Perspectief

From Waste to Resource (W2R)

Ecological design for production of chemicals and energy from organic residues

February 2010

Abstract

The W2R program aims to develop processes for an industry integrated production of resources from waste, in line with the waste=food credo defined in the cradle-to-cradle manifesto. Integration of industrial production processes with the effective valorisation of the generated organic residues will minimize the ecological footprint, and contribute to more sustainable agroindustrial production.

The research program is constructed around the basic concept of using mixed (non-defined) microbial cultures for conversion of organic residues to valuable products. In the first step of such a production process, water soluble volatile fatty acids are liberated from complex organic material by microbial conversion of the biomass constituents. In a second step, the volatile fatty acids are converted to end-products like biopolymers or methane containing biogas. Successful development of a process like biopolymer production from waste requires a multidisciplinary approach involving upstream biopolymer production as well as downstream product recovery and effective application of the polymer produced. The W2R program aims at facilitating such an integrated approach to establish implementation in industry of the processes proposed..

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1 Technology landscape

1.1 Goals and Approach

The goal of the W2R program is to develop nature-inspired, operationally simple and robust, and cost-effective, integrated processes for the production of resources from organic residues. The program aims at bridging the fundamental gap between traditional environmental and industrial biotechnology based approaches[8]. The objective is to use the mixed microbial culture approach derived from environmental biotechnology for the establishment of bulk chemical production processes as are typically associated with industrial biotechnology.

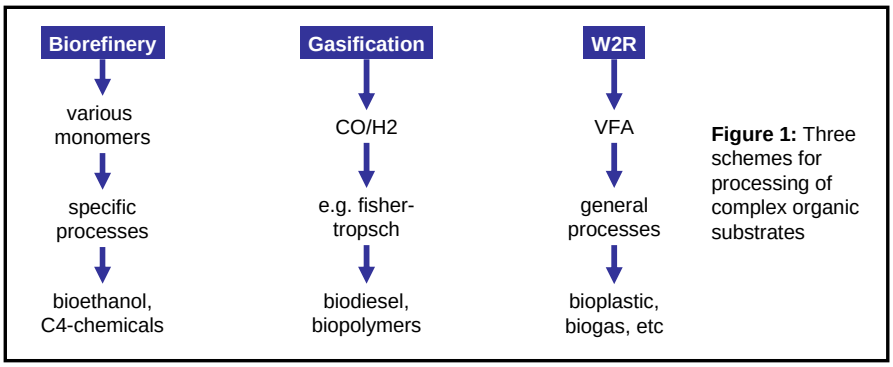

Figure 1: Three schemes for processing of complex organic substrates

Current approaches for processing complex biomass are based on (i) primary gasification to syn gas, or (ii) an initial separation of monomers in a biorefinery (see Figure 1). Both approaches have their limitations in terms of the energy requirements involved, and the limited range of suitable type of biomass. Both methods are, furthermore, not suitable for organic residues with high water content like those frequently encountered in agro-industrial processes.

We propose an alternative route for valorisation of these kinds of organic residues that remain after harvesting, processing and use of agricultural products. We advocate the development of processes based on environmental biotechnology principles but directed towards product formation besides the traditional aim of water or solid waste treatment. The proposed processing route consists of three steps, with Volatile Fatty Acids (VFA) as key intermediate and is referred to as W2R in Figure 1 and 2:

- The production of VFA from organic residues by anaerobic fermentation, including procedures for enhanced enzymatic hydrolysis. Anaerobic biodegradation pathways converge at VFA, making them the principal intermediates for biotechnological processing of organic residues.
- VFA conversion into chemicals or energy in a second step. This step should typically involve a phase transition (gaseous or solid end product) in order to separate the product from the water-based substrate.
- Downstream processing and upgrading of the end products.

