Towards a European Membrane Strategic Business & Research Agenda

This document results from a work initiated by the European Network of Excellence NanoMemPro (EC - FP6 project - n° 500623) in June 2006.

For this work the opinion of a significant number of experts, public institutions and private companies was sought on several occasions (phone calls, reviewing tasks, meetings...). I would like to address my warm thanks to all of them; indeed without their contribution this work would not have been possible. I will not take the risk of doing an exhaustive list because I will certainly forget one or several contributors. Simply I want to address a specific mention to a few of the most solicited partners: the members of NanoMemPro, the national contact points who were appointed in each country to information, the national societies and groups active in the field of membrane technologies like the DGMT in Germany or the CFM in France and the consulting firm ALCIMED which as a subcontractor helped us during a few months to structure this report and to give it the form which it has today.

Undoubtedly, this roadmap represents a consensus of the views of the various European actors involved in this domain. It should be used as ground for the Strategic and Business Research Agenda (SBRA) which the Network of Excellence will set up for the years to come. As such it will provide the orientations of the actions to launch and support within the framework of the European Membrane House (EMH). This international non-profit making association intends to be the Durable Integrate Structure (DIS) whose objective will be to contribute to the industrial development of membrane technologies in Europe. This association, acting in a complementary and synergistic way with the European Membrane Society (EMS), the reference learning scientific society on membranes in Europe, should complete the organisation of a European Membrane Research Area (EMRA).

Of course, the document hereafter presented constitutes a starting document only which will be supplemented and updated annually by the EMH. Wishing you a good reading, and eager to receive your comments and suggestions, With all our best regards

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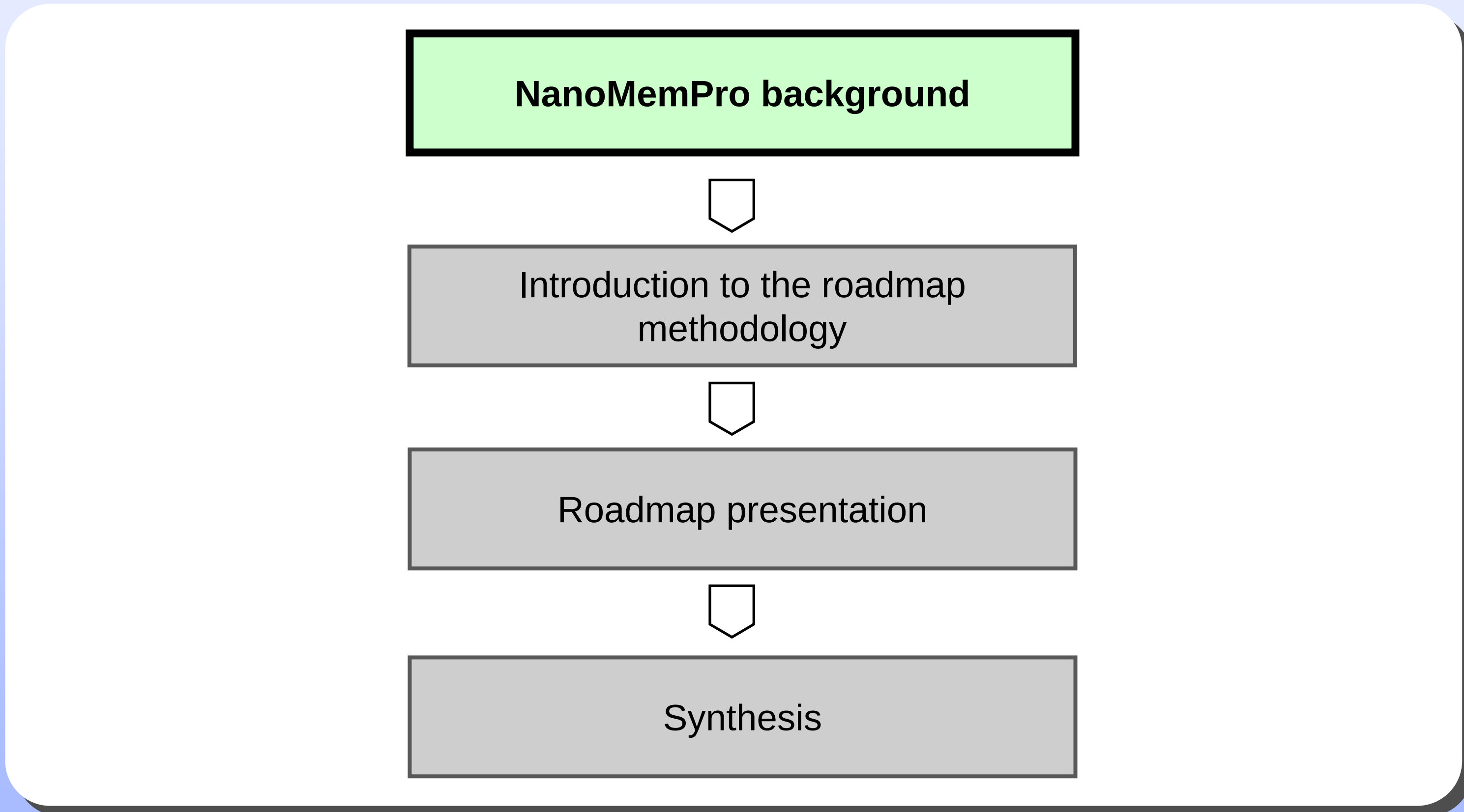
NanoMemPro background



NanoMemPro background
Introduction

In today's economy, **engineers and scientists must respond to the strongly changing needs of industrial processes** which aim to satisfy at the same time the always stronger constraints on raw materials, energy saving and environment impact imposed by a sustainable development and the always increasing demand of consumer for new products with specific end-use properties. To answer correctly these requests which are a bit contradictory, **process intensification appears as a privileged path to handle the future**.

Basically process intensification aims at replacing large, expensive, energy-intensive equipment or processes with ones that are smaller, less costly, more efficient and which minimize environmental impact, increase safety, improve remote control and automation and insure a better product quality. To reach the goals several “ingredients” can be used such as new materials, operating modes and/or multifunctional operations, with **strongly integrated multidisciplinary and multiscale approaches**. Most of the time **new functional materials, designed at the micro- if not at the nanoscale level** will be involved. As regards operations and processes, **the new concept of “integration” will replace the old-fashioned idea of “addition”**. Chemical engineering will provide the most appropriate tools to link the different length scales, from the micro if not the nanoscale up to the scale of multifunctional apparatuses and whole plants.

Undoubtedly, **artificial membranes and related technologies answer very correctly to the different requests**.

NanoMemPro background
Introduction

Basically, a membrane is a **complex high performance multifunctional barrier** which separates two media and facilitates or inhibits the transport of various substances in a highly selective way. The industrial development of membranes dates back to the 60s with the implementation of the first water desalination plants based on the reverse osmosis technology. Meanwhile, haemodialysis membranes arose as a major advance in solving problems of kidney deficiency. Since this pioneering period where European industries played a prominent role, membrane processes have evolved and found use in many other applications with a strong socio-economic impact on citizens' daily life.

Today, **membrane science has a leading role in innovative processes** and is considered **one of the main strategic axes of research activities in all developed countries**. Advanced technology programs in the USA or Japan involve them, and with **an annual growth rate of 10 to 20 %**, and **a total world market above 10 billion Euros around 2010**, membranes are likely to become more and more important in the future. **Membranes are expected to play an increasingly central role in a lot of systems** (separation, filtration, reaction, artificial organs, packaging…) and **areas** (chemical or food industries, health, automotive, energy …) of main importance for our daily life since **membranes represent the most appropriate image of sustainable development** insofar as they are in general athermal and do not involve phase changes nor chemical additives.

NanoMemPro background
Introduction

And still, artificial membranes are just very coarse copies of biological cell membranes which ensure all the basic functions of life. To make artificial membranes increasingly effective intelligently multifunctional, biocompatible and sterilisable, chemically & thermally & bio-fouling resistant, processable into modules or filters and weld able with available techniques, i.e. to bring their performance closer to those of their biological model, it will be necessary to **control the properties of membrane materials on the nanoscale if not at the molecular level,** and to **strongly improve our global approach of membrane engineering.**

Based on that, the European Commission has decided to award **a four year financial support to a specific structuring project : the NanoMemPro Network of Excellence (NoE)** launched on 1st September 2004. This project is intended to smartly reorganize the membrane research and knowledge supply chain on the mid-long term, to strengthen links among the knowledge R&D, the component suppliers and the demand nets so that to **restore the European leadership in this field.**

The NoE will foster the production of new knowledge. It will contribute to the answer that the European R&D strategy has to bring to the changing economic and social requirements. It will reinforce European scientific excellence, promote competitiveness of EU companies and deliver concrete benefits to citizens. It will **accelerate the passage from current capital intensive products based on quantity economy to added value brain intensive products based on quality / performance economy.**

NanoMemPro background
Introduction

By connecting basic research to industrial demand and applications, the NoE is going to overcome boundaries and to give Europe a leading position in the development of membrane technologies at the international level, thanks to a short-to-long term agreement between all the parties: **the Strategic Business and Research Agenda (SBRA).**

In parallel, the NanoMemPro NoE is setting up **the European Membrane House (EMH),** an international non-profit association which **will cap all its activities in the future**. This association will aggregate NanoMemPro partners, additional laboratories and research centres selected for their scientific and technological expertise, and companies. It will especially **implement the roadmap for research** according to the directions and trends presented in the SBRA, and regularly update it. To this purpose, the association's three main tasks will be:

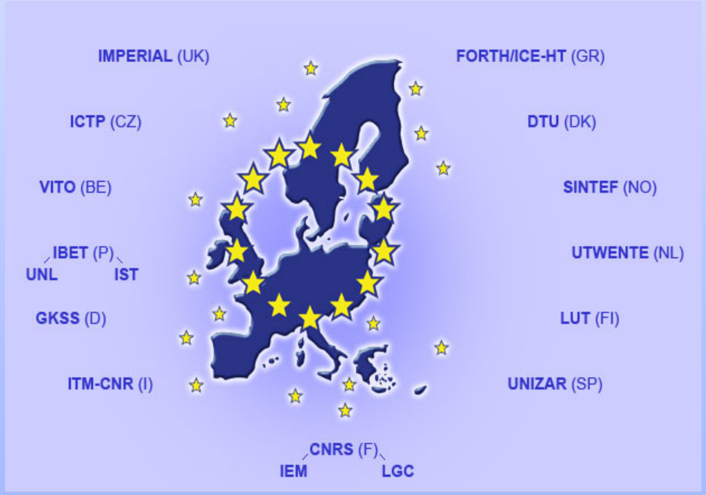
- to act as a melting pot for ideas, technological needs and demand, tools and means,
- to advise national and European institutions on new programmes or technologies of interest,
- to facilitate collaborative research projects and job creation.

NanoMemPro background
NanoMemPro in brief

➔ **NanoMemPro is the European Network of Excellence on Nanoscale-based Membrane Technologies created in 2004 with the support of the EU (http://www.nanomempro.com).**

NanoMemPro main characteristics

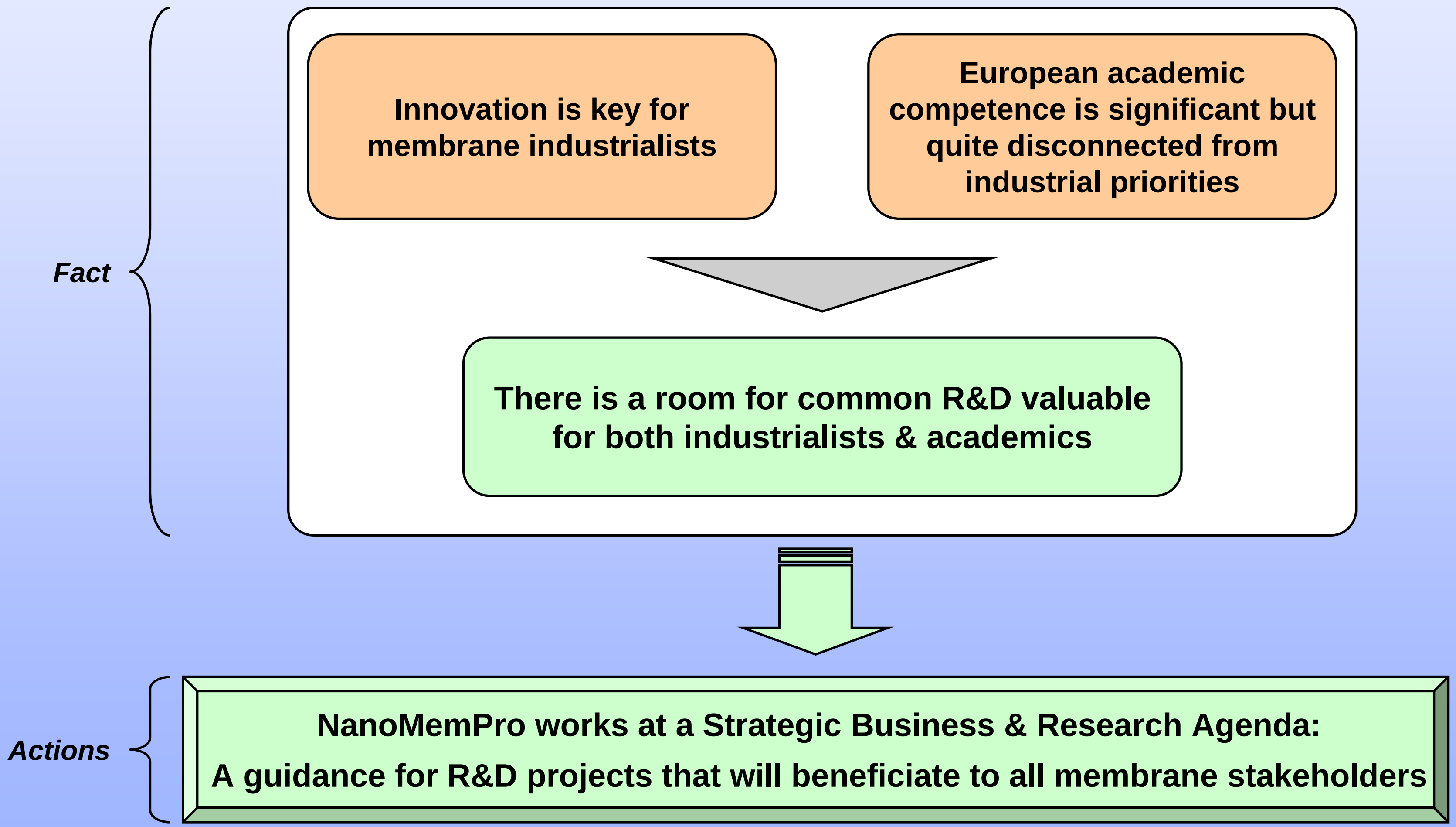
- **Joint initiative of 13 European partners, all leaders in the field of membrane technologies**
- **Funding by the EC reaches c. 6.4 m€ and comes from the Sixth Framework Program**
- **Launched in September 2004 for a 4 year duration**



NanoMemPro background

SBRA: Strategic Business & Research Agenda

➔ **It is working at its Strategic Business & Research Agenda to detect opportunities to involve industrialists & academics in valuable collaborative R&D projects.**



