Perspectief

11157 Smart Separations for Complex Systems (SMARTSep)
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Abstract

This program aims to establish the new separation principles/driving forces required for the *Smart-Sep*arations of the future as identified in the Innovation Roadmap Separation Technology. Separation processes account for more than 40% of the energy consumption and up to 70% to the investments within the (chemical) process industry. The major contributions originate from separating so-called complex systems, which are extremely difficult to separate due to strong molecular similarities and/or complex composition. As such, separation technology is a key factor in the competitive and sustainable production of high value added products, both for leading multinationals and innovative Small and Medium sized Enterprises (SME's).

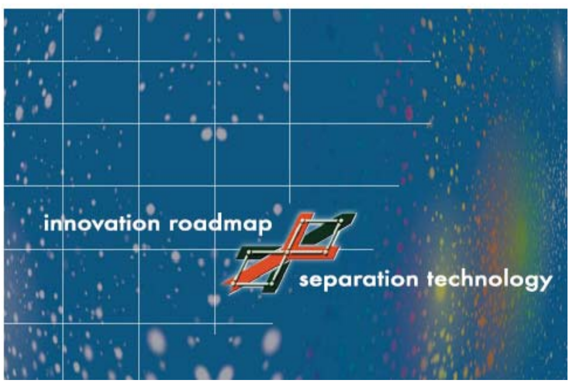
SmartSep focuses on four themes; (1) new principles/driving forces, (2) new materials, (3) new devices and (4) enabling sciences. The overall scientific challenge is to identify/discover those new principles/driving forces which can be applied in new materials and/or devices to open new routes for the complex mixture separation. As final result the SmartSep program will establish an integrated combination of new highly selective separation principles/driving forces, new materials and new devices for industrial scale separation processes. Additionally new methodologies will be established to support the targeting, development and design of technologies and/or processes employing the established new principles/driving forces by advanced modelling techniques.

The application perspective of the SmartSep program is intrinsically high because the topics originate from the long term needs defined by the Dutch process industry in the Innovation Roadmap Separation Technology. SmartSep distinguishes itself by focusing on the long term (10-20 year) break-through needs, which are currently not addressed in the short-medium term (5-10 year) oriented programs of existing initiatives. Maximization of application perspective will be secured by an intensive utilization trajectory to ensure optimal embedding of follow-up valorisation activities within suitable programs/initiatives. Therefore SmartSep is a unique initiative that will combine the generation and valorisation of a multitude of new principle/driving force based separation technologies with the transition of current cooperation platforms into a nation wide lasting multi-disciplinary cooperation network between industry, institutes and academia.

Contents

1 Setting and Relevance

Within the (chemical) process industry separation processes contribute for more than 40% to the energy consumption and up to 70% to the investments in new installations. The major part of these contributions originates from the separation of so-called **complex systems** consisting of molecules/particles with very similar properties (isomers, enantiomers, colloidal particles etc.) or containing a large variety of components/particles such as encountered in natural feed stocks, fermentation, biorefineries etc. Already in 2004 the main conclusion from the Innovation Roadmap Separation Technology (Figure 1) was that for these complex systems the capabilities of the existing separation principles/technologies will be too limited to initiate the required breakthroughs with respect to energy consumption (50-80% reduction), competitiveness (75% intensification) and value generation through increased quality in 10-15 years time. A clear need was identified for the establishment of new **SMART** separations that utilize new highly **S**elective separation principles, require **M**inimal footprint, are industrially **A**pplicable, **R**esource effective and easily **T**argeted towards different complex systems.

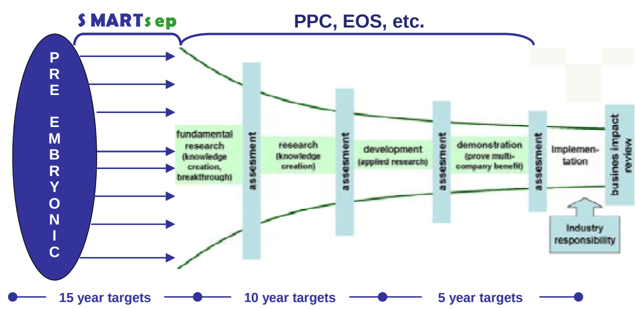


(Figure 1)

