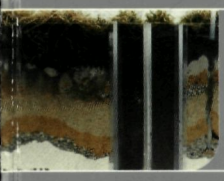

# SCIENTIFIC REPORT 1999

VITO
Flemish Institute for Technological Research
MOL

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NORDIC "SWAN"

# Scientific Report 1999


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# Introduction

In line with its redefined mission Vito has committed itself to ***stimulate sustainable technological development*** and is expanding its R&D potential, its knowledge base and its highly specialised service capabilities accordingly. This general objective is translated into concrete actions and projects in ten ***centres of expertise***, which cover three major activity domains, namely energy, environment and materials. A selection of the successes that were achieved in 1999 is presented in this annual scientific report.

A few years ago Vito decided to operate as a customer-driven but independent research company. The majority of its activities has therefore become part of contractual agreements with either public authorities or industrial clients. However, an important part of the research capacity remains devoted to strategic (self-initiated) R&D. This allows Vito to build up expertise and strengthen the knowledge base prior to customer or market requirements: Vito wants the answers before the questions are asked.

During last year's dioxin crisis the effectiveness of this approach became cristal clear. The availability of highly qualified laboratory facilities and the know-how of our employees based on over a decade of active involvements in European networks dealing with dioxins and PCBs, were crucial supports to the Belgian authorities. Investing in future technology developments therefore continues to be a key-point of our strategy, which you will find reflected in the items treated under the different headings of the centres of expertise further in this report.

Seizing and creating opportunities for co-operation with other players in the field of R&D and innovation has become a fixed habit in our approach. Embedding our strategic R&D in a number of national and international (European) projects and networks is used as a multiplicator for the efficiency of our R&D efforts.
In this context Vito is also supporting a number of PhD students, who perform their research work in the laboratories of Vito under a common promotor supervision of a university professor and a Vito researcher. In 1999 four new grants were awarded and four students obtained their PhD degree.

The considerable increase of the scientific output, which was achieved in 1998, could be consolidated in 1999. The dominance of the number of reports is due to the priority, which is given to tailoring our expertise so as to be able to respond adequately to the needs of industrial and public clients. However, in a number of high-tech fields Vito was also very prominently present on the international publication scene, as evidenced by the publication lists, which are included in this report (Fig. I1).

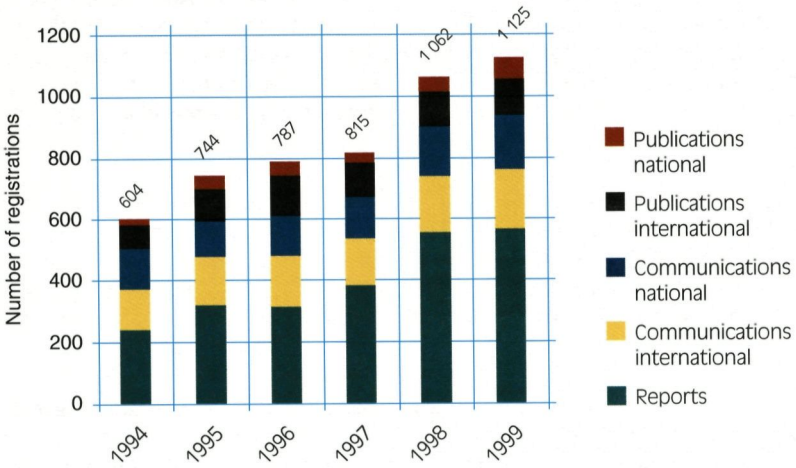


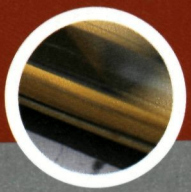

*Fig. I1: Evolution of the scientific output*

This publication has been conceived to inform you about our mode of operation and about the technology fields we are active in, by highlighting a number of our recent accomplishments. We hope that it can be the starting point for many new fruitful co-operations, yielding sound solutions for the technological challenges that you, we and our society will encounter tomorrow.

**Dr Rik Schrooten**
Managing director

# Energy

Rational use of energy



Traffic and environment

Product and process assessment

# Rational use of energy



*In the field of Rational use of energy (RUE), Vito's main task is to generate and disseminate reliable information on where, how and how much saving can be realised in a realistic way and without loss of production or comfort. Research and development is performed on specific technologies. Evaluation and dissemination of results of new and proven technology is carried out in promotional programmes and networking.*
*As there is a close link between Rational use of energy and 'Renewable energy' programmes such as cold/heat storage and biomass are also undertaken. In the near future more specific technological topics will be covered, and from 2000, the centre will be renamed as 'ENERGY TECHNOLOGY'.*

## Energy technology demonstration projects

Vito monitors and evaluates demonstration projects within the context of the Flemish Demonstration Programme for Novel Energy Technology. This is necessary in order to obtain accurate and reliable evaluation data, as the equipment suppliers only guarantee theoretical results, and are not very interested in doing on site efficiency evaluation. During a period of at least one year energy flows and other relevant parameters are measured. Based on these measurements a technological analysis of the new technology, an economic evaluation and a determination of the primary energy savings and $CO_2$ emission reductions are made.
Three projects of combined heat and power generation (CHP) showed good results. The first is a CHP installation in an horticulture company. The electricity produced is delivered to the national grid and the heat produced is used for greenhouse heating and water heating. New elements in this project are the use of the $CO_2$ produced by the CHP for increasing growth and production of the plants, and the use of a flue gas condenser for increasing the thermal efficiency. The CHP reduces the primary energy consumption with 15,016 GJ/year or 31 % compared to separated production of heat and power. The payback time of the investment for the company is 5 years.
The CHP installation of a company, which manufactures polyethylene for floppy disks and for foam packing materials, has been monitored in a second project. The blowing medium for the material is butane. Part of the butane is recovered from the production sites and is used as fuel in a CHP. The electricity produced is used in the production plant, the heat produced is used for heating the production sites and for driving an absorption water chiller. The primary energy saving amounts to 20,000 GJ/year. The simple payback period is 5 years.
A third project involves a dairy company. The electricity produced is delivered to the national grid, the heat is used for the production of process steam and supply water. The reduction of the primary energy consumption amounts to 13,909 GJ/year. The simple payback period of the investments is 2.4 years for the company.

## A thermo-technical laboratory and demonstration facilities

Vito has developed a new technical laboratory for research and testing of thermal energy systems with a maximum thermal power of 400 kW. Dynamic tests of (combinations of) thermal systems at different water temperatures (between 6 °C and 95 °C) can be performed. Combined with this thermo-technical laboratory a demonstration facility for energy efficient building technologies has been worked out. Small scale combined heat and power, heat pumps, efficient and condensing boilers can be demonstrated under real working conditions for potential users (in particular for starting small and midsized enterprises). Other energy efficient technologies for the building industry are solar collector systems for the production of hot tap water and photovoltaic solar systems for the production of electricity. In addition a demonstration facility for energy efficient lighting for buildings has been worked out. The project is acknowledged as strategically important and funded by the European regional development fund (ERDF).

## Energy efficiency of domestic heating

Technical tools for the evaluation of existing heating systems and the correct choice of new technologies have been further developed and put into practice. In a European project (SAVE) a joint research between 11 laboratories resulted in 'BOILSIM', a computer tool to calculate the annual efficieny of old and modern heating systems. In this framework Vito did set up an extensive database with the energy characteristics of different boiler types used throughout the EU.

The BOILSIM programme was translated into an evaluation tool for the Flemish installers, called VLAMEK. This tool makes it possible for an installer to make a quick but fairly accurate estimation of the energetic, economic and ecologic benefits of energy saving measures for heating installations. As a try-out the tool was applied to about 40 dwellings in co-operation with several installers and the Belgian oil and gas industry. The results show that about 50 % of the end-users were planning to carry out the energy saving measures proposed on the basis of the VLAMEK calculation tool. Most of the measures relate to the replacement of boilers or burners and resulted in energy savings up to 35 %.

The developed evaluation tools were also used in a study for the Belgian energy sector in which the efficiencies of modern heating systems were compared for different building types. Specific conclusions were drawn with respect to the importance of condensing boilers and modulating burners: under low heat demand, e.g. in well insulated dwellings, the annual efficiency of modern on/off boilers can decrease significantly, while modulating burners show a constant performance even at loads lower than 5 %.

## Combined heat and power

In 1999 a project on 'CHP and $CO_2$ emissions' was carried out on behalf of Electrabel/SPE. Based on prior Vito work, the main conclusion was that CHP could substantially contribute to a reduction of $CO_2$ emissions. However, for small scale CHP, (with limited operating hours) results were rather ambiguous. In comparison with new large-scale investments (gas fired combined cycle), small scale CHP may need additional power which, in the Belgian context of today, is provided by coal fired power plants which would have a negative impact on the final result.

For the promotional organism Belcogen a number of tasks were carried out in 1999. The guidebook on CHP has been published and will be updated on a regular basis as well as the inventory of CHP projects in Flanders. (Fig. REG 1)

Vito continued to perform CHP feasibility studies for different sectors. In 1999 an important study was made for the hospital Stuivenberg in Antwerp.

*Fig. REG 1: Demonstration of the combined use of heat and power (CHP) in horticulture. The addition of a flue gas catalyst and a condensor allows to use the flue gases for $CO_2$ fertilisation in the greenhouse.*

## Thermal energy storage

Ambient thermal energy, winter cold and summer heat from the air, can be stored in aquifers (ATES – Aquifer thermal energy storage) and can be used for cooling purposes in summer and for pre-heating in winter. A cold/heat storage system can be used for cooling a building or an industrial process, resulting in energy savings of between 40 and 80 %. Introducing energy storage increases the use of renewable energy and has a positive impact on the environment as compared with conventional cooling installations.

Vito is promoting ATES in Flanders since four years and feasibility studies have been carried out. Two installations are in service now, three are under construction and the design work has started for five other projects. Vito has realised a breakthrough in the Flemish market of the technology of ATES and this effort will be continued by a spin-off firm. As a support to the authorities responsible for water licences (AMINAL), Vito has made a detailed inventory of the hydrogeology of Flanders in relation to the applicability of ATES.

A feasibility study was initiated on the technology for high temperature (> 50 °C) thermal energy storage in the underground (UTES) at high temperatures (> 50 °C) with vertical heat exchangers. Such type of energy storage can improve the attractivity of the utilisation of renewable energies, in particular solar energy and the utilisation of waste heat from industrial processes. In connection with CHP (Combined heat and power) energy storage will improve the energy savings even more. The project 'High Temperature Thermal Energy Storage in Saturated Sand Layers with Vertical Heat Exchangers', running under the Fifth Framework Programme of the EU, will explore the application of UTES in conditions which are not only typical for Flanders, but for many regions in Europe.

## Power electronics and lighting

The EUREKA ELGADI project in co-operation with VERDEYEN NV, SYLVANIA NV and IES SA (France) has been completed. This resulted in new dimmable electronic ballasts for street lighting with fault monitoring for 70, 150 and 250 W HPS lamps. These ballasts are commercialised under licence by VERDEYEN. The development of new ballast types and accessories is continued.

A new electrical safety relay (Fig. REG 2) was developed in the ERDF framework (European Regional Development Fund) for EUROPOWER bvba. This device protects users and electrical equipment against electrical hazards by monitoring insulation faults, frequency and voltage. It is particularly useful for mobile power units because the star point of the generator (or transformer) must not be connected to earth, which is not always done in practice although it is required when using a residual current detector. This system can be manufactured cheaply and will increase safety in the application of small mobile electrical power units.

*Fig. REG 2: Safety relay for mobile power units*

An evaluation for a new daylighting system developed by ETAP NV was started in the framework of a VLIET-bis (IWT) project. The system consists of a special retro-reflective solar blind, a dedicated reflector at the ceiling and lighting fixtures equipped with a daylight responsive dimming system. Strategic research was focused on inverters for electrical generators, grid-coupled inverters, daylighting systems and new types of lamp ballasts.

## Energy efficiency networking

Vito is the Belgian representative in the International Energy Agency's CADDET (Centre for analysis and dissemination of demonstrated energy technologies) information network. This network collects and disseminates information on energy efficient technologies and renewable energy in 13 countries. Vito also runs the Belgian National Team through which information is distributed by means of newsletters, brochures, reports, workshops and a database. By the end of 1999, 980 Belgian subscribers from industry, utilities, consultants, institutes, energy end-users, suppliers and government were grouped in the CADDET Energy Efficiency network. Via these networks, Flemish energy technology, used in industry or in SME's, is promoted at an international level.

As main partner in VTC (Vlaamse thermie coördinatie), Vito also participates in the Organisation for the Promotion of Energy Technologies (OPET) network.

The OPET network is a collaborative venture between the demonstration component of the JOULE-THERMIE Programme (Joint opportunities for unconventional or long-term energy supply). It is formed of 41 OPET's, located in all member states of the European Union and associated countries such as Norway, Iceland, Liechtenstein and Israel. In 1998, 13 fellow members were added to the OPETs Network (FEMOPETs) to cover the Central European area.

Each year VTC implements a targeted set of actions, aimed primarily at a given technology or sector, focusing on how to provide activities which meet the real needs of market actors. In 1999 focus was on information days on renewable energy in social housing, biomass database, replacement of old domestic boilers and the organisation of SME information days on RUE.

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# Traffic and environment

*The centre of expertise Traffic and environment evaluates and optimises the energy and environmental aspects of vehicle and fuel technologies, components of drive trains and traffic. Special attention is given to experimental studies identifying the relation between real traffic situations and the performances of new technologies. Important research efforts are put in the development of tools and models for supporting market orientated projects. Voem, Vito's on-the-road emission and energy monitoring system, and E²Trac, Vito's test infrastructure for drivelines have become internationally acknowledged tools for the control and improvement of the environmental impact of traffic.*



## On the road measurements with VOEM

The European legislative emission tests for vehicles are not representative enough for real traffic behaviour. To get realistic numbers for the gaseous emissions an in house developed and validated on-board tailpipe emission monitoring system VOEM is used. The entire system is built into the vehicle and the energy parameters and the exhaust gas emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides ($NO_x$) and carbon dioxide ($CO_2$) are measured while the vehicle is actually driven on the road. Recently Voem was upgraded with a module for dynamic mass particulate matter (PM) emission measurements. The new part consists of a Tapered element oscillating microbalance (TEOM) measuring device coupled with a portable micro dilution tunnel sampling system. The TEOM is mounted in vehicles in such a way that the influence of on-road conditions such as shocks, vibrations and accelerations is minimal. It proved to have a zero stability below 2 mg/m$^3$. The system is computer controlled. The VOEM PM measurements were successfully validated versus a constant volume sampling chassis dynamometer.

To demonstrate the system capabilities a latest technology EURO-2 diesel city bus, owned by the Brussels public transport company MIVB, was measured. The bus was selected from a group of similar vehicles based upon its low opacity reading. On a circuit a city cycle was driven in both power and economy mode. The CO, HC, $NO_x$ and PM emissions in power mode were respectively 5, 1.3, 20, and 0.5 g/km. In economy mode the results were respectively 6, 1.0, 19 and 0.9 g/km. Although the bus was by 10 % more energy efficient in the economy mode, the PM emissions were nevertheless higher. This PM emission increase is due to the engine operating in low lambda conditions for longer periods in economy mode

## Realistic testing cycles for heavy duty vehicles

In the framework of the Impulse programme for energy technology of the flemish government (VLIET), a research project was set up to develop a test methodology for the evaluation of the environmental impact of heavy duty vehicles (HDV). By environmental impact is meant the fuel consumption and emissions of $CO_2$, CO, HC and $NO_x$. HDV are, in contrast with passenger cars, not subject to a type-approval test for the vehicle. Only the engines of the HDV are subject to a type-approval test, but in view of the wide variety in the use of the engines, it is not evident to transpose the engine's test results to the environmental impact of the vehicle under realistic operating conditions.

However, there is a need for a methodological evaluation of this impact, both for fleet owners and policy makers. They need a scientific base for their decisions when buying respectively promoting environmentally friendly vehicles.

Two major criteria must be kept in mind in the development of testing cycles. The testing cycle must be representative for the daily operation of these vehicles, and the tests must be reproducible. To deal with these two requirements, the commonly used approach of speed-vs-time profiles was abandoned. The main reason for doing this, is that in reality the vehicle itself has a major impact on its kinematics, certainly during the acceleration phases. Therefore the approach of a speed-vs-distance approach is followed, in which the term 'speed' must be interpreted as the targetted speed at each location. It are the intrinsic vehicle capacities that define at which locations the maximum speed level is reached or not. Fig. V&M 1 illustrates this principle: both the maximum speed levels of the testing cycle and the actual speed levels as measured with the tested vehicle are plotted.

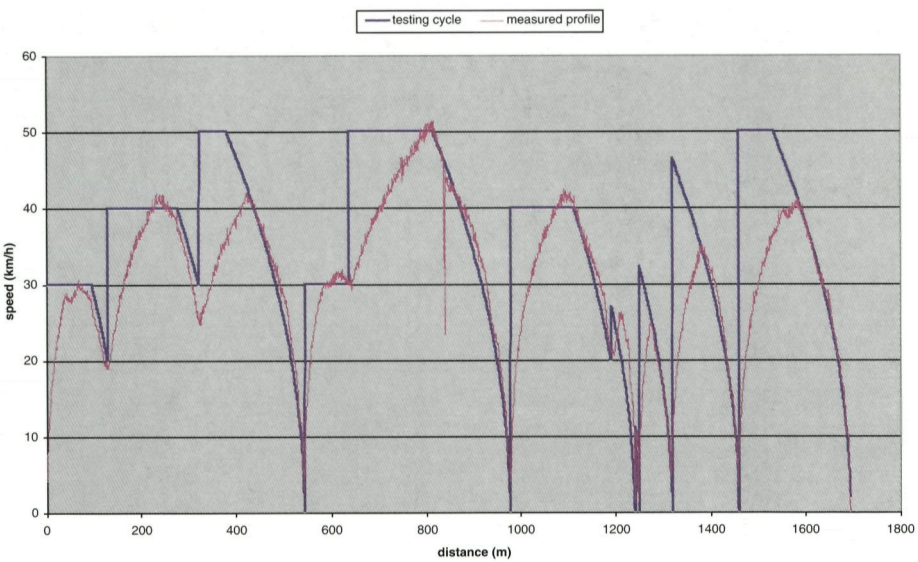


*Fig. V&M 1: Realistic behaviour of a vehicle driving a test cycle. The bold line represents the targetted speed during the test cycle; the thin line represents the speed recorded during an actual test. The fact that the bold line does not impose the full kinematic behaviour of the vehicle, guarantees a realistic operation of the vehicle during the test.*

Two methodological aspects were investigated in detail. The first concerns the extraction of representative speed-vs-distance profiles out of the registered daily operations of a vehicle. The second concerns the best practice to achieve repeatable test results using this speed-vs-distance approach. For this purpose a driver-guidance system was developed, that specifies amongst others the driving behaviour. First results obtained with this system show that an adequate repeatability of the test is feasible.

The results of the study are discussed in the COST 346-network. This COST action compares different methodologies and models to quantify the real emissions of HDV.

## Evaluation of hybrid and natural gas vehicles

Manufacturers invest a lot in the development of new engines and drivetrains for complying with the most stringent emission legislations. However, minimal energy consumption and emissions can only be guaranteed if the technology is chosen as a function of the application. This is particularly true for HDV and the effect is most pronounced for HDV running on gaseous fuels or HDV with hybrid traction. Vito carried out different measuring campaigns for various national and international clients to quantify the effect of the chosen technology on the environmental performance of the vehicle in real operating conditions.