NanoMemPro background
ALCIMED input

➔ **NanoMemPro has signed a one year contract with the consultancy firm ALCIMED. By way of this contract, the company catalyzed the preparation of the SBRA on the one hand and the links between the NoE and private companies on the other hand.**

2004 → ***2006*** → ***2007***

For 2 years, NanoMemPro has been shaping a European pole of excellence on membranes, driven by industrialists' demand…

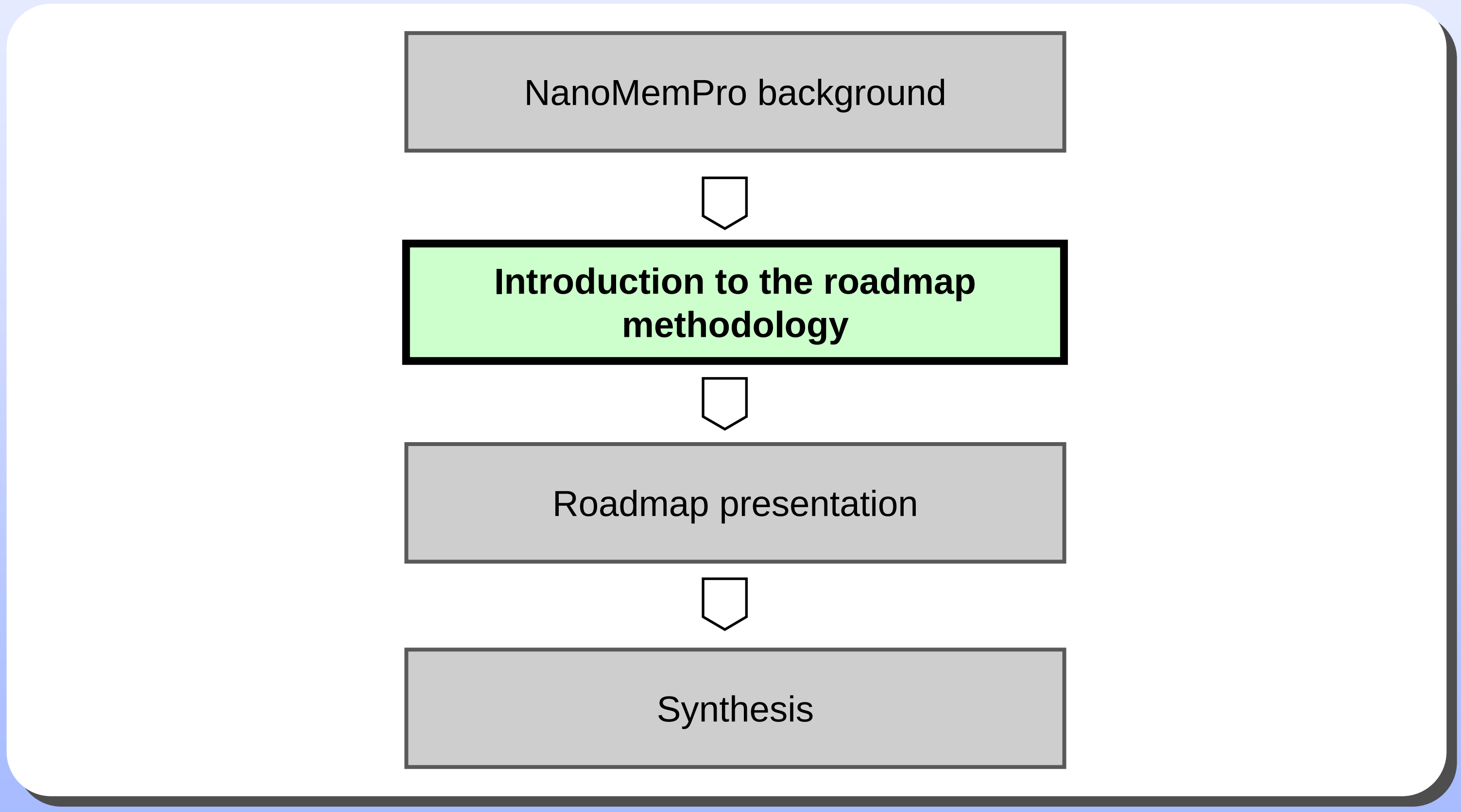
- ✓ **Assembling of 13 European universities, leaders of the academic world in membranes**
- ✓ **Set up of a Club of Interest on membrane science, dedicated to industrialists**
- ✓ **Creation of a legal entity to accommodate R&D projects with industry**

… and ALCIMED has been catalyzing this action by assisting NanoMemPro in building a membrane industry roadmap.

Objectives:
Facilitate the implementation of valuable partnerships between NanoMemPro and industrialists

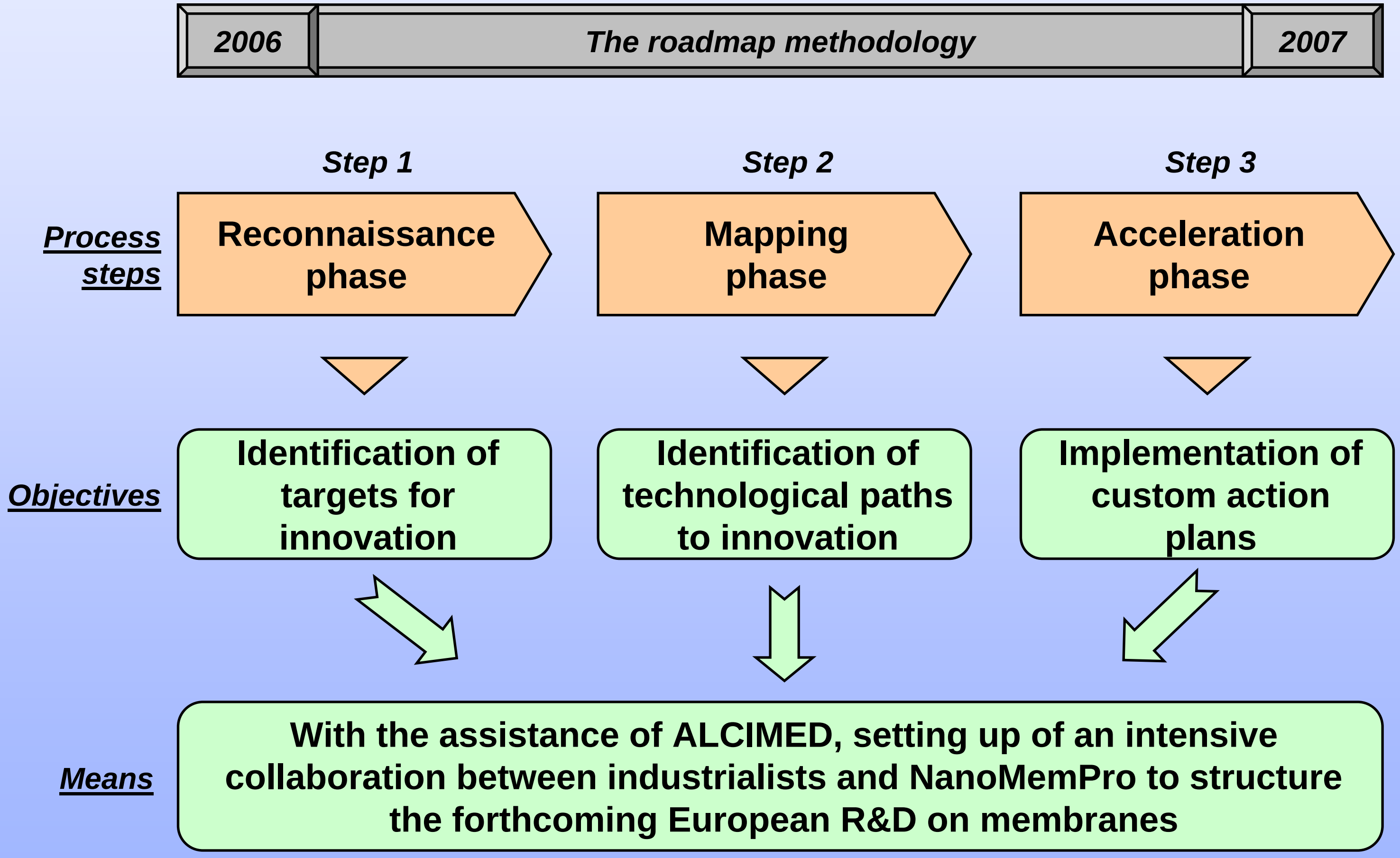
Means:
Achieve a roadmap to making industrialists of all membrane related sectors federate with NanoMemPro and the European Membrane House

Introduction to the roadmap methodology



Introduction to the roadmap methodology

➔ **The roadmap has been designed as a 3 step process characterized by an intensive collaboration between industrialists and research institutes.**



Introduction to the roadmap methodology

Reconnaissance phase - results

➔ **Involving 230 industrialists and mapping industries' requirements for membrane innovation, the reconnaissance phase is already completed.**

RECONNAISSANCE PHASE key questions answered:

Where are we today?

Where innovations would emerge tomorrow?

A strong industrial basis involved

> 230 people contacted

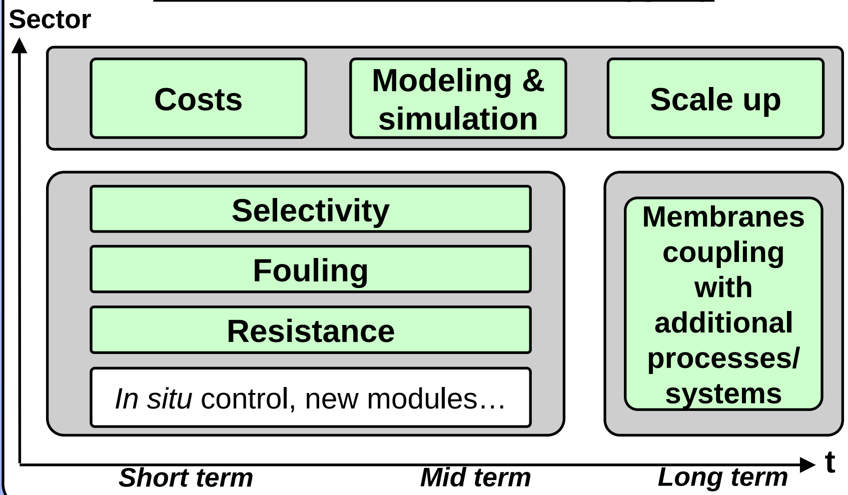
- ✓ c.230 industrialists invited to the 1st workshops
- ✓ >70 industrialists interviewed (phone)
- ✓ 40 industrialists participating in the 1st workshops

