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Ecologically Sound Pulp Production: How the Interaction of World Market Conditions, Corporate Capability and Environmental Policy Determines Success and Failure of Environmental Innovations

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Abbreviations

AG	Aktiengesellschaft (stock corporation)
BFH	Bundesforschungsanstalt für Forst- und Holzwirtschaft (federal research institution for forestry and timber industry)
BGA	Bundesgesundheitsamt (federal health agency)
BMBF	Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (federal ministry of education and research)
BMFT	Bundesministerium für Forschung und Technologie (predecessor of BMBF till 1984)
BMG	Bundesministerium für Gesundheit (federal ministry of health)
BMI	Bundesministerium des Innern (federal ministry of interior, responsible for environmental affairs till 1986, when the BMU was established)
BML	Bundesministerium für Ernährung, Landwirtschaft und Forsten (federal ministry of agriculture)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (federal ministry of the environment)
DLR	German center for aviation and aerospace, research project management body "Environmental research and technology"
DVGW	Deuscher Verein des Gas- und Wasserfaches (German association of gas and water utilities)
FRG	Federal Republic of Germany
GDR	German Democratic Republic
NGO	nongovernmental organisation
PTWT	Projektträger Wassertechnologie (research project management body "Water technology and sludge treatment" at the (nuclear) research center Karlsruhe)
PWA	Papierwerke Waldhof-Aschaffenburg AG
SCA	Svenska Cellulosa
UBA	Umweltbundesamt (federal environmental agency)
VDP	Verband deutscher Papierfabriken (association of German paper mills)
VDZ	Verband Deutscher Zeitschriftenverleger (association of German periodicals)

AbwAG	Abwasserabgabengesetz (wastewater levy act)
AbwV	Abwasserverordnung (wastewater ordinance)
AbwasserVwV	Abwasser-Verwaltungsvorschrift (administrative regulation of wastewater)
AOX	adsorbierbare organisch gebundene Halogene (halogenated organic compounds, primarily chlorinated organic compounds)
ASAM	alkali-sulfite-anthraquinone-methanol
BAT	best available techniques (as defined in Article 2(11) of the IPPC Directive
BImSchG	Bundes-Immissionsschutzgesetz (federal air quality act)
BREF	Best Available Techniques Reference Document
C	chlorination bleaching stage using molecular chlorine dispersed and dissolved in water
COD	chemical oxygen demand
CTMP	chemi-thermo-mechanical pulp
D	chlorine dioxide bleaching stage using an aqueous solution of ClO_2
DOC	dissolved organic carbon
DTPA	diethylene triamine penta-acetic acid
E	extraction bleaching stage using NaOH
ECF	elemental chlorine free

EDTA	ethylene diamine tetra-acetic acid
EMAS	environmental management and auditing system
EOP	extraction bleaching stage using sodium hydroxide with subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent
EP	environmental policy
ETP	ecology-oriented technology policy
H	hypo-chlorite bleaching stage
IPPC	Integrated pollution prevention and control
kappa	a measure of residual lignin content in unbleached pulp, determined after pulping and prior to bleaching
KrW/AbfG	Kreislaufwirtschafts- und Abfallgesetz (recycling and waste management act, replacing the waste management act in 1996)
O	oxygen bleaching stage
P	alkaline bleaching stage with hydrogen peroxide as liquid
Q	acid bleaching stage where chelating agent EDTA or DTPA has been used for removal of metals
R&D	research and development
TCF	totally chlorine free
UVP	Umweltverträglichkeitsprüfung (environmental impact assessment)
UVPG	Gesetz über die Umweltverträglichkeitsprüfung (environmental impact assessment act)
WHG	Wasserhaushaltsgesetz (federal water act)
Z	ozone bleaching stage using gaseous ozone

Summary

The case studies investigate political bargaining as well as innovation processes around efforts to reduce environmental pollution in pulp production. The development and diffusion of corresponding environmental technologies depend on their technical viability, their economic viability, the (global) socioeconomic structures of the pulp and paper industry, environmental policy regulations, and situational circumstances, reflecting the interests and relative power of actors involved. Taking into account a time period of nearly 30 years (1970 - 2000) various innovative efforts are summarized. These environmental innovations are examples of different approaches and foci to deal with environmental problems of pulp production by appropriate technologies, namely wastewater purification by aluminium oxide or by combined aerobic and anaerobic biological treatment, substitution of molecular chlorine bleaching by peroxide bleaching or by high pressure oxygen bleaching, and alternative pulping technologies, i.e. the ASAM process and the Organocell process. Because structural framework conditions, particularly the availability of public funds, left considerable scope of action, situational conditions often paved the way for starting an environmental R&D project and for its success or failure.

In the 1970s the (perceived) pressure of environmental problems was so strong that environmental regulation of pulp production was considered necessary. Because of fierce competition on the world market, however, the pulp industry could hardly afford on a short-term basis the investments required for environmental protection measures without public subsidies. Therefore, ETP contributed significant funding to allow for the development of a considerable number of technological options in the 1970s and 1980s. Most of them failed, however, for various reasons, but some of them succeeded to become established practice since about the 1990s. EP and ETP played a key role in achieving large reductions of ecologically hazardous substances emitted during pulp production, by introducing a wastewater levy, by setting increasingly tighter environmental (emission and ambient quality control) standards, and by funding the development of corresponding environmental technologies. A good deal of coordination of EP and ETP took place, which influenced both the standard setting process and technology development.

Whereas EP activities met fierce opposition of the pulp and paper industry in the 1970s and 1980s, involvement in related bargaining processes, in conjunction with an increasing environmental concern and a corresponding greening of industry in general, led to social learning processes of this industry which resulted in growing commitment and a voluntary declaration in favour of ecologically sound pulp production in the 1990s. A campaign of Greenpeace attacking environmental problems of pulp and paper production and public debate on chlorine-free paper probably enhanced this change in attitude. However, the corresponding actual demand of publishers for chlorine-free paper and clear environmental regulations were the main driving forces for improved environmental protection and consciousness in pulp production.

Thus, different phases of development with varying attitudes and approaches of the main actors towards environmental protection and technology development in pulp production can be distinguished: environmental problem pressure and installation of available (end-of-pipe) technologies (1970-1980), generous public funding of environmental technology development and preparation of environmental regulation (1975-1985), passing and enhancing environmental standards and diffusion of environmental innovations (1980-1995), further progress and differentiation of environmental regulation and environmental technologies applied (1990-2000). These changing contextual conditions implied differing policy strategies and tactics of EP and ETP.

1 Purpose and methodology of the case studies

These case studies investigate political bargaining as well as innovation processes around efforts to reduce environmental pollution in pulp production.[1] The development and diffusion of corresponding environmental technologies relate to the three steps of pulping by cooking wood chips with chemicals, pulp bleaching, and subsequent waste management. Their success or failure especially depends on their technical viability, their economic viability, the (global) socioeconomic structures of the pulp and paper industry, environmental policy regulations, and situational circumstances, reflecting the interests and relative power of actors involved. Taking into account a time period of nearly 30 years (1970 - 2000) various innovative efforts are summarized in a rather general perspective, which embeds them in overall development trends explaining their success or failure over subsequent phases of technological trajectories, followed and does not reconstruct individual environmental innovations in detail. This approach allows to understand better why some environmental technologies concerning pulp production have been socially established and others not.

The main purpose of the case studies is to study the influence of regulatory networks and framework conditions upon corresponding innovation processes, particularly the role of environmental policy (EP) and ecology-oriented technology policy (ETP) and their mutual coordination within this context (IIUW 1998).

The study is mainly based on 17 loosely structured, sometimes multiple interviews with key persons involved in these regulatory and innovation processes, mostly conducted by telephone in March 2000 and lasting between one half and two hours. Furthermore, some literature, documents and research reports dealing with pulp production and related environmental problems, technologies and regulations have been studied. Finally, the draft report of the case study has been circulated to the interviewees for critical reading and comments, which have been taken into account according to my personal assessment, provided that I received them.

The interviews were made with (former) representatives of the following institutions: BMU (1), UBA (2), BGA (1), DLR (1), PTWT (1), Greenpeace (1), and managers and scientific experts in charge of pulp-related R&D projects (10). Some further knowledgeable persons did not want to be interviewed for various reasons or could not be addressed any more.

The details of regulatory networks and innovation processes were successively recognised and understood during the various subsequent interviews, mainly conducted from February through April 2000, so that critical questions about controversial issues and less openly presented intangibles could be posed on a better knowledge basis particularly in the later interviews.

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[1] They have been funded by the EU Commission as part of the ENVINNO-project (IIUW 1998).

From a methodological point of view, the demand to perform one (in-depth) case study within one-month workload necessarily implies limited validity of its results for several reasons.

1. It allows hardly any (systematic scientific) verification procedures beyond confronting individual interviewees with diverging opinions of other persons interviewed and beyond asking the interviewees for corrections of and critical comments on the draft report.
2. Analysis of relevant contextual literature on pulp and paper production and related industries, on environmental impacts of pulp production, on corporate strategies, and on the regulatory contexts was not possible, either.
3. Reliance on the remembrance of case histories by only few still available persons engaged in projects 20 or more years ago, without many documents recorded, implies further validation problems.
4. Two of the environmental R&D projects, presented in more detail, are only summarized from corresponding project reports and not based on personal interviews, allowing even less reliable reconstruction of the social processes involved in conducting the project.
5. In case of opposing opinions on the technical (or economic) viability of a newly developed (environmental) technology, it is hard to judge the validity of corresponding statements concerning R&D projects of a more distant past; so some risky evaluative assessments had to be made.
6. The whole setting of partly overlapping stories of environmental innovations and regulations is too complex to allow a detailed analysis and description of specific innovation processes and of informal agreements and arrangements behind the scenes. Thus, a scientific assessment of the validity of the case histories and of their interpretation in social, political and ecological terms presented here was not possible either.
7. The presentation of the case studies on about 70 pages does not allow to eventually discussing subtleties and different possible interpretations of the innovation processes reconstructed.

Although in fact experimenting with different environmental technologies, the cases presented in more detail are primarily organised around three pulp mills and not around three specific environmental innovations in order to more clearly delineate the social networks underlying corresponding innovative efforts.

The general set-up of this report is the following: first, the physical and social setting of pulp production is sketched in section 2 concerning basic engineering features, environmental impacts, environmental technologies developed, socioeconomic structure and environmental regulations. Second, the specific case histories of innovative efforts investigated are described in section 3 in some more detail and embedded in a survey of other environmental technologies developed in parallel. Third, the essential determinants characterizing the overall process of the development and diffusion of environmental innovations in pulp production are discussed in section 4, such as problem perception, environmental regulation, R&D projects, policy action, (global) market conditions and competitive advantage. Finally, sections 5 to 7 summarize the findings of the case studies referring to actor constellations, innovation processes, contextual interpretation, and conclusions to be drawn.

2 The physical and social setting of pulp production

This section gives a short introductory survey over the main physical and social features of pulp production with special reference to its environmental aspects.

2.1 Characteristics and development of pulp production

Pulp as the raw material of paper production[2] is gained by chemical or mechanical treatment of wood.[3] To do so, after debarking, chipping and screening wood to chips one has to separate its three components cellulose, hemicelluloses, and lignin by chemicals into two main parts: cellulose (and hemicelluloses) for pulp, and lignin. Cooking is the main delignification process in order to dissolve the lignin and to free the fibre by subsequent washing and screening.[4] The lignin and many other organic substances are thus put into solution from which the chemicals and the energy content of the lignin and other organics may be recovered. The cellulose fibre extracted has to be bleached afterwards mainly for removing the remaining lignin and for improving pulp brightness.[5] Subsequently, the pulp has to be washed and screened again, and finally dried. Both the extraction and the bleaching process typically consist of a sequence of several, i.e. 2 to 7 (or even 10) subsequent stages. Finally, the waste products resulting from these processes have to be managed, frequently by using chemicals and energy recovery systems,[6] in accordance with existing environmental regulations, particularly those concerning wastewater release.

Concerning the pulping process, three types of chemical pulping processes have been developed in the 19th century, namely the sulfate or kraft process, the sulfite process,

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2 Apart from dissolving pulp, pulp is essentially (ca. 98% worldwide, 96% in Germany) used for all kinds of paper production, i.e. printing and writing paper (49%), packaging materials (38%, card and pasteboard), paper and pasteboard for technical and specific purposes (7%, e.g. decorating paper, filtering paper, photo raw paper, cigarette paper), fluff pulp and hygiene paper (6%, e.g. toilette paper, towel paper, cosmetic paper, tissue paper); dissolving pulp serves as raw material for producing viscose products, acetate products, cellulose ether, and cellulose nitrates (VDP 1999).

3 Wood is the main raw material but (sugar cane) bagasse and linters are used, too, whereas straw, hemp, grass, and other cellulose-bearing material are marginal.

4 "In mechanical pulping processes mechanical shear forces are used to pull the fibres apart and the majority of the lignin remains with the fibres although there is still dissolution of some organics." (European Commission 2000:10)

5 For dissolving pulp, mainly produced for chemical purposes, the main task is the separation of hemicelluloses, whereas the separation of lignin needs not to be achieved entirely.

6 "The cooking chemical recovery includes evaporation of the spent liquor to concentrated liquor, combustion of the concentrated liquor and preparation of new cooking acid from recovered chemicals... Besides the recovery of cooking chemicals the recovery boiler(s) produce steam. Often sulphite pulp mills operate auxiliary boilers burning bark, oil or other fuels. In these boilers, knots, rejects and sludge from the effluent purification may also be burned. The steam from the boilers is led to counter-pressure turbines where electrical power is produced." (European Commission 2000:127-128)

and the soda (as well as some other pulping) processes, which are currently responsible for about 80%, 6%, and 14% of worldwide pulp production, respectively (Jaakko Pöyry 1997).[7]

The primarily alkaline kraft process, which results from its active cooking chemicals sodium hydroxide (NaOH) and sodium sulfide (Na_2S), at least since the 1960s has been "the dominating chemical pulping process worldwide because of the superior pulp strength properties compared with sulphite process, its application to all wood species, as well as to the efficient chemical recovery systems which have been developed and implemented. But the chemistry of the Kraft process carries with it an inherent potential problem of malodorous compounds." (European Commission 2000:17) Kraft pulp, however, requires intense bleaching processes because the lignin residue is heavily condensed and difficult to remove.

"The production of sulphite pulps is much smaller than the production of kraft pulps and sulphite pulps are more used for special purposes in papermaking rather than being an alternative market pulp grade for kraft pulps." (European Commission 2000:123) The usually acid sulfite process can only be applied to few species of wood (beech, spruce in Germany), usually results in lower strength properties of the pulp, but needs less bleaching and offers much more flexibility (by changing the dosage and composition of the chemicals) than the kraft process.

In the FRG, predominantly the sulfite process was applied after the second world war because there existed - after 1958 and till 1999 - no more pulp mills using the kraft process, and new ones required comparatively high investment costs and would have met severe licensing problems because of their strong odour due to sulphur emissions and their enormous environmental pollution at that time.

The alkaline soda process is applied essentially for annual plants only, such as bagasse, linters, straw, and reed, mainly in Asia, Africa and South America.

Bleaching was mainly done by chlorine, primarily elementary chlorine (C), but also hypo-chlorite (H) and chlorine dioxide (D), and by alkaline extraction bleaching using sodium hydroxide (E). The use of oxygen based bleaching agents reduces or avoids chlorine emissions. Peroxide bleaching of ground wood was patented in Germany in 1905 already, and first used in 1940/41 (cf. Ehrhard/Alber 1998).

Although the black liquor resulting from cooking processes was collected in kraft pulp mills using boilers and a lime kiln rather from the very beginning and, since 1939, in sulfite pulp mills, too, discharge of wastes into wastewater and subsequently surface waters was rather common in the pulp and paper industry which contributed strongly to environmental pollution, at least till to the 1980s.[8]

In Germany production of chemical pulp had risen from 100.000 tons per year in 1890 to 1,5 million tons per year in 1939, and stagnated at around 800.000 tons per year in

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7 Mechanical pulping and chemi-mechanical pulping are not included in these figures.

8 For each ton of pulp produced more than an equivalent amount of organic material was dissolved and discharged into the rivers.

the Federal Republic of Germany since 1960, with a short increase to more than 1 million tons per year after German reunification in 1990 and again in 2000/01. Worldwide, pulp production grew from around 100 million tons per year in the early 1980s to around 140 million tons per year in the late 1990s. Furthermore, production of mechanically gained wood pulp grew in the FRG from about 700.000 tons per year in 1960 to over 1,6 million tons per year in 1990 and declined to 1,2 million tons per year in 1998; worldwide around 35 million tons of wood pulp are produced annually at present.

Paper consumption grew from ca. 2,5 million tons per year in the FRG in 1960 to ca. 16 million tons per year in 1998, compared to a global figure of around 300 million tons per year. The difference to pulp production is covered by imported pulp (ca.25%), recovered waste paper (40% in 1960,60% in 1998)[9] and fillers.

2.2 Environmental impacts of pulp production

Pulp mills tend to pollute the environment by their wastewater, emissions into the air, wastes, noise and smell, to use enormous amounts of water and to need quite some energy. Modern, environmentally relatively friendly pulp mills have considerably reduced these environmental burdens by means of a number of environmental measures for improved emission control, internal as well as external ones, so that the emissions have typically been reduced by 80% to 90% or more on a specific basis since about 1980. This has been achieved for example by wastewater purification up to production-integrated advanced wastewater treatment systems reusing treated process waters, by recovering chemicals applied, by generating self energy supply via burning wastes from pulp and paper manufacturing processes (rejects, sludge, and black liquor, in particular) thereby avoiding a waste disposal problem, or by rather closing water and processing cycles. "There is a development to close up water circuits in pulp and paper mills and a further reduction of discharges can be expected (towards effluent free mills). However, today there are no kraft mills operating full time, which completely recover all bleach plant effluent." (European Commission 2000:9) In addition, the growing share of recovered paper in paper production contributes to a lower demand for primary pulp.

The environmental impacts of pulp production mainly result from the chemicals used for both cooking and bleaching, such as sulphur, chlorine, chlorinated compounds, remaining organic and inorganic materials, lignin and undissolved fibre material, typically mixed up in the black liquor, and eventually Na and Mg salts, chelating agents and heavy metals such as manganese or iron. Thus, the major environmental problems of pulp production were wastewater loads, water consumption, and gaseous emissions, including malodorous sulphur compounds from kraft pulping.[10]

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[9] Worldwide waste paper recycling still amounts to only 43% (VDP 1999).

[10] "From the end of the 1970s until recently, the main emphasis was put on the role of chlorinated substances formed in the bleach plant. Dioxins and Furans had been detected in some effluents of pulp mills and the public discussion focussed on the harmful effects of chlorine bleaching. The public concern about the potential environmental hazard imposed by the use of chlorine in the bleach plants has brought about a drastic decrease in the use of molecular chlorine as a bleaching chemical during

The specific pattern of environmental impacts varies according to the local environs, to the production arrangement of, the technologies used in, and the environmental protection measures applied in a pulp mill, and therefore needs no further elaboration in this study.

In any case, pulp production belonged to those industries involving comparatively severe environmental pollution till to the 1980s.

2.3 Environmental technologies reducing environmental pollution

Particularly in Germany, from the 1970s to the 1990s considerable efforts were made to reduce environmental pollution of pulp production by wastewater treatment, by substituting (elemental) chlorine and hypo-chlorite in bleaching processes, by developing new, environmentally more sound pulping technologies, and by rather closed cycle (integrated) processing arrangements. Frequently, mutual interference of these differing efforts at the level of their chemical and physical impacts as well as additional requirements upon subsequent processes in a mill demanded a relatively comprehensive approach to harmonize many processing arrangements for successful application of environmental technologies.

Leaving aside efforts to reduce water consumption and basic measures to minimise atmospheric emissions, noise and smell, the main R&D projects, partly dealt with in this study, looked for various solutions to the following, primarily wastewater-related environmental problems.

1. Frequently in combination with efforts to optimise bleaching processes, including at least partial collection and utilization of bleach plant liquor, end-of-pipe technologies were the first type of environmental protection measures, mainly undertaken during the 1960s and 1970s and often induced by concern about the pollution of local rivers. They were directed towards wastewater treatment by (multistep) biological sewage treatment plants, which considerably decreased COD values from for example 20.000 mg/l to less than 1.000 mg/l.[11] Significantly, modern (biological) wastewater treatment was introduced in Germany from 1973 to 1977 at the Blankenstein sulfite pulp mill in the former GDR first (Geisenheiner 1982), with the help of Swiss and Austrian know-how, when the West German pulp industry still publicly declared the impracticability of such end-of-pipe technologies. However, biological purification processes do not tackle (chlorinated) ligneous effluents, the main polluting substances from pulp mills, aside from other chlorinated compounds in bleach plant effluents. Diverse attempts were made to purify effluents, for instance by adsorbing lignin with the help of appropriate compounds such as Al_2O_3

the last decade. The environmental control authorities in many countries have set severe restrictions on the discharges of chlorinated organics measured as AOX into the aquatic environment." (European Commission 2000:9)

[11] Without collection and separate treatment (burning) of bleaching liquor effective treatment of pulp mill wastewater effluents would have been extremely costly. Therefore (German) pulp mills typically installed corresponding wastewater treatment technologies only if their bleaching water filtrate could be handled accordingly.

in solid bed reactors and the thermal recovery of the loaded, exhausted absorbent in a rotary tubular kiln.

2. In the 1970s and 1980s different bleaching agents were tested at a laboratory level as well as on a large scale to substitute elementary chlorine, at first, and then chlorine compounds, altogether, in order to significantly reduce or eliminate AOX in (waste) water. Essentially four options were realised: oxygen, peroxide, ozone and peracetic acid. For sulfite processes peroxide bleaching (P), partly following extraction bleaching using NaOH (EP), possibly combined with oxygen as a reinforcing agent (EOP), has completely substituted chlorine bleaching and also reduced the number of bleaching stages needed in Germany since the 1990s. For modified kraft processes the other options, oxygen (O) or ozone (Z) bleaching stages - more than peroxide bleaching (P) - have been introduced in addition to chlorine dioxide bleaching (D)[12] and alkaline extraction bleaching (E) stages, allowing ECF bleaching, whereas TCF bleaching on the basis of peroxide and ozone bleaching stages (P, EOP, Z), supplemented by an acid bleaching stage where a chelating agent, either EDTA or DTPA, has been used for removal of metals (Q), meanwhile is established technology, too, but still is not widely applied in kraft pulp mills yet.
3. Since the 1970s various alternative pulping processes[13] have been developed and successfully tested at least in pilot plants in order to reduce environmental pollution by low water consumption, TCF bleaching, sulphur-free technology, a simpler cooking process and by far-reaching closed up recovery of cooking chemicals and to better use the raw material wood. These are in particular the ASAM process, the Organocell process, the Formacell process and the Milox process (cf. Jaakko Pöyry 1997). However, only the modified kraft process mainly developed in Scandinavian countries which - on the basis of application of extended (displacement) cooking processes, oxygen delignification, ECF (or even TCF) bleaching, rather complete chemicals recovery, nearly closed water cycles and of energy autarky of production - also drastically reduced environmental pollution of conventional kraft mills has been established in industrial pulp mills, meanwhile responsible for around 20% of worldwide pulp production. For reasons described in later sections, currently the other processes have no realistic chance to be introduced on a large scale except perhaps the ASAM process.
4. Together with efforts towards new or modified chemical processes of environmentally friendly cooking, delignification and bleaching a lot of development and testing endeavours were made to close to a large degree water cycles and pulp processing cycles by recycling chemicals, energy and water. Corresponding recycling arrangements and associated recovery systems depend on the specific conditions of the

[12] Only for high quality products requiring extreme brightness chlorine dioxide is still needed in the bleaching process. Concerning brightness of paper, it is important to note the trade-off that stronger bleaching efforts lead to a decrease in fibre quality in TCF processes. However, in contrast high brightness is achieved with chlorine dioxide without any negative impact on fibre quality. Compared to C-bleaching, D-bleaching results in much lower AOX. The plain substitution of Cl by ClO_2 results in only 20% of the former AOX value.

