

MSE 440 An introduction to sustainability strategies and the circular economy. Or the challenge for the composites industry.

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Good morning. Today we're going to look at an introduction to sustainability strategies and the circular economy. Or the challenge for the composites industry. Why give such a lecture? Well, during Covid, I followed three online courses. The first was around sustainability strategies and the circular economy, the second was business sustainability management, and the third sustainable finance.

During these courses, we had to define our own initiatives and one of mine was to give a course. So, I'd like to share with you what I've learned about this and apply it to composites. It's also important because a review of EPFL graduates after they'd left Lausanne, showed that sustainability was the second most sought-after skill. And this was actually lacking in the current curriculum. We also saw during these courses that the best way to teach sustainability was actually to embed it into a subject course rather than to give a separate lecture on this topic, which is why we're doing this today.

An overview of the course. First of all, we're going to look at sustainability. We're going to look at climate change briefly as the backdrop to the presentation. We're going to look at wealth inequality and the UN Sustainable Development goals. We're then going to look at what's called the Net Zero transition. And we'll then go on to look at an enabler towards this, which is a circular economic model. We'll then look at how we can enable sustainability and some psychology.

What I'd like to encourage you today is that now is the most exhilarating time to be an innovator. And students here in this room are the engineers who are going to address tomorrow's challenges. The learning objectives are to motivate a change from a linear economic model to a circular economic model. The industrial sector of interest, composite materials. Obviously, you can apply this to other aspects of either material science or mechanical engineering. I want you to go away with a summary of climate change effects and the net zero transition plan that's being proposed by people. I want you to know what sustainability strategies and the UN sustainable development goals are at a high level, the role of composites and the difference between linear and circular economic models. I also want you to think of your own sustainability initiatives.

Before we start, I want you to sit back and think of the year 2050. You can work out how old you might be. You can imagine how life might look. You can imagine life in a pessimistic scenario or in an optimistic scenario. What I'd like you to do is to think, what could society and technology look like if, if we get things right, here are some pictures that might motivate you. You can think about the energy transition, you can think about the change and how we travel. You can think about the hydrogen economy, Green cities, the change in personal transportation, people still being free and having fun. Equality, global south, global north, gender, rewilding of the landscapes. These are the things you could imagine for the future. Try and imagine a good future, and together we try and work towards this. This is important because when we look at climate change, there's lots of pessimism and we need to also look at a vision that's positive here. I'd like you before we start to type in a few words as to what you think sustainability is and just type them in to this slide.

Here's my definition. Sustainability is avoiding the depletion of our natural resources in order to maintain a balanced ecosystem and preserve natural capital while meeting the needs of the present without compromising the ability of future generations to meet their own needs. That's a very brief definition of sustainability. But as we go through this presentation and unpack it, you're going to see it means so much more and it's such a diverse and wide topic that one simple sentence can't really sum up the topic, what's driving sustainability?

We're going to look at several themes around sustainability which are fundamental in understanding the subject. The first is to introduce what's called the Holocene, and this is the stable geological epoch in the Earth history that we live in today. It's the stable climatic period during the last 10,000 years. If you look at this chart here, you can see a record from Greenland Ice Sheet, which is a proxy for atmospheric temperature. Deviation during the Holocene is extremely stable, which has been like that for 100,000 years. This is what's given our blue and green planet today and there are some amazing series. You can look at Earth from space to see the beauty of our planet.

We're coming from the Holocene, however, looking now since the industrial Revolution, you can see that this stable temperature range from the Holocene is now changing. Human influence has warmed the planet 1850-1900. We can see temperature is still relatively flat, but then it starts to rise, especially after 1950. You can see the difference between the natural factors only and the human and natural factors. And we've all seen this chart. The Earth's temperature has already increased by 1.3 degrees centigrade. I could show you different Youtube videos of the destruction to our planet as seen by satellites or glaciers collapsing in Greenland, or people trying to save trees from California wildfires. But the aim of this lecture is not to be pessimistic, it's to try and look towards positive scenarios to address this problem.

From this curve, we can ask ourselves, well, why has the temperature increased? The first thing to say is that this is not new. And for those of you who are material scientists, you will obviously have heard of the Arrhenius Equation. And what you may not know is that Arrhenius wrote a paper in 1896 correlating the influence of CO₂ in the air upon the temperature of the ground. His paper was quantifying the effects of carbon dioxide to the greenhouse effect in 1896. We can't say we didn't know.

Going back to why has the temperature of the Earth increased. Well, we can look at what's called the Great Acceleration, which is what people are calling this period from the 1950s onwards. And there are two ways of looking at this.

The first are socioeconomic trends, and we can see here six of the 12 that have been outlined. The first one is population growth. Well, there are more people on the planet now than there were in 1950. We can see the gross domestic product has increased, another hockey curve from 1950 to today, dramatic increase. With this comes a dramatic increase in global water usage. Also in primary energy usage, we see we're driving a lot more new cars than we used to, and we're using a lot more fertilizer. The population is booming. GDP is booming (but is it a good measure of progress?). We're using more energy, we're manufacturing more vehicles.

The trouble is, this has an effect on Earth system trends. At the same time, we see carbon dioxide rising from the industrial Revolution, particularly from the 1950s. We also see methane rising, which is an even more potent greenhouse gas. From this, we see the Earth's temperature increasing. The oceans are becoming more acidic, and the percentage decrease in species abundance versus undisturbed species is changing. The terrestrial biosphere is degrading. Ozone has also increased, although with the Kyoto Protocol we've managed to cap this. That's the success story so far. If we can do this for ozone, we could also argue, we could imagine we can do this for other things. These are only six of their system trends, and you can season up this excel sheet, that's the great acceleration. Another way of looking at

the great acceleration are the number of US patents filed as a measure of innovation since 1950. And again, you can see this dramatic increase in the number of US patents filed with time. Innovation and research as a proxy of patterns for research is also increasing. We need to find a way to capture the amazing advances we've made as a human society. Health, longevity, science and technology, travel, arts, but importantly, in a sustainable way, we mustn't take a mortgage on future generations. And this means it's my children and it's your children. We need to value our own mental and physical health. This great acceleration is also having an impact on our own mental and physical health. One year ago, a survey at EPFL showed that 30% of professors and 40% of students had mental health issues reported in the anonymous questionnaire. I've had my own issues with this. I had a burnout while I was at Dupont as I pushed too hard. This great acceleration is actually difficult to sustain without hurting ourselves. We need to remap how we can become more advanced as a society.

