

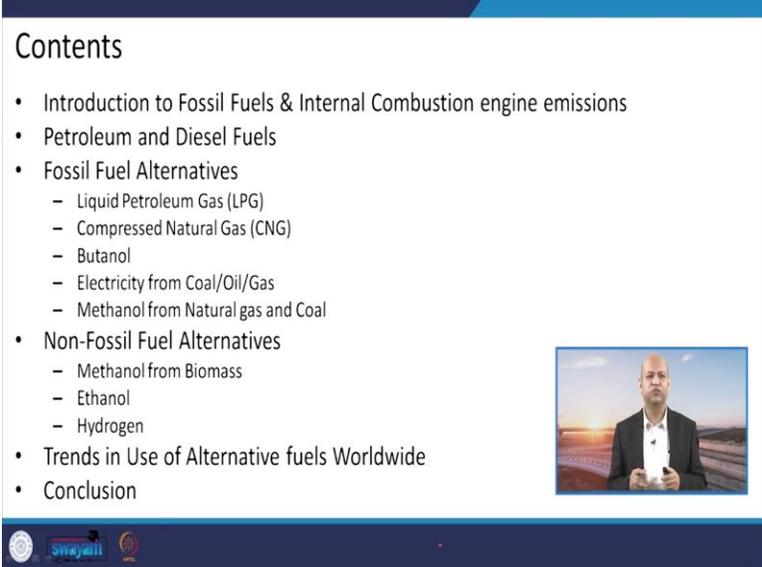
Sustainable Transportation Systems
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Lecture 47

Alternate Fuels and Sustainable Transportation

Hello, friends. Today we will discuss about Alternate Fuels with the perspective of sustainable transportation because all that our majority of the transportation system is based on fossil fuels. And fossil fuels basically what we know, like coal than diesel gasoline or petrol, so those, in comparison to those what kind of alternate better fuels can be there from the perspective of having less emissions or using less fuel.

Those kinds of things means increasing efficiency, reducing cost and increasing the accessibility to the fuel bracket or fuel basket, those kinds of things we will see in this particular lecture so that we can promote sustainable transportation system because the unsustainability aspects are basically related to these fossil fuels, which are diesel gasoline, or related to coal because coal was predominant fuel for steam engines in railways for several decades or centuries. You can see in that perspective. So, now, we are going towards cleaner fuels. We are rising in the ladder of the fuel or energy in a better perspective, better, like from the cost and environmental perspective.

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- Trends in Use of Alternative fuels Worldwide
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Well, so in this lecture we will see what is the internal combustion engine emissions from the fossil fuel-based engines, and then petrol and diesel fuels which are basically the predominant fuel nowadays, which are driving our whole transportation system you can say.

And then from fossil fuels also some alternatives are there. Means alternatives can be of two sorts. One, fossil fuel-based alternatives, means though they are fossil fuels, but better than diesel or petroleum or coal. So, how to go for that kind of alternatives which are by nature fossil fuel but better.

Then we also have another basket of non-fossil fuel-based alternatives. So, that also we will see that how they figure out or how they prove to be better or, best you can say from several angles when we think about sustainable transportation. And then what are the trends over the, different countries or worldwide, the, moving towards these alternate fuels or alternative fuels, and that way we will conclude.

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What are Fossil Fuels ?

- Currently, over 80% of world's motor vehicle fuel for road, rail, air and sea is met by fossil fuels, e.g., petroleum.

Fossil fuels are mainly crude oil, natural gas and coal that are made up of carbon, hydrogen, nitrogen, sulphur, oxygen elements and other minerals.

Natural Gas	Petroleum	Coal
Composition: Carbon Hydrogen Nitrogen Sulfur Oxygen	Composition: Carbon Hydrogen Nitrogen Sulfur Oxygen Minerals	Composition: Carbon Hydrogen Nitrogen Sulfur Oxygen Minerals

Fossil fuel elemental composition

Source: (British Plastics Federation, <https://www.bpf.co.uk/plastipedia/how-is-plastic-made.aspx>)

So, fossil fuels all of, basically these are hydrocarbons, and they have some other elements also very less amount. Otherwise carbon, hydrogen, nitrogen, some sulfur, some oxygen, those kinds of things are there. And petroleum and coal has some other impurities also that, maybe in a very small amount, but these are the constituents of these particularly three dominating fossil fuels, you can say.

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Typical IC Engine combustion



Evaporative Emissions

Refueling Losses

Exhaust Emissions

Typical Engine Combustion

Fuel + Air \rightarrow Unburned Hydrocarbons
+ $NO_x + CO + CO_2 + H_2O + N$

Complete Combustion

Fuel (hydrocarbons) + Air (O_2 & N) \rightarrow $CO_2 + H_2O + N$



Source: (US department of Energy)

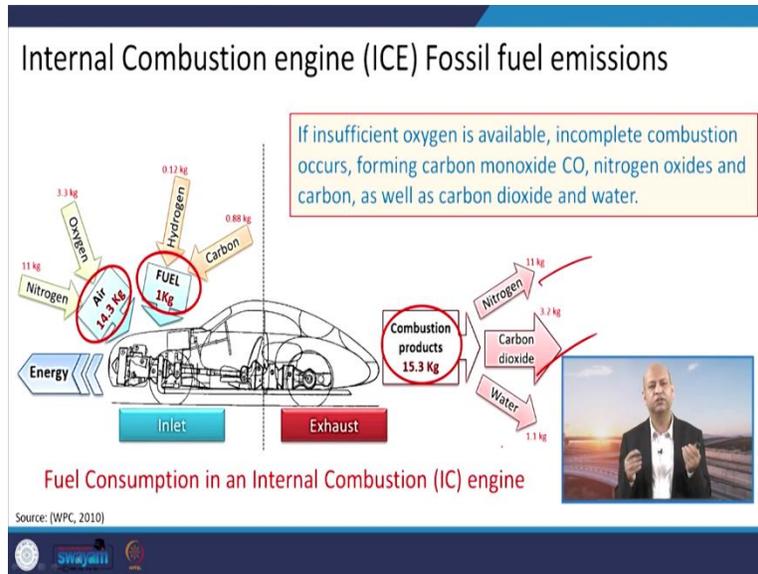
When we talk about the complete combustion, means stoichiometrically if we feel that the complete fuel will be converted into some product.

Complete Combustion: $Fuel (hydrocarbons) + Air (O_2 \& N) = CO_2 + H_2O + N$

Typical Engine Combustion: $Fuel + Air = Unburnedhydrocarbons + NO_x + CO + CO_2 + H_2O + N$

Like, because when air is there, and air has oxygen and nitrogen, so there will be like oxides or some thing, which is present in the fossil fuel, and then some oxides of the nitrogen also. And so complete combustion basically leads to CO 2, carbon dioxide, water vapor and oxygen, oxides of nitrogen, but even later on it also get converted into nitrogen, it is a long reaction.

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Well, when we talk about internal combustion engines, which are now dominating the transportation fleet, and this is based on like, input and output, so inlet there and exhaust. So, inlet means, if you see this air plus fuel, so air-fuel ratio has to be maintained according to the engine technology and that gives us energy and then combustion products are like nitrogen related products, carbon dioxide, water.

When, because this is theoretical, complete combustion, otherwise complete combustion does not occur. So, incomplete combustion is there then there are like carbon monoxide, or oxides of nitrogen, some carbon, those kinds of things are there, which are present, carbon soot also and that depends fuel to fuel, basically.

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Petroleum as Fuel

- Natural Petroleum is also known as Crude oil (Dark sticky liquid, that cannot be used without changing it).
- Earlier, Simple distillation was used to manufacture petrol from crude oil.
- Thermal cracking process introduced from 1913, cracking hydrocarbons into smaller particles, thus lowering boiling point (Increased petrol production).
- Later, catalysts were used for Thermal cracking process. (Speeds up reaction, producing higher Octane petrol)

Natural Petroleum Composition	
Carbon	83-87% ✓
Hydrogen	10-14%
Nitrogen	0.1-2%
Oxygen	0.05-1.5%
Sulphur	0.05-6%



Source: [WPC, 2010]

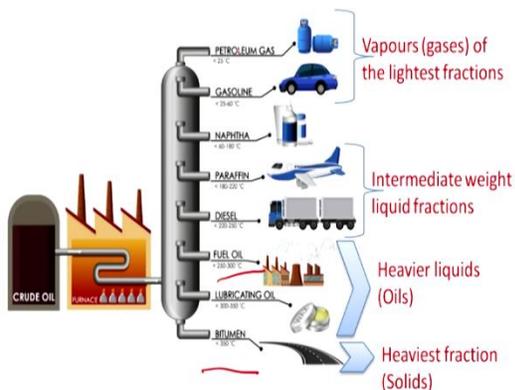


So, when we talk about petroleum as a fuel, so carbon is natural petroleum composition around 83 to 87 % composition is of carbon, and hydrogen is around 10 to 14 %, nitrogen very small amount, 0.1 to 2 %. So, means the product, compounds of the nitrogen will be from the air, nitrogen, as well as the nitrogen present in the fuel. So, that division should be basically understood.

And some oxygen is there, and oxygen really helped in oxidation, and that is why nowadays you might be hearing like oxygenated fuel, means already some oxygen is there and it helps in better oxidation. Sulfur components maybe they are like, in coal and in petrol. So, some SO₂, and those kinds of products maybe also there.

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Fractional Distillation of Crude Oil



Petroleum is decomposed into petroleum gas, gasoline, paraffin (kerosene), naphtha, light oil and heavy oil



Source: [British Plastics Federation, <https://www.bpf.co.uk/plastipedia/how-is-plastic-made.aspx>]



Well, refineries, what do refineries do? They basically refine. So, because the crude oil which we extract, we take out of the ground, so it is very sticky, dark kind of liquid compound. So, it is, then in refineries several kinds of processes takes place through distillation. So, the heaviest fraction is basically bitumen which is used in road construction and those kinds of activities. Then lubricating oil, then fuel oil which is used in industries, and then diesel comes, and then paraffin, and kerosene and the naphtha, gasoline, that is petrol, and petroleum gas, those liquefied petroleum gas which we use, that is the last product. So, those kinds of different chain of products are there which can be extracted from that particular activity of distillation in the refineries.

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Diesel Fuels

- Derived partly from distillation units of Crude oil and partly from other processing operations such as Catalytic cracking units.
- Made from hydrocarbons, boiling at 150-400°C.
- Normally produced by blending two or more refinery streams such as light gas oil, heavy gas and kerosene.
- Diesel fuels emits less CO₂ per kilometre travelled, than other fossil fuels. Other emissions such as benzene, butadiene and formaldehyde are also low comparatively.

Diesel has lower CO and hydrocarbon emissions when compared to petrol engines.



Source: (WPC, 2010)

swayam

Diesel as a fuel is good, basically, and it has lower carbon monoxide and hydrocarbon emissions when we compare with respect to the petrol or gasoline. Means, in other countries they call gasoline, in our country we call it petrol. Both, both term is same. So, the diesel is better in that sense that it emits less amount of carbon monoxide and hydrocarbons. But it has other problems like it can have like carbon soots, or some sulfur compounds may also be there, and like particles, those kinds of things may be there.

Otherwise, it is better in terms of emissions of CO₂ or even greenhouse gases like CO₂ per kilometer traveled because it has more power. Diesel has more power in comparison to the petrol. But it also emits like benzene and then butadiene, formaldehyde, but they are also lower comparatively. So, these are carcinogenic elements like benzene et cetera. So, we have to be careful about those emissions. Even though they are very small in amount but we need to be careful and we should know how much it is coming and how can we deal with it.

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Diesel Fuels (cont'd..)