[13] The term 'alternative pulping process' essentially refers to significant changes of cooking processes only, whereas the other components of the overall pulping process need not necessarily to be changed as well.

pulping processes chosen. The basic problem to be solved in such recycling processes is the control and separation of necessarily accumulating residues in order to avoid disturbances of genuine pulping processes or destructive effects upon the equipment, which may easily lead to rather complicated combinations of processing technologies.

5. Finally, the transformation of waste products such as lignin into marketable by-products reduces wastes generated and may increase profitability of pulp production. Corresponding efforts in this direction were particularly made during the development of the Organocell process, but hardly resulted in economically viable results. In the conventional calcium sulfite process, however, there was and is a market for the main by-product sulfonated lignin. This polymeric compound is used as an additive for concrete, for drilling hole cleaning in oil production etc.

Altogether an environmentally sound and economically attractive pulping process should, according to Jaakko Pöyry (1997:35-36) fulfill the following requirements:

1. suitable to use the whole raw material (wood)
2. applicable to a broad variety of raw materials including resinous and low-grade wood
3. suitable to produce high yields of well bleachable pulp with paper qualities at least as good as those provided by kraft pulp
4. simple chemical cooking and delignification process that can be realised in a closed system and is well adjustable on a continuous as well as a discontinuous basis
5. (elemental) chlorine free bleaching leading to high brightness common on the market
6. far-reaching closure of chemical cycles with a simple and effective chemicals recovery system
7. well-balanced energy supply by heat and electricity generation with the help of residues and wastes of pulp production
8. far-reaching closure of water cycles, leading to low water demand and low wastewater load
9. zero emission of pollutants into the air or at least no emission above prescribed environmental standards
10. (economic) utilization of by-products wherever feasible
11. low expenditure on investment
12. profitable business also in small production units.

The case studies describe how far some major environmental innovations succeeded in fulfilling these requirements.

2.4 Pulp production and consumption in Germany

In a medium term perspective the demand for dissolving pulp in Germany, as one of the world largest consumers, can be expected to stagnate for various reasons, whereas demand for paper grade pulp will probably grow further (Jaakko Pöyry 1997). The share of waste paper may largely cover this growth[14], though with the major expansion mainly outside Germany, whereas kraft pulp, wood pulp and fillers may more or less keep their shares, and the share of sulfite pulp will probably decline. Consequently, imported (coniferous and hardwood kraft) pulp (at present mainly from Sweden, Finland, Canada, and the USA) continues to play a major role. Thus, the erection of new pulp mills in Germany is rather unlikely.[15] Meanwhile a competitive pulp mill needs to at least produce 200.000 or even 500.000 tons of pulp per year, and its greenfield erection requires more than 500 million Euro.

The trend towards integrated pulp and paper production left only around one third of global pulp production offered on the market (market pulp). In Germany, all pulp is produced in integrated pulp and paper mills; only the Blankenstein mill, which converted its 20-year-old sulfite operation to kraft pulping and increased its capacity by 75% to 280.000 tons per year between 1996 and 1999[16], still produces market pulp. Integrated pulp and paper production facilitates changes towards environmentally more friendly processing techniques because trade-offs between them and pulp quality, for instance acceptability of somewhat lower brightness can be dealt with within the company and are not decided by external customers.

Whereas Germany has a large share in global paper production which was dominated by medium-sized firms nationally in the past (cf. Kirschten 1991), that have been bought up mostly by large foreign, mainly Swedish corporations especially during the last decade, its pulp production is comparatively low, as indicated above. Together with the dominance of pulp imports and the integration of pulp production in paper mills, conflicting interests between the pulp industry and the paper industry no longer play any significant role in Germany.

Overall, structure and development of the (German) pulp and paper industry are characterised by continuous concentration processes[17] (from ca. 300 firms before 1960 to ca. 100 firms in 1999), by repeated purchase and sale of existing mills by different companies,[18] often connected with bankruptcies, by successive shut down of pulp mills

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[14] In order to ensure the strength and other properties of the paper to be produced primary fibres usually have to be added to strengthen recovered waste paper, besides the use of fillers. Thus, waste paper will not completely substitute primary pulp. It is dominantly applied for producing lower quality paper, for instance newsprint. It therefore replaces mainly mechanical pulp, but not chemical pulp. In high quality paper typically no waste paper can be used because it is neither clean nor bright enough.

[15] In view of public subsidies for investments in new industrial plants in Eastern Germany, there is since years a still ongoing debate about building a new pulp mill at Stendal, but with declining chances to get realised.

[16] The necessary investments for this changeover to an environmentally tolerable kraft process were close to 300 million Euro, with one third coming from public subsidies.

[17] Meanwhile Haindl is the only big genuine German paper producer left with a world scale capacity of various grades of printing paper. Furthermore few German specialty producers still exist using linters for producing dissolving pulp sold to pharmaceutical and chemical industry.

[18] "In 25 years the number of paper machines in Europe has been reduced by about 60% while the total capacity has almost doubled. Many companies have grown by investing in new capacity but also by consolidating a large number of small obsolete paper and board mills. Thus, the European paper industry comprises a relatively small number of very large multi-national groups at one end of the scale yet a large number of small businesses at the other. The large number of relative small sized mills has developed niche strategies on the market. - There has been a significant change in the ownership structure in the last 10 years. Typical features in this development have been concentration of produ-

too small to rest profitable under stricter environmental regulations[19], by buying up the few larger pulp mills left in Germany by major foreign corporations, and by strongly fluctuating pulp prices in correlation with available stocks of market pulp and temporarily demand drops (between 400 and 1.000 US$).[20]

Reacting to severe problems of environmental pollution by pulp mills, to public environmental debate and protest, to growing demand for chlorine free pulp and paper, to upcoming environmental regulations, to pressure of environmental policy and to financial support of technology policy, German pulp producers - after a long period of (declining) resistance - undertook considerable efforts from the late 1970s onwards to reduce environmental pollution by chlorine-free bleaching, by efficient closing of pulp processing cycles and by minimising wastewater contamination. Following a similar proclamation in 1993 pulp and paper producers and publishers committed themselves to do their best of ecological care in forestry, pulp and paper production, paper recycling and printing in a voluntary declaration in 1996 and 1997 (at least if economically viable), though rendered more difficult by ongoing rationalization efforts in pulp mills leaving less manpower for environmental management tasks. Furthermore, pulp mills gradually practise environmental auditing according to EMAS or at least ISO 14000. By international comparison, environmental standards as well as practices in Germany clearly are among the most advanced ones at present. For instance, 80% of all TCF pulp produced worldwide is used in Germany.

2.5 Environmental regulation of pulp production

Although German pulp mills licensed after 1939 were already confronted with quite some emission restrictions, general environmental regulation of pulp production mainly developed over the past 30 years, in parallel with the evolution of environmental regulation in general. As an industry contributing significantly to environmental pollution the pulp and paper industry was given special attention by environmental policy.

The key regulations in this respect are the AbwAG passed in 1976, the AbwasserVwV annex 19 referring to §7a WHG, and the various ordinances of the BImSchG. The first one imposes levies on wastewater emissions that vary according to the volumes of specified hazardous substances emitted. The second one sets limit values for key parameters (particularly COD, AOX) in wastewater and formulates general requirements for ecologically sound pulp processing.[21] The environmental standards required by the AbwasserVWV annex 19, first enacted in 1982, have been strengthened and

cers into bigger companies and integration of paper mills with the overseas pulp producers or acquisitions or financial cooperation relationships between European and overseas manufacturers." (European Commission 2000:8)

19 The same holds true for the closure of all but one pulp mill in the former GDR, being small and not modernized for several decades.

20 "The price variation is not the same for all pulp and paper products. The closer a company is to the ultimate consumer, the smaller the price fluctuations of the product. For example, the price of pulp is much more volatile than that of tissue paper." (European Commission 2000:8)

21 In this context appropriate measurement techniques have to be specified, possibly accompanied by substantial bargaining processes leading to considerable delay in passing an ordinance.

enlarged in its amendments in 1989 and, quite probably, in 2000.[22] Authorization of a pulp mill or of related changes of its technical equipment and processes is dominated by licensing procedures according to the BImSchG, which put together approval decisions concerning air pollution, waste management, water supply, wastewater treatment, substances jeopardizing water quality, safety of installations, occupational safety, noise protection, fire protection, structural engineering, nature protection, and UVP.

Rechtsvorschrift	Genehmigungsverfahren	Genehmigungsverfahren schließt ab mit:
– Raumordnungsgesetz - ROG- – Gesetz über die Umweltverträglichkeitsprüfung UVPG – Naturschutzgesetz	Raumordnungsverfahren – ROV mit raumordnerischer Umweltverträglichkeitsprüfung	Raumordnerische Beurteilung
– Baugesetzbuch – BauGB-	Bauleitplanung (Erarbeitung des gemeindlichen Flächen nutzungsplanes ➔ Bebauungsplan)	Genehmigung und Bekanntmachung
– Bundes-Immissions-Schutzgesetz – BImSchG Mit u.a. VO zum BImSchG – VO über genehmigungsbedürftige Anlagen - 4. BImSchV – VO über das Genehmigungsverfahren - 9. BImSchV – Emissionsschutz-VO - 11. BImSchV – Störfall-VO - 12. BImSchV – VO über Großfeuerungsanlagen - 13. BImSchV – VO über Verbrennungsanlagen für Abfälle u. ähnl. Brennbare Stoffe - 17. BImSchV – Technische Anleitung Luft (TA Luft) – Technische Anleitung Lärm (TA Lärm) – Wärmenutzungs-VO	BImSch-Genehmigungsverfahren	Genehmigung mit Auflagen
– Wasserhaushaltsgesetz -WHG – Wassergesetze der Länder – Abfallgesetz –AbfG- bzw. das das AbfG ablösende Kreislaufwirtschafts- und Abfallgesetz - KrW/AbfG – Chemikaliengesetz – Gerätesicherheitsgesetz – Landesbauordnungen – Brandschutzgesetz – Gesetz über die Umweltverträglichkeitsprüfung – UVPG	BImSch-Genehmigungsverfahren	Genehmigung mit Auflagen
– Wasserhaushaltsgesetz .- WHG – – Wassergesetze der Länder	Wasserrechtliche Verfahren	Wasserrechtliche Erlaubnis

Table 1: Legal prescriptions for licensing a new pulp mill in Germany (Source: Jaakko Pöyry 1997:482/483)

[22] In particular, the COD limit value required has been lowered from between 80 and 350 kg/t pulp produced (depending on the pulp type) over 70 kg/t to 40/25 kg/t (referring to existing or new plants). Similarly, the AOX limit value was not denominated in the AbwasserVwV annex 19 in 1982, fixed at 1 kg/t in 1989 and lowered to 0,35/0,25 kg/t for existing and new plants, respectively, in 2000 in the corresponding annex 19 amendments. These are quite strict limit values by international comparison.

Meanwhile the erection or significant modification of a new or existing pulp mill, respectively, have to undergo a relatively complex licensing process according to various regulations[23], indicated in table 1, that lasts at least one year.[24]

3 Case histories

With increasing environmental concern and upcoming environmental regulation during the 1970s environmental policy forced and ecology-oriented technology policy supported R&D projects of the pulp industry and corresponding academic research institutes aiming at the reduction of environmental pollution. Although similar efforts could be observed in other (Western) countries, especially Sweden and later on Austria, as well, Germany has been a frontrunner undertaking manifold innovative endeavours in this respect.

In accordance with the focus of the ENVINNO project, at three locations two projects of environmental technology development respectively have been investigated in somewhat more detail. They are described and contextualized in the following sections. These environmental innovations are examples of different approaches and foci to deal with primarily wastewater-related environmental problems of pulp production by appropriate technologies, namely wastewater purification by aluminium oxide or by combined aerobic and anaerobic biological treatment, substitution of molecular chlorine bleaching by peroxide bleaching or by high pressure oxygen bleaching, and alternative pulping technologies, i.e. the ASAM process and the Organocell process. Two of these six R&D projects, namely two-step biological wastewater treatment at Ehingen and oxygen bleaching at Kelheim, are summarized solely on the basis of the final project reports and not of extended interviews with key persons involved in these projects.

3.1 Ehingen

The efforts of the pulp mill of Schwäbische Zellstoff AG in Ehingen to reduce its environmental pollution can be characterized by two main steps: successful tests and use of hydrogen peroxide (H_2O_2) to successively introduce chlorine-free bleaching in the 1970s and early 1980s, supplemented by an oxygen bleaching stage in 1983, minimised AOX emissions and provided the preconditions for the subsequent building of a biological purification plant in the late 1980s, using for the first time both aerobic and anaerobic purification techniques for wastewater treatment in pulp production.

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[23] These result from laws addressing areal planning, construction, ambient environmental quality, wastes, water regulation and protection, nature protection, and environmental impact assessment.

[24] The reconstruction of the Blankenstein pulp mill changing from the sulfite to the kraft process lasted 3 years in all from the start of project planning onwards.

3.1.1 Introduction of peroxide bleaching

The basic idea initiating the project was to reduce chlorine bleaching in order to allow treatment of bleach washing filtrate that was not possible as long as it contained chlorides leading to corrosive effects on the installations.[25] However, quality of the market pulp produced should not suffer in order not to lose customers.[26] Thus, in the early 1970s the concern was not AOX emission per se, but the future treatment of wastewater containing lignin and hemicelluloses implying high COD demand and, later, also it was the eventual formation of chlorinated dioxins by chlorine bleaching, as pointed out in the dioxin debate following the Seveso accident. Because the Ehingen pulp mill had no (biological) wastewater treatment plant, wastewater effluents were of particular importance because they affected filtration of drinking water downstream the Danube river and raised concern in the responsible water supply corporation Landes-wasserversorgung Baden-Württemberg, which approached the Schwäbische Zellstoff AG in this respect.

In 1971 the Schwäbische Zellstoff AG, which had an annual turnover of around 50 million Euro at that time, began to experiment with oxygen and peroxide bleaching on a laboratory scale. High pressure oxygen bleaching was already used for kraft pulp. The experiments with sulfite pulp led to mixed results and were not continued on a larger scale because of considerable financial means required. For the experiments with comparatively expensive peroxide the main German producer of hydrogen peroxide Degussa[27] was contacted which was well interested in opening up a potential new market for this product. With the technical assistance and the provision of laboratory facilities by Degussa the experiments showed the viability of peroxide bleaching, which was previously known to be feasible for mechanical pulp only.[28] In 1974, P-bleaching was then tested at a large-scale level leading to the conclusion that elemental chlorine could be substituted to a large degree.

On the basis of this knowledge application for BMFT funds appeared promising, and from 1975 through 1977 a subsequent R&D project systematically investigating P-bleaching of (calcium-based) sulfite pulp on a laboratory and an operational scale was co-funded with 0,8 million Euro, i.e. 50%, coming from the BMFT.[29] Funding of this project suited the interests of all parties concerned: the Schwäbische Zellstoff AG received significant support to continue its efforts in reducing C-bleaching for environmental protection purposes, Degussa had the chance to test at an operational level the usability of peroxide on a new market, the BMFT and the research project

[25] Burning, evaporation or recovery of wastes from cooking was well feasible because without hydrochloric acid originating from chlorine no significant problems of corrosion occurred.

[26] A major advantage of C-bleaching is that chlorine does not attack pulp.

[27] Faced with economic problems Degussa in 1999 merged with Hüls to the Degussa-Hüls company. A further merger with SKW Trostberg will take place in 2001.

[28] Furthermore, questions concerning the effects on pulp quality, i.e. viscosity, had to be answered.

[29] Furthermore, Degussa invested a considerable sum of altogether around 10 to 15 million Euro in its general program on testing and marketing P-bleaching in the following decade, started with the Schäbische Zellstoff AG, though these expenses for technology development remained below 5% of Degussa's turnover in this area.

management body responsible for promoting environmental technology development seized a good opportunity for ETP in that direction, EP could possibly expect evidence for the technical feasibility to meet certain environmental standards, and water utilities affected by pulp mills could envisage potential reduction of corresponding pollution of waters in the future.

Within the project, described in DLR 1991, the Schwäbische Zellstoff AG cautiously tested and expanded P-bleaching by cooperating with Degussa at a laboratory level, by first applying P-bleaching for short periods only, by monitoring satisfaction of customers with the pulp quality achieved[30], by gradually enlarging the share of P-bleaching, by investigating the limitations of P-bleaching concerning certain types of pulp and full substitution of chlorine in the pre-bleaching stage, by successfully testing and applying biological wastewater treatment and evaporation of wastes resulting from P-bleaching, and by ensuring that the water authority Tübingen[31] approved this configuration applying new methods, whereas the general license stemmed from 1940.[32] The aim of the project was not to eliminate, but only to reduce chlorine application. Similarly, ECF bleaching was no primary objective; not until end of 1977 it was partly applied. Apart from the ordinary operating personnel 1 chemist and between 2 or 3 laboratory technicians were continuously involved in this project, where manpower costs consumed much less than 50% of total project costs.

Based on an analysis of market structure, technological options and probable resistances of potential clients Degussa followed a strategy to demonstrate the advantages of applying peroxide and to respond to the specific problems of their customers in order to convince them to change to an expensive bleaching agent. Instead of trying to largely substitute chlorine by peroxide at once, Degussa was content with continuous widening of P-bleaching by successive optimisation of the whole process of bleaching and wastewater treatment based upon the mutual support of partial problem solutions found. For instance, the combination of P-bleaching experiments with modifications in the bleaching facilities allowed better and more intense washing that required in turn less water leading to efficiency gains and multiple use of water and chemicals. During and after the Ehingen project Degussa established contacts to all other pulp producers, too. It was the perspective of both peroxide supplier and user that the adoption of P-bleaching by other pulp producers was a necessary condition to permit price decrease for peroxide by economies of scale in peroxide production, which in turn made P-bleaching economically viable for the first time.

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[30] The Schwäbische Zellstoff AG at that time primarily produced high quality market pulp with the focus in dissolving grade specialties.

[31] This authority was involved in all environmental R&D projects of the Schwäbische Zellstoff AG described by being informed about, commenting and approving proceedings and decisions of the company and the funding organisations BMFT and UBA.

[32] The need to add chelating agents such as EDTA or DPTA in P-bleaching stages in order to prevent decomposition of peroxide by heavy metals was not yet perceived as an environmental issue itself around 1980 (cf. Conrad 2000b). It has to be noted that at that time no chelating agent was added. The washing configuration of the Ehingen pulp mill removed all detrimental heavy metals ahead of the bleach plant because of their solubility in the sulfite process.

Furthermore, after the successful completion of the R&D project described and ongoing experiments at the operational level the development of a high shear mixer in Sweden in 1982, that enormously facilitated the effective application of O-bleaching in domains of medium consistency[33], offered the chance to combine oxygen and peroxide in a bleaching plant allowing to oxidise lignin and to bleach in parallel. Such a combined bleaching facility reduced the demand for peroxide and thus the price of bleaching as well as the need for C-bleaching because together, oxygen and peroxide could fulfill most pulp quality requirements. However, the need to incorporate a high shear mixer in the bleaching tower implied the construction of a new bleaching plant which required the Schäbische Zellstoff AG to invest some more half million Euro. The pulp mill at Ehingen was the first one to install such a combined EOP bleaching plant around 1983, which is now present in all (German) sulfite pulp mills. Although a second and third D-bleaching or H-bleaching stage were still applied, already considerably reducing AOX contamination of wastewater by a factor 2 or 5, TCF bleaching experiments were pursued at that time, too, induced by the emerging debate on AOX. Especially after the R&D efforts at Baienfurt to purify pulp mill effluents by end-of-pipe technologies failed in 1980, as described in section 3.2.1, the strategy to reduce and avoid chlorine in pulp bleaching received further corroboration and proved to be the superior one. In any case, pulp production at Ehingen had considerably reduced its COD and AOX burden in wastewater effluents around 1985. Altogether the successive optimisation process towards chlorine-free bleaching met no severe technical obstacles, was pursued and promoted by the responsible managing director of the Schwäbische Zellstoff AG, was propagated in dozens of (scientific) articles, mostly together with Degussa, led to ECF bleaching after 1985 though connected with the loss of some customers because not every pulp quality could be achieved anymore.[34] Interestingly, since there was no patent acquired in the P-bleaching process because of the public funding involved, some patent-related disputes occurred in the USA several years later, when similar P-bleaching processes were developed there, too, without referring to the R&D results achieved at Ehingen.

In 1987 the Schwäbische Zellstoff AG was taken over by Hannover Papier Alfeld, which had been bought itself by the Swedish pulp producer NCB in 1970s.[35] In this context the pulp mill was complemented by a paper machine, operating since 1993, in order to change to integrated production facilities for economic reasons and to no longer produce primarily dissolving grade market pulp. The sales of pulp were shifted to paper grade qualities. With the complete change to TCF bleaching in 1991 this switch in pulp production strategy together with the advantage of being the first to offer chlorine-free paper increasingly demanded on the market strongly contributed to the survival of the plant at Ehingen on the market.

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[33] Before that time oxygen delignification was a complicated, expensive process because it required high consistency dewatering and a special reactor design and equipment.

[34] Meanwhile, these special dissolving pulps are produced predominantly from linters containing no lignin, which is done by specialty pulp producers.

[35] Being in economic troubles NCB sold both factories to the South African pulp and producer Sappi in 1992.

