Transition to sustainable industrial production
Towards a conceptual framework for analyzing incremental and radical process innovations in the metals producing industry

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Abstract

The metals producing industry has already been making a considerable effort to limit its environmental impact by means of incremental innovations in the area of its production processes as well in the use, disposal and recycling of its products.

Many production processes, however, are still important sources of environmental problems. Hence, more radical technological alternatives are necessary, which yield a higher environmental efficiency. Various radical alternatives have been developed, but these are scarcely implemented. This is because the existing production systems are highly embedded, which makes it difficult to redirect these systems effectively towards sustainable production.

In order to gain more insight into possible ways of transition towards sustainable production, this paper develops a conceptual framework which analyzes the technology choice processes within firms, especially between incremental and more radical process innovations. This framework is based on concepts of the systems approach, the quasi-evolutionary approach, and the social network approach.

The recognition of environmental problems pressing upon the metals production chain can be characterized as occurring reverse salients on the systems level, which are turned into critical problems for specific actors. The development of solution directions for these problems is mainly done in the setting of social networks, in which actors negotiate an agreement on dominant problem definitions and hence on preferred solution directions. The specific form of these solution directions depends on the network structure and dynamics, together with more traditional aspects as the economics, the history and routines of the firm, and the technological barriers and possibilities as recognized by the actors in the network. The framework is illustrated by an analysis of the choices between incremental and radical innovations at Company Zinc.

1. Introduction

The metals producing industry has already been limiting the environmental impact of its production processes to a large extent. In spite of all these efforts, some environmental problems are persistent in the metals producing industry, such as the production of large amounts of solid waste (e.g. jarosite, goethite, gypsum, red mud, spent pot linings, salt slags); emissions of airborne and waterborne pollutants (e.g. SO\textsubscript{2}, NO\textsubscript{x}, perfluorocarbons (PFCs), dioxins, polycyclic aromatic hydrocarbons (PAH)); high energy consumption, and the associated CO\textsubscript{2} emissions; depletion of natural resources; and moderate recycling rates (e.g. for zinc).

These environmental problems emphasize the need for further technological innovations in the metals producing industry, both incremental to tackle the relative smaller problems on
the short term, and radical innovations, to obtain higher eco-efficiencies (factor 20) on the long term.

At the moment, most of the innovations are incremental of character, such as optimization of the environmental performance through good housekeeping practices, environmental- and total quality management, appropriate end-of-pipe techniques, substitution of, or a ban on the use of environmentally unfriendly produced products, and recycling of waste and non-renewable materials.

A lot still remains to be done to clean up industrial processes, and the continued emphasis on ‘incrementalism’ may not match the scale of the transformation required in the 21st century. Much greater results will be necessary to achieve absolute reductions in materials and energy consumption over the next 50 years. Taking into account that since Third World countries will almost inevitably increase their consumption of energy and materials as they industrialize and raise their living standards, the need for more radical (system-) innovations towards cleaner industrial production is quite evident, as well as continuing incremental improvements [WCED, 1987; Wéttering & Opschoor, 1992; Weiszäcker et al., 1997].

Obviously, technological innovation is an important factor for economic growth and seems to play a central role in the long-term development of sustainable production [Vergragt & Jansen, 1993; Jansen, 1993; Vergragt & Grootveld, 1994]. Therefore, this paper focuses on the technological innovation perspective.

What is now meant by ‘incremental’ and ‘radical’ innovations? ‘Incremental’ process innovations are technical changes that adapt or improve a technology, based on an existing technical principle. Incremental improvements result in lowered costs, higher quality, or both, and learning-by-doing. ‘Radical’ process innovations involve the development or application of significant new technologies or ideas, totally new ways of producing products or services. They require new skills, processes and systems throughout the organization, and introduce an entirely new technology [Cf. Freeman & Perez, 1988; Kemp et al., 1994]. Incremental and radical are not the only two degrees of innovations, but in between more categories can be discerned.

In order to gain more insight in the way transition towards more sustainable industrial production can be steered, this study wants to elucidate the conditions under which technological innovations within firms are taking place more radically, by comparing them with the conditions for incremental innovations. In other words: this paper develops a conceptual framework which analyzes the technology choices within firms between incremental and more radical innovations.

