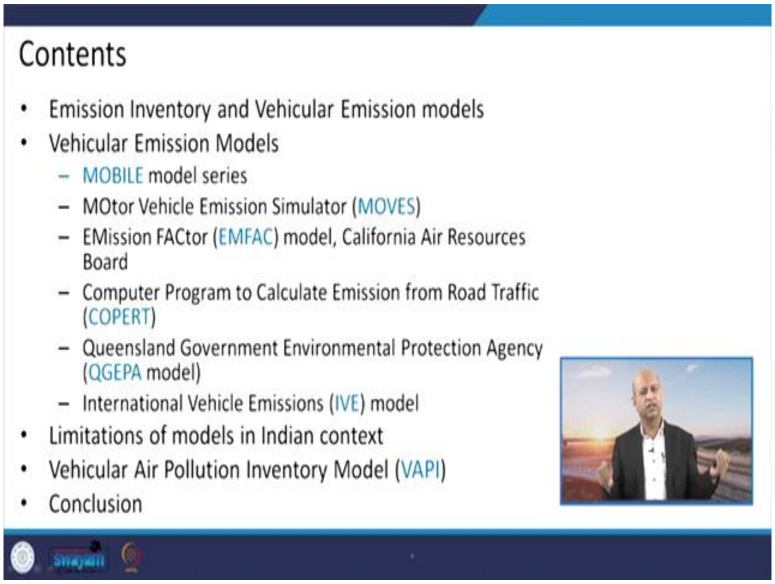
Sustainable Transportation Systems
Professor Bhola Ram Gurjar
Department of Civil Engineering
Indian Institute of Technology, Roorkee
Lecture 40
Modeling of Transport Emissions - I

Hello friends. Today we will have completely new topic like from the past, like environmental impact assessment or LCA then circular economy so today we will start to discussing about modeling of emissions from transportation sector. That is very important because if you want to see the air quality impacts or exposure assessment, from the emissions of transportation sector, then this is something which is very, very important aspect which we should know.

(Refer Slide Time: 0:01:00)

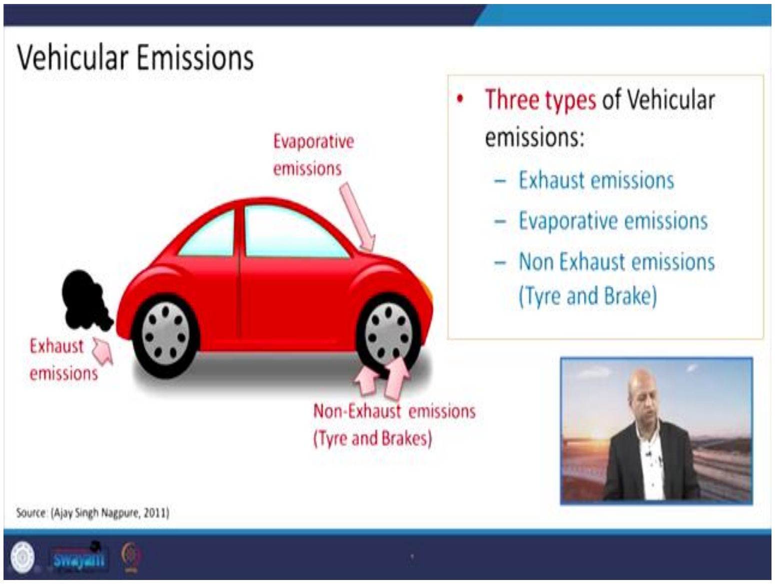


So, how to model the vehicular emissions and what is the role of emission inventories in a city, so in a city, different sectors are there of emissions, whether domestic, power plants, industrial and then transportation. So, for transportation we will focus today, this modeling efforts to develop an emission inventory so first of all we would like to discuss what kind of models are available across the world, which are used for modeling of emissions from different kind of vehicles.

So, like mobile model series then MOVES and then EMFAC of California Resources Board, then COPERT is there from European countries and then there is this QGEPA from Queensland Government Environmental Protection Agency in Australia.

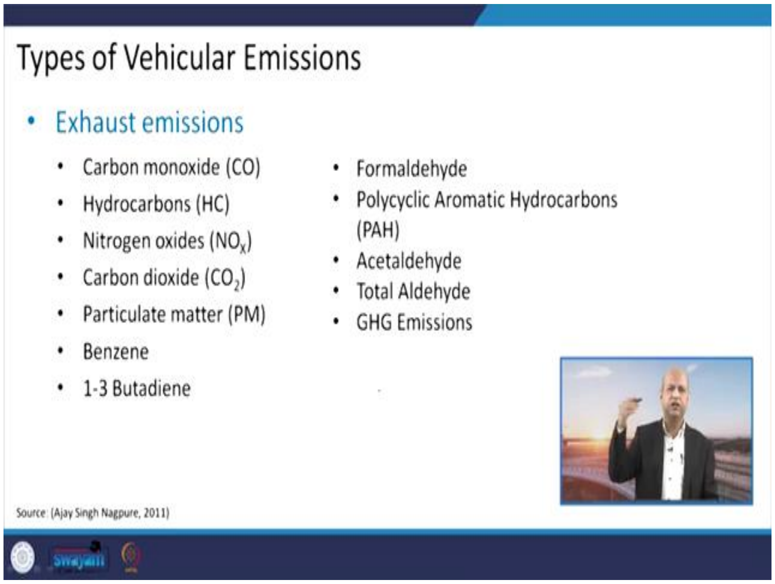
And then International Vehicle Emission IVE model, again from U.S.A. but specifically for developing countries and then we will discuss about limitations of these models which are available from different developed economies or developed countries and whether we can apply them in a developing country like India, what are the limitations, what are the challenges and then we will discuss our own model which has been developed in IIT Roorkee, that is known as Vehicular Air Pollution Inventory model VAPI. And at the last we will conclude all of these models related aspects and information.

(Refer Slide Time: 0:02:26)



So, when we talk about vehicular emissions we know that major emissions are coming from exhaust emissions that is the tailpipe emissions where fuel is burning and then it is coming as exhaust emissions, whether air pollutants or greenhouse gases, all those things. Then there are certain fugitive emissions, passive emissions, those are evaporative emissions means they come out of engine leakage of oil and those kind of things. Then other category is non-exhaust emissions that is from tyre and brakes, so abrasion related emissions or re-suspension of the dust. Those kind of are the emissions from non-exhaust sources.

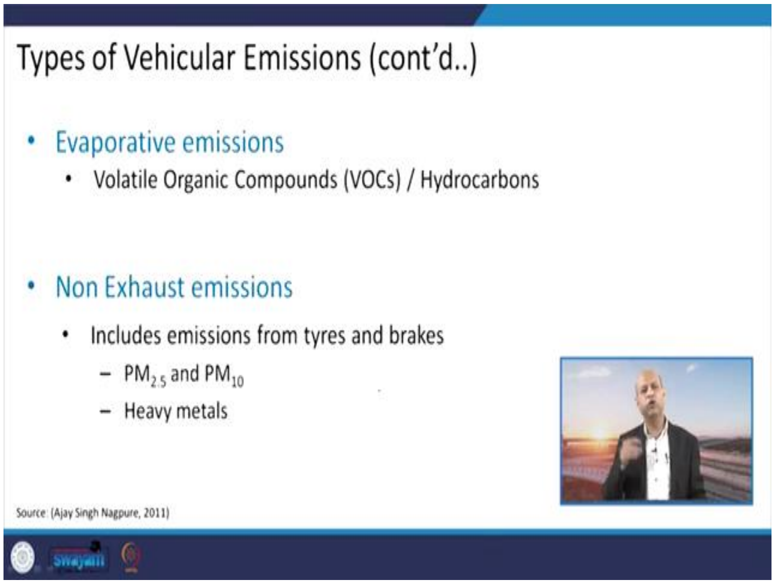
(Refer Slide Time: 0:03:11)



Well, when we see the vehicle emissions of different kind of list or categories then we see that exhaust emissions have a list of pollutants like carbon monoxide, hydrocarbons or VOCs that is volatile organic compounds or NOX that is the emissions of nitrogen compounds or oxides of nitrogen, then there is this emission of CO2 that is, every kind of burning activity really takes this CO2 out, because even when we are exhaling in our cells this kind of IC engine activity is going on, oxidation is going on, we are exhaling CO2.

So, any kind of, whether small or large combustion process that gives the emission of CO2. Then particulate matters may be there, benzene and this butadiene and formaldehyde, there may be like P-A-H of PAH that is polycyclic aromatic hydrocarbons and acetaldehyde, total aldehyde, greenhouse gas emissions and other toxic, heavy metals, those kind of things, may be there in the exhaust emissions.

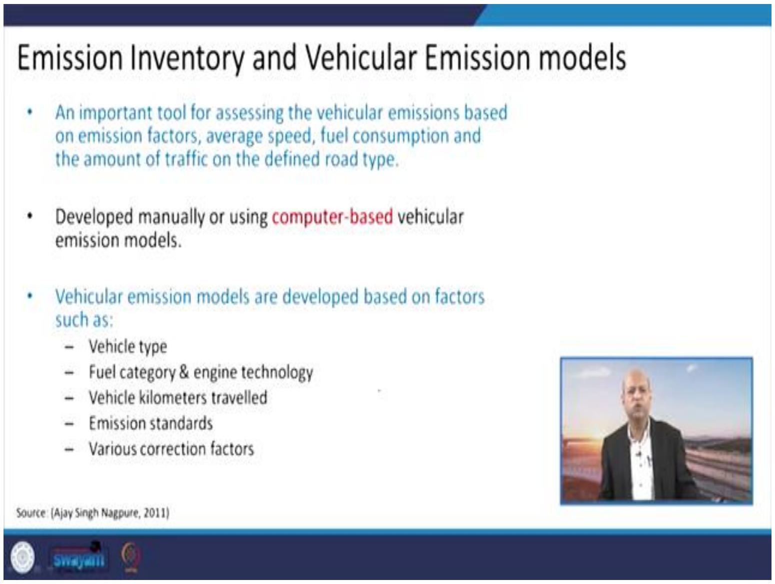
(Refer Slide Time: 0:04:23)



And if you talk about evaporative emissions, so basically those are VOCs, volatile organic compounds or hydrocarbons, they come as kind of evaporative emissions from leakages and those kind of channels.

Non-exhaust emissions like tyres and breaks, abrasions kind of activities, so very small fine particles may be there like PM 2.5 or even RSPM that is respirable suspended particulate matter, which is PM 10 and heavy metals, those kind of known exhaust emissions may be there.

(Refer Slide Time: 0:04:56)



So, what is the significance of emission inventory and how vehicular emission models help us to develop the emission inventory? So, when we want to use any dispersion model, let us say for trying to assess the air quality in an area, so what we need as input parameters, these emissions, emissions are the important input parameters.

If you do not have good emission inventory that is the values of emissions which are input parameter in dispersion modeling, you will not have good concentration estimations. So, emission inventory in that way is very important and because of that these vehicular emission models are important because they are the tools which are used for developing of emission inventories.

Then these computer based models are there and because nowadays we do computation and we can have several equations, computers calculate based on those equations very fast. So, we can write the program in computer language whether C++, Fortran or Matlab related equations, those kind of things you can use.

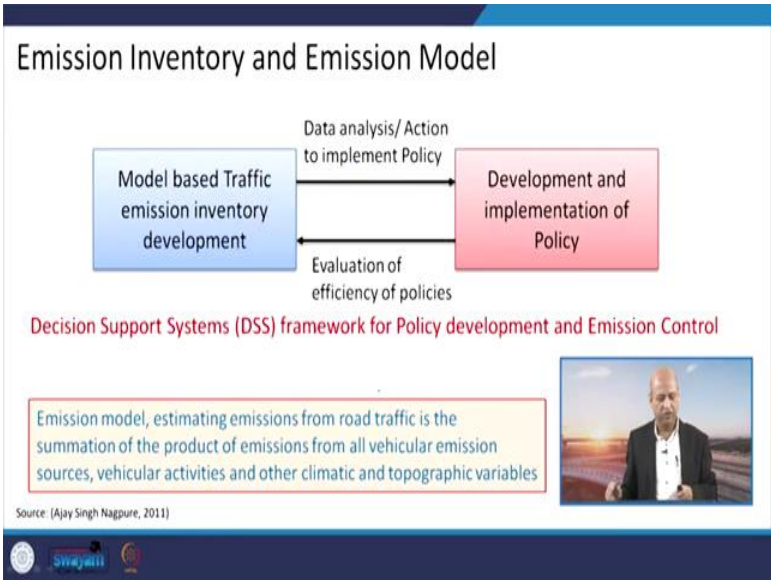
And when we develop emission inventory based on vehicular emission models, so mainly they are based on factors, emission factors, so emission factors are certain kind of emissions per unit of kilometer driven or mass unit of this fuel burned, that kind of emission factors may be there, and also there are other factors or variables like vehicle type, two wheeler emission will be different than the four wheelers.

Within four wheelers light commercial vehicle or heavy duty vehicles they will have different emissions, then fuel type also, the same car of CNG and LPG and diesel and petrol, they will have different kind of emission streams, in quantity as well as in characteristics. So, fuel category and then the engine technology, vehicle technology and these vehicle kilometer traveled, how many kilometers one vehicle travels in a day.

All those variable factors are there which influence the ultimate quantity of emissions, and then emission standards or factors, which are given like there are certain norms, EURO I, EURO II EURO III, in Bharat Stage I, Bharat Stage II in India, those kind of, like we are talking about BS VI or EURO VI kind of, from BS IV, leapfrogging. So, these norms are there, but actual emissions on the road may be different.

These norms are based on certain laboratory conditions those kind of things. Then we have correction factors based on altitude or temperature or pressure or humidity, because the same vehicle if you run on the, like in a plain city like Delhi or Meerut or any kind of city and then you go to Mussoorie or any hilly area, so the same vehicle will have different kind of emissions. So, because of those variable factors we have to do correction in emissions.