To sum up, the widening use of chlorine-free bleaching primarily originated in Germany, where 80% of all TCF pulp produced worldwide is sold today. Substitution started with peroxide bleaching in the 1970s, where several factors worked together: problem pressure generated by the lacking treatment of wastewater polluting downstream waters used for extracting drinking water preparation by the water utility, engagement of the responsible managing director of the Schwäbische Zellstoff AG in favour of environmental improvements, unfeasibility of purifying wastewater of chlorinated compounds, interest of a major peroxide producer in new markets, considerable EP pressure on the pulp and paper industry, financial support for developing peroxide bleaching by ETP, and for extensive wastewater treatment by EP. The combination of oxygen and peroxide bleaching in a newly developed high shear mixer, and the further development of EOP bleaching in the Alfeld pulp mill during the 1980s in principle permitted complete substitution of chlorine in bleaching sulfite pulp in the early 1980s. Intensified environmental regulations on wastes from pulp and paper production limiting AOX emissions, when finally enacted in 1990, led to rapid introduction of TCF bleaching in Germany. Furthermore, corresponding environmental debate and policy contributed to the development towards an overall environmentally more friendly attitude of the German pulp and paper industry and induced ongoing diffusion of at least ECF bleaching in most (Western) countries.

3.1.2 Two-step biological wastewater treatment

The success in substituting chlorine bleaching largely by combined peroxide and oxygen bleaching (EOP) provided both the chemical preconditions and the psychological basis to invest in an ambitious project of a combined aerobic and anaerobic biological wastewater treatment plant together with a pyrolysis plant in 1984 to 1990/91 which required nearly 20 million Euro investment costs, excluding the pyrolysis plant, and received public funds of about 8,5 million Euro by the UBA.

Furthermore, a flue gas desulphurisation plant was incorporated in the existing boiler plant in a parallel project lasting from 1981 to 1988, which led to only mixed results and was finally stopped in 1988. It required investment costs of 11,5 million Euro and was co-funded from 1981 to 1986 with ca. 5 million Euro by UBA, too, but is not presented here in detail. UBA had the opportunity to partly fund demonstration projects concerning reduction of air pollution and convinced the BMI to use the corresponding budget title to reduce water pollution, too. Such demonstration projects allowed EP to influence technology development beyond end-of-pipe technologies and to show an at that time reluctant pulp and paper industry the technical feasibility of effective wastewater treatment. In the context of ongoing bargaining processes on the amendment of the AbwasserVwV annex 19 adding a rather strict AOX limit value UBA was therefore ready to contribute up to 50% of total project costs.[36] At that time UBA

[36] For Degussa (and other peroxide suppliers) such an AOX standard was advantageous because it worked in favour of introducing P-bleaching.

co-funded a project of EOP bleaching at the operational level at the pulp mill Alfeld with 1,25 million Euro, too, which is shortly described in section 3.4.

Concerning the project of biological wastewater purification, during its first phase (ca. 1984-87) the pyrolysis plant which should evaporate and combust the EOP bleaching liquor and produce pyrolysis coke for adsorption purposes was built and laboratory and pilot plant experiments varying biological purification set-ups were carried out. During the second project phase (ca. 1988-91) the biological wastewater treatment plant was built and optimised, which was planned to utilize pyrolysis coke.

After several years of experiments the demonstration project was successful concerning combined aerobic and anaerobic wastewater treatment regularly applied since 1989, which reduced ligneous compounds in wastewater drastically as indicated by reduction of COD values of more than 70% after anaerobic treatment, of over 50% after aerobic treatment, and together of 80%. The demonstration project failed, however, to install a viable pyrolysis process for distilled bleaching liquor and producing coke because of the expensive price and technical defaults of the pyrolysis plant delivered by a foreign producer.[37] Having guaranteed its performance he after long disputes disassembled and took back the pyrolysis plant, which was started in 1987 and shut down in 1990.

Following the results of several years of laboratory and pilot plant experiments and external expert opinion the two-step biological wastewater treatment plant was installed in 1989 using 3 methane reactors built for anaerobic treatment of different wastewater streams by a sludge contact process and 4 (closed) tanks built for aerobic treatment by an activated sludge treatment. Whereas the anaerobic purification stage worked quite well from the beginning, the aerobic purification stage needed further improvements. To compensate for the failure of the pyrolysis plant the methane reactors were coated with adsorptive carrier material developed in cooperation with Bayer, a large German chemical corporation, and the newly constructed boiler to wash and burn sulfite liquor was modified to include (EOP) bleaching liquor. Furthermore, besides other environmental improvements in pulp processing the pre-bleaching sequence C/D-EOP was reversed into EOP-C/D reducing generation of AOX considerably.

Thus, the two-step biological wastewater treatment plant, needing 10 persons of technical personnel for its operation, proved to fulfill initial expectations well from 1990 on by reducing COD values of wastewater to about one quarter and AOX values to one third and to less than 1% after complete change to TCF bleaching, as confirmed by expert opinion (Jedele/Schilling 1991) commissioned by the regional government of Tübingen.

[37] In the meantime, newly developed fluidized bed techniques would in principle allow functioning pyrolysis.

3.2 Baienfurt

The R&D efforts towards environmentally sound pulp production at Baienfurt, situated at a small river falling into lake Konstanz, relate to two completely different environmental innovations, developed and tested in two different plants at two different periods of time. The first one concerns purification of pulping effluent of the existing pulp mill by aluminium oxide in 1977 to 1980, that failed for problems related to the thermal recovery of aluminium oxide necessary primarily for economic reasons. The second one concerns the development of the ASAM process as an alternative pulping process, which was deployed on a laboratory scale at the institute for wood technology of Hamburg university and developed and tested further in a pilot plant at Baienfurt in the 1980s and 1990s. The ASAM process tries to combine several pulping techniques in such a way that their respective advantages are realised and their disadvantages are avoided. The development of the ASAM process proved to be successful, but it has not yet been implemented on an industrial scale for various reasons.

3.2.1 Wastewater purification by aluminium oxide

Because of the guidelines of the international water protection commission for lake Konstanz, introduced in 1971, the pulp and cardboard factory at Baienfurt, owned by the Feldmühle AG, had to purify its wastewaters rather completely or to close the mill. A one-stage biological wastewater treatment plant, reducing COD concentrations to below 1000 mg/l, was installed around 1970 and a second stage was added in 1974, reducing COD values to 600 mg/l. However, the main polluting substances, AOX-lignin compounds contained in the bleach plant effluent were resistant to biological degradation. Therefore, between 1971 and 1974 diverse physico-chemical purification techniques were tested together with biological degradation, partly up to semi-technical plants: flocculation with lime or salts, catalytic oxidation, ultra-filtration with capillars and membranes, adsorption on activated carbon, electrochemical techniques, radioactive irradiation, and ozonisation. After all attempts failed to show satisfactory results, systematic experiments were made concerning lignin absorption to (granular) aluminium oxide in solid bed reactors, and the thermal recovery of the loaded, exhausted absorbent in a rotary tubular kiln. First, laboratory and large-scale experiments were performed in collaboration with the DVGW research unit at the university of Karlsruhe (cf. McLachlan 1977, Fischer 1978), partly funded by the state government of Baden-Württemberg. Then a large plant was installed with four solid bed reactors and a recovery kiln (Förster/Solbach 1979). This project was co-funded (50%) by the BMFT under the auspices of PTWT. Total project costs amounted to about 5,5 million Euro, and additional manpower of one full-time equivalent was engaged in the project for two years. The intended environmental project objectives to reduce the COD value and to discolour the wastewater were achieved. Because aluminium oxide (Al_2O_3) was expensive and was needed in immense quantities in order to offer large surfaces for effective adsorption processes, it had to be regenerated for economic (and environmental) reasons. However, the chlorine contained in the absorbed substances, converted into hydrochloric acid during combustion, led to severe corrosion of the materials coating the tubular kiln. In spite of experimenting with various coating materials and with different sizes and arrangements of granular aluminium oxide this problem could not be solved, and after 3 to 4 months the recovery kiln was more or less ruined. Thus, ultimately the solid bed reactors served sedimentation purposes for the pulp wastewater, whereas the original goal of the project to purify bleach plant effluent in a technically and economically viable manner had failed and consequently was not pursued further.[38]

3.2.2 Development of the ASAM process

The initial formation and development of the new pulping process ASAM is connected with its main inventor, professor Patt at Hamburg university, who was already involved in developing ozone bleaching, mentioned above, with the interest of EP, TP and certain companies in an ecologically sound pulp production, and with the interest of the German pulp industry in keeping its raw material basis by a production process meeting increasingly strict environmental regulations.

The basic underlying objective was the development of a complete pulp production plant fulfilling in particular the following requirements:

1. It is able to process all wood species what is unfeasible for the sulfite process prevailing in Germany.
2. It produces pulp qualities superior to the sulfite process and at least equal to the kraft process.
3. It is environmentally friendly because of TCF bleaching, chemicals recovery, and offering the chance to close the water loop, which can already be achieved by modifications of existing conventional pulping techniques.
4. It is economically competitive.

Basically the ASAM process is an alkaline sulfite process supported by methanol as an organic solvent and anthraquinone as a redox catalyst (for a summarizing description see cf. DLR 1990, Jaakko Pöyry 1997, Schubert et al. 1993, 1994, Teder/Sjöström 1994). On principle, the equipment of an ASAM pulp mill differs from that of a kraft pulp mill only by its facilities to recover methanol and to convert chemicals after black liquor combustion. Its advantages over the dominant kraft process are the following ones (Jaakko Pöyry 1997:113): somewhat higher pulp yields (<3%) implying less wood input, equal or even greater pulp strength, favourable bleachability of ASAM pulp allowing TCF bleaching without any problems, less bleaching stages facilitating closure of processing cycles, separation of sodium and sulphur components in the recovery process allowing the application of sulphur-free soda lye in the bleaching process, significant reduction of bad smell by prevention of hydrogen sulfide (H_2S) emission. These advantages of the ASAM process have been developed and demonstrated by

[38] In hindsight, this was a fortunate decision. Even if the corrosion problem eventually could have been solved with very expensive construction material, the regeneration temperature for aluminium oxide is at a level that generates the highest amounts of chlorinated dioxins, as is known today.

R&D efforts lasting around a decade from 1985 to 1994. Its disadvantages result primarily from the complicated multi-step recovery process of chemicals implying additional investment costs. Furthermore, the cooking process requires high pressure (11-14 bar), and water recycling cannot be realised completely because water flows containing heavy metals such as manganese destroy hydrogen peroxide applied in bleaching and therefore have to be channelled separately to the wastewater treatment plant. The ASAM process, unlike the kraft process and like the sulfite process, is well suited for dissolving pulp, which is a minor market segment, however, compared to paper grade pulp.

At present, a simpler recovery process based on modern pyrolysis techniques is just tested in a pilot plant in the USA. This technology may allow a shorter bleaching sequence with a better chance of complete water recycling. These experiments being successful, the chance of the ASAM process to be introduced on an industrial scale will grow once more. Besides other reasons described below, the failure of corresponding efforts in the past is due to parallel considerable improvements of the dominant kraft process which made it environmentally more friendly than in the past, as indicated by the approval of the change to the modified kraft process in the Blankenstein pulp mill. By comparison, other alternative pulping processes such as Organocell, Formacell, or Milox currently have no real chance of market penetration (Jaakko Pöyry 1997).

The history of the ASAM process can be summarized as follows. Between 1985 and 1989 the concept was developed, discussed and tested on a laboratory scale at Hamburg university, largely funded by the BMFT via DLR with 440.000 Euro. From 1989 through 1994 the ASAM process was studied in a pilot plant at Baienfurt consisting of a cooking and chlorine free bleaching departments and methanol recovery facilities. This project was funded mainly by Kraftanlagen Heidelberg, a subsidiary of Agiv, with 9,5 million Euro, and by public grants of about 3,8 million Euro, with 3,3 million Euro provided by the BMFT via DLR again. From 1994 through 1996 some further variations of the ASAM process were studied, and in 1999 the pilot plant was shut down, incidentally in parallel with the closure of the small Baienfurt pulp mill. Finally, having demonstrated its technical viability and even partial superiority several attempts have been made since 1994 to introduce the ASAM process on an industrial scale by attracting interest of major investors in market introduction of this new pulping technology, which all failed, however, for reasons indicated below.

When the favourable results of the R&D project developing the ASAM process at the university of Hamburg were disseminated among and positively perceived by interested actors, plans to build a pilot plant with a capacity of 5 tons per day at Baienfurt to develop the ASAM process further to the point of series production assumed definite form. The Feldmühle AG owning the Baienfurt pulp and cardboard factory showed interest in the new pulping process, and therefore was ready to rent out old buildings for installing the pilot plant and to provide the necessary infrastructure such as water supply, electricity and steam. Kraftanlagen Heidelberg was willing to construct the pilot plant hoping to benefit from this development process by future construction and sale of large-scale pulp mills, and selected someone who had just finished his dissertation on the ASAM process at the institute for wood technology, Hamburg university, to manage the pilot plant. The scientists of this university institute had a genuine interest in seeing their concept further developed towards market introduction. The BMFT granted the considerable amount of 3.3 million Euro in order to provide sufficient incentive to develop the ASAM process to the point of series production from 1988 through 1991[39], whereas DLR was in charge of supervising project development.[40] Some additional funding came from the EU Commission for a joint R&D project with Italian researchers addressing the use of low-grade wood qualities. The BMU as well as the department of environment of the state Baden-Württemberg were informed of the project that was likely provide technological capability to further reduce wastewater contamination by pulp mills.

The pilot plant was established in 1989 and managed independently from the neighbouring pulp and cardboard factory. The subsequent systematic investigations and development processes showed the successful results, partly listed above. The major problems to be solved in the early 1990s were the appropriate separation of a water flow containing heavy metals from the water flow conducted in a closed cycle, mentioned above, and the trouble-free integration of the TCF bleach plant, developed by the company Austrian Energy & Environment, in the ASAM process, where the main task consisted in bringing together many individual steps into a harmonious overall process.[41] Finally, some concern arose from the use of the chelating agent EDTA needed in P-bleaching, because the alternative option of acid extraction interrupts the alkaline water cycle and thus made closure of the water cycle more complex. Altogether around 25 people were continuously involved in the project, with around 17 being engaged in actual plant operation, 3 to 5 doing related research at Hamburg university, and 3 from Kraftanlagen Heidelberg dealing with planning, sales and marketing.

After the industrial feasibility of the ASAM processing technology had been demonstrated in 1993 the continued operation or - without corresponding personnel after 1996 - at least the availability of the pilot plant provided the reference needed in the attempts of building a corresponding pulp mill on an industrial scale producing at least 200.000 tons of pulp per year, although this required further expenditures of ca. 1,5 million Euro. In 1999 there was no reason anymore to keep the pilot plant ready for further experiments with the ASAM process. At the same time, the Swedish pulp producer Stora, which had bought up the pulp and paper plants of the Feldmühle AG in 1991, shut down the pulp mill at Baienfurt because its relatively small size made it not profitable any longer.

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[39] The duration of the project was subsequently extended till 1993.

[40] In addition, in 1989 the BMFT provided further funds of 270.000 Euro to the institute for wood technology to produce pulp from annual plants via the ASAM process in an R&D project, ultimately lasting 4 years.

[41] Chemicals recovery, successfully tested by Austrian Energy & Environment in a small pilot plant at Graz, adding a liquor burning boiler, a conversion system including a causticization installation, and lime recovery to the existing evaporation facility with methanol recovery, failed because real loop closure could not be achieved.

Whereas the overall development of the ASAM process led to favourable technological results, that was not the case on the investment side. Various corporations were approached by the managers of the pilot plant and by the owners of the Asam Technologie GmbH newly funded in 1994 because these corporations were interested in and capable of building a first pulp mill on an industrial scale based on the ASAM process. However, either they were not willing to take the financial risk of introducing a new pulping technology on the highly competitive pulp market or they suffered huge losses elsewhere in their business. Thus, the diffusion story of a rather far-reaching environmental innovation up till now exhibits a pattern of repeated withdrawals of diverse companies seriously considering market introduction of the ASAM process.

1. The Feldmühle AG considered in 1990 to build a new pulp mill at Wittenberge in the former GDR, possibly utilizing the ASAM process. Since Stora in 1991, however, which owned primarily pulp mills based on the kraft process, bought up the company this option was not pursued further.
2. Around 1992/93 the option to convert an existing pulp mill in Canada based on sodium sulfite and owned by Stora, which suited well the purpose to change to the ASAM process, was seriously envisaged as a joint venture of Stora and Kraftanlagen Heidelberg. Each company should invest approximately 75 million US$ to cover the costs of the conversion. As Kraftanlagen Heidelberg realised, however, that it would have to advance more than 50 million Euro, but would receive orders of only 2,5 to 5 million Euro itself and would have to subcontract most of the construction orders because it had no corresponding production facilities, it was no longer willing to take this financial risk.
3. Having realised its limited benefits obtainable from the ASAM process and experiencing declining profits, Kraftanlagen Heidelberg in 1994 sold the pilot plant and the ASAM technology to the Austrian companies Voest-Alpine and Austrian Energy & Environment, that had developed a recovery technology already. In the then newly founded Asam Technologie GmbH, operating the pilot plant, Kraftanlagen Heidelberg remained a silent partner with a 15% share, whereas Voest-Alpine possessed 51% and Austrian Energy & Environment 34%. However, being involved in various pulp and paper production activities, both companies developed no subsequent action program to look for an industrial scale application of the ASAM process. Furthermore, in 1995 Voest-Alpine sold its pulp division to the US-American company Ingersoll-Rand, where it became incorporated as Impco-Voest-Alpine in its pulping division Impco. Again, the new owners wanted first to evaluate the perspectives of the ASAM process before taking any investment decisions.
4. In 1994/95 the modification of the pulp mill at Kelheim, which had gone bankrupt in 1993, as described below, in order to establish the ASAM process on an industrial scale was seriously discussed. The interested investor Landecker, owning large pulp mills and plants producing pulp and paper-making machines in the USA, was willing to contribute 15 million Euro, if the Bavarian state government would provide another 50 million Euro initially indicated in view of the anyhow upcoming decommissioning costs. After the disappointing experiences with the new pulping

process Organocell there existed understandable reservations, in general, to heavily invest in another new pulping process still unproven on an industrial scale, too. So, when the Bavarian state government after having postponed this decision finally offered only around one quarter of the subsidies envisaged first, and parallel attempts to reanimate the Organocell process at Kelheim continued, being initiated by the trustee in bankruptcy, these potential investors withdrew, and Landecker invested in different industries in North America.

5. In 1996 the US-American corporation Beloit, in particular producing papermaking machines, bought Impco from Ingersoll-Rand. This was connected with a renewed willingness to consider new projects seriously. However, with decreasing pulp prices the economic basis was no longer given for an investment of 30 million $ envisaged to introduce the ASAM process at the pulp factory Longview Fibers in the USA.
6. In 1996-98 the Swedish pulp and paper producer SCA (Svenska Cellulosa), which had bought up PWA and thereby the pulp and paper mill at Stockstadt in 1991 and which was strategically approached by Asam Technologie GmbH because it owned 3 sulfite pulp mills and only 1 kraft pulp mill, was considering to change the pulp mill at Stockstadt towards the ASAM process in combination with a new recovery technology based on pyrolysis. SCA was prepared to invest 150 million Euro into this modified plant producing 500 tons pulp daily[42]; however, Beloit as the supplier of the new machinery had to bear the risk. Corresponding insurance concepts were already negotiated with the big insurance company Allianz. In order to get all the patents concerning the ASAM process Beloit purchased the 34% share in ASAM Technologie GmbH from Austrian Energy & Environment in early 1998. Asam Technologie GmbH would have to care for basic engineering tasks in this industrial-scale project. Finally, it was not realised, however, because Beloit made extreme losses in its export of papermaking machines to Asia, and was therefore no longer able to take the financial risk required by SCA.
7. As mentioned above, the South African pulp and paper producer Sappi (South African pulp and paper industries) since 1999 has been investigating a recovery technology based on pyrolysis on an industrial scale. In case of successful results the test of the ASAM process on an industrial scale might well still occur in a not to distant future.

The reason for the failure of market introduction of the ASAM process can be seen in a combination of the following factors. The relevant innovation promoters cared for successful technological development and economic market analysis, but were not sufficiently aware of the problem related to the risk capital needed for market introduction. In view of the failure of the Organocell process potent investors have been hesitant to be first on the market with a new pulping technology if their return on investment cannot be expected within five years or so. Because of considerable (environmental) improvements of the (modified) kraft process the ASAM process may

[42] As a further step, SCA even thought of building a completely new pulp mill for 550 million Euro with an even higher production capacity of 800 tons per day.

well claim to possess technical and economic qualities equal but not clearly superior to it. Therefore it appears reasonable for a pulp producer to rely on well known and proven processes and installations when a new pulp mill is built just every few years on the world, especially on a highly competitive pulp market with fluctuating prices and not unusual bankruptcies.[43] Furthermore the major patents of the ASAM process are meanwhile owned by US American companies, whereas Scandinavian companies typically offer cheaper construction of pulp mills than these American corporations. Consequently, the latter ones are less interested in introducing the ASAM process because they do not have these patents, so that it appears economically unfavourable to build a pulp mill based on the ASAM process in Europe.

To sum up, against the background of rising environmental concern about and regulation of pulp production two quite independent environmental innovations were developed and tested in different plants of the pulp and cardboard factory at Baienfurt close to lake Konstanz in the late 1970s, and in the late 1980s and early 1990s. Both received considerable support by public funding. The first innovation to absorb ligneous compounds by aluminium oxide failed for technical reasons (corrosion of the recovery plant), and was therefore abandoned. The second comparatively comprehensive innovation, the ASAM process, proved to be technically viable but failed up to the present to be introduced on an industrial scale for various situational economic reasons. After its successful development in a pilot plant further improvements concerning recovery technology and bleaching processes were developed via cooperation of the key university institute which first developed the ASAM process and private pulp-related (machine producing) corporations without public funding anymore.

3.3 Kelheim

As in Baienfurt, two (or even three) different pulp-related R&D projects tried to implement the environmental technologies developed in the pulp mill at Kelheim. The first one concerns bleaching of sulfite pulp by means of oxygen and intensified chlorine dioxide treatment to eliminate use of chlorine, and the improvement of the existing thermal wastewater treatment plant, evaporating and burning cooking and bleaching effluents, to reduce specific wastewater volume and COD level, successfully carried out by the Papierwerke Waldhof-Aschaffenburg AG (PWA) from around 1977 to 1984 though without continuation of this specific bleaching arrangement when German pulp mills changed to TCF bleaching in 1990/91, as described above. The second one concerns the development and upscaling to an industrial level of the Organocell process as an alternative pulping process based on methanol and caustic soda, which was developed by the company Organocell and other (sub-) subsidiaries of the MD-Verwaltungsgesellschaft from 1977 through 1993. The Organocell process failed at the

[43] Typically, the process to convince other people of the advantages of the ASAM process, so that they are prepared to decide in favour of corresponding investments, seems to be harder within a (large) corporation, where they immediately tend to ask after the profits to be gained, than in external debate.

operational level for various reasons leading to bankruptcy of the associated company Organocell in 1993. Afterwards some negotiations took place around 1994/95 to modify the still existing Kelheim pulp mill for introducing the ASAM process on an industrial scale there, but led to no positive result, as described in the previous section.

