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ABSTRACT The policy category of 'strategic science' is enjoying increasing popularity. Through a case study of membrane technology, as a scientific-technological field and as a newly-emerging 'world' of membranes, this paper shows how such policy labels and rhetorical claims are filled up, and new social realities are created. The key step is the way in which promises put forward, and expectations being voiced, require actors to position themselves with respect to a future technology. Thus a shared agenda is built up at the same time as a 'world of membranes gels'. The rhetorical space opened up by strategic science and technology policy is then filled up by *actual* strategic sciences and technologies.

The Rise of Membrane Technology:

From Rhetorics to Social Reality

Harro van Lente and Arie Rip

Before the end of the 1970s, there was no such thing as 'membrane technology': now there is, definitely; it is recognized widely, and taken up in science and technology policy programmes. There are more cases of such scientific-technological fields which emerged (or finally came into their own) over the last decade, and they are related to the general phenomenon of science and technology becoming *strategic*, in a number of senses: a strategic resource for enterprises and national states; the object of strategic policymaking; and, last but not least, an activity that is shot through with strategic considerations – of the scientists themselves, and of science administrators, industrialists, policymakers, public groups and movements. The study of particular scientific-technological fields, like membrane technology, allows us to explore the dynamics of strategic science and technology.

Rather than surveying many fields, and diagnosing the new situation, we report a detailed case study. The dynamics of strategic science and technology are made up of interrelated processes of interest definition (often in quite general and promissory terms), resource mobilization strategies and how these interlock, and the gradual emergence of social realities structured by the earlier rhetorics: these processes can only be traced in a case-study approach.[1] Such processes occur in many walks of life, and have been studied there; we will be able, in addition, to use a number of existing analytical approaches to organize our empirical material.

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In this introduction, we indicate how the general question can be articulated further: What is the nature of the new setting of strategic science and technology? How can the phenomenon of promises about science and technology be captured by the concept of 'rhetorical space'? How is coherence achieved in emerging 'worlds' of (in our case) membrane technology? Specification of analytical approaches will be done later, in relation to the case-study material.

The notion of *strategic science and technology* is recent. It emerged some two decades ago in the UK (and, though with different terminology, in France and Germany), while in the USA it was explicitly articulated only in the early 1990s. One characteristic feature is how policymakers, as well as some industrialists, have become interested in whole fields of science and technology, rather than specific projects. In the case of membrane technology, for example, while there had been policy interest in membrane processes before, this was related to *specific* issues like desalination of water. But now the policy interest in membrane processes is an interest in stimulating a scientific technology *as such*, rather than for its specific problem-solving abilities. The special category, 'strategic science', now used in science policy to accommodate the new interest, reflects this point. In one often-cited definition, John Irvine and Ben Martin say:

> Strategic research [is] basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognized current or future practical problems.[2]

It is the potential of such strategic science that is attractive to policymakers and industrialists – and also, in the more glamorous areas of micro-electronics, telematics and biotechnology, to the general public. Resources and goodwill are mobilized for such areas, and competitive struggles between countries now also include competition in strategic science.

By the 1980s, the notion of 'strategic science' was widely accepted in science and technology policy circles as a new category of science, located between the traditional categories of 'fundamental' and 'applied' science, and linked to fundamental science.[3] But it is not a different kind of research: it is basic research located in a different way. Expectations of potential – that is, promises – are what count now, rather than actually achieved understanding or immediate application. In this way, the rise of strategic science as a policy and funding category has created a 'space' in which promises can be floated: generally to whoever is willing to listen, and specifically directed toward sponsors of R&D who have an interest in promising areas of science.

Let us call this space *rhetorical space*, to emphasize the occurrence of claims intended to mobilize audiences. 'Space', in its metaphorical sense (which is, in fact, the Aristotelian idea of space, in contrast to our present Cartesian notion), is a locus for particular kinds of events, an opportunity for particular actions, and a gradient for, and thus a constraint on, the range of actions. Such a space is objectively 'there', because it enables and constrains. But it cannot be pointed at or measured, except through the actions that are enabled and constrained.[4] 'Space' appears as a given to the actors, and shapes their action. But in acting, they modify and sometimes transform it.

The space opened up by strategic science and technology is not yet fully articulated. Its emerging nature is being determined by the interlocking of actor strategies which are themselves predicated on other institutionalized interests and cultures. Rhetorical space starts as a locus, a privileged place for particular activities – in this case, voicing promises about new science and technology and getting a hearing.

Such activities are not new. Voicing expectations has been part and parcel of doing science and mobilizing resources through the ages. In fact, knowledge claims (generalizations of findings, up to the speculations found in the final sections of research papers) already voice expectations, in this case about the validity of the wider claims. And they are put forward to mobilize interest and, hopefully, reputation. Promises and expectations, including broad and interesting claims, are a way to get your audience to listen. Randall Collins pictured science as . . .

> . . . an open plain with men [*sic*] scattered throughout it, shouting: 'Listen to me! Listen to me!' . . . [The] fundamental process is a competition for attention.[5]

The traditional (and continuing) activity of promising in science and technology was oriented to *local* promises, and the work of enrolling allies had to be done anew for each particular case. In strategic science, expectation statements are allowed more scope, and take the shape of generalized promises.

The emergence of a rhetorical space for strategic science and technology was helped by the availability of funds and goodwill. By 1980, almost all Western industrialized countries started to increase their support for R&D, and with specific attention to stimulating innovation. Resources for strategic science were therefore available, and government agencies were eager to fill their portfolios with attractive-sounding R&D programmes. Sometimes they would even press scientists and technologists to come up with promising proposals.

In this collusion of scientists and policymakers, a repertoire (and the related skills) of the 'dialectics of promise' have emerged. Scientists argue that field X is promising, and thus 'strong', in the sense that investments in it will have a good rate of return; but also 'weak', in the sense that without such funding, the field will surely wither away. Policymakers (and their advisers), on their side, have developed skills in decoding such ambivalent messages.[6]

Thus, rhetorical space is on the map. It offers a ready-made slot for locating claims about strategic science and technology. At the same time, recognized procedures for handling such claims, and a repertoire for making them, have emerged.

In parallel with the rhetorical strategies in relation to a promising area of research, one sees actors move into position, create linkages, and define the new activity for themselves and for others. As the actors themselves phrase it, a '*world of membrane technology*' emerges, where you know who is who, and what the important issues are. In a first phase, the dynamics will be predominantly rhetorical, and it is often decisively important to find the right labels to be used as 'currency' in presentations and debates. As we will show, 'membrane technology' itself started its life as such a label. In a transitional period, network building and the formation of a new 'world', guided by the label, are the dominant dynamics. Thus, a rhetorical entity is successful in creating space (now at a lower level) for specific resource mobilization, network activities, and the production of scientific and technical results, more or less in line with the promises.

Membrane technology thus appears as an example of a scientific-technological field which profits from the opportunities provided by 'strategic science and technology', and is partly shaped by it. At the same time, it is an instance of the general process in which strategic science and technology become 'filled in', and become a 'social reality'. Thus, it is a case that can be used to explore the dynamics of this process.

Two mechanisms are particularly important, because they relate to projections, expectations and scenarios, as part of actions and interactions: 'mutual positioning' and 'agenda building'. As we will argue, these mechanisms explain how lasting effects can be created, partly unintentionally. They are also forms of coordination which can occur without commitment of actors to a shared project, while their outcome, even if not necessarily consensual, is to make the new scientific-technological field a 'going concern'.

In both mutual positioning and agenda building, there is a symbiosis of scientific spokespersons for membrane technology, policymakers interested in strategic science and technology, and a variety of industrial and other actors linked up – or being rounded up – with membrane technology. This is the analyst's way of arguing that a 'world of membrane technology' has emerged, with newly recognized activities, interactions and coordination of actions. This heterogeneous world will determine the further evolution of the scientific-technical field of membrane technology.

The key questions we have to focus on empirically are therefore how heterogeneous actors start to interact and become mutually dependent, in the same movement as the rhetorical entity 'membrane technology' becomes a social reality. The emphasis will be on statements from actors (on public occasions, as well as statements solicited in interviews) showing how they position themselves in the new membrane world. The analysis of the (often informal, and not officially documented) processes requires the use of heterogeneous evidence which can be only partially integrated. We think, however, that we can present a plausible view, both of the new dynamic in the emergence and development of scientific and technological fields, and of the processes and mechanisms at work.

The Rise of 'Membrane Technology' as a Rhetorical Entity

Promises and claims contain a rhetorical element, in the sense that they seek to mobilize relevant audiences. When there is a 'breakthrough' – a new phenomenon or a sudden and dramatically improved performance, which draws the interest of many actors, and creates a new domain, or a surge of new activities in an existing domain – the rhetorics are striking. For example, a 'Woodstock of Physics' occurred when high-temperature superconductivity was first presented at a conference.[7]

In the case of membrane technology there was no such breakthrough. A number of strands of development already existed, and while there certainly were transformations, no particular step can be singled out as the 'moving force' for the new development. In industry, membrane systems had been used and incrementally improved. The most important techniques in this respect, in terms of diffusion and commercial value, are reverse osmosis, microfiltration and dialysis.[8] But, for these, there were no dramatic improvements in performance.

The rise of membrane technology did not follow the breakthrough route. What happened was that a rhetorical entity, 'membrane technology', was postulated. Expectations did not refer to a 'breakthrough', but to this rhetorical entity as such. And when it becomes widely recognized, a *reversal* takes place: the various strands of the development of membrane processes are seen in a different light – namely, as part of membrane technology, a promising entity, that needed wider attention, application and research.