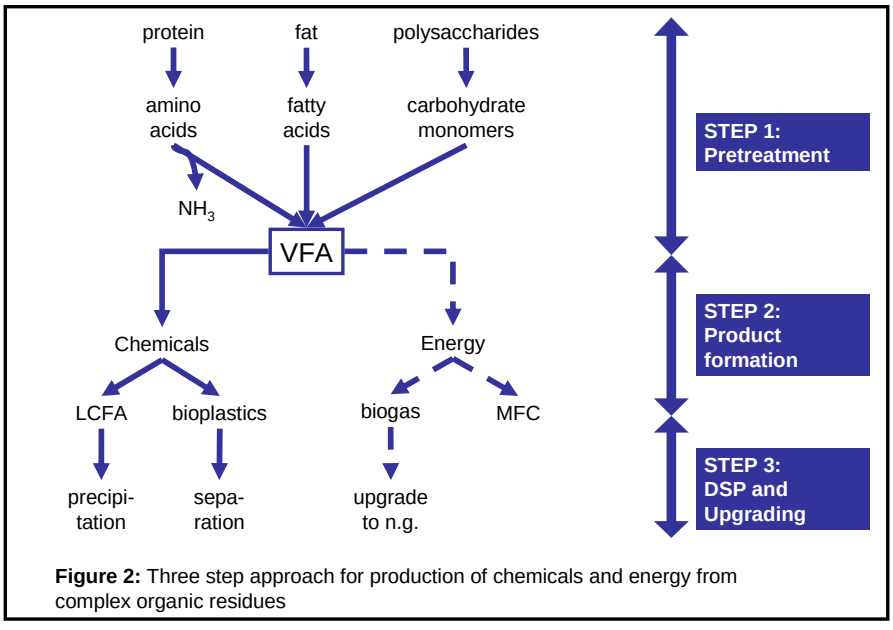

Figure 2: Three step approach for production of chemicals and energy from complex organic residues

VFA form the key intermediates in the scheme proposed due to their central role in the anaerobic degradation of the principal constituents of complex substrates: carbohydrates, protein and fat (Figure 2). New technology will need to be developed that aims for the optimization of VFA-production from complex substrates (Step 1). And to develop processes for the production of chemicals and energy from VFAs (Step 2). Additionally, technology is needed for separation and purification of the products made by the mixed microbial cultures (Step 3). The program intends to apply ecological principles for process development to minimize operational costs. We are convinced that bulk scale production of chemicals and bioenergy from organic residues cannot be based on pure culture-based bioprocesses, due to the high costs of substrate sterilization and other operational costs. Bioprocesses derived from current wastewater treatment plant principles are much cheaper in operation and construction per amount of substrate converted.

The bioplastic (polyhydroxyalkanoate, PHA) production process investigated in recent years at the TU Delft is currently the best example of a process based on ecological principles that allows for the production at efficiencies and rates comparable to industrial biotechnology-based processes. This line of research will therefore serve as an example for other processes to be developed. The well-established biogas production process (anaerobic digestion) is considered as accepted technology, and is only included in the program when true innovative applications are proposed. Other biochemicals that can be aimed for in the *W2R* program include long chain fatty acids (LCFA) or alcohols produced by biohydrogenation of VFA, or microbial storage polymers different from PHA. Niche applications can furthermore be defined aiming for direct electricity production from VFA in microbial fuel cells (MFC).

Valorisation of substrates formerly described as waste is essential to establish a sustainable society incorporating cradle-to-cradle based concepts. The use of organic residues for production of chemicals and biofuels bypasses the discussion on food versus non-food application of biomass and is therefore in line with the Cramer's criteria for sustainable biomass. Industries are more and more aware that production processes should be implemented in a sustainable processing scheme that optimizes the valorisation of all agricultural intermediate products while minimizing the emissions into the environment. It has been estimated that effective harvesting of the potential energy available in waste can account for 7-25% of the overall energy demand. This opens up the specific need for technology that combines the traditional low-cost methodology from waste treatment based processes, aimed at eliminating environmental pollution, with the maximization of productivity objectives, as defined for industrial biotechnology. It furthermore requires direct collaboration between industrial partners that either have experience with the biotechnological production of chemicals and bioenergy (DSM, Nedalco, Purac, etc), and the companies with extensive experience in processing of organic residues (Paques BV, AVR). The W2R program can play an important role in facilitating this

1.2 International landscape

The concepts proposed in the W2R program are new. Evidently, there is a strong community working on the waste treatment side of the program, as well as the bioproduct (industrial biotechnology) side of the program. However, convincing examples that have been implemented in industry of combinations of both fields are not available. Some research groups have recently initiated work in a similar direction. The only established process in this field is the anaerobic digestion process that is widely applied for valorisation of waste.

1.3 Distinctive character of the program

Effective valorisation of agroindustrial biomass is an intensively investigated topic. The distinctive nature of the W2R program is based on the following characteristics:

- The use of a different processing route for organic substrates based on the fate of organic substrates in natural ecosystems. This route is based on the role of volatile fatty acids as central intermediates that can be formed from organic residues, and will serve as building blocks for final product formation,
- The application of mixed microbial communities for processing of the biomass. This approach excludes the need for energy intensive disinfection and allows for straightforward process operation,
- The use of organic residues (with a high water content) formerly referred to as waste as raw material for the processes to be developed.