The paper is structured as follows: section 2 describes the ‘embeddedness’ of the present metals producing industry, and the barriers impeding radical innovations in this sector. These barriers already give an indication of the various conditions under which radical innovations are more difficult to implement. Section 3 then introduces three technology dynamic approaches, which each explain a part of the conditions under which technology choices are being made, and which seem to complement each other. The building blocks

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2. The ‘radicalness’ of a process innovation is conceptualized in Moors et al. (1998), where a technological criterion is used to determine the extent to which an innovation constitutes a radical departure from the existing production process.
of these theories are joined in a conceptual framework. This framework could be used for
the analysis of the choices within firms between incremental and more radical innova-
tions. Based on this conceptual framework, section 4 analyzes the choices between vari-
ous process innovations in the zinc production process of Company Zinc. Section 5 pre-
sents the first results and the paper ends with some concluding remarks.

2. Embeddedness of the metals producing industry

According to Pavitt’s taxonomy of different sectoral patterns of innovations, the metals
producing firms belong to the scale intensive sector[3] [Pavitt, 1984].

These firms are involved in large-scale fabrication and assembly production. Their cus-
tomers are price-sensitive, and the firms try to reach competitive advantage by exploitation
of economies of scale, process secrecy and know-how, technical lags and patents. Scale in-
tensive firms are usually mature and large and produce a relative big amount of their own
process technology. For both process and product innovation, suppliers will - apart from
R&D within and outside the company - be a main source of innovations. [Cf. Van der Poel,
1998]. Studies of technological change in scale-intensive sectors have shown that large
changes in the production processes are problematic. More radical innovations are indeed
developed in R&D, but are scarcely implemented, because the established production
processes are traditional and rather inert for change. In scale-intensive industries, the
manufacturing technology could not be regarded as a technology that stands alone, but as
as a part of a highly intertwined production system, both technologically (physically) and
socially [Pavitt, 1984; Tidd et al., 1997].

As a production process becomes more elaborated, and the investments in it become
large, selective improvement of process elements becomes increasingly difficult. The
process is so well integrated that changes are very costly, since they must consider the
whole processing and intertwined production system. Process redesign comes more
slowly but may be stimulated by the development of a new technology or by a sudden or
cumulative shift in the requirements of the market environment. If changes are resisted,
as market and technical forces continue to evolve, then the stage is set for revolutionary
(radical) as opposed to evolutionary (incremental) change within a productive segment
[Abernathy et al., 1975].

Hence, the strong ‘embeddedness’ of a particular technology within the large, mature
production system often hinders fundamental renewal of technology and makes radical
change very difficult.

This explains why manufacturers initially concentrate on the development of add-on or end-
of-pipe technologies, which can be more easily incorporated into the existing production
processes, and which require modest changes in the organization of production. Especially
in the short term, strategies of adopting incremental innovation tend to predominate over
those requiring radical technologies and total reorientation of the established production
systems. Additionally, the existing technologies benefit from the dynamic effects of scale

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3. In Pavitt’s taxonomy, sectors have been grouped into the following four categories: supplier-
dominated, scale-intensive, specialized suppliers, and science-based. This taxonomy reflects the role
played by technological-related factors in shaping innovative activities, and is helpful in understanding
the different ways technology is taken up in firms and sectors [Pavitt, 1984, pp.364].
and from the phenomena of learning by doing within the existing production system. These are translated into price reductions, scale advantages, and a whole series of improvements, such as better performance, wider applications, longer life cycles and increased reliability. The present Hall-Héroult aluminium production process, for example, has already been in use for more than 100 years.

In some cases, the culture in the firm, the workers themselves, can also hinder the introduction of new technologies, due to employment consequences and changes in duties [Malaman, 1996]. All these factors are further maintaining and embedding the existing production system, which makes it very difficult to bring radical innovations about.

To conclude, the embeddedness of the production technologies contributes to a large extent to the relative stability of the metals producing system, in which mainly minor adaptations to the existing production system are taking place.

