catalysing innovation
Regiegroep Chemie

Roadmap Process Intensification

Interim Report: PI-Roadmap project plan

Bijlage 4 bij 'Innovatie door, in en van de Nederlandse chemische sector'

Den Haag, 1 augustus 2007

Platform Chain Efficiency
Action Group Process Intensification

INTERIM REPORT ACTION GROUP PROCESS INTENSIFICATION
(Issued to the Platform Chain Efficiency of the Energy Transition and the Dutch PI stakeholders)
Sittard, 1 June 2007

Final Draft

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Annexes:

1. Introduction

Recently, acceleration can be observed worldwide in the development of innovative process technologies referred to as Process Intensification or PI. These technologies often combine known unit operations in an innovative fashion, sometimes using novel equipment or processing methods, such as advanced distillation, micro reactors, alternative energy forms, etc. Recent worldwide developments in energy and climate support the need for faster and broader application of the innovative PI-technologies. A study in 2006 showed that PI offers substantial opportunities to modernise the process Dutch industry (oil refinery, petrochemicals, bulk chemicals, specialty chemicals, pharma and food). Over time substantial savings are possible (energy down, CO_2 emissions down, cost down). Therefore the Dutch Energy Initiative, a Private-Public Partnership, has initiated a project with the objective to accelerate the introduction of PI in the Dutch process industry. The project team (Action Group PI, or AGPI, members have signed this report) formally reports to the Platform Chain Efficiency. The project is further supported and guided by a Senior Advisory Board with the following members:

Ir. J.G. Dopper, former member Board of Directors DSM, chairman Platform Chain Efficiency, member Taskforce Energy Transition,
Dr. Ir. G. A. van Harten, President DOW Benelux,
Drs. L.M.L.H.A. Hermans, President MKB (small and medium-sized businesses), Netherlands,
Ir. G.J. van Luijk, chairman Board of Directors, Technical University, Delft,
Prof. dr. E.M. Meijer, Senior Vice President Global Unilever Foods R&D,
Prof.dr.ir. J.T.F.Keurentjes, TU Eindhoven on behalf of AkzoNobel.

This is the first interim report. It explains the project and reports on progress and further planning.

2. Reading Suggestions

The report provides a general explanation of the project.
Reading the paragraphs 3 through 12 will give the reader a fair picture. All further information is contained in the annexes.

3. Objectives, methodology

Main purposes of the project are to save energy, bring down CO_2 emissions and cut cost in the Dutch process industry through accelerated introduction of promising PI technologies. This will be achieved by confronting the opportunities these innovative PI technologies offer, researched in the context of this project, with the priorities/needs/opportunities in the industry. Options for improved operations will come forward from such a confrontation. Such options then should be evaluated further. A Quick Scan instrument has been developed to support evaluation. Screening of options will be done in close interaction with the industry. Promising PI technologies should subsequently be adopted by and implemented in the industry. This can be done by individual companies implementing a PI technology or by consortia of companies, especially when additional development is still needed before actual implementation. Also international cooperation can be effective.

Expected developments in the industry, the possible impact of PI and recommended actions will be laid down in a document, a PI Roadmap. This Roadmap will be published in January 2008. We expect that a diligent implementation of PI can reduce the consumption of energy in the Dutch process industry in 2050 with 20% (approx 100 Peta Joule) with corresponding reductions in CO_2 emissions and in cost. The project is being carried out involving senior managers and experts from both the Dutch industry and technology providers including universities.
The project plan has been submitted to them and suggestions have been included. The project is set up as a Dutch Public-Private partnership. Both the industry and public bodies are expected to participate in the funding (roughly fifty/fifty). The project has been started in Q4 2006 and will run until Q2 2008.
The investment/development actions taken by the industry as a follow-up in 2008 and onwards are not considered part of the project.

4. The Action Plan in more detail

The present Action Plan consists of three elements:

Element 1. Create an up-to-date and well accessible picture of the worldwide available science and technology for PI.

This documentation will be called “Facts and Figures”. Such documentation does not exist and is in itself of great value for anyone considering implementing PI technologies. The Facts and Figures will be based on contributions by numerous PI experts worldwide, on a patent search and on a literature search. The data so collected will be summarized in Technology Reports in such a way that possibilities for each of the ca 60 selected PI technologies become transparent.

This activity will be executed by the Action Group PI in cooperation with worldwide PI experts in Q2 and Q3 2007. This activity is well under way by now. Seventy experts worldwide have received questionnaires; about 40 answers are now received. Approximately, 1000 relevant patents have been located. Also some 1000 relevant patents have been located. Also, some 1000 relevant literature places have been located. Recruiting to write the Technology Reports and the Fact and Figures document has recently been started. See further annex 1.

Element 2. Write a PI Roadmap explaining the positive impact PI can have for the Dutch process industry.

To write the Roadmap we will first describe expected long-term developments under different economic scenario’s for the different industry sectors and the major Priorities/Needs/Opportunities (PNO) of the industry. Using different scenarios will make the conclusions more robust. Next we will confront these PNOs with the possibilities offered by PI as described in Facts and Figures and then select the PI technologies with real promise for the process industry. To do this, four Section Teams are being set up for different industry sectors (Oil refining and large volume chemicals, Specialty chemicals and Pharma, Bio/Agro products and Consumer products). Opportunities and ideas brought forward can be screened by an instrument called PI Quick Scan. Opportunities based on business goals will thus be selected, described, their possible effects estimated and actions suggested and carried out. An overview of the challenges, the opportunities and the expected effects will be laid down in four Sector Roadmaps by each of the four Sector Teams. The AGPI will consolidate the Sector Roadmaps into one Roadmap for the Dutch process industry.

Note: The possibility to perform Quick Scans will be brought to the attention of the industry in cooperation with the VNCI and the MKB. Companies are welcome to use this instrument to evaluate ideas coming from the project or ideas the company have themselves for PI applications. Part of the cost of the scan will be carried by the company.

This activity will be carried out with the help of the above Sector Teams and use leading expert opinions under supervision of the Action Group PI. Recruiting of the Sector Teams (3 to 4 members each) has started. The Sector Teams should have their first meeting in June. A group of experts will carry out Quick Scans as needed. Both, the Quick Scan and the experts, are now available and the first scans will be carried out before the summer holidays. This second project element will require intensive interaction with the industry. It is planned for Q3 and Q4 2007. See annex 2 for a further description of the Quick Scan instrument and annex 3 for a template of the Industry Roadmaps. Annex 4 contains an assignment letter for the Sector Teams.

Element 3. Promote actual commercial application by presenting options to the industry and organizing/brokering action in the industry.

This is considered a mayor deliverable of the project. Showing opportunities to the industry, triggering action, brokering cooperation. Some applications have already matured and quick wins will be possible. Often, further development/refining of technologies will be needed and cooperation between potential users, equipment and technology suppliers will be necessary to realize actual introduction. In some cases this can be supported by (partial) public funding. Equipment suppliers, technology providers (including universities) may be party to such cooperation. In certain cases international consortia will be needed. The timing of the project is such that FP7 calls in May 2008 can still be made if desired.

Note: If companies feel certain opportunities show sufficient promise they are expected to gradually take over from the project organization. Investments for implementation or development of PI fall outside the scope of the PI project.

This activity will be executed the second half of 2007 and further in 2008. The Sector Teams will start in Q3 and Q4 and contact potential users with ideas. The Action Group PI will support and continue in Q1 and Q2 2008 to point out options to companies, suggest cooperation between relevant players etc. and will help to organize such cooperation.

The power of this approach is created by bringing together the available PI expertise on the one hand and the needs of companies on the other hand. Individual companies and company departments often do not have sufficient insight in the options PI is already offering and therefore do not act or act later than necessary. Altogether the project will thus yield three main results. First of all scientific, technical and commercial data on PI. This documentation will support PI deployment, also after this project is ended. Secondly a PI Roadmap describing possibilities and suggesting actions. This PI Roadmap will be widely published and thus hopefully will also be a lasting inspiration for experts and managers to look at PI for solutions. And thirdly, last but not least, the start of actual development and investment activities in the industry. The design of the Action Plan is aimed at maximizing the number of useful and profitable introductions of PI Technologies in the Dutch and European process industry.

The eventual execution of development activities and investments, by individual companies or in cooperation, will be the responsibility of the industry itself, possibly with support of public funding. Technology providers, including Universities, will often be partners in such cooperation. These development activities and investments are considered by us to be the most important result of the project.

We hope our activities will help universities to include PI in their curriculum. The technical data can certainly be helpful to do so.

5. Support from the Industry

A preliminary study (see annex 10) in 2006 by experts from Dutch industry and universities suggest that the use of PI can reduce the energy consumption and CO_2 emission of the process industry by more than 20%, in specific cases by more than 50%. Operational cost will decrease accordingly. Also safety, quality and other relevant factors can be improved. The Action Plan as presented here has been communicated to responsible management of leading Dutch companies (AKZO, DMV, DOW, DSM, ECN, Huntsman, Lyondell, Rohm and Haas, Shell, Unipol Holland, Zeton) and with branch organizations (VNCI, MKB) and has received full support. The industry has also pledged substantial support in terms of money and manpower. A Senior Advisory Board (see Introduction) has been formed with executive managers from industry and universities to lend support and guidance.

Annex 5 presents a list of the currently interested PI Roadmap network.
At present we consult with the industry to recruit adequate manpower for the Sector Teams.