3.3.1 High pressure oxygen bleaching

Induced by the request of the Bavarian environmental authorities in 1976 to present concepts and plans to improve wastewater quality of the Kelheim pulp mill, located at the Danube river, the PWA and its subsidiary, the Bayerische Zellstoff AG operating this pulp mill, established an environmental protection project designed to better catch cooking liquor and to eliminate of C-bleaching. The introduction of high pressure O-bleaching of sulfite pulp based on magnesium oxide (MgO) was first tested in laboratory experiments in 1977/78, in close collaboration with a professor from Trondheim, Norway, who owned a crucial patent mentioned below, a planning and consulting institute at Aschaffenburg and the research unit of SCA in Sweden. Oxygen bleaching under high pressure was selected because it had been already developed for kraft pulping by Sappi and corresponding experiences already existed in 6 kraft mills in 1977, because the yet untested application of MgO appeared to be feasible, too, according to a patent in Norway, because Z-bleaching was not yet tested in practice, and because P-bleaching appeared to be too expensive and to lead to problems in producing dissolving pulp.

Afterwards cooking and bleaching plants of the pulp mill in particular were strongly modified, what required corresponding comparatively rapid (informal and formal) approval procedures from 1978 through 1981. Because of delays in construction work and delivery dates O-bleaching started in 1981 only and was investigated further until 1984 with successful results, in principle, though bleaching costs increased by at least 15 Euro per ton pulp and pulp properties tended to show a slightly reduced brightness level, a lower viscosity range, increased hydrolytical degradation accompanied by reduced delignification, which in turn called for intensified D-bleaching (Partbauer et al. 1984). Considerable manpower of the Bayerische Zellstoff AG, PWA and external (supply) companies went into the environmental protection project. Total project costs (between 1977 and 1983/84), including additional personnel training, amounted to 26 million Euro, with 19,5 million Euro (75%) attributed to the R&D project on O-bleaching and 8 million Euro provided by the BMFT via PTWT. In view of the considerably large additional bleaching costs outside the Kelheim pulp mill the high pressure O-bleaching technique was not used for sulfite pulp production and thus experienced no diffusion at all. It is common practice now in kraft pulp production under lower pressure and with medium consistency using high shear mixers for oxygen addition.

In view of lacking profitability of the Kelheim pulp mill producing dissolving grade market pulps its owner PWA intended to close down it a few years later. Finally, the Bayerische Zellstoff AG was taken over by the Organocell GmbH in 1988, which reconstructed the pulp mill facilities in order to introduce the Organocell process at an industrial level.

3.3.2 Development of the Organocell process

The basic idea of the Organocell process is to cook and delignify wood by organic solvents and thereby to avoid sulphur and chlorine use in pulp production, to economically produce the pulp quality required for modern paper production in smaller plants with higher productivity, and to produce marketable lignin as a by-product of the pulping process (DLR 1990, 1991, Dahlmann/Thiel 1989, Edel 1989, Jaakko Pöyry 1997). In its original concept a two-stage alkaline pulping process of methanol-water extraction and soda-anthraquinone (AQ) cooking was applied.[44] Concerning machinery equipment and chemical reactions, the Organocell process resembles the kraft process, however, substituting sulphur by methanol to separate lignin. The other characteristics are not necessarily connected with the Organocell process, because it can be realised by evaporating and burning lignin in the conventional way, too, and because its pulp also tends to require several bleaching stages and TCF bleaching cannot be applied as easily as after the sulfite process. Thus, the main machinery represents conventional technology except for methanol handling in the evaporation and cooking, and even these systems are in use elsewhere in the chemical industry, and the recovery boiler, which again represents old sulfite technology of liquor burning. In principle, the Organocell process can supply dissolving, fluff and paper grade pulp. The advantages of the Organocell process refer to the applicability to different sorts of wood, the potential use of extracted (sulphur-free) lignin, the non-use of sulphur because of its environmental impacts, and the eventually achievable high quality of pulp produced. In practice, however, neither the attempts to extract and market lignin (cf. Wittner 1988, Jaakko Pöyry 1997:106) nor the efforts to produce paper grade pulp of the aspired quality proved to be successful. The difficulties of the Organocell process relate to its considerable engineering problems with upscaling, particularly the achievability of high quality paper grade pulp, the rather high volumes of water and soda required complicating their recycling and recovery, the many bleaching stages required for TCF bleaching, the high pressure required for the digester (above 13 bar), and to its doubtful economic profitability.

The story of the Organocell process can be described as follows. During the mid 1970s the ecologically oriented co-owner Nicolaus of the MD-Papierfabriken at Dachau, near Munich, interpreted the first oil crisis as a sign of future scarcity of raw materials, including pulp, listened to a presentation of Kleinert, the inventor of the environmentally friendly Kleinert process to produce pulp using aqueous alcohols and afterwards checked the feasibility of the technique on site in Canada. For these reasons he prepared a project proposal intended to enable his paper mill to supply its own pulp. This could not be achieved economically by conventional pulping processes because

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[44] This two-stage process was replaced by a one-stage AQ cooking with methanol as an additional solvent in the Kelheim pulp mill for (doubtful) economic reasons.

of the necessary production volumes required, which were beyond the scope of comparatively small-scale paper producers such as MD-Papierfabriken.[45] The pilot project was funded by the BMFT via DLR contributing 50% of project costs in 1977 through 1980, as were the subsequent upscaling projects in the pilot plant in 1981 through 1983, and by building a demonstration plant in 1984 through 1989, summing up to altogether more than 10 million Euro of R&D grants, including two projects at both Munich universities addressing lignin extraction and utilization. In addition, the EU Commission granted close to another 500.000 Euro for two other projects concerning lignin utilization, too. ETP was quite optimistic and therefore keen to support development of the Organocell process because a small paper factory with a turnover of around 150 million Euro was willing to undertake considerable investments, and because the professional statements and, later on, advertising campaigns of its proponents sounded very favourable, although they could hardly be assessed thoroughly by BMFT officials.

The first R&D project with a size of 2,15 million Euro developing the Organocell process in a newly built pilot plant, costing 0,8 million Euro, was done in cooperation with an external engineering consultant. It took more than one year until the pilot plant was built in Pasing/Munich in 1978, operated by the MD-Papierfabriken Dachau, a partial subsidiary of the MD-Verwaltungsgesellschaft, which was bought up by Burda partly (28%) in the mid 1970s and completely (100%) in the mid 1980s.[46] Because the pilot plant did not work well, it was modified, where a new pump ordered could be delivered after 6 months only. Whereas the external consulting engineer wanted to test three differing pulping techniques, the project leader of MD-Papierfabriken focused on the Organocell process. In turn, this R&D cooperation was finished. Trials with pulping processes based solely on ethanol or on a one-stage acid ethanol cooking process following the Kleinert process proved to be technically unviable. After one year of unsuccessful experimenting the idea of a two-stage pulping process consisting of an acid and an alkaline part, patented in 1982, offered a possible solution in 1980.

In the second R&D project with a size of 1,55 million Euro a break-through was realised so that pulp of good sulfite quality could be produced for the first time though on the laboratory scale only, whereas the experiments to optimise the pilot plant involving about 5 persons were continued. Whereas the ordinary paper producing staff remained sceptical on the Organocell process, the development team was optimistic about its further development and - with the project leader belonging to the works council at the same time - convinced Nicolaus as co-owner of MD-Papierfabriken to decide in favour of further investment in a demonstration plant. For this purpose the Organocell GmbH was founded in 1984, as a 74% subsidiary of the Technocell AG and a 26% subsidiary of the MD-Papierfabriken, both being at that time themselves 51% or 75% subsidiaries of the MD-Verwaltungsgesellschaft.

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45 Interestingly, Jaakko Pöyry (1997) in their comparative assessment of different pulping processes came to the conclusion that a pulp mill based on the Organocell process has to have a production capacity at least as large as conventional ones.

46 The MD-Verwaltungsgesellschaft also owns 75% of MD-Papierfabriken.

This demonstration plant was built and tested as a small-scale pulp mill with a pulp production capacity of 5 tons per day between 1984 and 1989.[47] Its costs came to about 16 million Euro, again with 50% being co-funded by the BMFT via DLR in two projects, lasting from 1984 to 1987, and from 1987 to 1989. About 30 people were involved in operating the plant. Now full-scale pulp production had to be tested in order to prove the viability of the Organocell process, where pulping and recovery processes (particularly of soda[48] and methanol) had to be harmonized. Furthermore the separation and reprocessing of accumulating lignin had to be developed, which was mainly done by PhD and diploma students at different universities.[49] Related efforts to find a market for lignin, be it chemical, fertilizer, pharmaceutical, even cigarette industry, or feed producers, indicated considerable market potentials, led to actual contacts with prospective customers, but ultimately failed to open the door to substantial sales because of excessively high prices of the reprocessed lignin envisaged. The demonstration plant was completed in 1985. Extensive experiments were made with both the one-stage and the two-stage cooking process. The bleaching process, substituting chlorine by oxygen and chlorine dioxide as bleaching agents, was limited to three stages resulting in a brightness of only 85%. The demonstration plant met quite some operational problems such as clogged tubings, corroded membranes or deficient flap-valves, common for new technical plants, and had to be largely reengineered. Also the quality of the pulp produced varied. It was difficult to continuously operate the demonstration plant for longer periods of several days. Only from 1988 onward it could be operated continuously in three shifts. Nevertheless, the experiments demonstrated in 1987/88 that the Organocell process was technically feasible and able to produce pulp of acceptable quality, even though its upscaling to an industrial scale would involve considerable further development efforts.[50]

With promising R&D results of the demonstration plant in mind, the Organocell GmbH and its parent companies negotiated with PWA in 1987 to buy the Bayerische Zellstoff AG operating the pulp mill at Kelheim. This was a favourable option to pursue because this pulp mill produced different types of pulp, because its staff could be taken over, because relevant infrastructural supply was already provided, because it was not too far from Munich, because the Organocell GmbH had to be the first on the market in order to significantly benefit from its development of the Organocell process, and because the Bavarian government was willing to subsidize the necessary reconstructions with up to 50 million Euro in view of the diverse negative economic and social impacts of closing the Kelheim pulp mill, as intended by PWA. In 1988 the Organocell GmbH took over the Bayerische Zellstoff AG, backed by considerable

[47] The decision in favour of such a smaller plant largely resulted from the possibility to build it in the Pasing factory again, whereas the alternative option to build a 40-ton-per-day plant would have imposed the need to change to another location.

[48] In fact, soda was never recycled by causticization in the demonstration plant.

[49] A further dissertation at Graz university studied the usefulness of hemicelluloses.

[50] No external partners were actively involved in this development process because corresponding attempts were made only rarely and offers to support development were even turned down, because one was afraid to give away internal know-how or potential candidates expected a return on their investments already after few years.

financial support of 7 million Euro, and founded, together with Thyssen Rheinstahl Technik, a subsidiary of Thyssen, the Organocell Thyssen GmbH, with each party bringing in 50% of the capital stock. The Organocell Thyssen GmbH had the task to plan, erect and operate Organocell plants, i.e. in Kelheim.

The reconstruction of the Kelheim pulp mill on the basis of the Organocell process was planned and approved from 1988 through 1990 and carried out from 1990 through 1992.[51] During that period there were significant technical and personal changes, which decisively contributed to the later failure of the Kelheim pulp mill, its reasons being explained subsequently.

1. The new managers, coming from the side of Thyssen or hired subsequently, adhered to a somewhat different perspective of technology implementation than the development team at Pasing, favoured sophisticated information technology equipments, but had limited technical competence of genuine pulp processing technology. This led to differences in the approach and design of the Kelheim plant within the planning process and to its inferior design, in the end.
2. Their planning attitudes tended to increase costs because the newly founded company Organocell Thyssen GmbH could add 10% to the reconstruction costs as planning expenditures, and because they were sometimes not aware of inexpensive suppliers of equipment because of their limited know-how in the field. Consequently, the projected costs rose from 75 million Euro, calculated by the project managers at Pasing in 1987, to be spent mainly the for the cooking plant and the recovery boiler which had to be purchased, over 125 million Euro total costs in official estimates in 1988/89, as opposed to internal estimates of 175 million Euro, to 325 million Euro in the end. When the Organocell GmbH declared itself bankrupt in 1993, the corresponding liabilities amounted to 355 million Euro. Whereas the Technocell AG invested 60 million Euro, the banking consortium associated with the Kelheim project finally provided credits over 290 million Euro.[52]
3. Beyond these economic considerations just presented, personal interests in gaining income from patents may well have contributed to the change from the originally planned and tested two-stage cooking process back to a one-stage cooking process in the Kelheim plant. The managing director of the Technocell AG, one managing director of both the Organocell GmbH and the Organocell Thyssen GmbH, being a former patent attorney of the Technocell AG and a friend of the former one, and one chemist hired by him took out a patent for this modified one-stage cooking process, whereas the managing director of both the Organocell GmbH and the Bayerische Zellstoff GmbH as the technically competent project leader of the demonstration plant held the patent for the two-stage cooking process.

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[51] Particularly during this period of time considerable marketing efforts were made to convince credit grantors and a sceptical pulp community of the advantages of the Organocell process and to raise sufficient investment capital for modifying and operating the Kelheim pulp mill correspondingly. This led to an overselling of the technical, economic and ecological quality features of the Pasing demonstration plant and, later, of the Kelheim pulp mill, and to unfair criticism of the environmental performance of existing sulfite pulp mills.

[52] For this reason the subsidies provided by the Bavarian state government remained limited. And for a plant on an industrial scale the BMFT was not permitted to supply additional grants.

Although the viability of this latter process on an industrial scale would still have to be demonstrated, the one-stage cooking process - at least without a further acid washing process unfortunately, however, leading to problems of materials corrosion - clearly could not deal with manganese stemming from pine wood destroying peroxide applied in bleaching. And experiments in the pilot plant in 1983 had already indicated that the one-stage cooking process was only capable to produce acceptable fluff pulp, but not adequate paper grade pulp. In any case, the change in the technical design of the Organocell process when upscaling it to an industrial level for the first time necessarily implied a high additional risk of failure because upscaling from a demonstration plant to an industrial plant typically already leads to considerable adaptation problems without such alterations.[53]

4. These discrepancies in perspective and interest led to discord and also intrigues between the managing directors. Their results were that the crucial figure, the managing director of the Technocell AG, was no longer open to technical warnings and criticism, or a neutral expertise voiced or suggested by the project leaders of the Pasing demonstration plant. Furthermore, these latter one lost their authorities in the Kelheim mill reconstruction project and left the corporation in 1989 and 1990, respectively; in addition the expertise of the staff at Pasing acquired by 10 years of development work deliberately was not brought in into the Kelheim project. Finally, a later law suit on patent compensation lasting for three years was won by the former project leader and managing director, but could not be realised by him because of the bankruptcy situation.
5. Apart from changes in the technical design the Kelheim pulp mill was bothered by mechanical faults, exceptional machinery, and sloppy design of piping in no way related to the process-specific features, leading to frequent shut downs with production losses of 70% during the first year of its operation. The fluff pulp produced was suitable for hygienic products, but the paper grade pulp was plagued by the results of unstable operation and low strength. Discrepancies between the already existing facilities and the for economic reasons enlarged nominal pulp production capacity from 110.000 to 150.000 tons per year[54] resulted in serious misfits between different installation components, including insufficient power supply.
6. The digester supplied by the company Kamyr, the world market leader of kraft process cooking and bleaching plants, was not designed appropriately mainly because of insufficient supply of technical data from the Pasing demonstration plant, leading to disruptions and break-downs during operation of the Kelheim pulp mill.
7. Chemicals recovery in the recovery boiler met many difficulties, for instance broken pipes, ash accumulation, drum level control, superheater drains, or the green liquor system, which were again largely due to inappropriate design specifications already leading to various modifications of the recovery boiler by the package supplier

[53] Significantly, the expert opinion commissioned by the credit granting banks after bankruptcy of the Kelheim mill clearly stated that the main reason for the bankruptcy was not the Organocell process, but the inferior design of the mill.

[54] Nature and monument protection activists lobbied for a limitation to 90.000 tons per year in order to keep the size of the pulp mill small enough to avoid disturbance of the view onto the Danube river.

Steinmüller who provided the whole recovery system and guaranteed its reliable operation.

8. Depressed pulp prices of 350 Euro per ton[55] did not allow the Bayerische Zellstoff AG, operating the Kelheim pulp mill, to cover its production costs even if the mill had reached full capacity and optimal performance, whereas the Organocell Thyssen GmbH assumed to be able to sell high quality dissolving pulp for 600 Euro per ton, which the pulping process applied, however, did not yield.

In 1992 the reconstructed pulp mill at Kelheim started test operation, but had to be shut down again already in 1993 for economic reasons resulting particularly from many unexpected standstills, leading to bankruptcy of the Bayerische Zellstoff AG, and in turn of their parent and holding companies, the Organocell GmbH and the Technocell GmbH. Reinforced by the critical expert opinions taken to assess the reasons of this failure, the Burda group owing the MD-Verwaltungsgesellschaft was not prepared to invest about another 50 million Euro, required to cover the losses conceivable for the next two years, and the necessary technical rearrangements.

From 1993 to 1996, in the aftermath of the shut down of the Kelheim mill, the credit granting banks commissioned experts to evaluate its failure reasons and the economic prospects of its further operation, and insisted on the liability of the Technocell GmbH beyond the limited liability of the Bayerische Zellstoff AG of only 45 million Euro in order to minimise their losses. Accompanied by considerable controversial debate, quite some efforts were made by various actors concerned, well beyond the trustee in bankruptcy, the (largely communal) Donaupark GmbH, to find new investors and operators for the Kelheim mill: either to adjust the Organocell process by selling reprocessed lignin, too, or to introduce the ASAM process, or to sell machinery equipment to Indonesia,[56] or finally to sell the pulp mill in 1996 for dismantling it. Because the latter operation would cost still more than 50 million Euro and the Bavarian state government or local municipalities have been unwilling to provide considerable subsidies for this purpose, dismantling has been only partly performed up to the present.[57]

To sum up: the environmental technologies introduced in the Kelheim pulp mill did not survive on the market in spite of their technical viability, in principle.

High pressure oxygen bleaching was too costly and not applied elsewhere for sulfite pulp.

Based on the conviction and engagement of the former owner of the MD-Papierfabriken and the responsible project director, the Organocell process could be successfully developed in Pasing/Munich within about a decade though with still diverging

[55] Pulp prices are primarily fixed in US $ on the world market. Thus, in 1993 already a low $/DM exchange rate led to low pulp prices in Germany.

[56] The Swiss project management company already involved in the insolvency process and commissioned to do so proved to be unable to pay the 11 million Euro agreed upon for the sale.

[57] Meanwhile considerable waste residues from 110 years of pulp production have been detected in the ground, and about 17 million Euro, mainly provided by the Bavarian state government, have been spent for corresponding waste management efforts until late 2000. From 2001 onward the Donaupark GmbH intends to take possession of the site for free and to make it an industrial district.

assessments of its technical and economic viability. Corresponding professional debate was at least partly missing in this respect. Neither parallel advancements in sulfite and kraft pulping solving the problem of unwanted sulphur emission nor trade-offs between pulp bleaching requirements and abstention from acid washing, demanding sulphur of chlorine compounds, were seriously taken into account.

The Organocell process failed on the industrial scale, the reasons being organisational mismanagement and severe personal conflicts, the associated non-utilization of competence and experience available from the preceding R&D projects, the change in the cooking process and inferior design of the plant, frequent shut downs because of various significant technical operation problems leading to extremely poor financial performance, insufficient development of and investments in marketable lignin by-products, drastic price decrease of pulp, and the unwillingness of potential investors to make the necessary additional investments in order to improve effective capacity and pulp quality of the Kelheim pulp mill, because of obvious risks concerning their not only short term but even long term profitability.

3.4 Other environmental R&D projects in Germany

In order to contextualize and to put into perspective the case studies on environmental innovations in pulp production presented in the previous sections, other environmental R&D projects and the role of public funding as well as the overall features of pulp-related attempts towards environmental innovation in Germany are summarized in this section, whereas the subsequent one gives an overview of related efforts outside Germany.

The overall picture of environmental R&D projects can be described as one where quite diverse concepts were developed and tested in (university) research laboratories, in pilot plants and in pulp mills by separate as well as by joint projects of academic and industrial R&D groups, which received (partial) public funding in the late 1970s and 1980s mainly from the BMFT, but also from state ministries. Interestingly, the R&D projects addressed to varying degrees all relevant dimensions of an ecologically sound pulp production process in the 1970s already, i.e. wastewater treatment by various purification techniques, substitution of chlorine bleaching, development of new (chemical) cooking and delignification processes, and closing pulp processing cycles by chemicals and energy recovery systems as well as minimising wastewater effluents and external energy inputs. Further environmental impacts of (sulfite) pulp production such as wood handling, atmospheric emissions or noise have been dealt with more routinely in order to successively reduce them.[58]

Frequently, these projects were initiated because of environmental problem pressure perceived and accepted as significant, in combination with the possibility to thereby

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[58] Environmental improvements of (energy-intensive) mechanical pulping and chemi-mechanical pulping, recovered paper processing, papermaking and related processes are not dealt with in this study, and environmental improvements of the kraft (sulphate) pulping process were mainly developed outside Germany for reasons already indicated and summarized in the subsequent section.

reduce wastewater levies according to the AbwAG. Indeed, nearly all pulp mills received some public funding for environment-related R&D projects,[59] which are not listed here completely (see cf. DLR 1990, 1991, 1996, Kernforschungszentrum Karlsruhe 1990). Few of these projects resulted in economically viable technologies, and even they were not taken over by other pulp mills until required to fulfill certain environmental (emission) standards by corresponding environmental regulation. Examples of technical innovations not successful on the market are ozone bleaching in the sulfite process (small scale experiments at Stockstadt), high pressure oxygen bleaching (Kelheim)[60], chemicals recovery by pyrolysis (Ehingen), wastewater treatment by aluminium oxide (Baienfurt), and the newly developed ASAM, Formacell, or Organocell pulping processes.

As described by Jaakko Pöyry (1997) the Formacell process, being a further development of the Acetocell process after 1992, still is in a rather initial development phase. The latter process has only been tested in a pilot plant in Gschwend near Stuttgart 1989-93, but not yet at the level of a demonstration plant. Supported by some public funding, the continuous development efforts, pursued since about 1984 by Nimz and collaborators at the BFH in Hamburg as the pioneers of the Formacell process, resulted in the technical design of a corresponding demonstration plant in 1994/95. However, no investor was found, and the Veba Oel AG, which in 1991 completely took over the Acetocell GmbH, operating the pilot plant, terminated its marketing efforts of the Acetocell process in 1995. In principle at least, the Formacell process, which uses acetic acid and formic acid as dissolving agents, and ozone in acetic acid and - for higher degrees of brightness - peracetic acid in butyl acetate within the bleaching process and produces paper grade pulp as well as dissolving pulp, can be performed in a completely closed system with a chemicals recovery process differing from conventional techniques, and without wastewater, and could thus lead to a radical change in processing techniques and the technology of pulp production. At present, however, there exist no chances to introduce this new pulping technology in the market, as the problems of its practical application at the large-scale level appear to be enormous and the pulp and paper industry showed and shows no interest in the Formacell process.

