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Environment Division

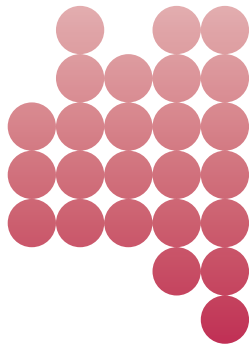
Veolia Environnement's greenhouse gas emissions represent 39.5 million tons of CO₂ equivalent,

i.e. one thousandth of worldwide emissions. This figure is significant enough for the Group to dedicate over 70% of its research programs to the fight against climate change.

Improving the energy efficiency of our processes; exploiting renewable sources of energy to produce heat, electricity or biofuels; capturing and storing certain greenhouse gases (CH₄, CO₂): these are the objectives for limiting or eliminating greenhouse gas emissions.

A focus on several aspects of the work carried out by Veolia Environnement's researchers.





INTERVIEW

“Over 70% of Veolia’s research programs focus on the fight against climate change”



**Michel
Dutang,**

Veolia
Environnement's
Research Director

What is the Veolia Environnement group doing to meet the European objectives in terms of the fight against climate change?

“In its capacity as environmental services provider, Veolia Environnement is particularly involved in the fight against climate change. Our activities contribute to limiting greenhouse gas emissions: public transport prevents the emissions of individual cars, ecological landfill management reduces methane dispersion, correct boiler maintenance curbs the energy consumption and emissions associated with these boilers.

However, the 100,000 or so sites that the Group operates throughout the world on behalf of its clients, in particular the combustion facilities and landfills,

“Our activities contribute to limiting greenhouse gas emissions”

generate considerable greenhouse gas emissions: 1/1,000th of worldwide emissions in total. In addition, in the regions where the Group is developing – Asia, the American continent, Central and Eastern Europe – the CO₂ issue, already significant, is becoming more acute. All this explains why the Group is seriously mobilizing to limit greenhouse gas emissions.”

How is Veolia Environnement's commitment reflected in terms of research?

“Over 70% of our research programs focus on the fight against climate change. Our research focuses on three major aspects: improving energy efficiency and controlling the requirements, developing the use of renewable sources of energy and capturing and recovering or storing greenhouse gases (methane, CO₂).”

Where are you with the energy optimization of the processes?

“We have been striving to improve the efficiency of the energy facilities managed by the Group for a long time. For example, our research consists of mitigating boiler clogging phenomena and optimizing the combustion process.

In particular, we have developed a sensor for the economical and continuous identification of the quality characteristics of natural gas, thereby making it possible to regulate the combustion of the boilers operated by Dalkia. This process is now being sold by one of our partners.

We are also developing advanced combustion modeling tools and we are working to improve the waste-to-energy process. Furthermore, we are trying to reduce usage consumption. For example, we are studying energy recovery systems in the case of water management. For electric buses and tramways, we are assessing systems designed to recover energy during the deceleration phase. We have also developed a modeling tool which quantifies the air renewal rate in a refrigerating warehouse according to its usage conditions, with a view to adjusting cold production according to the requirements. Finally, we are involved in projects designed to optimize the maintenance of water supply systems, resulting in water leakage prevention, thereby avoiding the energy consumption associated with the unnecessary over-production of drinking water.”

What are your advances in the bioenergy domain?

“Our research aimed at exploiting the energy potential of biomass⁽¹⁾ takes multiple forms and applies to the industrial and residential sectors as well as transport. It relates in particular to waste recovery, which constitutes a significant source of biomass. For example, we are trying to improve the energy efficiency of the boilers running on untreated wood waste. In 2006, we commissioned a pilot biomass boiler with a view to characterizing the combustion of waste such as that from sawmills and the paper industry or that associated with tree felling. We are examining the combinations which provide the best return. We are also exploring the different biofuel production processes. We are

testing diester (30% rapeseed oil ester and 70% diesel) on bus and coach fleets. We are working to manufacture biofuels from used edible oils. We are taking an interest in the production of biomethane, or bioNGV, from the biogas emitted by the fermentation of biodegradable waste. This is one of the methods for recovering the methane captured in landfills. The problem is to obtain a product presenting similar characteristics to those of natural gas so as to use it in housing boilers or in vehicles. We must also examine its transport conditions. Finally, we must make sure that the cost of this process is reasonable and that its environmental footprint is attractive.”