The processes developed in the W2R program will offer an alternative and/or a contribution to the existing routes for processing of biomass shown in Figure 1.

1.4 Economic impact of W2R

The effective valorisation of organic residues will be of vital importance in a more sustainable society that aims for implementation of cradle-to-cradle based concepts for the use of agricultural resources. It fits within the sustainability objectives of the Dutch government and will allow Dutch industry to develop integrated concepts for processing of agro industrial products.

The added value of conducting the research proposed in the W2R program is that it facilitates the multidisciplinary nature of the research required. The different steps in the overall processing scheme are interdependent, requiring adequate exchange of information between research projects and the industries involved.

Another important factor is the participation of the different types of industry that will be required to bridge the current gap between waste treatment and industrial biotechnology, including food industries. It is evident that efforts from both sides are required to facilitate the

concept of conversion of organic residues to chemicals and energy.

1.5 Relevance for the Netherlands

The processes developed in the W2R program will add to the sustainability objectives of agro industrial production. Methods for effective valorisation of organic residues generated during agro industrial production provides Dutch industry with:

Strength

The first main strength of the processes proposed in the W2R program is the fundamental advantage of using waste for the production of new resources. This fits very well with the objectives defined in the cradle-to-cradle manifesto and the production processes do not interfere with food production. The second main advantage is use of mixed microbial communities for processing of the biomass, which minimizes the energy input (no sterilization required) and excludes the need for the use of genetically modified microorganisms

Weakness

Not a weakness, but a limitation to the type of processes proposed in the W2R program is the range of products that can be aimed for. The end products are limited to those playing a role in the natural cycles of the elements, and are preferably not soluble in water, like a gas or a intracellular solid such as biopolymers. Non- or poorly water soluble products will simplify cost effective down stream processing significantly.

Opportunity

The main opportunity we see is related to the threat indicated below. The W2R program enables the development of a research network that covers the different fields required to establish the processes proposed. It will also facilitate the cooperation between industries that are traditionally not related, like environmental biotechnology companies and (bio)polymer producing industries.

Threat

Effective process development requires a close cooperation between both knowledge institutes and different types of industries. For example, the research on down stream processing of biopolymers requires a regular supply of raw material that needs to be supplied by other participants in the program. This can only be established in close cooperation between research institutes and industries involved.

1.6 Other (inter)national initiatives

A major other national initiative is the B(E)-Basic program for industrial biotechnology. However, B(E)-Basic has a clear focus on the production of chemicals and biofuels according to the biorefinery route in Figure 1. To a large extent, this program aims at producing high added value products, using specialized, genetically modified strains of microorganisms with pure glucose as the substrate.

The W2R program is complementary to a program like B(E)-Basic due to its clear focus on organic residues. It aims at utilizing the residues generated in the processes that are proposed in the B(E)-Basic program.

The W2R program allows for multidisciplinary research that is currently part of different research programs, like the polymer institute for investigating polymer properties and B(E)-Basic for biotechnological product development. It clearly has its own niche in the current range of research and development initiatives.

Internationally there are other initiatives that aim for more effective valorisation of organic residues. However, to our knowledge there are no other integrated programs that specifically combine microbial community-based biotechnology with downstream processing and product application.

The W2R program provides a unique opportunity to conduct the kind of multidisciplinary research that is currently required to bring the processes closer to practical application in industry.

2 Ambition and goals

2.1 Strategy

The strategy chosen in the W2R program is twofold:

- The first aim is to develop at least one process up to the point that it can be introduced into the industrial market. This should become a proof of principle for the approach promoted in the W2R program.

  This requires an integrated and multidisciplinary projects that includes upstream bioprocessing of biomass, down stream product recovery, product utilization, as well as overall integration in an industrial production scheme.

- The second aim is to identify, novel microbial community-based processes that in the future may lead to novel applications of the concept proposed (see Figure 2). This research primarily aims at finding new microbial community based bioprocesses for production of different biopolymers, or other end products.