On behalf of the Flemish Administration for natural resources and energy (ANRE), Vito has evaluated a hybrid bus of the Flemish public transport company, De Lijn. The main goal of this evaluation was to investigate the possibilities for enhancing the performance of the bus. A bus equipped with the VOEM system was driven on a circuit or on the actual exploitation route. Fig. V&M 2 illustrates that the power, generated by the engine under these conditions, varied with the state-of-charge (SOC) of the battery. When the battery is almost fully charged the power of the engine is low, while under low SOC the engine power is high. Under normal operation of the bus in the city of Leuven, the SOC of the battery stays above 60 Ah. The engine is therefore working under low power conditions, for which the fuel efficiency is low and the emissions are high. This situation could be improved by installing a smaller engine.

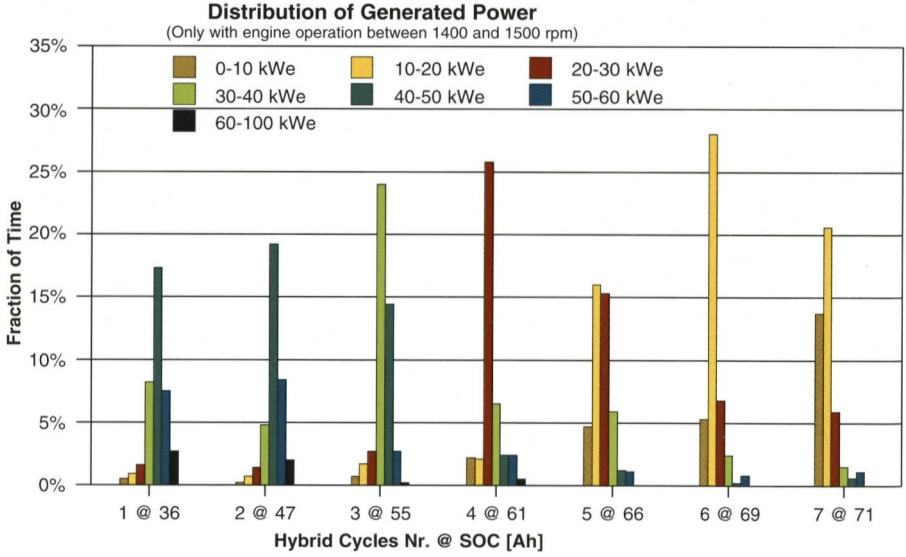


*Fig. V&M 2: Engine power as a function of the state-of-charge (SOC) of the battery. When the state-of-charge of the battery increases from 36 Ah to 71 Ah (fully loaded), the average engine power decreases from 45 kWe to 15 kWe.*

In the framework of an international project, the fuel consumption and emissions of a natural gas bus with a stoechiometric engine were measured under various load conditions with VOEM. This was done on a test track, used by the local public transport company. The measurements were performed with a fully loaded bus (6,400 kg), an average load (3,700 kg) and a small load (1,000 kg). The results, given in Table V&M 1, show that the emissions, especially $NO_x$ and CO, are

influenced by the load conditions. This can be ascribed to the different working points of the engine. Under heavy loads the engine works more under maximum torque conditions, while under low loads higher engine speeds are obtained. The $CO_2$ emissions are directly related to the fuel consumption, which increases with the total mass (load) of the vehicle.

| Load kg | $CO_2$ g/km | CO g/km | HC g/km | $NO_x$ g/km |
|---|---|---|---|---|
| 6,400 | 1,461 | 0.46 | 0.18 | 1.92 |
| 3,700 | 1,385 | 0.63 | 0.16 | 0.82 |
| 1,000 | 1,137 | 0.30 | 0.11 | 2.84 |

*Table V&M 1: Emissions of a natural gas bus under different loading conditions, according to a testing cycle of a public transport company.*

The city of Turnhout started in 1999 a demonstration project financed by ANRE with 3 light duty trucks running on natural gas. The gasoline engines of three Ford transit vans were converted to bi-fuel natural gas-gasoline engines. The vehicles can drive on natural gas or on gasoline. The project was set up to demonstrate the potential of natural gas as a practical and environmentally friendly fuel. To investigate the environmental benefits of the vehicles, measurements with VOEM were carried out. Tests were performed on the highway, rural ways as well as on city roads. Driving on the rural roads and the highway gave a fuel consumption that was 20 - 25 % lower as compared to city driving (Table V&M 2). The lower carbon-hydrogen ratio of natural gas compared to gasoline resulted in lower $CO_2$ emissions (10 - 15 %) for the natural gas driving for all three road types. For the other emissions (CO, HC and $NO_x$) the same straight relation between natural gas and gasoline was not found. In the city the natural gas vehicle had lower $NO_x$ emissions but equal CO and HC emissions as compared to gasoline, whereas on the highway CO emissions were lower but $NO_x$ emissions were higher. This is mainly due to the fuel-control system. For gasoline the engine is capable to keep the air-fuel ratio close to stoechiometric (average lambda around 0.99). When the engine runs on natural gas the air-fuel mixture tends to be rich. Especially under city conditions, with a higher fuel consumption and a dynamic load, the air-fuel mixture becomes rich (lambda-value around 0.977) resulting in low $NO_x$ but high CO emissions.

| Fuel | Road type | Emissions $CO_2$ (g/km) | CO (g/km) | HC (g/km) | $NO_x$ (g/km) |
|---|---|---|---|---|---|
| Natural gas | City | 337 | 2.0 | 0.05 | 0.20 |
| | Rural | 274 | 1.0 | 0.19 | 0.25 |
| | Highway | 275 | 0.1 | 0.03 | 0.53 |
| Gasoline | City | 392 | 2.5 | 0.03 | 1.28 |
| | Rural | 297 | 1.9 | 0.02 | 0.53 |
| | Highway | 305 | 2.5 | 0.04 | 0.37 |

*Table V&M 2: Emissions of a bi-fuelled van (natural gas-gasoline) under different traffic conditions*

## Models and databases

For the calculation of emissions from road transport, Vito developed the emission model TEMAT. This model calculates historical emissions and predicts future emissions for different scenarios. The emissions are calculated from the emission factors, the vehicle fleet and the annual mileage. These three parameters vary with year, fuel, age, emission norm, road type, traffic conditions and cylinder capacity. The emission factors for cold and hot emissions and evaporation emissions are taken into account. Different composition of the future fleet can be calculated starting from the mobility demand and the historic fleet composition. Therefore, a variable surviving curve was implemented in the model.

Scenarios can be defined by combining different tables with input data that quantify the three basic parameters. Because of its flexibility, the TEMAT model can be used to evaluate different scenarios, which include present and/or future measures for road transport. The model can be adapted to the Flemish, Belgian or even European situation. The TEMAT model strengthens the scientific basis for evaluating different measures in transport. It is an important tool for advising policy makers in relation to traffic and environmental problems.

A database was developed and put on the internet to inform the consumers on the fuel consumption of new cars available on the Belgian market. In this way, it is expected that a shift in purchase behaviour towards more fuel-efficient cars can be provoked. Each car receives a 'fuel economy label'. This label is based on the fuel economy of the car compared to cars of the same size (defined as length x width) and the same fuel type. The comparison is made by means of a regression analysis on fuel consumption as a function of size. The fuel efficiency is expressed as the deviation in terms of percentage of the regression line. On behalf of ANRE, research is carried out to investigate the possible introduction of other, more market oriented, parameters. Information is given on the difference between official fuel consumption data and on-the-road consumption and emissions, effects of driving behaviour and traffic conditions. Recommendations are made for economical driving. One year after the introduction of the Internet database 25,000 visitors were registered, or an average of 63 visitors a day (http://www.vito.be/autoverbruik) (in Dutch).

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# Product and process assessment

*The centre of expertise Product and process assessment develops integral evaluation methods for products and processes taking into account environmental, energetic and social aspects. The implementation of these methodologies in practice supports authorities and companies in their commitment for a sustainable management of the environment.*

## Life cycle assessment and ecodesign

A demonstration project on ecodesign has been initiated. The project is funded by the European LIFE programme and is executed by the Regional Development Authority of West Flanders (GOM West-Vlaanderen), the VDAB Training and Education Group and Vito. The goal of the project is to give the Flemish industry the opportunity to build up knowledge and expertise in the area of sustainable product design (ecodesign) and to stimulate companies to implement this methodology in their design process.

Furthermore, Vito has participated in a project that aimed at the inventarisation and analysis of the state-of-the-art of ecodesign in Europe. This project has been executed through the ESTO network (European Science and Technology Observatory) by a consortium of 5 institutes acquainted with the subject of ecodesign. Vito conducted the country studies for Belgium, France and Luxembourg. The main conclusion regarding the situation in Belgium is that ecodesign became only recently a topic of interest for research institutes as well as for companies. However, it seems that ecodesign is gaining momentum now, especially in the Flemish Region. The LIFE-project mentioned earlier illustrates this.

A cleaner production information network (CPIN), a WWW-based pilot project commissioned by the European Environment Agency (EEA), has been established. This European network aims to promote cleaner production in Europe by improving communication between scientists and industry. It is the intention to set up a global telematic network, based on the experience with the European network.

## Assessment of environmental damage costs of energy and transport

Vito develops and applies methodologies for the evaluation of environmental damage caused by economic activities. To this purpose, Vito is part of the European-wide ExternE network of scientific institutes that apply the ExternE methodology for the assessment of external costs of energy and transport, i.e. the calculation of impacts and damages for public health, the natural and man-made environment. These tools and data are further developed and applied for projects performed on behalf of national and regional authorities and the industry. The main work of Vito in this area covers a wide range of issues and clients (Fig. PPE 1):

- Vito participates in European (EU, Joule) and national research projects (OSTC) to calculate the external costs of transport in Belgium. A detailed, European model has been implemented for Belgium to assess external costs for different vehicles on selected trajectories. These results were introduced into a model for the calculation of external costs at a more aggregated level (e.g. all passenger cars for a certain year).
- As co-ordinator of the ExternE Concerted Action network Vito organised two meetings in Brussels. It showed that, in all EU-countries, the expertise built up with the EU Joule contracts, has been further developed and applied in national research programs, government agencies and industries.

- In the framework of a research project (VLIET bis) for the Flemish government Vito made first estimates of the external costs caused by air emissions from all energy uses in Flanders.
- The ExternE accounting framework is further being completed and integrated with expertise and models in related fields (emissions, dispersion models, human and eco-toxicity) in view of an integrated approach for risk assessment.

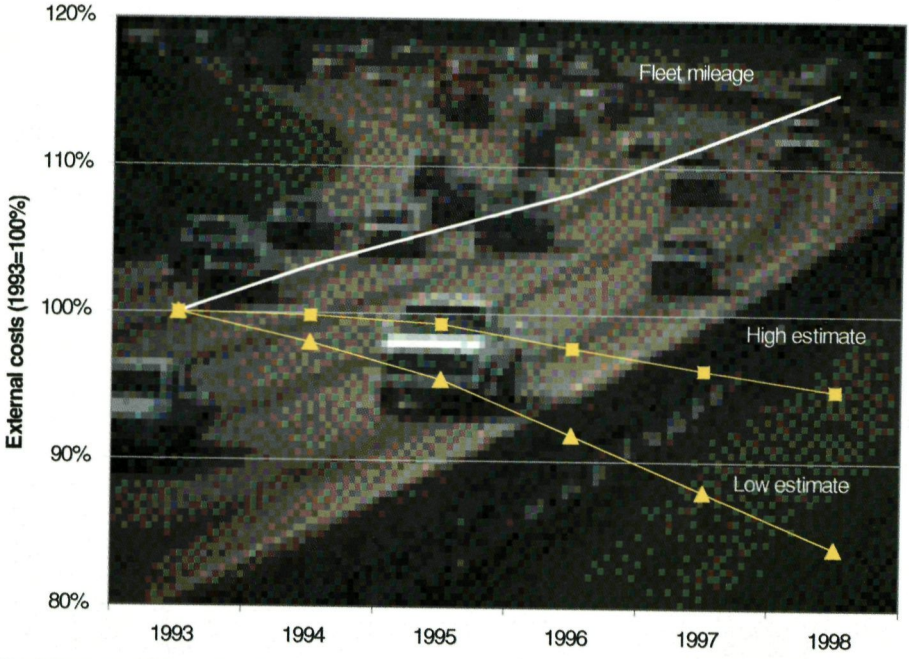


*Fig. PPE 1: Evolution of fleet mileage and external costs from air pollutants for Belgian passenger cars over the period 1993 - 1998*

## Technology assessment

The project group Technology assessment concentrated its work on the elaboration of its network activities and performed different studies for a variety of clients in the field of sustainable development.

The group continued its role as the Belgian representative in the European ESTO network (European Science and Technology Observatory) on behalf to the Institute for Prospective Technological Studies at Seville. The ESTO network is composed of seventeen European institutions from 12 countries, all with experience in the field of scientific and technological assessment at the national level. ESTO aims at detecting at an early stage scientific or technological breakthroughs, trends and events of potential socio-economic importance, which may require action at a European decision-making level. The main clients for these activities are European science and technology policy-makers, in particular within the Commission.

The European Vocational Training Association commissioned a study that analysed the existing and professional education and training responses to support the improved environmental performance of SME's in Belgium. This resulted in a national profile that provided the basis for a series of recommendations aimed at each of the key actors and to which European Commission

policies could be directed to support implementation.
For the College of Europe in Bruges a definition study was supported on a proposed research and training initiative for the United Nations University. This centre will be located in Bruges and will deal with issues in the field of inter- and intra-regional integration.

## The Flemish centre for Best available techniques (BAT) and the Energy and environment information system (EMIS)

The centre for Best available techniques (BAT) is founded by the Flemish Government and hosted by Vito. The BAT centre collects, evaluates and distributes information on environmentally friendly techniques. In 1999 BAT reports on laundries, vegetable processing, ceramic industry, service stations and used oil processing were published.
Laundries face a difficult economic situation: the market is declining and internal competition is fierce. The extensive use of process water and energy as well as the quality of the waste water are the key environmental issues for this industry. The BAT selected consists of waste water purification using biological systems for larger laundries and several measures of good housekeeping, including the installation of mangle hoods and frequent maintenance of equipment (Fig. PPE 2).

*Fig. PPE 2: Example of a 'Best available technique' for the laundry sector: automatic dispensers reduce the detergent consumption and water pollution.*

The BAT study on the service stations focused mainly on the techniques for preventing petrol vapour emissions and, more particularly, the vapour recovery during car tank filling (so-called stage II systems). Emissions of volatile organic compounds released during the filling of the petrol car tanks contribute to the creation of ozone in the lower layers of the atmosphere, cause odour pollution and can present danger to human health. Vapour recovery was shown to be BAT for most of the service stations. A regulation to introduce vapour recovery (stage II) was suggested to the Flemish authorities. The average cost of stage II vapour recovery is 0.04 to 0.09 BEF per litre. It will reduce VOC emission in Flandres by about 1,000 tonnes per year.

The clay processing industry produces ceramic products by heating clays or loam. Air pollution is the main environmental issue for the clay processing industry. Through the flue gases that arise during the baking process, the sector is a source of $SO_x$, HF, HCl, dust, VOC and other emissions. BAT for flue gas purification are $CaCO_3$ adsorption and post combustion (of initial VOC > 150 mg/Nm$^3$). By applying the BAT measures, the Flemish clay processing industry should be able to accomplish emission reductions of 25 % for $SO_2$, 76 % for HF, 50 % for HCl, 65 % for dust and 53 % for VOC. In turn, an average Flemish enterprise will have to carry an additional yearly cost of 10 million BEF, as a minimum. BAT associated emission limit values proposed, depending on clay composition, are: $SO_x$: 500 - 2 500 mg/Nm$^3$, HF 5 - 15 mg/Nm$^3$, HCl: 30 mg/Nm$^3$, dust: 50 mg/Nm$^3$ and VOC: 50 - 150 mg/Nm$^3$.

The key environmental problems for the 'fruit and vegetable processing industry' are the use of large volumes of groundwater and the production of waste water polluted with organic carbon, nitrogen and phosphorus. BAT on waste water treatment are e.g.:

- primary and aerobic waste water treatment for small potato peeling enterprises;
- primary, anaerobic and aerobic waste water treatment, including nitrification / denitrification / defosfatation for larger companies.

Annual waste water treatment costs for an average enterprise were estimated to be 15 - 20 million BEF. Water-saving BAT measures and re-use of water might cause a 25 - 30 % decrease in the use of ground water.

Used oil is processed in the Flemish region by different processes, including the removal of sediment and water, incineration and injection in blast furnaces. A new initiative is the re-refining route that yields distillates suitable for the production of base oil. BAT assessment showed that the re-refining project and the use in the blast furnace are the most preferred options. Almost as good are recycling of industrial oils, co-combustion in cement kilns and the use as fuel in a hazardous waste incinerator. When the 170,000 ton of used oil that are annually produced in Flanders, are treated according to BAT, $SO_2$ emission could be lowered from 2,000 to below 200 t/y. The emission of metals would be reduced to 36,000 kg/y as compared to the total of 40,000 kg/y.

The EMIS website (http://www.emis.vito.be) has seen an ever increasing number of visitors. In December, 15,000 visitors found information on energy or the environment on EMIS. Popular themes like the new legislation, jobs, the green guide, etc. have been continuously updated. The important changes of the Vlarem-legislation (first of May 1999) have been incorporated the same day in the Flemish navigator (http://www2.vito.be/navigator/default.asp). In co-operation with the Flemish Waste Agency OVAM and Infomil (NL) and the Dutch provinces, a new site (http://www.milieuwinst.nl) has been established where SMEs and households can easily find hints for environmental pollution prevention. Further, the Felnet site was officially opened (http://www.felnet.org). The Felnet website gives access to the integrated library catalogue of Flander's most important environmental libraries.

## Energy and environmental studies

The Energy and environmental studies project group focused its activities on emission and emission reduction related studies. These studies concerned mainly the global warming issue and were linked to the regional and federal policies. The challenge is the selection of greenhouse gas reduction measures to achieve reduction targets, as agreed within the Climate Convention UNFCCC, without threat to our economy or standard of living. As one of the major tools used to evaluate policies and measures and emission projections, the MARKAL model is used, an energy technology optimisation model developed through the Energy Technology System Analysis

Programme (ETSAP) of the International Energy Agency (IEA). The OSTC funds the scientific work and development related to this model, for which Vito together with CES Centre of Environmental Studies of the KULeuven are the national contacts. At Vito, the model is used to assess the federal greenhouse gas reduction plan, to update the Flemish regional $CO_2$/RUE policy plan and to assess the impact of different global warming reduction scenarios on the electricity production plan (Fig. PPE 3).

