Develop eco-friendly products and packaging.

Organizations integrating environmental sustainability into their strategies contribute to global efforts in mitigating climate change and preserving natural ecosystems.

Then comes the planet that is environmental sustainability in environmental sustainability. We emphasize minimizing negative environmental impacts. Companies focusing on this aspect strive to reduce carbon footprints. And greenhouse gas emissions, implement energy efficiency. And renewable energy solutions, adopt sustainable resource management. And waste reduction practices, develop eco-friendly products and packaging.

So in this, when we talk about environmental sustainability, resource conservation and ecosystem protection is very important. Pollution and waste reduction are very important. Renewable energy and efficiency are important. Organizations integrating environmental sustainability into their strategies contribute to global efforts in mitigating climate change. And preserving natural ecosystems.



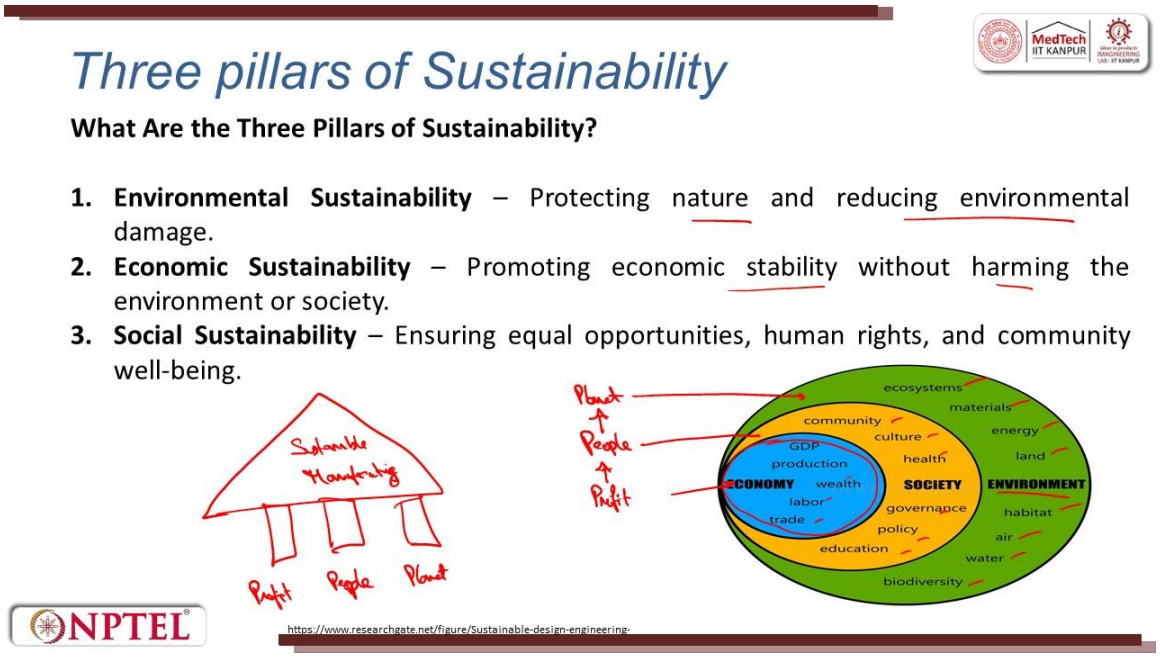
Then comes profit, it is economic sustainability. While financial success remains a key objective. The TBL model urges businesses to achieve profitability in an ethical and responsible manner. Economic sustainability involves generating long-term value for stakeholders. Rather than short-term gains, long-term means when we're talking about sustainability. The sustainable products which have long-term benefits in place of short-term immediate benefits.

That could be somewhere higher in terms of profit but for long-term benefit. When we try to design or use a material that is more biodegradable. So that is a long-term benefit. In the future, the overall cycle from cradle to grave, when we talk about life cycle assessment. We'll talk about life cycle assessment in the coming lectures.

That is when the ore is extracted from the very birth of the material. It converts through various cycles, through various processes of material. It is reused, then it goes through disposal. To the point of disposal, the overall long-term benefit is more focused here. That is long-term value for the stakeholders.

Then investing in innovation and sustainable technologies. Practicing transparent financial reporting and corporate governance. When I say transparent financial reporting, here we also have carbon reporting. That would, though, come under environmental sustainability. But when we talk about financial reporting.

Financial gains are now linked to the carbon footprints or carbon accounting systems as well. That is the carbon credits that you develop. Supporting fair trade and ethical business practices. A well-balanced economic strategy ensures businesses longevity. While maintaining ethical standards and benefiting the society.



Three pillars of sustainability once again talking about in this illustration in a way economy is a smaller part. That is now financial gains when we talk about profit though it

is taken as a pillar itself. All the three we talk about profit people and planet. This is where your sustainable manufacturing is standing on. But profit is a smaller in which GDP production, wealth, labor trade.

That is promoting economic stability without harming the environmental society. Then come society, community, culture, health, governance policy. This was being focused since long. We'll call it as people here. This is society.

Now, more focus is given to the planet when we talk from the sustainable manufacturing viewpoint. It is environmental sustainability. So, I will put an arrow indicating that more focus is given here: ecosystems, materials, energy, land, habitat, air, water, biodiversity. That is, protecting nature and reducing environmental damage is the major focus.

Now, how do we implement the triple bottom line? Now, I'm talking about the general viewpoint—what are the different elements, the different pillars of sustainability? We have to take all of them and, in unison, develop a system so that all of this is implemented.

Now, the point is how to implement the triple bottom line. We need to define the goals, and when we talk about ESG—that is, environmental, social, and governance— The company's focus is on one of these three specific elements.

