ACTION PLAN
PROCESS INTENSIFICATION

Creative Energy
Energy Transition

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Front cover illustration
Intensified methane steam reformer based on Micro channel Reactor technology (conventional plant in the background)
Courtesy: Velocys Inc., Plain City, Ohio, USA

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Energy Transition

PI EXAMPLE **PETCHEM SECTOR** – HIGH-GRAVITY ROTATING PACKED BEDS

Traditional technology

A system of absorption-stripping columns: the main product ($HClO$) has to be removed as quickly as possible from the reaction environment to prevent its decomposition (1)

PI technology

Reactive stripping in High Gravity (HiGee) Rotating Packed Beds: the reactants are subjected to intensive contact and the product is immediately removed via stripping using high rotating apparatus (2) with a specially designed packing (3)

Benefits

- Equipment size decreased by a factor of ca. 40
- Ca. 15% higher product yield
- 50% reduction of the stripping gas
- 1/3 reduction in waste water & chlorinated by
- Same processing capacity

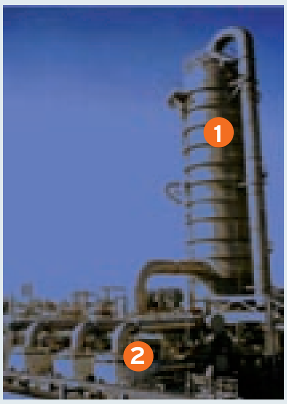


Photo coourtesy of Dow Chemical Company

PI EXAMPLE **FINEPHARM SECTOR** – MICRO REACTOR

Traditional technology

Stirred Tank Reactor: the reactants are mixed in a large vessel, and the heat is removed through the jacket or a heat transfer coil (1)

PI technology

Micro Reactor: the reactants are mixed, and the heat is removed through thousands of micro channels, fabricated by micromachining (2) or lithography

Benefits

- Equipment content 3 liters versus 10 m^3
- 20% higher selectivity 20% higher material yield
- Process more reliable because continuous instead of batch
- Same capacity (1700 kg/h)

Photo courtesy of DSM an Borshungszentrum Karlsruhe

PI EXAMPLE **INFOOD SECTOR** – PULSE COMBUSTION DRYING

Traditional technology

Continuous burner-based drying: direct-heated dryers where the drying gas consisting of fresh air, recycled air and the hot combustion gases from a burner is in direct contact with the material to be dry. Direct firing is most commonly applied in textile industry, paper manufacture, chemicals, and agro-food production.

PI technology

Pulse combustion drying: periodic combustion of fuel generates intensive pressure, velocity, and to certain extent, temperature waves propagated from the combustion chamber to the drying chamber. Because of oscillatory nature of the momentum transfer, pulse combustion intensifies the rates of heat and mass transfer thus accelerates drying rates. Technology can be easily retrofitted in the existing dryers!

Liquid spray exiting a rotary-valve pulse combustor into spray dryer (Courtesy of Pulse Combustion Systems, San Rafael, CA, USA)

Benefits

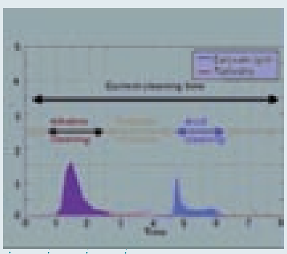
- improved powder quality
- reduced energy consumption by 17-36%
- increased dryer throughput.

(Data on technology applied in 2003 at Berghausen Corporation, Cincinnati, Ohio, USA)

PI EXAMPLE **CONFOOD SECTOR** – INTELLIGENT CLEANING

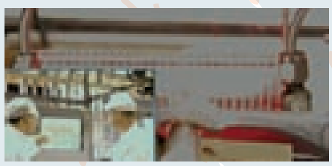
Traditional technology

Standardized long cleaning cycles: downtime of food production equipment due to fouling and cleaning; cleaning procedure based on worst case in the past



PI technology

Intelligent cleaning: in line sensors measure production and cleaning efficiency; self learning computer models determine optimal cleaning conditions depending on product composition and degree of fouling



Benefits

- Increased capacity; downtime of food processing equipment reduced by 50%
- Decreased use of water and cleaning agents
- Increased flexibility; cleaning conditions automatically adjusted to (new) food composition

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CONTENTS

EXECUTIVE SUMMARY

The process industry is of significant importance to the Dutch economy, accounting for 28% of industrial employment, 5-6% of GDP in direct effects and more than 10% including indirect effects. At the same time, the process industry is a major consumer of energy. Process Intensification will contribute significantly to the competitiveness of the Dutch and European process industries by making industrial processes faster, more efficient and better for the environment. Accelerating the implementation of Process Intensification (PI) will help realize the goals of Dutch Energy Transition, and the need for a sustainable and economically strong process industry.

Process intensification addresses the need for energy savings, CO_2 emission reduction and enhanced cost competitiveness throughout the process industry. The potential benefits of PI that have been identified are significant:

- Petro and bulk chemicals (PETCHEM): Higher overall energy efficiency – 5% (10-20 years), 20% (30-40 years)
- Specialty chemicals, pharmaceuticals (FINEPHARM): Overall cost reduction (and related energy savings due to higher raw material yield) – 20% (5-10 years), 50% (10-15 years)
- Food ingredients (INFOOD):
  - Higher energy efficiency in water removal – 25% (5-10 years), 75% (10-15 years)
  - Lower costs through intensified processes throughout the value chain – 30% (10 years), 60% (30-40 years)
- Consumer foods (CONFOOD):
  - Higher energy efficiency in preservation process – 10-15% (10 years), 30-40% (40 years)
  - Through capacity increase – 60% (40 years)
  - Through move from batch to continuous processes – 30% (40 years)

The Action Plan PI will accelerate the implementation of PI in the Dutch process industry, aiming to realize PI technologies in the factories through three interrelated activities: a research program, a piloting & demonstration facility and knowledge & technology transfer. The activities of the research program are fully integrated along the R&D value chain, from fundamental/applied research to piloting & demonstration. (Figure 1).

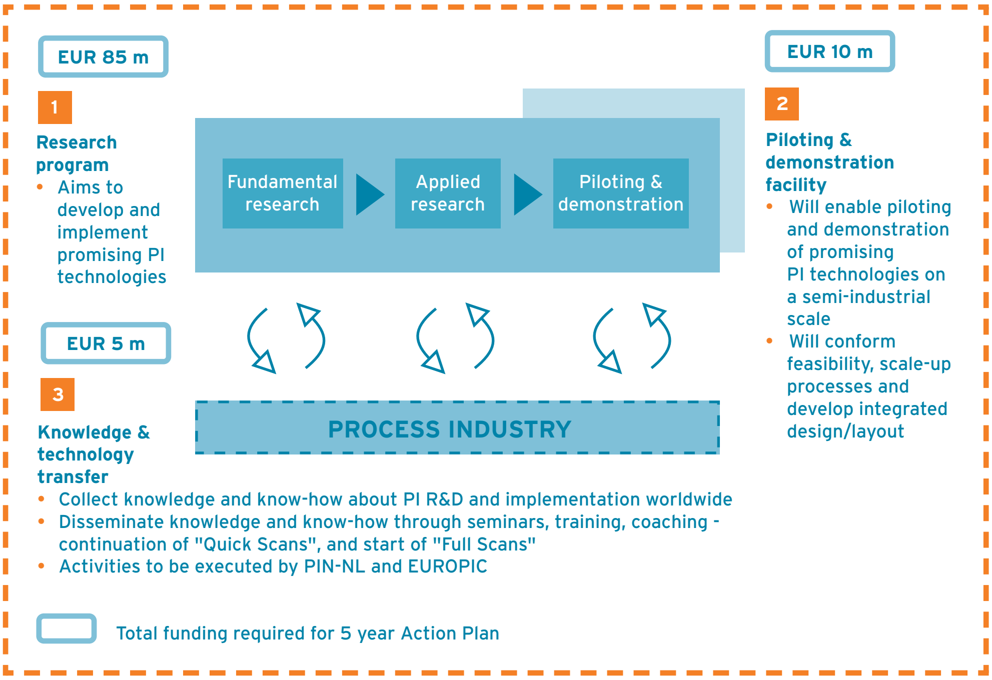


Figure 1 The activities of the Action Plan PI

The **research program** aims to develop and implement PI technologies through steering and bundling of research and development activities. The research program is organized in eleven program lines along three axes: PI Thrust Areas, PI Enabling Technologies and PI Special Themes. (Figure 2) Each program line integrates fundamental/applied research and piloting & demonstration activities, and is thus focused on getting PI technology into the factory.

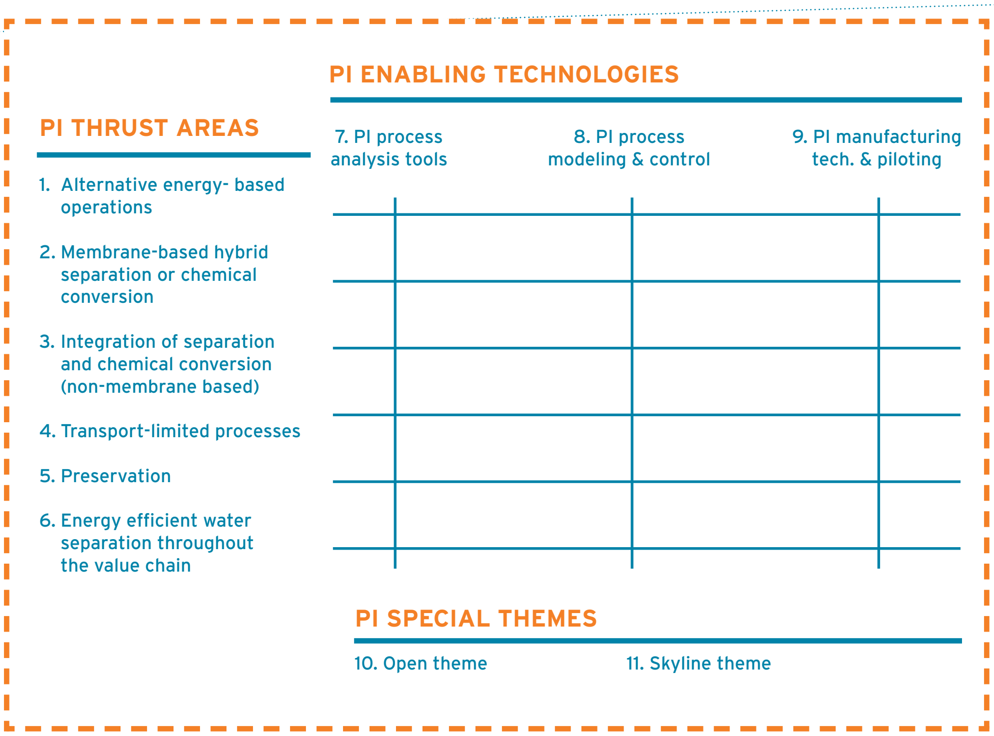


Figure 2 Overview of program lines of the research program

The lack of accessible piloting & demonstration possibilities is a major barrier to implementation of PI technology. To overcome this barrier, a **piloting & demonstration facility** will be set-up to enable piloting & demonstration of promising PI technologies on a semi-industrial scale. The objective is to confirm feasibility, scale-up processes and control and develop an integrated design/layout.

Another major barrier to the implementation of PI technology is limited awareness of available and developing PI technologies and their applications. **Knowledge & technology transfer** aims to tackle this barrier by collecting knowledge and know-how about PI R&D and implementation world-wide and disseminating this knowledge and know-how through seminars, training and coaching. Execution of 'Quick Scans' of factories where PI technology can be applied will continue and 'Full Scans' will begin.

The Action Plan PI will be steered by a lean organization focusing on allocation of funds and monitoring/control of progress and quality. The Action Plan PI will align its activities and cooperate with several neighboring organizations.

The Action Plan PI will start in September 2008, run for five years, and will provide a temporary stimulus to the implementation of PI. All activities will be executed by and embedded in existing structures of the participating partners.

INTRODUCTION

The Dutch process industry is vital to the economy
The process industry lies at the heart of the key innovative areas 'Chemistry' and 'Flowers & Food' that were recently identified by the Dutch Innovation Platform. The sector accounts for over 50%[1] of industrial production (EUR 115 bn), 28%[1] of industrial employment (175 k FTEs) and 5-6% of GDP[1] (Gross Domestic Product). Its contribution to GDP is also an indirect one, and is significant.

On a European scale, the process industry also represents an important contribution to the economy. In 2006, the EUR 563 bn in European chemical industry sales accounted for approximately 35% of world sales.[2]

The Dutch process industry is a major energy consumer
More than 35% of energy consumption in the Netherlands stems from industry (1,075 PJ), both energetic and non-energetic (raw materials).[3] Within this, the process industry is the largest energy consumer, constituting roughly 75% of total industry energy consumption (760 PJ) – 50% energetic and 50% non-energetic (raw materials).[3]

Figure 3 provides a breakdown of energy consumption in the Netherlands, including the process industry's impact.

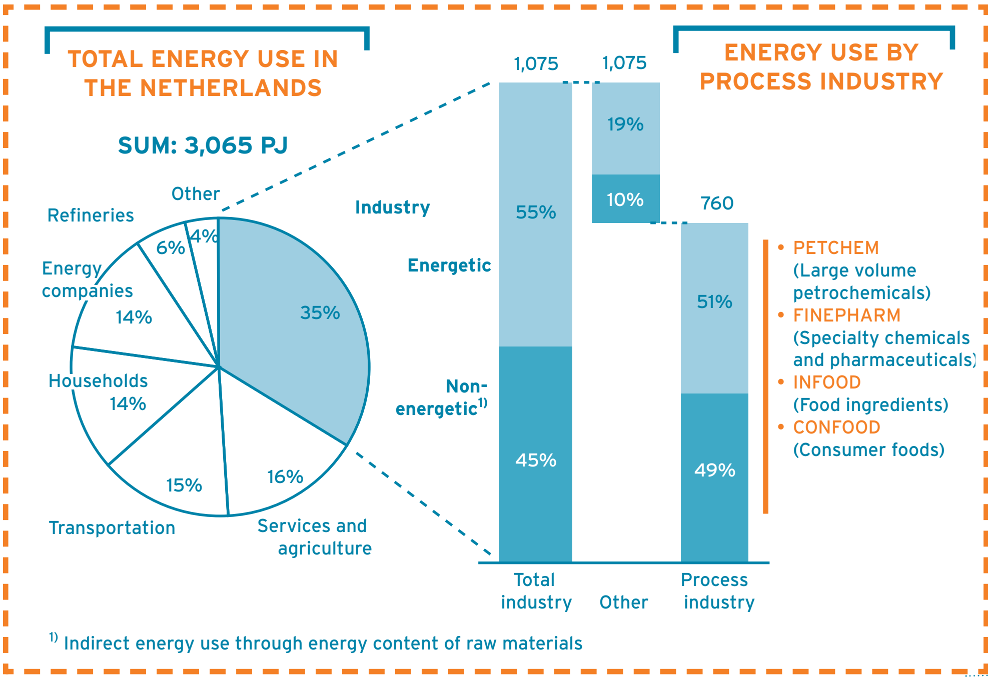


Figure 3 (Process) industry energy consumption in 2000 [PJ][3]

1 Source: CBS, 2000
2 Source: Cefic, 2006
3 Source: ECN, "Biomass in the Dutch Energy Infrastructure in 2030"; CBS, 2000

Accelerated implementation of Process Intensification will help realize the ambition of the Dutch Energy Transition and the endeavors of the chemical and food sectors to achieve a sustainable and economically strong process industry

Process Intensification is one if the transition paths of the Platform Chain Efficiency of the Dutch Energy Transition, which is working towards a sustainable energy system. The aim of this transition path is to realize a 20% reduction in the energy consumption of the process industry by 2050 through PI implementation alone.

Process Intensification is also part of the Business Plan for Innovation of the Chemical Industry presented by "Regiegroep Chemie", which aims to double the chemical sector's contribution to Dutch GDP within 10 years and halve the chemical sector's use of fossil fuels within 25 years.

Process Intensification is also central to the ambition of the Food & Nutrition Delta innovation program to make the Netherlands a European leader in food innovation.

The Action Plan PI aims to accelerate the implementation of Process Intensification, supporting these and other important initiatives. Figure 4 provides a schematic overview of the benefits op Process Intensification.

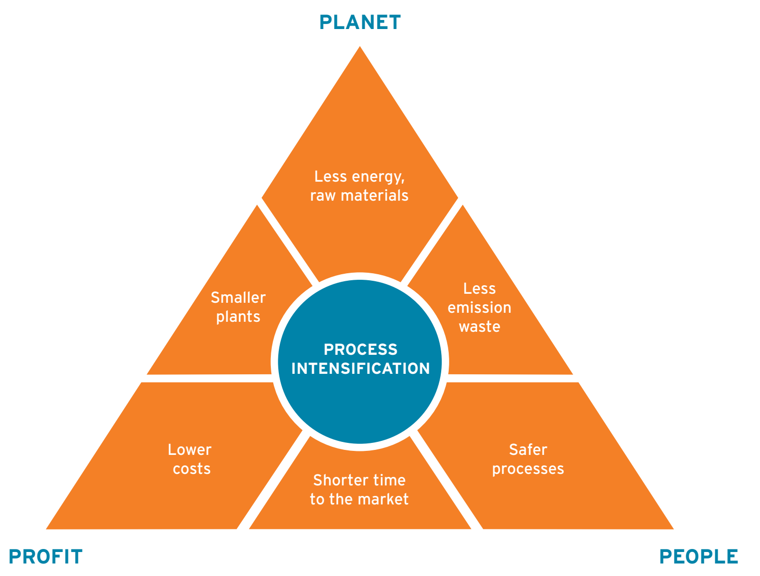


Figure 4 The benefits of Process Intensification for people, planet and profit

Process Intensification provides radically innovative principles ("paradigm shift") in process and equipment design which can benefit (often with more than a factor of two) process and chain efficiency, capital and operating expenses, quality, wastes, process safety and more.

Acceleration of Process Intensification in the Dutch process industry must be considered within a European context
Accelerated implementation of PI can only be achieved through effective cooperation between the Dutch and European process industries and knowledge infrastructures. European-wide cooperation will broaden the scope of the program, extending the Action Plan PI so that it can garner sufficient critical mass, especially with equipment/service providers. Cooperative partnerships of this scope will also influence the European agenda, ensuring Dutch interests are taken into account, and direct European funding to the Netherlands, particularly from the FP7 program.

European partners include:
- ProcessNet (DECHEMA/VDI - Fachsektion Prozessintensivierung)
- The European Federation of Chemical Engineering (Working Party on Process Intensification)
- The European Technology Platform for Sustainable Chemistry (SusChem)
- Société Française de Génie des Procédés

The potential benefits of Process Intensification are energy savings, reduction of CO_2 emissions and enhanced cost competitiveness
Process Intensification addresses several needs of the process industry, and these needs vary somewhat between sectors. The benefits promised by PI will significantly impact each sector in one way or another. For some industry sectors such INFOOD and CONFOOD, direct energy savings might be limited but indirect benefits will be substantial. Figure 5 provides an overview of the needs of the process industry addressed by Process Intensification.