(Refer Slide Time: 0:08:07)



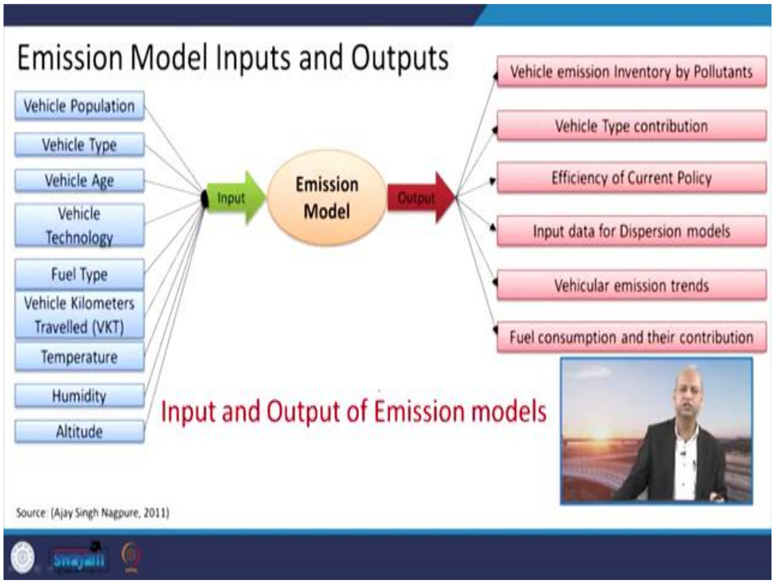
When we talk about emission inventory and models, this is very simple schematic diagram which can take you to this conceptual understanding of development of emission inventory, so the data analysis, which are needed for policy making and policy implementations, so we have to have some models which can estimate the emissions of different pollutants.

So, for the road traffic or different kind of sources may be there as we have discussed exhaust, non-exhaust and evaporative those kind of things. All things have to be combined when we want to talk about emissions from vehicles, total emissions, cumulative way, and then we have to apply correction factor so that our emission inventory or the estimated values of the emissions are nearer to the actual value.

Though we can never estimate the true emissions, because there are so many variable factors we cannot convert them into some mathematical equation, so there will be some gap, there are so many uncertainties, even same car will emit different emission streams if different people drive, because they have habits of pushing the accelerator at different frequency and then at different roads or different route you take, your vehicle will have different kind of emissions.

So, depending upon the speed, the driving cycle and the terrain, topography, everything, so many variables are there, we cannot model them or simulate them in reality but we try, and we try as much as possible so that our estimation values or estimated values are nearer to the actual one.

(Refer Slide Time: 0:09:29)



As much precise value we can estimate that will give the better estimations of the dispersion modeling, which will give concentration values, and those concentration values will give us idea what is the quality of air in an area, and how much exposure may be there. So, you can translate that concentration into health risk assessment also.

So that is why this is the series, emission models will give you the emission values, those emissions values will be used by dispersion modeling and then estimating air quality and health risk. So, that is why this emission modeling efforts have to be very, very precise, as much as possible.

And emission model inputs and outputs when we talk then like inputs are vehicular population in a city if you want to develop emission inventory, then we should know how many vehicle are there in the city, again, there will be uncertainty because registered vehicles will be there, plus although registered vehicles, quantity is given for certain year, but some people may be living in different city and they have taken that vehicle.

So that vehicle is not running on the roads of that city, but in that city other vehicles may be coming there because people from other cities may be working there, and living there. So, these kind of, and then everyday some people come in the city, some people go out, so all those kind of uncertainties are there, but still we want to estimate the vehicular population so that we can know how many vehicles are contributing to the emissions to the urban area.

Then the types of the vehicle, two wheeler, three wheeler, four wheeler, and within the two wheeler whether it is four stroke engine driven vehicle or two stroke engine, similarly in four wheeler you will have whether gasoline driven or CNG driven or diesel driven, those kind of, and vehicle age also.

As vehicle becomes old, emissions will be more. It also depends upon the maintenance also, and the usage, how you are using, you are taking care of it or not, but naturally age factor is there and that is why after certain age there are policies that the vehicles will be taken out of the road, because they are a lot of emission discharging sources or emitting sources.

Then vehicular technology as we have done, vehicular fuel type, CNG and all those, then vehicles kilometers traveled by any vehicle, so that is also to be taken, then other factors, correction factors like temperature, humidity, altitude as we have discussed all those will be the input parameters, and what we will having, the output?

We will having the output of emissions, values. So, those values can be again taken into different way like vehicle emission inventory by pollutants, means how much pollutant of CO2 or this greenhouse gas or hydrocarbon or NOX or SO2 is coming out of that or PM2.5 those kind of, means the pollutant type of emission values you will have.

Also, the vehicle type contribution, you will also have, like how much contribution is there in a particular pollutant from two wheeler, three wheeler, four wheeler, means you will be able to know different values and that will give you, that matrix will give you an idea that which area you should control first if you want to reduce certain pollutant, because you will know from which vehicle, how much amount of that pollutant is coming out.

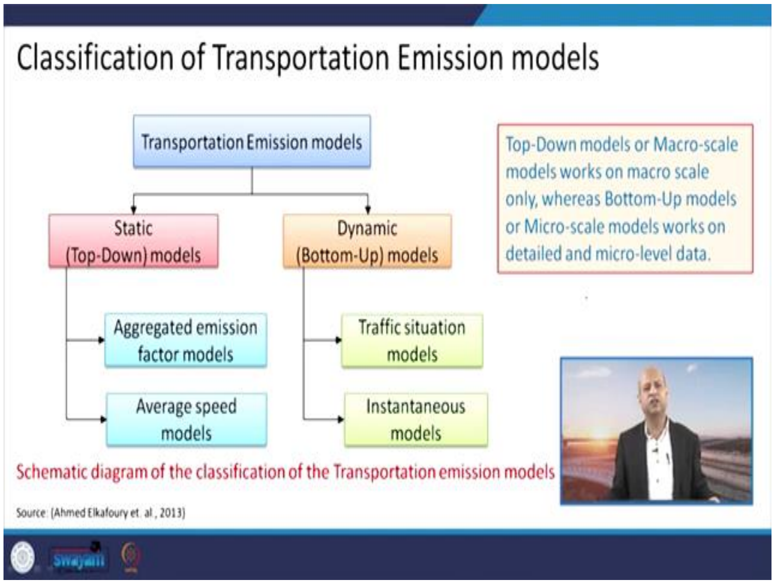
Then efficiency of the current policy, because, for example CNG has been implemented in Delhi. So, if you want to see whether, how much emission reduction is there after CNG implementation so our emission inventory will give values, before that, before CNG implementation this much of PM2.5, now this much of PM2.5. So, effectiveness of policy also evaluated based on emission inventories.

Then input data for dispersion models, as I said this value which is coming out of emission inventory models or emission models, they will be input parameters for the dispersion models. Then vehicular emission trends, means over the years how much emission is increasing on the basis of certain types of vehicles, then fuel consumption and their contribution.

So, you also know how much fuel is consumed in a city, you can validate whether that fuel consumption is reflected in the emission of a particular pollutant or not, so indirectly air quality concentration and the fuel consumption they can be surrogate parameters to give you idea whether your emission inventory is okay or not.

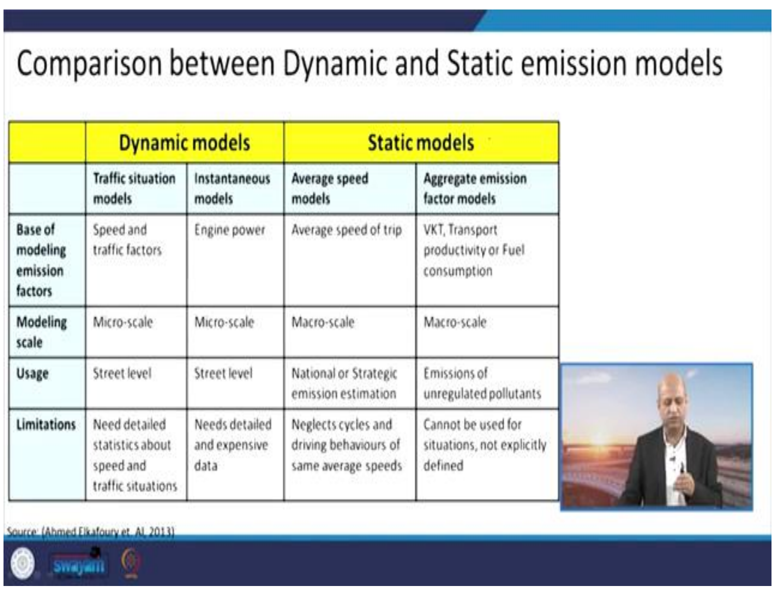
Because the trends will be there, that kind of trend or emission inventory based on pollutants and vehicle categories and also trends of air quality concentration at certain points in that city and also the fuel consumption, and as you know that from transport sector basically the dominating pollutants are NOX and CO, those kind of things. So, they can be the, kind of again, surrogate parameters to reflect whether your emission inventory is okay or not, when you compare with the air quality data.

(Refer Slide Time: 0:14:52)



When we classify the transportation emission models then we can say that one can be the static model and other dynamic model, bottom up approach or top down approach, depending upon how do we estimate, what kind of parameters we are taking and that will give you an idea.

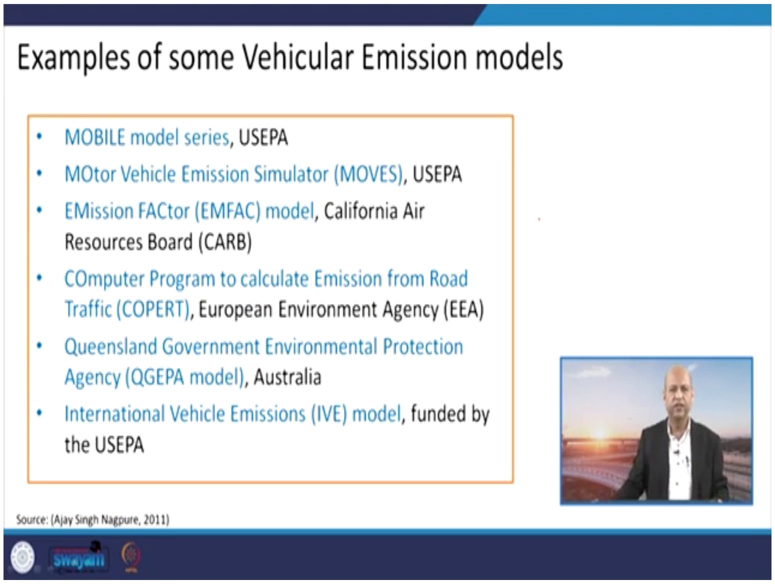
(Refer Slide Time: 0:15:12)



Then dynamic models and static models that is like traffic simulation models or instantaneous models, so it will depend on what kind of values are available basically. So, speed and traffic factors if it is available in dynamic model, then traffic simulation model is the part of that. Engine power related things, if available, then it is a part of instantaneous model.

Similarly in static, means you need to have some average speed of the trip, if you do not have detailed data so static models are like vehicle kilometer traveled, transport productivity or fuel consumption, so these metrics will give you an idea about what is the difference between dynamic models and static models, which are popular.

(Refer Slide Time: 0:15:52)



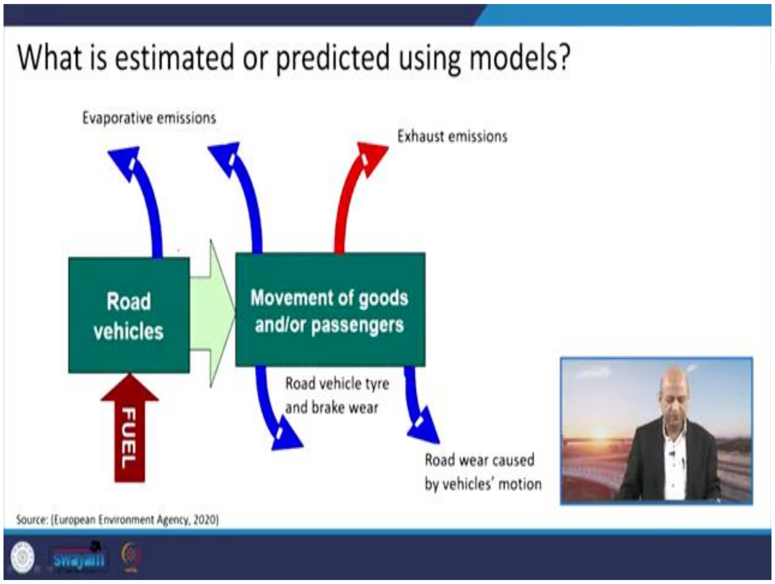
Then if we give the example or we consider the examples of some important vehicular emission models, so as initially I discussed that there are models from different countries and in developed countries they have their own models depending upon how much data is available, what kind of technology they are using in transportation sector.

So they incorporated in their equations and relationship. So, we have like MOBILE model series, means they are updated year by year. So, the series of MOBILE models are there, after that MOVES model was developed. So, these are developed by USEPA, United States Environmental Protection Agency.

But in United States there are some states which have their own models like in California, California Air Resources Board that has developed their own model which is known as emission factor model EMFAC. Then there is like in Europe the popular model is COPERT, which is computer program to calculate emission from road traffic that is abbreviated as COPERT.

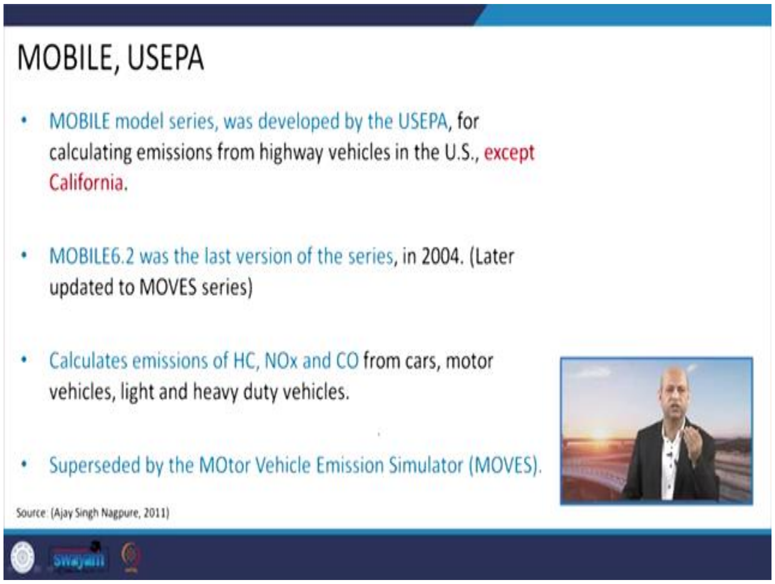
In Australia one is this Queensland Government Environmental Protection Agency model that is QGEPA model, and in USEPA another model was developed by USEPA in the U.S. that is International Vehicle Emissions, IVE model, that was particularly developed for developing countries, taking in to consideration what kind of data may be available, and this IVE model has been implemented in Pune city in India also. So, these are the different models available at present, important models, are otherwise there are other models also.