The environmental element is definitely accounted for because ESG stands for 'environment' itself. So, some companies focus more on developing something for society. Some companies focus more on developing products that are greener. So, that is how we design. To implement the triple bottom line—how do we implement it?

Achieving a successful triple bottom line strategy requires purposeful leadership and a commitment to sustainable innovation. Organizations can take the following steps. That is, they can define clear sustainability goals. That is, establish measurable objectives that align with corporate values and industry practices. Specific goals.

When I talk about what we are trying to do, are we trying to reduce energy consumption or reduce waste generation, or are we focusing on developing bio or green materials? We need to engage these stakeholders, that is, collaborate with employees, customers, suppliers, and communities to drive sustainable initiatives. There are a lot of advertisements and commercials nowadays that talk about different ratings. Like if you need to purchase a refrigerator, a 5-star rating.

If you need to purchase a product, that is, maybe cups which are developed through the material. That is, biodegradable cups made of paper or so. So, all the people, including customers, need to be educated on what the need for the triple bottom line is nowadays. We need to integrate sustainable practices in a way. We need to implement responsible sourcing and waste reduction.

And energy-efficient technologies and measures, and reporting progress, are the most important points here. Anyway, among all the points, we need to focus on them. But to measure—the way to measure, the way to develop the matrix, the matrix of measurement. When I talk about the matrix, the matrix could be specific to unit manufacturing. Unit manufacturing processes, in a way, for specific machining.

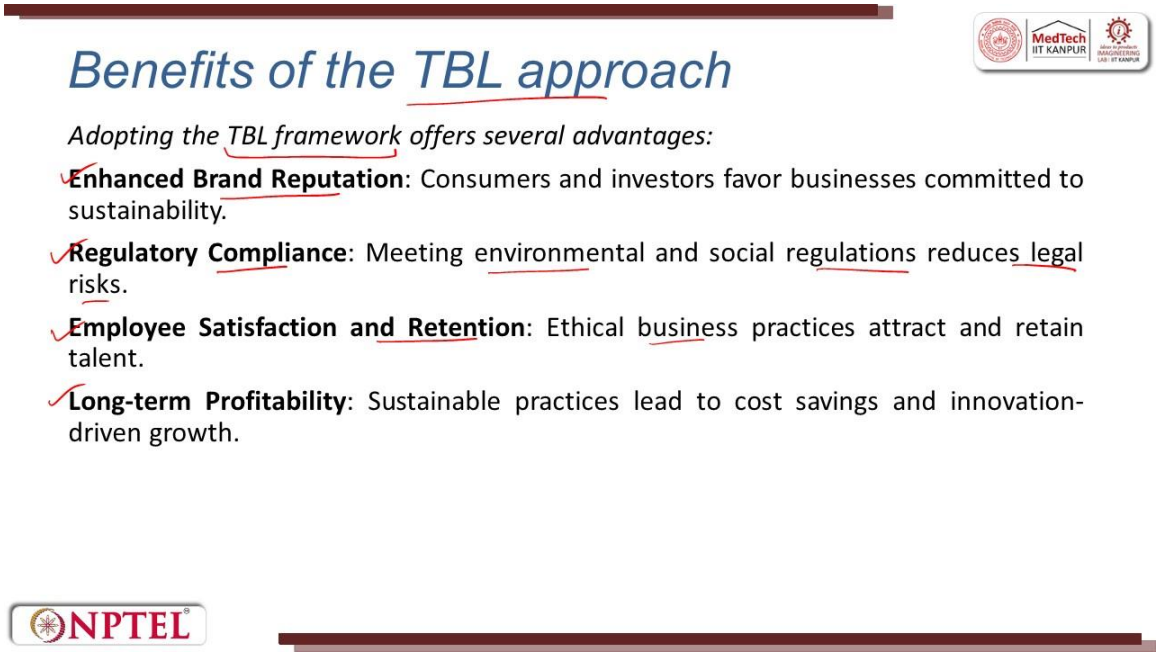
How do we measure? What is the energy consumption? How is this reduced for a specific machine? What is the utilization of cutting fluid? And how is this cutting fluid being replaced with biodegradable cutting fluid or reducing the consumption of cutting fluid? How is it benefiting? This is a specific metric for the unit manufacturing process only. And in the production line itself, there could be the supply of material or the transfer of material in material handling from one machine to another. How is that going? Is it using manual labor? Is it using automated systems?

How is that being managed? Then, certain metrics may be in logistics as well. How do we transport? Using bigger trucks? Using smaller trucks? What is the efficiency? And all those things are to be measured and reported.

That means we utilize sustainability metrics and transparent reporting to track impact and ensure accountability. Then you foster a culture of responsibility. That is each and every person. That is what we call it as a responsibility. TPM, total productive maintenance is actually a concept which is there a part of the TQM, total quality management.

Where the person who is working on the machine itself works on the maintenance of the machine. Each person who is the operator of the machine is taught to also maintain the machine to some extent. In the similar concept, we have total environmental maintenance. That is the people who are working in different parts all the stakeholders. When they are educated about sustainable manufacturing in the factory itself.

Where they are working the sustainable practices are introduced that is reducing the use of paper. That is reusing something the bottles that you are using the water bottles could be reused for some other purposes. All those parts are introduced here. So that is we encourage employees and leadership to champion ethical and sustainable decision making. Although adopting TBL principles requires effort and investment. It leads to long-term business benefits for businesses and society as a whole.



The benefits of the TBL approach are definite when we try to adopt it. A TBL framework has several advantages, such as enhanced brand reputation. That is because consumers and investors favor businesses committed to sustainability. Nowadays, even amendments have come that restrict the use of specific elements.