6. Technology providers

ECN, Delft University of Technology and other technology providers are presently actively cooperating in the project. Further help may be needed.

7. Government involvement

The Dutch Government has been leading in setting up strategy initiatives directed at the future of the chemical industry (Regiegroep Chemie) and a sustainable energy situation (Taskforce Energy Transition). The Government supports by partially funding this PI project. Some senior officers of SenterNovem, a Branch of the Ministry of Economic Affairs (EZ), are actively cooperating in preparation of the project.

8. International context

The Dutch industry will not always be able/willing to carry out development or investment projects without involving international partners with relevant expertise or business interest. The PI project therefore requires an international dimension. In first line we have contacted German branch organizations and industry with a proposal to cooperate. There is willingness to do so (see further annex 6). Networking on a European level is also initiated through contacts with the European Federation of Chemical Engineering and some national organizations (see annex 7 for more).

9. Budget and funding

Annex 8 gives the main outlines of the budget and funding. Funding is now partially available, sufficiently so to support the currently running activities. The summary shows a small deficit of 35 K€ on the total of 725 K€ external cost. This will either be supplied by additional industry funding, or will be saved in the cost. It is expected that by June the pending contributions from industry and government will be granted.

10. Timeline

Annex 11 outlines the planning and provides also some insight in the interconnection between the different project activities.

11. Communication

We will make sure that the industry is aware of this PI project. Numerous meetings with relevant parties have been held in Q1 and Q2. Direct mailing has been done in May to inform a substantial number of organizations. MKB and VNCI have promised their support and will include information in their house magazines. We consider organizing workshops in Q3 to bring our work to the attention of the industry. Flyers are already available for the project and for the PI Quick Scan. The Taskforce Energy Transition will also promote the Energy Transition initiative of which this PI project is a part. Annex 9 gives an overview of presentations where attention to the PI Roadmap has been attracted.

12. The Action Group PI

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Prof. dr. ir. A. (Andrzej) Stankiewicz, TU Delft, Chairman of the Dutch Process Intensification Network (PIN-NL).
Ir. D. (Dick) Venderbos, former CTO, BG Director DSM, chairman up to 1-6-2007.
Ir. W. F (Willem) de Vries, SenterNovem, External Secretary Action Group PI.
Associate member: Dr. H. Schoenmakers, BASF, Member of the Steering Board Fachsektion Prozessintensivierung (DECHEMA / VDOI – ProcessNet)

P.M.:
Ir. D. Venderbos will be succeeded as chairman of AGPI as of 1-6-2007 by
Prof. dr. H. (Hans) de Wit, former CTO Corus, former Board member TNO,

Signed for the Action Group,

Ir. D. Venderbos

Annex 1: Facts and Figures

Project plan “Facts & Figures”

Contents

1. Introduction

1.1 Approach

The task Facts & Figures is an essential part of the PI Action Plan. For 4 different sectors of the process industry, Sector Teams will construct a sector-specific roadmap. The 4 Sector Teams have to be able to assess whether specific PI technologies have a large potential for their sector. In order to do so the task "Facts and Figures" will supply them with the necessary information. The Sector Teams groups will only be able to make the assessment if the information delivered by F&F is specific and targeted.
Based on the information, the Sector Teams will be able to assess:

- Potential applications of the technology;
- Current status and barriers to implementation;
- Main stakeholders.

The general approach can be summarized as follows:

1. Select and agree on list of PI technologies;
2. Collect and analyze information from different sources (experts, patents, literature, technology suppliers);
3. Write ca. 60 Technology Reports (TR);
4. Classify the PI technologies according to their potential/importance and double-cheque the more important TRs on completeness/quality;
5. Write a comprehensive Facts and Figures document.

1.2 Overview of activities

1.2.1 List of PI technologies

PI is not a set of well defined and clearly defined limited set of technology. What is and what is not PI is not immediately evident. Furthermore it is necessary to define exactly what we mean by a specific technology. It is therefore not enough to write down a list of names of technologies. Such a list of the PI technologies which are considered must also include a short description of what is meant to avoid confusion. In Appendix A such a short description has been shown as an example.

1.2.2 Collect and analyse information

The key elements in this activity, as described in figure 1.1, are:

- Patent analysis;
- Literature analysis;
- PI expert questionnaire;
- Information from technology suppliers.

Figure 1.1: key elements to analyse information

Patent analysis:	• Compile relevant patents abstracts (excel) that can be used by the people who write the Technology Reports. • Identify which relevant aspects are addressed (benefits identified/quantified, barriers, applications considered) • Identify stakeholders and "hot-issues"
Literature analysis	• Assess how much information is available on each technology and rank which are the main sources of information • Compile relevant literature abstracts for each technology • Identify and collect key publications (in particular high-quality reviews) per PI technology for use by the people who write the TRs.
PI Expert questionnaire	• Collect information from worldwide experts on the existing and potential benefits and barriers concerning the technology of their expertise.
Technology provider	• Collect information from technology providers/ licensers (for example Uhde, ABB, etc.) on technologies they are developing/providing .

Figure 1.2: Table of contents for the Technology Reports

1. Technology
- 1.1 Description of technology / working principle
- 1.2 Types and "versions"
- 1.3 Stage of development

2. Benefits
- 2.1 Existing technology (currently used/reference technology)
- 2.2 Known commercial applications
- 2.3 Known demonstration projects
- 2.4 Applications discussed in literature
- 2.5 Proven or expected benefits

3. Barriers
- 3.1 Technology development issues
- 2.2 Challenges in developing processes based on the technology

4. Where can information be found?
- 4.1 Key publications
- 4.2 Literature overview
- 4.3 Relevant patents and patent holders
- 4.4 Institutes/companies working on the technology

5. Stakeholders
- 5.1 Suppliers/developers
- 5.2 End users

1.2.3 Write Technology Reports

Technology Reports are written for each technology based on returned questionnaire forms, patent abstracts and analysis, literature. A fixed template for these reports is used and is shown above in figure 1.2

The Technology Reports should be very compact and to-the-point. The available information needs to be condensed to a summary per chapter of maximum 2-3 page (technology, application, issues, information and stakeholders) leading to technology reports of maximum 10 pages.

1.2.4 Ranking and evaluating the Technology Reports

Based on the Technology Reports, the panel will write a comprehensive document, Facts and Figures on PI. This document will give an overview of the present development of PI and its present and future potential to improve industrial processes with an emphasis on energy savings, reduction of CO2 emissions and reduction of cost.

- The importance of the technology for the different sectors;
- Whether essential information is missing in the TRs for important PI technologies.

If needed, flaws in important TRs will be repaired.

1.2.5 Review of reports by PI experts

To finalize the reports, experts will be asked to review and edit the technology reports. In principle the experts who have supplied information by filling in the questionnaire will be the primary authors. If no such expert is available, other experts will be approached.

2. More detailed description of the Fact and Figures activities

The first two tasks are: demarcation of the relevant PI technologies and collecting the required information. On some subjects, for example micro-reactors, reactive distillation, membrane reactors, there is much information available. To give a single example, more than 500 publications have dealt with the subject of reactive distillation alone (Stitt, 2005). The key is then in collecting only the information relevant to understanding the potential of the technology in the range of conceivable applications. In other areas much less information will be available.

2.1 List of PI technologies

In the preliminary phase of the project a list of 60+ technologies has been assembled for further consideration. It is not always immediately evident what is included in the definition of a technology. For example the term membrane reactor covers a wide area of technologies. Furthermore it is not always clear where the border lies between improvement of existing process and process intensification. To make sure the collected data and subsequent analysis is consistent, it is important that it is absolutely clear what is included and the first deliverable is a document which gives the complete list of the 60+ technologies considered and gives a short description of technologies (maximum 1/2 A4). The list of currently identified Technologies is provided in Appendix B.

2.2 Patent analysis

2.2.1 Objective

The objectives of the patent analysis:

- **Abstract "database"**: Create a database of patent abstracts for each of the PI technologies, which can be used as source of technical information for the Technology Reports;
- **Interest and applications**: Assess in which areas a large patent activity can be seen and in which areas activities have been limited (or little has been published) and which applications are considered;
- **Benefits and barriers**: determine what can be achieved and which technical barriers are addressed in the R&D for each of the technologies;
- **Stakeholders**: Identify which companies/institutes are involved and could possibly be approached.

2.2.2 Refining the patent search

Starting point is a first patent search has been carried out by Jos Winnink (patent agency). Using keywords supplied by AGPI, OCN has generated a "database" of relevant patents (number, title, abstract, inventor, company). Subsequently a number of iterations are necessary to refine the search. This focuses on two issues (see Figure 2.1):

- **Increase coverage**: To see if the search has included the most important patents, it is important to identify which relevant patents have not been found in the search;
- **Improve relevance**: Eliminating the patents which are not relevant.