We shall document the shift in some detail, identifying the role of spokespersons, and the construction of audiences. Thus, we follow the basic components of rhetorical analysis – the study of skilful, possibly strategic, discourse (or communication, or handling of symbols).[9] According to Chaïm Perelman, the three components of rhetorical analysis to be studied are 'speaker', 'argumentation/discourse', and 'audience'.[10] Instead of 'speaker', we use 'spokesperson', to capture a broader range of situations. In this, we are influenced by French semiotics, where the notion of 'enunciator' in a text can be used also to analyze communication and interaction.[11] The performative argumentation is reconstructed in terms of actions and justifications, and the statements and texts produced in this context. Note that we need not be limited to explicitly persuasive speech, nor even to speaking and writing. There are rhetorics of presentation involved in behaviour, in the set-up of a poster session, in the choices of illustrations and covers of brochures.[12] The last component of rhetorical analysis, 'audience', is usefully defined as 'the set of those that the speaker wants to influence with his argumentation/discourse'.[13]

The Introduction of an Umbrella Term

Although interest in membranes and their functions had grown, there had been no umbrella term. Authors were content to list functions and processes – for example, membrane filtration, dialysis, gas separation with membranes, pervaporation, electrodialysis, liquid membranes, membrane bioreactors.[14] By the end of the 1970s, however, the term 'membrane technology' was increasingly used as an easy shorthand in innovation policy, in technical publications, in symposia and meetings. In 1981, for instance, the Japanese Ministry of International Trade and Industry (MITI) identified synthetic membranes as a 'Basic Technology for Future Industry'.[15] In 1983, the first Annual Membrane Technology and Planning Conference was held in the USA, and it is now a regular event. In Europe, membranes were selected as one of the areas of particular emphasis in the Basic Research in Industrial Technologies for Europe (BRITE) programme, in which universities and industries in France, (West) Germany, the Netherlands, the United Kingdom, Italy, Denmark and Spain participated.[16] At a national scale, governments started stimulation programmes.[17]

The label of membrane technology is not just a derivative of what happens to be popular in policy circles: it has its own career in the realm of science. The *Journal of Membrane Science* was launched in 1976 'to draw together a new field', tentatively called 'membranology'.[18] By 1987, the editor, H.K. Lonsdale, reflecting on the growth of the field, wanted to put its house in order. It is increasingly difficult to define a membrane, he wrote, and 'it's getting tougher all the time, because our perceptions of membranes, and what we make them out of, and what we do with them keep getting broader all the time'. Ten years before, his definition would have been something like this: 'A membrane is a thin, usually polymeric, film that exhibits permselectivity'. To the uninitiated (the public), he usually just said that a membrane is 'a very fine filter'. But now things have changed. For instance, 'what about these new ceramic "membranes" now being offered commercially for microfiltration and even for ultrafiltration?'. And finally, he asks his readers to send the 'perfect definition of a membrane, one that the fewest number of membranologists would argue with'.[19] In 1989, Lonsdale published the second part of this editorial: it sums up the various definitions the readers had sent in; he concludes that . . .

> . . . they all seem to hover around the same point. They support my contention that a membrane isn't just an object in the abstract, but its definition must embody its function. As the functions we ask membranes to carry out broaden, so must our definition.[20]

Clearly, there is variety, and some spokespersons want to contain it. In the meantime, the umbrella term becomes established as part of the repertoires of scientists, industrialists and policymakers. One useful indicator is how articles and other products of research are classified in indices. In the *Index Guides* of the *Chemical Abstracts* we do indeed see changes in classification, although more complex than just the introduction of a new umbrella term. Each Guide covers five years' publications; in Table 1 we summarize the differences in indexes with regard to 'membranes'. There are three changes here that, taken together, indicate that the study of membranes is more and more a study of membrane technology.

TABLE 1
Changes in the Indexes of the *Chemical Abstracts*

Years	1967–71	1972–76	1977–81	1982–86
Headings	Membranes	Membranes	Membranes and Diaphragms	Membranes, Membranes Biological
Cross-references ('See also . . .')	Dialysis Diaphragms etc.	Dialysis Diaphragms etc.	Filtering materials	Filtering materials
Example of process or artefact under the heading	–	Ion-exchanging	Ion-exchanger	Ion-exchanger
#numbered entries (period 1967–71 = 100)	100	180	310	430
#entries other topics (total in *Chem. Abstr.*) (period 1967–71 = 100)	100	137	170	177

First, the *Index Guide* of 1982–86 clusters biological and synthetic membranes no longer under one heading, but under 'Membranes, biological' and 'Membranes', respectively. So synthetic membranes are the general case, and biological membranes represent a special case. Second, the first association with membranes has changed – at least if we interpret the '*See also . . .*' immediately following the heading as a first association of subject. With the *Guide* of 1977–81, we no longer read a list of items including 'dialysis', 'Donnan equilibrium' and 'osmosis', but just one item: 'filtering materials'. Third, the character of the items mentioned under 'Membranes' has changed: less a list of natural or technical processes, and more a collection of artefacts – for example, 'ion-exchangers', instead of 'ion-exchanging'. Besides this qualitative change, an indication of quantitative change can also be inferred from the *Chemical Abstracts*: there is an increase in articles about membranes, and one that is higher than for other topics (last row of Table 1).

Together with the introduction and establishment of the umbrella term, a *history* is created, the history of membrane technology, which in a sense creates the field henceforth to be covered by that term. Before the 1980s, different processes with membranes are used and proposed as interesting alternatives for other techniques. There is no reason, however, to think that all these processes (membrane filtration, haemodialysis, gas separation with membranes, electrodialysis) belong, or should belong, to one technology. They have different histories, are used for different purposes, and are made by different firms. In the late 1970s and early 1980s, however, membrane technologists were creating a history for themselves. It is a history with founding fathers and other heroes, with Hard Times and Golden Ages.[21]

The changed appreciation of the research on reverse osmosis between the 1960s and today offers a nice example. In the 1960s, the US Department of the Interior (Office of Saline Water) spent something like $90m on the research and development of reverse osmosis, an application of transport processes across membranes to desalinate (sea)water. The problems that could be addressed by reverse osmosis were the poor quality of drinking-water in the southern states, and water supply to arid regions. Membrane researchers now reformulate this episode in terms of 'membrane technology':

> Despite the fact that no membrane industry as such existed, the US Government made a far-sighted commitment to the new technology. ... During this 'Golden Age', hollow fibers, spiral-wound modules, asymmetric membranes, thin-film composites and all the other basic components of current membrane technology were developed.[22]

Membrane Technology as a Generalized Promise

The way in which membrane technology became an entity by itself is visible in the ways in which membranes are introduced in articles. Drawing on magazines of the chemical engineering and chemistry communities of three countries, we show, in Table 2, typical words that occur in titles of articles about what is now regarded as a part of 'membrane technology'. We compare two periods of six years each. Given that these magazines function as forums for practitioners in which agenda building occurs, and realizing that authors try to capture the audience through the titles of their contributions, shifts in the frequencies of title words indicate shifts in the

TABLE 2
Frequencies of Title-Words of Articles in Chemical (Engineering) Magazines

	Filtration	Osmosis	Membrane	Technology	Total
The Chemical Engineer (UK)					
1978–83	9	3	6	1	18
1984–89	5	–	14	4	22
Procestechniek (NL)					
1978–83	15	3	14	3	22
1984–89	3	–	17	12	22
Chemisch Magazine (NL)					
1978–83	–	1	4	–	5
1984–89	1	–	15	3	15
Chemie Ingenieur Technik (FRG)					
1978–83	7	5	28	5	42
1984–89	5	4	38	7	56
Total					
1978–83	31	12	52	9	87
1984–89	14	4	84	26	115

shared 'funnel of interests'.[23] We see an increase in articles flagging 'membranes' in their title. Even more interesting is the shift of (membrane) 'filtration' to (membrane) 'technology', and the disappearance of 'osmosis' from the titles.

The nature of this shift can be further specified by comparing the first sentences of articles in one of the magazines listed in Table 2, *Procestechniek*. Table 3 gives the titles and the first sentences of three articles from 1978, and three from 1986. Articles from 1978 typically begin with a problem (technical and/or social), and discuss some solutions. Processes with membranes are presented as alternatives for other techniques with or without membranes, sometimes not because of the actual performance but because of the perceived potentialities. Articles from 1986, on the other hand, state that 'membrane technology is developing itself', explain what sub-areas it has (filtration, dialysis, and so on) and discuss (future) applications. Instead of a list of processes that can be used as alternative options for a function like 'desalination', we now hear about a technology that is developing itself, and offers the world various opportunities. In one

TABLE 3
First Sentences from Articles in *Procestechniek*

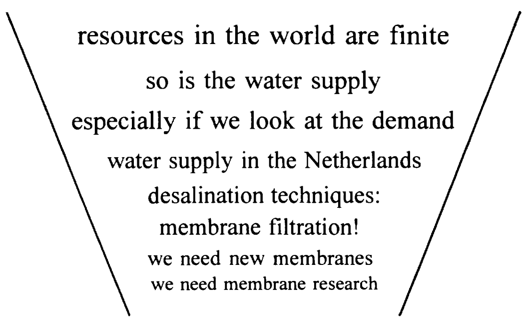
Years	Title	First sentence
1978	The production of drinking and industry water with hyperfiltration from ground and surface water	Hyperfiltration has originally been developed to desalinate water.
	Ultrafiltration of diluted potato juice	The production water of potatoes of which starch will be extracted, contains . . .
	The purification by reserve osmosis of effluent of biological purifying plants of water of the river IJssel	In the future, the fabrication of drinking and production water will depend more and more on the availability of surface water.
1986	The history of membrane technology	The history of membrane technology goes back to 1748, when the French Abbé Nollet published his observations on osmotic phenomena.
	Membrane technology for the chemical industry	Membrane technology is an extensive area, in which the development of membranes, devices and processes is still going on. Some parts of this technology, like . . .
	Membrane technology a solid growth technology	What are membranes, what can they perform, and what may one expect of them in the future? This article gives an answer.

Source: *Procestechniek*, Vol. 33 (1978), 503–12; ibid., 677–80; ibid., 746–53; *Procestechniek*, Vol. 41 (1986), 47 (no. 3); ibid., 48–54 (no. 3); ibid., 140–43 (no. 9).

case, a short history of 'the' membrane technology appears, in which the author feels the need to explain how it is possible that 'it' developed so slowly before 1960.

The change in the 'funnel of interest' can be illustrated in detail by contrasting two articles from *Procestechniek*, by the same author, C.A. ('Kees') Smolders, but written four years apart (1978 and 1982).[24] In the earlier article, 'Waarom Membraan Filtratie?' ('Why Membrane Filtration?'), the 'funnel of interest' is wide, and encompasses a heterogeneous set of problems: economic, social, technical and scientific. The justificatory argument is structured as shown in Figure 1.[25] That it is not yet straightforward to write about membrane filtration 'as such' is revealed by the size of the introduction about water supply: in a text of just seven pages, it takes up exactly half.

FIGURE 1
The Funnel of Interest for Membrane Research



In the later (1982) article, there is no longer any discussion of membranes as an alternative option that needs wider attention. The first sentence of 'Vorming, Structuur en Eigenschappen van Membranen' ('Formation, Structure and Properties of Membranes') already posits an inevitable development:

> Because membrane filtration can be applied in a very broad range, it is necessary to produce membranes with all sorts of properties.[26]

Later on we hear about the reason that membrane filtration can be applied in a very broad range:

> Because there is a continuing development to produce special ('tailor-made') membranes, the number of possible applications will increase in the future.[27]

This is assured in the conclusion (after descriptions and assessments of the various membrane processes):

> The number of separation problems for which membranes can be applied is almost unlimited.[28]

The research area is no longer introduced as an answer to societal problems, but is presented as a generalized promise, and thus significant for its own sake. This reversal from a dependent to an independent entity allows texts to be about solutions looking for problems and applications, rather than about problems looking for an answer. The applications are mentioned, but are not very specific. Audiences are identified, but what they should do with membranes, apart from supporting research on membranes, is not indicated.