(Refer Slide Time: 0:17:39)



Then what do we do with the models? Like road vehicles, so the fuel data, evaporative emissions from the fuel and moment of the goods and passengers, so they have this exhaust emissions and road wear caused by vehicular motion so non-exhaust emissions. So, this is the picture which we already know about.

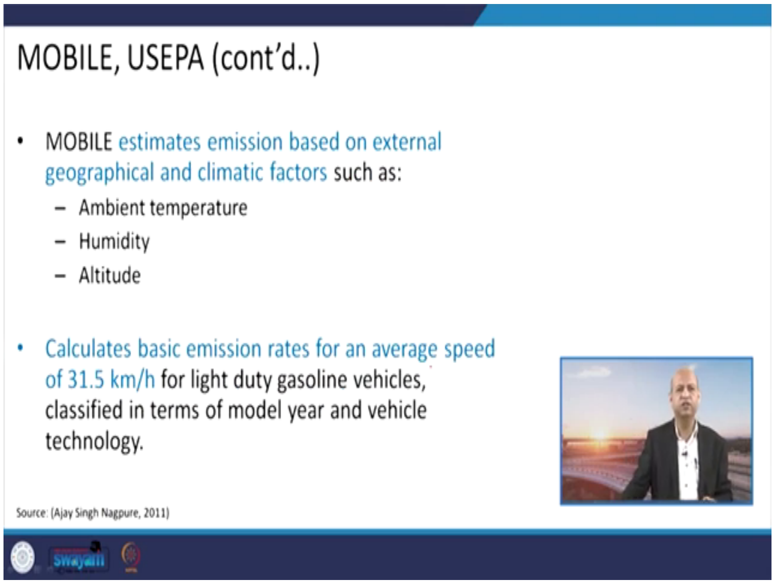
(Refer Slide Time: 0:18:00)



Now we discuss in brief about these models which have listed like MOBILE in USEPA. So, this is the series which was developed by USEPA and they are using like different kind of highways related data, and then in 2004, they had this 6.2 series, MOBILE 6.2, later it was updated as MOVES, means they completely changed the strategy and new model strategy or new model framework was developed which is known as the MOVES.

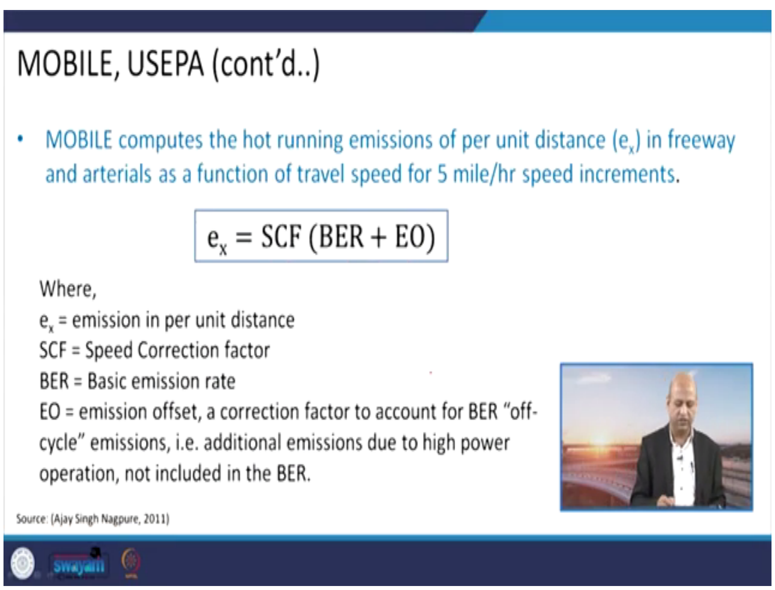
This MOBILE model can calculate different pollutants like hydrocarbons, NOX and CO, these are basically the dominating pollutants from transportation sector, so their focus is more on those emissions from cars, motor vehicles or light and heavy duty vehicles for transportation of goods, et cetera, and it was suspended and then superseded by MOVES, the new model.

(Refer Slide Time: 0:18:59)



And there are other features of the MOBILE model basically, like it also consider these correction factors which are geographical and climatic factors related to temperature, humidity, altitude and so, and the basic emission rates for an average speed of 31.5 kilometer per hour, this has been based on some service. So, that has been used for these model calculations.

(Refer Slide Time: 0:19:25)

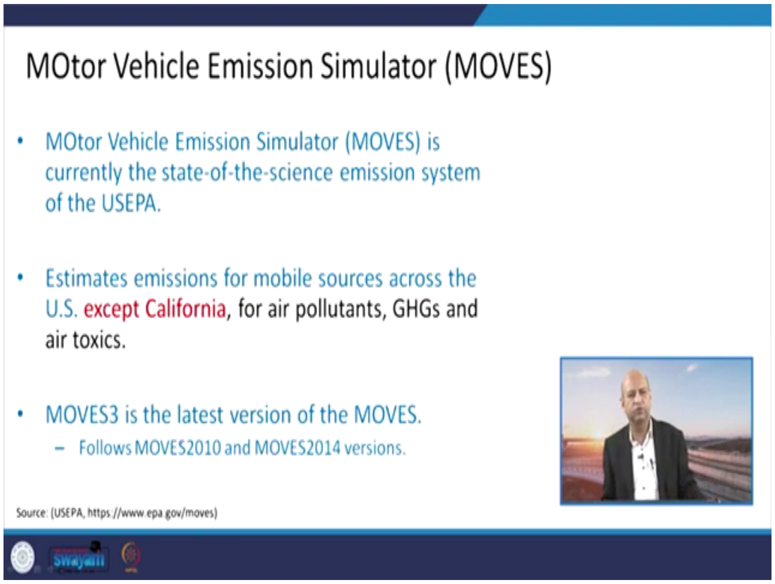


And this is the basic equation which you can see

$$e_x = SCF\ (BER + EO)$$

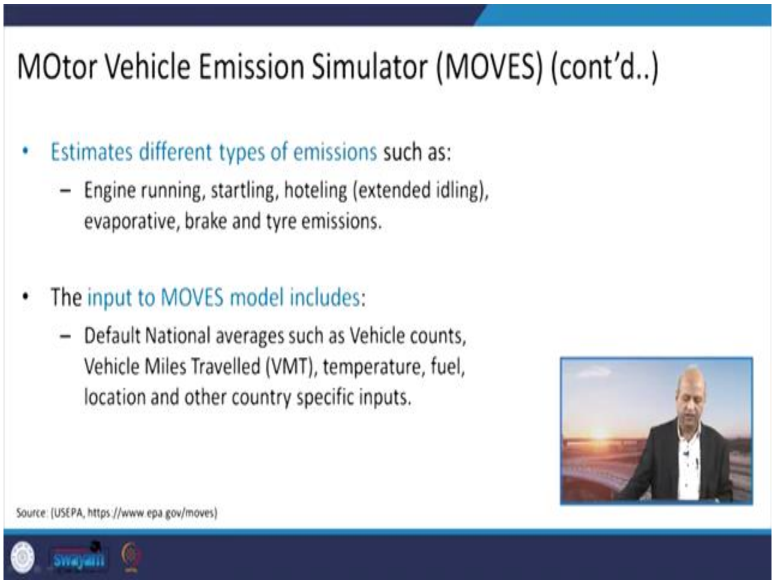
like these emissions in per unit distance and then this SCF, this is the speed correction factor, multiplied by BER plus EO. BER is basic emission rate and then EO is emission offset because of certain factors, which are taken into account.

(Refer Slide Time: 0:19:47)



Then we talk about MOVES model, Motor Vehicle Emission Simulator. So, this is the model which is used by several states of U.S.A except in California, and this can estimate pollutants of different nature and greenhouse gases, as well as toxic elements also which are emitted from transportation sector.

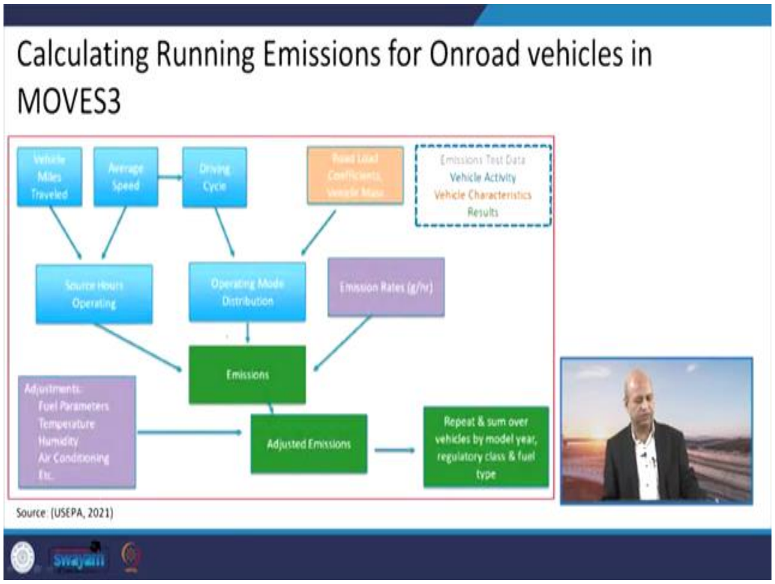
(Refer Slide Time: 0:20:11)



And like engine running, then startling, hoteling that is extended, idling condition, evaporative, break, tyre emissions so exhaustive, means it is a very kind of detailed modeling effort which can give you all kind of pollutant emissions from different activities related to transportation sector and then the input values which are needed for this are mainly vehicle counts and then the vehicle miles traveled VMT, temperature, fuel, location and other country specific inputs.

Because they will influence the driving patterns, topographical related features, temperature, humidity all those things will be depending upon those locations, so that is also one important input parameter.

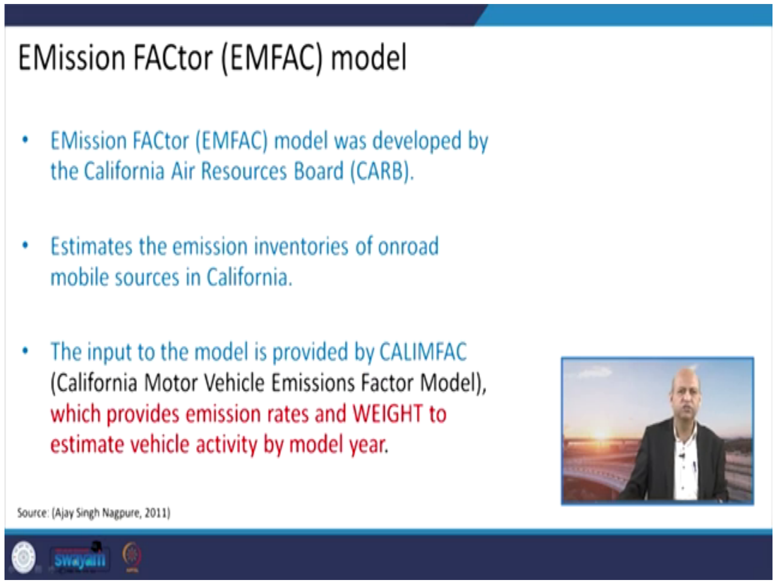
(Refer Slide Time: 0:20:58)



This is the flow chart which gives us an idea about this running, calculating the running emissions for on road vehicles by MOVES 3 version. So, as I said vehicle miles traveled then average speed, driving cycle, so the source, hours operating then operating this distribution, emission rates, all those ultimately they give some emissions and those are then adjustment by correction factors.

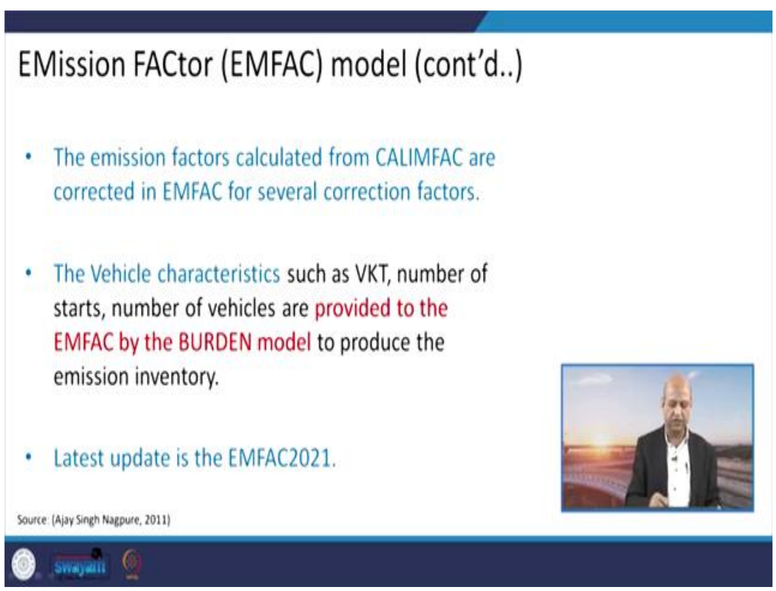
So, the adjusted emissions or corrected emissions are there which gives some values and this is repeated for all kind of pollutants and later on clubbed together so that cumulative emissions we can estimate from different categories of vehicle.