What are the major greenhouse gas contributors? This is for the year 2016, our world data, and you can see a map of global greenhouse gas emissions by sector. What you can see is that the activities as material scientists and engineers touches so much. Transport contributes 16% and is a leading source of greenhouse gas emissions with road aviation and shipping. Chemicals is also an important contributor at 6%. Then you can look at iron and steel, 7% cement, 3%. Of course, it's not just the primary material forms or the use of these in transport, it's also the use in residential buildings and other industries. This is where CO₂ is coming from and we need to look at the role of composite materials and how composites are used as materials.

Another model that people use when looking at sustainability is the Planetary Boundary Model, which is from the Stockholm Resilience Center, Professor Stephan. What he's done is to divide the planet up by different boundaries and different categories. We have climate change as a boundary, and if it's green, it's below a safe boundary. Orange is increasing risk and red is beyond a zone of uncertainty, it's very high risk. Novel entities are not yet quantified. We'll come back to this. Stratospheric ozone depletion - the Kyoto protocol has helped to keep this into green area, atmospheric area. Not yet quantified ocean acidification. We're fast approaching the edge of the green limit. So this is something really to be taken seriously also because it takes a very long time to reverse this. Something that's massively out of balance is nitrogen phosphorous cycles, the biochemical flows which comes from agriculture, it comes from fertilizers, it comes from animal waste runoff into the water system. This is something which we've really got wrong. Freshwater use that's still green, although there are issues with this around the nitrogen phosphorous flows, land system change, we are terraforming our planets. This is also approaching the red zone. We're also widely out of control in the extinctions per million species years. In that biodiversity index is suffering.

One which we need to look at as material scientists in particular are these novel entities. Generation X has invented many very novel chemicals and product forms. The trouble is that some of these, not all, of course, are toxic and long life substances that humans release into the atmosphere and they can be persistent organic pollutants. If you take one example, product developed by 3M perfluorooctanoic acid, which is a processing aid used in making teflon PTFE. You may have heard of the film, dark waters and the huge scandal around this involving 3M and Dupont. This chemical is present in sea eagles, it's present in dolphins, it's present in us, and it's a cancer inducing chemical.

The problem is for a chemical to pose a threat to Earth system, you need three conditions. It has to have a disruptive effect on a vital Earth system process, but the effect is not discovered until it's a problem at the global scale. Well really you should discover it before then. And three, the effect is not readily reversible. Well, how do you remove perfluorooctanoic acid from us? Novel entities is something we need to be really careful with as material scientists and engineers.

Another model people look at is what's called Earth Overshoot Day. This is the date that humanities resource consumption for a year exceeds Earth's capacity to regenerate those resources in that year. It represents the level by which the human population exceeds the sustainable amount of resources. And it reports the day in which humanity enters environmental deficit spending as an equation. It's the world biocapacity divided by the world ecological footprint. And you can map this by country. You can see when do we overshoot, essentially, for Switzerland? By the middle of May, we've used up our yearly allocation of Earth's resources, after which we go into deficit. We're taking a loan. Germany. Very similar. This is serious because we are overshooting the biocapacity of the Earth.

Another important concept is the Shifting Base Line Syndrome. This is the gradual change in the accepted norms for the condition of the natural environment due to a lack of experience, memory, and or knowledge of its past condition. You can see here that if you lived in the 1800s and you went on holiday and you went snorkelling, you would see all these fish and that would appear normal to you. However, if you were transported back to forward to 2019, you'd be horrified. You'd be shocked. But because the person going snorkelling in 2019 has never been snorkelling in 1800, it looks normal to them. Although we don't like the plastic bags, we really don't know how many fish there should be in the sea, what we consider to be a healthy environment. Now, past generations were considered to be degraded and what we judge to be degraded. Now the next generation, shockingly, will consider to be healthy or normal. It's normal to have plastic in the ocean without memory, knowledge, or experience of past environmental conditions. Current generations cannot perceive how much their environment has changed because they are comparing it to their own normal base line and not to historical base lines. This is a real problem for us as humans, the shifting baseline syndrome.

Here's an example of a shifting baseline syndrome. So we're going to play this video, which shows a view of the Aletsch Glacier. It shows an animation of the melting of the largest glacier in the Alps. In 2080 you know it used to be bigger, but of the shifting baseline syndrome, it looks normal to your kids.

The next topic to look at, a key topic in sustainability, is the Anthropocene. This follows on from the Holocene, is the proposed geological epoch dating from the commencement of significant human impact on the Earth's geology and ecosystems. It is the proposed epoch that starts when humans had a significant impact on the Earth's geology and its ecosystems, including, but not limited to, anthropogenic climate change. The start date range could be from the agricultural revolution, but more interestingly and relevantly, it's from the peak in radio nucleides from atomic bomb testing in the 1950s, which is now present in Earth's geology. This was proposed in September 2021 to the International Commission on Stratigraphy, locating the markers to the time period commencing with the great acceleration and the atomic age. It's a new geological epoch, Holocene to Anthropocene.

Here's an example of what we've done in the Anthropocene. We've terraformed the planet. This is not a word which was invented in Minecraft. It's been around for much longer than that. This is a diamond mine. You can see the apartment buildings behind. Atomic bomb testing - since the 1950s, 75 years later, 2.5 million people have been killed as a result of cancer from the atmospheric. Nuclear testing is present in the Earth's geological history. We've done amazing things as well. During the Anthropocene we stood on the moon. We've seen the Earth from space and we've invented amazing surgical procedures to prolong life.