Spokespersons of Membrane Technology

While magazines and reports may present 'membrane technology' as an entity, this does not, of course, imply that there now *is* such a technology, and that it is developing itself. There is indeed ongoing research and development, there are specific products and marketing of new applications. There is also rhetorical work. Behind the articles, reports and discussions, are authors who try to convince a readership. In doing so, authors may become *spokespersons*. They speak *for* a technology, rather than directly to their own interest. They are not spokespersons in the sense that they *represent* an organization, but are more like those who on their own initiative speak for an economic sector or an academic discipline. Thus, they aggregate a domain while they speak for it.[29] In our case (and more emphatically so than in the case of an economic sector or an academic discipline), they speak for a field that is still a promise. They are '*promise champions*', one could say, analogous to the 'product champions' working to realize an innovation: and they often realize that they are playing such a role.

An example of such a spokesperson is the Editor of the *Journal of Membrane Science*, H.K. Lonsdale, whose activities we have already noted. In his often-cited review article, 'The Growth of Membrane Technology' (1982), Lonsdale tries to bind together all the parts of 'this highly fragmented technology, covering such wide-ranging applications', which relates to different scientific disciplines and in which different industries are involved. His point (that is, his 'method of aggregation') is that 'the glue that binds all of these varied applications and disciplines together is transport across membranes'.[30] In the structure of his article, all the parts of 'this highly fragmented technology' earn a place according to the specific way in which they discuss 'transport across membranes': they are thus positioned as partial techniques belonging to the *one* 'membrane technology'.

The role of spokespersons is not limited to editors of journals. Research leaders of university groups can dedicate themselves to the task of uniting a field and pushing a promise. An example is Professor Kees Smolders (who is also a member of the editorial board of the *Journal of Membrane Science*). In the Netherlands, he was one of the pioneers of membrane research, and he was the leading figure in setting up and realizing a national research programme on membranes. His status as a representative of the entity 'membrane technology' is recognized by many others. This goes so far that he is sometimes called '*Mr Membrane Technology*', and his Department in the University of Twente is called the 'Mecca of Membranes'.[31]

Being a promise champion implies that your fate is connected with the fate of the promise. If the promise becomes widely accepted and implemented in research programmes, and receives industrial attention, you will be honoured for having a clear mind, and being able to see ahead.[32] But if the promise fails to materialize, you will be looked upon as a Don Quixote – unless, of course, you had other irons in the fire, and were able to shift in time.

The role of promise champions is connected to the new context of strategic science. There is rhetorical space for a new type of argument and a new type of audience: when science and technology policy focuses on stimulating strategic areas that potentially lead to innovation, policymakers *need* interesting technologies to fill their portfolios. Promise champions can fulfil those needs, even if the promises are not as 'clear' as they needed to be in former funding regimes. With strategic science, a new audience is born – an audience that is interested in 'great expectations'. The mobilization strategies of promise champions, and the need to fill portfolios of policymakers, now interlock.[33]

Constructing an Audience

Promise champions need not be individuals. In fact, in the age of strategic science and technology, a plethora of collective actors has emerged to carry and protect new developments, from biotechnology directorates (in the UK),[34] and innovation programme committees (in the Netherlands and Germany), to Platforms for HDTV.[35] Such collective actors are heterogeneous – combining, explicitly or implicitly, science, industry, government, and sometimes also social organizations. In the case of membrane technology, we single out the Dutch Programme Committee on Membrane Technology, to trace how such a collective actor goes about constructing audiences.

One goal actively pursued by this Programme Committee was to raise interest in membrane technology in those firms that they regarded as relevant. For instance, the Committee wrote two booklets about membrane technology in the Netherlands,[36] which argued that such a thing as membrane technology exists, that it is increasingly used by industry, and that it has a shining future. It turned out, however, to be unclear where exactly this technology is used: 'It appeared difficult to find all membrane installations in Dutch industry and services'.[37] The Programme Committee is here attributing an interest to firms, even when the firms themselves do not recognize it – yet.

The gap between presumed and actual involvement of industry is a typical phenomenon of strategic science and technology. It also was encountered in a survey of membrane activities in the UK, published at about the same time: 'It was surprising how many companies operating in the filtration and water processing field replied that they were not interested in membrane separation'; and a 'very few companies were found that admitted they were carrying out research at bench and pilot scale on the application of membrane separations'. The conclusion was *not* that industry is not interested: 'Indeed, it would cast doubt on their ability to remain competitive in international markets if they were not doing so'.[38] Clearly, it is axiomatic that industry *should* be interested, because membrane separation is a strategic technology. So policy agencies, together with spokespersons for membrane technology, are constructing an audience for their activities – or, as they would say, for membrane technology.

The Dutch Committee tried to interest industry by organizing poster sessions and public lectures every year (at the so-called 'IOP Days'), the lectures eventually appearing in a journal called *Membraantechnologie*, published and circulated by the Committee. All firms that are supposed to be 'potentially interested' are invited to these IOP Days. How did this work out? There is not, or not necessarily, a direct instrumental value to the firms involved in IOP Days. The ratio 'poster/persons' in Table 4 indicates that, at an IOP Day, researchers are presenting themselves to firms, hoping for support for their projects. Representatives of the firms, on the other hand, complained that the posters were 'too scientific'. While they did not question the scientific value of the results presented, they thought the economic relevance – purportedly the reason for supporting this research – was not made clear. They went so far as to suggest to the Programme Committee that it should be obligatory to indicate technical and economic relevance on every poster. As one participant from industry formulated it, 'they now just organize a scientific meeting, paid by the IOP money'.[39]

The gap between scientists and industrialists is a well-known phenomenon. What is striking is how firms, nevertheless, do come to these Days, 'because you hear a lot about membranes today, and you want to find out what's going on'. Another indication that these Days are seen as important events is that even those who are not working on IOP projects are willing to present their activities – for instance, new firms that have started with the production of membranes or separation installations. For such firms, there is no obligation towards a funding agency to visit their factories, or to support specific research on their behalf. But they feel obliged to present their activities, because a relevant audience is being constructed, and they have to be visible to it. In doing so, they reinforce the interest in membrane technology, giving it a life of its own, independent of any 'programme

TABLE 4
Background of Participants at the IOP Day, 1989

Background	# Posters	# Persons	Ratio
University	26	72	0.36
Research institute	19	40	0.48
Firm	6	82	0.07

committee'. What was at first a label is now becoming an entity that exerts force on others.

The Rise of Membrane Technology as a Social Reality

Thus far, our argument has been that membrane technology emerged as a label around which expectations were formulated. The specific rhetorics of membrane technology were reinforced by the space opened up by strategic science and technology. The rhetorics were part of the actor strategies of spokespersons who were seeking and constructing an audience among scientists, and in government and industrial circles.

The next step of our analysis is to discuss how these rhetorical activities had effects and moved actors, and how activities interlocked. For this step we cannot base ourselves in the literature on rhetorics, because this literature limits itself to text, discourse and the relationship between rhetorics and a *given* community. Here, however, we have a situation where there is no community, yet. Science policy implementation studies should have encountered such situations, but very little attention has been paid to the mechanisms involved. Their focus is on outcomes, and on advice to policymakers.

Following an early suggestion of Michel Callon,[40] we suggest that it is the *scenario-like* character of the promises and projections of membrane technology which moves the actors. And when they move in terms of the scenario, they reinforce it, make it more forceful. This approach gains plausibility when one recognizes that individual expectation statements already contain a 'script': it indicates promising activities of research and technical development to be undertaken, by the enunciator of the statement and/or by others.[41] These actors intend to mobilize support in specific ways, and are assessed by their scripts – in, for example, discussions about priorities and strategic orientations. Because of this embedded script, responses to the expectation statements will have an action component: following the script or going against it, partly or wholly.[42]

The heterogeneous actors who start moving and linking up in terms of the scenarios, create (as they themselves often phrase it) a membrane *world*. 'You know this little world'; and 'Yes, it is a small world, in Europe you start to know everybody. And even at the global level; when I am in the USA, I recognize the people by now'. In an interview, a manager of a membrane company indicated their position with regard to another company in these terms: 'They are no competitors of ours, that makes it easy. We are part of the same world, but with another product'.[43]

The actor-category 'world' refers to a set of heterogeneous actors, related by their shared interest in the promise of membrane technology, and by the mutual dependencies in their activities. There is a clear overlap with the central concept of 'social world' analysis, but this analysis cannot be applied directly here. We want to capture what we think is a new kind of dynamic in which actors relate to each other, while not yet embedded in an established social structure.[44]

The next question is: What binds together the heterogeneous actors, and makes them take each other's actions into account? The actors themselves would say that it is their shared interest in membrane technology that creates the linkages. But now that we have shown how 'membrane technology' emerged as a rhetorical entity, and how audiences were actively constructed, their argument cannot reflect the actual processes. It is phrased with the benefit of hindsight, after the reversal to a more or less independent 'membrane technology' has taken place.

We shall answer this question about the emerging social reality of membrane technology by considering three interrelated phenomena. First, what happens is that actors take up positions and make linkages. One effect is that *nodes* are created, which introduce irreversibilities into the process. Actors like Professor Smolders, locations like the 'Mecca of Membranes', or a special stimulation programme, can become such nodes, as well as firms or research institutes which can play key roles in the emerging world.

Second, mutual positioning of actors creates dependencies which do not rely on any direct linkages, especially through the articulation of a more-or-less shared *agenda* for the membrane world. As we shall show for the example of three firms with membrane technology activities, this is a self-reinforcing process, where positioning induces agenda building, and the resulting agenda stimulates further positioning.[45]

A third phenomenon is how strategic information is inferred from the positions expressed, or taken up in other ways, by actors, and how *reputation building* allows further *coordination*. Again, these are to some extent self-reinforcing processes.

It is with these three building blocks that we can trace the transformation from rhetorics to social reality, avoiding an explanation of the process in terms of its eventual outcomes.

The World of Membrane Technology Gels

We will continue to use the Dutch developments as an example, and start the analysis where we stopped: rhetorical work as part of actor strategies. The gradual emergence of a membrane world that is independent of actor strategies can be shown in the stages of Professor Smolders' career. When Smolders started research on membranes, it was as part of a research programme in macromolecular chemistry and polymer studies. Linkages with other actors were created through collaboration with a variety of firms (Wafilin, AKZO, Shell) and research institutes (TNO, NIZO, KIWA).[46] At the same time, he tried to promote membrane filtration by organizing meetings, and by publishing articles in magazines for chemical engineers about the importance of membrane filtration (see the examples, in the preceding section, of how he sought to capture audiences). In the magazine *Procestechniek*, he wrote editorials and articles with titles such as 'Why Membrane Filtration', 'Membrane Filtration as Technological Innovation', and 'Membrane Filtration: A Steady Growth' (our translation). There, and in other interactions, Smolders' position was that governments of Western industrial countries have become interested in innovation-induced economic growth; that membrane filtration is an immature, yet promising technology; and that the creation of a government-funded research programme on membrane filtration is recommended. His own interests and those of membrane filtration coincided.

