



NanoMemPro

The European Network of Excellence on Nanoscale based membrane technologies

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.

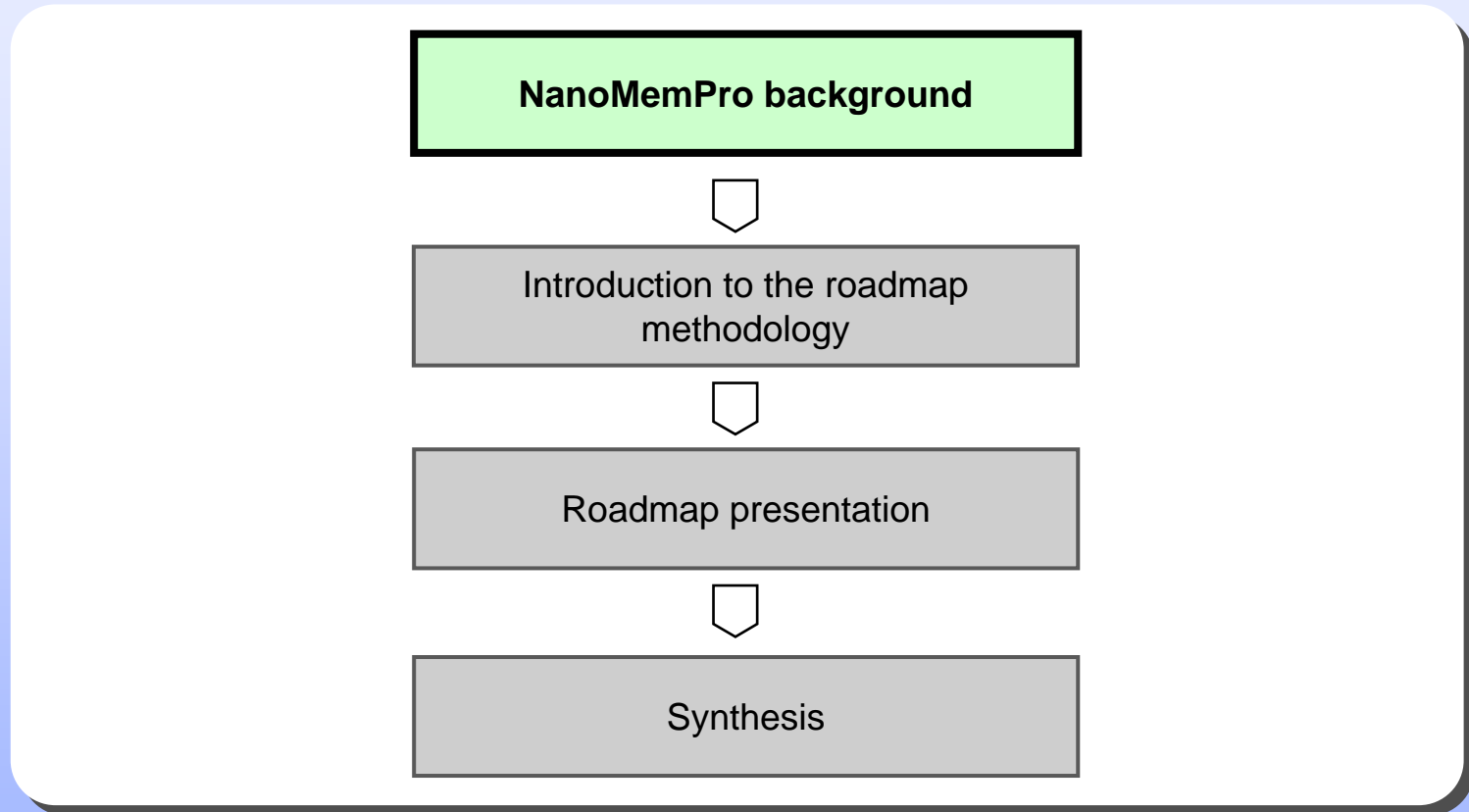
Undoubtedly, this roadmap represents a consensus of the views of the various European actors involved in this domain. It should be used as ground for the Strategic and Business Research Agenda (SBRA) which the Network of Excellence will set up for the years to come. As such it will provide the orientations 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.

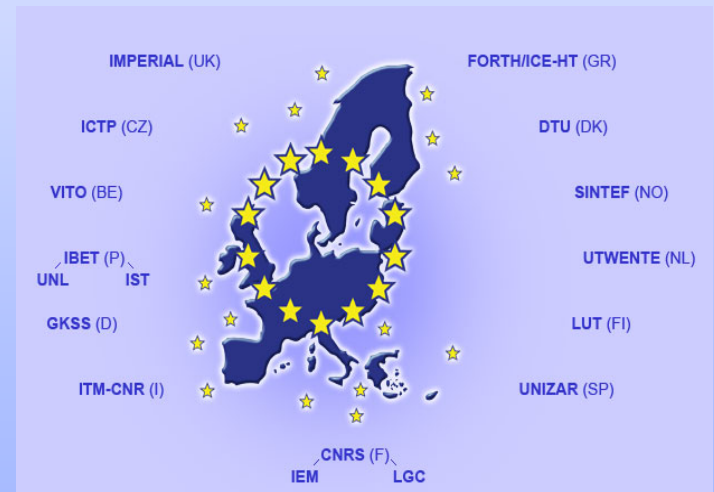
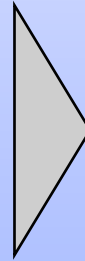
NanoMemPro background

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

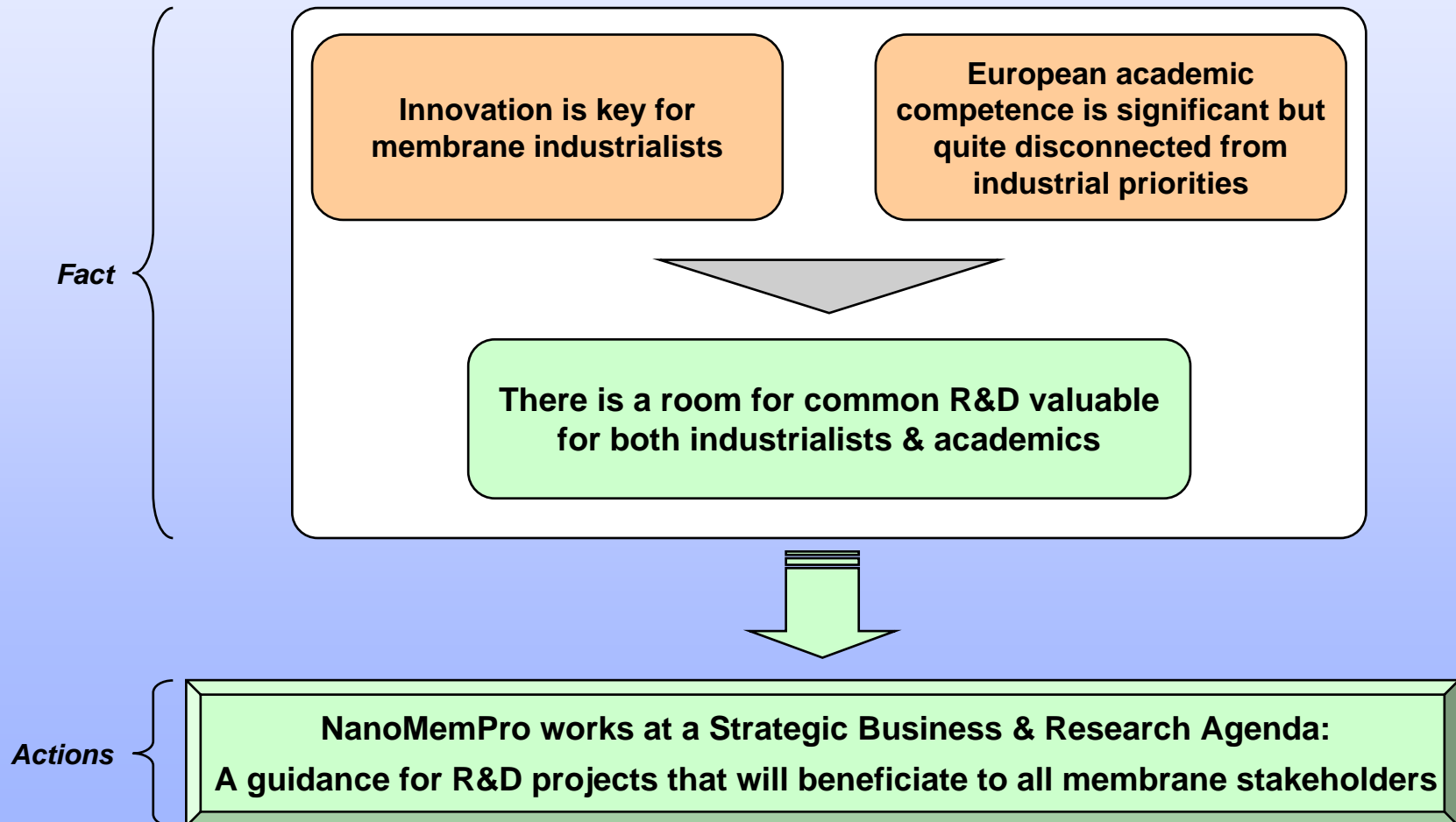
- ⇒ Joint initiative of 13 European partners, all leaders in the field of membrane technologies
- ⇒ Funding by the EC reaches c. 6.4 m€ and comes from the Sixth Framework Program
- ⇒ Launched in September 2004 for a 4 year duration



NanoMemPro background

SBRA: Strategic Business & Research Agenda

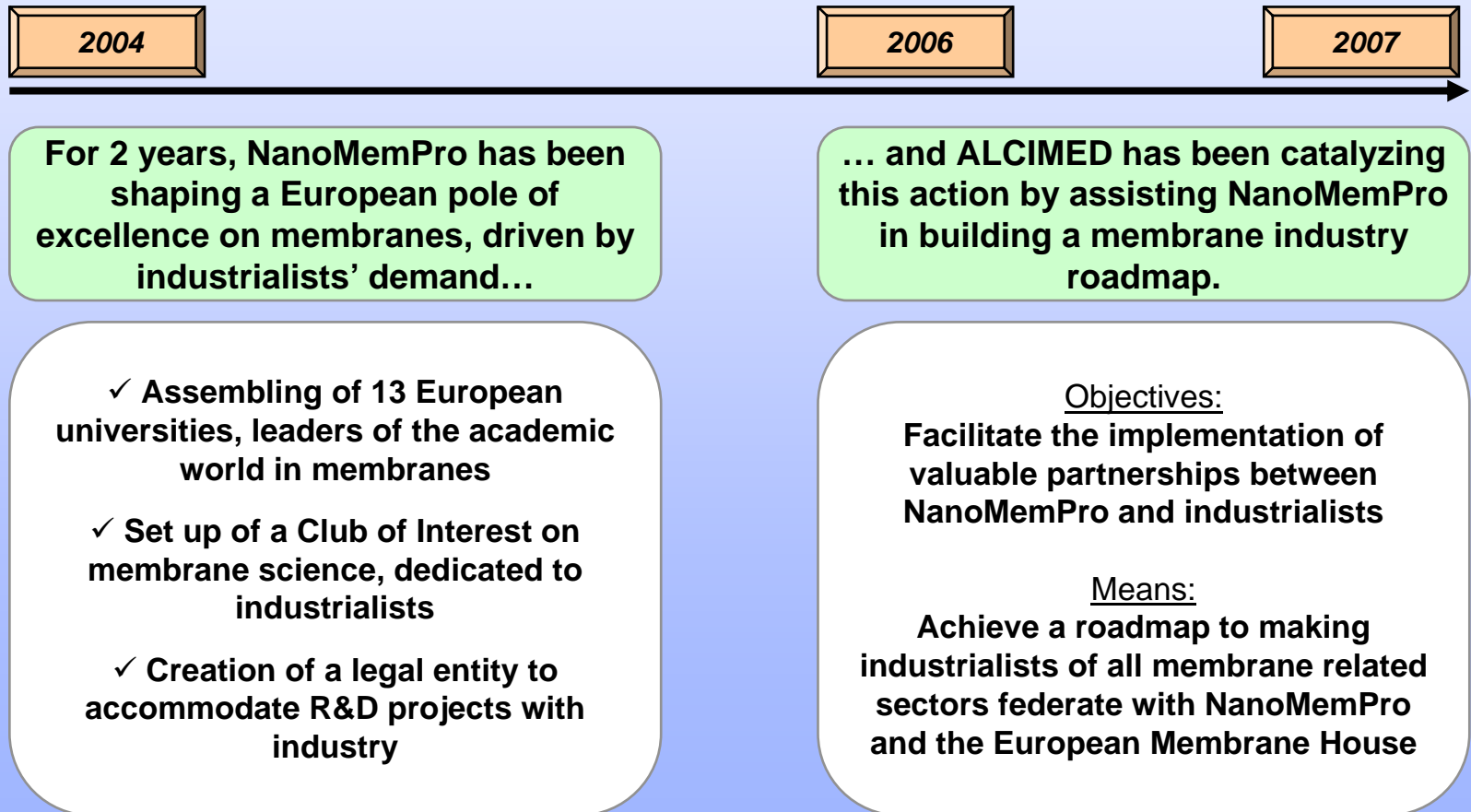
- It is working at its Strategic Business & Research Agenda to detect opportunities to involve industrialists & academics in valuable collaborative R&D projects.



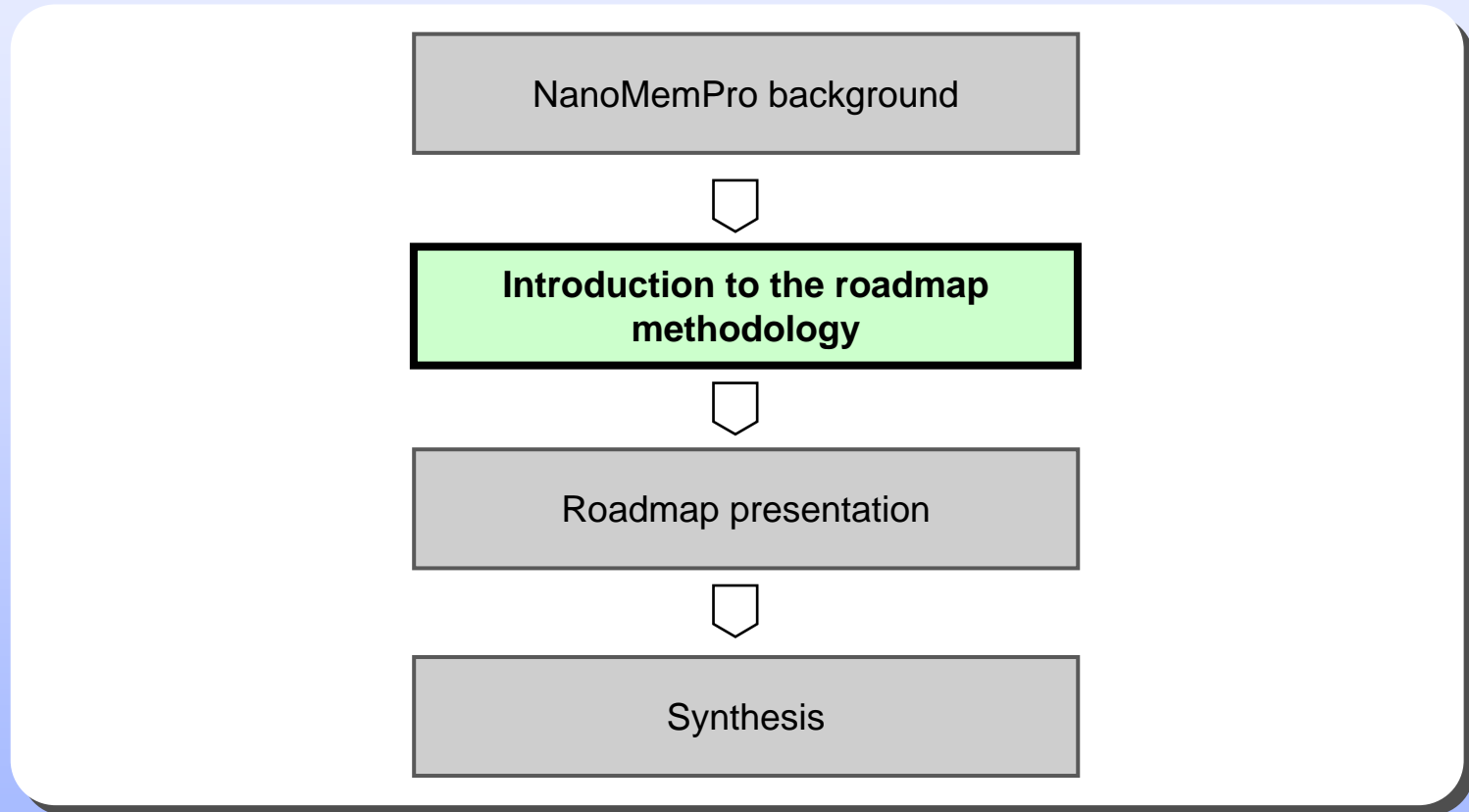
NanoMemPro background

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.