New (SMART) separations based on new principles and driving forces are needed not only to suite the future demands of the chemical and related industries. Those separations are expected to play a crucial role in successful realization of numerous new technologies which are envisaged as milestones on the way to a full sustainable society of the 21st century. Examples of such "milestones" recently identified by leading European scientists during the so-called Delft Skyline Debates (Action Plan Process Intensification) include:

- efficient technologies for distributed separation in diluted systems
- efficient technologies for worldwide clean water supply
- high-efficient decentralized electricity generation
- low-cost small scale processing technologies for production applications in various environments
- intensified production technologies for recyclable (composite) materials
- intensified fuel cell based systems (including biomass)
- sustainable recovery of scarce elements
- production system for personalized medicine
- functioning devices for fuels directly from sunlight

The **main barrier** for the initiation of research projects on the establishment of technologies and processes based on new separation principles/driving forces within the currently available initiatives is the long timeframe of 10-15 years required to go from discovery to application. As illustrated in figure 2 below, the present public-private cooperation programs have a (desired) strong focus on industry demand with a bias towards short and medium term (5-10 year) gains. At the same time the new separation principles/driving forces required to address the long term (>10 yrs) objectives are typically in the so-called pre-embryonic stage of research where, although the first discoveries have been done, minimal knowledge exists on how to apply them to establish new technology concepts. This lack of knowledge is the main hurdle for taking them up within the present public-private cooperation programs. Therefore, it is the main aim of this program to stimulate explorative research targeted at bringing new separation principles/driving forces from the stage of first discovery to a level of technological maturity that enables their utilization within national research co-operations to establish the **SMART SEP**aration processes required for the sustainable society of the future.

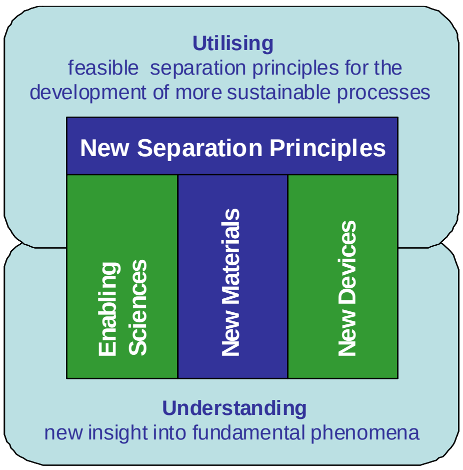


(Figure 2)

2 Goals and Ambitions

As final result the SmartSep program will establish an integrated combination of **new highly selective separation principles/driving forces** for complex systems that are shown to be potentially applicable in new materials and new devices which can be applied in industrial scale separation processes. Additionally new methodologies will be established to support the targeting, development and design of technologies and/or processes employing the established new principles/driving forces by advanced modelling techniques such as molecular modelling and computational fluid dynamics.

The projects in SmartSep will show that the principles under development have the potential to lead to effective and efficient application, and that they will contribute to an improvement in sustainability of industrial processes. Starting point of SmartSep are those principles of which the conception has been published in recent scientific literature. The projects do not have to demonstrate the technical operation at larger scales, but will show the potential technical feasibility of the principles mentioned in practice. The program aims at projects with high ambition but still in the incubator phase, the goal is that approximately half of the projects would be so successful that they are taken further in shorter-term research initiatives, for example within DSTI, APPI, Wetsus, ISPT, EOS and others.



(Figure 3)

2.1 Establish New Separation Principles / Driving Forces

The programme primarily aims at opening up new principles or driving forces for separation processes which lead to better and more sustainable processes. However, as is shown in figure 3 above, these new principles are often the result of innovative developments in material and construction technologies, on nano-, meso-, micro- or macro-scale, as well as in enabling sciences. Thus, a significant part of a project may include the development of new materials or devices, or the development of methods (e.g., analytic, measurements or modelling / simulation). However, these will serve the goal of the new separation principle(s) or use of new driving forces while their understanding should come from existing scientific literature

The ambition is that the work will be on separation principles that are generic; i.e., it should be applicable not for one specific separation issue, but be applicable on a broader field. This also applies to the enabling parts of the project: for example work on making modelling suitable for the project should have broader applicability (on separation processes and principles); the same holds for the materials and devices.

In the way described above, it is clear that SmartSep brings technology from the incubator phase to the level it can be used as starting point in open innovation platforms (e.g DSTI, Wetsus); which have a clear focus on industrial applications and success.