Various barriers can be discerned within the embedded metals production system, which impede the implementation of radical cleaner production technologies.

These include lack of capital, the pressure of the price-sensitive metals market, the inertia of the current capital investments, the varying depreciation times which hamper the compatibility of new technologies, the complex physical intertwinement of the existing production system, the lack of knowledge interaction, the absence of environmental legislation and international harmonization, the organization structure and conservative culture of the firm, including the perception of the employees towards innovation, and the stage of technology development itself [Moors et al, 1998].

These barriers already indicate some of the conditions under which firms prefer to choose for incremental innovations. The next section introduces three technology dynamic approaches, each dealing with technology choice processes in a certain way.

3. Towards a conceptual framework studying incremental and radical innovations

This section develops the conceptual framework that elucidates the conditions determining the choice within firms between incremental and more radical process innovations. This framework is derived from insights of various technology dynamics approaches, and can be used as a frame in which empirical cases can be described and analyzed. Three technology dynamics approaches are discerned which explain technology choice processes and which seem to complement each other when technology development is considered as a multi-layered process.

Hughes’ systems approach conceptualizes technology choices at the systems level (macro-level) of the production system under study [Hughes, 1983, 1986, 1987]. Yet, actors are making these choices, and in order to understand their driving forces, it is necessary to leave the macro-analysis of the systems approach. Instead, the researcher must go to the micro-level, the level of the individual actor, its interests, resources and relations. These aspects are dealt with in the social (industrial) network approach [Cf. Granovetter, 1973,1985; Håkansson, 1987; Mulder,1992]. The production system and the network of actors are not acting separately from each other. Even facing similar technological conditions, firms can make different choices, depending on the firms’ underlying rules, routines, experiences and knowledge-bases, and differences in history. The (quasi-
evolutionary approach developed the concept of ‘technological regime’\footnote{A technological regime can be defined as “the whole complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up the totality of a technology”. A technological regime is thus the technology-specific context of a technology which prestructures the kind of problem-solving activities that engineers are likely to do, a structure that both enables and constrains certain changes. Within this complex, the accommodation between its elements is never perfect; there are always tensions and a need for further improvement. [Kemp et al, 1998]} \cite{Nelson1977, Nelson1982, Van den Belt1987, Kemp1994, Kemp1998}. This regime concept connects on a sort of meso-level the individual actors, their resources and relations, through rules, with the overall production system under study\footnote{The development of the conceptual framework and the choice for the three technology dynamics approaches is further explained in the thesis in progress of the first author.}.

The building blocks of these approaches could be linked in a conceptual framework, which describes and analyzes choices processes between incremental and more radical innovations.

The conceptual framework starts with the definition of the production system under study. This production system is causing certain environmental problems. When these problems are severe enough, more external pressure will be put upon the system (and maybe also internal pressure) to find solutions for these problems.

At a certain moment, a ‘reverse salients’\footnote{A reverse salient is a military metaphor which depicts constraints or critical lags on various ‘fronts’ of the advancing system under study [Hughes, 1983].} will occur on the systems level, due to this (environmental) pressure. Reverse salients appear when one part of the production system does not develop in pace with the rest of the system, thereby threatening its continued expansions. Hence, the occurrence of a potential crisis at systems level, which would lag the whole production system, can be characterized as a reverse salient.

These reverse salients are perceived differently by the various actors involved in the system. Some of them regard them as severe problems which should be solved, others do not. The ways in which the reverse salients are identified, defined and resolved reflect the various interests and interpretations of actors. This turns the reverse salient into various ‘critical problems’\footnote{Critical problems are reverse salients which been been identified and conceptualized into solvable form by creative system builders [Hughes, 1983].} for specific actors. Thus, the transition of reverse salients into critical problems is carried out by human action. This transition is a creative step, performed by actors within the system, which have to make the choice between potential incremental or radical solution directions \cite{Summerton1992}.