Whereas P-bleaching and Z-bleaching for environmental reasons were first developed in Germany in the 1970s, experiments with O-bleaching, more suitable for kraft pulping, were pursued in Sweden first and in South Africa by Sappi. Corresponding projects at Kelheim and Alfeld were co-funded by the BMFT and UBA, respectively, in the 1980s only (Partbauer et al. 1984, Dalpke 1989). Furthermore, in the early 1980s the BMFT funded via PTWT two research projects focusing on Z-bleaching, where trials in a pilot

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[59] Thus, one may notice that closed cycle technologies were already developed in the late 1970s, and that P-bleaching was also tried for ground wood pulp by the paper technology institute in Munich in 1989 to 1991, funded by 160.000 Euro.

[60] This type of bleaching has been developed and patented by Sappi in South Africa in 1970. However, a much less expensive medium consistency low pressure version is current standard in kraft pulping. So its transfer to the sulfite process led to a combined application of oxygen and peroxide as implemented at the Ehingen plant.

plant at Stockstadt were performed in cooperation with the company Mannesmann-Demag, which built the plant producing (quite expensive) ozone. These experiments showed that Z-bleaching requires a special technology and can be successfully applied under specific conditions (Patt/Wang 1981, Patt 1984).

Within this ETP context UBA focussed - in accordance with the BMU - its funding on specific development and demonstration projects at Alfeld and Ehingen in the 1980s in order to clearly demonstrate the technical feasibility of certain bleaching and waste treatment technologies. As a consequence, German pulp mills changed to TCF bleaching in 1990/91 (Mannheim, already in 1989, Alfeld, Ehingen, Stockstadt, Baienfurt, and, later, Kelheim) or were shut down (Bonafort, Karlsruhe-Maxau, pulp mills of the former GDR).[61]

Within the long-term, since 1982 ongoing corporate project "pollution-free factory" of the Hannoversche Papierfabriken AG, operating the integrated pulp and paper mill at Alfeld, which mainly aimed at wastewater treatment, utilisation of (wood) residues, chemicals recovery, and ECF bleaching, after continuous improvements of the digesting, bleaching and wastewater treatment processes in 1986 to 1989 an ECF bleaching sequence EOP - H - P and, since 1990, the even TCF bleaching sequence EOP - P - P could be established in a demonstration bleaching plant.[62] This development project was funded by UBA with 1,25 million Euro (50%) in 1985 to 1988, whereas the other 1,25 million Euro provided by the company were set off against the wastewater levy[63] (Dalpke 1989). Similar to the Ehingen pulp mill, Degussa was the other main participant disposing of the necessary competence on peroxide production and handling. Patents deliberately could not be acquired within this project in order to pass on its experiences at least in German speaking EU countries. Whereas the responsible engineer even received threatening letters from actors opposing ECF and TCF bleaching, when the Alfeld pulp mill introduced (elemental) chlorine-free bleaching in 1986 and 1990, respectively, TCF bleaching of the type developed at Alfeld and Mannheim was quickly introduced in all German pulp mills in 1990/91 for reasons indicated above. Interestingly, it should be denoted once more that the Hannoversche Papierfabriken AG, more than 50% of which had been taken over by the Swedish pulp and paper corporation NCB in the 1970s, bought the Schwäbische Zellstoff AG in Ehingen in 1987 and transformed the mill into an integrated pulp and paper mill by adding a new paper machine. In 1992 Sappi bought 60% of both German mills for a very high price, and in 1993 most of the remaining shares. This example illustrates the strong competition and ongoing concentration process in the pulp and paper industry on a global scale.

With economies of scale compensating gradual price decrease from 900 Euro per ton peroxide in 1980, Degussa as the world's second largest peroxide producer was able to considerably enlarge peroxide sales for pulp bleaching in the 1980s although it had no

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[61] Kelheim and Baienfurt were shut down (for other reasons) in 1993 and 1999.

[62] This project introduced P-bleaching in the pre-bleaching stage, whereas at Ehingen it was introduced initially in the second bleaching stage.

[63] Only under this condition the company was prepared to carry out this development project.

monopoly position in that respect. In the 1990s, however, new competitors and corresponding overcapacities due to large public subsidies available for building (new) industrial plants in the former GDR led to strong price decrease for peroxide (500 and, at the lowest level, even below 300 Euro/t H_2O_2) and the closure of one peroxide production plant by Degussa in the late 1990s. In parallel to the growing international debate on AOX risks, initiated by the respective German debate, Degussa, apart from selling peroxide to pulp producers on the European market, became active in North America since the mid 1980s in order to substitute C-bleaching by combining P-bleaching and D-bleaching for kraft pulp, too, and to convince even US pulp producers to do so. Meanwhile P-bleaching of kraft pulp - as one of several bleaching stages - is rather common in Scandinavia, Canada and Brazil, and meanwhile is also applied or close to be implemented in nearly all pulp mills in the USA.

Thus, after the amendment of the AbwasserVwV annex 19 came into force in 1990 all German pulp mills, if not shut down, quickly changed to TCF bleaching within one year.[64] The instant change to TCF bleaching omitting the intermediate step of ECF bleaching was mainly due to the fact that the new legal requirements on wastewater effluents made it cheaper to introduce new technological installations in pulp mills at once.[65] Other environmental regulations such as the need to supervise chlorine storage according to the ordinance on hazardous substances (*Gefahrstoffverordnung*) supported this change to TCF bleaching, too. Meanwhile, bleaching of sulfite pulp in Germany typically involves only two or even just one stage of combined oxygen and peroxide bleaching (EOP) and/or just peroxide bleaching (P) using NaOH.

Furthermore, the reconstruction and change of the pulp mill of Rosenthal at Blankenstein to the modified kraft process was co-funded by large amounts of public funds available within the reconstruction program of the German government[66] in the 1990s, as outlined above. However, practically no genuine R&D funding was provided by ETP to also develop the modified kraft process,[67] essentially because of its complete lack in West Germany.

Otherwise, public R&D funds clearly diminished to small amounts in the 1990s, after the essential environmental techniques had been developed.[68] Subsequent (ongoing)

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[64] One should bear in mind that this was possible because only sulfite pulp mills existed in Germany and sulfite pulp is much easier to bleach than kraft pulp.

[65] Interestingly, just those key persons of the pulp and paper industry who fiercely opposed (stringent) AOX standards defended them as well as associated TCF bleaching on international symposia since 1990, where for example North American pulp producers lobbied for readmission of C-bleaching in Germany.

[66] This program offered private investors huge public subsidies in case of adjusting existing or building new industrial plants in the states of the former GDR promising future competitive production. These policy efforts to rebuild East German economy led to both quite some successes and a lot of failures of such new plants.

[67] As described in the subsequent section, it was mainly developed in Scandinavian countries during the 1980s and 1990s. However, in collaboration with foreign companies, the main inventor of the ASAM process currently experiments with ozone-free bleaching in the kraft process, using only O-bleaching and P-bleaching.

[68] Already the report on water research funded by the BMBF (Forschungszentrum Karlsruhe 1997) lists no pulp-related R&D projects anymore for the period 1990-96. Nevertheless, some public R&D funds

optimisation processes were funded by the pulp industry itself, although supported by the possibility to thereby reduce its wastewater levy.

For instance, because of the orientation towards (hygienic) tissue products implying somewhat lower demands on fibre brightness a MgO-based bleaching technology could be developed and implemented in the Mannheim sulfite pulp mill between 1986 and 1995. Replacing NaOH by $Mg(OH)_2$ in the first bleaching stage and introducing single-stage bleaching permits closure of the bleach plant and involves further environmental advantages, too (Nimmerfroh et al. 1995). The development costs of ca. 5 million Euro could be covered more or less by thereby reduced wastewater levies.

It appears worth noting that different actors showed differing orientations with respect to the R&D projects they were engaged in: some were strongly convinced of the technical viability and optimisability of their favourite techniques though taking into account relevant economic and political aspects, for instance the leaders of the projects developing the Organocell process or the ASAM process; others were first of all concerned with the economic viability of a process which therefore certainly had to prove its technical feasibility, for instance the leaders of the projects developing peroxide bleaching at Alfeld and at Ehingen; key EP promoters, for instance in UBA, believed in the effectiveness of environmental policy regulations if giving due regard to their technical and economic viability with the help of appropriate technologies.

Because technical and even more practical (social) problems allow always different reasonable solutions, controversy about the (relative) superiority of one or another technical arrangement and process is well justified in most cases (Ravetz 1971). As a consequence, the parallel development and competition of various (environmental) technologies in order to reduce environmental pollution in pulp production could be pursued for good reasons.

The reverse of the medal is the enhanced probability of over-optimistic (false) pretences and insufficient technical expertise of participants in corresponding (scientific) judgements and debates. Examples thereof were the presentation of the ecological advantages of the Organocell process (envisaged) in the Kelheim pulp mill by its representatives in the late 1980s and early 1990s in corresponding business and political circles, or the presentation of high pressure oxygen bleaching, developed at Kelheim after 1980, as a success story much later by scientists evaluating ETP (ECOTEC 1988, Angerer et al. 1997) as well as by the responsible head of PTWT (Kernforschungszentrum Karlsruhe 1990) although this technique was nowhere further used in sulfite pulp mills for obvious economic reasons.[69]

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are still spent, for instance for alternative pulping processes in the 1990s, namely variants of the Formacell process.

[69] This latter example clearly demonstrates the doubtful validity of secondary (case) studies carried out superficially by just one or two (telephone) interviews as well as the precarious reliability of statements by research project management bodies in case of combined information overload and time scarcity!

Summing up, one may well describe pulp-related environmental R&D over the last 25 years as a sequence of projects, where well founded political and public environmental concern, (pending) environmental policy regulations, and extensive public funding induced considerable, parallel and manifold R&D efforts which frequently led to technically viable, but only partly to economically viable results. Nevertheless, together with environmental learning processes in the pulp industry, these R&D projects resulted, especially during the 1980s, in a technological trajectory of ecologically much sounder sulfite pulp processing (energy and chemicals recovery, TCF bleaching, sophisticated waste treatment, integrated production) in Germany than before so that emissions into water and air (COD, AOX, SO_4; SO_2, NO_X) as well as the consumption of chemicals and energy have been drastically reduced per unit of pulp produced, typically by around 90% (Geisenheiner/Drieschmanns 2000). This whole process took place within the frame conditions of fierce competition on the world market, growing demand for paper products, typically strong price cycles for wood, pulp and paper, typically lasting 4 to 8 years, ongoing international economic concentration processes in the pulp and paper industry, and a rising share of recovered waste paper.

Thus, best available techniques for sulfite pulp mills are considered to be (European Commission 2000:v-vi):

– "Dry debarking of wood;
– Increased delignification before the bleach plant by extended or modified cooking;
– Highly efficient brown stock washing and closed cycle brown stock screening;
– Effective spill monitoring containment and recovery system;
– Closure of the bleach plant when sodium based cooking processes are being used;
– TCF bleaching;
– Neutralising of weak liquor before evaporation followed by re-use of most condensate in the process of anaerobic treatment;
– For prevention of unnecessary loading and occasional upsets in the external effluent treatment due to process cooking and recovery liquors and dirty condensates sufficiently large buffer tanks for storage are considered necessary;
– In addition to process-integrated measures and primary treatment biological treatment is considered BAT for sulfite pulp mills."

Table 2 lists them and their environmental impacts in somewhat more detail.

3.5 Environmental R&D in other countries

Although Germany clearly was a front-runner in developing environmental technologies, though essentially limited to sulfite-based pulp production, clearly comparable R&D projects to improve environmental protection were carried out in many other countries as well, however primarily addressing dominant kraft pulping.[70] Many of them were pursued in Scandinavian countries, which have both an internationally important pulp and paper industry and comparatively strict environmental standards and regulations.

70 Lenzing in Austria tested quite some variants in sulfite pulping.

Techniques to consider in the determination of BAT	Effects on the consumption and emission level (cross-media effects)				
	Chemical consumption	Energy consumption	Emission to water	Emission to air	Solid waste
Dry debarking (see kraft)	O	↑ in debarking	↓ COD, ↓ TSS, ↓ flow	O	O
Extended cooking to a low kappa Continuous (a) or batch (b)	↑ in cooking ↓ in bleaching	(↑/↓) in cooking ↑ evaporation	↓ COD	O	O
Oxygen delignification	↑ in O2-stage ↓ in bleaching	↑ in O2-stage ↓ in bleaching	↓ COD	O	O
Closed screening (see kraft)	O	O	↓ COD	O	O
Efficient washing and process control (see kraft)	↓ in bleaching ↓ in cooking	↑ washing (elec.)	↓	O	O
Collection of allmost all spillages (see kraft)	O	↑ evaporation	↓	O	O
TCF bleaching (vs. ECF) (at the same incoming low kappa)	(↑/↓)	(↑/↓)	(↓ COD), ↓ AOX, ↑ N chel. agent	O	O
Partly closure of the bleach plant + increased evaporation	↑ in bleaching	↑ evaporation	↓	O	O
Closure of the bleach plant in sodium s. mills	↓	↓	↓	O	O
Neutralizing of weak liquor before evaporation	↑	O	(↑/↓)	↓	O
Separate treatment of the condensates or re-use in the process	O	↓	↓	O	O
Buffer tanks for concentrated liquids (see kraft)	O	O	↓	O	O
Biological waste water treatment (see kraft)	↑	↑	↑	(↑/↓) odour	Sludge burning ?
Installation of ESP and multi-stage scrubbers on the recovery boiler	↓	↓	O	↓	O
Collection and incineration of odorous gases in the recovery boiler and/or in a venturi-washer	O	↑	O	↓	O
Emission optimised recovery boiler	O	O	O	↓	O
Low NOx auxiliary boilers (see kraft)	O	O	O	↓ NOx	O
SNCR on bark boilers (see kraft)	↑ urea	↑ handling system	O	↓ NOx	O
ESP on bark boiler (see kraft)	O	↑ electricity	O	↓ dust	O
Emission optimised incineration of residues with energy recovery (see kraft)	O	↓ heat recovery	O	(↑/↓)	↓
Notes: ↑ = increase; ↓ = decrease; 0 = no (or negligible) effect. (↑/↓) = may or may not have an effect/little impact depending on the conditions					

Table 2: Overview of available techniques in sulfite pulping and their impact on the environment and the mill performance, respectively (Source: European Commission 2000:141)

Significantly, these major environmental improvements were comprehensively applied within greenfield erections, in particular, where large investments permitted the application of an overall ecological concept according to best international environmental standards, whereas in Germany mainly continuous, but necessarily limited environmental improvements by repairing and supplementing already existing (old) pulp mills predominated, except for the complete reconstruction of the Blankenstein mill.

Whereas one main focus of environmental R&D addressing pulp production thus was on Scandinavian countries and Germany, further technological concepts and projects have also been developed in North America (cf. Norberg-Bohm/Rossi 1997, Rossi 1998). Furthermore, other projects addressed different types of wood (processing) in Southern countries such as Brazil or Indonesia, and clearly, innovative adoptions of environmental technologies, already developed elsewhere, occurred frequently, for instance ECF bleaching in Spain (Cuerda García-Junceda et al. 2000). Similar to Germany, a lot of public funding is characteristic for pulp related R&D projects in Sweden, Finland, or partly Canada, too, mainly focusing on kraft pulping for obvious reasons. And similarly, too, these environmental R&D projects addressed in particular chemicals and energy recovery, closure of pulp processing cycles, chlorine-free (oxygen and ozone) bleaching, wastewater treatment, and - particularly important for kraft pulping - the handling of gaseous sulphur compounds (emission of SO_2 and H_2S).The major result of these efforts was the so-called modified kraft process. Leaving aside mechanical and semi-chemical pulp with around a 20% share in world pulp production, its share in global chemical pulp production meanwhile amounts to 20%, whereas conventional kraft pulping still accounts for about 60%, leaving 7% for sulfite pulp and 13% for other, mainly soda-based pulping processes, primarily used for annual plants. As for bleaching, unbleached kraft pulp still amounts to less than 25% of all kraft pulp produced, whereas ECF kraft pulp meanwhile accounts for about 50%, and TCF kraft pulp for clearly less than 10%. In Western Europe unbleached kraft pulp contributes around 20% to kraft pulp production. For sulfite pulp production TCF bleaching amounts to about 70% worldwide, and nearly 100% in Western Europe.

According to Jaakko Pöyry (1997:160-162) the modified kraft process is characterised by low kappa numbers, modified (displacement) cooking processes, an oxygen delignification stage, ECF and eventually TCF bleaching[71], chemicals recovery, low water consumption by largely closed pulp processing systems, control and elimination of odour (sulphur compounds), and pulp production that is self-sufficient in energy supply. The modified kraft process, which can utilize all kinds of wood and produce paper, fluff and even dissolving pulp with required qualities, thus is able to satisfy environmental requirements, which makes it highly competitive because it is a technically and economically well-established pulp production process. These various modifications of the kraft process were primarily developed and tested in Scandinavian countries since the

[71] Today, TCF bleaching is applied as standard procedure in just a few mills amounting to probably less than 5% for all kraft pulping worldwide. Only the Swedish company SCA exclusively uses TCF bleaching, though this is partly because it runs mainly sulfite mills. Taking into account all costs and quality aspects, it is doubted by numerous experts if ECF bleaching really is ecologically less advanced than TCF bleaching.

early 1980s and started to penetrate the world market since the late 1980s. However, these environmental improvements are less familiar in North America, Russia or Asia than in European countries.

According to European Commission (2000:iii) best available techniques for kraft pulp mills are considered to be:

- "Dry debarking of wood;
- Increased delignification before the bleach plant by extended or modified cooking and additional oxygen stages;
- Highly efficient brown stock washing and closed cycle brown stock screening;
- Elemental chlorine free (ECF) bleaching with low AOX or totally chlorine-free (TCF) bleaching;
- Recycling of some, mainly alkaline process water from the bleach plant;
- Effective spill monitoring, containment and recovery system;
- Stripping and reuse of the condensates from the evaporation plant;
- Sufficient capacity of the black liquor evaporation plant and the recovery boiler to cope with the additional liquor and dry solids load;
- Collection and reuse of clean cooling waters;
- provision of sufficiently large buffer tanks for storage of spilled cooking and recovery liquors and dirty condensates to prevent sudden peaks of loading and occasional upsets in the external effluent treatment plant;
- In addition to process-integrated measures, primary treatment and biological treatment is considered BAT for kraft pulp mills."

Table 3 lists them and their environmental impacts in somewhat more detail.

The main alternative pulping process deployed outside Germany is the Milox process, which has been developed primarily in Finland. The Finnish pulp and paper research institute Keskuslaboratorio Oy developed the Milox process since 1984. It uses formic acid and hydrogen peroxide as main pulping chemicals in a sulphur-free three-stage cooking process, applies TCF bleaching based on peroxide, requires a rather complex recovery system of chemicals differing from conventional techniques, results in acetic acid and (potentially) sulphur-free lignin as by-products, and is suitable for leaf-wood and annual plants only. Together with the company Kemira Oy and the center for technological development (TEKES) a pilot plant, including a chemicals recovery plant later on, was built and tested in 1990 through 1993, followed by a feasibility study on a pulp mill using the Milox process in 1994. Up to the present, the Milox process like other pulping processes based on organic acids has not been introduced in the market of pulp production. It is estimated that there are limited advantages over existing pulping technologies, though large amounts of peroxide are required for bleaching because of high kappa numbers.

Candidate Best Available Techniques	Effects on the consumption and emission level (cross-media effects)					Impact on the production process
	Chemical consumption	Energy consumption	Emission to water	Emission to air	Solid waste	E.g. energy balance, yield, mill performance
3.3.1 Dry debarking	n.e.	↑ in debarking	↓ COD ↓ TSS ↓ flow	n.e.	n.e.	↑ energy generation in bark boilers
3.3.2 Extended modified cooking to a low kappa Continuous (c) or batch (b)	↑ in cooking ↑ lime demand ↓ in bleaching	(↑) cooking (c) ↓ cooking (b) (↑) evaporation, (↑) lime kiln	↓ COD ↓ AOX	↑ odour	n.e.	↑ energy generation, (↑/↓) final pulp yield
3.3.3 Closed screening	n.e.	n.e.	↓	n.e.	n.e.	n.e.
3.3.4 Oxygen delignification	↑ in O_2-stage ↓ in bleaching	↑ O_2-stage ↑ white liquor oxidation ↑ caustic.&lime kiln	↓	n.e.	(↑) dregs	(↑ energy generation)
3.3.5 Ozone bleaching	↑ in O_3-stage ↓ in bleaching	↑ O_3-stage ↑ O_3 generation ↓ in bleaching	↓	n.e.	n.e.	n.e.
3.3.6 ECF bleaching technique (vs. TCF) [1] (at same incoming low Kappa)	(↑/↓)	(↑/↓)	↑ AOX ↑ ClO_3^-	↑ Cl_2	n.e.	n.e.
3.3.7 TCF bleaching technique (vs. ECF) [1] (at same incoming low Kappa)	(↑/↓)	(↑/↓)	(↓ COD) ↓ AOX ↑ N chelat. agent)	n.e.	n.e.	n.e.(↓ pulp yield)
3.3.8. Partly closure of the bleach plant + increased evaporation	↑ bleaching	↑ evaporation	↓	(↑)	(↑ dregs)	(↓ water consumption)
3.3.9 Collection of allmost all spillages	n.e.	(↑ evaporation)	↓	n.e.	n.e.	n.e.
3.3.10 Efficient washing and process control	↓ bleaching ↓ cooking	↑ washing (electr.)	↓	n.e.	n.e.	
3.3.11 Stripping and re-use of condensates	↓ in bleaching	↑ steam	↓ COD, N	↓ odour	n.e.	n.e.
3.3.12 Buffer tanks for concentrated liquids	n.e.	n.e.	↓	n.e.	n.e.	n.e.
3.3.13 Biological waste water treatment	↑	↑	↓	(↑odour)	↑	Sludge burning ?
3.3.14 Tertiary treatment (precipitation)	↑	↑	↓	n.e.	↑	Sludge burning ?
3.3.15 Increase of DS of black liquor	n.e.	↑ evaporation	n.e.	↓ SO2 (↑ NOx)	n.e.	↑ evaporation capac. needed, ↑ energy generation in the rec. boiler, ↑ prod. Capacity
3.3.16 Installation of scrubbers on the recovery boiler	n.e.	(↑)	n.e.	↓	n.e.	(↑/↓) energy balance
3.3.17 Incineration of odorous gases in the recovery boiler	↓ S make-up demand ↑ S excess	↑ handling system	n.e.	↓ TRS	n.e.	↑ energy generation (burning with heat recovery)
3.3.18 Incineration of odorous gases in the lime kiln	↓ S make-up demand ↑ S excess	↑ handling system	n.e.	↓ TRS	n.e.	(↑ energy generation)
3.3.19 Incineration of odorous gases in a separate furnace + scrubber	↓ S make-up demand ↑ S excess	↑ handling system	n.e.	↓ TRS (↑ NOx)	n.e.	↑ energy generation (burning with heat recovery)
3.3.20 Low NOx auxiliary boilers Low NOx burners in the lime kiln	n.e.	n.e.	n.e.	↓NOx	n.e.	n.e.
3.3.21 SNCR on bark boilers	↑ urea/NH3	↑ handling system	n.e.	↓Nox (↑ NH3)	n.e.	n.e.
3.3.22 Low NOx recovery boiler by using Over Fire Air technique (OFA)	n.e.	n.e.	n.e.	↓NOx	n.e.	n.e.
3.3.23 Improved washing of lime mud	n.e.	n.e.	n.e.	↓TRS	n.e.	n.e.
3.3.24 ESP on bark boiler and lime kiln	n.e.	↑ electricity	n.e.	↓ dust	n.e.	n.e.