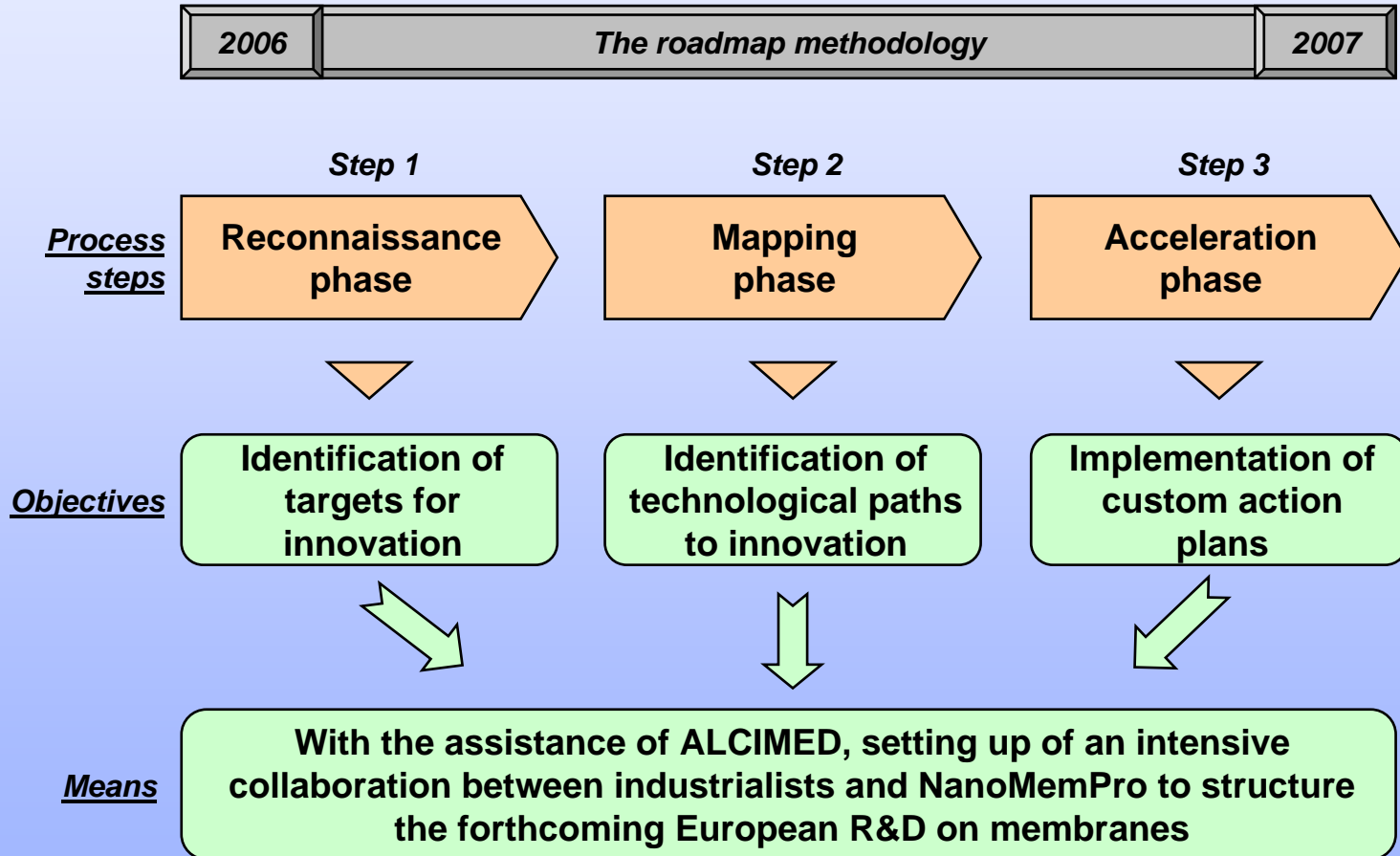


Introduction to the roadmap methodology



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

Sector ↑

Costs

Modeling & simulation

Scale up

Selectivity

Fouling

Resistance

In situ control, new modules...

Membranes coupling with additional processes/ systems

Short term

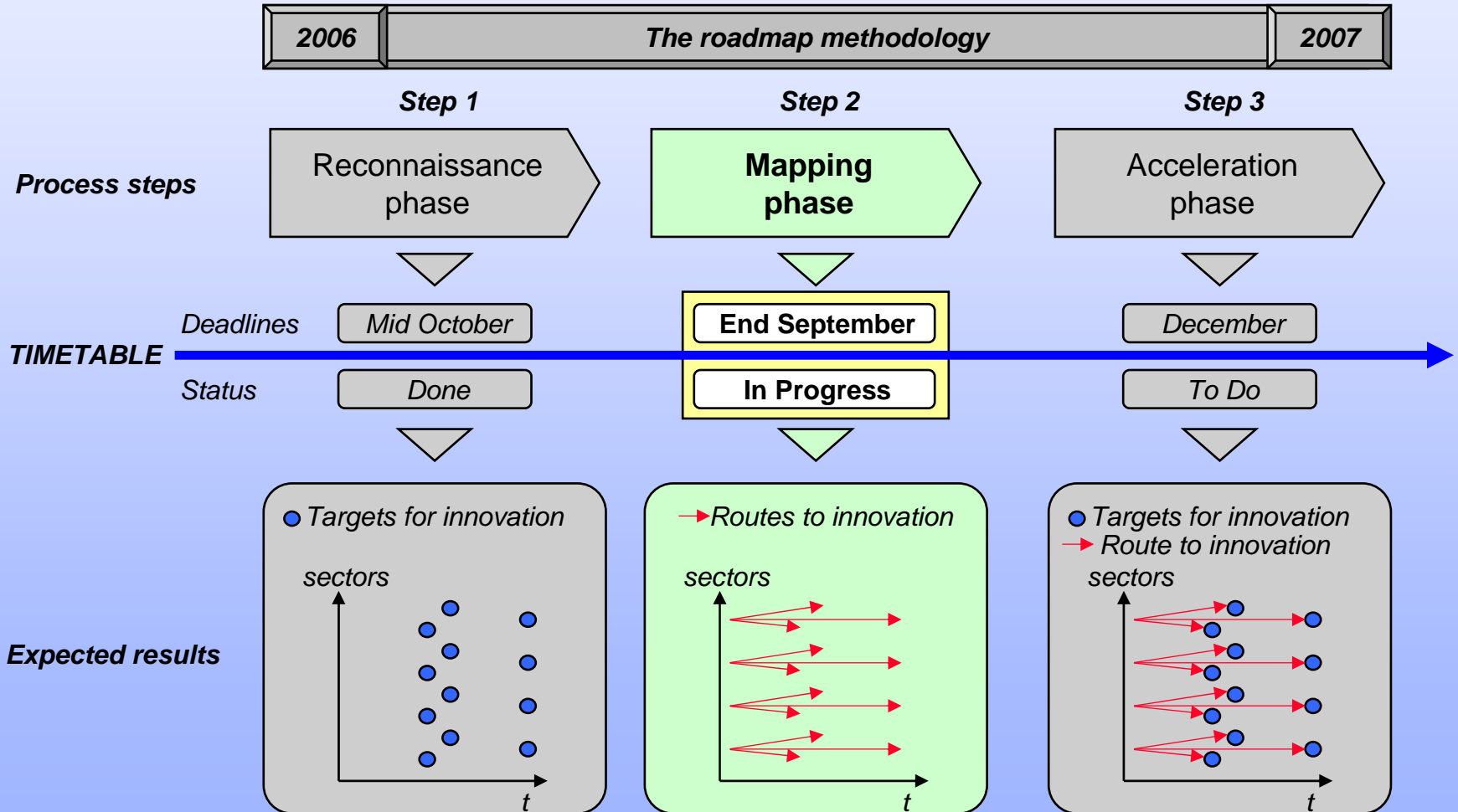
Mid term

Long term → t

Introduction to the roadmap methodology

Mapping phase timetable

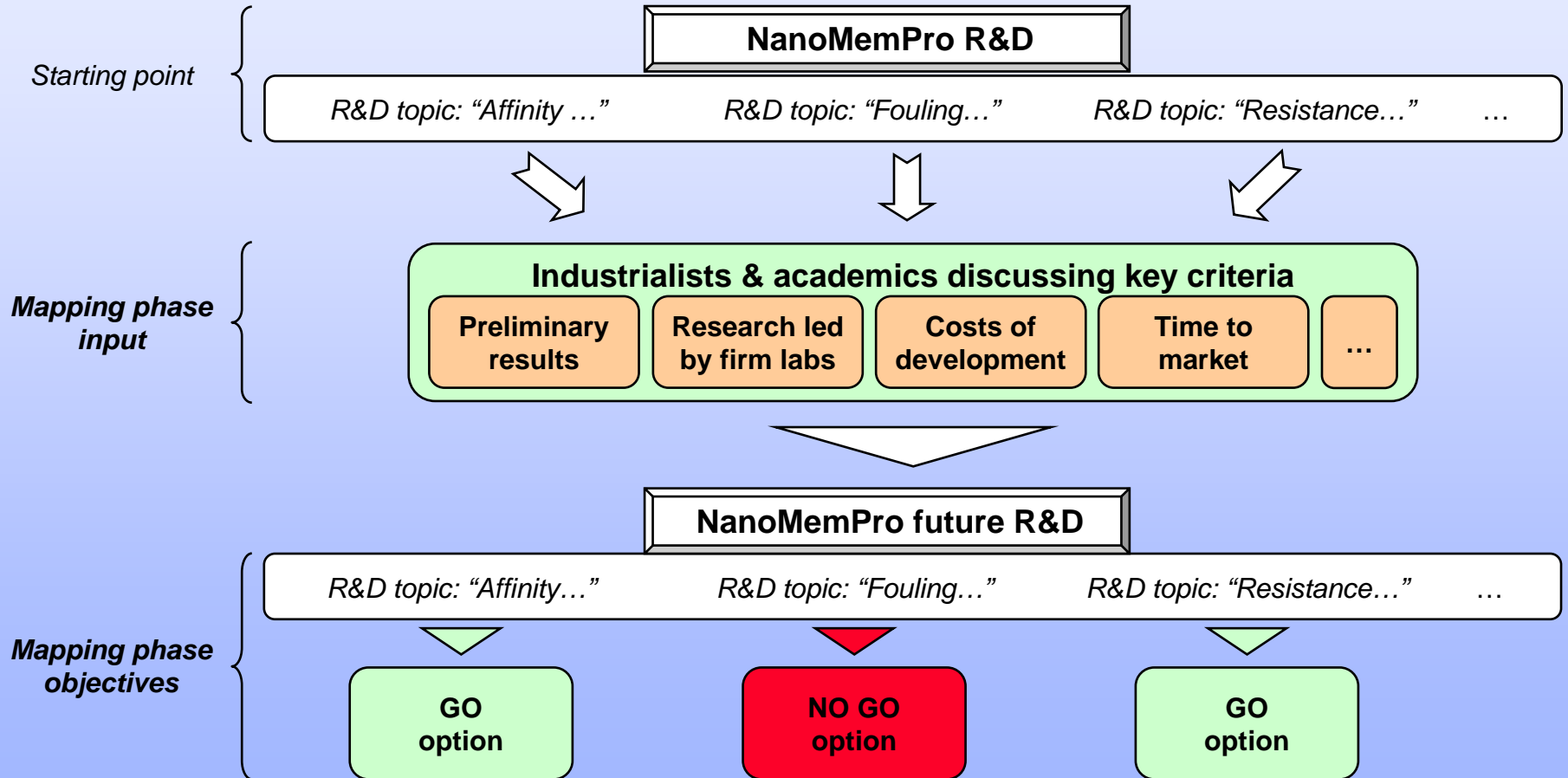
→ The workshops held in February contributed to the mapping phase, the achievement of the roadmap being targeted at the end of summertime.



Introduction to the roadmap methodology

Mapping phase objectives

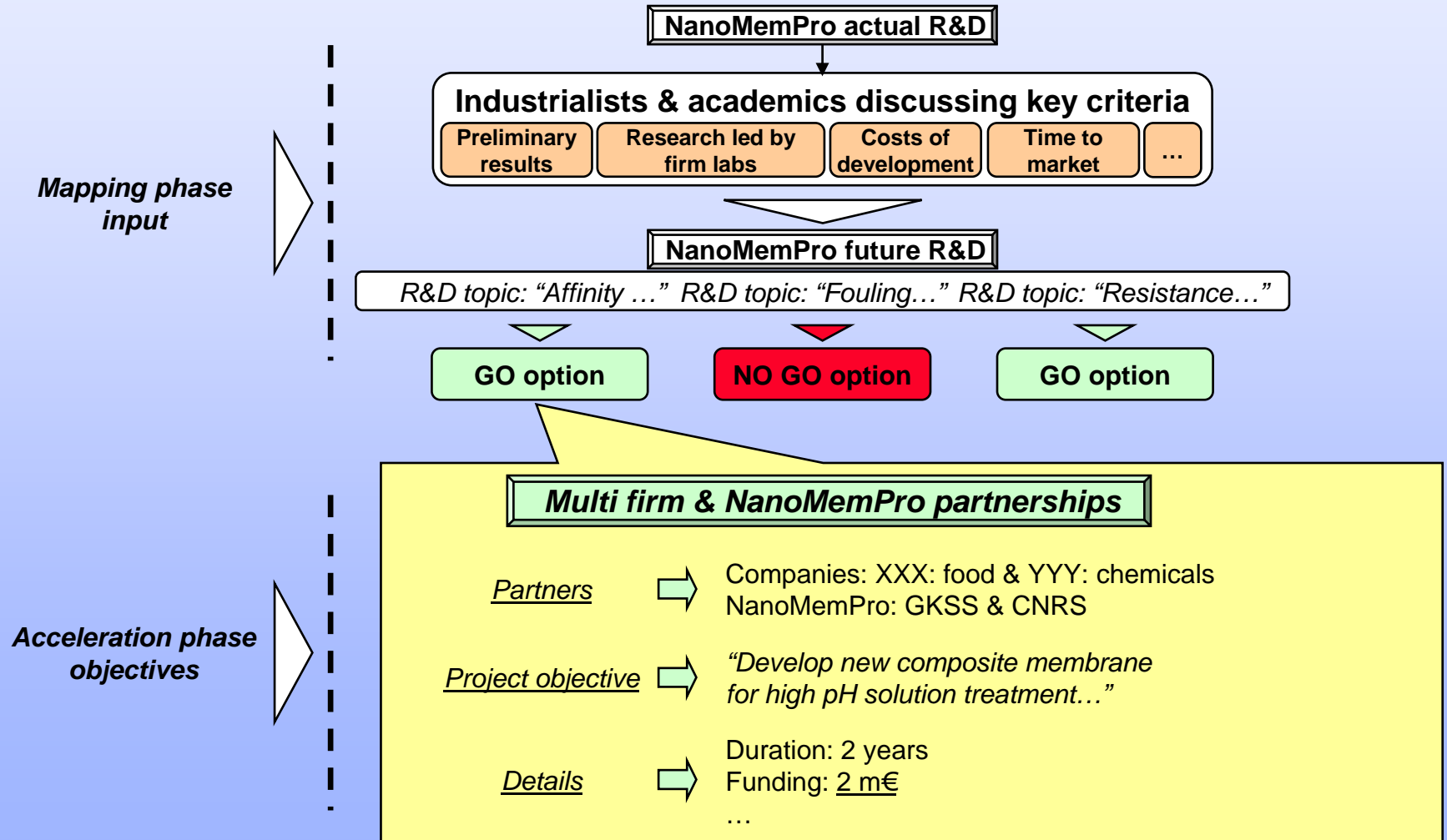
- The mapping phase aims at having a critical vision of NanoMemPro R&D to select the most relevant options considering industrial demand & potential funding.