(1) Biomass means organic matter excluding hydrocarbons and their derivatives.

What is the issue at stake with methane capture and recovery?

“This is a dual issue with regard to the reduction in greenhouse gas emissions. Methane is the main component of the biogas emitted by the decomposition of biodegradable waste; its greenhouse factor is twenty times higher than that of CO₂. Therefore it is crucial to eliminate these emissions. In addition, it constitutes a source of green energy: it can be used to replace a fossil resource in the production of electricity, heat (these processes are already mastered) or a biofuel. Veolia is currently capturing and recovering methane in over 80% of its landfills. Our research aims at optimizing our capture processes, intensifying and increasing methane production and improving its quality to maximize recovery possibilities.”

Where are you with your research on CO₂ capture, transport and storage or recovery?

“In 2005, we initiated a program on the capture, transport, storage or recovery of CO₂. This program aims at complementing the solutions offered by the Group in order to reduce greenhouse gas emissions and fight against climate

change. 50% of the Group’s greenhouse gas emissions are currently generated by the management of combustion facilities. Veolia’s development in world regions primarily using fossil fuels such as coal also requires the development of different technological solutions designed to reduce CO₂ emissions. When the use of renewable sources of energy is impossible, and after optimizing energy efficiency and demand control, CO₂ can be captured. As the Group manages facilities of different sizes, we are studying capture technologies adapted to varying emission rates. Given the dispersion of these emissions and in order to implement sustainable solutions, we must also focus on the transport issue and find secure storage solutions, economically viable and ecologically friendly. To this end, we launched a geological CO₂ capture-storage pilot project in March 2008 in North of the Paris region. Finally, we are also working on CO₂ capture and recovery. Certain industrial processes (for example the petrochemical industry) use CO₂. The capture and recovery process consists of capturing CO₂ on one of our sites and supplying it to a nearby industrial company to be used in its manufacturing process.”

How do you rate the ecological relevance of these innovations?

“We use the lifecycle analysis (LCA) method almost systematically when establishing the environmental footprint of new processes, in particular to analyze the different processes with regard to wastewater sludge energy recovery, biofuel production, biogas recovery or to evaluate CO₂ capture and storage systems. We integrate all types of impact on the environment, at any given moment, over the entire chain: we establish the greenhouse gas footprint and the other types of impact on the environment. For example, the fact that cultivating plants to produce biofuel requires a lot of water raises questions on the overall environmental footprint of this solution.” ■

The production of biohydrogen?

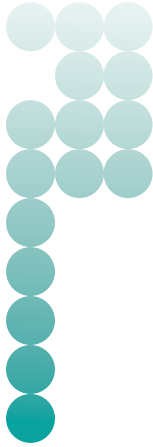
Veolia Environnement’s R&D is exploring a possible solution which could open up very promising perspectives for a post-oil economy: the methanization of the sludge generated by wastewater treatment plants and of biodegradable waste (biodegradation without oxygen). One of the methanization processes produces both methane and hydrogen. If it turns out to be viable, this waste-to-energy process could be used to produce fuel, whether fixed or on-board, as the production of hydrogen is currently very energy consuming.

The European Union’s 3 “20s”

In order to fight against climate change and divide the amount of greenhouse gas emissions by 4 by 2050, the European Union set 3 objectives to be complied with by 2020: 20% reduction in greenhouse gas emissions, 20% improvement in energy efficiency, 20% renewable sources of energy in the final energy consumption, the latter being a binding objective.

The French National Conference on the Environment defined the fight against climate change as one of its major priorities

The conclusions of the Conference, published in November 2007, define the reduction in the energy consumption of buildings (which represents 42.5% of the energy demand) and transport (37%) as one of its priorities. With regard to energy production, they stipulate the development of autonomous and decentralized systems linked to the centralized system, based in particular on renewable sources of energy. The installation of collective biomass boilers and renewable heat systems will be encouraged. Among priority research guidelines are the reduction in fossil fuel consumption, the production of carbon-free energy, carbon capture, storage and recycling and second-generation biofuels.