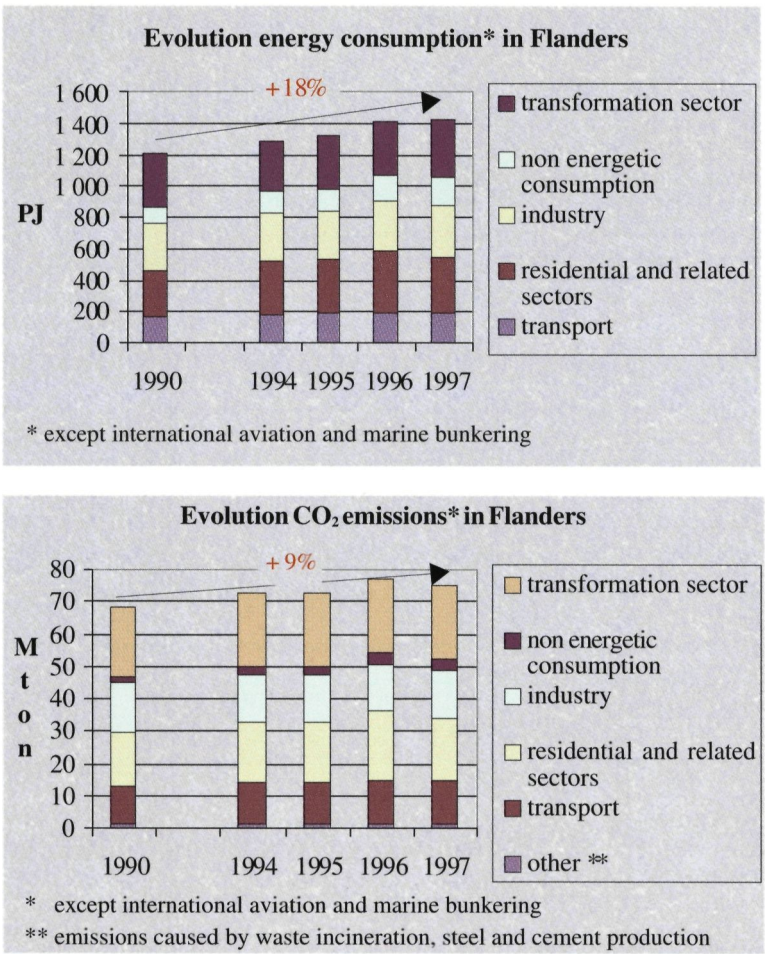


*Fig. PPE 3: Evolution of energy consumption and $CO_2$ emissions in Flanders over the period 1990 - 1997, based on Flemish energy and $CO_2$ emission inventory data collected by Vito.*

For each of these studies a sound basis of high quality data is required. Vito further improved the quality of the Flemish energy and $CO_2$ emission inventories by detailed inquiries of industry. In collaboration with the Institut Wallon, responsible for establishing the Walloon region inventories, a common methodology and data base has been developed in order to aggregate regional ener-

gy balances at the Belgian level. The annual energy balance and $CO_2$ emission inventory for Flanders were published for the year 1996. The regional inventories have been used to establish the Belgian emission inventories for 1996 and a preliminary inventory for 1997. These detailed and complete inventories are required for making emission projections and for evaluating emission reduction measures.

## Water pinch analysis

Water pinch analysis is a methodology for optimising the water management in complex industrial environments. In the past process integration techniques based on pinch analysis have been successfully applied to improve the energy efficiency in the chemical and process industries.

To extend its activities in water pinch analyses Vito has joined the 'Water pinch club', which was created by Linnhoff March. The activities on process simulation and process optimisation by pinch analysis were actively promoted in a Water pinch analysis seminar, which was jointly organised with Linnhoff March in Antwerp.

The application of WaterPinch® in oil refining and petrochemical processes has demonstrated that water savings up to 25 % can be achieved, when the changes are limited to adaptations of the piping and the control systems. More radical interventions such as process modifications or the selective regeneration of waste water allow even savings exceeding 50 %.

Vito focuses on water pinch studies, but whenever appropriate energy saving aspects (energy pinch) are also addressed. Vito is involved in several EU projects, in which water and energy pinch are combined and procedures for an overall optimised scheme are developed. Vito also extends its general knowledge on pinch technology towards other areas and is involved in a EU project on development and application of chemical pinch technology.

Vito has carried out water pinch studies for different companies with water licensing or waste water problems. The feasibility of the proposed process modifications are supported by simulation tests, using an Aspen Plus™ process simulator, and by laboratory or pilot scale regeneration tests, which provide valuable information for the final implementation of the optimisation scheme. Vito has carried out water and energy optimisation studies for companies in the food, steel and energy sector. As part of the project, investment roadmaps provide the necessary information for the companies concerning the investment cost required for the implementation of the proposed process schemes.

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# Environment

Environmental diagnostics

Remote sensing and atmospheric processes

Environmental toxicology

Environmental technology

# Environmental diagnostics



*The centre of expertise Environmental diagnostics has extended its activities continuously during the last year. Thereby we had numerous opportunities to demonstrate our competence, objectivity and reliability as a research partner for the government and for the industry. In this respect we can refer to the crucial role we played in circumscribing and solving the recent dioxin crisis in Belgium.*

*However, the most important task of the Environmental diagnostics group remains its role as the Flemish reference laboratory and as the structural scientific partner of the Flemish environmental administrations. In this way Vito meets an important structural need of the Flemish authorities. This can be illustrated by a number of new assignments that were granted last year such as:*

- *recognition of laboratories in the framework of the Flemish decree on overfertilisation (on behalf of VLM);*
- *studies for a sectorial smell regulation (on behalf of AMINAL);*
- *control system for soil investigations to keep an eye on the quality of the commercial services of recognised soil remediation experts and laboratories (on behalf of OVAM);*
- *further development of the network for continuous monitoring of the ambient air quality (on behalf of VMM).*

*In addition highly specialised and multidisciplinary environmental studies are undertaken at the request of the industry. Routine analyses or investigations that can be performed by commercial laboratories or consultants are not addressed.*

## Analytical support during the dioxin crisis in Belgium

End of May 1999 it was disclosed that an accidental contamination of feed had occurred in Belgium in the beginning of the year, resulting in high concentrations of dioxins and PCBs in chicken fat. Immediately the Ministry of Public Health installed an expert group to advise the authorities on the analytical approach to clear blocked stocks of products for the market, on cut-off values for the residues in food and on a monitoring plan.

Being considered as the centre of expertise in Belgium for analyses of dioxins and PCBs, Vito was entrusted a key role in working towards a suitable and feasible analytical approach. During the first decade of June the highest priority was given to gather critical evidence on the chemical pattern of the contamination. In a report to the European Commission it could then be pointed out that the pattern of the dioxins was virtually identical to that in the contaminated rice oil that poisoned 2,000 people in 1968 in Yusho, Japan (Fig. DIA 1). The pattern of PCBs in the feed was matched to a mixture of two widely used transformer oils. The concentrations of the PCBs (sum of 7 indicator congeners) and dioxins (toxicity equivalents) in the feed, as well as in eggs and poultry, were found to correlate closely, having an average ratio of about 50,000:1. Based on this information the European Commission could be convinced to follow a pragmatic approach, consisting of a screening of food items for PCBs with fixed cut-off values. This test is indeed much faster and cheaper than a dioxin analysis, and allows to achieve the required huge laboratory capacity within a reasonable time. During and after the crisis period Vito has been the reliable adviser on analytical aspects for the authorities. It contributed to the development of a normalised procedure for PCB analyses in feed and food, informed the dioxin commission of the Belgian parliament on analytical matters, and continues to be involved in the scientific steering of follow-up studies.

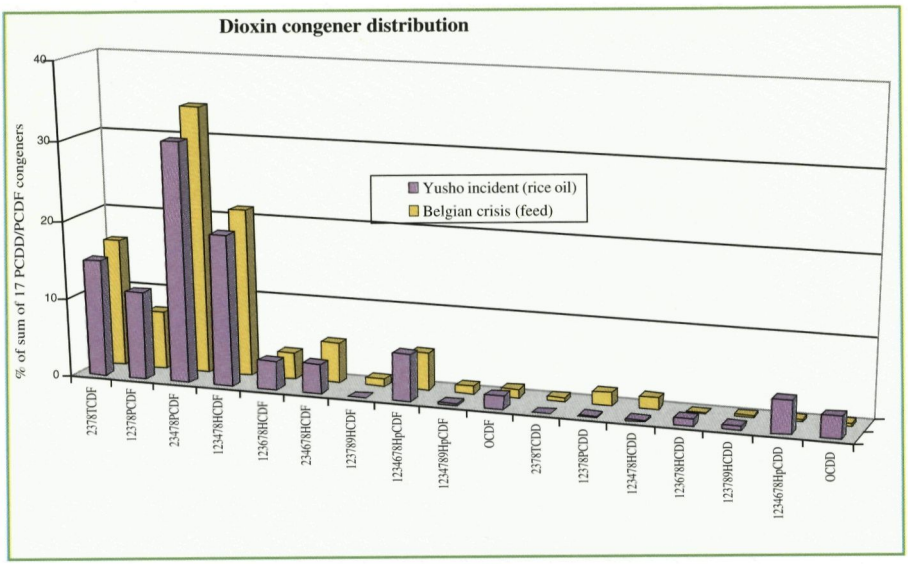


*Fig. DIA 1: The pattern of the dioxin contaminants in Belgian feed products was virtually identical to that in a PCB contaminated Japanese rice oil (Yusko incident); in an early stage of the dioxin crisis this was strong evidence for identifying PCB as the external contaminant.*

Obviously the dioxin crisis strongly influenced the laboratory activities. Following the request from the federal ministries to give highest priority to the analytical support during the crisis, ongoing research and analytical servicing were temporarily frozen and the organic laboratory was fully oriented towards PCB and dioxin analysis of feed and food. Most of the samples originated from the dedicated control of suspect farms, but Vito was also frequently asked to provide reference values when analyses by other laboratories appeared contradictory or dubious. The advanced technical principles (e.g. isotope dilution) and quality control of the Vito methods ensured the highest degree of reliability. Among the crucial dioxin analyses a series of ten consumer milk samples should be mentioned; they had been collected in March-May 1999 as part of the existing dioxin monitoring programme to which Vito collaborates since 1993. The results, obtained within about 1 week, turned out to be strong evidence for withdrawing a European ban on Belgian dairy products.

## Structural analysis of soot for source determination

The increase of fine aerosol in the environment has been a hot topic during the last years. Particles with small diameters can penetrate deeply into the airways and thus can cause a lot of harmful health effects. One of the least understood atmospheric aerosols is soot, a major component of fine atmospherical dust. Incomplete combustion forms particles, which condense into a black aerosol when cooling down. Due to their small dimensions (10 nm to 2 µm), their structure, and the ability to adsorb thousands of different species, these particles can cause severe health problems to men. Because soot strongly scatters and absorbs light and because it enhances cloud formation, it plays an important role in 'global change'. These effects are strengthened by the long residence times in the atmosphere and consequently by the possibility to be transported over long distances.

Because the effects soot causes depend crucially on its size, morphology, internal structure, and chemical composition, these features are studied to understand how these effects are produced and how they could be avoided. Since these structure characteristics are the result of the formation conditions and the combustion process, it might even be possible to use it as a means to identify the origin of environmental soot particles.

The main source of soot in the atmosphere is diesel traffic. Other important sources are heating, air traffic and industry. Therefore, we focus in this study on soot emitted by a car, running on diesel and biodiesel, both at idle run and at stationary regime, soot from an oil-fired domestic heating installation and soot from a jet aircraft exhaust. Carbon black, a commercial product with similar features as soot, is used as a reference material.

By performing individual particle analyses (e.g. by electron microscopy) both the morphology and the composition of single particles can be measured. The main advantage over bulk analysis is that we gain more detailed information on the nature of the particles, their origin, their formation processes and potential transformation they may undergo in the environment. In order to link these parameters up, the particles are characterised as a function of their aerodynamic diameter. The aerodynamic diameter is an important physical parameter for describing diffusional or inertial deposition of aerosols into the human respiratory system. A methodology was established to characterise the complex aggregate morphology (Fig. DIA 2) with automated image analysis of electron microscopic photographs.

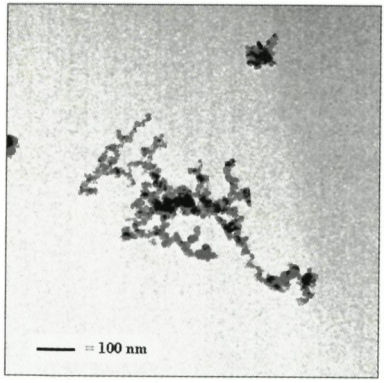


*Fig. DIA 2: Electron microscopical picture of two diesel soot particles, exhibiting the typical soot aggregate morphology.*

By studying the electronic bonding state of carbon, the main constituent of soot, we found that the soot from domestic heating, diesel soot and carbon black all have a significant amount of single bonding character. Diesel soot seems to have rather a double bonding character and shows a tendency towards forming polycrystalline grains. Elemental analysis shows that carbon, oxygen and sulphur, probably in the form of adsorbed sulphate, are present in all soot types. The chemical composition differs for soot from different sources. For example, no potassium nor calcium are observed in soot from an aircraft engine, which gives us a means to distinguish it from all other types of soot.

The size distributions of the soot aggregates show that the majority occurs in the smallest fraction of the studied range (0.15 - 0.45 µm). This trend is most pronounced for aircraft exhaust soot, with almost 80 % of the particles having a size of 0.15 µm. On the basis of these results, it might be possible to determine the origin of soot in the environment.

## Vito's expertise in soil pollution investigations

Vito is carrying out soil investigations on behalf of government departments such as OVAM (Public Waste Agency of Flanders) and on behalf of the industry.

For OVAM, Vito has been conducting two types of investigations. Those specifically requested to verify results of investigations carried out by recognised soil remediation experts (since 1995 the Flemish decree on soil remediation allows OVAM to recognise such experts) and investigations where it is necessary to evaluate and investigate complicated soil contamination problems. The industry is also requesting support from Vito for the more complex pollution problems. Routine studies (e.g. exploratory and descriptive soil investigations) are not conducted on behalf of the industry.

On a yearly basis 20 to 40 investigations are conducted at the request of OVAM to verify the site investigation results prepared by recognised soil remediation experts. The investigations done by Vito include inventory and evaluation of data, critical quality assessment of the investigation report, extra fieldwork and analyses of soil and groundwater samples (Fig. DIA 3). This system of random control by the reference laboratory was set up by OVAM to control and to assure the quality of the services delivered by commercial labs and by recognised soil remediation experts.

*Fig. DIA 3: Geoprobe equipment for advanced soil and groundwater sampling*

OVAM also sollicitates the support of Vito for pollution problems which are particularly complex with respect to hydrogeological aspects or the type of contaminant and for which the combined expertise of several experts is required. As an example the study of groundwater pollution in the industrial area Vilvoorde - Machelen (north of Brussels) can be mentioned. An extensive inventory completed with field work (including the installation of 37 observation wells with depths ranging from 6 up to 32 m) and a detailed study of the geology and hydrogeology of the area, allowed to gain a better overview and understanding of the pollution problems of the site (mainly BTEX and chlorinated hydrocarbons). The data collected for this study are used for risk evaluation and will be used to support the selection of remedial actions needed in the area.
Another interesting groundwater pollution study concerns the regional soil and groundwater pollution by heavy metals in the Campine area (north - east of Belgium). This project includes the study of the unsaturated and saturated zones. For the unsaturated zone a mathematical model has been developed to describe the transport processes of heavy metals towards the saturated zone. For the saturated zone groundwater flow modelling has identified the flow paths which made it possible to understand the regional transport of pollutants like zinc and cadmium. An important result of this study is the understanding of the groundwater recharge causing pollution of the surface waters in the area.

## Validation of analytical methods and interlaboratory comparison for the analysis of manure, soil, fertiliser, water and animal feed

The spreading of manure on farmland is essential for agriculture but overfertilisation has a negative influence on the environment because nutrients pollute the soil and the groundwater. The phosphate content of the majority of farmlands is too high and recent concentration increases of nitrate and phosphate in the groundwater are obvious. There was a need for a legislation to regulate this situation while maintaining a sustainable agriculture.

With regard to the use and production of manure the Flemish legislation provides a number of measures in order to decrease the negative influence on the environment. One of them is the restriction of the amount and the limitation of the period for spreading of manure on farmland. These measures are meant to limit the leaching of nutrients (mainly nitrate) into the groundwater. In order to examine the leaching of nutrients, their concentrations in soil will be determined yearly for every farmland during autumn, when most nutrients should have been consumed. The legislation also gives farmers the opportunity to assess a minerals balance of their farm. This should give them the possibility to keep input (i.e. animal feed) and output (i.e. manure, wastewater) of nutrients in balance.

All these measures give rise to huge numbers of analyses, mainly of soil but also of manure, fertiliser, water and animal feed. On behalf of the 'Vlaamse Landmaatschappij (VLM)' which is responsible for the implementation of the legislation with regard to manure, Vito provided the analytical methods for up to 19 parameters in 5 matrices and organised an interlaboratory comparison. Due to the big differences in composition of the matrices, different methods are needed for measuring the same parameter in different matrices.

As we had little experience with some of these matrices, all standardised methods were compared. In consultation with experts, the most suitable methods were selected. A compromise between very accurate and more convenient methods had to be found, as fast methods are preferred due to the large number of samples. As some standardised methods tend to be labour-intensive and time-consuming some of them could not be adopted without modifications. For manure and soil analysis most of the methods were adapted to routine analysis. Every modified analytical method was subjected to a brief validation and some performance characteristics were evaluated. All procedures were put together in a compendium and made available to the laboratories on the Vito web site (http://www.vito.be).

In the spring of 1999, laboratories got the opportunity to participate in an interlaboratory comparison for all those parameters in the different matrices. Samples were provided and checked for their composition and homogeneity by our laboratory. About 30 laboratories participated. The variation of the results was surprisingly low. The processing of the data was performed, selection criteria were established and recommendations for the accreditation of the laboratories and modifications to some analytical methods were formulated. This interlaboratory comparison resulted in the selection of 15 laboratories for routine analysis of all parameters.

In the autumn of 1999 research was performed in order to improve and modify some analytical methods. This resulted in a first update of the compendium. Laboratories who did not succeed in the first interlaboratory comparison got the opportunity to participate in a second one at the end of the year 1999.

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# Remote sensing and atmospheric processes



*The centre of expertise Remote sensing and atmospheric processes develops and applies methodologies for the monitoring of terrestrial and atmospheric processes by means of computer modelling and remote sensing. The centre operates processing and archiving facilities for remote sensing data and evaluates air quality at local, urban and regional levels.*

As we strive to realise synergies in research, most of our projects are performed in close co-operation with universities and institutes. More in particular, research tasks were combined with the UCL (image processing), Ulg, VUB (land cover classification), UG, UIA (carbon fluxes) and FUL and Gembloux (agriculture). At the international level, research forces were joined with the JRC Space Applications Institute with respect to the applicability of VEGETATION imagery in land cover classification and agriculture, and the use of radar images for land cover characterisation in Africa. Synergy was found with RIVM and the VMM for the improvement of the regional scale air pollution model EUROS and the further development of the other urban and regional modelling tools. For the hyperspectral imaging activities, a fruitfull co-operation with RSL (Remote Sensing Laboratories – University Zürich) was achieved. Vito also participated in several European networks and COST actions related to Earth Observation and Air Quality.

## VEGETATION imagery: improved processing and development of applications

Vito hosts the image processing and central archiving centre of the VEGETATION instrument on board the SPOT4 satellite. Purpose of the instrument is the daily monitoring of the world vegetation cover, an emanation of the implementation of global systematic observation systems called for in the framework of several environmental treaties. Vito is also responsible for the administrative and technical co-ordination of all ground segments, including satellite programming, data reception, data processing, archiving and quality assessment. In 1999, more than 12,000 VEGETATION image products were produced for end-users, a volume of more than 200 times the earth's surface. Most of these products were delivered on CD-ROM for scientific end-users. The elapsed time between the observation at the sensor in space and the delivery of the fully processed image product, was on average only one day! A continuous and high-level archive of decadal world syntheses products has been built from April 1998 onwards. A powerful VEGETATION image catalogue and user interface have been established on the web (http://www.vgt.vito.be).