As a result, he indeed received funding for research projects, and his major success was the mission of rapporteurs to Japan in 1982 (March–April), of which he was the leader. Such missions were organized to prepare for a special stimulation programme. In 1981, the Dutch Ministry of Economic Affairs and the Office of Science Policy started a range of innovation stimulation programmes in specific areas, the so-called 'Innovation-Oriented Research Programmes' (IOP). The first was on biotechnology.[47] The important point here is how, through its members, the mission to Japan aggregated representatives from organizations with which Smolders already had contacts: TNO, Wafilin, AKZO, KIWA, the traditional membrane industries and research institutes. The rapporteurs, not surprisingly, concluded that Japan was investing a lot of money in membranes, and that a research programme on membranes was needed in the Netherlands. In addition, they introduced the umbrella term 'membrane technology'. When they left, their official mission was to report on 'membrane filtration technology' in Japan; but when they returned and reported, they flagged 'membrane technology' in the title and text of their report.[48] Thus, they were assembling relevant actors, and using a new label to claim that these belonged together.

The promise was more important than any direct relevance of membrane technology. A policymaker who was responsible for the programmes at the Ministry of Economic Affairs at the time, later recalled how Smolders, 'with his enthusiasm, expertise, technical knowledge and his vision of the future, succeeded in selling this [membrane technology]'. He himself thought it was an 'interesting opportunity for the Ministry to try out its innovation stimulation measures', but it was not easy to sell it to others within the Ministry (which had a tradition of fiscal measures and links with industries, and had only recently started up a technology policy). Membrane technology lacked a link with industrial activities and 'therefore, within the Ministry, it was not such a great subject'.[49] Nevertheless, the Ministry of Economic Affairs and the Office of Science Policy established a Programme on Membrane Technology for eight years, as was strongly advised by the rapporteurs. The budget was, in total, Dfl 25.8 million. Universities and research institutes could propose research projects; each project should have a supervisory group, preferably including a representative of industry. Smolders was appointed as Chairman of the Programme Committee of the IOP.[50]

The stage was now set for getting the rewards for being a promise champion, as well as further network building. The main recipient of IOP funding was Smolders' group (about a third of all projects), and by the end of the 1980s this research group had become the largest university group on membrane research in the world. But it is clear that Smolders' group was not the only one that benefited from the stimulation programme: by 1990, about 70 researchers who had been associated with the programme were working in some 45 membrane research projects; in total, 220 person-years have been funded by the IOP (the research projects are subsidized to 50%).[51] Table 5 shows the increase in the number of researchers (regular employees) involved in membrane research.

TABLE 5
Number of Membrane Researchers at Universities and Research Institutes

	1983	1989
University of Twente	5	10
University of Wageningen	–	2
TNO (applied research)	10	22
NIZO (dairy research)	4	10
ECN (energy research)	–	3

Source: IOP's *Netwerken voor Strategisch Onderzoek* (The Hague: Ministry of Economic Affairs, 1989).
Note: This list only gives the main universities and research institutes doing membrane research. PhD students and other temporary employees are not included.

The overall movement, then, is an increase in actors taking up positions, making linkages and creating nodes in the emerging world of membrane technology. Before the IOP, Wafilin (now Stork-Friesland) was the only producer of membranes in the Netherlands – there were several firms importing membranes and installations – but after 1984, other firms started production. A small and strongly R&D-oriented firm, X-Flow (which will be discussed in some detail below), drew a lot of publicity. However, firms that only produce installations, or are specialized in engineering, are still in the majority.

Other changes are the various collaborations supporting R&D on membranes, or on installations. The Agricultural University of Wageningen and NIZO started a membrane laboratory to investigate applications in milk processing; ECN and a group led by Professor Burggraaf (University of Twente) founded an institute for ceramics research, in which ceramic membranes are studied; and small-scale collaborations emerged between firms and research groups in universities and research institutes.

The world of membranes gels. Some actors consciously work to that end. The task of the IOP Programme Committee was to stimulate all kinds of contacts between industry and universities, to create a 'network' or 'infrastructure' that will be strong enough to ensure further development when the IOP period is over.[52] So the IOP is not just an innovation programme: its intended outcomes are broader than just innovations. The IOP builds on, and then reinforces, a transition to an interest in a technology 'as such', and tries to construct a new sector or field around it. And the technology 'as such' is supported, as we indicated, by a cluster of actors: innovation policymakers, intermediary actors in the R&D system, scientists from universities and research institutes, technologists and firms. The audience has stabilized, and while participants may shift, membrane technology will survive because interest in it will be ensured.

The process appears to have become irreversible. In 1991, when the IOP on membranes expired, the Programme Committee tried to secure further funding. It took the initiative to establish a Foundation for Separation Technology in the Netherlands,[53] which in its turn (unsuccessfully) applied for an IOP on separation technology. The Programme Committee also started the Dutch Membrane Society, 'an independent society to support the development of membrane technology'.[54] Another initiative is the foundation of a European Membrane Institute, supported by the Commission of the European Community, in which the University of Twente cooperates with five other universities in Europe. The partners are chosen because 'they cover the whole area of membrane technology'; Professor Smolders, who retired from his chair in 1991, has been appointed as the 'independent chairman' of the institute.[55]

These attempts demonstrate that the Programme Committee was acting for the technology 'as such', rather than as implementers of a specific, and limited, part of government policy.[56]

Towards an Agenda: A Detailed Example of Three Firms Positioning Themselves

Because expectation statements contain a script of the future world, they position the relevant actors, explicitly or implicitly. And since they are public or semi-public statements that can be drawn upon by others, expectation statements require some response from the actors being positioned. An actor that does not like the role allocated to him or her in the script must react, either by protesting against the role, or by contesting the nature of the expectations.[57] The positioning and counter-positioning create an *agenda* for activities in the membrane world, for example through specifications of the kind of membrane that is needed, or options to be preferred and directions to go.

Of the inhabitants of the membrane world, *firms* are particularly interesting, because they are much closer to implementation of promises than researchers who have, in the words of C.P. Snow, 'the future in their bones',[58] and will move from one hopeful future to the next.

First, we will consider two firms that work in different parts of the membrane world, but still take each other into account: 'X-Flow', a small firm that originated from IOP-related research,[59] and 'Hoogovens Industrial Ceramics' (HIC), a subsidiary company of the large firm Hoogovens.[60] The former produces polymeric hollow fibre membranes; the latter tubular ceramic membranes. The two firms position themselves in different ways, as inhabitants of the new membrane world. An example is how they give lectures at the IOP presentations and at membrane science conferences: X-Flow gives detailed scientific lectures,[61] whereas HIC only gives a global overview of its activities.[62] But both present themselves as being at the forefront, at least in the Netherlands. This positioning is accepted by the Programme Committee, which 'uses' both firms as proof that the IOP formula works well. In an IOP brochure, the first two outcomes mentioned in the list of 'successful results' concern X-Flow and HIC.[63]

The technical and market expectations of both firms are drawn from expectations that are shared in the wider circle of the membrane world. In fact, both firms define their strategic goals, and the internal agendas derived from them, in terms of these shared expectations. When X-Flow started, for instance, it oriented itself on the 'signals' of the wider circle, and these still guide its search directions:

> We got signals that the market existed in principle, and this was confirmed from all sides ... [People said:] We want this and that, and then we will buy it. And every time we heard the same thing: membranes should be hydrophilic, they should be steam sterilizable, and the fouling should be minimal.

Another example is that both HIC and X-Flow expect that the importance of applications with organic solvents (until now a difficult area for membranes) will grow. As a result, the research on membranes for such applications is high on the agenda in both firms, and both try to collaborate with firms with expertise in this area.[64]

These two firms are involved in mutual strategic positioning with respect to the new technology. The following interview quotations are indicative. X-Flow about HIC:

> The development of ceramic membranes is not possible for small firms. It is too expensive, you need a big firm behind you ... But I really doubt whether all this is worth the trouble: ceramic membranes will always be more expensive.

While HIC says about X-Flow:

> For them it is more difficult, and easier at the same time, than for us. They lack the support of a large firm, so they have little resources to start with. But on the other hand, for small firms like them it is not necessary to grow that much. If they have found a market niche, they can stay there. We are forced to grow in order to pay the huge investments back to Hoogovens.

Their mutual positioning affects their internal agendas and their search strategies. When X-Flow's R&D manager is talking about its research agenda, he puts the specifications of the material he is looking for in the light of the polymer–ceramics distinction and competition:

> I am in charge of the R&D here. What I am interested in is the following: when will a polymer be available on the market in greater quantities, which resists higher temperatures, has a longer life time, which has this and that properties, and so on, and so on. ... Just to enhance the

possibilities of applications of this [polymeric] material. Thus, to continue the competition with ceramics.

This last sentence, we note, was unsolicited.

When expectations are shared and strategies interlock, an agenda for the world of membrane technology is created, and this includes indications of which specifications are important. With the positioning of HIC and X-Flow at the forefront of membrane technology in the Netherlands, the polymer–ceramics distinction earned a prominent place on the agenda of Dutch membrane research in the 1990s. From a scientific or technical point of view alone, it is not clear why ceramic *versus* polymer should be the issue of the next decade. It can only be understood if we consider the positioning of the firms (as taking the lead in the development of membrane technology), and the shared expectations (especially those concerned with organic solvent applications).

The effect of the strategies of X-Flow and HIC on the agenda of the world of membrane technology is unintended. X-Flow and HIC pursue their strategies in terms of their own interests, given their perceptions of their positions. Other actors may explicitly work towards building a shared agenda, although even then outcomes are not guaranteed. The IOP Programme Committee provides an example of explicit agenda building. In general, spokespersons for membrane technology would be working to this end. To make the agenda forceful, there must be technical specificity. It is thus that Professor Smolders' definition of the ideal membrane should be understood:

> In many places in the world there is much attention to membrane technology as a new separation technology. ... Yet, the 'ideal' membrane, which can stand 5 mg/l chlorine, bacteria (aerobe and anaerobe), a pH of 2 to 10, a relatively high temperature of 50°C and a lifetime of at least 5 years, is not available.[65]

While actors expect agenda-building activities from public spokespersons, interestingly enough, attempts to influence the agenda of the field can also be found among firms. Shell, and specifically its Central Research Laboratory in Amsterdam, positioned itself, and took part in the membrane world, with the aim of reorienting the agenda, rather than becoming a producer itself.

> From the beginning our strategy has been: not to become a membrane manufacturer. We are not going to develop our own membrane business. What we want instead is to assure that the right technology for our company will be available on the market [in the future]. We've chosen to do this by doing research, by supporting university research and by cooperating with other firms. We want to assure the development of membranes that can be used for our applications.[66]

It was for such reasons that Shell supported X-Flow. It also created visibility more generally, for example by hosting an IOP Day in the Central Research Laboratory. Its strategy to focus on achievements of membrane technology as a field was successful in its own terms, and it interlocked with the mobilization strategies of Smolders and others:

> We have been able to influence the development in the Netherlands. Our requirements for applications differ from those of a brewery or a producer of cheese. Because we were already doing some research in-house, we have been able to influence to some extent the directions of research within the IOP. . . . It is an interaction. At the Shell Laboratory we were doing research on membranes, and so did Smolders' group. When Smolders could show that some interest in industry existed, he got IOP funding for his research. The help was mutual, [because] within Shell then, people increasingly said: 'You hear a lot about membranes nowadays, isn't it time to do something with membranes? It is a new technology, so we have to spend money on it'. In such a climate our research project [on membranes] could survive before it could show actual results.