Importance to industry	PETCHEM	FINEPHARM	INFOOD	CONFOOD
High	• Energy savings • Cost competitiveness • Safety [1] • Regulation	• Selectivity • Cost competitiveness • Sustainability • Lead time	• Cost competitiveness (driven by raw material and energy cost for processing)	• Cost competitiveness • Yield • Line availability • Product quality • Food safety • Product functionality
Medium	• Social impact • Reliability [1]	• Safety [1] • Reliability [1]	• Selectivity on end-product • Reliability on tolerances	• Energy saving • Plant safety • Flexibility
Low		• Energy savings	• Selectivity on waste streams	

[1] Threshold requirement

Figure 5 Needs addressed by PI per industry sector

Figure 6 shows the potential benefits of Process Intensification per industry sector.

	Benefits from PI	Short/mid-term potential	Long-term potential
PETCHEM	• Overall higher energy efficiency	5% (10-20 years)	20% (30-40 years)
FINEPHARM	• Overall cost reduction from higher selectivity and process step integration	20% (5-10 years)	50% (10-15 years)
INFOOD	• Higher energy efficiency in water removal • Lower costs through PI along the value chain	5% (10-20 years) 30% (10 years)	75% (10-15 years) 60% (30-40 years)
CONFOOD	• Higher energy efficiency: • In preservation process • Through capacity increase • Through batch to continuous	10-15% (10 years)	30-40% (40 years) 60% (40 years) 30% (40 years)

Figure 6 Potential benefits of PI per industry sector

Extensive preparation went into this Action Plan, including: gathering facts & figures, performing quick scans and developing the PI Roadmap

The project team 'Action Group PI', or 'AGPI', which reports to the Dutch Energy Transition, started in Q4, 2006 and initiated the following activities:

- **Facts & Figures:** The status of PI worldwide has been identified through questionnaires sent to 70 experts, patents (approximately 1,000), and a comprehensive review of scientific publications. 72 PI technologies have been identified, of which 46 have been described in full in "technology reports" by globally recognized experts
- **Quick Scans:** VNCI has asked its members to perform a so-called "Quick Scan" in order to identify the PI potential in specific plants. 40 Quick Scans have been executed so far, with the objective to have Quick Scans from all Dutch chemical companies complete by the end of 2008. From the Quick Scans executed in 2005/2006, it appeared that chemical companies expect important benefits from PI. Expected potential of PI in the short term was evaluated as "significant" in 30% of the cases, and "average" in another 30%; in the long term, these percentages were 40% and 60% respectively

- **PI Roadmap[4]:** Promising PI technologies are identified in the Roadmap, which also describes barriers to their implementation. Several technology roadmaps, specifying actions needed and potential benefits, were built and are outlined here. It recommends several activities, including non-technical issues, that must be undertaken to accelerate PI implementation. The report also serves as an informative manual for any process technologist who wants to enhance his/her knowledge of process intensification technologies and/or use PI in the optimization of his/her production process

So far, PI technology has not been able to reach its full potential in the industry sectors considered. Several barriers stand in its way

PI represents a radical new approach in process technology. PI changes to the production process are more drastic than simply replacing one piece of equipment with another. Switching from batch to continuous processes requires new control systems and alterations to process logistics. Combining multiple process steps into hybrid systems will impact system integration as a whole (e.g. eliminating a distillation process changes the steam balance of a site).

PI is a highly multidisciplinary field. Developing PI technologies requires new knowledge and know-how in a wide range of areas: from materials science to catalyses, process technology and chemistry to process economics. Pulling the supply chain together requires intensive knowledge transfer, preparation and foresight. End-users need to be aware of the potential PI holds for their processes. Researchers need to be able to understand requirements for industrial application (e.g. in terms of manufacturability and reliability). Equipment suppliers known to industry need to be aware of the opportunities at hand. The more partners there are in the supply chain, the more difficult IP issues become. These and other challenges and prospects make PI an exciting and lucrative development.

Introduction of PI technology requires significant investment in an environment where payback times for investments need to be short. Large investments in current technology (including know-how) and competition against its reliability limit the introduction of PI. Managing the technical and financial risks requires developing new scale-up approaches and dedicated piloting facilities.

4 The PI Roadmap can be found on the disc inserted in this report

Common barriers to the implementation of PI technologies are summarized in Figure 7.

Technical/equipment	Economic	Culture/organization
• Additional fundamental research required for several PI technologies • Several PI technologies have been implemented in a limited number of plants, but have a much wider application potential • Reliability demands (unproven technology) • Limited piloting possibilities • Retrofitting PI technologies in current plants difficult	• Insufficient pay-back on new process technology • Suppliers for industrial applications are not present or insufficiently involved	• Lack of PI knowledge and know-how in the industry • Lack of awareness of international developments • Lack of chain vision • IP issues for cooperation during R&D/development

Figure 7 Barriers to PI implementation

This document describes how the Action Plan PI will address these barriers and accelerate the implementation of PI.

I VISION AND GOALS

1 VISION

For the Dutch process industry, sustainability and competitiveness are vital objectives. The potential benefits of PI for the process industry are significant in terms of energy saving, reduction of CO_2 emissions and enhanced cost competitiveness. Increasing the selectivity of reactions through PI will lead to higher material yields. Lead times of entire production processes can be reduced, and optimization throughout the value chain can lead to reductions in energy and waste costs. PI can realize smaller plants, positively affecting perceptions of the process industry at large.

Though the Netherlands is home to leading PI research, many PI technologies which have been implemented abroad have yet to reach Dutch soil. There are several reasons for this gap. Though state-of-the-art, Dutch research is scattered among too many knowledge institutes and industrial R&D departments. Promising PI technologies require considerable fundamental and applied research effort which cannot be achieved by players working in isolation. A lack of piloting & demonstration facilities, or possibilities to pilot on existing production lines, are major bottlenecks in implementation. The industrialization of PI is also faced with insufficient PI knowledge and know-how among process technologists.

2 MISSION

The Action Plan PI will accelerate the implementation of PI in the Dutch process industry, getting PI technology into the factory, through:
- Steering and bundling research and development activities;
- Piloting & demonstration of promising PI technologies on a semi-industrial scale;
- Transferring PI technology and knowledge.

3 AMBITION

The Action Plan PI aims to:
- Provide immediate and lasting stimulus to the implementation of PI in the Dutch process industry;
- Realize a 20% reduction in energy consumption by the process industry by 2050 through PI implementation alone;
- Contribute to doubling the chemical sector's contribution to the Dutch Gross National Product within 10 years and halve the chemical sector's use of fossil raw materials within 25 years[5];

5 Source: Business Plan Regiegroep Chemie, July 2006

– Bundle, focus and create new research in areas that are crucial for the impact of PI;
– Make a facility available for the piloting & demonstration of innovative PI technologies on a semi-industrial scale;
– Establish an intensive exchange of knowledge and know-how between the knowledge infrastructure and the process industry on how to implement PI technologies;
– Cooperate European-wide to broaden the scope of the program, influence the European PI agenda and direct European funding to the Netherlands.

4 BENEFITS

The Action Plan PI will align PI knowledge development and transfer with the needs of the process industry. How industry, knowledge infrastructure and government will benefit is described below.

A Benefits for industry

Industrial partners will benefit from easier access to specialist knowledge and know-how of PI technologies, and will have the opportunity to pilot and demonstrate new PI technologies on a semi-industrial scale. Industrial partners will obtain access to world-class research and the possibility to steer this research to complement in-house research. Through additional resources, more risk-bearing, long-term research can be executed.

B Benefits for knowledge infrastructure

Research will be focused on industrially relevant challenges, and knowledge infrastructure partners will benefit from intensive collaboration with industry in the implementation of PI. Knowledge infrastructure partners will gain the advantage of authorship of and/or involvement in academic publications and other forms of knowledge distribution. The Action Plan PI secures the availability of long-term funding for integrated research projects and less labor-intensive access to funding such as European funds.

C Benefits for government

The Action Plan PI will greatly contribute to the societal goals of sustainability, including reduction of energy consumption and CO_2 emissions. The commitment from both industrial and knowledge infrastructure partners maximizes chances for the efficient use of public funds. Another important benefit is that the Action Plan PI provides a temporary stimulus to the implementation of PI. All activities will be executed by and embedded in existing structures and partners, making it a virtual and temporary program.

Benefits for industry, knowledge infrastructure and funding partners are listed in Figure 8.

Industry

- Provides access to world-class research
- Multiplies a company's own contribution (for example, for pre-competitive research) by a factor of four
- Offers the possibility to influence the steering and target-setting of fundamental research
- Enables companies to conduct more risk-bearing, long-term oriented research through additional resources
- Complements a company's own industrial research activities
- Develops well-trained engineers and researchers
- Stimulates conversion of knowledge in concrete commercial applications
- Creates one portal for acquiring relevant knowledge

Knowledge infrastructure

- Focuses research on areas where a leading position in the international market can be achieved and maintained
- Gains access to high tech industrial infrastructure
- Develops and attracts world-class researchers and research activities
- Authorship and/or involvement in academic publications and other forms of knowledge distribution
- Secures availability of long-term funding for integrated research programs
- Contributes to the goal of the three Technical Universities to align their activities in the 3TU initiative
- Creates less labor-intensive access to funding with less overhead than the regular application procedures of, for example, European funds

Funding partners

- Commitment from both industrial and knowledge infrastructure partners maximizes chances for using public funds efficiently
- Private investments increase the yield on public funds through the matching principle
- Virtual and temporary program, all activities executed by and embedded in existing structures and partners
- The collaboration enables stimulation of innovation throughout the entire chain and industry

Figure 8 Benefits of the Action Plan PI for industry, knowledge infrastructure and government

II ACTIVITIES

The Action Plan PI will accelerate the implementation of PI in the Dutch process industry through three main activities: a research program, a piloting & demonstration facility and knowledge & technology transfer
These activities work hand-in-hand. A research program will steer and bundle research and development activities. A piloting & demonstration facility will enable piloting of promising PI technologies on a semi-industrial scale. Knowledge & technology transfer will disseminate existing and developing Process Intensification knowledge and technologies. Ultimately, these three activities working in concert will accelerate the implementation of PI.

The activities of the Action Plan PI are presented in Figure 9.

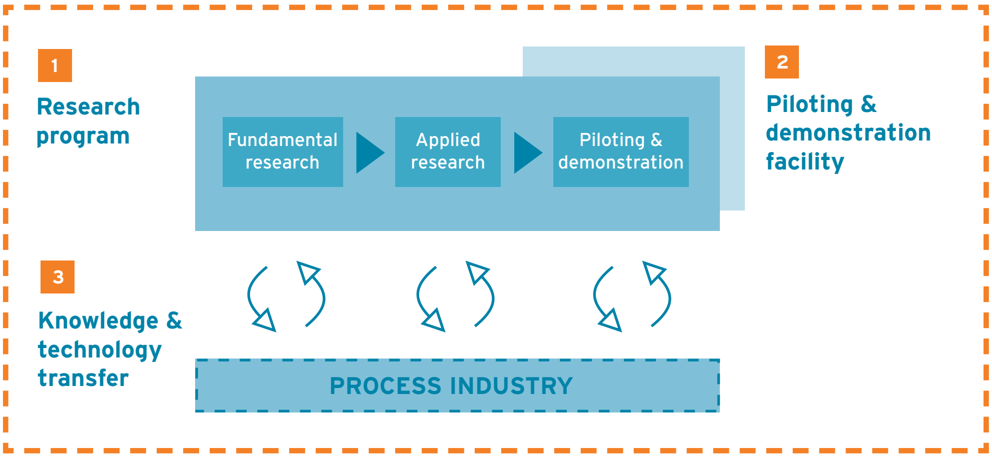


Figure 9 Activities of the Action Plan PI

1 RESEARCH PROGRAM

The research program aims to develop and implement promising Process Intensification technologies through fundamental and applied research, piloting and demonstration.
It is organized in eleven program lines along three axes: PI Thrust Areas, PI Enabling Technologies and PI Special Themes. Each program line integrates fundamental/applied research and piloting & demonstration activities, and is thus focused on getting PI technology into the factory.

PI Thrust Areas entail six program lines that focus on the implementation of the most promising Process Intensification technologies based on the assessments in the PI Roadmap: alternative energy-based operations, membrane-based hybrid separation or chemical conversion, integration of separation and chemical conversion (non-membrane based), transport-limited processes, preservation, and energy efficient water separation throughout the value chain.

PI Enabling Technologies entail three generic program lines that enable Process Intensification technologies to be implemented successfully: PI process analysis tools, PI process modeling & control and PI manufacturing technology & piloting.

PI Special Themes entail two program lines aimed to implement Process Intensification technologies along specific themes: the open theme and the skyline theme. The open theme will give consortia to possibility to start-up a project along one of the themes identified in the European Roadmap for Process Intensification, such as ‘from batch to continuous’, ‘heat limited reactions’, ‘water removal processes’, ‘primary process intensification’, ‘capacity increase’ and ‘high throughput / process development’. The skyline theme will develop a vision of processes and products of the future, and will explore value chain optimizations

An overview of the program lines of the research program is provided in Figure 10. All program lines will be discussed in detail in Chapter III.

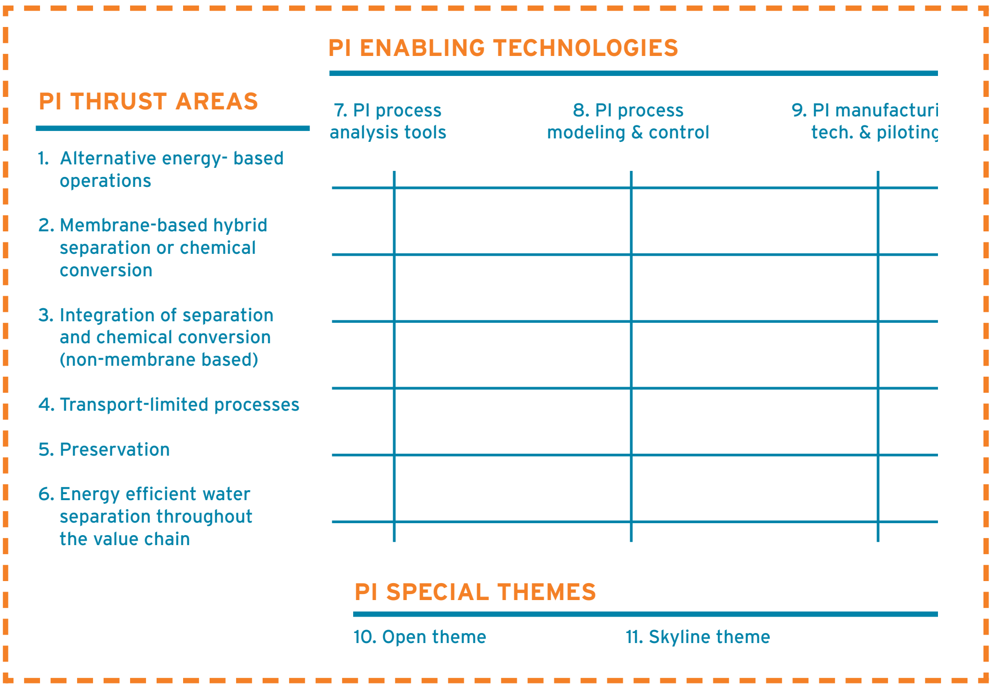


Figure 10 Overview of program lines of the research program

2 PILOTING & DEMONSTRATION FACILITY

The lack of a piloting & demonstration facility is a major barrier to accelerated implementation of PI technology

Introducing PI technology requires significant investment in an environment where payback times for investments need to be short. Large investments in current technology (including know-how) and competition against its reliability limit the introduction of PI. Managing the technical and financial risks requires developing new scale-up approaches and dedicated piloting facilities.

Many barriers to implementation of Process Intensification begin with the lack of a suitable piloting & demonstration facility. There are no piloting & demonstration facilities or possibilities to pilot on existing production lines. Furthermore, high (technical and financial) risks exist in the development of a first industrial prototype and in first implementation (retrofitting) of PI modules in existing production lines/plants. In the 1990s, many pilot facilities were closed down because process engineers believed new processes could be simulated with numerical modeling. Since then, engineers have discovered that piloting on a scale of 1:10 to 1:6 is indispensable to the demonstration of industrial and economical feasibility.

To overcome this major barrier, the Action Plan PI will establish a facility where promising PI technologies can be piloted and demonstrated on a semi-industrial scale

The facility will be located on non-commercial premises, such as a knowledge institute, to avoid confidentiality issues. Such a facility will be made available by partners as part of their in-kind contribution to the Action Plan PI. The Action Plan PI will in turn invest in the existing facility to tailor it to the specific needs of piloting and demonstrating PI technology, such as a mixing station, a flexible storage facility, measurement equipment, a control room and waste disposal facilities. It will be operated by a dedicated team of piloting specialists, made available by the hosting organization. This team will be specially trained to pilot and demonstrate the feasibility of novel PI technology.

Novel pilot PI equipment that is developed and funded by the program lines will be tested in the pilot facility. The facility will also be used by individual companies outside the Action Plan PI that will bring in their own PI test equipment.

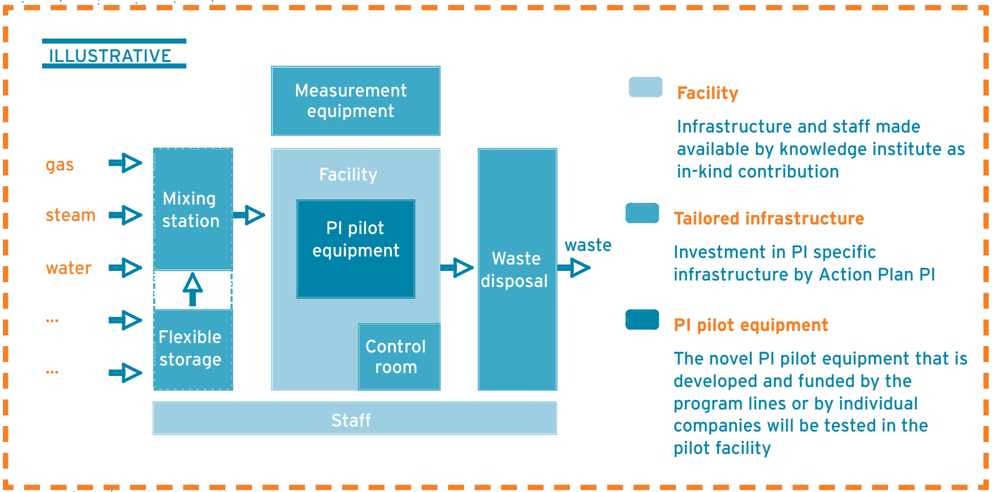


Figure 11 Illustrative layout of piloting & demonstration facility

The objective of the piloting & demonstration facility is to confirm feasibility, scale-up processes and control and develop integrated design/layout (Figure 12)
The feasibility and reliability of proposed PI processes will be confirmed at the facility on a semi-industrial scale, which will test the implementation of process changes, resolve process bottlenecks and produce products which can be tested in turn. The facility will also investigate scale-up processes and control, generating critical information about the behavior of large-scale processes. And importantly, integrated designs and layouts will be investigated and developed for use in the design, construction and operation of large-scale plants.

The facilities will add most value in the PETCHEM and INFOOD sectors, due to the large scale of the industrial processes, which necessitates extensive piloting and demonstration programs on a semi-industrial scale.

