COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE REFRIGERATOR INDUSTRY

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THE REFRIGERATOR INDUSTRY
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EXECUTIVE SUMMARY

In 1987, the Montreal Protocol, an international environmental agreement to reduce and phase out chlorofluorocarbons (CFCs), catapulted the world's refrigerator makers from a slow life that for many decades had seen no major product innovation into one where they would be forced to either innovate within an extremely short time period and engage in major technical development or else quit their industry.

CFCs were believed to be major depleters of the ozone layer in the stratosphere, causing increased skin cancer and global warming. Since refrigerators depended on them as coolants and as blowing agents used in the production of foam insulation, the stipulations of the Montreal Protocol, which initially required a CFC ban by the year 2000, then by 1995, were a massive threat to the refrigerator industry.

The Montreal Protocol was not a law by itself, it merely required its signatory countries to enact legislation requiring the phaseout of CFCs and other ozone-depleting substances at the latest by the date it stipulated. In most cases the regulation that was subsequently enacted by the individual countries followed the deadline recommended in the protocol. Germany was the only nation to require an earlier phaseout date, forcing its refrigerator industry to search and find even faster a safe substitute for CFCs, but providing it at the same time with an opportunity to gain a first mover advantage over foreign competing nations.

Any CFC substitute that was researched had to be not only in compliance with the stipulations set forth by the Montreal Protocol, but also be at least as energy efficient, be safe to the user, and be as economical as possible. Energy efficiency was particularly important, because many countries either had energy efficiency laws (as was the case in the U.S.) or very demanding customers (as was the case in Germany) which provided pressure to offer only energy efficient appliances. Safety was also an important concern. Many countries, including the U.S. and European countries, had laws regulating appliance safety.

By the early 1990s it had become evident that there were two major technological avenues that could be followed to comply with the Montreal Protocol. One involved the use of hydrofluorocarbons (HFCs) as coolants and hydrochlorofluorocarbons (HCFCs) as blowing agents for insulating foams. HFCS were in compliance with the Montreal Protocol and thought to be safe to the refrigerator's user. However, they were slightly less energy efficient - a disadvantage that could be offset by small changes to the refrigerators design. They were also more expensive than CFCs, causing in Germany an average increase in refrigerator prices by some 5 % to 8 % . Their major drawback was that, while not dangerous to the earth's ozone layer. they were a powerful greenhouse gas that was thought to contribute to global warming and climate change. There was no regulation on HFCs, but the slight risk that they might be regulated Sometime in the future meant that refrigerator makers which focused on HFCs risked focusing on a transitory solution.

HCFCS were an even riskier substitute - from an environmental as well as from a competitive point of view. Refrigerator insulation foams blown with HCFCs were economical, provided sufficient energy efficiency and posed no safety risk. However, HCFCs contributed to global warming and posed a risk to the ozone layer. For this reason, the Montreal Protocol required their phaseout by the year 2020. Thus, manufacturers developing HCFC-based insulation foams followed a dead end; they could be sure to be forced once again to convert their production to a new technology in the foreseeable future.

The other major technological route to follow besides employing HFCs and HCFCs involved the use of hydrocarbons. Hydrocarbons, such as propanes, butanes, isobutanes. or pentanes, could be used both as refrigerants and as blowing agents for polystyrene insulating foams. They were environmentally benign, could easily be obtained all over the world, and were very cheap. Theoretically hydrocarbons provided better energy efficiency than HFCs and HCFCs, although practically hydrocarbon-blown insulations were slightly less efficient, requiring somewhat thicker insulations. Hydrocarbons were explosive and thus represented a certain safety risk during refrigerator production as well as during refrigerator usage, but this risk could be minimized to acceptable levels by introducing suitable safety equipment. Like HFC- and HCFC-based systems, refrigerators employing hydrocarbons cost some 5% to 8% more than CFC-based refrigerators. Unlike HFC- and HCFC-based systems, they did not pose any environmental risks and thus were certain never to be banned for environmental reasons, rendering research efforts and production equipment obsolete.

By early 1994, most refrigerator makers in the world were focusing on the HFC/HCFC alternative with all its environmental risks. The only exception was Germany, where, after a sometimes agonizing struggle to decide which technological route to choose, most refrigerator makers had decided to adopt the hydrocarbon route which did not pose any environmental risks and with further research and experience was likely to be as cost-efficient as the HFC/HCFC route. How was it possible that the German refrigerator industry, a highly competitive industry representing 11.1% of the world's refrigerator production and 13.4% of the world's exports of refrigerators, had chosen a technological route that was difficult from that chosen by the rest of the world?

There were several reasons, among them stricter and earlier regulation, which had sensitized producers and consumers to the issue -- a very demanding and environmentally conscious home market -- as well as a chance event in the form of a pressure campaign by an environmental group that had hit precisely at the right time and at the right place.

The first hydrogen-based refrigerator had been built in Germany by the small East German manufacturer Foron after the environmental pressure group Greenpeace had acquainted it with the technology and awarded it a small $15,000 development contract. Greenpeace also conducted a publicity campaign that prompted a large number of environmentally conscious Germans to place orders for the newly developed refrigerator. The extraordinary success of the campaign convinced not only Foron that the hydrocarbon-technology had real market potential, but also its West German competitors, who had initially developed HFC/HCFC-based refrigerators. Subsequently, one competitor after another announced similar hydrocarbon-based refrigerators.

At the same time as the Greenpeace campaign in Germany, there had been a more formal program in the United States, that had also aimed at facilitating change and innovation in the refrigerator industry. The Super Efficient Refrigerator Program (SERP), had been a $30 million contest conducted by the U.S. Environmental Protection Agency and some 25 utilities to develop a CFC-free refrigerator that would exceed federal energy efficiency standards by at least 25 % However, unlike the case in Germany, SERP had not led to true innovation concerning environmental friendliness. There were a number of possible reasons why SERP had not lived up to its environmental innovation potential.

SERP had placed only very small emphasis - 3% of the maximum score achievable to the winner - on environmental friendliness beyond and above the requirement not to use CFCs.

The contest had been overly restrictive with respect to the eligibility of potential contest entrants who were required to have large production facilities and a strong distribution network. This unnecessarily limited the group of potential contestants and with it the number of innovative solutions entered into the contest.

The American market was not nearly as environmentally conscious as the German market, resulting in less demand pressure on American producers to develop environmentally sound products.

Competition had focused for too many years on marketing and distribution. Given the vast geographical area of the United States and dealer networks that changed only very slowly, the industry was paralyzed and made it incapable of technology competition, more so than the German refrigerator industry which had never been assured of its geographical markets.

U .S, manufacturers lacked the technical capabilities. In Germany, an early voluntary agreement had forced manufacturers to innovate and reduce the CFC-content in the insulating foam by 50%, providing them with valuable experience. U.S. manufacturers had not received such early warnings in the form of voluntary agreements from their government. Forced to phase out CFC-based blowing agents, they lacked the necessary experience and simply substituted CFCs with HCFCs, a stop-gap measure which would force them to convert once again in the foreseeable future, since HCFCs were also to be phased out under the Montreal Protocol.

Overly strict liability laws combined with unflexible safety laws were another hindrance to innovation in the U.S. They prevented the refrigerator industry from adopting hydrocarbon-based refrigerants which might pose a very slight risk of explosion - a risk that in Germany had proven to be negligible.

It was claimed that many technically and economically feasible alternatives such as the hydrocarbon technology were not attractive to the U.S. refrigerator industry, because they were not patentable. Likewise, alternative refrigerants like hydrocarbons were said to be not attractive to refrigerant manufacturers because they were non-chemical alternatives and their adoption would effectively force them out of the market. In the absence of strong pressure from sophisticated refrigerator buyers, as was the case in Germany (where 70,000 people had been willing to pre-order an environmentally friendly refrigerator that was not even in production), lack of patentability and unattractive profit expectations for refrigerants could indeed have contributed to the U.S. industry's hesitance to convert to truly environmentally benign solutions.

* A fact that may have contributed to the U.S. refrigerator industry's aversion to risk the development of new and truly environmentally friendly refrigerators was General Electric's $450 million pre-tax charge to replace 1.1 million newly-designed refrigerator compressors that proved defective in 1988.

* A general obstacle to energy efficiency innovation that affected U.S producers was that the buying decision for refrigerators tended to be dominated by initial cost rather than total life-cycle cost considerations. Even if economically irrational, buyers often opted for refrigerators that were less expensive to buy in the first place but more expensive to operate in the long-run. The fact that the buying decision for a particular refrigerator model often was made by a person other than the ultimate user who would have to pay the energy bills also led to precedence being given to initital cost over total cost.[1] Either case resulted in the purchase of less energy efficient, thus environmentally unfriendly refrigerators, and provided producers with a disincentive to develop energy-saving refrigerators. A possible solution for overcoming this obstacle to innovation was introducing regulation that would require sellers to provide information about total life-cycle cost, but the effectiveness of similar labeling regulation had proven to be limited in the past. A second, more theoretical, solution was increasing energy prices to force users to incorporate energy use considerations fully into their purchasing decision. A third solution, and one which had proven to be very effective in the U.S., was support of demand-side management programs offered by utilities in the form of cash rebates to customers which bought new, energy efficient refrigerators or discarded old, energy intensive ones (see below).

1. ZVEI Zentralverband der Elektrotechnischen und Elektronischen Industrie: Werner Scholz. Personal communication to the author.

INDUSTRY STRUCTURE

Product

Product Description

Refrigerators were used to cool perishable foodstuffs to low temperatures, thus inhibiting the destructive action of bacteria, yeast, and mold. They were used both in private households as well as in commercial settings. Almost every refrigerator in use in the 1990s was based on the vapor-compression principle, whereby a gas was first heated by compression, then cooled down to ambient temperature and then further cooled by letting it rapidly expand. The first usable refrigerator was believed to have been built by an American physician, John Gorrie, in 1844, although the vapor-compression principle had been known for centuries.

The basic active components of a vapor-compression refrigerator were a compressor, a condenser, an expansion device (which could be a valve, a capillary tube, an engine, or a turbine), and an evaporator. A gas refrigerant was first compressed, usually by a piston compressor. It was then led into the condenser, a long and winding tube surrounded by air or water which removed some of the heat energy and cooled the vapor down to ambient temperature. Next, the cooled vapor was passed through an expansion valve into the evaporator, an area of much lower pressure. As it evaporated and drew the energy of its expansion from its surroundings, the refrigerant cooled down to temperatures, which were considerably lower than the food compartment surrounding the evaporator, thus cooling the food compartment. In a final step, the refrigerant was fed back into the compressor for a next cycle in the cooling process.[2] Since World War II the predominant refrigerant used had been a freon gas, usually the chlorofluorocarbon CFC-12, which had been preferred for its energy efficiency, low toxicity, stability, and its well-known physical properties (see Tables 4, 5, and 6). However, freons were harmful to the environment and thus were to be phased out under international and national agreements and laws (see below).

The other critical element besides the active refrigeration system was the refrigerator's passive insulation

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2. Encyclopaedia Britannica, 15th ed., S.V. "refrigeration"

which facilitated maintaining low temperatures and low energy usage. Most refrigerators consisted of a thermoformed plastic inner liner and a steel outer case with polyurethane foam insulation in between. Until the early 1990s the blowing agent used for the polyurethane foam had also usually been a freon gas, typically CFC- 1l. Thus, both the refrigerator's refrigerant and its insulation posed environmental threats.

Substitutes

Possible substitutes for refrigerators ranged from a number of alternative food preservation techniques such as drying or canning to different storage techniques such as a cold basement or outside storage spaces in cold climates. The fact that in Western societies almost every household had at least one refrigerator indicated, however, that most of these substitutes were actually complements.

Production Process

The production of refrigerators had much in common with the production of automobiles. As in automobile production the basic steps were stamping, casting, machining, body assembly, and final assembly. Automated and flexible production systems were quite common. Many parts such as compressors, electric motors, heating elements, belts, or valves were sourced from outside suppliers and many producers, particularly in Germany where appliance makers traditionally had been characterized by low degrees of backward integration, were striving to decrease their share of in-house production. Parts of strategic importance to the performance or quality of the appliance, however, were typically developed and produced in-house.

As in the automobile industry, there was continuous upgrading of existing product lines. Every eight to ten years a new product generation was introduced. The shift to a new generation was estimated to cost some DMlOO million, including product development and retooling costs.

Buyers

Buyer Description

Refrigerators were bought by private and commercial users to be operated in both newly built or existing premises and as initial installments and replacements. Refrigerators for private use in existing homes were almost always bought as replacements, because use in most European countries as well as the United States penetration oil rates were close to 100%.

The most important purchasing criteria for domestic refrigerators in the approximate order of their importance were:

* reliability and durability, i.e. high quality (through brand name recognition),
* low price.
* low noise,
* appearance,
* low operating costs (energy consumption), and
* environmental soundness.

Other purchasing criteria were:

* ease of use and cleaning,
* prompt and efficient service.
* easy to understand instructions, as well as
* added features, such as special lights, separately accessible compartments, or glass shelves.

Still other criteria were assumed as a "given" and thus did not greatly influence the purchasing decision. These included:

* a low risk of fire,
* no odors,
* a convenient defrost system, and
* stable temperatures.

The purchasing decision for a refrigerator for private use was often made by someone other than the ultimate end user, representing a disincentive to buy energy-saving, expensive refrigerators, because the end user and not the buyer would ultimately pay the energy bills. This was often the case in countries such as the U.S. or Switzerland (but not Germany), where apartments were often leased with fully furnished kitchens and the decision of which refrigerator model to buy was made by the apartment's lessor.

Distribution was highly important and the distribution networks of the large established manufacturers could constitute almost insurmountable entry barriers for industry newcomers. Hence, large market share shifts could only be achieved through takeovers. Service networks were of less strategic importance for refrigerators than for many other appliances, such as washing machines, dryers, or dishwashers, because there were fewer mechanical parts requiring service in a refrigerator.

Distribution Channels

There was a large variety of distribution channels in the refrigerator industry, ranging from specialized appliance stores to furniture stores to department stores to discount stores to kitchen remodelers to builder-contractors to plumbing contractors. The relative importance of these channels differed considerably from country to country. Specialized appliance stores accounted for two thirds of all appliance sales in Germany and even more in Italy. In France, only one third of all appliance sales were made through specialized stores, the rest going through supermarkets and so-called hypermarkets.

Suppliers

A critical part of the refrigerator industry was the suppliers of refrigerants and blowing agents for insulating foams, which, until the mid-1980s, had been primarily CFCs. CFC production was dominated by a small number of large chemical firms with world-wide operations. In the late 1980s, during the last years of full capacity CFC-production, the American firm DuPont had been the world's largest producer of CFCs with an estimated world market share of 25%. They were followed by ICI of the U.K., Atochem of France and Allied-Signal of the U.S., each with about 10% of the world market.[3] The three leading German chemical firms, Hoechst, BASF and Bayer, also engaged in the production of CFCs, but on a much smaller scale than the firms mentioned above.

Environmental Regulation

Environmental Risks

Three different aspects of a refrigerator gave rise to environmental concern: Chlorofluorocarbons (CFCs) in the refrigerator's refrigerant and its insulation, the refrigerator energy usage, and a possible risk to the user from electro-magnetic fields (EMFs).

3. "ICI to Invest 60 M Pounds on Plants Making Alternative to CFCs." Financial Times, November 23, 1988, p. 9.

Most refrigerators made since the 1940s used as a refrigerant a chlorofluorocarbon (CFC) which had been found to damage the ozone layer. This layer was a concentration of ozone gas about 25 miles above the surface of the earth, that blocked out harmful ultraviolet light and played an important role in regulating the earth's climate. CFCs, when released into the atmosphere, slowly rise into the stratosphere, where they break down and release Chlorine. The chlorine then reacts with the naturally occurring ozone, permitting more ultraviolet radiation to reach the earth and contributing to global warming, For- CFC-based coolants there was a risk of their being released to the atmosphere accidentally during production, through damages to the cooling system during use, accidentally or on purpose during service, and, most likely. upon disposal. Until the mid- 1980s, when the problem had been recognized, refrigerator disposal had usually meant that its CFCs were simply released, although a recovery was technically feasible and, indeed, had been mandated by law in the early 1990s in many countries, including the U.S. and Germany. In addition to the CFCS outright release to the atmosphere, there was a risk posed by the refrigerator's compressor oil which usually absorbed some of the CFC, thus creating additional environmental damage upon product disposal.

In 1990, 260,000 tons of CFC were consumed worldwide as coolants or refrigerants with 207,000 tons (79.6%) used to air condition buildings and automobiles. Another 19,000 tons (7.3%) were used in refrigeration systems, mostly for domestic refrigeration (9,500 tons), followed by industrial (4,500 tons) and commercial (4,500 tons) refrigeration. The remaining 34,000 tons (13.1%) were used in heat pumps and other industrial purposes.[4] A conventional refrigerator used about 420 to 450 grams of CFCs - 120 to 150 grams in the refrigerant, the remaining 300 to 600 grams in the insulation (see below)[5]

CFCs were also contained in the refrigerator's insulation. Most refrigerators employed rigid polyurethane foams as insulation. These foams were light and fire resistant, could be used as structural building materials and had good insulation properties. Their major drawback was the blowing agent used to produce the foam, usually the chlorofluorocarbon CFC- 11. It was environmentally damaging not only

4. UNEP 1991a, cited in Cohen and Pickaver 1992, 12.

5. "Umweltrelevanz und Entsorgungspfade von Kiihl- und Gefriergertiten. Anhvort der Bundesregierung auf Kleine Anfrage." In: Umwelt No. 6/1993, p. 230.

during the production stage, but also during the refrigerator's use and its disposal. A conventional refrigerator's urethane insulation contained between 300 and 600 grams of CFC.[6] During a refrigerator's lifetime a considerable percentage of the CFC contained in the insulation was diffused and released to the environment, thereby damaging the environment and resulting in an average loss of insulation capacity of 40% after 15 years.[7]

In 1990, global consumption of CFCs for all foam applications amounted to 168,000 tons. The amount used for appliance insulation purposes was difficult to determine, but it did not exceed 106,000 tons (63 %).[8]

The environmental risk associated with the disposal of refrigerators with CFC-based refrigerants and insulation had led to recycling programs in many countries, but the actual costs of refrigerator recycling were difficult to determine. A German-designed machine for the recycling of refrigerators which allowed recovery and liquefaction of 97% of the CFCs cost DM2.5-3.0 million and had an annual capacity of 168,000 refrigerators.[9] Assuming a seven-year write-off period and a rate of recycling at full capacity, this would amount to a cost of only DM2.13-2.55 per refrigerator. To arrive at a final cost of disposal one would of course have to factor in transport and labor costs, as well as capital costs other than the recycling machine itself and any costs or benefits of final disposal.

A second environmental issue concerning refrigerators was their energy consumption, which, to the extent that the electricity used had been produced by burning fossil fuels, contributed to global warming. Refrigerators and freezers were major users of electrical energy, accounting for approximately 20% of

6. "Umweltrelevanz und Entsorgungspfade von Ktihl- und Gefriergeraten. Antwort der Bundesregierung auf Kleine Anfrage." In: Umwelt No. 6/1993, p. 230.

7. "Kampf urn Gkokuehlschrank: Greenpeace widerspricht der Kritik von Konkurrenten." Siiddeutsche Zeitung, October 29, 1992, p. WS5.

8. UNEP 1991b, cited in Cohen and Pickaver 1992, 31.

9. "Germany: Kahl-Gruppe/Berthold Wachtel Develops Plant for Recycling Refrigerators." Handelsblatt, October 4, 1991, p. 24 (Reuter Textline).