2.2 Interdisciplinary work and synergy

Even though the basis of the W2R program is microbial community-based biotechnology, various other aspects of the processes to be developed will need to be covered as well. To develop a waste based biopolymer production process for example, a combined effort into bioprocesses, down stream processing, product utilization and industrial integration is required. There is a down-stream dependency of the upstream achievements for generating the raw material required, and adequate collaboration is therefore a prerequisite.

3 Industrial Relevance & Utilization

General

For utilization of the process concepts proposed, a good collaboration between the different types of industry is required: waste treatment-oriented companies will need to collaborate with both waste producers as well as product development companies. To establish this, regular progress meetings will be organized between researchers and industries involved in the different projects. Besides the progress meetings of the individual projects, an annual meeting will be organized that brings all participants in the program together and allows for obtaining an overview of the work conducted in the program. In a later stage of the program, an international conference will be organized to enhance the international visibility of the W2R program.

Pilot plant

A first step in the utilization can be established by development of a pilot plant facility, aimed at biopolymer production. The pilot plant allows for demonstration an example process on a semi commercial scale and will generate large amounts of product of industrial quality. This is essential for investigating downstream processing and upgrading methods aimed at maximization of the product yield. It will furthermore allow the industrial partners to investigate potential marketing and implementation of a *W2R* based production process.

Knowledge transfer

Knowledge transfer between researchers and industry will be enhanced by establishing user committees and the organization of an annual workshop. The leading role of Dutch research and industry in the *W2R* field will be propagated by organization of international seminars and conferences

4 Application fields

Program requirements:

The main aspects of the W2R program are:

- The program aims specifically for agroindustrial residues; low value substrates (organic waste) originating from agro industrial activities, typically with a high water content,
- The program aims for application of microbial communities based processes for production of resources from waste,
- Volatile fatty acids are the anticipated intermediates in the processes

Program limitations

Excluded from the W2R program are:

- Fully physical-chemical methods for conversion of biomass into novel resources,
- Nutrient recovery methods, as long as they are not directly related to a microbial community based process for valorisation of organic waste,
- No substrate pretreatment methods as intensively investigated for development of the 2nd generation biofuels are included in the program.

Ideal project proposal

The W2R program facilitates two types of project proposals:

- Projects that aim for development of a specific microbial community based bioprocess. This kind of projects may include the more explorative investigation of a specific process, for a specific application. It may furthermore concern a specific new method to establish a microbial community based process for production of chemicals or bioenergy. To ensure a multidisciplinary approach, the projects should involve at least two research groups with a different background. Example topics are:
    - Specific applications of bioelectrochemical systems,
    - Processes using different strategies for producing biopolymers,
    - Or to produce different biopolymers like lipids with algae.
- Larger, integrated multidisciplinary projects that aim for investigating the different aspects of the production process proposed. In these multidisciplinary projects different researchers will need to collaborate to develop a prosperous concept for conversion of waste into novel resources. The basis of the process to be developed should be a microbial community based bioprocess. The research may include the development of a pilot scale facility, but may also include life cycle assessment oriented research to explore the market possibilities.

5 Coherence and Knowledge Transfer

To optimise knowledge transfer between the projects within the program and to ensure program coherence, the program committee with support of STW will:

- Actively stimulate communication within the user committees of the different projects
- Coordinate interactions between the users committees of the different projects
- Organisation of regular (i.e., annual) W2R workshops to exchange knowledge

Knowledge transfer outside the program will be established by:

- Workshops for a broad forum of end-users and experts in innovation trajectories
- Press releases
- Publications in peer reviewed journals and popular papers/journals
- Stimulation of active participation of project members in national and international conferences
- Intensification of interactions with small and medium enterprises (MKB Nederland)

6 Organization of the Program

6.1 Coherence

The program focus and description is based on a workshop held in January 2010, with 30 participants from academic and industrial background (see also Appendix A). The background of the participants covered the whole chain of research and process design to manufacturing and application.

For the guarding of the goals and coherence a program committee is installed by the STW-board. This committee will screen the pre-proposals and will advise the applicants on the fit of the proposal with the program. After the ranking of the full proposals by referees and a jury, the list of ranked proposals will be reviewed by the program committee on relevance to the program goals and on coherence. The program committee will advise the STW board on the cohesion of the ranked proposals. Based on the jury report and the program committee advice, the STW board will decide which of the proposals will be granted.

6.2 Budget

For this call a budget of M€ 3.4 is available which must be matched by the contributions of potential technology users (companies/institutes) to a total of at least M€ 4.5. The maximum of project costs that can be requested from STW is k€ 750 per project. A contribution of potential "users" of at least 25% of the total project budget is compulsory and adds up to the requested amount.