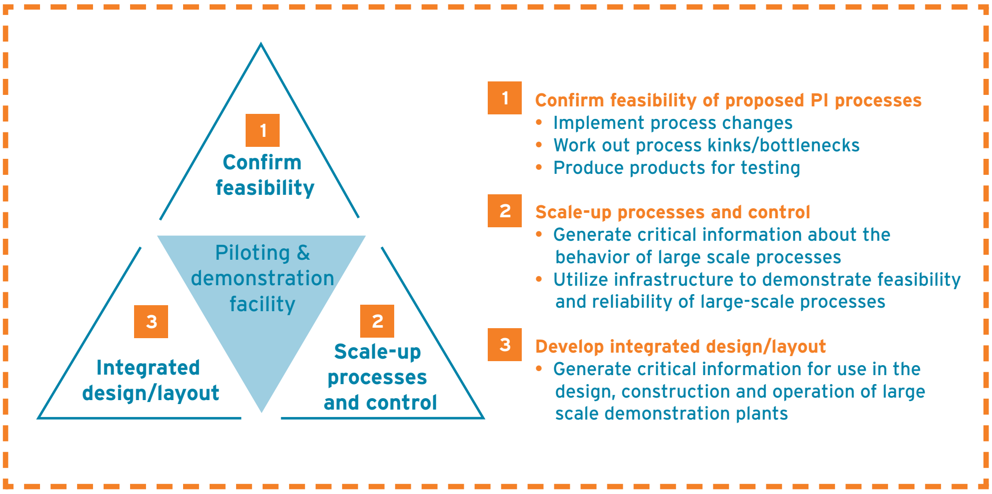


Figure 12 Objectives of piloting & demonstration facility

The piloting & demonstration facility is closely aligned with program line 9, 'Manufacturing technology & piloting', that develops manufacturing technology and specific piloting skills

This program line (see Figure 13) aims to develop manufacturing technology for the proper selection of materials and geometries for specific process equipment. This may take the form of an engineering toolkit. Expertise in dimensioning, planning and execution of efficient and representative pilot programs, as well as predicting the reliability of full-scale production, will also be developed. The program line aims to build a modeling tool which can predict full-scale process performance using semi-industrial scale pilot results and will explore standardization of PI process equipment, defining the proper interfaces between units.

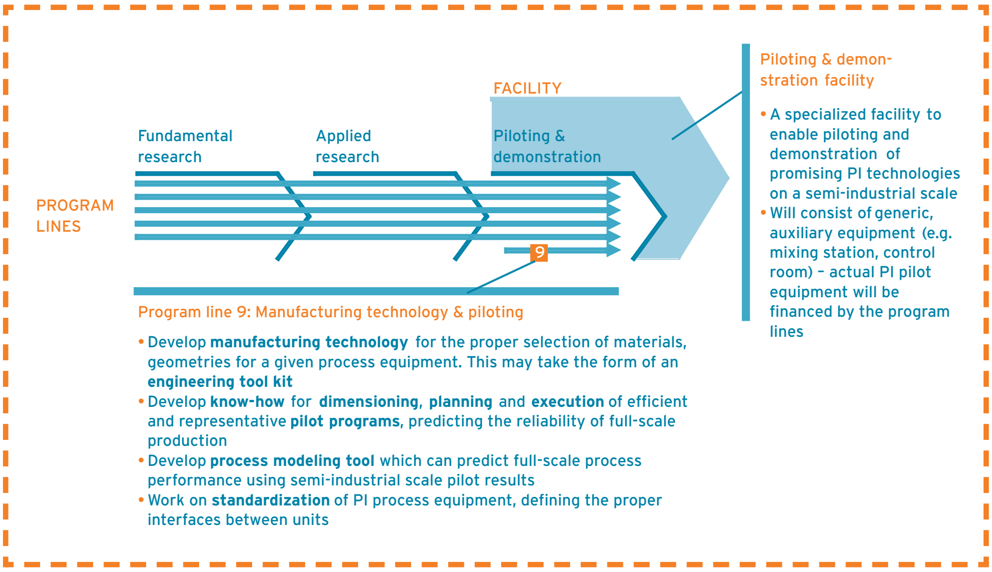


Figure 13 Alignment of program line 9 and the piloting & demonstration facility

The facility will be hosted by a knowledge institute which has the necessary infrastructure and affinity with PI. A limited number of PI technologies will be piloted and demonstrated in European research centers, leveraging the EUROPIC network

In the Netherlands, four non-commercial organizations have the large-scale facilities and infrastructure to host a PI piloting & demonstration facility: ECN, TNO, TU Delft and WUR. Ideally, the host's experience will be in line with current research activities (e.g. TNO has experience with hybrid membrane separation and HEX reactors, ECN has experience with alternative energy-based operations and membrane reactors). For a limited number of PI technologies, a piloting & demonstration facility has already been built by partners in the EUROPIC network. For these specific technologies, the Action Plan PI will leverage its network and cooperate with these partners.

To ensure partner commitment and funding for the tailored facilities, most of the funding will be supplied upfront

Financing the piloting & demonstration facility will be organized differently from the research program. One option is to allocate available piloting time proportional to the funding supplied upfront by participating companies and knowledge institutes. Most of the funding will have to be supplied at the start of a project to ensure partner commitment and finance the tailored facilities.

The initial contract will be for five years. After finalization of the Action Plan PI, non-depreciated assets will be transferred to the hosting partner at commercial rates, and the piloting & demonstration facility will continue to be operated by the hosting partner.

Technology suppliers are very interested in participating in the piloting & demonstration facility

AGPI discussed possible merits and barriers of a piloting & demonstration facility with several technology suppliers. These technology suppliers in most cases use there own facilities, but if necessary they will use third party facilities. No real barriers exist to using a third party facility for piloting. Advantage to the technology providers of a piloting facility is exposure of their product. IP and secrecy are concerns that need to be addressed if more technologies are tested at a single piloting facility. Although technology suppliers expect that the end-users (protecting "their" chemistry) might be the larger barrier. Limitation of capacity (kg/hr) and analytical capabilities are named as reasons to use other facilities than their own. Getting involved in a project as a partner (e.g. supplying hardware and knowledge as in kind contribution) requires a certain degree of exclusivity for technology suppliers to get involved.

3 KNOWLEDGE & TECHNOLOGY TRANSFER

Knowledge & technology transfer aims to support and accelerate the application of existing Process Intensification knowledge and technologies

The PI Roadmap identified the following barriers to knowledge transfer:

- Limited awareness of available and developing PI technologies and their applications among process technologists in industry
- Reluctance of plant managers to use new technology instead of proven technology. Cultural shifts and mindset changes are needed

Knowledge & technology transfer will oversee two activities: intelligence and transfer. The intelligence activity will collect knowledge and know-how about PI R&D and implementation worldwide (i.e. continue to build on 'Facts and Figures'). The transfer activity will disseminate knowledge and know-how through seminars, trainings and coaching. It will also continue the 'Quick Scans' and start 'Full Scans' in the industry.

In the Netherlands, these activities will be executed by the Dutch Process Intensification Network (PIN-NL). On a European level, these activities will be executed by the European Process Intensification Center (EUROPIC). As such, participants in the Action Plan PI will automatically become a member of EUROPIC.

All knowledge & technology transfer will be organized within the IP policy that is developed for the Action Plan PI (see Chapter VI).

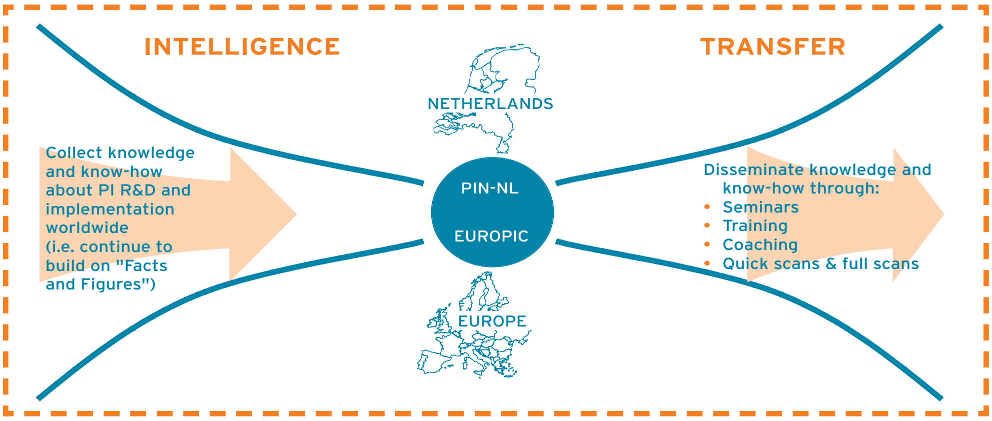


Figure 14 Activities of knowledge & technology transfer

4 PERFORMANCE INDICATORS

To enable transparent reporting of the results of the program to the partners and stakeholders, a pragmatic and measurable set of performance indicators will be tracked

The performance indicators will include:
- Relevance to society
- Market orientation and industrial relevance
- International position
- Scientific/academic orientation and education (quality and quantity of research)
- Short-term and long-term wins of PI implementation
- Finance and efficiency

These performance indicators will be directly linked to program activities. Figure 15 outlines an initial proposal of performance indicators. Final selection and quantification will be made through discussions with industry before the program starts.

Strategic Objective	Performance Indicator	Target 2009 - 2013
Relevance to society	% Energy savings	A
	% CO_2 emissions reduction	B
Market orientation and relevance to industry	Number of industrial partners	C
	Percentage of industry contribution in total budget	D
	Number of established or transferred patents	E
	Number of spin-off companies	F
	Number of Program researchers finding employment in the industry	G
	Participant attendance and evaluation of K&T transfer activities	H
International position	Participation in EU programs (number of projects)	I
	% EU funding of total budget	J
Scientific/academic orientation and education	Number of papers in internationally recognised journals	K
	Number of completed PhDs	L
Short-term and long-term wins of PI implementation	Number of PI technologies pilotted and demonstrated	M
Finance and efficiency	Ratio indirect / total costs	N
	Expenditure on knowledge transfer	O

Figure 15 Suggested set of performance indicators[6]

6 Adapted from: Ministry of Economic Affairs; Letter of Minister to Parliament about TTIs (December 2002)

III RESEARCH PROGRAM

The research program aims to develop and implement promising Process Intensification technologies through fundamental and applied research, piloting and demonstration

The research program is organized into 11 program lines along three axes: PI Thrust Areas, PI Enabling Technologies and PI Special Themes. Each program line integrates fundamental and/or applied research with piloting & demonstration activities, and is thus focused on getting PI technology into the factory.

The research program is based on the PI Roadmap[7]

The Roadmap identifies promising PI technologies and the barriers to their implementation. Several technology roadmaps, specifying actions needed and potential benefits, were built and are outlined in the Roadmap. The PI Roadmap recommends several activities, including non-technical actions, that must be undertaken to accelerate PI implementation. An overview of the PI Roadmaps developed by the sector teams is provided in Figure 16.

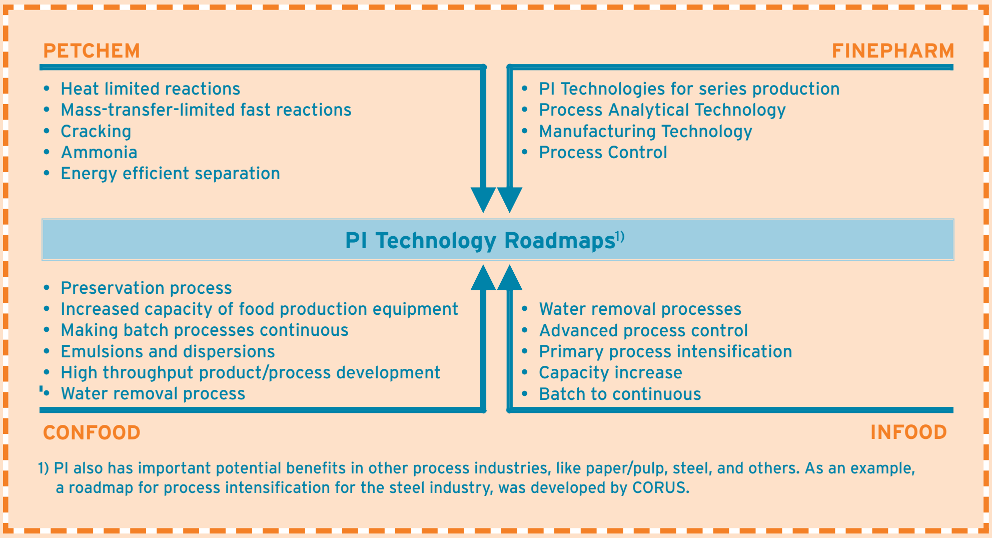


Figure 16 PI technology Roadmaps developed by the sector teams

7 The PI Roadmap can be found on the disc inserted in this report

Based on the PI Roadmap, the most applicable PI technologies have been selected and assigned to the program lines

The initial selection of PI technologies was based on the number of times a PI technology was mentioned in the PI Roadmap. To ensure focus on specific process industry sector needs, the program lines also incorporate the themes identified in the PI technology roadmaps developed by the sector teams. The resulting program lines address the general and specific needs of all process industry sectors, as presented in Figure 17.

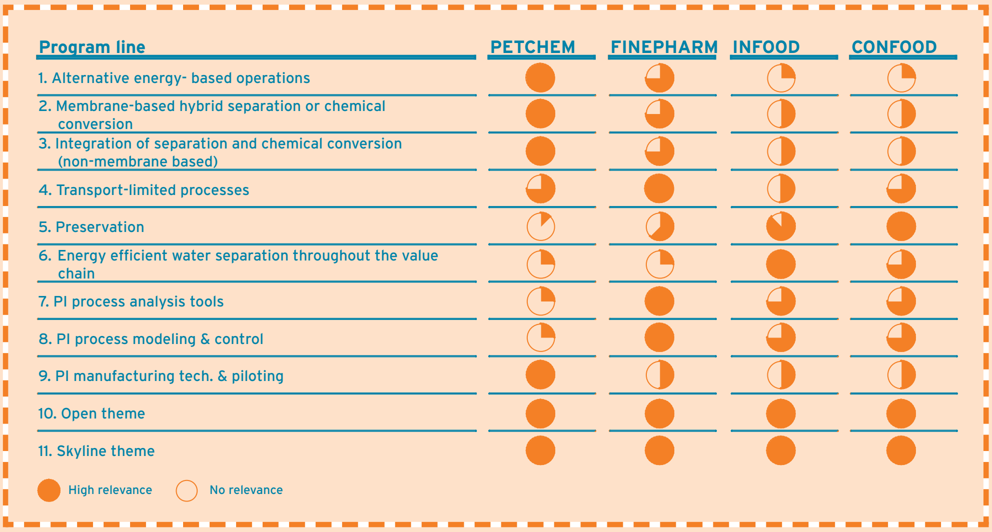


Figure 17 Relevance of program lines per process industry sector

The program lines have been outlined according to a common structure

The problem statement and approach section describes the scientific and/or economic problem that will be addressed by the program line and elaborates on the approach that will be used to solve the problem(s). The character of activities and the scientific/technological innovativeness of the program line in light of international developments are then specified. If the program line also includes fundamental research, the scientific excellence of the participating knowledge groups is detailed.

The program line goals section describes the milestones and deliverables of the program line. It also indicates any risks which may stand in the way of achieving the objectives of the project and which measures will be taken to minimize these risks.

The program line cost estimate specifies estimated costs of the program line for the total running period of five years.

PROGRAM LINE 1 ALTERNATIVE ENERGY BASED OPERATIONS

A Problem statement and approach

A.1 Problem statement

Process operations can be intensified when we remove or reduce performance limitations or enhance the driving forces behind processes. The latter is sometimes related to the way "energy" is transferred to the system, but our understanding and mastery of certain phenomena – which can potentially serve as "alternative energies" – are at varying stages of maturity. More mature technologies may simply require new or better equipment, while embryonic technologies must struggle to convince the industry of the worth behind their development in the first place.

Several technologies are applicable here. Based on the difference in density between two phases, processes driven by gravity can be enhanced by applying a centrifugal field. Chemical rate, which is traditionally enhanced by increasing the mean energy of the molecules (Arhenius), can also be affected by directly transferring a quant of energy to the electron in the molecular bond (photochemistry). This transfer even leads to new results that are not possible through conventional methods. Microwave heating, for example, does not rely on convection or conduction and is able to heat viscous or solid materials without the need for high temperature gradients. It can also make use of differences in absorbance, enabling it to heat (catalyst) specific particles that absorb microwaves well. Next to such traditional examples, the PI field is also exploring a number of phenomena (e.g. ultra sound, electromagnetic fields) which are less understood but which hold significant promise. The maturity of the field of alternative energy technologies ranges widely.

Alternative energy based operations must achieve the following milestones:

1. Deliver undisputed evidence for the advantages claimed by proving technical and economical feasibility
2. Determine the range of application where the advantages can meet their potential
3. Develop equipment and methods to meet industrial standards (e.g. robustness, scale, economy)

A.2 Project approach

Due to the range of technological maturity, a uniform approach cannot be adopted for all alternative energy technologies. Embryonic technologies will require many years (>10) of fundamental research. Even after delivering evidence of their usefulness, they may still face opposition due to limited ranges of application.

Therefore, the status of the range of alternative energy technologies will first be determined. Those that have not reached the first two milestones will not be within the scope of this program, though these should be actively monitored should breakthroughs occur. Technologies that show enough potential and which could reach industrial demonstration (i.e. pilot) in the near future (<5 years) will be targeted for further development. The early involvement of equipment suppliers is crucial for success.

A.3 Character of the activities

To make our selection, we will first determine the status of the technologies. Fundamental research results and information will therefore be measured and tested against applied research and industry. The actual development program will mostly consist of applied research.

A.4 Innovativeness and scientific excellence

Making the selection will require tapping into the knowledge base of the world's leading R&D groups in specific fields. Evaluation of the information will require that field experts are located in the Netherlands. Challenging fundamental research results can be handled by the 3 TUs, TNO and industry partners.

B Program line goals

B.1 Milestones and deliverables

We will first investigate the status of the technologies in this area. This involves research, evaluation and analysis and developing hypotheses for each technology considered. Since the number of alternative energy based operations is large, we suggest narrowing the list down to a selection based on maturity and industry attractiveness. The deliverable of this activity will be position papers (milestones 1 and 2 above) on each of the selected technologies within one year.

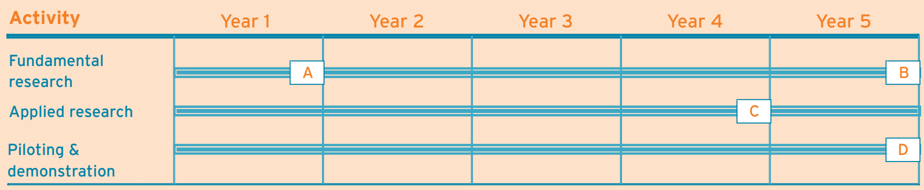
Preselected technologies:
- Centrifugal field (RPB, SDR, rotating plant concept, multi-stage separator)
- Microwave (viscous systems, biphasic, catalyst particles)
- Plasma(DBD)/photo (radicals generation at low temperatures)
- Supersonic gas dispersion

Based on the position papers, the three most promising technologies will be selected and an R&D program started to prepare them for an industrial pilot (milestone 3). This will take about three years. The deliverable at the end of this stage will be a conceptual design for a demonstration of each of the technologies.

The final stage will be the actual demonstration in an industrial pilot of the most promising technology (in cooperation with an equipment supplier). We estimate that only one or two candidates will reach this stage within the timeframe of the project.

Since developments in the world continue, we suggest that all technologies are actively monitored during the five year period. This concurrent stage will deliver an updated position paper on these technologies at the end of the project.