TECHNOLOGIES

A pilot biomass boiler

Veolia's Research has been working on energy production from biomass for several years. Since 2006, research teams have benefited from a thermal test hall including, among other things, a 400 kW biomass boiler. In addition to the improvement in the efficiency and operation of the facility, the teams' objective is to evaluate the energy and environmental relevance of the different biofuels: wood waste, energy farming, agricultural residue.

Biomass is the number one source of renewable energy for heat production and has taken off in the past few years: the development of this process can help comply with the objectives stipulated by the European Union in terms of renewable sources of energy. In France, heat production from renewable sources is due to increase by 50%.

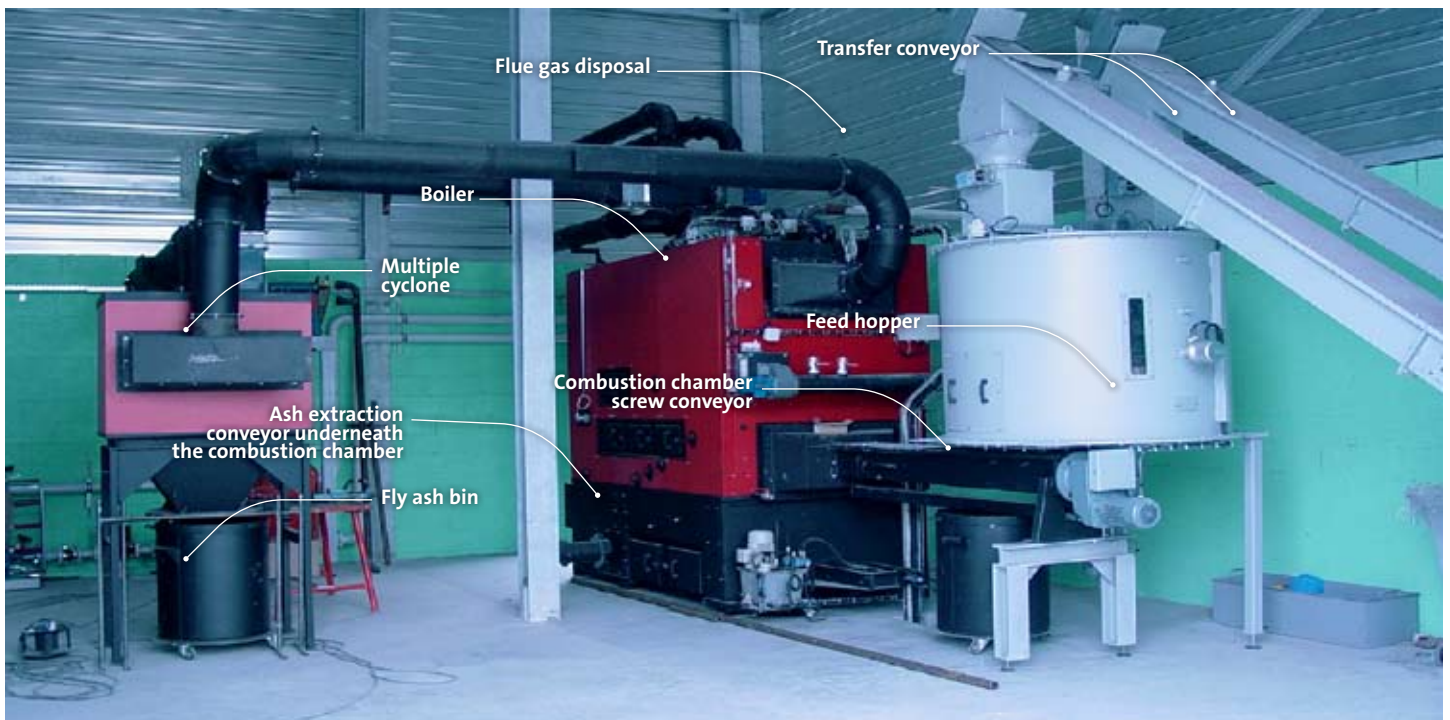
Neutral CO₂ footprint

"Energy" wood can provide a crucial contribution. As with all vegetation, wood absorbs CO₂ when it grows, then captures carbon and discharges oxygen. "During its combustion, it emits as much CO₂ as it previously absorbed. Its CO₂ footprint is therefore considered neutral provided its consumption remains reasonable and there are no secondary