- Diesel vehicles have better fuel economy compared to petrol vehicles.
- Cheaper to maintain.
- Higher capital costs.
- Diesel vehicles have more Sulphur emissions and decreases fuel quality.



Source: (WPC, 2010)

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Then what are the negative points? Negative points can be like higher capital cost, it is needed. And then it also has like sulfur emissions and decreases fuel quality because of that. So, desulfurized kind of diesel process may be required for better fuel quality. Otherwise there are many advantages of diesel driven vehicles. They have a lot of power that is why, a lot, most of these trucks ec., they are driven by diesel.

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Alternative Fuels

- **Fossil Fuel Alternatives**
 - Liquid Petroleum Gas (LPG)
 - Compressed Natural Gas (CNG)
 - Butanol
 - Electricity from Coal/Oil/Gas
 - Methanol from Natural gas and Coal
- **Non-Fossil Fuel Alternatives**
 - Methanol from Biomass
 - Ethanol
 - Biodiesel and Renewable diesel
 - Electricity from Renewable sources
 - Hydrogen



Swayam

When we talk about alternative fuels based on the fossil fuel, then we talk about basically the LPG, that is Liquid Petroleum Gas, CNG Compressed Natural Gas, then butanol, then electricity from

coal, oil, gas power plants. We derive electricity, then electricity can charge the batteries, batteries can be used by the vehicles. So, that we, again that is alternate fuel.

Methanol from natural gas or coal means again transformation. So, these are alternate fuels in terms of better emission, better emission means less emissions of pollutants. And clean energy. So, non-polluting or less polluting, you can say. Then if we talk about non-fossil fuel alternatives, so they are like methanol from biomass, ethanol also then, bio diesel as a renewable diesel, and electricity from renewable sources, like hydro power, solar, when electricity is produced and that is also one alternative. And hydrogen cells can be there, or hydrogen as a fuel can also be used. So, these are alternatives which are non-fossil because they are derived from other sources, which are not fossil fuel basically.

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The "Food Vs. Fuel" debate

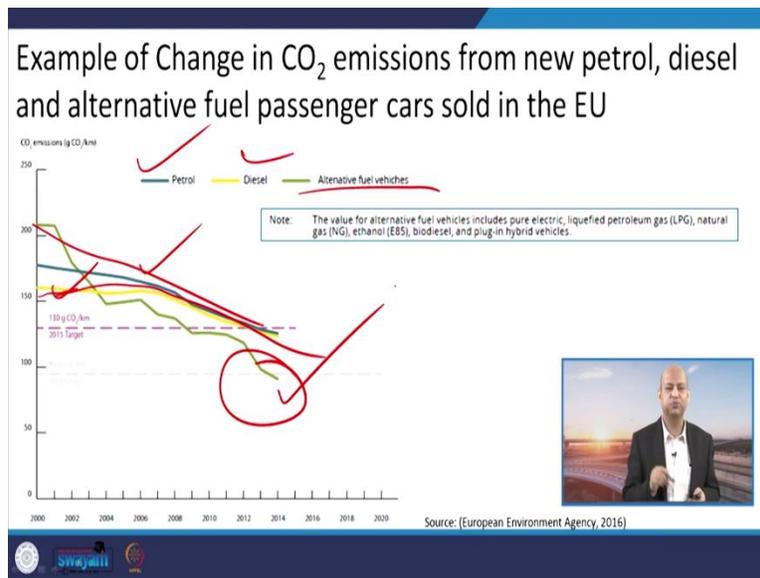
- Trade-offs of utilizing grains and oilseeds for biofuels production versus animal feed and human food.
- U.S. uses corn for production of fuel which is equivalent to food requirement of 412 million people for entire year.
- If this practice goes on, more & more farmland & farm products will be used as raw material for fuel production and shortage of food for millions of people will be occurred.

The slide features a background image of a cornfield. Overlaid on the image is a circular icon with a fork and knife labeled 'Food' and a fuel nozzle icon labeled 'Fuel', with the word 'OR' between them. A small inset image shows a man in a suit speaking.

But the big debate is there when we talk about non fossil fuel based, or biomass based fuels then there is a policy debate, food versus fuel because people say that if you are using corn or sugarcane et cetera, to tranche, late it into or transfer it into, or transform, or transform it into these methanol or ethanol kind of bio-fuels or bio diesel, or these kind of energy sources, then basically you are using the land which can be used for food crops. So, that is a competition or conflict of interest, whether we are here to fill the tanks of the cars or we are here to feed the stomach of the people. So, that is a policy debate and if some countries are struggling with feeding their population, then that is not a good way.

But then other school of thought is there that if you are good in converting these kinds of crops and that soil supports these fuel crops, and if you can get fuel out of that, then you can also trade and you can get food from, in exchange of that kind of thing. So, there are different kinds of schools of thoughts. You can read about them later on, but this is one important aspect which you should know that how trade offs are there, means, where we should lead our lands utilization or agricultural land.

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Well, then there are some examples of emissions of CO₂ from like petrol, diesel and alternative fuel, passenger cars which are sold in EU. New petrol cars or new diesel cars, which are better in technology. So, day by day basically engine technology is improving. So, the same car, same model, but better technology, they are giving better mileage. With, with one liter you are traveling more, and emissions are reducing drastically. That means the same model car, 10 years ago, if it was emitting x amount of let us say CO₂ then it will be a meeting let us say x divided by 100 or so like that.

So, you can see the trend here, in like, petrol driven vehicles and diesel driven vehicles in Europe and alternative fuel vehicles. So, the emissions of CO₂ per kilometer driven is basically reducing. And in alternative fuels basically technology is becoming more and more better, you can say. So, because their reduction of emissions of CO₂ per kilometer driven of the distance is decreasing fast in case of alternative fuels. So, that means the public awareness and environment friendly technological kind of innovations, they are giving boost to these alternative fuel related vehicles.

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Liquid Petroleum gas (LPG)

- Produced from Raw natural gas and also from refining of crude oil (Also known as **Propane**).
- **Mixture of light hydrocarbons**, gaseous at normal temperatures and liquefy at moderate or reduced temperatures.
- Main component gases are Propane (C_3H_8), Propylene (C_3H_6) and Butane (C_4H_{10}).
- 15% lower exhaust and evaporative GHG emissions, compared to petrol vehicles.

LPG is a **non renewable resource**



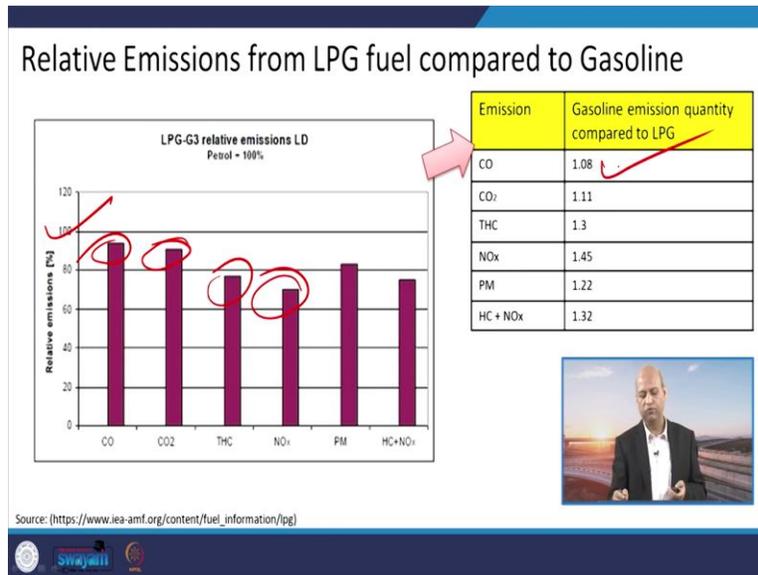
Source: (WPC, 2010)

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Well, when we talk about LPG then, it is a mixture of hydrocarbons. Of course, these fossil fuels are basically hydrocarbons. And it has 15 percent lower exhaust and operative greenhouse gas emissions when we compare with the petrol driven vehicles. But of course, LPG is also non-renewable, like other fossil fuels. So, again, there is a debate that should we go for alternate fuels of the fossil fuel nature or non-fossil fuel.

But step by step, we have to go. We cannot change within one night from one type of technology to another. And of course, in certain sectors, we can go for leapfrog kind of changes, but incremental changes also helps in the economy, because otherwise disruptive kind of changes sometimes gives a lot of uncomfot situations to the people.

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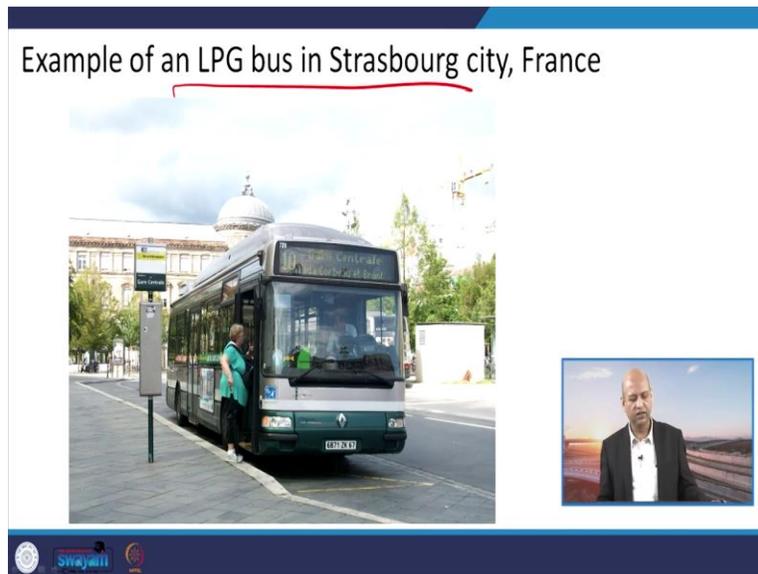
Well, if you see the relative emissions from LPG in comparison to the gasoline or petrol, so see if this 100 unit is from the petrol, then the CO is only around like 90 or so 95, or CO 2 is around 85 or so, and this, total hydrocarbons less than 80, then NO_x, emissions of NO_x that may be like 70 or so particulate matter, just beyond 81, 82 something like that. Hydrocarbons plus NO_x, less than 80. So, means, the emissions of different kinds of pollutants are less than the petrol. So, that way it is a cleaner fuel, you can say. And emissions of gasoline, this is inversely, means more like CO is 1.08 times then the LPG, those kind of things are there.

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There are several cities in different countries which are using LPG for their cars or cabs. Like this is one pictorial representation of Hong Kong, where LPG related taxi cabs are used quite in a significant shear, it is having in taxis services.

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And then example of LPG bus in Strasbourg, city of France. So, buses are being used, or the engine is based on LPG.

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Compressed Natural gas (CNG)

- Natural gas is a mixture of gases, mainly hydrocarbons.
- 87-97% volume of the hydrocarbons is Methane (CH_4).
Other components includes ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), nitrogen, oxygen and carbon dioxide.
- Compressed and used as automotive fuel.
- Excellent fuel for spark ignition engines. Older cars are easier to convert from petrol to CNG but the process is expensive.

It should be noted that Methane is a more active GHG than CO_2 (21 times worse).

Source: (WPC, 2010)



The slide contains a list of bullet points about Compressed Natural Gas (CNG). A red-bordered box highlights a note about Methane being a more active GHG than CO2. A small inset video in the bottom right corner shows a man in a suit speaking.

Then CNG, which many of that like big experiment policy implementation was in mega city Delhi where all public transportation system was converted to CNG because it is a cleaner fuel in

comparison to diesel and petrol. So, you can say that other components for example, methane et cetera in that perspective, there are issues basically, like, 87 to 97 % volume of the hydrocarbons is methane, basically. And methane is very, the potency of green, global warming is, of methane is more than much more than CO₂. If one unit of the CO₂ then it is 21 times then the CO₂.