Introduction to the roadmap methodology

Acceleration phase

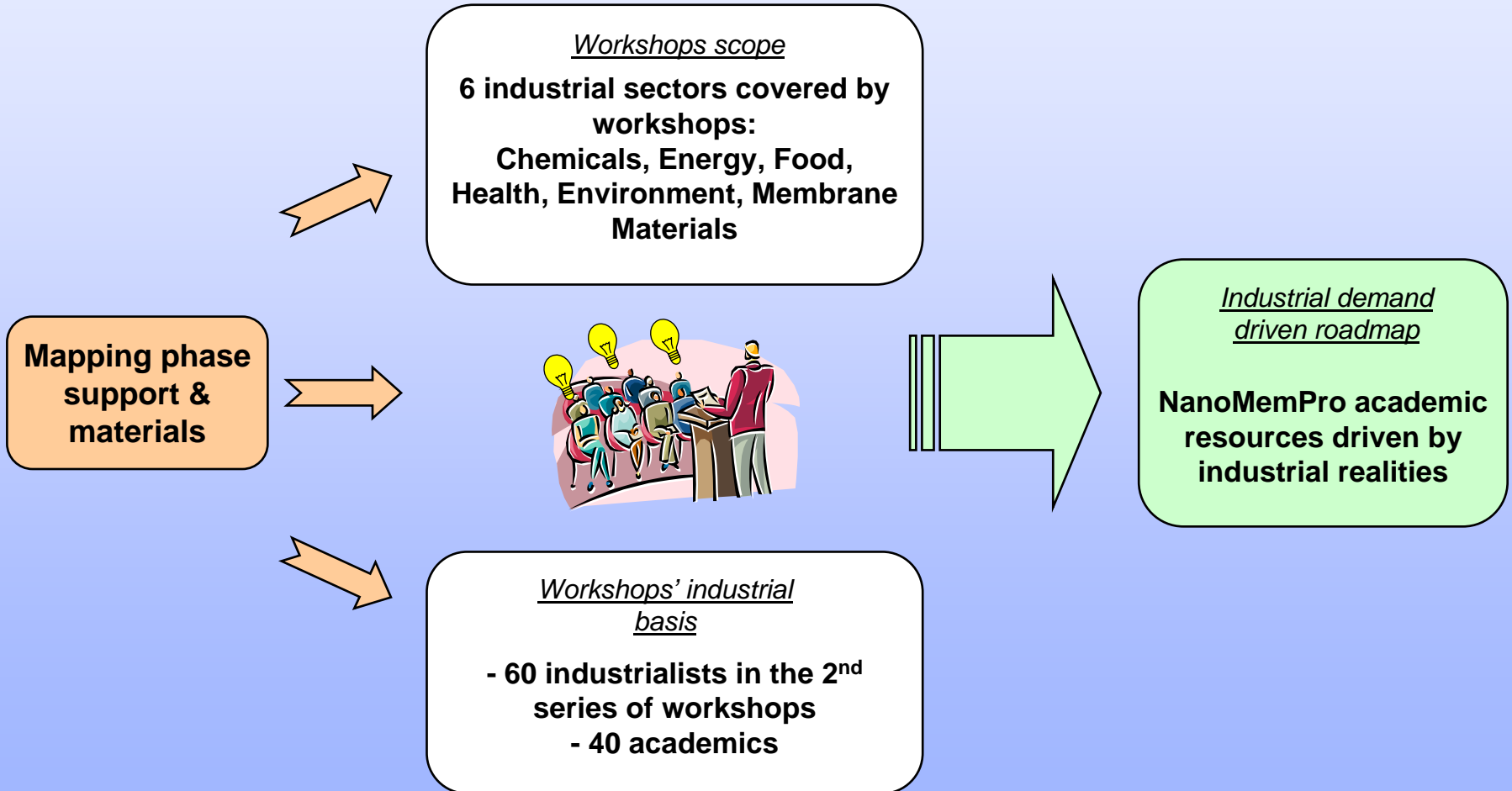
- Common multi firm & NanoMemPro partnerships on R&D projects targeting specific innovations being formalized during the acceleration phase.



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.



Introduction to the roadmap methodology

Mapping phase topics

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

Workshop:
Chemicals

Solvent media
treatment with
membrane
processes

Integration of
membrane
technologies &
process
intensification

New membrane
processes

Monitoring,
modeling, simulation
and process design

Workshop:
Energy

Gas treatment

Batteries and fuel
cells

New membrane
energy production
systems

H₂ and CO₂ new
challenges

Workshop:
Environment

Membranes as "Best
Available
Technologies" for
environmental
issues

Drinking water
membrane
production processes
vs. traditional physico
chemical ones

Membrane
desalination
processes for
drinking water vs.
thermal processes

Workshop:
Food

Innovative
membrane based
processes in food
production and
processing

Integrated
membrane
processes

New packaging

Membrane
processes to control
and improve food
texturation

Workshop:
Health

Bio compatibility

Intelligent
membranes &
medical devices

Separating
processes for the
pharmaceutical
industry

Workshop:
**Membrane
materials**

Inorganic
membranes &
manufacturing
processes

Mixed matrix
membranes &
manufacturing
processes

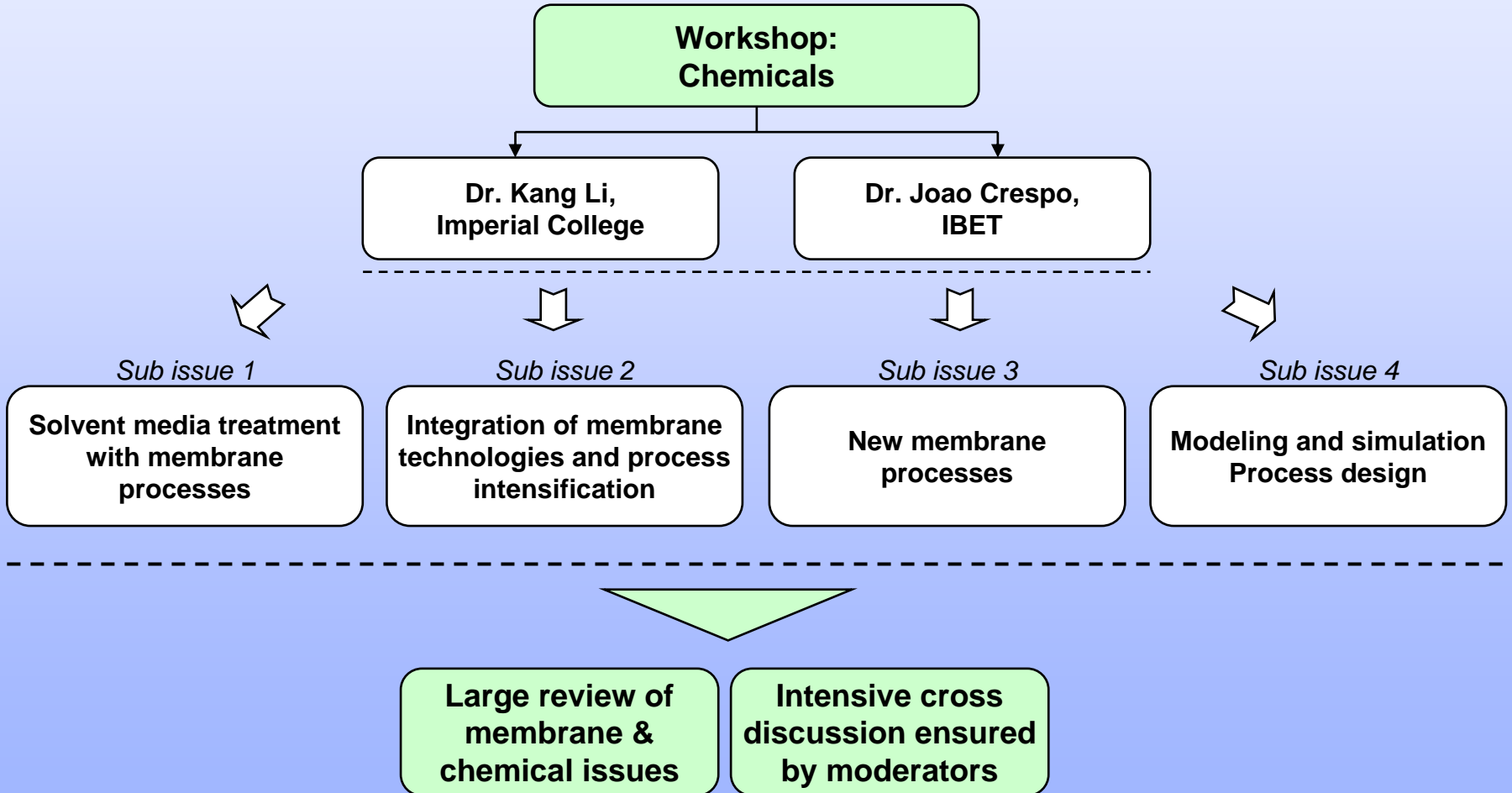
Organic membranes
& manufacturing
processes

Modeling and
simulation for
improved material
design

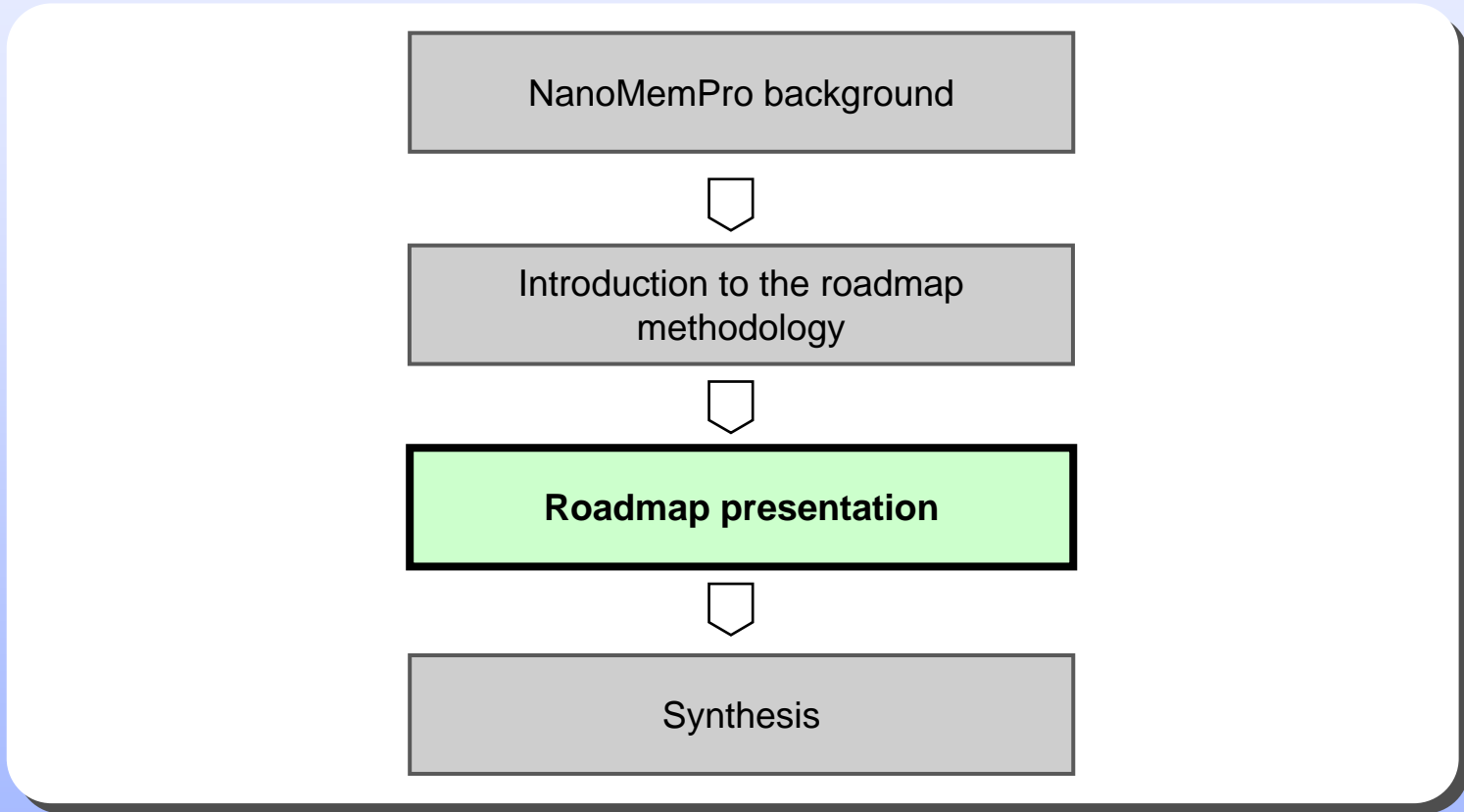
Introduction to the roadmap methodology

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.



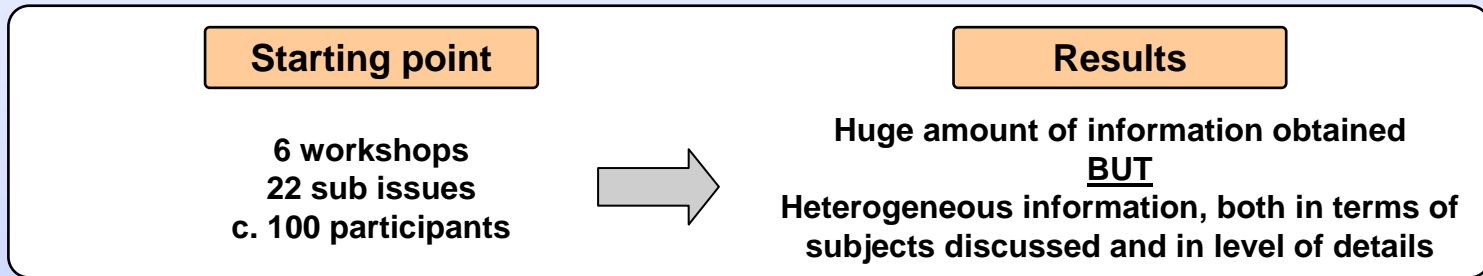
Roadmap presentation



Roadmap presentation

Information treatment

- A segmentation work was achieved in order to reconstitute all the information received during the working sessions.