Figure 1

Environmental Regulation in Germany: Refrigerators					
Focus / Media	**Suppliers**	**Production**	**Usage**	**Service**	**Disposal**
Market Incentives					
Voluntary Agreement	Voluntary early phase-out of CFC-productlon	Voluntary CFC-phaseout, Voluntary energy efficiency standards, Voluntary energy labeling			
Eco-Labels		Blue Angel Label awarded to environmentally friendly products			
Disclosure Requirements	Presence of ozone-damaging CFCs to be revealed (FCKW-Halon-Verbots-Verordnung)	Presence of ozone-damaging CFCs to be revealed (FCKW-Halon-Verbots-Verordnuna			
Direct Regulation	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban after 1994 (FCKW-Halon-Verbotsverordnung)	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban after 1994 (FCKW-Halon-Verbotsverordnung)	CFC-ban after 1995 (Montreal Protocol. EC directive, CFC-ban after 1994 (FCKW-Halon-Verbo!sverordnung)	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban after 1994 (FCKW-Halon-Verbotaverordnung)	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban atter 1994 (FCKW-Halon-Verbotaverordnung). Abfallgesetz Take-back of used refrigerators (Elektronlk-Schrott-Verordnunq. not yet enacted)
Other		TechnIcal products to be sold only with safety attest [Gerateslcherhelts-sesetz)			

normal typeface small impact — underlined medium impact — bold: large impact the domestic electricity usage in the U.S.[10] The data was similar for Germany, where some 21.4% of the country's domestic electricity usage and some 4.5 % of its total electricity usage was for refrigerators and freezers.[11] The average British refrigerator used 1.9kWh per liter of volume, compared with commercially available models in Denmark which used 0.4kWh and models under development which used just 0.2kWh. Freezers in the U.K. used 2.4kWh per liter of volume, compared with 0.9kWh for mass-produced models already available (woods of Canada and AEG of Germany) and with just 0.4kWh in models being developed during the late 1980s (see Table 3).[12]

A final environmental concern involving not only refrigerators but any electric appliance were the electro-magnetic fields (EMFs) which they emitted. While some biological effects from EMFs had been established, such as on the pineal gland, which regulated circadian rhythms, scientific research about the dangers from EMFs was far from conclusive. In any case, its possible dangers could be reduced sharply by dividing a refrigerators electrical circuits into parallel circuits running in opposite directions which would cause the fields to cancel each other out. In 1994, EMFs were neither the subject of any environmental regulation nor the target of any innovative efforts by manufacturers.

Current Environmental Regulation

Refrigerators were the subject of a considerable amount of regulation all over the world. Most regulation concerned the production and use of CFCs, while some concerned the refrigerator's energy usage. The most important "law", however, was not a law: The "Montreal Protocol on Substances that Deplete the Ozone Layer" of 1987, amended in 1990 and 1992, was an international treaty which required the more than 75 countries that had signed it to enact regulation concerning the use and production of chlorofluoro-carbons (CFCs) and hydrochlorofluorocarbons (HCFCs), two substances which, among other uses, were employed in refrigerators. The original Montreal Protocol of 1987 had required freezing the production of CFCs at their 1986 levels, followed by progressive reductions in production. In 1990, the protocol

10. Harkness. 1992.

11. "Umweltrelevanz und Entsorgungspfade von Kiihl- und GefriergerAten. Antwort der Bundesregierung auf Kleine Afrage." In: Umwelt No. 6/1993, p. 230.

12. "The Real Problem with Fridges." The Financial Times. Power Europe. Energy Section. March 16, 1989.

was amended and the Year 2000 was set as a CFC-phaseout date. The protocol's 1992 amendment established the year 2020 as a phaseout date for HCFCs and moved the CFC-phaseout date up to 1995 (Table 6).

In Europe, the Montreal Protocol had been responded to, both, by a directive passed by the European Community, as well as by specific laws passed by the respective member countries. The European Community directive, passed in 1992 at the urging of the German government, called upon the member countries to ban production and consumption of CFCs by the end of 1995. The specific German law was the FCKW-Halon-Verbots-Verordnung (CFC-Halon-Prohibition-Decree).[13] It had already been enacted in 1991, but had set an even stricter deadline than both the EC directive and the 1992 Montreal Protocol amendments. After 1994. it was prohibited in Germany to use or produce CFCs, to import or produce appliances containing CFCS, to release CFCs to the environment (making recycling of old refrigerators mandatory). The law made Germany the world's first country to have completely phased out CFCs and firmly established Germany as a first-mover with respect to CFCs.

The FCKW-Halon-Verbots-Verordnung was accompanied in Germany by several voluntary agreements. On May 30. 1990. German producers of CFCs had signed a voluntary, but binding agreement with the German minister of the environment that required them to cease producing as well as take back and recycle the substances mentioned in the Montreal Protocol by the end of 1995. The FCKW-Halon-Verbots-Verordnung, which was subsequently drafted, specifically took this agreement into account.[14] This first voluntary agreement was followed on July 15, 1992 by a "voluntary binding announcement" by the six German producers of refrigerators who pledged to have converted 10% of their production to CFC-free technologies by the end of 1993. On April 22, 1993 they submitted another binding announcement to the German Ministry of the Environment and pledged to have converted not 10%, but

13. Bundesgesetzblatt 1991.

14. "FCKW-Ausstiegskonzept endgultig beschlossen. Umwelt Nr. 611991.

75% of their production by the end of 1993, and to completely exit CFC-technologies by mid-1994 in their both their domestic and their foreign plants.[15]

In most countries, refrigerators were also the subject of safety regulations which impacted upon a manufacturer's choice of cooling technologies, refrigerants, etc. The respective law in Germany was the Geratesicherheitsgesetz which decreed that technical products could only be sold if they did not endanger the life or health of their user or other third persons. Unlike safety regulation in many other countries, the German Geratesicherheitsgesetz did not prescribe specific technologies which could or could not be used, relying instead on a certification system under which products could only be sold after a prototype had received a so-called Sicherheitszeichen-Genehmigungs-Ausweis (safety mark award certificate) from an independent, government-acknowledged (but not government-owned) testing agency.[16] In early 1994 a European Community directive on refrigerator safety had not yet been enacted, but the draft of the EN 378 European Refrigeration Standard was said to be modelled closely after the German law.[17]

Particularly in Northern Europe, refrigerator disposal was also frequently regulated. In Germany, the FCKW-Halon-Verbotsverordnung (see above) the Abfallgesetz (waste law), a law dealing with waste disposal in general, as well as the Altdlverordnung (waste oil decree), a decree dealing with waste oils including refrigerator compressor oil, already had some influence on refrigerator disposal. There was not yet, however, a law dealing specifically with refrigerators or appliances. The German Elektronik-schrottverordnung (electronic waste decree) was intended to address this issue.[18] Originally intended for enactment by January 1994, but subsequently delayed for at least one year, this much debated law was to require all manufacturers and importers of electric and electronic appliances to take them back after their useful life and recycle them.

15. "Deutsche Hersteller versprechen fir Mitte 1994: Deutsche Kiihlschranke ohne FCKW." Stiddeutsche Zeitung, April 23, 1993.

16. TUV Product Service, 1992.

17. Greenpeace: Glitscher, W. Personal communication to the author

18. Bundesminister fiir Umwelt, Naturschutz und Reaktorsicherheit, 1992.

Many Countries including the United States, also regulated a refrigerator's energy consumption. In Germany, there was no specific regulation concerning energy consumption, but a voluntary program for energy efficiency targets for white goods combined with energy labelling. This program had been established at the urging Of the government with efficiency improvement targets ranging from 3-5% for electric cookers, 7-10% for washing machines, 10-15 % for dishwashers and 15-20% for refrigerators and freezers. All targets had subsequently been exceeded by a wide margin.[19]

Besides outright regulation and voluntary agreements, German refrigerator makers also had to decide on whether to adhere to the requirements of the German Blue Angel label. This was Europe's first and oldest eco-label which only products meeting specific environmental requirements were allowed to carry. The Blue Angel, introduced by the German government in 1977, was supported but not controlled by the government and had considerable impact on purchasing decisions. It was awarded by the so-called Jury Umweltzeichen (environmental labelling jury) comprised of representatives from industry, environmental protection organizations, consumer associations, trade unions, the press, governmental advisory bodies, and the states. For a refrigerator to qualify for the label, it had to employ CFC-free coolants and insulation materials. be energy efficient, and provide information on proper disposal practices.[20]

Focus of Regulation

In most countries regulation affecting refrigerators focused on the product and its disposal, to some extent also on the production process and on product maintenance. Legislation concerning product use was not existent.

Type of Regulation

Most regulation concerning refrigerators took the form of outright command-and-control regulation or performance standards. In addition, and this was particularly true for Germany, voluntary agreements

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19. "Energy Efficiency Signals from Brussels." Financial Times, October 16. 1991, Survey Section, p. V.

20. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1 1993.

or announcements as well as labelling schemes were important. There was no refrigerator regulation taking the form of market incentives in Germany.

COMPETITION

Germany

Competitiveness Overview

With a 1990 production volume of 5.042 million refrigerators and freezers, representing a world production share of 11.1 %, Germany was the world's third largest unit producer of domestic refrigerators and freezer, behind the United States and Japan. It was followed by China, Italy, South Korea, Brazil and the United Kingdom (Table 1). Data to show comparative refrigerator production by value was unavailable, but it would have shown Germany as the world's second-largest or even largest producer of refrigerators, for the country's refrigerator industry focused on the high end of the market, leading to much higher unit values than those in competing countries.

In most countries the refrigerator industry was oriented primarily towards its own domestic market. The German refrigerator industry, however, was export oriented. With a 1990 world export share of 13.4%, West Germany was the second largest exporter of domestic refrigerators and freezers. West Germany was surpassed only by Italy which accounted for 28.7% of the world's exports of refrigerators and freezers, but followed by the United States. With $394.9 million, Germany ran the world's second highest trade balance for refrigerators in 1990 (Table 2).

Leading Firms

The German domestic refrigerator industry consisted of six firms: Five were located in West Germany, while the sixth was based in the East German state of Saxony. The largest producer was Bosch-Siemens Hausgerite (BSHG) with a 1991 refrigerator and freezer production of 2.3 million units. Headquartered in the Bavarian town of Munich, BSHG was owned 50% by Siemens and 50% by Bosch, two leading German producers of electric and electronic goods. The firm distributed its products separately through Siemens Elektrogerate of Munich and Bosch-Hausgerate of Stuttgart under the Siemens and Bosch names, respectively, as well as under the Constructa-Neff name. Besides refrigerators and freezers, the firm's product range covered washing machines, dryers, dishwashers, heating appliances, water heating appliances, vacuum cleaners and other small domestic appliances, drink-dispensing machines, air conditioners, as well as TV, video, hi-fi and portable audio equipment. In 1992, BSHG had 23,600 employees and total sales of DM7.0 billion for an operating income of DM270 million. 55.3% of the firm's sales were achieved within Germany, the remaining 44.7% abroad. In 1993, BSHG had expanded its refrigerator plant in Giengen in South Germany to an annual production capacity of 2 million units, making it the world's largest production facility for refrigerators.[21] Like its other German competitors, Bosch-Siemens competed primarily on the European markets. To extend its reach into the American market Bosch-Siemens had begun in 1992 to cooperate with Maytag from the U.S.[22]

An estimated annual production of 1.2 million refrigerators made Liebherr-Hausgerate, based in Ochsenhausen in South Germany, the second largest producer of refrigerators in Germany. Liebherr was the German market leader, accounting for more than 30 % of the German market for freezers and 23 % of the German refrigerator sales.[23] Unlike its German competitors, who all produced a full line of domestic appliances, Liebherr concentrated on refrigerators and freezers. In 1991, Liebherr-Hausgerlte had sales of DM727 million and 2,100 employees.

AEG Hausgerate of Nuremberg was the second largest appliance maker in Germany and, with an estimated annual production of 600,000 units, thought to be Germany's third largest producer of refrigerators. AEG Hausgerate was a subsidiary of the large German electrical and electronics goods company AEG which in turn was owned by the largest German corporation, the luxury-car-maker Daimler-Benz. In 1992, AEG Hausgerate had some 10.000 employees, sales of DM2.66 billion, and a net income of DM60 million Its chief operating subsidiaries included AEG Telefunken Hausgerate, Duofrost Kiihl- und Gefriergerate and Rondo Hausgerate. Refrigerators and freezers were built at a plant in Kassel. AEG was not as shy as its other German competitors in cooperating with other firms or sourcing from competitors. It bought lower-priced refrigerators from Merloni of Italy, and was also thought to have acquired refrigerators from Foron Hausgerate, formerly dkk Scharfenstein. During the late 1960s and early 1970s AEG Hausgertite had followed an expansion-by-acquisition strategy and

21. "In Giengen entsteht die weltgrbt3te Uihlschrank-Fabrik." Stiddeutsche Zeitung, September 7, 1993, set: Wirtschaft.

22. "Bei Haushaltsgersten rollt die ijko-Welle." Siiddeutsche Zeitung, May 21, 1993.

23. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1, 1993.

acquired the German producer of built-in kitchens Alno, the German domestic-appliance-makers Neff, Zanker and Kuppersbusch, the household goods side of Linde, three-quarters of a Brown Boverie subsidiary, and a 20 % minority share of Zanussi of Italy, then the largest European producer of domestic appliances. AEG subsequently failed to consolidate its takeovers and had to divest Alno, Neff and the minority share in Zanussi, as well as close the ultra-modem freezer plant it had acquired from Linde. After severe financial difficulties AEG in 1983 applied under the German Vergleich scheme for court protection from its creditors. It was subsequently acquired by Daimler-Benz which failed to consolidate it into its own line of businesses (automobiles and aircraft). In 1992 Swedish Electrolux acquired 10% of AEG Hausgerate's capital and in late 1993 announced its intention to acquire the remaining 90% in a transaction estimated to be worth DM1 billion.[24]

Bauknecht was located in Stuttgart, the capital of the South German state of Baden-Wurttemberg. Bauhecht had 1990 sales of DMl .17 billion, of which DM292 million were attributable to its cooling freezing-division. Its net profit amounted to DM11.2 million. With DM1.6 billion, Bauknecht's sales had been substantially higher in 1981. Bauknecht had been family-owned until 1982, when as a result of mismanagement and wrong product-positioning, it had run into financial difficulties and sought court protection from its creditors. Bauknecht was subsequently bailed out by the home appliance division of the Dutch electrical goods giant Philips, which, in turn, had been sold to Whirlpool of the United States in 1987.

Miele of Gutersloh between the North German cities of Hannover and Cologne was often nicknamed the "Mercedes" of the appliance business, because of its concentration on the production of luxury, high-quality, high-price units. Miele was the only family-owned appliance maker in Germany. In 1989, Miele's turnover was DM2.6 billion. More than 80% of it was accounted for by household appliances, primarily washing machines, tumble-dryers and dishwashers, and to a lesser extent refrigerators. Foreign sales accounted for 56% of turnover; nevertheless, Western Europe generated 97% of the group's turnover, with EC countries accounting for more than 80%. In 1990, Miele employed 14,400 employees of whom some 60% were based in Germany. Like most of its competitors, Miele attributed part of its

24. "Demontage des Elektrokonzems AEG." Neue Ztircher Zenung. December 12, 1993, no. 287. p. 30.

growth to acquisitions, having acquired the German appliance producers Cordes and Imperial in 1986 and 1989, respectively.

The sixth German producer of refrigerators was Foron, formerly dkk Scharfenstein. Based in the Saxonian town of Scharfenstein in the former German Democratic Republic, Foron was much smaller than its West German competitors. Due to its successful introduction of the first truly environmentally friendly refrigerator to the German market in 1992, however, Foron had made a major impact on the German refrigerator industry and was generally acknowledged as a most important innovator (see below), In 1993, Foron had 670 employees and sales of DM200 million for an unspecified net loss. For 1994 the firm expected sales to increase to DM250 million and to post a profit for the first time since its privatization in late 1992.[25]

An important force in the German white goods market besides the manufacturers themselves was the mail order company Quelle. Quelle did not engage in actual production but bought OEM appliances from other producers, primarily from Zanussi in Italy, but also from an Electrolux plant in the United Kingdom, from AEG, as well as from Foron. Quelle was thought to have a German market share of 10%, mainly in the lower to medium price segment.

The United States

Competitiveness Overview

The United States was the world's largest producer of refrigerators. In 1990, 7.8 million refrigerators and freezers were produced in the U.S., translating into an approximate world production share of 17.3 % (Table 1). The U.S. were also a significant exporter of refrigerators and freezers and accounted for a world export share of 10.7 % and a trade surplus of $157.1 million (Table 2). The U.S. domestic appliance industry was dominated by five firms who accounted for 96% of the U.S. market. Despite industry complaints about sharp competition, excess capacity and pressure on margins, the Federal Trade

25. "Foron macht mit dem oko-Ktihlschrank Furore. " Siiddeutsche Zeitung. July 26, 1993.

Commission 1991 was believed to be examining possible price-fixing by the five large appliance makers[26]

Leading Firms

The leading U.S. refrigerator producer was General Electric with a 1990 domestic market share of 35.0%, followed by Whirlpool with 23.0%) White Consolidated (Electrolux) with 18.0%, Maytag (13.0%), and Raytheon (7.0%).[27]

General Electric Appliances was a subsidiary of GE, the leading American electric and electronics goods multinational. Headquartered in Louisville, Kentucky, GE Appliances produced refrigerators at its large Appliance Park plant in Louisville, as well as in Bloomington, Indiana, and in Decatur, Alabama. General Electric was part of a European alliance of appliance makers, that included Thomson Electromenager of France, GEC of the United Kingdom, Fagor, the leading Spanish white goods group, and the Italian producer Ocean.[28] In 1992, GE Appliances had sales of $5.7 billion for an operating profit of $467 million.

Whirlpool Corp. was the world's leading manufacturer and marketer of major home appliances and the United States' second largest refrigerator maker. Headquartered in Benton Harbor, the company manufactured in 12 countries and marketed products under 10 major brand names in more than 120 countries. Most of Whirlpool's refrigeration production was concentrated in Evansville, Indiana. In 1991, Whirlpool had completed the acquisition of the appliance division of the major Dutch electronics goods producer Philips, giving it, among others, control of the German appliance maker Bauknecht. In 1990, 63 % of sales and 79% of profits were sourced from North America. Home appliances accounted for 97% of total turnover in the same year. Turnover for 1990 was $ 6.6 billion, up 5.3% from 1989, for a net income of $72 million, down from $187 million in 1989.

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26. Tait, N. and van de Krol, 1991.
27. Investext, March 18, 1991. Cited in: Gale Market Share Reporter 2nd Edition 1992.
28. Dawkins, 1992.

The third largest producer of refrigerators in the U.S. was White Consolidated, a subsidiary of the Swedish appliance maker Electrolux since 1985/86. Headquartered in Cleveland, Ohio, White produced a large range of appliances but was particularly strong in the U.S. refrigeration and cooker markets. The firm sold its refrigerators under the brand names of, among others, Frigidaire, Kelvinator, Tappan, and Eureka.

Maytag, headquartered in Newton, Iowa, was the fourth largest appliance manufacturer in the U.S. It sold refrigerators under the Jenn-Air brand name and, since 1989, under the Maytag name. After a $23 million operating loss showing in its European markets in 1990, Maytag had consolidated its European operations and entered into an alliance with Bosch-Siemens Hausgerate in hopes of improving its European market share. In 1990, Maytag had sales of $3 billion, for a profit of $99 million.