Like chromium 6, which is used in the leather industry, particularly in Kanpur. A few years back, Kanpur was also known as the leather city of the world. Now, the river Ganges has been contaminated by the water. That was being completely disposed of into the river Ganges, where chromium 6 was being released. Now, the regulation of water treatment plants has helped to address that.

And also, the systems where the industry is located have been moved to a neighboring city. Where the population is not as large. So, an industrial park has been developed in a city now close to Kanpur. So, these certain Initiatives are being taken by the government itself.

So enhanced business reputation that we are working upon, the business that is focusing on sustainability, debt favors, regulatory compliances. That is meeting environmental and social regulations. That is what I am talking about one of the examples in leather industry. So this reduces the legal risks. Employee satisfaction and retention, ethical business practices attract and retain talent. Long-term profitability is also there.

Challenges in implementing TBL

Despite its advantages, businesses face several challenges in implementing the TBL approach:

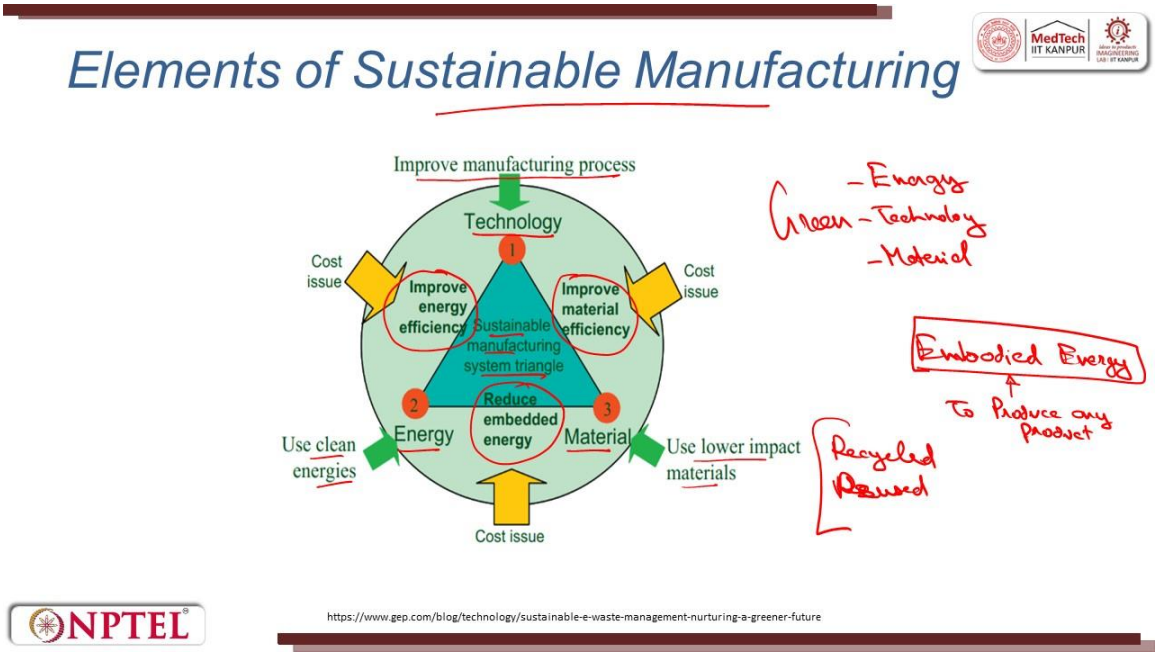
- **Measuring Social and Environmental Impact**: Unlike financial performance, quantifying sustainability metrics can be complex.
- **Initial Investment Costs**: Sustainable transitions often require substantial upfront investments. NPV IRR BEP
- **Balancing Interests**: Aligning the goals of stakeholders, investors, and sustainability initiatives can be challenging.

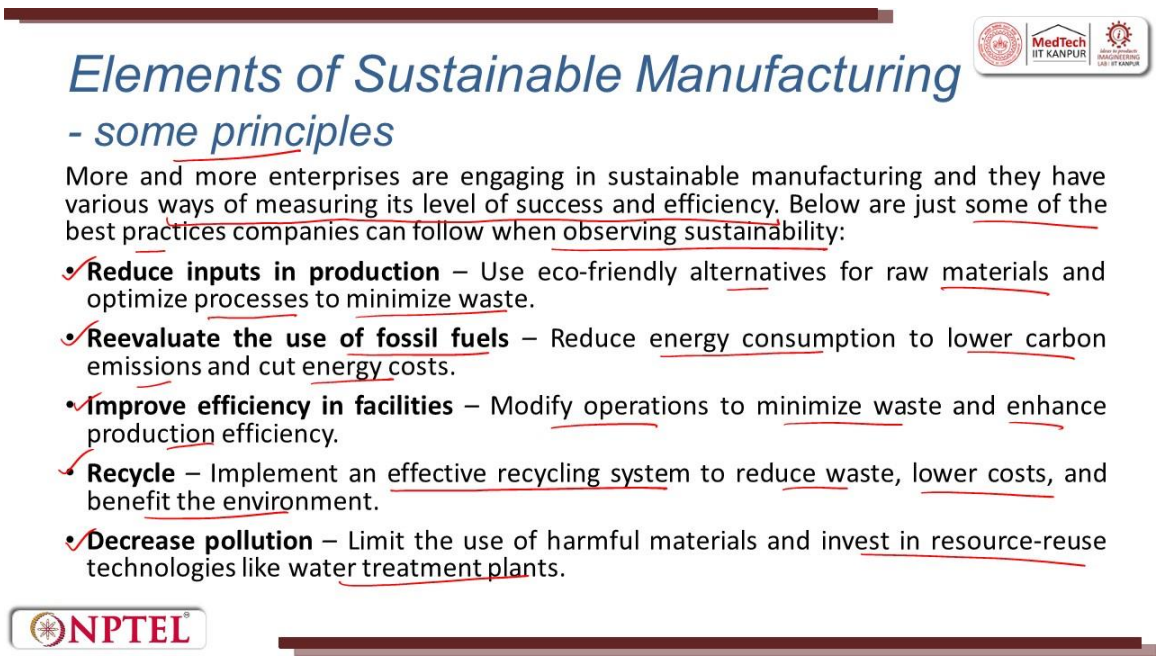
However, there are certain challenges. Measuring social and environmental impact, unlike financial performance, quantifying sustainability metrics are complex. Because different machines that you purchase are of different makeup. The energy consumption that they do and different kinds of the material handling systems.