The users do not have to co-finance up-front in the program but may contribute in-kind (materials, equipment, facilities etc.) and/or financially in the project wherein they will participate.

To realize the ambitions of the program a budget of 70 k€ for workshops, conferences, events and a website will be reserved on program level. This funding will be made available by the STW board upon advice of the program committee

6.3 Who can apply

Scientists employed by Dutch universities or institutes recognized by NWO are eligible to submit a (pre) proposal (see OTP-guidelines of STW for eligibility criteria). Since W2R is a multidisciplinary program, projects where at least two of the four themes are addressed, are required.

6.4 Proposals and selection

The selection of proposals will be done in two steps: a call for pre-proposals and an invitation to the applicants of pre-proposals to submit full proposals. The pre-proposals will be evaluated by the program committee. The STW board will decide on the funding of the full proposals.

6.5 Funding

Project grants will cover:

- Personnel costs (including PhD and Postdoctoral researchers, technical assistants and programmers)
- Material costs (including national travel costs)
- International travel costs
- Costs for equipment

The institution(s) of the applicant(s) ensure(s) the required infrastructure, the supervision and the fitting into the research program of the research institute. STW may verify this with the dean or the executive board of the institute.

The expertise required for the research must be available at the requesting institute(s), so that external consultants will not be necessary. When foreign universities and institutes that cannot apply for STW-funding (e.g. TNO) are involved in the program, these parties take care of their own funding.

6.6 How to submit?

In order to minimize the time needed for writing and evaluating the proposals, it is compulsory to submit a preliminary proposal. All pre-proposals must be written in accordance with the formal guidelines that can be found in the call for pre-proposals. Only pre-proposals written in English and in accordance with the guidelines will be accepted for evaluation. Pre-proposals should be sent to STW via Iris (on-line electronic submission system of STW). Pre-proposals should be submitted to STW before Monday April 26, 2010 at 12.00 a.m. Pre-proposals submitted after this deadline will not be accepted.

6.7 Pre-proposals

Pre-proposals should contain a short description (3 A4) of the proposed research, utilization paragraph and estimated budget. The proposal should make clear which potential users will contribute to the project. Support letters are optional for the pre-proposals but can be included (letters of intent are accepted).

6.8 Full Proposals

Full proposals must consist of a detailed description of the expected results, planning of the research and a utilization paragraph. The utilization paragraph should include the important industrial challenges that will be solved, the time frame to implementation and the expected bottlenecks during the implementation. Companies and institutes, which will potentially contribute, should be involved bottom-up during the preparation of the proposal.

A full proposal will be evaluated only if it is preceded by a pre-proposal.

The scientific quality and the utilization perspective of the full proposals will be evaluated individually by peer review. An independent jury of about eight (inter)national experts of universities and industry (applicants will be excluded) will rank the full proposals. Each jury member will give 3 marks for each proposal: one for scientific quality, one for utilization potential and one for the strategic fit within the program. The marks will be averaged with equal weight to one final score for the proposal which determines the ranking. In addition to the ranking by the jury the program committee will formulate an advice on the cohesion between the project proposals and their relevance for the program. The decision of the STW board will be based on the ranking by the jury and the advice of the program committee.

The guidelines for full proposals are based on the 'Open Technology Program (OTP)' with as main difference that the potential technology users (companies/institutes) should contribute for at least 25% of the total project costs. The proposals should therefore be accompanied by a 'letter of participation' in which the contribution has been made explicit and in which details are given on what, when and how these contributions will be made available. For more details see: 'richtlijnen voor het Open Technologie-programma' (www.stw.nl).

6.9 Assessment and selection criteria

Upon receiving a pre-proposal STW will decide on its admission (eligibility criteria). The program committee will assess the strategic fit within the research program and its topics. Each individual program committee member will give a mark for the strategic fit for each proposal. Then, in a plenary session the program committee will discuss all pre-proposals and formulate an advice to the applicants. This advice can be:

1. to submit a full proposal or
2. to adjust the proposal so that it would better fit into the program or
3. not to enter the subsequent selection procedure.

