Chapter 8
A Toolkit for Integrated Roadmaps: Employing Nanotechnologies in Water and Wastewater Treatment

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8.1 Introduction

This chapter introduces a new approach of roadmapping for emerging technologies. This approach provides special trajectories of R&D, technologies, products and markets for a given application. The chapter highlights the use of roadmapping techniques for emerging technologies from a technological, as well as a market perspective; the integration of technology and market roadmaps; how such roadmaps can be included in the process of strategic decision-making at different levels; and how such roadmaps can be used for different purposes while ensuring a sustainable innovation flow for specific application fields.

This new approach – the integrated roadmapping approach – combines new manufacturing opportunities with potential consumer preferences towards innovative products. To determine alternative paths of innovation, the roadmap uses a scenario-based approach. These scenarios provide a long-term framework for roadmapping by constructing socio-economic narratives of the future, and by specifying future challenges. The roadmaps appear as a time-scheduled sequence of steps towards the implementation of scenario options.

The integrated roadmap determines a set of strategic goals for technology markets and develops measures to achieve these goals by taking into account alternative scenarios (or paths), and then choosing the most effective one. The roadmap is also aimed at the implementation of a co-ordination mechanism of stakeholder actions in order to achieve the strategic goals. It gives an opportunity to make a connection between grand challenges and concrete measures to meet them. One of the most urgent issues today is a sharpening of ecological problems. A variety of researchers concur that the key challenge for future development is

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providing pure water for citizens. Thus, the feasibility and appropriateness of the integrated approach has been tested on selected nanotechnology related applications and markets.

This chapter assesses the role of Foresight and roadmapping in policy-making, strategic planning and project and innovation management at both an industry as well as more general level.

Maintaining a constant, clean, consumable water supply is one of the major challenges nations around the world are facing however the technological challenges of water treatment (for the general public as well as industry), remain insufficiently resolved. Correspondingly, the problem of water quality – and hence the closely related problem of water purification – remains one of the biggest social concerns in modern world. Importance of water supplying issue is also corroborated by social surveys. As evidenced by the Eurobarometer, 68 % of Europeans consider water quality problems as very serious for these countries. Around nine out of ten respondents in Romania (94 %), Italy (91 %) and France (89 %) consider water quality a serious problem for their country (Flash Eurobarometer 2012). Concerns over water quality are expressed by 34 % of the population of Russia, dominating almost all other social and domestic/household problems (Shuvalova 2010). Accordingly, a wide range of technology specialists and policy-makers are becoming increasingly interested in these challenges.

The survey presented in Fig. 8.1 clearly indicates that Russian citizens most frequently consider socially relevant technologies among priorities. People believe that technologies that contribute to solving ecological problems are of the utmost importance, along with new cures for illnesses that cause high mortality and disability rates in Russia (cancer, cardio-vascular diseases, injuries etc.). It becomes evident that the development of water treatment and purification systems is a primary concern to the end users – in this case, the country's population. Hence, new approaches to advance technologies that can address these problems are urgently needed.

Given the existing level of water treatment technologies, there is evidence to suggest that just 1 % of surface water sources in Russia meet the standards that would guarantee that the production of drinking water meets all hygienic requirements defined by WHO (2011). The amount of water intake sources that do not meet such standards and requirements generally exceeds 35 % (WHO 2009a, b; Onishchenko 2011). Between 50 % and 70 % of the Russian water supply and sewage infrastructure is worn out to the point of causing secondary pollution (Rosvodokanal 2011), which leads to the excessive use of chlorination, causing increased risks of disease. The consequences of this are 12,000 deaths a year caused by poor-quality water (WHO 2009b), and an increased accident rate, causing both direct and indirect waste of water (soil erosion, damage to roads and building basements, etc.). According to WHO data the disability-adjusted life year (DALY) connected with water-related problems in Russia is one of the worst in the world (Fig. 8.2). It means that existing systems of water supply in Russia is ineffecient at all and it follows that there is an urgent need for new technologies – such as nanotechnologies – to meet these challenges.

Since poor water infrastructure is one of the most urgent issues facing both the whole world and Russia, it is necessary to elaborate a clear strategy of long-term

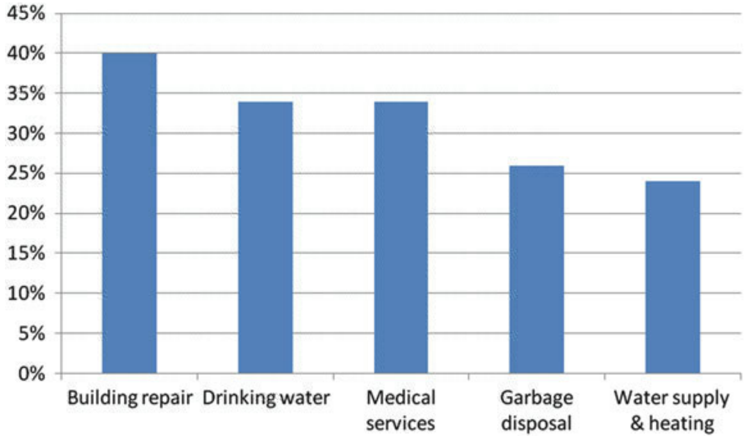

Fig. 8.1 Most common social concerns in Russia (Shuvalova (2010)) (*share of all respondents*)