Many sector surveyed

- ✓ Membrane manufacturers
- ✓ Engineering companies
- ✓ Membrane end users

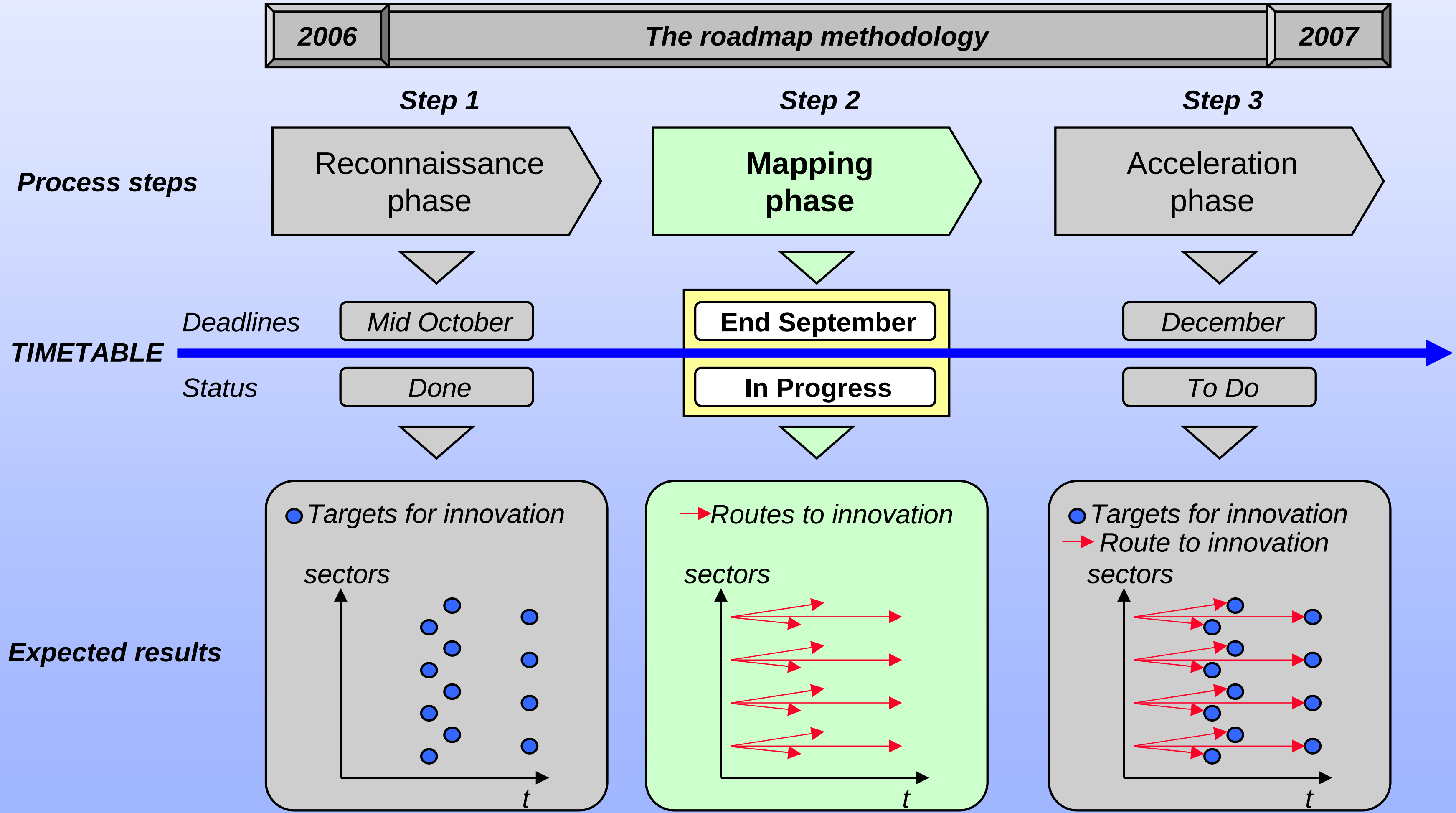
A mapping of industrial needs achieved

Business driven innovation mapping



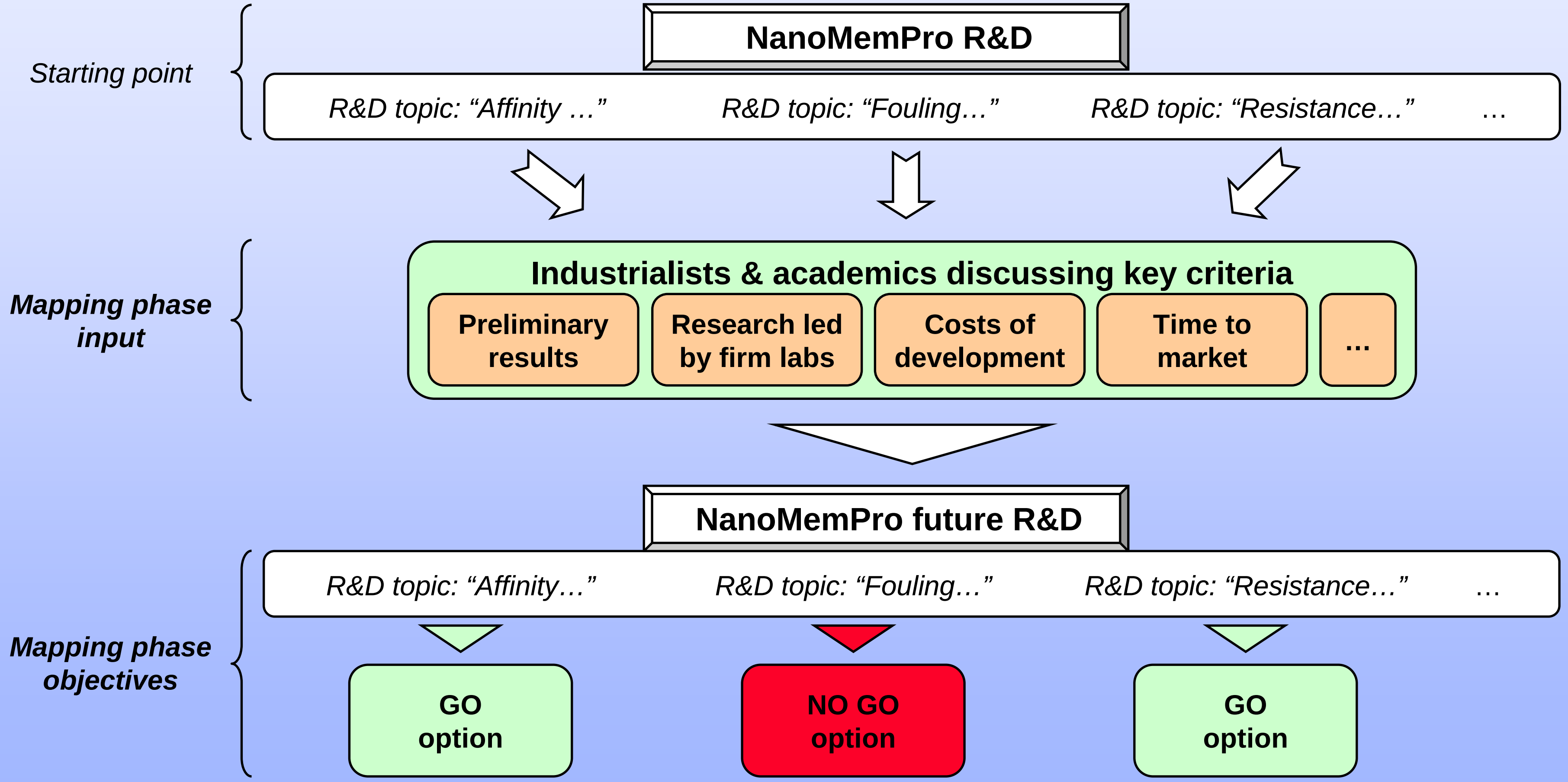
Introduction to the roadmap methodology
Mapping phase timetable

➔ **The workshops held in February contributed to the mapping phase, the achievement of the roadmap being targeted at the end of summertime.**



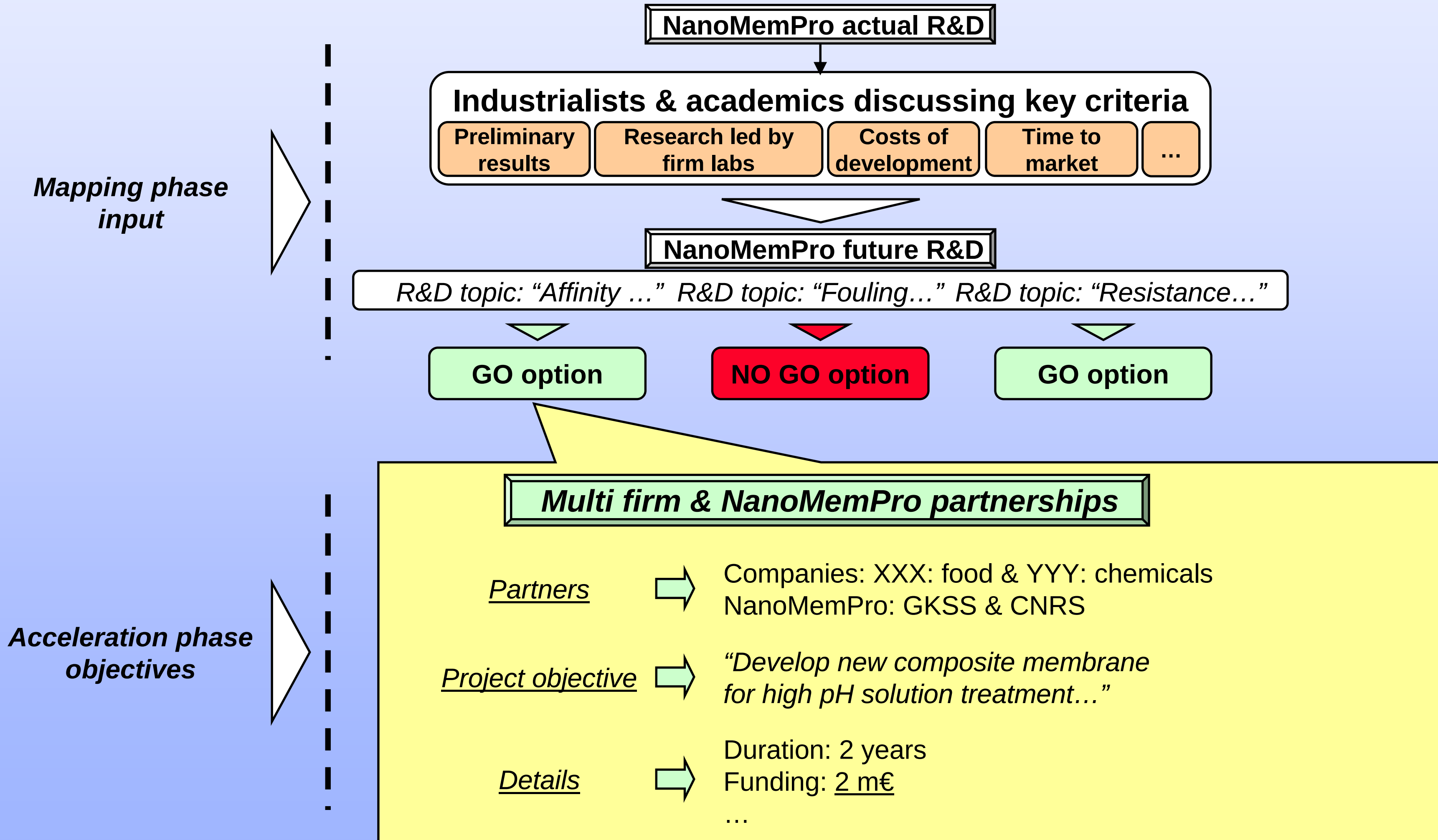
Introduction to the roadmap methodology
Mapping phase objectives

➔ **The mapping phase aims at having a critical vision of NanoMemPro R&D to select the most relevant options considering industrial demand & potential funding.**



Introduction to the roadmap methodology
Acceleration phase

➔ **Common multi firm & NanoMemPro partnerships on R&D projects targeting specific innovations being formalized during the acceleration phase.**



Introduction to the roadmap methodology
Mapping phase spirit

➔ **During the mapping phase, we still cultivate an industrialist devoted spirit by organizing 6 industrial sector workshops gathering 100 participants.**

Workshops scope

6 industrial sectors covered by workshops:
Chemicals, Energy, Food, Health, Environment, Membrane Materials

Mapping phase support & materials

Industrial demand driven roadmap

NanoMemPro academic resources driven by industrial realities

Workshops' industrial basis

- 60 industrialists in the 2nd series of workshops
- 40 academics

Introduction to the roadmap methodology

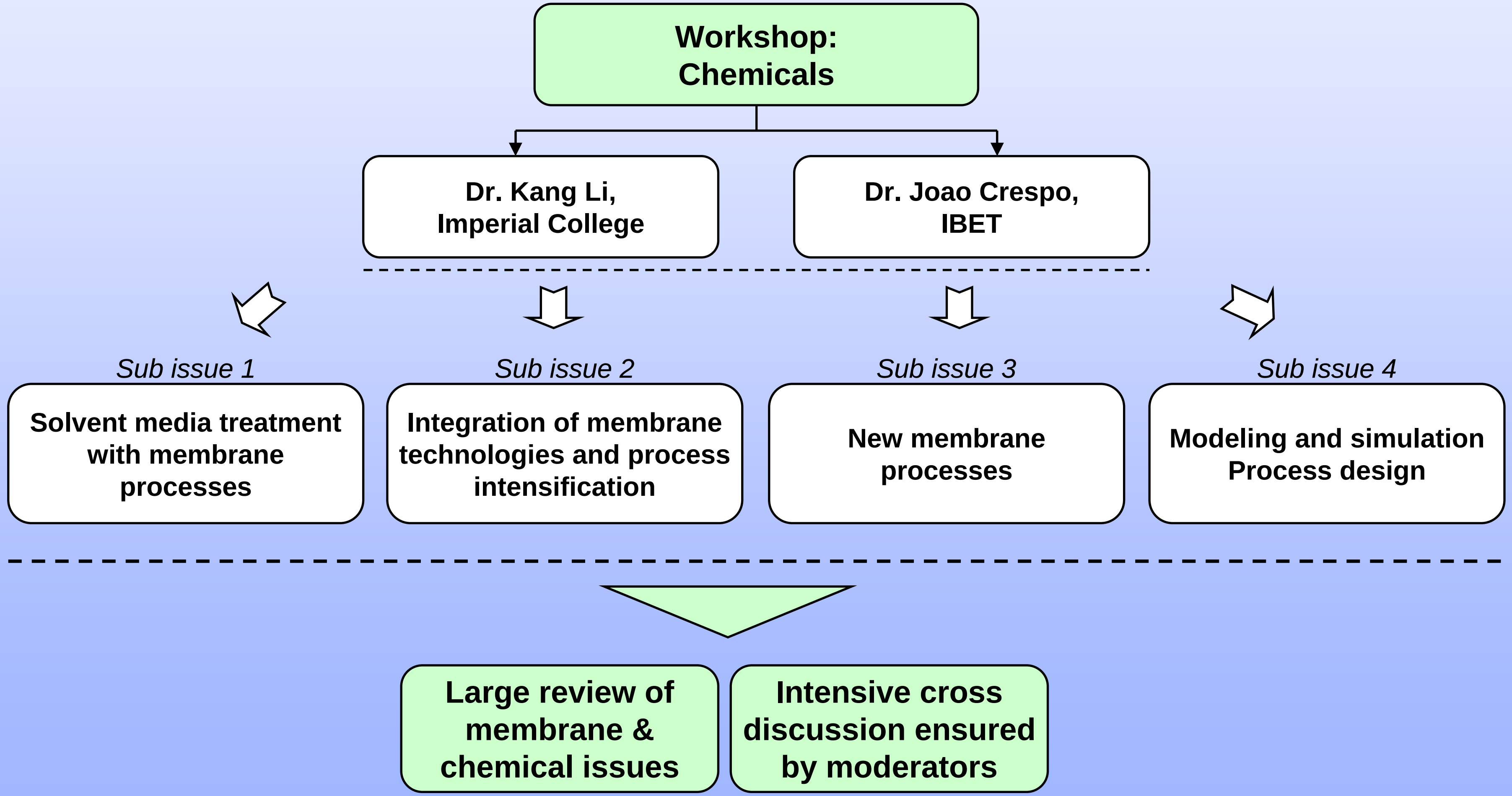
Mapping phase topics

➔ **Many issues were discussed, ensuring a broad coverage of membrane industrialists' concerns.**

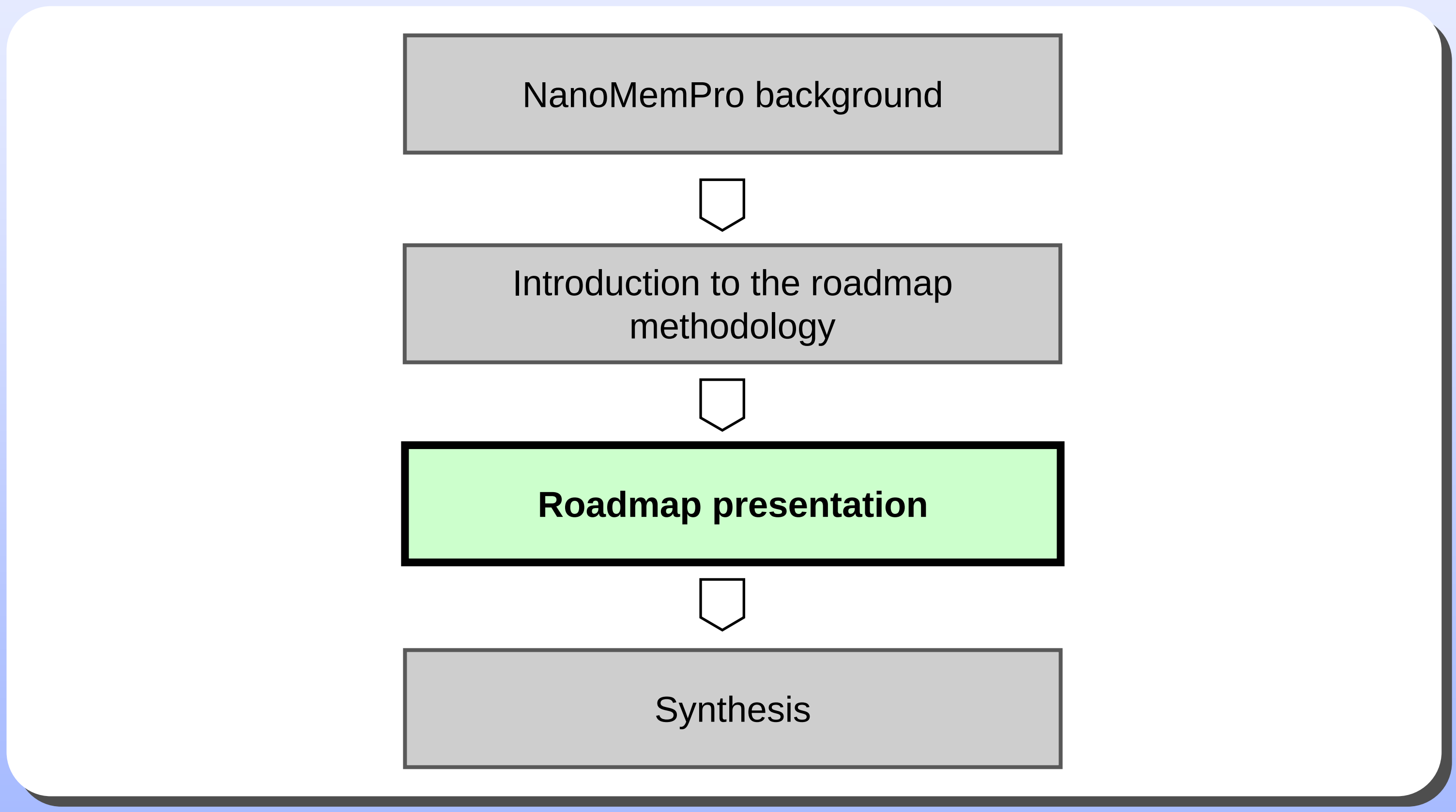
Workshop: **Chemicals**	Workshop: **Energy**	Workshop: **Environment**	Workshop: **Food**	Workshop: **Health**	Workshop: **Membrane materials**
Solvent media treatment with membrane processes	Gas treatment	Membranes as "Best Available Technologies" for environmental issues	Innovative membrane based processes in food production and processing	Bio compatibility	Inorganic membranes & manufacturing processes
Integration of membrane technologies & process intensification	Batteries and fuel cells	Drinking water membrane production processes vs. traditional physico chemical ones	Integrated membrane processes	Intelligent membranes & medical devices	Mixed matrix membranes & manufacturing processes
New membrane processes	New membrane energy production systems	Membrane desalination processes for drinking water vs. thermal processes	New packaging	Separating processes for the pharmaceutical industry	Organic membranes & manufacturing processes
Monitoring, modeling, simulation and process design	H2 and CO2 new challenges		Membrane processes to control and improve food texturation		Modeling and simulation for improved material design