Figure 1 visualizes these first steps of the conceptual framework, i.e. the definition of the current production system, the occurrence of a reverse salient on systems level, caused by (environmental) pressure, and the identification and conceptualization of the reverse salients into various critical problems by specific actors.
This figure leaves us with the question *how* actors make choices between incremental and radical innovations. While the reverse salient is recognized on the systems level, and could be a serious problem for the continued existence of the production system, various actors at the network level, are involved in the choice between potential technological solutions.

Hence, the development of solution directions is mainly done in the setting of social networks in which an agreement is negotiated on a ‘dominant problem definition’⁸, and hence on preferred solution directions. The *choice* between various innovation processes (in this study between incremental and radical process innovations) is then the outcome of the negotiation processes between actors about what becomes the dominant problem definition [Vergragt 1988]. The specific form of these solution directions, in other words, the conditions determining the choice, depends on the network structure together with the rules and history of the technological regime and the technological possibilities as recognized by the actors in the network.

In addition to systems actors, firm-external (=contextual) actors could influence the negotiation process. These contextual actors include customers, consumers, suppliers, competitors, universities, entrepreneurs, regulatory authorities, environmentalists, and critical consumers. The systems actors have to account for these contextual actors in their choice processes. In fact, these contextual actors have their own reasons (not) to innovate, their own problem definitions, which could be conflicting with the problem definition of the systems-actors.

Consequently, the negotiation process about what becomes the dominant problem definition is influenced by the functional interdependence between the systems actors and contextual actors in a network structure, by their knowledge base, their power relations, and their history and routines [Håkansson, 1987]. As a matter of fact, the industrial net-

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⁸ A dominant problem definition is the result of negotiations between relevant actors about what they see as the most relevant problems that have to be solved in order to continue the innovation project [Vergragt, 1988].
work structure is a carrier of history through rules and regulations, routines, transactions, relationship-specific investments, and through socialization of action [Lundgren, 1995].

Hence, we define the innovation regime as a connection level, encompassing various rules and forces that bind the actors within their networks to their system components. This regime also determines the innovation boundaries. Figure 2 visualizes this part of the conceptual framework.

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**Figure 2: Conceptual framework visualizing choice making**

**Frame of analysis and research methodology**

Based upon the developed conceptual framework, the following frame of analysis can be built up. It is a kind of ‘step-by-step’ device, which can be followed to unravel and analyze the empirical cases in the metals producing industry:

1. Definition of the existing technological system
2. External or internal pressure put upon the system
3. Occurring reverse salient on systems level
4. Transition of reverse salient in critical problems (potential solution directions)
5. Actors, interests and resources enrolled in transition process
6. Negotiation process towards dominant problem definition
The PhD-work is based on a comparative case study design, in which the choice processes for incremental or more radical technological changes are studied for three metals producing processes, i.e. zinc, aluminium, and iron/steel production. For each metal, two cases were studied. The six case studies were based on semi-structured interviews with various system-actors of the zinc-, aluminium-, and iron/steel industry, working either in R&D laboratories, engineering, the production plants, or as environmental or strategic managers. In addition, some contextual actors were interviewed, such as researchers in universities, governmental authorities and environmental bodies. The case studies were further based on qualitative document analyses [Yin, 1994].

The next section presents the analysis of one of these empirical cases, the zinc production system of Company Zinc, according to the mentioned step-by-step device.

4. An example: analysis of choice processes at Company Zinc

This section elaborates an example in the zinc producing industry. It elucidates the choices between incremental and radical process innovations at Company Zinc, based on the framework.

First, we show how zinc production fits within the zinc production and consumption chain. The flows of zinc in society encompasses zinc-ore mining, primary zinc production, semi-fabrication of zinc, industrial as well as consumer use of zinc, zinc recycling, and zinc waste. Figure 3 shows the zinc production and consumption chain.

![Figure 3: Zinc production and consumption chain](image)

Within the zinc production and consumption chain we focus on the ‘primary zinc production’ step. Figure 4 gives an overview of the steps in zinc production.
Environmental problems related to primary zinc production
The most pressing environmental problems related to primary zinc production are found in the following categories [Cf. Daniëls et al., 1993; Schinkel et al., 1995; Warhurst et al., 1996]:

◊ Waste: the release of large amounts of the iron-bearing residues jarosite or goethite [±0.6 ton jarosite/ton of zinc produced]. Due to the contents of amongst others cadmium, arsenic and lead, these residues may be classified as hazardous, and they should be impounded in isolated ponds. Furthermore, ± 0.06 ton gypsum per ton of zinc produced is formed during zinc production. In addition, sludge of the water cleaning system is regarded as waste.