So, emission of methane is not so good, but other pollutants, emissions like particulate matters are very less, but NO_x emissions are also there. So, some emissions may be still a problem, but not so but other emissions can be reduced significantly like particle, soot and those kinds of things.

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Compressed Natural gas (CNG) (cont'd..)

- Less difference between emissions from CNG vehicles and petrol engines with catalytic converters.
- While CO emissions remain same for both, NO_x emissions are higher from CNG vehicles. Overall, slightly less emission from CNG vehicles.
- Substantially reduces particulate emissions too very low levels, especially in new dedicated CNG engines for buses and trucks.

Source: (WPC, 2010)

If you see this CNG emissions, from these CNG vehicles, so like CO₂ emissions in grams per kilometer from a gasoline car and traveling 50 kilometer per hour, that speed, and with and without catalytic converters. So, these are the emissions from this gasoline car. And with catalytic converter it is much less reduced, but in CNG vehicles you can have certain advantages.

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Compressed Natural gas (CNG)

Engine

- Near-zero NO_x
- 90% reduction in NO_x



Vehicle Cost

- Slightly higher maintenance cost

Vehicle Performance

- 10-15% fuel efficiency degradation
- 15-20% less torque and horsepower
- Quieter operation than diesel.



Source: (WPC, 2010)



Well, this like near zero NO_x emissions, but still NO_x emissions are there but 90 percent reduction can be achieved in these technologies based on the CNG. And then their performance, like, 10 to 15 % fuel efficiency degradation because it consumes more. 15 to 20 % less torque and horsepower means power is less rather than diesel or so. But quieter operation than diesel. Diesel engines make noise, but CNG is better in that sense. And the cost is slightly higher. But if you compare with like reduction, NO_x emissions, reduction in particulate matter emissions, and other things, then it is a good advantage in that sense.

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Example of Low-floor CNG buses in Delhi, India





Photo Source: (Economic times)



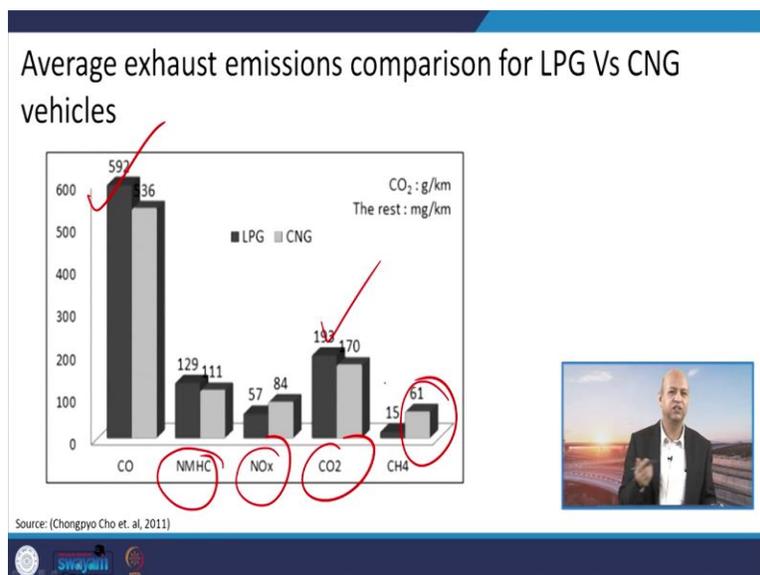
Low floor busses CNG in Delhi, there are, now hundreds of buses are there, which are playing on the roads and giving services to the people.

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But at the initial stage basically, long queues were there because infrastructure was not so appropriate, but slowly, these have been catered and now adequate facilities have been given, but still there is, there are issues at certain pockets.

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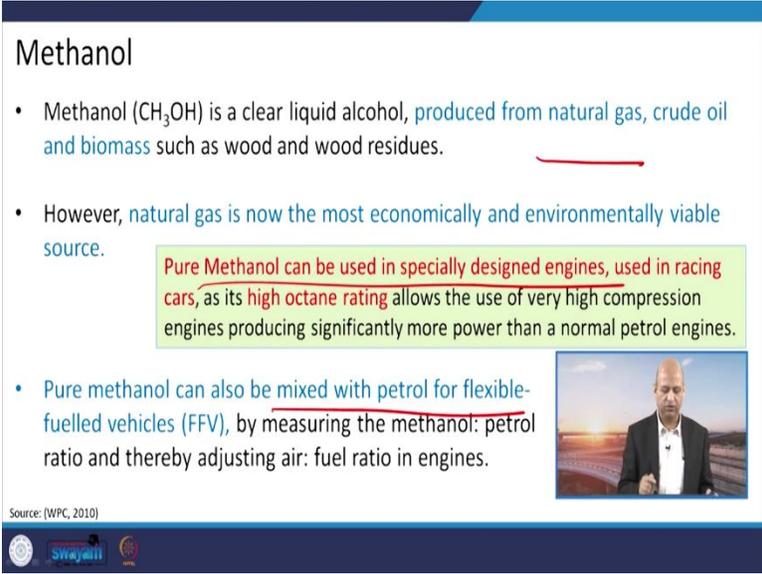


When we talk about exhaust emissions, comparison of LPG versus CNG, then you can see that like LPG emissions of CO is a little higher than the CNG emission. Similarly, like non-methane

hydrocarbons are less in case of CNG in comparison to LPG, but NO_x emissions are a little higher. In LPG it is less than in CNG it is more.

CO₂, again, advantage is there that CNG emissions are less than the LPG, but methane emissions as we have discussed that it is around four times more than the LPG. And methane is greenhouse gas and those are the issues, but we expect that more innovations will come and these kinds of issues can be sorted out in future. Let us hope so.

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Methanol

- Methanol (CH₃OH) is a clear liquid alcohol, produced from natural gas, crude oil and biomass such as wood and wood residues.
- However, natural gas is now the most economically and environmentally viable source.
- Pure methanol can also be mixed with petrol for flexible-fuelled vehicles (FFV), by measuring the methanol: petrol ratio and thereby adjusting air: fuel ratio in engines.

Pure Methanol can be used in specially designed engines, used in racing cars, as its high octane rating allows the use of very high compression engines producing significantly more power than a normal petrol engines.

Source: [WPC, 2010]

The slide features a video inset of a man in a suit speaking, and logos for Swayam and other organizations at the bottom.

When we talk about like methanol, methanol can be produced from fossil fuels as well as non-fossil fuel kind of sources. So, it is basically clear liquid alcohol and produced from natural gas or crude oil and biomass also, wood and wood residues that can be converted into that. And this pure methanol can also be mixed with petrol. So, some ratio can be mixed means, rather than petrol you can have some kind of mixing. So, pure methanol can be used in a specially designed engines, like racing cars because it has very high octane rating, a lot of power, so instantaneous power can be great.

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Methanol as a Fuel

- As a fuel for normal cars, water solubility of methanol poses a problem, and cannot be blended with petrol above 5%, without adding co-solvents.
- Although Methanol vehicles emits less concentrations of CO, hydrocarbons and nitrogen oxides, it is a prime contributor of formaldehyde emissions, a Carcinogen.
- Methanol leads to greater emissions of unburnt fuel emissions of methanol and methane.

Methanol has potential to reduce GHG emissions, only if it is derived from a biomass source.



Source: (WPC, 2010)

SVKM's

But there are some issues, like it is prime amateur contributor to the formaldehyde emissions which is carcinogen, carcinogenic, means it can cause cancer. Otherwise there are good points. Methanol has potential to reduce greenhouse gas emissions in comparison to other sources because when we produce from biomass then it is a renewable resource which can produce the methane, methanol. Then methanol leads to greater emissions of unburned fuel emissions of methanol and methane. So, these are the negative points. Otherwise there are some advantages and, which are promoting the use of methanol in certain quantity.

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Methanol as a Fuel (cont'd..)

- After combustion, Methanol does not produce soot or sulphur oxides, and produce very less nitrogen emissions than any other fuel.
- High cost fuel, compared to petrol but relatively cheap when compared with other alternatives.
- Extremely toxic, corrosive and hazardous to handle. Therefore, a conventional vehicle's fuel system requires modifications before use.
- Greater fuel consumption per unit volume, compared to petrol, but can deliver more power.



Source: (WPC, 2010)

SVKM's

Other issues are like high cost fuel compared to petrol, but relatively cheap when we compare it with other alternatives. And then extremely toxic and corrosive and hazardous to handle. So, it needs lot of skills to handle it. And the conventional vehicles fuel system requires modification before we use methanol as a part of the fuel. But greater fuel consumption per unit of volume when compared to petrol, but it can deliver more power. So, means there are trade-offs. Some good points, some not so good points. We have to choose.

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Example of Methanol-blended vehicles in China



- China currently leads the world in methanol fuel blending.
 - M15 (15% methanol and 85% gasoline)
- Methanol now makes up some 8% of China's fuel pool.



Source: (Kai Zhao, 2019)

wwwnews.cn

Swayam

Well, the blending of methanol is happening in several countries and China is one of the leading country in that sense, it is using M15, that is 15 % of methanol and 85 % of petrol or gasoline, they are mixing, like, 15-85 ratio. And it can, means around 8 % of the China's fuel pool basically met by the methanol.

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Ethanol

- Currently, the most widely used alternative fuel in the world.
- Mostly produced from crops containing sugar (Ex. Sugar cane) or by pre-treatment of starch crops (Ex. Corn or wheat) or cellulose to produce sugar.
- The **fermentation process** uses the conversion of sugars by yeast **into ethanol and carbon dioxide**.
- Ethanol requires less oxygen for combustion, compared to methanol and petrol.



Source: (WPC, 2010)



Then, there is another alternative which is ethanol. And this is most widely used alternative fuel in the world, if you talk about in comparison to other available alternate fuels. And this can be produced by fermentation process and it can be converted from the sugar and yeast, those kinds of things are used for production of ethanol. It requires less oxygen for combustion compared to methanol and petrol. So, there are like certain attributes.

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Production of Ethanol

Step 1 $(C_6H_{10}O_5)_n + n(H_2O) \rightarrow (C_6H_{12}O_6)$
Starch Water Glucose

Step 2 $(C_6H_{12}O_6) \xrightarrow{\text{Yeast}} 2(C_2H_5OH) + 2CO_2$
Glucose Ethanol



Production of Bioethanol from Biomass

PLANT BIOMASS

Pre-treatment
Steam explosion/Ammonia
fiber explosion CO₂ explosion
acid or alkali hydrolysis/
biological or enzymatic process

Consolidated Bio Processing (CBP)
Simultaneous saccharification
and fermentation (SSF)

Saccharification → Fermentation

Enzyme production

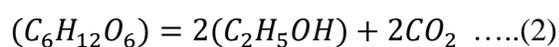
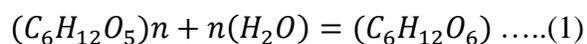
Steam & power generation

Solid separation

Distillation

Bioethanol

Source: (B. I. Sahni et al., 2013)



This is the starch, and water then creates glucose, and in step 2, when yeast is used for fermentation, it gives the ethanol and carbon dioxide So, that way one can produce the ethanol.

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Ethanol as a Fuel

- Ethanol can be blended with petrol directly, upto 20%. Above this, Cold starting an engine may become a problem.
- Have similar technical and performance levels as with methanol, but it is less toxic and corrosive.
- Ethanol has high affinity for water and is a major drawback.
 - Ex. If a petrol-ethanol blend fuel is mixed in a drain or pool of water, the petrol may be skimmed off the top, but ethanol will dissolve & is almost impossible to recover.