The Raytheon Appliance Group was the U.S. ' fifth-largest seller of refrigerators, which were sold under the Amana name. The group was a division of Raytheon, based in Lexington, Massachusetts, a producer of military weaponry systems, civil aircraft, appliances, and environmental services. In 1992, the Appliance Group had sales of $1.1 billion for an operating income of $34 million.

Distinctive Environmental Regulation in the United States

Like every developed country, the U.S. had signed the Montreal Protocol, which initially required them to ban CFCs at the latest by the year 2000, then by 1995. The Montreal Protocol had been responded to in the U.S. by provisions in the Clean Air Act Amendments of 1990 requiring the phaseout of CFCs by 2000. In 1992. in a presidential order issued by then-President Bush that anticipated the 1992 Montreal protocol amendments by a few months, the deadline had been moved up to the end of 1995.

Besides outright regulation of CFCs, the U.S. had also introduced some innovative market incentives to speed up the phaseout. Federal excise taxes had been imposed on ozonedepleting chemicals and on imported products containing or manufactured with these chemicals. The taxes on CFC-11 and CFC-12, both used in refrigerator manufacturing, were at $1.37 per pound in 1991. In 1992 they rose to $1.67

per pound, and reached $3.35 by early 1993, making CFCs more expensive than their newly developed replacement refrigerant HFC-134a.[29]

Refrigerator energy usage was regulated in the U.S. by law. Authorized by the National Appliance Energy conservation Act (NAECA) of 1987, the U.S. Department of Energy (DOE) in 1990 had issued strict refrigerator energy standards which had to be met for 1993 production. On average, these standards required a 25-30 % additional efficiency increase over the Act's 1990 requirements and possible further efficiency increases for 1998.[30] Specifically, a 18ft^3 top-mount refrigerator manufactured in the U.S. in 1990 could consume between 750 and 860kWh/year, while a refrigerator of the same size manufactured in 1993 was required to consume only 689kWh/year.[31] A further increase in U.S. energy standards was expected for 1998.

In addition to energy efficiency regulation, there was also regulation requiring manufacturers to disclose their product's energy efficiency. As a result of the U.S. Energy and Policy Conservation Act of 1975, the Federal Trade Commission required since 1979 efficiency labels for seven appliance categories including refrigerators.

A distinct feature of the United States was the amount of conservation and load management services that utilities offered to their customers. By 1990, more than 500 utilities had offered over 1,000 "demand-side management" (DSM) programs, many in the form of rebates to customers who bought new energy efficient appliances or discarded old ones.[32] The best-known of these DSM-programs was the Super Efficient Refrigerator Program (SERP). a $30-million contest to develop an energy efficient, CFC-free refrigerator (see below). DSM-programs were a result of the fact that it could be more profitable for a utility to sell less rather than more energy due to the increased cost and difficulties of locating new power

29. "Household Consumer Durables; Household Appliances." U.S. Industrial Outlook, Chapter 37, January 1992." DuPont's CFC-Phaseout Ahead of Schedule." The Weekly Home Furnishings Newspaper, March 15, 1993, vol. 67, no. 11, p. 124.

30. Waidron 1992, I

31. EPA February 1992, p. 6.

32. EPA February 1992, p. 102.

plants to produce more energy. The increase in DSM programs was also a result of new or stricter environmental regulations that made it more attractive to shut down old, high-emission power plants rather than rebuilding them, as well as pressure from environmentally concerned customers and pressure groups. By promoting a change towards more energy efficient appliances and signaling to producers that there was a market for energy efficient appliances, DSM-programs were a possible means of fostering innovation in the refrigerator industry.

Unlike the case in most northern European countries, appliance disposal was not yet considered an environmental problem in the United States. Even though the country was running out of landfill space, there was not yet federal legislation requiring the take-back or recycling of disposed appliances.

Responses to Environmental Regulation in the U.S.

Characteristic of the American refrigerator industry was the fierce competition over marketing, distribution and sales combined with a lack of competition over product features, technology or environmental safety. When it was required to develop new technological alternatives to CFC-based refrigerants and insulations, the U.S. refrigerator industry, which, like most of its international competition, had not engaged in any real product innovation since the 1950s, was very slow to respond. In 1994, most American refrigerators were focusing on the same technology: HFC-134a as refrigerants and some type of HCFC (which was to be phased out by 2020 under the Montreal Protocol) as blowing agent for the insulation foam.

Japan

With a production of 5.048 million refrigerators and freezers in 1990, representing a world production share of 11.1% , Japan was the world's second largest producer country (Table 1). However, most of the production was aimed towards the domestic Japanese market. Japanese domestic appliance makers were uncompetitive internationally. Japanese refrigerators and freezers accounted for only a 3.2% world export share in 1990 (Table 2). There were ten large producers of refrigerators in Japan, including Matsushita Electric Industrial Company, Toshiba, Hitachi, Sanio, and Sharp.

Like all signatory countries of the Montreal Protocol, Japanese firms were required to have phased out the use of CFCs after 1995 and the use of HCFCs after 2020. The Japanese law regulating the CFC-phaseout was the "Law concerning the Protection of the Ozone Layer through the Regulation of Specified Substances and Other Measures" which had first come into effect on July 1, 1989.[33] As was the case in the United States, Japanese regulation concerning CFCs was as strict as it was in Germany, nor did Japanese phaseout deadlines anticipate those of the Montreal Protocol, as was the case in Germany, and, to a much lesser extent, in the U.S.

Japanese firms were not a driving force in the global search for CFC-replacements. Instead they continued to invest heavily in environmentally harmful coolants and insulation and were reluctant to begin early conversion of production lines to new products. In February 1992, for instance, the same month that the major German refrigerator producers announced they would all market truly environmentally friendly non-CFC, non-HCFC, and non-HFC refrigerators, Japanese companies were still at the research stage and announced a three-to-six-year, $5 million joint-study of the safety of HFC-32 for use in aerosols and refrigerators.[34]

Production of the first CFC-free refrigerators in Japan only started in early 1993 and sales began in October of 1993. Initially announced in August 1992 as being up to 40% more expensive,[35] an estimate which by August 1993 was lowered to l0-15% ,36 the new Japanese refrigerators did not employ any innovative technologies, relying instead on HFC-134a as refrigerants and HCFC-141b and HCFC-22, two substances to be phased out under the Montreal Protocol after 2020, as insulation blowing agents. In international comparison, Japanese refrigerators were very expensive and price-uncompetitive. A typical

33. Masuda, 1991.

34. "Japanese Companies Announce Project to Test CFC Substitute." Agence France Presse, February 4, 1992.

35. "Electric Appliance Makers to Produce CFC-Free Refrigerators, Starting in 1993." The Bureau of National Affairs, International Environment Reporter Current Report Japan. August 12, 1992, vol. 15, no. 16, p. 522.

36. "Ten Manufacturers to Begin Sales of CFC-Free Refrigerators in October." The Bureau of National Affairs. International Environment Reporter Current Report Japan. August 25, 1993, vol. 16, no. 17, p. 622.

350-liter, CFC-free refrigerator cost $1,500-2,000 - about three times the price of U .S .-made products.[37]

The slow speed of innovation and the fact that German firms were innovating faster and had chosen a direction that could be more promising, was even acknowledged by the Japan Electrical Manufacturers' Association, whose head of planning in early 1993 stated that Japanese manufacturers should ignore the German development as long as it had only been in the hands of a small east German company. Now, that Bosch-Siemens and the other big German producers had also adopted the new technology it was perceived as a threat in Japan, but: "Japan has chosen to go the road of HFCs and HCFCs, so things can't be changed so quickly. "[38]

Italy

With an estimated world production share of 9.0%) Italy was the fifth largest producer of refrigerators and freezers in the world (Table 1). The Italian refrigerator industry was very export intensive and had been for many years the world's leading exporter of refrigerators and freezer. In 1990, Italian firms accounted for 28.7% of the world's exports of refrigerators and freezers and a trade surplus of $964 million, almost 2.5 times higher than that of Germany, whose refrigerator makers accounted the world's second highest trade surplus (Table 2). Unlike their German competitors which concentrated on the high end of the market, Italian producers of refrigerators focused more on the medium-price segment of the market. The leading Italian firms were Zanussi. a subsidiary of the Swedish domestic appliances giant Electrolux, Merloni Elettrodomestici, Candy, and Ocean. In recent decades Italian firms had expanded considerably by acquiring domestic as well as foreign firms. Thus Merloni had bought Colston of the United Kingdom in 1979, Indesit of Italy in 1987, the fitted kitchen specialist Scholtts of France in 1989, and Fundicao de Oeiras of Portugal of 1989. Likewise, Candy had bought Rosieres of France 1987, the European operations of Kelvinator in 1981, Zerowatt of Italy in 1985, and Gasfire of Italy in 1986, while Ocean had bought the Italian firm San Giorgio in 1984.

37. "Ten Manufacturers to Begin Sales of CFC-Free Refrigerators in October." The Bureau of National Affairs, International Environment Repotter Current Report Japan. August 25, 1993, vol. 16, no. 17, p. 622.

38. "Germans Beat Japanese in Making CFC-Free Refrigerators. " Kyodo News Service, Japan Economic Newswire, February 27, 1993.

There was no regulation in Italy, concerning refrigerators, that was distinctively different from European standards. Italian firms were not renowned for seeking innovative solutions to address the CFC-problem.

Sweden

Sweden accounted for Only 3.3 % of the world's exports of refrigerators and freezers in 1990. The country was not renowned for the competitiveness of its indigenous refrigerator industry, but only for the fact that it was home 10 Electrolux, the largest European producer of appliances. Electrolux was a conglomerate of about 500 firms, of which about half were in Sweden. Overall the group has a presence in 48 countries. Its main areas of interest were large household appliances, vacuum cleaners, sewing machines, and home electronics. Beginning in the 1970s Electrolux had followed a very aggressive acquisition strategy. Among Electrolux' acquisitions had been Arthur Martin (France, 1976), Therma (Switzerland, 1977), Zanussi (Italy, 1984), Ibelsa-Zanussi (Spain, 1984), Zanker (Germany, 1985), White Consolidated (USA, 1986), Thorn-EM1 Appliances (United Kingdom, 1987), Corbero (Spain, l988), Domar (Spain, 1988), Buderus Juno (Germany, 1989), and AEG Hausgerate (Germany, 1994). These acquisitions had allowed Electrolux to increase its European market share from 8% in 1980 to 22% in 1988.[39]

Electrolux manufactured refrigerators and freezers in Italy, Sweden, Finland and Spain with the largest refrigerator plant being the Arthur Martin Company in France, which marketed its products under the Arthur Martin and Faure brand names. In 1990, Electrolux had sales of SEK82.4 billion ($14.64 billion) for a net income of only SEK741 million ($131.6 million).

Environmental regulation concerning refrigerators was stricter in Sweden than in many other countries. In 1992, for instance, Sweden had proposed an immediate ban on all products containing CFCs, HCFCs and other ozone-harming products where alternatives existed. This went beyond the then 1997 CFC

39. Serafin 1991. 119

phase-out agreed by the EC, and Sweden, which had applied to join the EC, was warned by the EC that the move would be a barrier to trade because it would rule out the export of refrigerators and other products which used ozone-depleting substances.[40]

Sweden had had its own form of the Super Efficient Refrigerator Program (SERP) two years before the American program (see below) had been launched. In 1990, the Swedish energy authority ran a competition for an efficient, environmentally-friendly refrigerator which did not damage the earth's ozone layer. Five companies took part and the first prize, an order for 500 refrigerators, had gone to Electrolux for a system which used HCFC-123 instead of CFC-11 as a polyurethane foam insulation blowing agent (which still had the potential to damage the ozone layer and contribute to global warming), used 30% less electricity and cost 30% more.[41]

40. "EC 'trying to stop Sweden from barring all CFCs'". The Daily Telegraph September 19, 1992, p. 10.

41. "Sweden: Electrolux Produce an Environmentally Friendly Refrigerator." Reuter Textline: Dagens Industri, August 21, 1990, p. 7, 14.

By 1994, a number of different technologies that addressed the environmental problem posed by refrigerators had been developed or were under consideration. There were several new refrigerants, new cooling methods, new blowing agents for insulations, and new insulation methods. Methods to improve energy efficiency had been devised and concepts to address the disposal problem were being discussed. Judging the competitive implications of these technologies required not only assessments of their effects on product and production costs, but also had to take into account their environmental friendliness, energy efficiency, safety, and effect on utility.

Refrigerants and Cooling Methods

HFC-134a

The most commonly cited technological solution to the environmental threat posed by CFCs in refrigerants was their replacement with hydrofluorocarbons (HFCs). Particularly, the hydrofluorocarbon HFC-134a was the primary focus of development efforts for refrigerator makers all over the world with the exception of Germany, where refrigerator makers had changed their focus from HFCs to hydrocarbon (see below). HFCs had been developed soon after the ban on CFCs had been announced by the major CFC-producers who had poured hundreds of millions of dollars into their development and production facilities (see below) and praised them as environmentally friendly, safe, and energy- and cost-efficient replacements (Table 4).

However, by early 1994 it appeared as if HFCs were neither as environmentally friendly, nor as safe, nor as energy efficient, nor as cost-efficient as their producers asserted. Unlike CFCs, HFCs did indeed pose no threat to the earth's ozone layer as their so-called ozone depletion potential (ODP) was zero. They were, however, powerful global warming gases. One kilogram of HFC-134a had the global warming potential (GWP) of 1.2 to 3.2 tons of CO_2 - the world's major greenhouse gas. The global warming potential of the worldwide production of about 200,000 tons of HFC-134a predicted by the chemical industry, equalled roughly that of all CO_2 emissions of an industrialized nation the size of

France or England.[42] While there was not yet any legally binding agreement to reduce or stop further growth of emissions of gases contributing to global warming, there was a definitive likelihood of such an agreement to be signed in the future. The United Nations Convention on Climate Change which had been drafted during the Earth Summit on Environment and Development in Rio de Janeiro in 1992, did not yet contain binding limits, but was due to be revised, possibly as early as late 1994. Should the Parties to the Climate Convention decide to limit the use of HFCs or even ban them, those refrigerant producers and refrigerator makers who had placed all their development efforts on HFCs would once again have to develop new refrigerants.

HFC-134a was not a cheap CFC-substitute. Its production process - basically a two-stage process which required the production of CFC and its subsequent dechlorination into HFC - made it inherently more expensive than CFC, because there was always one additional production step. In 1992, and in the absence of taxes on CFCs, as was the case in Germany, HFC-134a was ten times as expensive as CFC-12: DM50/kg for HFC-134a compared to DM5/kg for CFC-12.[43] Other sources estimated a price differential of five times.[44] Given the small amount of refrigerant needed, 80 grams and an average refrigerator price of DM500, the higher price of HFCs did not pose a major problem, for it translated into a very small price increase of only DM1.80-3.60 or 0.35-0.7%.

However, HFC-134a was not an easy drop-in replacement for CFCs, as was sometimes asserted. It required modified compressors and synthetic compressor oils which were ten times more expensive than conventional oils for use with CFC-based refrigerants (DM15-30/kg).[45] In fact, the British HFC-134a producer ICI estimated the cost of converting existing cooling equipment in Europe alone to be around DM100 billion.[46]

42. Greenpeace. Greenfreeze: The World's first CFC- and HFC-free Refrigerators. N. p.. n. y.

43. Schwarz and Leisewitz, 1992, 31.

44. "ICI to Invest 60 M Pounds on Plants Making Alternative to CFCs." Financial Times, November 23, 1988, p. 9.

45. Schwarz and Leisewitz, 1992, 32.

46. Europa Chemie no. 23, 1992, p. 2. Cited in: Schwarz and Leisewitz, 1992. 3.

The final impact on a refrigerator's cost was difficult to judge, because manufacturers did not release the necessary numbers. In early 1994, CFC-free refrigerators on average cost some 6-8% more in Germany, regardless of the chosen refrigerant (HFC or hydrocarbon) and insulation method (blown with HCFCs or hydrocarbons, see below) .[47] In a Price-sensitive market these price increases could be considered significant. They were, however, much lower than some initial predictions which had estimated the conversion to result in 40% price increases in Japan.[48] and 30% in Sweden.[49]

Hydrocarbons

Instead of HFCs, CFC-based refrigerants could also be substituted by hydrocarbons, usually isobutanes or a mix of propane and butane. Hydrocarbon-based refrigerants were first introduced in Germany in the early 1990s, but they were far from being a new technology. Until the 1920s, propane-based refrigerants had been used in many refrigerators. Only with the development of CFCs which were not flammable and thus could not explode had hydrocarbon-based refrigerants become forgotten. By early 1994, they had become the technology of choice, because they represented the environmentally safest solution. Hydrocarbons had no ozone depletion potential, and, unlike the case of HFCs, only a negligible global warming potential (Table 4). Thus. there was no danger of hydrocarbon-based refrigerants being banned in the near future, a scenario that was possible with HFCs.

Hydrocarbons were flammable and thus posed a risk of explosion during refrigerator production as well as during usage. A common consensus was that the risk of explosion during production could be well controlled, although this required adding very expensive safety equipment. Initially, the situation had not been clear with respect to the refrigerator's safety during its usage. For many months after the first announcement of hydrocarbon-based refrigerants, opponents had maintained that they presented an uncontrollable danger of explosion. These voices were subdued in December 1992 when the official

47. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1, 1993.

48. "Electric Appliance Makers to Produce CFC-Free Refrigerators, Starting in 1993." The Bureau of National Affairs, International Environment Reporter Current Report Japan. August 12, 1992, vol. 15, no. 16, p. 522.

49 "Sweden: Electrolux Produce an Environmentally Friendly Refrigerator." Reuter Textline: Dagens Industri, August 21, 1990, p. 7, 14.

German safety testing agency, the Technischer Uberwachungsverein awarded its seal of approval to the first German refrigerator using a hydrocarbon-based refrigerant. By 1994, there was a common consensus in Europe that hydrocarbons using modem sealing technologies were a safe technology for refrigerators. In fact, the new EN 378 European Refrigeration Standard was expected to permit without restrictions up to one kilogram of inflammable refrigerants like hydrocarbons in small hermetically sealed refrigerators, although only 20 grams were required for a household refrigerator.[50]

Like HFCs, hydrocarbon-based refrigerants used as a “drop-in” replacement for CFCs in a conventional refrigerator were less energy efficient than CFCs. Research demonstrated, however, that theoretically hydrocarbons were energetically more efficient than CFCs and HFCs.[51] The theory proved to be right, when German firms managed to improve the energy efficiency of hydrocarbon-based refrigerators from an initial disadvantage of 12% to an equal match with CFC-based refrigerators.[52]

An initial drawback of hydrocarbon refrigerants had been the fact that they could only be used for cooling down to one temperature, preventing manufacturers from offering refrigerators with freezer compartments. The first hydrocarbon-based refrigerator in Germany, for instance, had no freezer compartment. By 1994, however, technological advances, particularly a switch away from the initial propane/butane mix towards isobutanes, allowed to offer combine refrigerator/freezers with hydrocarbon coolants.[53]

Hydrocarbon-based refrigerants were less expensive than HFCs. Unlike HFCs which were produced only by a limited number of multinational chemical firms, propane or butane could be obtained almost anywhere on the world and it was cheap, DM6-7/kg, compared to DM5O/kg for HFC-134a.[54] Even

50. Greenpeace. Greenfreeze: The World’s first CFC- and HFC-free Refrigerators. N. p.. n. y.

51. See, for instance, Diihlinger, 1991.

52. Greenpeace. Der Kiihlschrank-Krimi. Short Chronology of the dkk ScharfenstetiForon events. No place, no year.

53. Liebherr-Hausgertite GmbH: Futterer, B., Kaufm&nischer GeschPfisfiihrer. Personal communication to the author.

54. Schwarz and Leisewitz, 1992, 31.

compared to CFC-12 which cost less than DM5/kg it had a price advantage, because the required amount of propane/butane was less than 50% of the required amount of CFC-12. Other economical advantages of hydrocarbons were that they could be used with ordinary mineral oil instead of costly synthetic oils as was necessary with HFCS. Hydrocarbons could even be retrofitted in existing CFC appliances. And disposal of hydrocarbon-based refrigerators promised to be less costly, because the propane, butane, or isobutane could simply be burned in the end and did not have to be vacuum-pumped out and recycled.