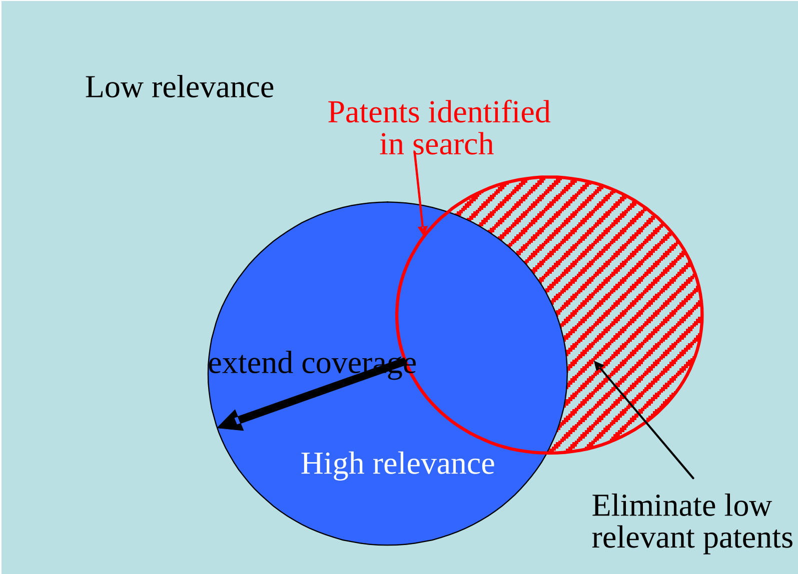


Figure 2.1 *Improving the patent search by improving coverage and relevance*

Coverage

By looking for patents using a different approach, for example by searching on a company name (e.g. technology providers) or by searching other sources (incl. internet searchers) we will identify patents which are relevant but which were not found in the search. New keywords will be generated to refine the search strategy to include the patents which where found.
This will result in an overview (database) of patent numbers, titles and abstracts per technology.

Increasing relevance

A lot of effort is required to eliminate non-relevant patents. Instead of adding keywords to find more patents, specific keywords are used to exclude patents with low relevance. The most important reasons for eliminating patents are:

- The **application** is not relevant for the process industry (refining, chemical industry, food).
- The patent focuses only on developing an **enabling technology** (catalyst development, membranes, etc.);
- The patent describes **processes and products** which are not of interest for the process industry (for example general technologies to improve coatings).

The deliverables of the patent search are:

⇨ List of PI technologies + short description (Word document);
⇨ List of developers (experts) and technology providers;
⇨ List of key words which IS used in the literature and patent database;
⇨ A “database” (in Excel) of patents and relevant patents abstracts per technology (typically 20-50 abstracts per technology, number of patent titles will vary per technology);
⇨ A selection of (5-10) key patents per technology to be reviewed in more detail by external experts.

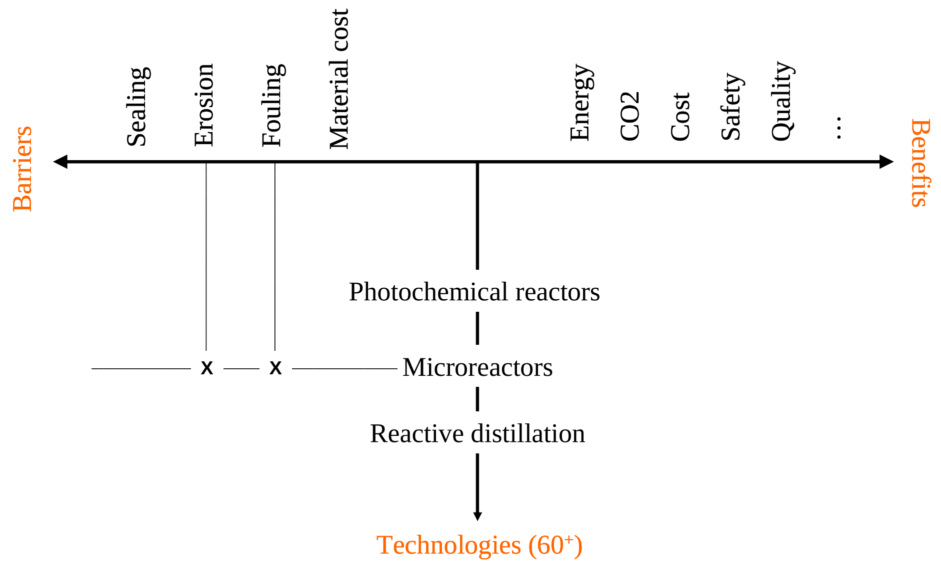


Figure 2.2 *Matrix of benefits and barriers of PI technologies*

2.2.3 Qualitative analysis of the patent abstracts and full patents

The second step is to analyse the patents more qualitatively. The objective ultimately IS to be able to assess barriers and benefits for PI technologies (see Figure 2.2). Therefore the main questions to be answered by the qualitative analysis are:

- Do the **benefits** claimed and by the patents correspond to the benefits which are relevant TO the roadmap (with an emphasis on energy savings, reduction of CO_2 emissions and cost? Are these claims quantified?
- Which technical and economical **barriers** are addressed by the patents?

Other questions of interest are:

- **Who** is working on a specific technology?
- **Applications** which are identified.

The list of abstracts and full text patents will reviewed by the action group. The information will be used to compile:

⇨ A short summary of the relevant issues per technology: stakeholders, benefits identified and quantified, barriers addressed, applications considered (½A4).
⇨ A list of stakeholders, applications, barriers and benefits found in the patent analysis. These will be stored in the Excel working document "**technology_data.xls**".

2.3 Literature analysis

2.3.1 Objective

The objectives of the literature analysis are:

- **Information availability**: Evaluate how much information is available in the public domain for each PI technology. Identify most promising sources of information (i.e. are there good review articles/monographs available?). Particular attention will be devoted to information found on the internet.
- **Abstract "database"**: Create a database of literature abstracts for each of the PI technologies, which can be used as source of technical information for the technology reports.

- **Key publications**: Assess which are the key publications per technology (10-20) containing information on issues and applications.

The information collected in the literature analysis will be used in writing the technology reports and fill the benefit-barrier matrix (Figure 2.2).

2.3.2 Refining the literature searches

Literature searches are carried out in different scientific databases, initially using the same keywords as the patents search. Although a different search strategy will be used, the same process of refining by increasingly adding keywords and adding exclusion to eliminate less relevant literature will be used. Again this is a labour-intensive process of working through a large number of titles and abstracts to classify and eliminate.

Deliverables are:

- ⇨ Excel document which gives an overview of how much and which type of information is available for each of the technologies
- ⇨ Database (e.g. Excel or Reference Manager) with titles and with literature abstracts (typically 50-100 abstracts) searchable per technology
- ⇨ Excel database (or other software) (>1000) searchable on technology
- ⇨ Key publications (10-20) for all 60+ PI technologies

2.3.3 Analysis of the literature

As in the patents search, the focus is on identifying the elements of the “PI-matrix” in Figure 2.2 (benefits and barriers) and more specific on the elements in the draft technology report. The actual summarizing of the information which is found in literature will be done in the following activity (“Draft technology reports”). However, in within this task different lists are compiled which can be used later on in the process.

The most important “literature analysis” deliverables is:

- ⇨ An update of the working document Excel file “**technology_data.xls**” with (for each technology) references found to applications, stakeholders, barriers, benefits.

2.4 Expert questionnaire

A questionnaire has been sent to PI experts who are renowned in their field. The main purpose is to identify existing commercial applications and technology providers. The list of experts which were identified is shown in 0

The deliverables for this task will be:

- ⇨ A list of experts who have been contacted
- ⇨ A set of returned/filled expert questionnaires for further analysis.
- ⇨ An update of the working document “**technology_data.xls**”

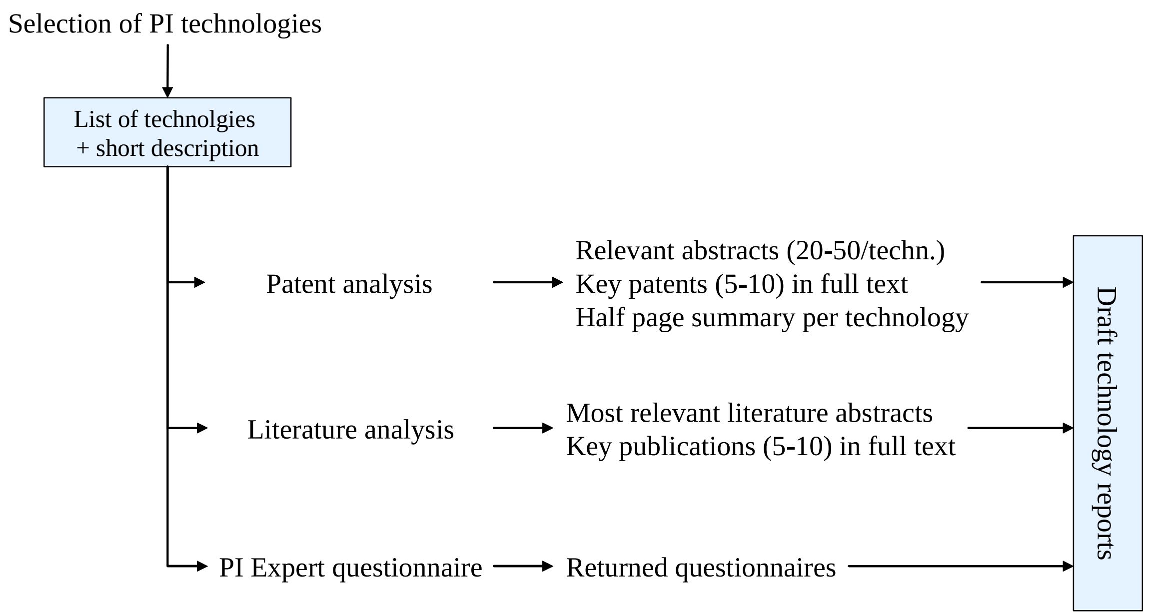


Figure 2.3: *Input for the draft technology reports*

2.5 Technology Reports

2.5.1 Writing the Technology Reports

The information collected in the previous activities is mainly used to draft the 60 technology reports. The table of contents of the draft reports is as shown earlier in in figure 1..