The program committee will evaluate the fit of the pre-proposals within the framework of the program and will use the following considerations:

- To what extent does the proposal fit within the research topics of the program?
- The project should be carried out by at least two clearly collaborating researchers (PhD and Post-docs);
- The project is based on a collaboration between two clearly collaborating groups. The proposal must make clear how the collaboration between the groups will be implemented and it should become apparent how the different knowledge fields and expertise domains are integrated;
- Do the proposals overlap each other and if so, what are the consequences for the funding?
- Projects must combine excellent scientific research with an innovative approach;
- The goal of the program is to bring at least one process close to implementation in industry. Clearly defined ideas on utilization are therefore very important

Full proposals will be evaluated by peer review on scientific quality and utilization potential.

Scientific quality:

- Originality and innovative character of the proposal
- Contribution to the aims of the Perspectief program
- Expected impact on the scientific community
- Research method
- Time schedule
- Budget
- Infrastructure

Utilization:

- Potential economic impact
- Past performance in utilization by the applicants
- Contribution to the development of applied knowledge and aims of the program
- Impact on utilization if the project is carried out successfully
- Different steps needed (time path) to utilize the results
- Chance on patents and/or know how agreements
- Participation of users

The jury will be asked to assess the proposals on these aspects and also on the strategic fit within the program.

6.10 Time schedule SmartSeparations proposals

Call for pre-proposals open	Monday March 1, 2010
Deadline pre-proposals	**Monday April 26, 2010, 12.00 a.m**
Notification to applicants pre-proposal of the positive/negative advice to submit full proposal	Tuesday June 8, 2010
Deadline full proposals	**Wednesday September 1, 2010, 12.00 a.m.**
Start review by experts	Tuesday September 21, 2010
Protocol sent to applicants	Tuesday October 19, 2010
Deadline comments applicants	Tuesday October 26, 2010
Ranking by jury ready	Friday November 19, 2010
Advice Program Committee to STW board ready	Friday December 3, 2010
Decision by STW board on funding + notification to applicants	**Friday December 10, 2010**

7 Program Committee

- Dr. Ir. R. Kleerebezem (program leader), Department of Biotechnology, Environmental Biotechnology group, Delft University of Technology
- Prof. Dr. Alfons J. M. Stams, Laboratory of Microbiology, Microbial Physiology group, Wageningen University
- Prof. Dr. J.B. van Lier, Faculty of Civil Engineering and Geosciences, Department of Water Management, Section Sanitary EngineeringDelft University of Technology
- Ir. Carl Schulz, Paques B.V., Balk
- Dr. Ir. Cor A. M. De Laat, general manager of the Cosun Food Technology Centre, Roosendaal
- Dr. M. Hensing, DSM Biotechnology Centre, Delft

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This document has been compiled by STW on the basis of aforementioned workshop of February 2010, and the inputs of Robbert Kleerebezem (TU Delft) and Ron Winkler (STW) d.d. 2010, 19 February.

Appendix A. List of people invited and present at the workshop

P. Baets	Purac Biochem B.V.
N.C. van den Berg	Pharmafilter
Ir. P.A.M. Besseling	Ministerie van L.N.V.
Ir, J. Buizert	IV-Industie B.V.
Dr. T. Cohen	Ecofys Netherlands B.V.
Ir. C. van Driel	Agentschap NL
Dr. R. Duchateau	TU Eindhoven
H. Feenstra	Akzo Nobel Industrial Chemicals B.V.
R. Franklin	Biothane
Dr. J.G.P. Goosens	TU Eindhoven
Dr. Ir. H.V.M. Hamelers	Wageningen Universiteit en Research
Dr. M. Hensing	DSM Biotechnology Center
Dr. Ir. K.J. Keesman	Wageningen Universiteit en Research
P. Kelly	Mirel Plastics
Dr. Ir. R. Kleerebezem	TU Delft
Dr. J. Krooneman	Bioclear B.V.
Ir. K.W. Kwant	Agentschap NL
Dr. Ir. A.A.M. de Laat	Cosun Food Technology Centre
A. van der Last	Avebe UA
Prof. Dr. J.B. van Lier	TU Delft
Dr. Ir. R. Meulepas	UNESCO-IHE
Dr. Ir. G. Muyzer	TU Delft
Dr. Ir. E.E. Neuteboom	NWO-CW
Dr. M.K. Patel	Universiteit Utrecht
Dr. C.M. Plugge	Wageningen Universiteit en Research
Ir. C.E. Schultz	Paques B.V.
J. Tamis	TU Delft
B. Versprille	Veolia Water
Ir. E. Wortel	Pharmafilter
Ir. C.E. Zagt	Bareau