In a European framework, Vito contributes to the development of improvements to the VEGETATION image processing algorithms and manages the implementation of these improvements in the operational environment. In 1999, algorithms for cloud, snow and cloud shadow masking have been developed and demonstrated (Fig. TAP 1). Clouds obstruct the viewing of the earth's surface by satellites operating in the visual and infrared spectrum. On the basis of their particular spectral behaviour, clouds can be detected and eliminated from the image before further processing. Genetic algorithm and neural network techniques were applied to optimise the discrimination of clouds from clear sky and to reallocate ambiguous pixels, which were classified as both cloudy and snow covered. A further enhancement was to introduce a region of uncertainty for the cloud mask. A novel approach was developed to detect cloud shadow. It uses information from the cloud mask, radiometry and geometry (observation and illumination angles), to forecast cloud height, and consequently mask shadowed pixels. The output of the algorithm includes a three level cloud mask (cloud-uncertain-clear), a two level snow mask and a two level shadow

mask. A first version of the cloud mask, which was specifically tuned to the format of the current cloud mask algorithm in the VEGETATION processing chain, but which altered the thresholds to those calculated with the genetic algorithm, dramatically improved the quality of the original cloud mask.

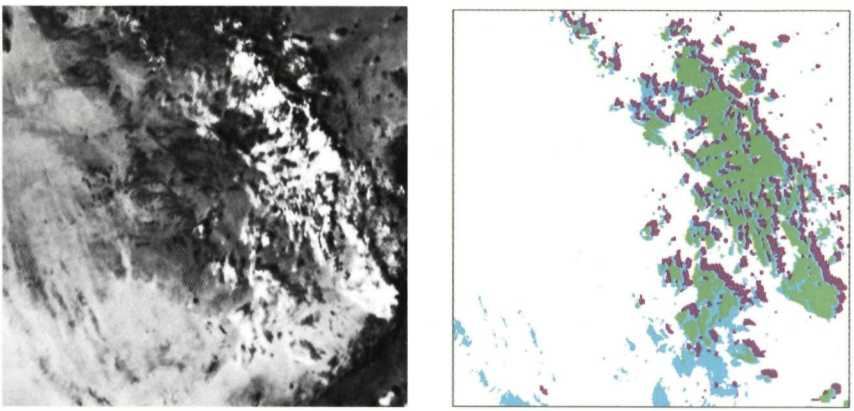

*Fig. TAP 1: Vito has developed new and fully automated algorithms for cloud, snow and cloud shadow masking for use in the VEGETATION image processing chain. The figure illustrates this approach on an image of the Sahara desert in Algeria. Left: VEGETATION image in near-infrared; right: the corresponding cloud mask (green: cloud, blue: uncertain) and shadow mask (purple).*

We have brought our research on the applicability of VEGETATION images to real world problems a step further. Our C-Fix model estimates for a given location three types of carbon fluxes on a daily basis: Gross Primary Production (GPP), Net Primary Production (NPP) and Net Ecosystem Production (NEP). GPP represents the gross uptake of carbon by photosynthesis, NPP already accounts for the autotrophic respiratory losses. Finally, NEP also includes the soil respiration losses, caused by the heterotrophic decomposition of soil organic litter. The reliable quantification of these fluxes is one of the main scientific challenges within the context of global warming. C-Fix works with NOAA-AVHRR or VEGETATION images and meteorological parameters as input. C-Fix was applied with reasonable success for the Belgian territory. Within the frame of a European project, the C-Fix model has been upscaled towards application at the European continental scale and has been calibrated with ground-based experiments at six European sites.

Research on landcover classification and the estimation of biome proportions yielded a methodology for the analyses of global VEGETATION synthesis images for a full yearly vegetation cycle. These images are classified with a sub-pixel supervised classification technique using high resolution ground cover data as training sets. The result consists of estimates of areal proportions for each class and for each pixel (1 $km^2$), which is different from a traditional classification map where each pixel is assigned to one class. This means that the output is composed of multiple layers, each layer representing one class and each pixel containing the percentage of this pixel covered by that class. Traditional landcover classification exercises were performed for Central Africa based on a full year of VEGETATION images (Fig. TAP 2), and for the south and south-west of Ivory Coast based on LANDSAT TM images.

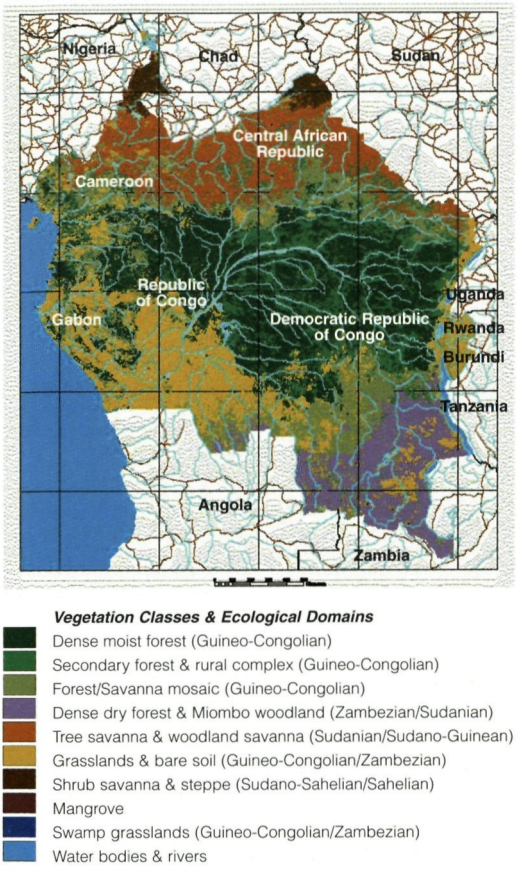


*Fig. TAP 2: New vegetation map of Central Africa, derived from SPOT-VEGETATION images of 1998 (update of the JRC TREES map of 1992)*

In the context of a federal research project, the European crop yield forecasting system (Monitoring of Agriculture by Remote Sensing – MARS, JRC Space Applications Institute) was adapted for application to Belgium. This will provide the Ministry of Agriculture with a tool for yield estimation and prediction per agricultural region. The Belgian Crop Growth Monitoring System (B-CGMS) will also be useful to evaluate the magnitude of losses caused by extreme events. In the European forecasting system, the output of satellite image processing and crop growth modelling are acquired independently and are subsequently submitted to a spatio-temporal comparison. Within the B-CGMS project, Vito concentrates on the integration of processed VEGETATION data in crop growth models. Land use data per parcel and specific crop reflectances were combined in a spectral unmixing technique, resulting in temporal reflectance profiles for each crop of interest. Subsequently, these profiles were used in a production efficiency model for the estimation of produced biomass. In the next phase, the biomass estimates will be integrated in the crop growth model to enhance the accuracy of agricultural yield estimates.

## Development of new remote sensing techniques

Vito took part in an industrial partnership for the conceptual design and market analysis of an end-to-end earth observation system based on a bi-spectral high resolution sensor mounted in a mini-satellite. Vito also defined products and services in the environment and forestry application fields of ESA's European Remote Sensing Information System.

Within the framework of an ESA R&D programme, Vito started together with a Swiss university partner the development of the hyperspectral imaging spectrometer APEX. APEX is an airborne experiment for future space missions, and serves scientific goals targeted towards advanced image processing and application development. APEX offers hyperspectral data in approx. 300 bands in a range between 400 and 2,500 nm and at a spatial ground resolution of 2 to 5 m. Hyperspectral resolution greatly extends the scope of traditional remote sensing. The detection of many narrow spectral channels presents opportunities for much more precise identification of features than is possible with broadband sensors. In 1999, Vito designed the calibration, quality assurance and exploitation schemes, and developed the hardware concept for the processing and archiving facility. Industry finalised under the supervision of both institutes the detailed engineering of the sensor. Once developed, Vito will assume the responsibility for the exploitation and the image processing facility of the instrument.

Satellite radar images are used to bridge an information gap in the practice of atmospheric transport and deposition modelling. The current practice of modelling low altitude airflows and derived deposition, relies on inaccurate estimates of the aerodynamic roughness at a very coarse scale. The SarScape project aims at the derivation of these surface roughness parameters at a much more precise and detailed level. A mapping procedure for the relevant landscape structural characteristics was developed, based on radar image textural features. In the first stage, the image is segmented based on intensity gradients, such that areas with homogeneous texture features are delineated. Second, these homogeneous areas are characterised by a limited set of complementary parameters (the texture signature). These parameters result from the description of shape features of the local auto-correlation function (or power spectrum), produced from the image by Fourier transforms. After testing and tuning, the extraction method was applied to a data set covering the Region of Flanders (Fig. TAP 3). The resulting landscape structure maps will be incorporated in a regional atmospheric transport and deposition model, applied to estimate forest sensitivity to pollutant deposition.

*Fig. TAP 3: The SarScape image of Flanders shows the structural characteristics of the landscape which are relevant for atmospheric transport and deposition modelling (aerodynamic surface roughness). SarScape is based on textural features of satellite radar images.*

## Modelling of atmospheric processes

Vito's SMOGSTOP model was used to forecast maximum hourly ozone concentration during the summer of 1999. The programme operated flawlessly and achieved good results throughout the summer. A new sort of models was added to SMOGSTOP, based on neural network technology (one model for every one of 25 ozone measuring stations in Belgium). The big advantage of the new neural network models lies in the fact that they are much less sensitive to the structure and characteristics of the explanatory variables. This results in models which are far easier to adapt to other regions, with other characteristics of ozone formation than those which govern the Belgian situation.

At the same national scale, Vito co-ordinates the improvements and upscaling of the European Operational Smog Model (EUROS). The EUROS model was implemented in Flanders to analyse tropospheric ozone pollution and to evaluate policy measures. In the framework of a federal research programme on sustainable development, EUROS is now being upscaled and improved to serve as the standard evaluation tool for all policy levels within Belgium. In 1999 Vito introduced improvements in the way the mixing height is estimated. Various methods to determine the mixing height from the meteorological fields have been applied to two three-dimensional meteorological data sets: one with a coarse resolution covering the whole of Europe; and one with a high resolution limited to the BENELUX and the North of France. A further improvement resulted in a dynamic emission inventory for the European countries that are covered by the EUROS domain. The inventory provides the spatial and temporal variations in anthropogenic emissions for six source categories and the spatial distribution of biogenic emissions varying with temperature.

High priority was given to the development of tools for the simulation of urban air quality and the evaluation of policy measures. Within our urban modelling system AURORA, an Eulerian dispersion model (EDM) was developed, which calculates the advection and diffusion of pollutant concentrations on a three-dimensional numerical grid. EDM requires pollutant emissions and meteorological variables (wind components, turbulent diffusion coefficients) as input. EDM was applied to a highly urbanised area in Northern Belgium encompassing the cities of Antwerp and Brussels. The meteorological parameters were computed for the specific topography and land use of the area, and under conditions characteristic of a mid-latitude summer anticyclone. Owing to the urban heat island phenomenon, the resulting surface wind fields exhibit strong convergence patterns over the city centres. EDM was run with idealised traffic-related emissions originating from urban areas only. The resulting near-surface concentrations in the early afternoon are displayed in Fig. TAP 4, clearly showing the impact of land use patterns on pollutant concentrations. Vito used this modelling approach in MESOCOM, a mesoscale atmospheric model intercomparison exercise involving 15 European research teams and led by the Joint Research Centre (Ispra).

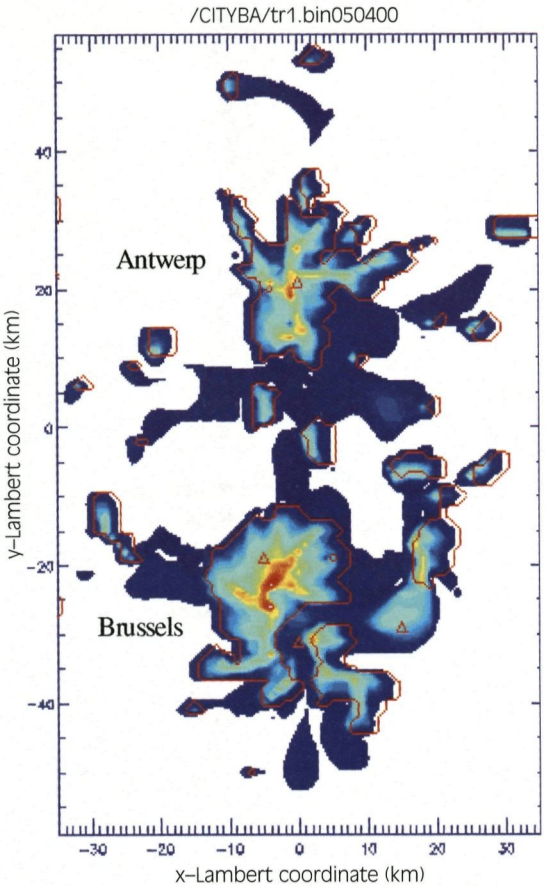


*Fig. TAP 4: Tracer concentrations near the surface at 14:00 local solar time, ranging from low (blue) to high (red) values, for a region encompassing Antwerp and Brussels. The areas within the red lines correspond to urban land use. Due to the converging surface wind patterns over the larger urban areas, pollutant concentrations are seen to reach their highest values close to the city centres.*

On behalf of the provincial administration of Oost-Vlaanderen, the local air quality of the Antwerp Linkeroever was investigated with the atmospheric transport and dispersion model IFDM. For more than twenty pollutants emitted by industry, traffic and residential heating, yearly averaged concentrations and percentiles of daily and hourly concentrations were calculated. These results were compared with available ambient air quality measurements and interpreted with respect to current and future air quality standards. This study was part of the province's strategic plan on land use and environment. The IFDM model was also used in studies related to airborne lead, dioxins and odour.

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# Environmental toxicology

*The effects of non-ionising radiation and the influence of environmental pollutants on human health are major research items of the expertise centre. Experimental work addresses the effects of diesel and urban air particles and the sensitising potential of pesticides in relation to the enhanced occurrence of asthma and different types of allergies. A lot of effort is given to bioassay-based detection of toxicity in environmental matrices (water, soil, air, ...) and in food. Specific methods and appropriate extraction procedures are developed to identify the presence of genotoxicants, endocrine disruptors and dioxin-like compounds. Ecotoxicity tests to identify the ecotoxicological hazard of pure chemicals are conducted under the stringent quality standards of GLP (Good laboratory practices) for which our accreditation was prolonged.*

## Development and validation of in vitro assays to investigate effects of immuno-haematotoxicants

Vito actively supports the 3 R's principle of Reduction, Refinement and Replacement of animals in toxicity testing according to EC guideline 86-609. Where it is appropriate alternative tests are implemented in our research activities. Vito represents the scientific research institutes in the Belgian Platform for Alternative Methods which was created in 1999. For the study of the toxic effects of environmental chemicals on the human immuno-haemopoietic system we develop specific in vitro models to address problems such as inflammatory changes in lung cells caused by diesel particles and sensitisation of the skin caused by some pesticides.

Dioxins, some PCBs and some polyaromatic hydrocarbons (PAHs) are considered as immuno-suppressants. Haemopoietic stem cells and early blood progenitor cells may be target cells because they should supply the body over a life-time with bloodforming cells including the immune cells. Various other chemicals such as anti-cancer drugs also affect these progenitors. We currently participate in an international validation study for haematotoxicity testing in vitro in order to predict reduced production of granulocytes and macrophages. The study is supported by ECVAM (European centre for validation of alternative methods).

One of the major advantages of in vitro testing is the possibility to study effects directly on human cells and tissues, which allows to omit the difficult extrapolation from animals to humans. It remains difficult however to extrapolate from in vitro to the in vivo situations. Extensive validation (reproducibility of the in vitro test and prediction power for in vivo effects) is essential. A standard operating procedure (SOP) was first established to quantify in vitro the direct adverse effects of xenobiotics on clonal colony formation by a progenitor cell of granulocytes and macrophages (CFU-GM) giving rise to neutrophiles. In an initial phase (protocol refinement), two cell culture media, containing different growth factors were compared and the two tests were applied to both human (bone marrow and umbilical cord blood) and mouse (bone marrow) CFU-GM. In a second phase (protocol transfer) the SOP was transferred to four laboratories to verify the linearity of the assay response and its interlaboratory reproducibility. A further phase (protocol performance) allowed to generate a prediction model by testing a panel of six anticancer drugs. The results showed that the assay is linear under SOP conditions, and the in vitro endpoints were highly reproducible within and between laboratories. The 90 % inhibitory concentration values (IC90) from both tests accurately predicted the human maximum tolerated dose (MTD) for four to five out of the six anticancer drugs. As expected, both tests failed to accurately predict the human MTD of a drug that needs bioactivation in the liver.

The prediction model selected for this study of prevalidation can predict a human MTD by adjusting the animal derived MTD for the differential sensitivity between CFU-GM from the animal species and the human. This model can be used without knowledge of pharmacokinetic differences across species. Nevertheless, this model should be capable of predicting human exposure levels within fourfold of the actual (the inter-species variation in tolerated dose due to differences in clearance rates), and this is sufficiently accurate to contribute to the establishment of permissible exposure limits.

On the basis of these results, a formal validation phase was started. An interlaboratory blind trial is actually going on using a type A test for 20 xenobiotics which represent a spectrum of potential haematotoxicants.

## Endocrine disrupting compounds: occurrence and aquatic toxicity

Various environmental chemicals, such as several pesticides, PCB's, phtalates and alkylphenolic compounds, have the potential for endocrine disruption. In addition natural and synthetic hormones have been detected in aquatic ecosystems. The potential risks of these compounds for human health is under scientific review, while effects on the reproduction of wildlife populations have already been documented. Biological tests have been optimised and validated either for screening of the estrogenic potency of water samples or for the assessment of reproduction effects on fish.

The estrogen-inducible screen with a recombinant yeast strain (YES-assay) and human breast cancer cells, transfected with pVit-tk-Luc (MVLN-assay), both based on estrogen receptor binding, have been evaluated for their sensitivity, reproducibility and ease of use to assess estrogenic activity. Dose-response curves were produced for several representative compounds of diverse chemical groups. In addition both test systems have been used to monitor estrogenic potency in Flemish rivers, effluents of municipal waste water treatment plants and resources for drinking water production (study supported by SVW). The highest estrogenic potency was demonstrated in the rivers with values above 5 ng/l E2-equivalents for most sampling points. These levels of estrogenic activity are likely to have significant effects on the reproduction of natural fish populations.

Fish exposure studies with zebrafish and trout were performed in laboratory conditions to assess the effects of known estrogenic compounds on reproduction related parameters. An ELISA-method has been optimised to quantify the induction of vitellogenin, a yolk protein as an early biomarker in zebrafish. Experiments with adult male and female zebrafish have shown that changes of vitellogenin are predictive for harmful effects on ovaria and testis. Figures TOX 1 and 2 show a time-dependent relationship between vitellogenin induction and decrease of ovaria size during a 24 days exposure to 10 ng/l ethinylestradiol. Comparative experiments with 25 ng/l ethinylestradiol confirmed these findings and showed more pronounced effects. After 24 days, the estrogenic compound was removed and fish were allowed to recover in control water. Data on ovaria somatic index (OSI) and vitellogenin demonstrate that observed deleterious effects are reversible and reach normal values within 3 weeks. The methods to measure reproduction related parameters are now well standardised and will be applied to assess endocrine disruption in fish during in situ exposure experiments in Flemish rivers.