Global warming thus far. Where are we? In 2016, the planet had warmed 1.1 degrees C, above this historical baseline from the Holocene for 2000 years, the global temperatures were constant until the unprecedented warming began in the mid 20th century. How do we address this climate change scenarios? Well, there are five climate change scenarios to try and mitigate or reduce this effect. This is a very low emissions target which meets this 1.5 degrees C cap agreed in Paris with a likely warming of 1.4 degrees by the year 2,100. It overshoots the target just above 1.5 degrees C mid-century. Then

there's the low emissions, the mid high and the very high. What we're going to look at shortly in this lecture is this very low emissions scenario. We're not going to dwell on these very high emissions scenarios, which is really business as usual. We're going to look at how we can together work towards what we call net zero. The two shared socioeconomic pathways stay below two degrees C require net zero emissions by mid-century and carbon removal. This is really important because three degrees of global warming is quite plausible and truly disastrous. This is no longer just in climate journals. This is known in mainstream journals that people read at the railway station on aeroplanes.

Before we look at net zero, what are some key issues for Switzerland? Well, we are net importers of CO₂. We have a high standard of living and this wealth drives consumption based CO₂ emissions. This diagram here looks at CO₂ emissions embedded in trade. It's CO₂ that you're buying into the country, which is made elsewhere. And Switzerland is one of the worst. While our production based CO₂ emissions in Switzerland have dropped from 1990 to today at the same, which is great, and we can of course do more. Our consumption based CO₂ emissions have gone up. We are bringing in CO₂ from another countries. We should also note, the biggest polluters in Switzerland in terms of CO₂ are coming from the concrete and the pharmaceutical industries, one has to be the biggest and this is who they are. Our real issue is consumption based CO₂ in Switzerland.\

Also looking at Switzerland and the report from Meteo Swiss. This is the Medan case, not the lowest case, but if we don't address these targets and achieve net zero by mid century, Switzerland will be hotter than the global average. You can see the evolution of temperature in the west of Switzerland. When you're retired and you're in your apartment and the sun is shining, it's going to be really hot and steamy, and this is not what we want, We need to take action to avoid this.

We've all probably heard of Cop 26 and which in Glasgow last year. This is a very interesting climate tracker where we can look at what the pledges and targets were and the policies and actions. This is a little chart looking at the global mean temperature increase by 2,100. And you can see the Optimistic Scenario, which assumes full implementation of all announced targets, including net zero targets. Then we've got pledges and targets. Targets only and policies and actions. The big problem is that the pledges and targets made so far, we then see a 2.1 degrees C increase. Worryingly, things that have been put into policy and action are looking then at plus three degrees C. We had this ambition gap of the greenhouse gas emissions, where it needs to come down to for this 1.5 degrees C target in green. And the ambition gap, compared to policies and actions, which is the blue at the top, we have this delta, this gap. We need to do more work.

We've looked at climate change as an issue. We're now going to look at wealth inequality, because at the same time the planetary boundaries have been exceeded. So again, to see that the social foundations of our planets are being eroded. Dollar Millionaires make up 0.7% of the adult population, but hold 46% of global wealth. The richest 1% own half the world's wealth a study finds and there's a garage just around the corner where I live in Gland, which sells these kinds of supercars. And my son likes to go and look at them too. Now you may say richest 1% that's not me. Well, when you leave Switzerland and you're working, maybe in industry, actually you will be in the world's richest 1%. Even more worryingly, the world's 26 richest people own as much as the poorest 50%. Something's gone wrong, this doesn't make sense, it's not sustainable.

We can then look at how carbon emissions correlate to wealth. And Oxfam have issued a report where the richest 1% of the world have used two times as much carbon as the poorest 50% of the population over the last 25 years. Here you can see the richest 1% and then you can see the poorest 50% So there you are. These are the main categories of consumption among the highest emitters in the EU and the top 1% of emitters, You can see air travel is a huge category. As well as land travel and housing. In the

top 10% of emitters, it's mainly land travel and housing with manufactured products. Of course, these aren't the same amounts, they're just looking at percentage contributions.

Ban Ki-moon, Deputy Chair of the Elders, and the former General of the United Nations has said our current economic model, which is the neoliberal model, has been enabler of catastrophic climate change and equally catastrophic inequality. Addressing the disproportionate carbon emissions from the wealthiest in society must be a key priority.

This then leads us to another key model in sustainability, which is Professor Kate Ratworth's Donut Model. This is being presented at the World Economic Forum, and it's quite famous. What it does is it says, well, we have these planetary boundaries which we are exceeding in certain areas. But we also have a social foundation and we are also succeeding or having a shortfall in these. There's a shortfall in these different categories of water, food and health and education, income and work, peace and justice, political voice, social equality, gender equality, housing, etc. We have an ecological ceiling and we have a social foundation and shortfalls. We need to find the safe and just place where we can live between these social and planetary boundaries, which is this green area in the middle. This should be humanity's 21st century goal.

The United Nations has set for 2030, what it calls its sustainable development goals. These aim to address many of those issues. On the previous slide, it looks at climate, but it also looks at the social issues of poverty and hunger, and good health and education, gender equality. It looks at clean and affordable energy. We need an energy transition. Decent work and economic growth. Yes, that's still important. And industry innovation and infrastructure needs to prosper. Reduced inequalities, both gender, religion, etc, okay? Wealth, sustainable cities and communities, responsible consumption and production. Climate action, life below water, life on land. There's many of these, and some people would argue that some of them contradict. And maybe they do, maybe they don't. But we're going to pick out a few of these where composites can contribute to many of these. Composites can contribute to clean water and sanitation, affordable and clean energy, industry innovation and infrastructure, sustainable cities and communities, and climate action. Looking at these a little bit more detail, looking at renewable energy, composites has an important role to play in wind energy, looking at resilient infrastructure, sustainable industrialization. Yes, composites has a role here. High technology industries are more resilient. Number 13, climate change, it's now code red on the UN's webpage says, Has changed since last year. Composites has a role to play here. We'll see later in lightweighting structures and the hydrogen economy. However, composites has a bit of a problem when it comes to goal number 12, sustainable consumption and Production. We need to move from a linear to a circular economy. To address this sustainable consumption and production. The circular economy is key to Sdg 12 and composites. Industry needs to become a lot more circular than it is today.