For each technology and for each of the 5 paragraphs ((1) Technology, (2) Applications, (3) Development and issues, (4) Information sources and (5) Stakeholders) a separate word-document will be made which contains on the first pages the summary (i.e. the text for the draft technology report). Background information will be collected in next pages of the same word document.

- ⇨ A series 60+ of draft technology reports
- ⇨ An update of the working document Excel file “technology_data.xls” with information on applications, stakeholders, barriers, benefits.

2.5.2 Organizing comments

To ensure the quality of the draft reports while minimizing the effort required producing them, a panel of experts from industry will be asked to comment on the draft Technology Reports. This panel will rank the technologies as to their importance/potential and will write a comprehensive overview, the “Facts and Figures on PI” document.

3. Other issues

3.1 Status

The focus of the Facts & Figures has been on defining the process. However, the data collection in Facts and Figures started in the first half of 2007 on the three issues:

- Patent analysis: The first search was carried out, which gave a total of 2500 possibly relevant patents for all technology. The first round of working through the titles to eliminate non-relevant patents and categorise the remaining patents will be finished shortly. A refined patent search and preliminary analysis of the data will take place before the end of the second quarter of 2007.
- Literature analysis: The search for key publications and overview articles has started recently. The data structures for storing the information have been prepared.
- Reply forms: Most work has been done on the questionnaires. The reply form was sent to more than 50 experts directly and DECHEMA agreed to contact another 10 German experts. Reply forms for approximately 30 were returned so far. After analysis of the reply's additional questionnaires will be sent out.

3.2 Access to data

Another complicated issue is the access to the data and reports to be given to different parties. Giving full access to a wide group of stakeholders will increase the impact of our work. Increasing exposure may also encourage technology providers and experts to supply information. However, a careful balance needs to be found with the interest of those investing in the PI project: Dutch companies and institutes investing money and time, the Dutch government, experts supplying valuable information.
Therefore for access to the data the following arrangement is proposed:

- TU Delft and ECN will manage and have mutual access to a data structure that will contain all rough data: literature and patent PDF files, literature searches, reply forms, abstracts, etc.
- Those who will write a technology report will be given access to all data on that specific technology.
- The technology reports will be made available to all participants in the Dutch Roadmap and will remain confidential for 2 years after the roadmap terminates.
- A 10-page document will be made that summarizes the findings of the review reports. This will be available for unlimited distribution.
- The technology reports will be available to PI experts who have contributed by providing information and reviewing technology reports.

Appendix A: Sample of Technology description, intro of Technology report

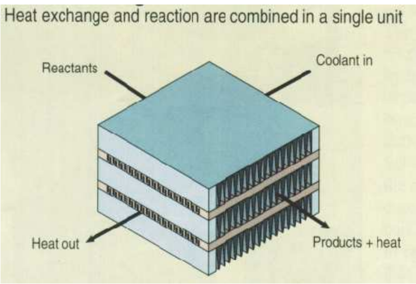
CODE.: 1.2.3
TECHNOLOGY: Heat Exchangers (HEX) reactors, including milli-channel reactors

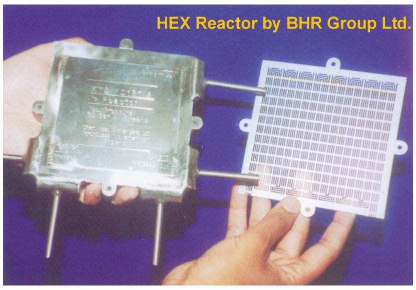
SUBCODE:

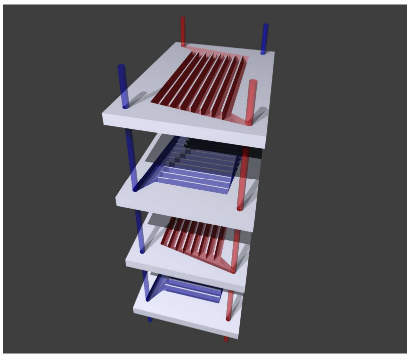
SUB-TECHNOLOGY:

DESCRIPTION/BASIC FEATURES:
Heat exchanger (HEX) reactors and millireactors have usually structure similar to plate heat exchangers. In those reactors porous catalyst plates and/or profile plates are stacked in a sandwich-like structure. Co current, counter current and crossflow cooling is possible. Another form of HEX reactor is the so-called Helix reactor, developed at TNO institute and shown in Fig B

ILLUSTRATION:







(A) Crosswise stacked HEX millireactor

(B) Helix reactor developed at TNO

TYPICAL PARAMETER VALUES/LIMITS:

Heat transfer areas:	typically 0.1 - 2200 m^2
Heat transfer coefficients:	typically 3500 - 7500 W/m^2K
Operating pressures:	typically up to 25 bar

ADDITIONAL REMARKS:

Appendix B List of identified PI-technologies (further extension possible)

Class		Code	Name of technology
Structured devices	Non-reactive	1.1.1	Advanced heat exchangers (hex)
		1.1.2	Micro channel heat exchangers
		1.1.3	Structured internals for mass transfer operations
		1.1.4	Static mixers
		1.1.5	Micro mixers
	Reactive	1.2.1	Foam reactors
		1.2.2	Micro reactors
		1.2.3	Milli-channel reactors
		1.2.4	Millisecond reactors
		1.2.5	Monolith reactors
		1.2.6	Static mixers-reactors
		1.2.7	Membrane reactors (catalytic)
Hybrid	Non-reactive	2.1.1	Adsorptive distillation
		2.1.2	Extractive crystallization
		2.1.3	Extractive distillation
		2.1.4	Heat-integrated distillation
		2.1.5	Membrane absorption/stripping
		2.1.6	Membrane adsorption
		2.1.7	Membrane crystallization
		2.1.8	Membrane distillation
		2.1.9	Membrane extraction
		2.1.10	Static mixers-heat exchangers
	Reactive	2.2.1	Heat exchange reactor
		2.2.2	Membrane reactor (RSP)
		2.2.3	Reactive absorption
		2.2.4	Reactive adsorption
		2.2.5	Reactive comminution
		2.2.6	Reactive crystallization
		2.2.7	Reactive distillation
		2.2.8	Reactive extraction
		2.2.9	Reactive extrusion
Energy transfer	Rotating	3.1.1	Centrifugal adsorption technology
		3.1.2	Centrifugal extractors
		3.1.3	Rotating Packed Beds
		3.1.4	Rotor-stator mixers

		3.1.5	Spinning Disc Reactors (SDRs)
		3.1.6	Viscous heating
		3.1.7	Rotating foam reactor
	Impulse	3.2.1	Ejector (Venturi) -based reactors
		3.2.2	Hydrodynamic cavitation reactors
		3.2.3	Impinging streams reactor
		3.2.4	Pulsed compression reactor
		3.2.5	Sonochemical reactors
		3.2.6	Ultrasound-enhanced crystallization
		3.2.7	Ultrasound-enhanced phase dispersion / mass transfer
		3.2.8	Supersonic Gas-Liquid Reactors
	Electromagnetic	3.3.1	Electric field-enhanced extraction
		3.3.2	Electrochemical reactors
		3.3.3	Microwave drying
		3.3.4	Microwave extraction
		3.3.5	Microwave reactors
		3.3.6	Photochemical reactors
		3.3.7	Plasma reactors
Dynamic	Dynamic	4.1.1	Continuous Oscillatory Baffled Reactors
		4.1.2	Reverse flow reactors
		4.1.3	Chemical looping
		4.1.4	Non-steady operation of gas/liquid beds
		4.1.5	Pulsed chromatographic reactor
Other	Supercritical	5.1.1	Supercritical reactor
		5.1.2	Supercritical separation

Appendix C: List of experts for Questionnaire (continuously updated and extended)