Notes: ↑ = increase; ↓ = decrease; n.e. = no (or negligible) effect. (↑/↓) = may or may not have an effect/little impact depending on the conditions; [1] assumed that there is an efficient waste water treatment

Table 3: Overview of available techniques in kraft pulping and their impact on the environment and the mill performance, respectively (Source: European Commission 2000:60)

One further example of an environmental innovation, namely a new recovery boiler technology, has not seen widespread recognition. The straw pulp mill in Fredericia, Denmark, had intended to solve its effluent discharge problems with this new technology. Despite the theoretically simple and straightforward approach the combustion process suffered from severe difficulties. The mill could not afford the redesign of the recovery boiler requiring unpredictable investment costs, and went bankrupt around 1995.

Summing up, environmental innovations concerning pulp production from the 1970s onward primarily occurred in countries with comparatively stricter EP regulation and with a significant pulp and paper industry, i.e. particularly in Sweden and Finland for kraft pulping, and in Germany for sulfite pulping. Alternative ecologically favourable pulping processes (ASAM, Organocell, Formacell, Milox) were developed in Germany and Finland, too, up to the level of a demonstration or at least a pilot plant. These R&D efforts were largely due to related environmental regulations and substantial public funding. Diffusion of these environmental technologies occurred rather rapidly (within around one decade) in Western Europe, whereas they were adopted only slowly and partly in other major pulp producing countries, such as Canada, USA, Brazil, Russia, Japan, China, or Indonesia. For this reason ecologically sound pulp production - with still increasing production figures in spite of a gradually growing share of recovered paper used - appears to become general practice on a global scale quite reluctantly only.

4 The role of policy action

Based on this overview over the evolution of environmental protection measures and successes in pulp production and the more detailed description of three cases in previous sections, the following ones serve to interpret these processes by addressing particularly the interplay of innovation and diffusion processes of new cooking and bleaching techniques, their interaction with environmental policy and technology policy development, and the actor and network configurations involved. The emphasis of this section is on the role of policy action and interpolicy coordination during major phases of development. Concerning pulp production, one may (in West Germany) reasonably distinguish the triggering-off phase of politically perceived environmental problem pressure and of preparing environmental policy regulation in the early 1970s, the phase of elaborating and developing new concepts and techniques of environmental protection with a dominant role of ETP in the late 1970s and early 1980s, and the phase of environmental regulation and technology diffusion in the 1980s and, in a more relaxed and less confrontational manner, in the 1990s, too.

4.1 Environmental problem pressure

In the early 1970s environmental policy developed vigorously in West Germany. At that time an urgent task was clearly seen in overcoming major environmental damages by air and water pollution. One major source was water pollution by pulp production.

Particularly in cases, when drinking water was drawn from rivers where huge volumes of wastewater effluents were emitted by pulp mills located upstream, the problem pressure to reduce water pollution became urgent.

As EP could not enforce directives in a way to guarantee water protection effectively the federal government introduced the wastewater levy act (AbwAG) in 1974 providing economic incentives for industries to reduce their wastewater emissions by a levy collected per wastewater unit. An expert opinion (Rincke et al. 1975) discussed and demonstrated in detail economically viable modes of such a wastewater levy for the German pulp and paper industry, and considerably influenced its final stipulations. Whereas the paper industry - contrary to its own propaganda - could well afford biological treatment of its effluents without being economically threatened, the burden for the pulp industry was considered so high that compensatory measures appeared necessary, especially because aerobic and anaerobic treatment stages become effective after the elimination of chlorine as a bleaching agent only. Such measures were exemptions in case of building wastewater treatment plants, as well as a longer transition period, and spending the wastewater levy for related water protection measures by corresponding public subsidies for the pulp industry, for instance for corresponding environmental R&D projects. Against strong resistance of (pulp and paper) industry, the AbwAG was passed in 1976; the wastewater levy was collected, however, only from 1981 onward with distinctly rising rates until 1986. In conjunction with setting standards for wastewaters according to the WHG in the AbwasserVwV described below, the implementation of the AbwAG, in particular by corresponding state ordinances, thus took place primarily in the 1980s.

In retrospect the pulp industry - in contrast to the paper industry - is one of few industries that was in fact strongly pushed by this act to develop and to change towards an ecologically sound pulp production. Thus, environmental policy regulations indeed prepared the ground for environmental innovations in pulp production during the 1970s and 1980s.

4.2 New concepts and R&D projects

The development of environmental technologies aiming at the management and reduction of environmental pollution by pulp production has been summarized in section 2.3 already. The corresponding R&D projects were mostly well embedded in an overall technological regime of for about a century in several technological trajectories (continuously) ongoing development and improvement of pulping technologies (see cf. Jaakko Pöyry 1997). Although these projects frequently experimented with new concepts in the design of pulping processes they were primarily incremental innovations insofar as they used and combined existing know-how of chemical engineering and processing technology in order to reduce or to avoid environmental pollution by modifying and optimising pulping processes in already existing pulp mills, in particular. Thus, they were confronted with the typical trial-and-error settings and scaling-up problems of optimising complex technological systems on the basis of new arrangements developed on a laboratory and pilot plant scale, as clearly illustrated in the case studies presented. Concerning new alternative pulping processes and the closure of the pulping process, by implementing an effective process for the recovery of all inorganic pulping chemicals, they cannot be classified as just incremental innovations only, even though the ASAM process, for instance, is mainly the intelligent combination of several known pulping techniques.

Altogether a development trend towards a more comprehensive perspective of pulp and paper production and their related environmental problems can be discerned in the direction and design of these environmental R&D projects, for instance by changing from wastewater treatment to the avoidance of chlorine bleaching, to the recovery of chemicals and energy, and to closed systems of the pulping process, though such a comprehensive perspective was in principle already developed in the 1970s.

In view of rising public and political concern about environmental pollution ETP was quite open and willing to fund and thereby push corresponding environmental technologies as can seen from the manifold environmental R&D projects addressing pulp production which were (partly) funded by the BMFT and promoted and administered by the research project management bodies DLR and PTWT during the 1970s and 1980s. Thus, when this favourable orientation of technology policy met with interested and competent actors in science and industry affiliated with pulp production, promising R&D projects were launched and carried out in scientific institutes and pulp mills. This setting favoured experimentation with various concepts and arrangements of relevant environmental technologies, but did not systematically preclude questionable technological ideas and project objectives, for it was not based on a *substantive* overall ETP concept. Because there undoubtedly exist quite different technological options to limit wastewater load, namely external purification of the effluent, after-treatment of incurring waste, or closed cycles of pulping processes, and because the environmental impacts of different pulping processes depend on the specific modes of their technical realization and not just on their basic (chemical) features[72], such a policy approach of ETP appears well justifiable, even if EP (correctly) evaluated some projects as futile.

Furthermore, however, as long as corresponding (pending) mandatory environmental regulations and standards were missing, little diffusion of such newly developed environmental technologies occurred because they were typically associated with additional costs of pulp production and required considerable investments in altering the few existing (old) pulp mills in West Germany. Thus, this diffusion process which was necessary to effectively reduce environmental pollution by pulp mills strongly depended on regulatory and economic incentives for the pulp industry provided by corresponding EP regulations, namely the AbwAG and the AbwasserVwV becoming effective during the 1980s. Significantly, the chlorine-free bleaching process developed in the Alfeld pulp mill[73] proved to be the (politically intended) state-of-the-art

[72] The environmental compatibility of the modified kraft process, applied in the Blankenstein pulp mill, demonstrates this, as opposed to the traditional kraft process.

[73] As pointed out in section 3.4 it was funded directly by UBA within the investment program of the BMI/BMU and indirectly by reductions of the wastewater levy made possible by the AbwAG.

environmental technology, which was taken over by all German sulfite pulp mills after 1990, if not shut down for economic reasons in view of the 1989 amendment of the AbwasserVwV annex 19.

Further environmental R&D projects were still carried out since the 1990s, but direct involvement of public policy by funding clearly declined, except for the special case of reconstructing the Blankenstein pulp mill. Although pressure by EP on the pulp and paper industry to apply best available technologies continued (AbwV annex 19 amendment, probably issued in 2000, BREF for pulp and paper production; European Commission 2000), currently further environmental innovations will tend to be mainly determined by economic interests and considerations of the major (non-German) corporations in the pulp and paper industry which dominate the world market.

4.3 Environmental regulation and technology diffusion

Based on the overview given in previous sections, in the following the political bargaining processes resulting in the environmental regulations which paved the way for the diffusion of environmental innovations mentioned are described in somewhat more detail for the various (amended) annexes 19 of the administrative regulation on wastewater.

After the AbwAG was passed in 1976 a working group consisting of representatives of federal and state environmental ministries and subordinate agencies as well as of the pulp and paper industry developed through intense and controversial bargaining processes AbwasserVwV annex 19 from 1977 to 1980.[74] Formally issued in 1982 this annex for the first time set various standards for wastewater of pulp and paper production concerning wastewater volumes, wastewater substances, chemical and biochemical oxygen demand and fish toxicity. Permissible levels of AOX emission were not yet debated and only added in the first amendment issued in 1989 though chlorine-free bleaching techniques were mentioned as the state of the art in the annotations to the annex, which address the administration implementing it, and therefore as measures to be performed. From 1986 to 1989 a similar working group negotiated this first amendment, though without representatives of industry because they had tended to block any progress in the first working group. The 1989 amendment to AbwasserVwV annex 19A, addressing pulp production only, reduced the old standards considerably, for example to 70 kg/t COD, and fixed an AOX standard of 1 kg per ton pulp produced from 1990 onwards.[75] From 1997 to 2000, again a similar working group developed the AbwV annex 19 part I, which replaced the 1989 amendment, probably in

[74] An initiative by the European Commission to issue a corresponding wastewater directive petered out because of severe scepticism of member countries.

[75] Since this AOX standard became effective for high viscose pulp in 1993 only because of the strong lobbying of governmental representatives and of the pulp industry from Bavaria the nickname of this annex is lex Kelheim. The high viscosity sulfite dissolving pulp grades, produced by the Kelheim mill, required C-bleaching. As a consequence, the Kelheim mill was forced to look for other pulp grades to be sold on the market. Ironically, just this pulp mill developed the high consistency, high temperature oxygen delignification that could not be applied for the high viscosity pulp grades produced, because these oxygen bleaching stage conditions destroyed the viscosity.

late 2000, and resulted in further reduction of pulp related standards, namely COD to 25 kg/t and AOX to 0 for sulfite pulp and to 0,25 kg/t for kraft pulp, and in additional limit values for phosphorus and nitrogen. Furthermore, requirements to minimise waste residues as far as feasible under given circumstances by appropriate techniques are listed, for instance chemicals recovery, closed cooking cycles, chlorine-free bleaching, or minimisation and retention of organic chelating agents.

About the same time the European IPPC Bureau negotiated the BREF note on BAT in the pulp and paper industry (European Commission 2000) that was passed in 2000. This detailed BREF (ca. 500 pages), a hybrid of a compulsory and persuasive policy instrument, is of political significance because according to the IPPC directive (96/61/EC) it has to be taken into account in public licensing procedures. As a consequence, strong lobbying by affected industries, intense efforts of information gathering on BAT, and bargaining between different national actors take place around the elaboration of a BREF note.

In the political bargaining processes around AbwasserVwV annex 19 in the late 1970s and again in the 1980s the pulp industry fiercely declared the technical and/or economic unfeasibility of environmental protection measures in order to fulfill the standards envisaged for wastewater effluents, such as COD and AOX limit values. The counter strategy of (federal) EP was to demonstrate the technical viability of corresponding environmental protection measures that would then allow to fix effective standards and to stimulate the pulp industry to introduce them because of the (rising) wastewater levy. For this purpose, information was not only gathered through inspection of German pulp mills, but also from foreign environmental protection efforts, particularly in Sweden. Because EP could in principle set certain environmental standards and fund the development of end-of-pipe technologies of wastewater treatment, but not tell industry which processing technology to develop and to apply in order to meet these standards, UBA convinced the BMU to also use funds of its investment program, that aimed primarily at the development of air pollution prevention technologies, for R&D projects demonstrating the viability of certain technologies to avoid water pollution by pulp production. The development of EOP bleaching at the Alfeld and Ehingen mills and of combined aerobic and anaerobic wastewater purification and - unsuccessfully - of chemicals recovery and distillation by pyrolysis at the Ehingen mill were the major projects resulting from this strategy. These demonstration projects proved to be more successful than the R&D projects funded by the BMFT, for their results were taken over by other pulp mills, subsequently.

Despite their interest in safe drinking water extraction the representatives of those states (*Länder*) with pulp mills, such as Bavaria and Baden-Württemberg, opposed (strict) environmental standards because of the strongly perceived risks of (local) economic decline and loss of employment following increased production costs and eventual shut-down of "their" pulp mills. Whereas the BMU and UBA got information from Degussa, which was certainly interested in the substitution of chlorine bleaching by peroxide bleaching, about the feasibility of peroxide bleaching, and whereas the pulp and paper industry (quietly) prepared for a change to TCF bleaching[76] given the perceived unavoidability of - publicly still strongly opposed - future AOX standards,[77] some state governments still tried to forgo (stricter) environmental limit values and felt ashamed after these new standards were met in pulp mills by obviously well viable environmental technologies.

The establishment of the standards was to a large extent possible only because few key persons in the BMU and UBA persistently pursued this objective and - backed by public concern and some representatives of public authorities involved - stood the enormous pressure exerted by opposing actors.[78] They also succeeded in setting the standards because these were not very demanding any longer - even if quite strict by international comparison - when becoming effective (e.g. no AOX standard in the AbwasserVwV annex 19 issued in 1982, only 1 and not 0,5 kg/t AOX in the amended annex 19 issued in 1989), for the pulp industry was well able to fulfill stricter limit values with techniques already available contrary to its own public statements. Because pulp mills indeed reduced their emissions more than legally required when retrofitting their installations, this approach of imposing not tough limit values can be defended against plausible criticism by environmentalists as perhaps being more effective than a more rigorous regulatory approach. Thus, it may well have led to similar actual wastewater emissions and helped learning processes and more cooperative attitudes to evolve in the pulp industry. Very rigorous standards, however, might well have suffered severe implementation deficits when the AbwasserVwV annex 19 was to be actually put into force by state and local administration.

Whereas the 1982 AbwasserVwV annex 19 was essentially the result of the negotiation processes indicated above in conjunction with the economic effectiveness of the AbwAG, the change to TCF bleaching by the pulp industry was not only due to the 1989 amendment to AbwasserVwV annex 19 but at least as much to market forces. These originated from publishers, in particular, who started to demand chlorine-free paper since 1991 because they were confronted with public debate and protest addressing chlorine and possible dioxin risks of pulp and paper, which was organised by Greenpeace, in particular.

Rather by chance Greenpeace came across high loads of chlorinated compounds discharged into river waters in 1985, when travelling up the Rhine river. Then, in searching for alternatives and in learning by doing (study of crucial documents, chlorine-free paper products produced in Sweden) it launched a campaign in favour of chlorine-free paper around 1990. Advocating a similar brightness quality of paper

[76] These preparations and corresponding investments explain why all West German pulp mills - if not shut down - were able to change to TCF bleaching so quickly in 1990/91.

[77] AOX are admittedly hazardous for human health and difficult to extract from drinking water. And the pulp and paper industry contributed more than 50% to the AOX load of, for instance, the Rhine river in the 1980s.

[78] As an anecdote it should be mentioned in this context that even the former minister of interior, Zimmermann, fiercely resisted the former prime minister of Bavaria, Strauß, despite the fact that the latter was the party leader of the (Bavarian) CSU to which the former belonged, too.

produced by chlorine-free bleached pulp,[79] pulling off the coup of a chlorine-free copy of the well-known magazine "Der Spiegel" in 1991,[80] that received enormous publicity, and organising protest postcards of readers to publishers, Greenpeace mobilised sufficient public pressure so that many publishers gradually switched to chlorine-free books, magazines and other print products in order to avoid public protest.[81] To emphasize the role of Greenpeace in the "greening" of the German pulp and paper industry[82] does not imply, however, that this NGO, and not the BMU and UBA, was the key actor in this process. Whereas this may well be true for some chemicals, as the stop of dumping diluted acid in the North Sea (cf. Ditz 1989, Ökopol 1999), Greenpeace started its campaign for chlorine-free paper only lately, and the options of EP to enforce ecological limit values were more developed than those of Greenpeace, even if they were less strict than feasible on technical grounds.

With the change to TCF bleaching scientific representatives of German pulp producers already in 1990 defended the AOX limit value (for sulfite pulping) on (international) symposia where for example Canadian pulp producers lobbied for renewed admission of chlorine bleaching. With Germany being a rather large pulp (and paper) market and with German paper producers dominating the German pulp and paper industry (mostly integrated production, more than 80% of chemical pulp imported) they were in the comfortable position of exerting pressure to get at least ECF pulp for its considerable amounts of pulp imported. Furthermore, together with the decreasing importance of pulp production issues for the pulp and paper industry, learning processes and changes in attitude took place leading to the voluntary declaration of the pulp and paper industry and publishers mentioned above (VDZ/VDP 1996) stating their commitment to do their best for ecological care in forestry, pulp and paper production, paper recycling and printing. Even though this declaration may well be classified only as symbolic policy, it reflects corresponding learning processes and reorientations as well as actual changes towards an ecologically more sound pulp and paper production. Thus, in spite of still ongoing resistance and lobbying against further substantial environmental regulations of pulp and paper production, for instance via the recent BREF note, the wastewater ordinance annex 19 part I, to be issued in late 2000, was developed within a rather consensual approach. There was agreement on the technologies to be applied, for instance TCF bleaching, multi-step biological

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79 Only for high quality products requiring an extraordinary degree of brightness chlorine dioxide is still needed in the bleaching process. Concerning brightness of paper, it is important to note the trade-off between stronger bleaching and fibre quality.

80 To get this "Anti-Spiegel" printed required quite a clever strategy of Greenpeace in order to find a paper producer and a printer for this purpose. If the paper producer would have known the objective, he would not have supplied the chlorine-free paper required, and the printer did not stop to print this special magazine only because of considerable recovery claims voiced by Greenpeace.

81 In retrospect a Greenpeace representative judged the shift of the organisation's activity focus to forest protection and ecological forestry in 1992 as too early because TCF bleaching was not introduced on a global scale, and even ECF bleaching though connected with much lower chlorine emissions did not yet develop to the dominant bleaching mode in kraft pulping. Furthermore, customers seem to be no longer willing to pay a higher price for chlorine-free paper products.

82 Similar observations were made by Kisser/Kirschten (1995) for Austria. Typically, Greenpeace played a major role in pushing ECF and TCF bleaching in many industrialised and developing countries (Sonnenfeld 2000).

wastewater purification, chemicals recovery, and the main issues concerned the size of the wastewater levy and the necessary extent of further environmental improvements. Through ample communication with all of the 6 and now 5 pulp mill companies left, the pulp industry was indirectly, but clearly involved in the drafting process of AbwV annex 19 part I by the administrative working group. Significant delays in finalising this new annex 19 were not caused by opposition of the pulp industry but by formal bureaucratic misunderstandings among the responsible public actors involved, concerning for example the definition of measurement procedures, or the formulation relating to chelating agents.[83]

Having succeeded in limiting and strongly reducing wastewater load of pulp production by to a large degree integrated environmental technologies and being provided with the in ecological terms most advanced sulfite pulp mills in the EU,[84] on the one hand, German environmental policy currently (understandably) is less keen on further substantial environmental improvements and shows more appreciation of the pulp industry's concerns. On the other hand, the pulp and paper industry meanwhile accepts reasonable demands for environmental protection and even introduces environmental management systems and ecoaccounts (cf. Sixta 1995). Thus, it is no wonder that the German pulp and paper industry for the time being is coming along with EP and that further environmental innovations are no longer primarily made in Germany, but elsewhere.

In retrospect, the conclusion appears well justified that EP and ETP *together* were crucial factors to effect via environmental regulation (environmental standards and levies) and promotion of technology development both environmental innovations *and* their diffusion in German pulp production facilities. Without these policy measures they would have been developed at best much later induced by external market demand, as can be seen from other countries, where EP and ETP did not play a significant role. However, in the last resort economic viability and the technological trajectory prevailing in pulp processing were decisive for the success of few specific technological options, as demonstrated by the failure of (new) alternative pulping processes in particular.

Concerning environmental innovation, public funding of R&D projects by the BMFT/BMBF or by the BMU and, indirectly, by reduction of the wastewater levy (i.e. ETP) was in most cases a necessary condition, whereas (pending) environmental regulation (i.e. EP) put pressure on the pulp and paper industry to become interested in such R&D projects. Concerning diffusion of these environmental innovations, environmental regulation was a necessary condition, whereas usually ETP had no legal competence and also consciously saw no reason for further public funding in this respect, once the techniques to fulfill EP requirements had been developed.

Interpolicy coordination between EP and ETP was well prevalent in the 1970s and 1980s, as self-evident mutual regard of relevant policies, partly as conscious coordina-

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83 Interestingly, the need of chelating agents such as EDTA to prevent peroxide decomposition by heavy metals in P-bleaching leads to a trade-off between the latter and D-bleaching because EP aims at the prevention of both, chlorine and EDTA to be released into wastewater effluents, though the environmental and health hazards of AOX are much larger than of EDTA.