Other Coolants

Besides HFCs and hydrocarbons, other environmentally benign coolants were being researched for their practical and commercial feasibility in the early 1990s. Discussed most often were ammonia-based coolants, which were energetically more efficient than CFCs and were particularly appropriate for achieving very low temperatures. For this reason, ammonia-based systems were primarily used in large scale commercial refrigeration applications.

Other Cooling Technologies

Manufacturers also researched alternative cooling techniques, that were altogether different from the predominant vapor-compression principle. However, none of these techniques was at a development stage that would allow it to be used commercially within the next future.

One alternative cooling technology was based on the Stirling motor. Still in the early development stage (although Stirling motors had been researched for decades), they were expected to cost about 20% more than existing domestic refrigerators, but be very safe since they were operated with helium, posed no risk whatsoever to the ‘environment, and were predicted to be 80% more efficient than conventional vapor compression machines. Another technology had been proposed by researchers from California. Their system used very high energy sound waves which caused inert gases to oscillate so they could cool their surroundings. [55]

55 Price. 1990.

Foam Blowing Agents and Insulation Methods

HCFCs

Similar to the debate over CFC-substitutes - HFCs or hydrocarbons - was the debate over alternative blowing agents for refrigerator insulations. Most refrigerator makers in the world were trying to meet the 1995 deadline for a CFC-phaseout by converting to blowing agents on the basis of hydrochlorofluorocarbon, usually HCFC-22, HCFC- 141 b, HCFC- 142b or HCFC-22/142b blends, However, these blowing agents could at best only be a stop-gap measure for they had to be phased out by 2020 according to the Montreal Protocol.

HCFCs had a much smaller ozone depletion potential than CFCs, somewhere between 2 and 11%. However, this measure ignored their short- to medium-term impact, as it was usually calculated over 500 years. HCFCs disintegrated much faster in the atmosphere and thus had a much larger effect on a short term basis. As a result, HCFCs produced in the 1990s were expected to hit the ozone layer precisely during the period of highest risk of extraordinary ozone loss, at a time when it was most sensitive to additional damage.[56] The problem was increased by the fact that HCFCs also were powerful global warming gases that were estimated to be 300 to 4,100 times more potent global warming gases than carbon dioxide (Table 5). Many observers thus considered HCFCs as "part of the problem, not part of the solution" and expected the deadline for their phaseout to be moved up, as had been the case several times with the deadline for CFCs. Producers developing HCFC-based blowing systems thus were developing into a dead-end and would at some foreseeable future be forced to convert their production once again.

HCFCs were more expensive than CFCs, resulting in an increase in the price of the insulation foam. In 1990, for instance, HCFC-22, a commonly proposed substitute blowing agent for insulations to be used in deep freezers and commercial refrigerators, was some 3 to 4 times more expensive than a conventional CFC.[57]

56. Greenpeace. Greenfreeze: The World's first CFC- and HFC-free Refrigerators. N. p., n. y"

57. Marsh, 1990.

Hydrocarbons

Given the fact that HCFCs were an agreed-upon transitory solution, it was amazing that almost all refrigerator makers In the world were concentrating their development efforts on their use as substitute blowing agents. The only exception was Germany, where the leading manufacturers concentrated on the use of hydrocarbons, such as n-pentane or cyclopentane, as a blowing agent alternative.

Hydrocarbon-based blowing agents had the advantage of being environmentally benign, thus there was no threat of any regulation requiring their phaseout. However, the insulating properties of pentane-blown foams initially were not as good as those of foams that had been blown with HCFCs, In order to maintain the same level of energy efficiency, manufacturers thus had to slightly increase the thickness of the refrigerator's walls, leading to a small reduction in the refrigerator's capacity. For instance, in 1992, a German refrigerator with pentane-blown insulation required a capacity reduction of 5 liters to 150 liters.[58] Many refrigerator makers maintained that this capacity reduction was unacceptable, although it was questionable if the user would even notice this capacity reduction of 3.3 % _ Further technical improvements subsequently allowed German producers to produce energy efficient refrigerators with hydrocarbon-blown walls that were as thick as HCFC-blown walls. In 1994, for instance, Bosch-Siemens introduced the world's most energy efficient refrigerator in its class, a 130 liter refrigerator with hydrocarbon-based coolant and insulation, walls of standard thickness and an energy consumption of only 0.46kWh per 24 hours.[S9]

Hydrocarbons were explosives. This led to increased production costs because manufacturing systems had to be made explosion proof. Retrofitting an existing foam production system to hydrocarbons was estimated to increase foam costs by 20-25 % while adding explosion proofing measures to a new system was thought to lead to an increase of only 5% .[60]

58. Schwarz and Leisewitz, 1992, 18.

59. Greenpeace: Glitscher, W. Personal communication to the author.

60. Greenpeace: Glitscher, W. Personal communication to the author.

Other Insulation Technologies

Besides research into which type of blowing agent to use for insulation foams, there was also considerable development work concerning other non-foam insulation technologies. Most often discussed were vacuum isolation panels (VIPs), made of thin plastic film walls that had been filled with zeolite powder and then evacuated. VIPs had exceptionally good insulation properties and were environmentally benign, but were still very expensive in 1994. The first refrigerators with vacuum panels had been introduced almost simultaneously in early 1993 by AEG in Germany and by Sharp in Japan.[61] The AEG model used VIPs on the side walls and polyurethane in the comers and used 15% less electricity than current models, AEG planned to introduce by 1995 models that only used vacuum panels and would require only one-third to one-half the electricity of current models, but be about one-third more expensive. The leading producer of VIPs in Europe and the United States was the German firm Degussa, in Japan it was Sharp.

Energy Consumption

Besides the fundamental decision on what kind of cooling technology and insulation method to choose, there was a large number of possible small changes a refrigerator maker could make to the hermetic system and the cabinet that did not directly affect the environment, but increased energy efficiency and thus indirectly improved the environment. Among the possible ways to improve refrigerator energy efficiency were more efficient compressors, variable speed fans and defrost that only worked when necessary, improved heat exchangers, changes to the refrigerator's evaporation system, thicker insulations, advanced gaskets, as well as better latches.[62] Manufacturer's experimented with all these technologies, but as of early 1994 no consensus concerning their cost effectiveness had been reached.

Refrigerator Disposal

Refrigerator disposal was a great concern to both regulators and consumers, particularly in Germany and the Northern European countries, but less so in the United States and even less in Japan. The

61. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1, 1993. "High Cost Hindering Adoption of VIP, CFC-Free Refrigerators." The Nikkei Weekly, March 8, 1993, p. 13.

62. EPA February 1992, p. 102.

fundamental decision concerning refrigerants and insulation blowing agent - HFCs and HCFCs or hydrocarbons - had a great impact on the ease and environmental safety with which a refrigerator could be disposed of. HFCS and HCFCS posed considerable threats to the environment and had to be recycled using costly equipment, while hydrocarbons were much more benign.

In Germany, the upcoming Elektronikschrottverordnung, a law that would force manufacturers themselves to take back discarded appliances, put particular pressure on the industry to devise and facilitate economically feasible recycling methods.

In 1993, for instance, Miele announced that it was able to recycle 90% of a washing machine, although this was not yet economically viable. Miele is among several German manufacturers embossing plastic components with a code indicating the type of polymer used, enabling scrapped components to be sorted.[63]

Two Different Routes to Achieving Change

By early 1994 it appeared to be clear that German and American manufacturers were pursuing different routes on their way to substituting CFC-based refrigerants and insulations - and that the German route, propane-butane or isobutane as refrigerants and insulations blown with pentane or cyclopentane or vacuum panels, appeared to be more promising, ecologically and economically, than the American route, where HFC-134a-based refrigerants had become the accepted choice. To understand why these different routes had been chosen, it is necessary to describe the most important events on both sides of the Atlantic which had led to these choices.

Greenfreeze and the Adoption of Hydrocarbon Refrigerants in Germany

The decisive events in Germany were those surrounding the East German firm dkk Scharfenstein's introduction of the first truly environmentally friendly refrigerator which contained neither CFCs, HFCs, nor HCFCs. Under communism, dkk Scharfenstein had been the only refrigerator manufacturer in East Germany, selling 1 million refrigerators and freezers annually and employing 5,500 workers. After the

63. Erlick, 1993.

unification of the two Germanies in 1991, annual production fell dramatically to 176,000 refrigerators and 54,000 freezers, which translated into annual sales of $48 million and a loss of $57.8 million. The firm had to reduce its workforce to 1,800 in 1991, followed by a further reduction to 600 in 1992.

At the same time, the German section of the environmental organization Greenpeace was investigating the commercial feasibility of a new, truly environmentally-friendly refrigerator technology which had been invented at the Hygiene-Institut in Dortmund, Germany a few years ago and was using neither CFCs, nor HFCs or HCFCs, relying instead on a mixture of propane-butane as a refrigerant. In early 1992, shortly before a public conference where all German refrigerator makers with the exception of dkk announced they would concentrate on HFC-134a as a replacement for the soon-to-be-banned refrigerant CFC, Greenpeace approached dkk for the first time to investigate if it would be interested in the new HFC- and HCFC-free technology. A curious circumstance made dkk particularly attractive to Greenpeace: Like competing products, dkk's refrigerators employed CFCs as refrigerants, but unlike its competitors, its insulations were already CFC-free. The lack of appropriate production facilities in the former GDR had forced dkk to innovate around this disadvantage and develop a CFC-free polystyrene insulation that compensated its slightly inferior insulation capabilities with a higher material thickness (38mm instead of 3Omm). Following a series of meetings between representatives from Foron, Greenpeace and the Dortmund Hygiene-Institut, Greenpeace sent another signal in July 1992 and awarded dkk a small contract valued at DM26,OOO to produce 10 working prototypes of the world's first refrigerator that would be completely CFC- and HFC-free and instead use a mixture of propane and butane as refrigerant and a polystyrene insulation blown with pentane.[64] The same month, dkk's owner, the German privatization agency Treuhandanstalt. announced its intention to liquidate dkk, following the termination of merger negotiations with Bosch-Siemens which had considered buying the firm.

With an inferior product, monthly losses of DM3 million and the threat of being liquidated, dkk was desperate for a new innovative product and decided to risk the commercial development of the first refrigerator which contained neither CFCs, HCFCs or HFCs. In a reversal of its traditional practice of refusing to actively promote commercial products, for the first time in its history Greenpeace ran a

64. Greenpeace. Greenfreeze: Die Chronologie einer umweltreclmischen Revolution. N. p,, n. y.

publicity campaign for the new "Greenfreeze" asking Germans to send in pre-orders for the new refrigerator which was tentatively priced at DM600-700, some DMl00 higher than the market price for conventional refrigerators containing CFCs .[65] The campaign irritated Treuhand officials, but quickly found favor in Bonn, where politicians eager to display environmental concern urged that the company be saved. In a letter to Birgit Breuel, the Treuhand president, the Gem Environmental Minister Klaus Topfer urged the Treuhand to "use every possibility to maintain this company's capability for existence. "[66]

The campaign also irritated the German Chemicals Industry Federation (VCI) which, representing the producers of the substitute refrigerant HFC-134a, publicly contended that hydrocarbon-based refrigerators used 40% more energy than CFC-based refrigerators and that polystyrene insulation was less effective than other insulators. A spokesman of the Industry Federation was quoted as describing the direction of this development as a dead-end.[67] Hoechst, the largest German producer of HFC-134a, also publicly denounced the "Dortmund mixture" as being energetically inefficient .[68] By the time of these denouncements dkk had already proven that the propane-butane mixture was not only as efficient, but theoretically even more efficient than CFC. Greenpeace also countered that, while the polystyrene insulation was indeed less efficient than conventional foams, this disadvantage had already been addressed by making it slightly thicker, reducing an average refrigerator's volume by a mere 5 liters from 145 to 150 liters.

The established West German competitors initially ridiculed dkk's new technology. Their general reaction was: "A refrigerator which works with cigarette lighter gas? Ridiculous! If that would work,

65. Culp and Mapleston, 1993.

66. Protzman, 1992.

67. "DKK Scharfenstein may be saved by CFC-Free Refrigerator." Frankfuner Allgemeine Zeitung, July 22, 1992 (Reuter Textline).

68. Greenpeace. Der Ktilschrank-Krimi. Short Chronology of the dkk Scharfenstein/Foron events. No place, no year.

everybody would have done it by now. "[69] A spokesman for the German electrical and electronics industry association ZVEI explained that dkk's propane-butane mixture was a considerable safety risk because of its inflammability, and the press spokesman for Bosch-Siemens said that the dkk refrigerator was only an apparent solution to environmental concerns, because there was no question of it matching the level of energy usage of conventional appliances.[70] When it became obvious that the Greenpeace campaign, which was attracting tremendous publicity in the German media, was beginning to threaten their own products, Bosch-Siemens, AEG, Bauknecht, Electrolux, Liebherr, and Miele reacted and sent a joint letter to their trading partners. The letter stated that the insulation material and the refrigerant used in dkk's refrigerator were less efficient than their own technologies, and also that hydrocarbon-based coolants were technically unsound and posed a significant risks of explosion during the refrigerator's usage.[71] The letter did not meet its sender's objectives, resulting instead in a public outcry and precisely the kind of media attention that dkk and Greenpeace needed. Saxony's finance minister immediately described the letter as "immoral discrimination against a competitor" .[72] A short time later, after Greenpeace had intervened at the German antitrust office, the letter's senders were required to sign a declaration that they would cease distributing the letter.[73] The alleged risk of explosion, though theoretically possible, was proven to be negligible, when in December 1992 the refrigerator received the required safety mark award certificate from the Bavarian testing agency Technischer uberwachungsverein (TUV). This established that the refrigerator's 20 grams of propane/butane refrigerant - the same amount that was contained in a cigarette lighter - was a safe alternative.[74]

69. Greenpeace. Der Kiihlschrank-Krimi. Short Chronology of the dkk ScharfensteinIForon events. No place, no year.

70. "DKK's 'Eco-Fridge' Given 'Blue Angel' Award, but still Little Interest from Western Manufacturers." Frankfurter Allgemeine Zeitung, August 8, 1992, p. 13. (Reuter Textline).

71, "Germany: Established Manufacturers Criticize DKK Scharfenstein's 'Eco-Fridge'". Reuter Textline: Frankfurter Allgemeine Zeitung, October 5, 1992, p. 16.

72. "Germany: Established Manufacturers Criticize DKK Scharfenstein's 'Eco-Fridge'". Reuter Textline: Frankfurter Allgemeine Zeitung, October 5, 1992, p. 16.

73. Greenpeace. Greenfreeze: Die Chronologie einer umwelttechnischen Revolution. N. p., n. y.

74. TiiV Product Service (ed.), December 9, 1992.

The publicity made the campaign, which initially cost $68,000, extraordinarily successfu.l[75] The ‘ German fridge ” or “Greenfreeze” as it had come to be called, received worldwide media attention. Less than four weeks after its start in August 1992, the campaign had attracted pre-orders for 70,000 refrigerators from environmentally conscious German customers plus an order for 20,000 units with an option for another 50,000 by Quelle, the leading German mail-order company.[76] (Unprecedented in the appliance industry, particularly for a product that was not even on the market.) That August, dkk was also visited by the German minister of the environment who declared that the “Greenfreeze” stood good chances of becoming the first German refrigerator to be awarded the prestigious Blue Angel eco-label. Shortly thereafter, the Treuhandanstalt announced it would not liquidate the firm, but invest DM5 million into the further development of the refrigerator. In November 1992, when a consortium of investors from Berlin and the firm’s management acquired the firm, it was renamed Foron Hausgerate and pledged to invest DM35 million over the following years,

With Foron’s future existence assured, Greenpeace changed its tactic and began to focus on the other German manufacturers. With advertisements and private negotiations it tried to convince them of the merits of the new technology. In February 1993 the sensation was perfect: Not only did Foron officially introduce its new refrigerator to the market, but, during the world’s largest appliance fair, Domotechnica, in Cologne. Bosch-Siemens, Liebherr and Miele announced the introduction of new refrigerator models that would work with propane and butane as refrigerants and employ insulations blown with pentane. Within only seven months, from September 1992, when they had contended that the propane/butane technology was not only inefficient but also dangerous, to February 1993, when they announced refrigerators using the same technology, the firms had made a complete turnaround. In March 1993, with Foron having successfully begun mass-producing its new refrigerator, Greenpeace formally terminated its relationship with Foron - after a campaign that had cost it DM500,OOO and had reached all its intended goals .[77]

75. Protzman, 1992.

76. Greenpeace: Glitscher, W. Personal communication to the author.

77. “Der TijV gibt dem ijko-Ktilschrank seinen Segen.” Siiddeutsche Zeitung, December 18. 1992.

In the following months the "Greenfreeze" proved to be extraordinarily successful. Not only was it awarded the expected Blue Angel eco-label, Foron's management was also presented with the environment award by the renowned Bundesstiftung Umwelt (Federal Foundation Environment). Most importantly, it met with very strong demand in the German market even though it was more expensive than competing products containing CFCs. By July 1993, five months after production had begun, Foron had already sold 35,000 units. Demand was outstripping production capacity which had reached its limits with 800 units a day, preventing Foron from selling an additional 75,000 units in 1993 for which there was demand. [78]

Foron's technology proved to be not only a small environmental niche but within a very short time became the dominating technology in Germany. By May 1993. Bosch-Siemens and Liebherr had converted their entire insulation production to pentane-blown foams. In November 1993, a few months after it had converted its insulation production from CFC-12 to HFC-134a, market pressure forced AEG to convert a second time, this time to foams blown with cyclopentane. By February 1994, Bosch-Siemens, Liebherr, and AEG had announced that they would convert the major part of their refrigerator production to the Greenfreeze technology.[79]

An interesting observation concerning the "dkk/Foron incident" was that the boldest and quickest innovative solutions in Germany had been announced by the four German firms who had their home base in Germany. while the two foreign-owned German producers had been much more timid. Specifically, the four early movers with completely CFC- and HFC-free refrigerators on the market - Foron, followed by Bosch-Siemens, Liebherr, and Miele - were German-owned firms. The other two producers in Germany, who had been late and very hesitant to convert were owned and controlled by foreign firms: Bauknecht by Philips which itself was a subsidiary of Whirlpool and AEG by Electrolux. It could be argued that the German-owned firms, being closer to the German market, had been forced to respond faster to the advanced environmental needs of the German customer, than the foreign-owned firms which also had to respond to signals from other, possibly less advanced markets.

78. "Foron macht mit dem Oko-Ktihlschrank Furore. " Suddeutsche Zeitung, July 26, 1993.