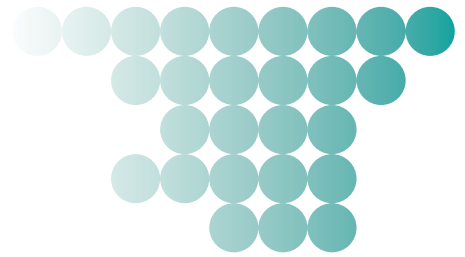
emissions due to poor combustion" explains Karim Tabet, an engineer with the research Center on energy and waste management. "For 1 ton of wood produced, 1.5 ton of CO₂ is captured and 1.1 ton of oxygen discharged. Wood combustion results in the discharge into the air of an amount of CO₂ exactly equivalent to that previously captured by the tree or by that which will replace it in the future. We can therefore talk about renewable carbon."

Energy and environmental assessment

Veolia Environnement's pilot biomass boiler, with a 400 kW capacity, could supply forty families with domestic hot water. Researchers have examined the combustion of several types of wood – wood chip, bark, pallet waste etc. –



The biomass boiler is fed by two 40 m³ storage bins with vibrating bottom in order to facilitate fuel extraction. This fuel is transported by 2 endless belts to a 1.4 m³ cylindrical hopper acting as an equalization tank. If the bins are filled with separate fuels, they are mixed in the hopper. Inside the boiler, a mobile sloping grid helps ember and ash flow. A 3-level air injection system, i.e. one more level than in a traditional wood boiler of this type, optimizes combustion. The recycling of part of the flue gases provides an additional means of enhancing combustion and controlling temperature distribution. Recycled flue gases mixed with fresh air can be injected above or below the grid. Fly ash is captured by a multiple cyclone. Fuel gas flow rate and O₂, CO₂, NO_x, SO₂, VOC and dust content is continuously monitored.



in order to assess, among other things, the influence of the type of fuel on the emission level and the quality of ash produced.

The energy and environmental performance of other biofuels is also being studied: energy farming – miscanthus, switchgrass, short-rotation coppice, sorghum – as well as the residue generated by agriculture and the food and beverage industry – cereal straw, vine shoots, rapeseed oil meal, wheat distillers' grains etc. For the moment, the initial miscanthus combustion tests seem positive in terms of emissions and energy efficiency.

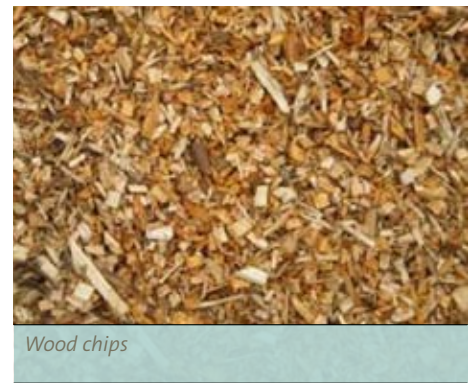
“Veolia Environnement’s pilot biomass boiler, with a 400 kW capacity, could supply forty families with domestic hot water.”

Combustion optimization

The other project researchers are working on is the optimization of the facility’s efficiency. In this respect, the combustion process must be improved and comprehensive combustion guaranteed. This requires that a number of conditions be met in terms of temperature, gas residence time and air mix and ventilation. “The combustion air must be divided into primary and secondary air”, points out Karim Tabet. “Primary air dries the fuel and oxidizes solid carbon while secondary air burns the pyrolytic gases generated by the thermal decomposition of wood. The correct distribution of primary and secondary air in the facility’s combustion chamber is crucial for the combustion process.” Excess oxygen must also be provided in order to properly burn all pyrolytic gases, guarantee the homogeneous mixture between secondary air and pyrolytic gases and operate at a temperature of roughly 850°C. The boiler is fitted with multiple measurement devices, notably to continuously monitor combustion quality parameters: combustion chamber temperature, boiler capacity, oxygen rate and carbon monoxide content of combustion flue gases.