Technologies to be monitored:
- Ultrasound (dispersion, reactor, crystallization)
- Hydrodynamic cavitation reactor
- Electric field enhanced operations
- Pulsed compression
- Impinging streams
- Plasma (GlidArc)



Milestone	Deliverable
A	Position paper on status of pre-selected alternative energy-based technologies
B	Updated position paper on status of all alternative energy-based technologies
C	Conceptual design for a demonstration pilot for the three most promising technologies
D	Demonstration of one technology in an industrial pilot (in cooperation with equipment supplier)

Figure 18 Milestones and deliverables

B.2 Risk assessment and management

The translation of fundamental know-how into an industrial application is a multidisciplinary task. It requires close cooperation between academia, industry partners and future equipment suppliers. Early and close involvement of receiving parties is crucial.

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Status reports on selected technologies	0.4	0.2		
Monitoring of all technologies	0.6	0.2		
Development of 3 technologies		3.4	0.2	
Demonstration of 1 technology		0.2	0.8	
Total	**1**	**4**	**1**	**6**

PROGRAM LINE 2 MEMBRANE-BASED HYBRID SEPARATION OR CHEMICAL CONVERSION

A Problem statement and approach

A.1 Problem statement

Membrane technology has the scope to improve petro, petrochemical and chemical processes. Membranes can especially (partly) replace distillative separations that account for ca. 40% of energy consumption in the petrochemical industry. Membranes can also be used to enhance equilibrium-limited reactions (e.g. methane reforming, ammonia or methanol synthesis, alkane dehydrogenation, alkanol dehydration), purify feeds, break azeotropes and remove products that inhibit reaction (industrial biotechnology).

Membrane uses include:

1. Isolated unit operation for separations
2. Integration with other separation methods, in so-called hybrid membrane separations, such as pervaporation and pertraction
3. Integration with chemical conversion, in membrane reactors including non-reactive or reactive membranes

In this program line, all three uses are taken together (i) as most application problems will likely be related to the membrane itself, and (ii) in order to find the most optimum membrane configuration suited to specific applications. For membrane applications that are not Process Intensification in a strict sense (i.e. usage 1), cooperation with DSTI will be pursued. Note that development of new membrane materials is not part of the scope of this program line, but has a home in current DSTI programs. However, problems encountered during application development will be communicated to membrane suppliers to allow them to contribute to effective solutions.

Up to now, membrane technology has not been part of the standard toolbox of process designers and engineers in the process industry. In general, it is not a proven technology and large-scale introduction of membrane processes, despite their potential advantages, is hampered by lack of:

- A good membrane material selection process for the operation window required for a certain application. Aspects of such a process include membrane flux, selectivity, stability/lifetime issues in relation to high temperature/pressure operation, solvent resistance, pH window, fouling, etc.
- Standardization of design rules and engineering solutions for modules (i.e. sealing and surface-to-volume ratio, cleaning, replacement strategies) and system concepts
- Insight into total cost of ownership
- Shared experiences with promising applications in terms of costs and profits, test results, operational reliability, etc.
- Successful results from large-scale application

In order to become a mature technology for use in the process industry and to capture its energy savings potential, development of membranes, membrane systems and applications has to become more demand-driven and address the barriers to its development. Market development will then follow, enabling low-cost, large-scale manufacturing.

Eventually, large-scale application in existing plants will take place based on the opportunities at hand (e.g. the incentive of incremental capacity).

A.2 Project approach

In the project proposals, emphasis should be placed on the development of actual applications using existing membrane materials, and not on development of new membrane materials.

One or two membrane-based systems should be demonstrated on a semi-industrial scale. Challenges exist in the following areas:

- Ethylene cracking:
  - Removal of H_2 (and CH_4) from cracked gases to reduce chilling need
  - Upfront separation of olefins and paraffins to simplify distillative separations to carbon number separations alone
  - Upfront aromatics separation to reduce the throughput of the olefin separation train
- Fischer-Tropsch: Removal of water, downstream of reactor
- Refinery applications: Identifying pre-separations in crude streams (like mole-weight or aromatic separations)
- Equilibrium-limited reactions:
  - Methane steam reforming, including water gas shift. Removal of H_2, CO and/or CO_2, preferably in the reactors
  - Ammonia synthesis. Removal of NH_3, either in the synthesis reactor or downstream
  - Methanol synthesis. Removal of methanol, either in the synthesis reactor or downstream
  - Alkane (ethane, propane) dehydrogenation. Removal of hydrogen in the reactor with/without hydrogen oxidation
  - Alcohol (ethanol, tert. butanol) dehydration. Removal of water in the reactor
- Oxidation reactions:
  - Provide oxygen-enriched air, centrally or delocalized by production site
  - Provide a controlled amount of O_2 through a membrane for safety or higher selectivity
- Various addition reactions. Addition of EO, PO, phosgene, Cl_2 in a controlled way via a membrane into a liquid-full reactor, prevention of gas cap with unconverted feed. In some cases, this might lead to conversion of batch processes into more efficient continuous processes
- Industrial biotechnology applications:
  - Prevent product inhibition by product removal in the reactor
  - Facilitate water removal in work-up
- Water removal from food ingredients

A.3 Character of the activities

This program line will take a multidisciplinary approach that includes:

- Applied research towards promising applications (i.e. semi-quantitative scoping studies); membrane, membrane reactor and hybrid system conceptual design and configuration studies; (CFD) modeling of modules and membrane reactors, laboratory experiments on performance of membranes in realistic conditions; influence on product quality; endurance tests, (standardized) module design, including sealing concepts, and operation, control systems, maintenance procedures
- Scale-up studies and field tests in piloting & demonstration facility
- Supported by fundamental research, conceptual (process) design studies and techno-economic evaluations that will provide insight into technological and economic advantages/disadvantages, energy consumption, yield and selectivity, capex and opex issues and R&D issues to be addressed

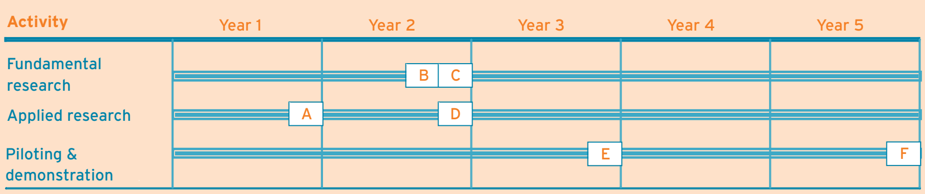
In all equilibrium-limited cases and if a membrane reactor is considered, kinetics should be developed for conditions close to equilibrium, including catalyst deactivation behavior.

A.4 Innovativeness and scientific excellence

The science and technology base within universities, research institutes and end-users is fairly well developed. By bridging the gap between laboratory and industrial applications, an array of scientific, (detailed) engineering, production and market innovations is expected from which Dutch membrane manufacturers and technology providers, as well process owners, might profit. A market pull for membranes and membrane systems is expected, which will lead to innovations in the manufacturing industry. Innovativeness is expected in the development of applications, where specific problems will be addressed and membrane configurations (e.g. separate unit operation, hybrid or reactive) developed as a result.

B Program line goals

B.1 Milestones and deliverables



Milestone	Deliverable	Milestone	Deliverable
A	Selection of application(s) in cooperation with industrial partners	D	Conceptual process design
B	Selection of membrane material (on basis of performance tests)	E	Pilot plant design
C	Kinetic study (if appropriate: close to equilibrium conditions)	F	Proof of principle demo

Figure 19 Milestones and deliverables

B.2 Risk assessment and management

Risks associated with this program line are:

- Selection of “wrong” examples to be piloted. The selection process, based on technology status and stakeholder interests, should serve to avoid this
- Lack of application-focus. Program might default to the membrane material and/or membrane system selection phase
- Approach may be too mono-disciplinary. A multidisciplinary approach is required

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
A. Selection of applications		1.5		1.5
B. Selection of membrane materials, module and system concepts	1	0.5		1.5
C. Kinetic study	1			1
D. Conceptual process design		1.5		1.5
E. Pilot plant design			0.5	0.5
F. Demonstrated proof of principle			4.5	4.5
Total	**2**	**3.5**	**5**	**10.5**

PROGRAM LINE 3 INTEGRATION OF SEPARATION AND CHEMICAL CONVERSION (NON-MEMBRANE BASED)

A Problem statement and approach

A.1 Problem statement

Processes can be made more efficient by combining different technologies. Applications may apply to certain areas of a production chain or the production chain as a whole; separation order may be changed. A review of the entire production chain, taking as the starting point the chemical or physical steps involved, can be achieved by process synthesis. For this approach, which mandates a true paradigm shift, a special program will be developed.

Even synthesis implementation of known combinations is hindered by lack of experience with one or more of the technologies and by limited know-how (i.e. knowledge transfer). Proof of concept for a specific process in most (new) applications is difficult to obtain as little demonstration equipment is available. Proof of principle can usually be reached, but on a small scale, most often laboratory.

If integrated unit operations are combined, operating windows different from those of the current process steps may be needed to take full advantage of the technology combination. This may be especially true in the case of a catalytic reaction (NB: Hybrid systems using membranes will be tackled in program line 2).

Efficient flexible commercial demonstration facilities need to be established. This can be new facilities aimed at certain technology (combinations) or existing facilities at Shell, Akzo or DSM if third party use is allowed. However, flexible does not mean that every technology can be proven in a single facility; tests of certain ranges of technologies within ranges of conditions should, however, be possible. Application of mobile test units at commercial production facilities would ease implementation testing. The availability of existing test facilities (for third parties), like those at Akzo or Shell, should be communicated.

Transfer of existing know-how, process modeling and synthesis capabilities must be intensified. New process control or modeling capabilities may be required for implementation at SMEs.

The following barriers still exist for integration of separation and chemical conversion:

– Modeling and availability of flexible testing facilities: Proof of concept is needed before commercial implementation is feasible
– Existence of application specific (modular systems)
– Knowledge transfer: unfamiliarity with available technology combinations (e.g. divided wall column, reactive absorption)

- Lack of process design tools/know-how
- Controllability (degrees of freedom)
- New construction materials may be required
- The combination of technologies may require new operating windows for the process steps
- Availability of appropriate catalyses: New operating windows may require catalyst development (catalysis roadmap)

A.2 Project approach

Development will start with the selection of a number of potential applications, where more than one of the given technological approaches will be possible in principle. The intention is not simply to prove reactive distillation in several applications, but to prove more technology combinations in demonstration processes. Focus will remain on those technologies expected to be applicable in more than one system. A good balance must be struck between mid-term and long-term R&D, and a pilot facility for demonstration of the units will be necessary.

A wide range of chemical systems could profit from this program line, such as:

- Mono Chloro Acetic acid (reactive distillation)
- Organic Carbonates (catalytic distillation)
- High fructose corn syrup (simulated moving bed reactors)
- Production of optical pure pharmaceuticals (reactive extraction)
- Olefins separation from paraffins (reactive absorption)

Potential partners are: ECN, TNO, TU Delft, WUR, and TU Eindhoven.

Other activities include:

- Kinetic and thermodynamic modeling so that potential applications can be evaluated and to optimize specific applications to evaluate new operation windows
- Development of knowledge base of available technology applications for know-how transfer (e.g. solvent database)
- Process synthesis to determine the optimum combinations of technologies

A.3 Character of the activities

Applied research. As proof of concept of most technology combinations has been reached in the laboratory, proof of concept on a semi-commercial scale must be reached to overcome the barriers. Industry, however, is challenged here to determine which PI technology can be beneficial for a specific process. To answer this, the results of the PI Quick Scans can be evaluated by PI experts to determine potential success areas.

For some technology/application combinations, fundamental research may be required.

A.4 Innovativeness and scientific excellence

The science and technology base within universities, research institutes and end-users is fairly well developed for most technologies, but a limited number of applications and technologies is still fairly new.

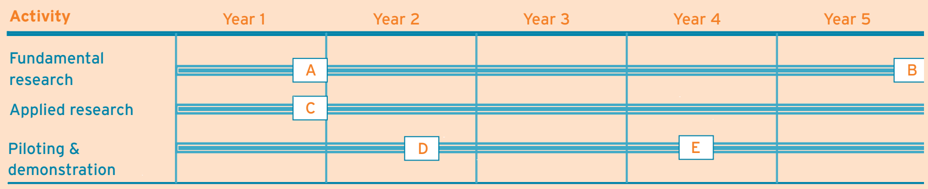
Innovativeness will be demonstrated in the development of the application.

Modeling, proof of concept and semi-industrial scale piloting will be the deliverables of this program line.

B Program line goals

B.1 Milestones and deliverables

The aim of this program line is the proof of concept of five innovative processes.



Milestone	Deliverable
A	1-3 specific new applications selected for proof of principle on a laboratory scale
B	Proof of principle demonstrated for a specific new application on a laboratory scale
C	5-8 specific applications in new processes selected for proof of concept
D	Proof of concept on a semi-industrial scale of 1-2 applications
E	Five known applications fully demonstrated on a semi-industrial scale

Figure 20 Milestones and deliverables

B.2 Risk assessment and management

Considerable technological uncertainty exists within the range of technologies in this area. This risk can be managed from the start by focusing on those technologies with potential in more than one application.

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Total	2	8	5	15

PROGRAM LINE 4 TRANSPORT-LIMITED PROCESSES

A Problem statement and approach

A.1 Problem statement

In the bulk chemical, petrochemical and food sectors, continuous processing is an established manufacturing method thanks to the availability of dedicated production units. In the case of fine chemicals and pharmaceuticals, the situation is different. These sectors are characterized by the production of many different products in relatively small volumes, synthesized by multiple-step processes. Optimization in terms of lower operational costs resulted in the batch-operated, multipurpose plant becoming the dominant production facility.

Recent developments in PI technologies could revolutionize the way we approach process development, technology utilization and facility design in these sectors. Here we are dealing with mass transfer-limited reactions, so continuous, highly productive PI modules in synthesis and downstream processing will result, in principal, in substantial reduction of development time, production costs, waste production, raw material consumption (because of improved selectivity of the chemical conversions) and increased safety, while maintaining flexibility and re-configurability. The production facility would become a multipurpose, serial production train.

The majority of PETCHEM processes with high heat production or consumption in the reactor are categorized as heat transport-limited reactions. This sector needs:

- Increased energy efficiency
- Complete temperature control, which will increase safety (runaway prevention), lower selectivity, reduce fouling and better utilization of the catalyst
- Capital cost reduction, lower running cost and longer runtime

PETCHEM faces the following technological limitations/bottlenecks:

- Radial and axial temperature gradients on the reactor-scale to address insufficient heat transfers. Current inefficiencies directly impact reactor performance, leading to lower selectivity, more byproducts and catalyst deactivation
- The high heat flux reactors available are too expensive and have proven to be unstable; they must also be tuned each time to the desired reaction. They usually contain the catalyst in the form of a coating and, as a result, traditional commercially available catalysts cannot be used and a large catalyst synthesis program is needed
- Catalyst performance (i.e. activity, selectivity and stability) is often unsatisfactory at “easy” temperatures

The main technical hurdles faced by FINEPHARM are:

- Structured reactors allowing high mass transfer rates are too expensive and not a proven technology (e.g. catalyst coated reactors)

- Reactors/devices should be multifunctional/multipurpose (e.g. in terms of residence time distribution). The residence time distribution in continuous processing is often unfavorable compared to that of batch systems

The overall objective of the program line is the development and implementation of structured devices that have proven (with technical, economic evidence) that they offer advantages over existing continuous or batch technologies. An additional objective is the testing of the adequacy of process modeling and control tools available which are not sufficiently used on an industrial scale.

A.2 Project approach

The program aims to implement structured devices within five years. The program will start with the selection of structured devices in combination with potential applications. The actual development of separation devices (DSP) will be an activity of the DSTI program, and will not be included in this program line.

The heart of a process is the reactor; in many cases, its design and operation will be the location of innovation. It is not the purpose of this program line, however, to limit its work to the reactor alone. Process design and experimental demonstration of the process will be the ultimate objective. Scale-down of the reactor and other components is essential.

The program could include:
- Development of structured reactors, including microreactors (and anti-fouling measures)
- Investigation into selection catalysts, elucidation kinetics, stability, window of operation
- The study of the potential of increased selectivity of existing reactors in other operating windows
- Design of multi dispersion/injection systems
- Evaluation of pipe-reactors and/or multi-tube, loop reactors
- Assessment of the introduction of inerts to improve mixing and heat transfer without "metal"
- Application of vibration to enhance mixing and heat transfer
- Design and construction of mini-plants

A.4 Innovativeness and scientific excellence

Innovation can be realized for equipment suppliers when the fundamental know-how is translated into industrial application. To reach this, cooperation between three TUs, TNO, equipment suppliers and industrial partners necessary.

Attention should be paid to developments outside the Dutch network, as there is substantial activity in this area in Europe.

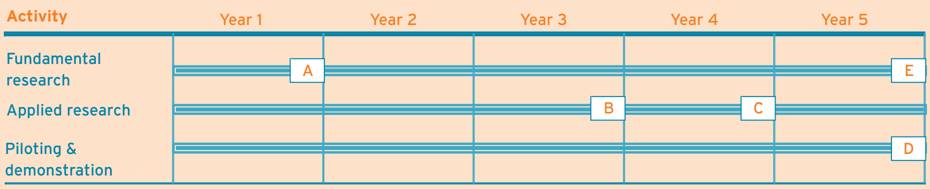
B Program line goals

B.1 Milestones and deliverables

The first activity will be the selection of 3-5 promising devices. This requires information gathering, evaluation and developing a shared position between academia, industrial partners and equipment suppliers. The deliverable of this activity will be a position paper on each of the selected technologies.

In the second phase, an R&D program will be started to develop the selected devices towards an industrial pilot. In the third year, an intermediate selection will be made of one or two of the most promising devices. The deliverable at the end of the fourth year is the realization of a pilot. The final stage will be the actual demonstration in an industrial pilot of these technologies (in cooperation with equipment suppliers).

Since technological developments are continuous and occur at an increasingly fast pace, we suggest that all devices are actively monitored during the five year period of this project. This concurrent stage will deliver an updated position paper on these structured devices at the end of the project.



Milestone	Deliverable
A	Position paper on selection of 3-5 promising devices
B	Development of 3-5 promising candidates towards industrial demonstration, with selection of one or two most promising in three years
C	Conceptual design of demonstration pilot for the most promising technologies

Milestone	Deliverable
D	Demonstration of one or two technologies in an industrial pilot (in cooperation with equipment suppliers)
E	Updated position paper on status of all structured devices

Figure 21 Milestones and deliverables

B.2 Risk assessment and management

The translation of fundamental know-how into industrial application is a multidisciplinary task requiring close cooperation between academia, industry partners and future end-users. Early and close involvement of end-users is crucial.

Interesting developments outside the network should be closely monitored and the program should be adapted accordingly (to prevent duplication and identification of new breakthroughs).

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Preparing selection of devices	0.8			
Monitoring of all devices	0.2			
Development of 2-3 devices		4		
Demonstration of 2 devices			5	
Total	**1**	**4**	**5**	**10**

PROGRAM LINE 5 PRESERVATION

A Problem statement and approach

A.1 Problem statement

Preservation is an important step in providing safe and stable food products in the marketplace. Current practice is dominated by thermal treatment, which has both favorable and unfavorable consequences. One of the key problems is the fact that treatments are based on a worst case approach which over-treats the bulk of the material. This results in quality losses, material losses and excessive energy use (e.g. due to heat-induced fouling, cleaning, waste stream handling). For this reason, techniques which can provide more targeted handling of microorganisms, avoiding detrimental effects on the rest of the food product, must be established. This could either be through the development of dedicated equipment or the use of special ingredients.