84 Only Austrian pulp mills show a similarly advanced environmental performance.

tion of policy programs, and occasionally as conscious coordination of specific projects.[85]

It occurred, first of all, as internal ETP coordination, where the responsible research project management bodies DLR and PTWT, and - though with diminishing funds - UBA, had to agree on their mutual domains ((integrated) environmental technology within the pulping process; wastewater treatment; waste treatment) and to exchange relevant information with each other, with the responsible (federal) ministries BMFT and BMU, and also with state ministries responsible for a specific pulp mill involved in a R&D project. Although formally subordinate to the BMU and thus belonging to EP, UBA (as a research project management body) functionally relates to ETP insofar as it gathers environmentally relevant scientific and technical information and funds R&D projects. Furthermore, the obligatory early departmental coordination ensured agreement of different federal ministries to an R&D project. Certainly, there existed friction and controversy between ETP (and EP) actors, which were debated in the expert meetings deciding about and evaluating ongoing R&D projects. Thus, EP actors were well sceptical about the viability of some R&D projects funded by the BMFT.

Genuine EP/ETP interpolicy coordination primarily took place in the working group(s), headed by the BMU, charged to develop AbwasserVwV annex 19. Here the feasibility of certain standards according to available technical options and their further development was debated, involving - beyond (local) economic and employment concerns - (indirect) arguments in both directions: public funding of environmental technology development allowing more rigorous standards, as well as setting stricter limit values inducing further technology development, possibly supported by public funding. Beyond mutual regard of EP and ETP this proceeding clearly involves elements of a conscious coordination of policy programs, too.

As far as the funding by UBA of specific development and demonstration projects at Alfeld and Ehingen in the 1980s is concerned, which should demonstrate the technical feasibility of certain bleaching and waste treatment technologies so that the environmental standards envisaged in AbwasserVwV annex 19 could be met, one may well interpret this strategy as conscious EP/ETP coordination of specific projects.

Altogether, coordination of EP and ETP, that in general is often observed at a low level only, occurred and was successful to quite some degree concerning environmental protection in pulp production. Certainly, some positive funding decisions by the BMFT lacked technical competence and could have been avoided if other (administrative) bodies such as UBA had been consulted more extensively, and environmental standards could have been stricter than those introduced if more knowledge about already available technological options had been obtainable. However, a higher degree of EP/ETP interpolicy coordination was unlikely to result in more effective environmental protection measures than the ones achieved.

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[85] See Conrad (2000a) for a more detailed elaboration of the concept of interpolicy coordination.

4.4 The need for a long-term perspective

This section places the outcomes of pulp-related German EP and ETP in a wider context and evaluates them correspondingly.

First, the viability of pulp-related environmental (technology) policy objectives was and is strongly influenced by the following factors:

- fierce (international) competition in a still growing market,
- typical price cycles lasting 4 to 8 years,
- acquisition of German pulp mills by large foreign paper corporations,
- high share of imported (chemical) pulp (over 80%),
- displacement of market pulp by integrated pulp and paper production during the 1970s and 1980s,
- special situation of exclusive sulfite pulping in West Germany, contrasting dominant kraft pulping on the world market,
- successful development of modified kraft pulping in Scandinavia leading to its licensing during the reconstruction of the Blankenstein pulp mill supported by huge public subsidies,
- great and still growing share of waste paper (ca. 60%) in paper production.

The strong price competition, in conjunction with high imports of partly advantageous kraft pulp and with cheap recovered paper, impedes costly (sulfite) pulp production due to environmental protection measures. Furthermore, major markets such as Canada, USA, or Brazil showed little interest in TCF pulp.

The mutual reinforcement of quasi-periodic pulp and paper price cycles also works counter passing on additional environmental costs because newly erected pulp mills lead to an only discontinuous capacity increase and demand is very price sensitive. This effect was particularly visible in case of declining market prices around 1970-73, 1977-78, 1983-85, 1992-93 and 1995-96, possibly accentuated further by the prevailing price fixing in US dollars. One may even suspect a tendency to lower market prices due to (obvious) competitive moves of established pulp producers when a new ecologically advanced pulp mill will supply the market with additional pulp.

Within the ongoing globalisation and concentration process in pulp and paper production, partly induced by the enormous investment costs needed for building new competitive pulp mills, the purchase of German pulp mills because of competitive strategies of foreign pulp producers gives them enlarged bargaining power vis-à-vis unpleasant environmental regulations. Currently, the remaining big German pulp mills are owned by Sappi (Alfeld and Ehingen, since 1992), SCA[86] (Mannheim since 1995), MoDo (Stockstadt since 1995), Mercer[87] (Blankenstein, since 1994), and till 1999 Stora, itself merged with Enso in 1998 (Baienfurt, since 1991).[88]

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[86] Interestingly, owing several sulfite pulp mills, SCA tends to show the relatively strongest interest in environmental protection efforts compared to other large pulp producers.

[87] Mercer International Inc. is an investor group, formally situated at Zürich/Switzerland, based in Canada, formerly also including a South Korean shareholder, which is not a genuine pulp and paper

Integrated paper production allows mutual coordination of pulp and paper production processes and implies somewhat more independence from pulp price fluctuations, which is in principle favourable for the development and/or adoption of environmental technologies. Further support in this direction comes from the greater strength of (economic) interests of the paper industry as opposed to those of the pulp industry, both represented by the VDP. This mainly results from the weak domestic basis of pulp production, the greater economic value added in paper production compared to pulp production, and the preponderance of integrated production. As a consequence, the concern of the paper industry to supply for instance chlorine-free paper to publishers and other customers is more important than the concern for additional environmental costs of pulp production.

Within Germany, the predominance of sulfite pulping for understandable reasons allowed to focus on R&D projects and environmental standards oriented towards environmental improvements within this pulping process although the development of alternative pulping options was funded, too. After successful development of the modified kraft process in Scandinavia, however, EP no longer had sound environmental reasons for licensing kraft pulping and ECF bleaching in the Blankenstein pulp mill in 1999 after the complete reconstruction of the old sulfite pulp mill.

The large share of waste paper in paper production, consciously promoted by EP, and the costs of recovered paper processing certainly influence the pulp market. However, for pragmatic reasons no substantial overall policy strategy or even program exists that consciously tries to mutually harmonize the amounts of pulp and recovered paper produced according to ecological criteria, though their relative distribution by the market will not tend to include them automatically.

Altogether, these factors allow some scope for EP and ETP, however, under relatively stringent economic constraints. Thus, the national introduction of TCF bleaching, far-going closure of the bleach plant, and biological wastewater treatment induced some extension of related technologies into other countries, though mostly restricted to the less important sulfite process, but did not lead to their global diffusion. Instead, for instance ECF bleaching experienced considerable diffusion on a global scale. In addition, because of the high share of imported pulp in Germany a considerable amount of paper sold still stems from pulp produced without these environmental techniques. And the strong and long-term funding of alternative pulping processes did even not result in their application in (new) pulp mills in Germany either because of their lacking economic viability (Organocell) or because of the inertia of prevailing technological trajectories (e.g. modified kraft pulp) and the risk averse attitude of potential (foreign) investors (ASAM).

producer, but only looks for profitable investment opportunities. Up to the present, it did not yet succeed in reselling the Blankenstein pulp mill despite some interest of a Finnish pulp producer.

[88] It can be stated that the main interest of these acquisitions was in strengthening the buyer's position in the world's fourth largest paper market, whereas the pulp mills provided some additional incentive because they could be kept in operation, after their main environmental problems had been solved and production was economical since the 1990s.

As long as the political system does not dispose of capacities[89] to develop (economically viable) complex technical systems such as an ecologically sound pulping process on its own, it can only try to induce the development of corresponding environmental technologies by appropriate policy strategies and instruments. Taking into account the typical egotisms and eigendynamic[90] of and the related frictions between different policy areas and political organisations such as ministries and agencies, and being aware of the failure of many R&D projects funded, one can say that German ETP and EP may well be judged to have indeed used their scope of action to induce environmental innovations (and their subsequent diffusion), concerning both established and new cooking, bleaching, and waste management processes. Whereas alternative pulping processes failed to penetrate the market, the ecologically oriented alteration of the sulfite process in the 1980s (as well as the adaptive innovation of the modified kraft process in the 1990s) took place to a large degree in all German pulp mills leading to enormous reduction of pollutants in their wastewater effluents.

Concerning time horizons of an effective ETP, it has to take into account both the necessary periods of time required by various development processes and their timely positive interplay. Time is needed for

1. successful commercial upscaling of environmental innovations beyond R&D projects that proved to be technically viable in laboratory, pilot and demonstration plants,
2. the diffusion of new technological arrangements by adaptive innovations of other pulp producers,
3. the erection of a new pulp mill, where to incorporate environmental technologies,
4. the eventual (social and technical) installation of a new technological trajectory (e.g. alternative pulping processes);
5. the political negotiation and acceptance of related environmental regulations and standards, including the coordination of different levels (federal, state, supra-national (EU)) and fields (technology, economic, environmental, fiscal policy) of politics,
6. the actual implementation of these regulations and standards,
7. effects of postponement caused by possibly low market prices for pulp, lacking financial resources, the dependence of building new pulp mills on the phasing out of old ones, and the change in ownership of a pulp mill.

This list clearly demonstrates that routine adoption of environmental innovations in pulp processing typically requires at least one or two decades and cannot be accelerated significantly, and thus the need for a long-term perspective of effective ETP. And the list also indicates that without the timely positive interplay of corresponding social processes, where the key actors in corporations, public authorities or R&D institutions

[89] The prominent example in this respect is the public ownership of an industry, which is frequently connected, however, with doubtful economic and political impacts.

[7]8 This term means to the (social) dynamics induced by the vested interests, sunk costs, and inertia of a system, institution, or group, once it has become firmly established and developed its own momentum.

realise the window of opportunity, the (policy-induced) adoption of environmental innovations becomes blocked by lack of concurrence of economic, sociocultural, regulatory and other provisions or at least occurs later (cf. Edquist 1997, Hemmelskamp 1999, Hemmelskamp et al. 2000, Klemmer 1999), as can be illustrated by the examples of Spain or the USA (Blazejczak/Edler 1999).

Summing up, EP and ETP played a crucial role in Germany in triggering the innovation and diffusion of environmental technologies in pulp production during the 1970s and 1980s, in particular. Economic incentives, in particular, provided by the AbwAG and by public co-funding, induced considerable R&D efforts of the pulp industry, and technologically not excessively demanding environmental standards and regulations pushed the diffusion of technically and economically viable environmental innovations. These policy stimuli of innovation and diffusion processes were supported by corresponding market forces due to the demand of publishers for chlorine-free paper. This demand was sparked by public pressure initiated by a Greenpeace campaign. The shift in policy support from end-of-pipe oriented wastewater treatment to integrated technologies saving water and energy, recovering chemicals, substituting chlorine bleaching, and closing processing cycles in pulp production as well as the patience and persistence of EP in spite of partial change of responsible persons deserves recognition. Similarly, the far-reaching reduction of public funding of pulp-related R&D projects in the 1990s parallel to ongoing EP pressure on the pulp industry to attain the rather complete closure of all pulp processing cycles as far as economically viable appears justifiable, after major objectives of environmental protection in pulp production by appropriate techniques had been achieved.

In spite of this rather positive evaluation of EP and ETP, however, at best the partial and slow diffusion of environmental innovations observed in pulp production at the global level could be expected under given socioeconomic conditions and reasonable social science assumptions.

5 Actors and networks

This section presents the actor constellation concerning environmental innovations in pulp production at the general as well as the case specific level, inquires into the interests, perceptions and strategies of the actors involved, and indicates the pattern and impact of related actor networks.

The actors involved in the cases investigated can be defined at two levels: organisations and individuals. Because the various individuals in principle acted according to the rules and interests of their organisational units, on the one hand, and because key persons and, possibly, personal conflicting issues within organisational units played a crucial role for the specific development path of a case history, on the other hand, it appears appropriate to pragmatically analyse actor behaviour and constellation at the levels of organisational units and of key individuals, without striving for a theoretically coherent concept of actor constellations. Although frequently organisational sub-units within a macro-organisation such as the BMBF are the true organisational actors, with typically around 5 to 20 individuals belonging to these sub-units, it is in this context often satisfactory to nominally conceive of macro-organisations as essential actors.

Similarly, the network concept is applied only at a phenomenological level in this study, without going into its theoretical differentiations (see cf. Hellmer et al. 1999, Kowol 1998, Sydow/Windeler 2000), when addressing networks around environmental innovations, although regulatory, business and knowledge networks are distinguished for this purpose, which typically follow different tasks and consist of different actors (van Dijken et al. 1999).

At the general level, the macro-actors to be denominated are environmental, technology policy, and economic ministries, pulp and paper corporations and their associations, suppliers and customers of pulp production units, scientific research institutions and possibly environmental organisations such as Greenpeace. More concretely, the general actor constellation consisted of

– the responsible units of the BMU and UBA, and of the BMFT/BMBF,
– the research project management bodies DLR and PTWT,
– the environmental and economic state ministries concerned,
– the companies operating German pulp mills,
– the (foreign) (pulp and paper) corporations owning these companies,
– the VDP,
– the companies supplying the equipment for the pulp mills, in particular Degussa providing peroxide for P-bleaching,
– the customers of pulp and paper products such as publishers,
– academic and corporate research units involved in pulp-related R&D projects,
– Greenpeace,
– and, primarily at the local level, regional and communal administrative units implementing environmental regulations in pulp mills or affected by related polluting emissions.

The interests, strategies and perceptions of these actors have already been described in previous sections. To sum up, all actors largely proceeded according to their interests, problem perceptions and strategic orientations, frequently connected with a clever use of existing economic and political framework conditions. On the basis of a common, at least partial acknowledgement of the social need to limit and to reduce environmental pollution by pulp production, a negotiation process balancing the controversial actor interests was feasible that led, within 2 and more decades, to increasingly rigorous environmental standards and regulations. The corresponding compromises could be reached because all parties involved in the negotiation processes had significant bargaining power so that no actor was able to impose its position completely.

EP was strong enough to pass effective, but not excessively strict environmental regulations; the VDP could threaten to (have to) shut down pulp mills if these regulations were too rigorous or introduced too rapidly introduced environmental regulations; the state ministries could have their necessary agreement (to pass water regulations) depend on the inclusion of smooth transitional rules and temporary exceptions; ETP could - under these circumstances - induce the development of environmental technologies by (partly) funding it, particularly if combined with the legally foreseen reduction of the wastewater levy to be paid; suppliers of environmental protection facilities could demonstrate the technical feasibility to fulfill certain environmental standards; publishers could demand chlorine-free paper; and Greenpeace could transform public environmental concern into (economic) pressure upon key actors such as publishers.

Furthermore, the gradual (environmental) learning process induced by the negotiation processes[91], the growing priority of paper issues over pulp issues in the German pulp and paper industry, the actual implementation of environmental protection technologies demonstrating their viability to their adversaries, and the effective reduction of environmental pollution in pulp production together have been gradually leading to a softening of controversial interests because of decreasing pressure caused by ecological problems and more similar problem perceptions and solution strategies of the actors, at least since the 1990s. Their basic tenets can be enumerated as follows: environmental pollution by pulp production can be and meanwhile has been limited to an acceptable level; corresponding development of environmental technologies should be funded by public resources to a large extent; therefore related environmental regulations (slowly) were considered acceptable; their economic impacts do not undermine competitiveness of integrated paper production, at least within Germany; German pulp mills meanwhile are among the ecologically most advanced ones by international comparison. Thus, the environmental protection measures actually introduced certainly were not the optimal ones that could have been achieved in most cases, but all (macro-)actors evaluated the arrangements reached as at least acceptable, if not satisfactory for their purposes in ecological, economic or political terms.

Concerning environmental R&D projects, all participating actors were more or less in favour of them, particularly if supported by public funding; criticism mainly came from competing pulp companies, although nearly all of them received public funds to conduct such a R&D project. Despite the eigendynamic typically induced by project commitment it should be noted, however, that, apart from R&D projects addressing alternative pulping processes, the dominant objective tended to remain one of successful (innovative) performance of a well specified project of applying, integrating and optimising available technological concepts and not one of a far reaching environmental innovation. This illustrates the significant momentum (and inertia) resulting from an established technological trajectory, conceivable in the sphere of sulfite pulping.

At the case study level of specific environmental technology development the following actors are to be listed (see section 3):

[91] At least to some degree, they required valid technical arguments to defend one's bargaining position.

Ehingen, peroxide bleaching: Schwäbische Zellstoff AG, Degussa, Kamyr (Swedish producer of a high shear mixer); BMFT, DLR, regional water authority Tübingen, water supply corporation Landeswasserversorgung Baden-Württemberg; key person: responsible managing director of the pulp mill.

Ehingen, biological wastewater treatment and pyrolysis: Schwäbische Zellstoff AG, producers of the pyrolysis plant and of the biological purification plant; UBA, BMU, TÜV Südwest, Stuttgart university.

Baienfurt, wastewater purification: Feldmühle AG, pulp and cardboard factory Baienfurt, DVGW research unit; BMFT, PTWT, regional water authority.

Baienfurt, ASAM process: institute for wood technology at Hamburg university, Kraftanlagen Heidelberg, Asam Technologie GmbH, Feldmühle AG, pulp and cardboard factory Baienfurt, Austrian Energy & Environment, Voest-Alpine, Impco-Voest-Alpine, Ingersoll-Rand, Beloit, Landecker, Stora, SCA, Sappi; BMFT, DLR, BMU, state ministry of environment of Baden-Württemberg, EU Commission; key persons: main inventor of the ASAM process, responsible managing director of the pilot plant.

Kelheim, high pressure oxygen bleaching: PWA, Bayerische Zellstoff AG, various suppliers of installations, mixed project group with external cooperating institutes; BMFT, PTWT, Bavarian and communal licensing authorities.

Kelheim, Organocell process: MD-Verwaltungsgesellschaft, MD-Papierfabriken, Technocell AG, Organocell GmbH, Organocell Thyssen GmbH, Bayerische Zellstoff AG, external engineering office, Munich university, technical university of Munich, other universities, Burda, PWA, Thyssen Rheinstahl Technik, suppliers of pulp-related plants: Kamyr, Steinmüller; BMFT, DLR, Bavarian government, Bavarian and communal licensing authorities, group of credit granting banks, Donaupark GmbH, EU Commission, Jaakko Pöyry; key persons: Nicolaus (co-owner of MD-Papierfabriken), project leader and managing director of Bayerische Zellstoff AG and Organocell GmbH, managing director of Organocell Thyssen GmbH and Organocell GmbH, managing director of Technocell AG.

These actor constellations indicate three typical features:

1. Only a few actors were substantially involved in the R&D projects, namely the project participants of the pulp mill, between 5 and 20 persons; sometimes cooperating academic research groups; and, to a varying degree of collaboration, equipment and chemicals suppliers, Degussa in particular. The other actors were related to the R&D project essentially either because of (partial) ownership of the pulp mill or technology, or because of environmental regulation or public project funding. They largely took the role of enabling and controlling the R&D projects by providing and limiting (financial) resources and by assessing project-related environmental improvements, but hardly intervened in them by substantive contributions.

2. Whereas the number of actors involved was rather limited for the bleaching and purification technologies developed, it was considerable for alternative pulping processes. In the ASAM case this higher number was due to subsequent changes in ownership of the technology and the corresponding installations and to various efforts of the proponents of the ASAM process to gain competent investors for its market introduction. In the Organocell case the reasons lay in the somewhat sophisticated ownership structure of the companies engaged in the Organocell process and in the various creditors involved in as well as companies possibly interested in taking over the bankrupt pulp mill company. Otherwise, apart from more academic researchers participating in the development of these new pulping technologies than in the other R&D projects investigated, a similar low number of actors was engaged in developing these environmental technologies, too.
3. Though to a somewhat varying degree, the successful performance of the R&D projects demonstrating at least their technical viability was clearly dependent on the engagement and competence of the responsible project leaders. Whereas personal controversy was of little importance in carrying out most R&D projects, diverging technology management attitudes and correlated personal conflicts among the responsible managing directors strongly contributed to the failure of the Organocell project.

Addressing the network character of environmental R&D projects, one can clearly distinguish between relatively distinct (though still partly overlapping) knowledge, business, and regulatory networks. However, as the network concept presupposes more than occasional communication at least between its central members and its members belonging to more than one or two organisational (sub)units, only some of the actor constellations may be classified as true networks. Other actor constellations form at best very loose networks, and thus may be better conceived of as, for instance, technical circles or business groups.

At the general level, a regulatory network involved in or related to the negotiation processes around AbwAG and AbwasserVwV annex 19 can be plausibly assumed, as described in section 4.3. Similarly, moulded by competition and common lobbying, there is a partly European or even international business network consisting of pulp and paper producers, their associations, related research institutes, and, partially, suppliers of related equipment and customers of pulp and paper products, that focuses on pulp (and paper) business issues. As far as one or several general loose (to some degree international) knowledge networks can be assumed, these are often closely connected to the business network and consist of technical and economic experts of pulp processing issues, who are mostly members of the organisations constituting the business network and therefore typically tend to advance biased propositions besides publishing articles in special (scientific) periodicals. They communicate on the features, feasibility and advantages of special technologies, meet in their professional committees and at professional conferences, and keep contact to the scientific community overlapping with these knowledge networks.

Concerning individual R&D projects, it appears more appropriate to speak of project teams, and not of (knowledge) networks, which communicate and keep contacts as far as necessary with the top management, with competent technical experts (from other pulp mills), with suppliers and possibly customers of pulp production equipments, with the responsible research project management body, and with environmental authorities. Continuous communication and collaboration, however, is mostly limited to the members of the project team which - aside from the pulp mill concerned - may or may not include participants from other research institutes or consulting agencies, as indicated above. Depending on the perceived competitive need for secrecy, the degree of professional communication differed for the R&D projects investigated.

Altogether, the actor constellation of these R&D projects typically consisted of a central project team composed of 5 to 20 individuals, which was embedded in a wider circle of technical experts, on the one hand, and in the project-specific business network as well as in the regulatory network, on the other hand, all of them more or less aware of the project and its results. Because of the similarity of the cases and the lack of more specified network features, it seems justified to presuppose this type of network pattern as a rather representative one for environmental R&D concerning pulp production. Only the ASAM case reflects features of genuine innovation networks, as described in literature (Dosi et al. 1988, Freeman 1991, Kowol 1998), whereas just rudimentary forms of them could be found in the other cases investigated.

6 Interpretation perspectives

This section summarizes the major factors at different levels underlying pulp-related environmental innovations, focussing on the cases investigated. This is done in conformity with an interpretation perspective according to which the interaction dynamics of structural, institutional, actor, situational, problem perspective and strategic capability factors ultimately determine innovation processes.

Because the innovation processes addressed have not been studied in detail at a micro-level, only plausible appraisals and no stringent evidence about the significance of the factors denominated here can be given. Certainly, the theoretically crucial reference to the interaction dynamics of structural, institutional, situational, framing and action-oriented factors of influence which tend to mutually reinforce their impact on the innovation processes appears to be a reasonable conceptual assumption (Conrad 1998). Without their substantial description, however, the conclusion that these interaction dynamics essentially underlie the innovation processes described remains only a plausible hypothesis not tested by empirical reconstruction and evaluation.