B. Kraushaar-Czarnetzki	U Karlsruhe	1.1.1	Foam reactors
J. Schouten	TU Eindhoven	1.1.1	Foam reactors
M. Dierselhuis	Syntics	1.1.2	Micro-channel reactors
V. Hessel	IMM	1.1.2	Micro-channel reactors
W. Ehrfeld	Ehrefeld Mikrotechnik	1.1.2	Micro-channel reactors
J. Schouten	TU Eindhoven	1.1.2	Micro-channel reactors
J. Lerou	Velocys	1.1.2	Micro-channel reactors
A. Renken	EPFL, Lausanne	1.1.4	Millisecond reactors
H. Stitt	Johnson Matthey	1.1.4	Millisecond reactors
L. Schmidt	U. Minnesota	1.1.4	Millisecond reactors
Ph. Caze	Corning	1.1.5	Monolith reactors
J. Moulijn	TU Delft	1.1.5	Monolith reactors
-	Sulzer	1.1.6	Static mixers-reactors
T.Tsotis	U. Southern Cal	1.1.7	Membrane reactors (catalytic)
B. Thonon	Greth CEA	1.2.1	Advanced heat exchangers (hex)
J Harmsen	Shell	1.2.1	Advanced heat exchangers (hex)
B. Thonon	Greth CEA	1.2.2	Micro channel heat exchangers
	Sulzer	1.2.3	Structured internals for mass transfer operations
	Koch-Glitch	1.2.3	Structured internals for mass transfer operations
A. Gorak	U Dortmund	1.2.3	Structured internals for mass transfer operations
-	Sulzer	1.2.4	Static mixers
-	Chemineer	1.2.4	Static mixers
A. Green	BHR	1.2.4	Static mixers
K. T. Yu	Tianjing U	2.1.1	Adsorptive distillation
S. Al-Asheh	U Quatar	2.1.1	Adsorptive distillation
K-M. Ng	Hong-Kong UST	2.1.2	Extractive crystallization
P. Jansens	TU Delft	2.1.2	Extractive crystallization
J. Gentry	GTC Technology	2.1.3	Extractive distillation
Z. Olujic	TU Delft	2.1.4	Heat-integrated distillation
J.Huggill	ECN	2.1.4	Heat-integrated distillation
O. Falk-Pedersen	Kvaerner	2.1.5	Membrane absorption/stripping
B. Jansen	TNO	2.1.5	Membrane absorption/stripping
O. Falk-Pedersen	Kvaerner	2.1.5	Membrane absorption/stripping
O. A. Reif	Sartorius	2.1.6	Membrane adsorption
R. Freitag	U Bayreuth	2.1.6	Membrane adsorption

A. Strancar	BIA Separations	2.1.6	Membrane adsorption
A. Lajmi	Pall	2.1.6	Membrane adsorption
E. Drioli	U Calabria	2.1.7	Membrane crystallization
B. Jansen	TNO	2.1.7	Membrane crystallization
V. van Hoof	VITO	2.1.8	Membrane distillation
E. Drioli	U Calabria	2.1.8	Membrane distillation
F. Banat	Jordan UST	2.1.8	Membrane distillation
B. Jansen	TNO	2.1.8	Membrane distillation
Z. Olujic	TU Delft	2.1.8	Membrane distillation
M. Gryta	TU Szcecin	2.1.8	Membrane distillation
B. Jansen	TNO	2.1.9	Membrane extraction ()
D. Agar	Univ. Dortmund	2.2.1	Heat exchange reactor
T. Noren	Alfa Laval	2.2.1	Heat exchange reactor
A. Green	BHR	2.2.1	Heat exchange reactor
E. Drioli	U Calabria	2.2.2	Membrane reactor (RSP)
F. Kapteijn	TU Delft	2.2.2	Membrane reactor (RSP)
T. Tsotsis	U Southern California	2.2.2	Membrane reactor (RSP)
A. Gorak	U Dortmund	2.2.3	Reactive absorption
M. Morbidelli	ETHZ	2.2.4	Reactive adsorption
U. Hoffmann	U Clausthal	2.2.5	Reactive comminution
K-M. Ng	Hong-Kong UST	2.2.6	Reactive crystallization
J. Harmsen	Shell	2.2.7	Reactive distillation
H.-J. Bart	U Kaiserslautern	2.2.8	Reactive extraction
C. Hagberg	NFM/Welding Engineers	2.2.9	Reactive extrusion
L. van der Wielen	TU Delft	3.1.1	Centrifugal adsorption technology
Mitch M. St. George	CINC Processing Equipment		Centrifugal extractors
J.F. Chen	U Bejing	3.1.3	Rotating Packed Beds
D. Trent	Dow Chemical	3.1.3	Rotating Packed Beds
-	Charles Ross & Son	3.1.4	Rotor-stator mixers
	Silverson Machines	3.1.4	Rotor-stator mixers
J. Banning	Jaygo, US	3.1.4	Rotor-stator mixers
C. Ramshaw	Protensive	3.1.5	Spinning Disc Reactors (SDRs)
K. Boodhoo	U Newcastle	3.1.5	Spinning Disc Reactors (SDRs)
R. Jachuck	U Clarkson	3.1.5	Spinning Disc Reactors (SDRs)
J. Schouten	TU Eindhoven	3.1.7	Rotating foam reactor
-	Davy Technology	3.2.1	Ejector (Venturi) -based reactors
P. Kerkhof	TUE	3.2.1	Ejector (Venturi) -based reactors
A. Green	BHR	3.2.1	Ejector (Venturi) -based reactors
A. B. Pandit	U Mumbai	3.2.2	Hydrodynamic cavitation reactors
A. Vogelpohl	U Clausthal	3.2.3	Impinging streams reactor
E. Gaddis	U Clausthal	3.2.3	Impinging streams reactor
M. Sohrabi	Amirkabir UT	3.2.3	Impinging streams reactor
U. Neis	U Hamburg-Harburg	3.2.5	Sonochemical reactors

A. B. Pandit	U Mumbai	3.2.5	Sonochemical reactors
T. J. Mason	U Coventry	3.2.5	Sonochemical reactors
M. Knowlton	Ultrasonic Energy Systems	3.2.5	Sonochemical reactors
H.-J. Bart	U Kaiserslautern	3.2.6	Ultrasound-enhanced crystallization
P. Jansens	TU Delft	3.2.6	Ultrasound-enhanced crystallization
U. Neis	U Hamburg-Harburg	3.2.7	Ultrasound-enhanced phase dispersion / mass transfer
A. B. Pandit	U Mumbai	3.2.7	Ultrasound-enhanced phase dispersion / mass transfer
T. J. Mason	U Coventry	3.2.7	Ultrasound-enhanced phase dispersion / mass transfer
M. Knowlton	Ultrasonic Energy Systems	3.2.7	Ultrasound-enhanced phase dispersion / mass transfer
X.-W. Ni	NiTech Solutions	3.2.8	Supersonic Gas-Liquid Reactors
J. E. Anderson	Praxair	3.2.8	Supersonic Gas-Liquid Reactors
D. McLean	AMT	3.3.3	Microwave drying
E. Esveld	Wageningen UR	3.3.3	Microwave drying
M. Collins_Jr	CEM Corp	3.3.3	Microwave drying
-	Milestone	3.3.4	Microwave extraction
D. McLean	AMT	3.3.4	Microwave extraction
U. S. Schubert	TUE	3.3.5	Microwave reactors
D. Bogdal	Cracow UT	3.3.5	Microwave reactors
P. Penczek	IchP	3.3.5	Microwave reactors
M. Collins_Jr	CEM Corp	3.3.5	Microwave reactors
B. Ondruschka	U Jena	3.3.5	Microwave reactors
C. O. Kappe	U Graz	3.3.5	Microwave reactors
H. de Lasa	U Ontario	3.3.6	Photochemical reactors
G. Mul	TU Delft	3.3.6	Photochemical reactors
A. Ray (U Singapore, SG)		3.3.6	Photochemical reactors
A. Scranton	U Iowa	3.3.6	Photochemical reactors
A.T-Raissi	Florida Solar Energy Center	3.3.6	Photochemical reactors
A. Czernichowski	U Orleans	3.3.7	Plasma reactors
G. Eigenberger	U Stuttgart	4.1.2	Reverse flow reactors
J. Matros	Matros Technologies	4.1.2	Reverse flow reactors
G. Witkamp	TU Delft	5.1.1	Supercritical reactor
A. de Haan	TU Eindhoven	5.1.2	Supercritical separation
G. Witkamp	TU Delft	5.1.2	Supercritical separation

ANNEX 2: PI Quick Scans

PROCESS INTENSIFICATION QUICK SCANS

The PI Quick Scans are a low-cost, efficient method to provide the company with a quick insight into arising opportunities for achieving substantial efficiency improvements in its production facility by the implementation of the innovative PI-technologies. DSM has granted the Action Group the right to carry out free of charge the PI-Quick Scans for the purpose of the Roadmap using its “BLUEPRINT” methodology. Several scans with the above methodology have been performed in 2005 and 2006 and were highly appraised by the companies involved.

Benefits
By carrying out PI Quick Scans awareness is created and information is provided to the companies regarding the short- and long-term possibilities for improving their processes with intensified solutions. On the other hand, PI Quick Scans provide the Action Group PI with information concerning the needs of the Dutch companies for specific PI technologies. Such information is of primary importance for the PI roadmap.

How it works?
In the PI Quick Scans identification and evaluation of the PI-opportunities in the given process takes place based on the information provided by the customer. The scans are performed by Dutch top experts in the field of Process Intensification (PI) assigned by the Action Group PI, using the “BLUEPRINT” methodology developed at DSM and operating under the License Agreement with DSM. The process flow sheets are discussed with the customer by two experts: a general PI-specialist and an expert specializing in the type of processes under consideration (polymerizations, food, etc.). Subsequently, the information received from the customer is analyzed by the PI-experts and the process is assessed on potency for PI-improvements on the short/medium and long term.

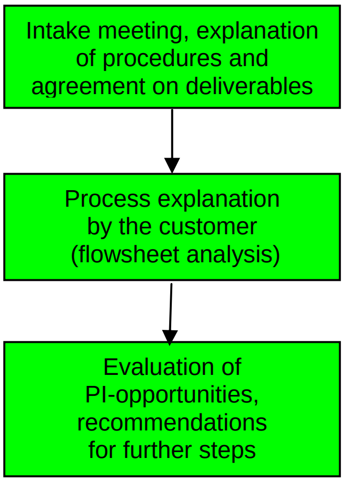
Deliverables
Deliverable from the PI-Quick Scan is a short Management Summary including the score and its justification, as well as recommendations for further phases (directions of further R&D activities, contacts to technology providers, etc.). Often, the PI-Quick Scans lead to general process engineering spin-offs and opportunities. Those opportunities are then also described in the Management Summary.