◊ Emissions: per ton of zinc produced about 0.004 ton of sulphur dioxide is formed.

◊ High energy consumption: primary zinc production consumes about 15 GJe/ton of zinc. Electrolysis uses about 80% of that amount.

◊ Depletion of natural resources: Economic reserves for zinc ores are estimated rather low. According to Daniëls et al., 1993, these reserves will be consumed within 50 years, due to a high increase of the production of zinc.

◊ Recycling rate: Due to the dissipate use of zinc (particularly as corrosion protective material on cars (50% of all produced zinc), where zinc serves as a sacrificial anode), recycling of zinc is rather difficult (about 30%).

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9. For more specific information and technical details on zinc production, we refer to Moors et. al., 1995, and the thesis in progress.
Cleaner production alternatives
Increasing pressure from environmentalists, increasing processing and dumping costs of waste, expiring dumping concessions, environmental legislation, danger of hazardous elements reporting to the groundwater due to damaged ponds etc, make rethinking and modification of the current primary zinc production imperative. Numerous proven process technology for the recovery of zinc from its concentrates and the intermediate products arising during the processing of concentrates are available. Figure 5 gives some examples, in increasing order of technical change [Cf. Schinkel et al., 1995; Reuter et al., 1995].

- desulphuring of sulphur dioxide emissions,
- improvement of the energy efficiency,
- increased recovery of secondary zinc, melting of recycled zinc
- treatment process for inertising of jarosite residue,
- pressure leaching process,
- new/inert anode technology
- Beneficiation and processing of low-iron containing zinc sulphide concentrates
- changeover from sulphate to chloride milieu,
- electrothermal processes
- direct recovery of zinc from sulphide concentrate

Figure 5: More sustainable production alternatives

Introduction Company Zinc
Company Zinc is one of the larger zinc producers in the world, with a production capacity of more than 200,000 tons of zinc annually (i.e. about 4% of the world zinc production). At the moment, Company Zinc is 100% owned by a large smelting and mining holding company.

Company Zinc is one of the most modern zinc producing plants in the world, and it has been producing zinc since 1882. The company obtains its zinc sulphide concentrates from about twenty mines all over the world. It produces zinc by the most common zinc production method, as shown in Fig. 4. Furthermore, it produces some byproducts, such as sulphuric acid, cadmium metal and copper- and cobalt-enriched residues.

Company Zinc is an important employer in its region: about 600 people are working directly at the company, and about 1000 people are indirectly associated.

So far, this section has presented some background information about zinc production in general, the associated environmental problems, the more sustainable production alternatives, and an introduction of Company Zinc. Next, we use the developed conceptual framework to analyze some process innovations at Company Zinc.

1. Definition of the production system of Company Zinc
The zinc production system of Company Zinc consists of the primary process, including all the technical hardware to manufacture the zinc metal, the byproducts, as well as the underlying organizational infrastructure. In fact, all the parts which fall under the central control of Company Zinc’s management, belong to the production system of Company Zinc.
This implies that the central production unit, as described in the six steps of Fig.4, is involved, some raw material suppliers (for example mining companies, which have a contract with Company Zinc for the delivery of zinc concentrates), Company Zinc’s own power plants, the co- and by-products plants (for cadmium metal and sulphuric acid), but also technical services, involved in day-to-day troubleshooting, Company Zinc’s engineering and environmental departments, and its marketing and finance departments.

2. Pressure put upon the production system of Company Zinc
Due to external governmental and societal pressure, the jarosite residue is the most important problem for Company Zinc. This residue is released in the current zinc production process as waste, and contains many impurities. It is temporarily stored in four isolated ponds to avoid pollution of soil and underground water, until an appropriate solution has been found to treat this residue. Company Zinc’s long-term environmental program, as agreed with the national authorities in 1993, principally involves the sealing and capping of the four jarosite ponds and two gypsum ponds to ensure that they remain environmentally benign into the future. In addition to the pressure on jarosite disposal, the provincial authorities and environmental groups are regarding the sulphur dioxide emissions as a considerable environmental problem.