Introduction to the roadmap methodology
Mapping phase workshop focus

➔ **In order to have detailed and interactive working sessions, each workshop was led by moderators and organized to deal with several main topics.**



Roadmap presentation



Roadmap presentation
Information treatment

➔ **A segmentation work was achieved in order to restitute all the information received during the working sessions.**

Starting point

6 workshops
22 sub issues
c. 100 participants

Results

Huge amount of information obtained
BUT
Heterogeneous information, both in terms of subjects discussed and in level of details

A segmentation was made to restitute all findings with two main approaches:
a *technical approach* and a *market & industrial approach*

Technical approach

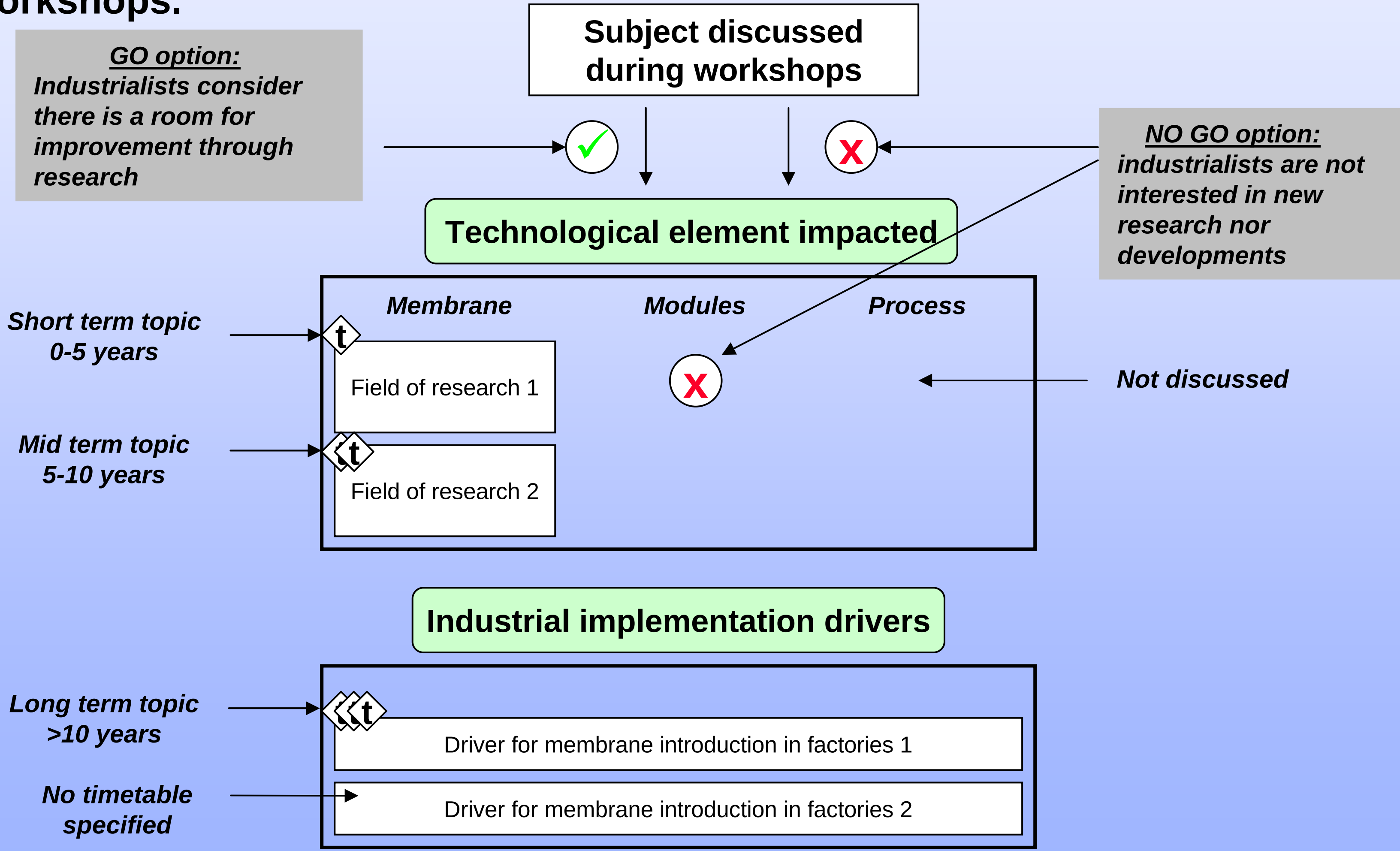
- **Developments needed**
- **Associated timetable**: short / mid / long term
- **Part of the technology impacted**: membrane / module / process
- **Specification mentioned**: T°C, pressure, pH…

Market & industrial approach

- **Industrial and market drivers and brakes**
- **Environmental issues:** costs, acceptance…
- **Regulatory issues**
- **Competitive issues**

Roadmap presentation
Information treatment

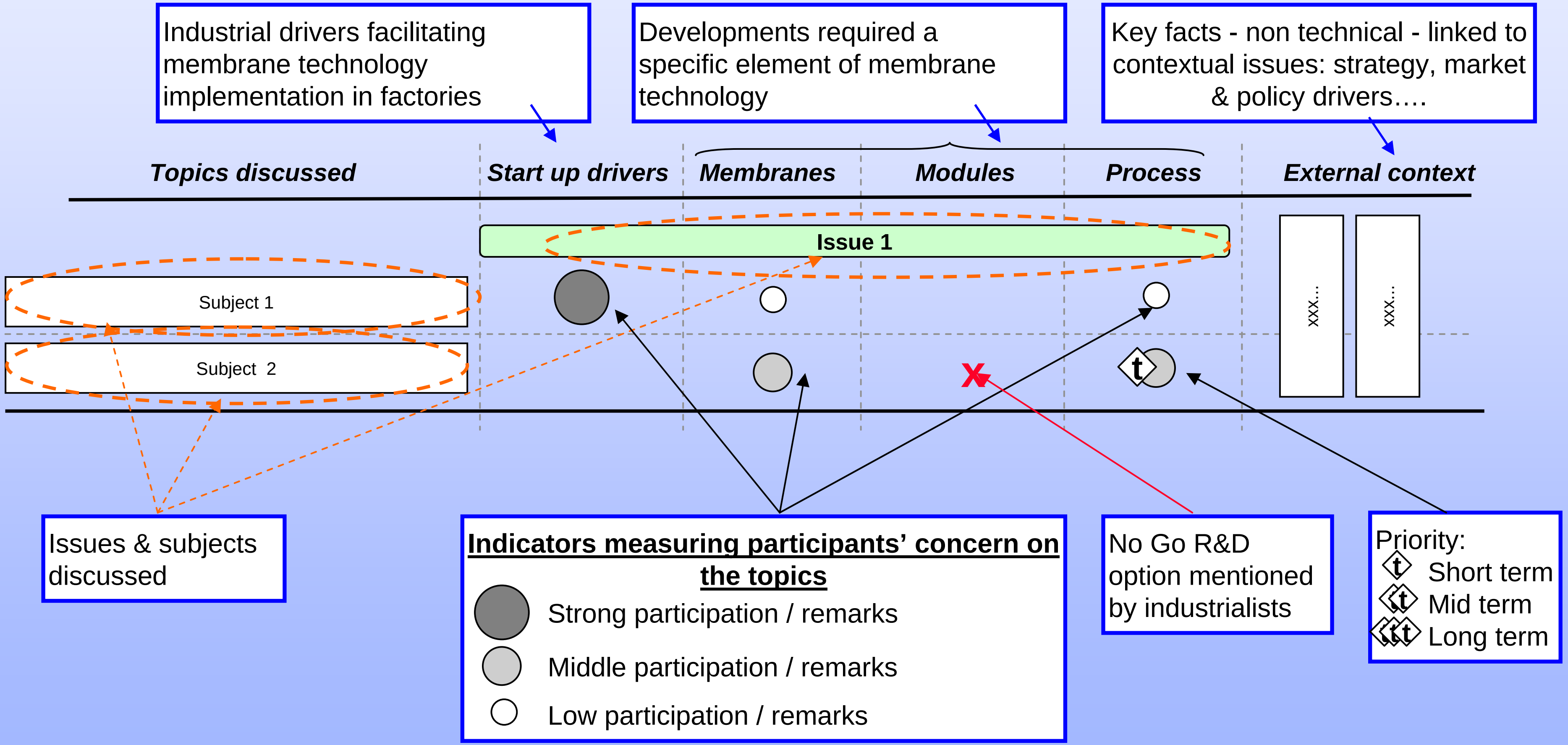
➔ **Each of the 22 subjects discussed was therefore translated into a specific framework giving an exhaustive overview of what was told during the workshops.**



Roadmap presentation

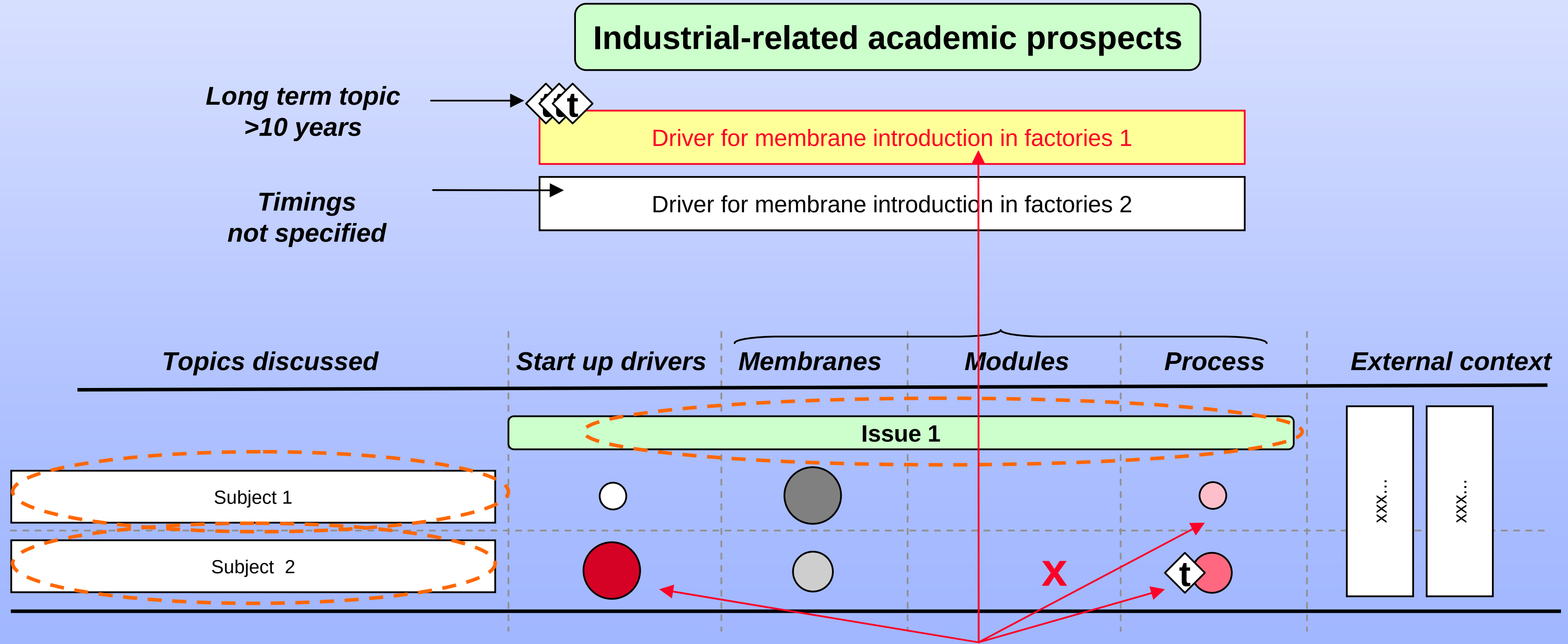
Information treatment

➔ **Then, for each workshop, all corresponding subject's frameworks were synthesized into a preliminary roadmap.**



Roadmap presentation
Information treatment

➔ **Other information was added, from a prospective exercise of NanoMemPro core partners on the development of membrane technologies (summarized in a document entitled "Dreams"). In order to keep information traceable, different colors were used for this contribution (red/pink for indicators and yellow/red for drivers)**



Roadmap presentation

Workshop:
Chemicals

Workshop:
Energy

Workshop:
Environment

Workshop:
Food

Workshop:
Health

Workshop:
Membrane materials

Roadmap presentation

Chemicals

Workshop:
Chemicals

Workshop:
Energy

Workshop:
Environment

Workshop:
Food

Workshop:
Health

Workshop:
Membrane materials

Roadmap presentation
Chemicals

Membranes offer attractive prospects for the chemical and petrochemical industries. At first, because of their great potential for the recovery, recycling or valorisation of by-products, particularly molecular species and solvents, they lead to more environment-friendly and valuable processes. Through the new concepts of membrane reactors which for example extend the field of homogeneous operation due to the easy free catalyst recycling, or by offering original support to fix them, and membrane contactors which compete with traditional operations such as distillation and extraction, they open original ways for process intensification.

The presence of a strong expertise in chemical and process engineering in these industries should facilitate their development, provided that these technologies are considered with the same attention as older and more traditional ones. Particularly new modelling and simulation tools will have to be developed to predict performance, with new flowsheets involving membranes. From that point of view, education will have a major part to play.

