

**Geoenvironmental Engineering (Environmental Geotechnology): Landfills, Slurry  
Ponds & Contaminated Sites**  
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**Lecture - 17**  
**Generation and Control of Landfill Gas**

Good day to all of you, and welcome back to this class on geoenvironmental engineering or environmental geotechnics if you recall we have looked at liners of landfills we have looked at covers and we have also looked last time how we extract the Leachate from the base of a landfill and today we are going to look at how we extract the landfill gas which is generated inside a landfill.

So, if I presume that the cover of landfill is impervious and the liner is impervious the cover may or may not be impervious for example, the municipal solid waste covers may have claimed them, but may not have a geomembrane. So, they may allow some limited moisture into the landfill, but presuming that both the cover and the liner is impervious, we have a balloon, right and if inside the balloon, gas is being produced by some reactions which are taking place what will happen to the balloon?

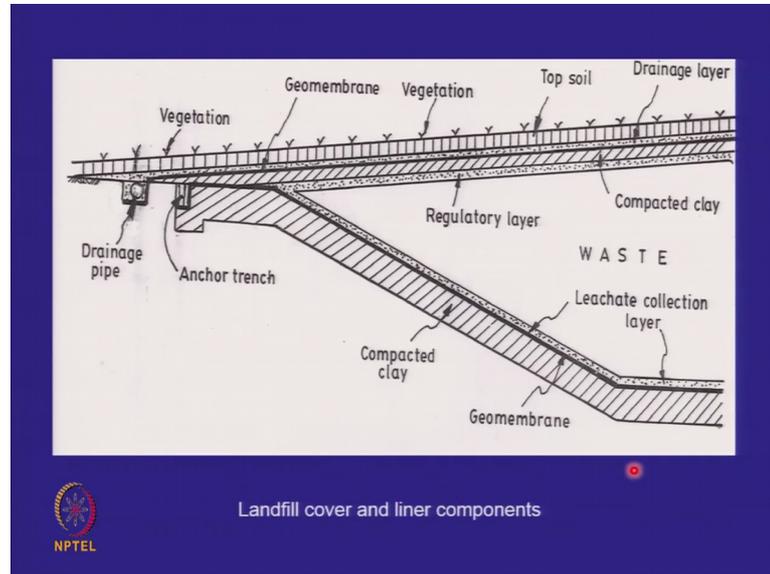
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It will start off become bigger and bigger until one day it will go bang. So, that is what we have done we put a cover we put a liner from the bottom you are taking out the Leachate, but what about the gas. So, remember as the gas is generated it creates pressure and therefore, it wants to come out from somewhere. So, if you have a balloon and if you make a pinprick what will happen quickly the gas will come out and the balloon will deflate.

So, we need to see how we collect this gas because you make a pinprick the gas will go out into the atmosphere you cannot run after it and say all right let me just collect it and treat it. So, you need to allow it to come out of a pathway where at the end you can do whatever you want with that gas, right. So, in the case of a Leachate collection system what happens the Leachate comes out from a well or from a side slope riser and then it goes to a Leachate treatment plant which may have a holding tank where the Leachate

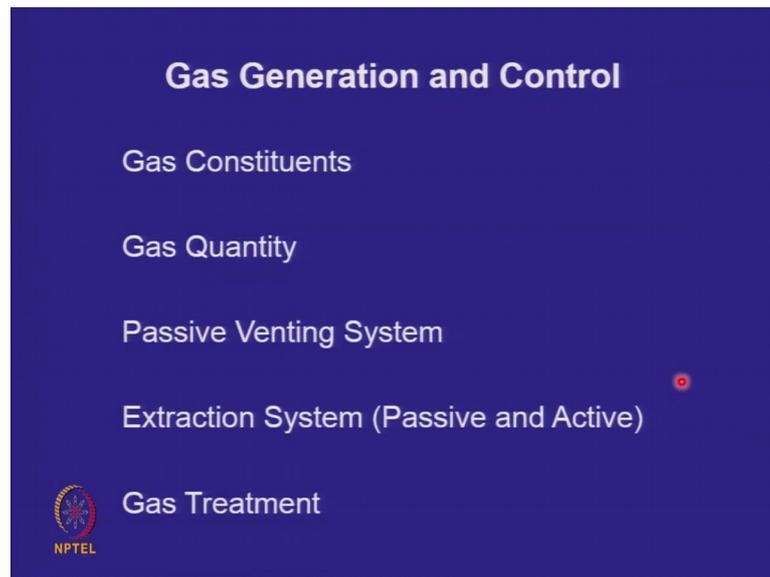
will be collected or it may go into a tanker which takes it to an offsite effluent treatment plant.

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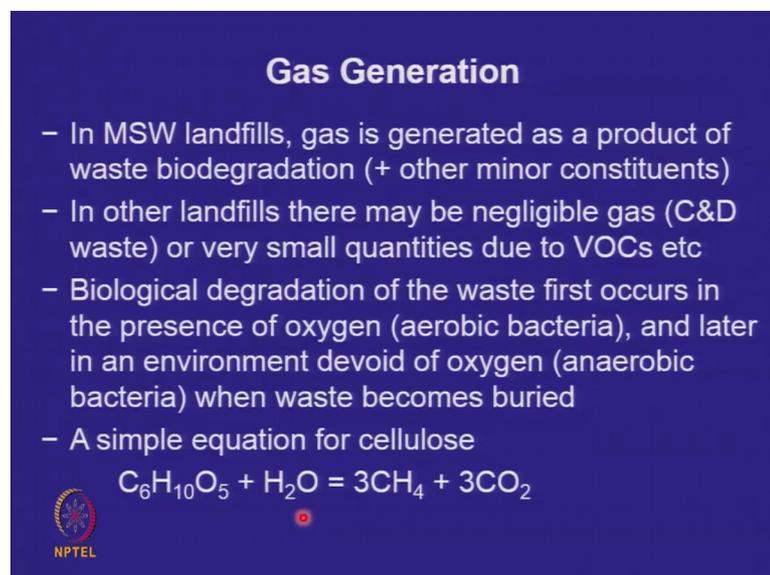
So, what do we do with gas let us have a look we will just remember this cross section that we have gas is being generated here it will put pressure on all sides it will put pressure here it will put pressure on this side it will put pressure downwards and wherever it gets a preferential path to come out it will come out. So, if you do not put any preferential path in the cover the gas will have a tendency to come out to the Leachate collection layer why it is a high permeability layer as long as the high permeability layer is full of water the gas cannot come out, but if at any point of time the Leachate collection layer does not have Leachate there is preferential path for the gas to flow out.