Different kinds of weights which are produced to quantify them. Though there are systems already developed but to implement them to the ground level to the each of the factories. Even to the small MSMEs which are there they could use those systems in their level that is having still a big challenge. Initial investment costs are there initial investment costs these are to be calculated in NPV net present value. And IRR internal rate of return.

These are the metrics which help us to see when this investment would be covered. Or maybe even the break-even chart, taking a break-even point. That is, in how many years or after how many sales of the products. This initial cost would be covered, and that is to be calculated. Sustainable transitions often require substantial upfront investments.

Balancing interests, that is, aligning the goals of stakeholders. Investors and sustainability initiatives can be challenging. Having talked about the triple bottom line, that is, what are the pillars of sustainability.





Let me now talk about some strategies or some elements of sustainable manufacturing. Here are some elements when we talk about sustainable manufacturing. We need to talk about different directions, either technology, energy, or material. That is, either we could have green energy, green technology, or green material.

When we talk about green technology, that is, improving the manufacturing process. There are certain ways that we will discuss in the coming lectures. That is, we can use different kinds of smoothing systems, such as minimum quantity lubrication.

Maybe the quantity of the lubricant or the quantity of the cutting fluid that you use goes into the water eventually. So that is minimized. Or we use cryogenic engineering, cryogenic treatment. This means we do the machining at a very low temperature. So that the machining happens quickly.

But the initial investment is higher, so certain technological systems are required. Then comes green energy, which is clean energy. Clean energy means either reducing energy consumption. Regular energy consumption that you are using could be reduced. Or taking energy from renewable sources.

Maybe you have not completed some part; the energy could be taken from green sources. Or renewable sources of energy, such as solar or wind, could be implemented. So, then we have green material, which means we use materials that have a lower impact. Here,

materials that could be recycled or reused are taken more into account. When we talk about technology and material in unison, this refers to improving material efficiency.

And when we talk about technology and energy, we talk about improving the energy efficiency. This is where the technology has to focus. And energy and material, we try to reduce the embedded energy within the material. There is embodied energy as well. I will put the word.

We'll talk about embodied energy that means the energy that is consumed to develop specific product. For example to manufacture a car in a specific country there is energy consumption right. In India this energy consumption is related to the amount of the carbon footprint that is generated. Now it depends upon the sources of energy. Sources of energy in India is majorly the thermal power sources.

In France you see the sources could be the nuclear resources which are there. So nuclear energy produces very less pollution. That is very less carbon footprint in comparison to what we do in thermal power plants here in India. So embodied energy is the energy that is there to produce. Any product.

Again, in the sustainable manufacturing system triangle. We are going to focus on environmental, societal, and economic aspects. And we need to manage waste. We need to manage energy consumption overall, manage the manufacturing cost as well. As some of the principles, more and more enterprises are engaging in sustainable infrastructure.

Nowadays, they have various ways of measuring their level of success and efficiency. Below are just some of the practices companies can follow when observing sustainability. It is to reduce inputs in production, use eco-friendly alternatives for raw materials, and optimize processes to minimize waste. Re-evaluate the use of fossil fuels, that is, reduce energy consumption to lower carbon emissions and cut energy costs. Improve efficiency in facilities, modify operations to minimize waste and enhance production efficiency, recycle, implement.

An effective recycling system to reduce waste, lower costs, and benefit the environment, decrease pollution. It is to limit the use of harmful materials and invest in resource reuse technologies like water treatment plants. These are all the points which I just discussed about water treatment, about recycling, about reuse, and etc.

Elements of Sustainable Manufacturing

Smart and sustainable manufacturing systems incorporate several vital elements contributing to environmentally responsible and socially conscious production processes. These elements include:

- **Renewable Energy Integration:** Adopting renewable energy sources, such as solar, wind, or hydropower, to power manufacturing.
- **Resource Efficiency:** Prioritizing efficient use of materials and resources through waste reduction, recycling, and reusing materials.
- **Life Cycle Assessments:** Conduct thorough assessments to evaluate the environmental impact of a product. You can do it from raw material extraction through manufacturing, distribution, use, and eventual disposal.
- **Green Technologies:** Implementing environmentally friendly technologies and processes, such as energy-efficient equipment and sustainable production methods.

Elements of Sustainable Manufacturing

- **Supply Chain Sustainability:** Ensuring that sustainability principles extend throughout the supply chain, collaborating with suppliers.
- **Continuous Improvement:** Committing to ongoing improvement by adopting new technologies, processes, and sustainable practices. They emerge to stay at the forefront of environmental responsibility in manufacturing.

Now talking further about elements of sustainable manufacturing, smart and sustainable manufacturing systems. Incorporate several vital elements nowadays which contribute to environmentally responsible and socially conscious production systems.