Roadmap presentation
Chemicals

Integration of membrane technologies and process intensification

Membranes → ***Modules*** → ***Process***

General issues

- For purification of specialty chemicals in low volume, there is a need to prove that membranes work and this for each unique application
- For base chemicals, there is a need to evaluate the cost of the technological process (fouling / lifetime + coupling with the reactor)

Polymer membranes

- T°C resistance to 200°C / 250°C AND pressure resistance to 120 bars and a cut off < 200D → Work on seals and support material resistance
- Membranes should keep their hydrophobicity and resist to fouling for a longer time

- Develop test protocols to evaluate and predict a membrane's lifetime and resistance
- Communicate on membrane properties as industrialists are currently reluctant to introduce them in their process
- Give precise information on protocols to correctly use membranes and respect their conditions of use
- Develop technologies to achieve 100% separation of organics in waste water

Roadmap presentation
Chemicals

Solvent media treatment with membrane processes

Membranes	*Modules*	*Process*
Develop a membrane resistant to N-methylpyrolidone to compete with expensive distillation →	Work on a better understanding of membrane stability from a macroscopic point of view but also regarding what is happening at the core of the membrane	
	Work on stable and operational modules for NF membranes whatever the solvent	
Membranes for specific issues like separation of isomers having the same boiling point		

- t For each NF membrane and for each solvent, necessity to have a stable point of operation (no swelling) among all membranes suppliers (which are currently start up suppliers) and guaranteed cut-off and rejection rates.
- t Necessity to have norms and quality control to determine the quality of membranes, to compare each other and to begin working on modeling issues
- t Membranes producers are not really interested by the chemical market and much more focused on pharmaceutical and waste water ones. A market should be found to launch the technology (probably the petrochemical one)
- t Drying of solvents by pervaporation with the need for new materials and new hybrid processing schemes: a small but well established area with an interesting growth potential mostly dependant on the success in the biofuels application field (particularly drying bio-ethanol)
- t Try to find ways to increase value and / or reduce costs of the process when using membranes compared to other competitive technologies (extraction)

Roadmap presentation
Chemicals

New membrane applications (1/2)

Membranes	*Modules*	*Process*
Paraffin/olefin separation		
Improve membrane materials: cost / temperature and pressure change during the process / better solvents for contactors / safety issues of minor components produced →	Need for more compact membrane modules if energetic costs are reduced	
Removal of toxic compounds in waste water		
Need to have a good separation of aqueous and organic fluxes and to manage the presence of salts and corrosive solids		
Membrane cascades to simulate chromatography		
Reduce costs, enhance selectivity and develop cheaper commercial products		
H_2SO_4		
During the concentration phase, the pH is too acid for the polymeric membranes and the viscosity is also too high for ceramic membranes in the separation phase		

Roadmap presentation
Chemicals

New membrane applications (2/2)

A study of membrane problems for the top 10 chemical products (H_2SO_4 -see previous slide- but also H_3PO_4, ethylene, syngas…) is required to have a more relevant sight of membrane challenges in chemical industries

80% of research for membranes (and not 100% as there already exist dozen different polymers) and the rest for processes, upstream

For each new membrane, find different applications, and evaluate the global cost of the process

Standardization of membranes is needed in order to have the possibility to easily change modules

Be ready to propose membrane processes for the new chemical plants as investments in membranes will not be made in existing units

NanoMemPro should collaborate and exchange with the Technology platforms in Brussels

Roadmap presentation
Chemicals

Monitoring, modeling, simulation and process design

Membranes	*Modules*	*Process*

Database

- Need to build a general database for modeling
- Need to design tests able to adapt to different systems
- Need of both a dynamic database and a dynamic model to be able to evaluate the gap between the prediction and the observation at each stage of development, from lab to industry
- Industrialists will probably not share their own results but are ready to work on common reference projects

Software

- Work on already existing tools like ASPEN or NanoFlux to integrate them in compatible and existing environments
- Create a reliable database to feed the different tools

New module design

- Need for spacer design in function of the temperature and viscosity
- Design of new modules for NF with a simulation tool

Roadmap presentation

Chemicals - Overview

Topics discussed	*Start up drivers*	*Membranes*	*Modules*	*Process*
Integration of membranes technologies and process intensification				
General issues: specialty vs. base chemicals	◐			○
Polymeric membranes	◐	●		
Solvent media treatment with membrane processes				
General issues	●	◐	◐	
New membrane applications				
H2SO4 treatment	◐	◐		○
Paraffin/ olefin separation	◐	●	○	○
Removal of toxic compounds in waste water	◐	●		○
Membrane cascades to simulate chromatography		◐		○
Monitoring, modeling, simulation and process design				
Database	●			
Software	◐			
New module design			◐	

External context

Costs brake: 1. Membranes must demonstrate they bring value to processes, especially more value than competitive technologies. 2. Costs were mentioned as brakes. In basic chemicals, the first question was « how much does it cost? ». 3. The funding issue remains strong, there is a need for industrial funds, however fund providers appeared to be rare.

Industrial playground: 1. Acceptance is low in companies due to the lack of confidence in fouling prediction and corresponding impacts on membrane performance evolution. 2. Companies are not ready to share data even for database construction. The propriety issue is strong. 3. Spread good usage specifications.

Directions required by companies: 1. Efforts must be focused on existing technologies. Industrialists are expecting technology improvements, not creation, from NanoMemPro. 2. A market orientated strategy must be cultivated.

Roadmap presentation

Energy

Workshop:
Chemicals

Workshop:
Energy

Workshop:
Environment

Workshop:
Food

Workshop:
Health

Workshop:
Membrane materials

Roadmap presentation
Energy

The conclusion of the IPCC is that the current global warming and climate changes are results of greenhouse gas emissions due to human activities. The world energy demand will continue to increase in the foreseeable future emphasising the importance of establishing sustainable energy technology. Membrane technology is expected to intrude the three main areas focused to mitigate the greenhouse gas problem: CO_2 capture, energy saving and renewable energy. Membrane gas separation plays a key role in CO_2 capture technology (CO_2, H_2 and O_2 separation). Considerably energy saving is possible by process intensification using membrane technology. Such process intensification spans widely, e.g. from elimination of phase conversion in distillation and evaporation to transformation of energy conversion from thermal to electrochemical routes. Examples are energy efficient production of potable water by RO, pervaporation, and fuel cells. Membranes will open up new possibilities and making production of renewable energy technology more efficient. Saline power generation and bio-fuel production are examples where membranes play a key role. This road map aims to present some main focus areas in the field of sustainable energy where membranes are most prominent.

Roadmap presentation
Energy

Transversal issues about membranes and energy

Membrane — ***Modules*** — ***Process***

Need to improve the understanding between membrane performance, module design and processes
Understand relationships between properties and materials and improve characterization

Enhance flux and selectivity

t Enhance membrane stability (time, temperature, chemical/mechanical properties)

Prepare compact membrane modules with high membrane area per volume unit

t Developing upscale manufacturing methods that retain lab scale performance to large scale applications

t Integration of membranes modules in processes designed for membrane applications

t Need of success stories for membranes to keep them in industry

t t Need of co-developments between industry & technical institutes on process

t Need for an energetic policy within the energy area to drive membranes developments and set targets

Roadmap presentation
Energy

Energy savings

Membranes

- Selectivity and stability are the most important improvement topics
- Industrialize available membranes
- Production of more stable membranes

Modules

- Develop modules with better hydrodynamic performance, cheap production and solve sealing technology
- Hybrid modules and other separation technologies: membrane reactors

Process

- Select the most important applications based upon energy savings, e.g.
- Hydrocarbons + olefin-paraffins
- Dehydration of organics by pervaporation
- Ammonia (or hydrogen) separation in NH_3 production plants
- Oxygen separation from air
- NF and homogeneous catalysis

Need for field tests to prove reliability

Launching customers' applications

Roadmap presentation

Energy

CO_2 capture

Membrane ***Modules*** ***Process***

High temperature oxygen membranes for replacement of cryogenic oxygen production facilitating CO_2 capture.

Work on hybrid membrane processes (coupling membrane with a conventional separation technology)

Work on novel power cycle generation design to implement membrane technology in an efficient way.

Enhance flux

Long term behavior tests & long term experiments on efficiency (1-5 years) to guarantee long term performances

Membrane durability

Module design
Sealing technology

Low production cost

Fuel separation technologies, CH_4/CO_2, H_2/CO_2

Need to adjust industrial processes to facilitate CO_2 capture

Focus on large point emissions

Roadmap presentation
Energy

H_2 separation

Polymer membrane

- Development of new polymeric membrane materials and polymeric/inorganic composite membranes
- Selectivity and stability are the most important improvement topics

Modules

- Develop modules and membranes able to operate up to 250°C in H_2 separation

Process

- More and more H_2 needed for refining

Inorganic membrane

- Industrialize **inorganic** membranes
- Develop membranes to separate low carbons (C1 & C2) at low concentration while keeping H2 at high pressure in refining
- Production of stable **Pd** membranes in terms of performance: decrease Pd amount and increase fluxes → Develop less expensive modules and sealing → Optimization of module integration
- Develop novel proton conductors for hydrogen separation and electrolysis

Modules:

- Develop modules able to treat huge quantities of H_2
- Develop less expensive modules and sealing

Process:

- Develop hybrid processes, membranes and adsorbents
- Develop sensitivity models for membrane performance and economics of various applications
- Optimization of module integration
- Demonstrations in pilot plants

- Need of H_2 separation to refine deeper and deeper
- Need of H_2 purification to improve fuel cells
- Opportunity to use membranes to debottleneck petrochemical units
- Membrane processes for Hydrogen production for large scale power generation, transport sector and medium sized stationary applications

Roadmap presentation
Energy

Fuel cells

Membrane | ***Modules*** | ***Process***

Development of new electrolyte materials

Both up-scaling and miniaturization of fuel cell technology

PEMFC for portable and small scale applications → work on low temperature resistance

PEMFC for large applications → work on high temperature resistance

Need for reliability and performance in cycling procedure

Need for technologies to understand the mesoscale level of the material, need for modeling and understanding of micro and nanofluidics

High temperature fuel cells based on ceramic oxygen ion conductors or proton conductors

There is no fuel cell manufacturer in Europe to drive membrane developments and European companies are behind Japan and North America

Need for communication within the fuel cell community and for combining materials and engineering

Roadmap presentation
Energy

Gas treatment

Gas drying (water removal)

Sulfur removal

Drying of gases is not a target application for membranes as better competitive technologies exist (with membranes, methane is lost during drying)

Membrane | ***Modules*** | ***Process***

Methane removal from natural gas and biogas

Membranes able to separate methane from CO_2

Membrane contactors + solvent

Define specific operating ranges for membranes

Calculations to confirm cost reduction by methane recovery at low pressure

Need for existing material optimization and for process calculation

Roadmap presentation
Energy

New membranes

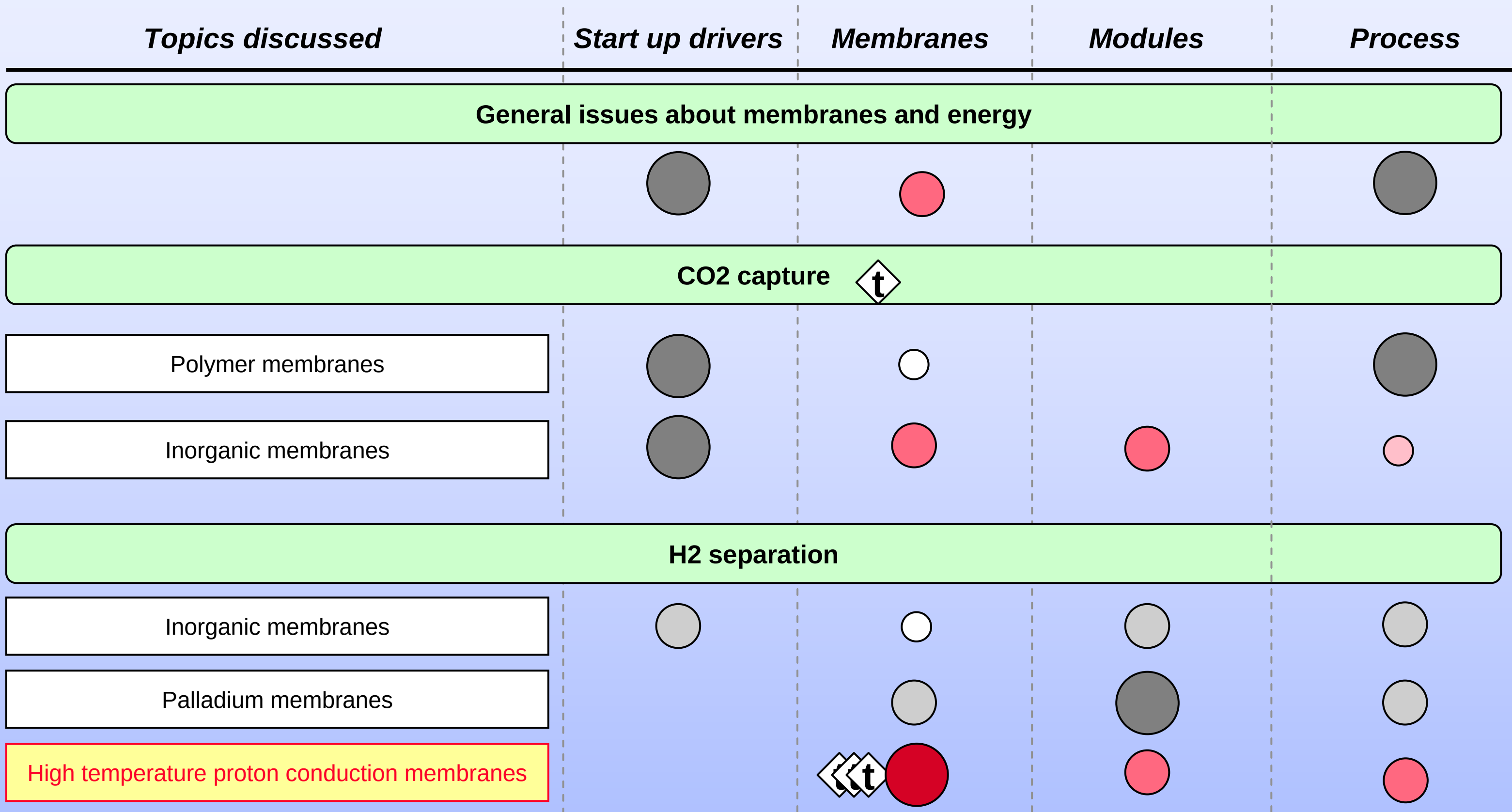
Membrane	*Modules*	*Process*
Development of new less hydrophilic nanoporous membranes improving selectivity and reducing fouling		Need for process calculations
Development of new membranes with higher chemical, thermal and mechanical stability	Module design and sealing technology	Novel process design and integration, process intensification