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So, we will look at the following aspects of gas what are the constituents of landfill gas what kind of quantities are generated what are the venting and extraction systems and how do we treat once you collected the gas what do we do with it.

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So, first let us remember that in municipal solid waste landfills which has got significant biodegradable content food waste paper wood leaves gas is generated as a product of waste biodegradation and that is a significant amount of gas plus there are other minor constituents I mean from your household if some nail polish is coming out or some

acetone is coming out that is a volatile organic compounds. So, there will be some volatilization of the household chemicals some something if some paint thinner is there all these things you can smell. So, these are all volatile compounds. So, that those are minor constituents, but the main gas is from waste biodegradation.

In other landfills there may be no gas or negligible amount of gas for example, if you have construction and demolition waste it is not going to produce any gas if you have hazardous waste it will depend entirely on the amount of organic content in the hazardous waste if it is in organic hazardous waste it may have very little negligible gas or it may have some VOCs, but otherwise you will not have significant quantities; however, if the hazardous waste itself is also biodegradable and comes from a industry which is dealing with such products then you can have gas.

So, what we see is that when you bring waste to a landfill and you spread it out then biological degradation of the waste occurs in the presence of oxygen the white space has oxygen in it right and the aerobic bacteria are able to react with the with the waste and give you aerobic decomposition, but the wastes fills up rapidly in a landfill. So, once the initial oxygen is removed or utilized then no more oxygen comes in because you are putting a daily cover a cover at the end of the day a soil cover at the end of the day and the waste gets buried.

So, later anaerobic bacteria take over and we have anaerobic degradation. So, if you look at aerobic degradation it is in the absence of oxygen and if I took at one of the biodegradable components it is cellulose then the reaction is something like this, it is a very simple equation, I am not looking at lignin, I am not looking at other constituents just a simple equation and what you find is you found methane and you form carbon dioxide.

So, this is anaerobic if it was aerobic there would have been an oxygen content here and there would have been a different product of the degradation.

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**Gas Generation**

- When waste is spread in layers, oxygen is present in the void space. In the presence of oxygen, appropriate nutrients and moisture, aerobic bacteria usually generate water, carbon dioxide, organic acids and inorganic minerals
- Due to daily covering of waste, the oxygen supply to the waste is depleted. This depletion of oxygen, moisture and nutrients inhibits the aerobic process and initiate the anaerobic decomposition process
- In the initial phase of anaerobic decomposition the principal gas produced is carbon dioxide. With time, the amount of carbon dioxide decreases and methane increases, each reaching a plateau.

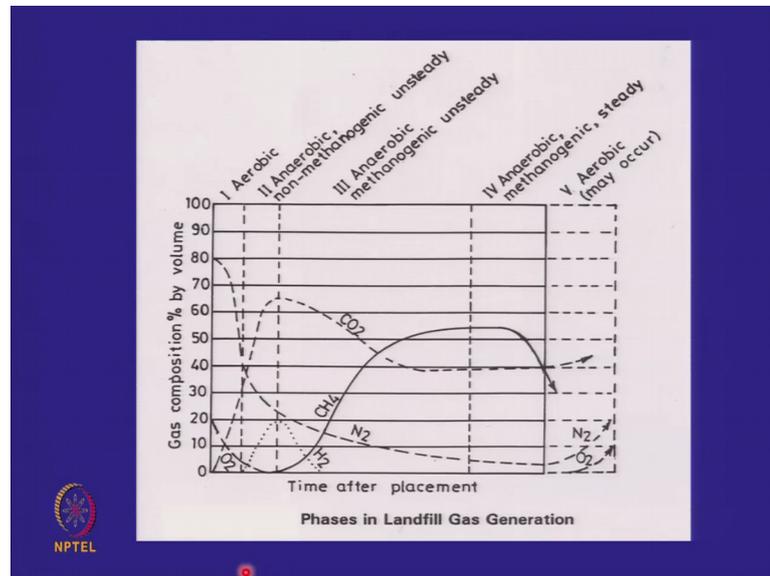


So, just you a reemphasize when waste is spread in layers oxygen is present in the void space in the presence of oxygen aerobic bacteria take over they generate water carbon dioxide organic acids and inorganic minerals, but the depletion of oxygen results in the anaerobic decomposition process taking over and the principle gas produced in the initial phase is carbon dioxide, but with time methane increases reaching a plateau. So, you have this mix of carbon dioxide and methane. So, if you put in a gas extraction well in any of the landfills out will come some methane and carbon dioxide methane is combustible.

So, if you go to a landfill and put in a little pipe and you take a matchstick and put it at the top of the pipe a flame will come up just like in your kitchen and that is the methane gas which will be burning of course, you should not do this because by do doing this you might send the flame inside the landfill, and the landfill will start to burn. And you may not be able to put it off in your kitchen you can put off the flame by turning off a knob or on the ground surface you can put off a flame by covering it with soil or with fire extinguisher, but once a flame goes into the landfill and it will smolder inside you do not no matter what you do at the surface unless you can go after the flame into the into that pipe which you put the landfill will remain on fire.

So, all these issues about burning landfills accrue to the fact that methane is inflammable and it will burn if it gets access to a spark from a human being or from other if I look at the way the processes are.

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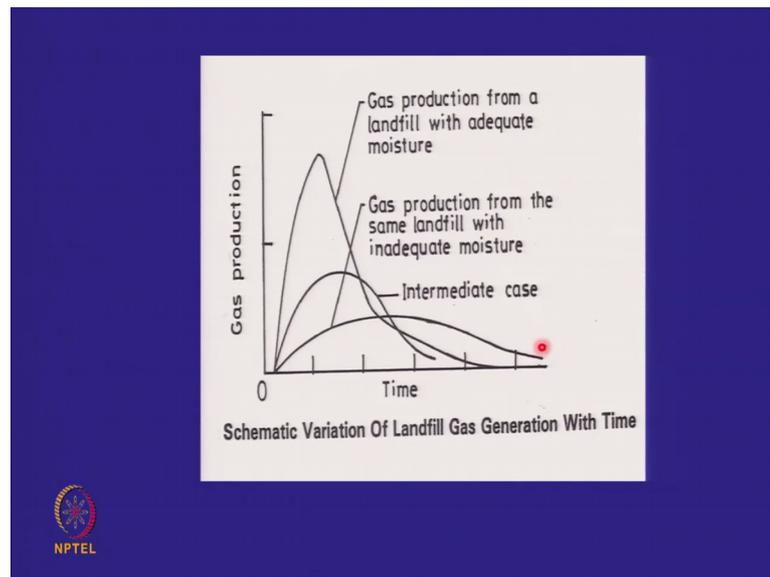
If you look at this first is aerobic phase, right in the atmosphere what are the main constituents of which are the 2 gases in the atmosphere which are predominant?