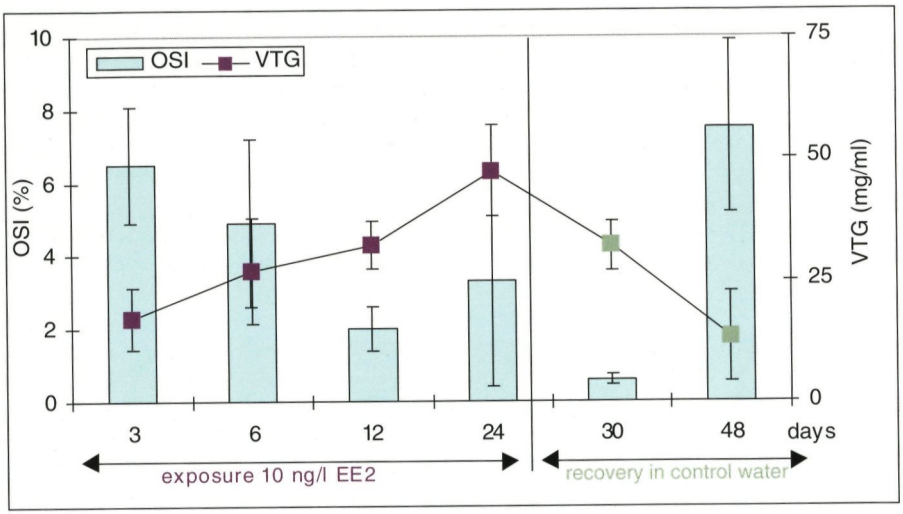


*Fig. TOX 1: Mean values (±SD) of ovaria somatic index (OSI) and vitellogenin production (VTG) in adult female zebrafish as a function of exposure time to 10 ng/l of ethinylestradiol (EE2) which is the synthetic homologue of the female sex hormone and which is found in sewage and surface waters. Removal of the pollutant results in recovery of the ovarian function (green bars).*

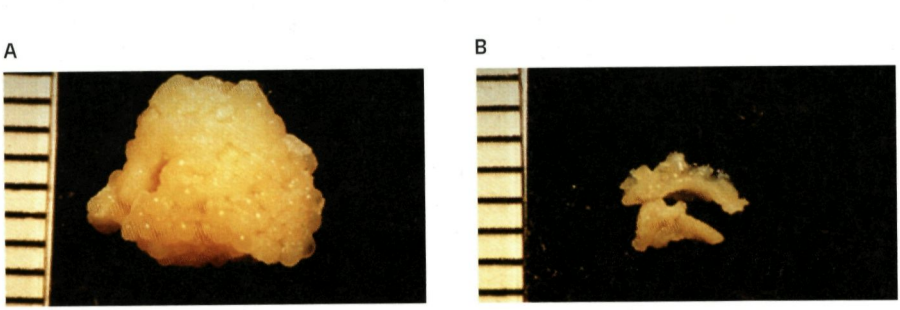


*Fig. TOX 2: Ovaria from female zebrafish exposed to control water (A) and exposed to water with 10 ng/l ethinylestradiol (B). Three weeks exposure to an endocrine-disrupting compound reduces the size of the ovaria drastically which no longer contain any matured eggs.*

## Soil ecotoxicity tests applied to Flemish environmental soil samples

At present, risk assessment of contaminated soils is mainly based on chemical analyses of a priority list of toxic substances, corrected for the total amount of organic and inorganic matter present in the soil. This analytical approach does not allow for mixture toxicity, nor does it take into account the bioavailibility of pollutants. Bioassays provide an alternative because they constitute a measure for environmentally relevant toxicity, i.e. the effects of a bioavailable fraction of interacting pollutants set in a complex environmental matrix. Increasing evidence suggests that a single bioassay will never be able to provide a full picture of the quality of the environment. Only a test battery composed of different bioassays on different species belonging to different trophic levels may contain sufficient discriminatory power and reduced uncertainty to allow for an accurate assessment of the state of the environment. Ideally, a multitude of biological end-points (i.e. biological variables such as survival, reproduction, enzyme activity, gene induction and others) should be included in such a test battery.

A different but equally obstinate problem is often given by the absence of suitable non-contaminated reference soils when field plots have to be evaluated. This problem is directly related to the confounding factors that may exist for different biological end-points when applied under different environmental conditions. Indeed, not only the bioavailable fraction of pollutants may be influenced by the soil characteristics such as pH, cation exchange capacity, clay content and the percentage organic matter, but also the physiology of the test organisms and thus their response to the bioavailable fraction of pollution.

In a collaborative research with the Universities of Ghent (UG), Louvain (KU Leuven) and Diepenbeek (LUC), a test battery composed of 30 bioassays of varying biological end-points has been compared with regard to their sensitivity to Cd and Zn and their robustness when applied to different soil matrices and soil pH. The impact at microbial level was assessed using metal sensing whole cell biosensors (Biomet®) and a bacterial genotoxicity sensor (Vitotox®). Methane oxidation, nitrification and soil respiration were included to probe microbial community effects. At the level of primary producers lethality and morphological effects were studied in 4 different plant species, including ***Brassica sativus, Trifolium pratense, Lolium perenne*** and ***Phaseolis vulgaris.*** In case of ***Phaseolis vulgaris*** also a number of sub-lethal endpoints were included both in the roots and the leaves i.e. malic enzyme, guiacol peroxidase and glutamate dehydrogenase. ***Eisenia foetida*** was included as a representative of the soil decomposing micro-invertebrates community. Apart from lethality and loss of weight also heat-shock protein synthesis and an array of immunological parameters were studied, including agglutination, phagocytosis, phenoloxidase activity and neutral red uptake. In order to compare above-mentioned endpoints, the experiments were run in parallel in 4 field soils with different soil characteristics contaminated with increasing concentrations of Cd (2, 20 and 200 mg/kg) and Zn (300, 600 and 3,000 mg/kg) and adjusted to three different pH's. Additionally also historically contaminated field soils with different soil characteristics and a heavy metal burden were included.

From these experiments the soil pH was identified as the single most important factor influencing both the bioavailability of Cd and Zn and the responsiveness of the different end-points (Fig. TOX 3). Whereas nitrification, soil respiration and morphological alterations in vascular plants rank among the most sensitive end-points tested, they were equally sensitive to changes in composition and pH of the soil. In contrast, most endpoints in ***E. foetida*** were shown to be robust but their sensitivity for Cd was low. The Biomet® whole cell biosensors rank among the best bioassays when both sensitivity and the robustness of the test are taken into account. Partly based on these results the Biomet® has been recognised by the Flemish authorities as a valid tool to assess heavy-metal contamination in soils.

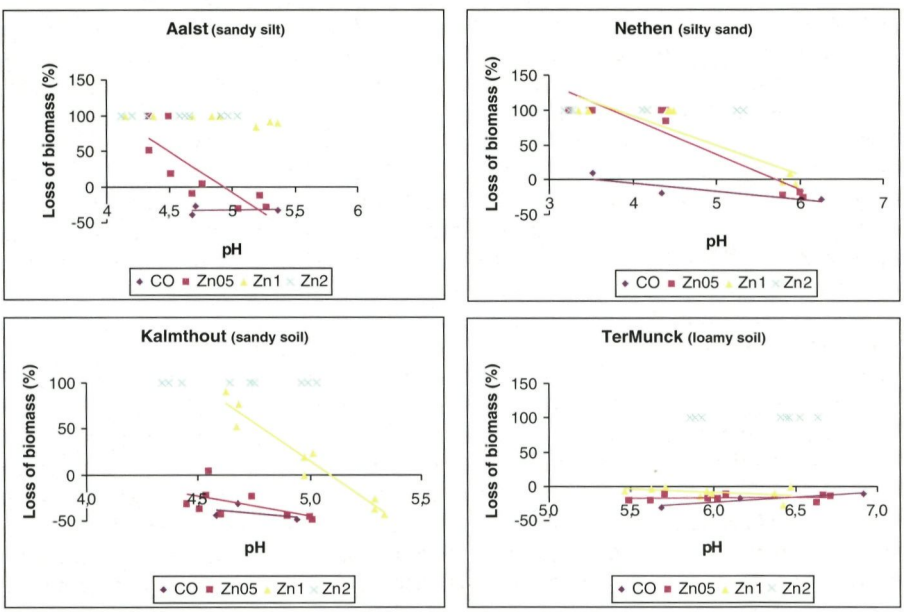


*Fig. TOX 3: Toxic effects are pH dependent – higher toxicity at lower pH. The pH effects are modulated by the type of soil as shown by the loss of biomass (%) in Eisenia foetida in response to increasing concentrations of zinc. CO: control soil; Zn05: 300 mg/kg Zn; Zn1: 600 mg/kg Zn and Zn2: 3,000 mg/kg. Kalmthout, Aalst, Nethen and TerMunck soils were classified as sandy, sandy-loam, loamy-sand and silt soils respectively.*

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*1999/TOX/R/0070*

# Environmental technology

*The centre of expertise Environmental technology has further strengthened its capacity to assist industry with the implementation of new technologies by extending its arsenal of multi-functional demonstration facilities. In 1999 a soil washing pilot plant (PILBO) was taken into operation, which allowed to evaluate new soil and waste treatments on a relevant large scale. The efficiency of water treatments with sand filters inoculated with microorganisms was also demonstrated on a pilot scale. Heavy metals as well as cyanides, nitrates and some COD could be removed by applying this technology to non-ferrous industry waste water, waste water of the surface treatment industry, mine drainage water and contaminated groundwaters. The Vito membrane bioreactor BICMER proved to be a valid tool for the treatment of the landfill leachates of a dumpsite in Germany. Soft remediation technologies such as phytoremediation for soils contaminated with heavy metals were demonstrated in the field. Finally the Promotion and demonstration centre for environmental technology (PRODEM) handled more than 50 industrial requests (mainly by SMEs) for analysing and solving environmental problems.*

## Demonstration experiments for the treatment of heavy metal polluted soils: in situ treatment by immobilisation, phytoextraction and bio-extraction

Soils with elevated concentrations of heavy metals, such as zinc, cadmium and lead, are found in the northern part of the Province of Limburg and the Antwerp Campine area mainly as a consequence of the activities of the former non-ferrous industry. In this area, the surface contaminated with a Cd content higher than 3 mg/kg is about 75 $km^2$. The total surface with an increased Cd content (> 1 mg/kg) is even estimated at more than 280 $km^2$.

'Hard' remediation techniques, such as excavation and removal of contaminated soil or leaching and extraction of the heavy metals, are drastic, expensive and not always effective remediation methods. New 'soft' remediation techniques are therefore developed, which are inexpensive, easy to implement, environmentally sound and effective to reduce the environmental risks of heavy metal polluted soils. On demand of the Flemish public waste corporation (OVAM), three techniques - immobilisation, phyto-extraction and bio-extraction - were further developed and demonstrated. The project, which ran from July 1996 till April 1999, was carried out by the Limburgs Universitair Centrum and Vito (Fig. MIT 1).


*Fig. MIT 1: Vito and LUC worked together on field tests for phyto-extraction and phyto-stabilisation.*

To immobilise heavy metals in soils, additives altering the chemical and physical structure of the heavy metal contaminants are mixed with the top layer. As a consequence the heavy metals are not or to a lesser extent available for uptake by organisms, thus decreasing the toxicity of these contaminants for organisms such as plants, worms and bacteria, as well as the risks for human health. The treated soil becomes suitable for planting. Immobilisation also decreases the risks of leaching of heavy metals into the groundwater. This technique is very suitable for the treatment of large sites contaminated with moderate to high levels of heavy metals. The experiments were carried out in laboratory conditions and on field plots located in Balen, Mol, Neerpelt and Overpelt (in the North-east of Belgium). Biological and physico-chemical evaluation methods were applied. The results are very encouraging, showing a decrease of metal concentrations available for plants, worms and bacteria. The treatment with cyclonic ashes and treatments where cyclonic ashes were used in combination with other products showed the highest immobilisation degree. Laboratory experiments demonstrated that heavy metals are effectively immobilised for at least 30 years, thus showing that immobilisation is also a sustainable remediation technique.

In the phyto-extraction approach plants are used to remove heavy metals from lightly polluted soils. Some plant species are able to accumulate large amounts of metals in their aboveground parts. When these plant species have also a high biomass production that is easy to harvest, they are suitable for phyto-extraction. On lightly polluted sites in Mol-Wezel, Balen and Neerpelt (in the Northeast of Belgium) phyto-extraction experiments with rapes were carried out. At present phyto-extraction could not be proven to be sufficiently effective to be applied in practice.

For the remediation technique bio-extraction, unmodified bacteria are used which are able to concentrate metals in their biomass. Cultures of these bacteria are mixed with heavy metal polluted soil in a 'Biometal sludge reactor' (BMSR) (Fig. MIT 2). Nutrients are added, and the pH of the soil sludge is controlled during incubation. The available metals are accumulated by the bacteria and bound at their cell surfaces. The heavy metal loaded biomass, which remains in suspension, is removed from the clean soil together with the supernatant. The bacteria are then separated from the water phase by flotation, resulting in clean process water and a small biomass fraction with a high concentration of heavy metals. This fraction can either be used for recovery of metals, or be dumped on a licensed waste site. This technique is very suitable for the treatment of soils contaminated with low concentrations of heavy metals. Based on the results of the laboratory tests, a demonstration experiment was set up in Mol-Wezel. Treatment of the soil in the BMSR reactor, allowed to lower the Cd content from more than 3 mg/kg to below the norm of 1 mg/kg soil (dry weight).

*Fig. MIT 2: In this Biometal sludge reactor (BMSR) special bacteria are mixed with soil contaminated with heavy metals. The metals are linked to the biomass, which is removed from the process water after settling of the soil.*

The BIOMET® test was used for the evaluation of the different soft remediation techniques. The BIOMET® test, which has been developed at Vito test, allows to quantify the bio-availability of specific heavy metals in soils within 5 hours. Based on the outcome of this project, BIOMET® was officially recognised by OVAM as an ecological relevant test to determine the bio-availability of heavy metals.
The techniques developed and evaluated during this project are available for commercialisation by Flemish SMEs.

## Mobile and modular pilot plant for soil washing (PILBO)

At the beginning of 1999, Vito has commissioned a new mobile test plant for recycling contaminated soil and solid waste. This plant can be used to simulate the common types of commercial soil washing plants. The results of a test can be used to evaluate the technical feasibility, the quality of the produced material fractions and the economical aspects of the waste treatment process. The modular construction allows to simulate different process configurations, as required for the specific problem to be handled. Different wastes may be treated in this installation, such as polluted soil, dredging soil, sand from sieving recycled construction materials, sludge from sewer cleaning and sand from street cleaning.
The installation is mobile, with a capacity of 0.5 - 1.2 tons per hour. The following techniques for separation and cleansing are included (Fig. MIT 3):

- sieving (vibrating screens and rotating drumscreen);
- hydrocycloning;
- separation with a spiral classifier (screw);
- attrition scrubbing;
- coal spiral gravity separation;
- froth flotation;
- coagulation/flocculation, thickening and dewatering.

*Fig. MIT 3: The PILBO (Pilot for soil washing) is used for solving soil, sludge and solid waste problems. The facility allows to apply sequences of different separation and cleaning techniques to relevant quantities of contaminated samples.*

The pilot plant has been used for a number of projects on behalf of authorities and industry.
During infrastructure construction activities in the city of Kortrijk, over 100,000 tons of soil were discovered which were polluted by historic disposal activities. Vito performed treatability tests on 4 different representative lots of soil, with the process configuration described above. It turned out that half of the soil could be cleansed for reuse as soil and that almost all of the material could be treated for reuse as construction material.
In another project, 10 tons of sewer cleaning sludge were cleansed on behalf of a company planning to order a soil washing installation. The test was done to evaluate which process steps would be the most suitable for the application. It was concluded that a relatively simple process would be sufficient to transform their material into a product that would meet the requirements for reuse as construction material, and in some cases for reuse as soil.
A third project was done on behalf of a company designing and building installations for the treatment of household refuse. A process was developed for the separation of a residual fraction of household waste treatment which up till now was combusted. A number of product streams were isolated from this residue which could be reused beneficially. The process was demonstrated for a large number of interested parties, including industry, problem owners and foreign and local authorities. The Flemish Environment minister, Vera Dua, asked Vito to evaluate the process in the broader perspective of Flemish domestic waste management.
A demonstration project for the treatment of soil contaminated by the industrial operation of gas plants was run under the european Life program at the location of the gas plant of Lier. Together with the contracting company Envisan-Jan De Nul, Vito has demonstrated the potential of on-site soil washing by treating 50 tons of soil contaminated with PAH and cyanides.
At the end of the twentieth century, Vito's centre for Environmental technology has acquired the tools and experience needed to investigate a wide range of applications for recycling polluted soils and solid wastes on behalf of the industry and the authorities.

## Promotion and demonstration centre for environmental technology (PRODEM)

PRODEM operates as an advisory centre with regard to environmental aspects of industrial activities and introduction of environmentally friendly technologies. Via technological hardware and elaborated know-how, the centre has proven to be a guide for Flemish companies in their search for techno-economical solutions for their environment-related problems. The projects are very specific and handle aspects related to water, air (odour), refuse or soil contamination.

### Case study: feasibility study for anaerobic treatment of a synthetic emulsion from a metal finishing industry

Many metal finishing industries use different natural and synthetic emulsions for lubricating and cooling purposes. After use, these emulsions have to be removed because they usually contain high (> 500 mg/l) concentrations of heavy metals such as zinc and copper, as well as mineral oils. Most of the time these emulsions have to be removed for external handling. At the request of order of a big metal finishing company, the possibility for anaerobic treatment of a certain synthetic emulsion was studied. In the study the degree of toxicity of the emulsion with respect to anaerobic biomass was evaluated and an advice was given concerning the feasibility of such anaerobic treatment.

The toxicity of the waste emulsion for anaerobic biomass was studied by exposing different dilutions of the emulsion to a certain amount of anaerobic sludge. In Fig. MIT 4 the biogas production is shown when different dilutions of the waste emulsion are spiked with 1 g/l acetic acid. Between a dilution rate of 12 and 4, the waste emulsion starts to inhibit the degradation of acetic acid which results in an increased lag period. As a dilution factor of twelve might be necessary to prevent toxic effects, a degradation efficiency of more than 90 % would be required for a continuous anaerobic reactor treating undiluted water. As this is quite high, it is necessary to dilute the influent for such a continuous reactor as well.

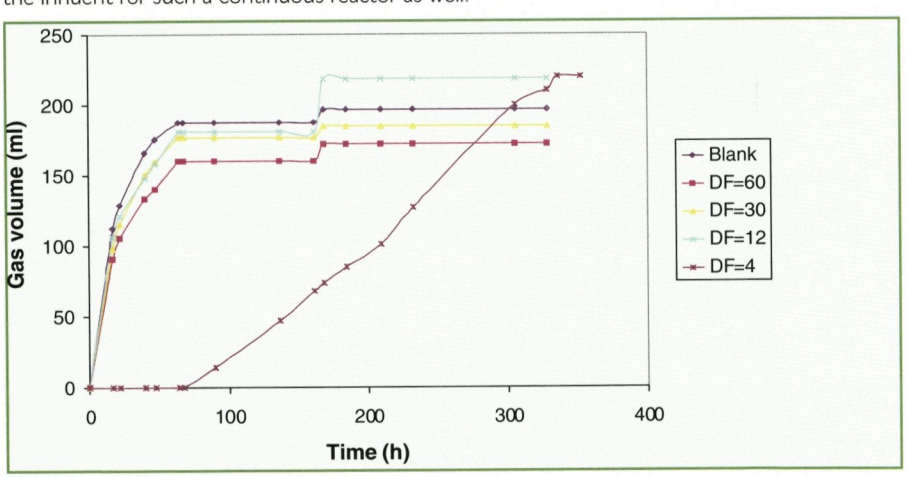


*Fig. MIT 4: Different dilutions of a waste emulsion were exposed to an anaerobic sludge spiked with acetic acid. The biogas production was measured as a function of time. It can be seen that for a dilution factor (DF) between 4 and 12 the waste emulsion starts to inhibit the biodegradation. It can be concluded that a dilution factor of 10 is required for handling this waste emulsion with the anaerobic process.*

In a second stage, the degradation of a twelve times diluted waste emulsion in an upflow anaerobic sludge blanket reactor (UASB) (Fig. MIT 5) was studied. In this lab-scale reactor, the COD reduction efficiency increases to 80 % at a COD loading of 0.043 kg/m$^3$h and a hydraulic retention time of 2 days. Minimal residual COD's of 1,000 mg/l are measured. As these values are still a lot above the objective, it could be concluded that anaerobic treatment without a physico-chemical pretreatment was not feasible for this specific waste stream.