79. Greenpeace. Greenfreeze: Die Chronologie einer umwelttechmschen Revolution. N. p., n. y.

It was also interesting to ask whether the “dkk Scharfenstein incident” was a result of environmental regulation or of the pressure provided from Greenpeace’s actions. While it is difficult to separate the two reasons from one another, it is probably fair to say that the Greenpeace action would not have met with such a success, would it not have been for clear regulatory signals by the German government - aimed at both producers and consumers - that conventional refrigerators were environmentally unsafe and had to be phased out.

SERP and the Adoption of HFG134a Refrigerants in the U.S.

What Foron had done in Germany - force innovation onto an industry which had not seen any real product innovation for decades - the Super Efficient Refrigerator Program (SERP) had tried to do for the refrigerator industry in the United States. SERP was a $30 million contest to develop and market a refrigerator that would use no CFCs and exceed 1993 federal energy-efficiency standards by 30 to 50%. It was sponsored by, among others, the U.S. Environmental Protection Agency and 25 electric utilities who. based upon the number of residential customers they served, had committed between $150,000 to $7 million fo the prize money which was to be paid out to the winning manufacturer in the form of cash rebates per refrigerator sold. Consumer savings from reduced energy usage due to the program were projected by SERP at from $240 million to $480 million annually.[80]

The award was made based on a complicated scoring formula which assigned a weight of 75% to the economic efficiency of each proposal, 22 % on the manufacturer’s technical and corporate capabilities, and 3% on other special attributes, such as non-chlorine HCFC-substitutes. A winning entry had to be CFC-free, but HCFCs were perfectly acceptable and only 3% of the maximum score could be gained by developing a HCFC-free technology .[81] In fact, no additional points could be scored with a HFC-free refrigerator. Thus, SERP provided no incentives to develop a truly environmentally friendly technology.

80. “Whirlpool, Frigidaire Named Finalists in Utility Contest for Efficient Fridge.” Electric Utility Week (formerly Electrical Week), p. 2, December 14, 1992.

81. SERP Inc., 1992

SERP also placed much emphasis on “corporate reliability”, demanding that contestants had mass-production facilities as well as a national distribution and service network. This requirement restricted the contest to large, established refrigerator manufacturers and effectively excluded small, potentially more innovative firms such as the small refrigerator maker Sun Frost of Arcata, California, which claimed to produce a refrigerator that not only met the contest’s requirements but also was the world’s most energy-efficient .[82] Likewise, Foron, the developer of Germany’s “Ecofridge”, would have been excluded from SERP and thus would have been unable to perform its role of catalyst for change that it had played in Germany.

SERP was launched in 1990 with 14 contenders to compete for the prize. After a first round of eliminations in December 1992 only two were left: Whirlpool and Frigidaire Corp. In June 1993 SERP announced Whirlpool to be the winner. The winning entry was energy efficient, but not truly environmentally friendly by German standards for it used HFC-134a as a refrigerant.

SERP had brought about some change, but the question remains whether it could have fostered more innovative solutions. It was stated already that the contest may have been overly restrictive with respect to potential entrants and that it did not place real emphasis on environmental friendliness. However, there were other factors beyond these which also limited the extent of innovation. The German hydrocarbon technology would not have been eligible for entry because U.S. safety laws were not as flexible as German safety laws and prohibited the use of explosive refrigerants (even if the amount of refrigerant used equalled that in a cigarette lighter which was deemed “safe”). In the U.S. there was also always the threat of multi-million dollar liability lawsuits. should a refrigerator really happen to explode. Finally, the U.S. refrigerator industry was probably even less accustomed to product innovation than the German refrigerator industry. Competition, though fierce, had been based for too many decades on non-product issues such as marketing and distribution. In February 1993, at a time when the major German refrigerator makers were already marketing or had announced they would market hydrocarbon-based refrigerators, American manufacturers were still fighting that technology. A spokesman of Whirlpool was quoted: “We are still not certain that the propane-butane mixture does not bring the danger of

82. ECONEWS August 1992.

explosion" "This technology has been around for over 20 years. Why should it work today if it was not acceptable then?'[83]

Competitive Effects in Supplier Industries

Supplier Indutries

Probably more affected by the ban on CFCs than the refrigerator industry itself were the suppliers of refrigerants which had been asked to either develop non-ozone depleting refrigerants within a very short the period or to exit their business and leave the field to suppliers of alternative, perhaps non-chemical refrigerants such as propane or butane. Anticipating a world-wide annual market of 200,000 tons valued at DM10 billion for the CFC-replacement HFC-134a, the leading CFC-producers had invested heavily in research and production facilities. Until mid-1992, the two major refrigerant suppliers, DuPont and ICI. had already invested DM700 million each into research of and production facilities for the replacement refrigerant HFC- 134a.[84] Hoechst, a refrigerant producer from Germany, was known to have invested at least DM50 million to build a HFC-134a-plant with an annual capacity of 10,000 tons.[85] Production of alternative lubricants was also costly. In 1992 ICI announced a DMl8 million investment to set up production for a HFC-134-compatible lubricant.[86]

The high stakes involved led to some rather drastic actions from refrigerant makers. In 1990, when the signatory states of the Montreal Protocol were meeting in London to discuss, among other topics, a future ban on HCFCs which were known to be environmentally damaging but considered to be a stop-gap measure until the development of safer replacements. ICI and DuPont, in a joint announcement, threatened to halt all further investments into safe CFC alternatives if HCFCs were banned within a time period that would nor allow them to recoup their investments. ICI and DuPont said they needed at least

83. Kabel, 1993.

84. Europa Chemie no. 23, 1992, p. 2. Cited in: Schwarz and Leisewitz, 1992, 3.

85. "West Germany: Hoechst is to Reduce CFC Production by 50% by 1992/1993." Blick auf Hoechst, December 1. 1989 (Reuter Textline, Chemicals Business News Base, February 15, 1990).

86. "France: Oil for Refrigerating Machines - ICI Expands French Production." Europa Chemie, April 6, 1992, p. 2 (Reuter Textline, Chemicals Business News Base, May 15, 1992).

a 30-year life-cycle to recoup a fair profit from their HCFC-plants.[87] Perhaps not altogether coincidental. ly, during that year's talks the Montreal Protocol signatory states agreed to a HCFC-phase-out by the year 2020.

The CFC producers had also been forced to innovate in the area of blowing agents for isolating foam. Due to a considerable extent to the voluntary agreement between producers and the German government to cut CFC-contents in foams by 50%, German foam producers had begun very early to search for formulas for less CFC-intensive foams. In 1989, for instance, the leading German chemicals producer Bayer announced it had developed a method to partially replace CFCs by water. The water reacted with isocyanate and formed carbon dioxide, to be used as a blowing agent for rigid polyurethane foams. The new method, which could be used without modification in existing processing plants, cut CFC-usage in polyurethane foams by 50% and did not affect the insulating properties of the foam. It was adopted within a short time by most European producers of refrigeration units.[88] Pressure from the voluntary agreement had thus provided Bayer with a valuable first mover advantage.

American foam formulators, on the other hand, had not been pressured to innovate early to reduce CFC-contents. As a result, U.S. refrigerator makers, when required by the Montreal protocol and domestic law to cease CFC-usage, were initially unable to do so while still meeting U.S. minimum electricity efficiency requirements. Some German firms were able to do due to their prior experience with innovative CFC-reducing methods.[89]

International Effects

By early 1994 the new hydrocarbon technology which had been developed in Germany was still too new as to allow estimates of its acceptance in foreign markets. There were some who said that the 5% price differential was too high to make the technology competitive on foreign markets, such as the French

87. "UK: Firms Threaten Research Into CFC Alternative." The Guardian, June 23, 1990, p. 2 (Reuter Textline).

88. "Bayer Reduces Use of CFCs in Production of Rigid Polyurethane Foams." Kunststoffe German Plastics, November 23, 1989, p. 5 (Reuter Textline: Chemical Busmess NewsBase, February 27, 1990.

89. Liebherr-Hausgerate GmbH: Futterer, B., Kaufrn&nnischer Geschiftsfiihrer. Personal communication to the author.

market.[90] Others said that the price differential would only be temporary and might even turn into a price advantage given further experience and improvements. Indeed, it seemed as if there was considerable potential for the new technology to be adopted abroad. In November 1993, for instance, the Australian appliance manufacturer Email announced it would begin production of "Greenfreeze" refrigerators in 1994.[91] Likewise, by early 1994, Greenpeace had already presented the refrigerator in China, Japan, and lndia where it had met with great interest.

lt was unequivocally accepted that Greenfreeze had provided German manufacturers with a first-mover advantage, but the exact value of this first-mover advantage was still subject to debate: The basic hydrocarbon technology was old and not patentable, allowing any foreign competitor to develop similar models. In addition, in the refrigerator industry success on foreign markets continued to be less a function of superior technology, depending still to a large extent on the manufacturer's existing distribution network.

90. Liebherr-Hausgerate GmbH: Futterer, B., KaufrMnnischer Gesch~ftshihrer. Personal communication to the author.

91. Greenpeace. Greenfreeze: Die Chronologie einer umwelttechnlschen Revolution. N. p., n. y.

APPENDIX

Table 1

Domestic Refrigerators and Freezers World Production

	1985		1990		Annual Compound Growth
	Units (1000s)	Share of Total	Units (1000s)	Share of Total	
AFRICA	892	2.5%	994	2.2%	2.2%
Canada	510	1.4%	NA	NA	NA
U.S.	6,419	18.0%	7,817	17.3%	4.0%
NORTH AMERICA	7,313	20.6%	8,821	19.5%	3.8%
Brazil	1,706	4.8%	2,441	5.4%	7.4%
SOUTH AMERICA	2,173	6.1%	3,016	6.7%	12.1%
China	1,448	4.1%	4,631	10.2%	22.1%
Japan	5,354	15.1%	5,048	11.1%	-1.2%
South Korea	1,864	5.2%	2,827	6.2%	8.7%
ASIA	11,488	32.3%	15,704	34.7%	6.5%
Denmark	915	2.6%	NA	NA	NA
France	436	1.2%	596	1.3%	6.5%
West Germany	2,788	7.8%	5,042	11.1%	7.7%
East Germany	973	2.7%			4.0%
Italy *	3,357	9.4%	4,082	9.0%	5.0%
Spain *	1,082	3.0%	1,268	2.8%	4.0%
U.K.	1,266	3.6%	1,312	2.9%	0.7%
Sweden	510	1.4%	NA	NA	NA
EUROPE	14,593	41.0%	16,757	37.0%	2.8%
TOTAL	35,567	100.0%	45,292	100.0%	5.0%

Note: A * denotes data from 1989 instead of 1990.
Source: U.N. lndustrial Statistics Yearbook. Statistisches Bundesamt.

Table 2

Domestic Refrigerators and Freezers International Trade Data

	1986			1990		
	World Export Share	World Import Share	Trade Balance	World Export Share	World Import Share	Trade Balance
Italy	28.9%	1.8%	$478.1	28.7%	2.7%	$964.3
West Germany	15.6%	9.5%	$91.7	15.6%	13.4%	$394.9
United States	4.7%	13.8%	-$188.1	10.7%	6.3%	$157.1
Denmark	8.2%	1.1%	$124.8	8.3%	1.1%	$265.8
South Korea	4.6%	0.1%	$80.3	4.7%	0.5%	$156.0
Yugoslavia	3.2%	0.2%	$52.2	4.2%	0.4%	$141.3
Sweden	5.2%	2.5%	$44.0	3.3%	2.9%	$11.8
Japan	11.0%	0.2%	$190.7	3.2%	1.6%	$61.0
Spain	1.8%	1.5%	$2.8	2.8%	7.4%	-$173.3
Austria	2.9%	2.5%	$1.7	2.3%	2.5%	-$9.8
Other	13.9%	66.8%	NA	16.2%	61.2%	NA
Total	$1,775.2	$1,958.5	NA	$3,718.5	$3,718.5	NA

Note: Amounts in $ millions.
Source: U.N. Annual Trade Statistics, Vol. II.

Table 3

Energy Efficiency of Selected British Electrical Appliances (kWh per Year)		
Appliance	U.K. Average	Best Available
Refrigerator/Freezer (0.5m^3)	1,100	75 - 180
Freezer	1,000	80 - 180
Refrigerator (0.2m^3, Frost-Free)	450	30 - 80
Washing Machine	400	40 - 120
Dishwasher	500	50 - 240
Clothes Dryer	520	10 - 90
Color TV	340	70

Note: Volumes are for illustration only; average includes a wide mixture of sizes. Fridges discussed have no frozen food compartment. Freezers are manual defrost.

Source: UK Friends of the Earth. Quoted in: "The Real Problem with Fridges." The Financial Times. Power Europe. Energv Section. March 16. 1989.

Table 4

Refrigerants and Alternative Technologies: Advantages and Disadvantages			
Name	Usage	Advantages	Disadvantages
CFC-12 (CF2C12)	Traditional standard coolant for domestic and commercial refrigerators (produced by ICI, DuPont, Hoechst. Kali-Chemie and many others)	Good cooling properties; very well-known; low production costs	GWP 7300 times higher than Co2; ODP equivalent to 0.9 kg of CFC-11; remains 130 years in atmosphere; to be phased out after 1993 (Germany). 1995 (U.S., EC, Montreal Protocol)
HCFC-22 (CHF2C1)	CFC-12 replacement (produced by DuPont, ICI)	Suitable for very low-temperature supermarket refrigerators	GWP 1500-4100 times higher than CO2; ODP equivalent to 0.04-0.06 kg of CFC-II, remains 15 years in atmosphere; to be phased out by 2020 (Montreal Protocol)
CFC-115	Traditional coolant for process and cold storage warehouse refrigeration		To be phased out after 1994 (Germany), 1995 (U.S., EC, Montreal Protocol)
HFC-134a (C2H2F4)	CFC-I2 replacement primarily for use in domestic refrigerators; offered by most established refngerator manufacturers (produced primarily by DuPont, ICI, also by Hoechst, Elf Atochem. AustmontiFemtzzt-Montedtson)	No ODP; requires little product design changes because of chemical similarity to CFC-12	GWP 1200-3200 times higher than CO,; remains 16 years in atmosphere; requires compressor and compressor oil redesign; cost 5 times as much as HFC-152 a to produce, 3-5 % less energy efficient as CFC-12
HFC-143a (CH3CF2)	CFC-12 replacement	No ODP	GWP 1300 times higher than CO2; remains 54 years in atmosphere; flammable
HFC-152a (CH3CHF2)	Possible CFC- 12 replacement for residential refrigerators and freezers	No ODP; easy to manufacture, 5% more energy efficient. low toxicity	GWP 140-510 tunes higher than CO2; remains 1.7 years in atmosphere; flammable
CFC/HCFC-502	Possible CFC-12 replacement for low temperatures; blend of CFCs and HCFCs		GWP. ODP; to be phased out (Montreal Protocol)
Hydrocarbons [propane-butane mix, isobutane)	CFC-12 replacement primarily for use in domestic refngerators; was well established before the use of CFCs; (first offered by Foron (ex dkk Scharfenstein) of Germany. followed by a number of German producers)	Negligible GWP; no ODP; 50% less costly that HFC-134a; widely available: theoretically more energy efficient as CFC-12. can be used with existing vapor-compression technology with little changes	Slight risk of explosion; initially less energy efficient as CFC-12 in practice; can't achieve very low temperatures; US legislation forbids use of propane in domestic refrigerators
Ammonia (vapor-compression cycle)	Alternative refrigerant used in the majority of German and American cold storage applications; used in domestic refrigeration before the advent of CFCs; being researched in Germany and the U.S. for domestic refrigeration	No GWP. no ODP: well-known and -proven technology, said to be technically superior to HFC-134a and typically about 4% its cost	Risk of explosion

Refrigerants and Alternative Technologies: Advantages and Disadvantages

Name	Usage	Advantages	Disadvantages
Ammonia-water mix (absorption cycle)	Absorption system using ammoma as refrigerant; well established for domestic and industrial refrigeration; used in 5% of the German household market	No GWP. no ODP	Risk of explosion; efficiency comparable to conventional vapor-compression systems only if primary or waste heat from a combined heat and power unit is available
Adsorption cycle (zeolite-water mix)	Alternative technology using zeolite (a naturally occurring hygroscopic) mineral in a heat pump with natural gas a heat source; being researched in Germany for use in mobile coolers, domestic refrigeration and air conditioning	No GWP, no ODP	Unproven technology
Stirling cycle (helium)	Stirling heat engine powered by helium: being researched by European and American manufacturers	NO GWP, no ODP; predictions are for an 81% efficiency increase over conventional vapor compression machines	Unproven technology: limited supply of helium may become an obstacle to widespread use

Vote: GWP = Global Warming Potential. ODP = Ozone Depletion Potential.

Table 5

Refrigerator Insulations: Advantages and Disadvantages			
Name	Usage	Advantages	Disadvantages
CFC-11 (CFC13)	Traditional standard blowing agent for polyurethane foam insulation	Good insulation; well known	GWP 3500 times higher than CO2; serious ODP; remains 120 years in atmosphere; to be phased out after 1994 (Germany), 1995 (U.S.. EC, Montreal Protocol)
HCFC-22 (CHF2Cl)	Blowing agent for polyurethane foams, CFC-11 replacement	Not flammable	GWP 1500-4100 times higher than CO2; ODP 0.04-0.06 kg of CFC-11, remains 15 years in atmosphere; to be phased out by 2020 (Montreal Protocol)
HCFC-123 (CHC12CF3)	Blowing agent for polyurethane foams, CFC-11 replacement	Not flammable	GWP 85-310 times higher than CO,; ODP equivalent to 0.013-0.022 kg of CFC-11: remains 1.6 years in atmosphere; high toxicity, to be phased out by 2020 (Montreal Protocol)
HFC-134a (C2H2F4)	Blowing agent for polyurethane foams, CFC-11 replacement, (produced primarily by DuPont. ICI, also by Hoechst, Elf Atochem, Ausimont/Ferruzzi-Montedison)	Not flammable, no ODP	GWP 1200-3200 tunes higher than C02; remains 16 years in atmosphere
HCFC-141b (CH3,CCl2F)	Blowing agent for polyurethane foams, CFC-11 replacement, (used by several European and Japanese firms)		GWP 440-1500 times higher than CO2;ODP equivalent to 0.07-0.11 kg of CFC-11; remains 8 years in atmosphere, flammable, unknown toxicity, to be phased out by 2020 (Montreal Protocol)
HCFC-142b (CH3CClF2)	Blowing agent for polyurethane foams, CFC-11 replacement	Low toxicity	GWP 1600-4700 times higher than CO2; ODP equivalent to 0.05-.06 kg of CFC-11; remains 19 years in atmosphere. to be phased out by 2020 (Montreal Protocol)
Carbon-dioxide (CO2)	Possible blowing agent for polyurethane foams, CFC-1 I replacement	No ODP	GWP; remains some 120 years in atmosphere
Cyclopentane	Blowing agent for polyurethane foams, CFC-11 replacement, used or researched by several German firms (produced among others by Exxon)	Low toxicity	Dangerous to handle; less effective insulator than CFC-11
N-pentane	Possible blowing agent for polyurethane foams, CFC-11 replacement		
UPT	Possible blowing agent for polyurethane foams (fluoride compound), CFC-11 replacement		

Refrigerator Insulations: Advantages and Disadvantages			
Time	Usage	Advantages	Disadvantages
Vacuum lnsulation Panel (VIP)	Airtight plastic sheets filled with silica particles under a vacuum (developed among others by AEG. Sharp, Matsushita. Toshiba)	No ODP; no GWP; much better insulation than CFC-based polyurethanes allow thinner walls or better energy efficiency	Twice as expensive as polyurethane foam; reliability data unavailable; still difficult to produce
Note: GWP = Global Warming Potential. ODP = Ozone Depletion Potential.			