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Nitrogen and oxygen; so, nitrogen is very high oxygen is high in the aerobic phase they both deplete and then the anaerobic phase takes over now there are subsets of this phase we need not go into details of this, but what we see is that carbon dioxide is formed and slowly the methane begins to form and eventually methane is generated for a larger period of time.

So, you have these methanogenic phases 3 and 4 and aerobic may occur later if ever there is access to more oxygen and in terms of how long do these reactions occur well this the aerobic phase may be a few months aerobic phase may be a few months the anaerobic phase may be some years whether the anaerobic is slow or fast there was a H<sub>2</sub>O in the equation if you recall the previous equation we saw. So, if you give access to moisture it will degrade faster if you do not give it access to moisture it will degrade slower.

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So, if you have a landfill with adequate moisture and something like a bioreactor landfill where you are re-circulating the Leachate it is a landfill with adequate moisture and therefore, it will give you a lot of gas, but it will give you a gas for a short period of time and what a what is this time that I am talking of maybe 5 to 10 years. So, a bioreactor landfill may give you a lot of gas for 5 to 10 years or little more.

However, when we do daily cover and we make a dry term landfill no moisture is available. So, the process of degradation slows down and therefore, this graph shows that the peak is no longer there it is a much lower production rate, but it lasts for a longer time in a sense all the; I degradable material has to biodegrade. So, if you look at the area beneath this and you look at the area beneath this they have to be similar.

So, dry term landfills the way we are discussing it may continue to give you gas for 20 to 25 years. So, it may not stabilize that fast, but remember that gas peaks and gas then slows down.

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## Gas Constituents

**Major Constituents:**  
 Methane (*Greenhouse gas; colorless, odorless, lighter than air; highly explosive in conc. of 5 to 25% in air*)  
 Carbon Dioxide (*Colorless, odorless, heavier than air, soluble in water, increase water hardness and decreases pH*)

**Others:**  
 Nitrogen  
 Hydrogen  
 Ammonia  
 Hydrogen Sulphide  
 Oxygen  
 Carbon Monoxide  
 Trace VOCs: acetone, benzene, chloroform



And if you look at the major constituents as I said methane and carbon dioxide are your major landfill gas constituents. So, if you have a municipal solid waste landfill you have to have a very robust gas extraction system the others gases which you will get in a municipal solid waste landfill of nitrogen hydrogen ammonia hydrogen sulfide oxygen carbon monoxide and as I said some of the trace volatile organic compounds and if you were to analyze a gas sample from a landfill.

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**Table 2 : Typical Constituents of Municipal Landfill Gas**

Constituent	Range (Percentage or Concentration)
<b>Major Constituents</b>	
Methane	30 to 60%
Carbon dioxide	34 to 60%
Nitrogen	1 to 21%
Oxygen	0.1 to 2%
Hydrogen Sulphide	0 to 1%
Carbon Monoxide	0 to 0.2%
Hydrogen	0 to 0.2%
Ammonia	0.1 to 1%
<b>Trace Constituents</b>	
Acetone	0 to 240 ppm
Benzene	0 to 39 ppm
Vinyl Chloride	0 to 44 ppm
Toluene	8 to 280 ppm
Chloroform	0 to 12 ppm
Dichloromethane	1 to 620 ppm
Diethylene Chloride	0 to 20 ppm
Vinyl Acetate	0 to 240 ppm
Trichloroethane	0 to 13 ppm
Perchloroethane	0 to 19 ppm
Others	Variable



It would have this kind of constituents we said methane and carbon dioxide are the most predominant and they will be in the range of 30 to 60 percent depending on whether you are in phase 2 or phase 3 phase 2 carbon dioxide will predominate phase 3 methane will predominate others are very lower please note and all these trace constituents are now down to less than few hundred ppm, but you can detect all these. So, that was the kind of gas we are interested in methane for 2 reasons it is a greenhouse gas.

So, we do not want to allow it to escape to the atmosphere and it is highly explosive occasionally it will accumulate in basements of nearby houses and boom. So, there are if you look to literature a few tens of incidents of explosion it will not explode in the air in the air it will burn, but if it keeps on if you have a house let us say 300 meters away from a landfill which has a basement and some our preferential path forms between the decomposing landfill and it goes to that basement it accumulate once it accumulates and once it reaches a concentration of more than 5 percent 10 percent you can have an explosion. So, that is the problem with methane and it is because it is combustible you can recover energy from it.

So, you should carbon dioxide of course, is also colorless and odorless one thing I also want you to notice that methane is lighter than air methane is lighter than air and carbon dioxide is heavier than air and if carbon dioxide is heavier than air it tends to sit down in a landfill methane is lighter than air it tends to go to the top of the landfill; however, if it is a balloon even if you have a heavier than air gas eventually wherever you make the pinhole if you come out because it will have accumulated under some pressure; however, if carbon dioxide mixes with water it will increase its hardness and  $H_2CO_3$ , one can talk about. So, pH will go down. So, it does do ground water it does affect the groundwater if you have not got a good liner at the bottom, but our main aim is if I go if I burn methane it becomes carbon dioxide, right,  $CH_4 + O_2$  will give you  $CO_2 + H_2O$ , but carbon dioxide is also a greenhouse gas, but much less effect.

So, methane is supposed to be 21 times more have more greenhouse effect than carbon dioxide.

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### Gas Quantity

- Under normal conditions, the rate of gas production, reaches a peak within the first few years and then slowly tapers off, continuing in many cases for periods up to 25 years or more
- In many landfills the available moisture is insufficient to allow for the complete conversion of the biodegradable organic constituents in the MSW
- When the moisture content of the landfill is limited, the gas production curve is more flattened out and is extended over a greater period of time



What about gas quantity as I said under normal conditions the rate of gas production reaches a peak within a few years and we look at the rate of production in the next slide and it tapers off, but in a dry term landfill gas may come out for 25 years when moisture content is limited gas production is more flattened out when moisture content is high the gas picks up earlier.