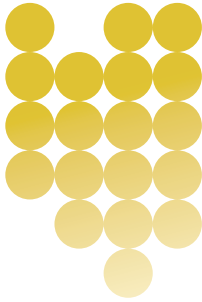
Fuel storage bins



Wood chips



Miscanthus is a perennial herb: for 20 years it re-grows after each annual harvest without having to be replanted. It requires almost no fertilizers or pesticides and has high biomass yield (roughly 20 tons of dry solids/ha/year).



RESEARCH PROGRAM

Waiting for second-generation biofuels

Veolia Environnement's first biofuel tests on bus and coach fleets were carried out 20 years ago. Initiated with diester, a mixture of 30% rapeseed oil ester and 70% diesel, they are continuing with the new products offered on the market. Roughly 700 Veolia Transport vehicles currently operate on diester – with an added cost per kilometer ranging from 3 to 5%.

The Group's research has been focusing on second-generation biofuels for the last 2 years, seemingly more environmentally interesting than agricultural biofuels: potential resources are less limited and these processes do not compete with the food process (see box opposite). This time, the idea is not only to study their compatibility with vehicles and the discharge they generate but also to manufacture them from the waste treated by Veolia Environmental Services.

We highlight two processes: used edible oils and BioNGV.

Article 1 Recycle frying oil into ester

With Veolia Environmental Services and Veolia Transport, Veolia's Research is striving to implement a biofuel production process from the used edible

“...Veolia Environnement tested BioNGV production from the biogas generated by a non-hazardous waste landfill” oil collected in restaurants and institutional food service facilities. Ongoing studies aim at defining the characteristics of a mixture adapted to public transport vehicles

and evaluating the environmental impact of the global process. Collection, filtration, esterification, a 30/70 mixture with diesel, usage by Veolia Transport's fleet: this is the recycling chain envisaged by the Group for used edible oils.

Veolia Environmental Services is currently collecting and filtering oils and has launched the construction of an esterification unit. Veolia's and Veolia Transport's Research has been testing this biofuel on 3 coaches for 1 year.

Promising results

“Its characteristics are similar to those of a traditional biofuel. In terms of exhaust fumes, its behavior is just as good. However, in light of the study carried out along with Ademe, its environmental footprint is better” explains Jean-Loup Gauducheau, an engineer from Veolia Transport's research team. A Lifecycle Analysis is under way to evaluate all types of environmental impact of the process, from oil collection to product manufacture, and compare them with those associated with diesel and agricultural biofuels. There are already several favorable elements.

“As the starting point is waste, we prevent the consumption of fossil fuels and upstream nuisances associated with energy farming,” continues the researcher. “In addition, Veolia Environmental Services will use the heat provided by a waste incineration plant to esterify the oil.” As for the product itself, work is continuing to develop different formulations and test them on more recent vehicles.

Article 2 Supply waste collection trucks with BioNGV

Following a international feasibility survey, Veolia Environnement tested BioNGV production from the biogas generated by a non-hazardous waste landfill. When organic materials such as food waste, wood waste or agricultural waste decompose, they release biogas. This gas, roughly 50% of which is made up of methane, can be recovered as fuel. However, for this solution to be viable, at least 3 conditions must be met: transform biogas into quality gas, i.e. meeting NGV recommendations (natural gas for vehicles); availability of a fleet of vehicles operating on NGV; have a production source located along the route of these vehicles.



Experiments in transport

Some of Veolia Transport's fleets are already operating on BioNGV. On the West Coast of the USA for example, certain vehicles are supplied with BioNGV from the biogas generated by a

non-hazardous waste landfill. In Sweden, since 1998, buses have been getting their supplies from a plant which methanizes agricultural waste such as manure.