These elements include renewable energy integration. That is adopting renewable energy sources such as solar, wind, and hydropower for the power used in manufacturing. Resource efficiency prioritizes the efficient use of materials and resources through waste reduction, recycling, and reusing materials. Nowadays, additive manufacturing exists in

which no waste or scrap is generated at all. You only use filament, powder, or sheets and keep manufacturing layer by layer.

So in that case, the material waste is minimal. But the production rate is very low, even though it is now taking new leaps. But still, mass production—when we need to manufacture 10,000 pieces a day— is not there, though design flexibility is very high in additive manufacturing. So certain resource efficiency—that is, prioritizing the use of materials, etc.—

and recycling the materials—these all need to be taken care of. Life cycle assessment—this I will talk about in the next lecture—conduct thorough assessments. To evaluate the environmental impact of a product, you can do it from raw material extraction through manufacturing, distribution, use, and eventual disposal. This is what I just called 'cradle to grave.'

Then green technologies. implementing environmental friendly technologies and processes such as energy efficient equipment. And sustainable production methods these are very important. These are there to minimize emissions and to minimize resource consumption along with this. Supply chain that is supply chain sustainability ensuring that sustainability principles extend throughout the supply chain.

Collaborating with suppliers is very important. These are the suppliers who adhere to the eco-friendly standards. For instance, at Medtech IIT Kanpur, we have ISO 13485. This ISO 13485 system says the vendor from whom you are purchasing the materials should also have an ISO system implemented with them. That is, the material that you are purchasing should also have a track of where this material has come from.

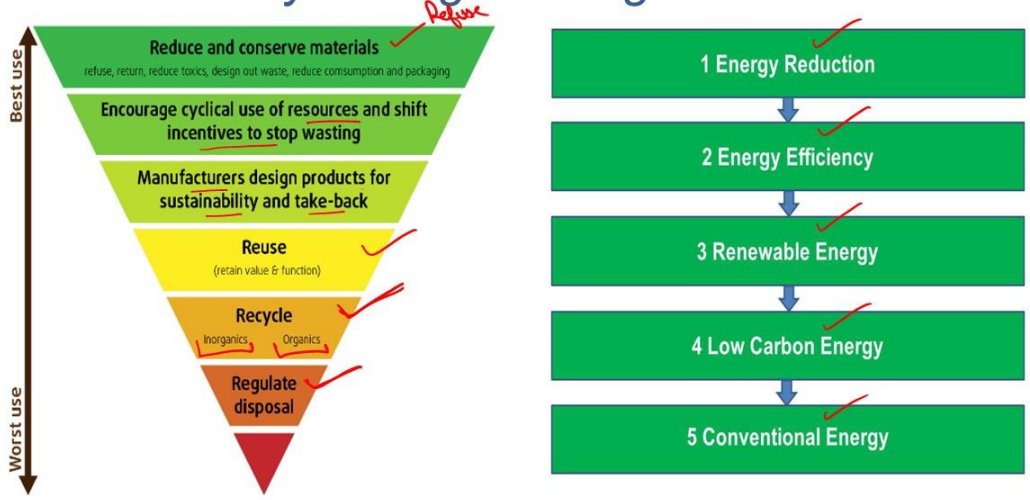
Who is the manufacturer, and if anything goes bad in the product that we are developing through Medtech IIT Kanpur. That material could also be tracked that who was given that material. Similarly ESG suggests ESG. As I said environmental social governance when you try to implement the green technology in your system. The green technologies is the material that you are consumed.

You have to also talk with the suppliers who are also having the certification. Which are having certain green batches on the materials. So those are important so continuous improvement. Committing to ongoing improvement by adopting new technologies, processes and sustainable practices. They emerge to stay at the forefront of environmental responsibility in manufacturing.

Sustainability in Engineering

- **Economic Sustainability** – Engineered systems must be cost-effective and financially viable to ensure long-term affordability and efficiency.
- **Environmental Sustainability** – Systems should minimize environmental impact by reducing pollution, conserving resources, and preventing ecosystem degradation.
- **Functional Sustainability** – Designs must meet user needs, ensuring reliability, health, safety, and performance throughout the system's life cycle.
- **Physical Sustainability** – Systems should withstand operational forces, accidental stresses, and natural hazards to maintain durability and resilience.
- **Political Sustainability** – Engineering solutions should align with public policies, regulations, and governance frameworks for societal approval and legal compliance.
- **Social Sustainability** – Projects must be socially acceptable, ethically responsible, and beneficial to communities affected by their implementation.

Sustainability in Engineering



https://www.researchgate.net/figure/Sustainable-design-engineering-SDE-discipline-sketch_fig1_342115870

When we talk about sustainability in engineering. I have talked about economic sustainability in which engineering system must be cost-effective and financially viable. Environmental sustainability is being talked about. Functional sustainability is also there in engineering. The function of the product.

The designs must meet user needs, ensuring reliability, health, safety. And performance throughout the system's life cycle. Then physical sustainability systems should withstand operational forces, accidental stresses and natural hazards to maintain durability and

resilience. Political sustainability engineering solutions should align with the public policies, regulations, governance frameworks for societal approval and legal compliance. Social sustainability products or projects that you're working upon should be socially acceptable.

This we have already talked about. So now I have introduced functional, physical, and political sustainability. Those are the regulations when I talk about sustainability in engineering. The other three—economic, environmental, and social—were already discussed. When we were talking about sustainability as a whole.

In engineering: energy reduction, energy efficiency, renewable energy, low-carbon energy, and conventional energy. This is how we proceed. From the top to bottom. And as I have talked about, reducing and conserving materials is one of the major endeavors we undertake. That is, we even refuse.