The knowledge built up in this program line can also find application in the fine/pharma-chemistry sector e.g. in the production of biologicals, white biotechnology and the formulation of drug substances into drug products.

Needs:
- Milder techniques that require less energy and lead to better product quality
- More selective or targeted treatment of ingredients
- More effective removal of micro traces
- Increased flexibility and capacity in processing (e.g. less cleaning after batch run)
- Increased flexibility in processing (e.g. shorter changeover times)

In most cases the applicability of alternative methods relies on the achievable product shelf life, which can only be reached if the results can be validated or, more importantly, predicted. Accurate, validated models are required to describe the microbial death kinetics of organisms involved. This is a generic constraint, but builds on the vast knowledge base available in the academic world and food companies.

Drivers:
- Improved product quality – proven mild preservation techniques will lead to better and more controlled taste and safety
- Reduced operational costs of food production – decreased fouling and less cleaning will improve the energy efficiency of the process per kg product and will thus decrease operational costs
- Reduced transport costs – improved preservation techniques may lead to reduced cooling costs (i.e. cooling will become unnecessary)
- Reduced waste of raw materials – due to extended shelf-life less products will be off-spec and therefore less considered waste
- Eased requirements for ingredients with regards to microbiological

specification, offering better potential for global sourcing, without jeopardizing food safety
- (Product) quality improvements – as the food industry is not the most energy intensive industry, the focus is not so much on energy savings but on the prevention of quality losses. However, where energy consumption can be limited, this will almost automatically lead to improved production speed and reduced need for intermediate cleaning. This will indirectly reduce energy consumption
- By improving product throughput, reducing downtime due to cleaning, a much larger area can be supplied from the same plant

Current practice is based on bulk treatment which uses a worst case approach. The obvious step is to deviate from this approach and provide targeted treatment of smaller product volumes. This requires reliable, scalable technology at a much smaller scale. It is believed that PI will be able to deliver solutions in this vein. Potential developments could include the separation of microorganisms from the bulk material, completely avoiding the necessity of thermal treatment, or better methods for fast heating and cooling. By minimizing thermal treatment in general, fouling levels can be reduced.

At this time, little is done in the field of foods to adopt PI principles. As such, the sector is lagging behind the chemical and pharma sectors in adopting new process technologies and related equipment.

A.2 Project approach

Promising PI technologies for preservation are:

1. Split stream processes
2. Reduced fouling and improved cleaning
3. Alternative energy transfer
4. Mechanical separation/adsorption
5. Anti-bacteria/virus treatment with other bacteria/viruses

Barriers, required research, timing and actions are detailed below per technology.

1. Split stream processes

Barriers: In current processing, there is insufficient selectivity to separate microorganisms reliably from the bulk food product. As safety guidelines are extremely strict, very high selectivity yields are required. When product streams are split into separate streams for processing, the final product needs to be assembled in an aseptic way to avoid recontamination. This requires advances in current equipment: more intelligent hardware that allows for various recombination solutions. Particularly for non-liquid solid particle and liquid mixtures and small/large volume mixing, this presents a challenge.

Research required: For highly selective solutions, much more fundamental research is required. For the aseptic recombination of product streams, the development of practical solutions requires applied research
Time until implementation: 5-15 years

2. *Reduced fouling and improved cleaning*
Barriers: Fouling is a given in the processing of foods and accounts for 50-80% of operational production costs. Because cleaning is based on good manufacturing practices and standard operating procedures, cleaning takes very conservative approaches to avoid any potential problems. Should appropriate measurement and control techniques become available, the industry could move towards much more intelligent operations and save on cleaning time. The main barrier, however, is the availability of reliable sensors, control points and control strategies.

The use of alternative materials and hygienic design in the process plants is also necessary. Some fundamental issues have to be tackled while new surface materials are developed: how to avoid contamination of food materials, how to guarantee food grade status, how to be sure that no corrosion occurs, how to ensure that all bacterial traces are removed, how to create complete stick free surfaces (lotus effect), etc.

Research required: Fundamental (mainly developing new surface materials)
Time until implementation: 10 years

3. *Alternative energy transfer – reduced contact with equipment and milder treatment (e.g. ultrasound, UV light, radio frequency and pulse from electric fields)*
Barriers: Alternative energy sources are available. In many cases these technologies have an advantage when penetration depths (1-2 millimeters) as well as volumes are small. However, to ensure proper throughput, scaling-up is necessary.

For many technologies (e.g. volumetric heating using microwaves, ohmic heating) the key problem is to retain homogeneous treatment of the product while scaling-up.

Other barriers:
- Limited depth of penetration
- Limited throughput
- Validation needs to be tackled to be accepted by legal bodies
- Energy efficiencies decrease while scaling-up

Research required: Applied
Time until implementation: 5-10 years

4. *Mechanical separation/adsorption*
Barriers: A mechanical separation or adsorption technique can only be accepted when extreme efficiencies can be achieved. This implies very high selectivity (up to 99.9999%) and yields. Due to the low concentration of spoilage microorganisms, not only the local separation must be efficient, but also the complete (split) stream must be in contact with the separator or adsorbent. In order to be accepted as a reliable technology, validation is a key challenge, and long lead times are to be expected. Food authorities are reluctant to accept new technologies.

Research required: Fundamental
Time until implementation: >15 years (approval of new technology alone requires 3-5 years)

5. *Anti-bacteria/virus treatment with other bacteria/viruses*
Barriers: In order to use such an approach, sufficiently effective bacteria and/or viruses must be identified. It will be difficult to demonstrate that the required effect has been achieved on the target microorganisms. Even when effective, trust in the product must be built. Consumer acceptance (marketing issues), validation and legislation (long negotiation processes with food authorities) are crucial but difficult barriers to overcome.

Research required: Fundamental
Time until implementation: >15 years (approval of new technology alone requires 3-5 years)

All of the activities mentioned here are additionally challenged with the isolation of the food industry from the latest developments in the chemical and pharma industries. This makes it difficult to know and asses the latest developments in PI technology in general. Such developments, as well, are not applicable to food systems. On top of that, food product volume sizes will limit the use of small, dedicated equipment. Cleanable materials and cleanable equipment are clear bottlenecks to applying PI equipment solutions.

A.3 Character of the activities

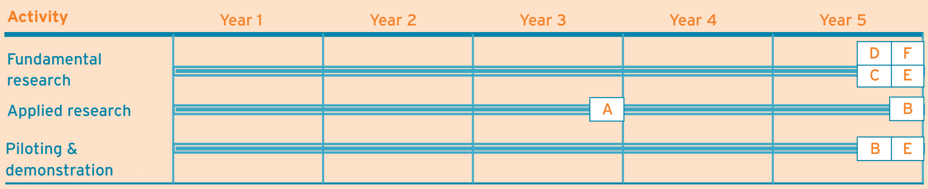
The research required is basically fundamental and applied in nature.

A.4 Innovativeness and scientific excellence

This research requires major breakthroughs to enable successful implementation in the marketplace. When successful, preservation steps will fundamentally change. This program line requires access to WUR, NIZO Food Research, University of Utrecht and three TUs.

B Program line goals

B.1 Milestones and deliverables



Milestone	Deliverable
A	Development of equipment for aseptic combination of split stream processes (0)- pilot plant after three years
B	Development of equipment for aseptic combination of split stream processes (0)- industrial scale-up after five years
C	Proof of principle of reduced fouling and improved cleaning (1) for 3-4 products after five years
D	Demonstration and validation of two technologies for alternative energy transfer (2) after 2-3 years
E	Validation of two technologies for alternative energy transfer (2) at semi-industrial scale after five years
F	Proof of concept of mechanical separation/adsorption and Anti-bacteria/virus treatment with other bacteria/viruses (3 & 4) within five years

Figure 22 Milestones and deliverables

The program as proposed has clear links to a number of other program lines:

- Program line 2, membrane based systems
- Program lines 7, 8 and 9 in the pursuit of better controlled, instrumented production systems that enable the transition from batch to continuous processing where applicable

B.2 Risk assessment and management

The biggest risk is associated with the validation and legislation of any new type of preservation treatment and/or equipment. This risk should be managed by the early involvement of legal bodies.

A generic risk and entry barrier is the fact that the capital already installed in the food industry will not be replaced easily unless there are clear and proven benefits.

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Total	3	4	3	10

PROGRAM LINE 6 EFFICIENT WATER SEPARATION THROUGHOUT THE VALUE CHAIN

A Problem statement and approach

A.1 Problem statement

The agro-based production in the food sector is characterized by large volumes of diluted streams. Crops with short storage limits such as milk, sugar beets and potatoes present particular challenges. The production chain begins with land, crop or farm, continues with transportation, factory processing and refining, and ends with derivatization processes of the agro materials. The rise of crops dedicated to bio-ethanol and bio-diesel will compete for valuable land and will require intensified crops, land usage and process approaches (e.g. bio refineries).

Most food production processes are energy inefficient due to repeated heat exchange (energy) and water removal throughout the various steps. Costs can be reduced by removing water throughout the value chain, upstream in particular (e.g. during harvesting and other primary processes). Processes can also be made more efficient by removing water by using other solvents or by making the process steps less water consuming. The ideal is a waterless process throughout the value chain; in certain instances, this has already been achieved. The entire production chain of water-rich agricultural products like milk, beets and potatoes, from soil to consumer, should be reconsidered to prevent the transport of large quantities of water between the production site and the factory.

The following promising water separation technologies still face a range of barriers:

- *Membrane filtration* – fouling, flux, viscosity (dust), selectivity and robustness
- *Zeolites* (in water removal when temperatures < 60 °C are required) – complexity (i.e. a two-step process during which the remaining water needs to be removed by technologies such as microwaves in order to reach quality/purity requirements), high investment costs and unknown technology; combined research; additional benefit: milder processes due to lower temperatures (lower temperatures lead to better product quality)
- *Water displacement* – high investment costs, limited low-scale applications (known in Germany and South Africa), up-scaling (current pilots achieve max. 3-4 liters) and solvent food grade (e.g. per-chloride as a solvent is not feasible)
- Product extraction with *specific/generic ligands* – Separation of ligands from end product, specificity of ligands and up-scaling the pilot processes; application: separate large volumes of proteins from fats/water; filtration with *'virtual' membranes/ultrasound*; selectiveness, robustness
- Crystallization (at low temperatures) – Up-scaling and finding application
- Energy efficient falling film evaporators – limited by viscosity of concentrate, dependency on pretreated raw materials

A.2 Project approach

Development will start with the selection of a 3-5 food production chains. The economic benefits of optimized water separation throughout each chain will be studied, using one or more of the above mentioned technologies. The focus will be on technologies expected to be multifunctional in these production chains. A good balance must also be established between mid-term and long-term R&D (e.g. the virtual membrane and the crystallization technique expect application after 2022).

A.3 Character of the activities

Most of the activities in this field will be a combination of fundamental and applied research, except for membrane filtration which will be fully applied:

- Membrane filtration: applied research
- Zeolites: combined fundamental and applied research
- Water displacement: combined fundamental and applied research
- Virtual membrane filtration/ultrasound: fundamental research
- Product extraction with ligands: combined fundamental and applied research
- Crystallization: combined fundamental and applied research
- Evaporation: applied research

A.4 Innovativeness and scientific excellence

Most water separation processes consume significant amounts of energy. Energy efficient processes do exist but face high barriers (i.e. investment costs, product changes and losses, inflexibility). This program line, therefore, leads to both energy and cost savings. Energy efficiency alone can increase to 90%.

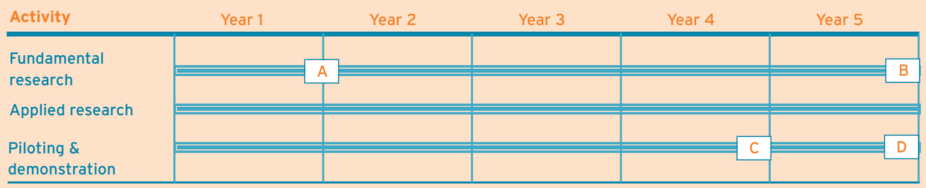
The Netherlands has an excellent scientific reputation in membranes and zeolites research. TU Delft holds a good position in crystallization. For ligand extraction, TU Eindhoven (Andre de Haan) and CATCHMABS (Peter Sijmons) have conducted important research. The University of Leiden has performed groundbreaking fundamental experiments on ligands. The necessary disciplines like chemical processing and materials science and technology are strongholds of the Dutch (technological) universities.

B Program line goals

B.1 Milestones and deliverables

The first year will be devoted to the (economic and technical) value chain optimization study of 5-7 food production chains. The production chains with the highest improvement potential and the most promising water separation technologies will be developed.

Over the next four years, fundamental research will be performed into the material properties of zeolites, membranes and others, and into the selectivity/specificity of potential separation processes (e.g. ligands, crystallization, extraction). At the same time, applied research will concentrate on developing 1-2 applications in the selected production chains to establish the potential of these separation processes. In the last year of this program line, scaling-up work will be undertaken alongside the applied research to achieve the first successful pilot on a semi-industrial scale.



Milestone	Deliverable	Milestone	Deliverable
A	Value chain optimization identified, selection of most promising technologies	C	Proof-of-concept of 1-2 promising (short-term potential) technologies
B	Material development of most promising (long-term potential) technologies	D	Successful semi-industrial pilot with one water separation process

Figure 23 Milestones and deliverables

B.2 Risk assessment and management

Considerable technological uncertainty exists for the wide range of technologies addressed here. It is therefore imperative that risks are removed at the start of the project by focusing on those technologies most feasible for the production chains considered.

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Total	2.5	2.5	2	7

PROGRAM LINE 7 PI PROCESS ANALYSIS TOOLS

A Problem statement and approach

A.1 Problem statement

Contrary to large PETCHEM processes, many INFOOD, CONFOOD and FINEPHARM production processes are not optimized, resulting in decreased capacity utilization (10-20%) and a portion of the end-product falling outside of specifications (10-20%). Costs of non-optimized production amount to 1-2% of total turnover, which represents EUR 100-200 m per year in the Dutch dairy industry alone. This excludes the costs of those products that are deliberately produced at a quality level above specifications in order to avoid rejects.

Reasons to maintain non-optimized production include:

- Unknown fluctuations in raw material quality (e.g. seasonal effects, different suppliers, variations in composition of intermediate chemicals production processes)
- The absence of an adequate physico-chemical model describing the relationship between process parameters and product quality
- The suboptimal design and control of processes

The excuses for non-optimized production can be precluded by the introduction of new and improved sensor techniques. Current sensory systems are too slow, inaccurate or not robust in industrial processes. Fast, accurate and robust online sensors are needed to determine whether products are within specification and whether processes are running optimally. This will e.g. enable the transition from batch to continuous processing. Continuous processing of particularly pharmaceuticals will only be FDA-approved if the end-product is continuously analyzed with sufficient accuracy and reliability.

The need for adequate sensors is also evident from a process control point of view. Without accurate sensors, product quality cannot be steered by adjusting process parameters. A significant development of available sensor techniques is therefore required. On the other hand, many parameters that determine product composition can currently not be measured online: color, turbidity, taste, odor, low concentrations of reactants and intermediates and microbiological components (contaminants like penicillin, viruses and pesticides). To this end, completely new sensor techniques need to be developed. Additionally, the amount of information obtained from standard techniques could be much improved by more sophisticated signal analysis techniques.

A.2 Project approach

The demand for fast in-situ characterization is obvious; offline (lab) characterization of produced samples is laborious and time consuming, and consequently cannot provide real-time feedback on product quality. Optical analysis techniques, such as spectroscopies (UV, VIS, (N)IR, Raman) and refractive index detection, are intrinsically powerful because of their extensive usability in combination with 'noncontact' (remote) sensing characteristics. The application of standard 'bulky' equipment is an option in some cases, but not preferred due to performance concerns, ease of applicability and the residence time needed for analysis next to the residence time needed for production.

The advantage of spectroscopies is that they can be performed using optical fibers, requiring only a small measuring spot (volume). In-situ and online analysis using fiberoptic spectroscopic techniques allows for real-time adjustment of operating conditions based on current data, maintaining process optimization.

The integration of optical techniques for analysis of small volumes already functions to some extent (microchip 'TriPlex', Lionix BV). Microchips have led to innovative sensing principles such as the exploitation of the properties of micro ring resonators and interferometric principles, in addition to the optimization of 'straightforward' evanescent wave and spectrometric (absorption) detection. This technology also makes it possible to integrate a number of sensing windows in one sensor, allowing characterization at different phases of the synthesis process simultaneously.

The availability and rapid development of new and more accurate analysis modules means fast implementation and testing within five years. Sensors will be developed within academic institutes in close cooperation with sensor manufacturing companies to ensure the valorization of the knowledge that is developed. Model experiments will be performed at academic institutes. Once proof of concept of a type of microanalysis module has been demonstrated, additional experiments on 'real' reactions and systems will be performed in industrial conditions. The sensors will develop in functionality and performance, starting with 'straightforward' detection of physico-chemical properties and eventually integrating extra novel functions. These novel functions are especially seen in the field of (micro)biology; fundamental research is rapidly developing supersensitive, fast sensory systems and techniques for complex target components.

A.3 Character of the activities

In the development of new sensor techniques, especially in the fields of (micro)biology and microchip sensors, research is at a fundamental stage. A huge diversification in different (bio)chemical compounds can be achieved within the next five years. New techniques need to be made suitable for industrial use, which primarily requires applied research and development. The increase in sensitivity and response time of more standard spectroscopic measurement techniques (UV/VIS, (N)IR, Raman) also requires primarily applied research and development. These standard spectroscopic techniques can be further developed to increase the amount of information obtained from measured spectra. Ultimately, the developed prototype sensory systems need to be tested in industrial processes.

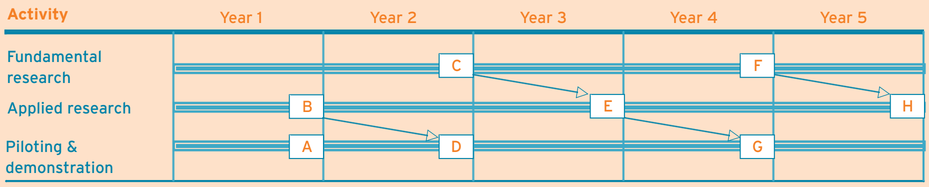
A.4 Innovativeness and scientific excellence

The development of faster and more accurate sensors is quite a scientific challenge. State-of-the-art research into new sensor techniques that meet these needs is being conducted at several Dutch universities. The challenge is to bring these techniques to industry. A close cooperation between universities and Dutch research institutes (three TUs, WUR, Radboud, TNO, NIZO), sensor producers and industry ensures the innovation of current industrial production processes, how they are run and how they are designed. The development of this new generation of sensors facilitates the transition from batch to continuous processing and enables the control and optimization of the production process.

B Program line goals

B.1 Milestones and deliverables

During the first two years, new sensory systems will be applied in industrial conditions. Some will require a measure of development to become functional. Others can be more readily applied and could already be piloted. Fundamental research into new sensory systems will have its first results after two years. These systems will be developed into applicable sensor systems which will be tested in industrial conditions.



Milestone	Deliverable
A	Evaluation of currently available sensory systems with or without improved sensory capacity
B	Industrial pilot sensor available based on currently available new sensory system
C	First new sensory system from fundamental research
D	Evaluation of existing pilot sensor system (milestone B)
E	First new industrial pilot sensor available (based on deliverable C)
F	Second new sensory system from fundamental research
G	Evaluation of first new pilot sensor system (milestone E)
H	Second new industrial pilot sensor available (based on deliverable F)

Figure 24 Milestones and deliverables

B.2 Risk assessment and management

The translation of fundamental know-how into industrial application is a multi-disciplinary task requiring close cooperation between academia, industry partners and future end-users. Early and close involvement of end-users is crucial for valorization.