Ethanol is a Renewable source, unlike Oil, gas or coal. Additionally, it can sometimes be manufactured from waste material too.

Source: [WPC, 2010]

The slide features a video inset of a man in a suit speaking, and logos for 'Swayam' and 'WPC' at the bottom.

And as a fuel again, you can have some, percentage, like ethanol can be blended with petrol up to 20 %. Above this there are issues, like cold starting becomes a problem. Then ethanol has a high affinity for water, and it is a kind of drawback. And like petrol may be skimmed off at the top, but it will not be taken out of that particular situation.

So, this is again a renewable source unlike oil. Ethanol is a renewable source because we are producing it from sugarcane and other kinds of crops. And then it is also manufactured from waste material. So, waste management kind of thing is also there. So, these are win-win situation. That you can produce it from the waste as well as you can produce it from other renewable sources. So, that way it is carbon neutral. In essence, you can say.

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Ethanol as a Fuel (cont'd..)

- Ethanol in ethanol-petrol blend fuel gets easily biodegraded or diluted to non-toxic concentrations if leaked with water, when compared with petrol.
- Large area of crops is required to produce ethanol and to meet the fuel needs.
- Although CO emissions are very less, aldehyde emissions are more in ethanol fuel (aldehydes can irritate eyes)

Similar to Methanol, Ethanol has potential to reduce GHG emissions, depending on the production source.

- Ex. Ethanol's full fuel cycle GHG emissions are said to be 30-180% from maize & 0-115% from wood, of the emissions from the petrol, it replaces.

Ethanol production is 2-3 times expensive than petrol production

Source: (WPC, 2010)



Then large area of the crops is required to produce the ethanol. So, to meet the fuel demand. So, as I said that crop-car debate is there. Should we have the crop for cars, or crop for the food, food and fuel debate, food versus fuel. Although CO emissions are very less, but aldehyde emissions are more, and they can irritate eyes. So, those are health issues kind of thing from dimensions. So, every kind of fuel has certain characteristics, some good points, some bad points, so we have to see which we can afford to deal with.

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Example of Public transportation in Stockholm city



Stockholm city has 21% of its public transport buses fuelled with ethanol

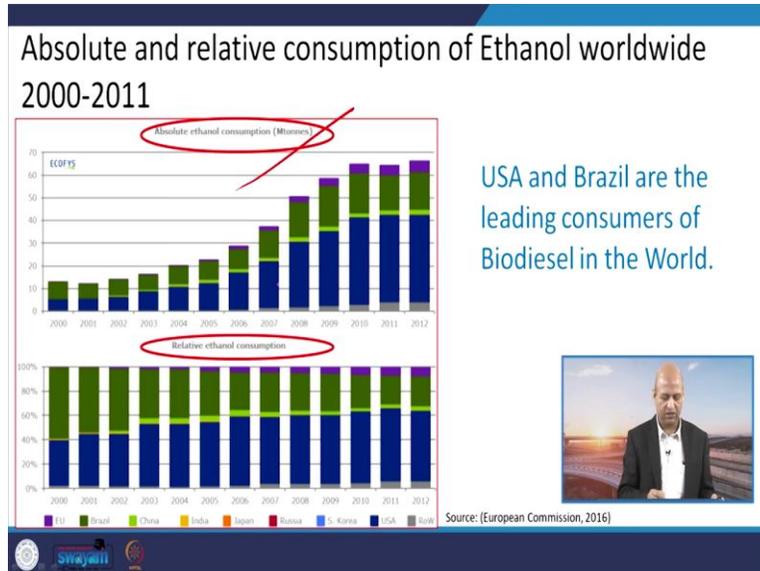


Source: (<https://www.biofuel-express.com/en/stockholm-is-the-worlds-first-capital-with-100-fossil-free-bus-services/>)



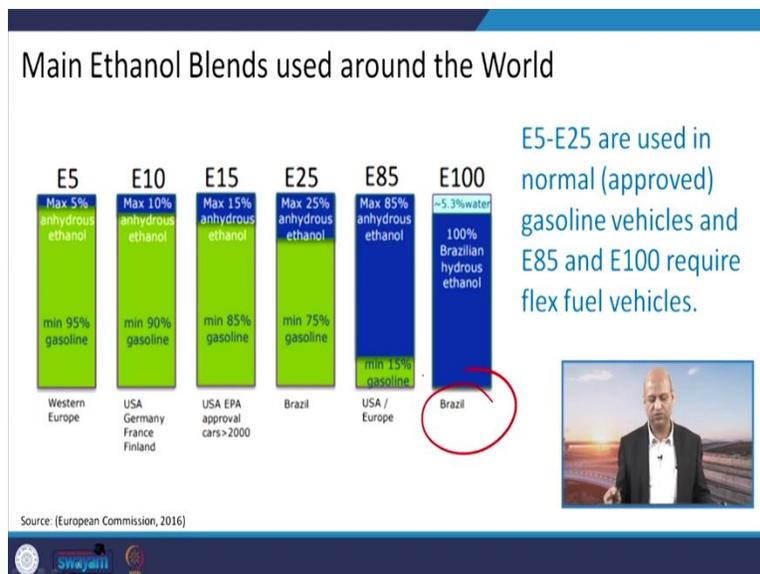
Then if you see it is uses, like in the Stockholm city, 21 % of the public transport buses are fueled by ethanol. So, this is the popular fuel, you can say, from availability, accessibility and so on.

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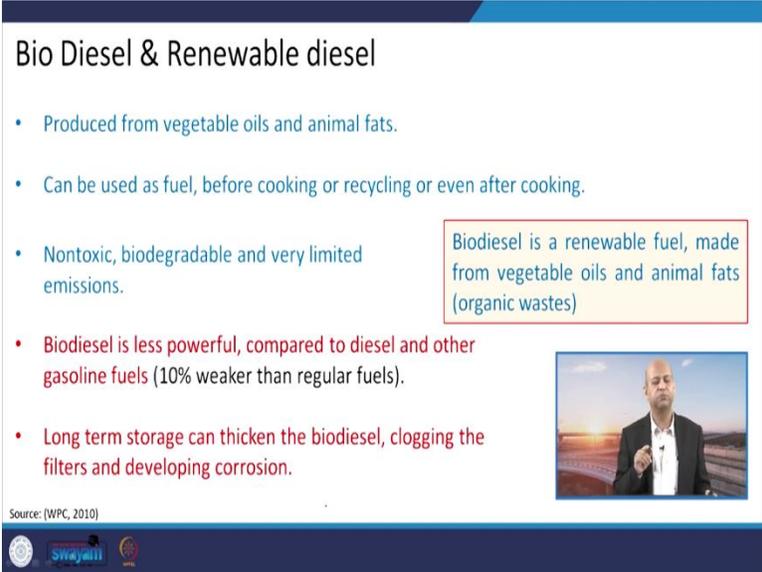
U.S. and Brazil are the leading consumers of the bio diesel in the world. When we talk about like ethanol and those other kind of bio resources or bio fuels then these two countries are really producing lot of, ethanol consumption, you can see that trend. They are absolute stands as well as relative, increasing day by day.

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The blending of ethanol can happen like if E5, that is 5 %, 10 %, 15, 25, 85, even 100 %. So, like, in Brazil they also use this 100 % kind of ethanol. So, that kind of engine technology is there. Otherwise blending can be depending upon which kind of engine technology you are using and how much ethanol is easily available.

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Bio Diesel & Renewable diesel

- Produced from vegetable oils and animal fats.
- Can be used as fuel, before cooking or recycling or even after cooking.
- Nontoxic, biodegradable and very limited emissions.
- Biodiesel is less powerful, compared to diesel and other gasoline fuels (10% weaker than regular fuels).
- Long term storage can thicken the biodiesel, clogging the filters and developing corrosion.

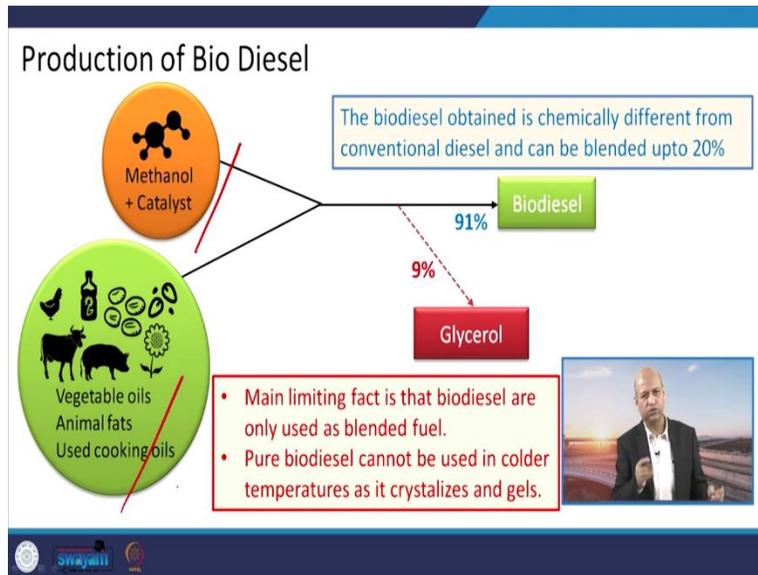
Biodiesel is a renewable fuel, made from vegetable oils and animal fats (organic wastes)

Source: (WPC, 2010)

The slide features a video inset showing a man in a suit speaking. At the bottom, there are logos for 'Swayam' and 'WPC'.

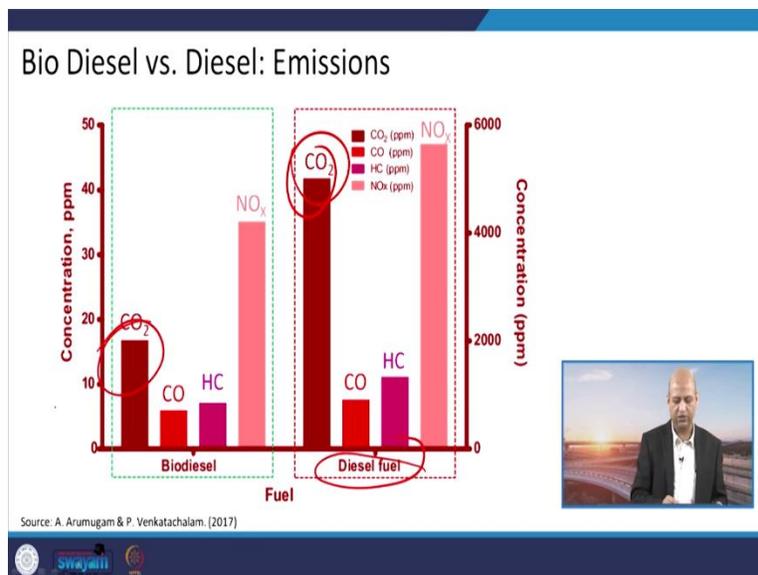
When we talk about bio diesel and renewable diesel, then bio diesel is less powerful in comparison to the other gasoline fuels etc., 10 % weaker. But because it is the bio source, so renewable, and renewable is like carbon neutral kind of thing you can say, because you can again harvest it. And when CO₂ goes then plants or crops will consume the CO₂ then again you will get the fuel. Those kind of thing. Long term storage can thicken this bio diesel and clogging of the filters can also be, can also happen. And then some corrosion related issues can also be there.

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Production of bio fuels basically can be like methanol plus catalyst and vegetable oils, animal fats used for cooking oil, those kinds of waste oil can also be converted into this bio diesel. So, these are different processes.

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And when we talk about like bio diesel versus the fossil fuel diesel emissions, then you see the bio diesel emissions and this diesel fuel, so much less, like CO₂, this much unit, more than 40, it is less than 20. Similarly, CO is little bit comparable but hydrocarbons are less, and the NO_x emissions are also less in comparison to the diesel.