(Refer Slide Time: 0:21:43)



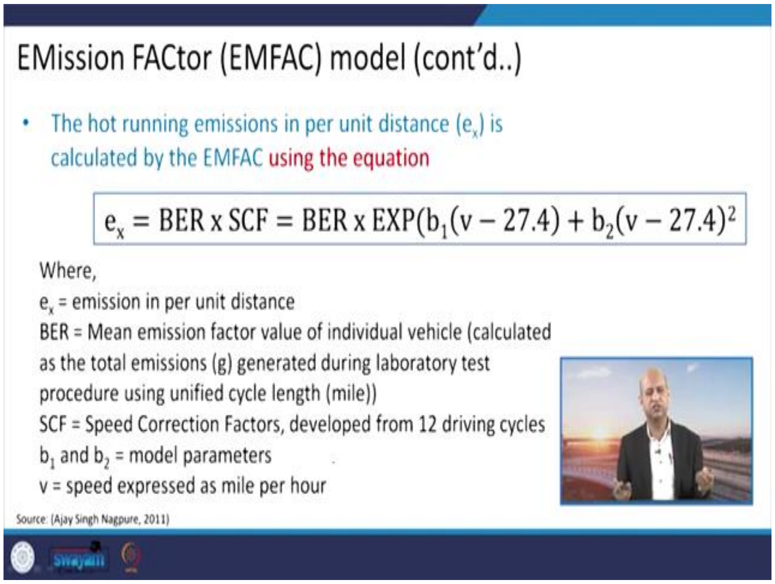
Then there is this another model which is known as EMFAC model or emission factor model. So, this is basically used for again on road mobile sources and the input values are provided by this CALIMFAC California motor vehicle emissions factors. So, this model is basically developed by California Air Resources Board so in California this is the model which is used basically, rather than other models which are available. So, this provides the estimations for the particular state.

(Refer Slide Time: 0:22:25)



And it can have some input parameters like vehicle characteristics, VKT, ETC., number of starts, number of vehicles are provided by another model which estimate the number of vehicle, city wise and then this latest version of this model is 2021, so they regularly update the modeling framework basically.

(Refer Slide Time: 0:22:48)

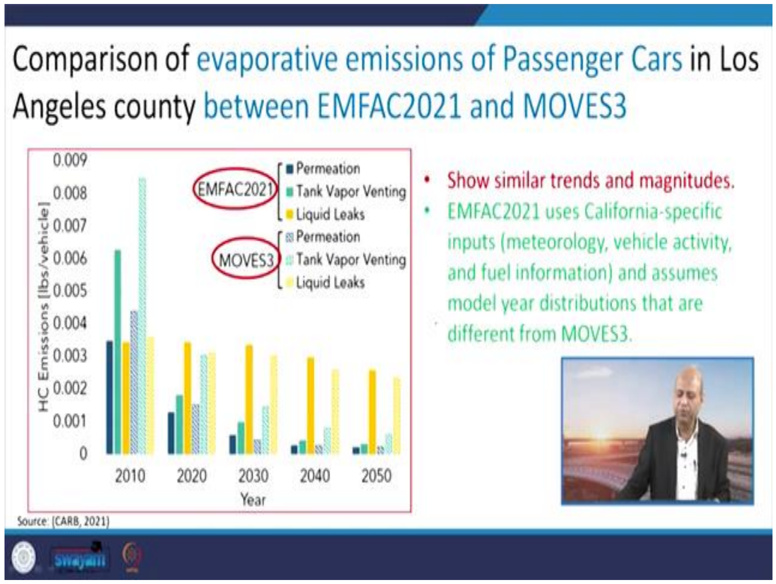


Then if we want to see the basic equation,

$$e_x = BER \times SCF = BER \times EXP(b1(v - 27.4) + (v - 27.4)2$$

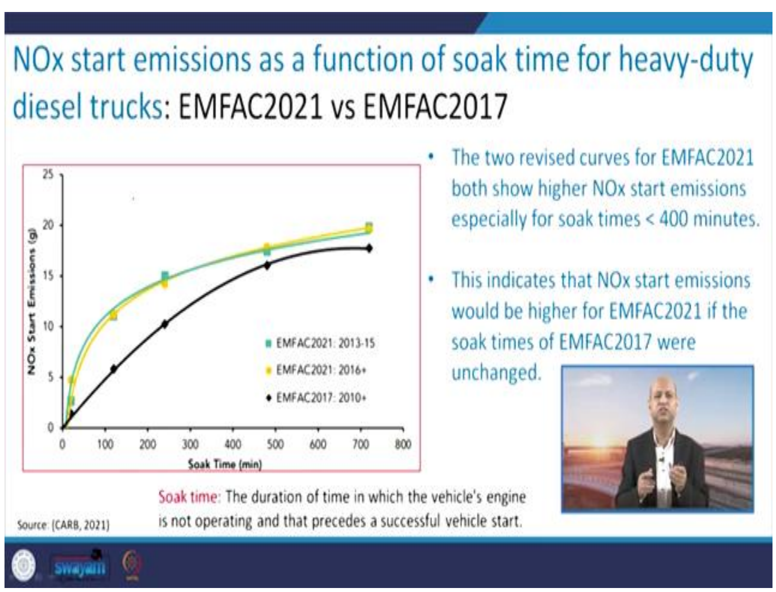
it is again similar as we have seen earlier, so BER that is the basic emission rate which is multiplied by this correction factor, speed correction factors, 12 driving cycles, different speeds, so they give the values, so this is expanded, then these are the constant parameters, B1, B2 model parameters. Then speed, expressed as miles per hour is there. Certain constant values are there. So, ultimately this emission in per unit distance we can calculate for a particular vehicle and particular pollutant.

(Refer Slide Time: 0:23:24)



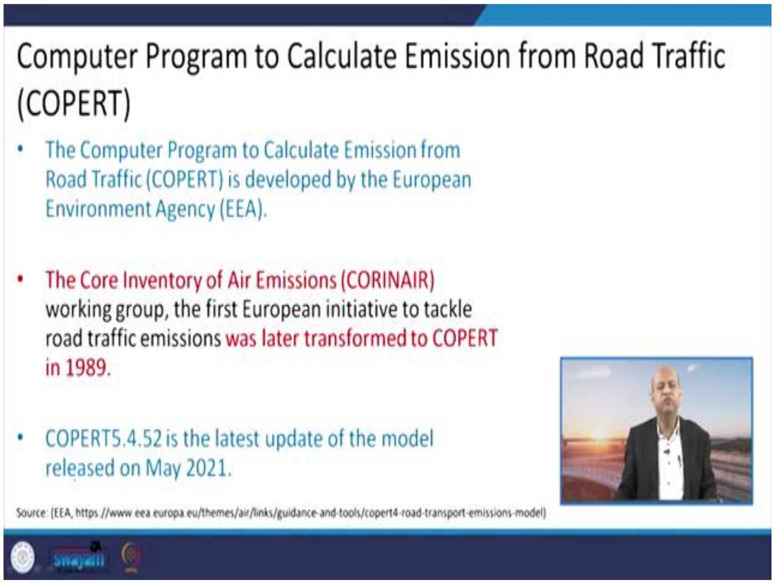
If you want to compare like how much these correctness or what is, whether it is estimated lower values or higher values, if we use like MOVES and EMFAC, so this is one interesting example basically you see, these liquid leaks, like this one, tank vapors so EFMAC these values, so most of the values estimated on higher side from the EFMAC and the moves estimations are on lower side and that depends again because if dedicated model is there for a particular state and if they have exhaustive data set their emissions may be better. But if other modeling technique is there and those data is not up to the mark then values may differ.

(Refer Slide Time: 0:24:11)



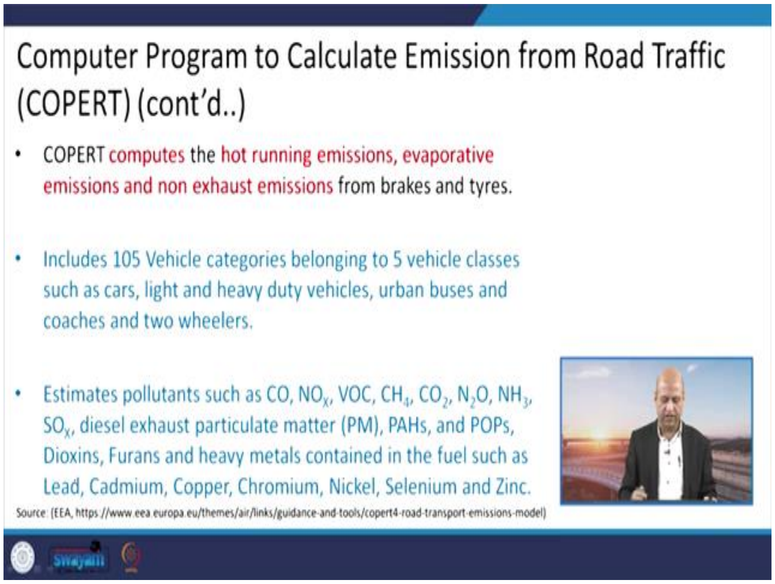
So that, otherwise trend is same, but values are a little bit different, and if we compare like the new version of the EFMAC 2021, with the 2017, so again 2017 models and these different models have different kind of trends, so because of those value's variations you have the better inventory for values of the traffic related parameters so your estimations are little bit different, but the trend is the same as you can see.

(Refer Slide Time: 0:24:45)



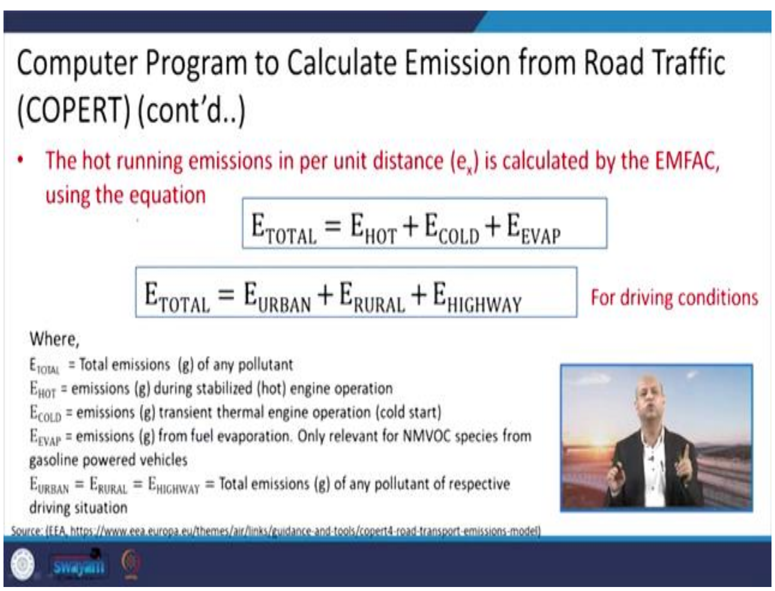
Then we discuss about this COPERT model which is quite popular in European countries, this is a computer program to calculate emissions from road traffic.

(Refer Slide Time: 0:25:05)



So in Europe they are using it and this is again very data intensive model and that gives a lot of streams for emission estimates, like you can see CO, NOX, VOC, methane, CO2, N2O, NH3, it is a whole, all kind of range of pollutants, it can be used for estimating this hot running emissions as well as evaporative emissions and exhaust emissions. All kind of emissions can be estimated, so this is very detailed model and wonderful model basically, but for European countries.

(Refer Slide Time: 0:25:28)



But some countries use it when they do not have their own modeling efforts, and we will see why did we develop our own model because of some limitations, which we will see later on. These are the equations which are basically used for this COPERT model,

$$E_{Total} = E_{Hot} + E_{Cold} + E_{Evap}$$

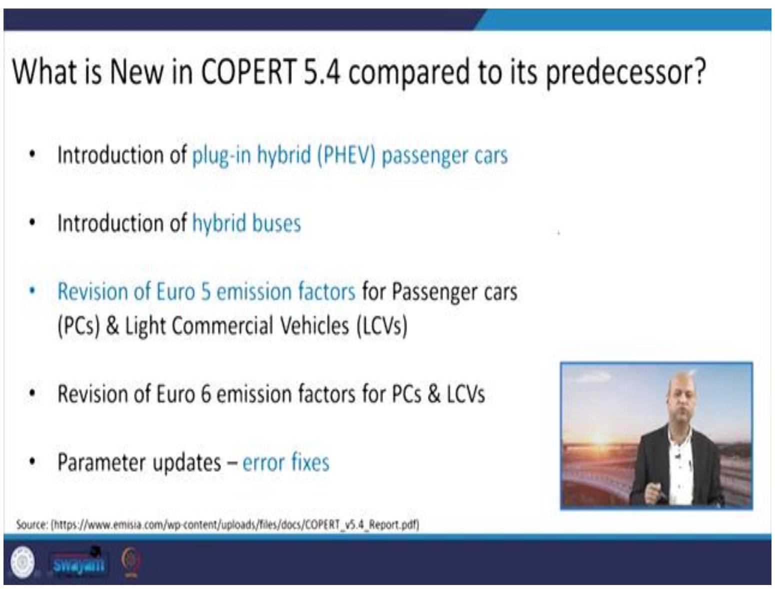
so these total emissions in like, Hot means emission during stabilized hot engine operation when it is running, cold means when you are starting, E evaporation means evaporative models.

So, those emissions are there which are clubbed together, so the total emission is calculated. So, total emissions then you can also have in different areas like urban area, rural area on highway, so that way you can have the regional emission inventory basically for different driving conditions.

$$E_{Total} = E_{Urban} + E_{Rural} + E_{Highway}$$

So, this model in that way is a versatile model I would say.

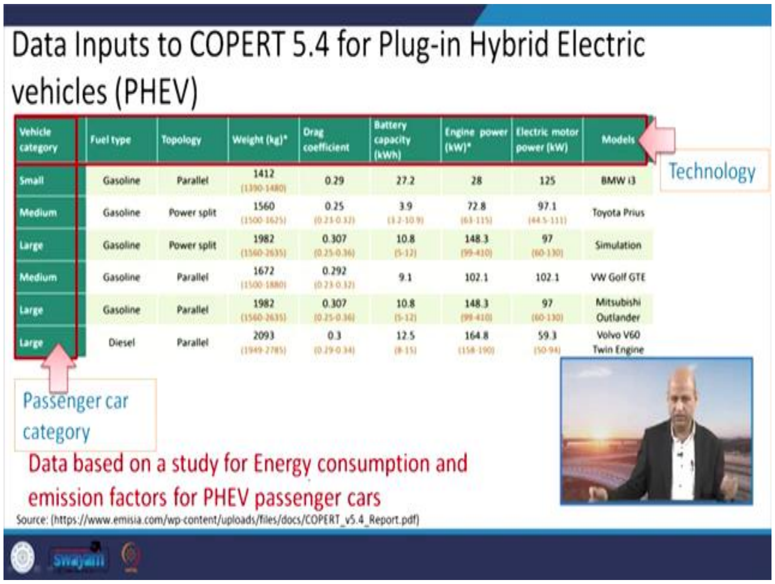
(Refer Slide Time: 0:26:23)



And now a new version of the COPERT 5.4, this has also included the relevant information for plug-in hybrid vehicles, passenger cars and hybrid buses, because in Europe this is being popular as you can see in different data. So, this revision of EURO V emission factors have been incorporated, earlier EURO IV was there, and for light and commercial vehicles, passenger cars all these factors have been incorporated.