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Existing sensor techniques with slight modifications			0.25	0.25
New sensor techniques from fundamental research		1	0.5	1.5
Development of new sensor techniques	1	2	0.25	3.25
Total	**1**	**3**	**1**	**5**

PROGRAM LINE 8 PI PROCESS MODELING & CONTROL

A Problem statement and approach

A.1 Problem statement

Undesired fluctuations and lack of complete control in many of today's production processes result in decreased capacity utilization (10-20%) and a percentage of the end-product falling outside of specifications (10-20%). Costs of insufficient process control are estimated to amount to 1-2% of total turnover, which represents an amount of EUR 100-200 m per year in the Dutch dairy industry alone. This excludes the cost of products that are deliberately produced at a quality above specification in order to avoid rejects. Fluctuations in raw material quality (seasonal effect and different suppliers) are an important reason behind process instability. Furthermore, as each step of the process is optimized and controlled separately, there is no integrated optimization of the complete process and a lack of knowledge of how deviations in previous steps influence the steps that follow. There is also a lack of information about intermediate products and whether they fall within specifications. Controllability of the overall process is ensured by buffering or mixing between unit operations or by elaborate quality checks between process steps.

Process Intensification generally results in processes with a higher degree of integration and interaction between process steps and smaller process timescales. Process control plays an important role here. Only optimization of the entire integrated production process ensures that the advantages of intensified processes or process parts are fully exploited. Such control must be based on:

A. Thorough understanding of the physics and chemistry of the process
B. Overall (constrained) optimization of the entire process, from raw materials to end products. Such optimization should be based on cost functions that describe actual operational targets such as product quality, quantity or cost

Advanced, preferably model based, control technology is therefore indispensable when implementing intensified processes, but advanced model based control is still relatively new. Although adequate tools exist for linear or linearized models, full non-linear constrained control has only been demonstrated in specific applications. General, robust tools are still missing.

As PI technology introduces new physics into the processes that need to be controlled, additional models are most likely needed and existing tools tested for applicability and robustness with the newly developed technology.

As intensified processes are more closely integrated, control will lean towards non-linear by definition. The need for truly non-linear (constrained) model based control technology is thus greater. The development of a general toolkit to implement non-linear model based control is desired.

A.2 Project approach

Available model reduction technology will be applied to the models of processes developed in program lines 1-6. Using reduced models and available optimization and control algorithms, advanced control concepts will be developed for one process from each of these program lines. These available modeling & control tools will be adapted to integral process control in order to achieve optimal integration of intensified new process technology in the existing environment. The tools will be tested on an industrial scale using one or two of the developments from program lines 1-6. Awareness of the tools available will ultimately be improved (see Knowledge & Technology transfer).
Parallel to this development, the available tools will be collected in a general toolkit for developing and implementing model based control and optimization. This toolkit will be expanded with tools for truly non-linear model based control.

Partners will be: A&F/WUR, NIZO, TNO, TU Delft, TU/e and suppliers of advanced control systems.

A.3 Character of the activities

Fundamental research is required to develop adequate models of the new physics introduced by Process Intensification. Most of these models will be developed in program lines 1-6 to support the technology development. However, applications of the models to control places special requirements on the models. It is thus likely that some of the models from program lines 1-6 will need to be developed further specifically for the development of control. Sensors will be developed in program line 7. A limited amount of fundamental research is foreseen in this program line to develop new sensors that are needed only for control.

Applied research will be conducted to make existing sensors more robust and compatible with intensified processes. Applied research is necessary for developing control concepts based on models and existing algorithms. Further applied research is needed to demonstrate two of these concepts.

A.4 Innovativeness and scientific excellence

Today's industrial processes are mostly indirectly controlled. While the parameters to control are product quality, quantity and safety, the parameters actually controlled are usually temperatures, pressures and throughputs. This results in:

- Large dependence on operator expertise and experience
- Difficulty in optimizing the process with respect to economic parameters such as product quality, cost or energy use
- Complex process integration: since all processes are still controlled on a minute level, the integrated process has a large degree of freedom that is difficult to control

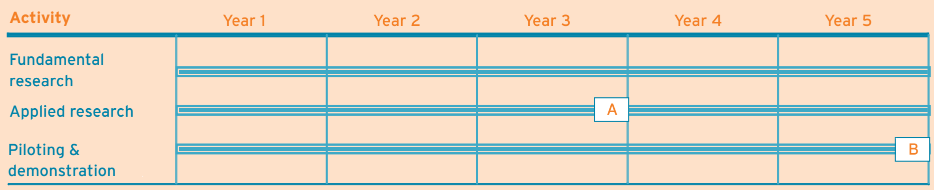
Many processes are therefore suboptimal. The development in this program line will take a large step forward towards simpler, higher level and optimized process control, suitable for intensified and highly integrated processes.

Research groups with world class scientific capabilities (applied physics, chemistry), which are required for fundamental research into models, are present in the Netherlands at the 3TUs and Philips. TU Delft and TU/e have internationally leading research groups on model based control. TNO and NIZO have both developed and demonstrated some of the most advanced process control systems available today.

B Program line goals

B.1 Milestones and deliverables

During the first three years of the program line, development activities will concentrate on achieving successful control concepts for five applications with integral modeling of the production process: at least one for each of the program lines 1-6. The last two years will focus on achieving successful trials on an industrial scale with the control of intensified processes in two factories.



Milestone	Deliverable
A	Successful control concepts developed for five applications with integral modelling of the production process: at least one for each of the program lines 1 to 4
B	Successful trials on an industrial scale executed with the control of intensified processes in 2 factories

Figure 25 Milestones and deliverables

B.2 Risk assessment and management

For the testing of modeling and control tools, an important requirement is the ample availability of industrial piloting facilities, which will be addressed by the piloting & demonstration facility.

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Total		3	2	5

PROGRAM LINE 9 MANUFACTURING TECHNOLOGY & PILOTING

A Problem statement and approach

A.1 Problem statement

Intensified process technology, such as microreactors, micro-structured surfaces and alternative ways of supplying energy to the reacting system, are currently mostly available in a laboratory environment. Up-scaling to full-scale industrial production at reasonable equipment costs still requires substantial development.

This development normally consists of five steps:
1. Testing the new technology in the lab
2. Scaling the technology to 1-10% of full industrial scale, including the required production technology and testing in a controlled environment
3. Design of system integration of the technology in the existing production environment and deployment of mass production technology for producing the process equipment at reasonable costs
4. A pilot of the technology on a side-stream in the industrial environment
5. Building the first plant

Step 1 is sufficiently accommodated and knowledge available at universities, GTIs and in industry. The research in program lines 1-6 focuses on this step. Steps 4 and 5 are usually done by industry and not in open innovation. The intermediate steps are essential to convince plant managers that the new technology is ready to be tested and adopted. These steps require specific skills, knowledge and facilities that are not sufficiently available. It is also usually during these steps that the future equipment supplier is involved for the first time. Once proof of principle is achieved, the technology needs to be made robust and mass production ability achieved.

This program line will address this and other issues:
- Systems engineering (e.g. uniform design of industrial chemical equipment/ process systems)
- Pilot facilities are almost completely absent, therefore testing as in that needed for step 2 is costly and time consuming
- Financing of the design, manufacture and testing of an initial industrial equipment prototype is very difficult due to high risk and technical uncertainty
- Insufficient integration of manufacturing and process knowledge. This leads to process (and equipment) designs that are too expensive to manufacture. Integration of the chain from product development through process development to equipment manufacturing is essential

A.2 Project approach

This program line depends on achieving close cooperation throughout the value chain to build the new PI technology on an industrial scale. We will build a network is built that includes:

- Process operators
- Manufacturing companies that can provide PI equipment or have ambitions to do so
- GTIs as a focal point for piloting and system integration knowledge
- Engineering contractors

Since close cooperation can only be built by working on a specific project, this network should select two PI technologies that are well enough developed to enter the piloting and manufacturing development stage. The network will form consortia to bring these technologies from laboratory environments to the stage where they can be tested in a pilot on a side-stream in a production environment.

Research required: Financing, networking and applied research
Time until implementation: 3 years, after the first two years of the program (i.e. when pilots from program lines 1-6 start being developed)

Parallel to these specific developments, the network will develop tools to scale PI technology reliably from laboratory to full-scale. These tools include:
- Models and general guidelines to bring PI equipment to a scale that can meet required production capacity
- Models to design integrated equipment including mechanical integrity and choice of material
- Models to extrapolate pilot tests to predict long-term behavior of the full-scale process in a real production environment
- An overview of available manufacturing technology and guidelines to avoid unnecessary production costs from poor equipment design
- Guidelines and tools to estimate production costs of the newly developed equipment as early in the development as possible

Research required: Investment and applied research
Time until implementation: 1-2 years, after the first two years of the program

A.3 Character of the activities

Action: Develop know-how for the design of full-scale PI equipment and integrate this with the applied research for production lines
Research required: Applied
Time until implementation: 4 years

Action: Develop know-how for the planning and execution of efficient and representative pilot programs for applied research
Research required: Applied
Time until implementation: 5 years

Action: Work on standardization of PI process equipment, defining the proper interfaces between units
Research required: Applied
Time until implementation: 3 years

Action: Build an engineering toolkit that assists with selecting the proper materials, proper geometries and the right manufacturing technology for a given process. This may take the form of an expert system and engineering principles or guidelines
Research required: Applied
Time until implementation: 4 years (in close cooperation with the pilot facility)

Action: Develop techniques for mass production of PI equipment
Research: Applied
Time until implementation: 5-10 years

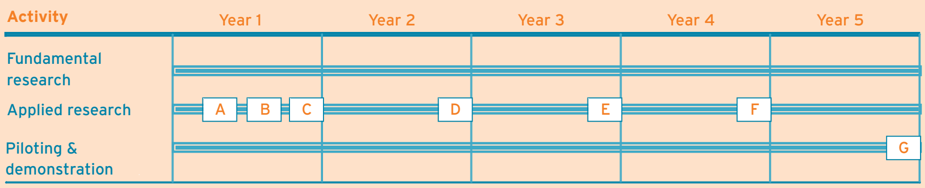
A.4 Innovativeness and scientific excellence

The innovation in this activity lies in the integration of knowledge and the development of tools that will facilitate and accelerate the implementation of newly developed process technologies.

Scientific excellence: TNO and 3TUs, suppliers, engineering contractors.

B Program line goals

B.1 Milestones and deliverables



Milestone	Deliverable
A	Plan for pilot facility
B	Two PI technologies selected for up-scaling and manufacturing
C	Project plan ready for up-scaling and manufacturing of two PI technologies
D	First tests at 1-10% performed
E	Definition of interfaces between units Proposal for standardization
F	Guidelines for piloting and demonstration Model toolkit to assist design and manufacturing
G	Two PI technologies demonstrated

Figure 26 Milestones and deliverables

B.2 Risk assessment and management

The project approach consists of working on two specific technologies and at the same time, using the experience gained there to develop more generic tools and facilities. This enables the construction of an infrastructure (both hardware and knowledge) to facilitate and accelerate the implementation of new PI technology in the Netherlands.

The main risks are:

- It may not be possible to find two suitable and specific PI technologies that can be immediately addressed
- The PI technologies may be so specific that they prohibit the development of generic tools and facilities

These risks need to be assessed during an initial feasibility study. Should they manifest, they can be managed by broadening the scope of this program line to include developments elsewhere in Europe.

C. Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Total		1	4	5

PROGRAM LINE 10 OPEN THEME

A Problem statement and approach

A.1 Problem statement and approach

Program lines 1 to 9 cover most of the roadmaps proposed in the PI Roadmap. However, six roadmaps have not been addressed, for various reasons. Some roadmaps are too specific, focusing on a single process (e.g. ethylene cracking, ammonia and steel roadmaps) and connecting them to one of the program lines would create an artificial relationship.

It is also true that each of these three roadmaps is so specific that stakeholders will be able to propose a program based on the roadmap alone. The descriptions are detailed; technological limitations and barriers are described and improvement potential outlined. In this sense, it is up to prospective stakeholders to decide whether or not to invest in the development of these processes. These roadmaps are therefore encompassed in this ‘open’ program line.

The remaining three roadmaps – increased capacity of food production, emulsions and dispersions and high throughput product/process development for food – are less detailed in their descriptions and are also open to a variety of possible programs. These roadmaps are therefore also encompassed by the open program line.

The open program line, however, is about more than just filling in the gaps. Stake-holders are explicitly solicited for proposals for innovative PI-based solutions which cannot be categorized under one of the nine other program lines. These proposals may also take into account prospective changes in raw materials supply as part of a bio-based economy. Some of these proposals may even be considered stepping-stones for the long-term perspectives that will be outlined by the “skyline” program line.

A.2 Character of the activities and innovativeness

The character of the activities may vary from fundamental through applied research to piloting & demonstration activities. The proposals in this open program will be considered with an open mind but at the same time will have to meet the same criteria of the other program lines: real step-changes in process efficiency are expected, and scientific excellence in R&D is required.

B Program line goals

For this open program line, no milestones and deliverables can be specified at this stage. However, these will be a prerequisite for program proposals.

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Total	1.5	1.5	2	5

PROGRAM LINE 11 SKYLINE THEME

A Problem statement and approach

A.1 Problem statement

In 2007, the Dutch Energy Transition program – in cooperation with other European partners – prepared the *European Roadmap for Process Intensification*. The resulting Roadmap Report takes the first step in defining the relevant R&D themes and setting various forms of collaborations for the coming years. As the European Roadmap starts at today's processes and equipment, the current Roadmap focuses on short/mid-term developments.

This year, the Roadmap will be expanded with a scientific "Skyline" which will address the sustainable process industries beyond 2050 and develop a vision for technological developments in Process Intensification that will be needed to realize that "Skyline".

How can we utilize the solar or wind energy in chemical processing? What is needed on the part of chemical engineering to make "white biotech" processes or production of fuels from renewable feedstocks really economically and technically feasible? What can chemical engineering do to control the complex reaction paths in such a way that the percentage of by-products is brought to zero? These are only some examples of the issues at hand, of which Process Intensification will play a significant role in their solutions.

A.2 Project approach

A "PI Skyline Team" of international experts will be organized which includes both academics and industrialists known for their visionary thinking and ability to look beyond the horizons of current R&D developments. The objective of the Skyline Team is to come up with innovative and out-of-the-box solutions that will propel the Action Plan PI forward. The PI Skyline Team will be set-up and chaired by Prof. Andrzej Stankiewicz of Delft University of Technology, Chairman of the EFCE Working Party on Process Intensification and Director of EUROPIC, the European Process Intensification Centre.

The Skyline Team will develop a vision of processes and products of the future, and will explore value chain optimizations. It will sketch the market of the far future (30-50 years) and develop a long-term Roadmap based on the industry vision that already exists within, for example, Suschem.

It is expected that over the course of scientific discussions and debates, the PI Skyline Team will sketch realistic scenarios for a sustainable process industry over ca. 50 years, covering all four process industry sectors (PETCHEM, FINEPHARM, CONFOOD, INFOOD). Examples of the issues that might be considered when sketching the scenarios post-2050 include:

– Feedstocks and fuels, including renewables (biorefineries, white-bio processes, etc.)

- (New, functional) products
- (New) synthetic/catalytic concepts
- Novel plant concepts (modular, flexible, mobile, etc.)
- Use of renewable energy (sunlight, wind, geothermal, etc.) in manufacturing
- Environmental issues (waste, CO_2, water, climate change, etc.)
- Societal issues (health, safety, etc.)

The Skyline Team will then envisage necessary new developments in process technology in general and in Process Intensification in particular. It is important that the Team develops its vision on a sufficiently high abstraction level and that it will later translate that vision into the required scientific efforts that have to be undertaken in the coming decennia.

It may happen that in doing so, the PI Skyline Team will analyze developments in disciplines other than chemical and process engineering, such as applied physics, materials science, electronics, (bio)chemistry and (bio)catalysis, nanotechnology, etc., and will determine those areas in which interdisciplinary collaboration will be beneficial for the development of the new generation of intensified processes.

A.3 Character of the activities

The activities of the Skyline Team can be characterized as fundamental research. The scientific efforts that will be undertaken to realize the vision developed by the Skyline Team may vary from fundamental through applied research to piloting & demonstration activities.

A.4 Innovativeness and scientific excellence

As the objective of the Skyline Team is to come up with out-of-the-box solutions that will propel the Action Plan PI forward, the Skyline Team will be highly innovative. The team structure of leading academics and industrialists will guarantee the scientific excellence.

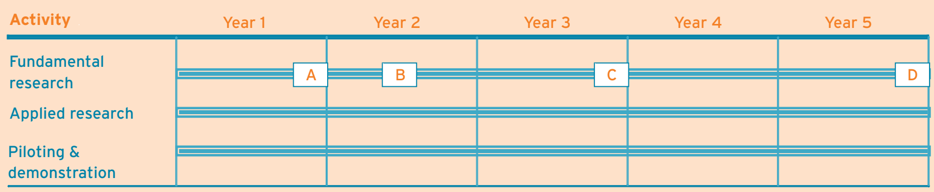
B Program line goals

B.1 Milestones and deliverables

The first deliverable of the project will be a set of defined scientific areas/themes ("building blocks") in which specific research efforts must be undertaken in the coming decennia and a proposal of the action plan to successfully start those research efforts.

The second deliverable will be an extensive value chain optimization study that identifies possibilities for significant process improvements over the whole value chain.

A third deliverable will be an analysis of and report on the potential of three promising technologies.



Milestone	Deliverable
A	Set of defined scientific areas/themes ("building blocks") in which specific research efforts have to be undertaken in the coming decennia
B	Proposal of the action plan to start the research efforts specified in milestone A
C	Extensive value chain optimization study that identifies possibilities for significant process improvements over the whole value chain
D	Paper on future potential of 3 innovative technologies

Figure 27 Milestones and deliverables

C Program line cost estimate

[EUR m]	Fundamental research	Applied research	Piloting/ demonstration	Total
Total	5			5

IV CONSORTIUM

The action Plan PI is a public-private partnership between industry, knowledge infrastructure and government. Knowledge infrastructure partners – mainly universities and contract research organizations (CROs) – will generate knowledge for and within the Action Plan PI. Industrial partners will use this knowledge for commercial purposes.

Industry and knowledge infrastructure investments will be matched by government subsidies from various sources and ministries, which include the Ministry of Economic Affairs (EZ), the Ministry of Agriculture (LNV) and the Ministry of Education, Culture and Science (OC&W). The "Interdepartementale Programmadirectie EnergieTransitie" (IPE) could play a coordinating role. Regiegroep Chemie will provide guidance and access to the Innovation Platform that advises the Ministry of Economic Affairs on strategic innovation budgets. The Action Plan PI is therefore aligned with the interests of several representative bodies which are stakeholders in the Action Plan PI.

Despite the marketing and PR efforts of the Action Plan PI, a large number of companies for which PI can be very interesting might not be aware of the possibilities to participate in the project call. The Action Plan PI will therefore organize the project call proactively, bringing together potential consortium partners (e.g. companies that participated in the Quick Scans) and invite them to write a project proposal.