We're now going to look at the Net Zero Transition. Looking at this most aggressive scenario to limit climate change or global warming, warming requires sharp CO₂ cuts to achieve net zero CO₂ by 2050. This is the very low emissions target and we need to avoid the high emissions scenario which means carrying on business as usual.

What does net zero mean? Well, it basically means you take all the human caused greenhouse gas emissions and you put them on the balance with human caused removals. This balance needs to swing to a neutral position when you sum fossil fuel combustion and industry, land use change, agriculture, and you look at CO₂ and methane against what we remove, which is almost nothing, that needs to become equal. Obviously, for it to become equal, we need to have a significant reduction in the greenhouse gas emissions with an increase in CO₂ removals. We call this anthropogenic carbon removals versus anthropogenic greenhouse gas emissions. The current state of greenhouse gas emissions is greater than 55 gigatons of carbon equivalent per year. And that needs to come right down.

Well, how can we do this? This seems to be an impossible job. Well, we can look at this, lots of people have been studying this. How to get to netzero 2050? 1st thing to say is that the world's population is going to carry on increasing to 2050, and so is the Gross Domestic Product, see data from the International Energy Agency and their report. Second thing to say is that the energy supply in the net zero economy, you can see they are hoping it's going to peak in the 2020s. This is a net zero economy scenario. I actually think it will carry on rising before it falls. But what you can see is with time, even though the population increases, the total energy supply is actually decreasing. And you can see the energy mix is changing. And you can see a big increase in solar photovoltaics in wind and a big reduction in natural gas and coal. We'll see a drop in oil supply. We'll see an increase in critical mineral demand, particularly for electrification, and a big increase in solar photovoltaic and wind in electricity generation. How will CO2 emission and abatement evolve, 2050? Well, emissions need to fall and abatement needs to increase. There needs to be a massive change in how electricity is generated. Changes in how we approach buildings and transport and industry in general. And then we can look at bio energy with carbon capture and direct air capture with carbon capture and storage. Okay, so you can see that the carbon capture amount we can really achieve is quite low. And the best way to address this really is to reduce emissions by sector.

What are some of the netzero 2050 milestones? Focus more towards composites. Well, by 2030, people are predicting a one Terawatt per year annual increase in solar and wind energy additions. So that's big news for the wind industry, which uses composites. Automotive manufacturers plan to build 54 million battery electric vehicles by 2030. Greater than 50% of total vehicle production. And they're investing \$1.2 trillion to do this as composites are used in vehicles and maybe used more in the future to make them lighter. This has a big impact on the composite industry. By 2035, we might see the first net zero emission commercial aircraft and we might see net zero electricity generation. In the EU, 2040, Airbus are projecting, there'll be 40,000 new passenger and freighter aircraft. Which use composites, coal and oil power will be phased out by 2050. There'll be twice as many automobiles on the road as there are today. And 86% of these will be electric and 70% of the power generated will be by solar, photovoltaic and wind. So these are some of the big targets we need to get to, to achieve net zero in the reduction scenarios. Okay, these are scenarios. But if you focus on these goals and people are starting to focus on them, the positive thing is that the automotive manufacturers have stated they are investing this 1.2 billion to transition the automotive industry from fossil fuel to electric opportunities for composites.

So what are the enablers to a netzero 2050 transition? This comes from the McKinsey Company report. The net zero transition, what it could cost and what it could bring. Well, we need effective international collaboration. We need an orderly and just transition. We can't leave it too late. And we need to do this in an equitable way between different countries. Need society to change its behavior. We need to innovate in newly emerging technologies, which is where we can help. There'll be a transportation transition to electric vehicles which will affect many of your careers. Petrochemical is going to start to move to biomass feedstock, which will again affect many of your careers. The transition to renewable energy, wind, the hydrogen economy, which uses composites to store hydrogen. We need to change how we look at agriculture, food and diet. We haven't touched much on this today, but it's really, really important.

Another enabler is the circular economy and that's what we're going to focus on next. Before we do a few more words around transportation CO2 just to illustrate what we've already achieved. As I said before, transportation CO2 contributes to 75% of emissions from the sector road transportation. Okay. There'll be twice as many cars by 2050 today are much more efficient than they used to be, but we're driving many more kilometers. What's important is that we don't recharge our cars from a coal fired grid. Because in that case, this life cycle study from the EU, in grams per kilometer CO2, shows you're absolutely worse than a petrol car, if you use a mixed grid, you're only a little bit better. Only when you recharge your electric vehicle using renewable energy, does it really make that much of a difference?

We need to have enough power in place to be able to recharge, which is why the energy transition is also absolutely critical.

Looking at climate change and road transportation, the impact of climate change that comes from our cars is well known, but the impact of manufacturing them is often overlooked. So if you look at the top 12 automotive manufacturers globally and all the steel, plastics, glass, aluminum, rubber, and other components that go into them, they globally generate more greenhouse gases per year than the entire EU. What we're going to see is that electrifying transportation can solve part of the problem. It will halve the emissions from vehicles on average, but we also need to move to a circular economy for cars. This is also interesting because if you look at the ESGs, electric vehicles today do not give lower ESG ratings versus conventional OEMs. This is the environmental and social governance ratings. What you can see is that Tesla is no better than Toyota or Mercedes. They are all as engineers and scientists, pretty much the same. They all score medium. While the product may be different, how we make the product needs to change. It needs to become circular, not linear.