2.2 Position of The Netherlands in a worldwide development

Within The Netherlands we have an **internationally unique knowledge base** and **strategic cooperation** between industry, institutes and universities in separation technology, which can play an important role in the global developments towards a cleaner, more sustainable and energy extensive industry. The US Vision 2020 Separations Roadmap confirmed the tremendous opportunities for the US economy but never materialized in a joint research program. The same holds for Europe where these intensive national cooperation programs are virtually non existent. Therefore the SmartSep program is **unique** in generating and valorising a multitude of new separation technologies that will significantly contribute to the extension of current cooperation platforms into a nation wide, **lasting** multidisciplinary cooperation network between industry, institutes and academia.

The Netherlands, with its **excellent knowledge base in separation technology** can play an important role in the global developments towards a cleaner, more sustainable and energy extensive process industry. Short and medium term objectives are currently adequately addressed in internationally unique cooperation initiatives between industry, institutes and universities such as DSTI, EOS and PI. The limitation of these initiatives is however that due to their industry driven nature mainly existing separation principles are used to achieve timely implementation. To address the long term objectives of the Innovation Roadmap Separation Technology with respect to sustainability (50-80% energy reduction, zero waste production) and competitiveness (75% intensification) it is crucial to establish a special program that addresses the establishment of totally new separation technologies employing unconventional principles/driving forces. Such a program requires a **significant multidisciplinary effort**, which is unlikely to be achieved in the project oriented open competition programs (Open Technology Program, ECHO, TOP) and individual subsidy schemes (Veni, Vidi, Vici etc) of the Dutch Organization for Scientific Research (NWO). Other programs, such as ASPECT and IBOS focus on improving the efficiency of chemical transformations by development of new catalytic processes, but these programs do not include downstream processing activities. In the area of process intensification, microreactor technology is investigated in e.g. Microned and Process on a Chip (PoaC), but these programs only focus on one of the many aspects of separation technology and therefore don't offer a comprehensive approach to the problem. Therefore the SmartSep program offers a concerted effort in which multidisciplinary projects address all aspects required to combine the establishment of new separation principles/driving forces with maximizing their future outlook on industrial utilization. Furthermore, this initiative will put the Dutch process technology community in a leading role within Europe, and SmartSep can be used as catalyst for a more comprehensive European collaboration.

2.3 Relation with public policy and funding programs

Based on an analysis of opportunities for the Dutch economy as a whole, the Dutch Ministry of Economic Affairs initiated in 2003 a study which resulted in the Innovation Roadmap Separation Technology. Based on this Innovation Roadmap a long-term research strategy was established which resulted in the foundation of the Dutch Separation Technology Institute (DSTI) in 2006. The objective of the DSTI initiative is to realize a **joint long-term innovation program** and **long lasting cooperation platform** to realize competitive and breakout innovations on Separation Technology. The existing project portfolio is typically focussed on short-medium term (5-10 year) projects with an outlook on implementation within a reasonable timeframe. The main contributions of the SmartSep program will be addressing the long term (10-20 year) break-through needs as identified in the Innovation Roadmap Separation Technology but are currently not addressed.

Although the SmartSep program links up very well with the DSTI, it also has a strong connection to intensified separation themes as identified within the European Roadmap Process Intensification and IChemE 2007 roadmap for Chemical Engineering. Additional links exist with various SenterNovem programs (EOS, TS, Dutch Biorefinery Initiative), separation technology research within WETSUS and new device development within Microned. Furthermore, a logical connection can be made to the more chemistry and catalysis oriented programs of the ACTS portfolio (ASPECT, IBOS, PoaC, BBasic). The proposed program agrees very well with the focus of the Dutch Organization for Scientific Research (NWO) on **complexity and sustainability**. Execution of this program will in particular contribute significantly to the NWO themes *dynamics of complex systems* and *use of nanoscience and – technology*. The recently approved National Nano Initiative (NNI), which is the successor of the successful NanoNed program, also opens up possibilities for collaboration, when nanotechnology concepts are to be introduced in separation processes.

2.4 Summary

The SmartSep program aims to provide the technology for the next step in separations in the Dutch process industry, based on separation principles that may be known already, but which is not yet applied or suitable for large-scale industrial separations. The technology should open up the door to significant improvement (‘step changes’) in sustainability and process effectivity. Aiming at long term relevance, the SmartSep program is derived from the Technology Roadmap that was created under auspices of the Ministry of Economic Affairs and is well positioned relative to other initiatives and consortia.