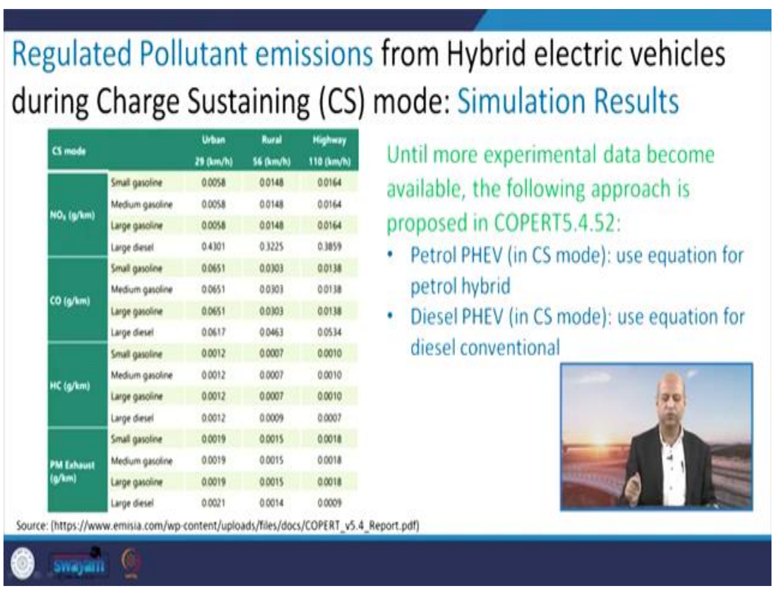
EURO VI emissions factors for these PHEVs that is plug-in hybrid vehicles and LCVs light commercial vehicles are available, and parameter's update means, some errors because of old parameters so that fixing error's possibility is also there in this model that is incorporated in there.

(Refer Slide Time: 0:27:10)



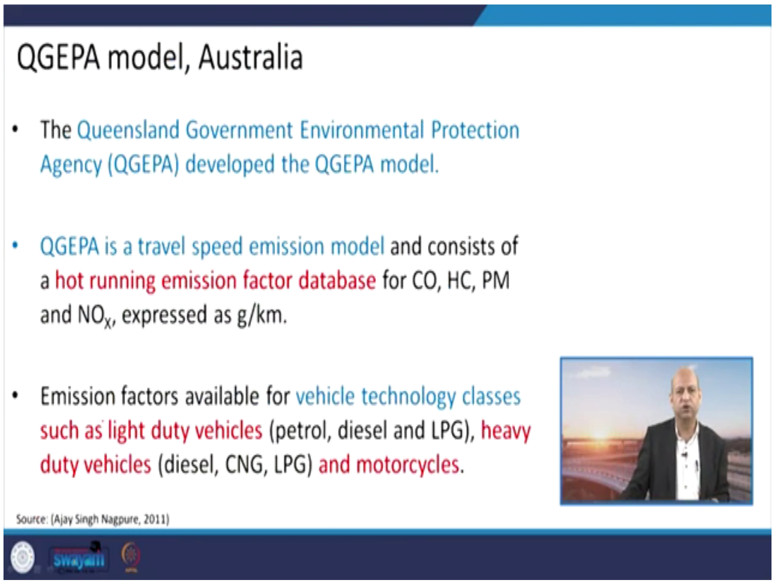
When you see this metric or table you can see the data inputs for this new version of the COPERT for plug-in hybrid electric, so fuel type like gasoline or diesel, topology where the parallel power split, parallel, those kind of thing, how much weight is there, drag coefficient, battery capacity, because in hybrid and these plug-in hybrid electric vehicles we have battery, and engine power, electric motor power, models. All these things basically influence the emissions, because emissions factors will vary accordingly, so all these are there in the model.

(Refer Slide Time: 0:27:47)



Also, like regulated pollutant emissions for hybrid electric vehicles during the charge sustaining mode, so that is also given, for urban area, for rural area, for highway, NOX, CO, hydrocarbons, particulate matter, so where your vehicle is running, whether in rural area, urban area or on express ways, so accordingly the speed and their emission factors will also vary.

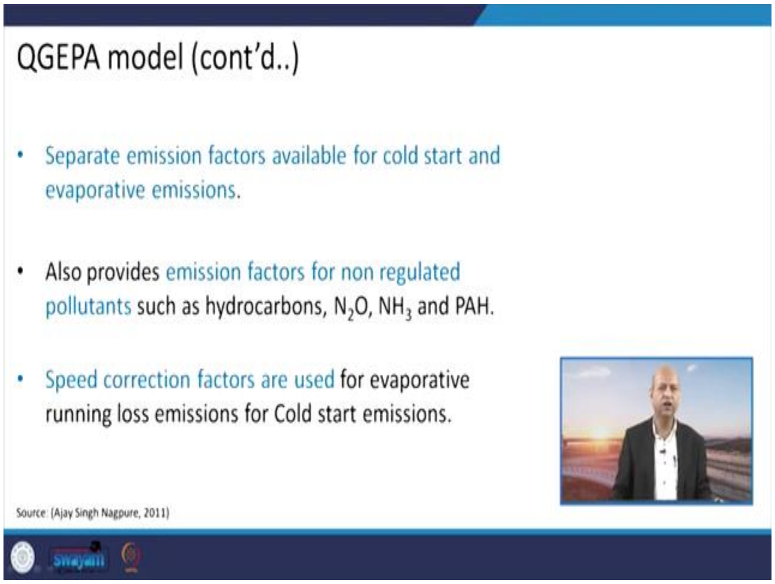
(Refer Slide Time: 0:28:15)



Next model is this QGEPA model from Australia, so that is this Queensland Government Environmental Protection Agency developed this particular model and this can be used for hot running emission factor database and that can include like CO, hydrocarbons, particulate matter and NOX, because they are, most of the dominating emissions as you know in gram per kilometer or per kilometer driven, so how much emission will be there.

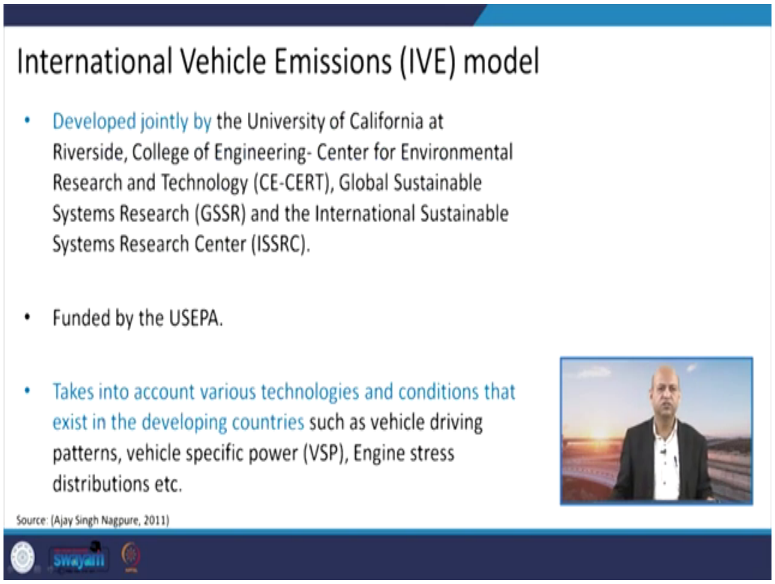
So, emission factors which are available for different kind of technology or vehicle class, such as light duty vehicles or CNG related or petrol related heavy duty vehicles, so all those different kind of motorcycles, all emission factors are there which are part of this QGEPA model.

(Refer Slide Time: 0:29:03)



And separate emission factors are available for different states like cold start or evaporative emissions, and then it can also provide emission factors for non-regulated pollutants like hydrocarbons, N2O, ammonia, PAH, they do not have some values or specified values, how much emission should be regulated but they can estimate and then speed correction factors can also be used for better estimation. So, these are the particular features of this model.

(Refer Slide Time: 0:29:34)

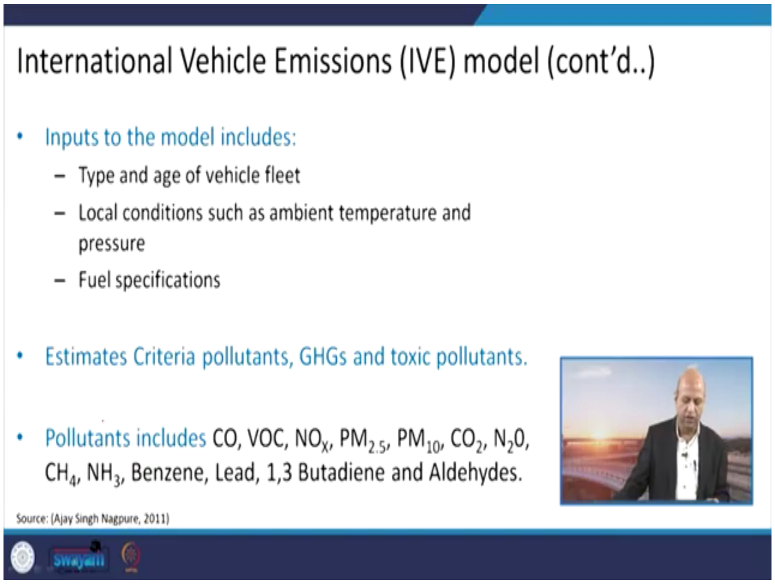


Next is this international vehicle emission model, developed by USEPA, and that is developed by the joint efforts of University of California and the College of Engineering, Center for

Environmental Research and Technology, Global Sustainable Systems Research Center and International Sustainable System's Research Center, all these centers have joined hand and developed this model for developing countries basically.

But it was funded by USEPA because they wanted to know what is the emission kind of trends and the conditions in different cities of developing countries, and it can take in to account like whatever technology different countries are using, but this is data extensive or intensive basically.

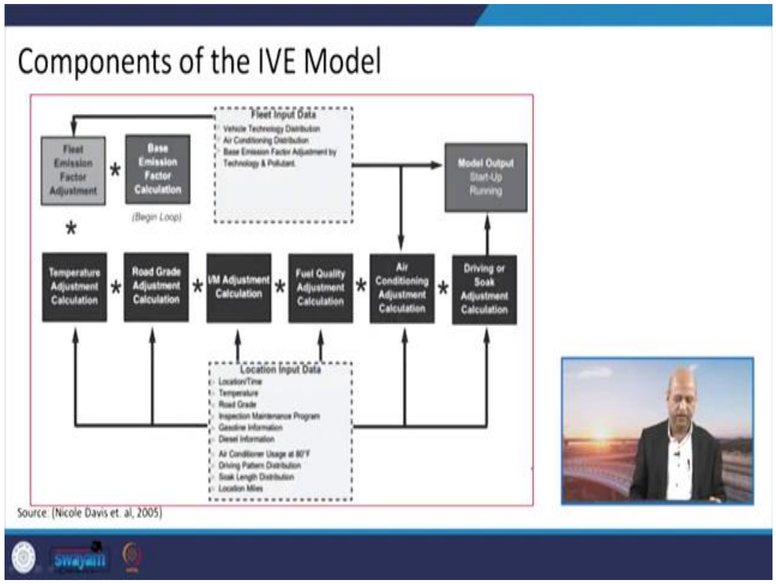
(Refer Slide Time: 0:30:22)



Inputs like type and age of the vehicle in this particular model, local conditions again temperature pressure, etc., fuel specifications, the proper fuel specifications must be there, otherwise estimations will not be right, estimation's criteria like greenhouse gases or toxic pollutants or criteria pollutants.

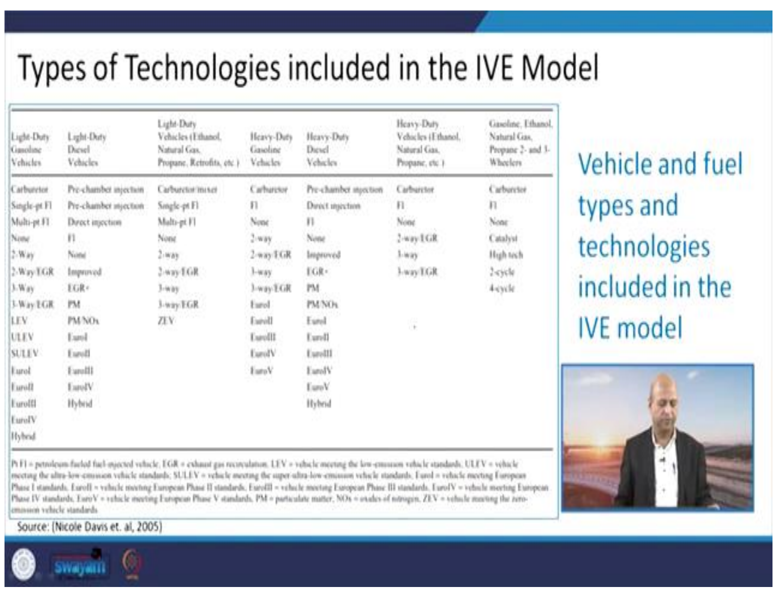
All those emissions can be calculated and a series of, means it is a good number of pollutants which can be estimated from IVE model, like CO, VOC, NOX, PM2.5, PM10, carbon dioxide, nitrous oxide, methane, ammonia, benzene, lead, all those, means, as in MOVES you have seen.