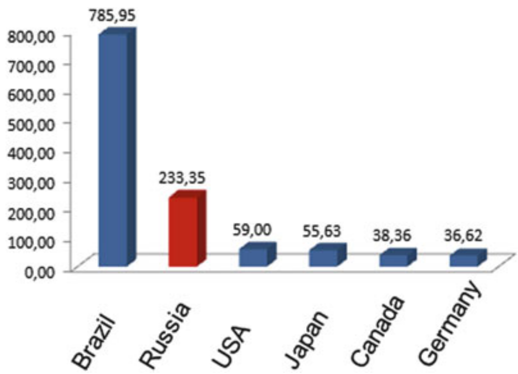

Fig. 8.2 DALY connected with water-related problems in different countries (WHO (2009b))

development on the basis of integrated roadmapping approach. The integrated roadmap takes advantage of a broad range of expert knowledge relating to the most important nanotechnologies, nanoproducts, and nanocomponents (interim products) that could be used for water treatment purposes. Roadmap development procedures as part of Foresight include a broad discussion among the representatives of science and research, as well as education and business networks to establish a consensus on future development (Ahuja et al. 2005; De Smedt 2006; Heger and Rohrbeck 2012; Kappel 2001; Kynkäänniemi 2007; Rohrbeck 2008; Saritas and Oner 2004; Vishnevskiy and Karasev 2010; Whalen 2007).

This chapter suggests a new methodological approach to integrated roadmapping that allows the best, and most promising innovative products to be revealed, and the potential impact of emerging technologies to assess.

Table 8.1 Benefits and limitations of technology push and market pull approaches

Approaches/ features	Benefits	Limitations
Technology push	Wide analysis of prospective innovation technologies, products development, and detailed investigation of their main properties	Inadequate investigation of future market requirements, stakeholder behavior, and preferences
Market pull	Comprehensive study of potential market development employing different scenarios, revealing which innovation products will be in great demand in the long-term	Insufficient revelation of resource basis for meeting market needs

8.2 Roadmapping for the Investigation of the Water Treatment Industry

Roadmaps as an element of Foresight studies have a rather short history, spanning only a few decades (Willyard and McClees 1987). However, the importance of employing roadmaps has grown significantly in recent years and they have come into great demand both in the corporate and public sectors. Roadmaps are now one of the most important tools of strategic planning and are actively used for shaping investment and innovation policies.

There are two main methodological approaches to roadmaps: market-driven and technology-driven (Table 8.1). The market-drive approach presupposes that the first point of the analysis is a market demand (see Albright and Kappel 2003; Daim and Oliver 2008; Holmes and Ferrill 2005; Lee et al. 2009a; Phaal et al. 2001 etc.), while the technology-driven approach identifies new technologies and seeks to define the market needs that could be served by them (see Kim et al. 2009; Lee et al. 2007; Lichtenthaler 2008; Lee et al. 2009b etc.).

Given the scarcity of freshwater resources, the establishment of a water resources management system is becoming essential (IWMI 2007; IAASTD 2008; UNEP 2010, 2012b). While global water assets are sufficient enough to supply global human demand, the water deficit is worsening (IAASTD 2008; UNEP 2012a).

With the rise of global awareness of water scarcity and the intensification of international collaboration for the management of water assets, the demand for reliable water management within national borders is also increasing (UNEP 2012b, Molden and Freken 2007; Whalen 2007, WWDR 2009; Young 2011). The tools to design, vector, monitor, and modify a national water management system and to boost its performance are currently of growing interest. In this regard, a roadmapping framework is commonly used in international practice to align objectives, strategic priorities, and participation of multiple actors in national water treatment systems.

An overview of the roadmaps developed for water treatment systems provides some considerations to take into account while making the roadmap for the employment of nanotechnologies in the Russian water treatment industry.

Roadmapping practices at the national level fall either into the proactive or reactive categories. They are proactive when they address the problem, in terms of prevention, before it arises. The approaches are classified as reactive when they overcome pre-existing issues and deal with their consequences. As the study of international economic practices shows, the roadmap-building processes in the water industry is triggered by issues of water resource availability (initial resource scarcity or its eventual shrinkage), the allocation or coordination of water assets, and infrastructure issues. All of these issues are aggravated by reactive strategic decisions.

Milestones in the use of roadmaps for water treatment have occurred in the following countries: the United States of America (which is a leader in this respect), Australia, the Scandinavian countries, Egypt, and China. On the one hand, there are countries that rely on roadmapping because they face physical water scarcity,[1] often due to areas with arid climates (Middle East and North Africa, Central Africa and Central Asia, etc.). Even rather water-sustained regions often comprise local zones where water assets are strongly limited. Countries mentioned in Table 8.2 have areas of physical water scarcity (SNL 2003; Hinkebein and Price 2005; Youssef et al. 2006; Arnold et al. 2008).

On the other hand, many countries face areas of economic water scarcity[2] – those with inadequate infrastructure, rather than a resource deficit. These include areas of Central Africa, South Asia, and certain areas in the North-East of Latin America. These examples exhibit a water shortage caused by, or attributed to, human impact, rather than to matters of ecosystem water assets (Hinkebein and Price 2005; Arnold et al. 2008, etc.).

The motivation for a roadmap is most often an indigenous one, related to water system performance, rather than an exogenous one, induced by naturally determined water problems. Roadmapping is uniquely in its ability to combine and visualize a multilateral analysis of economic factors, investments, risks, and stakeholders (Saritas et al. 2004, etc.).