3. Occurring reverse salient on systems level
In the eighties, under growing environmental demand of the regulatory authorities and societal groups, it became more difficult for Company Zinc to obtain a licence from the provincial authorities to build a new pond for jarosite storage. Then, Company Zinc started to recognize the jarosite residue as a major problem. Until then, the company had been able to delay the development of a more radical solution to the jarosite problem. Nevertheless, the pressure from the authorities increased, and the jarosite problem became a severe problem and finally a crisis, which threatened the whole zinc production system. If the company couldn’t obtain a licence for a new jarosite pond, it had to stop producing zinc, because every additional ton of zinc produced delivered about 0.6 ton of jarosite residue, which had to be stored. Thus, the jarosite residue problem occurred as a reverse salient on the systems level, by which the existing production system reached a deadlock, making it impossible to produce zinc anymore.

4. Transition of the reverse salient into critical problems
The occurrence of the jarosite problem on systems level triggered Company Zinc to be innovative. In order to stay in business, the management of Company Zinc was seeking various solutions to the jarosite problem, together with the technical staff, and the provincial authorities.

First of all, the environmental manager of Company Zinc, in charge of dealing with the regulatory bodies, tried to get a licence for a new jarosite pond from the provincial authorities to enlarge the storage capacity. When it became almost impossible for the management of Company Zinc to obtain that licence and when the external pressure of the provincial environmental groups and neighbors grew, the management of Company Zinc decided to search for other solutions. The process researchers of Company Zinc had some external contacts with the researchers of the holding company, a national technical university, a public research institute and some international metals producing competitors. A ‘Jarosite Working Group’ was formed, including various experts in the field, with the goal of developing a process to treat the jarosite. For a long time, it remained uncer-
tain whether the jarosite treatment method was technologically feasible. After 3-4 years of research and testing at a competitor’s plant, the treatment process turned out to be technologically feasible. However, in addition to the high capital investments to build the treatment facility, the process itself consumed a lot of energy, making the operational costs very high. These costs were circumvented by co-treatment of other waste materials, such as polluted sludge and waste oil, as energy sources in the process. Yet, some provincial authorities and the regional Water Boards didn’t want to give up their control over waste oil and polluted sludge. They were already developing facilities to treat these waste streams. These developments impeded the economic advantageous co-treatment plan for jarosite.

In the end of 1992, the jarosite treatment process was not considered to be economically viable, and the company had chosen for final storage of jarosite with the regulatory claim in the licence that Company Zinc was not allowed to build new jarosite ponds anymore. Consequently, the company had to find another solution to the jarosite problem, otherwise, it had to shut down.

In 1993, the holding company of Company Zinc found a potential solution for the jarosite problem, when they discovered a mine with a large amount of low-iron containing zinc ores in Australia. When this low-iron containing zinc concentrate was processed, no jarosite residue was formed anymore. Driven by severe external pressure, Company Zinc had put major claims on this mine with ‘clean’ low-iron containing zinc ore. There were, however, some problems associated with the development of that mine. More than 5000 Aboriginals, living in the area around the future mine, had been blocking the mining project. They didn’t want to sacrifice their ‘holy’ territory and hunting areas. In 1997, after many negotiations, an agreement was concluded between the holding company, the local Aboriginal communities and the regional government about the exploitation of low-iron zinc deposits as feed-stock for Company Zinc.

Summing up, some of the solutions could be characterized as incremental, such as the increased storage capacity of jarosite in new ponds, being an end-of-pipe solution, others as being more radical, major innovations, such as the development of a process to treat the jarosite waste, or the use of low-iron containing zinc ore in the production process (in-process innovations).