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Example of Bio Diesel powered buses in a Norwegian city, Trondheim



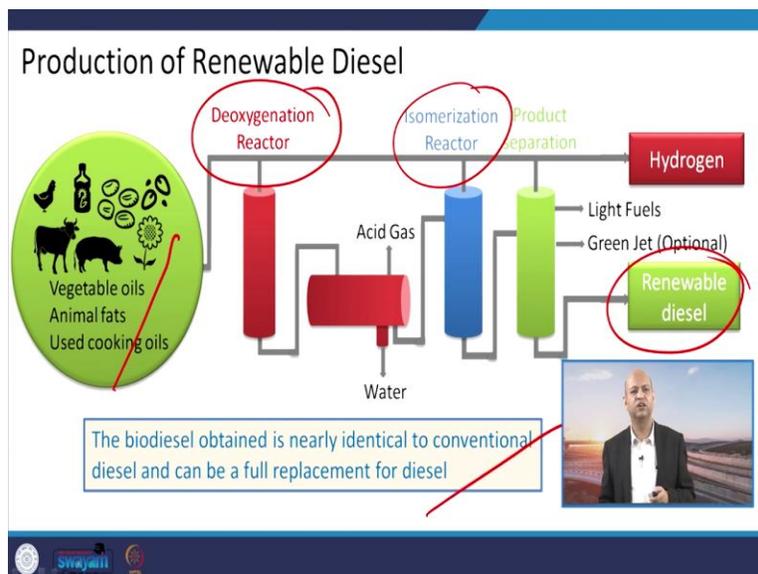
A total of 189 green buses offer an efficient and clean solution for inner-city traffic in Trondheim, Norway.



Source: (<https://www.canadianbiomassmagazine.ca/norwegian-city-adds-biofuel-buses-to-fleet/>)

Bio diesel powered buses are being used in several countries like in Norwegian city of Trondheim. They are using around 189, around 190 green buses based on this bio diesel.

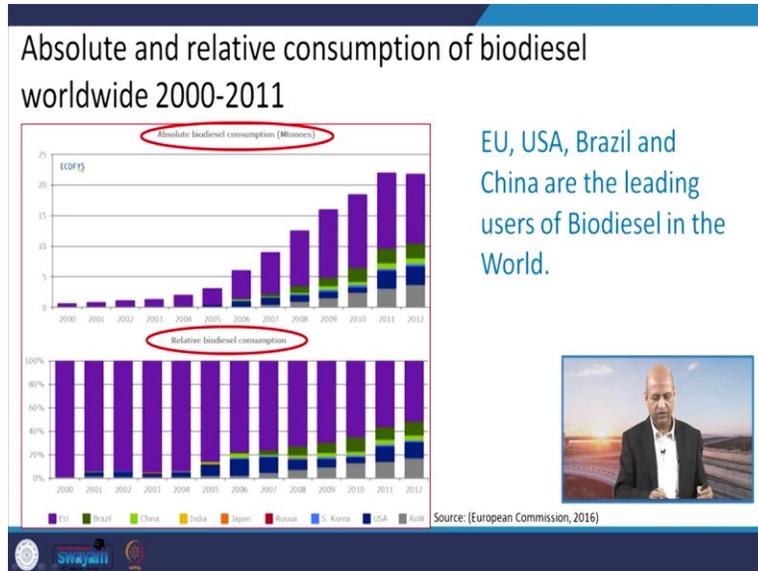
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When we talk about how to produce the renewable diesel, then again vegetable oils, animal fats and those used cooking oil can be used by deoxygenation reactor. And then acid gas is taken out, water is taken out, and the isomerization reactor gives the, this further process. And the product separation is taken and renewable diesel is produced ultimately. And this bio diesel is obtained. It is almost identical to the conventional diesel and can be a full replacement for the diesel. So, that,

those kinds of technologies are also available nowadays. And it can be used in future in a good quantity.

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Well, we talk about like absolute and relative consumption of bio diesel, if you see the trend from 2000 to 2011, then you can see in European Union, USA, Brazil and China it is increasing. The trend is increasing the uses.

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Butanol

- Very competitive renewable source of biofuel.
- Better alternative for gasoline or diesel fuel in terms of combustion characteristics, engine performance and exhaust emissions.
- Butanol production includes various methods for fermentation.
- Butanol (acetone, ethanol and iso-propanol) are naturally formed by a number of clostridia (bacteria).
- However, studies are limited when compared to ethanol or biodiesel or other alternatives.

Source: [B. L. Sahi et. al, 2013]

Butanol, another like, very competitive renewable source of the bio fuel, which is, the production includes various methods of fermentation like ethanol, and it is like acetone, ethanol, isopropanol,

these combinations are there. And they are naturally formed by a number of like, bacteria. And, but some mysteries are limited, compared to ethanol and bio diesel. So, more research is needed for making it a good alternate fuel, but there is a potential.

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The slide is titled "Battery / Electric" and contains the following content:

- Electricity can be used as an efficient alternative fuel.
- Fuel-cell vehicles run on electricity produced through an electrochemical reaction, when hydrogen and oxygen are combined.
- Biggest benefit is that they produce electricity without combustion.
- Challenge is that most of the electricity generated today is from coal or natural gas.

A callout box on the right states: "Battery powered electric vehicles store power in batteries that are recharged by plugging the vehicle into an electric source."

A video inset shows a man in a suit speaking against a sunset background.

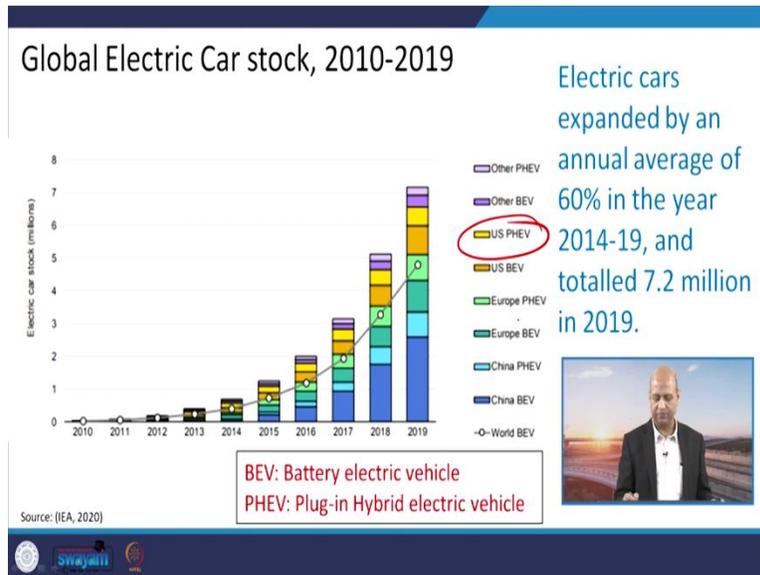
Source: ()

Logos for Swayam and other institutions are visible at the bottom.

When we talk about battery and electric, like electricity and where from you get the electricity, if it is coming from fossil fuel like coal et cetera, then of course, that is an issue. But if you have renewable resources, hydro power or solar, and that we are getting the electricity and with that you are charging the battery and you are using the battery for driving your two wheeler or car or even trucks and buses nowadays, lithium ion batteries are good quality batteries are coming nowadays. And I am very hopeful that in future we will have more, battery technology in that direction. So, that is the future of like, EV, E-vehicles or electric vehicles. And it is noiseless it is pollution-less, a lot of advantages are there.

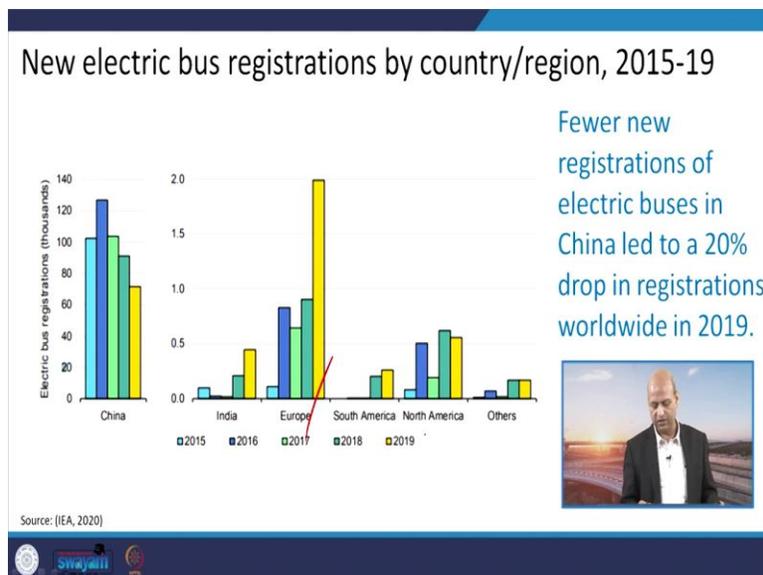
So, in cities where I know sometimes we feel so much chopped in winters when inversion is there, a lot of pollution is there, if battery operated vehicles will be there then these kinds of issues will be drastically reduced because then transport related emissions will be almost zero. That will be great advantage.

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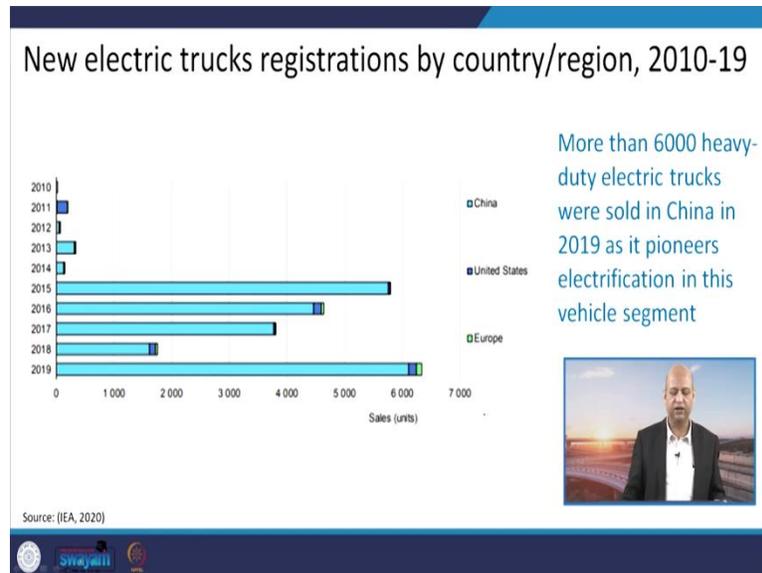
When we see the global electric car stock from 2010 to 2019, so it is increasing. Like, this PHEV, that is plugged-in hybrid electric vehicle. So, petrol maybe there initially, to drive, and then switch over to the battery and when battery is not so powerful you can again switch over to the gasoline or so. Those kinds of arrangements are there. These kinds of hybrid, the engines, hybrid cars are available in the market and their popularity is going on, increasing day by day. So, you can see like in several countries basically, this trend is going, increasing day by day.

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When we talk about new electric bus registration by country or region, from 2015 to '19, so in China it reduced, so, means, I am not sure whether it is because they have exported a lot of, these vehicles, but in other countries it is increasing. Like Europe, it has increased drastically. Even in India, the registered E-vehicles are increasing. And then North America, everywhere, means trends are good.

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When we talk about 2010 to '19 trend of new electric trucks registration, then again the situation is good, means it is appreciable that we are moving in that direction where we can replace even the heavy trucks by the better driven trucks.

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Electricity from Renewable sources as fuel

- Electric powered vehicles (car) or trains may use electricity directly from solar power.
- In case of high demand of energy in operation, it may full-fill partial requirement as supplementary with direct electricity source.