The call for water-steering system to give the public audience knowledge about water management is becoming louder. The misbalancing factors amount to administrative, economic, social, technological, or environmental issues, and sometimes their combination (SNL 2003, 2006; Means 2004; Youssef et al. 2006; NWAR 2009).

Today competition for freshwater resources among the agricultural, domestic (municipal) and industrial sectors is iinntensifying. This competition is causing an increase, water consumption, treatment, supply, and sewage facilities construction (SNL 2006; IWMI 2007; FAO 2012). While the agricultural sector is frequently

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[1] Under a physical scarcity, water consumption is limited by ecosystem frontiers, while water assets development is approaching or has already exceeded sustainable limits (IWMI 2007).

[2] In the areas of economic water scarcity, natural water assets could be available locally to meet human demands but the access to water is limited by human, institutional, and financial capital, or sometimes infrastructure capacities (IWMI 2007).

Table 8.2 International roadmaps: examples of water industry and infrastructure enhancement

Project	Country	Research problem	Research area	Type	Foresight methods
Sandia National Laboratories (2003)	US	Establishing the governmental policy for the water industry using scenario approach conveying water assets, supply system demands with technology solution	Water supply system demands	Market pull (mixed with technology push)	Working groups
					Scenario analysis
					Literature review
			Water treatment technologies assessment and alignment		Expert Interview
					Rudimentary routes based on relevance tree analysis
			Traditional		Backcasting
			Enhanced traditional		The elements of SWOT-analysis
			Alternative		Cross-impact analysis
			Sustainable		
			Technology process and consumer properties		Mapping
			Implementation issues (R&D and financing)		Risks analysis
			Global collaboration		
Means (2004)	US	R&D and project evaluation and selection to meet the challenges	Water treatment technologies	Market pull	Workshops
					Desk research
			Regulations and system management		Literature review
			Technology process properties		Technology portfolio analysis
					Backcasting
			Sustainability issues (energy efficiency)		Elements of SWOT-analysis
					Voting
Elliott (2005)	US	Problem-oriented approach: Effectiveness of energy usage within water treatment and supply industry	Comprehensive water system development (water treatment, supply and sewage infrastructure mutual development)	Market pull	Questionnaires, surveys
					Workshop
					Brainstorming
			Stakeholders and target audience consolidation		

Hinkebein and Price (2005)	US	To identify, evaluate, prioritize research areas, to provide R&D to satisfy near, mid and long-term water supply challenges addressing the implementation issues and collaboration at the global scale	Financial aspects and profitability of technologies Water treatment technologies Advanced traditional (evolutionary) New-generation (revolutionary) Product-technology properties Technologies sustainability improvement Post-treatment waste disposal Water resources Available now Unavailable (challenges)	Market pull	Working group Workshops and sessions Five-steps roadmapping process Quantitative evaluation Cross-impact analysis Mapping
Youssef et al. (2006)	Egypt	Shared vision for Government water industry strategic planning up to 2025 regarding the broad political, technical, economic and social context within the scenario development	Water resources modes Water treatment technologies modes Driving forces International collaboration on water facilities Technology process properties Sustainability issues	Market pull	Content analysis Driving forces analysis Questionnaire survey Scenario analysis (mini-scenarios for policy-making and 2–3 global scenarios) Experts panels Focus groups Brainstorming
Arnold et al. (2008)	Scandinavian Countries (which Scandinavian countries? There are only three/four. . . they should be named)	Investigate the innovative technology niches to consolidate the stakeholders' to provide the larger global market share	Water and wastewater treatment technologies assessment and alignment	Technology push	Content Analysis Patent analysis Bibliometric analysis Technical project expertise

(continued)

Table 8.2 (continued)

Project	Country	Research problem	Research area	Type	Foresight methods
			Advanced traditional New and emerging Estimation of product-technology properties Technology process performance Consumer attributes Sustainability issues Assessment of technologies for core competences zones		Working group Technology portfolio The elements of SWOT-analysis
National Water Account Roadmap (2009)	Australia	Shaping the profile and instruments of water provision public policy at the national and sectoral level for both supply and demand sides	Sectoral water resources management Water production and consumer portfolio Risk-analysis: Water resources Treatment technologies Key stakeholders	Market pull (with elements of technology push)	Expert Panels Simulation Quantitative indicators Scanning Desk research Data modeling Benchmarking Reporting Stakeholder analysis

limited in its use of treated water,[3] the municipal sector puts very strong requirements on treated, e.g. purified water. The issues that roadmaps address in the examples above – namely, water scarcity, and wastewater industry performance – fall into two categories: water supply capacities, and water quality provisioning (Arnold et al. 2008). The supply issue refers to the availability of water and wastewater supply and disposal networks to the population. The quality issue refers to the goal of water safety and quality. To meet standards and requirements, the treatment process is under governmental control.

Judging by the countries listed in Table 8.3, the roadmapping process within the water industry is typically under the guidance of governmental bodies or state-owned organizations. Moreover, the majority of roadmaps are government-initiated and implemented by relevant management maturity systems and institutes.

Analyzing the methodology framework of these roadmaps it becomes clear that the technology push motivations behind roadmapping tend to be water supply, capacities, and/or infrastructure provision. The demand-side reasons explain why roadmap development is performed mostly by market pull methods (Means 2004; Elliott 2005; Hinkebein and Price 2005; Youssef et al. 2006) rather than technology push methods (Arnold et al. 2008). Also the consistency of demand and supply-side drivers illustrates the need for both tmarket pull and technology push methodologies (SNL 2006; NWAR 2009).