NON-EXHAUSTIVE

PROCESS INDUSTRY USERS

PETCHEM
- Akzo Nobel
- Broomchemie
- Caldic
- DOW
- Dr Kolb
- DuPont
- Eastman
- Exxon
- Huntsman
- Lyondell
- Nerefco
- Q8
- Sabic
- Shell
- Shin Etsu
- Teijn Twaron
- Total
- Voridian
- Yara
- Zuid-Chemie
- ...

FINEPHARM
- Albemarle
- Arkema
- Cerexagri
- DSM
- Hexionchemie
- International Flavours
- Organon
- PFW
- Quest
- Rohm & Haas
- Solvay
- Sonneborn
- Unipol
- Uniquema
- Zeton
- ...

INFOOD
- ADM
- Avebe
- Cargill
- Cosun
- DMV Campina
- DSM
- Nedalco
- SuikerUnie
- ...

CONFOOD
- Bavaria
- Friesland Foods
- Heineken
- Nestle
- Numico
- Nutreco
- Purac
- Unilever
- ...

EQUIPMENT SUPPLIERS

Equipment manufac
- Alfa-Laval
- Chart
- Corning
- Honeywell
- IPCOS
- Lindauer Dornier
- Lionix
- Mettler
- NAP
- Niro
- NiTech solutions
- Philips
- Rousselet-Robatel
- SAB
- Sensata
- Sulzer
- Syntics
- Velocys
- Westfalia
- ...

Engineering consultants
- ABB
- AkerKvaerner
- Bodec
- Dierselhuis
- Fluor
- PDC
- Tebodin
- ...

KNOWLEDGE PROVIDERS

Research institutes
- ECN
- TNO
- WUR A&F
- ...

Universities
- TU Delft
- TU/e
- UTwente
- WUR
- University of Toulouse
- University of Dortmund
- University of Toulouse
- ...

Figure 28 (Non-exhaustive) overview of companies and knowledge institutes to which PI is relevant

1 INDUSTRIAL PARTNERS

All companies in the process industry, regardless of size, can participate in the Action Plan PI. These companies can be part of the process industry, equipment suppliers or engineering consultants. Participation of non-Dutch companies will be encouraged as long as it supports or improves the competitive position of the Dutch companies involved (e.g. technology providers that are primarily located abroad). At least two industrial partners must participate in each project.

AGPI discussed possible merits and barriers of the program with several technology suppliers. These technology suppliers were very interested in the Action Plan PI, while getting involved in a project as a partner (e.g. supplying hardware and knowledge as in kind contribution) would require a certain degree of exclusivity.

Contributions from industrial partners will be predominantly cash. In-kind contributions are also possible (e.g. temporary transfer of research capacity to the Action Plan PI). For small company industrial partners the minimal yearly financial contribution will be EUR 20 k, increasing quickly to the range of EUR 100 k - 1.000 k for the larger partners. The minimum yearly additional contribution for participation in a single research project will be EUR 20 k.

2 KNOWLEDGE INFRASTRUCTURE PARTNERS

Cross-border knowledge infrastructure (Flanders, NRWF) participation is encouraged. At least one knowledge infrastructure partner must participate in each project.

Contribution from knowledge infrastructure partners will be predominantly in-kind (e.g. temporary transfer of research capacity to the Action Plan PI).

3 GOVERNMENT

The Dutch government, represented by the Interdepartementale Programmadirectie EnergieTransitie (IPE) funds the Action Plan PI through the matching principle: the government will match the total investment amount from either the industrial or the knowledge infrastructure partners, whichever amount is lowest. The matching percentage will depend on the character of the activity:

- Fundamental research (e.g. 75%)
- Applied research (e.g. 50%)
- Pre-competitive development such as piloting & demonstration (e.g. 25%)
- Knowledge & technology transfer

Also the source of funding will depend on the character of the activity. For example, the EOS program could be a funding source for the fundamental component of the research plan.
As the government can discontinue funding at its discretion, it holds an important influence over PI and its future direction.

4 STAKEHOLDERS

As the process industry is of significant importance to the Dutch and European economy, the Action Plan PI has many stakeholders. Because these stakeholders have the same or related objectives, the Action Plan PI will work closely with these organizations. The following organizations are stakeholders in the initiative: VNCI, MKB Nederland, SusChem, EFCE, CEFIC, ProcessNet. The stakeholders are depicted in Figure 29.

Figure 29 Stakeholders

V NEIGHBORING ORGANIZATIONS

The Action Plan PI will align and cooperate with neighboring organizations
The Netherlands holds a strong competitive position in the process industry. Many companies and knowledge institutes work together as a result, collaborating in several initiatives in the field. The Action Plan PI will work closely with neighboring organizations; plans will be aligned and there will be cooperation in areas where synergy can be achieved. Through such alignment and cooperation, the Action Plan PI aims to build an effective and efficient innovative system for Process Intensification in the Netherlands.

Each neighboring organization is described below (Figure 30), followed by a detailed explanation of how the Action Plan PI will align activities and/or cooperate.

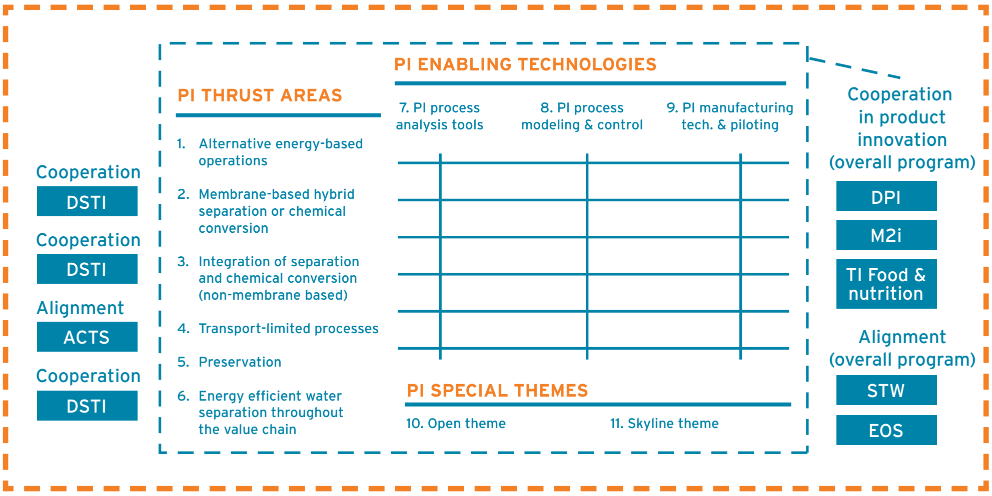


Figure 30 Alignment and cooperation with neighboring organizations

1 ACTS (ADVANCED CHEMICAL TECHNOLOGIES FOR SUSTAINABILITY)

ACTS is the Dutch platform for pre-competitive research in chemistry and chemical technology in which catalysis plays a pivotal role. In ACTS, government, industry, university and knowledge institutes cooperate in public-private partnerships.

It is the mission of ACTS to initiate and support the development of new technological concepts for the sustainable production of materials and energy carriers, essential for the supply of food, comfort, health, shelter and mobility to the inhabitants of tomorrow's world.

– A limited number of ACTS projects, such as PoaC (Process on a Chip), are related to the field of PI. The Action Plan PI will align its activities with these projects in program line 4, Transport-limited processes.

2 DPI (DUTCH POLYMER INSTITUTE) AND PIP (POLYMER INNOVATION PROGRAM)

DPI (Dutch Polymer Institute)

DPI is a public-private partnership funded by industry, universities and government, established to perform exploratory research in the area of polymer materials.

DPI aims to combine scientific excellence with a real innovative impact on industry, thereby creating a new mindset in both industrial and academic research. DPI's ambition is to be a polymer technology center of excellence.

PIP (Polymer Innovation Program)

The Dutch Polymer Institute and the DPI Value Centre are responsible for the execution of the Polymer Innovation Program, in close cooperation with the «Regiegroep Chemie».

The aim is to accomplish a "quantum leap" in the contribution of the Dutch polymer, science, technology and business communities to quality of life, sustainability and economic growth.

In cases where PI technology innovations can lead to new products, cooperation with DPI and PIP will be valuable. In such cases, DPI/PIP and the Action Plan PI will work together to establish cooperation parameters.

3 DSTI (DUTCH SEPARATION TECHNOLOGY INSTITUTE)

DSTI is a cooperation between industry, universities and knowledge institutes. DSTI aims to realize competitive and breakthrough innovations in separation technology in order to strengthen the international position of the Dutch process industry and its technology supply base. Apart from developing knowledge, the institute aims at demonstration and application of breakthrough process technology.

Solutions are considered to arise from:
- Modeling to improve fundamental understanding, better scale-up predictability and risk management, and detailed engineering principles;
- Membrane and affinity technologies;
- Upgrading existing approaches/developing hybrid systems.

The Action Plan PI will cooperate with DSTI in three program lines which involve separation technology:
- Program line 2: Membrane-based hybrid separations or chemical conversion
- Program line 3: Integration of separation and chemical conversion (non-membrane based)
- Program line 6: Energy efficient water separation throughout the value chain

AGPI and DSTI have already held extensive talks to shape this cooperation.

4 M2i (MATERIALS INNOVATION INSTITUTE)

M2i aims to become a world-class institute for fundamental and applied research in the fields of structural and functional materials. By working closely together with high level academic and industrial partners, it delivers new materials for economic growth of our industry and for creating a sustainable society.

M2i strongly emphasizes the process of transforming knowledge generated by research into new materials applied in new products or processes for the industrial partners of M2i, SMEs and start-up companies. Organizing dedicated valorization activities is one of the main tasks of M2i.

In cases where PI technology innovations can lead to new products, cooperation with M2i will be valuable. In such cases, M2i and the Action Plan PI will work together to establish the parameters of such cooperation.

5 FND (FOOD & NUTRITION DELTA)

The Food & Nutrition Delta is an innovation program, aiming to establish the Netherlands as a European leader in food and nutrition innovation. The program is being executed in two phases: TI Food & Nutrition and Food & Nutrition Delta 2.

TI Food & Nutrition

TI F&N, formerly known as the Wageningen Centre for Food Sciences (WCFS), is a public-private partnership that generates vision on scientific breakthroughs in food and nutrition, resulting in the development of innovative products and technologies that respond to consumer demands for safe, tasty and healthy foods.

TI F&N plays a major role in providing its industry partners with leads for the development of new, healthy foods with regard to major health concerns such as obesity and metabolic syndrome. These leads are essential for developing safe food products with excellent taste qualities, products that meet increasingly complex and specific nutritional requirements such as low fat, high protein, low salt and low carbohydrate. Another focus lies in generating a knowledge base for use in developing fermented foods with improved functionality and which may target microbial activity in the gastrointestinal tract.

In cases where PI technology innovations can lead to new products, cooperation with TI F&N will be valuable. In such cases, TI F&N and the Action Plan PI will work together to establish the parameters of such cooperation.

Food & Nutrition Delta 2

The Food & Nutrition Delta 2 is an innovation program that will create networks and platforms in an integrated manner to develop new technologies to enhance new business development in the food industry, particularly focused on SMEs.
The program is organized into the following themes:

- Food & health
- Sensory & structure
- Bio-ingredients & functionality
- Consumer behavior
- Safety & preservation
- Adjacent technology

Two FDN 2 themes, Safety & preservation and Adjacent technology (which include separation, process analysis and micro processing) are related to the field of PI. FND 2 and the Action Plan for PI will align their activities around these themes in order to ensure synergies.

6 OTHERS

The Action Plan PI with closely cooperate with several other (governmental) organizations.

Technology Foundation STW

The Technology Foundation STW is the Dutch foundation for university research. Tenured university staff can apply for a research grant, provided that their proposal includes utilization (i.e. the embedding of the results in society). The STW actively supports utilization by involving market parties in the users committee.

A limited number of STW projects, such as GSPT (Green & Smart Process Technologies) are related to the field of PI. The Action Plan PI will align its activities with these projects.

EOS (Energy Research Subsidy)

The Energy Research Subsidy program aims to initiate and support innovation and research in the fields of energy efficiency and sustainable energy. Besides funding, it sets up brainstorming sessions, workshops and conferences to help spark innovation.

Process Intensification will become one of the key research areas of the EOS program. The Action Plan PI will therefore align its activities with this key area, and the EOS program could become a funding source for the fundamental component of the research program.

VI ORGANIZATION

1 STRUCTURE

A lean organization will steer the Action Plan PI, focusing on allocation of funds and monitoring/control of progress and quality

The organization of the Action Plan PI will consist of a Program Committee, a Program Manager and two committees with specific tasks. Together they will focus on steering the Action Plan PI: allocation of funds, monitoring/control of progress and scientific quality of the execution of the plan. The Program Manager will be hired by the Action Plan PI on a temporary basis.

The plan itself will be executed by participating industrial and knowledge infrastructure partners, and partner resources and infrastructure will be utilized as much as possible. Support functions (financial, secretarial, PR) will be as lean as possible, and staff will be made available by the hosting organization through SLA agreements. All staff involved will remain on the payrolls of participating industrial and knowledge infrastructure partners. Biannual stakeholder gatherings will provide progress updates.

The legal status of the Action Plan PI will probably be a foundation (stichting). The organization will have a temporary character and will be dissolved in five years, upon the conclusion of the plan.

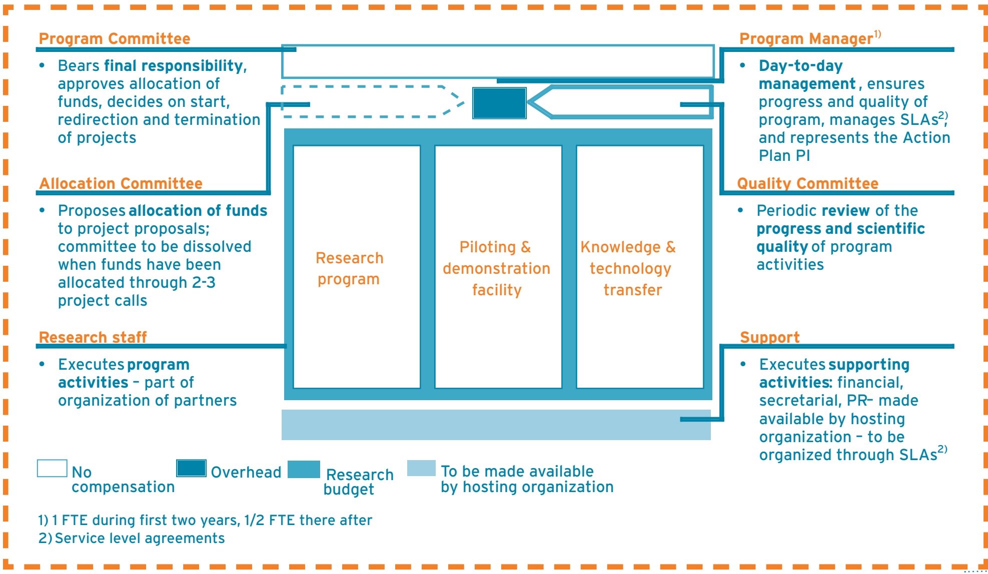


Figure 31 Action Plan PI organizational structure

Program Committee

The Program Committee is the official governing board of the Action Plan PI Foundation. It will consist of 3-5 members, participating on a personal basis, and chaired by someone with an industrial background and independent profile; other seats will be held by people with knowledge infrastructure or industrial backgrounds.

The Program Committee bears final responsibility for the Action Plan PI, formally approves the annual activities' plans and budgets, appoints the Program Manager and ensures effective alignment and cooperation with neighboring organizations. It will stay in close contact with the Program Manager and will meet on a regular basis (once every 1-2 months).

Program Manager

The Program Manager is responsible for the day-to-day management of the Action Plan PI and reports to the Program Committee. He/she monitors and reports on the progress and (scientific) quality of the activities, acquires new partners and funding, manages the SLAs for the Support Staff, represents the Action Plan PI within the (inter)national industrial and academic communities and prepares the meetings of the Program Committee, the Allocation/Quality committees and the biannual stakeholder gatherings.

The position of Program Manager will be 1 FTE during the launch and first two years of the program, after which this position will become a part-time function.

Allocation Committee

The Allocation Committee advises the Program Committee on the allocation of the funds of the Action Plan PI to project proposals turned in after a project call. It ensures that the activities of the Action Plan PI fit well with scientific and technological resources supplied by the partners.

The Allocation Committee is a temporary committee and assembles only when necessary, and will become active during the 2-3 project calls organized by the Action Plan PI. Seats in the Allocation Committee will be held by industrial and knowledge infrastructure partners, and will be appointed by the Program Committee. A member of the Allocation Committee cannot also be a member of the Program Committee.

Quality Committee

The Quality Committee advises the Program Committee on the scientific quality of research conducted and the achieved acceleration of PI implementation.

The Quality Committee will assemble 1-2 times a year, and will review the scientific quality of research performed. It will also assess the actual progress of industry implementation of PI. Seats will be held by industrial and knowledge infrastructure partners, and will be appointed by the Program Committee. A member of the Quality Committee cannot also be a member of the Program Committee

Research program

The projects within the program lines of the research program will be led by a Project Manager, and executed by Fellows and PhD students.

A **Project Manager** will be appointed to each project. A Project Manager may manage several projects at the same time and will be on the payroll of one of the partners (in-kind funding). His/her responsibility is to coordinate the research projects; he/she will keep a close eye on progress and will deliver progress reports, recommending and executing corrective actions if the expected results of a project fall behind agreed deliverables and timing. As it is our ultimate objective to get PI technology into the factory, projects aimed at applied research and piloting & demonstration would be managed by a project manager from one of the industry partner. For fundamental research, a project manager could be an academic. Each consortium that organizes a project will determine its own organization, governance and reporting lines.

Research will be conducted by **Fellows** and **PhD students**. Fellows are either post-docs or industry researchers. Fellows can be on the payroll of participating industrial and knowledge infrastructure partners, but can also be recruited from other research groups worldwide. The scientific quality of their work will be the responsibility of the **Affiliated Professor** or industrial R&D manager that runs the research group.

To ensure that the research in the Action Plan PI is world-class, research performed by or under the responsibility of **Visiting Professors** and **Visiting Researchers** from other knowledge infrastructures will be encouraged. The best way to create this exchange is to have visiting scientists who can contribute 0.5-1 year to one of the projects.

Piloting & demonstration facility

The piloting facility will be led by a **Project Manager.** While both the Project Manager and the staff of the pilot facility will be on the payroll of the partners (in-kind funding), staff will be assigned to the piloting facility for a period of several years to ensure that piloting skills are developed and sustained. During the start-up phase of the piloting facility, the Project Manager will also be heavily involved in setting up the facility and attracting partners.

Knowledge & technology transfer

Knowledge & technology transfer activities of the Action Plan PI will be executed by PIN-NL for the Netherlands, and by EUROPIC for Europe. The Program Manager will oversee these activities. The Action Plan PI will provide funding for these activities, and will ensure that the knowledge and technology that is developed in the Action Plan is transferred effectively.

Support staff

The Action Plan PI will not have its own support staff. All supporting functions will be outsourced under an SLA (Service Level Agreement), managed by the Program

Manager. These supporting functions should be made available by the hosting organization and are not part of the in-kind contribution. The functions include a financial controller, a financial assistant, an assistant responsible for PR and communication and a management assistant. Except for the full-time management assistant, all support staff will work part-time for the Action Plan PI

2 REQUIRED SKILLS AND EXPERIENCE

Program Manager

The Program Manager of the Action Plan PI will have broad experience in the execution and management of R&D. He/she will have a strong vision for the direction and organization of knowledge development and transfer in the field of Process Intensification. He/she will also have established a wide network in the Dutch and European process industries and academic community. The Program Manager will be able to attract contributions and negotiate partnerships with industrial and knowledge infrastructure partners. He/she should be able to manage people in difficult situations.