Image: Solar powered train & rikshaw

Image source: emangzine.com, timesofindia.com



So, electricity from renewable sources as a fuel is the coming thing, incoming thing and the future source of energy for the transportation sector that will make the transportation sector in real sense sustainable, because the environment will not be harmed in that sense. Of course, people argue that if you see the lifecycle assessment from, kind of, cradle to grave or from source to end then when you are extracting, mining material for batteries et cetera or vehicles, there are certain emissions. Of course, there are, which are otherwise also.

My point is the fossil fuel related emissions will go away when we transfer towards battery or electric vehicles, which are driven by these renewable sources of electricity. That would be the wonderful scenario, you can see the solar power based these, trains and rickshaws. These are incoming things. Next 10 years scenario will be greatly changed basically.

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Hydrogen as a Fuel

- Produced from water through Hydrolysis, using electricity.
- Limitless supply of hydrogen in water, if sufficient electricity is available.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

- Produced from hydrocarbons, in reaction with steam.
- Though simple process, it utilizes earth's reserves of hydrocarbons to produce hydrogen, making it not a true non-fossil alternative.
- Can be made a renewable source, if hydrocarbons can be derived from vegetable oils/ plants (Expensive process)

Source: (WPC, 2010)

And a lot of policy changes are going in India. We are promoting solar energy. In last few years, just I read an article yesterday, that the power plants which have been, executed or implemented in last one or two years, the 90 % of power plants are from solar and wind, not from the coal. So, these kind of good signs are there.

Hydrogen as a fuel, it is a big debate, and it is a clean fuel because the emissions are only water vapor, although some modeling studies are there and people say that a lot of humidity may occur if so many vehicle drive on the hydrogen, but there are other issues also because hydrogen is very inflammable. So, carrying it into a very tight and sturdy tank is a challenge.

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Hydrogen as a Fuel (cont'd..)

```
graph LR; Feedstock --> Reformer; H2O --> Reformer; Reformer --> Shift_Convertor[Shift Converter]; Shift_Convertor --> Purification_Unit[Purification Unit]; Purification_Unit --> H2; Purification_Unit --> CO2[CO2]
```

- Hydrogen burning **at high temperatures**, burns nitrogen also, **forming nitrogen oxides**.
 - Temperature can be **controlled by introducing water** to the hydrogen/ air mixture.
 - Also be **controlled by cooling the combustion** by using excess air.

Hydrogen fuel can completely avoid GHG emissions and be a renewable source of fuel, only if the electricity used in the production process is derived from a non-renewable source.
Ex. Solar, wind, hydro power.

Source: [WPC, 2010; B. L. Salvi et. al, 2013]

But hydrogen fuel cells kind of things are there, and they are in thing, a lot of research is going on. So, hydrogen cell can produce electricity. And again, the zero-emission kind of thing, from pollutant perspective, not from water vapor. Water vapor is also greenhouse gas, please remember it. So, in that sense it is not zero emission. There is emission. Zero emission only, like electric, battery driven. But before disposal of battery, it is another issue, that is another challenge. But from tailpipe emissions, I always talk about those. So, those are the emissions almost zero. Only resuspended dust on the road and those kinds of emissions maybe there. So, very less.

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Characteristics of Hydrogen as a Fuel

- Non-toxic fuel.
- Currently used as fuel only in space rockets, though some automobile prototypes exist for testing and use.
- Storage is the main concern. Requires heavy and expensive tank.
- Safety concerns in storage, use and distribution.
 - Very flammable over a wide range of air: fuel ratios
 - Burns rapidly with a high temperature.



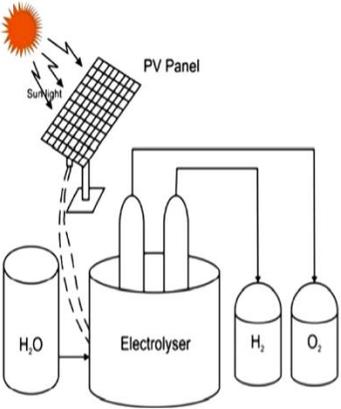
Source: (WPC, 2010)



Characteristics of hydrogen as a fuel. It is non-toxic, but as I said its storage is a big problem. It can blast. It is like you are carrying a bomb along with you. So, this safety, security issue is very paramount, and if research goes on, we can make it more safer, then it is fine.

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Hydrogen from Renewable sources



Schematic diagram of photovoltaic hydrogen production system



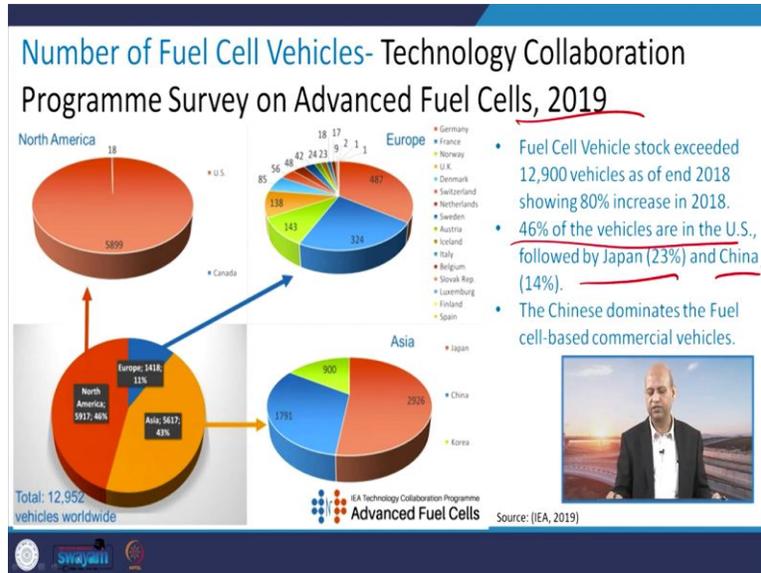
Source: (B. L. Salvi et. al, 2013)



Hydrogen from renewable sources. So, if you, how to get the hydrogen? Basically, you can get from water, but from water, if you want to break the hydrogen molecule, how would you do that? You need some energy source. If you are getting that energy source from fossil fuel, again, the

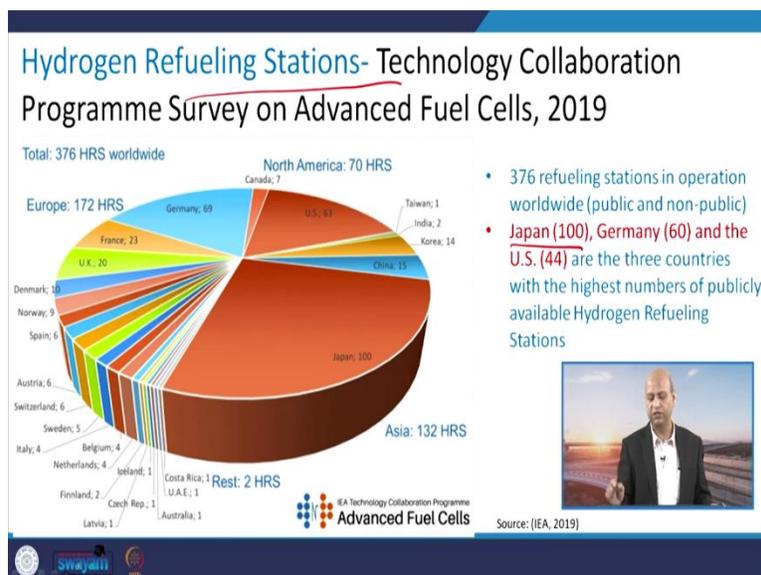
story same. So, no, no advantage is there. So, if you get that electricity from solar or some renewable sources then a story is more attracting.

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Number of fuel cell wheels, technology, the survey which is of 2019, so you can see 46 percent of the vehicles in the U.S. followed by Japan and China. So, they are the leading countries from fossil fuel technology.

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And again, like Japan 100, hydrogen refueling stations, 100 stations in Japan, in Germany at 60, U.S., it is 44. So, infrastructure is also being developed in that direction.

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Example of Linköping city, Sweden: Biogas for Urban transport

- Total biogas production: 7.7 million m³ /year.
- Linköping city uses 100% biogas for Urban transportation.
- Linköping got the first 27 buses in 1997, since 2002 all the diesel buses in operation in Linköping have been replaced by biomethane buses.
- Other modes such as trains and cars are also run on biogas.
- CO₂ emissions are down by 25 % since 1990.
- Target to be carbon-neutral city by year 2025.



Image: Biogas train
Source: iea-biogas.net



Swajani

When we talk about the biogas, I have personally visited this place, Linköping it is called, although spelling is L I N K O P I N G, but pronunciation is Linköping. This Linköping city in Sweden, it has, this complete public transportation system is based on biogas. And that biogas is generated from like the waste from the slaughterhouse or organic waste from the houses.

So, they create this methane, clean it properly. I was surprised to see the facility because in Sweden it is negative temperature most of the time. In those harsh weather and climate they can produce methane and they can drive their, these buses and also taxis, and even one train is being driven by the biogas.

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The Linköping Biogas plant, Sweden



FACTS

- Treatment of slaughter house waste and industrial organic waste
- Start of operation: 1996
- Total biogas production: 7.7 million m³/year
- Digester volume: 2 * 3700 m³
- Upgraded biogas delivered to vehicles (97% methane): 4.7 million Nm³/year (2005)
- Total investment: 14 million EUR
- 64 biogas buses
- 12 public biogas filling stations (2005)

The Linköping Biogas plant



Source: Swayamii

This is the plant of biogas and they are producing lot of clean fuel in that sense.

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Alternate Fuels: Production process at a glance

Biodiesel	Natural Gas	Propane	Electric	Ethanol	Fuel Cell
Crop Cultivation	Extraction	Capture	Generation	Crop Cultivation	Sourcing
Processing	Scrubbing	Liquefying	Station Installation	Processing	Hydrogen Extraction
Distributing	Distributing	Distributing	Fueling	Distributing	Distributing
Fueling	Compressing	Fueling		Fueling	Fueling
	Fueling				

Production operations for Alternate fuels from Raw material to fuelling station

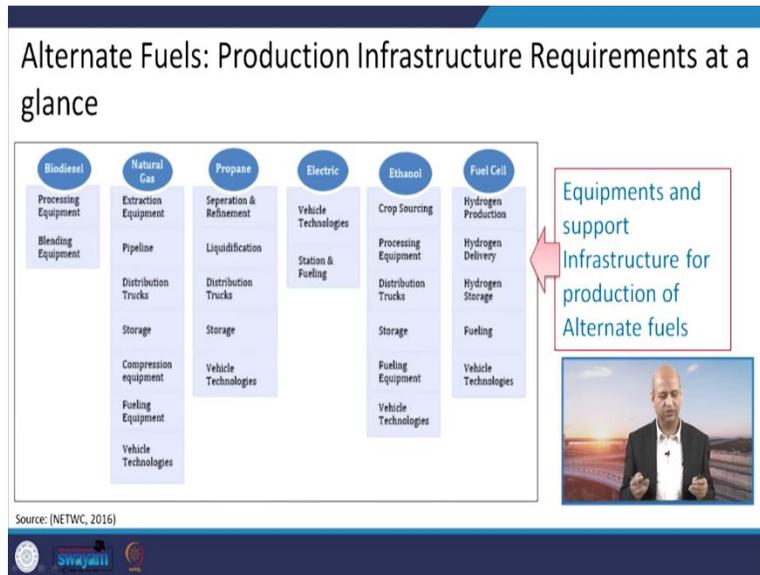


Source: (NETWC, 2016)

Source: Swayamii

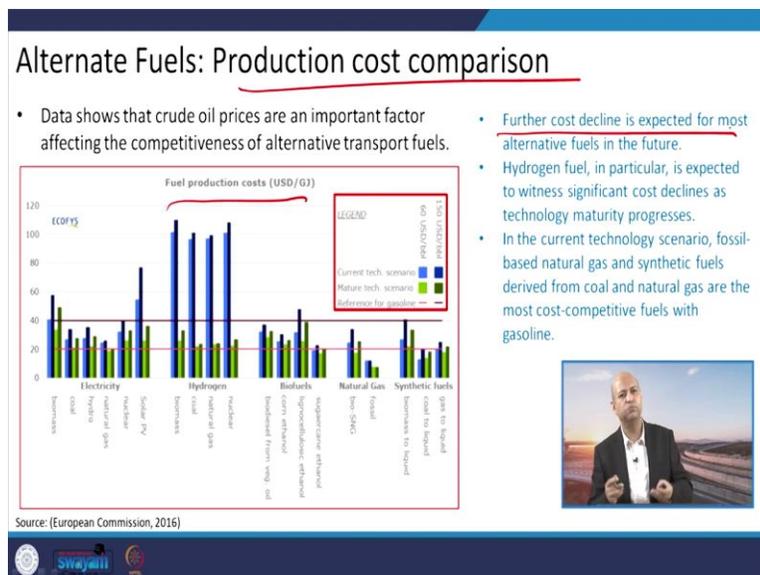
If we see these alternate fuels production in a glance, so there are like bio diesel, natural gas or this propane, electric, ethanol, fuel cell. So, every country has different share, basically depending upon their stage of the economic growth and the technology available.