Changing transport requires changing how we move ourselves. The benefits of circular urban design can go beyond reduced emissions from transport. It can also create safer, more livable cities with resilient communities. The goal here is a 15 minute city. City developers can reach all the places they need to. Within a 15 minute walk or bike ride. That will be very positive from my perspective. No need to commute to EPFL. This is going to require ride sharing, cycling and walking, and buses, and of course, more trains, it's going to require a reduction of the number of cars per household. Looking at behavioural change, we need to use bikes and we need to walk and run.

Aerospace likes to look at the revenue load per tonne of passengers or freight carried per kilometer. The Rtk, revenue tonne per kilometer. What you can see is that the CO2 emissions per revenue tonne kilometer has dropped with time due to technology gains, composites using aerospace in making the planes more efficient and more efficient engines. However, there's a societal change you can see has increased. There's more revenue ton kilometers with time and then hence more CO2 emission. This is increasing faster than technology. Innovation is still needed in technology, but societal change is needed. Aviation, CO2 per capita. You can see which countries are the biggest offenders between domestic and international. And of course, it's the global north. How can aerospace look in 2050? Well, we're going to be using sustainable fuels such as hydrogen. Operations and propulsion technologies will enable the sector's 2050 net zero objective. Airbus foresees demand for 40,000 new aircraft by 2040. Turbofan, Turboprop blended wing hydrogen based. You can see here how we can look at the global CO2 emissions from aviation. You've got 2019, 2020 and then 2050. This drop due to Covid where emissions drops because we simply changed our behaviour. We'll reduce the number of flights by 2050. There will be more flights, but there'll be more efficient fuels and the fuels will emit less CO2, we need to have behavioural changes shifting to high speed rail, capping business flights, capping long haul leisure flights. We need to get the aviation's global CO2 emissions down by a mix of technology and a mix of behavioural changes.

Another topic that is going to become a big issue in the net zero economy is stranded assets. You can imagine this being power generation or petrochemical plants where there are significant assets in place and it takes a long time to break even on the investment. However, like this big ship, once you change course, you can then have a big impact. The time needed to put new CAPEX in place is an urgent issue. Clean power, energy efficient plants, the urban environment, new ways of making materials, the EV, infrastructure. Stranded assets, which are items that are redundant before the end of their usual operational life. Could be ten to \$20T by 2050. If we delay, as in orange here, the amount of stranded assets will increase. Actually, we need to start on this as soon as possible. Stranded assets also gives an opportunity, while we need to decrease investment in coal fired power stations.

This graph looks at how we need to actually invest capital in the net zero economy, both by sector and by technology area. This is going to create growth and new employment. We need to look at transportation, electrification, hydrogen, and infrastructure, where there's going to be huge growth in employment and investment. The IEA estimates the capital investment needs to reach 4.5% of GDP by 2030. Actually, 7.5% is potentially more likely in a report by more recent report by Mckinsey, where they say there will be \$275T accumulative spending is needed on physical assets between 2021-2050 to reach netzero. In today's terms, that is, 50% of global corporate profits, a quarter of global tax revenue, 15% gross fixed capital formation, 7% of household spending. To put that in perspective, global armed spending today is 2 trillion per year, okay? The US spends 3.7% of its GDP on its military. So you can see we need to spend an equivalent amount.

Covid spent significant amounts of money. We take the two years of Covid financial aid. We keep on doing this all the way to 2050. But with three to four times the effort we put into Covid. Three to four times the spending of Covid every year to 2050 and we will reach net zero. The major difference compared to Covid is value creation, smart projects, and employment.

Finally, some good news in the US has recently legislated their Inflation Reduction Act. And this has provided \$370 billion for climate and energy clean energy provisions. And it's the most aggressive climate investment ever taken by Congress, which should result in a 40% reduction in carbon emissions by 2030.

So now we're going to take a break and we'll come back in 5 min. I hope you had a good break.

We've taken a look at sustainability and climate change, wealth inequality, and the UN sustainable development goals. We've looked at the net zero transition, which is needed to address climate change. We're now going to dive into more detail into the circular economy before looking at enabling sustainability.

Economics very simply defined as the efficient allocation of scarce resources. The current economic model has failed in that resources are not efficiently allocated. This doesn't mean that the current system is a failure, it means that it's not the optimum solution. The problem is that we overproduce, we overconsume, and we overtrade. How many of you have old laptop screens and old phones, which you have cluttered around you in your house. This is the overconsumption and people are making too many things. We are buying too many things and people are overtrading. Hypothesis is that we need a new economic model.

If we look at the EU we see some shocking statistics. First of all, for food agriculture uses 70% of global water consumption. Obviously, if we want to grow feed stock for biofuels, this will increase and compete. 31% of food waste is lost in the value chain. 46% of still edible mass is lost. 60, 75% of packaging is lost. After the first cycle, 9 million tons of plastic floods into the ocean each year. Looking at some more statistics, 90% of the time our cars are idle, transportation contributes 21% of global CO2 emissions. 60% of office space is not used during office hours. 90 billion tons of natural resources are extracted per year, going to increase 2x by 2050. 9% find their way back. Fast fashion is responsible for 10% of global CO2 emissions. What we buy will drive what people produce. This is like a critical fault on your car dashboard, that is a problem. The thing is that 72% of all economic activity is related to the end user. If the end user decides to change what they buy, this will have an enormous impact. If we all decide to stop buying a certain product, that particular manufacturer will go bankrupt. We are inefficient as a society and we need to improve this. Many inefficiencies are money lying on the floor, which, if we pick up, will hugely benefit the environment. The issue is our linear economy, which is a unidirectional approach of extract, make use and dispose. We assume there are infinite resources. We take them, we make things, and we dispose of them. And we assume the Earth has an infinite regenerative capacity.