The researchers at Shell succeeded in interesting the production departments; they received orders (and funding) to do membrane research.

> Then you have market pull [that is to say, the operating companies within Shell ask for it], which is a favourable situation for us.[67]

What we see here is how firms, of their own accord and also stimulated through the existence of an IOP and the actions of the IOP Committee, position themselves in the membrane world. When their strategies interlock, interdependencies are created and maintained through a shared agenda in the world of membranes. In this way, irreversibilities are introduced into the process.

Information and Reputation in the World of Membrane Technology

Companies, individuals in companies, as well as scientists and science and technology policymakers, all value information about probable directions of technologies, and about the spectrum of possible options. They go to the 'Membrane Technology and Planning Conference', read *The Journal of Membrane Science*, or buy the market reports of the *Business Communication Company*. Or they invest in informal intelligence activities, up to friendly and unfriendly spying. Or they pay for advice, and commission reports.

Mutual positioning is another source of information, and when drawn upon in this way, it reinforces the tying together of actors. In the membrane world, people are prepared to make inferences on the basis of what other actors do (or refrain from doing):

> The establishment of such an IOP on Membrane Technology, that is an indication. If the Dutch government invests so many million guilders in membranes, it must have its reasons. It must have relevant information – so its support of membranes is a clear signal.

And:

> Gas separation gets a lot of attention. Every self-respecting research institution puts some effort into it.

And:

> Non-water separation [organic solvent separation] is developed by some of the giants, like Shell and BP. So if one of them does it, you can be sure the others must do it also. That there are large interests involved is certain, because everybody is close-mouthed about it.[68]

Explicit or implicit positioning clearly offers important information, even if it may be based on logically dubious inferences (for example, when silence is seen as a positive indication). Note that in the world of membranes (and in general), information is not only read in texts, but also in acts. If an actor does something (or avoids doing something), s/he inevitably takes a position, and this positioning is recognized by others. By acting, you 'say' something. The action of big international firms like Shell and BP 'being close-mouthed about organic solvent separation' is read by others as saying that, in this part of the market, 'large interests are involved'. Readable action includes readable non-action.[69]

Further important sources of information are the *reputations* of firms, of research institutes and of individuals. Once (provisionally) established, reputations reduce the costs of search for relevant partners, or identification of competitors. The membrane experts in a firm know who is who in the membrane world, and select accordingly:

> For gas separation, X, Y, and the combination of A and B are important. Z is also active, but their membranes are less good. And then you have C, and D is also quite good. Those are the ones I would approach to get an offer, the rest I would leave aside.[70]

Conversely, reputation is actively sought, because actors are aware that it guides the search strategies of others: it highlights one's presence in the membrane world, and in other relevant worlds.

> When Hoogovens [a big steel company] finally says, OK, we will publicize in the steel world that your membranes are good, that we buy your membranes, that is a sign. All other members of the steel world will pause and think: 'Are they indeed good?'. And their acceptance of our product depends on the reputation Hoogovens itself has in the steel world. That's how things go.

The small membrane company X-Flow actively attempts to build a reputation by publicizing that Shell is working with it, and supporting it. And this strategy is recognized for what it is worth by others: 'That's the advertising they need, that big companies trust them'.

In the case of the membrane world, one can see the importance of *future* technology: actors position themselves explicitly in terms of future developments and situations. And not just passively, as if they responded to the future technology as a given variable: to ensure that future is part of their strategy:

> At the moment we're just investing . . . : making new contacts, taking care of the experiments and making sure that the technological development is going as fast as we want it to go.

Future technology is also important to the way in which reputations are built:

> If we succeed in realizing an almost impossible separation, if it is a technological success, whatever its commercial value, people who have always thought it was impossible will be interested and come to us. So this is a reason to attempt certain projects: it is such a showpiece if you are able to bring it off. The project itself will run at a loss, too bad, but you get useful publicity.

It is for the same reasons that public presentations and publications are made by actors who would normally not be eager to share their findings widely. And this creates a new cultural norm:

> Everybody is publishing. By now, it has become fashionable to publish. There are even people who stand up and give market information, publicly.

By showing to others that they are on a promising trajectory *and* that they are the leaders in that direction, firms hope to force, or at least persuade, others to go in the same direction and, if they do, to take account of them in the first place.[71]

Conclusion and Discussion

Membrane technology is no longer just a new label. A variety of actors have arranged themselves with respect to 'membrane technology', and a new world of membranes has emerged. While one can analyze each particular bit of history in terms of the efforts and interactions of actors (for example, of Smolders, and of the Dutch Programme Committee), these are only part of an overall change. There are structural changes (like the increase of the number of membrane researchers at universities, the entrance of new firms in the membrane business, and the various small-scale collaborations), and these are paralleled by cultural changes, in universities and research institutes, as well as in industry. Expectations and search behaviours have changed. Visibility of the umbrella term of 'membrane technology' has led marketing people and engineers in firms to ask: 'Shouldn't we do something with membranes? There's so much talk about them, that we have to try them out'.[72] Heuristics in the design and development of separation devices now contain the prescription to check the possibilities of membrane technology. At a conference about membranes and biotechnology, for instance, several participants from industry said that they did not have any experience with membranes, but 'you hear a lot about them, so we have to check what's going on. Besides, our customers also keep asking about it'.[73] People now know better where membrane research is done, which are the important firms, and what are important developments to follow.

We have demonstrated mechanisms involved in the emergence of the membrane world, and shown how these could be effective because of the rise of strategic science and technology. The key phenomenon is the way in which actors position themselves and others in relation to a future technology. When mutual positioning and the concomitant strategies interlock, some coordination occurs, including reputation, visibility strategies, and 'unwritten rules'.

In the resulting world of membrane technology, there are industrialists working with membranes, policymakers interested in innovative areas, and researchers seeking support. The backbone of this world is provided by shared expectations about the proclaimed field of membrane technology, and, at a later stage, a non-local, decontextualized agenda, which is available to all participants.

The world of membrane technology has become a social reality, and a scientific-technological field of membrane technology is now recognizably in place. One indicator is that a certain hierarchy in expectation statements has become established over time. When scientists and technologists offer expectations about the potential of membranes, and industrialists and government officials accept such statements and invest in their follow-up, a basic pattern for activities in the emerging social world of membrane technology is created; further opportunities for resource mobilization with expectation statements arise, where the expectations can be more specific. When the basis has been laid, one can go on immediately to discuss, say, the relative merits of different kinds of membranes. The issue of whether ceramic or polymeric membranes are the most promising currently stands high on the agenda of the membrane world, but this is possible only because the potential of membranes in general has now been accepted.

A similar point can be made by looking at how specific actors mobilize others with the help of expectations. Their successes (or, better, the outcomes) are not just a matter of their adeptness in enrolling others. Even in bilateral negotiations, success depends on the extent to which the membrane world has become accepted. And actors invest in building up such a world, as we have seen in the way they mobilize goodwill through publications in magazines, through reports and public statements and, occasionally, in persuading industrialists to express interest in the further development of membranes. Smolders, who has been particularly active in this respect in the Netherlands and internationally, thus deserves the label accorded him: 'Mr Membrane Technology'. But the fact that he is now widely seen as the central actor and spokesperson is an indicator of the stabilization of the membrane technology world, rather than simply a reflection of Smolders' entrepreneurial capabilities. Without such a world, there would be no Mr Membrane Technology.

How generalizable are our findings? While some aspects of the developments that we have traced may be particular to the case of membrane technology, we think that there is a general pattern. There are already data, limited but suggestive, on the dynamics of other fields, which support this claim.[74] What we have been able to do in this case study of membrane technology is to understand the sociocognitive dynamics in such fields, where future shape and promises are as important as the actual production of artefacts and validation of knowledge claims.[75]

Present-day scientific-technical communities are strategically oriented. They are creating a kind of science where promises and assessments, and the rhetorics (and counter-rhetorics) that go with them, are an integral part of 'doing science'. In particular, the possibility of strategic science reinforces certain dynamics of scientific-technological fields by allowing spokespersons for a new field to be recognized in their role as promise champions.

The second feature of the new pattern is the way the field as a whole is the object of action (and becomes an established framework). While the simple fact of being future-oriented is as old as modern science, promises are now offered and discussed in terms of whole scientific-technological fields, and new audiences are included (and, to some extent, are constructed for that very purpose). Viewed from the side of science (that is, from existing fields), one sees 'hybrid communities' emerge.[76] Such communities, however, inhabit a heterogeneous world, and are sustained by being part of such a world.[77] The case of membrane technology is then a particularly striking example because, as a scientific-technological field, it came into being only through the emergence of such a world. So one should go one step further, and not start with scientific fields, in their traditional definition, but with worlds and their inhabitants. Then it becomes less relevant to talk of 'hybrid communities', and the actual processes in such worlds become the focus of study. Reputation and agenda building turn out not to be limited to the scientific-technological field.

The third feature is reflexivity. Scientists themselves think in terms of the new pattern, when they ask themselves whether an area is in the 'bandwagon' stage, the 'disappointment' stage, or the 'realistic growth' stage. Recently, a membrane researcher felt it important to include in his PhD dissertation, in addition to his research results, a graph presenting different stages of various separation techniques, in terms of a 'G-factor'. The graph over time shows three stages: 'euphoria' (a rapidly rising G-factor), 'temporary disillusion' (decline), and 'realism' (a moderate increase); and all current separation techniques are positioned in one of these stages.[78] It is clearly important to actors to make some assessment of 'the stage at which a field is' – intuitively in making choices, and sometimes explicitly – and, as with the G-factor graphs, in terms of a *phase-model* of development.[79]

Having shown how our case study of membrane technology offers general insights,[80] we can make a further step. The dynamics of the emergence of a world of membranes and a field of membrane technology is an example of the emergence and stabilization of strategic science and technology itself. The rhetorical space offered by the new category of 'strategic science' turns out to be filled up by what are, at least at first, rhetorical entities like 'membrane technology'. 'Membranes' became a buzz word, noted by industrialists and brought up when discussing problems and new ventures. Gradually, activities of industrialists, policymakers and researchers interlocked, and eventually a world emerged: the rhetorical entity became a social reality.

This movement by which an umbrella term, here the notion of 'membrane technology', is filled in, is at the same time a movement by which 'strategic science' *itself* is filled in and articulated. 'Strategic science and technology' started as a new category: it provided space for rhetorical entities which subsequently became social realities. And these then grew into examples of actual strategic science. The rhetorical space created by the policy category of 'strategic science' is being filled in.