Table 6

Important Milestones in the History of the Refrigerator Industry	
1928	Financed by Frigidaire Corporation the first modern refrigerant, CFC-12, is developed at General Motors' research laboratories.
1931	Production of CFC-12 and CFC-11 begins in the U.S.
1940s	Additional refrigerants such as CFC-113 and CFC-114, as well as HCFC-22 are developed. Falling prices and their superior safety characteristics result in CFCs and HCFCs becoming the refrigerant of choice for most commercial and domestic cooling applications.
1950s	With the vapor-compression principle having been universally accepted for refrigerators, refrigeration technology will remain basically unchanged from now on until the early 1990s.
1974	"Stratospheric Sink for Chlorofluormethanes: Chlorine Atom-Catalyzed Destruction of Ozone" by Molina and Rowland is published in Nature, alerting for the first time to the ozone-depleting characteristics of CFCs.
1978	The U.S. bans the use of CFCs in non-essential aerosol spray cans.
1985	The Vienna Convention on the Ozone Layer is adopted by 19 countries and the European Community, agreeing in principle on the reduction of CFCs to protect the earth's ozone layer. The world's leading CFC producer, DuPont, as well as the U.S. Chemical Manufacturers Association urge the United States to withdraw from negotiations.
1987	The Montreal Protocol on Substances that Deplete the Ozone Layer is signed, freezing production and use of CFCs at 1986 levels and reducing the amounts by 50% over the ensuing 10 years (the Protocol will eventually be signed by 76 countries, but not India or China as well as many developing countries). For the first time in history production of an environmentally harmful substance is globally banned. U.S. firms support withdrawal, European firms oppose it.
1990	The London Amendments of the Montreal Protocol call for a 50% reduction of CFCs by 1995 and a total ban by the year 2000. The Clean Air Act Amendments are enacted in the U.S., requiring the phaseout of CFCs, halons, and carbon tetrachloride by 2000, methyl chloroform by 2002, and HCFCs by 2030.
1991	The German FCKW-Halon-Verbots-Verordnung (CFC-Halon-Prohibition-Decree) is enacted, prohibiting the use of CFCs by January 1995, thus making Germany the world's first country to completely phase out CFCs.

Important Milestones in the History of the Refrigerator Industry	
1992	Sponsored by the U.S. EPA and financed by 25 public and private power utilities, the Super Efficient Refrigerator Program (SERP) is launched. It offers a $30 million price to the firm which develops and delivers 300,000 to 500,000 CFC-free refrigerators and exceed U. S energy-efficiency standards by at least 30 % . The U.S. Congress and the European Community (in April 1992) both pass legislation to ban production and consumption of CFCs by the end of 1995 (EC). Germany pledges a CFC-ban by the end of 1994. The Montreal Protocol is once again tightened to require a CFC-ban after 1995 and to also include restrictions on HCFCs which will have to be phased out by 2020.
1993	The East German firm Foron, formerly dkk Scharfenstein, begins to market the world's first CFC- and HCFC-free refrigerator. It uses hydrocarbons - a mixture of propane and butane - as a refrigerant. Other major German producers, which had previously denounced the technology as unsafe, also announce propane-butane refrigerator. Other German refrigerator makers, after initially having rejected the Foron product as unsafe, begin to market similar propane-butane refrigerators. The Super Efficient Refrigerator Program (SERP) announces Whirlpool as the winner of its $30 million contest to develop an environmentally friendly and energy-efftcient refrigerator. The winning entry uses HFC-134 as a refrigerant, thus still contributing to global warming.

Table 7

Glossary

Blowing Agent: A gas used to process plastic into insulation and packaging foam.

Chlorofluorocarbon (CFC): Known widely as CFCs, these chemicals in recent years have been shown to deplete ozone in the atmosphere. An international treaty - the Montreal Protocol - as well as national laws will ban production for most uses by 1995. The main class of CFCs, known as chloromethanes and including CFC-11 and CFC-12, achieved stunning success as refrigerants, replacing flammable chemicals such as ammonia.

Freon: DuPont's trade name for chlorofluorocarbons used as refrigerants, solvents, or blowing agents.

Greenhouse Effect (Global Warming): Naturally occurring water vapor and carbon dioxide trap infrared rays from the sun, warming the atmosphere. Without this, the earth's average temperature would be 20 degrees below zero instead of 60 degrees Fahrenheit. Human activities have increased the amount of carbon dioxide and trace gases in the atmosphere, which traps more of the sun's infrared rays, Because warmer air holds more water vapor, the warming effect would be compounded. In the view of many scientists, the average temperature of the earth is already increasing. Anticipated effects of global warming include sea level rise and a change in the areas that are suitable for farming.

Hydrochlorofluorocarbon (HCFC): A chlorofluorocarbon with a hydrogen atom, which makes it much more reactive in the lower atmosphere than a simple CFC. Because their life span is shorter, HCFCs are less likely to reach the upper atmosphere and deplete the ozone layer.

Hydrofluorocarbon (HFC): A fluorocarbon that contains no chlorine and has no known effect on the ozone layer, but contributes to global warming. HFCs being considered to replace CFCs include HFC-134a for refrigeration and auto and residential air conditioning, HFC-143 for refrigeration, HFC-152a for many refrigeration and air conditioning applications and HFC-123 for commercial air conditioning.

Ozone: An unstable form of oxygen formed when three oxygen atoms bind together. Atmospheric oxygen normally consists of two oxygen atoms. At ground level oxygen irritates the lungs and is a major component of smog. In the upper atmosphere, it forms the protective ozone layer.

Ozone Layer: A high concentration of ozone gas about 25 miles above the earth, blocking much of the harmful ultraviolet radiation from the sun. Increased ultraviolet radiation causes cataracts and, in light-skinned people, skin cancer. It also reduces crop yields and may harm such life forms as phytoplankton, which are part of the basis of the marine food chain.

Refrigerant: A chemical used in air conditioning and refrigeration systems. It absorbs heat when it evaporates, removing it from the air that is to be cooled. The heat is later released away from the cooled space when the chemical is compressed into a liquid state.

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COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE DRY CELL BATTERY INDUSTRY

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THE DRY CELL BATTERY INDUSTRY
CONTENTS

EXECUTIVE SUMMARY

Throughout the twentieth century and well into the 1980s, dry cell battery technology had remained more or less the same. All dry cells were based on a simple chemical reaction discovered by Alessandro Volta in 1796.

Towards the end of the 198Os, however, significant changes were forced onto the dry cell battery industry, due to two major developments:

* The electronic appliance sector exerted strong demand pressure onto the industry, because it required ever-smaller, lighter and more powerful batteries to power portable goods such as computers, camcorders, and telephones.

* There was also growing environmental concern over the highly toxic metals mercury and cadmium that were contained in the batteries that were produced at the time. They threatened to be released into the soil in landfills or, even worse, to the air if waste containing batteries was incinerated.

German legislators and producers reacted primarily to the second development as the following overview of the history of German legislation concerning batteries shows:

* At a comparably early stage, in 1988, a voluntary agreement between legislators and the German battery industry had been reached with the goal of preventing having to recycle all batteries. Otherwise, German manufacturers feared, legislation to that extent might be enacted at a later stage. The agreement required the industry to reduce the mercury in non-rechargeable batteries and to pay for the recycling of cadmium-containing cells as well as those batteries, whose mercury content could not be reduced. If fulfilled to satisfaction no further legislation would follow, but doing so required high return rates of “to-be-recycled” batteries.

* By the early 1990s, it had become clear that the requirement could not be met. Even though public awareness of the environmental risks associated with batteries had risen substantially, lack of technical understanding prevented successful sorting of batteries, a critical prerequisite for high recycling rates.

* In 1994 recycling of all batteries or levies was thus envisioned by German legislators.

Market pressures and environmental regulation spurred significant research and development activities all over the world. On one hand, this led to the reduction of mercury in non-rechargeable batteries.

Over a period of several years German producers spent approximately $26 million, equal to about 3% of a single year's revenues, to achieve this goal. On the other hand, alternatives to cadmium-containing rechargeable cells were developed, after it had become clear that the cadmium could not be eliminated. Commercially viable alternatives were found in rechargeable alkaline, nickel metal hydride and lithium batteries.

As a result of the major world-wide research efforts, new product innovations had been developed, which were technologically more advanced than the hazardous waste containing batteries they were intended to replace. The expenditures into the "greening" of the batteries were more than offset by new batteries that could be sold at a higher price because of their higher energy density or rechargeability.

The competitiveness of the German producers, however, had decreased in the wake of these developments. Even though German legislation might have led to first mover advantages, German producers were not able to reap them. In Japan and to a lesser extent in the United States, however, pressures from demanding customers and supporting industries had led to superior and more innovative product developments.

INDUSTRY STRUCTURE

Product

Product Description

Dry cell batteries were to be separated from so called wet cell batteries used in cars and industrial applications. Dry cells were used in many portable applications such as telephones, computers, calculators, game-boys, etc., as well as in stationary equipment provided that the power needed was not very large. Wet cells on the other hand were used, whenever there were fairly large power requirements, They were, as a rule of thumb, far heavier than dry cells. (Figure 1 shows the most important types and formulations of dry cells as well as their typical uses.)

The technology of converting electrical energy to chemical energy and back again dates to Alessandro Volta's 1796 wet cell. All batteries worked on the same principle: electrodes of two different materials exchanged ions through a liquid or gel-like electrolyte. The movement of ions created an excess of electrons at the negatively charged anode. When a charged battery was connected to a circuit, the excess electrons flowed through the circuit to the positive terminal, creating current.

The standard dry cell battery (zinc carbon) was developed decades ago, as were most of the chemical reactions used in them and in the more "modem" batteries as sources of power.[1] Mercury's use in batteries using zinc as anode was to act as a so called inhibitor which inhibits the selfdischarge of the battery.[2] Although there were far more advanced technological alternatives available, the market share of the standard battery in the dry cell batteries market was in excess of 40% in the early 1990s.[3]

1. Dreyfuss 1984, 103.

2. Hiller 1990. 1.

3. ZVEI estimate for German share of batteries disposed in 1992, cited in Baumann / Muth 1993, 5. Nickel metal hydride and lithium batteries are excluded.

Figure 1

Dry Cell Battery Types			
Battery Type	**Formulation**	**Common Name**	**Comments**
Primary Cells (non-rechargeable)	Zinc Carbon	Standard Batteries	All uses
	Alkaline Manganese	Long Life Batteries	All uses. typically whenever more power and longevity required
	Lithium	Lithium Batteries	Expensive. therefore whenever extreme small size. extreme longevity and very small self-discharge rate is of benefit. ie hearing aids, pacemakers photographic equipment etc
	Mercuric Oxides	Button Cells	Hearing aids, photographic equipment
	Sliver Oxides		Electronic watches, Calculator
	Zinc Air		Hearing aids
Secondary Cells (rechargeable)	Nickel Cadmium	NiCad	All uses. except where high self-discharge rate is disadvantage Today primarily used in camcorders, portable computers, portable phones etc
	Nickel Metal Hydride	NiMH	Uses as NiCad, but even higher self-discharge rate (approx. 2% per day)
	Lithium	Lithium Ion	Primarily used for audio and video equipment, mobile telecommunications and personal computers

Source: Europile 1991, 2. Silberg 1993, 60.

During the 1980s; dry cell batteries became the object of a hard-fought, high-stakes technological race. Because of the ever-increasing market for portable goods such as calculators, electronic games, walkmans, laptops, palmtops, telephones, vacuum cleaners, and power drills whose market drivers were size, weight, longevity and power. Manufacturers scurried to improve existing batteries and develop new ones for those products.[4]

4. Dreyfuss 1984, 103.

In the sector of primary batteries (non-rechargeable), the first outcome of research and development expenditures had been the alkaline battery in the 1970s. Although the alkaline battery had better longevity than the standard zinc carbon battery, it was still fighting for greater consumer acceptance and larger market shares, in comparison to standard batteries in the early 1990s. Rechargeable batteries because of their targeting of the longevity market primarily competed with the alkaline sector. Thus their growth did not affect the sales of comparably cheap standard batteries, but rather the alkaline sector.[5] The market share of alkalines in Germany was approximately 35% in 1992.[6] A second alternative to standard zinc carbons, the lithium battery, was developed in the 1980s. It promised to be better still with regard to longevity.

Button cells had a total market share of approximately 8% in the early 1990s in Germany.[7] In the secondary (rechargeable) cells segment, the research and development efforts first led to the development of nickel-cadmium cells (NiCads), followed by nickel-metal-hydride (NiMH) batteries. The latest development, which was expected to arrive on the market in the mid-1990s was the rechargeable lithium cell. In the early 1990s, NiCads had a market share of approximately 12% in Germany, NiMHs had only just been introduced.[8]

Lithium batteries were even more powerful than other dry cell batteries. They were extremely small and had the additional advantage that their self-discharge rate (amount of energy lost by battery not in use) was very small even over long periods of time. Due to their high price, their use up to the early 1990s had been limited to specialties where the battery's price was not critical such as pacemakers, hearing aids

5. Key note (1991), 11.

6. ZVEI estimate for German share of batteries disposed in 1992, cited in Baumann / Muth 1993, 5. Nickel metal hydride and lithium batteries are excluded.

7. ZVEI estimate for German share of batteries disposed in 1992. cited in Baumann / Muth 1993, 5. Nickel metal hydride arid lithium batteries are excluded.

8. ZVEI estimate for German share of batteries disposed in 1992, cited in Baumann / Muth 1993, 5. Nickel metal hydride and lithium batteries are excluded.

and other specialty applications. Batteries containing lithium were smaller but less compatible with products on the market in the early 1990.[9]

Whereas the market for primary batteries seemed fairly divided with regard to typical uses of the individual types - each battery type had typical uses for which it was suited best - there was the principal substitutability of primary by secondary batteries. Most types of secondary batteries could be recharged 300 to 1500 times, [10] an advantage, which more than offset the higher initial cost of the battery and its recharger. Panasonic, a producer of both single-use and rechargeable batteries, estimated that, depending on battery type and usage, alkaline batteries were several hundred to several thousand times more expensive than rechargeables.[11]

By the early 1990s, however, many consumers were still unaware of these advantages. In addition rechargeables could not be used for all applications that were suitable for primary batteries, because of some inherent technological restrictions. The most important was their high self-discharge rate, which for instance. prevented their use in smoke detectors and flash-lights. Thus, despite their obvious economic advantages, it was unclear how acceptable rechargeable batteries would become for consumer goods users. [12]

The development of the rechargeable batteries market to some extend depended on battery rechargers, which had to be fast and efficient in order to gain acceptance with the consumer.[13] Beginning in the mid-198Os, with the development of advanced electronic controls that regulated the recharging process, there had been considerable progress in this field and most manufacturers predicted large growth rates in for the future. A very important development in the rechargeable field was the nickel metal hydride battery. It functioned similar to nickel cadmium batteries (NiCads), but contained less toxic metals.

9. Silberg 1993, 60.

10. Baumann/ Muth 1993, 63.

11. Melnykovych 1993.

12. Melnykovych 1993.

13. Silberg 1993, 60.

Even more hopes were put into the rechargeable lithium cell. In 1993, their market in Japan was $952 million and was expected to grow to $2.38 billion by the year 2000.[14] Lithium ion technology offered an even higher energy density than NiMHs.[15] Companies strong in end products, such as Sony or A&T Battery, were expected to challenge the leaders in the rechargeable battery market, Sanyo and Matsushita Battery, who together commanded around 80% of Japan's NiCad battery market in the early 1990s.[16] In 1992, most manufacturers agreed, that two to three years were still needed to remove technical glitches and reduce the cost of lithium batteries to make them competitive to Nicad or NiMH batteries.[17]

A strong pressure to innovate in the battery industry was spurred to a considerable extent by demand from the electronic goods industry. While electronics manufacturers produced ever smaller and more clever machines, the sleepy battery business had barely changed. Most portable devices had become so light that batteries accounted for 25% of their weight by the early 1990s, compared with 10% a decade earlier. With advances in microchip technology having made even tinier electronic products possible, battery makers were scrambling to come up with lighter, more powerful and longer-lasting batteries.[18] This led to:

* Toshiba America Consumer Products to introduce a line of mercury-free alkaline batteries;[19]
* Rayovac to announce a rechargeable alkaline battery that was based on a new technology developed by Battery Technologies of Canada;[20] and
* Duracell to appeal for standard sizes in the rechargeable battery market (as in primary market) to improve its competitiveness against integrated battery and electronic appliances manufacturers. Manufacturers of electronic appliances seemed to be against it.[21]

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14. Reuter 1993a; Exchange rate Yen/$105

15. Eisenstodt 1993, 42.

16. Moffett 1992.

17. Economist 1992.

18. Reuter 1993.

19. Home Furnishings Newspaper 1992, 89.

20. Silberg 1993, 60.

21. Silberg 1993, 60.

To summarize, with regards to the product there was a general tendency towards longevity as a result of the extreme increase in high-drain portable electrical equipment as well as a tendency towards environmentally friendly batteries as a result of regulatory and consumer pressure.[22]

Substitutes

Next to the more fundamental question of whether or not use of electrical mains instead of batteries was a more sensible ecological solution, the battery market itself contained products that could be regarded as substitutes. Another possible substitute to batteries was solar power. There were, for instance, solar powered pocket calculators.

Production Process

The production process of batteries was fairly similar regardless of the specific battery type. With regard to standard cells, zinc ingots were melted down as the first stage of the battery-making process. The molten metal was cooled by water, then ran through a stamping machine. Calots, or blanks the size of an overweight florin. were punched out. and the remaining metal was returned to the furnace. Next was the mixing plant, where manganese ore was grounded down in a giant chemistry set to act as the electrolyte. It was mixed with other chemicals to a black powder in a mixing process that was often remotely controlled by computer. Next the zinc calots were stamped into hollow tubes. In a further step the batteries finally came together. The outer casing was filled with a separator paper, a bottom washer, the chemical mix as well as a carbon rod. Finally, a bitumen and a plastic seal were poured on top. Each battery was tested automatically, then left for five days to settle, and tested again.[23]

Entry or Exit Barriers

An important entry barrier to the battery market was the ability to serve the total battery needs of retail partners and consumers. In particular the Japanese leaders in the rechargeable field had difficulties penetrating the world market without an alliance with a company that had a large distribution network, as there still was considerable education of the consumer to be done. This was exemplified by the entry

22. Key note 1991, 1.

23. Bowen 1993.

of Sanyo, together with Matsushita market leader of NiCads, into the American market: In order to gain access to the U.S. market, Sanyo was required to form a joint marketing agreement for a new brand of battery products carrying a “dual mark” product logo with General Electric.[24]

Another entry barrier, in this case primarily for European and American producers, was the tendency of manufacturers of portable appliances to use non-standard battery sizes to seize the after-sale market. This barrier prompted the American producer Duracell to push for the standardization of NiMH power packs.[25]

Buyers

Buyer Description

Since dry cell batteries were needed for diverse applications, there was no single most important purchasing criterium, other than price. Other purchasing criteria were power, longevity, ease of use, and to a lesser extent environmental friendliness and brand recognition.