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### Landfill Gas Recovery

Literature : 1 to 8 litres/kg/year or cu.m/ton/year

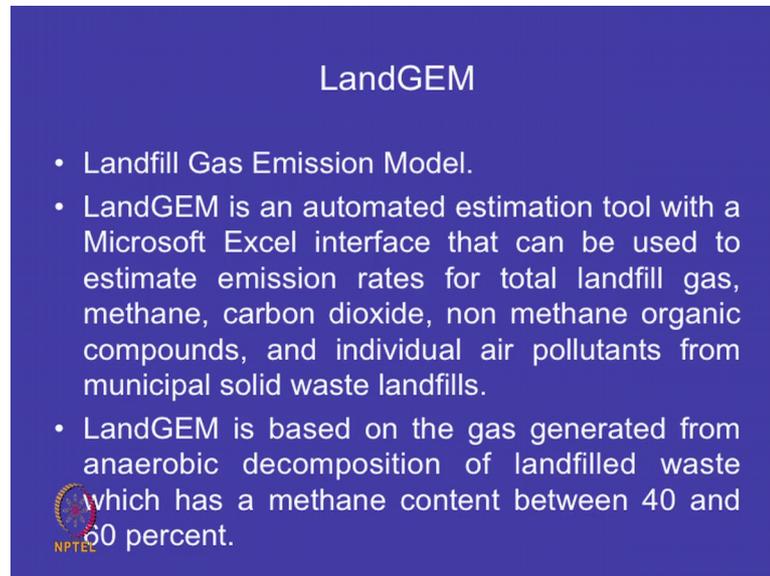
NEERI (Bhide (1993)):  
6 to 10 cu.m per hour per well in 5 to 8 m deep landfill of size 8 hectares

Europe (Hogland (1997)):  
Total potential  $\approx$  200 to 300 cu.m per ton, 50 to 75% recoverable by efficient system in 10 to 20 years  
Output observed : 10 to 20 cu.m per hour per well  
10 m deep, 15 to 20 cm dia, 30 to 75 m spacing  
50 to 100 kW of energy / well;  
1 MW energy  $\approx$  15 to 20 wells)



So, if I look at literature because you know there are a lot of models which exist for gas generation and which model have you and it has anybody been following a model for landfill gas generation; Mohith, have you done anything about landfill gas generation?

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### LandGEM

- Landfill Gas Emission Model.
- LandGEM is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas, methane, carbon dioxide, non methane organic compounds, and individual air pollutants from municipal solid waste landfills.
- LandGEM is based on the gas generated from anaerobic decomposition of landfilled waste which has a methane content between 40 and 60 percent.

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But there is a USCPA, LandGEM model, you can Google it, it is a free software the problem with all these models is they do not give you very accurate output because of the heterogeneity of the waste and the fact that inside the municipal solid waste it is not like a controlled environment you know you are doing this by degradation in a reactor in a factory you can control everything ph temperature oxygen moisture everything can be controlled how much is it in the vessel, but if I am doing it in the landfill nothing is controlled.

So, it is taking its own pathways the wastage is coming is heterogeneous it is coming from so many households and so many markets. So, it is sometimes difficult to get an accurate estimation you can get a very variable estimate, but a variable estimate is better than having no estimate. So, if you look at literature the rate of production of gas is typically 1 to 8 cubic meters per ton of waste per year right.

So, that is what you will find in literature and if you look at the gas production rates reported from wells if you have a waste mass and you put a well in it then you get 6 to 10 cubic meters per hour per well this is India in 1 or 2 landfills and if I look at Europe here is 6 to 10 here it is 10 to 20 cubic meter per hour per well, but you remember this is more

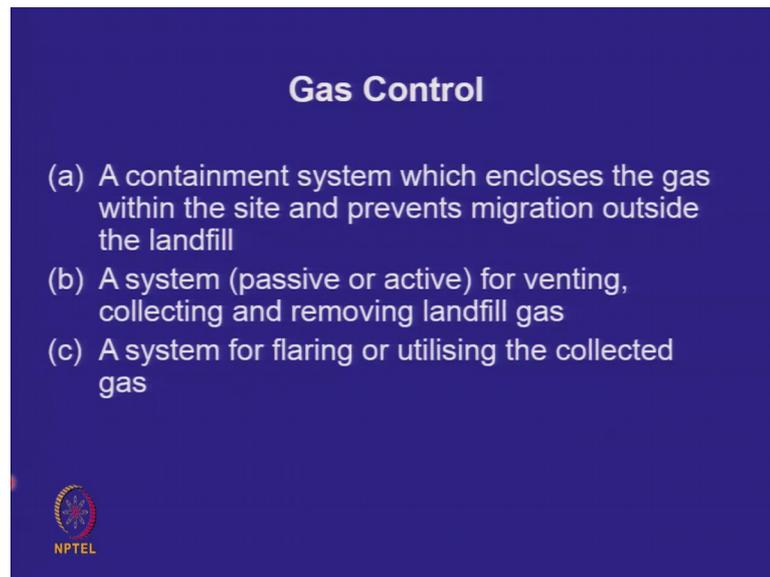
efficient system the here the landfill that we are talking of is a well designed landfill with a liner and a cover whereas, here we are talking of a open ways down if you have an open ways down and you put a well in it this is the kind of gas production rate that you get if you have a well designed landfill with a cover and a liner you will get a higher output.

So, this translates to about 50 to 100 kilowatts of energy per well also look at the depth here they were talking about 5 to 8 meter deep landfill and here the talking of 10 meter deep landfill and they are having typically gas wells at a spacing of 30 to 75 meters. So, if you have 15 to 20 wells of this kind you can generate one megawatt of energy for 20 to 25 years that is the European experience, our what is happening in our waste dumps and obvious dumps we have been accumulating waste we have some huge huge mountain, but what there is no cover there is no liner and these have been all having a lot of moisture. So, whatever the gas was has been generated at a good rate and the old waste dumps therefore, have significant biodegradation which has already taken place.