The limitations of the water industry supply system vary from a lack of infrastructure to insolvency and inconsistency of facilities (obsolescence, wear and tear, etc.). It is these issues which tend to drive roadmapping in the countries listed in Table 8.3. This is also because large economies (in terms of population or territory), such as Russia, China, Australia, and the United States, are more vulnerable to infrastructure issues.

The significant investments required for roadmapping initiatives are the main reason why few developing countries have implemented such projects. The bulk of countries utilizing roadmaps for water systems belong to either the higher- or upper-middle income countries, according to the World Bank classification (the one exception being Egypt).

Consequently, national roadmaps illustrate the problem-oriented approach towards the consistency of water treatment technology processes (SNL 2003; Youssef et al. 2006); technology properties adjustment (Means 2004; Arnold et al. 2008) and customization (Youssef et al. 2006; NWAR 2009) often within the functional and communication alignment across stakeholders (SNL 2006; NWAR 2009). Evolution in the scale and scope of roadmapping is also quite evident: the resolution of a single concern, which initiated the roadmap, might develop into a broader and more complex analysis of systemic issues.

[3] On the global scale the largest amount of fresh water for agriculture (up to the 80 %) is coming from green water (rainfall stored in soil moisture); the rest is usually given by blue water (water withdrawals from rivers, reservoirs, lakes, and aquifers) (IWMI 2007).

Table 8.3 National water assets: context for water industry management applying the Foresight approaches

Country	Water sources scarcity	Welfare (income-based)	Population supplied by water supply system	Population supplied by wastewater system	Water industry issues addressed	Water management strategy
Egypt	Absolute water scarcity	Lower middle income country	98 % (2009)	–	Physical water resources scarcity Collaboration among water industry agents International collaboration on water resources provision	Reactive
Australia	Areas of physical water scarcity Areas with poorly estimated water assets feasibility	High income country	98 % (2004)	90 % (2004)	Bating the water scarcity in local areas	Reactive
US	Local areas of physical water scarcity Approaching physical water scarcity Areas with poorly estimated water assets feasibility	High-income country	85 % (2005)	70 % (2005)	Physical water scarcity in local areas Water assets allocation Water treatment technologies and supply system Regulation of industrial agents coordination	Reactive
Russian Federation	Local areas of physical water scarcity Areas of approaching physical water scarcity	Upper middle income country	80 % (2010)	60 % (2010)	Coordination	Reactive
China	Areas of physical water scarcity Areas of approaching physical water scarcity Local areas of economic water scarcity	Upper middle income country	50 % (2005)	45 % (2004)	Physical and economic water scarcity in local areas	Reactive

Scandinavian Countries	Neither physical nor economic water scarcity	High income country	85–90 % (2007)	av. 85 % (2007)	Thorough analysis of social and environmental water issues Water resources international provision	Proactive

Source: FAO Stat, World Bank Databank, UN Data, Wisinfo

8.3 Roadmapping Methodology

Roadmapping pilot first began with the formulation of research questions. Based on these, the authors developed an integrated roadmap approach. This integrated roadmap took into account the well-established, and commonly applied, concepts of market and technology roadmaps. After that, both approaches were combined and their inherent limitations minimized, while the potentials benefits of both methods were integrated and leveraged. Furthermore, the integrated roadmap allowed for alternative options to be explored and prioritized from a more systematic viewpoint, including from both the market and the technology perspectives. At the same time, an area of technology (or field of study), suitable for a pilot study of the integrated roadmap, was sought. Eventually the methodology pilot was tested on nanotechnology applications for water purification solutions in Russia (Gokhberg et al. 2012; Sokolov et al. 2011; Vishnevskiy and Karasev 2011, 2012; Vishnevskiy et al. 2012).

The integrated roadmap is a resumptive document performing a multilevel system of strategic development in the subject area within a given time frame. It includes indicators that quantify the economic effectiveness of new technologies and products, which possess high demand potential. This roadmapping exercise relies on multiple Foresight methodologies, employing a multi-staged process of desk research, field study, expert involvement, and scenario development. The framework developed by the integrated roadmap highlights priorities for the further development of nano-enabled products for water treatment, and serves as a source for future study.

The roadmap is developed using both qualitative and quantitative methods, including survey data and evidence-based analytics. It summarizes expert opinions regarding the most important nanotechnologies, nanoproducts, and nanocomponents (interim products) that could be used for water treatment purposes. The study was based on analysing marketing data, official statistics, and expert, as well as population, surveys.

One of the most significant challenges when researching emerging technologies is the collection of valid and reliable data; this is accomplished mainly by the creation of expert groups. As a result, we introduced an approach based on both objective and subjective criteria.

The quality of a roadmap is strongly determined by the quality and reliability of the information used in its development. For the chosen pilot study, such information and data was mainly gathered from experts. However, because their knowledge and experiences, as tacit knowledge, were not sufficiently documented, it was necessary to identify and chose these experts carefully. Therefore, a unique approach – based on specific selection criteria – was applied, in order to identify and select those holding a suitable level of tacit knowledge. First, knowledge holders had to be authors of publications in internationally reviewed scientific journals included in the ISI Thomson database with a citation index for the previous 5 years in the nanotechnology field above the world average. Second, these knowledge holders had to represent an enterprise or organisation recognized as a leading Russian nanotechnology-related enterprise/organisation, and had to have been nominated as experts by the management of that organisation/enterprise. Finally, they needed to have been nominated as experts by at least three other previously recognized technology and/or market experts; this condition was justified by the fact that the science and technology communities are closely interrelated.