Balance between chemical engineering & material science

Need for flow sheeting running in parallel with testing and development

Roadmap presentation

Energy - Overview

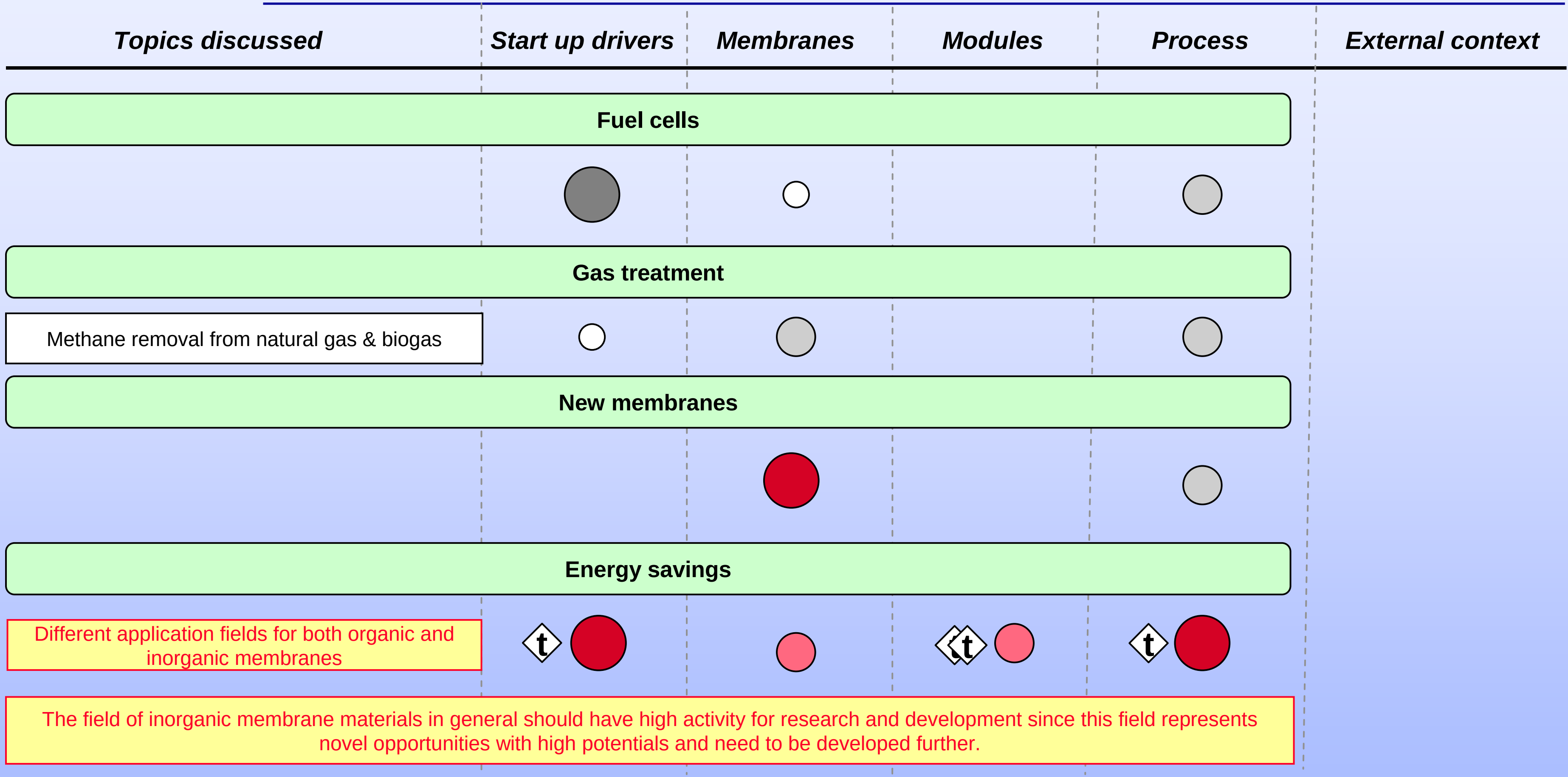


Lack of strategy: 1. Europe is late compared to the USA. Furthermore, it still works as an aggregation of different countries. 2. Europe does not have a clear strategy since governmental policies are not clear.

Collaborative approach not achieved: 1. Need to involve engineering departments to work on existing developments & to stretch them to industries. 2. Industrialists will engage only second priority projects in NanoMemPro. 3. Launching applications and industries requires money from the EU to support companies willing to take a risk. 4.Links to be done with other networks (on fuel cells, batteries, ...).

Applications selection difficulties: 1. Applications remain highly dependent of governmental positions. 2. Top priority applications must be viable ones only.

Roadmap presentation
Energy - Overview



Roadmap presentation
Environment

Workshop:
Chemicals

Workshop:
Energy

Workshop:
Environment

Workshop:
Food

Workshop:
Health

Workshop:
Membrane materials

Roadmap presentation
Environment

Membranes are very competitive with others, and generally, older technologies, for liquid and particularly potable, process, and waste water treatment. The faulty notion that water is free and available in unlimited quantities has led to poor water conservation and inefficient use. Only 1% of the world's water is available in a fresh form, 98% being salty in the oceans and 2% frozen at poles. As a consequence sea water and brackish desalting, municipal wastewater treatment, industrial effluent processing, drinking water production have become crucial problems for the future of our societies which are strongly demanding new solutions. Traditional membrane technologies - RO, UF, NF, EDR - as well as new concepts – MBR, membrane contactors - participate in the strong effort which is being developed at the world level. Regarding gas treatment, CO_2 capture and storage (sequestration) has become today a major topic as regards potential climate changes. VOC removal for pollution control, with recovery and if possible recycling of valuable process vapours, is another point of interest. Environmental regulations with favourable process economics will drive these new membrane applications.

Roadmap presentation
Environment

General considerations, BAT and Standards

Membranes	*Modules*	*Process*

BREF documents have a European range of application: Although the listed technologies are recent but not state-of-the-art, BREFS may help developing countries to improve their technologies and to comply with European regulations

One target of the EMH (European Membrane House) could be to lobby at the EC in favor of programmes to develop European Standards for membrane processes

Need to set up membrane demonstration platforms dedicated to environmental technologies

Need for EC programmes on membrane life cycle analysis due to the large amounts of membranes used in water and waste water treatment plants in operation around the world

Roadmap presentation
Environment

Drinking water

Membrane	*Modules*	*Process*
Better membrane chemistry for anti-fouling: antibacterial ions in the membrane, Teflon or silver coating	Develop and design modules which could operate without pre-treatment (remove salts and avoid problems with organics)	Hybrid processes: - Ion-exchange MBRs - Photocatalysis + membrane - NF or UF an activated carbon
	Develop devices to increase shear stress. Explore low flux / low energy but large membranes as strategies for anti-fouling	Treatment of concentrate streams

Need for testing methods to have prediction models / process development and simulation tools → need for this to collect information from different problems: continental database on fouling. Construct synthetic water models to evaluate the type of fouling associated. Set up a platform with divert streams for parallel tests.

Understand the impact of fouling on the microscale (top surfaces, structure of the membrane) / fingerprints of biofilm development, signature of performances.

Control roughness of the membrane surface	Identify where are the problems of the destruction of the membrane. Design modules to protect membranes	COV removal
Membrane with carbon nanotubes		Pathogens, micropollutants, viruses, NO_3, SO_4 removal
		Integrity testing of processes for biocontaminants

Need to simplify membrane production: use of less solvent, homogeneous pore size

Roadmap presentation
Environment

Desalination

Membrane | *Modules* | *Process*

- New thin film composite membranes more stable against chlorine and other disinfectants – Breakthrough material to improve flux and rejection while decreasing energy consumption (carbon nantubes) – New hydrophobic porous membranes for applications with membrane contactors (distillation / crystallization…)
- Progress in EDR and NF for converting brackish water into fresh water
- Multi barrier treatment methods : membranes combined with traditional or advanced water treatment, or a pair of processes in tandem (as an example to protect RO membranes from high fouling in large-scale sea water desalination)- Hybridisation of processes.
- Development of entirely new integrated membrane plants with new process control and optimisation tools

A huge and ever growing market with new specific problems to consider for the well-being of population and environmental impact

Disposal of huge amounts of waste brines produced by the desalination plants

RO-desalinated deep-seawater for the production of bottled - water

Effluent processing (out of MBR)

Membrane | *Modules* | *Process*

- New UF stainless-steel membranes and modules (textile)
- Solvent resistant membranes (latex)
- Adsorbent containing membranes- Recovery of oestrogen compounds, mercury and other toxic substances from coal-burning power plants…
- Hybrid processes : emulsification + membrane / adsorption + membrane

Because of the rarefaction of natural water sources, the need for "closed-loop technologies" which aim at achieve zero liquid discharge by recycling all in-plant water streams. Membranes are ideally suited for such purposes in various industrial processes: textile, pulp and paper, tanning, latex, biotechnology…

Roadmap presentation
Environment

MBR

Membrane	*Modules*	*Process*
Membrane with longer lifetime are required	Optimisation of reactor concept to reduce membrane fouling	Need for better sludge post processing
Next generation materials (e.g. disposable membranes, materials with better life cycle analysis)		Need to predict the uncertainties (cost, cleaning, fouling) and lifetime
		Need to reduce the concentrated activated sludge (air interface issues)
		Hybrid MBR with other physico chemical processes

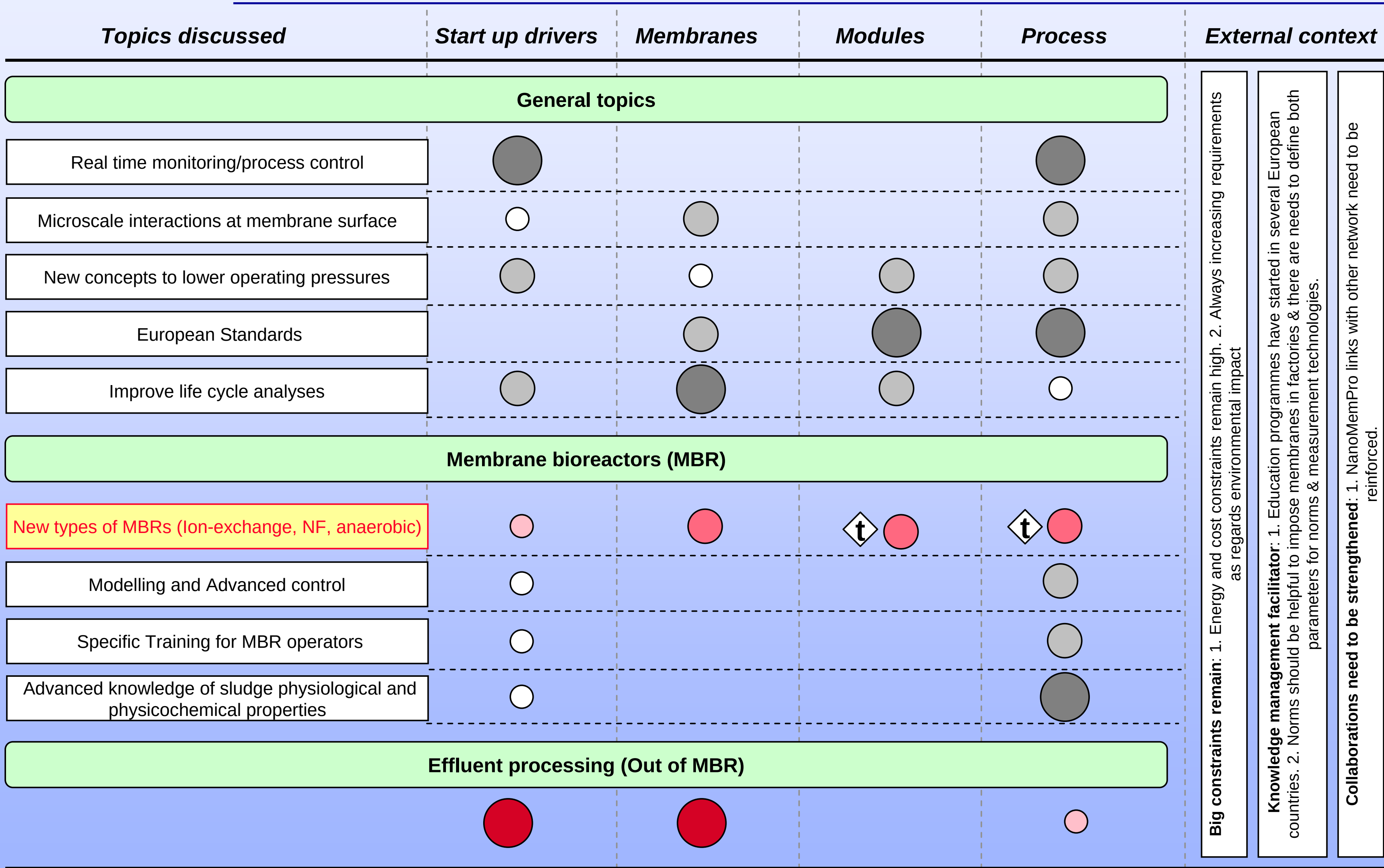
Need to understand what happens at the microscale level when cleaning:

Need for the development of real time monitoring for correction actions and to define what are the most influenced parameters

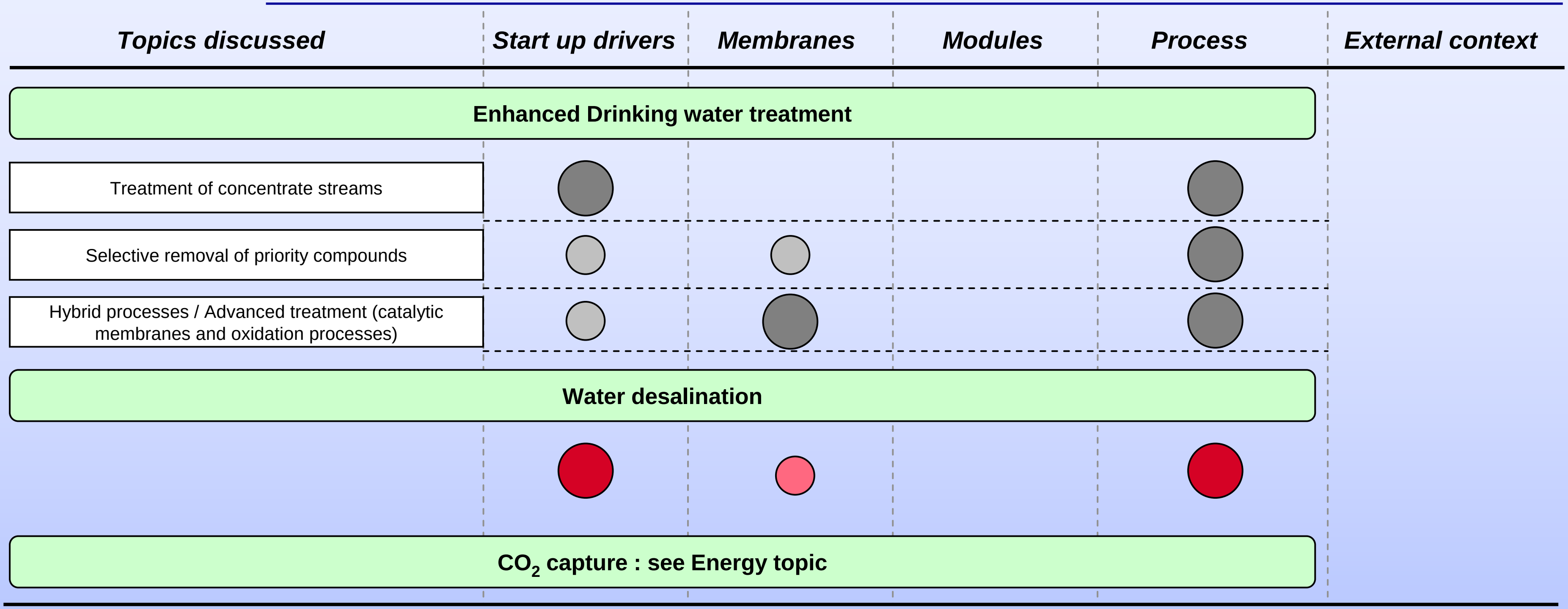
R&D need to account for two applications: industrial and municipal MBRs:
- Sizes are different
- Pre-treatment and cleaning technologies are different
- The feed charge can be very different

Need for training operators who handle MBR reactors and run advanced control systems

Roadmap presentation
Environment - Overview



Roadmap presentation
Environment - Overview



Roadmap presentation
Food

Workshop:
Chemicals

Workshop:
Energy

Workshop:
Environment

Workshop:
Food

Workshop:
Health

Workshop:
Membrane materials

Preliminary roadmap representation
Food

Membrane technology has been used in specific applications of the food industry since more than 30 years. These processes include concentration of whey protein, milk solid separation, juice clarification, cold sterilization, salt removal, effluent treatment. Reverse osmosis, ultrafiltration, and microfiltration are the most commonly used membrane operations, even if there are niche markets for other technologies: pervaporation for de-alcoholization of wine and beer, electrodilyasis for tartrate recovery in wine or deacidification of fruit juices. Nanofiltration (for selective recovery of high value compounds), membrane reactors (with enzymes for biotransformation or viscosity reduction), and membrane contactors (membrane evaporation for the concentration of fruit juices as an example) have emerged as technologies with a strong potential in the future and often need only optimisation and demonstration activities in order to take then to markets.