We are attempting to take out the gas by covering these waste dumps and putting some wells in it there have been 2 experiments one in Gorai and 1 in Gazipur in Delhi the amount of gas that has come out has been 50 percent or less than what was estimated using the various models as well as the gas extraction well tests you know before you put a set of wells you do one well and you find out are you getting this kind of output well they got pretty good output, but what they did not know was that over a period of time that output is not going to sustain because that is the first value chose being drilled whereas, these figures are coming from several wells in a well designed landfills close to at the bottom.

So, currently the experience with gas extraction in India from old waste dumps has not been very great because there is a kind of a critical point beyond which you can make an investment if you can get that much gas, but if you do not get that much gas do not make an investment because you will not get your return on investment.

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**Gas Control**

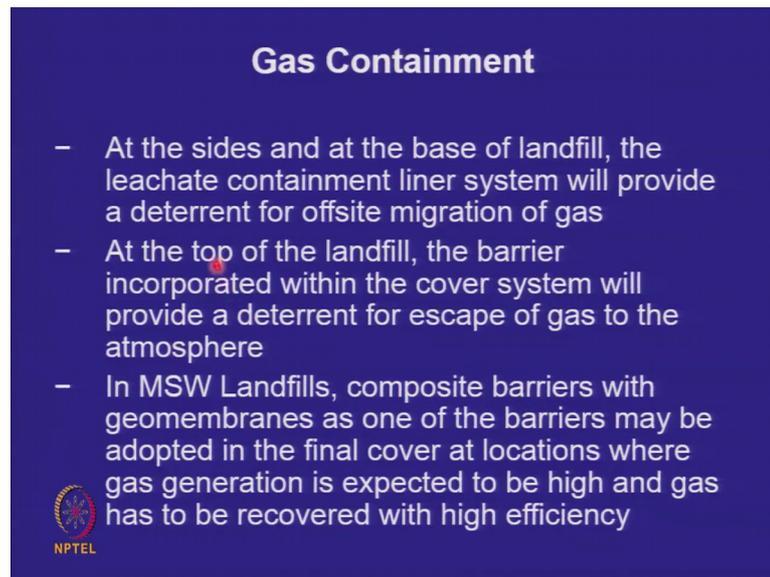
- (a) A containment system which encloses the gas within the site and prevents migration outside the landfill
- (b) A system (passive or active) for venting, collecting and removing landfill gas
- (c) A system for flaring or utilising the collected gas

  
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So, maybe this will stabilize in a few years when we have more data how do you control gas simple have a containment system I make a balloon which encloses the gas and to arrange the migration outside and then you have a system where the gas can come out along specific pathways for venting. So, venting means you are allowing the gas to come out through pipes and leaving it to the atmosphere. So, what is how is venting better than an uncovered landfill in uncovered landfill; landfill gas is coming out from the entire surface and you cannot collect it in a vented system you have a cover and on top of the cover there is a little pipe or sets of pipes through which gas is coming out at the moment you do not have money to put a flaring unit you do not have money to do, but at least you know that the gas comes out from these 10 points and at any point in the future you can put a header pipe join these and take them to a gas control collection treatment system.

So, then you need a system for flaring it the cheapest option is to flare because all you have to do is you burn methane into carbon dioxide you may not recover the energy, but you can also utilize the gas for cooking purposes for heating purposes or for electricity generation it is not that simple this gas smells very terrible it is not like the odorless gas which comes into your house in a gas cylinder. So, you have to scrubber it you have to clean it you have to deodorize the gas and once you start doing that you get more and more sludge which is coming out because you are going to clean up the gas. So, there have to be specific gas cleanup activities to utilize this gas, but it is utilizable.

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**Gas Containment**

- At the sides and at the base of landfill, the leachate containment liner system will provide a deterrent for offsite migration of gas
- At the top of the landfill, the barrier incorporated within the cover system will provide a deterrent for escape of gas to the atmosphere
- In MSW Landfills, composite barriers with geomembranes as one of the barriers may be adopted in the final cover at locations where gas generation is expected to be high and gas has to be recovered with high efficiency

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So, when you talk of containment the liner at the bottom acts like a containment and the barrier at the top axis with containment if you are going to want to extract the gas for the purpose of generating electricity you will need a geomembrane at the top otherwise your gas collection efficiency will be very low clay is a barrier to water when water passes through the clay even if there are some desiccation cracks the clothes because the double layer is formed, but if you have gas and the clay is dry it has desiccation crack is going to run out of the crack then it is not going to swell and cell field where as clear cell fields to water.

So, clay is not a good barrier for collecting gas efficiently it is a good barrier to collect the airs through vents, but if you want high efficiency collection; that means, if hundred units of gas are generated if I want to collect 50 to 75 units that is high efficiency for that I do need something at the top and I do need something at the bottom. So, that it does not escape.

So, composite barrier has to be used no it is not prescribed in the municipal solid waste management rules. So, if you are going to say I am going to design a municipal solid waste landfills with gas recovery well you have to have a geomembrane in the in the cover.

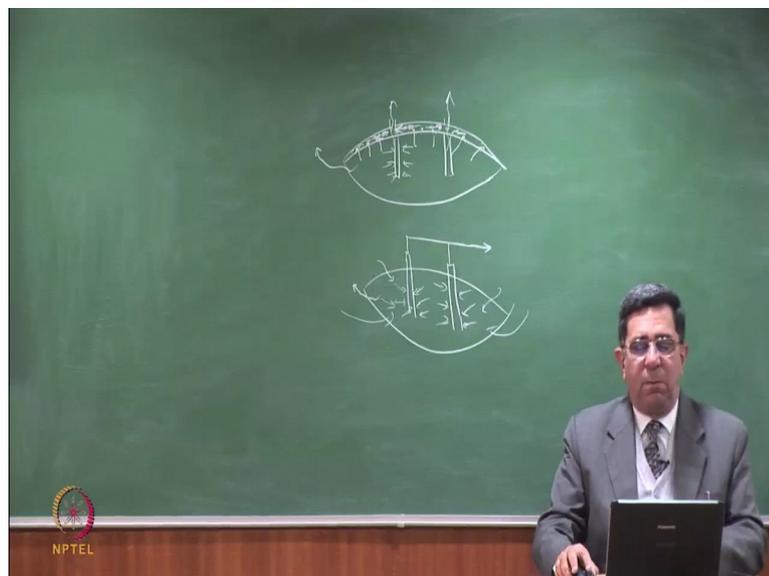
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### Passive Systems

- In passive systems, the pressure of the gas that is generated serves as the driving force for the movement of gases
- Passive control is achieved by providing drainage paths of higher permeability within the landfill to ensure that the gas flows in the desired direction
- Gas drainage paths are just beneath the landfill covers or interceptor trenches or venting columns
- Vents are installed through the final landfill cover extending down into or just above the waste mass
- A perimeter trench system, consisting of gravel-filled interceptor trenches containing horizontal perforated plastic pipes is also used.