Notes

1. Robert K. Yin, *Case-Study Research: Design and Methods* (Newbury Park, CA: Sage, 1989).
2. John Irvine and Ben R. Martin, *Foresight in Science: Picking the Winners* (London & Dover, Kent: Frances Pinter, 1984), 4.
3. The notion of strategic science emerged to make sense of an intermediate kind of research. In the early 1970s, the distinction between fundamental science, strategic science and tactical science had been popular (*A Framework for Government Research and Development* [London: HMSO, Cmnd. 4814, 'The Dainton Report', 1971]), while others had located strategic research as a subcategory of applied research (Lord Rothschild, 'Forty-five Varieties of Research [and Development]', *Nature*, Vol. 239 [13 October 1972], 373–79). In contrast, in Irvine and Martin's later, and most influential view, strategic research was seen as part of basic research (Irvine & Martin, op. cit. note 2). In Britain, the science policy category of strategic research continued to be debated, for example in the attempt of the Advisory Board for the Research Councils to show that their (as well as academic) basic research should be counted as 'strategic' (*A Strategy for the Science Base* [London: HMSO, May 1987], 17), while the practice of, for example, the Science Research Council definitely contained elements of strategic science: see Jacqueline Senker, 'Evaluating the Funding of Strategic Science: Some Lessons from British Experience', *Research Policy*, Vol. 20 (1991), 29–43. The notion is also used to characterize the linkages of universities and institutes for fundamental research with high-level users of research (see, for an example of such a focus, Ron Johnston, 'Strategic Policy for Science', in Susan E. Cozzens, Peter Healey, Arie Rip and John Ziman [eds], *The Research System in Transition*, NATO-ASI Series, Series D, Vol. 57 [Dordrecht, Boston, MA & London: Kluwer Academic, 1990], 213–26), and is used in policy statements to indicate a new and desirable kind of scientific research. The science and technology stimulation programmes of the 1970s had prepared the ground, and the increasing use of prospective assessments of innovative potential of scientific areas is an indicator of the recognition that fundamental science can be of strategic importance.
4. Pierre Bourdieu's notion of 'field' is a sociological version of metaphorical space, and he uses 'space' and 'locus' interchangeably to discuss it: see, for example, P. Bourdieu, 'The Specificity of the Scientific Field and the Social Conditions of the Progress of Reason', *Social Science Information*, Vol. 14, No. 6 (December 1975), 19–47. Note that Bourdieu's concept of 'field' here refers to the institution of science as a whole, not to a particular disciplinary or thematic field: this is in much the same way as religion or education are analyzed as 'fields', in, for example, Pierre Bourdieu and Jean-Claude Passeron (trans. Richard Nice), *Reproduction in Education, Society and Culture* (London: Sage, 1977), especially in the translator's introduction, at xv–xvi. The space opened up by strategic science and technology can be seen as a 'field', but it is not a fully

articulated field. The struggles of the actors are partially determined by the interlocking of actor strategies derived from other 'fields' (traditional science, policy, industry), and for the other part by the explicit emphasis on future relevance.

5. Randall Collins, *Conflict Sociology: Toward an Explanatory Science* (New York: Academic Press, 1975), 480.
6. For examples and analysis, see Harro van Lente, 'De dialectiek van beloftevol onderzoek', *Kennis & Methode*, Vol. 16, No. 2 (Spring 1992), 150–71. An English version of this article in available in H. van Lente, *Promising Technology: The Dynamics of Expectations in Technological Developments* (Delft: Eburon [PhD thesis, University of Twente], 1993), 125–44.
7. The Special Panel discussion at the Annual Meeting of the American Physical Society (New York, 18 March 1987) attracted almost 3000 physicists, and continued for nine hours: see Michael Kenward, 'The Heat is On for Superconductors', *New Scientist* (7 May 1987), 46–51. For further data, and an interesting discussion of the question of how such a breakthrough is also part of ongoing developments, see Helga Nowotny and Ulricke Felt, *After the Breakthrough: The Emergence of High-Temperature Superconductivity as a Research Field* (Cambridge: Cambridge University Press, 1997). See also Dorothea Jansen, 'National Research Systems and Change: The Reaction of the British and German Research Systems to the Discovery of High-T_c Superconductors', *Research Policy*, Vol. 23 (1994), 357–74.
8. In 1983, 80% of the value of membranes sold were from these three techniques: $670m of $835m: see Patrick Meares, *Synthetic Membranes and Their Applications*, report prepared for the Science and Engineering Research Council (Exeter: University of Exeter, July 1985), 21. In Europe, the situation is even more striking: about 60% of the European membrane production is in dialysis membranes, most of them made by Enka Membrana, Germany: see Eduardo Drioli and Heiner Strathmann, *Report on Scientific and Industrial Membrane Development in Europe*, paper delivered at a conference in Stresa, Italy (Stuttgart, FRG: Fraunhofer Institut für Grenzflach- und Bioverfahrenstechnik, June 1984).
9. See Charles Bazerman's opening Chapter, on 'A Contention Over the Term Rhetoric', in Theresa Enos and Stuart C. Brown (eds), *Defining the New Rhetorics* (New York: Sage, 1993), 3–7.
10. Chaïm Perelman (trans. Maarten Henket), *Retorica en argumentatie* (Baarn, The Netherlands: Ambo, 1979), 26: translated from the French; *L'Empire rhétorique: Rhétorique et argumentation* (Paris: J. Vrin, 1977).
11. See Bruno Latour, 'A Relativistic Account of Einstein's Theory of Relativity', *Social Studies of Science*, Vol. 18, No.1 (February 1988), 3–44, and Françoise Bastide (trans. Greg Myers), 'A Night with Saturn', *Science, Technology, & Human Values*, Vol. 17, No. 3 (Summer 1992), 259–81, esp. Myers' notes, 277–80. The move from texts to actors and interactions is made, and discussed, in the first part of Michel Callon, John Law and Arie Rip, *Mapping the Dynamics of Science and Technology* (London: Macmillan, 1986), esp. 9–11, and Chapter 5, 67–83.
12. Compare Hanno H.J. Ehses, 'Although rhetoric has developed as a method that deals fundamentally with speaking and writing, rhetorical principles have been transferred into various other media, as well (. . . painting, architecture, music) . . . [For] analyzing advertisement, Bonsiepe demonstrated that visual rhetoric is possible on the basis of verbal rhetoric': H.H.J. Ehses, 'Representing Macbeth: A Case Study in Visual Rhetoric', in Victor Margolin (ed.), *Design Discourse: History/Theory/Criticism* (Chicago, IL: The University of Chicago Press, 1989), 187–97, at 188.
13. Perelman (1979), op. cit. note 10, 26.
14. This list can be found in many publications (for example, H.K. Lonsdale, 'The Growth of Membrane Technology', *Journal of Membrane Science*, Vol. 10 [1982], 81–181), and also structures the preliminary study for the Dutch innovation programme, about which we have more to say later on: see Dick Bargeman, *Innovatiegerichte Onderzoekprogramma's: Voorstudie Membranen* (Enschede: TH Twente, 1982).

15. This Japanese membranes project, on 'Synthetic Membranes for New Separation Technology', was directed by the Agency of Industrial Science and Technology (AIST) of the Ministry of Industry and Trade (MITI), as part of their overall R&D stimulation programme on 'Basic Technology', set up in October 1981. For this information, we draw on the report of the Dutch mission to Japan: see note 48, below.
16. *Evaluation of the First BRITE Programme (1985–1988)*, Commission of the European Communities, Research Evaluation Report No. 25 (Bruxelles: EUR 11782, July 1988).
17. In Italy, for instance, the National Project on Fine Chemistry, and in the UK the Science and Engineering Council Programme: see R.W. Baker, E.L. Cussler, W. Eykamp, W.J. Koros, R.L. Riley and H. Strathmann, *Membrane Separation Systems – A Research & Development Needs Assessment*, Vols 1 & 2 (Washington, DC: Department of Energy, Report No. DE-AC01-88ER30133, March 1990), Section 4, 21 (this report is paginated in separate 'blocks', each starting at 'p. 1'). And in 1984, the Dutch Ministry of Economic Affairs installed an Innovation Oriented Research Programme on Membrane Technology: 'Instellingsbericht IOPm', *Nederlandse Staatscourant* (28 December 1983), 11–14.
18. In the first issue, the editorial statement argued why the new journal was appropriate: 'Our purpose in launching this new journal is to recognize and draw together a new field – one that might be called "membranology". It deals with the science and technology of membrane processes': *Journal of Membrane Science*, Vol. 1 (1976), 1. There is always a dilemma in legitimating a new journal as different from others, but also to be justified in terms of established referents. This dilemma has been analyzed by Joan M. Morris, 'Paradox in the Discourse of Science', in Robert Wuthnow (ed.), *Vocabularies of Public Life* (London & New York: Routledge, 1992), 91–107. In the editorial quotation above, this dilemma is resolved by emphasizing that it is a *new* field that has to be recognized.
19. H.K. Lonsdale, 'What is a Membrane?', *Journal of Membrane Science*, Vol. 34 (1987), 125–26. Lonsdale worked at Bend Research, a contract research company at Bend, Oregon, USA.
20. H.K. Lonsdale, 'What is a Membrane?: Part II', *Journal of Membrane Science*, Vol. 43 (1989), 1–3.
21. For one emphatic example, see Lonsdale, op. cit. note 14. For the kind of routine overview of the history of the research and applications of membranes, see William G. Presswood, 'The Membrane Filter: Its History and Characteristics', in B.J. Dutka (ed.), *Membrane Filtration: Applications, Techniques and Problems* (New York: Marcel Dekker, 1981), 1–17. The term 'creation' is applicable, because the history, and especially the continuity and orientation to what it has now become, is a projection. Pnina Abir-Am has shown how molecular biology, itself the outcome of a struggle for dominance in the 1950s and 1960s, created a history going back to the 1930s. A number of historians of science helped in that effort. See P. Abir-Am, 'Themes, Genders and Orders of Legitimation in the Consolidation of New Scientific Disciplines: Deconstructing the Historiography of Molecular Biology', *History of Science*, Vol. 23 (1985), 73–117.
22. Report of the US Department of Energy, Baker *et al.*, op. cit. note 17, Vol. 1, Section 4, 21. The status of this Report will be discussed later.
23. For an elaboration of this notion, see John Law, 'The Heterogeneity of Texts', in Callon, Law & Rip, op. cit. note 11, 67–83.
24. C.A. Smolders, 'Waarom Membraan Filtratie?', *Procestechniek*, Vol. 33 (1978), 362–68; Smolders, 'Vorming, Structuur en Eigenschappen van Membranen', *Procestechniek*, Vol. 37 (1982), 66–71 (no. 4) and 25–29 (no. 5).
25. Here, and in the following quotations from articles in Dutch, the translations are ours.
26. Smolders (1982), op. cit. note 24 (no. 4), 66.
27. Ibid. (no. 4), 71.
28. Ibid. (no. 5), 29.
29. In our analysis of the activities of spokespersons, and especially the way in which they aggregate heterogeneous elements into a working whole that they claim to represent, we have profited from actor-network theory. See, for an example, Michel Callon, 'Some

Elements of a Sociology of Translations: Domestications of the Scallops and Fisherman of St Brieuc Bay', in J. Law (ed.), *Power, Action and Belief: A New Sociology of Knowledge?* (London: Routledge & Kegan Paul, 1986), 196–233.