The SmartSep program will be coherent, which is ensured by user committees for each project, a program committee that guards program coherence and synergy, and regular workshops in which projects are interrelated. The results of the projects should be suitable to take up by initiatives that aim at shorter timescales to implementation (e.g., DSTI, Wetsus and others).

The results should be generic, and thus should be suitable for a range of applications (which is important for the dissemination) and should demonstrate a significant reduction in energy and utilities use, environmental pressure and should lead to products that have better quality.

3 Research Topics

The program has a primary aim to develop separation technologies that are currently in an embryonic stage, towards applicability for large-scale industrial processing. The technology could for example be reported for use on analytical scale, or be reported within a context that is not related to industrial separation. The *ab initio* invention of new separation principles are not by definition out of scope, but will be if their horizon for potential for large-scale application within a 15-20 year timeframe is considered unrealistic.

The separation principles should not be on separation of one specific component, but should allow separation of one or more classes of components from complex mixtures, such as to ensure that the principle will have sufficient potential applications. The project should ideally provide in guidelines on how to apply the separation principles based on the fundamental properties of the streams that are to be separated.

Many new separation principles require the development of a specific type of device or a specific type of material. Their development is within the scope of the program, as long as they serve the purpose of development of the separation principle. Thus, the isolated development of a device or material is not part of this program. In line with this, the projects may include the development of ‘enabling’ expertise or technology in other fields – for example in simulation and modelling, analytical capabilities or in experimental infrastructure.

The projects will have to demonstrate the fundamental effectiveness of the separation principle (proof of principle), and in addition should show (for example by founded estimations of theoretical specific requirements of energy, utilities and raw materials, and production of waste) that the separation technology will ultimately contribute significantly to a more sustainable production, and to better products. This should be evident in (amongst others) compliance with the principles of green chemistry and technology (see also Appendix C).

To ensure coherence in the program, the projects should be applicable to at least two of the four themes as described in chapter 5: *new principles or driving forces*, *new materials*, *new devices* and *enabling sciences*; the first theme should always be part of a project (see also figure 3). For matter of program coherence, projects that would aim at avoiding separations are not within the scope.

In summary, the program *includes*

- separation technology
- application of novel (embryonic) separation principles, or principles that come from other areas
- developments of new materials, devices or enabling expertise that are necessary for the development of the separation principle

The program should

- work on technologies that in principle are applicable on large scale
- should have the potential to contribute to a significant improvement in sustainability and product quality.
- comply with the principles of green chemistry and technology
- have broad application perspective that can be generalised

The program will *not* include projects that

- are based on established or known principles or driving forces
- aim at improving existing materials or devices (or enabling technologies)
- are solely device driven, or have no application in separation technology
- are specific for one component or molecule
- have primary focus on synthesis or reaction
- are aimed at avoiding separation.

4 Scientific Goals/Challenges

As illustrated by figure 3 SmartSep focuses on four themes. The **leading overall scientific challenge** is to identify/discover those new principles/driving forces (theme 1) which have the potential to be applied in new materials (theme 2) and/or devices (theme 3) to open new routes for the separation of complex mixtures on industrially relevant scale. Research in the fields of these three themes is foreseen to be highly facilitated by recent advances in computational technology and simulation capabilities. That is why within SmartSep also strong support will be given to the multi-disciplinary development of so-called enabling model based technologies/sciences (theme 4). Since nowadays many phenomena can be simulated with high precision, the **main scientific challenge** is to establish multi-scale methodologies which yield results that are applicable to real, non - simplified industrially relevant systems.