In passive systems gas will come out on its own under its own self driven pressure you have to just give the preferential pathway.

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If I have a well designed containment system and remember containment for gas is much more difficult than containment for water then if I have let us say 2 vents right gas will come out on in these vents at its own pressure this is called a passive system when you want to take a suction pump and start applying suction in those vents (Refer Time: 25:45) I will take out more gas that becomes a active system.

So, an active system is one in which you actively use energy like a blower or a suction pump to take out the gas; a passive system is one in which you;

Student: (Refer Time: 26:03).

Take whatever comes out; that means, gas will come out from air you have passive system, but gas may also be coming out from you now if there is some leak it will also be going somewhere else because there is positive pressure then only the gas comes out instead of this if I have the same system, but now I use an active system and I am sucking out the gas of the air, what is happening; whatever is inside this is go into this well. So, here gas used to travel and come out here the gradient for the gas to travel is more.

Student: (Refer Time: 27:04).

Why because you have a negative pressure inside this. So, you collect more gas what happens to this gas which was escaping. So, since there is no positive pressure in the heart of the landfill maybe this does not want to go out it wants to go this way. So, when you do active collection your efficiencies go up when you put geomembranes and containment at the top and the bottom your efficiencies go up can I get a lot of gas by doing a lot of suction I just now said you do not do any section less gas will come out you do suction more gas will come out I do more suction more gas will come out why not?

Well, I cannot produce more gas then I cannot suck out your gas and what is being produced inside suction does not hasten the process of gas formation you want more gas you put in some more water give it more moisture it will generate more gas and then you can take out the more gas and suppose like wanting to meet a target you know you are a manager at the site and your owner says if you can bring me instead of 10 cubic meters per hour 15 cubic meters per hour here is your bonus.

So, what you do you will tell you a pumper operator [FL] put more section let us get more gas out of it let us get both of you and I get bonus what will happen well if your liner and cover is not good enough air is going to start coming in if you apply too much suction what will happen gas will not being produced if there are any leaks in the system air will come start coming in from the side and from the top.

So, you cannot produce more gas you cannot collect more gas than what is being produced inside the waste and that is fundamental now both you and I are not biochemists we do not deal with biodegradable material we do not do with deal with the chemistry of it and we do not deal with how the ph oxygen moisture content of the reaction gives me more gas or less gas. So, this the entire stock geometry of this is done by biochemical engineers, but what I am giving you is that what happens in landfills what kind of figures that emerged.

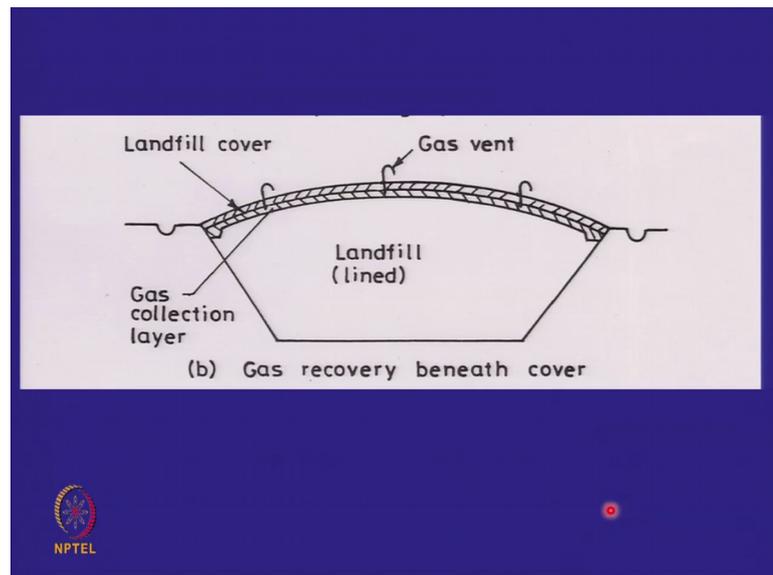
So, in passive system is the pressure of the gas is the driving force and in passive systems what do you do you have a cover.

Student: (Refer Time: 29:48).

Just put a gravel blanket under the cover; that means, if I put a gravel blanket under the cover then this is off course an exaggerated view then all the gas which is coming out we will come into the gravel blanket and then it will travel in this high drainage path to the vents. So, good passive system is one which has a gravel blanket in the top you want even a better passive system you can make the wells and fill them up with gravel you are not applying any suction. So, it is still passive then the under self pressure it goes to a closer drainage path the moment you start extracting that is the time then you are brought into an active system.

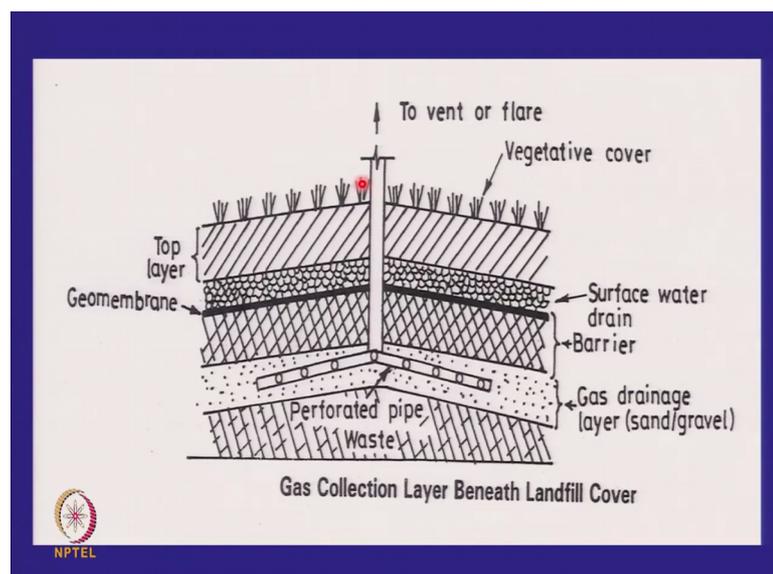
So, passive control is achieved by providing drainage paths of higher permeability gas drainage paths are just beneath the cover or interceptor trenches or venting columns and vents are installed through the cover system and the parameter trench is given all around the landfill.