30. Lonsdale, op. cit. note 14, 82. That his article has to be interpreted as a binding-together-attempt can also be concluded from the length of this article: 100 pages and 429 footnotes. Furthermore, it shows 35 photographs of people whom, with hindsight, Lonsdale recognizes as important for the history of membrane technology (the set includes himself), and it contains a listing of about 80 books and journals that might be helpful for the scientist or engineer just entering the membrane field.
31. These phrases and labels were used in a number of interviews, and also in public presentations by scientists and administrators in 1989 and 1990.
32. Professor Smolders is so honoured. An example can be found in the International Symposium on 'Progress in Membrane Science and Technology 1991' (Enschede, The Netherlands: EFCE Event No. 441, University of Twente, 25–28 June 1991), which was 'organized on the occasion of the retirement of professor dr C.A. Smolders, who has directed the Membrane Technology group at the University of Twente for the last 23 years' (quoted from the 'Second Circular Provisional Programme'). Again, there is some reconstruction of the past to suit the present in this statement: the name of Professor Smolders' Department is 'Macromolecular Chemistry', but since the beginning of the 1980s it has sometimes been referred to as 'Membrane Technology'. Smolders was the *Honorary* Chairman of the organizing committee, as well as of the scientific committee of this symposium. During this meeting, he received a medal from the European Society for Membrane Science and Technology, marking his eminent role in the development of membrane technology in Europe: *Chemisch Weekblad* (27 June 1991).
33. Arie Rip and Anton Nederhof make this point for biotechnology: A. Rip and A.J. Nederhof, 'Between Dirigism and Laissez-faire: Effects of Implementing the Science Policy Priority for Biotechnology in the Netherlands', *Research Policy*, Vol. 15 (1986), 253–68. Dorothea Jansen (op. cit. note 7) analyzes high-T superconductivity in the United Kingdom and Germany; her structural analysis shows productive networks of promise champions and policymakers in Germany, but gaps in the UK, due to the relatively distant attitudes of British government departments.
34. Brian Balmer and Margaret Sharp, 'The Battle for Biotechnology: Scientific and Technological Paradigms and the Management of Biotechnology in Britain in the 1980s', *Research Policy*, Vol. 22 (1993), 463–78.
35. Van Lente (1993), op. cit. note 6, and A. Rip, 'Introduction of a New Technology: Making Use of Recent Insights from Sociology and Economics of Technology', *Technology Analysis & Strategic Management*, Vol. 7 (1995), 417–31.
36. Entitled, simply, *Membraantechnologie in Nederland*: Part 1 was published in 1986, Part 2 in 1987.
37. Ibid., Part 2, 16.
38. Meares, op. cit. note 8, 27 & 35.
39. These and subsequent quotations in this section are from participants at the IOP Day on 5 October 1990, at Ede.
40. M. Callon, 'The Sociology of an Actor-Network: The Case of the Electric Vehicle', in Callon, Law & Rip, op. cit. note 11, 19–34.
41. The notion of 'script' is used by Madeleine Akrich and Bruno Latour to capture the (implicit) messages and guidelines in artefacts: see M. Akrich, 'The De-Scription of Technical Objects', in Wiebe E. Bijker and John Law (eds), *Shaping Technology/Building Society: Studies in Sociotechnical Change* (Cambridge, MA: The MIT Press, 1992), 205–24; and B. Latour, 'Where Are the Missing Masses? The Sociology of a Few Mundane Artefacts', in ibid., 225–58.
42. Van Lente's case study of an industrial research project, Tenax (an industrial polymer to be used as isolation material in high-voltage transmission cables), shows both types of responses to the embedded script: see van Lente (1993), op. cit. note 6, 43–88.

43. These quotations are from interviews with H.D.W. Roesink (7 December 1989) and F. Muilwijk (13 February 1990), research managers at, respectively, X-Flow and HIC. See below for further details about these two firms.
44. '[Strauss] defined social worlds as groups with shared commitments to certain activities, sharing resources of many kinds to achieve their goals, and building shared ideologies about how to go about their business. Social worlds form fundamental building blocks of collective action and . . . are the principal affiliative mechanisms through which people organize social life': Adele E. Clarke, 'Social Worlds/Arenas Theory as Organizational Theory', in David R. Maines (ed.), *Social Organization and Social Process: Essays in Honor of Anselm Strauss* (New York: Aldine De Gruyter, 1991), 119–58, at 131. For further discussion of the notion of 'social world', see Anselm Strauss, 'A Social World Perspective', *Studies in Symbolic Interaction*, Vol. 1, (1978), 119–28, and Elihu Gerson, 'Scientific Work and Social World', *Knowledge: Creation, Diffusion, Utilization*, Vol. 4 (1983), 357–77. A brief overview of studies in this tradition is given by Adele E. Clarke, 'A Social Worlds Research Adventure: The Case of Reproductive Science', in Susan E. Cozzens and Thomas F. Gieryn (eds), *Theories of Science in Society* (Bloomington & Indianapolis, IN: Indiana University Press, 1990), 15–42. In the case of 'emerging worlds', shared commitments do not yet exist, but coordination of action occurs in other ways. In her 1991 overview (in Maines [ed.], above, 142–43), Clarke supports this point about the coordination of action when she notes: 'What actors actually *do* is central because we assume that they are likely to have multiple simultaneous commitments and these may well be in conflict, making simplistic rationality impossible. Their actions show us the concrete outcomes, without the necessity of discovering their mental processes'.
45. Our analysis of positioning (and mutual positioning) has profited from the work of Rom Harré and Luk van Langenhove: see, for example, B. Davies and R. Harré, 'Positioning: The Discursive Production of Selves', *Journal of the Theory of Social Behaviour*, Vol. 20 (1990), 43–63; L. van Langenhove and R. Harré, 'Positioning and Autobiography: Telling Your Life', in Nikolas Coupland and Jon F. Nussbaum (eds), *Discourse and Lifespan Identity* (Newbury Park, CA, London & New Delhi: Sage, 1993), 81–99. There is also a clear link with Erving Goffman's work: see, for example, E. Goffman, *The Presentation of Self in Everyday Life* (Garden City, NY: Doubleday Anchor, 1959). The difference is that Goffman (and Harré and van Langenhove, in most of their examples) focus on presentation and positioning of self in direct encounters, while our analysis of the inhabitants of the membrane world looks at presentation of self *and* of (future) technology (the actors themselves also present their identity in terms of technology), and traces coordination at the collective level – for example, through shared agendas, rather than coordination in direct encounters.
46. Wafilin is a subsidiary firm of Wavin, a producer of plastics; AKZO and Shell are multinational chemical and oil companies, respectively; TNO, NIZO and KIWA are partly government-subsidized research institutes for applied research, dairy research and water purification, respectively.
47. See Rip & Nederhof, op. cit. note 33.
48. *Membraantechnologie in Japan, Verslag van een Rapporteursmissie* (The Hague: Ministry of Economic Affairs, October 1982). In the preliminary study, earlier in 1982, the umbrella term was not yet used: as we have seen, the author was content to list functions and processes – membrane filtration, dialysis, gas separation with membranes, pervaporation, electrodialysis, liquid membranes, membrane bioreactors (Bargeman, op. cit. note 14).
49. B.J. Terpelle, in 'The Retirement of Prof. Kees Smolders', *UTmediair*, Vol. 3 (June 1991), 8.
50. The procedures around the IOP on membrane technology have been published in the *Staatscourant*, op. cit. note 17.
51. IOP brochure, *Holland: Your Stimulating Partner in Membrane Technology* (Hengelo: Tebodin, 1990), 6. The changes that can be observed can be viewed as the outcome of the IOP, and there clearly are causal links between its activities and increased interest

and participation in membrane technology. But this is occurring as part of a more general process of actors taking up positions, making linkages and creating nodes in the emerging world of membrane technology. The IOP activities are possible, and effective, as a consequence of the dynamic of the overall process.

52. The creation of networks is a general aim of all innovation-oriented government programmes. It is emphasized in the title of the Policy Report of the Ministry of Economic Affairs on IOPs: *Networks for Strategic Research* (Den Haag, 1989). The importance of infrastructure was highlighted in the text establishing the IOP on Membrane Technology: 'A programme will be stopped if the knowledge produced has been picked up by industry, if there are good contacts and if a good infrastructure has been realized': *Staatscourant*, op. cit. note 17, 12. By now, a special word has been coined, *verankering*, to describe this goal of IOPs: to anchor the strategic orientation in ongoing work and in research agendas, so that it will continue after the conclusion of the IOP; see Arie Rip and Barend J.R. van der Meulen, 'The Patchwork of the Dutch Evaluation System', *Research Evaluation*, Vol. 5 (1995), 45–53.
53. 'Stichting Scheidingstechnologie Nederland', *Membraantechnologie*, Vol. 4 (1989), 5.
54. 'Nederlands Membranen Genootschap': the quotation appears in *Chemisch Weekblad*, Vol. 47 (21 November 1991), 462.
55. The partners are the universities of Aken and Stuttgart (FRG), Bath (UK), Calabria (Italy) and Montpellier (France). The first quotation is from *UTmediair*, Vol. 4 (January 1992), 5; the second from A.C.M. Franken and C.A. Smolders, *European Membrane Institute, a Feasibility Study* (Enschede: University of Twente, 1991), 6.
56. We would claim that this is a general phenomenon in strategic science and technology policy. The Dutch biotechnology programme committee, for instance, identified itself with its technology 'as such', in a similar way: see Rip & Nederhof, op. cit. note 33.
57. For novel, emerging technologies and for possible priorities in science and technology policy, such contests are a fact of life for practitioners, and they have been described occasionally in the science and technology studies literature: see Callon's discussion of the 'socio-technical scenarios' put forward by Renault and Electricité de France (Callon, op. cit. note 40), and Alfonso H. Molina, 'In Search of Insights into the Generation of Techno-Economic Trends: Micro- and Macro-Constituencies in the Microprocessor Industry', *Research Policy*, Vol. 22 (1993), 479–506. The thrust of Molina's article is concerned with industrial trends and constituencies, but his analysis of claims and counterclaims about RISC and CISC microprocessors, and the way in which actor-strategies interact and lead to redefinition of the macro-level, is very similar to our analysis.
58. C.P. Snow, *The Two Cultures and a Second Look* (Cambridge: Cambridge University Press, 1962), 21.
59. X-Flow was founded in January 1986 by Dick Koenhen, as a successor of Koenhen Watertreatment Consultants. The *raison d'être* of the new firm was the production of hollow fibre membranes with special characteristics. Since 1985, R&D manager Erik Roesink, then a graduate student of Smolders, had been working in an IOP project on these special membranes. In the beginning of this project, a set of goals was formulated: the membranes should be thermoresistent, steam sterilizable, and hydrophilic. Koenhen expected that such membranes would be more appropriate than the traditional ones for food processing, hospitals and waste water purification. When Roesink finished his research with a patent (January 1989) and a dissertation (May 1989), there were already some applications of these membranes. In September 1989, X-Flow concluded an agreement with the Dutch/English multinational company Shell, based on the latter's interest in the product.
60. In 1988, Hoogovens Industrial Ceramics (HIC) was founded as a subsidiary company of the large Dutch firm Hoogovens, one of the major producers of steel in Europe. Hoogovens had been looking for other products besides steel. An internal report of 1986 emphasized competitive advantage and competence as the two criteria: (a) the new technology should require large financial resources, so that only big firms like Hoogovens could afford it; and (b) Hoogovens should already have some acquaintance