A segmentation was made to reconstitute 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...

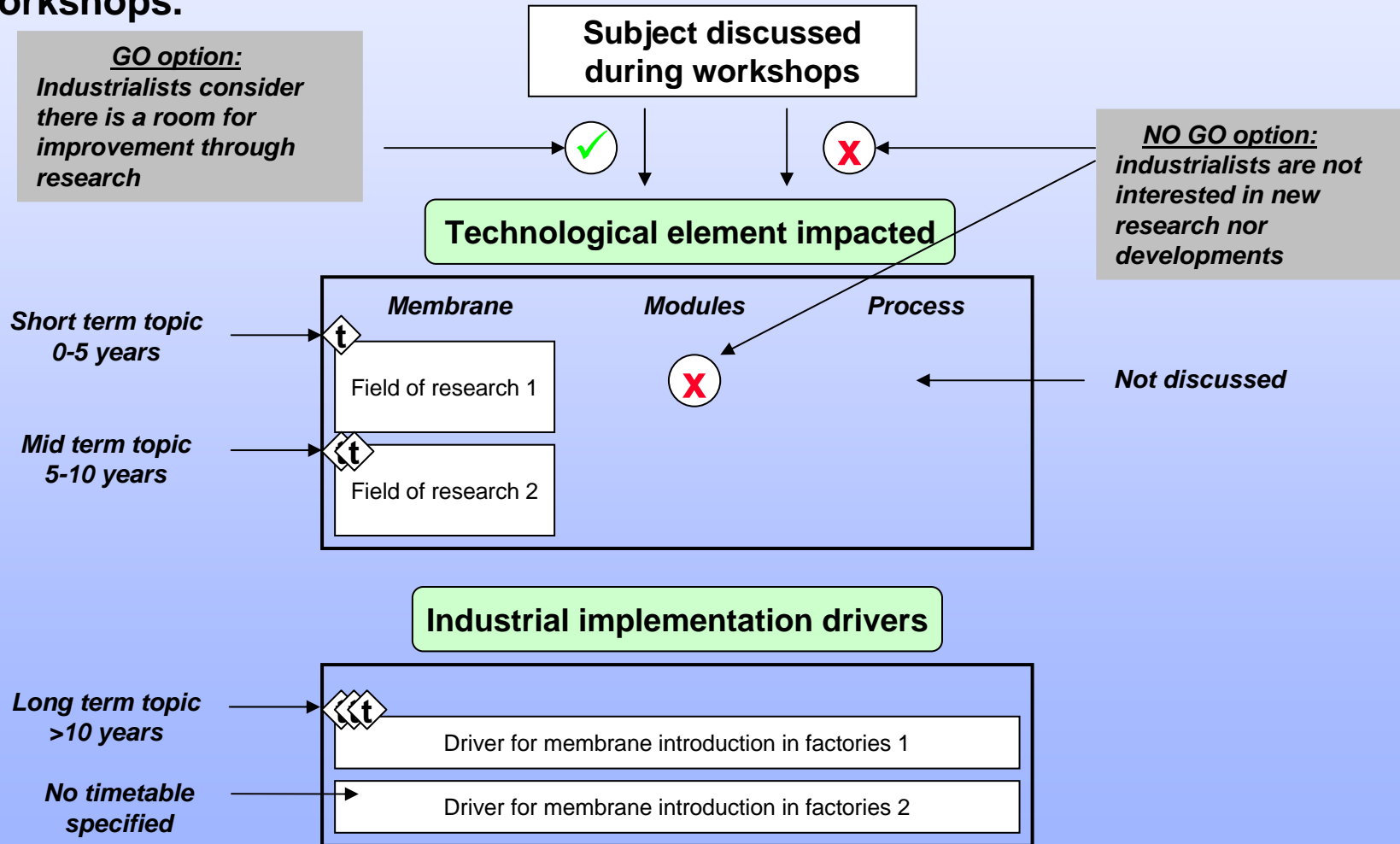
Market & industrial approach

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

Roadmap presentation

Information treatment

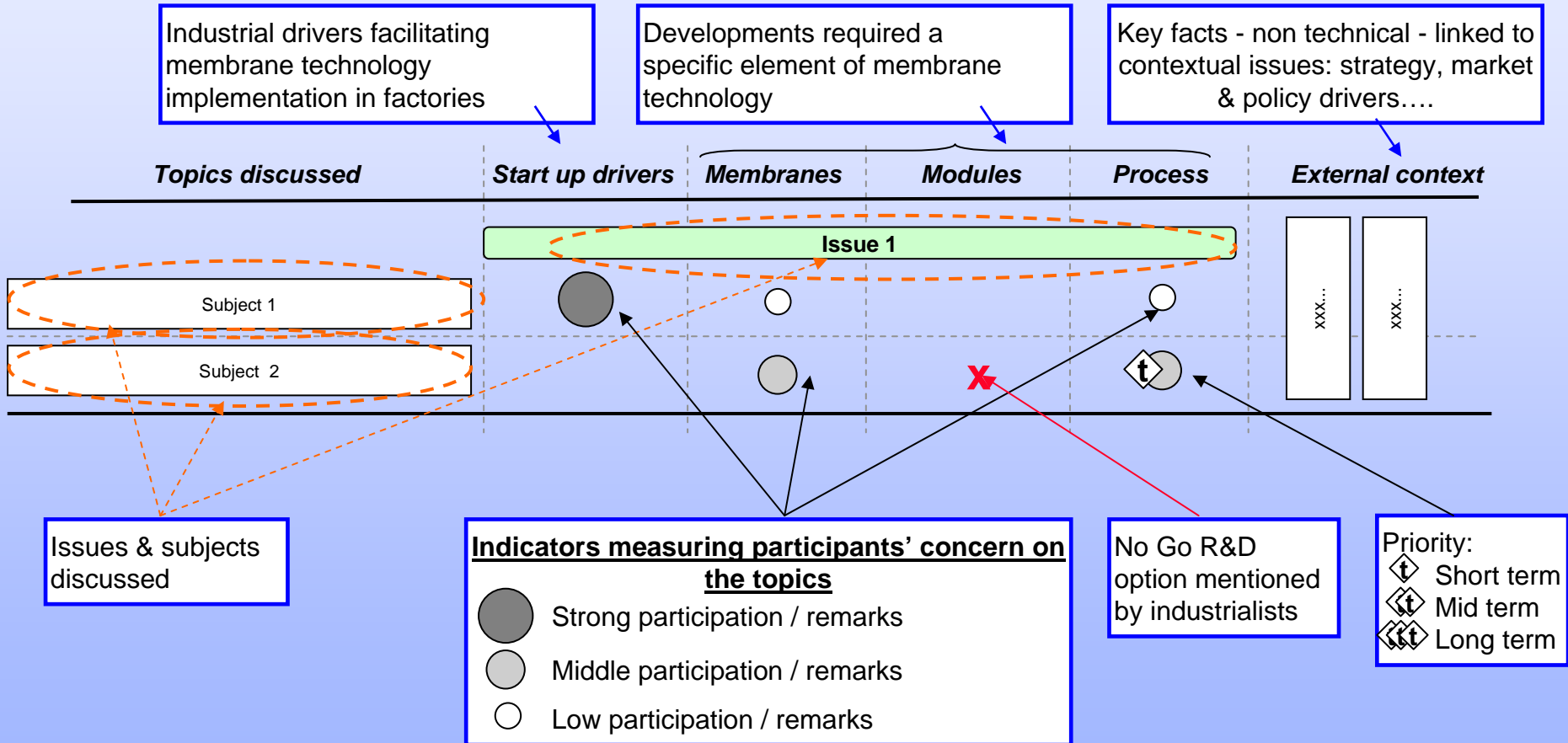
- Each of the 22 subjects discussed was therefore translated into a specific framework giving an exhaustive overview of what was told during the workshops.



Roadmap presentation

Information treatment

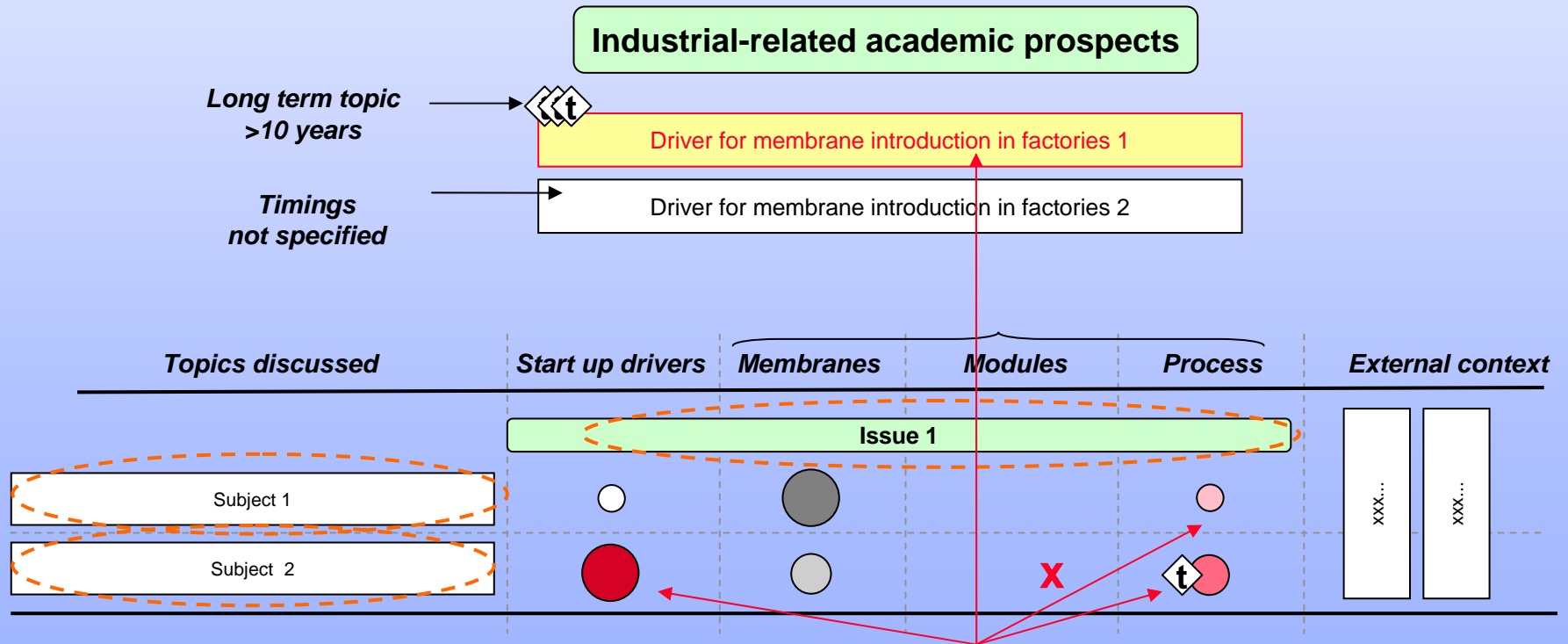
→ Then, for each workshop, all corresponding subject's frameworks were synthesized into a preliminary roadmap.



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

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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



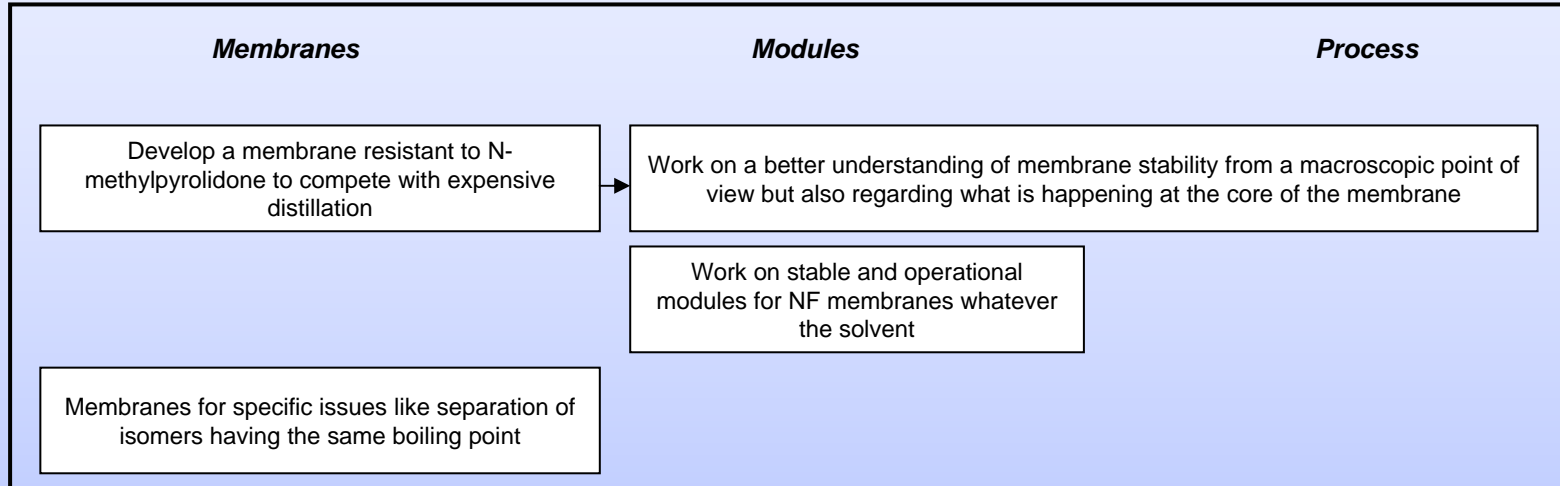
Develop technologies to achieve 100% separation of organics in waste water