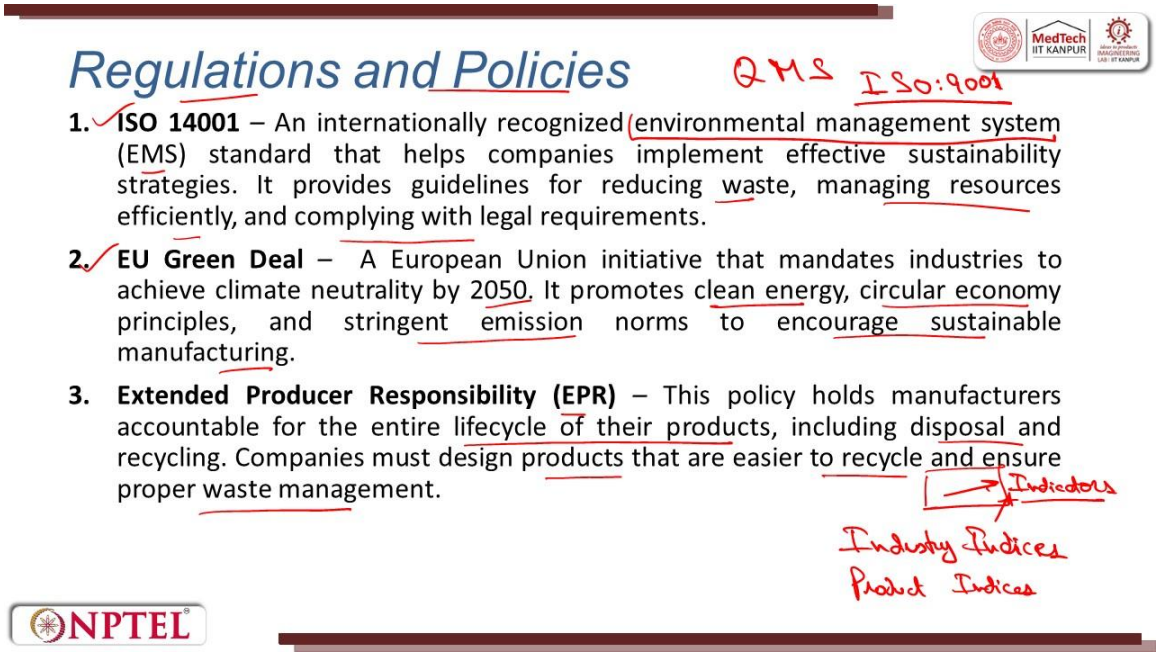
Using something to refuse means minimizing consumption. Even if we can do something without a disposable water bottle each day. We try to use a bottle that is refilled each day. So, we try to refuse something, then encourage cyclic use of resources and shift it. Incentives to stop wasting: manufacturers design products for sustainability.

And take back system that is we can take back the product. We can try to recycle it whenever required reuse if you purchase a product. You try to use it for some time, you purchase a car. You try to use that car for five years. Then what does happen to the car?

You sell it to the other person, the person who takes the used car. It goes as a second-hand car to the other person. This is reusing of the product, recycling. When the car has gone through its complete use cycle. The initial 15 years of certification, the recertification of pollution, etc.

You keep on getting, then it goes to the overall dismantling. When we dismantle. The metallic material, the plastic material is segregated. Then this metallic material is sometimes recast it to reuse it. As we have seen the casting process in the beginning lectures as well.

So those could also be there. The recycle, inorganics and organics are recycled separately. Then only we go for disposal. That there should be the last resort.



Talking about the political sustainability. There are certain regulation and policies such as ISO 14001. This is an internationally recognized environmental management system. As we have the QMS quality management system which is known as ISO 9001. This is EMS, Environmental Management System standard. That helps companies to implement effective sustainability strategies.

It provides guidelines for reducing waste, managing resources efficiently, and complying with legal requirements. Then we have EU Green Deal. EU is European Union. A European Union initiative that mandates industries to achieve climate neutrality by 2050. So there are indices which are there for different kinds of the products or industry.

There are industry indices. When I say indices, this means they have indicators. There are also product indices. Indicators mean, for example, in an industry, I am talking about the EU Green Deal. It talks about promoting clean energy, circular economy principles, and standard emission norms to encourage sustainable manufacturing.

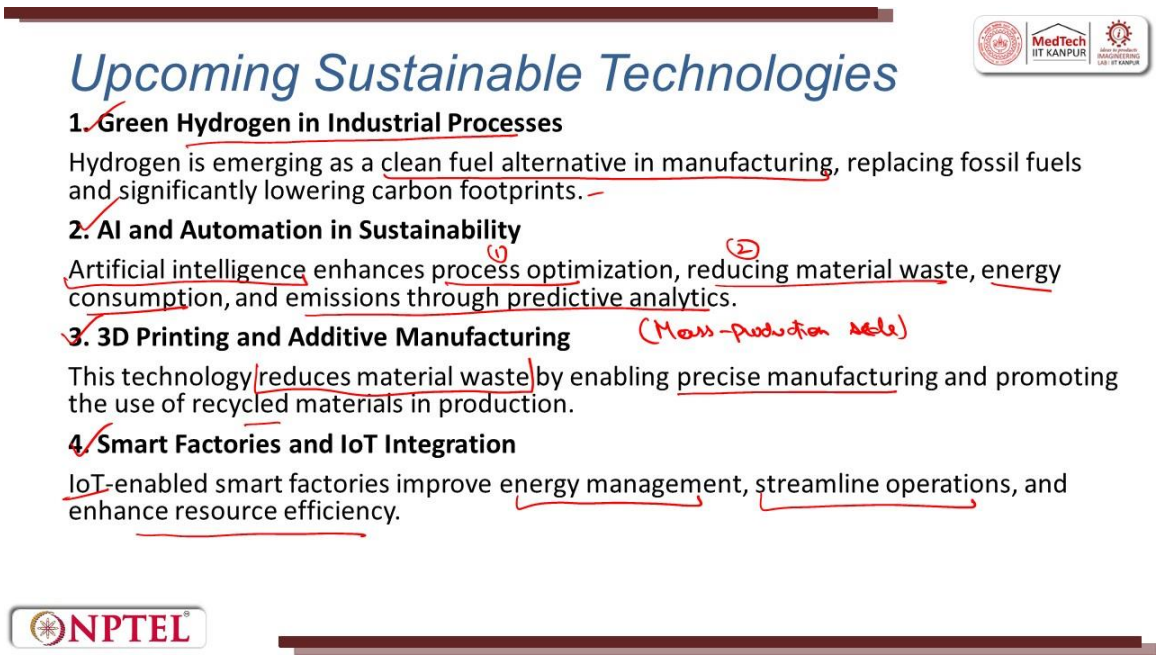
There are indices. What is the amount of pollution generated per unit of the product you are manufacturing? What is the water consumption? What is the air pollution being generated? What is transportation?