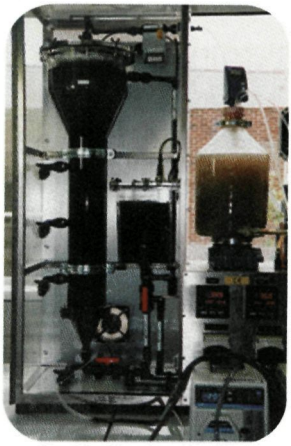

*Fig. MIT 5: Lab-scale upflow anaerobic sludge blanket reactor (UASB) used to demonstrate and optimise the treatment of waste flows at the request of industrial clients.*

### Case study: optimisation of the physico-chemical treatment of a tank cleaning waste water with a mobile pilot installation

A tank cleaning company experienced problems with too high suspended solid concentrations in the effluent of a biological waste water treatment. A pilot study (Fig. MIT 6) was developed to determine the possibilities of reducing the amount of suspended solids by using a physico-chemical treatment. Several coagulants and flocculants were tested and their optimum concentrations could be determined.

*Fig. MIT 6: Pilot test for waste water treatment at the site of a tank cleaning company. The addition of coagulants and flocculants allowed to reduce the amount of suspended solids in the effluent.*

The advantage of testing wastewater with the mobile Prodem pilot installations is significant: it is a real time simulation with real waste water, with its fluctuating characteristics. Online, there is a follow-up of several characteristics such as pH, conductivity and turbidity. The physico-chemical treatment is tested by adding coagulants and flocculants. In addition it is also possible to test the separation of the sludge by performing flotation or sedimentation tests.

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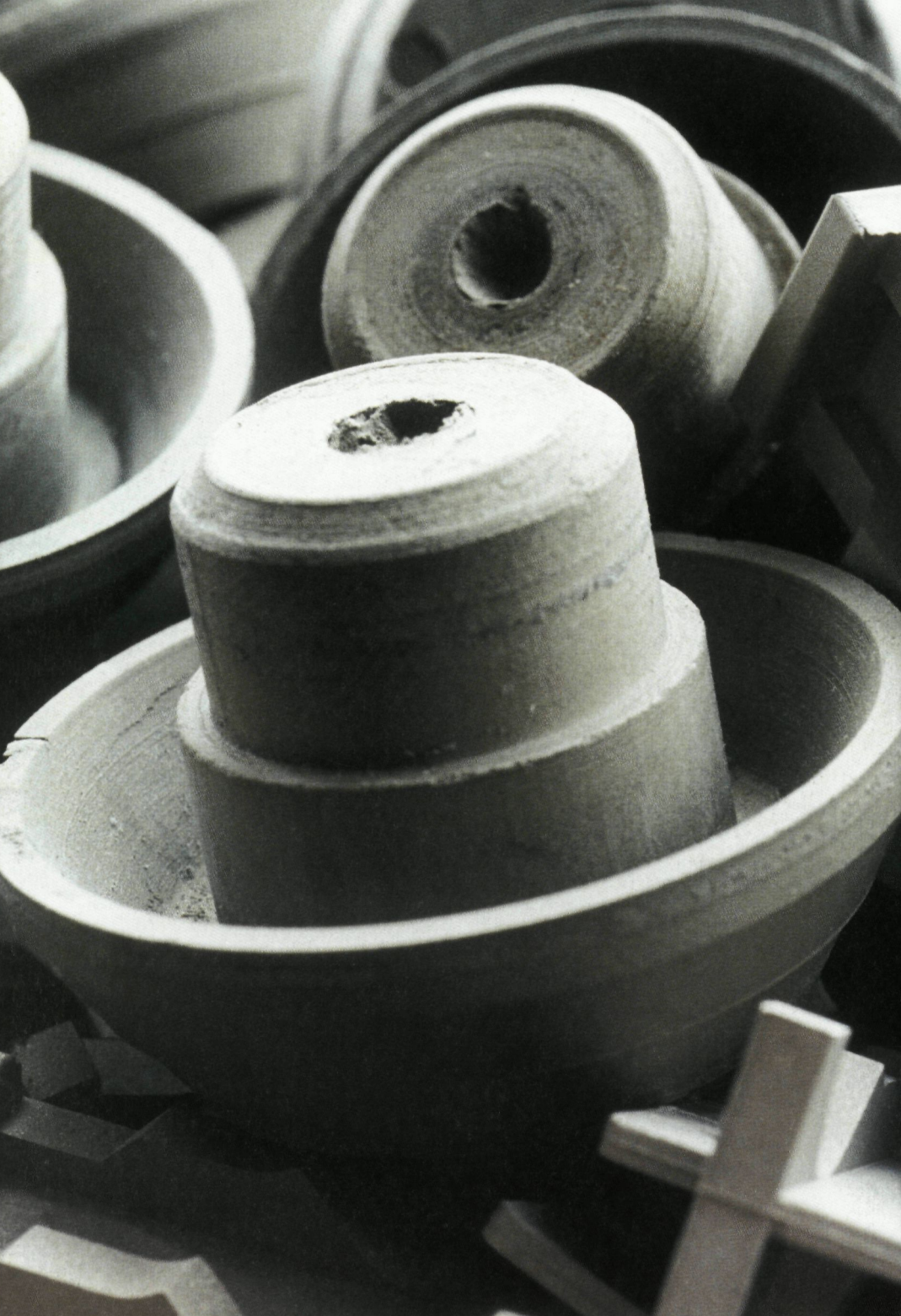

# Materials

Materials technology

Process technology

Raw materials

# Materials technology

*The centre of expertise Materials technology supports the proper implementation of innovative materials and related processing technologies in the industry. Surface technology, laser technology, ceramic materials and powder metallurgy, and from the year 2000 on also non-ferrous melt processing control are its key R&D fields. Excellent analysis and test facilities complement these competencies to form an integrated, powerful tool which is able to offer adequate solutions for the company of tomorrow.*

*Major objectives of the research activities are the extension of component lifetimes, product quality improvement, and enhancing production system efficiencies. This will contribute to the conservation of our material and energy resources, and hence to a sustainable development of our industrial world.*

Strategic research focuses on the development of atmospheric plasma processes as an economic route to surface treatments, economic powder processing methods to produce ceramic components of high quality, and laser cladding as a means to produce hard, wear resistant coatings on components with a complex geometry. In addition, state-of-the-art tribological test facilities and material databases were installed to even better assist companies in providing innovative solutions to material friction and wear cases.
The R&D efforts are strengthened by embedding them in a number of national and international (European) projects and networks. In 1999 Vito hosted the COST 516 Tribology Symposium, which was attended by over 60 participants from 21 countries.
Short-term research contracts have been concluded with over 80 companies, of which over 25 % were SME companies. Moreover, 19 SME companies in the Turnhout region collaborate with Vito in a ERDF funded project – IBEMA – which aims at strengthening the economic activity by introducing innovative material technologies.

## Vito establishes a laser demonstration centre *(Fig. MAT 1)*

A major issue in 1999 has been the establishment of the Vito Laser Centre, with the support of the European Regional Development Fund (ERDF). State-of-the-art laser facilities are being installed, equipped with the necessary robots and 3D machines for component manipulation. By the end of the year 2000 a wide range of lasers will be available, with power ranging from a few 10 W up to 20 kW. This includes a novel high power diode laser with a fibre optic beam delivery system. The specific target of this centre is the promotion and implementation of laser technology in the Flemish industry, particularly SMEs. Besides welding and lasertooling, the application of wear and corrosion resistant layers by laser cladding is being explored. In 1999 several industrial projects were already completed successfully.

*Fig. MAT 1: Lasers can be used to apply wear and corrosion resistant coatings on components with complex geometries. The picture shows a co-axial laser cladding head, which was specifically designed for this purpose.*

For a major Belgian space engineering company a laser welding procedure for the fabrication of aluminium heat exchangers used in satellites was developed. Two different welds were necessary to join the concentric tubes in the structure, an overlap weld between the two tubes and the welding of an end plug onto each tube. The welding had to be carried out without filler material to avoid loss of mechanical strength, and the specifications were very strict. In order to overcome the high reflection of the $CO_2$ laser beam by the metal, the extremities of the tubes were sandblasted and the laser beam was tilted. A special clamping system was developed and the tubes were preheated to allow free shrinkage and avoid cracks in the weld. The ramping of the power, which is critical to avoid the formation of pores, had to be programmed differently for each of the weld types. Control of the welds by X-ray analysis, He-leak tightness measurements, metallographic and mechanical tests showed that a success rate of 90 % was achieved. Moreover, the mechanical properties of the laser welds were 2.5 times better than those of TIG welds, due to the lower heat input during laser welding. The complete heat exchanger has now been constructed and will soon be installed in a satellite.

The laser cladding technique allows components to be coated locally with a thick wear and corrosion resistant layer. The outer layer of the substrate is heated by a laser beam and is simultaneously covered by a clad material fusing onto the substrate, forming a protective coating. These coatings show good adhesion, low dilution with the substrate and low porosity in comparison with conventional spraying techniques.

By order of a Belgian SME manufacturer of specialty components, flange rolls for the food and beverage can industry were successfully treated. When these rollers are made of hardened tool steel, their lifetime is limited due to the high wear rate of the flange grooves. Using a $CO_2$ laser equipped with a special co-axial cladding head, layers containing tungsten carbide were cladded at this critical location. Cracking of the layers, due to thermal mismatch between substrate and layer, could be avoided by preheating the rollers to some hundred degrees. Field testing of the treated rollers showed that the lifetime could be increased by almost a factor ten.

## Glow discharge at atmospheric pressure provides many opportunities *(Fig. MAT 2)*

Glow discharges in gasses at atmospheric pressure find their use in an increasing number of applications. Basically the plasmas are stabilised between electrodes in an inert gas but more importantly, the addition of a small amount of reactive gas such as oxygen or hydrocarbons allows the plasma to be used as a tool for the activation and cleaning of surfaces or for the deposition of coatings.

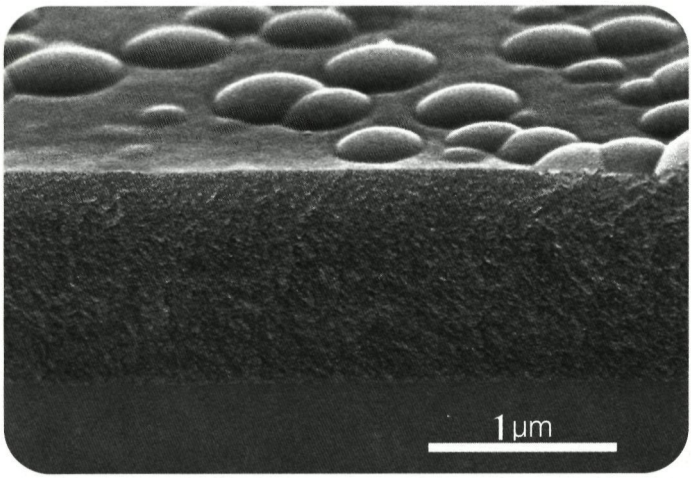


*Fig. MAT 2: Atmospheric glow discharge processes can be used to activate or clean surfaces and to deposit coatings. The picture shows a dense polymer film, which was deposited in an atmospheric plasma process.*

The main advantage of the process is the absence of expensive vacuum equipment and its simplicity of use. Whether this technology can be used for sophisticated processes, such as the deposition of inorganic compounds, is still an open but very pertinent question. The driving force behind the development of atmospheric glow discharge processes is not only environmental but also economic, as it can become an adequate and elegant alternative for many present day industrial techniques. Research at Vito concentrates on the development of industrial applications of atmospheric plasmas. At the end of 1999, two home-built plasma rigs are in operation. The first one is designed for a more basic analysis of plasma properties, while the second one is dedicated to the treatment in a continuous process of polymer films, fabrics, and others. A third facility, tailored to the deposition of coatings, is under construction.

The activities in 1999 concentrated on the stabilisation of plasmas in a series of gas mixtures. Much effort was devoted to the analysis of the physical properties of the plasma. An extensive study of optical emission spectra revealed that these processes can be amazingly complex. In some mixtures, a small change in the concentration of one of the gases has a tremendous effect. In a preliminary study, plasma polymerisation in atmospheric glow discharges has been investigated. Polymer films were deposited from methane, propylene and acetylene precursors, using helium and argon as carrier gas. Infrared analysis showed that these coatings showed polymer like features, but their physical characteristics strongly depend on the precursor mixture and the process conditions. It could also be demonstrated that an organo-metallic, silicon containing compound polymerises in an atmospheric glow discharge. This is very promising because it indicates that plasma assisted metal-organic chemical vapour deposition at atmospheric pressure could become feasible.

Activation and cleaning of material surfaces are applications of atmospheric glow discharge that are closer to industrial implementation. Several projects are running or in preparation with industrial partners on polymer films, fabrics and metals. These projects focus on the configuration and optimisation of process conditions.

## Economic processing of ceramic materials tailored to specific applications *(Fig. MAT 3)*

Strong reaction bonded aluminium oxide (RBAO) membrane supports were synthesised with pore sizes ranging from 0.2 to 5 µm. The produced RBAO porous substrates are outstanding compared to conventional membrane supports because of their high mechanical strength and homogeneous pore size distribution. This resulted in a transfer of the Vito patent to Cobra Technologies B.V., a Dutch company. Cobra Technologies will integrate this technology in ceramic membrane modules for pervaporation and ultrafiltration.

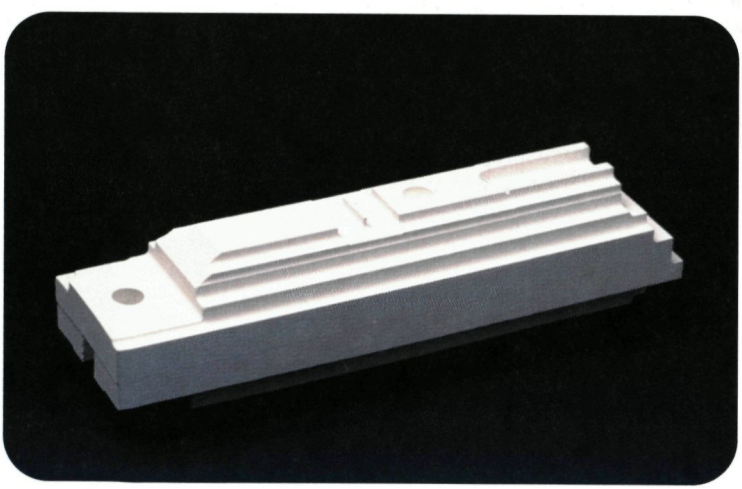

*Fig. MAT 3: A gelcast component, which was machined prior to sintering. Machining unsintered bodies is possible because of the exceptionally high green strength of gelcast bodies.*

Economically attractive manufacturing routes for high quality ceramic and powder-metallurgical components, processing techniques such as gelcasting and electrophoretic deposition are further developed.

In gelcasting, the first step is the preparation of a concentrated slurry of powders in a solution of organic monomers. This slurry is cast in a mould and subsequently polymerised to form a green body of the powder held in a polymeric gel. After demoulding, the gel is dried and the green compact is sintered to full density. Research at Vito focuses on the processing of stable slurries, the selection of mould materials, green machining and the optimisation of the drying process. The main advantages of gelcasting are:

- low equipment capital cost;
- generic process;
- capability to produce both large thick-walled blanks and small components with fine features;
- high green strength (up to 20 MPa) allowing green machining;
- very homogeneous material properties;
- low binder contents resulting in easy binder removal.

In addition, Vito has started research in the area of electrophoretic deposition of materials. This technique consists of applying an electric field to a suspension of charged powder particles. In response to the electric field the particles move (electrophoresis) and deposit on one of the electrodes. Since the shape of the deposit is a replica of the shape of the electrodes, various shapes can be obtained. Coatings as well as free standing objects can be produced.

Like gelcasting, electrophoretic deposition can be applied to almost any material. Another major advantage is that it allows microstructural engineering: by consecutive deposition from two or more suspensions, layered materials can be obtained. The layer thickness can be varied between ~ 2 µm and several millimeters. Moreover, by adjusting the solids composition of a suspension during deposition, local composition variations and graded materials can also be fabricated. Current work at Vito focuses on electrophoretic deposition of dielectric materials for multi-layer ceramic capacitors.

## Progress in scratch testing to measure the adhesion of coatings *(Fig. MAT 4)*

Coating technology is fundamentally dependent upon good adhesion between the coating and the substrate, and in many cases adhesion is the limiting factor for the wider application of the technology. Therefore, a reproducible and reliable test method to assess adhesion of coatings is essential. The scratch test is routinely used in industry and research organisations because it is a quick and simple engineering test method. It consists of drawing a diamond stylus across the surface under increasing normal load, either stepwise or continuously, until coating spallation failure events are observed in the scratch track. Research has been carried out to fine-tune the scratch test procedure and to improve the accuracy and reproducibility of the results.

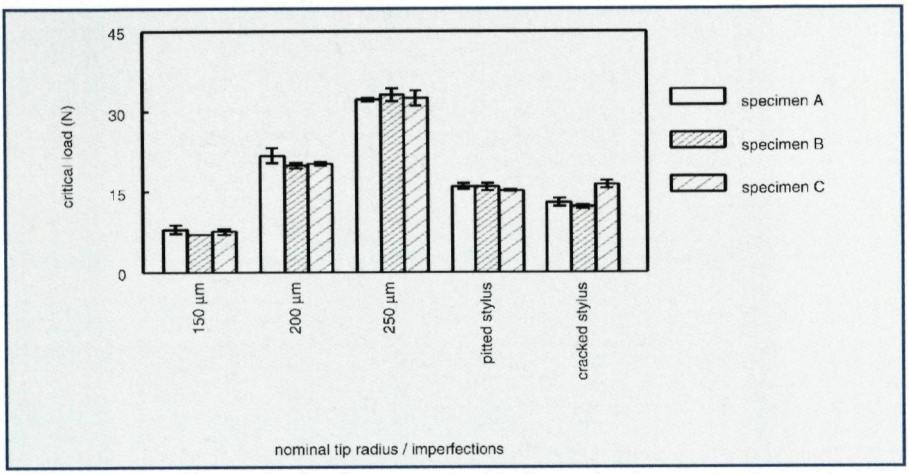


*Fig. MAT 4: Reference materials are developed for the scratch test, which is used for qualifying the adhesion of coatings. In the figure the sensitivity is shown of a candidate reference material (DLC on hardened P/M high speed steel) to imperfect stylus properties. Specimens A, B and C stem from different coating batches.*

In the framework of a standardisation programme of the Belgian federal office for scientific, technical and cultural affairs (OSTC), different scratch test operation modes have been assessed to determine the adhesion of a series of distinct coating types with intentionally varied adhesion properties. It was demonstrated that critical loads obtained by the conventional single pass progressive load scratch test mode (SPST) cannot be used as stand alone values. The failure mode as well as the magnitude of the failure event are equally important to assess adhesion properties. In general, the constant load scratch test operation mode (CLST) allows the better discrimination between better or poorer adhesion properties than does the standard SPST method. The multi-pass scratch test operation mode (MPST) also seems to be better to rank the adhesion properties of coatings. With the current state-of-the-art equipment, however, the CLST and MPST modes are very time- and effort consuming. Currently, the extension and automation of scratch test operation modes to facilitate the use of more advanced test regimes is explored in a European funded project. The findings of the OSTC project have led to a substantial revision of the European pre-Standard ENV 1071-3.