Roadmap presentation

Chemicals



Solvent media treatment with membrane processes



- 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

H₂SO₄

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

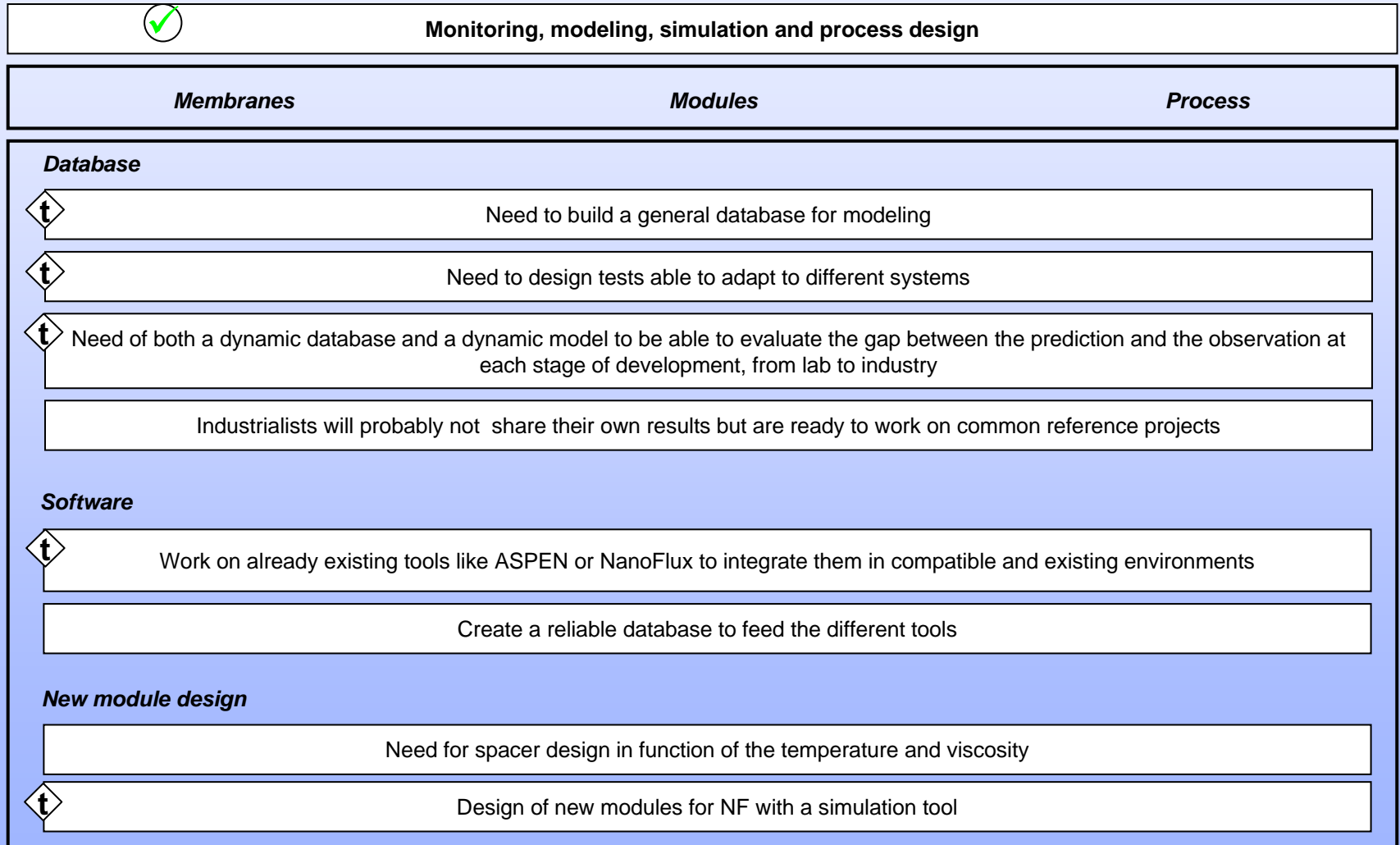
Standardization of membranes is needed in order to have the possibility to easily change modules

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



Roadmap presentation

Chemicals - Overview

Topics discussed	Start up drivers	Membranes	Modules	Process	External context
Integration of membranes technologies and process intensification					<p>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.</p> <p>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.</p> <p>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.</p>
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			○		

Roadmap presentation

Energy

Workshop:
Chemicals

Workshop:
Energy

Workshop:
Environment

Workshop:
Food

Workshop:
Health

Workshop:
Membrane materials

Roadmap presentation

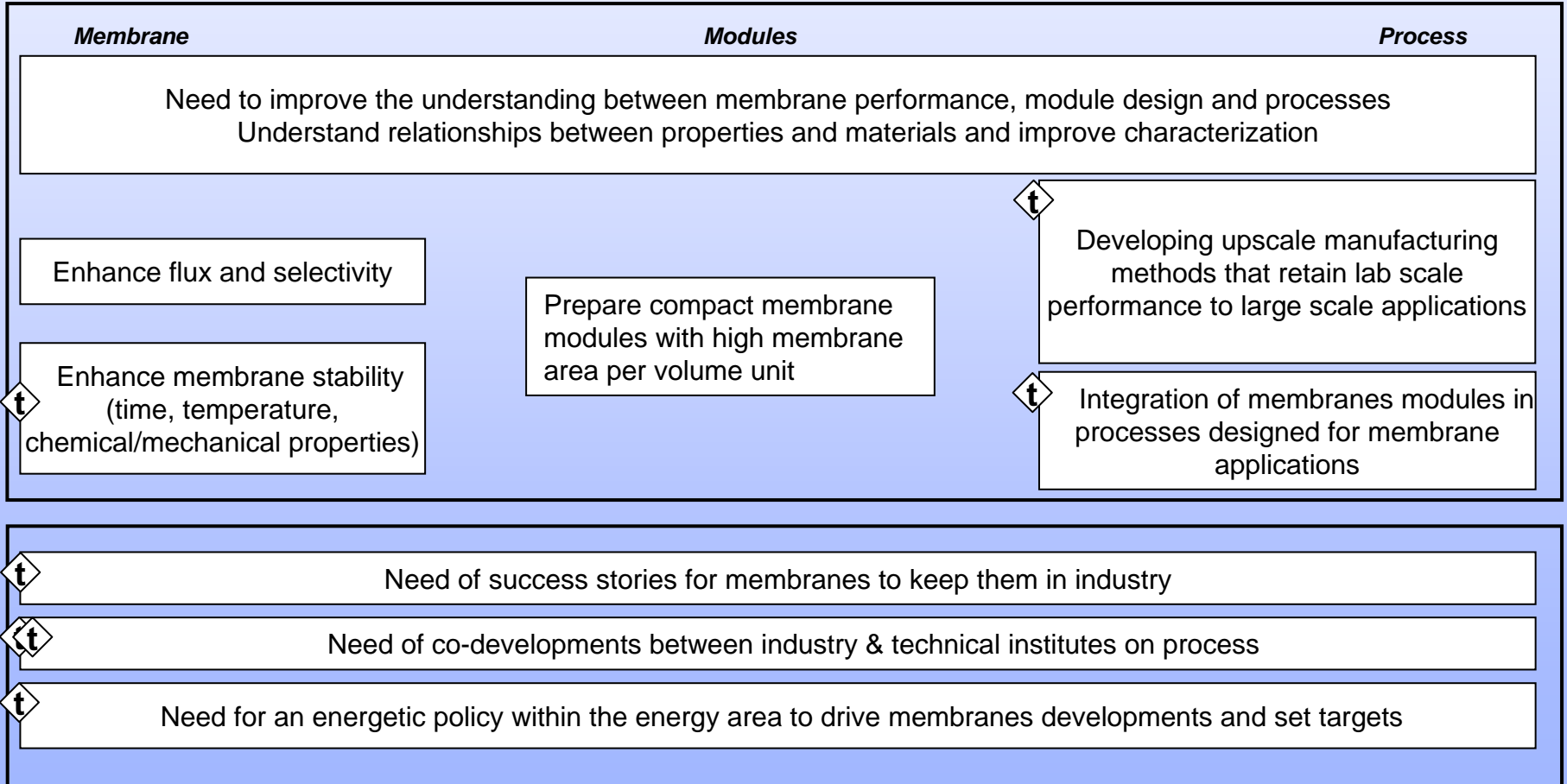
Energy

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: CO₂ capture, energy saving and renewable energy. Membrane gas separation plays a key role in CO₂ capture technology (CO₂, H₂ and O₂ 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



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



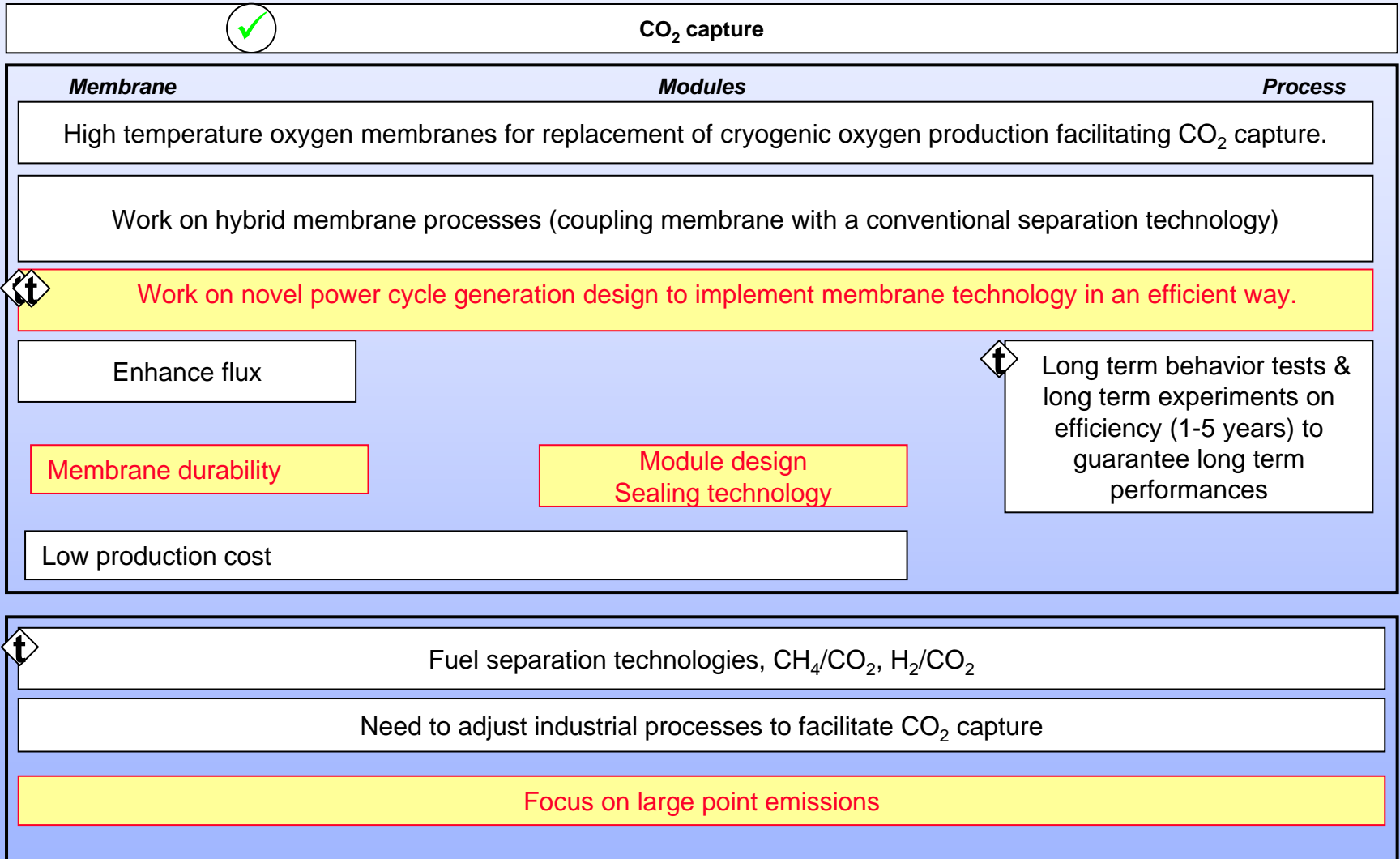
Need for field tests to prove reliability