4.1 New Principles/Driving Forces

Most of the current separation technologies employ traditional principles/driving forces such as differences in volatility, solubility or size/density differences. Most of these principles are not suited to separate specific target components from complex mixtures and/or compounds with very similar properties due to their insufficient specificity. Furthermore most of these technologies make excessive use of resources such as energy and chemicals creating significant amounts of waste. Therefore it is imperative that the establishment of **new principles/driving forces** that avoid or strongly reduce the use of auxiliary resources is crucial to achieve the breakthroughs required to establish the sustainable processes of the future. Although this can be partly achieved by avoiding complicated separation processes, by establishing more efficient synthetic procedures, in most cases the focus has to be on developing novel separation technology concepts. Typical examples could be new force fields such as magnetic or electric fields, thermal or optical switching, utilization of complex rheology such as shear banding, new affinity principles such as supramolecular or template crystallization, on/off separations etc. These new force fields have not been applied in industrial separation applications yet but the proof of principle has been shown. In the SmartSep program the proof of their applicability to the separation of industrial relevant systems could be investigated. Next to the above given examples; also technologies used in analytical separations which are not yet applied in industrial systems are within the scope of the program. Combination of existing principles which leads to break-through new technologies will also be considered. Major aim should be principles that utilize no (or minimal) resources/utilities such as chemicals, water, and energy and therefore improve the sustainability of the processes.

4.2 New Materials

The **main hurdles** for applying most current affinity materials in industrial separations are their high cost, low productivity and low versatility. A clear example is Molecular Imprinted Polymer technology with an active site density at least three orders of magnitude lower than regular adsorbents. It is a clear challenge to establish new materials that enable cost effective utilization of the established new principles/driving forces in new devices. A **challenging direction** originates from the relatively undefined structure of many materials that have been used in separation systems (membranes, carriers). Recent developments in the micro- and nanotechnologies enable system design almost from the molecular/colloidal level and up, ultimately resulting in highly defined materials, providing extremely good performance. Current developments however, remain often a matter of very small scale with little emphasis on scaling up while most industrially relevant processes require handling capacities in the range of 1-1000 m^3/hr. It is therefore **highly desirable** to **valorize** these achievements and fabricate new high capacity, low-cost separation media that can be cost effectively employed at the scale of real process streams. Application to real process streams provides a second challenge arising from the requirement to operate most materials currently employed in new separation technologies at mild conditions (low T, low p, neutral pH, solid-free solutions) even though process conditions are different. Adjustments of operating conditions to meet the operating window of the materials require pre-treatments such as cooling, dilution, addition of chemicals for neutralization or filtration. Therefore these new materials should be designed such that they are able to perform separations under harsher process conditions.

4.3 New Devices

The current devices applied in industrial separation processes have been mainly developed for technologies applying traditional separation principles. They are thus often only suitable for processing dilute streams. Therefore it is imperative for **optimal application perspective** to establish devices dedicated for the optimal utilization of new principles/driving forces and new materials in an industrial environment. **Especially challenging** are devices that have the potential of being used at the (sometimes extreme) conditions of real processes, are applicable for large streams (10-1000 m^3/hr) and enable significant intensification compared to existing devices, for instance through micro structuring of continuous flow equipment etc. Other interesting options that offer high potential to reach preparative scale are scaling up of analytical separation principles to economically attractive preparative devices and the concept of numbering out small scale analytical separation processes.

4.4 Enabling Sciences

Modeling and computational simulations can make **major contributions** to SmartSep. The use of computational tools can strongly enhance the degree of understanding at molecular, microscopic and mesoscopic scales and thereby guide/assist/speedup the research within the other three themes. The scientific state of the art is that most of the relevant phenomena/interactions can be calculated with high precision, but this is limited to one size scale and using simplified model systems (high vacuum, infinite dilution). In practice, interactions between different size scales often dominate the behavior (multi-scale coupling), while the behavior of real systems is much more complex than a model system. For instance, colloidal scale phenomena determine the behavior on micrometer scale, which then determines the macroscopic behavior. The same holds for molecular interactions on a nanometer scale. All these size scales have different time scales. The direct coupling of these scales (both in time and space), necessary to predict the macroscopic system behavior is highly demanding and thereby strongly inhibited from a computational point of view. The **scientific challenge** is therefore to establish **new methodologies** to couple these size scales ('coarse graining') which yield results that are applicable to real, non-simplified systems. The real system behavior is strongly influenced by their environment and intensification by the new separation principles requires predictions of system behavior at high concentrations. Both should thus be addressed by the new simulation methodologies. Projects focusing on in depth modeling studies without direct separation application are out of scope of this program.