Based on these criteria, 100+ knowledge holders were identified and selected.

These experts contributed to the collection and processing of a large amount of data and information. For this purpose a variety of methods were used. The methods were grouped into several categories on the basis of the Foresight diamond (Popper 2008), taking into consideration practical experiences with these methods in a wide range of Foresight studies. Eventually the process of developing the roadmap was completed in five phases (Fig. 8.3).

Thus, the proposed sequence of methods for the evaluation of emerging technologies is as follows. In the first phase, the field of study is analysed on the basis of surveys, Delphi, and a study of key domestic and international technologies. This analysis allows for the identification of project scope, targets, and directions of further research. These directions are discussed in a special workshops, giving us an opportunity to specify the main themes of research during the second stage.

The desk research phase identifies the most significant trends in the researched field and brings to light the most promising technologies, products, and services. During this stage the creation of a preliminary version of a list of top-ranking experts in the subject field is a reasonable goal.

During the third stage, in-depth interviews with the most qualified experts in the field are conducted. This allows for the collection of so-called “tacit knowledge” – information that is not yet codified in papers, books, etc. After the aggregation of interview results, expert panels are held on each direction of the research, followed by a final expert panel to achieve a consensus between major stakeholders concerning chains R&D-technologies-products-markets.

Then a vision of the future is created using brainstorming and creative analysis. Through backcasting, the most desirable future scenario is formulated on the basis of the results of the previous stages, and after that the necessary actions to achieve this scenario are outlined. At this stage, special attention is given to stakeholders analysis, which determines how the roadmap, and its results, will be used by its beneficiaries. In the next stage, all the elements of the R&D-technologies-products-market chain, including SWOT-analysis and cross-impact analysis, are employed. In order to reveal extraordinary events that could dramatically influence subject field, methods to identify wild cards – low probability, high impact events – and weak signals – early warning signs of changes in trends and systems – are appropriate. These provide a set of innovation strategies for the subject field, taking into account alternative pathways.

At the final stage, possible scenarios of future development in the subject field are discussed and workshops with leading project experts. During these workshops

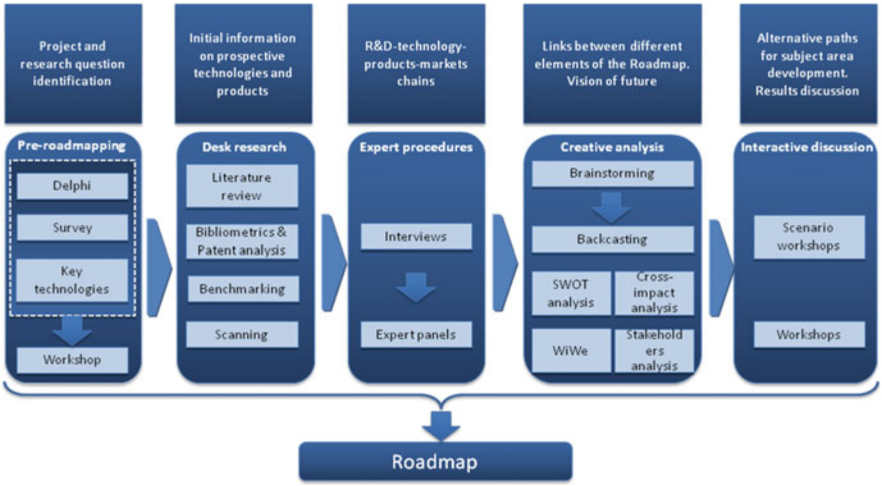

Fig. 8.3 Proposed scheme of integrated roadmap

quantitative and qualitative assessments of future market dynamics are finalized, a draft of the roadmap is produced, and a discussion with a broad circle of stakeholders is held. After public discussions have been held a final version of the roadmap is completed.

Employing these methods gives us an opportunity to develop a roadmap with the following structure (Fig. 8.4).

The integrated roadmap includes four main layers:

- **Technologies**. This layer contains a description of the most promising technologies within the defined time frame. It provides a SWOT-analysis of these technologies that summarizes the benefits and limitations of each one. It also provides a forecast of target properties required to satisfy market needs and a set of technological tasks necessary to reach these. In the final analysis, it gives an opportunity to estimate prospects for each technology in terms of readiness for implementation and potential outcomes.
- **Products**. This layer provides a brief description of prospective products in terms of readiness for commercialization and potential effects for the researched area. It also provides a time frame for commercialization as well as the most promising market niches for each product.
- **Markets**. The methodological approach illustrates three scenarios of potential market development: pessimistic, optimistic, and moderate. It also provides a brief description of the main market features and possible strategies for each market. Thus, all markets are ranked from the most promising down to the least.
- **Alternatives**. The integrated roadmap also reveals possible developments of alternative products. It takes into account the dynamics of the main product properties, the opportunities for export of these products, and their cost among others.