Price
The price of a PI-Quick Scan ranges from 4000 euro for processes of low/average complexity, to 6000 euro for processes of high complexity. This covers 3-4 person-days, including a ½ day session with 2 PI-experts at the customer. The company may claim the reimbursement of a significant part of that cost (2800 and 4200 euro, respectively) from the MJA program of SenterNovem.

Confidentiality
To protect specific proprietary Know-how of the client all PI-Quick Scans are carried out under the Secrecy Agreements signed by our PI-experts with the customer.

Capacity and availability

The recruitment of the companies and the administration of the PI Quick Scans are in the responsibility of SenterNovem, who does it in consultation with VNCI. An information flyer on PI Quick Scans has been prepared and is distributed via both organizations. The first few scans are in progress by mid may 2007. Expectation is that circa 30 companies/plants will be scanned in 2007. Four general PI-experts are currently available in the Quick Scans team. Recruitment is on its way of the specialized experts, particularly in the food processing.



Three-step scheme of the PI Quick Scan

Deployment

The Action Group PI will bring the Quick Scan option to the attention of the industry. Also the VNCI has formulated as an objective to promote the Quick Scan with its members with the purpose of realising 30 to 40 scans before the end of 2008.

ANNEX 3: Template for the PI Roadmap.

(To be published in January 2008)

Executive Summary

The Executive Summary will contain the following three blocs:

1. Short description of the PI Roadmap, its context, where does it come from, where are we now, what is the further planning. The same template is to be used for sector roadmaps in November 2007.

2. Main conclusions of the PI Roadmap explaining the probable development of the (sectors of) the Dutch process industry under different economic scenario's, their priorities/needs/opportunities, the present state of development of 60 PI technologies and their potential for addressing the priorities/needs/opportunities in the industry and, last but not least, a survey of projects already being undertaken to realise implementation of promising PI technologies. Suggestions for future action are mentioned.

3. Acknowledgements, people, companies, (public) organisations.

Chapter 1) Development of the Dutch process industry until 2050, its priorities/needs/
opportunities.

- Present significance of the Dutch process industry (volume, added value, export surplus, employment, spin off to other sectors, consumption of energy, CO2 emission etc). Split up of key figures over the four main sectors (Large volume chemicals, Specialty chemicals and pharma, Consumer products, Ingredients from Agro products).
- Possible developments under different scenario's. How will this industry develop between now and 2050 under different economic scenario's. Variables for such scenarios can be the cost of energy, worldwide economic growth and developments in climate triggering legal frameworks. Consequences of such scenarios will be different for the respective sectors and should therefore be assessed per sector by four Sector Teams to be subsequently consolidated by the AGPI.

Note 1: These future projections serve to judge the priorities/needs/opportunities of the industry under different probable scenario's and then judge the options to use PI. This is a well known approach allowing more robust predictions. It is not the main purpose however of this PI project to make economic scenario's. We must restrict ourselves to some main variables. Good candidates are the energy price (what happens if oil goes to 100 $ / barrel) and legal restrictions (what happens if CO_2 emissions will be heavily taxed).

Note 2: The Sector Teams need to use the same general background variables to develop their sector projections. Remember we need to consolidate the sectors into one picture for the industry! This implies we (the AGPI) need to define the general scenarios before the summer holidays!

The Sector Teams will subsequently work out sector scenarios to assess the most important priorities/needs/opportunities (NPOs) for each sector.
These NPOs will later (see chapter 3) serve to define the role PI can play to address the needs of the industry.
The AGPI will consolidate the four sectors into a total picture for the Dutch process industry. The AGPI may decide to add cross sector considerations or add possible consequences of emerging “green” raw materials, biomass energy etc.

Chapter 2) Fact an Figures on PI, what can it do (not do) for us.

This chapter is the Facts and Figures document written by the panel. It will be organised by the AGPI with the help of numerous experts worldwide. Essentially this chapter will be based on the 60 Review reports for the selected PI technologies. The chapter explains what can be done (given the technical and economic merits) with a given PI Technology and explains how far these technologies have already matured into industrial application. The chapter also explains what needs to be done in terms of further development to enable actual use of promising technologies. Wherever possible, examples of actual use or potential use will be given to facilitate scouting for further use.

The document Facts and Figures must be written in such manner that it is/remains well accessible for experts in the field trying to find solutions for their companies needs. Thus the Roadmap will allow for further progress even after the present PI project will be finished mid 2008.

Chapter 3) Selected PI opportunities, industrial actions, forward projections.

This chapter reports the opportunities for PI projects so far adopted by or in discussion with the Dutch industry and makes a forward projection of the possible long-term impact based on the data available in December 2007. The potential projects are developed as follows.

Based on the PNOs as defined in chapter 1 on the one hand and based on the potential of promising PI opportunities as defined in chapter 2 on the other hand the Sector Teams will scout for opportunities. A suggested procedure is to make preliminary selections (long lists) and screen such selections together with potential users in the industry. The initial selection (long list) is therefore presented to the potential users explaining the potential of the selected PI technology for their processes. The potential users then have to decide if further action is justified and, if so, gradually take the action in their own hands. It will be useful in some cases to bring together interested potential users (brokering) around common interests. Such a brokering activity can lead to cooperation in application or development projects. This may also happen cross sector!
In certain cases it will be useful to contact equipment suppliers or technology providers for further developments towards implementation.

The interaction process will certainly also have international dimensions. Dutch companies will not always be able (or willing) to follow up promising leads on their own or find suitable Dutch partners.

This process of listing opportunities and subsequently screening them with the industry will best be organised as follows:

1) The Sector Teams make a long list of PI technologies holding promise for their sector, indicating possible applications.
2) The Sector Teams organise interaction with potential users in their sector and promote an active further role of the industrial partners if enough promise is judged to be present.
3) The AGPI closely monitors the activity of the four Sector Teams to locate and act on cross sector opportunities and international opportunities.
4) The Sector Teams write a report presenting the PI technologies first selected (long list) and describing the actions being taken in cooperation with the industry. A prediction/estimate will be added of the possible long-term effects (if possible until 2050) for the sector if PI technologies are diligently introduced. This report is submitted to the AGPI on December 1, 2007.
5) The AGPI writes a consolidated report explaining the PI opportunities, the actions already underway and actions it feels should still be taken and estimates of the impact for the total Dutch process industry in terms of energy savings, reductions of CO_2 emissions, cost savings, order of investment figures and other relevant effects.

4) Recommendation for further action.

Writing the PI Roadmap, however important, is not a purpose in itself. Main objective of this PI project is to accelerate the industrial introduction of PI. It is therefore important to complement the Roadmap with a chapter suggesting actions to be taken in 2008 and onwards to further realise such introduction.
The actions will come forward during the work on the project and may also be suggested by the stakeholders.
The AGPI will write this chapter 4, based on the contributions from the sector teams.

ANNEX 4: Draft Assignment letter for the Sector Teams Process Intensification (PI)

(NB: Without annexes)

Dear Sirs,

The Action Group PI welcomes you and your Sector Team to the PI project. The activities of your Sector Team are being organised as an essential part of the PI project. The PI project aims to accelerate profitable introduction of PI into the Dutch process industry. The action plan designed to do this is being carried out by the Action Group PI (AGPI) as a part of the Dutch Energy Transition Initiative. The AGPI reports to the Taskforce Energy Transition through the Chain Efficiency Platform.

In this document the AGPI explains what we hope and expect your Sector Team will achieve in the coming months. We describe the deliverables. And we do suggestions for the working methods. This document is kept quite short and condensed. Further information is contained in enclosures. Annex 1 is a draft of the first Interim-report to by delivered per June 1 by the AGPI to the Chain Efficiency Platform. It should give you a fair general impression of the total PI project. As you will see, the activities of your Sector Team are an essential building block of the total project.

To enable a focused approach we have chosen to divide the Dutch process industry into four clusters of sectors and to set up four Sector Teams, each addressing one cluster of sectors with a more or less homogeneous set of industries. The split up is made as follows:

- The Sector “Large volume chemicals” : Oil refinery, petrochemicals, bulk chemicals, polymers.
- The Sector “Specialty chemicals and pharma” : Smaller volume chemicals, often more complicated, ingredients for pharma and pharma products.
- The Sector “Consumer products”: Food, feed, personal care, lifestyle.
- The Sector “Ingredients based on Agro feedstock’s” : Sugar, starch, extracted proteins, vegetable oils.

Deliverables for your Sector Team:

Deliverable 1, Define priorities, needs and opportunities (PNO’s)

Define the most important priorities/needs/opportunities (PNO’s) of the Dutch companies in your sector for the period 2007-2050. Please give special emphasis on energy consumption, CO_2 emission and cost reduction. Use your judgement, the data at your disposal and acquire additional data as needed.

Obviously PNOs will depend on general economic developments. Therefore a simple scenario approach will be used with different developments for some important variables. All Sector Teams are asked to use the same background scenario prepared by the AGPI. Thus we will be able to develop a homogeneous vision and to consolidate the results of the four Sector Teams into one vision for the Dutch process industry. Each of the scenario's may lead to different main priorities (often referred to as "High level drivers") and to different PNO's. Please define these PNOs as specific as you can. This will be helpful to find PI technologies for addressing such PNOs.