Standard zinc carbon and alkaline primary batteries were primarily bought for comparably “simple” uses such as flashlights. The remaining comparably expensive non-rechargeable batteries (non-rechargeable lithium and button cells) were used for more advanced appliances where high power and low weight as well as longevity were of utmost importance, such as in cameras and hearing-aids. The still more expensive rechargeable batteries (NiCads. NiMHs and rechargeable lithium cells) were bought for even more technologically advanced appliances such as portable telephones, microcomputers or hand-held power tools.

Forty percent of batteries were bought for portable or audio uses, 21% for toys and games, 17 % for flashlights, 12 % for cameras and 10% for miscellaneous reasons .[26]

24. Newswire 1993.
25 Silberg 1993, 60.
26. Home Furnishings Newspaper 1992, 3.

Distribution Channels

As battery purchases often arose as a result of "distress" demand, there was a high level of sales through convenience stores such as tobacco stores, news agents and gas stations, which offered extended opening hours and convenient locations (Table 5). Electrical retailers sold many batteries with new equipment, but had not been able to penetrate the aftersale market. Supermarkets and grocers sold just under 30% of total sales.[27] This distribution pattern varied from battery type to battery type. While supermarkets and grocers tended to sell a larger section of the standard battery sector, electrical retailers were particularly strong in the alkaline sector.[28]

Switching Costs

In the primary battery market (non-rechargeable), switching costs were low because battery sizes and voltages had been standardized since 1926, allowing an easy exchange of batteries from different manufacturers.[29] However, with regard to the secondary battery market, there were some potentially high switching costs. Producers of portable devices tried carefully to uphold these costs by designing equipment that only facilitated their own batteries, allowing them to capture the aftermarket.

Environmental Regulation

Environmental Risks

Mercury and cadmium used in varying contents in almost all dry cell batteries with the exception of zinc air and primary and secondary lithium cells, posed a great threat to the environment when disposed, as their casing began to leak after some period of time. If these batteries were incinerated, the situation became even worse, as it was very expensive to filter the incinerator's air output to accommodate ever-growing battery numbers. Figure 2 lists the greatest environmental risks in production, use and disposal per battery type.

27. Key note 1991, 5.
28. Key note 1991, 5.
29. Dreyfuss 1984, 103.

The greatest environmental threats resulted from mercuric oxide button cells and non-recycled NiCad secondary cells, since these contained the most hazardous waste by weight. In the early 1990s, mercuric oxide button cells experienced decreasing sales and had been announced by manufacturers to be taken off the market by the mid-1990s due to rising costs of disposal and recycling combined with better alternatives.[30] In total, the mercury from dry cell batteries accounted for a sizeable proportion of the mercury content in household waste not incinerated, approximately 9 tons in 1991. This amount was expected to decrease as a result of decreasing sales of mercuric oxide cells.[31]

German dry cell battery producers accounted for approximately 33% of the total cadmium consumption in Germany.[32]

Current Environmental Regulation

Battery manufacturers were subject to a range of environmental regulations. The most important "regulation" in Germany, however, was not a law, but a voluntary agreement between the German Ministry of the Environment and German battery producers and importers signed in 1988. It required them to reduce the mercury content of batteries and to start recycling programs. Specific legislation was to be passed in Germany in the summer of 1994. It had been necessitated by a 1991 E.C. directive that required E.C. member countries to enact legislation forcing reduced mercury contents and regulating recycling programs. Figure 3 summarizes the most important contents of these regulations.

The voluntary agreement of 1988 between German battery producers, importers and retailers, and the Ministry of the Environment indisputably put pressure on the industry with regard to the "greening" of the batteries. The fact that batteries containing hazardous wastes were to be recycled and had to carry a label saying so, meant that the consumer had the chance to distinguish "clean" (no recycling label) from

30. Baumann / Muth 1993, 28; Taylor 1993.

31. They were the fifth highest cause of mercury in non-incinerated waste surpassed only by normal household waste (60 tons), Alkaline-chlorine-electrolytes (47 tons), fossil fuel power plants (21 tons) and dentists (10 tons). Source: Baumann / Muth 1993, 111/112.

32. Figures for 1989, Source: Rauhut (n.d.), 6 cited in Hiller 1992, 1; Similar figures in Baumann / Muth 1993, 114.

hazardous (recycling label) batteries.[33] However, accompanying information programs to educate the general public were poor, resulting in fairly low recycling rates. This forced the German Ministry of the Environment to plan specific legislation that would assure adherence to the stricter standards set by the E.C. directive enacted in 1991. The E.C. directive had originally been pushed primarily by German authorities to reduce unfair market conditions for German producers that resulted from the previous voluntary German agreement. In 1994 German battery producers were, together with their European competitors, fighting heavily against both the introduction of recycling for all batteries, which in their eyes was unnecessary and economically not feasible, and the introduction of a levy on batteries.[34]

The regulation with regards to informing the public was unclear and rather diffuse both in the E.C. directive as well as in the voluntary agreement. Clear and specific public education programs, however, were a prerequisite for high battery return rates. The general public needed to be informed well to be able to distinguish those batteries that were to be recycled from those not to be recycled in order to avoid high sorting costs before recycling. By 1994, six years after the voluntary agreement had been signed, it became obvious that low public awareness had led to low battery return rates and high sorting costs, hence, posing the greatest problem. This resulted in German legislators pushing for the recycling of all batteries as well as levies on some battery types.

Technologically there seemed to be no feasible way to reduce the cadmium content of NiCad batteries which could reach some 20 % Thus, regulation regarding NiCads was limited to recycling and disclosure requirements. With the arrival of feasible and environmentally sound alternatives to NiCads (NiMH, lithium ion), it could be hypothesized that in the long run NiCads would simply be forbidden or made unattractive by requiring extraordinarily high levies on them in the E.C.

The E.C. directive also included the possibility, but not the requirement, to impose a levy on batteries to help pay for recycling or to charge a deposit on sales of batteries in order to encourage consumers to

33. German Ministry of the Environment 1992, 2.

34. See discussion of logic behind recycling and levy below.

Figure 2

Environmental Regulation: The German Battery Industry

Regulation / Battery Type	E.C. Directive	German Voluntary Agreement	Proposed German Regulation
All Batteries In General	Prohibit appliances with non-removable batteries as from January 1, 1994, Develop programs to reduce hazardous waste, Organize recycling programs, Inform public; Revise above programs regularly to accommodate technical progress	Prefer batteries without hazardous waste In production, development. Industry to finance research to reach goal to reduce mercury content in alkalines to 0.1% by 1990, <0.1% by 1993	Collect and recycle all dry cell batteries
Zinc Carbon Batteries		Reduce mercury content from 0.01% to 0%	
Alkaline Manganese Batteries	Mercury content <0.025% as from January 1 1993 Separate collection and disposal	Reduce mercury content from 0.35% to <0.15% by end of 1988, Collect and recycle if mercury content>O.1% (paid by producer)	Mercury content <0.25%
Button Cells (Mercuric Oxides, Silver Oxides, Zinc Air)	Separate collection and disposal if more than 25mg mercury Dlsclose hazardous waste content	Collect and recycle (paid by producer)	&close if more than 25mg mercury
Lithium Batteries	No specific regulation	No specific regulation	No specific regulation
Nickel Cadmium Batteries	Separate collectIon and disposal if cadmium content >O.025%	Collect and recycle (paid by producer)	Dlsclose if more than 0.025% cadmium
Nickel Metal Hydride Batteries	No specific regulation	No specific regulation	No specific regulation
Lithium Ion Batteries	No specific regulation	No specific regulation	No specific regulation

The E.C. directive was passed on March 18, 1991 and came into effect on January 1, 1993. Directive was to be taken up by national law by September 18. 1992.
Voluntary agreement was between German Ministry of the Environment and Industry and Retailers in Germany from September 9, 1988.
Percentages concern content by weight.

return them for recycling when used.[35] Until the early 1990s these measures had been successfully fought

35. E.C. directive 1991, paragraph 7.

against by producers and importers, who accused them to be an unnecessary regulation of trade, although both Swiss and German legislators were thinking about such solutions. If recycling rates could not be increased in Germany, such measures were expected to be taken by the Ministry of the Environment in order to increase battery return rates.

Other regulations concerning the dry cell battery market, but not directed at it included:

* Legislation covering waste in general ("Abfallgesetz" of September 18, 1990), which set out the priorities in the handling of waste in general. Similar to legislation in the E.C., this law gave priority to waste reduction in general over its utilization or recycling, which in turn had priority over disposal. Recycling was to be carried out if technically possible, if it could "reasonably" be expected. and if a market for resulting goods or energy existed or could be created. These measures were to be paid for by the party that was obliged to dispose of the good by law. In the case of the battery industry this was the manufacturer who had voluntarily agreed to take on this obligation; .[36]

* Legislation regulating the ways of disposal per type of waste ("Technische Anleitung Abfall" of April 1, 1991). According to this regulation, NiCads and batteries containing mercury had to be disposed of in expensive underground landfills. Other dry cells could be disposed of in less costly hazardous waste landfills;[37]

* Legislation regulating which chemicals were to be considered as hazardous waste ("Abfall-bestimmungs-Verordnung" of October 1, 1990);

* Legislation regulating which goods had to be recycled in accordance with the "Abfallgesetz" ("Reststoffbestimmungs-Verordnung" of October 1, 1990); and

* Legislation regulating emissions by incinerators ("Verordnung uber Verbrennungsanlagen fur Abfalle und ahnliche brennbare Stoffe - 17. BlmSchV" of December 1, 1990). This regulation set emission limits. For cadmium these were 0.02 mg/Nm^3, 11% O_2. and for mercury 0.05 mg/Nm^3, 11% O_2.

Focus of Regulation

Battery regulation was aimed primarily at the producer. Even recycling laws were aimed at the battery industry itself, since battery manufacturers were required to facilitate the recycling programs. Neither

36. Baumann / Muth 1993, 6.

37. Baumann / Muth 1993, 7.

the actual battery production process, nor battery use was regulated since there were no apparent dangers in these fields. Battery disposal was the main focus of regulation. The E.C. directive's goal was to sensibly reduce the level of hazardous waste disposal in whatever way technically feasible. Informing the public and setting up recycling schemes were part of such solutions.

Type of Regulation

Most of the regulations governing batteries were performance standards or outright command-and-control measures. There were regulations forbidding appliances from which batteries could not be removed easily, standards which regulated the level of cadmium and mercury emissions from incinerators, and limits on mercury and cadmium contents.

Other types of regulations included disclosure requirements in order to enable effective recycling programs and voluntary agreements like the agreement to reduce mercury in primary batteries and to recycle mercuric oxide cells and NiCads between German producers and importers and the German Ministry of the Environment. There were also some market-type regulations such as the E.C. directive's inclusion of the possibility to enact the imposition of a levy on batteries to help pay for recycling or to charge a deposit on sales of batteries.[38]

Industry/Government Interaction

It was interesting to observe the evolution of the regulation setting process in the battery industry. In 1988, German producers and importers signed a voluntary agreement, burdening them with substantial investments into "greening" their products and setting up collection schemes. The reason for the industry to do so was that the hope to get around the necessity to recycle all primary batteries containing mercury.[39] In addition, the argument might have been to act early, so as to have clear planning possibilities and later reap first-mover advantages.

38. E.C. directive 1991, paragraph 7.

39. See discussion below.

Undoubtedly the German industry had managed to reduce the level of mercury level in household waste dramatically by research and development activities. Up to the early 1990s recycling programs had not been successful, with the effect that the E.C. directive's goals were not being met in Germany by means of the voluntary agreement. In the eyes of some officials at the German Ministry of the Environment, this had been the result of the producers' and importers' efforts to try to impose the responsibility of sorting the batteries onto the general public. This did not work. The average consumer was not able to separate hazardous from non-hazardous batteries.[40] The German legislators in effect had no other choice than to impose tougher rules - recycling of all batteries, which meant there was no necessity of sorting for the consumer. Also, a levy seemed likely, at least in the long run. The apparent strategy of the producers to get around further regulation with the help of the voluntary agreement had in effect not worked out.

40. Bundesumweltamt: Genest. Personal communication to the author

COMPETITION

Germany

Competitiveness Overview

Germany was the fourth largest exporter of dry cells in the early 1990s after Belgium, USA, and Japan. In 1991, the German export share in the dry cell battery market was approximately 8% of world exports (Table l-3). At the same time, Germany was the world's second largest importer with a share of 8% of world battery imports. This resulted in Germany having the third largest negative trade balance with regard to batteries, after the Netherlands and Hong Kong (Table l-3).

In 1992, the German dry cell battery market amounted to approximately $790 million,[41] compared to the $4.2 billion market in Japan.[42] It was interesting to note the difference in the segmentation of these markets. Secondary cells were much less significant in the German than in the Japanese market, accounting for only 33% of the German markets' value in 1992,[43] compared to a very high 66% in Japan.[44]

Leading Firms

The German battery industry employed approximately 12,000 employees and had revenues of approximately $1.2 billion per year in the early 1990s.[45] German battery production was dominated by Varta, the leading German battery maker, which employed some 9,000 people. Varta produced a complete range of batteries (Table 4).

41. Author's own estimate.

42. Economist 1993.

43. 87.8 % primary by weight, which approximates to 66% by value. Source: Baumann/ Muth 1993, 5.

41. Economist 1993. See Tables 1 and 2 in the appendix.

45. Baumann / Muth 1993, 4. Exchange rate DM/$1.70.

Distinctive Strategies or Features in Country

The German dry cell battery industry was not distinguished by its inventiveness. In the 1970s and 1980s, the rapid developments in the rechargeable battery market pushed mainly by appliances producers' need for smaller and more powerful batteries had been largely missed by German producers. Another reason for this fact was the buyer segmentation (see above). Towards the end of the 1980s however, the largest producer, Varta, engaged in major research and development activities to avoid losing out from this largest growing segment of the market, especially of the NiMH and lithium ion types. It also formed a joint venture for the development of rechargeables with Toshiba and Duracell, none of whom were market leaders in this sector of the market.

It thus appeared as if Germany's battery producers were more or less waiting for the best technical development in the field and only then reacting to the market. This strategy was financed by profits in other business segments - Varta was a whole range producer of batteries and earned most of its revenue in the wet cell automotive sector. Its results were shrinking German market shares in the dry cell market and an uncompetitive position in the growing rechargeable battery market, a segment where Japanese producers had become world leading.

Japan

Competitiveness Overview

Japan's export share in dry batteries had fallen from 17% in 1987 to around 13% in 1991, possibly as a result of trying to improve their world market position by establishing production plants outside of Japan (Table l-3). Japan was the world's third largest exporting country.

Japanese dry cell battery imports were very small, accounting to only 1.9% of world imports in 1991. This left Japan with a huge trade surplus of more than $250 million in 1991 (Table l-3).[46] The Japanese dry cell battery market totalled US $4.2 billion in the early 199Os, of which approximately 66% were secondary cells.

46. United Nations, International Trade Statistics Yearbook, vol. II, var. ed.

Leading Firms

The Japanese battery industry was dominated by a small number of firms. Sanyo and Matsushita together commanded 80% of the Japanese NiCad sector[47] and Sanyo, Matsushita and Toshiba were the strongest contenders for the growing NiMH segment. Other producers included Sony Energytec, Hitachi Maxell and Furukawa Battery.

Distinctive Strategies or Features in Japan

Japanese producers concentrated mainly on the secondary dry cell market, which was driven by sophisticated demand from world-leading Japanese producers of electric and electronic appliances. By the early 1990s it had become more and more apparent that this had been a very wise choice, since mounting worldwide "greening" pressure had made rechargeable cells very attractive to consumers. With NiMH and the even more advanced rechargeable lithium cells, rechargeable products that were environmentally friendly had been developed. These were widely expected to experience dramatic growth rates throughout the 1990s to the detriment of primary cells.

The United States

Competitiveness Overview

The U.S. was the world's second largest exporter of dry cell batteries after Belgium (whose battery industry was dominated by American firms). The American export share in the dry cell battery market had increased from 8.68% in 1987 to more than 14% of world exports in 1991 (Table l-3). This increase was the result of the growing strength of the two leading U.S. battery makers, Duracell and Ralston Purina. At the same time, the U.S. import share had decreased to just above 8% of world imports in 1991, giving the U.S. a large trade surplus in the dry cell battery market.

The U.S. battery industry changed dramatically during the mid-1980s. From being a large net importer of batteries in 1987, the U.S. had become the third largest net exporter, preceded only by Belgium and

47. Moffett 1992.

Japan. As in Germany, but unlike the case in Japan, secondary cells represented a rather small share of the American market and accounted for only 25% of domestic battery sales in the early 1990s.[48]

Leading Firms

The U.S. battery market amounted to some $3 billion per year in the early 1990s,[49] of which approximately two thirds or $2 billion were sales of alkaline batteries.[50] The market for rechargeable cells amounted to $650 million in the early 1990s and was expected to grow to $1 billion by 1995.[51]

The largest producer in the U.S. was Ralston Purina. Though at root a pet food company, Ralston had become the biggest battery-maker in 1985, after it acquired U.S. Eveready from Union Carbide. In 1992, it also acquired U.K. Eveready from Hanson.[52] Ralston Purina, in addition to its strong base in standard life primary cells, had two alkaline battery factories in France and in Switzerland.[53]

The other large American producer was Duracell, the world leader in the alkaline sector of the market, which in the early 1990s was still growing, although in principal substitutable by rechargeable batteries, In the early 199Os, the combined domestic market share of Ralston Purina and Duracell was approximately 80%. However, it was seriously threatened by the growing share of rechargeable batteries. a sector that was dominated by Japanese producers.[54]

Other important American producers included Rayovac, producing primarily button cells, with a domestic market share of 10% and Kodak, producing primarily lithium cells, with a share of 7% .[55]

48. Author's own estimate.
49. Rudd and Tait 1992, 1.
50. Liesse 1993.
51. Gale Research 1993, 4.
52. Cowe 1992. 13.
53. Bowen 1993a.
54. Author's own estimate.
55. Thomson Financial Networks 1992.

EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

Reduction of Mercury Content in Primary Batteries

Regulation-induced innovation had a strong impact on the battery industry's competitiveness - both positive and negative. One area of innovation that was particularly affected was the reduction of mercury content in batteries. As a result of their voluntary agreement to reduce the mercury content in primary batteries, German producers had invested heavily into research and development and associated production process changes of alternative technologies. German producers, namely Varta, the only primary battery producer in Germany, were thought to have invested $26.5 million into reducing the mercury level in zinc carbon and alkaline batteries, representing some 257% of the European total of $106 million.[56] This amount was the result of research and development, changes in the production process, plus extensive field tests to appraise the technical feasibility of the reformulated batteries. Mercury, which had been used in nearly all batteries to lessen the internal generation of explosive gas, had been reduced by the introduction of zinc of a higher concentration.[57]

The reason why this investment had seemed attractive at the time was the fact that batteries containing little or no mercury could be disposed of together with normal household waste, rather than having to be recycled or collected and then disposed of in specialized and expensive landfills -- the cost of which according to German legislation the battery industry was to bear. The cost of battery reformulation thus promised to be offset by reduced costs of disposal, which had been expected to amount to approximately $600 per ton.[58] However, as mentioned, the promise did not materialize since the zinc used in batteries was later also declared a hazardous waste by German legislation because it included traces of cadmium. Thus mercury free batteries could still be disposed of only in specialized landfills.

Contrary to expectations, the removal of mercury from primary batteries had not reduced the cost of raw materials, since the mercury had been replaced by cleaner, and therefore more expensive, zinc, while the

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56. German Battery Producer's Association: Kiehne, Director. Personal communication to the author.