5. **Actors and resources enrolled in the transition process**

The following firm-internal (systems-) and firm-external (contextual-) actors (including their resources) were involved in the transition of the jarosite problem, in the mentioned solution directions:

First, the management of Company Zinc considered the obtainment of a licence for a new jarosite pond, as a potential solution to increase the storage capacity. In the first instance, the environmental manager of Company Zinc was negotiating with the provincial authorities about a new licence. Later, provincial environmental groups were also discussing with the environmental manager and the director of the company about the potential hazards of leaking jarosite ponds.

In addition to these groups, the national authorities (especially Environmental Affairs), the local political parties, the employees unions, nature conservation and local environmental groups, consumer associations, and the neighbors to the company were pressing Company Zinc to find a definitive solution to the jarosite residue problem, instead of in-

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10. The Water Boards are authorities controlling water quality, and operating water treatment facilities.
creasing the storage capacity. In contrast, the national zinc branch organization, the competitors and the European Zinc Institute were proving that jarosite storage in isolated ponds didn’t cause any environmental damage at all.

When the environmental pressure of provincial and national authorities and of environmental groups increases, the management of Company Zinc decided to look after a jarosite treatment process. They allocated research money for it and formed a ‘Jarosite Working Group’, including Company Zinc’s own process researchers, the environmental manager, experts from other zinc producing companies, universities, technical institutes, authorities, and environmental consultancy. The jarosite treatment process turned out to be economically feasible, when jarosite was treated together with waste oil or sludge as energy sources. However, regional Water Boards were already developing their own treatment facility for sludge, and the provincial authorities already agreed upon another destination for waste oil. Company Zinc couldn’t pay the costs for the treatment process itself. The national authorities didn’t want to subsidize the process, being cautious to establish a precedent. So, the jarosite treatment process was canceled.

Then, the holding company of Company Zinc found another solution to the jarosite problem, when they discovered a mine with a large amount of low-iron containing zinc ore in Australia. The regional authorities in Australia were involved in giving the licences for exploitation of the mine. At Company Zinc, the process researchers and environmental manager started to look after the process changes which had to be made when this low-iron containing zinc concentrate was fed in the conventional process. These process developments were studied together with researchers of the holding company. In Australia, the Aboriginals community became a serious partner in the negotiations about the exploitation of the mine. The rights of the Aboriginals were also defended by the international Earth Alarm organization. Finally, the holding company, regional authorities in Australia, and the Aboriginals came to an agreement that the mine could be exploited. Hence, Company Zinc did find a solution for their future jarosite residue, by not producing it at all. Yet, it is no solution for the treatment of the already existing jarosite.

6. Negotiation process towards dominant problem definition

The story about the jarosite problem of Company Zinc, the mentioned solution directions, and the actors involved, revealed various interesting negotiation processes towards preferred solution directions. Taking the obtainment of a licence for a new jarosite pond into account, the environmental manager of Company Zinc tried several times to negotiate a temporary licence for a new pond with the provincial authorities, providing that Company Zinc should try to find a final solution to the jarosite problem. Sometimes, he succeeded, which gave the company some delay in developing the jarosite treatment process. When Company Zinc was developing the jarosite treatment process, many firm-internal and firm-external actors were involved, in a rather loose ‘Jarosite Working Group’ network structure. This network was very open, and the actors were influenced by many new ideas of amongst others universities and competitor firms. This informal network stimulated the development of the jarosite treatment process to a large extent. The process turned out to be technologically feasible. It was even possible to process jarosite together with other waste streams, such as sludge and waste oil. This co-treatment made the process economically feasible. However, the regional Water Boards and some provincial authorities were in charge of the treatment of polluted sludge and waste oil. They didn’t want to give up their interests in and control over building their own sludge treatment facilities. Furthermore, the national authorities (i.e. Economic and Environmental Affairs)
didn’t want to finance a part of the expensive jarosite treatment process. The national authorities feared to establish a precedent, while the Waterboards and some provincial authorities didn’t want to give up their autonomy over ‘their’ waste streams. Thus, a political controversy between the various actors in the network seemed to exist, which impeded the negotiation process to the jarosite treatment process.