But we've seen this is not true. We've seen the Earth overshoot day. We've seen in the planetary boundaries. And we've seen the impact on the social foundation in the Donut model. This is not true. Linear models can be seen in economic terms as a market failure. We have not yet found applied models where we as a society can reflect the hidden environmental costs in market prices. This needs to happen to respect the environment, we over-produce, we over trade. We've created significant impacts on the environment such that serious changes are needed.

The circular economy seeks to rebuild capital. And this capital can be financial, manufactured, human, social, or natural, and it ensures enhanced flows of goods and services. The circular economy diagram here presented by the Ellen Macarthur Foundation illustrates what this circular economy is. We can look at the technical cycle it seeks to maintain and prolong and share, to reuse and redistribute, refurbished and remanufacture and recycling is at the tail end of a circular economy. If we can maintain and prolong the item, we start to develop these more closed loop cycles. We also need to look at the biological cycle. Not so much of our focus today. You can read more about it on this web page. This is the idea of the circular economy.

The key elements of the circular economy is a fundamental change in the way goods are made and used. And this means we need to reuse and redistribute, remanufacture and refurbish, recirculate materials, maintain and prolong, regenerate, share and recycle. We need to close loops. Design out waste and pollution, keep products and materials in use. Regenerate natural systems. We must transition from linear systems that we've been trained as engineers, scientists, and business people. To optimize to a circular model. Again, re, use, repurpose, remanufacture, recycle, regenerate, avoid resource leakage in the system. Create durable products, look at lease rather than buy. Design out waste and pollution. We need to find opportunities where our waste is somebody else's feedstock. We need to keep products and materials in use. We need to regenerate natural systems.

Linear to circular is a journey. Change cannot happen overnight, yet it can start and continue and grow and it needs to. On a more urgent imperative than we realize, we need to shift the system from linear to circular. Again, re, use, redistribute, remanufacture, refurbish, recirculate materials, maintain and prolong, regenerate, share and recycle. The only R word that's not here is relocate. That's not part of the circular economy. We don't relocate our problems somewhere else. Circular economic business models close, material and energy is recycled within the system, and via reuse, refurbishing, and recycling. They slow, they extend the use phase of the product. They intensify the asset to use it more E.g. by sharing. It's not sitting there like a car when it's parked in mid day doing nothing. They dematerialize, virtual approaches to a physical asset that could be Netflix, rather than buying DVDs.

Key terms are efficiency and productivity. Economic and financial viability, recovery, recycling, sharing platforms, extending the life of assets, a service versus a product. If the machine is turned off, the assets not working for you. How does a circular economic model tackle climate change? This graph looks at current emissions split between energy and products. It then looks at the products and it says, let's focus on food, steel, cement, plastic, and aluminum to get to zero emissions. They believe that a 45% reduction can be achieved by circular economy and the other 55% can be reduced by looking at emerging technology. Carbon capture, storage and diet. Industry is responsible for around 21% of global CO2 emissions. 60% of this is produced out of cement, steel, plastics, and aluminum. Use of these materials in passenger cars and buildings is 73% of the emissions from reducing these four materials alone. As material scientists and engineers, our raws are cement, steel, plastics, aluminum. We are using these lots in buildings and cars. Very important to look at this, looking at how a circular economy can then reduce CO2, we've got the current scenario, the baseline scenario in 2050, and how can we reduce to have a circular scenario in 2050. With this 40% reduction, waste elimination, reusing the products, materials, recirculation, you can see how these bring down the total global CO2 emissions. We can cut CO2 emissions from cement, steel, plastic, and aluminum by 40% by 2050. That's half of the net zero

emissions target. For these key materials, we can make better use of products and materials within key sectors such as environment and mobility. The solutions are cost effective and offer system wide benefits.

So looking at the cost of emissions reductions in Euro per tonne of CO₂. This one here you can see things which save money and things that cost money. The width of the bar gives you the emissions reduction potential if we share cars, if we prolong their lifetime, we remanufacture them. We look at buildings. You can see here plastics, high quality recycling plastics, reusing aluminum. Increasing collection, things that cost a bit of money. Avoid downgrading aluminium. Increasing recycling, chemical recycling. Lots of recycling, things going on here. Cars, light weighting. This is actually more expensive. It doesn't save as much, but it's still really important. More important really, than is to say how we make the car. As we said earlier, we need to design with circularity in mind because recycling is the tail end of the best case linear economic model is among the least efficient circular strategies.

You can look here at the Circular Design Guide. It's very interesting publication which basically says we need to move beyond recycling and waste management to a fundamental change production and consumption systems. One example of this is mud genes, where less than 1% of the material used to make clothing currently results in new clothing. And this gives a loss of \$100 billion per year. And Mud Genes networks a lease system, a circular economy for personal transport. Well, if we design lighter vehicles, fewer materials are needed to make them. Unless energy is required to power them. We can save about 90 megatons of CO₂. If we make them last longer, we can further cut 200 million tons of CO₂. And some of these electric vehicle platforms will roll for a very long time as there are less moving mechanical plants. If we share vehicles, it will also save CO₂. Then if we manufacture and reuse an engine 85% less carbon intensive than making a new one, this further saves CO₂. Looking at a circular scenario for passenger cars to reduce CO₂ by 70% In 2050, we've got the current situation base line 2050 2X increasing in cars per year.

This is how we save by light weighting, by sharing a longer lifetime. And light weighting can also look at designing out waste and pollution. We're using less of them and here we're keeping products and materials in use. We reuse and remanufacture, and this gives us a much lower number. An example, first of all, looking at a closed loop value chain, a Jaguar Land Rover created new materials and production systems to introduce closed loop aluminium. What you can see is it helped them to reduce the global warming potential of an engine by 14%. Because recycled aluminium requires 90% energy in production and primary material, they recovered 30,000 tons of press shop scrap and reduce their greenhouse gas emissions at novels by 30%. However, secondary aluminium only represents 37% of the total aluminium used in the US, in Europe. So we have to go further there. The enablers to this were material, suitability, and innovation. A value chain network needs to be established, and progressive leadership was needed. When you read this case study about what made this possible, leadership was so important, the value chain was so important. Yes, they needed material innovation. But without these other two aspects, it wouldn't happen.