Launching customers' applications

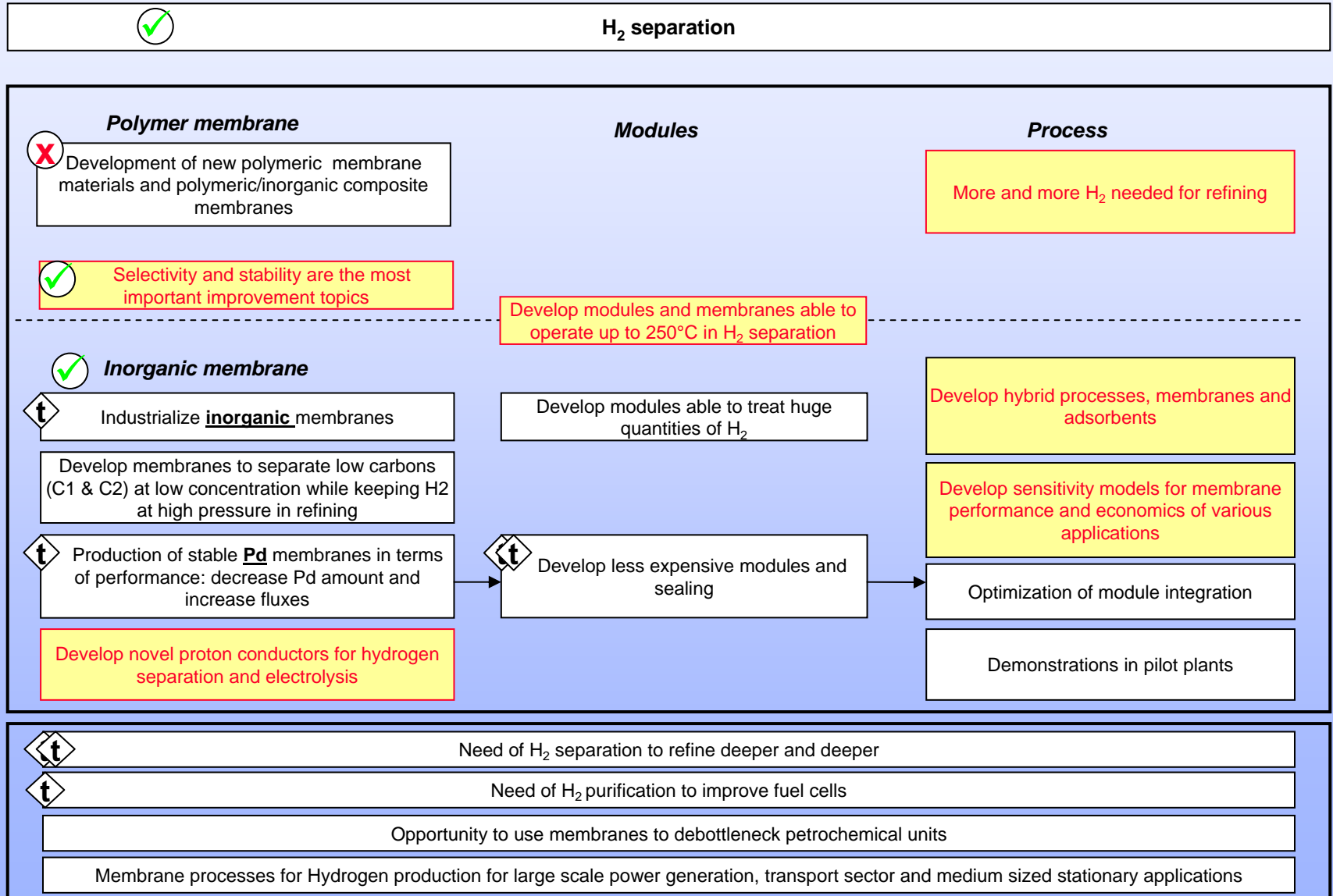
Roadmap presentation

Energy



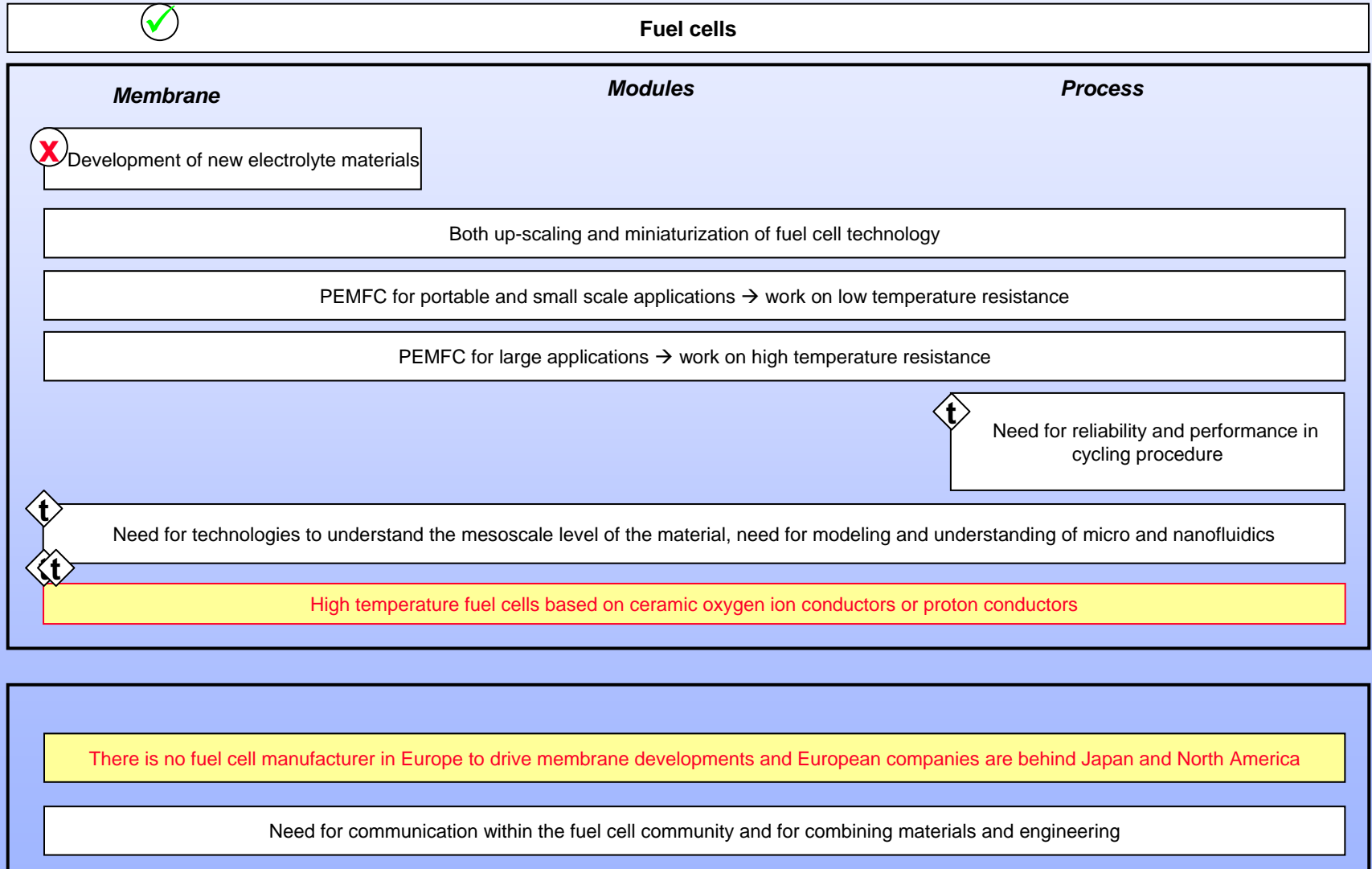
Roadmap presentation

Energy



Roadmap presentation


Energy




Roadmap presentation



Energy


Gas treatment

 **Gas drying (water removal)**

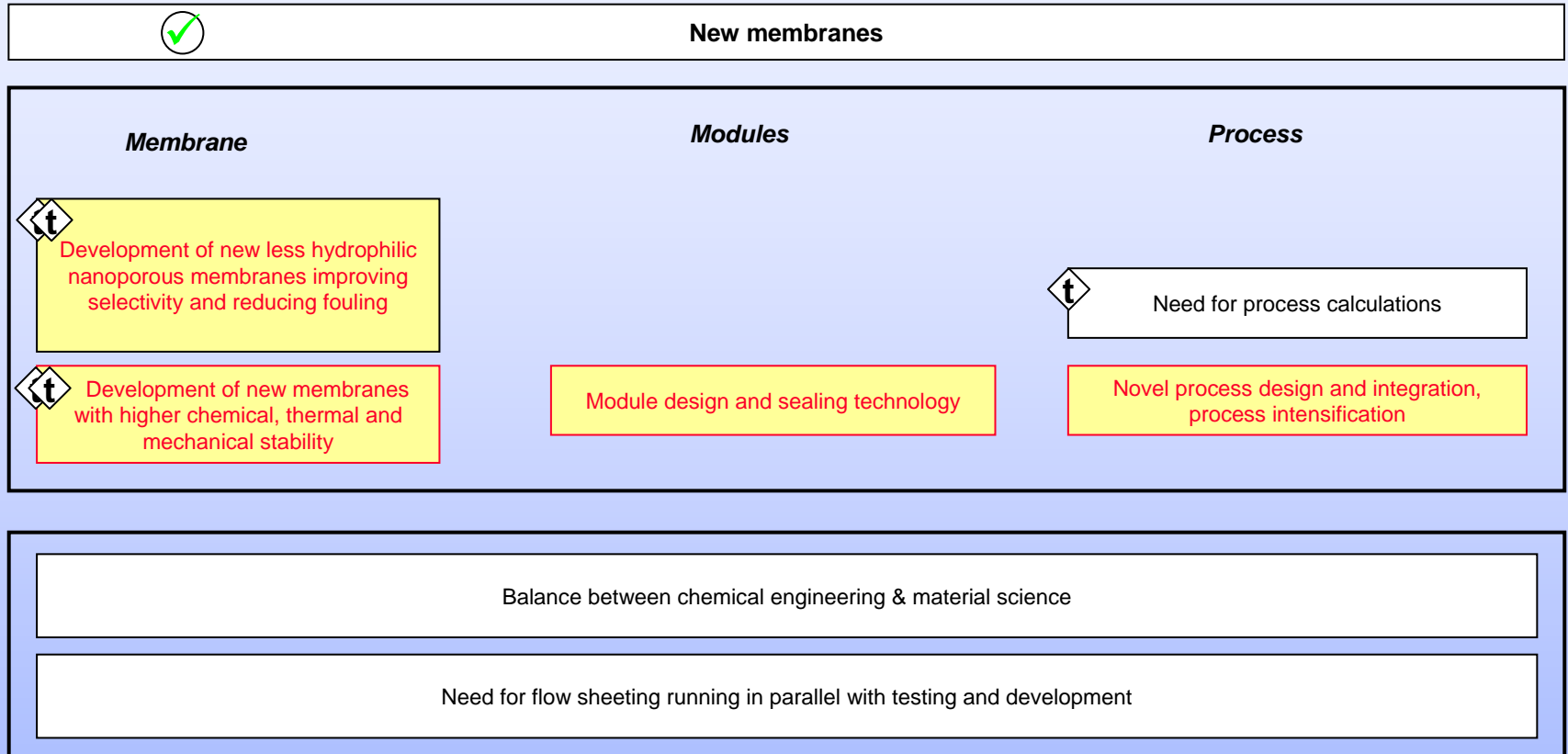
 **Sulfur removal**

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

<i>Membrane</i>	<i>Modules</i>	<i>Process</i>
<div style="border: 1px solid black; padding: 5px; display: inline-block;">  Methane removal from natural gas and biogas </div>		
<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">  Membranes able to separate methane from CO₂ </div> <div style="border: 1px solid black; padding: 5px;"> Membrane contactors + solvent </div>		
<div style="border: 1px solid black; padding: 5px; display: inline-block; width: 80%;"> Define specific operating ranges for membranes </div>		
		<div style="border: 1px solid black; padding: 5px; width: fit-content; margin-left: auto;"> Calculations to confirm cost reduction by methane recovery at low pressure </div>
<div style="border: 1px solid black; padding: 10px; width: 80%; margin: 0 auto;"> Need for existing material optimization and for process calculation </div>		

Roadmap presentation

Energy



Roadmap presentation

Energy - Overview

Topics discussed	Start up drivers	Membranes	Modules	Process	External context
General issues about membranes and energy					
	●	●		●	
CO2 capture †					
Polymer membranes	●	○		●	
Inorganic membranes	●	●	●	●	
H2 separation					
Inorganic membranes	●	○	●	●	
Palladium membranes		●	●	●	
High temperature proton conduction membranes		◀◀◀●	●	●	











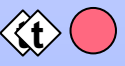
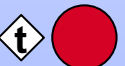
Lack of strategy: 1. Europe is late compared to the USA. Furthermore, it still works as an aggregation of different countries. 2. Europe does not have a clear strategy since governmental policies are not clear.

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

Topics discussed	Start up drivers	Membranes	Modules	Process	External context
Fuel cells					
					
Gas treatment					
Methane removal from natural gas & biogas					
New membranes					
					
Energy savings					
Different application fields for both organic and inorganic membranes					
The field of inorganic membrane materials in general should have high activity for research and development since this field represents novel opportunities with high potentials and need to be developed further.					

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, CO₂ 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

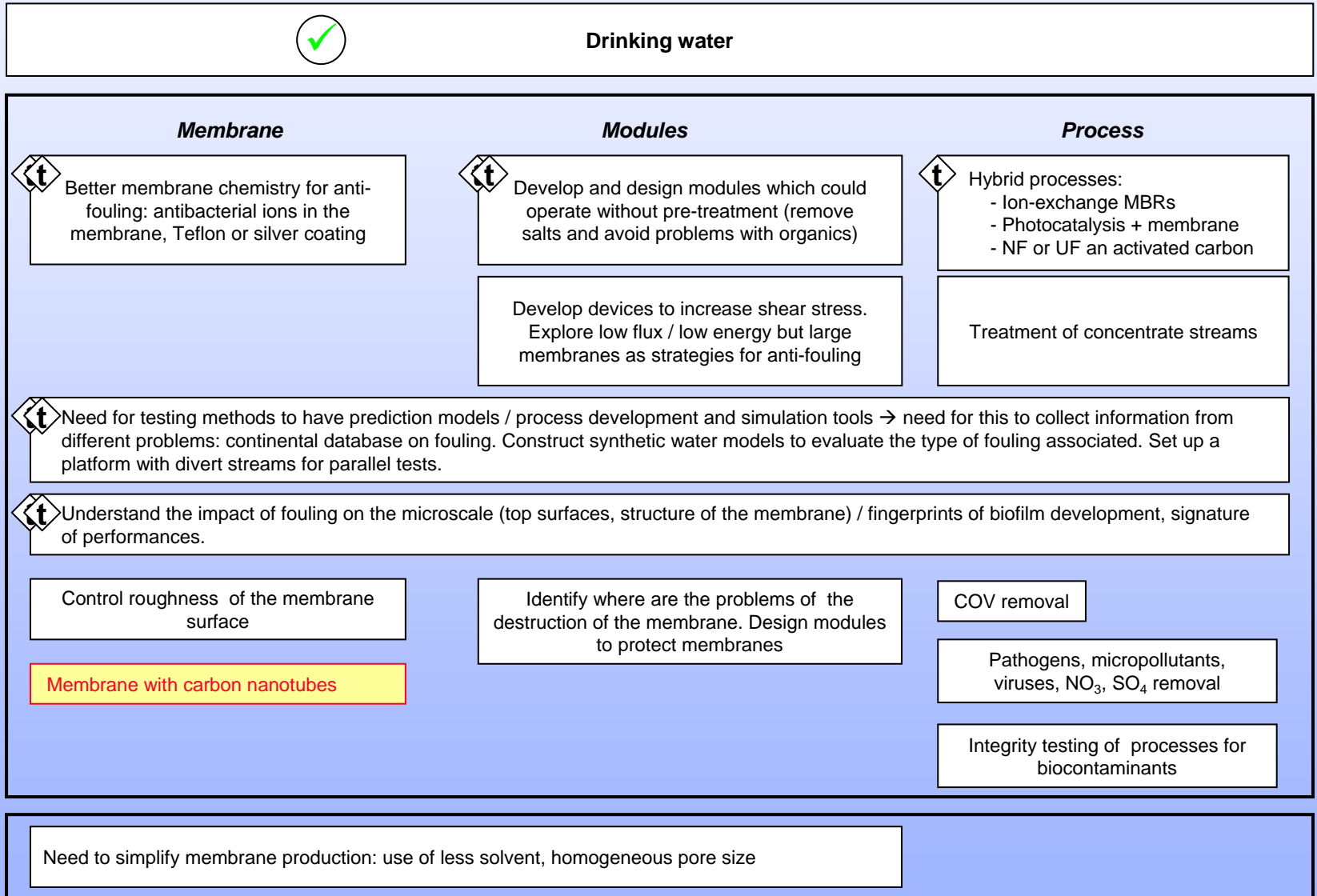
One target of the EMH (European Membrane House) could be to lobby at the EC in favor of programmes to develop European Standards for membrane processes

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



Roadmap presentation

Environment



Desalination

Membrane	Modules	Process
<p>t New thin film composite membranes more stable against chlorine and other disinfectants – Breakthrough material to improve flux and rejection while decreasing energy consumption (carbon nanotubes) – New hydrophobic porous membranes for applications with membrane contactors (distillation / crystallization...)</p>	<p>Progress in EDR and NF for converting brackish water into fresh water</p>	<p>tt 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.</p> <p>tt Development of entirely new integrated membrane plants with new process control and optimisation tools</p>

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



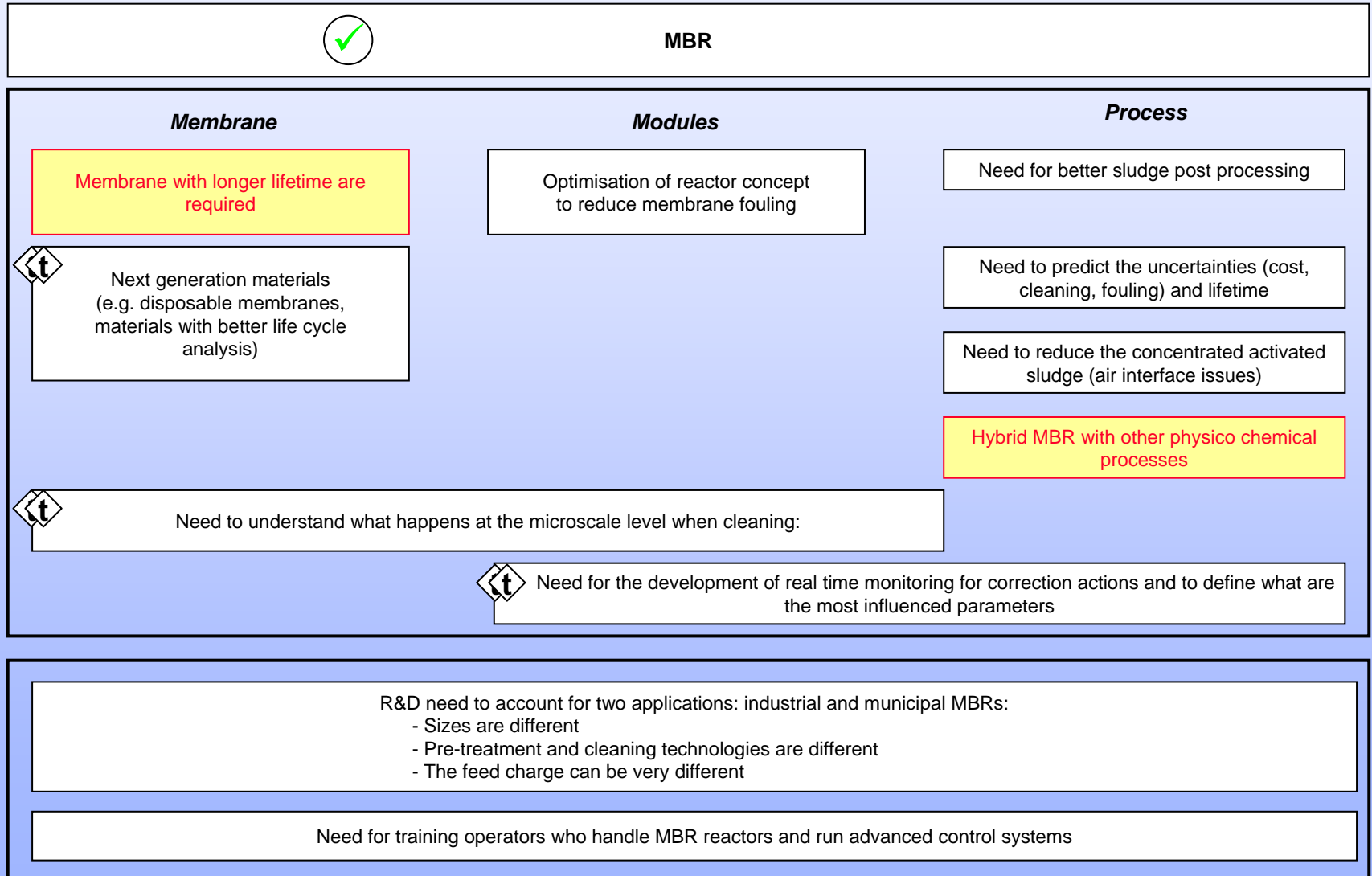
Effluent processing (out of MBR)