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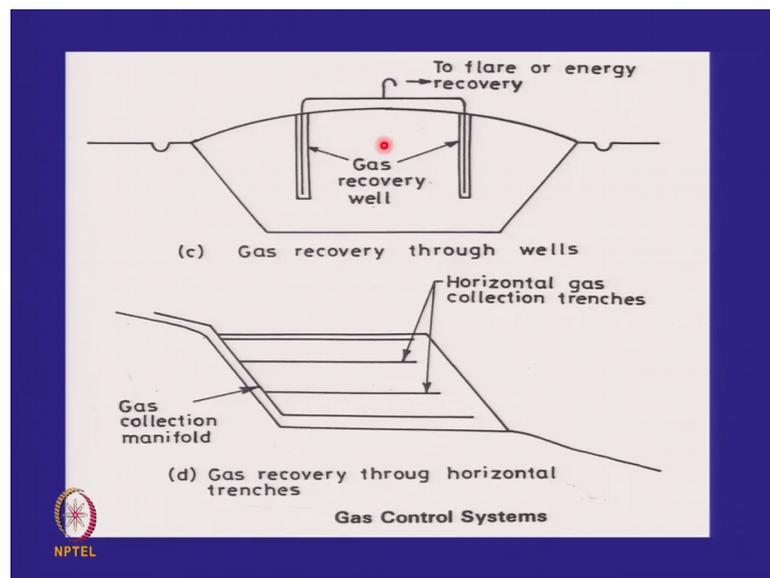
So, very simply this is your cover and this is your gravel or the gas collection layer which we have already talked about and these are your pipes or vents through which the gas will come out they are facing downwards because you do not want rainwater to go through is vents down into the waste this is your passive vent you can see some trenches here these are trenches for any gas from the parameter, but for this 2 function well the liner must be there.

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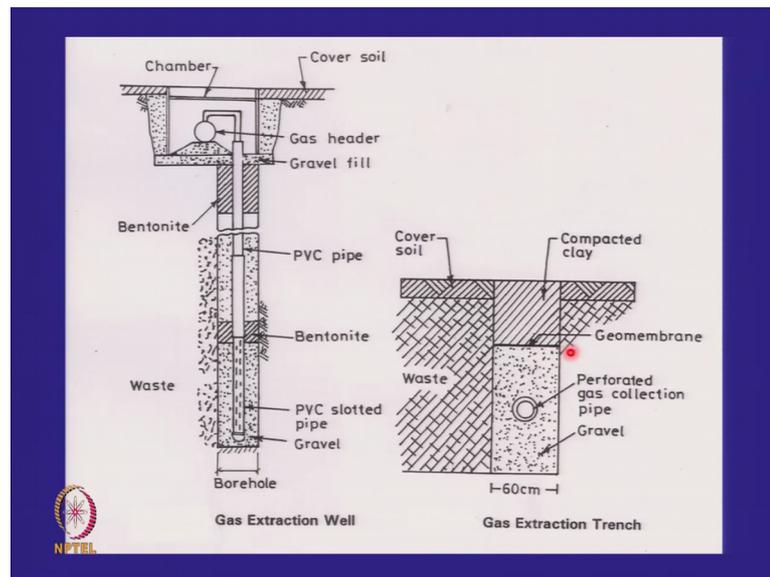
So, that the gas cannot work from any other way, but only come out through the top if I look at it a little closely I have my waste I will have a foundation layer if required or gas collection layer or composite barrier or surface drainage layer and the top soil and the protective layer and this is the vent today you may allow it to went into the atmosphere tomorrow if the government says- no, greenhouse gas emissions you will put a header pipe and flare it and you like that, but this is the concept of a passive venting system.

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You can also have wells and if these wells are filled with gravel and there is no suction which is applied they are still passive you can also have horizontal drains these may have a pipe of these may be just gravel drains with the filter criteria being satisfied between the waste and the gravel if they come out under its own pressure they are still passive.

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So, this is a gas extraction well which will be used in an active or passive case like a tube well like a tube well perforated pipe gravel pack around it a pipe is takes you to the top and connects to a gas header pipe the header pipe goes to a suction pump or a blower which pulls in the gas if it is active or the header pipe goes to a vent if it is passive. So, all the gas have the tendency to go towards the slotted pipe there is a bentonite seal here this is not slotted.

So, here this is the place where you are collecting the gas this can be pretty long this is a typical trench the pipe horizontal trench waste the perforated pipe and you will have to have between the gravel and the waste to geotextile filter separators right and you have put compacted clay at the top you do not want that you do not want to extract air through this pipe you do not want anything to come in from the top in this pipe.

So, these trenches can also be put in the waste or horizontal trenches as you are laying the waste you can make horizontal trenches and get your gas out.

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### Gas Extraction Systems (Active Systems)

- In active gas control systems, energy in the form of an induced suction is used to extract gas from within the waste
- The main components of such a system are :
  - a) Gas wells or drains in the waste
  - b) Pipework leading from the wells to the pumps
  - c) Condensate traps to remove condensed liquid from the systems
  - d) Pumps which induce suction and remove the gas and transmit the gas to flares, diffusers or a utilization plant

So, in the active systems you are inducing suction nothing else is changed and that is used to extract the gas if you keep the system under negative pressure all the time no methane is going to escape and therefore, your landfill gas landfill fires will not be there, but we have to make that investment and you have to put a cover at the top if you do not close your old waste dumps and you do not do your gas collection properly you are going to have continued with this problem of fires and smoke on the landfill. So, the main components are gas wells or drains in the waste pipe network leading from the wells to the pumps moisture is also coming out of this gas water vapor. So, you have to have condensate traps to remove this moisture and then you have to take it for treatment of flaring.

So, you have pumps which induce suction which remove the gas and transmit the graphs of flares to diffusers or to utilization plant the only difference between the passive and the active is the presence of a extraction unit for taking out the gas and making everything flow towards that path.