Regarding the exploitation of the mine with low-iron containing zinc ore, the network between Company Zinc and its holding company had already been established, because of the formal business structure. Company Zinc was owned by the holding company, which gave Company Zinc already some control over the new mining project. However, the Aboriginals turned out to be a serious party in this project, because they were blocking the exploitation. The Aboriginals were negotiating in Australia, based on the Native Title Act. The Aboriginals were delaying the choice for the dominant problem definition, this is the exploitation and use of the low-iron containing zinc ore as feedstock in the zinc production process of Company Zinc. Finally an agreement reached between the holding company, the local Aboriginal communities and the Australian regional government was registered with the Native Title Tribunal, about the exploitation of the low-iron zinc sulphide deposits.

To conclude, for Company Zinc, the firm internal actors first negotiate on incremental, end-of-pipe solutions to the jarosite problem, such as obtaining temporarily licences for new jarosite storage ponds. When this solution is not accepted anymore by the firm external, regulatory actors, the management of Company Zinc is forced to look after more radical solutions, which possibly exceed the existing production system. The process researchers of Company Zinc set up a ’Jarosite Working Group’ network, in which firm-internal as well as firm-external experts were informally negotiating on more radical solutions to the jarosite problem. A technologically feasible solution was found, but its further development was blocked by lack of capital together with conflicting interests and power exertion of some firm-external actors, such as the provincial and national authorities and the Water Boards. The negotiation on the exploitation of the low-iron containing ore showed that in addition to the most common firm-internal and firm-external actors, such as Company Zinc, the holding company, the regulatory bodies, and environmental groups, the power of certain firm-external actors upstream the production chain, such as the Aboriginals communities, also have to be taken into account.

These examples show that even if potential incremental and radical solution directions to the reverse salient are available, the choices between them depend on the setting of the social networks, in which various firm-internal (systems) actors and firm-external (contextual) actors negotiate an agreement on dominant problem definitions and hence on preferred solution directions.

5. Conclusions

The example of Company Zinc showed that the developed conceptual framework, and the following step-by-step protocol, are useful devices for the description and analysis of choice processes between more or less radical innovations.

As an answer to the increasing external (environmental) pressure put upon Company Zinc, the company first intended to look after incremental, add-on, solution directions, such as the enlargement of the jarosite storage capacity in new ponds. When this solution
was not tolerated anymore by influential contextual actors, Company Zinc choose to develop a more radical solution, namely the jarosite treatment process. However, this innovation process failed, because some important actors had different perceptions of the problem. The Water Boards, for example, wanted to keep their autonomy, and the national authorities were not willing to subsidize the project, thereby impeding the negotiation process towards a dominant problem definition.

Then, Company Zinc introduced a third option, the exploitation of a ‘low-iron’ containing zinc-concentrate, which would not produce jarosite anymore. In first instance, the tight coupling of Company Zinc to the holding company, its drive to develop the new mine, and the increasing pressure from national authorities and environmental groups, ease the negotiation towards this solution direction. However, the local communities at the mine side had also to be taken into account in the negotiation process.

Accordingly, the following preliminary conclusions can be drawn: Pressure can be regarded as an important trigger of innovation. This often concerns, but not always, external pressure. If the problems cannot be solved inside the existing (production) system, more radical, system-exceeding solutions are looked for. The nature of these solutions is determined by the specific arrangement of actors and their problem definitions in the network, together with more traditional aspects as the economics, the history and routines of the firm, and the technological barriers as recognized by the actors in the network.

The Company Zinc example only gave some examples of technology choice processes between incremental and radical innovations inside one company. In order to be able to make more general conclusions, the technology choices in another zinc producing company has been studied, as well as within other metals producing industries in the sector.

The comparison between various metals will provide more information on the differences and similarities in network structure, dynamics, and thus on the specific conditions for technology choices between incremental and more radical innovation. Such comparisons will be made in the ongoing PhD-work, on which this paper is based.

Based upon the developed conceptual framework, a frame of analysis has been set up, consisting of a 6 steps protocol, which can be followed to unravel and analyze the conditions determining technology choices, especially between incremental and more radical solution directions. When it follows from the other cases that this protocol is an useful device, it will be refined, according to the new findings, and then its generality could be tested in other industrial cases.

References


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