Deliverable 2, Find opportunities to use PI technologies to address the PNO's of your sector and initiate implementation by the industry

Another important building block of this PI project is to create a comprehensive overview of the present position in Science and Technology for PI technologies (see also annex 1). This overview will be organised by the AGPI and will be made available to your Sector Team in September 2007. You need to study it and combine its insights with the insights into PNOs as created by your Sector Team in order to find solutions to PNOs based on promising PI technologies. We suggest that you make "long-lists" of such ideas and then screen them in close cooperation with companies in your sector that are potential users/beneficiaries. In certain cases screening may be done using the Quick Scan instrument developed in the context of this project (see annex 1).
If certain ideas, after screening, are judged to hold sufficient promise your Sector Team is asked to find a company or a consortium of companies willing to adopt the idea and develop/implement it further.

Deliverable 3, Write a Sector Roadmap.

Combine the findings under 1 and 2 in one single document, called Sector Roadmap. This Roadmap summarises the PNOs under the chosen scenario's and their possible solutions. Give your best judgment about what PI can do for your sector between now and 2050 if diligently developed and introduced in industrial practice. Here again emphasis should be laid on energy consumption, CO_2 emission and cost reduction. Give numbers or brackets if you can. If you feel certain actions should be considered/taken please include such suggestions. The Sector Roadmap must be ready on 1 December 2007.
The AGPI will consolidate the four Sector Roadmaps into one PI Roadmap for the Dutch process industry as a whole. Therefore you are asked to use the template given in
Annex 3, the template for the PI Roadmap.

Deliverable 4, Special assignment.

Find/select one possible short term introduction of a PI technology with beneficial effects on energy, CO_2 and cost and take action towards the industry to initiate implementation. Some ideas have already been suggested by the PI group doing the 2006 pre-project. It is fully up to your team however to select.
The purpose of this special assignment is to create fast visible action and to create a learning effect. It also stresses the notion that actual implementation is the final and most important objective of our project.

Suggested working procedure.

1) A core group of 3 or 4 experts from leading companies is selected to form the Sector Team on the basis of consultations between the AGPI and such industries. A chairman is selected by the team itself and a facilitator is assigned to help guiding the actions. The facilitator has recent experience with similar activities (not a professional advisor).

2) The chairman of the Sector Team will become an associated member of the AGPI and makes sure that the actions of the Sector Team are well coordinated with the rest of the
PI project.

3) The Sector Team starts its work in June 2007 and should be ready in December 2007. It designs a detailed action plan with clear deadlines, meeting dates etc. aimed at producing the deliverables on the shortest possible notice but not later than December 2007 (Sector Roadmap is to be submitted on 1 December 2007!!). Please refer also to a simplified network planning for the total PI project given in annex 11. The plan should include a budget (to be approved by the AGPI). For PI Quick Scans a separate budget will be available.

3) The Sector Team recruits additional members or ad hoc help as needed or uses outside help were useful.

Concluding remark.

Introduction of new, useful PI technologies can help achieve an important reduction of energy use, CO_2 emission and support the competitiveness and sustainability of the (Dutch) process industry and is therefore of high economical and social relevance. The members of the Workshop, by accepting their assignment, agree to this and commit to doing their utmost to deliver the results as described above.

ANNEX 5: Industry support

PI Roadmap Dutch Network up to april 2007

Company	**Name**
Akzo Nobel	H. Feenstra
Akzo Nobel	R. de Graaf
Akzo Nobel	R. Hettema
Akzo Nobel	A. van der Meer
Akzo Nobel	K. de Weerd
Arkema Group	P. Kevenaar
AVEBE	M. Giuseppin
Bodec	M. Geboers
Cargill	G. van Bommel
Cargill	W. Bux
Cexagri	J. Alebregtse
Cosun	E. Poiesz
DMV International	A. Verver
DMV International	F. Buikstra
DSM	G. van Binsbergen
DSM	M. Kuczynski
DSM	G. Kwant
DSM	B. Nap
DSM	E. van de Sandt
DSM	V. Schyns
DOW	C. Bosman
DOW	G. van Harten
DOW	H.L. Pelt
DOW	M. Steijns
ECN	P. Alderliesten
ECN	J. Hugill
Hexion	S. Rens-Vanderlee
House of Innovation	F. Smeets
Huntsman	A.J. Gow
Huntsman	J. Koole
Huntsman	R. Scheffer
Huntsman	A.J. Zeeuw
Kvaerner	A. Mahashabde
Kvaerner	R. Venkatesan
Lyondell	J.P. Benders
Lyondell	Chr. Fetter
Lyondell	F.W. Hesselink
Lyondell	T. Olijve
MKB	L. Hermans
NIZO	J. Escher

Company	**Name**
NIZO	P. de Jong
Organon	F . Kaspersen
Organon	A. Sanders
PDC	H. Keuken
Pentri	M. Dierselhuis
PFW	E. Druif
PFW	E. Philipse
PFW	P. Spierings
Process Design Center	F. Dautzenberg
Purac	W.J. Groot
Shell	J. Zomerman
Shell	J. van der Eijk
Shell	A. Grondman
Shell	H. Haan
Shell	J. Harmsen
Shell	W. Hesselink
Sonneborn	H. de Rooij
Suikerunie	D. Vermeulen
Tebodin	C. Blom
TNO	D. Verdoes
TNO	H. Werij
Traxxys	H. Akse
TU Twente, Fac. TNW	H. van den Berg
TU Eindhoven	M. de Croon
TU Eindhoven	J van der Schaaf
TU Delft	G.J. van Luijk
TU Eindhoven, Fac. Scheikunde	J. Schouten
Unilever	A. Krijgsman
Unilever	E. Meijer
Unipol	J. van Straten
Unipol	J. van Zeeland
Uniqema	H. Vreeswijk
WUR	E. Esveld
WUR	F. Giezen
WUR	W. de Heij
WUR	J. Willemsen
Zeton	J. ter Harmsel
Zeton	H. van de Riet
	B.J. van Goor
	G. van Ingen
	B. Meijer
	R. Nijssen
	J. Peters

ANNEX 6: German networking

In Germany various R&D activities in the field of Process Intensification have been taking place already for a number of years. In some of the PI areas Germany has become an undoubted world leader, for example in micro reactor technologies. Strong interest of German companies in Process Intensification has resulted in multi-million programs in the field, such as Projekthaus Prozessintensivierung at Degussa, with 15 mln Euro research budget for 2006-2008.

An important role in the developments in Germany played DECHEMA/GVC/GVT by establishing in 2005 the Fachsektion Prozessintensivierung. In the Steering Board of the Fachsektion major German companies, including BASF, Bayer, Degussa, Merck, Uhde and Siemens, are represented. From the very beginning the Fachsektion had close relations with the Dutch Process Intensification Network and Prof. Stankiewicz, Chairman of PIN-NL, is also member of the Steering Board of the Fachsektion.

DECHEMA has also played a very important role in preparations of the SusChem's European Strategic Research Agenda and in setting a similar SRA in Germany (National SusChem Initiative). Both agendas include Process Intensification as one of the main research topics. Since 2006 the process engineering parts of DECHEMA and VDI have been merged into a single organization called ProcessNET.

Action Group PI maintains continuous contacts with Fachsektion Prozessintensivierung. Dr. Schoenmakers (BASF), member of the Steering Board of the Fachsektion, participates in the working meetings of the AG PI.

On 12 March 2007 the Action Group (Mr. Dopper, Mr. Venderbos and Dr. De Groot) paid a visit to ProcessNET, during which the main lines of further collaboration were discussed and set. The German side agreed to keep close contacts to the Action Group and support these activities by listing German experts for the evaluation of the possible PI technologies. The Roadmap is seen as an important and interesting step forward in Process Intensification. Research collaboration seems possible but question concerning the funding for German participants of the R&D consortia remains open.

After the March meeting ProcessNET performed two actions related to the PI Roadmap:

- A special AG PI letter concerning the roadmap was distributed to German stakeholders;
- Collecting PI Facts & Figures in Germany - a reply from concerning examples of Best Practices via Process Intensification was sent to all ProcessNET relations.

Additionally, Dr. Schoenmakers presented the activities of the Action Group to the members of the German National SusChem Initiative “Umwelt und Ressourcenschonung” (March 13, 2007).
On 5 June, 2007 AG PI (Prof. De Wit, Prof. Stankiewicz) will further inform the Steering Board of the Fachsektion Prozessintensivierung about the developments in the PI Roadmap. Also, a presentation about the Roadmap will take place during the German annual chemical engineering congress (Jahrestagung) in Aachen, in October 2007.

ANNEX 7: European networking

Next to the working relations with the German partners, intensive networking with other European organizations takes place. This is of particular importance for the Facts & Figures activity of the Roadmap and for gaining of a broad support for the European PPP's in the field. Those international contacts cover the European Federation of Chemical Engineering, European Technology Platform on Sustainable Chemistry (SUSCHEM), European Commission and several national organizations.