with the new area, to be able to assess the technological opportunities. New materials for the automobile industry, and ceramics, fulfilled these conditions. At that time, ceramic membranes were studied in IOP research projects, and the promise that research would enable prediction of the pore size in membranes triggered Hoogovens' interest. (At the time, the properties of the ceramic membranes produced could not be known beforehand.) When the IOP projects stopped, Hoogovens continued the research, together with ECN, the Netherlands Energy Research Foundation. HIC's strategy is to develop complete membrane installations, in interaction with clients. In November 1989, the Board of Directors decided to build a so-called production laboratory, to gain experience with membrane installations at an industrial scale.

61. For instance, at the Conference on 'Synthetic Membranes in Science and Industry', organized by the European Society of Membrane Science and Technology (Tübingen, 4–8 September 1989), and at the Eighth Annual Membrane and Technology Conference (Boston, MA, 15–17 October 1990).
62. At the IOP Day on 5 October 1989, both firms gave a lecture: X-Flow under the title 'New Hydrophilic Microporous Membranes Prepared from Polymer Blends'; and HIC on 'Specific Advantages of Ceramics as a Material for Membranes': both published in *Membraantechnologie*, Vol. 4 (1989), 8–10 and 13–14.
63. IOP brochure, op. cit. note 51, 6. The following quotations are from interviews with Roesink and Muilwijk, see note 43.
64. It is kept secret with which firms they collaborate. This contrasts with the public arena, in which most of the IOP activities are played out. There, expectations are constantly put forward and used in strategies. Industrial expectations (in this case, about separations with organic solvents), however, are semi-public at most – but they can gain public strength from actors being silent, as we will discuss in the next subsection.
65. C.A. Smolders and D. Bargeman, 'Membraantechnologie zal zich snel uitbreiden', *Chemisch Magazine* (January 1984), 42.
66. Quotations are from interviews with J.L.J. Rosenfeld (Head of the Separations Technology Department at the Central Research Laboratory of Shell, Amsterdam), and with A. van der Scheer, from the same Department (both interviews on 11 July 1990).
67. In a similar way, G.W. Meindersma, a promise champion for membranes in the multinational chemical firm DSM, attempted to create a niche for membrane research within his firm. In an interview (21 March 1990), he outlined his strategy:

> A few years ago I wrote a note about everything that should be possible in principle with membrane technology. I sent it out [internally], but I didn't get much reaction. It was too far removed from their daily concerns, apparently. Now we have another strategy. Now we invite people from production and I send them some notes with examples including that famous one of organic solvents [separation]. I hope that people get new ideas by these examples and that they say: 'Hey, if this is possible, then other things should be possible as well!'.

By referring to what happened in the field in general, he changed views inside DSM, but in doing so, he also reinforced the emergence of a membrane world and its agenda.

68. Unattributed quotations (here and in the following text) are from public discussions during IOP Days, over lunch or at the bar. They are indicative because, apparently, they could be made easily, and sometimes others would nod in agreement.
69. 'Readable' actions (that is, 'saying by doing') are the reverse of performative statements (namely, 'doing by saying'). In the philosophical literature, since John Austin's discussion of the illocutionary force of statements, performative statements have been discussed, while readable action appears to have been neglected. The work of Rom Harré and Luk van Langenhove on positioning (see note 45) is an exception. Pierre Bourdieu and Jean-Claude Passeron (op. cit. note 4) come close when they argue that the power of the speech act resides in the social authority delegated to a legitimate spokesman (the phrase is from the translator's introduction, at xvii). In the example of

Shell and BP being close-mouthed, the Bourdieu–Passeron-type reasoning is: they are taken to be authoritative, so they should be spokespersons; and if they do not then speak out, large interests must be involved. 'Readable action' has been studied in sociology, but mainly for its effects – for example, in the work by Robert K. Merton and others on the self-fulfilling character of lack of confidence in banks: see R.K. Merton, 'The Self-Fulfilling Prophecy', originally published in the *Antioch Review* (Summer 1948), and since reprinted as Chapter 13 of Merton, *Social Theory and Social Structure* (New York: Free Press, enlarged edn, 1968), 475–90. Seeing, or hearing about, other people withdrawing their account is a signal. The emphasis has been on the mass aspects, rather than on agenda-building. In economics, the strategic aspects of market signalling have been studied, but only in models and with the help of game theory, rather than in detailed empirical work.

70. Meindersma, interview, see note 67. The next quotation is also from this source, and the subsequent quotations in the rest of this section are from the interview with Muilwijk, loc. cit. note 43.
71. The phenomenon of strategic openness of firms is quite general, partly because of the importance of reputation building, and partly because of the possible advantage of presenting oneself as being ahead. Rémy Risser has coined the term *effet d'annonce* to capture this phenomenon: see R. Risser, *Innovation et Rupture: A propos de la théorie de l'évolution économique de Joseph A. Schumpeter* (Strasbourg: doctoral dissertation, Université Louis Pasteur, 1988). Risser also stresses the role of technological anticipations in techno-economic developments. The main thrust of his study is about firm strategy and switches between technological trajectories in already existing industrial sectors.
72. This is how G.W. Meindersma phrased it: interview, see note 67.
73. Overheard at Wagingen (7 March 1990).
74. See, for example, Robert M. Hazen, *The Breakthrough: The Race for the Superconductor* (New York: Summit Books, 1988); Joan H. Fujimura, 'The Molecular Biological Bandwagon in Cancer Research: Where Social Worlds Meet', *Social Problems*, Vol. 35 (1988), 261–83; Michael A. Rappa and Koenraad Debackere, 'The Emergence of a New Technology: The Case of Neural Networks' (Cambridge, MA: *MIT Paper* WP#3031-89-BPS, June 1989). The new pattern contains elements already visible earlier, because they relate to what one might call 'general promise dynamics', where a new finding or research site attracts researchers, and the number of imitative projects and publications increases rapidly, to decrease again after a certain period of time: see, for example, Kenneth O. May, 'Growth and Quality of the Mathematical Literature', *Isis*, Vol. 59 (1968), 363–71; and Frank M. McMillan, *The Chain Straighteners: Fruitful Innovation: The Discovery of Linear and Stereoregular Synthetic Polymers* (London: Macmillan, 1979).
75. The promise may refer to innovation, as in the case of membrane technology, but there are also areas in which the promise is strategically relevant, without any focus on technical innovation. For example, studies of the problems of global climate change involve similar dynamics to those visible in a wide range of applications of computer modelling.
76. See, for example, Wolfgang Van den Daele, Wolfgang Krohn and Peter Weingart (eds), *Geplante Forschung: Vergleichende Studien über den Einfluβ politischer Programme auf die Wissenschaftsentwicklung* (Frankfurt a. Main: Suhrkamp, 1979): and also the brief preview by the same authors in Everett Mendelsohn, P. Weingart and Richard Whitley (eds), *The Social Production of Scientific Knowledge, Sociology of the Sciences Yearbook*, No. 1 (Dordrecht, London & Boston, MA: Reidel, 1977), 219–42.
77. With the identification of the new pattern, it becomes clear that the notion of 'transepistemic arena', developed by Karin Knorr-Cetina to take non-disciplinary and non-scientific linkages into account, is still too sciento-centric: see Karin D. Knorr-Cetina, 'Scientific Communities or Transepistemic Arenas of Research? A Critique of Quasi-Economic Models of Science', *Social Studies of Science*, Vol. 12, No. 1 (February 1982), 101–30. There is no core of epistemic activity in strategic science fields, around

which other actors and interactions are assembled. Rather, there is a social world, with heterogeneous activities by industrialists, scientists, and government actors, which produces, *inter alia*, knowledge claims. Karin Knorr-Cetina's criticisms of some models of science have been important, and her insistence on resource relationships in a field of action which is integrated, not by what is shared, but by what is transmitted between agents (ibid., 119) is support for what we have observed – provided we take 'resources' to include expectations and information through positioning.

78. Evert Smit, *Modelling of the Diffusion of Gases through Membranes of Novel Polyimides* (Enschede: unpublished PhD dissertation, University of Twente, 1991): 'The G-factor stems from the outcry *gee*, expressing the state of exaltation of the industry for a specific method'(17).
79. Phase models are, in fact, part of the 'folk wisdom', and assessments of the phase of development achieved are made and discussed continually. For another, and well-known example, see the Starnberg model of pre-paradigmatic, paradigmatic and post-paradigmatic phases: it is discussed in A. Rip, 'A Cognitive Approach to Science Policy', *Research Policy*, Vol. 10 (1981), 294–311, and Wolf Schäfer (ed.), *Finalization in Science: The Social Orientation of Scientific Progress* (Dordrecht: Reidel, 1983). Not only science analysts use this phase model. Other actors (scientists as well as policymakers) try to assess the extent to which a 'paradigmatic' stage of a field has been achieved, to determine and defend their own actions, and to support or oppose those of others.
80. There may also be specifics, to be explored further. Membrane technology emphasizes materials, components and devices, rather than systems. There are good reasons to expect a difference between dynamics of work on (and worlds of) technical systems, and of technical components – cognitively/technically, as well as sociologically. Technical systems are constructed by enrolling specific allies, and expectations (one of the means of doing so) also remain specific; they often contain articulated scenarios of the world, enriched by the system to be constructed. Components, like membranes, must be made visible in a range of applications, in different sectors. So their construction can be, and must be, generalized construction: a variety of allies is needed, and a repertoire of specific and generalized expectations emerges, as was clear in our case study. In this sense, there is a contrast with the case studies in Wiebe E. Bijker, Thomas P. Hughes and Trevor Pinch (eds), *The Social Construction of Technological Systems* (Cambridge, MA: MIT Press, 1987), which almost exclusively focus on artefacts, often systems or devices, and not on materials.

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