The advantage of this fermentation process without oxygen is that it releases better quality biogas than non-hazardous waste landfills. Conversely, these landfills produce larger amounts of biogas without prior treatment – the methanization plant only retains the most fermentable waste. The relevance of the solutions largely depends on local contexts.

Enhance biogas

Veolia's researchers therefore started by examining different BioNGV experiments in order to determine the waste resources to be exploited on a test basis and the processes to be implemented. Veolia Environmental Services' Claye-Souilly site was selected. Several biogas enhancement processes will be tested, for their performance and cost. The idea is to isolate nitrogen, CO₂ and oxygen to attain a 90% methane ratio and eliminate pollutants such as metals and siloxanes.

A "full tank" of BioNGV

Thus produced, BioNGV will be transported by a pipe to a petrol station supplying the waste collection trucks operating on NGV. Researchers will also study the effects of this biofuel on vehicles and operating conditions. Subsequently, they will test it on waste transfer trucks. However, this requires an industrial partner willing to build a prototype truck operating on NGV. When will truckers be driving "bio" vehicles?

"The advantage of this fermentation process without oxygen is that it releases better quality biogas than non-hazardous waste landfills..."

The share of biofuels in fuel consumption: public objectives

European Union: 5.75% in 2010
 France: 7% in 2010, 10% in 2015

From one generation to the next

There is no official definition of first and second-generation biofuels, as both are produced from non-fossil organic materials, hence the lack of clarity in the boundaries of their respective scopes. However, in addition to the fact that the former is older than the latter, their differences lie in the raw materials and technologies used to produce them as well as their ability to fight against greenhouse effects.

Agricultural biofuels are first-generation biofuels: alcohol obtained by plant fermentation (beet and sugar cane, wheat etc.) and used purely or mixed with petrol; oil (rapeseed, sunflower etc.) which is etherized and incorporated into diesel (diester). The liquid fuels obtained from biomass (wood residue, leaves, straw, food waste, agricultural waste, entire plants etc.) via synthesis processes and used as such are part of second-generation biofuels.



Used edible oil collection

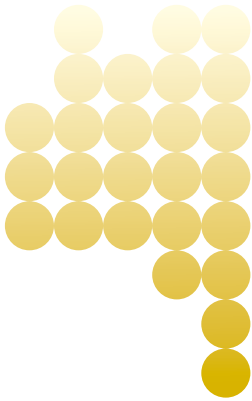


Petrol station

The environmental and economic assessment of first-generation agricultural biofuels, the efficiency of which is limited, is currently debatable. They are subject to much criticism. Competing with food crops, they seem to result in the overly intensive use of soil and an increase in the price of food products. The manufacture and spread of the fertilizers necessary for this type of energy farming is also a source of greenhouse gases.

According to a survey conducted among climate experts and presented during the Bali conference in December 2007, first-generation biofuels rank 18th in the list of technologies capable of reducing greenhouse gas emissions while second-generation biofuels rank 7th(1).

(1) Survey conducted in 2007 among climate experts and decision-makers by Globe Scan Incorporated on behalf of the World Bank, the Worldwide Union for Nature (UICN) and the International Development Research Center (CRDI).



RESEARCH PROGRAM

How to recover more biogas?

Over 60% of the waste treated by Veolia Environmental Services involves landfill processes. Its decomposition generates biogas, which contains 40 to 45% of methane. This methane has a greenhouse gas factor 21 times higher than that of CO₂ as well as high energy value (1 m³ of methane is equivalent to roughly 1 liter of petrol), hence the necessity to capture as much of it as possible with a view not only to reduce its environmental impact but also to recover it as heat and/or electricity, or maybe as biomethane for possible use as fuel in natural gas systems or fuel cells.

To this end, Veolia's research has developed degassing techniques and a tool for the automated management of capture systems. Another solution explored for the optimization of landfills' energy potential

“Biogas flow rate and pressure sometimes vary between the morning and afternoon, depending on the waste degradation conditions...”

is that of bioreactors, consisting of accelerating waste degradation (see Chronicles n°2). Veolia's researchers benefited from Veolia Environmental Services' expertise, in France and in the USA, in the development of a biogas capture technique known as “gradual technique”, which degasses non-hazardous waste landfills as they are being filled rather than once filled.