European Federation of Chemical Engineering
The Working Party on Process Intensification (WP PI) of the European Federation of Chemical Engineering has issued a formal support to the PI Roadmap initiative and presented it both to the European industry and to the European Commission. EFCE WP PI works together with the SUSCHEM platform in preparing the European chemical industry for the collaborative projects in the 7th Framework Program (see further). For the PI Roadmap the developments around the FP7 are of crucial importance, as far as possible acquiring of the European funds for the future Public-Private Partnerships in this area is concerned.
It has been agreed that the PI Roadmap will be made available to all Member Societies of the EFCE.

7th Framework Program
Process Intensification has become one of the important elements of the 7th Framework Program of the European Commission. PI-related topics in FP7 include, among others:

- *Process Intensification in Chemicals Production*
- *Innovative Pathways in Synthesis - Improving efficiency by smart synthesis, design and reduction of the number of reaction steps*
- *Application of alternative forms of energy for process intensification*
- *Process intensification in metals production*
- *Integration of Technologies for Intensified Sustainable Chemical Processes*
- *Industrial Scale Implementation of Process Intensification Strategies*
- *Production Technologies and equipment for Micro-Manufacturing.*

This means a unique opportunity of setting and carrying out collaborative projects in the field of PI in the coming seven years. Anticipating this arising opportunity the EFCE WP PI organized in collaboration with SUSCHEM a European industrial "PI-top". The meeting was held in Delft on 10 November, 2006. Sixteen of the key European companies were present, including Bayer, BASF, Degussa, Merck, Rhodia, DSM, Shell, Unilever, Akzo Nobel, Repsol and Arkema. As the result of the meeting 6 collaborative project proposals have been defined and submitted to the 1st Call of the FP7 program.

National organizations
Further contacts with several national organizations with concerning the PI Roadmap took place. Polish Chamber of Chemical Industry fully supports the road mapping initiative. Process Intensification Network UK and French Chemical Engineering Society will request their members to contribute the information to the Facts & Figures activity of the Roadmap and will support the initiative to form European R&D consortia in the field.

ANNEX 8: Budget and funding

PI roadmap Budget and funding					
	Cost				
Roadmap budget					
patent / literature search	150				
60 review reports	180				
Communication	30				
visits, international contacts	50				
Working groups and Workshops	175				
specialist advice	50				
Chairman action group	90		June 07 - June 08		
Subtotal external cost	*725*				
Related cost					
31 PI quick scans	134		clients and MJA/KEV program		
Action group PI	345		Dec 06 - June 08		
Total project cost	**1204**				
Contributions					
	Euro	**in kind**			
Total contributions	**759**	**445**			
Deficit	*35*				
Industry acknowledged	190	50			
Industry pending	*100*	50			
EZ innovation PI, pending	*300*				
scan clients	34				
EZ: MJA/KEV	100				
PKE (EZ), ECN, TUD		345			

ANNEX 9: **Roadmap PI in lectures/presentations held and planned for 2007:**

- DECHEMA/VDI (ProcessNET) Jahrestagung, Aachen, 18 October 2007.
- Petrochem Business Linqs, Wassenaar, 7 June 2007.
- Janssen Pharmaceutica (Beerse, Belgium), 24 May 2007
- Akzo Nobel R&D Conference, Groningen, 10 May 2007.
- 1st Int. Conf. Green Process Engineering, Toulouse, 24-26 April 2007.
- VNCI Policy Group Energy, Leidschendam, 12 January 2007
- AIChE Benelux Lecture Dinner Meeting, The Hague, 11 January, 2007.
- Ad hoc group on "Innovation and technology perspectives in energy intensive industries in Europe", EC, Brussels, 8 December 2006
- 4e lecture / debate evening STW en KINI NIRIA, Utrecht, 7 December 2006 (together with prof. J. Schouten)
- European Innovation Workshop, European Parliament, Brussels, 4-5 October 2006 (statement on behalf of the European Federation of Chemical Engineering).

PI-related interviews and press articles:

- "Process Innovation crucial for European chemistry", Petrochem, January 2007.

ANNEX 10: Main conclusions of the pre-project 2006

The following pages are a selection from the final report of the above project. No changes have been made. The project was carried out by a number of experts from industry and technology providers (see page 41) with the help of ADL. The pre-project was sponsored by the Platform Chain Efficiency.

The conclusions basically state that substantial potential exists to save energy in the Dutch processing industry with corresponding savings in CO2 emissions and cost. In 2050 energy consumption could be 20% reduced by diligent introduction of PI. The group concluded that such a perspective warranted further action and a PI project should be set up.

The Platform Chain Efficiency supported this conclusion and took the initiative to set up the present PI project.

Process Intensification (PI) is a set of radically innovative principles ("paradigm shift") in process design, which can bring significant benefits in terms of process and chain efficiency, capital and operating expenses, wastes, process safety, etc.

Based on such advantages, PI has the potential to bring enormous savings in energy use (25-45 PJ in 2030) and in the competitiveness of all process industry sectors (petro/base chemicals, fine chemicals /pharma, food processing, etc.).

Over the last few years, PI has already been applied in a modest way by individual users, but concrete steps towards broad adoption of PI are now needed in order to reach the large energy savings urgently required for a successful energy transition.

Over the short term stakeholders are not willing to collaborate due to confidentiality issues, but they are very interested to collaborate on pre-competitive research aimed at a real step change over the long term.

Examples* of Process-intensive equipment and methods are given in the table below

Process Intensification

Equipment		Methods			
Operations involving reactions	Operations without reactions	Multifunctional Reactors	Hybrid Separations	Alternative Energy Sources	Other Methods
■ Spinning Disk Reactor ■ Static Mixer Reactor (SMR) ■ Monolithic Reactor ■ Micro-reactor ■ Supersonic Reactor ■ Jet-Impingement Reactor	■ Static Mixer ■ Compact Heat Exchanger ■ Micro-channel Heat Exchanger ■ Rotor/Stator Mixer ■ Rotating Packed Bed ■ Centrifugal Adsorber	■ Heat Exchange (HEX) Reactor ■ Reverse-Flow Reactor ■ Reactive Distillation/ Absorption/ Adsorption/ Extraction/ Crystallization/ Extrusion ■ Membrane Reactor ■ Fuel Cell	■ Adsorptive Distillation ■ Extractive Distillation ■ Membrane Distillation/ Adsorption/ Absorption/ Crystallization ■ Extractive Crystallization ■ Solvent Sublation	■ High Gravity Fields ■ Ultrasound ■ Solar ■ Microwaves ■ Electric Field ■ Gliding Electric Discharges	■ Supercritical Fluid Processing ■ Dynamic (periodic) operation ■ Process Synthesis ■ Cryogenic Processing ■ …

Source: 'Serving the triple bottom line, process intensification role in sustainable manufacturing', A. Stankiewicz, 2005

The potential impact of PI for industry competitiveness is very significant

- **Improvement of major cost factors:**
  - Reduced energy use (for chemicals: energy ~ 20 % of current variable costs*)
  - Reduced capital investments
- **Enhanced adaptability to changing business environment:**
  - Increased flexibility to use different feedstocks
  - Reduced consumption of dwindling oil feedstock
  - Reduced requirements for site location
- **PI investments can have rapid pay-back (e.g. < 2 yrs) based on energy savings only**
- **LT competitiveness through enhanced process knowledge*:**
  - Ability to get more output from the same capital investment
- **Large new markets for equipment and service vendors**

* Source: Arthur D. Little study on competitiveness of the European chemical industry, 2005

PI can have a significant impact of the efficiency of industrial product chains

- PI can enable the efficient use of alternative feedstocks, e.g. valorization of materials previously considered as “waste”
- PI can lead to a reduced need for feedstock and related processing energy (e.g. less oil used to produce heat, and more to produce useful chemicals), thereby relieving the pressure on upstream supplies
- PI can enable “distributed processing” (in small units located at the place where processing creates the maximum benefit, e.g. where the feedstock/raw material is produced), thereby changing the structure of the whole chain and reducing the need for transportation
- Improved process control thanks to PI can enable to supply downstream users with products of a higher quality
- PI solutions can be transferred from one industry sector to another, e.g. from chemical to food processing industry (or reversely)

Concluding statement

“ I have been a **strong believer of Process Intensification** for many years, starting when I was Chief Technology Officer at DSM, because of the **enormous benefits** it can bring both to industry competitiveness, and to our planet earth by drastically reducing energy consumption and CO2 emissions.

I am very happy to see the renewed interest emerging in the Netherlands and in neighboring European countries to move PI from the stage of promises to tangible results.

I fully support the idea of assembling a North European group of leading industry and research stakeholders to draw a common Innovation Roadmap, as I am convinced that PI can only happen on a broad scale on the basis of a strong and widely shared vision.

Both as citizens of the earth, and as industry leaders, our common future depends on it ! ”

Emmo Meijer, senior vice-president Global Foods R&D at Unilever (and ex-CTO DSM)

Recognition

A special thanks to the members of the Core Team …

Andrzej Stankiewicz (TU Delft and DSM)
Arend de Groot (ECN)
Frans Kaspersen (Organon)
Henk Akse (Traxxys)
Jan Harmsen (Shell)
Joop Koole / Ramon Schefferd (Huntsman)
Kees de Weerd (Akzo Nobel)
Marcel Dierselhuis (Syntics)
Marten Japenga (Zeton BV)
Peter Alderliesten (ECN)
Venkat Venkatesan (Aker Kvaerner)

… for their significant efforts, expertise and enthusiasm

ANNEX 11: Overall planning