In a European project, which is co-ordinated by Vito, a certifiable reference material is developed, which allows to control the proper functioning of a scratch test instrument. This should allow to detect deviations of the shape of the stylus tip as well as errors in the load and displacement calibration or any other malfunctioning of the scratch test instrument. The sensitivity to stylus imperfections of candidate reference materials, such as DLC coated hard powder metallurgical steels, was investigated using styli with standard and aberrant tip geometries. The reproducibility of critical load values between test specimens from different coating batches proved to be very good.

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# Process technology

*The activities of the centre of expertise Process technology are focussed on the introduction of innovative technologies and the optimisation of existing technologies in the fields of membrane technology and aluminium melt processes. Feasibility studies in the field of membrane technology were executed for several companies, representing different industrial sectors. This has resulted in a wider industrial acceptance and implementation of membrane processes for purification and/or recuperation of process- and/or waste streams.*
*The work in the aluminium technology group was further directed towards the optimisation of the aluminium melt process by measuring key process parameters in a number of aluminium foundries. Statistical analysis of the experimental results allowed to formulate a number of recommendations for improving the existing melting processes.*

## Euromembrane '99

Thanks to the collaboration between Vito, the University of Leuven (KU Leuven) and the University of Antwerp (UIA), Belgium was selected as guest country for the Euromembrane '99 conference (Fig. PRO 1). This international meeting covers a broad range of fundamental and applied aspects of membrane technology. The conference was held in Leuven and was a great success with more then 500 participants from 42 countries.


*Fig. PRO 1: Opening session of the international conference Euromembrane '99*

Vito was responsible for the scientific as well as the practical organisation. Three specialists of Vito were members of the Scientific Committee. During the conference, different aspects of membrane research at Vito were presented in three oral and five poster presentations, including the keynote lecture of the session on water treatment. The high quality of the meeting certainly contributed to the international fame that Vito has gained in the membrane field.

## Organo-mineral membrane research

Vito has a long history in the field of membrane development, mainly focusing on the combination of polymeric and inorganic components, the so-called organo-mineral membranes, especially the Zirfon®-membranes. These membranes are formed by adding zirconia particles to a polysulfone solution. The presence of zirconia in the polysulfone casting solution causes adsorption of the polymer chains on the surface of the inorganic particles. This influences the membrane formation and consequently the resulting membrane properties. The technology for the synthesis of these organo-mineral type of membranes has recently been transferred to the spin-off company Prime membrane technologies (PMT). The evolution towards a mature technology is of course accompanied by a reduction of the fundamental research in this field. In 1999, the basic work on organo-mineral membranes was finalised by the publication of a second PhD thesis entitled 'Correlation between organo-mineral interactions and characteristics of composite membranes'. This publication summarises different studies on the physico-chemical properties of the polymer/solvent/inorganic filler suspensions and the structure and filtration properties of the resulting membranes.

## Demo tests of membrane technology for industry

The contract research activity on the demonstration of pressure driven membrane processes (micro- and ultrafiltration, nanofiltration and reverse osmosis) has been continued in 1999. For that purpose, the centre of expertise has invested over the past years in the construction and development of filtration loops on lab-scale, semi-lab-scale and pilot-scale. Especially the in-house developed software package Mefias® has shown a growing interest from the market. The software package controls filtration parameters such as flux, transmembrane pressure, cross-flow velocity, cleaning procedure and allows on-line data registration and treatment of these parameters. Thanks to the Mefias® software, the optimisation of filtration processes can be done in a fast and user-friendly way. The growing interest in both the filtration loops and the software has been proven by the sale of a second filtration loop, type MFU-46, equipped with the Mefias® software, to the new Bekaert spin-off, Bekaert Advanced Filtration (BAF).

Long term demonstration projects, such as the project supported by the Flemish centre for water research (SVW) (reported hereafter) clearly demonstrate the new challenges which nowadays can be fulfilled with membrane technology:

- in collaboration with one of the Flemish drinking water companies, PIDPA, it was demonstrated that for three out of four test locations, dead-end ultrafiltration is able to upgrade backwash water from the sandfilters to drinking water quality in a reliable and economic way;
- for a company in the food sector, it was demonstrated that a former waste stream containing an important amount of proteins, could be totally recovered after treatment with cross-flow ultrafiltration; both the water and the concentrated proteins could be reused.

Evaluation of ultrafiltration as a pre-treatment step for drinking water production (SVW project)
The pilot experiments on ultrafiltration of the first research period (mid 1997 to beginning of 1999) were successfully completed. As a result the drinking water company VMW decided to build a semi-industrial ultrafiltration plant, which should be operational early 2000.

*Fig. PRO 2: View of the mobile filtration loop for water applications*

During the second research period the first filtration unit operated at the Grobbendonk facility of PIDPA directly connected to canal water (Albertkanaal) (Fig. PRO 2). The other filtration unit was installed at the facility of VMW in Korbeek-Dijle (Leuven) directly connected to river Dijle water. Both waters are characterised by strong composition variations. For example the turbidity changes from 15 to 85 NTU, as a function of the weather conditions. Extensive exploratory research showed that membranes of two membrane suppliers operated in a quite stable fashion during long term experiments. In the case of PIDPA Grobbendonk, fluxes as high as 100 l/hm$^2$ combined with a water recovery of 95 % could be obtained, whereas in the case of VMW Korbeek Dijle a flux rate of 75 l/hm$^2$ combined with a water recovery as high as 97 % was attained. Moreover, it was found that the membranes needed to be cleaned only every two weeks with a combination of hypochlorite and sulfuric acid. This was ascribed to the use of ferrichloride as a flocculation agent prior to ultrafiltration. These experiments clearly show the possibility to find stable operational modes in order to produce water having the superior ultrafiltration quality.

## Ceramic membranes

The ceramic membrane research was in general directed to the applicability of ceramic nanofiltration and pervaporation membranes. The development efforts were focussed on a nanofiltration membrane with improved corrosion resistance.

The strength of ceramic nanofiltration membranes is their inherent temperature, mechanical and solvent resistance. Membranes which are chemically resistant in strong alkaline and/or acid environments have an important additional advantage. Based on last year results, the development of nanofiltration membranes resistant to a wide range of chemical environments was continued. Work was done on top layers of synthetic clay laponite and of titania. The optimised chemically resistant laponite membranes showed high salt rejections in combination with high fluxes. Correlating corrosion results with porosity measurements and structure determinations, allowed to find a way to produce titania suitable for chemically resistant membranes. The production route of chemically resistant titania nanofiltration membranes is now optimised on home-made and commercial tubular supports.

Dehydration of real solvent streams is the major research target for the application of ceramic pervaporation membranes. Comparative studies of silica and NaA zeolite membranes from various suppliers were performed in a labscale pervaporation unit for the dehydration of isopropanol/water mixtures. The influence of the temperature and the cross-flow velocity on the permeate flux was evaluated as well as the time and conditions required to achieve a stable and optimal operation.

## Electrochemical sensors

The industrial feasibility of a sensor for monitoring the effective aluminium content in zinc has been successfully demonstrated during tests in a galvanising plant. The patented technique enables real time continuous measurement of the effective aluminium concentration in zinc with a reproducibility and repeatability of a few 0.001 wt % of aluminium in the range of 0.1 wt % to 0.3 wt %. When continuously operated, service life can be several weeks. In Fig. PRO 3 the effective aluminium content as measured by a series of sensors is compared to chemical analyses (ICP and AAS) in a simulation of a galvanising process at 455 °C.

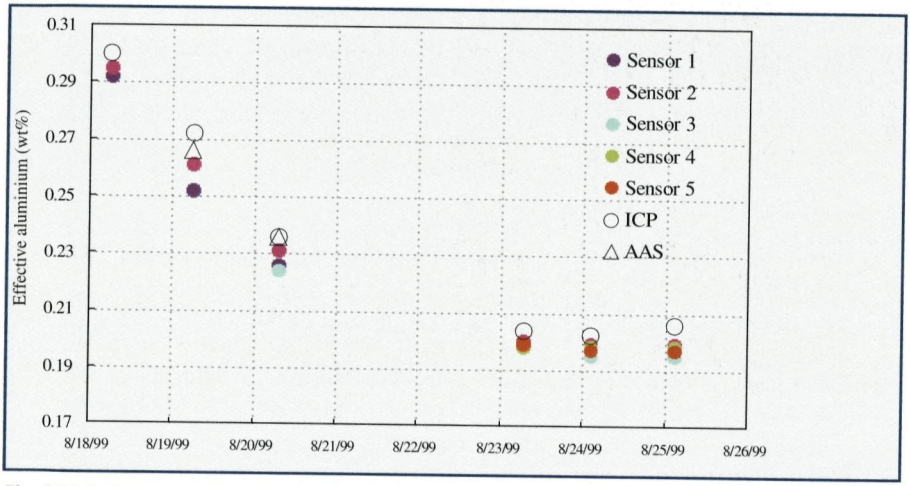


*Fig. PRO 3: Determination of the effective aluminium content by electrochemical sensors compared to chemical analyses in a simulated galvanising process at 455 °C. The melt has been diluted at selected time intervals.*

## Aluminium process technology

The work of the Aluminium process technology group is divided into two major parts: in the COSMA project (Controlled addition of sodium modifier to aluminium silicon foundry alloys) a system to add sodium modifier to molten aluminium-silicon foundry alloys is developed. The COSMA project, partly sponsored by IWT as a Eureka project, is carried out in close collaboration with the University of Cambridge, Verhaert Design & Development and Foseco International. The prototype system, shown in Fig. PRO 4, was presented at the Gifa exhibition of 1999 in Düsseldorf.


*Fig. PRO 4: COSMA prototype presented at Gifa '99 in Düsseldorf.*

The unit shown in Fig. PRO 4 is a combination of the COSMA system with a rotary-degassing unit. This combination enables an efficient distribution of the sodium in the aluminium melt.

In the PROCIAS project (Process control in aluminium melts) the aim is to improve the current melting processes in four Flemish aluminium foundries/cast houses. In every company an experimental design was set up, trying to determine the effect of the process parameters involved. In this experimental design, some process parameters are varied under well-defined conditions, enabling to estimate the effect of these variations on the final melt quality. In order to measure the quality of the liquid metal, some state-of-the-art measuring tools such as LiMCA, PoDFA and AlSCAN are used. In this project the quality of the liquid aluminium depends upon the amount of non-metallic inclusions and the hydrogen content. After finishing the first phase of this project several important effects could be observed. An illustration of such an important effect is shown in Fig. PRO 5. The response surface of a hydrogen measurement is shown as a function of temperature and degassing. It can be seen that low hydrogen values will be reached for high degassing values and low temperatures.

The knowledge of the most important process parameters enables to conduct a melting process in such a way that it leads to an improved molten metal quality.

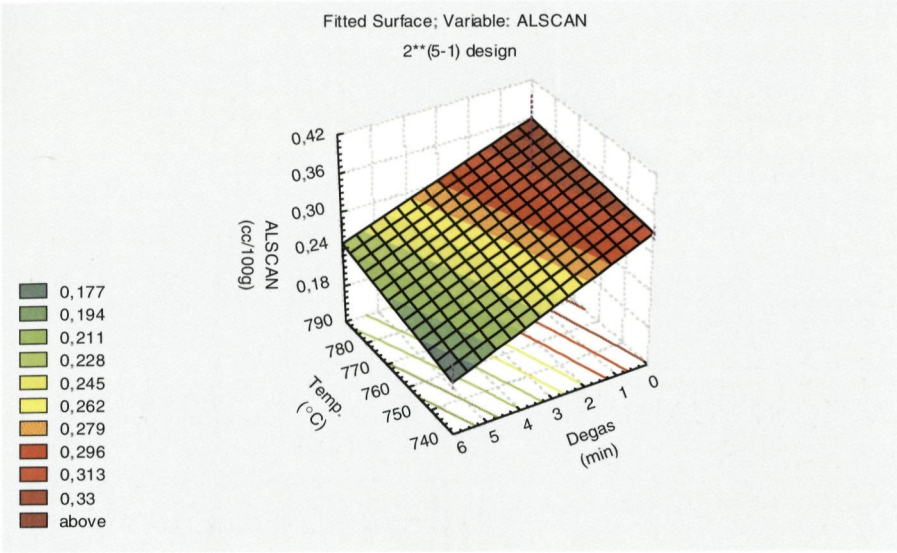


*Fig. PRO 5: Hydrogen response surface (cc $H_2$ /100 g Al) as a function of degassing time and melt temperature. Lower hydrogen contents are obtained at lower temperatures and for longer degassing times.*

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# Raw materials

*The centre of expertise Raw materials investigates and develops new techniques for the sustainable (re)use of raw materials, for industrial as well as governmental partners. Primary raw materials are studied in the 'Information Centre on Underground Energy Resources'. This centre focuses on the energetic valorisation of Flanders' deep subsurface. In the domain of secondary raw materials this centre performs applied research on recycling and valorisation of mineral residues and waste.*

## Energy resources in Flanders' deep subsurface

Vito's Information centre on underground energy resources is currently involved in the energetic valorisation of Flanders' deep subsurface. Actual feasibility studies commissioned by the Flemish Natural Resources and Energy Department (ANRE) focus on the alternative use of energy resources in the deep subsurface in possible combination with a reduction of greenhouse gases in the atmosphere. Two major topics have been dealt with during the past year: Flanders' potential of coalbed methane (CBM) recovery from deep coal seams in combination with the geological sequestration of $CO_2$ and an inventory of Flanders' geothermal energy resources.

Enhanced coalbed methane recovery possibly represents a new future for Flanders' deep coal reserves. A detailed study has been carried out based on all available borehole information and existing coal analyses in the Campine Coal Basin. As a result numerous maps have been produced allowing to estimate the overall minimum total methane gas reserve adsorbed to the coals. These theoretical reserves - up to depths of -1,500m - amount to about 300 billion $m^3$ of methane spread over a surface of about 1,590 $km^2$, which gives an average gas concentration content of about 190 million $m^3$ of $CH_4$ per $km^2$. Moreover, 6 positive anomalous areas, with higher values than the average gas-in-place content, have been identified in the basin and shall be investigated in a forthcoming study (Fig. GRO 1). An important fault zone, the Donderslag fault, subdivides the basin in two separate subbasins, each with a different gas content. The total 'gas-in-place' reserve of the anomalies in the eastern subbasin is about twice that of the anomalies located in the western one. Additionally the socio-economic factors influencing the economic application of enhanced CBM extraction from coals in the Campine Basin, are currently under investigation. These factors include: the presence of $CO_2$ producers ($CO_2$ emissions from fossil fuel combustion; process $CO_2$ from chemical processes), the amount of $CH_4$ consumers, the proximity of a gas distribution network, etc.

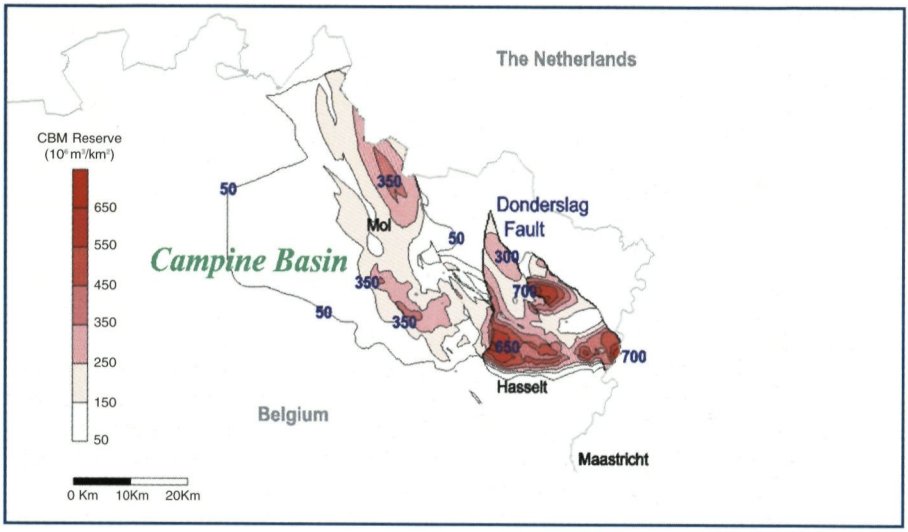


*Fig. GRO 1: Positive anomalous regions with high coalbed methane 'gas-in-place' concentrations in the Campine Basin. Note the marked difference between the eastern ad western subbasins.*

The Information Centre has also made a new geological inventory of potential geothermal reservoirs in Flanders. For each reservoir, not only the known geological parameters, reservoir characteristics and theoretical geothermal energy potential have been described in detail but also an overview of different possible ways of application has been given. Although Flanders is lacking high-enthalpy geothermal energy resources, it has still a very important potential of low-enthalpy geothermal reservoirs (aquifers with water temperatures below 150 °C). The largest concentration of those reservoirs is located in the Campine Basin area: indeed, here we can observe different reservoirs at a single locality but at different depths (in stratigraphic order): karstified Lower-Carboniferous limestones, Upper-Carboniferous Neeroeteren sandstones, Triassic sandstone reservoirs of the Buntsandstein, porous limestones of the Maastricht Formation (Upper Cretaceous) and a whole spectrum of more shallow Cenozoic sand aquifers. The theoretical geothermal energy potential of these deeper reservoirs amounts to about $114.10^8$ gigajoule, according to a recent study by Berckmans & Vandenberghe (1998).

The total geothermal energy potential of the shallow and colder (< 20 °C) reservoirs is unclear, because of important regional and local variations in their lithologic and hydraulic characteristics. For years Vito has been involved in the promotion and implementation of cold and heat storage in these shallow aquifers as a sustainable energy technology in the Flemish region (Fig. GRO 2).

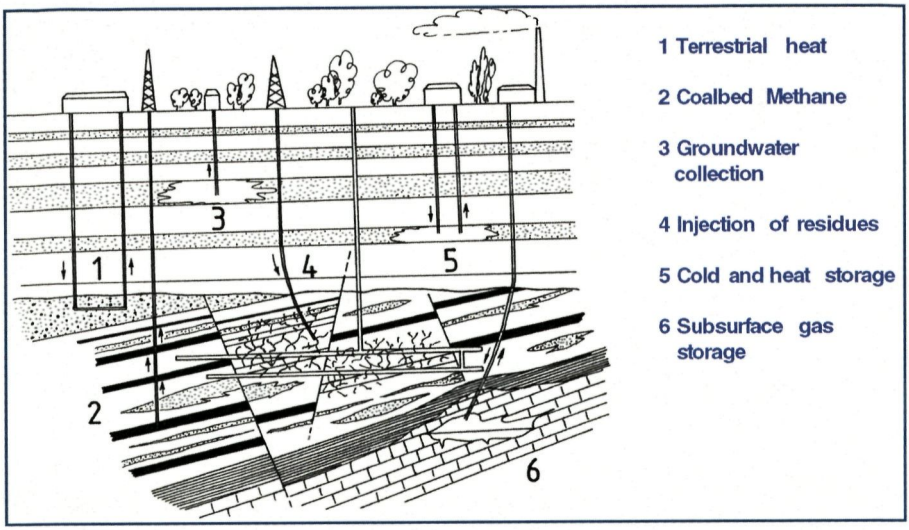


*Fig. GRO 2: Schematic illustration (not to scale) of the potential of the Flemish subsurface as underground energy source and as storage capacity*

The main constraints for the development of geothermal energy in Flanders are still the relatively low fossil fuel prices, the unawareness of this energy resource by potential user groups and the lack of information on the hydraulic behaviour of some important reservoirs. Wider use of geothermal energy in Flanders would require new exploration campaigns of the deep(er) reservoirs, additional hydraulic tests in abandoned geothermal wells and new information or scouting campaigns for identifying potential users and identifying their needs.