20% less greenhouse gases

This process has the dual advantage of preventing the emission of biogas into the air and releasing energy while landfill cells are being filled. Drainage pipes are installed horizontally in waste and connected to production boreholes. What is the optimal size of these systems, how must they be installed, how to avoid their premature failure? These questions have been answered by the researchers.

“With this capture technique, greenhouse gas emissions are reduced by 20% compared with final capture” explains Christophe Aran, Veolia Environmental Services' research director.

Make system regulation automatic

Once these systems are installed, they must be managed in order to optimize the capture process. Biogas flow rate and

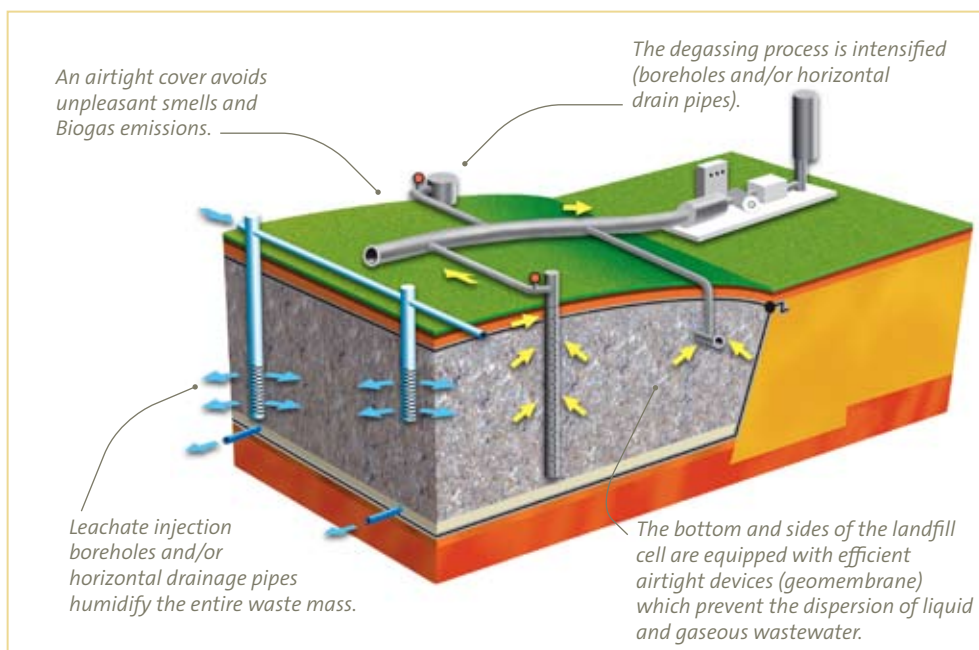
pressure sometimes vary between the morning and afternoon, depending on the waste degradation conditions, which themselves depend on the weather and atmospheric pressure. “The manual management of the systems is not fully satisfactory”, continues Christophe Aran. “When an operator opens the sewer gates after taking weekly or monthly measurements, these measurements are only valid at the time.

Furthermore, the handling of a gate in a given location has an effect on the other points of the system. A gate-by-gate regulation is therefore not an optimal system.”

40% extra biogas

An automated process was therefore developed to manage collection systems: Methacontrol®. It is used to regulate the opening of the gates in an optimal manner, in accordance with different, previously identified internal or external system parameters (gas quality, flow rate, atmospheric pressure for example). “The difficulty is to find the right level of negative pressure applied to landfill cells. You mustn't pump too much to avoid air infiltration, but just enough to prevent the emission of biogas into the air.”

Air infiltration deteriorates biogas quality, modifies the biological reactions of the waste mass and is likely to cause potential combustion, if not explosions. Methacontrol® has had conclusive results: on the industrial-scale research pilot, the amount of biogas collected exceeds that obtained using the manual technique by 40% (+/- 20%). The industrial development of this process is under way.



Bioreactor

Biogas production models

In order to optimize the size of biogas capture and recovery facilities, Veolia's researchers are developing biogas production models in accordance with the characteristics of incoming waste and landfill management techniques.