Most processes are using polymeric membranes, but inorganic membranes with a longer life-time and easier cleaning (sterilization) have a promising future.

Roadmap presentation
Food

Innovative membrane based processes in food production and processing (1/3)

Membrane

Bioreactors

- Consider membranes and biocatalysts (e.g. enzymes, cells, etc.) all together and develop generic methods to graft any kind of enzyme or to include them on the material
- Move from trial-and error to a predictive approach (i.e. modeling both on a bulk and microenvironment level)
- Better understanding of catalyst included within the membrane material (i.e. structure/function related interactions between biocatalyst and membrane; effects of microenvironment conditions on kinetics and transport properties)

Modules

- Improve module design
- Standardize manufacturing (e.g. dimension, connections, etc. so as to increase adaptability to various plants)

Process

- Increase process control of micro-reactors
- Keep biocatalysts active and achieve a good conversion, stability and reproducibility
- Target a total integration of many operations in 1 single membrane process

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- Convince industrialists that have had bad experiences with bioreactors and anticipate the technology fear within industrial conditions (i.e. proof the robustness of the technology by developing a sufficient number of established reference cases so as to convince decision makers of the potential of the technology)
- Achieve 2 different operations with good results for each
- Insist on the cleaning facilitation linked to operations' merging
- Work on costs to push the technology
- Work on safe, low energy input, waste minimization, low environment impact properties of the technology

Roadmap presentation
Food

Innovative membrane based processes in food production and processing (2/3)

	Membrane	*Modules*	*Process*
Packaging	Develop lower cost packaging membranes to compete with existing packaging solutions		
	Work on membranes able to work in a modified atmosphere, under UV and with antimicrobial protection (for the cheese industry for example)		
	Develop multifunctional, stimuli responsive (bio) packaging, reusable and/or recyclable		
Contactors		Use of membrane contactors is already a reality. Possible use on proteins crystallization as a polish step to an operation of filtration	
	Low cost hydrophobic membranes with increased stability	Innovative low cost modules with improved fluid dynamics and higher membrane surface per unit volume	Use of membrane contactors to achieve highly concentrated liquid food with benefits in fresh food shelf-life and lower cost for distribution (i.e. use MC as a post treatment step after RO)
		Innovative modules able to face highly concentrated puree	Use of membrane contactors as a new product formulation and co-products valorization process, including highly purified water

For membrane contactors, a strong action is needed to convince industrialists since competitive technologies are already working well.

Proof of the suitability of membrane contactors as a new formulation process (e.g. concentrating liquid beverage up to an osmotic pressure able to increase shelf-life of fresh food, valorization of co-products via crystallization, production of highly purified water)

Roadmap presentation
Food

Innovative membrane based processes in food production and processing (3/3)

	Membrane	*Modules*	*Process*
Sensors	✗ Limited developments required since other sensors technologies work well and have many capacities: on line, in-situ control…		
	Development of biohybrid membrane systems as biosensors for food applications (e.g. packaging, food safety and quality testing, etc.)		
Affinity membranes	Functionalized micro structured membranes with controlled organization of functional components	Modules with improved properties in terms of paths and residence time	Development of continuous membrane separation process (instead of chromatographic operation mode)

Work on large scale applications to facilitate membrane implementation and allow them to substitute ion exchange resins and other competitive technologies, such as preparative chromatography

Proof of the suitability of affinity membranes for fractionation and purification

Roadmap presentation
Food

Integrated membrane processes (1/2)

Membrane	*Modules*	*Process*
Improve pore size distribution	Modules with standard properties (e.g. size, connectors, etc.)	Optimize pre filtration to preserve product texturation and the process continuation
t Optimize pores to achieve a more precise fractionation of products in a limited ground surface → work on surface functionalization with proteins or other compounds	Design of new configuration of membrane assembling to intensify processes	Proof the robustness of integrated processes (hybrid membrane systems or together with other systems) with selected reference cases (juice, milk, wine, production of potable water, etc.)
Cope with issues of different texture of fluids treated during pre-concentration		t Integrate bioconversion and bio processing with membrane operations into productive and separative cycles
		t Develop innovative manufacturing/ processing lines able to move towards zero discharge/emission

Roadmap presentation
Food

Integrated membrane processes (2/2)

- Develop efficient cleaning procedures with limited water required and low costs in order to deal with the sterilization issue
- Reduce development time to fit with industrial constraints and competitiveness needs
- Strong need to have pilot plants to check results
- Anticipate the evolution of membrane performance with time
- Develop processes that allow meeting new regulations in terms of food safety, quality, waste minimization, environmental impact

Roadmap presentation
Food

Membrane emulsification and encapsulation

Membrane	***Modules***	***Process***
Inorganic membranes with pore size < 10 nm, uniform pore size distribution, geometric pore location on the membrane surface, mechanically resistant	Modules with standard properties (e.g. size, connectors, etc.)	Modeling of emulsification and encapsulation processes, scalable processes, processes compatible with aseptic and sterile conditions, high temperature (for sterilization), cleaning agent
Membranes with controlled pore size distribution	Design of new configuration of membrane modules and operation (e.g. rotating modules)	Thorough understanding of droplet process formation through understanding of process parameters
		Innovative product formulations (e.g. having low fat content, with nutraceutical properties, etc.)

Production of uniform micro-emulsions on a large scale (droplet size < 50 nm)

Production of controlled size distribution emulsions and capsules on a large scale

Roadmap presentation

Food - Overview

Topics discussed	*Start up drivers*	*Membranes*	*Modules*	*Process*	*Modeling*
Innovative membrane based processes in food production and processing					
Bio reactors					
Packaging					
Contactors					
Sensors					
Affinity membranes					
Integrated membrane processes					
Membrane emulsification and encapsulation					

External context

Strong industry imperatives: 1. Membrane technologies costs are too high, especially in comparison with other competitive technologies. 2. Time is a huge imperative in the food industry. As it is a consumer good industry, membrane technologies need to be developed quickly and implement quickly on production lines.

Development directions: 1. Developments should focus on existing membrane technologies to improve them & on operations that are already run in factories. 2. Sensors or packaging membranes could not impose today easily as many other techniques do exist, work well and have a low cost of use.

Roadmap presentation
Health

Workshop: Chemicals

Workshop: Energy

Workshop: Environment

Workshop: Food

Workshop: Health

Workshop: **Membrane materials**

Roadmap presentation
Health

Membranes are playing an increasing role in health through bio-separations and artificial organs. Time-realised delivery of drugs, hormones and other medicinal substances can be administered by means of rate-controlling membranes: patches, tablets or capsules composed of a central medicinal core surrounded by a membrane. Artificial and bio-artificial organs are also very quickly developing due to the increase of the population mean age and also due to the access to medicine of more and more people in the world (particularly in developing countries). Haemodialysis (artificial kidney technology) is probably the single most widespread and recognizable medical use of membranes. The single US market for drug delivery, artificial organs, sensing devices and guided-tissue regeneration is expected to rise from 1.3 billion $ in 2002 to about 2.2 billions $ in 2009. Like in other areas (chemicals, environment), separation and reaction (downstream bioprocessing, cell culture) for pharmaceutical production involve more and more membrane technologies. Sterile filtration, microfiltration, MW separation, environment charge and affinity purification are notably the most commonly used membrane technologies in the frame of biological industries. All these new tools are today of a main importance to guarantee health of people and to reduce social costs related to healthcare.

Roadmap presentation
Health

Bio-separation

Membrane	*Modules*	*Process*
Membranes for pharmaceutical production		
t Work on membranes resistant to aggressive and strong cleaning procedures in terms of: pressure, temperature and stretching	Develop single use devices (SUD)	Manage antigenic products created by cleaning procedures
t Mixed Matrix Membranes (MMM) containing particles with specific functionality (charge, chemistry, ligands etc) incorporated into polymer matrix	Development of modules (flat sheet or hollow fiber) with MMM	Develop processing limiting viral contamination: work on pumps, reduce pressures…
t Nanoporous fiber membranes for capillary electro-chromatography (CEC)	Development of fiber modules for separation of large amounts	

Biodegradability has to be considered in years and not in weeks

Combine membrane technologies in order to make them ready to go through clinical tests → take the regulatory constraints and time frame into account

Roadmap presentation
Health

Bio-compatibility

Membrane	*Modules*	*Process*
Haemocompatibility		
Understand mass transfer phenomena	New module design	Manage antigenic products created by cleaning procedures
Understand blood & membrane interactions	Scale up	Work on kinetics of blood removal to improve the process
Membranes with improved cell interactions (protein repulsive properties, surface geometry…)	Mass transfer modeling	Manage the need of ultra pure water to balance fluid extracted volume
Improve membranes for the ultra pure water management (UF)		
Work on membranes more resistant to sterilization		
No more research is needed on polymers since 2 different ones already exist and work well		

Develop more effective filtration technologies to decrease the amount of liquids treated and then time of treatment for patients

The development of membrane artificial devices has to be considered in years and not in weeks

- Do not limit to membrane filtration but be focused on a global system to add price premium to the technology
- Reach a milestone in the scale up capabilities (from 40g of cells from an artificial liver to 300g for a real liver)
- Include blood specialists in the network
- Take advantage on the parallels between artificial liver and other artificial organs for development

Roadmap presentation
Health

Artificial organs

Membrane	*Modules*	*Process*
Membranes for blood purification		
Mixed Matrix Membranes (MMM) containing particles with specific functionality (charge, chemistry etc) incorporated into polymer matrix	Development of modules (flat sheet or hollow fiber) with MMM	
Membranes for portable kidney		
Membranes to mimic natural kidney: To be used 24/7 – suitable biocompatibility and porosity, no fouling, regulation of ions (phosphates etc), no toxin back-diffusion	Development of portable kidney with suitable membrane area, hydrodynamics, etc.	
Membranes for bioartificial systems		
Membranes able to activate specific cellular functions and to develop microenvironment similar to that *in vivo*	Membrane configuration on the basis of the bioartificial systems (e.g., liver, neurons, pancreas, skin)	
Improvement of cell-membrane interactions by changing membrane properties (porosity, pore size, wettability) and by biomolecule immobilisation	Module design with control of fluid dynamics conditions and mass transfer to maintain cell viability and functions	

Biodegradability has to be considered in years and not in weeks

Combine membrane technologies in order to make them ready to go through clinical tests → take the regulatory constraints and time frame into account

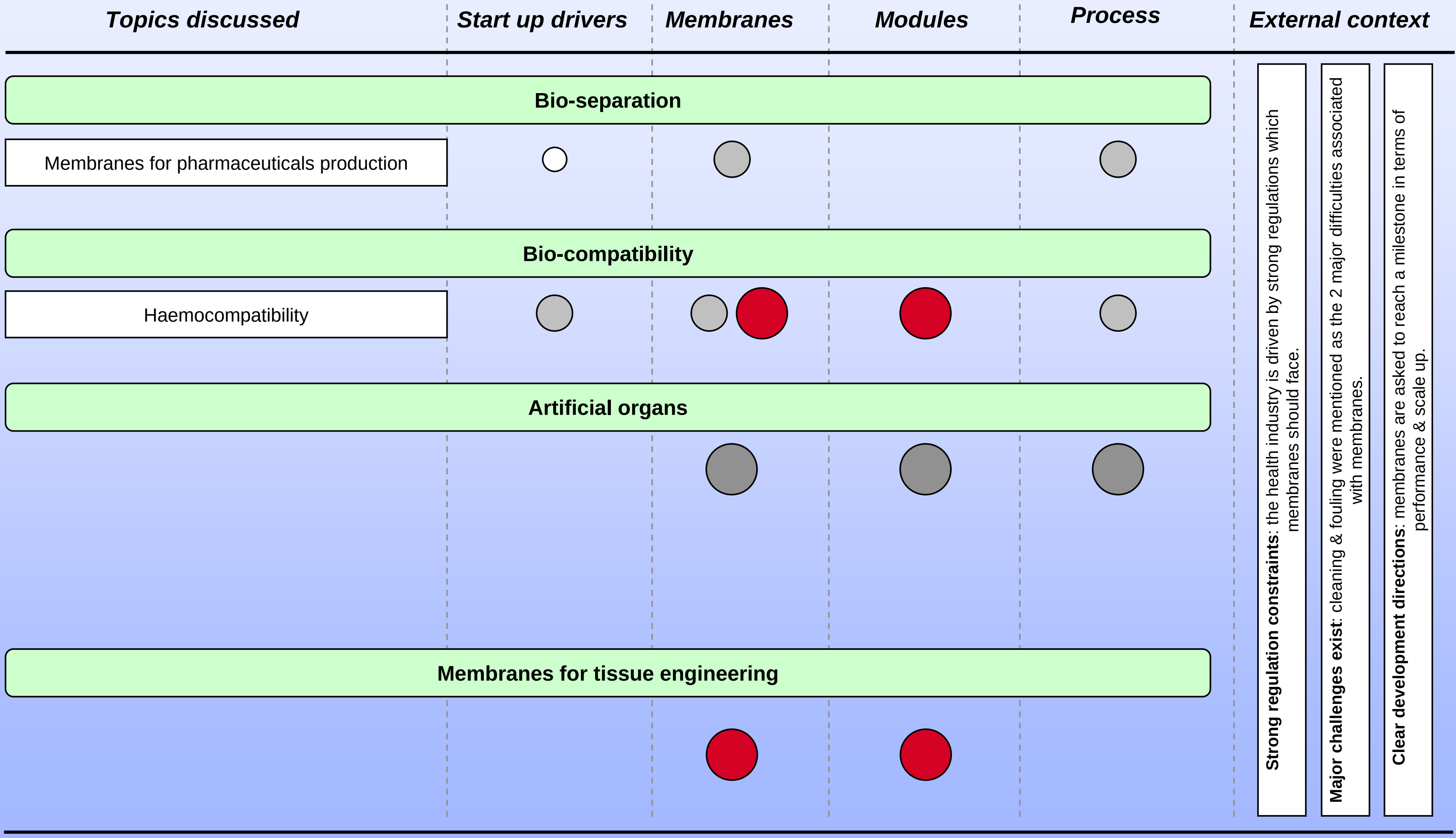
Roadmap presentation
Health

Membranes for Tissue Engineering

Membrane	*Modules*	*Process*
Membranes for tissue engineering	Development of suitable bioreactors for tissue engineering (delivery of nutrients – growth factors to cells etc)	Modeling of bioreactors for tissue engineering
Membranes from biocompatible and biodegradable materials (polymers, ceramics) as scaffolds for tissue engineering		
Porous membranes for tissue engineering using various methods (phase separation, salt leaching, electro-spinning)		
3 D porous scaffolds with efficient delivery of nutrients / oxygen to the seeded cells		
Membrane micro-fabrication to regulate cell behavior (cell alignment, proliferation, differentiation)		
Membrane roughness, porosity, micro-fabrication to regulate stem cell differentiation		