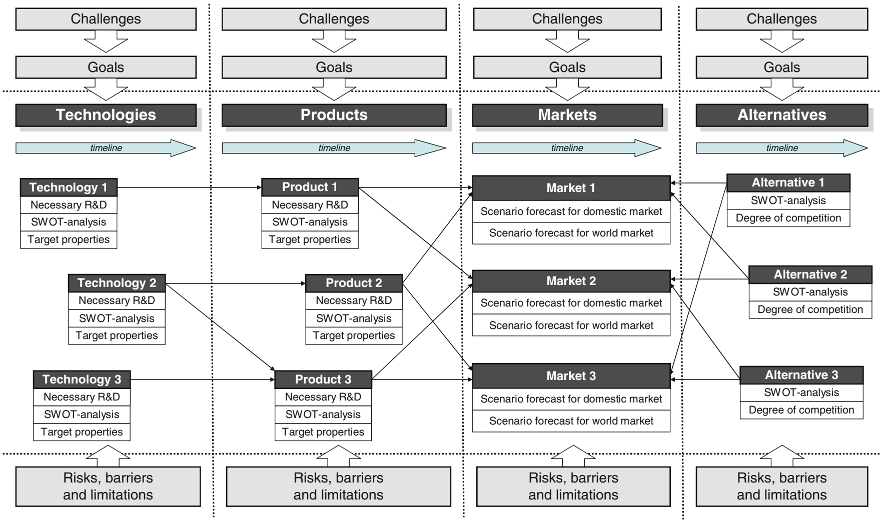

Fig. 8.4 Proposed scheme of integrated roadmap

For each layer we consider challenges and set goals based on these, taking into account all the risks in the field. The roadmap outlines the most significant challenges for the subject field in question and these challenges in turn help to develop innovative technologies and products capable of addressing them. It is especially important to identify all the conditions that could prevent further development of the research area. The severity of any threats will be estimated by the roadmap.

8.3.1 Output and Outcomes of Roadmap Development for Supply- and Demand-Side Analysis

Given the need for water resource, optimization of the water supply industry requires a large consolidation of stakeholder actions and views. The systematic efforts of resource convergence across the water and wastewater industry at various stages of the innovation and production cycle are assigned to the various layers of the integrated roadmap, and comprise multiple Foresight methods.

The roadmapping process was based on traditional industrial organization and demand-side conditions, and then extrapolated to technology issues aimed at tracking emerging technology trends. During the first stage, the distinguishing features of the water supply and wastewater industries, as well as the economic expectations of stakeholders, were identified.

The analysis shows that the Russian water industry faces several challenges regarding partial economic water resource shortages. Unequal water and wastewater supply infrastructure allocation, outdated and aging treatment facilities, obsolete treatment technologies, processes, machinery, and equipment, coupled with increasingly diversified water contamination across the regions are among them.

These terms shape potential demand for water technology solutions since the demand is driven by key industrial actors: large public-private (or government owned) agencies, which deliver treated water to industry and the public, and withdraw the sewage represent initial demand, whereas producers of technologies, processes solutions, and equipment is represent secondary demand.

During the second stage of the technological analysis which is aimed at tracking emerging technology issues, the roadmapping process employs the following steps from Foresight methods and mapping exercises: investigation of technology categories and technology products; linking together the R&D – technology – production chain; mapping out potential market segments for products introduction; developing an attainable time frame for product commercialization; identifying investment-attractive technologies.

First, consistent analysis of the technology portfolio, comprising the investigation of every single technology unit ranging from a particular technology to a technology cluster («technology group»), is made following the analysis scheme outlined below Table 8.4.

This scheme takes into account main technology properties; the application for market segments; the internal technical characteristics that make technologies or products superior or inferior to the alternatives, and those that indicate external water and wastewater treatment industry awareness. The list of methods used at this stage comprise a variety of desk research methods, expert panels, and a few creative analysis exercises (e.g., SWOT-analysis). On the one hand, this technology-side analysis resulted in the investigation of the processing properties of water-treatment technologies and products. For consistency, the primary nano-based technology is equated to the primary nano-based technological product unit due to similar "technology processes": for instance, microfiltration technology in water treatment matches the microfiltration membranes in terms of product development. On the other hand, the research for perspective market niches and competing products is also carried out, using SWOT analysis, mediating the technology and market extremes within the internal or external environment, while contributing to and limiting the distribution of technologies and products.

Table 8.1 shows the arguments in favour of microfiltration technology processes (microfiltration membrane technologies, components, and equipment) for certain water purification segments with tightened water quality standards; in particular, medicine, the food and beverage industry (including half-finished products, ingredients, and finished products), and air filtration. Both the technical properties and operational expenditures of the microfiltration membrane process are determined by consumer preferences, and based on this, market niches are assigned accordingly. The high level of technology readiness of these processes makes them applicable to the municipal sector at the initial stage of the water treatment process for centralized and decentralized water systems.

Table 8.4 Example of technology analysis: microfiltration membranes

Main characteristics	**Application areas of nanoproducts**
Process of mechanical filtration which allows to filter out fine suspensions, fine-dispersed and colloid impurities, algae, unicellular microorganisms larger than 0.1 μm	At initial stages of drinking water production and general water treatment Special industrial applications: medicine; food industry (including half-finished products, ingredients and finished products, alcoholic and soft drinks, vegetable oil and other products) Filtering for various technological environments Air and gas purification
Strengths	**Weaknesses**
Compact size of equipment Capacity can be easily increased due to modular structure The process can be automated	Rather short useful life Remove only some of the impurities working within a specific range Need to be regularly flushed and cleaned
Opportunities	**Threats**
Need to upgrade existing water treatment facilities More stringent requirements to waste water treatment Extremely rapid growth of water consumption Development of special-purpose water treatment segments	Conservative attitude of main users – centralised water supply systems Budget limitations
Competitive products	
Gravel filters, aeration, chemical treatment, disinfection	

In this way, the technology efficiency, and large-scale market application potential of microfiltration membrane processes in municipal and industrial water and wastewater treatment purposes, is proven.