(Refer Slide Time: 0:31:05)



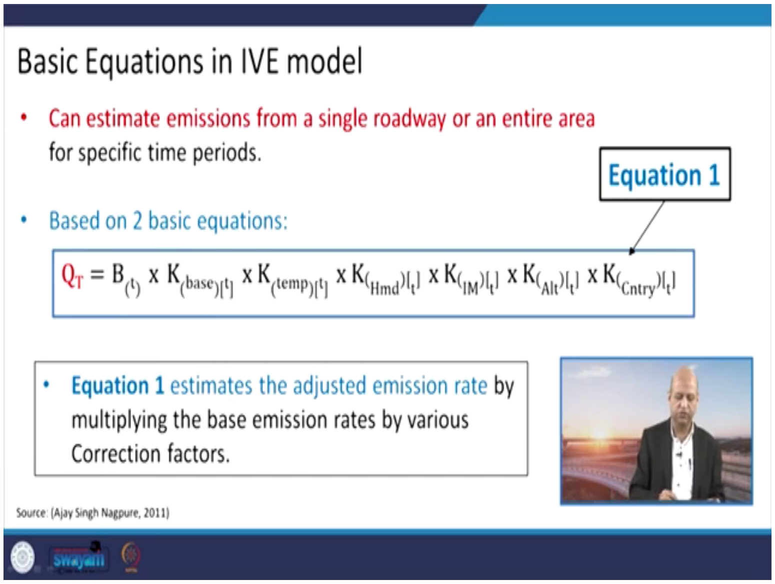
And this is basically the framework or the flowchart of the IVE model. So, you can see these input data like vehicle technology distribution, air conditioning distribution, all those things, and those correction factors are used and ultimately emission estimation is done.

(Refer Slide Time: 0:31:26)



Types of technologies included in IVE model is again quite detailed like carburetor or single petroleum fuel injection technology is there or two way or three way, catalytic converters, those kind of thing, then light duty diesel vehicle or light duty vehicles running from ethanol and natural gas or propane, those kind of, heavy duty gasoline vehicles, heavy duty diesel vehicles and these kind of different technologies. So, it is again have, so much information is needed if you want to estimate in a good way.

(Refer Slide Time: 0:32:00)

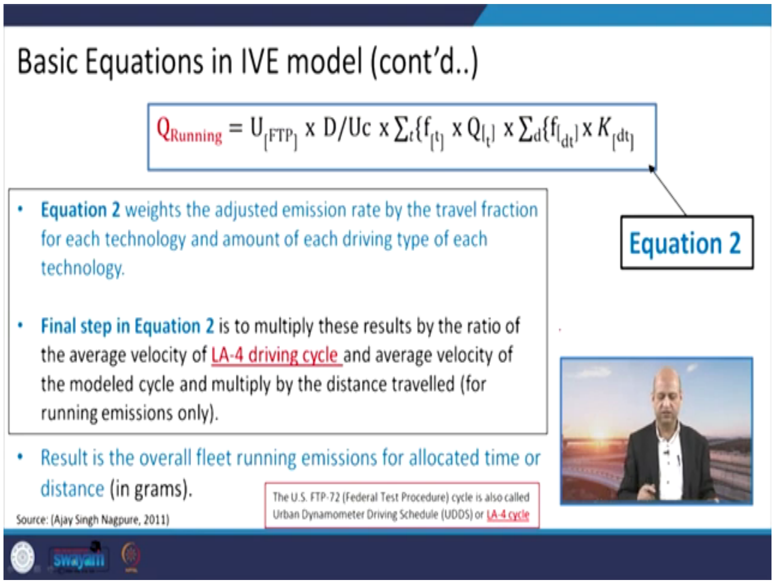


And that is the basic equation which is again similar. Only expression is different.

$$Q_T = B_{(t)} \times K_{(base)(t)} \times K_{(temp)(t)} \times K_{(Hmd)(t)} \times K_{(IM)(t)} \times K_{(Alt)(t)} \times K_{(Cntry)(t)}$$

So, the base emission correction factor then temperature related, humidity and the maintenance related, all those correction factors are applied, so that estimations are better.

(Refer Slide Time: 0:32:16)

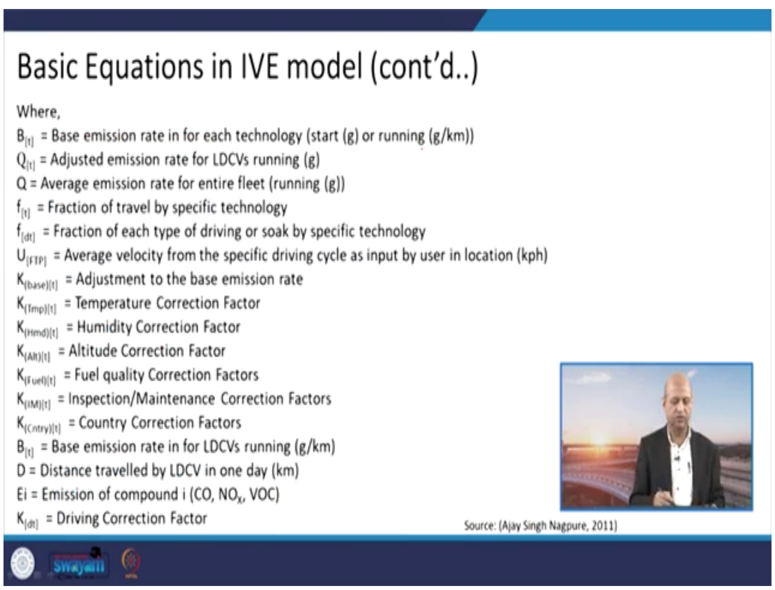


And this is again the basic model equation, the summation is there for a particular running phase and particular pollutant.

$$Q_{Running} = U_{[FTP]} \times D/U_c \times \sum_t \{f_{[t]} \times Q_{[t]} \times \sum_d \{f_{[dt]} \times K_{[dt]}$$

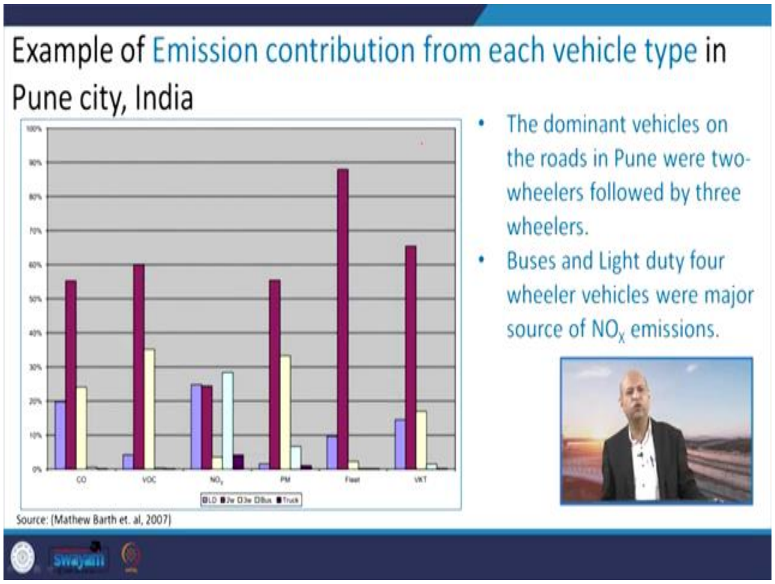
So, different driving cycles can also be included in this, so that you can change the patterns and you can have different values.

(Refer Slide Time: 0:32:34)



These are the nomenclature's name of those equations which we have just seen.

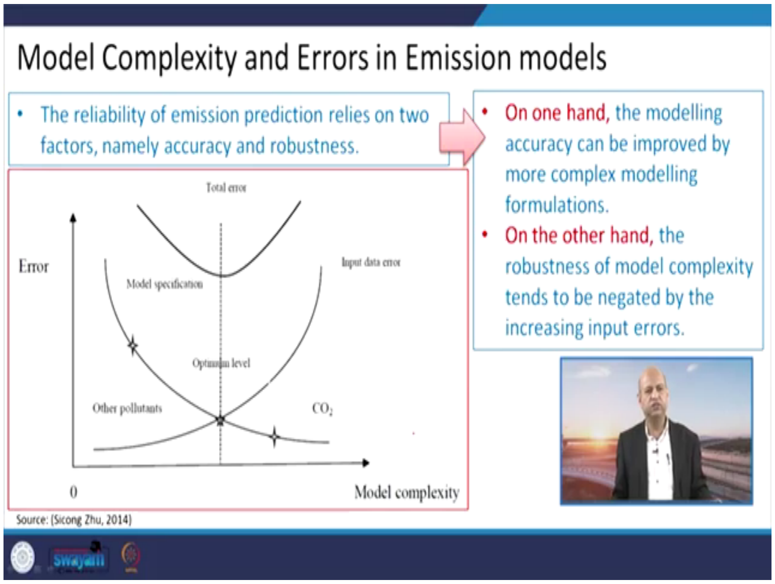
(Refer Slide Time: 0:32:40)



If we see this example of IVE model application in Pune city, so they estimated like this CO, VOC, etc., from two wheeler or buses and trucks and you can see like buses and light duty four wheelers they were major source of NOX emissions here you can see, this one and this one.

Otherwise, two wheelers are dominating in other pollutants whether it is VOCs or CO and fleet was, also number of vehicles is also maximum in case of two wheelers, and vehicle kilometer traveled by two wheelers is much more than other categories like buses or three wheelers.

(Refer Slide Time: 0:33:23)

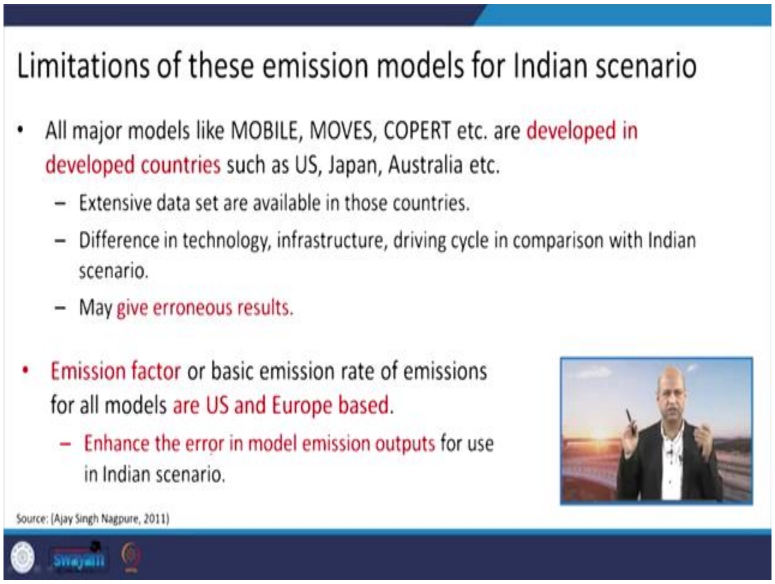


When we see the model complexity and the errors which can be because of this complexity of the model and this trade off whether, how much error we can afford and how much complex model we can use, so when you go for complex models basically you are having more and more parameters into calculation. So, your estimations may be better, but it becomes more complex and when model is more complex then chances of error are also more, because input parameters have some variability.

So that is why we want to strike the balance or optimization. You can see this model specifications when it goes, so errors are there, at certain point it reduces, but input data error related increases. So, model related specifications as vast as possible. So, model related error will be less but the input data related error will be more and that again will refute or fail our efforts basically.

So, the total error of this is more here and this is also more, so you do not need to be more complex and you do not need to be more erroneous estimations, better you can come to this optimization at this particular place, so that kind of balance can be there and we can reach to this particular conclusion.

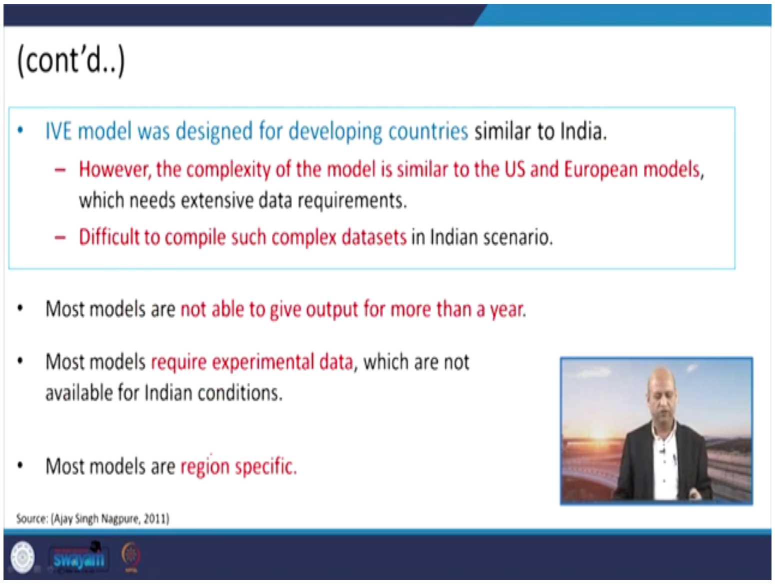
(Refer Slide Time: 0:34:44)

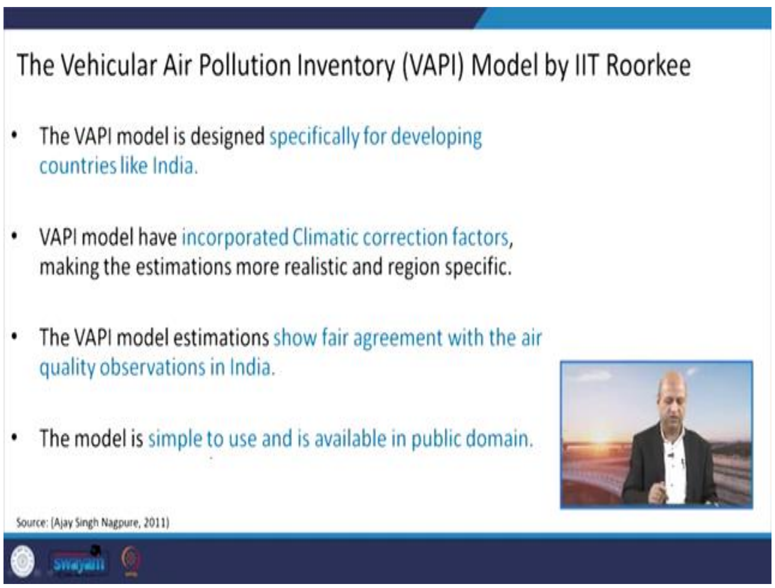


If we talk about limitations of these emissions models which we have discussed in Indian scenario or Indian context then basically what happens that in our cities if we want to estimate emissions, we do not have much reliable data and also the data available is not for every kind of input parameters.