5 Industrial Relevance & Utilization

The process industry (oil & gas, chemical, food, pharmaceutical, process water, paper) plays an **essential role** in the Dutch economy. The annual turnover contributes an impressive EUR 52 billion per year to the Dutch gross domestic product. Some 70,000 people are directly employed within the sector in more than 500 companies. It is estimated that the sector including supplies, transport, infrastructural investments and high level services accounts for 10% of the total industrial labour force and takes care of some 20% of the Dutch export value. Separation processes have a major influence on industrial energy consumption, product quality and product cost price. The energy consumption of the Dutch chemical and petrochemical industry was recently estimated at 530 PJ/year, of which more than 40% (217 PJ/year) could be allocated to separation processes. Construction of separation installations often requires up to 70% of the capital investments in new plants. As such, **separation technology** is a **key factor** in the competitive and sustainable production of **high value added products**, both for leading multinationals and innovative Small and Medium sized Enterprises (SME's).

The **application perspective** of the SmartSep program is **intrinsically high** due to its embedding in various national initiatives such as DSTI, WETSUS, B-BASIC, TIFN and regular funding programs for short and medium term R&D activities through the ministry of economic affairs (EOS, TS etc.). From a DSTI point of view the main reason for supporting the SmartSep program is the establishment of new technology concepts that provide the foundation for the future continuation of the DSTI program as part of the future national Institute for Sustainable Process Technology (ISPT). In this respect it is illustrative to look back to the NWO program Separation Technology which is currently nearing its completion. A recent analysis has shown that >80% of the technology concepts established in this program have been used as the basis for a variety of projects in the current DSTI program

The topics of the SmartSep program originate from the **long term needs** as defined by the Dutch process industry in the Innovation Roadmap Separation Technology. For this reason, successful discoveries/innovations/developments from the SmartSep program have an excellent outlook in terms of application perspective within the various national short and medium term programs. To achieve this goal an active utilization plan is crucial.

Within this utilisation program, active participation of potential users of the technology is of pivotal importance, despite the fact that the program focuses on long term research goals. Industrial participation is ensured by the establishment of user groups for each project within the program. The user group should preferably consist of technology developers and potential end-users of the technology under consideration.

Beside these project-based user groups, an effective communication structure on program level is proposed to maximise the chances of successful utilization on the long term. This will be performed by a stage-wise funnelling approach.

1. In the initial phase, all projects will be requested to draw a longlist of foreseen application fields. Using this long-list, but not limited to this list, potential industrial users and technology developers are invited

for a first broad workshop. The result of the workshop is a short list of attractive application fields of the principles under consideration within this programme. Furthermore, initial 'proofs of application' are designed in which the project teams including their user committee indicate how the proposed principle can be transformed into a sustainable, applicable and economically viable technology concept for the identified application fields. Such a workshop will be held during the first year of the programme.

2. Toward the end of the second year of the programme, a second workshop is organised where the findings of the research will be discussed in relation to the outcomes of the first workshop. A further sharpening of the potential application fields and 'proof of application' of the various projects within this program will be the result of these workshops. Participants of the second workshop are academics industries and technology developers active in the attractive fields of application, i.e. shortlist users. However, at this stage the participants of the workshop are not exclusively limited to the areas mentioned on the shortlist. External parties will also be included. This is to maintain the broad application scope at the early stages of the SmartSep programme.

3. In a final workshop at the end of the program period, the application potential of the established technologies within the program will be discussed and evaluated. Desired outcome is the identification of the further steps that need to be taken for the identified application/technology combinations and an outline of a research and development trajectory including interested partners and potential embedding in suitable programs (DSTI, PI, SenterNovem, Technoprojects of NL-Guts, Valorisation Grants etc.) These workshops will be supported by experts in the establishment of **innovation trajectories** such as STW valorisation workshop, Innovation Laboratory Eindhoven, Twijnstra the Bridge, and companies that can support the end users with the establishment of projects/programs such as PNO consultants, ETDC.

6 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) SmartSep 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 the establishment of new spin-off companies to implement new SmartSep ideas
- Set-up of intensive collaboration on program level with related PPS projects (DSTI, B-Basic, APPI, Wetsus, ISPT)
- Stimulation of active participation of project members in national and international conferences
- Intensification of interactions with small and medium enterprises (MKB Nederland)

7 Organization of the Program

7.1 Coherence

The program focus and description is based on a workshop held in February 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 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.

7.2 Budget

For this call a budget of M€ 4.5 is available which must be matched by the contributions of potential technology users (companies/institutes) to a total of at least M€ 6. 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. DSTI (Dutch Separation Technology Institute) has committed a maximum cash contribution of 1 M€ to the SmartSep program. Applicants can provide contributions of users themselves or request a contribution up to a maximum of 25% of the total project costs from the DSTI matching funding. Projects that request DSTI matching funding should comply with the DSTI criteria. (see also Appendix B)

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

7.3 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 SmartSep is a multidisciplinary program, projects where at least two of the four themes are addressed, are required.