Second, technological processes should be closely associated with market demand so that they can be brought to market quickly, and transformed and transmitted to products available for market application over short-, medium-, and long-term time horizons. Hence consumption properties are assigned to the product groups within the time scale which is differentiated by the basic stages of the innovation's life cycle, comprising research and development, technology prototype, and market application phases (Fig. 8.5). The nanotechnology-associated solutions are concentrated in physical and chemical treatment technologies, and therefore encompass the entire body of membrane processes (baromembrane, electromembrane, decontamination and membrane bioreactor processes); then sorption, coagulation and catalysis technologies; and finally some supplementary nanotechnologies and nanocomponents augmenting the filtration and purification processes.

The matrix view proposed above compresses the results of the analysis, and conveys the time frame of the R&D – technology – production chain of each technology process and product from the clusters listed above, along with the potential market niche available for its implementation and estimates. Here, the

Key and promising products	Expected year of mass production in the RF			Market segment					
	2010	2015	2020	CWS	CWC	IWT	SIWT	IWWT	MWWT
Membranes (LC, LPC, IR, IP)									
Microfiltration membranes	PP	MP	MP	X	X	X	X	X	X
Ultrafiltration membranes	PP	MP	MP	X	X	X	X	X	X
Nanofiltration membranes	PP	PP	MP			X	X		
Reverse osmosis membranes	PP	MP	MP			X	X		
Ion-exchange membranes	PP	MP	MP	X	X	X	X		
Membranes for membrane degassing	PP	MP	MP			X	X		
Membrane bioreactors	R&D	PP	PP					X	X
Membranes with dendrimers	PP	MP	MP	X	X				
Membranes with fullerenes	R&D	PP	MP	X	X				
Nanoreactive membranes	R&D	PP	MP	X	X	X			
Nanostructured membranes	R&D	PP	MP	X	X	X			
Nanocomposite membranes	PP	MP	MP	X	X		X		
Mixed membranes with non-organic and organic particles	R&D	PP	MP			X	X		
Membranes based on zeolite molecular sieve	R&D	PP	MP			X	X		

Key and promising products	Expected year of mass production in the RF			Market segment					
	2010	2015	2020	CWS	CWC	IWT	SIWT	IWWT	MWWT
Promising, supplementary and traditional technologies with potential nanocomponents employment (LC, LPC, IP)									
Ion-exchange nanostructured membranes	PP	PP	MP	X	X	X	X		
Nanosorbents	R&D	PP	MP	X	X			X	X
Active nanocatalysts inbuilt into membrane systems	PP	MP	MP		X	X		X	X
Nanosize biopolymers to remove impurities with adjustable properties	R&D	PP	MP			X	X		
Nanoparticles-based coagulants	PP	PP	MP						X
Nanocatalysts	PP	MP	MP	X	X	X	X	X	X

Legend

R&D – research and development; PP – pilot production; MP – mass production.	
LC – lower costs; LPC – lower power consumption; IR – increased resistance to high temperature and chemical agents; IP – increased productivity	
CWS – central water supply	SIWT – special industrial water treatment
CWC – collective water consumption	IWWT – industrial wastewater treatment
IWT – industrial water treatment	MWWT – municipal wastewater treatment

Fig. 8.5 Key features of nanoproduct estimation: R&D – technology – market chain

full set of potential market variables is listed, comprising centralized and decentralized water system treatment and supply, water treatment in industries with general purpose requirements (heating systems, some manufacturing processes, etc.), as well as specific requirements (medicines, medical solutions and liquids purification like hemodialysis, etc.).

The technology characteristics of the processes and products evolving through the phases of the innovation development cycle determine market options, and the time frame for commercialisation. For instance (Fig. 8.4), the broadest market application potential is found in micro- and ultrafiltrarion membrane processes in municipal and industrial water and wastewater treatment segments. The level of technological development of these baromembrane processes is one of the highest in comparison with the other applications. Jointly, these characteristics indicate a high probability of mass production market absorption in the near future. The other nanotechnology applications have smaller mass-market potential and consequently smaller-scale market implementation potential; for example, research on one of the supplementary nanocomponents in Russia – dendrimers and fullerenes for coupling the membranes – is at the initial stage of research and development. Sufficient time required for their realization as final products and the elaboration and production expenses, taking into account their adjusted technical properties, limit their application to municipal water treatment with vast differentiation of effective demand, various contamination level and treatment technologies objectives (Fig. 8.5).

At the next stage, the set of technology process parameters should be differentiated with respect to short-, medium-, and long-run time frames to show the evolution of the technology portfolio, and illustrate widest implementation possible (Fig. 8.6). This combination of supply- and demand-side analysis leads