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

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



Roadmap presentation

Environment - Overview

Topics discussed	Start up drivers	Membranes	Modules	Process	External context
General topics					
Real time monitoring/process control	●			●	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> Big constraints remain: 1. Energy and cost constraints remain high. 2. Always increasing requirements as regards environmental impact </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> Knowledge management facilitator: 1. Education programmes have started in several European countries. 2. Norms should be helpful to impose membranes in factories & there are needs to define both parameters for norms & measurement technologies. </div> <div style="border: 1px solid black; padding: 5px;"> Collaborations need to be strengthened: 1. NanoMemPro links with other network need to be reinforced. </div>
Microscale interactions at membrane surface	○	●		●	
New concepts to lower operating pressures	●	○	●	●	
European Standards		●	●	●	
Improve life cycle analyses	●	●	●	○	
Membrane bioreactors (MBR)					
New types of MBRs (Ion-exchange, NF, anaerobic)	●	●	⚠ ●	⚠ ●	
Modelling and Advanced control	○			●	
Specific Training for MBR operators	○			●	
Advanced knowledge of sludge physiological and physicochemical properties	○			●	
Effluent processing (Out of MBR)					
	●	●		●	

Roadmap presentation

Environment - Overview

Topics discussed	Start up drivers	Membranes	Modules	Process	External context
Enhanced Drinking water treatment					
Treatment of concentrate streams	●			●	
Selective removal of priority compounds	●	●		●	
Hybrid processes / Advanced treatment (catalytic membranes and oxidation processes)	●	●		●	
Water desalination					
	●	●		●	
CO₂ capture : see Energy topic					

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, electrodialysis 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 them to markets.

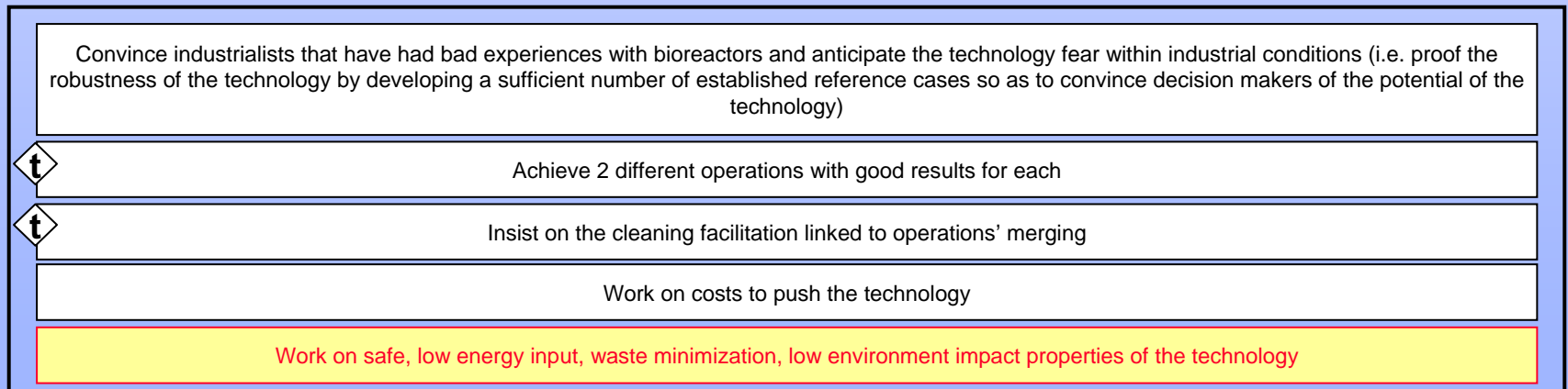
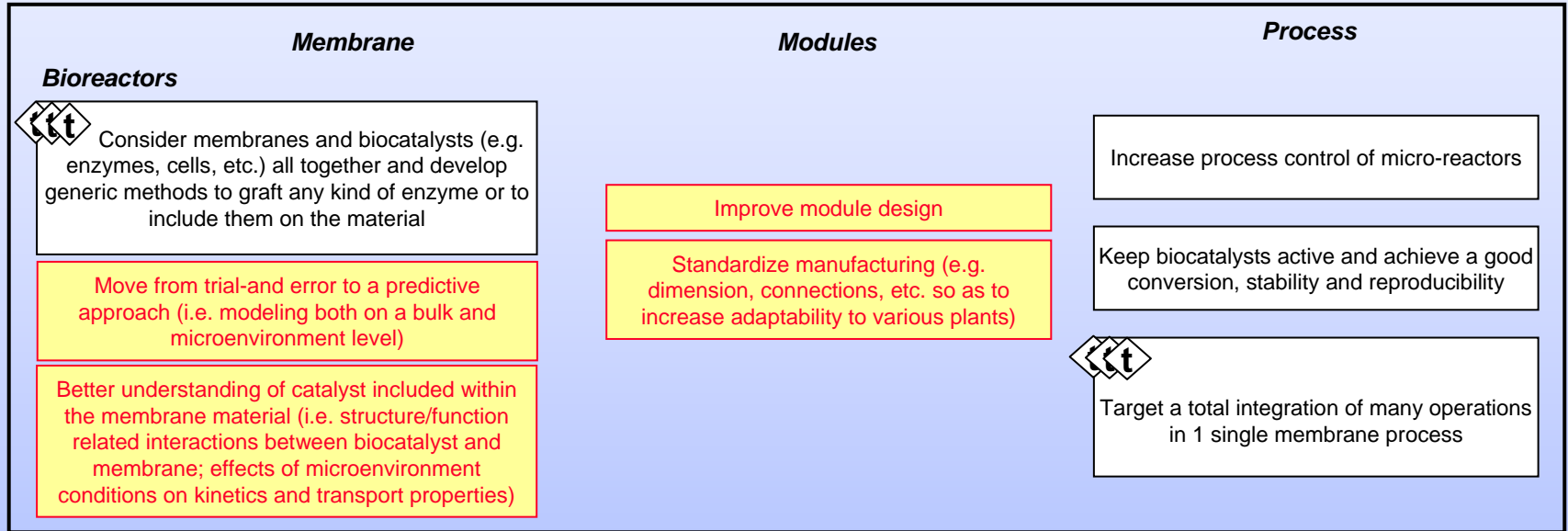
Most processes are using polymeric membranes, but inorganic membranes with a longer life-time and easier cleaning (sterilization) have a promising future.

Roadmap presentation

Food



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

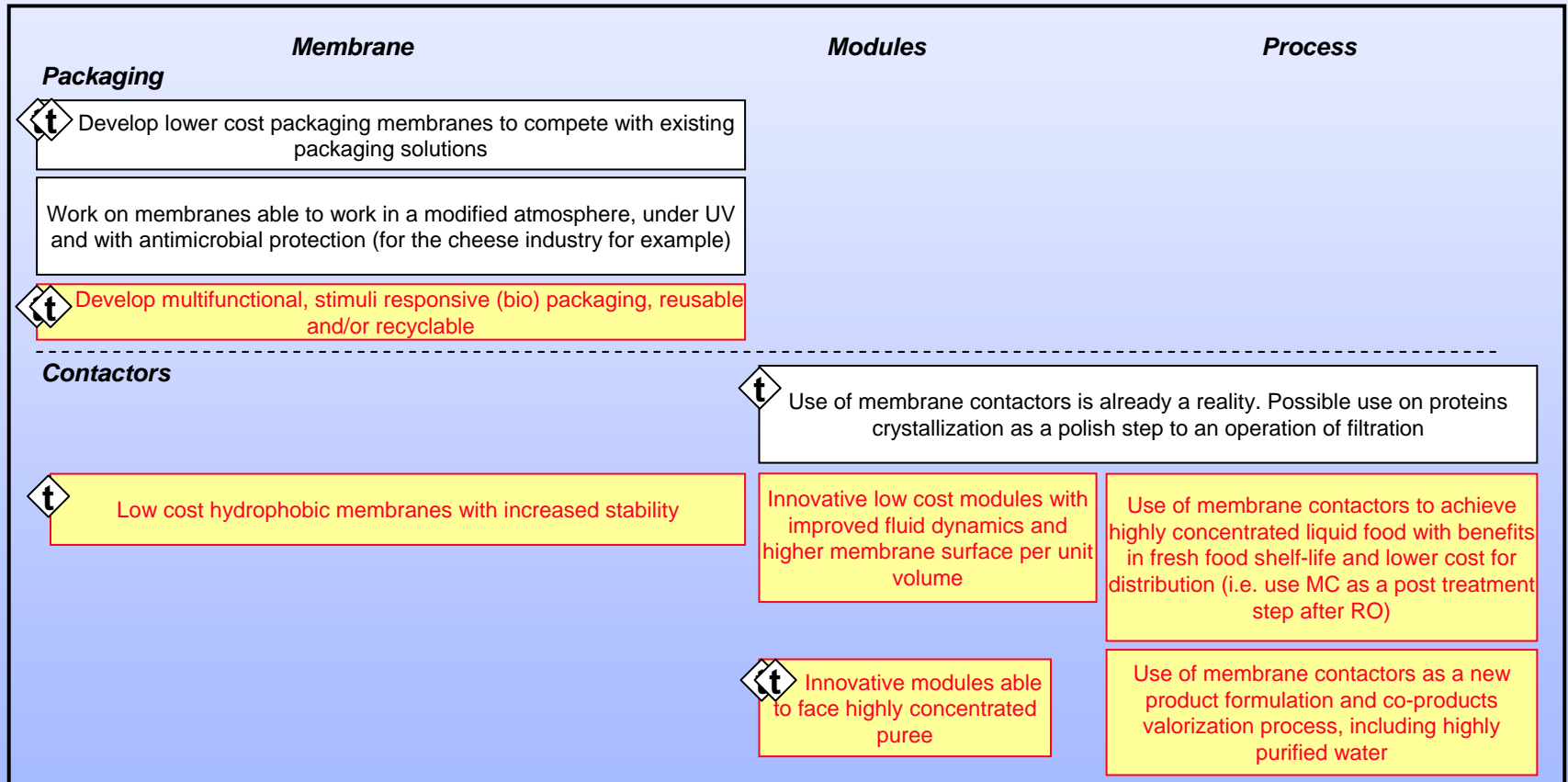


Roadmap presentation

Food



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



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

X 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

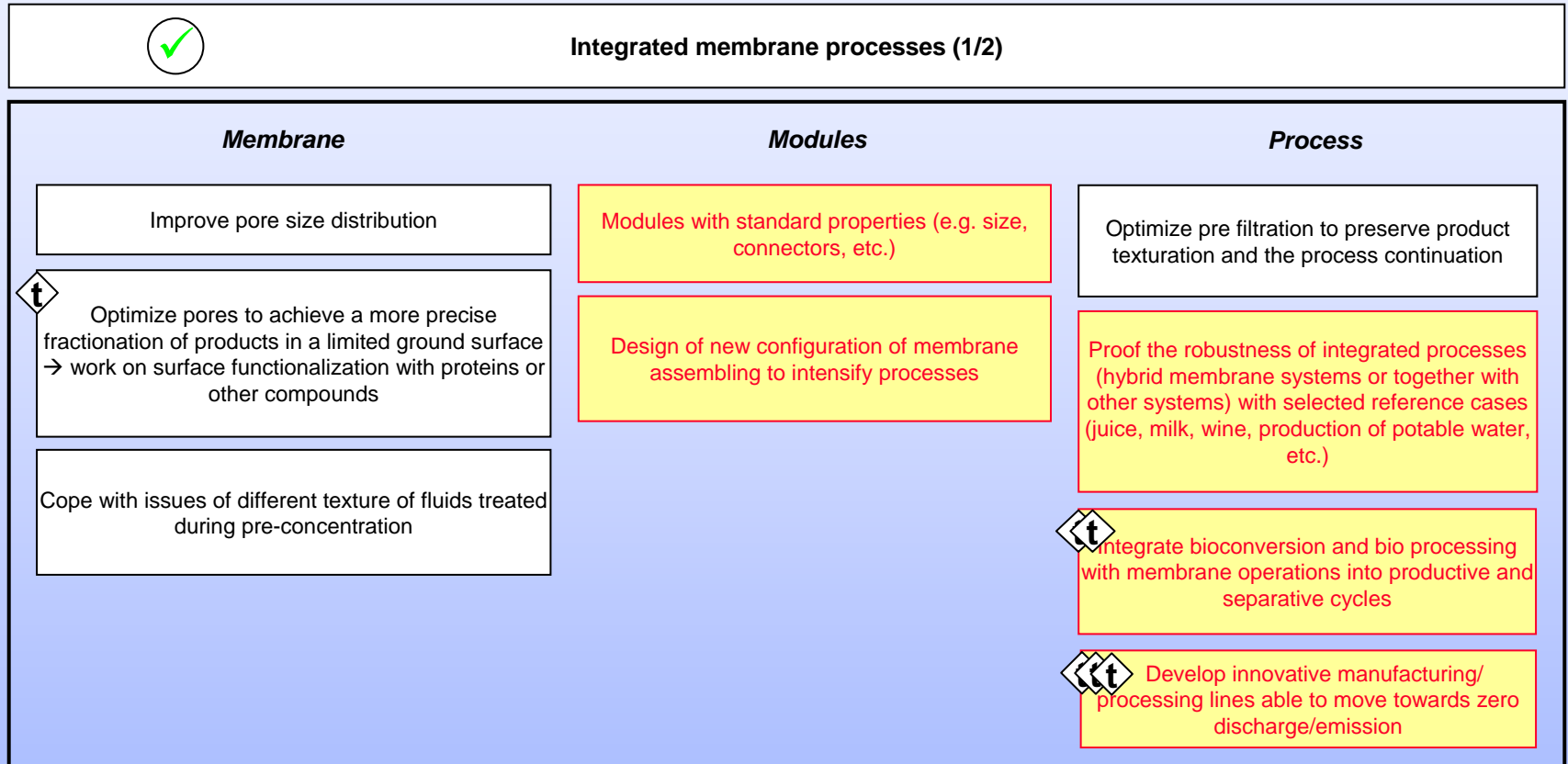
Development of continuous membrane separation process (instead of chromatographic operation mode)

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



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

Inorganic membranes with pore size < 10 nm, uniform pore size distribution, geometric pore location on the membrane surface, mechanically resistant

Membranes with controlled pore size distribution

Modules

Modules with standard properties (e.g. size, connectors, etc.)