7.4 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.

7.5 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.

7.6 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 Wednesday March 31st, 2010 at 12.00 a.m. Pre-proposals submitted after this deadline will not be accepted.

7.7 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 or/and whether (partial) matching funding of DSTI is requested. Support letters are optional for the pre-proposals but can be included (letters of intent are accepted).

The pre-proposals will be ranked by the program board on the basis of how well they fit within the scope of the program. The members of the program board will first assess the pre-proposals individually before discussing them plenary in the board. The program board will advise the applicants:

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

7.8 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).

7.9 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:

- How well do the goals of the project fit within the ambitions of the program. Do the expected results meet the industrial needs in the long term (2014-2018)?
- To what extent does the proposal fit within the research topics of the program?
- Does the program strengthen the separations technology expertise in The Netherlands in general and of the participants in the project in particular?
- To which extent is the project proposal multidisciplinary? What are the positive effects from the interdisciplinary cooperation? How is interaction in between researchers and between university and industry organized?
- Do the proposals overlap each other and if so, what are the consequences for the funding?

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.

7.10 Time schedule SmartSeparations proposals

Call for pre-proposals open	Monday March 1, 2010
Deadline pre-proposals	Wednesday March 31, 2010, 11:59 AM
Notification to applicants pre-proposal of the positive/negative advice to submit full proposal	Wednesday April 21, 2010
Call for full proposals	Monday May 3, 2010
Deadline full proposals	Wednesday July 28, 2010, 11:59 AM
Start review by experts	Thursday August 19, 2010
Protocol sent to applicants	Friday September 17, 2010
Deadline comments applicants	Friday September 24, 2010
Ranking by jury ready	Monday October 18, 2010
Advice Program Committee to STW board ready	Monday November 8, 2010
Decision by STW board on funding + notification to applicants	Monday November 22, 2010

8 Program Committee

- Prof. dr. ir. A.B. de Haan (program leader), Faculty Chemical Technology, University of Eindhoven
- Prof. dr. ir. R.M. Boom, Faculty of Food Process Engineering, Wageningen University
- Prof. dr. ir. H.J. Heeres, Faculty of Mathematics and Natural Sciences, University of Groningen
- Prof. dr. ir. A. Stankiewicz, Faculty of Process and Energy, Delft University of Technology
- Dr. D.F. Stamatialis, Faculty of Science and Technology. University of Twente
- Dr. ir. E.J.A.X. van de Sandt, DSM Biotechnology Center, Delft
- Dr. P.J.T. Bussmann, TNO Quality of Life, Zeist.
- Dr. J.W. Veldsink, FrieslandCampina, Deventer
- Ir. P. Alderliesten, ECN, Petten

STW Program Committee secretary:

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This document has been compiled by STW on the basis of aforementioned workshop of February 2010, and the inputs of: Andre de Haan (TU/e), Remko Boom (WUR), Andrzej Stankiewicz (TUD), Dimitrios Stamatialis (U Twente), Erik Heeres (RUG), Jan van Hest (RUN), Emile van de Sandt (DSM), Paul Bussmann (TNO), Jan Willem Veldsink (FCDF), Peter Alderliesten (ECN) and Monique Wiegel (STW) d.d. 2010, 15 February.

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

Lionix	H. Leeuwis
Agentschap NL	Drs. J. van der Ahe
Akzo Nobel	Ir. G. Bargeman
DSM	Dr. H. Bijl
Unilever	Dr. P. Bongers
Synton	Dr. M. Eppink
Feyecon	Dr. F. Wubboltz
Danone	Dr. T. van Baalen
TU-Delft	Dr. H.J. Kramer
TU-Eindhoven	Dr. J. van der Schaaf
TU-Eindhoven	Prof. B. Brouwers
Universiteit Wageningen	Dr. T. van Beek
Universiteit Wageningen	Prof. W. van Berkel
Universiteit Wageningen	Prof. H. Gruppen
Universiteit Utrecht	Prof. A. Philipse
Universiteit Utrecht	Prof. J. van Eerden
Universiteit Amsterdam	Dr. W. Kok
Universiteit Nijmegen	Prof. E. Vlieg
Universiteit Nijmegen	Prof. G. Groenenboom
ECN	Ir. P. Alderliesten
TNO, Delft	Dr. M. Roelands
Universiteit Wageningen	Dr.. B. Langelaan
NIZO	Dr. F. van Assema
WETSUS	Dr. G.J. Euverink
KWR	Dr. R. Hofman
DSTI	Dr. M. Plantenga
Universiteit Wageningen	Prof. R. Boom
RU-Groningen	Prof. E. Heeres
Universiteit Twente	Dr. D. Stamatialis
DSM	Dr. E. van de Sandt
TNO, Zeist	Dr. P. Bussmann