Going on from recycling out of tier one at the press shop to looking at remanufacturing operation which Renault has in its re factory. They have a reverse logistics ecosystem at partner companies that collects the old packs of parts, dismantles and checks them for conformity, then reassembles them and sells them on as genuine and guaranteed parts. The parts are 40% less expensive versus new, and they undergo the same quality checks. The volume of re manufactured engine parts is significant. Lot gearboxes, engines, turbos and injectors, and since 2012, greater than 112,000 gearboxes have been renovated. 73,000 engines, turbos, 50,000 injectors, 94,000 So it's significant. We're going to play a video from this.

So having shown a light on circular economic models, we do need to be a bit honest and say, well, why are circular supply chains so rare if they're more sustainable? And Professor Sofani has written an article in the Harvard Business Review. The barriers to circular supply chains. Successful examples tend to be local, with products and services made of relatively limited numbers of components. The reason for this, I mean, it's great to have the successful examples, but we are a global economy. Human supply chains focus on performance via specialized parts, and economy efficiency via economies of scale. In order to change this, consumers need to give up performance for environmental stability. Need to give up some of the economies of scale and make less sophisticated products, with more standardization designed in for local recycling versus aggregation.

Society needs to embrace this change for a circular supply chain evolving business models with circular economy, all businesses need sustainable business models to incorporate socially and environmentally sustainable practices. In the transition, they can keep running linear models while at the same time transferring circular models. We need to redesign our supply chains for agility as a lattice rather than the rigid constructs used today. Having onshore, nearshore, and offshore, rather than just the lowest cost location, we need to bring sustainability into our value propositions from start up to transformation, diversification and acquisitions. e.g. Ford has split its company into two as it ramps up electric vehicle production.

We need to avoid a race to the bottom of the linear economy. If we don't race to the bottom, we race to the top. Covid 19 has actually moved supply chain, thinking five years into the future. That's one positive thing that's come out of, we've been through here. You can give some feedback on what you think the circular economy is enabling sustainability.

What are some key enablers towards a circular economy? The first is government and policy, finance and investment is second, and the third is technology. We are going to look at technology, but we're going to start off by looking at government and policy, and finance and investment. A key thing for all of these is to have a transdisciplinary approach, especially with technology. We need to include what's going on in government and policy. We need to look at what people are investing to work together. We need education, we need to be consistent with our goals, and we need to build infrastructure. We need innovation not just in technology, but to address the problem of overconsumption and overproduction in government policies. These need to change in businesses. They need to innovate in how products are delivered. They need to innovate in their business models and their supply chain, how they recover and recycle, how they can increase product durability and change their service models. Innovation is needed by consumers in how we select and dispose of products.

So starting with government policy, its goal is to give vision, not to fix market failure, is to guide towards a circular economy and lubricate the system with funding, is to give incentives, financial support, the creation of opportunities, and to control depreciation. It needs to be direct, traceable, and measurable. Role of government policy is for collaborations public and private partnerships with the public sector, assumes risk, and the private sector provides the technology focused on circularity. Policy is needed to achieve growth, create jobs, stabilize and utilize the country's own resources. Reducing inputs.

Finance is another key enabler. Companies use financial metrics to look at different initiatives, different potentials for new products. They like to look at return on investments. And the bottom line normally used in a company is profit. One of the key messages from Professor Sofani, we need to focus on the triple bottom line, or the three P's people, planet and profit. A traditional company will tend to focus on microeconomics. What's happening inside the company? What is its return on investments? It may look at Meso economics, which is its competitive framework is competition. It needs to move to pestle level, thinking where it looks at what's going on in the world around it and the ESG's of environment, the society and the economy. Pestle level thinking is where you look at the economic factors, the social,

the technological, legal, political, environmental. We need to look at the three P's as the new bottom line. The triple bottom line. People, planet and profit. And not just planet and profits. But we mustn't forget to be socially progressive. Remember the donut model? Investors are reacting. There's already around half \$1T invested in impact investments. Investors are moving to favor sustainable enterprises, which can be seen as more attractive long term investment opportunities companies naturally need to remain profitable. Sustainability is an attractive and rapidly growing opportunity. It's growing at 30% per year. It's huge, it's double digit growth. It is a major mega trend. It's becoming \$1T business opportunity. There is a growing demand for such products and services. Need to have objectives, so companies establish social and environmental objectives and they need to monitor and review them.

Sustainable sustainability approaches can increase earnings before depreciation and amortization by reducing the cost of goods sold by efficiency gains and waste management. It can reduce operating expenses of a company by sharing leasing and service approaches. And it can increase revenue by creating more desirable products for customers who are sensitive to sustainability issues, it can increase gross margin. Although we should acknowledge that sustainable feed stocks can be more costly case by case basis.

To increase focus on sustainability, companies may need to change the earnings retention ratio, which is how much money is kept back and not given to shareholders. Less is paid as a dividend and more is reinvested.

Sustainable finance also covers capital budgeting, including the structure where capital is sourced and e.g. get equity from shareholders and owners, and the debt from banks and bondholders and the working capital. And the cash in and the cash out, it includes sustainable practices such as payment terms, supply conditions, and salaries. Moving on from traditional financial approaches, return on net assets or return on investment, which do not include the three P's, they're only look at profits, they're not looking at people on the planet.

People have developed what's called sustainable return on investment, where we need to look at profit, but also consider people on the planet. People are important to look at the social impact of an investment, including a fair wage people's life quality, health care, and sustainable employment and the planets, of course, the environmental footprint, greenhouse gas emissions, energy transportation, the built environment, sustainable return on investment hence aims to quantify both the financial and non financial benefits versus costs in monetary terms. And it's the first step towards quantifiable relative investment assessment. We need to move further towards monetarizing the value of people and the planet.