That is the amount of transportation happening. So all those indices become the indicators of your sustainable system. Then EPR, extended producer responsibility. This policy holds manufacturers accountable for the entire life cycle of their products,

including disposal and recycling. Companies must design products that are easy to recycle and ensure proper waste management.

Before closing this lecture, let me try to give you a brief introduction to the upcoming technologies which are there. There are upcoming sustainable technologies that is feature of sustainable tech in the world. Sustainable travel, it is eco-friendly wayfinders, bamboo flashlights, rainproof solar chargers, eco-friendly tech, that is smart appliances. For example, the lights of the room just gets off and you leave the room. There are light sensors, proximity sensors.

Then a smart irrigation sources, drip irrigation systems, green building, environmental benefits, clean. And renewable sources of energy, improved air quality, access to resource services. Then we have renewable energy sources, specifically solar, wind, biofuel, etc. Recycling technologies, smart home technology, financial benefits. Then they also have the financial benefits always.

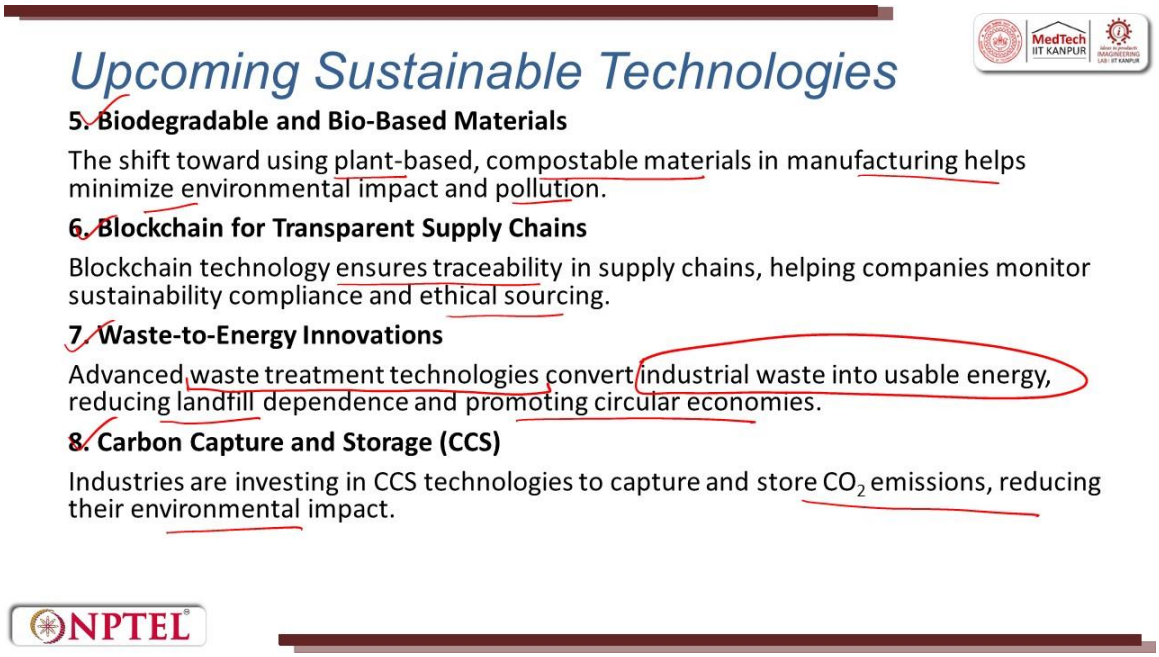


Let me try to talk about a few upcoming sustainable technologies. That is green hydrogen industrial processes. Hydrogen is emerging as a clean fuel alternative in manufacturing, replacing fossil fuel. And significantly lowering carbon footprints. AI and automation cannot be ignored here.

Artificial intelligence enhances process optimization, reducing material waste and energy consumption. And emissions through predictive analytics. 3D printing, additive manufacturing. As I talked about, the material waste is reduced to the minimum or almost no material waste is there. This helps to have precise manufacturing and promotes the use of recycled materials in production.

Though this is an upcoming technology, it has to be developed to a mass production scale. There are certain efforts being taken. For example, the nozzle that is there to develop or print it in one go. The multiple nozzles, 10 nozzles that work together to develop 10 components in one go. So those certain points are there in additive manufacturing as well.