Project Manager

A Project Manager will have broad experience in process technology research, and will be actively involved in a specific research area. He/she will have a minimum of six years of working experience managing complex research projects in industry or knowledge institutes, and excellent managerial and communication skills.

3 INTELLECTUAL PROPERTY RIGHTS

The Action Plan PI will develop a clear IP policy during the start-up phase of the action plan

The starting point for the IP plan is the set of rules as described for the PI Roadmap project in 2007. This dealt with the underlying information in the database and with the background information for the roadmap describing a period ending per 1-1-2010.

The guidelines for dealing with IP rights for the Action Plan PI will be valid for the full period of 5 years starting when the projects are initiated and will be developed before a call for proposals is sent out.

Collaboration between partners for a major part of the Action Plan PI will be as far as possible based on the concept of open innovation according to the Responsible Partnering Initiative[8].

8 See http://www.responsible-partnering.org/

However the character of the cooperation may vary considerably from contract research to multi-client pre-competitive projects. Dealing with IP rights is obviously most complicated for multi-client projects.

Inventions made within the framework of the Action Plan PI for multi-client projects will in principle be jointly owned by the partners, while the PI Program Manager will be responsible for the final organization of a just and fair settlement of the individual rights, based on the guidelines mentioned.

Partners from the knowledge infrastructure (Universities and RTO's) will when participating in projects formally agree at the start of a project with a set of rules (to be developed before the call for proposals is sent out), which protects the potential IP value of results from the projects.

Special rules will be designed for the piloting & demonstration facility, in such a way that it guarantees access to the facilities for all partners, while confidentiality will be assured if needed.

All knowledge & technology transfer will be organized in such a way that it neither hampers the application for patents nor harms license agreements. Also here a set of rules will be developed before the first call for proposals.

In summary, four sets of rules will be developed:

- Guidelines for dealing with IP rights among partners
- Rules to protect potential IP rights
- Rules for the piloting & demonstration facility.
- Rules for knowledge & technology transfer

4 BUILDING THE ACTION PLAN PI

The partners will agree on how the Action Plan PI will be built
The start-up process of the Action Plan PI will be agreed upon by the partners, and can be outlined as follows:

The Program Manager, in close cooperation with the Program Committee, will draft requirements for the research projects and issue a call for proposals. Partners will prepare project proposals within the scope of the program lines. At least three partners (of which at least two are an industrial partner) should cooperate in each research project. Research project proposals will be evaluated by the Allocation Committee, which will present its advice on the allocation of funds, consolidated into an annual Action Plan, to the Program Committee. The Action Plan will be then approved by the Program Committee.

VII FINANCIAL PLAN

This financial plan details the allocation of the annual budget of the Action Plan PI. (Figure 32)

The main objective of the financial set-up of the Action Plan PI is to allocate as much of the EUR 100 m budget as possible to the activities of the Action Plan
EUR 83 m has been allocated to the research program, accounting for 83% of the total budget . EUR 10 m has been allocated to the piloting & demonstration facility, accounting for 10% of the total budget. EUR 5 m has been allocated to knowledge & technology transfer, accounting for 5% of the total budget. EUR 2 m has been allocated to overhead, accounting for only 2% of the total budget.

A second important objective is to allocate the budget of the Action Plan to fundamental research, applied research and piloting & demonstration in such a way that it ensures effective development of PI technology, making sure PI technology gets into the factory.
In this vein, fundamental research accounts for ~20% of the total budget, applied research accounts for ~35% and piloting & demonstration for ~40%. These allocations are indicative and can differ based on the results of the project calls.

Activity	Fundamental research	Applied research	Piloting & demonstration	Total	Share of budget
RESEARCH PROGRAM [ALLOCATION IS INDICATIVE]					83%
1 Alternative energy-based operations	1	4	1	6	
2 Membrane-based hybrid separation or chemical conversion	2	3	5	10	
3 Integration of separation & chemical conversion (non-membrane based)	2	8	5	15	
4 Transport-limited processes	1	4	5	10	
5 Preservation	3	4	3	10	
6 Energy efficient water separation	2,5	2,5	2	7	
7 PI process analysis tools	1	3	1	5	
8 PI process modeling & control		3	2	5	
9 PI man. tech. & pilot facility		1	4	5	
10 Open theme	1,5	1,5	2	5	
11 Skyline theme	5			5	
PILOTING AND DEMONSTRATION FACILITY			10	10	10%
TECHNOLOGY & KNOWLEDGE TRANSFER				5	5%
OVERHEAD				2	2%
Total Action Plan PI	19	34	40	100	100%
Share of budget	~20%	~35%	~40%		

Figure 32 Budget allocation to Action Plan PI activities [EUR m]

1 FUNDING

Industrial partners, knowledge infrastructure and the Dutch government jointly provide EUR 100 m for the five year Action Plan PI
Industrial partners, knowledge infrastructure and the Dutch government jointly fund the Action Plan PI. It will run for five years, from 2009 to 2013. Total funds amount to EUR 100 m, annual funding to EUR 20 m.

The contribution of the Dutch government will depend on the character of the eventual activities of the research program (fundamental, applied, piloting & demonstration) and the funding instruments that will be mobilized.

After 2013, the activities of the Action Plan PI will be anchored in participating knowledge infrastructure and/or in neighboring organizations. Assets will be returned to the funding partners.

2 PROFIT & LOSS ACCOUNT

The overall Profit & Loss account, displayed in Figure 33, covers a five-year period (2009-2013)

It includes the following assumptions:

- All contributions from participants, in kind and cash, are considered cash equivalents and comprise cash inflow. The exact valuation of in-kind contributions will follow in the final operational plan
- Start-up costs are included
- IP costs are paid directly by the partners that (jointly) file each specific patent
- As the legal entity is a "stichting", it is not required under Dutch law to pay corporate taxes
- In case of an overrun, these funds are redistributed to the partners

Activity	Start-up	2009	2010	2011	2012	2013	Total	Share
TURNOVER								
Funding	-	20.000	20.000	20.000	20.000	20.000	100.000	100%
Total funding		20.000	20.000	20.000	20.000	20.000	100.000	
RESEARCH PROGRAM								
Research Staff	-	(5.809)	(10.325)	(14.678)	(15.266)	(15.876)	(61.954)	
Research related staff	-	(988)	(1.027)	(1.068)	(1.111)	(1.155)	(5.350)	
Research and equipment costs	-	(1.556)	(2.701)	(3.746)	(3.821)	(3.897)	(15.720)	
Subtotal		**(8.353)**	**(14.053)**	**(19.492)**	**(20.197)**	**(20.929)**	**(83.024)**	83%
PILOTING & DEMONSTRATION FACILITY								
Revenues (from non-partners)	-	-	-	500	500	500	1.500	
Research related staff	(49)	(490)	(783)	(1.098)	(1.142)	(1.187)	(4.749)	
Other research related costs	(4)	(60)	(92)	(125)	(127)	(130)	(538)	
Depreciation equipment	-	(600)	(600)	(600)	(600)	(600)	(3.000)	
Rent building	-	(500)	(510)	(520)	(531)	(541)	(2.602)	
Others	(100)	(100)	(102)	(104)	(106)	(108)	(620)	
Subtotal	**(153)**	**(1.750)**	**(2.086)**	**(1.947)**	**(2.006)**	**(2.067)**	**(10.009)**	10%
KNOWLEDGE & TECHNOLOGY TRANSFER								
Revenues (from quick and full scans)	-	263	263	263	263	263	1.313	
Knowledge & technology transfer costs		(756)	(932)	(1.022)	(1.042)	(1.063)	(4.816)	
Contribution to knowledgde networks		(300)	(306)	(312)	(318)	(325)	(1.561)	
Subtotal	-	**(794)**	**(976)**	**(1.071)**	**(1.098)**	**(1.125)**	**(5.065)**	5%
OVERHEAD								
Indirect personnel costs	(105)	(263)	(273)	(114)	(118)	(123)	(995)	
Office & IT costs	-	-	-	-	-	-	-	
Marketing & PR costs	(85)	(50)	(51)	(52)	(53)	(54)	(345)	
Project management	(400)	-	-	-	-	-	(400)	
Recruitment	(100)	(100)	-	-	-	-	(200)	
Others	(50)	(25)	(26)	(26)	(27)	(27)	(180)	
Subtotal	**(740)**	**(438)**	**(350)**	**(192)**	**(198)**	**(204)**	**(2.120)**	2%
Total costs	(893)	(11.334)	(17.465)	(22.702)	(23.499)	(24.325)	(100.218)	
EBIT	(893)	8.666	2.535	(2.702)	(3.499)	(4.325)	(218)	
Interest paid	(17)	-	-	-	-	-	-	
Interest received		54	85	65	37	0	241	
Overrun / deficit	(910)	8.719	2.620	(2.637)	(3.462)	(4.325)	23	

Figure 33 Projected P&L account 2009-2013 [EUR k]

3 PERSONNEL

As the main objective of the Action Plan PI is to allocate as much of the EUR 100 m budget as possible to research activities, almost all employees will work in this area

The current financial plan is based on an average staff size of around 200 FTE in the final three years of the program. Apart from the Program Manager, all staff will be on the payroll of participating organizations. Approximately 2 FTEs have been allocated to a small program office Staff includes the Program Manager, a management assistant, a financial controller and a financial administrator.
No FTEs have been allocated to the Program Committee, Allocation Committee and Quality Committee as the members of these committees will not receive compensation.

Approximately 180 FTEs have been allocated to the research program, accounting for ~93% of total staff. Research staff are project managers, fellows, AIO/OIOs and exchange students. Research related staff are affiliated and visiting professors and research support. To ensure the Action Plan PI can contract this number of researchers in the tight market, the program will work with a recruitment agency for which a significant budget has been reserved during start-up and the first year.

Approximately 12 FTEs have been allocated to the piloting & demonstration facility, accounting for ~6% of total staff. This includes the project manager and dedicated piloting & demonstration researchers.

No FTEs have been allocated to knowledge & technology transfer as these activities will be executed by PIN-NL and EUROPIC.

Activity	Payroll	Start-up	2009	2010	2011	2012	2013	Share
RESEARCH PROGRAM								
Project Manager	no		8	10	11	11	11	6%
Fellows	no		17	33	50	50	50	25%
AIO/OIO	no		42	66	86	86	86	44%
Exchange	no		8	17	25	25	25	13%
Research support	no		8	8	8	8	8	4%
Affiliated professors	no		2	2	2	2	2	1%
Visiting professors	no		1	1	1	1	1	1%
Subtotal			**85**	**137**	**183**	**183**	**183**	**93%**
PILOTING & DEMONSTRATION FACILITY								
Project Manager	no	0,4	1	1	1	1	1	1%
Researcher Pilot/Demo	no		3	6	9	9	9	5%
Research support	no		2	2	2	2	2	1%
Subtotal		**0,4**	**6**	**9**	**12**	**12**	**12**	**6%**
KNOWLEDGE & TECHNOLOGY TRANSFER								
PIN-NL	no	...	...	...	...	...	...	
EUROPIC	no	...	...	...	...	...	...	
Subtotal		...	...	...	...	...	...	
OVERHEAD								
Program Committee	no		...	...	...	...	...	
Program Manager	yes	0,4	1	1	0,4	0,4	0,4	0%
Allocation Committee	no		...	...	...	...	...	
Quality Committee	no		...	...	...	...	...	
Management Assistant	no		1	1	1	1	1	1%
Financial Controller	no		0,4	0,4	0,4	0,4	0,4	0%
Financial Administrator	no		0,4	0,4	0,4	0,4	0,4	0%
Subtotal		**0,4**	**3**	**3**	**2**	**2**	**2**	**1%**
Total staff		**0,8**	**94**	**149**	**197**	**197**	**197**	**100%**

Figure 34 Projected staff size 2009-2013 [FTE]

4 COSTS

Below, cost items shown in the P&L account are detailed.

A Research program

The research (related) staff dominates the costs of the research program – employee-related costs have been incorporated into personnel costs
As almost all employees work on research activities, research staff accounts for the largest portion of the budget. Apart from gross salary, the personnel costs contain employers' costs such as social securities, insurances and pension payments. A mark-up of 50% has been added to the gross salary of each employee to cover various types of additional costs (e.g. use of university support staff, travel, etc.).

All costs of conducting research, besides personnel costs, have been incorporated into research and equipment costs
An estimated EUR 10 k per FTE has been taken into account for costs related to use of materials and other elements needed for conducting research. An estimated EUR 10 k per FTE has been taken into account for costs related to equipment rental needed for conducting research. After finalization of the Action Plan PI, non-depreciated assets will be transferred to the project partners at commercial rates. EUR 1 k per FTE has been taken into account for costs related to scientific publication of research results.

B Piloting & demonstration facility

As in the research program, research (related) staff dominates the costs of the piloting & demonstration facility – employee-related costs have been incorporated into personnel costs
As in the research program, the personnel costs contain apart from the gross salary also employers' costs such as social securities, insurances and pension payments. A mark-up of 50% has been added to the gross salary of each employee to cover various types of additional costs (e.g. use of university support staff, travel, etc.). An estimated EUR 10 k per FTE has been taken into account for costs of specific training for piloting & demonstration facility staff to develop world-class know-how of tested PI technology and equipment.

Rent of the building and infrastructure will be part of the in-kind contribution, but significant investments are necessary to tailor the facility to the needs of PI
The knowledge institutes where the facility will be located make their infrastructure available as part of the in-kind contribution to the Action Plan PI. To tailor the piloting & demonstration facility to the needs of PI, significant investments in the range of EUR 3 m are necessary: for a mixing station, a flexible storage facility, measurement equipment, a control room and waste disposal facilities.

The tailored PI infrastructure will be depreciated in five years. The novel PI equipment that is developed in the program lines will be tested in the pilot facility – the costs of this equipment are taken into account in the research program. Once the facility is up and running, it will also be used by individual companies outside the Action Plan PI that will bring in their own PI test equipment. These companies will pay a compensation fee. The total revenues from these activities will amount to approximately EUR 500 k per year in the last three years of the program. After the Action Plan PI ends, non-depreciated assets will be transferred to the hosting partner at commercial rates, and the piloting & demonstration facility will continue to be operated by the hosting partner.

C Knowledge & technology transfer

Knowledge & technology transfer costs consist of general costs and contributions to PIN-NL and EUROPIC

General knowledge & technology transfer costs include conferences attended by research staff (1 per year), conferences organized (2 per year), workshops organized (25 per year), trainings organized (25 per year), Quick Scans performed (15 per year) and Full Scans performed (25 per year). In the Netherlands, these activities will be executed by the Dutch Process Intensification Network (PIN-NL); on a European level, these activities will be executed by the European Process Intensification Center (EUROPIC). Both PIN-NL and EUROPIC will receive an annual contribution of EUR 150 k as compensation for their activities.

D Overhead

The Action Plan PI will set-up a lean organization with only a Program Manager on the payroll

Indirect personnel costs cover the costs of the Program Manager. This Program Manager will be highly involved in the start-up phase of the program. Once the program has been up and running 2-3 years, this function will be reduced to a part-time position.

The back-office will be as lean as possible. Support staff such as a management assistant (full-time), a financial controller and a financial administrator (both part-time) will be made available by the hosting organization (N.B.: not as in-kind contribution). Like the costs of the back-office, office and IT costs are not taken into account as these will be made available by the hosting organization (N.B.: not as in-kind contribution). Marketing & PR costs, each approximating EUR 25 k per year, cover the expenses for designers and public relations. Costs for project management primarily cover costs of starting-up the program and the cost of legal advice.

To ensure the Action Plan PI can contract the needed researchers in the tight market, the program will work with a recruitment agency for which in total EUR 200 k budget has been reserved during start-up and the first year.

VIII IMPLEMENTATION AND COMPLETION PLAN

1 START UP

Actual realization of the Action Plan PI will start immediately upon approval of the program plan by the partners. In order to establish the program within available and existing infrastructure on the premises of participating partners, a brief realization period is required.

2 COMPLETION AND ANCHORING

The objective of the Action Plan PI is to give a temporary stimulus to the implementation of PI. Therefore, by December 31, 2013, the Action Plan in its current form will end and the organization will be discontinued.

In the two-year period before completion, the research program will develop a plan to anchor developed expertise and activities in the participating knowledge infrastructure and/or neighboring organizations. Each research project will be reviewed, and if the participants in the project wish to continue, planning for its funding and embedding in existing knowledge infrastructure will begin.

Knowledge & technology transfer will continue through PIN-NL and EUROPIC. Non-depreciated assets of the piloting & demonstration facility will be transferred to the hosting partner at commercial rates, along with the depreciated assets, and the facility will continue to be operated by the hosting partner.

ANNEX I – REFERENCES

References

- AGPI, Platform Chain Efficiency, European Roadmap for Process Intensification, 2008
- AGPI, Platform Chain Efficiency, Interim report: PI Roadmap project plan, June 2007
- A. de Groot, ECN, The chemical industry from an energy point of view, 2005
- Arthur D Little, Building a business case on Process Intensification, July 2006
- Regiegroep Chemie, Innovatie in, door en van de Nederlandse chemische sector, August 2007
- Regiegroep Chemie, Businessplan – Key area 'Chemistry' generates growth, July 2006

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ACTION PLAN PROCESS INTENSIFICATION

Process Intensification provides radically innovative principles ("paradigm shift") in process and equipment design which can benefit (often with more than a factor of two) process and chain efficiency, capital and operating expenses, quality, wastes, process safety and more.

The process industry is of significant importance to the Dutch economy. At the same time, the process industry is a major consumer of energy. Process Intensification will contribute significantly to the competitiveness of the Dutch and European process industries by making industrial processes faster, more efficient and better for the environment. Accelerating the implementation of Process Intensification (PI) will help realize the goals of Dutch Energy Transition, and subsequently the Dutch and European policies, and the need for a sustainable and economically strong process industry.

The Action Plan PI will accelerate the implementation of PI in the Dutch process industry, aiming to realize PI technologies in the factories through three interrelated activities: a research program, a piloting & demonstration facility and knowledge & technology transfer.

The **research program** aims to develop and implement PI technologies through steering and bundling of research and development activities. The research program is organized in eleven program lines along three axes: PI Thrust Areas, PI Enabling Technologies and PI Special Themes. Each program line integrates fundamental/applied research and piloting & demonstration activities, and is thus focused on getting PI technology into the factory.

The lack of accessible piloting & demonstration possibilities is a major barrier to implementation of PI technology. To overcome this barrier, a **piloting & demonstration facility** will be set-up to enable piloting & demonstration of promising PI technologies on a semi-industrial scale. The objective is to confirm feasibility, scale-up processes, and control and develop an integrated design/layout.

Another major barrier to the implementation of PI technology is limited awareness of available and developing PI technologies and their applications. **Knowledge & technology transfer** aims to tackle this barrier by collecting knowledge and know-how about PI R&D and implementation world-wide and disseminating this knowledge and know-how through seminars, training and coaching. Execution of "Quick Scans" for facilities will indicate where PI technology can be applied, and following "Full Scans" will identify the specific options for industry.

The Action Plan PI will be steered by a lean and temporary organization focusing on allocation of funds and monitoring/control of progress, coherence and quality. The Action Plan PI will align its activities and cooperate with several neighboring organizations working on Process R&D.

The Action Plan PI should start in September 2008, run for five years, and will provide a temporary stimulus to the implementation of PI. All activities will be executed by and embedded in existing structures of the participating partners.