Appendix B. DSTI funding

DSTI (Dutch Separation Technology Institute) is a public-private partnership in which industry, universities and knowledge institutes work closely together to develop separation technologies for application in different sectors of the Process Industry. So far, 45 companies active in fields ranging from Food, Pharmaceutical, Oil and Gas, Chemical and Process Water, and 10 universities and research institutes, have joined DSTI. The collective research program covers all aspects from (fundamental) knowledge generation to technology implementation.

Additional funding is available from the DSTI matching budget (1.0 M euro). Project teams can apply for additional funding up to a maximum of 25% of the total project costs. Projects that request for DSTI matching funding should comply with the DSTI criteria. The criteria relate to the project deliverables of the Smart Separations projects. To be eligible for matching by DSTI, all the following issues should be accounted for explicitly in the full project proposal:

1. Applicable to at least two of the DSTI industrial sectors
2. Clear description of the fit with roadmap targets from these DSTI industry sectors
3. Written support of at least three of the DSTI partners/members
4. Participation of at least one non-DSTI research group
5. Clear outline on future implementation perspective within DSTI

In the *full* proposal, the matching should be arranged. In order to request matching by DSTI, the *pre*-proposal should include:

- Explicit indication in the Smart Separation project pre-proposal if DSTI matching funding is requested.
- Clear indication of how to comply with the above listed DSTI criteria.
- The requested amount DSTI matching funding.

Selection and Assignment

The selection and judgment will be based upon the pre-proposals submitted to the Smart Separations program. Assignment of the DSTI matching funding will be judged by the members of the Program Committee in close consultancy with DSTI. Project applicants will be informed about the funding assignment together with the Smart Separations pre-proposal notification. The funding will be made available over the duration of the project.

Appendix C. Principles of Green Chemistry and Technology

Adapted from: F. M. Kerton, Green Chemical Technologies. In *Introduction to Chemicals from Biomass*, J. Clark, and F. Deswarte, Eds. John Wiley & Sons: Chichester (2008).

The development of environmentally friendly and economically sustainable chemical processes has been actively explored in the last two decades both at an academic and industrial level. The twelve principles of green chemistry and engineering (Table 1) should be considered as guidelines for the design of novel and the improvement of conventional processes. Factors to be taken into account are among others the type of reaction (stoichiometric versus catalytic), reagents, reaction conditions, chemical products (including waste) and solvents.

In this respect, the development and application of environmentally benign solvents in chemical processes is of prime importance (less hazardous chemical syntheses (principle 3) and the use of safer solvents and auxiliaries (principle 5)). The quest for such solvents is also highly stimulated by the fact that typical organic solvents contribute considerably to the emissions of volatile organic components (approximately 20 millions tons) into the atmosphere each year.

Table 1 The twelve principles of green chemistry and green engineering.

	Principles of green chemistry	Principles of green engineering
1	Prevention	Inherent Rather Than Circumstantial
2	Atom Economy	Prevention Instead of Treatment
3	Less Hazardous Chemical Syntheses	Design for Separation
4	Designing Safer Chemicals	Maximize Efficiency
5	Safer Solvents and Auxiliaries	Output-Pulled Versus Input-Pushed
6	Design for Energy Efficiency	Conserve Complexity
7	Use of Renewable Feed Stocks	Durability Rather Than Immortality
8	Reduce Derivatives	Meet Need, Minimize Excess
9	Catalysis	Minimize Material Diversity
10	Design for Degradation	Integrate Material and Energy Flows
11	Real-time analysis for Pollution Prevention	Design for Commercial ' Afterlife'
12	Inherently Safer Chemistry for Accident Prevention	Renewable Rather than Depleting