Design of new configuration of membrane modules and operation (e.g. rotating modules)

Process

Modeling of emulsification and encapsulation processes, scalable processes, processes compatible with aseptic and sterile conditions, high temperature (for sterilization), cleaning agent

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	External context
Innovative membrane based processes in food production and processing						
Bio reactors	●	●	○	●	●	
Packaging		●		●	●	
Contactors	●	○ ●	●		●	
Sensors				●		
Affinity membranes		●	●	●	●	
Integrated membrane processes						
	●	●	●	○ ●	●	
Membrane emulsification and encapsulation						
	●	●	●	●	●	

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 implemented 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

tt Mixed Matrix Membranes (MMM) containing particles with specific functionality (charge, chemistry, ligands etc) incorporated into polymer matrix

t Nanoporous fiber membranes for capillary electrochromatography (CEC)

Develop single use devices (SUD)

Development of modules (flat sheet or hollow fiber) with MMM

Development of fiber modules for separation of large amounts

Manage antigenic products created by cleaning procedures

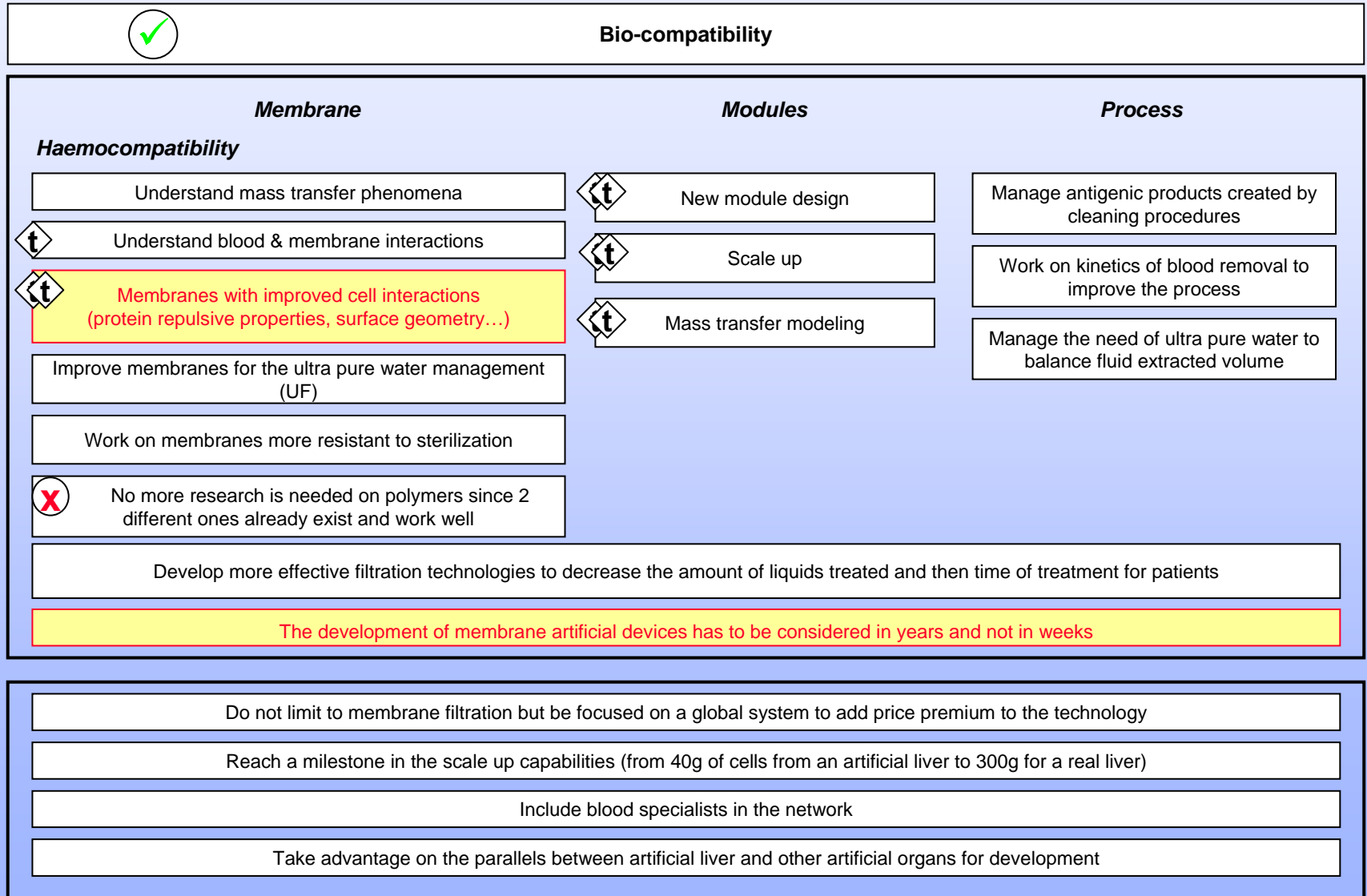
Develop processing limiting viral contamination: work on pumps, reduce pressures...

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



Roadmap presentation

Health



Artificial organs

Membrane

Modules

Process

Membranes for blood purification

t 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

t 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

t 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)

t 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

- 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

Development of suitable bioreactors for tissue engineering (delivery of nutrients – growth factors to cells etc)

Modeling of bioreactors for tissue engineering

Biodegradability has to be considered in years and not in weeks

Roadmap presentation

Health - Overview

Topics discussed	Start up drivers	Membranes	Modules	Process	External context
Bio-separation					
Membranes for pharmaceuticals production	○	●		●	
Bio-compatibility					
Haemocompatibility	●	● ●	●	●	
Artificial organs					
		●	●	●	
Membranes for tissue engineering					
		●	●		

Strong regulation constraints: the health industry is driven by strong regulations which membranes should face.

Major challenges exist: cleaning & fouling were mentioned as the 2 major difficulties associated with membranes.

Clear development directions: membranes are asked to reach a milestone in terms of performance & scale up.

Roadmap presentation

Membrane materials

**Workshop:
Chemicals**

**Workshop:
Energy**

**Workshop:
Environment**

**Workshop:
Food**

**Workshop:
Health**

**Workshop:
Membrane materials**

Roadmap presentation

Membrane materials

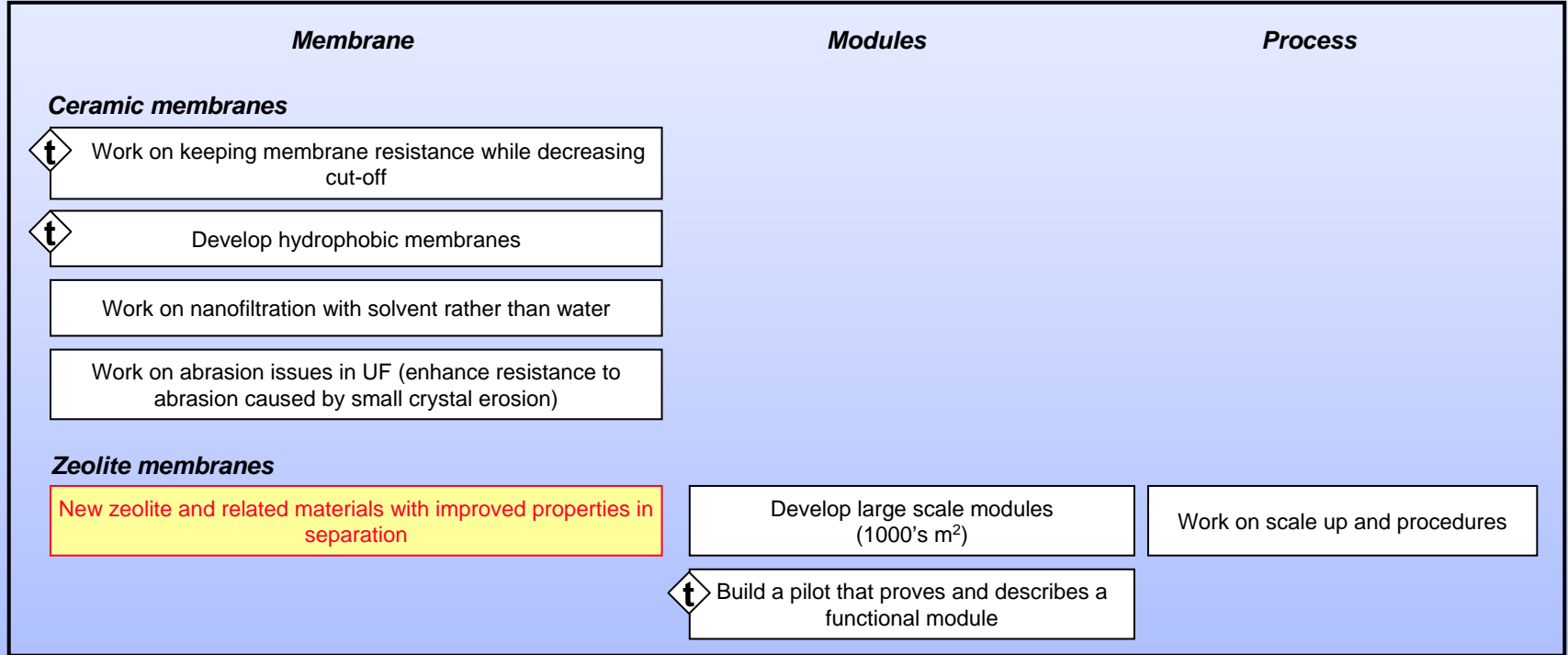
Membranes are essential to a range of applications: for potable water, power generation, tissue regeneration, packaging, beverages, separations needed for the chemical, car, and electronic industries. Beyond their traditional function in separation, other demands have appeared for specific uses in reaction (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



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

For supercritical CO₂ 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

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

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

<i>Membrane</i>	<i>Modules</i>	<i>Process</i>
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		
 Enhance proton exchange capacity for catalytic applications and deal with water management		
Drug release		
 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	 Work on module geometry, stability and reproducibility	
 Work on stability in temperature (no swelling)		
 Continue on sharp cut-off self assembly block copolymers (porous, isoporous ...)		
Develop quality control and predictability tools		

Roadmap presentation

Membrane materials



Mixed matrix membranes and manufacturing processes

Membrane

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

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



Continue on Ti-oxides tiny particles coating and blending in polymeric membranes

Modules

Process

Perform tests to enhance selectivity on butane / methane and CO₂ / 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

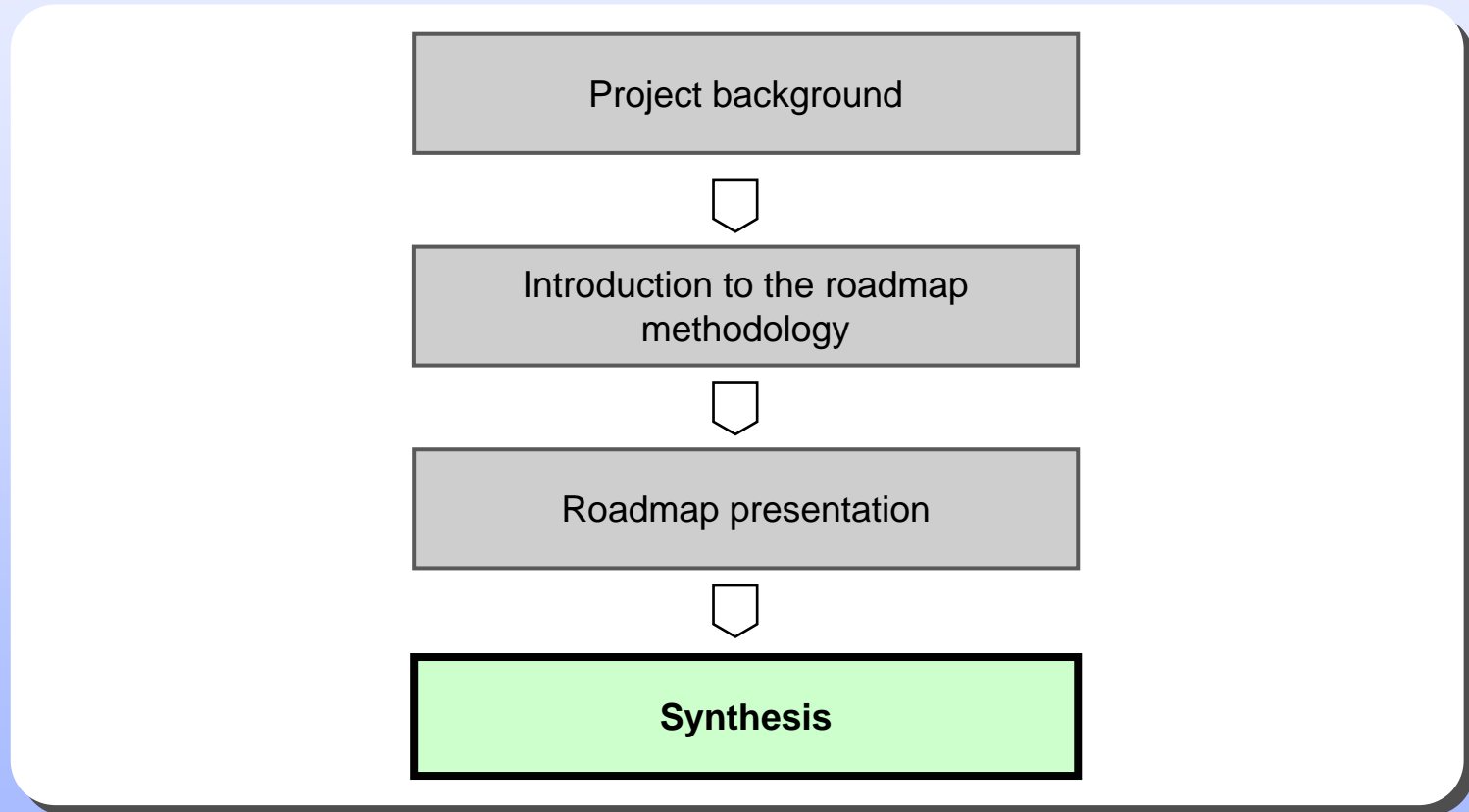
Investigate the role of membrane properties in process modeling, design and engineering

Roadmap presentation

Membrane materials - Overview

Topics discussed	Start up drivers	Membranes	Modules	Process	External context
Inorganic membranes and manufacturing processes					<p>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.</p> <p>Absence of industrial driver: there is no industrial driver to push membrane technologies.</p> <p>Application opportunities existence: N₂/H₂ separation membranes & air O₂ enrichment have been mentioned as market opportunities.</p>
Ceramic membranes		●			
Zeolite membranes	●		●	○	
Oxide membranes (porous)			○	○	
Oxide membranes (dense)		●			
Palladium membranes		○	●		
Organic membranes and manufacturing process – polymeric membranes -					
Gas separation		○	○	○	
Fuel cells		○ ●			
Drug release		○			
Pervaporation		○	○		
NF/UF		●	○	○	
Mixed matrix membranes and manufacturing process					
Zeolite hybrid membranes		●			
Titano-silicate hybrid membranes		○	○	○	
Modeling and simulation for improved material design					
	○	●		●	

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)	⬇	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
Protocols to correctly use membranes and respect their conditions of use	⬇			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
Standardization of membranes and modules	⬇		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Guarantees on long term performances	⬇	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
CROSS FERTILIZATION						
Collaboration with the technology platforms in Brussels, the fuel cell community ...	⬇	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		
Co-developments between labs and technical institutes	⬇	<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>	
Include other field specialists in the network	⬇⬇				<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
LOBBYING ACTIONS						
Lobbying on an energy policy	⬇	<input checked="" type="checkbox"/>				
Lobbying Europe to have certification and validation procedures	⬇	<input checked="" type="checkbox"/>				