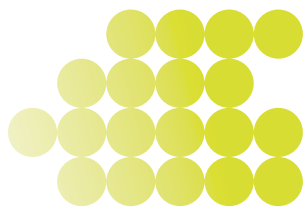
Diffuse emission measurement

Landfill gas emissions diffused into the air are currently measured in a mostly empirical manner. With the modeling tools, the sites' biogas production is estimated at a given time and the data obtained in the field via sewer flowmeters is estimated based on potential site production in order to obtain diffuse emissions.

Veolia's research teams are trying to obtain more accurate measurements, by using spectroscopic detection tools. Developed by English, Dutch, US and French teams, different techniques based on lasers, tracer gases, imaging software etc. have been compared on a pilot site. These tests will be continued in several landfills to select the most efficient technique.

Veolia Environmental Services' Landfills

Potentially, Veolia Environmental Services' non-hazardous landfills can produce roughly 580 million m³ of methane (2007 data), i.e. 490,000 tons of oil equivalent each year. This represents 1% of the oil consumption of the French transport sector, or 3% of the heavy fuel consumption in the residential and tertiary sectors.



3 QUESTIONS FOR...

Patrick Faisques

«Veolia Environnement has taken the path of capturing, transporting and storing CO₂»



What are the stakes with CO₂ storage?

“This is one of the solutions envisaged in the fight against climate change. The European Union’s objective is a 20% reduction in greenhouse gas emissions by 2020. The Commission, as part of its Climate action package, mentions CO₂ capture and storage as one of the main contributors to the worldwide reduction in greenhouse gases. It has just proposed a regulatory framework for this technology and encourages the construction of demonstration pilots in order to improve knowledge. The French national Conference on the environment also promoted the development of research in this domain. The objective is to make this solution available as quickly as possible. Veolia is already acting for better energy efficiency and the development of renewable sources of energy as well as alternative fuels. We are now committed to CO₂ capture-transport-storage.”

What research program is Veolia Environnement conducting in this domain?

“After an initial exploratory phase, we launched a pilot operation designed to merge multiple research programs. We will capture the CO₂ contained in the flue gases of an energy recovery unit, fed by non-hazardous waste landfill gas, in a geological reservoir. After examining several storage solutions abroad, we looked for geological structures capable of acting as a worldwide CO₂ reservoir: saline aquifers, over 1,500 meters deep, presenting optimal characteristics to retain CO₂. We identified a site adapted to these geological characteristics, in Claye-Souilly, Île-de-France region, near our research sites. With a volume of 200,000 tons of CO₂ due to be captured and stored each year, this

industrial-scale pilot will be the largest of its kind in France. Our objective is to operate the entire capture-transport-storage system by 2012.”

What precautions did you take before carrying out this large-scale test?

“Hydrocarbon producers have been re-injecting CO₂ into the subsoil for twenty years. They store it in geological reservoirs, former oil or gas fields, saline aquifers. We drew our inspiration from their practices. In addition, we called upon experts, geologists and storage engineering specialists to carry out technical feasibility studies: Geogreen, a joint venture between BRGM, the IFP and Geostock. The pre-feasibility study established that it was possible to store CO₂ in the Paris Basin under certain conditions. The ongoing feasibility study takes into account all possible risks with regard to the subsoil, its structure and other uses. It examines, among other things, whether saline groundwater tables are watertight and not connected to nearby tables, including surface groundwater used for drinking water production. In total, project feasibility will be examined for eighteen months. This group of experts is also in charge of making proposals for the operation of the reservoir – its size, injection rate etc. If its positive conclusions are confirmed, we will then develop our storage observation program to check that the operation is carried out in accordance with the previously modeled conditions, within a long-term perspective.”

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Chief Editor and editorial manager:

Fanny Demulier

Editor:

Émilie Pottier

Copywriting: Monik Malissard

Design: Dream On

Contact : Research Division

19 rue La Pérouse

75016 Paris - France

Tél. : +33 (0)1 71 75 10 88

Fax : +33 (0)1 71 75 05 92

Mail : fanny.demulier@veolia.com