Biodegradability has to be considered in years and not in weeks

Roadmap presentation
Health - Overview



Roadmap presentation

Membrane materials

Workshop:
Chemicals

Workshop:
Energy

Workshop:
Environment

Workshop:
Food

Workshop:
Health

Workshop:
Membrane materials

Roadmap presentation

Membrane materials

Membranes are essential to a range of applications: for potable water, power generation, tissue regeneration, packaging, beverages, separations needed for the chemical, car, and electronic industries. Beyond their traditional function in separation, other demands have appeared for specific uses in reaction (catalysis), phase contacting (membrane contactors), with vastly different rates according to the sector of application. Membranes with specific surface properties - hydrophobicity, hemocompatibility, oleophobicity, functionalised with specific ligands -, increased robustness - able to resist to solvents, to various cleaning agents, to endure high temperature or extreme pH conditions -, improved selectivity without flux loss, usable in standard host modules, are also strongly required in various areas. To answer all these requests various materials - polymers, ceramics, metal, hybrid - are available as well as different methods to prepare thin layers. Modeling and simulation have become a powerful tool to understand mechanisms and predict performance under given working conditions.

Roadmap presentation
Membrane materials

Inorganic membranes and manufacturing processes - Ceramic and zeolites

Membrane	*Modules*	*Process*
Ceramic membranes		
t Work on keeping membrane resistance while decreasing cut-off		
t Develop hydrophobic membranes		
Work on nanofiltration with solvent rather than water		
Work on abrasion issues in UF (enhance resistance to abrasion caused by small crystal erosion)		
Zeolite membranes		
New zeolite and related materials with improved properties in separation	Develop large scale modules (1000's m^2)	Work on scale up and procedures
	t Build a pilot that proves and describes a functional module	

Application of ceramic membranes for aprotic solvent treatment in resin condensation and in reactions in an oxidative environment

For supercritical CO_2 applications, zeolites may be more performing than polymeric membranes

The benefit of zeolite membranes should be clear and the goal reachable. Zeolites are considered to be late compared to ceramics that already are on the market. There is a lack of vision about zeolites for membrane and module production

Roadmap presentation

Membrane materials

Inorganic membranes and manufacturing processes – Oxide and metallic membranes

Membrane	*Modules*	*Process*
Oxide membranes		
No development needed on new (porous) materials	Tests required to show a membrane fits standards and quality control tests to prove membrane reliability	
Decrease price and enhance stability	Work on manufacturability issues	
Improve dense (mixed ion-electron conducting) membranes performance and stability		
Metal membranes		
Work on membrane robustness and on resistance to pressure and shock		Need for scale up support
Palladium membranes		
Improve resistance to the "on/off" cycle in micro reformers	Decrease the price of module that is more expensive than membrane	
Design membranes for reformers	Look at the membrane support (which may have been under-estimated)	

Applications may be on power and electricity production

For oxide membranes, Europe is behind as it is still trying to find new materials (research focus) while in the US million $ are already invested in scale up

Japanese focused their efforts on developing palladium membranes for reformers for toluene gas to produce H2

Roadmap presentation

Membrane materials

Organic membranes and manufacturing processes - Polymeric membranes

Membrane	*Modules*	*Process*

Gas separation

Processes able to work at low pressure and even under vacuum

Retrofitting of membranes & engineering to adapt modules to the boiler power plants

Fuel cells

t Enhance proton exchange capacity for catalytic applications and deal with water management

Drug release

t Enhance hydrophobicity by functionalizing membranes

Pervaporation

Increase PVA working temperature to 200°C (for pressurized liquids) and hydrothermal stability

Decrease module cost (large amounts of stainless steel are currently needed)

NF/UF

Need of a 200D cut-off

t Work on stability in temperature (no swelling)

t Continue on sharp cut-off self assembly block copolymers (porous, isoporous …)

t Work on module geometry, stability and reproducibility

Develop quality control and predictability tools

Roadmap presentation
Membrane materials

Mixed matrix membranes and manufacturing processes

Membrane	*Modules*	*Process*
Work on ceramic support + polymeric membrane outside to enhance the resistance for NF		
Mesoporous materials with pore wall modified by organic molecules		
Membranes with room temperature ionic liquids		

Zeolite hybrid membrane

Membrane	*Modules*	*Process*
Decrease binding process costs		
Increase compatibility between zeolite and glassy polymers to prevent phase separation at temperature, time and pressure by functionalizing zeolite surface		

Titanosilicate hybrid membrane

Membrane	*Modules / Process*
Continue on Ti-oxides tiny particles coating and blending in polymeric membranes	Perform tests to enhance selectivity on butane / methane and CO_2 / methane separation

Explore the potential of hybrid membranes to eliminate the high temperature manufacturing of high purity alumina support

Roadmap presentation
Membrane materials

Modeling and simulation for improved material design

Membrane	*Modules*	*Process*

Continue on simulation of pore blocking and fouling from SEM imaging

Work on stronger predictive models for degradation of the membrane

Continue on database building for species interaction and impact on fouling

Explore the limits of separation/permeability properties for polymeric and zeolite membranes

Reconstruct in 3D membrane materials for easier identification of internal morphologies

Investigate the role of membrane properties in process modeling, design and engineering

Roadmap presentation

Membrane materials - Overview

Topics discussed	*Start up drivers*	*Membranes*	*Modules*	*Process*
Inorganic membranes and manufacturing processes				
Ceramic membranes		● (grey)		
Zeolite membranes	● (grey)		● (grey)	○
Oxide membranes (porous)			○	○
Oxide membranes (dense)		● (red)		
Palladium membranes		○	● (grey)	
Organic membranes and manufacturing process – polymeric membranes -				
Gas separation		○	○	○
Fuel cells		○ ● (red)		
Drug release		○		
Pervaporation		○	○	
NF/UF		● (grey)	○	○
Mixed matrix membranes and manufacturing process				
Zeolite hybrid membranes		● (grey)		
Titano-silicate hybrid membranes		○	○	○
Modeling and simulation for improved material design				
	○	● (pink)		● (grey)

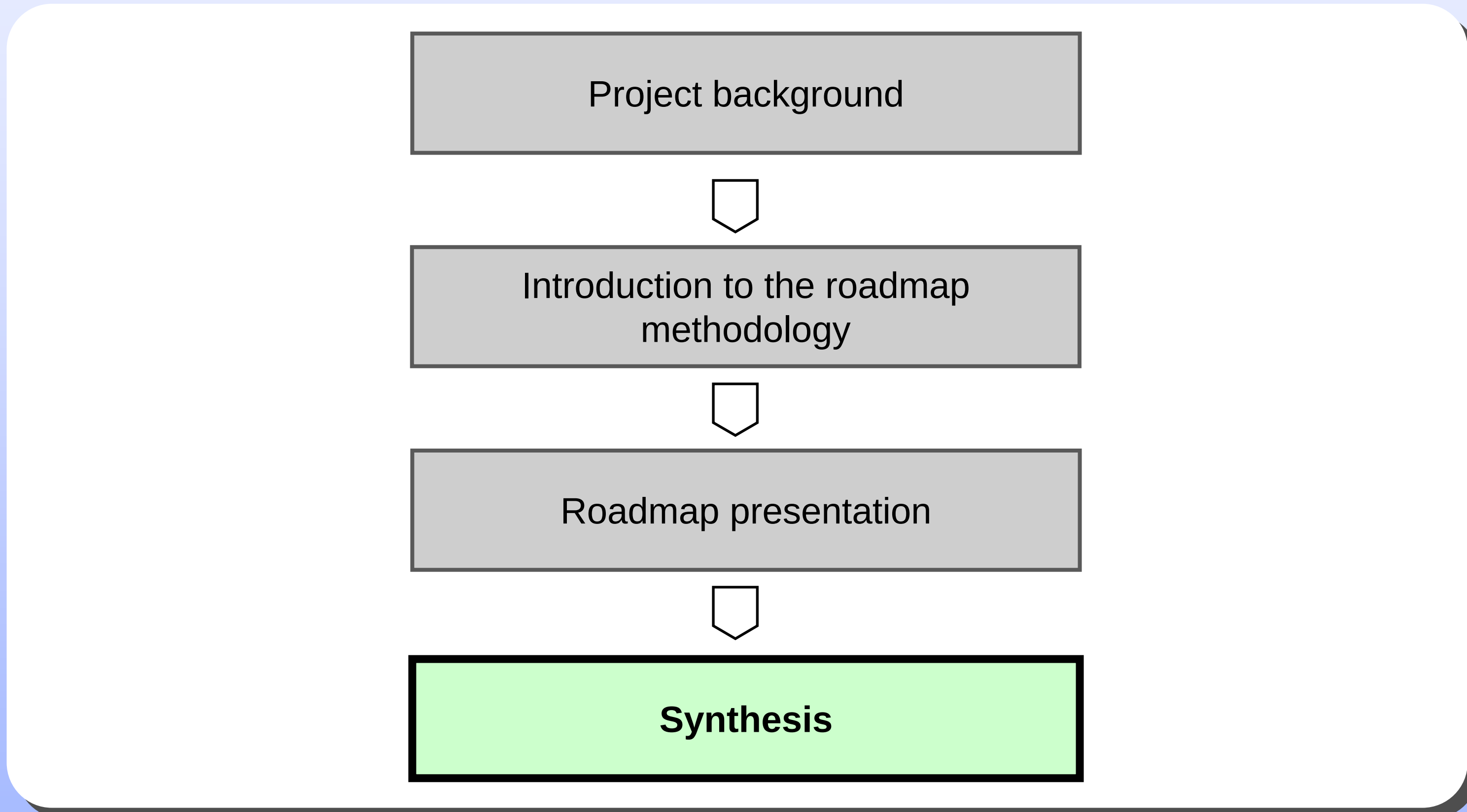
External context

Costs are too high: 1. Technology cost is too much expensive to allow its implementation. 2. The cost issue is transversal as in housing and process have major impacts on the global cost of use of the technology.

Absence of industrial driver: there is no industrial driver to push membrane technologies.

Application opportunities existence: N2/H2 separation membranes & air O2 enrichment have been mentioned as market opportunities.

Synthesis


Project background
Introduction to the roadmap methodology
Roadmap presentation
Synthesis

Synthesis

PRIORITY R&D	TIME FRAME	MARKETS				
		Energy	Environment	Chemicals	Health	Food
FUNDAMENTAL UNDERSTANDING AND NEW MATERIAL SYNTHESIS						
Temperature resistance / pressure resistance / selectivity / flux / aggressive conditions	◊	☑		☑	☑	☑
Hydrophobic membranes	◊	☑		☑	☑	☑
Support material properties	◊			☑	☑	☑
Understanding of membrane properties at a macroscopic level – relationships between properties and materials	◊◊	☑		☑		☑
Disposable membranes	◊◊◊		☑		☑	
Better membrane chemistry: coating / grafting / pore size…	◊		☑		☑	☑
Separation of organics and water	◊◊			☑		
MANUFACTURING AND PROCESSING						
Stable and operational modules	◊			☑		
Hybrid membrane processes	◊	☑				☑
Processing of membrane materials, manufacturing of membranes without solvent	◊◊	☑	☑			
Decrease the price of modules	◊	☑		☑	☑	
CHARACTERIZATION TOOLS						
Understand the mesoscale level	◊	☑				☑
Understand micro and nanofluidics	◊	☑				☑
Understand the microscale level when cleaning	◊		☑			

Synthesis

PRIORITY R&D	TIME FRAME	MARKETS				
		Energy	Environment	Chemicals	Health	Food
MODELING AND SIMULATION						
Build a common database	⇧	☑	☑	☑		
Build dynamic models	⇧		☑	☑	☑	☑
Improve existing simulation tools	⇧			☑		☑
Monitoring for real time corrections	⇧⇧		☑			
Prediction models	⇧⇧	☑	☑	☑	☑	☑
SCALE UP						
Larger membranes and standard modules	⇧	☑	☑	☑	☑	☑
Energy saving scale up	⇧	☑	☑	☑		
Process control	⇧			☑		☑
COMMUNICATION AND PROMOTION TOWARD INDUSTRIALISTS						
Communication on membrane properties	⇧			☑		☑
Focus on a market to launch the technology	⇧	☑		☑	☑	
Communicate on success stories	⇧	☑	☑			☑
Propose on-stage technologies	⇧	☑				

Synthesis

PRIORITY R&D	TIME FRAME	MARKETS				
		Energy	Environment	Chemicals	Health	Food
EDUCATION AND TRAINING						
Training to handle MBR reactors	◈		☑			
DEMONSTRATION ACTIONS						
Need to prove that a membrane works for a specific application	◈			☑		
Compare membranes with competitive technologies	◈					☑
Pilot plant demonstrations to check results	◈			☑		☑
TECHNICAL AND ECONOMIC EVALUATIONS						
Evaluation of the cost of the technological process / global process	◈		☑	☑		
Process and chemical calculations, definition of operating ranges	◈	☑		☑		

Synthesis

PRIORITY R&D	TIME FRAME	MARKETS: Energy	Environment	Chemicals	Health	Food
REGULATORY AND STANDARDIZATION ACTIONS						
Test protocols to evaluate membrane performance (lifetime)	◊t	☑	☑	☑		
Protocols to correctly use membranes and respect their conditions of use	◊t			☑	☑	
Standardization of membranes and modules	◊t		☑	☑	☑	☑
Guarantees on long term performances	◊t	☑	☑	☑		
CROSS FERTILIZATION						
Collaboration with the technology platforms in Brussels, the fuel cell community …	◊t	☑		☑		
Co-developments between labs and technical institutes	◊t	☑			☑	
Include other field specialists in the network	◊t◊t				☑	☑
LOBBYING ACTIONS						
Lobbying on an energy policy	◊t	☑				
Lobbying Europe to have certification and validation procedures	◊t	☑				