6.1 Structural framework conditions

Structural framework conditions refer to the manifold (contextual) settings that influence the direction and evolution of social processes independent of actors' (current) articulation of interests and modes of procedure. Concerning the pulp-related environmental innovations described, these structural framework conditions relate in particular to the domains of ecology and health, economics, corporate organisation and culture, law, politics and administration, general sociocultural conditions, and the (national) innovation system. Without going into their endless description, I summarize key contextual settings already described in previous sections.

Environmental and health problems and corresponding sociopolitical concerns mattered as legitimate (rational) criteria to reduce the at least up the 1970s enormous environmental pollution by the pulp industry and structure corresponding controversy, to negotiate, introduce and strengthen environmental regulation of pulp production (emissions), and as potential sources of economic costs caused by (additional) environmental protection measures required or losses in market share resulting from customer demand of chlorine-free pulp and paper.

Economic criteria and judgements played a crucial role for corporate investment in R&D projects in three respects. First, public co-funding and reduction of wastewater levies together with the threat to have to shut down a pulp mill without significant decrease of its emissions made this decision in favour of relatively cost-free R&D projects an easy one[92]. Second, fierce competition on the world market and the growing role of recovered paper made this cheap opportunity a quite attractive one for existing German pulp mills to either improve future competitiveness because of favourable ecological performance or to become a more valuable candidate for a takeover within the ongoing concentration process in the pulp and paper industry.[93] Third, obviously investment in the alternative pulping technologies ASAM or Organocell was strongly influenced by their economic perspectives perceived by (potential) investors, especially in view of the high investment costs for new, economically competitive pulp mills.[94]

Corporate organisation and culture clearly mattered because they permitted ecologically conscious project leaders to effectively organise and perform their R&D projects, on the one hand, and because they reflected the gradual change towards an environmentally responsible attitude of the pulp and paper industry (VDZ/VDP 1996), on the other hand. Furthermore, changes in corporate culture contributed to the failure of the Organocell process in Kelheim.

The relevant legal, political and administrative framework conditions pertained to the (pending) regulatory provisions for emissions of pulp production as well as their partially flexible local implementation ("lex Kelheim"), the promotion of environmental technology development either by R&D programs under the auspices of research project management bodies, or by EP investment programs, and the German federal

[92] Environmental authorities were indeed aware that they essentially bought the cooperation of pulp companies to develop environmental technologies by ultimately paying most of thereby incurring costs.

[93] Significantly, the reconstruction of the Blankenstein pulp mill received the largest amount of public subsidies provided for pulp-related investments in Germany.

[94] Furthermore, the idea to become independent from imported kraft pulp and related price fluctuations clearly contributed to the willingness of the owner of MD-Papierfabriken to invest considerable resources in the development of the Organocell process.

system of dividing responsibilities between federal, state and municipal authorities. Indirectly, the lack or lagging behind of (similar) environmental regulation of pulp production in foreign countries or at the EU level was also important because it weakened EP objectives to realise strict environmental standards in Germany.

General sociocultural conditions[95] typically tend to play the role of background variables where some of them, namely general environmental awareness and the eigendynamic of a commitment, once it has been made, probably did support the innovation processes.

The German landscape of R&D institutions and technology policy arrangements could well support pulp-related environmental technology development; however, the R&D projects under study were primarily carried out by the pulp companies as corporate in-house projects or in collaboration with suppliers such as Degussa. In addition, external (academic) research institutes performed exploratory or separable project steps, for instance addressing wastewater purification by aluminium oxide (DVGW research unit) or lignin utilization (universities of Munich). Thus, the German innovation system provided rather favourable framework conditions, but was of no special significance for carrying out the R&D projects under study except for the generous arrangements of their public funding, what should be counted, however, primarily as favourable economic boundary conditions.

6.2 Actor networks, institutional eigendynamic and situational conditions

The project-related actor constellations and the resulting quite limited formation of (loose) networks have been described in sections 3 to 5. Their main features can be seen in

- the typically small number of actors substantively involved in the R&D projects,
- their frequently close connection to and dependence on (changing) business actors and, more loosely, to the responsible research project management body, both promoting and funding the individual projects,
- and the regulatory context as solely a significant structural framework condition without actual intervention of actors engaged in the regulatory network, except UBA (as a research project management body) for launching a project.

Thus, quite some actors shaped the case-specific form of relevant structural framework conditions, whereas relatively few actors were actually involved in the R&D projects themselves. As a consequence, the competence, engagement, and attitude of the project managers and researchers strongly determined the development path of these

[95] One may list here the modernization capacity of a society, the importance of the state and public policy, the importance of public debate and the equivalent strength of civil society, the extent of division into different social classes or strata, the degree of public participation and socio-structurally entrenched substantive democracy, the significance of self-responsibility and liability of social actors, the degree of legalism, decentralized versus centralized (political) culture and decision-making procedures, the importance of postmaterialistic value orientations, environmental awareness of and behaviour by main actors and the population in general, and the significance and social influence of environmental NGOs.

R&D projects. As described below, their final success or failure, however, cannot be attributed to these individuals, except perhaps to some extent the failure of the Organocell process to some project managers.

Nevertheless, in spite of the preponderant lack of genuine innovation networks, both the institutionally entrenched orientations of the key actors (pulp companies, suppliers, EP and ETP actors etc.) within the knowledge, business, and regulatory networks, respectively, and the personal commitment of project managers and researchers, by mutually reinforcing each other induced some eigendynamic of the R&D projects, that stabilised the activities started and therefore at least delayed their termination as long as reasonably justifiable, as demonstrated by the ASAM and Organocell case studies in particular. Similarly, the project developing high pressure oxygen bleaching for sulfite pulping was completed despite its predictable economic unviability, and the projects utilizing aluminium oxide for wastewater purification or pyrolysis for distilling bleaching liquor were terminated very lately, too.

Although not mutually exchangeable, situational conditions tend to gain importance if structural framework conditions loose significance for the simple reason of thus increasing scope of action. Because structural framework conditions largely determined the 'if' but not the 'how' of the R&D projects under study, situational factors considerably influenced their specific pathway taken. For instance, the small scale of paper production by MD-Papierfabriken, the vested interest in and optimism of its owner towards the Organocell process, perceived as environmentally sound, the interest of PWA to sell the Bayerische Zellstoff AG, the technical and personal changes during the reconstruction of the Kelheim pulp mill, or the subsidies provided by the Bavarian government were all relevant situational conditions in this respect. Similar examples could be pointed out for the other R&D projects, too.

6.3 Varying problem perspectives and strategies for solutions

Differences in cognitive framing and problem solving strategy clearly shaped the bargaining processes around environmental regulation of pulp production, as pointed out in section 4. But this holds also true to quite some extent for the R&D projects investigated.

First, they reflect the belief in and the orientation towards the viability and superiority of certain types of technological solutions to environmental pollution problems, for instance end-of-pipe versus integrated technologies, closure of pulp processing cycles, or alternative ecologically more sound pulping processes. Second, they reflect the feasibility of different solutions to technical problems (cf. Ravetz 1971). By pursuing the fundamental purpose of any technology, namely to fulfill certain function(s), for instance environmental protection, the technology to be developed should provide an optimal solution to the underlying technical problem so that additional criteria, for example efficiency, low costs, few (unwanted) side-effects, are met simultaneously. Because it remains always a matter of judgement, at least to some degree, which solution satisfies best these various criteria, on principle there exist nearly always several technical options to solve environmental pollution problems, particularly in the predominant case of ongoing discovery of new scientific concepts and technical devices. Thus, (continuous) efforts to improve technical plants installed or to change and reconstruct them completely in order to optimise them according to their purpose reflect the very essence of R&D projects.[96] As long as these measures did not require considerable additional resources and did not lead to other unsolvable problems, they were discussed and undertaken largely within the project team only. However, in spite of these varied conditions of in principle variable technological arrangements, once defined, the R&D projects nevertheless still followed a rather foreseeable technological trajectory in the end.

Thus, one may conclude that problem perspectives and strategies for solution, shaped by the economic, political and technological selection environment, particularly influenced the selection of R&D projects considered worthwhile as well as the acceptance and diffusion of environmental technologies thereby achieved. This conclusion again reflects the influence of those promoters and implementers, i.e. mainly (large) pulp and paper corporations, who have sufficient resources, power and capacity to decide about the development and the (commercial) adoption of these environmental technologies according to the cognitive framing and resulting assessment of their technical, economic and social viability.

Because the focus of this study was on technologies of wastewater treatment, chlorine-free bleaching, and alternative pulping processes, the significance of this cognitive dimension of the selection environment and the resulting success or failure of technical options can be illustrated as follows.

Given the significance of wastewater effluents by pulp production and the corresponding pressure of EP to reduce them, the availability of basic concepts as well as of technical devices to purify wastewater by end-of-pipe technologies, the development and, partly, the (technical) failure of several purification technologies, and the diffusion of the technically and economically viable ones (combined aerobic and anaerobic biological wastewater treatment) were likely. Furthermore, the subsequent installation of recovery cycles in the pulping process during the 1980s and 1990s did not simply render superfluous biological purification of wastewater from pulp production.

Concerning chlorine-free bleaching, the undeniable health risks of AOX emissions, corresponding pressure of EP, the ETP-induced demonstration of the technical viability of ECF and TCF bleaching at Alfeld and Ehingen without serious quality deficiencies of paper, corresponding preparation of other pulp mills in collaboration with Degussa to switch to TCF bleaching, and the subsequent demand of publishers for chlorine-free paper led to several R&D projects to develop alternative bleaching techniques, to the rapid diffusion of the economically favourable combination of EOP bleaching and P-

[96] The various attempts to install a pyrolysis plant in the Ehingen pulp mill and subsequent substitutive measures realised, as described in Klein/Bürkert (1992), are a typical example in that respect.

bleaching stages,[97] and to the corresponding immediate introduction of TCF bleaching without recourse to ECF bleaching because of its perceived economic favourability, except for the modified kraft pulp mill of Rosenthal.

Concerning alternative pulping processes, it has to be emphasized that the existing sulfite process was not questioned on environmental grounds, but improved in its ecological performance, for instance by the just mentioned environmental technologies, and that the kraft process is applied again in Germany since 2000 after its significant ecologically favourable modification. Therefore the originally proclaimed ecological superiority of the ASAM process and the Organocell process over the established pulping processes lost persuasive power. The Organocell process failed to prove its technical and economic viability on an industrial scale. Without offering an economic advantage over the modified kraft process the ASAM process got no chance to prove its technical and economic viability on an industrial scale because of the additional investment risks involved in building a prototype of a new pulp mill with a new, not yet established pulping technology. Thus, there was much less reason (in Germany) to introduce alternative pulping processes as compared to TCF bleaching or biological wastewater purification.

6.4 Patterns of environmental innovation and diffusion

If one interprets success or failure of the environmental R&D projects investigated in terms of their match with a dominant technological paradigm and prevailing technological trajectories, the observed patterns of environmental innovation and diffusion are in accordance with these concepts (see cf. Dosi 1982, 1988, Dosi et al. 1988), too.

They have been developed within the context of innovation research by evolutionary economics in order to dynamically couple the classical explanations of successful innovations by technology push and demand pull (cf. Freeman 1974). A technological paradigm is "a 'pattern' of solution of selected technoeconomic problems based on highly selected principles derived from natural science, jointly with specific rules aimed to acquire new knowledge and safeguard it, whenever possible, against rapid diffusion to the competitors." (Dosi 1988:1127) Within such a paradigm different technological trajectories may evolve, each one defined as "the activity of technological process along the economic and technological trade-offs defined by a paradigm." (Dosi 1988: 1128) Because of this embedding in technological paradigms and trajectories technological evolution and change becomes a cumulative, irreversible, and selective process. The resulting path dependence generates both stabilisation promoting incremental innovations and lock-in effects preventing radical innovations because the latter ones question established technological trajectories or even technological paradigms.[98]

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[97] This does not imply that the various remaining sulfite pulp mills in Germany apply exactly the same bleaching sequence nowadays (see Jaakko Pöyry 1997:387).

[98] "Leadership in an old technological paradigm may be an obstacle to a swift diffusion of the new one, especially owing to the interplay between the constraint posed by the capital stock to readjustment or

One may interpret different pulping technologies as different technological trajectories within an established technological paradigm defining their common basic characteristics of the pulping process (debarking, cooking, delignification, washing, bleaching, recovery of chemicals and energy, controlled gaseous and water emissions, and wastewater treatment), whereas the development of specific new bleaching and wastewater purification techniques may be interpreted as innovations within the established technological trajectory of sulfite pulping. Thus, the introduction of new pulping technologies such as the ASAM process or the Organocell process can be expected to meet more obstacles than the one of new bleaching or wastewater purification techniques, as illustrated by the case studies.

Technical, economic and market viability of an environmental innovation is certainly influenced by their fit to established technological trajectories and paradigms because of the already prevailing preferences, the available competence, past investments, and veto power of their proponents. However, this viability is not completely determined by them, for they provide a competitive advantage for corresponding incremental innovations but do not invalidate genuine substantive criteria for assessing it. Thus, the use of aluminium oxide in wastewater treatment or the pyrolysis of bleaching liquor remained technically unviable under the conditions of the established technological trajectory. Therefore the patterns of innovation and diffusion investigated can only be partially explained by the prevalence of certain technological trajectories in pulping.

If not aiming at explaining, but only at describing technical, economic and market (social) viability in order to sketch the innovation and diffusion process of the pulp-related environmental technologies investigated, that can be done by indicating in the following table 4 if they proved their technical feasibility, their economic justifiability, and their penetration on the market.

Environmental technology	TF[a)]	EV[b)]	MP[c)]
Wastewater purification with aluminium oxide (Baienfurt)	-	-	-
Two-step biological wastewater treatment (Ehingen)	+	+	+
Pyrolysis (Ehingen)	(-)	-	-
Peroxide bleaching (Ehingen)	+	+	+
High pressure oxygen bleaching (Kelheim)	+	-	-
Organocell process (Kelheim)	(+)	-	-
ASAM process (Baienfurt)	+	+	-

[a)] technical feasibility, [b)] economic viability, [c)] market penetration

Table 4: Achievements of pulp-related environmental technologies under study

productive activities and the behavioural trends in 'old' companies which may embody differential expertise and enjoy high market shares in 'old' technologies." (Dosi et al. 1990:23)

7 Typical features and summarizing conclusions

The key features of the evolutionary process towards an ecologically sound pulp production to be derived from the three case studies and their general socioeconomic and political context, presented in the previous sections, can be summarized in the following conclusions. They address (a) environmental regulation and improvement of pulp production in general, (b) the environmental technologies investigated in the case studies, and (c) the major interaction dynamics directing success or failure of EP and ETP:

1. Pulp production is based on a rather complex set of mutually harmonized processing technologies. That offered many technological options to improve its ecological performance within and outside the technological trajectory of sulfite pulping and chlorine bleaching established in Germany. ETP contributed significant funding to allow for the development of a considerable number of such technological options in the 1970s and 1980s. Most of them failed, however, for various reasons, but some of them succeeded to become established practice since about the 1990s.
2. Fierce competition on the world market with substantial price cycles for pulp and paper, ongoing closure or integration of existing pulp mills in paper production, enormous economic concentration processes with repeated accompanying changes in ownership, large investments required for building new pulp mills with economically sufficient capacity, and the special situation of exclusive sulfite pulping in Germany after the second world war until the late 1990s, together make corporate capability (in terms of technical competence, management competence and available economic resources) crucial for successfully developing and installing environmental technologies in existing or new pulp mills.
3. EP and ETP played a key role in achieving large reductions of ecologically hazardous substances emitted during pulp production, by introducing a wastewater levy, by setting increasingly tighter environmental (emission and ambient quality control) standards, and by funding the development of corresponding environmental technologies. A good deal of coordination of EP and ETP took place that had influence on both the standard setting process and technology development. Further (ecologically favourable) improvements of interpolicy coordination appear feasible, though only to a limited extent.
4. Despite the politically reasonable focus on end-of-pipe technologies of wastewater treatment in the 1970s and on COD and AOX limit values, EP and ETP were aware of the pulping process as a whole and were concerned about integrated environmental protection measures closing various pulp processing cycles, as can be seen from the AbwV annex 19 and the BREF introduced in 2000.
5. The competence and engagement of key individuals was crucial for the success of both environmental policy and environmental technology development.
6. Because structural framework conditions, particularly the availability of public funds, left considerable scope of action, situational conditions often paved the way for starting an environmental R&D project and for its success or failure, as illustrated by the case studies.

7. Whereas EP activities met fierce opposition of the pulp and paper industry in the 1970s and 1980s, involvement in related bargaining processes, in conjunction with an increasing environmental concern and a corresponding greening of industry in general, led to social learning processes of this industry which resulted in growing commitment and a voluntary declaration in favour of ecologically sound pulp production. A campaign of Greenpeace attacking environmental problems of pulp and paper production and public debate on chlorine-free paper probably enhanced this change in attitude. However, the actual demand of publishers for chlorine-free paper and clear environmental regulations were the main driving forces for improved environmental protection and consciousness in pulp production.
8. Thus, different phases of development with varying attitudes and approaches of the main actors towards environmental protection and technology development in pulp production can be distinguished: environmental problem pressure and installation of available end-of-pipe technologies (1970-80), generous public funding of environmental technology development and preparation of environmental regulation (1975-1985), passing and enhancing environmental standards and diffusion of environmental innovations (1980-95), further progress and differentiation of environmental regulation and environmental technologies applied (1990-2000). These changing contextual conditions implied differing policy strategies and tactics of EP and ETP.

Concerning the environmental R&D projects investigated, the (incidental) focus was on wastewater treatment, chlorine-free bleaching, and two major alternative pulping processes, ASAM and Organocell, developed in Germany, that essentially took place at three pulp mill locations, namely Ehingen, Baienfurt and Kelheim.[99]

1. Because recycling of waste paper cannot completely substitute pulp as raw material of paper production, and because society's growing dependence on information is unlikely to lead to a paper-free future, there exist no reasonable alternatives to technical fix solutions limiting environmental pollution of pulp production.
2. Because of the complex setting of mutually harmonized processing technologies underlying pulp production, there exist many technical options to realize environmental protection measures, but they have to be integrated in these various cooking, delignification, washing, recovery, or bleaching cycles in order to avoid deleterious side effects of the pulping process. Therefore, the development and optimisation process of an environmental technology tends to be a quite demanding task with considerable probability of failure. This task needs competent cooperation of participating actors, particularly various specialists operating the pulp mill and suppliers of technical equipment, and harmonization of technical devices and processing arrangements of pulp production.[100]

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[99] This case study focus on certain pulp mills is due to pragmatic selection criteria and does not deny that other environmental technologies with similar objectives have been developed elsewhere, too, as demonstrated by the development of EOP-pre-bleaching in the Alfeld mill.

[100] Thus, the bad performance of the pyrolysis plant installed in the Ehingen pulp mill caused the failure of the pyrolysis plant to distill the bleaching liquor and to generate pyrolysis coke. - Thus, the digester, supplied by Kamyr, and the recovery boiler, supplied by Steinmüller, did not work properly in the

3. The research teams carrying out the R&D projects had and established contacts with other competent experts if necessary, for instance to suppliers or to academic experts, and they were well connected with the business circles and regulatory network relevant for the project; however, these contacts constituted a genuine innovation network in rudimentary form, at best.[101] With the partial exception of the ASAM project academically oriented research institutions were not strongly involved in these R&D projects.
4. Whereas the development of alternative pulping processes can be interpreted as a departure from the dominant technological trajectories of sulfite pulping, and particularly of kraft pulping outside Germany, the development of new bleaching and wastewater purification technologies should be viewed as occurring within these trajectories because corresponding basic research and patents frequently existed already and because they required fewer changes in the established pulp processing arrangements. Thus, the failure of alternative pulping processes at the industrial level, despite repeated (desperate) efforts to finally launch them, is partly due to their departure from the established technological trajectories, though there existed crucial differences between the ASAM process and the Organocell process in their technical and economic performance achieved, too.
5. The need to accommodate a (newly developed) environmental technology to various processing cycles in (already existing) pulp mills, and vice versa, too, makes it difficult to classify the new bleaching or purification technologies studied as still incremental or already radical innovations. They may be reasonably viewed as lying somewhere in between.
6. The diffusion of two of the environmental innovations under study, peroxide bleaching and combined aerobic and anaerobic biological wastewater treatment, was - apart from their favourable technical properties - strongly promoted by environmental standards passed via the 1989 amendment to AbwasserVwV annex 19. Ultimately, introduction or diffusion of quite a few environmental innovations could be observed especially during the 1990s that addressed diverse parts of the pulping process and led to considerable reductions of hazardous substances emitted, although a large number of environmental technologies developed failed to become established at an industrial level.

Referring to the title of this study, the interaction of world market conditions, corporate capability and environmental policy obviously determines to a large degree success or failure of environmental innovations in pulp production. Certainly, not all environmental technologies developed at Ehingen, Baienfurt, Kelheim, and other places proved to be technically viable, but most of them were. Without provision of public resources by ETP and effective EP measures towards the reduction of environmental pollution by pulp production, at least in Germany the environmental technologies under study most likely

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Kelheim pulp mill, which was due to imprecise specifications or incorrect information provided by the project managers of the pulp mill and to the unsatisfactory adaptation of associated processes to these new technical devices, but not simply to shortcomings of these suppliers.

[101] The network character was developed somewhat more as far as, for instance, the cooperation of the Ehingen pulp mill with Degussa or the delegation of small subprojects to university institutes were concerned.

would not have been developed. However, corporate capability, including technical and organisational competence, availability of capital, and competitive advantage, as well as favourable world market conditions were equally important for the successful introduction and market penetration of environmental innovations.

Whereas at Baienfurt the economically necessary recovery of aluminium oxide failed because of unsolvable corrosion problems of the tubular kiln, the failure of pyrolysing bleaching liquor at Ehingen and of the Organocell process at Kelheim was more due to insufficient technical management of these environmental technologies, finally stemming from a lack of corporate capability, than to insurmountable technical difficulties. The failure of high pressure oxygen bleaching developed at Kelheim was essentially due to its economic unviability; this failure cannot be attributed to world market conditions, however, in view of technically feasible cheaper alternative bleaching arrangements though not yet clearly recognizable at the time, when this bleaching technology was developed.

Concerning the other environmental technologies, namely peroxide bleaching and two-step (aerobic and anaerobic) biological purification of wastewater (Ehingen), and the ASAM process (Baienfurt), the first two - with some further modifications - became established practice for sulfite pulping, that remained a competitive niche on the world market dominated by kraft pulping. The ASAM process, however, has not been introduced up to the present on an industrial scale because of situationally missing corporate capability and unfavourable world market conditions.[102]

[102] The established technological trajectory of the (modified) kraft process, the failure of the Organocell process at Kelheim, and the unsatisfactory distribution of ASAM-related patents already largely explain the lack of necessary risk capital.

8 Literature

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