Part of this is already happening because companies following this greenhouse gas protocol, corporate standards, we can now classify a company's greenhouse gas emissions according to three scopes. And this is really big and this is really important and it's going to affect your activities in the future. Scope one is the reporting company's direct emissions. Scope two is the reporting company's indirect emissions. Scope three are the upstream and downstream activities. Most large companies report scope 1 and 2 and scope 3 is voluntary and the hardest to monitor. However, for most companies, the value chain scope 3 is responsible for the vast majority of emissions, often 90%. In March of this year, the United States Securities and Exchange Commission, anybody heard of them, they issued for public comment a rule that if adopted, would require reporting companies to provide climate related information in their registration statements and annual reports.

Scope 12.3 This is how it's split up in more detail. Scope one is in here, in the middle direct, it looks at the company facilities and company vehicles. Then we have the scope two, indirect, which is to purchase electricity. E.g. steam and heating and cooling for its own use. Relatively clear. Then we have scope

three, indirect, Upstream and downstream. Looking at upstream. Scope three, indirect, that's the processing of sold products, capital goods, fuel and energy related activities, transportation and distribution. The waste generated in operations, travel, employee commuting. Then you have the downstream activities. So that's once it leaves the factory gate, it goes to the final user, transportation. Of course, the processing of any products that are sold by somebody else, how their products are used, how they're treated at the end of life and investments. This is going to be really important in the future. As I said, most large companies report scope 1.2 Scope three is the hardest to monitor. Companies succeeding in reporting in all three scopes will gain a considerable competitive advantage.

You can see here an example from a composite company on how they're planning to reduce their scope, 1,2,3 emissions. This is on their webpage. Affects their business operations. What are some technological enablers to get zero? We've look at the political ones. These are some of the things presented in this course. Big data and the cloud, machine learning, hydrogen economy, the Internet of Things, and Industry 4.0 embedded sensors, increased functionalization, the digital transformation, additive manufacturing, blockchain crypto satellite technology to image from space, you can see methane leaks. E.g. materials research, of course, I had to add that one in. I think it's important.

AI and robotics are going to grow hugely into the future. And electrification of vehicles. The advanced material industry has a huge opportunity in many of these things to create a circular economy, create clean energy, and to mitigate climate change.

Finally, some psychology, we can look at human needs, and some psychology, we all look to fulfill our needs. Here is Maslow's hierarchy of needs, which is a triangle which starts off with the basic needs for food, water, warmth and rest. Then safety needs. We want to be safe and secure. We want to belong and feel loved, have intimate relationships and friends. We want to have a feeling of prestige and accomplishment. Above this, we want to self-actualize. We want to achieve our full potential, including being creative. As we look to self-actualize and may be prepared to pay more for an ecological, or bio-based, or premium product or the global north, the global south. Across the world, many are still trying to meet their basic human needs, food, water, and shelter. Furthermore, their needs are so pressing that they do not have the head space to consider the impact on future generations as they are trying to survive and feed their children. So there's a conflict.

We can go on to look at climate change and game theory. This is the prisoner's dilemma. We have two prisoners and they both want to get out. And the prisoner's dilemma essentially says, the best solution is that both prisoners remain silent. And they both get out within one year. If they both confess, they both stay in for five years. If one remains silent and the other confesses is 20 years. What this is saying is that people or nations might not cooperate, even though it could be in their best interest to do so. They both need to stay in for one year. By prioritizing their personal or national interests, individuals actually acting rationally can create a worse overall result. Feel like they are confessing, so that they get out faster. We need to embrace change, take the strain, and address the issue together. The dilemma then is that mutual cooperation yields a better outcome than mutual defection. But it is not the rational outcome because the choice to cooperate from a self-interested perspective is irrational.

During the sustainability course, they highlighted some work by Professor Henderson, who's a professor in Harvard Business School. The course she gave was the most popular at Harvard. She likes to talk about personal ethics and the board room. She's worked with the boards of many companies being in Harvard Business School. Thing she says is that there's money lying on the floor to be recovered from operational inefficiencies. She also points out that we need to introduce the true pricing of externalities to waste and emissions. She says these needs to become definers for success and promotion, really not just in theory. We need to reinvent capitalism as the old model did not effectively efficiently apply scarce resources and we are overheating the system and its people. We need to shift the ethical framework of

capitalism and our own behavior and buying decisions. She then goes on to say to look at our core values and our convictions. We are emotional people who have values and personal ethics, This is part of us, we cannot deny it. We are not true to ourselves. Without it, change cannot be catalysed to make the phase change occur in the ethical framework of capitalism. We need to redefine the box by which we are assessed beyond the bottom line of profit. And bring our convictions into the workplace, people, planet profit. And that the commitment to prosperity and freedom is wider than we think. She says, if we take risks in decision making, then we can choose to do this for what we really believe in our core values.

We Come to Alternative Futures. A Life on our Planet. David Attenborough, a famous naturalist, he has a witness statement and vision for the future. He's traveled the world. He was over 90 when he passed away. Looking at the natural world have been to one country 30 years ago. One country 30 years later. He says that we are at the end of the Holocene. He can see we're leaving indelible markers in a very geography around us, how we've terraformed our planet. He says that we need to act and use our scientific and technical skills and our creativity towards a sustainable future. We need to avoid ourselves becoming a character in one of Kim Stanley Robertson's novels. These are our alternative futures.

Together we can make a difference. It's not the politicians acting by themselves, It's each person doing what they can, influencing the people around them, who they interact with.

To summarize, we need to eliminate, to circulate and regenerate, we need to reduce emissions and meet the targets set out in the Paris Agreement. Half of the story is the transition to renewable energy to tackle climate change. The second half of our story that 45% of greenhouse gas emissions come from the main way we make and use food and products. This means we need to redesign our economy to eliminate waste and pollution, recirculate products and materials, and regenerate nature. We need a circular economy to help us reach net zero. This is a nice video from Helen Mcarthur Foundation, which we're just going to play.