## Recycling of gypsum from construction and demolition waste

Waste gypsum from the construction materials sector is an important part of the construction and demolition waste (CDW). Although pure gypsum can be recycled infinitely, impure waste gypsum is often disposed of or dispersed in the CDW stream. Source separation is not performed on a large scale and sorting units for CDW often do not perform a gypsum selection. The sulphate content is a major criterion in the valorisation of the CDW as a secondary aggregate for concrete. Sulphate affects the technical quality and hardening behaviour of aggregates. Therefore, the question arises whether the presence of residual gypsum in CDW masonry aggregates is a burden for effective valorisation. The gypsum sector approached Vito to solve this problem.
The actual gypsum content and sulphate leachability has been studied for a range of sorted and recycled aggregates. This was compared to the overall environmental quality of the material. A major difference exists between products from sorting and recycling units. Recycling units process CDW in a primarily mechanical way. They work under a strict quality policy and produce aggregates with certified quality. Sorting units process the mixed CDW streams. They perform a manual or partially mechanical separation. The difference in acceptance policy and treatment methods is reflected in the aggregate quality. Sulphate leaching levels are one order of magni-

tude higher for the sorted aggregates. Due to the solubility controlled leaching mechanism, the material with a gypsum content of a few percents (> 5 %) shows an identical sulphate emission as pure gypsum products. This holds for the sand fractions of the sorting units. Comparison according to the material type shows that sulphate leaching is always higher for the finer material. Additionally, clear differences occur between the various units. Plants with a wind sifter generate an aggregate with lower sulphate leaching, as compared to plants without this type of separation step. Also the metal content and leachability are higher for aggregates from sorting units. Visual analysis of the various products from sorting and recycling gave data on the gypsum content. On this basis, a material flow diagram of gypsum could be set up. In order to optimise gypsum recycling from CDW, source selection measures need to be taken and a centralised collection and treatment system needs to be set up. This may yield a gypsum recycling potential of 10,000 ton/y on the Flemish market. Gypsum recycling will reduce the sulphate content of secondary aggregates and therefore increase their valorisation potential. At the sorting units, further measures need to be taken in order to ensure compliance with environmental criteria, such as metal leaching.

## Recycling of sewage sludge: the toluene problem

The reuse of municipal and industrial sewage sludge as a secondary raw material, as a fertiliser or a soil improver is subject to stringent limits of the metals and organic pollutants content. Recently, an unexpected organic pollutant (toluene) was detected in high concentrations in both, municipal and industrial sewage sludge, prohibiting the valorisation of sludge in agriculture.

In an attempt to detect the possible sources of this pollution, the incoming, outgoing and intermediate streams of two municipal waste water treatment plants (one with and one without anaerobic digestion) were analysed for their toluene content. Both the influent and aqueous effluent of the plants were free of toluene, indicating that pollution by an external source was unlikely. The fact that only toluene – and no xylenes – were detected also excluded illegal dumping of solvents as possible source of pollution. Toluene was detected in minor concentrations (lower than the limit values) in intermediate sludge streams, but the toluene concentration in both the digested and undigested sludge destined for disposal or reuse always exceeded the limit values. This sludge was stored for several weeks under anaerobic conditions and digestion of the sludge prior to storage had a positive effect on the toluene content of the sludge.

It was found that during the anaerobic storage of the sludge, uncontrolled methanogenic fermentation reactions took place in the sludge. Methanogenic fermentation is responsible for biogas production in anaerobic sludge digesters, in which the reactions proceed in a controlled manner. Three main types of bacteriological reactions take place during methanogenic fermentation. The first step consists of the breakdown of macromolecules (polysaccharides, proteins and fats) by fermentative bacteria to acetate, $H_2$ and $CO_2$ or to intermediate aromatic and short chain fatty acids. In the second step, an $H_2$-producing acetogenic converts these intermediate aromatic and short chain fatty acids. The $H_2$-consuming methanogenic bacteria then convert the acetate, $H_2$ and $CO_2$, produced by both the fermentation and the acetogenic step, to $CH_4$ and $CO_2$. The consortium responsible for the methanogenic step is very sensitive to disturbances of their environment (pH, $H_2$ partial pressure, ...). As a result of such disturbances their methanogenic activity stops and $H_2$, produced in the acetogenic step, is disposed of by reduction of the carboxylic group to a methyl group. In this way benzoic acid can be reduced to toluene.

This hypothesis has been tested by following the toluene concentration in undigested sludge, both fresh and after anaerobic storage during several weeks, held under anaerobic conditions in a laboratory (Fig. GRO 3). Results indicate very fast initiation of the toluene formation in fresh sludge and continued increase of the toluene concentration in sludge that had been stored anaerobically before the test. The toluene concentrations reached up to 300 ppm dm (dry matter), concentrations that have also been detected during the campaign on the waste water treatment plants.

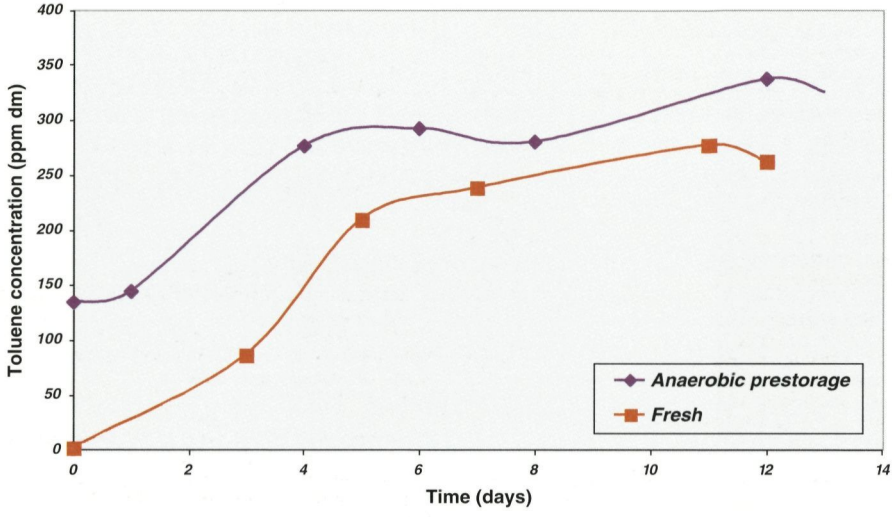


*Fig. GRO 3: Evolution of the toluene content (in ppm dry matter (dm)) of anaerobically prestored and of fresh undigested sludge as a function of time during anaerobic storage. The results indicate that the presence of toluene in sewage sludge is not necessarily due to an external pollution source but can be formed by natural bacteriological processes in the sludge. The toluene limit for use of the sludge as a secondary raw material, as a fertiliser or as soil improver is currently set at 1.1 ppm dm.*

From these data it is clear that the toluene contamination is not originating from an external polluting source but is formed by naturally occurring anaerobic bacteriological processes in the sewage sludge. Possible remedies to prohibit the formation of toluene are sludge storage under aerobic conditions, frequent aeration of the sludge or sludge liming (cessation of all bacteriological activity). The latter remedy has as a consequence that more sludge has to be disposed off.

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# COMPANY PROFILE

## Board of directors

**Chairman:**
Harry Martens, rector, LUC Diepenbeek

**Managing director:**
Rik Schrooten

**Members:**
Annick Clauwaert, advisor, Study service, ABVV, Brussels
Hugo Draulans, alderman, municipality of Dessel
Jan Huylenbroeck, civil engineer
Guy Marin, professor, University of Ghent
Camille Paulus, governor, province of Antwerp
Luc Platteau, general manager, Centexbel, Brussels
Norbert Van Belle, international vice president, Janssen Pharmaceutica, Beerse
Ingrid Vanden Berghe, director, CEPESS, Brussels
Paul Zeeuwts, chairman, IWT, Brussels

**Representative of Finance:**
Toon Tessier, advisor Social economy
Federal government, cabinet of the vice-prime minister and minister of Budget

**Commissioner:**
Hedwig Van Der Borght, director general, Administration for budget, accounting and financial management

**Observers at board meetings:**
Jan Gedopt, representative of LBC
Jacky Dekeyser, representative of BBTK
Roger D'Joos, representative of ACLVB

## Management committee:

Rik Schrooten, managing director
Christine Draguet, director Personnel & organisation
Jan G. Kretzschmar, research director
Theo Rymen, research director
Jos Proost, technical and administrative director

## Technical scientific advisory committees

The chief tasks of these advisory committees are:

- to review and guarantee external performance and quality of the research performed;
- to make recommendations for the (re)orientation of programmes and projects;
- to evaluate new programme proposals;
- to help promote collaboration with industry, universities and other technological research organisations.

### Technical scientific advisory committee energy

- William Bracke, chairman, managing director, Fina Research, Seneffe
- Ronnie Belmans, professor, Catholic university of Leuven (KUL)
- Paul Bulteel, secretary general, Eurelectric/Unipede, Brussels
- Jacques De Ruyck, professor, Free university of Brussels (VUB)
- Pieter Lagae, section head, Vereniging der Belgische gasvaklieden, Linkebeek
- Luk Peeters, division head, ANRE, Brussels
- Guido Vermeylen, vice-president, Union Minière, Olen

### Technical scientific advisory committee environment

- Rudy Verheyen, chairman, rector-chairman, University of Antwerp (UA)
- Raf Bouckaert, head Analytical laboratory, Bayer nv, Antwerp
- Wilfried De Nijs, general inspector, Flemish public waste corporation (OVAM), Mechelen
- Herman De Wel, director-member of staff, Flemish administration for environment, nature and land use (AMINAL), Brussels
- Frank Gérard, advisor, Flemish environmental agency (VMH), Antwerp
- Claude Klein, director, Chemical industry federation, Brussels
- Emiel Puttaert, advisor, Lippelo
- Willy Verstraete, professor, University of Ghent (RUG)

### Technical scientific advisory committee materials

- Guy Haemers, corporate vice-president, Bekaert nv, Kortrijk
- Carlo De Pauw, managing director, Belgian building research institute (WTCB), Brussels
- Urbain Meers, director Research and development, Sidmar nv, Ghent
- Wietze Meindersma, Membrane applications research, DSM, Geleen, the Netherlands
- Lambert Stals, professor, University centre of Limburg (LUC), Diepenbeek
- Luc Van Den Noortgate, director, Scientific and technical research centre of the metalworking industry (WTCM), Brussels
- Omer Van der Biest, professor, Catholic university of Leuven (KUL)
- Jean Vereecken, professor, Free university of Brussels (VUB)
- Gerrit Verspui, advisor, Eindhoven, the Netherlands

# Glossary of acronyms and abbreviations

| | |
|---|---|
| AAS | Atomic absorption spectroscopy |
| AISCAN | Aluminium scanning |
| AMINAL | Flemish administration for environment, nature and land use |
| ANRE | Flemisch administration for natural resources and energy |
| APEX | Airborne prism experiment (airborne hyperspectral imaging spectrometer) |
| ATES | Aquifer thermal energy storage system |
| AURORA | Air quality modelling in urban regions using an optimal resolution approach |
| BAT | Best available techniques |
| B-CGMS | Belgian crop growth monitoring system |
| BICMER | Biological composite membrane reactor |
| BIOMET® | Bio-metal sensor |
| BMSR | Biometal sludge reactor |
| BOILSIM | Boiler simulation software |
| BTEX | Benzine, toluene, ethylbenzene and xylene |
| CADDET | Centre for analysis and dissemination of demonstrated energy technologies |
| CBM | Coalbed methane |
| CDW | Construction and demolition waste |
| CES | Centre of Environmental Studies |
| C-fix | Carbon fixation – model for estimating the net amount of carbon fixed by vegetation |
| CFU-GM | Colony forming units by granulocytes and macrophages |
| CHP | Combined heat and power |
| COD | Chemical oxygen demand |
| COSMA | Controlled addition of sodium modifier to aluminium-silicon foundry alloys |
| COST | European co-operation in science and technology (EC programme) |
| CPIN | Cleaner production information network |
| ECVAM | European centre for validation of alternative methods |
| EDM | Eulerian dispersion model |
| EEA | European environment agency |
| ELGADI | Electronic ballast for gas discharge lamps |
| ELISA | Enzyme linked immunoabsorbent assay |
| EMIS | Energy and environment information systems |
| ERDF | European regional development fund |
| ESA | European space energy |
| ESTO | European science and technology observatory |
| ETSAP | Energy technology systems analysis programme |
| EUREKA | European initiative to raise the productivity and competitiveness of European industries |
| EUROS | European operational smog model |
| ExternE | Project GD XII Joule 'External cost of energy' |
| Felnet | Flanders environmental library network |
| FUL | University of Arlon |
| Gifa | Giessereifachmesse |
| GLP | Good laboratory practices |
| GOM | Gewestelijke ontwikkelingsmaatschappij – Regional development corporation |

| | |
|---|---|
| GPP | Gross primary production |
| HDV | Heavy duty vehicles |
| IBEMA | ERDF funded project to support innovation in SMEs by the introduction of new materials |
| ICP | Inductively coupled plasma (atomic absorption instrument) |
| IFDM | Immission frequency distribution model |
| IWT | Flemish institute for the promotion of scientific technological research in industry |
| JOULE | Joint opportunities for unconventional or long-term energy supply |
| JRC | Joint research centre at Ispra |
| KU Leuven | Katholieke universiteit Leuven – Catholic university Leuven |
| KWO | Koude-warmteopslag – Cold and heat storage |
| LCA | Life cycle analysis |
| LIFE | European initiative to contribute to the development and implementation of the EU environmental policy |
| LiMCA | Liquid metal cleanliness analyser |
| LUC | Limburgs universitair centrum |
| Mefias® | Membrane filtration assistance software |
| MESOCOM | Mesoscale atmospheric model intercomparison |
| MIVB | Brussels public transport company |
| MTD | Maximum tolerated dose |
| NEP | Net ecosystem production |
| NPP | Net primary production |
| NTU | Nephelometric turbidity units |
| OPET | Organisation for the promotion of energy technologies |
| OSI | Ovaria somatic index |
| OSTC | Federal office for scientific, technical and cultural affairs |
| OVAM | Flemish public waste corporation |
| PAH | Polycyclic aromatic hydrocarbons |
| PCB | Polychlorinated biphenil (Polychlorobifenyl) |
| PIDPA | Provinciale en intercommunale drinkwatermaatschappij der provincie Antwerpen |
| PILBO | Pilot plant for soil washing |
| PMT | Prime membrane technologies |
| PoDFA | Porous disc filtration apparate |
| PROCIAS | Process control in aluminium melts |
| PRODEM | Promotion and demonstration of environmentally friendly technologies |
| RBAO | Reaction bonded aluminium oxide |
| RIVM | Royal institute for public health and environment (NL) |
| RSL | Remote sensing laboratories, University of Zürich |
| RUE | Rational use of energy |
| SarScape | Vito model to derive structural parameters of a landscape from satellite radar images |
| SAVE | Specific actions for vigorous energy efficiency |
| SME | Small and midsized enterprises |
| SMOGSTOP | Smogstop model of groundlevel short ozone pollution |
| SOC | State of charge (battery) |
| SOP | Standard operating procedure |

| | |
|---|---|
| SPOT | Satellite probatoire d'observation de la terre |
| SVW | Studie- en samenwerkingsverband Vlaams water – Flemish centre for water research |
| TEMAT | Toekomstige emissies onder maatregelen in de transportsector – model for calculating historical emissions and predicting future emissions for different transport sector policies |
| TEOM | Tapered element oscillating microbalance |
| THERMIE | European programme on heat |
| UASB | Upflow anaerobic sludge blanket reactor |
| UCL | Université catholique de Louvain |
| UG | Universiteit Gent |
| UIA | Universitaire instelling Antwerpen |
| Ulg | Université de Liége |
| UNFCCC | United nations framework convention on climate change |
| UTES | Underground thermal energy storage |
| VDAB | Flemish employment service |
| VEGETATION | Name of the multi-spectral instrument onboard the SPOT4 satellite for the daily monitoring of the earth's vegetation cover (http:/www.vgt.vito.be) |
| VITOTOX® | Bioluminescence test for detection of genotoxic material |
| VLAMEK | Vlaamse methodiek voor ketelevaluatie – Flemish calculation tool for evaluating heating installations |
| VLAREM | Flemish regulations on the environmental permit |
| VLIET | Impulse programme for energy technology of the Flemish government |
| VLM | Vlaamse landmaatschappij – Flemish land use agency |
| VMM | Flemish environmental agency |
| VMW | Vlaamse maatschappij voor watervoorziening |
| VOC | Volatile organic compounds |
| VOEM | Vito's on-the-road emission and energy consumption measurement system |
| VTC | Vlaamse thermie coördinatie – Flemish thermie co-ordination |
| VUB | Vrije universiteit Brussel water research |
| Zirfon | Zirconia polysulphone composite material |

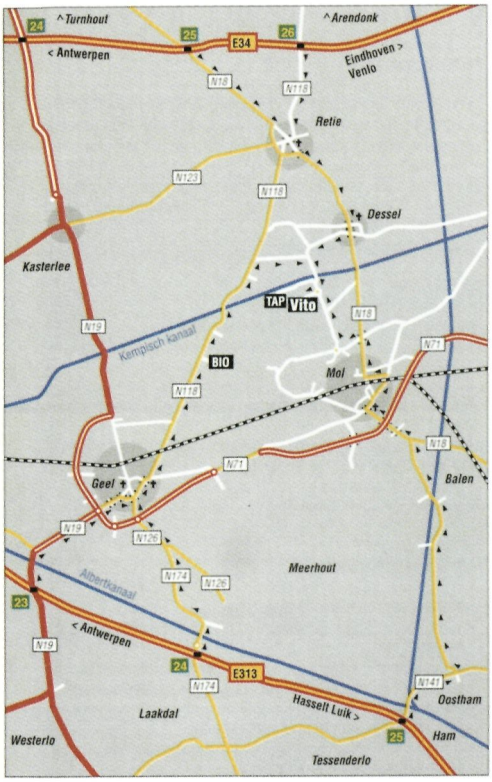
# Index

## X



## Z

# Location of Vito




## Via E313, exit 23:

- direction Geel via N19;
- go straight to a roundabout, there take direction Retie (NOT Mol);
- at the secoond lights, turn right in the direction of Retie (= N118);
- past the second lights, at the Church, turn left in the direction of Retie (= N118);
- after the canal, take the second street to the right (= Kastelsedijk);
- at the T-intersection, go to the right (= Boeretangsedreef, which becomes Gravenstraat);
- over the canal (= Boeretang).

## Via E313, exit 25:

- direction Ham via N141;
- in Oostham, go left in the direction of Mol and Balen;
- in Balen, take direction Mol via N18;
- at the second lights, go straight in the direction of Mol centre (= Molderdijk);
- at the following lights, turn right (= Graaf de Broquevillestraat);
- go straight to the railroad tracks (via Laar, Voogdijstraat and Rozenberg);
- past the tracks, turn left (= Leenhofstraat);
- at the T-intersection, turn right (= Turnhoutsebaan N18);
- at the lights, turn left (= Achterbos);
- at the roundabout, turn right (= Boeretang).

## Via E34, exit 25 or 26:

- direction Retie and Dessel via N18 (exit 25) or N118 (exit 26);
- in Dessel centre, at the second traffic lights turn right (= Hannekestraat which becomes Boeretangsedreef and Gravenstraat);
- over the canal (= Boeretang).

## Building BIO:

N118 Geel - Retie, from Geel: past the railroad tracks, take the seventh street to the right, from Retie: after the canal, take the second street to the left (see sign).

## Building TAP:

from Mol on the Boeretang *before* the canal turn left, from Dessel on the Boeretang. *after* the canal turn right, after ± 1.2 km turn left (see sign).

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# Notes

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