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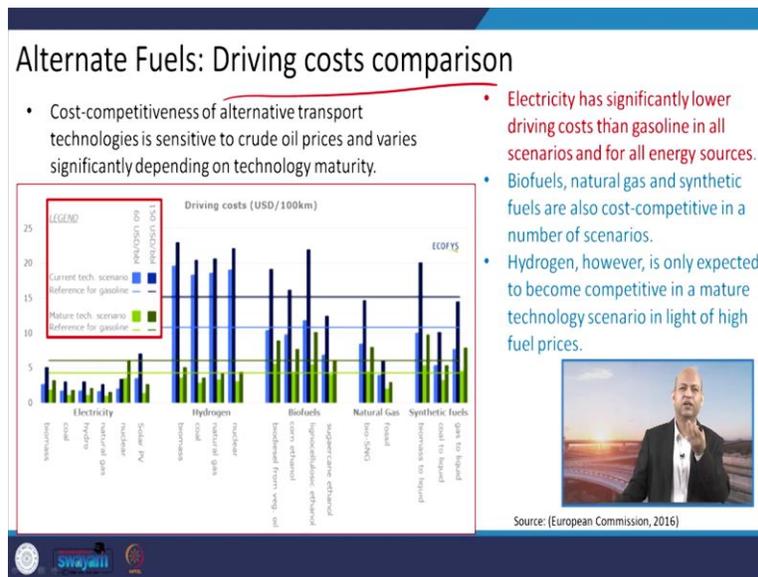
So, that way, but there are many issues like plus and minus, we have seen in these different slides, that some issues are there with respect to the power, some issues are there with respect to some emissions.

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When we see the production cost, when we compare, like, you can see this fuel production cost. So, again, there is a variation basically. So, the further cost decline is expected for most of the alternative fuels in the future because when use will be more, more demand will be there, mass production will reduce the cost automatically.

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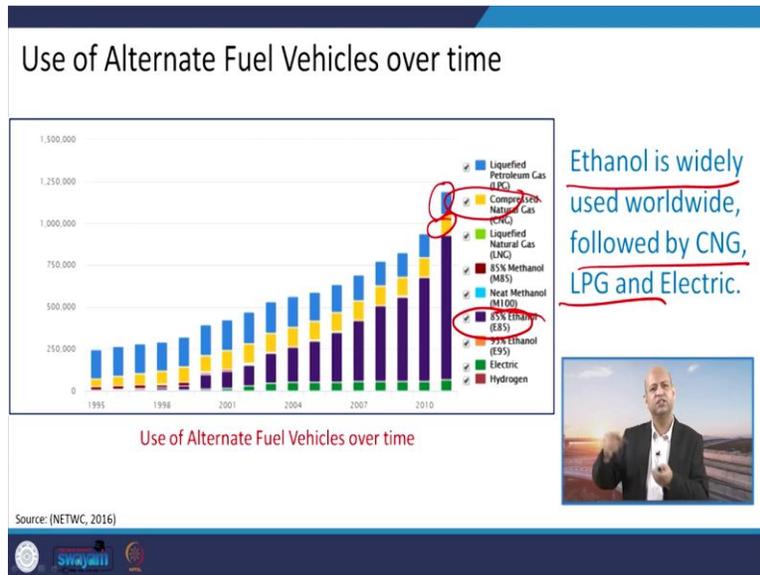


The driving cost comparison is also interesting, that electricity has significantly lower driving cost in comparison to the gasoline. Today morning, I was talking to a friend, he is working in this CRRI, Central Road Research Institute, very close to transportation related issues. So, he has bought one two wheeler, battery driven.

So, he was saying that he is enjoying this ride. It is quite comfortable for him to charge, and issues when this petrol prices are increasing and sometimes these odd-even issues are there, because those kind of battery driven vehicles do not have registration, they do not need licensing, means very small kind of thing, not the powerful ones, but small kind of, which has like 25 kilometer per hour speed kind of thing.

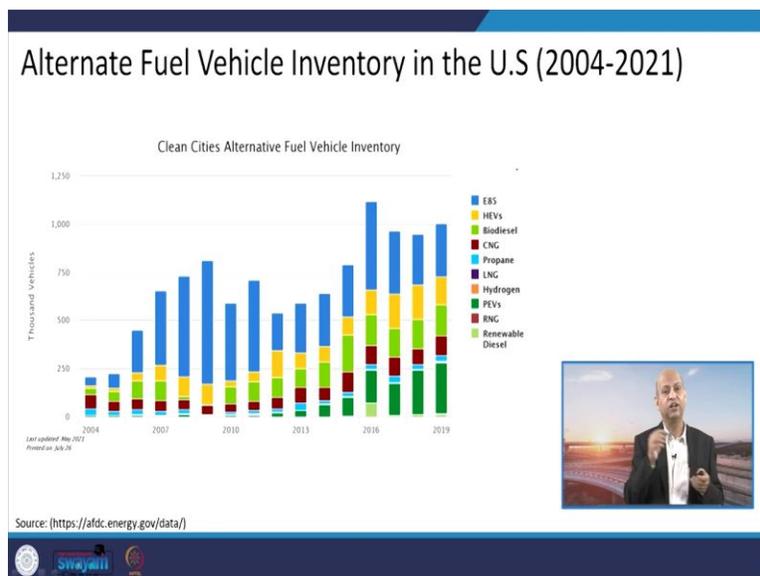
So, for daily use, means only in and around your, but there are cars are also available nowadays, battery driven, you can see, you can, people are buying, means good mileage are also there, they can run in one charge to up to even 300 to 400 kilometers. So, those kinds of technologies are coming. So, future is very good in that sense.

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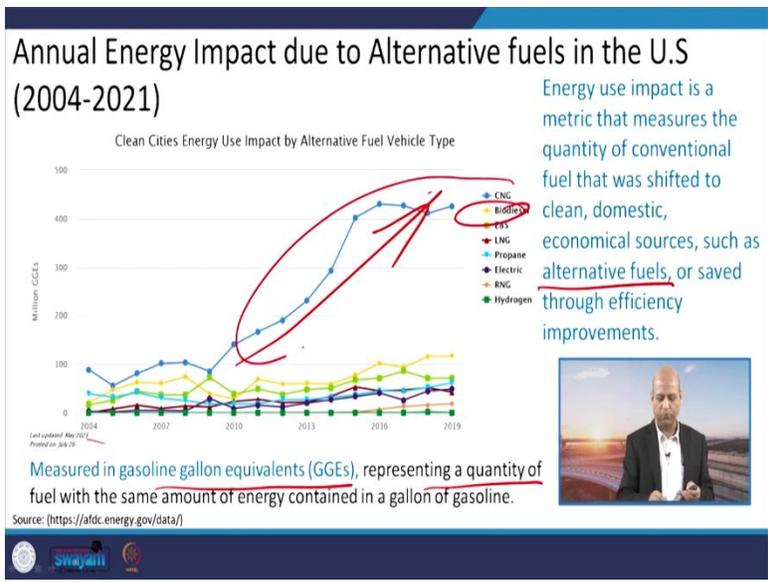
When we talk about alternate fuels vehicles over time, so see that ethanol is widely used worldwide and followed by CNG and LPG. So, this is the ethanol, you can see, this one, this one 84, 85 %. And this is the compressed natural gas, yellow one. Blue one is LPG. So, over the years, the share is increasing of each one, but ethanol is more welcoming kind of fuel.

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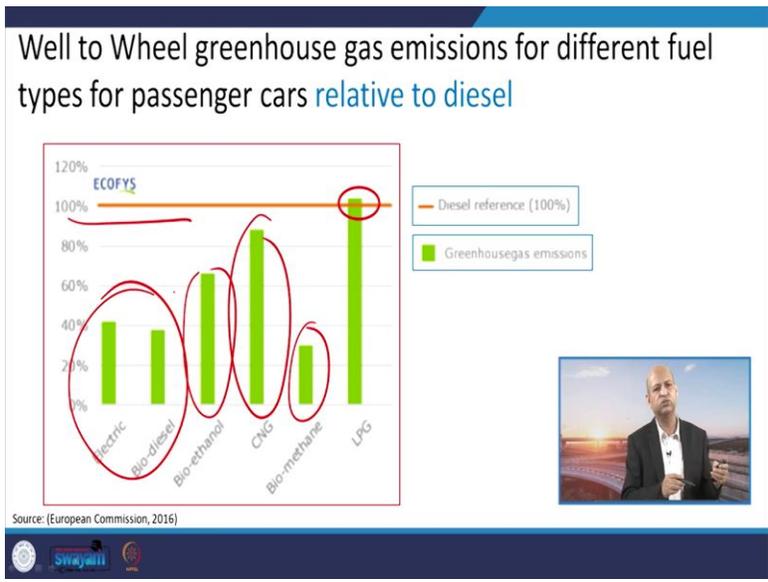
When we talk about alternate fuel vehicle inventory, so every year it is of course, fluctuating, but popularity is going on. In USA these, these kind of alternate fuel based vehicles inventory is there.

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Annual energy impact, if you see alternative fuels in the U.S., basically from 2004 to 2021, so you can see this gasoline, gallons equivalents, and representing a quantity of fuel, so this energy use impact is metric that measures the quantity of conventional fuel that was shifted from, to clean and domestic economically sources, such as alternative fuels. So, again, like CNG related so much trend is increasing by, day by day. And then other bio diesel, but the CNG related basically more popular in USA.