That is the biggest limitations these complex models have, because unless you have these detailed data set for input parameters your emission's inventory will not be the right one. So, that is why this motivation was there and in IIT Roorkee we developed another model for Indian context and that is known as the VAPI model which we will discuss here.

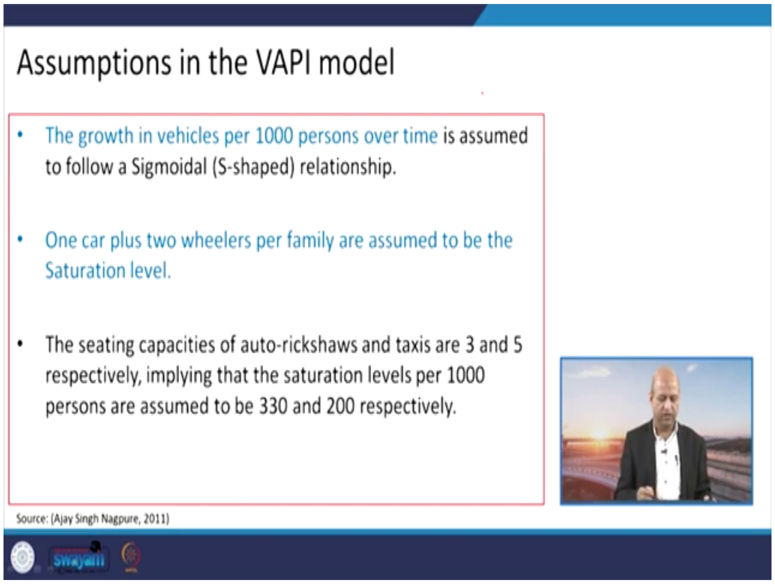
(Refer Slide Time: 0:35:26)





This is the VAPI model which was developed in IIT Roorkee and this is catering the requirements of the Indian conditions basically, so specifically for our cities we have taken in to account what information is available, also there are issues for certain models only for one year estimation was possible, and other limitations were there. But best practices of those models or best features have been incorporated and optimization have been achieved so that we can have good estimations of these pollutant emissions in Indian cities.

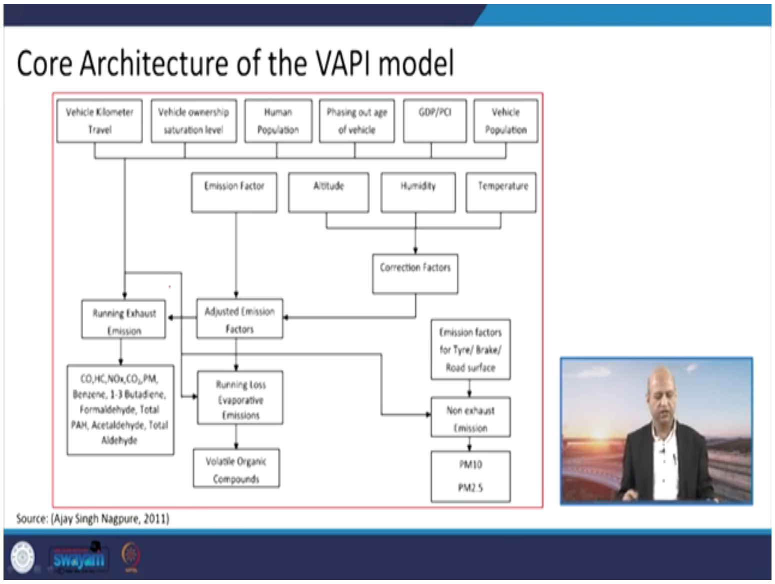
(Refer Slide Time: 0:36:06)



And these are the assumptions which we are taking into this model framework like the growth of population of the vehicles, per 1,000 persons, is assumed and it followed this sigmoidal, S shaped relationship, so that we can estimate at what stage the saturation value will be there. Then one car plus two wheelers per family was assumed that this is kind of saturation value, average, means not other people will go for more cars.

Although some families may have two cars, but some families do not have car, so this is the average value, which we agreed based on expert's judgment as well as the values which we got from literature, then the seating capacities are also depending upon whether it is a three wheeler or the cars, et cetera. So, accordingly, the number of persons using that vehicle have been calculated so that the passenger related journey can be estimated.

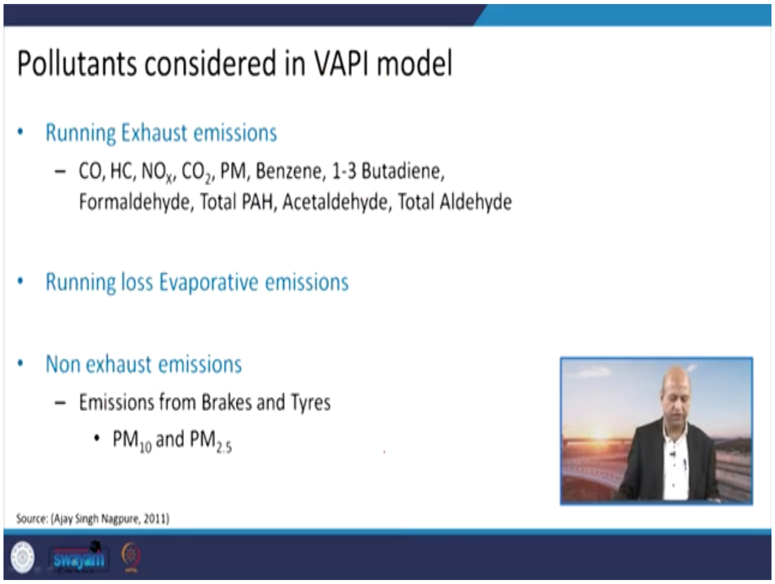
(Refer Slide Time: 0:37:10)



This is the core, fundamental architecture of the VAPI model, so the vehicle kilometer travel, vehicle ownership saturation level and human population because that will influence the purchasing power, purchasing, phasing out age of the vehicle, at what age it will be discarded from the road and then this GDP and this per capita income, PCI, and vehicle population, all these things were taken into account for developing this model.

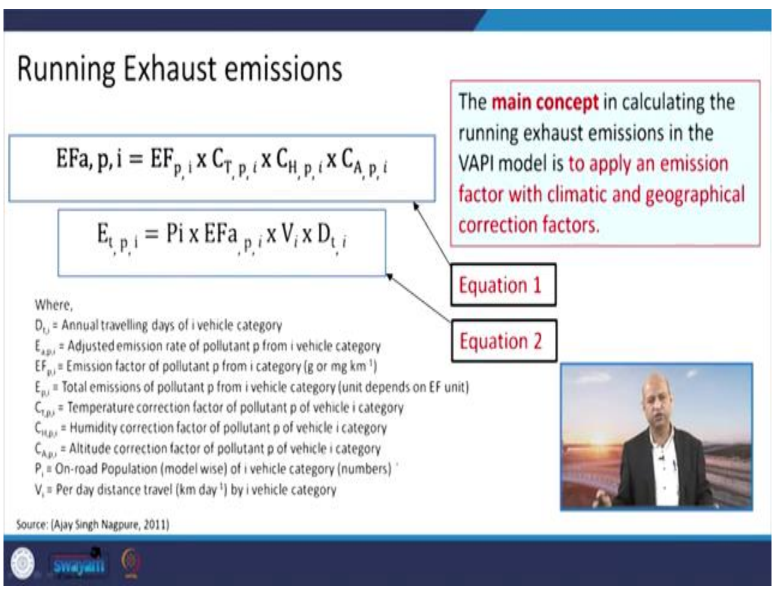
Then emission factor, altitude, humidity, temperature related correction factors. So, for different kind of like, if we go for running exhaust emissions we have taken emission estimates for CO, hydrocarbons, NOX, CO2, this particulate matter, total PH, all those, and then these adjusting factors were used and for non-exhaust emissions we just took PM10 and PM2.5 because for heavy metals, etc., there were some issues, but later on it was also added.

(Refer Slide Time: 0:38:14)



Pollutants considered for VAPI model as I just given you this list, all these pollutants were used for VAPI model and it is in public domain, that model is available you can also use.

(Refer Slide Time: 0:38:27)



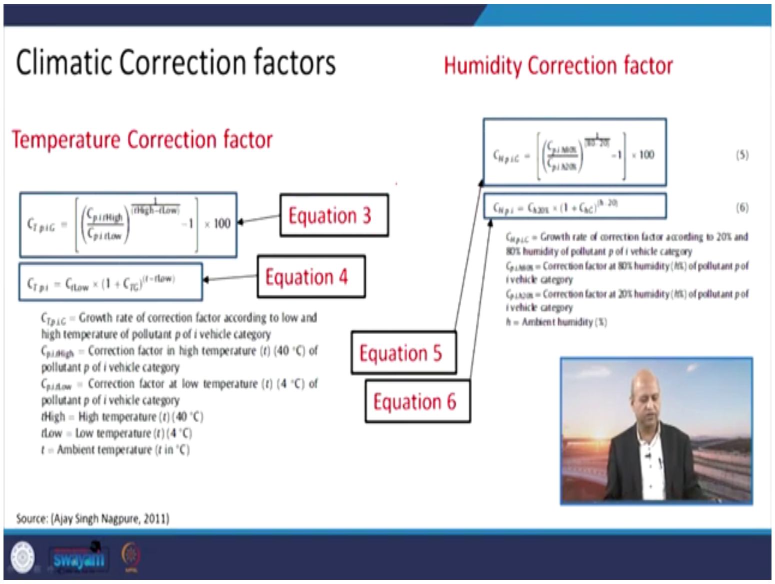
These are the basic equations for exhaust emissions,

$$EF_{a,p,i} = EF_{p,i} \times CT_{p,i} \times C_{H,p,i} \times C_{A,p,i}$$

$$E_{t,p,i} = PI \times EF_{a,p,i} \times V_i \times D_{t,i}$$

so emission factors are there, and then correction factors are there, so they are multiplied to calculate the real estimations.

(Refer Slide Time: 0:38:37)



Climate correction factors are given in these equations,

$$C_{T,p,i,G} = [(\frac{C_{p,i,tHigh}}{C_{p,i,tLow}})^{\frac{1}{(tHigh-tLow)}} - 1] \times 100$$

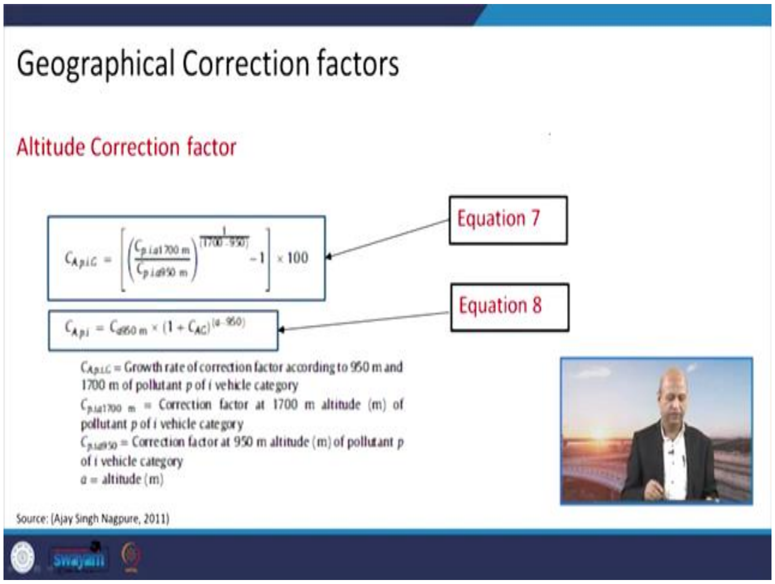
$$C_{T,p,i,G} = C_{tLow} \times (1 + C_{TG})^{(t-tLow)}$$

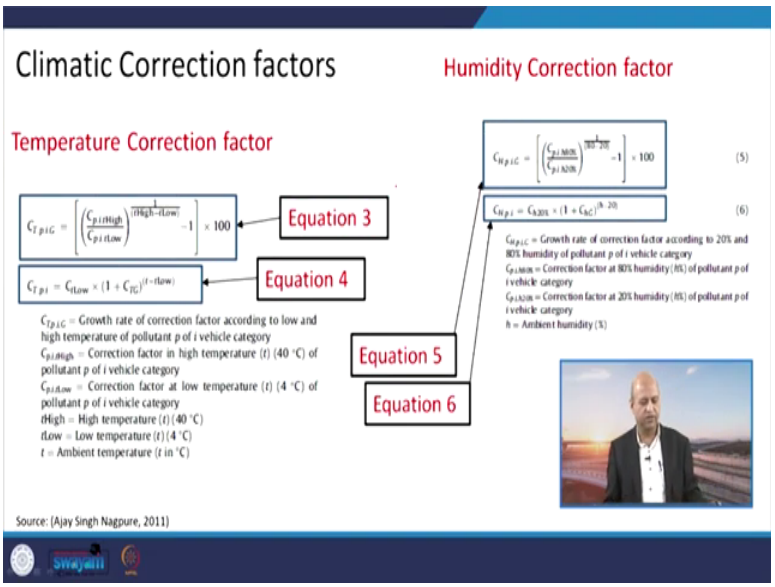
$$C_{H,p,i,G} = [(\frac{C_{p,i,h80\%}}{C_{p,i,h20\%}})^{\frac{1}{(80-20)}} - 1] \times 100$$

$$C_{H,p,i} = C_{h20\%} \times (1 + C_{hG})^{(h-20)}$$

you can go through and learn what are those parameters which are there for correction factors.