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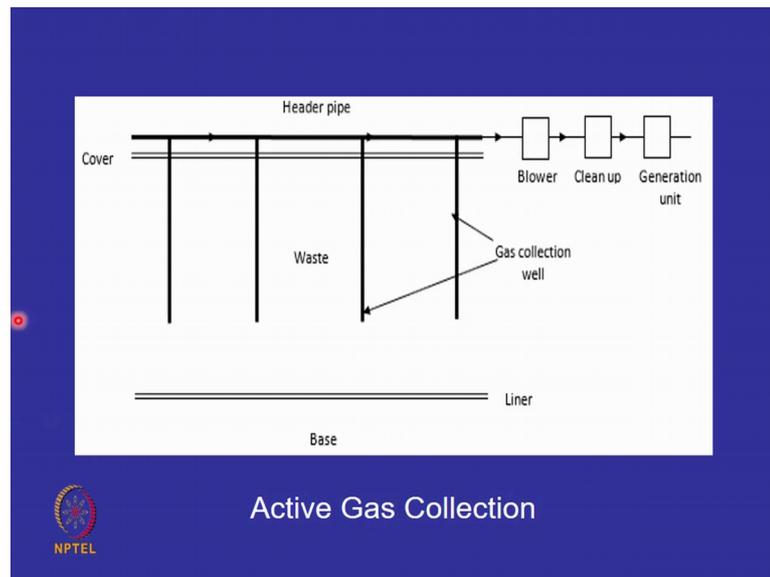
### (contd..) Gas Extraction Systems (Active Systems)

- Gas extraction wells of 0.3m to 1.0m diameter are drilled and HDPE pipes of 150 mm diameter with 10 to 20% perforation are used surrounded by a gravel packing and a bentonite seal at the top
- When a vacuum is applied, a zone or radius of influence is created that extends into the solid waste mass surrounding each well and within which the gas that is generated is drawn to the well and then to the header pipe



Typically the wells that we use are 1 foot to 3 feet in diameter and these are HDP pipes because you do not want the waste to interact with the other pipes. So, you make a well and in that you keep a smaller diameter perforated pipe with 10 to 20 percent perforations and surrounded by a packing when a vacuum is applied then just like you know how you have a zone of influence in a ground water well extraction we remember will be a circular radius of influence exactly like that there will be a radius of influence of each well and that is why the spacing typically varies between 35 to 75 meters 50 meters is very often adopted as the spacing between well; that means, the radius of influence is 25 meters.

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So, this gives you an over overview of how it looks like. So, you may have in any landfill they will be have a liner you have a cover and you have these wells these are the header pipes header pipe at a pipe header pipe all of them go to a suction pump or a blower the condensate the gas clean up it can either go for electricity generation or it can be used for the purpose of heating or for other purposes.

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### Gas Treatment

Landfill gas extracted from a landfill can be :

- a) Flared
- b) Used directly for heating / cooking
- c) Used for electricity generation
- d) Gas utilization helps offset the cost of gas control
- e) Direct use is more efficient than electricity generation
- f) Energy recovery should be considered in preference to flaring wherever possible
- g) Oxidative soil covers (soil only, soil + plant roots, soil + compost / bio char etc. under development (10 to 30% oxidation)

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So, what are the ways we are using this gas; gas can be flare no energy recovery is done, but greenhouse gas emissions are lower it can be used directly for heating and cooking

heating means in cold countries you are using hot water or you are using heating systems for heating your homes. So, if you have a landfill up to a particular distance this gas can actually be sent as a house heating gas or you can send it for cooking, but deodorizing is the major issue it can be used for generation of electricity.

So, if you are going to use it then you will be able to get some costs to offset the gas control systems if you are not if you are just flaring it then you have to just make an investment all the time into the system and between heating and electricity generation. Electricity generation of course, is very prominent because you can plug the electricity into any grid and somebody very far off can take electricity heating and cooking means there is a travel distance you should be within a few hundred meters or a kilometer or 2 hour.

So, for the core making use of the heating, direct use is more efficient than electricity generation and energy recovery should be care always considered in preference to flaring. So, this is the current state of the art of gas treatment, but what is happening on the development fund people are saying why do you burn it to converted to carbon dioxide let us oxidize the methane can be oxidized it. So, just like there are these bacteria we have these oxidative bacteria in the soil. So, normal soil if methane is passed through normal soil about 10 percent of the methane will get oxidated by the bacteria or the by these microbes inside the soil into carbon dioxide. So, you do not have to flare it, but it does not do this 100 percent.

So, actually oxidative soil covers are being developed they may be soil only or soil and plant roots or soil and compost and biochar and oxidation rates have been increased to 30 percent and higher and I think very not in the not too distant future we will be having soil covers which will oxidize the problem is replenishing everything has a capacity to oxidize if too much methane will come what will happen those microbes will not be repelled to replenish grow so, that when more methane comes they can do the oxidation. So, there is always the replenishment time if methane comes and does not come then its fine you oxidize then you regain yourself then you do it again, but if methane is coming continuously then it may kill the whole system which oxidizes you just like attenuation of capacity.

So, oxidative covers are now under development they will be passive they will have no investments they will not be at high temperature and that they are also one of the alternatives which we may examine in the future. So, gives you the overview of gas generation and what and how we control it as geotechnical engineers it is not so much important for us to do the chemistry of what is going on inside, but be sure that the cap is well made be sure that a gas collection layer does not mix with the layers around it all these preferential paths the drains the horizontal drains the wells that is all that we have to design. So, that we can get a lot of gas and we can use it efficiently.

So, if you have any questions I will be happy to answer if something if you feel there is another way better way of doing it or a different way of doing it. So, remember if you have a bioreactor landfill you are going to get more gas if you are going to get it for a lesser period of time. However, you will have more Leachate. So, there will be a cost of treating that instead because you cannot infinitely re-circulate the water.

So, power reactor landfills can stabilize faster and faster does not mean they will stabilize in 2 years they may stabilize in 5 to 10 years and ordinary landfills be stabilized in 20 years plus the same amount of gas is going to come out. So, it is not like the quantity is same because the reaction is going to give you one will come out faster and one will come out slower in the end energy recovery is all about rate of return on investment.

So, if you are a owner of a gas production facility you want to know how much money do I invest how much electricity do I get out of it and when I put it on the grid how much can I sell it for and do I get may return on investment. So, wherever there is no return on investment this is a nonconventional energy you can get a subsidy from the government, but for long term sustainability subsidy does not work example at the moment we are talking of solar power it has become pretty cheap. But still I understand there is a subsidy involved in it for solar power to survive by itself when it is the non subsidized node, then what is the rate at which a electricity will be produced same thing. Here if you can survive this on a non-subsidized mode then it will be there for a longer period of time right any questions, have a good day, enjoy yourself.