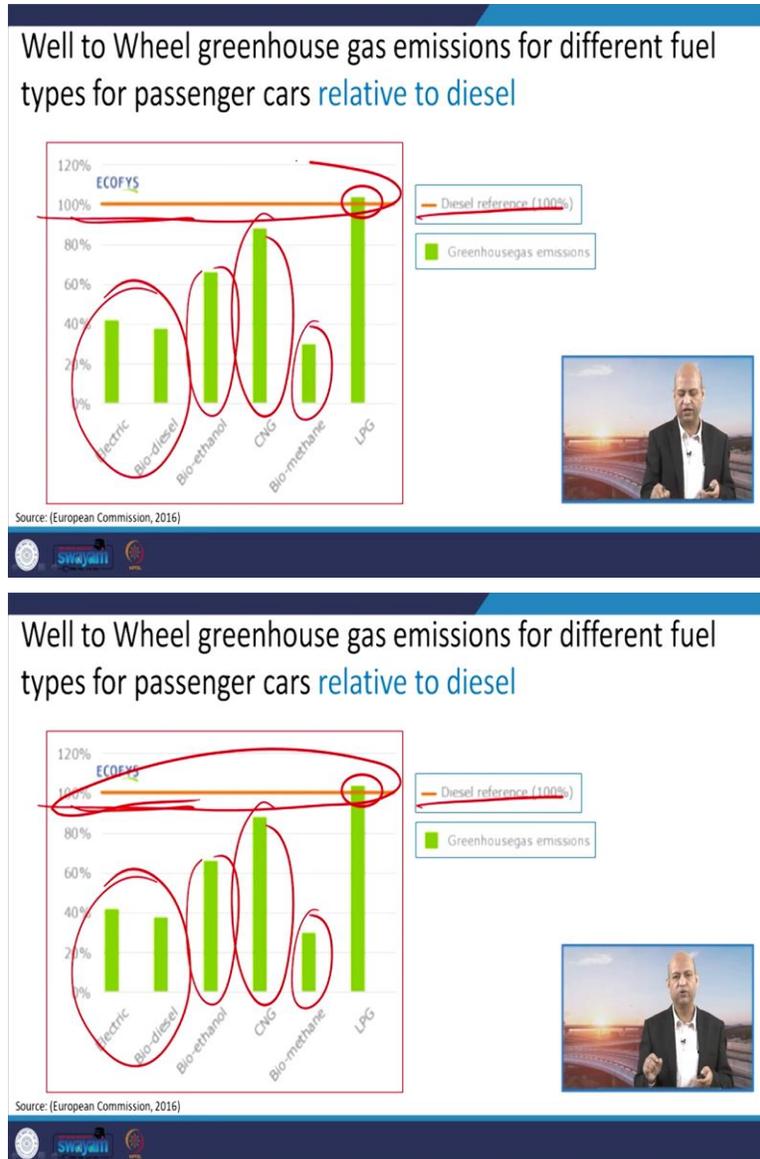
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And if you talk about like, LPG and other well to wheel, means like kind of lifecycle assessment in terms of greenhouse gas emissions, so you can see the electric and the bio diesel they are the

least emitters of greenhouse gases. You can see where this emission is coming from electric vehicles because, as I said when we are producing batteries, when we are producing the vehicles itself there are emissions. So, do those have been counted in that. But in terms of, LPG if you see this 100 unit, then even CNG is better and bio methane and bio ethanol all those bio related alternative fuels are very good.

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When we talk about greenhouse gas emissions in terms of other like, gasoline reference, that was the reference of diesel reference basically, this was the diesel reference. So, diesel reference, LPG

is almost same. But others were advantage. When we talk about gasoline reference, then more advantage is there, rather. More advantage is there.

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Policies and Incentives for Alternative fuels in Countries

Country	Importance policies	Important incentives	Country	Importance policies	Important incentives
Brazil	Proalcool programme: Gas stations obliged to sell ethanol	Proalcool programme: Ethanol price lower than gasoline's. Guaranteed remuneration of the producer. Financing to producers -increasing of production's capacity. Reduction of taxes for vehicles using hydrous ethanol	USA	Energy Independence and Security Act of 2007: loans for automobile manufacturers to develop EVs Next generation electric vehicle: provided funding for the production of batteries and their components Energy Policy Act: pilot projects for advanced vehicles	Energy Improvement and Extension Act of 2008: federal tax credit for PHEV buyers Clean vehicle rebate Project: rebates for zero emission vehicles and PHEVs State level incentives: tax reduction or exemptions and rebates for both EVs and PHEVs, and the non-fiscal incentives included free access to high occupancy vehicle lanes California has supported the production and sales of low emission vehicles (EVs) or zero emission vehicles (ZEVs) through imposing civil penalties on the manufacturers for non-compliance with the targets and credits for others
China	Government purchase of EVs Traffic restrictions Vehicle lottery (limited sales of conventional vehicles)	EV buyers gain subsidy, are not part of a vehicle lottery and have no traffic restrictions (lane use, licence plate based or other) Incentives for EV buyers in some cities for selected EVs			
Japan	R&D programmes for lithium-ion battery and fuel cell development Government purchase of Hydrogen Fueled vehicles	Incentives for fuel cell vehicle buyers and HRS infrastructure			
Russia	Innovation support for biofuel production	Incentives for the development of CNG and LNG refuelling infrastructure and pilots with natural gas vehicles			
South Korea	Market uptake and demand management: biodiesel blend mandate, promotion of natural gas for buses	Innovation support and incentives for natural gas vehicles (subsidies and low priced natural gas for public buses)			

Source: (European Commission, 2016)



So, the policies and incentives in each country, basically nowadays, countries are moving from fossil fuel dependency to renewable sources, and day by day, we are seeing good technologies. Initial teething problems are there but I am very hopeful that better technologies will be there.

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Alternative fuelled vehicles in some countries around the World

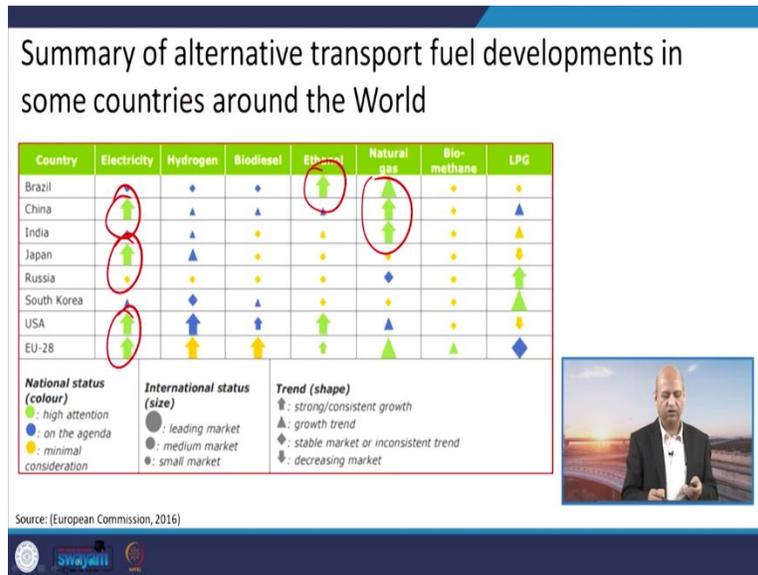
Country	Electricity (total number of Electric Vehicles sold, 2012)	Hydrogen (number of fuelling stations in service, 2014)	Biofuels (total biodiesel consumption, Mtonne, 2012)	Biofuels (total bioethanol consumption, Mtonne, 2012)	Natural Gas (natural gas vehicles in circulation, latest available, thousands)	LPG (LPG consumption, Mtonne, 2013)
EU	30,000+	72	11.41	5.23	1,099	5.42
Brazil	~0	1	2.51	16.45	1,744	0
China	9,934	2	0.82	1.98	1,577	0.73
India	~0	3	0.06	0.24	1,500	0.32
Japan	22,465	22	0.01	0.04	43	0.98
Russia	~0	0	0.00	0.00	90	2.85
S. Korea	548	12	0.33	0.01	36	3.99
USA	53,177	58	3.13	38.44	250	0.41

Source: (European Commission, 2016)



And alternative fuelled vehicles in countries, you can see the numbers. So, they are increasing every year.

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The summary of alternative transport fuel developments in some countries of the world, you can see, like, all these signs are of strong trend. So, most of the countries are having good trend in, in terms of electricity driven vehicles, or bio diesel related or natural gas related, those kind of things.

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Alternative fuels: India's approach

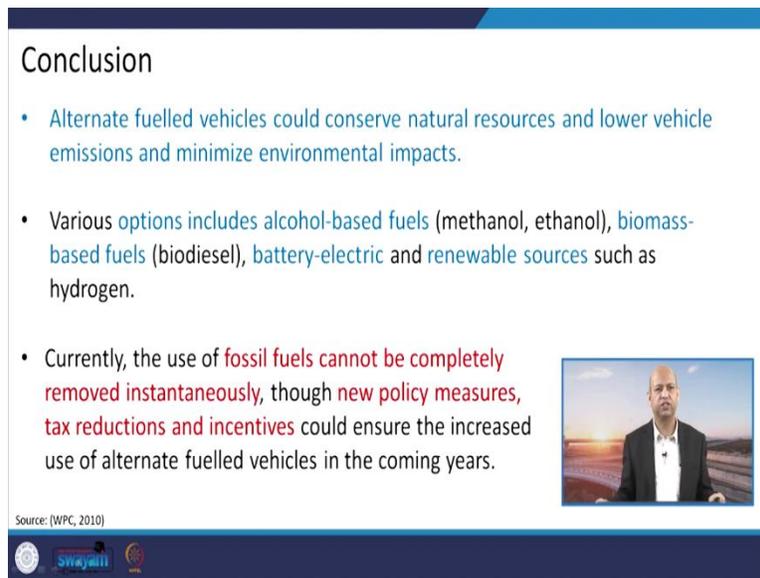
- Ethanol blending to 22% from current 7%. (In monetary terms, approx. 20 Rs. difference per liter of petrol compared to ethanol for customers and can save 1 lakh crore in oil import)
- Flexible engines compatible with CNG or higher blending of ethanol.
- 178 million tones surplus crop residual to be used for extracting alternative fuels.
- Indian railway is adopting solar energy for train operations through installing solar panels over the trains as pilot projects.



Well, in India, we are having this policy of ethanol blending to 22 % from current seven percent. This kind of policy, we are implementing. So, this will really help us in saving because we import lot of oil. So, 20 rupees difference per liter of petrol, the price will be reduced. And around 1 lakh crore rupees will be saved from the oil import kind of activity.

Then, there are some engines, flexible, compatible with CNG, and surplus crop residual is there which can be converted into ethanol. So, those kinds of technologies are coming. And then Indian Railway is also adopting solar energy related train operations. At the rooftop they are having solar panels. New things are coming, new innovations are coming. So, the policy-wise, India is really heading towards renewable resources of the energy and fuelling transport from those renewable resources.

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Conclusion

- Alternate fuelled vehicles could conserve natural resources and lower vehicle emissions and minimize environmental impacts.
- Various options includes alcohol-based fuels (methanol, ethanol), biomass-based fuels (biodiesel), battery-electric and renewable sources such as hydrogen.
- Currently, the use of fossil fuels cannot be completely removed instantaneously, though new policy measures, tax reductions and incentives could ensure the increased use of alternate fuelled vehicles in the coming years.

Source: [WPC, 2010]

The slide features a small video inset on the right side showing a man in a suit speaking. At the bottom, there are logos for 'Swayam' and other institutional affiliations.

So, we have seen that these alternate fuels, vehicles, they can conserve natural resources and they can also lower vehicle emissions or transport related emissions and they can minimize the environmental impacts, negative impacts, I mean. And then, there are various options like alcohol-based fuels, methanol, ethanol, biomass-based fuel, bio diesel, battery, electric, other renewable sources such as hydrogen, those kinds of things.

And the fossil fuel cannot be completely replaced by the renewable resources, right now. It will take time. But the new policy measures are really giving the boost or they are giving impetus because the subsidies and more taxes to fossil fuel and less taxes to the renewable resources, those kind of differential policy measures can improve the situation in future and we can have better transportation sector based on the alternate fuels.

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So, this is all for today. And this is the reference list where we have taken information. For your additional information you can go through that. Thank you for this lecture, for your attention.

Thanks a lot.