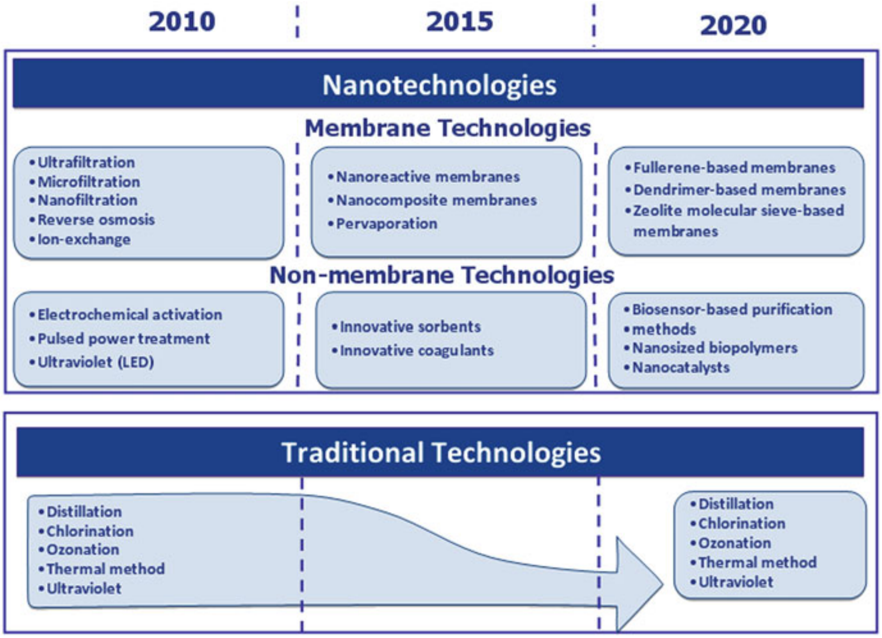

Fig. 8.6 Mapping the technologies inside technology groups by anticipated market appearance date

to the outline of emerging technology trends, which match trends in the usage of nanotechnology and non-nanotechnology. This study shows that these two technology aspects should be regarded as complements rather than substitutes. This is due to specific water and wastewater treatment industry peculiarities, particularly market scale; the size of potential demand; the notion that treated and supplied water is a "public good production" expenses, along with technology peculiarities of water and wastewater purification, including the gradual and multistage treatment process; the strict and highly-scrutinized water quality standards; the wide variety of contaminants; the continuous fluctuation of contaminants level over time, coupled with the dependency on supply system solutions. Yet, traditional technologies cannot be abandoned or replaced by new and emerging technologies in a rush.

The predicted outcome is one of large technology breakthroughs in the nanotechnology industry for both membrane and non-membrane processes (Fig. 8.6), and the resilience of key non-nanotechnology clusters with some evolution in technology properties. In the long-run, so-called "traditional technologies" (filtration, distillation, chlorination, etc.) which appeal to non-nanotechnology processes will retain significant market share despite their relative diminishment. The overall efficiency of traditional technologies in terms of processing and consumption properties is expected to improve. Governmental policy in the form of regulation, standardization, and legislation is regarded as one of the leading drivers of the Russian water and wastewater industry. This is characterized in large part by public supply agencies that shape municipal and industrial water consumption with continued minor interference. Moreover, the shared vision of roadmap stakeholders – which includes public authorities; public and private water, wastewater treatment and supply agencies; producers of technology units; as well as innovation network participants from knowledge-generation, especially high-tech, sectors – in maximizing their benefits is another driving force of the industry sector progress, which is based on the combination of traditional and emerging nanotechnology processes..

Meanwhile the progress in the use of sectoral nanotechnologies is coupled with the shift in their application. The expansion of water treatment nanotechnologies in the long run will contribute to, and supplement, traditional technologies, leading to their radical enhancement. These breakthroughs in emerging technologies will induce the development of new market segments and niches. This effect is associated with fundamentally new technology properties, such as varied selectivity to special contaminants and targeted or "personalized" treatment processes, to expand the flexibility and variability of water treatment services, to make the adjustment to water subjected to purification easier, and to augment the scalability of treatment volumes.

Once this happens, a new generation of sorption or coagulation applications will emerge in the development of nanotechnology non-membrane processes, making them adjustable to the other stages of basic traditional and nanotechnology processes development.

Another mapping exercise employed is the double-criteria system for risk-assessment. This system estimates the market prospects of innovation technology clusters, in which each cluster's based on the criteria of "urgency" and "importance". In terms of urgency, it is the short-term significance of products with high commercialization potential, and a high level of technological readiness. The importance, on the other hand, is the long-term significance, that relies on demand-side conditions, establishing the necessity of R&D investments. The plotted technology portfolio for the purposes of strategic planning across technology pathways integrates financing, commercialisation, and market adaptation decisions.

8.4 Conclusion

In conclusion, the example provided above demonstrates that roadmaps could be employed as an instrument of forecasting and planning in the sphere of emerging technologies, under the stipulation that some requirements are fulfilled. These requirements include the creation of a group of experts who will provide the necessary level of expertise on all the issues related to the development of the subject area; accumulation of a sufficient informational background; construction of an adequate sequence of Foresight methods, integration of creative, interactive, expert- and evidence-based methods; combined consideration of market pull and technology push approaches, taking into account different kinds of effects of implementing new technologies.

The proposed roadmapping approach takes into consideration both technological issues and their contribution to overcoming socioeconomic challenges. Roadmapping allows for the elaboration of comprehensive innovation strategies both for short-run time frames concerning the commercialization of products with high market readiness, as well as for long-term strategies for water sector development.

The methodology allows for the prediction of both the direct and indirect effects of the implementation of emerging technologies in the researched area. It also gives an opportunity to outline possible future developments of researched technologies in interfaced sectors. However, the main limitation of the methodology is the insufficient consideration of the indirect effects of using innovative technologies in fields with many interfaces.

The introduced approach could be useful not only in the sphere of emerging technologies. With some adaptation, it could be used in forecasting and strategic planning both for corporations and government bodies.

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