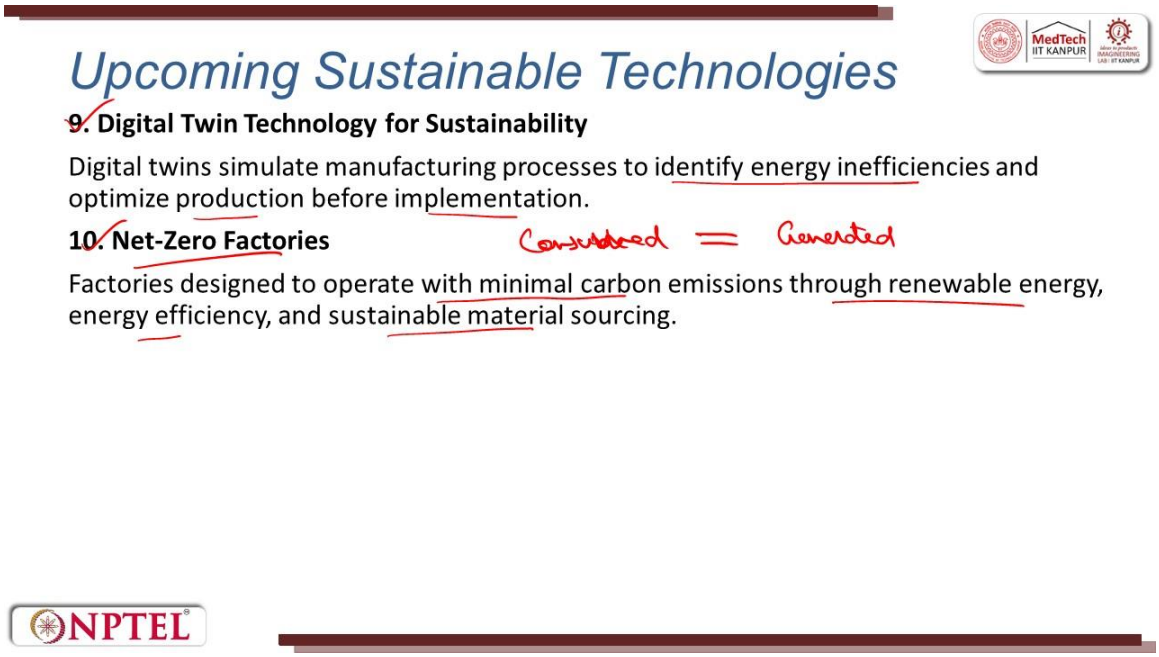
Smart factories and IoT integration. IoT enables smart factories to improve energy management, streamline operations, and enhance resource efficiency. The light sensor which I am talking about is there in the room. This light sensor turns off, the fan goes off, and the AC goes off when you leave the room. This is all IoT (Internet of Things) that uses sensors which help to manage the energy.



Biodegradable and bio-based materials. The shift towards using plant-based compostable materials in manufacturing helps minimize environmental impact and pollution. For example, in cutting fluids itself, when vegetable-based fluids are there. Which are nowadays being researched upon, and when these are disposed. They do not harm the environment at large.

Blockchain and transparent supply chains blockchain technology insurance traceability in supply chains. Helping companies monitor sustainability compliance and ethical sourcing ways to energy innovations. That is waste treatment technologies that convert industrial waste into usable energy. There are certain technologies where the used material is converted into something useful. That is for example glass that was being wasted.

That is somewhere there is a search that is happening that is going to convert. That glass into road material itself. Reducing landfill dependence and promoting circular economies, carbon capture and storage. Which I talked about, carbon credits, I talked about the carbon footprint. Industries are investing in CCS technologies to capture. And store carbon dioxide emissions and reducing their environmental impact.



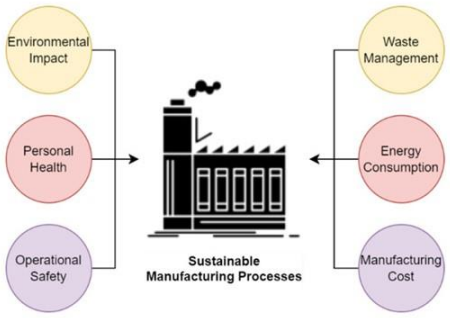
Along with this, two other systems such as digital twin technology for sustainability. Digital twin simulate manufacturing processes to identify energy inefficiencies. And optimize production before implementation. Digital twin is when you are doing the manufacturing along with this the systems are happening in a computer.

Whatever goes wrong with your actual manufacturing. Like for example in actual lathe machine if you are working the temperature is going beyond the limit is going very high. This will be rectified there in the digital twin itself.

Net zero factories are designed to operate with minimal carbon emissions. Through renewable energy energy efficiency and sustainable material sourcing that is net zero energy. That is being consumed is equal to the energy that is being generated that is net zero factories.

Summarise

- Sustainability in manufacturing is an essential paradigm shift that balances economic growth with environmental responsibility.
- As industries move towards greener practices, embracing innovation, regulatory compliance, and corporate responsibility will define the future of manufacturing.
- With technological advancements and global collaboration, the transition to sustainable production will not only benefit businesses but also contribute to a healthier planet.



https://www.gep.com/blog/technology/sustainable-e-waste-management-nurturing-a-greener-future

To summarize, sustainability in manufacturing is an essential paradigm shift. That balances economic growth with environmental responsibility. As industries move towards greener practices, embracing innovation, regulatory compliance. And corporate responsibility will define the future of manufacturing.

With technological advancements and global collaboration. The transition to sustainable production will not only benefit businesses, but also contribute to a healthier planet. This week, we will focus primarily on understanding sustainability in manufacturing systems. I have given you a brief introduction to what sustainability is. Now, we will talk about lifecycle assessment. Then, we will discuss the green unit manufacturing process, which is green machinery.

Thank you.