(Refer Slide Time: 0:38:47)





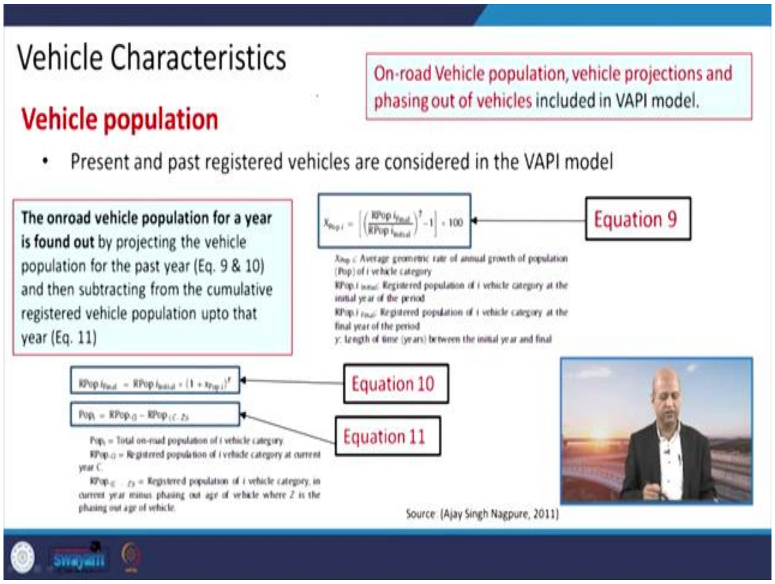
Altitude related or humidity related as we have seen.

$$C_{A,p,i,G} = [(\frac{C_{p,i,a1700\,m}}{C_{p,i,a950\,m}})^{\frac{1}{(1700-950)}} - 1] \times 100$$

$$C_{A,p,i} = C_{a950\,m} \times (1 + C_{AG})^{(a-950)}$$

Temperature related so all empirical relationships have been used for correction factors estimations.

(Refer Slide Time: 0:38:57)



When we do like characteristics of the vehicle, so you can have different kind of relationship,

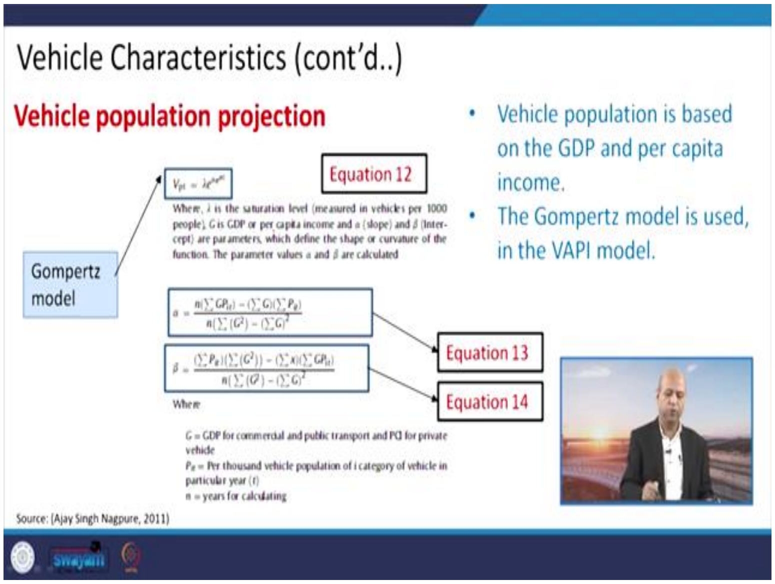
$$X_{Pop,i} = [(\frac{RPop.i_{final}}{RPop.i_{initial}})^{\frac{1}{y}} - 1] \times 100$$

$$RPop.i_{final} = RPop.i_{initial} \times (1 + X_{Pop.i})^{y}$$

$$Pop_i = RPop._G - RPop._{(c-z)i}$$

which has been used in this VAPI model, you can see these on road vehicles population for a year and then past year, so we can deduct how many people are discarded because of age, so that kind of calculation parameters are there for estimating the better number of population of vehicle.

(Refer Slide Time: 0:39:26)



And the population projection because this model can also be used for future estimations after 10 years, how much emissions will be there, because of growth of different vehicle category.

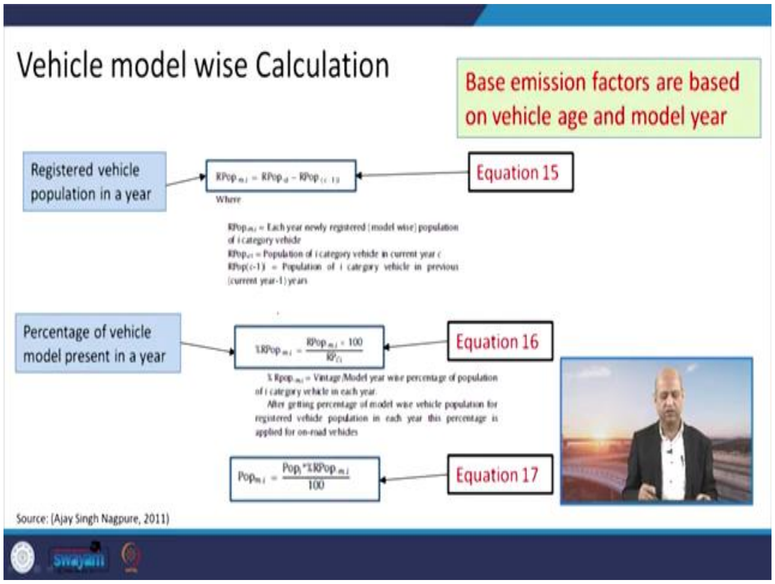
$$V_{PT} = \lambda e^{\alpha e^{\beta G}}$$

$$\alpha = \frac{n(\sum GP_{it}) - (\sum G) \times (\sum P_{it})}{n(\sum(G^2) - (\sum G)^2}$$

$$\beta = \frac{(\sum P_{it})(\sum(G)^2) - (\sum x)(\sum GP_{it})}{n(\sum(G^2) - (\sum G)^2}$$

So, this vehicle population projection has been used by this particular relationship and saturation values have been estimated accordingly.

(Refer Slide Time: 0:39:48)



And this vehicle model wise calculations have been there, because different models have different emission factors.

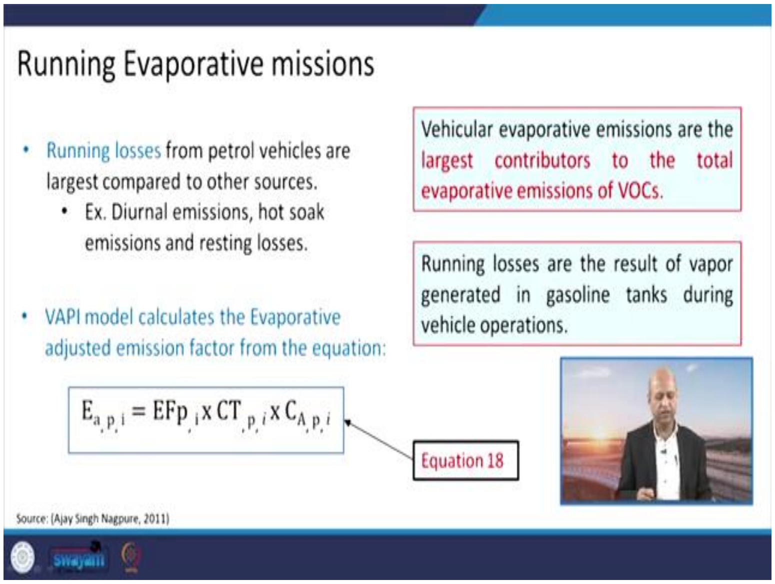
$$RPop_{m.i} = RPop._{ci} - RPop._{(c-1)i}$$

$$\%Pop_{m.i} = \frac{RPop_{m.i} \times 100}{RP_{ci}}$$

$$Pop_{m.i} = \frac{Pop_i \times \%Pop_{m.i}}{100}$$

So, accordingly, number of those model related passenger cars or two wheelers are there, so accordingly that value is picked by the model and use the appropriate emission factors and given the value.

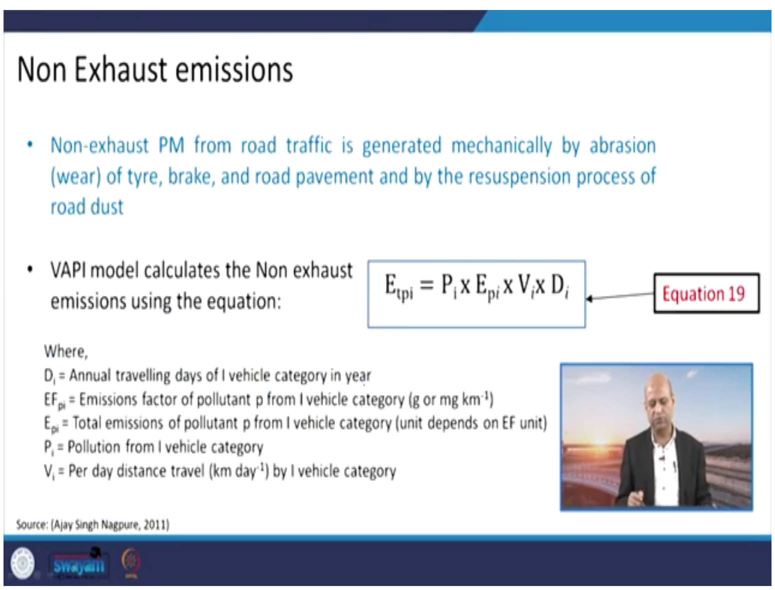
(Refer Slide Time: 0:40:07)



Then we can also have these relationships as we have seen for running evaporative emissions because these kind of fugitive emissions you can say which comes out of leakage, etc., that is also taken into account.

$$E_{a,p,i} = EF_{p,i} \times C_{t,p,i} \times C_{A,p,i}$$

(Refer Slide Time: 0:40:21)

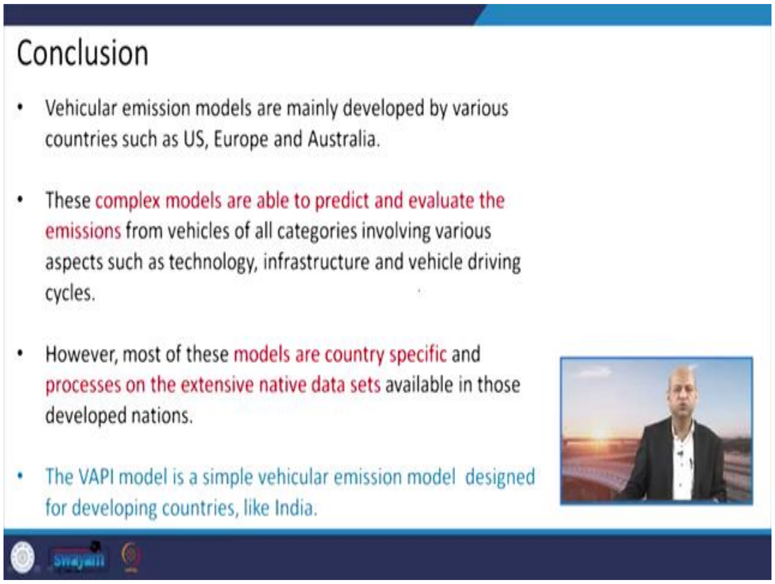


Non-exhaust emissions are estimated by this relationship

$$E_{t,p,i} = Pi \times E_{P,i} \times V_i \times D_i$$

and this is because of like brakes and tyre, those abrasions or wear and tear and those kind of emissions depending upon how much annual days are traveled and per day distance how much is there, and this E is total emissions of the pollutants and pi is pollution from a particular i vehicle category. Then it is summation is taken so that cumulative value is estimated.

(Refer Slide Time: 0:40:51)

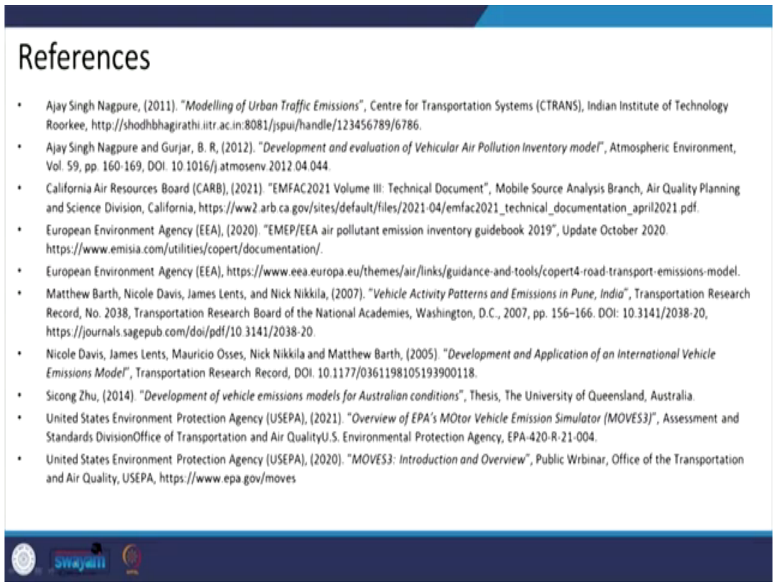


So in conclusion we can say that there are models available across the world, but they are meeting their own demands and they are very data intensive, which, in developing countries, are not much useful, because if you do not have reliable data and their indigenous emission factors then the emissions estimated by using those models of the developed countries may not be giving the right values or correct values and based on those values if we decide our policy framework then that may not fulfill the requirements.

So that is why this, there is a need for having our indigenous modeling efforts and we have done this through this VAPI model. So, this is all for today's introduction that what kind of models are available and what kind of new efforts are to be needed and this might have given you a broad picture about emission models basically.

How these emission inventories are developed because these emission inventories are nothing but the values of emissions, coming out of different vehicles and at different locations, and you can have a single value for city, but you can also distribute the values grid wise, 1 kilometer by 1 kilometer, 10 kilometer by 10 kilometer or along the road, so those kind of values are needed for input parameters of the dispersion models basically. So, this is all for today on this traffic emission modeling or vehicular emission modeling, I hope you have enjoyed it and you can go for additional information through these references.

(Refer Slide Time: 0:42:23)



So, next time we will be having kind of case study to use these models like IVE model, VAPI model and how they are used for ground level application for estimating values for different kind of cities, different kind of topographies and how, some policy based insights are taken out of those estimated values. So, see you in the next class for that particular lecture, thanks.