57. Europile 1991, 4.

58. Baumann / Muth 1993. 107.

production process itself had remained more or less the same.[59] It could not be determined, whether the, reduction of mercury levels in alkaline batteries had affected their production costs. As mercury was removed from primary batteries, the production process became safer since no more carcinogenic materials had to be handled. This resulted in a reduced liability exposure, which could not be quantified There was a curious by-product to the battery industry's efforts to develop environmentally friendly batteries. By concentrating on new product launches and marketing activities in the "green" battery sector, producers had encouraged consumers to think of batteries as potentially harmful products.[60]

Recharging of Primary Batteries

One of the most surprising developments in the battery industry was the 1992 announcement of the rechargeable alkaline battery. Rayovac, an American producer, introduced such a battery called "renewal" that was based on a technology developed by the inventor of the alkaline battery himself, Professor Kordesch at Battery Technologies of Canada.[61] Rayovac's new batteries could be recharged up to 25 times, but cost only twice as much as conventional alkaline cells. In addition, they had a much smaller self-discharge rate than conventional secondary cells (only 0.2% per month compared with up to 2% per day). Low self-discharge rates were important for two reasons. On one hand, they allowed secondary cells to be utilized in flash-lights and the like. On the other hand, rechargeable cells could be sold fully charged, which was valued by customers.[62]

Even more surprising was an announcement made in 1994 by a researcher of the renowned Eidgenossische Technische Hochschule (Technical University) in Zurich, Switzerland. Standard alkaline batteries could also be recharged several times. Manufacturers had always contended that alkalines could not be recharged, and would explode if attempted to be recharged. In fact, this was explicitly stated on all alkaline batteries sold in Germany. Provided that certain safety precautions were undertaken, standard alkaline batteries could be recharged in rechargers used for NiCads at least up to 10 times without

59. C. Emmerich: Braun, Marketing Director. Personal communication to the author.

60. Key Note 1991, 10.

61. Silberg 1993, 60.

62. Zinniker 1993. 2.

additional cost.[63] They had to be recharged before the batteries were completely empty (best results if recharged at 70% full) and over-recharging was dangerous, because it caused the batteries to burst, releasing its alkaline electrolyte into the recharger. The battery industries' claims, that recharging standard alkaline batteries would cause them to explode, were simply not true.[64] The alkaline battery suddenly threatened to be a low cost competitor for NiCad and NiMH batteries.

Interestingly, this technology was not new. It had been known since the first introduction of alkaline batteries, that in principle they could be recharged.[65] Even standard zinc carbon batteries were theoretically rechargeable, although no tests of its economic and technological feasibility were known. Rechargeable alkaline batteries and the recharging of standard alkaline batteries were still fairly new developments in 1994. surrounded with much uncertainty as to their feasibility. If successful, they would be a great bonus to the environment, since recharging a battery 10 times amounted to a waste reduction of 90 % , at considerably lower cost. However, they also promised to pose a tremendous dilemma to the battery industry, which would have to decide how to maintain its profitability in the face of falling sales of batteries that suddenly lasted 10 times longer. The beneficiary of rechargeable alkalines were likely to be the environment, the consumer, and the manufacturer of the recharging instrument. The battery producers, however, were only likely to lose.

It was unclear whether these innovations were spurred by strict environmental regulation or simple economic reasons. It should be noted however, that environmentally conscientious consumers and strict legislators had shook up an otherwise slow industry.[66] This had spurred a lot of innovations, of which the rechargeable alkaline cells was just one.

63. Zinniker 1993, 1.

64. Zinniker 1993, 3-4.

65. Linden 1993. Cited in Zinniker 1993, 1.

66. Economist 1993.

Levies on Rechargeable Nickel Cadmium Batteries

NiCad batteries were under strong pressure from regulators, because they contained large amounts of cadmium, a very toxic metal. By 1994, it was still impossible to reduce the Nicad battery's cadmium content. Thus, manufacturers and regulators focused their efforts on the recycling of NiCads.

As was mentioned before, the E.C. directive included the possibility to enact the imposition of a levy or sales deposit on batteries to help pay for their collection and recycling.[67] Such measures had until 1994 been successfully fought against by producers and importers who accused them to be an unnecessary trade restriction. In 1994, however, German as well as Swiss legislators were thinking about such a solution to help increase the consistently poor return rates on NiCads, causing the battery industry to rally against it with the following arguments:

* "Disadvantage" for producers of those batteries covered by the regulations since prices of their batteries would rise in comparison to possible alternative batteries;
* Risk of misuse was high, at least as long as other European countries did not enact similar legislation, since batteries for which no levy had been paid could be returned in countries with levy-systems to collect the levy. Origin labelling that would prevent this kind of "battery tourism" was accused of being too expensive; and
* A levy would be effective only after several years, since rechargeable batteries last up to seven years. (The long life-span was disputed by others.)

Since it was undisputed that a levy was some sort of burden for the producers and importers concerned, it was being negotiated whether the levy would only be enacted if recycling rates did not rise (i.e. if the prime objective of the levy could not be reached solely by better informing the public). If enacted, the NiCad levy would provide a strong incentive to the development of environmentally sounder alternatives, such as rechargeable alkalines, NiMH or rechargeable lithium cells (see below). Swiss regulators for example had suggested a levy of $1.33 on each NiCad cell, which would make competing batteries more attractive to consumers by this amount.[68]

67. E.C. directive (1991), paragraph 7.

68. Swiss Ministry of the Environment: Studer. Personal communication to the author. Exchange rate Sfr/$l.50.

Nickel-Metal-Hydride Rechargeable Batteries

Nickel-Metal-Hydride rechargeables were a fairly recent development. On first sight it seemed that the extreme growth rate of the rechargeable market had been spurred by environmental considerations, since the recharging of cells containing hazardous wastes was preferable to the disposal of huge amounts of primary cells. But, in reality, this growth had been caused primarily by the growth of the electronic appliances market, such as portable telephones. Since its producers where primarily based in Japan, the secondary dry cell sector was also dominated by this country.

The newest marketable development in the rechargeable field, the NiMH cell, had been developed in response to environmental concerns since the NiCad battery, which it was intended to substitute, had come under increasing environmental pressure all over the world. In the mid-1990s their price was still twice that of NiCad batteries and their self-discharge rate was reported to be twice as high as that of conventional NiCad rechargeable batteries. However, these disadvantages were offset by a 60% higher energy density which should give them an advantage in the portable field - some analysts predicted their growth rate would be three times as high as that of NiCad rechargeable batteries.[69] resulting in a share of more than 25% of the rechargeable market by the mid-1990s.[70] Also, the voltage was the same for either battery, meaning products built to accommodate NiCad batteries could still accommodate NiMH cells.

In terms of cost per unit of storage, NiMH batteries were as expensive to produce as the NiCad batteries they were intended to replace. With the realization of experience curve effects in large production volumes, it was reasonable to expect NiMH production costs to fall in the future. Given their double energy density, they were to initially sell for roughly twice the price of NiCads, not even factoring the price premium its customer might be willing to pay for the additional utility he derived from a

69. Silberg 1993, 60.

70. Moffett 1992.

comparably lighter and longer lasting battery.[71] The cost of converting from NiCad to NiMH production could not be determined, but one manufacturer reported to have spent some $2 million within two years.[72]

Battery Recycling

Since manufacturers were required to facilitate battery disposal or its recycling in Germany, much development work had focused on this area. Provided the content of batteries could not be made environmentally safe to begin with, recycling seemed to be the soundest solution, for it offered a chance to safely extract and either reuse or dispose of the hazardous materials a battery contained. Recycling of batteries had a long tradition in Germany, as wet cell batteries had been recycled for more than 100 years .[73]

According to the German battery industry, a number of prerequisites had to be met in order to make battery recycling of both primary and secondary batteries successful:

- A sufficiently high collection rate for recyclable batteries (given in principle, but exact levels highly disputed);
- Availability of recycling technology;
- Reusability of battery contents (given for mercury, silver, and cadmium); and
- Economic feasibility (given for mercury, if in sufficiently large concentrations, for silver. and to a lesser extent for cadmium, but not for zinc according to producers).[74]

Sufficiently high return rates (prerequisite 1) was the subject of much debate. Whereas producers claimed that the voluntary agreement requiring producers and retailers to take back batteries containing high levels of mercury and NiCads had lead to return rates of approximately 50% for NiCads and approximately 70% for mercuric oxides in the early 1990s, there were other sources which contended that the return

71. Economist 1992.

72. C. Emmerich: Braun. Marketing Director. Personal communication to the author. Exchange rate DM/$1.70.

73. Kiehne 1990, 1.

74. Hiller 1990, pp. 6.

rates were much lower (35% and 28% respectively).[75] These low rates had lead to the necessity of stricter regulation in Germany to comply with the E.C. directives' goals as was described above.

In the early 1990s several different recycling technologies were available (prerequisite 2). In principle one could recycle mixtures of all batteries in a single process, or separate batteries first at a cost of about $580 per ton and then recycle them individually.[76] The first method was employed in Switzerland by a company called Recytech at a cost of approximately $3,200 per ton.[77] Once sorted, NiCad rechargeables were recycled in a French plant in Snam, at a cost of approximately $2,900 per ton.[78] Button cells, once sorted, were recycled by the German company NQR for $7,650 per ton.[79] These costs did not include storage and shipping.

Reusability of raw materials contained in batteries (prerequisite 3) was given for mercury, silver and cadmium. Other chemicals were of no further value in the early 1990s and had to be disposed of in landfills (cost of disposal of non-reusable recycling products are included in costs of recycling above).

The last prerequisite was the most debated one. Its requirement would be fulfilled (i.e. a win-win situation realized) if the price of the recycled constituent was lower than the price on the prime market. Whether or not this was the case could not be determined.

To a great extent the economic feasibility was a function of the recycling rate. The prerequisite for a high recycling rate was strict disclosure requirements making separate collection of batteries possible. An alternative that was not favored by producers was the simple recycling of all batteries. In addition, to get wide participation rates, the general public had to be well informed. If recycling rates could be

75. Baumann / Muth 1993, 91.

76. Baumann / Muth 1993, 107.

77. Recytech, Amman: Marketing Director. Personal communication to the author. Exchange rate Sfr/$l.50

78. Baumann / Muth 1993, 107. Exchange rate DM/$1.70.

79. NQR: Personal communication to the author. Exchange rate DM/$1.70

increased it could be hypothesized that a viable recycling market would develop (in 1994 there were only a few recyclers) with the likely result of reduced recycling costs.

Taking the high costs of disposal or recycling into consideration, the reduced disposal costs of mercury free primary batteries thus represented a substantial offset to the initial cost of removing the mercury from batteries. The cost of disposing mercury free batteries in landfills was substantially lower than having to recycle batteries containing mercury.[80] Taking into consideration the above mentioned sorting and additional storage and shipping costs, this amounted to approximately $3,000 per ton.[81]

In addition, a possible offset in general terms was to be seen in reduced disposal costs if recycling of all batteries as proposed by German regulators could be waived by increasing return rates of environmentally hazardous batteries. If these return rates could be increased, the German legislature would have no reason to propose such regulation. This amounted to approximately $1,500 per ton.[82]

Indirect Effects in Pollution Control Industries

An industry that was indirectly affected by regulations concerning primary dry cell batteries was the incinerator industry. Since the permitted level of mercury and cadmium emissions had consistently decreased, high investments in filtering the incinerators' emissions were necessary. Estimates of some experts totalled such investments at $2 million with additional annual operating costs of about $150,000.[83] Taxpayers would bear the cost. Through the removal of mercury from primary cells these costs could be saved.

In addition, the development of alternative technologies was spurred by growing concern over mercury emissions from incinerators. An incinerator in Lee County, Florida, used a carbon injection system on

80. See discussion of removal of mercury from primary batteries above.

81. Author's own estimate ($588 sorting + $588 storage and shipping + $2,500 cheapest recycling - $600 disposal cost = $3,076).

82. Cost of recycling at only available recycler of all batteries in Switzerland minus approximate average disposal cost in mid 1990s ($1000 per ton).

83. Weber 1993, 1.

smokestacks, in which mercury attached to the carbon and was removed. The Lee County facility was the first in the U.S. to use this cheaper technology.[84]

International Effects

In a few instances, German manufacturers were able to transfer their German experience to foreign markets. Its pioneering development of low mercury-content batteries, for example, arguably gave Varta a first mover advantage. However, Varta was unable to translate this advantage into a market share increase.[85] Nevertheless it allowed Varta to use the experience gained in the German market to convey an environmentally concerned image in other markets. Varta had been the first brand to develop the concept of the green battery in the U.K., introducing a mercury-free zinc carbon formulation in January 1989. Its lead in this sector was partly due to the more environmentally-conscious German market, which had already taken to the idea, and also presaged moves by the European Community to regulate the level of mercury and other noxious materials in dry cell batteries subsequently. A number of other competitors rapidly jumped onto the green bandwagon -- Kodak, Philips, and Panasonic were selling mercury-reduced cells in the U.K. within a few months -- but Varta was said to have gained a significant advantage within the British market from this move.[86]

84. Weber 1993, 1.

85. Get-man Battery Producer's Association: Kiehne, Director. Personal communication to the author.

86. Key Note 1991, 4.

APPENDIX

Table 1

Dry Cell Batteries
World Export Share Development

	1987	1989	1991
Belgium	13.7%	15.0%	15.2%
United States	8.7%	11.7%	14.5%
Japan	17.1%	16.3%	13.1%
Hong Kong	4.3%	7.3%	7.8%
Germany	8.6%	8.3%	7.6%
U.K.	8.9%	5.5%	6.1%
China	2.8%	4.6%	5.6%
Netherlands	5.4%	5.1%	4.7%
Singapore	4.1%	4.5%	4.2%
Switzerland	5.3%	4.8%	3.9%
Other	21.3%	17.1%	17.3%
TOTAL	$1,475,512	$1,780,995	$2,454,445

Note: Amounts in $1,000
Source: United Nations. International Trade Statistics Yearbook, vol. II, var. ed.

Table 2

Dry Cell Batteries World Import Share Development			
	1987	1989	1991
Hong Kong	4.9%	6.4%	9.0%
Germany	8.2%	7.2%	8.5%
United States	15.4%	10.7%	8.1%
Netherlands	6.3%	8.7%	7.4%
U.K.	7.9%	7.4%	6.8%
Belgium	4.3%	4.3%	4.8%
Singapore	1.8%	2.4%	2.7%
Japan	0.7%	1.5%	2.1%
Switzerland	2.4%	2.1%	1.9%
China	0.2%	0.4%	0.7%
Other	48.2%	48.9%	48.1%
TOTAL	$1,538,611	$1,885,543	$2,469,695

Note: Amounts in $1,000
Source: United Nations. International Trade Statistics Yearbook, vol. II, var. ed.

Table 3

Dry Cell Batteries World Trade Balance Development			
	1987	1989	1991
Belgium	136,844	185,518	254,295
United States	-109,127	6,152	155,756
Japan	240,459	261,837	269,723
Hong Kong	-11,588	9,910	-30,458
Germany	667	11,724	-21,726
U.K.	10,146	-42,731	-17,958
China	39,008	75,210	120,528
Netherlands	-16,939	-73,730	-67,654
Singapore	33,179	34,185	37,992
Switzerland	41,325	46,69 1	47,998

Note: Exports-Imports, amounts in $1,000, historical prices.
Source: United Nations. International Trade Statistics Yearbook, vol. II, var. ed.

Table 4

Leading German Dry Cell Batteries Producers

Company	Sales	Exports	Employees	Year Founded	Comments
Varta AG, Hagen	Dry Cells: DM868 million (1992)	55%	14,000, of which 6,000 in dry cells world wide, 1,500 in dry cells Germany	1888	Produces a complete range of batteries, including automotive batteries
C. Emmerich, Frankfurt	8- 10 million cells	Low	Approximately 400	1946	Specializes in NiCads and NiMh
Sonnenschein Lithium, Budingen	DM22 million	64 %	Approximately 100	1910	Subsidiary of a small producer of a automotive and wet gel batteries; specializes in lithium cells

Source: Author’s own research.

Table 5

Sales of Dry Cell Batteries by Outlet in the U.K. (By Value)		
	1988	1990
Supermarkets and Grocers	28%	29%
Variety Stores	18%	17%
Confectionery-, Tobacco- and News-Sellers	10%	12%
Electrical Retailers	9%	8%
Chemists	8%	8%
Hardware and Do-It-Yourself Stores	5%	6%
Other	22%	20%
TOTAL	100.0%	100%
Source: Key Note 1991, 5.		

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COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE PRINTING INK INDUSTRY

This case study was prepared by Claas van der Linde, Hochschule St. Gallen. The research was conducted in collaboration with the Management Institute for Environment and Business (MEB) and the U.S. Environmental Protection Agency. Copyright 1994 by MEB. The author gratefully acknowledges the assistance provided by Michael Brockhaus.

THE PRINTING INK INDUSTRY
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EXECUTIVE SUMMARY

Most innovation in the printing ink industry occurred due to environmental pressures coupled with economic concerns. Printing inks were produced for use with printing machines, which, by a variety of different technologies, applied them in liquid form to some substance, usually paper, where they dried, Most printing inks consisted of two parts: A mix of pigments and resins which constituted the final print on the paper, and a liquid carrier that was used to transport the pigments to the paper, after which it was to dry by evaporation or oxidization.

Both parts, pigments and liquid, posed a series of threats to the environment which resulted in worldwide environmental regulation and corresponding innovation by printing ink manufacturers. In order to facilitate print saturation and deep gloss, the pigments used to contain toxic metals that could result in serious environmental problems during the printed matter's recycling or after its final disposal. Likewise, the liquids used as carrier fluids posed a number of problems. In order to facilitate quick drying of the ink, many of them usually contained volatile organic compounds (VOCs), which quickly evaporated after the ink had been applied; but were a threat to the environment, because they caused the formation of ozone in the air.

One environmental problem that was successfully solved during the mid-1980s was the danger associated with toxic metals in ink formulations, which contaminated the ink sludges resulting from paper recycling. Their removal and replacement with non-toxic substances had resulted in an improvement to the environment and had removed substantial regulatory pressure, but at the price of slightly higher raw material costs.

By the late 1980s and early 1990s legislation on the permitted level of volatile organic emissions was tightened in many countries. In order to comply with these regulations, the printing ink industry developed a number of alternatives, some of which had not only environmental but also economical advantages. A first area of innovation, and one that took place primarily in the United States, had been the replacement of mineral oils in inks with vegetable oils, particularly soy oils.

The major environmental advantage of soy inks was their low VOC content (O-4 % compared to 25%-40 % with conventional petroleum-based inks). This reduced their VOC-emissions significantly and lowered worker exposure to toxic chemicals. However there was a big question mark behind soy-based inks since soy-oils were suitable primarily for printing processes where the ink dried by being absorbed by the paper and not by evaporation. Printing processes that relied on drying by evaporation - and most VOC-emissions occurred during evaporation - were not suitable for soy-based inks or were very difficult to adapt.

The discussion about soy-based inks was characterized by widely differing declarations made by Americans and Europeans. In the U.S., the use of soy oil was supported by the domestic soy industry. Their soy oils had become a political issue and thus factors such as their environmental compatibility and the intensity and clarity of colors they produced were stressed. Contrasting this view, European critics stated the limited use of soy oils for cold set inks and associated problems in de-inking. They also asserted that soy-based inks were only cost competitive in the segment of colored inks, since black soy inks could cost up to twice as much as conventional petroleum-based inks. Therefore, European manufacturers did not adopt soy-based inks, but continued to innovate in highly refined petroleum oil which they maintained was environmentally friendly and offered better commercial viability at the same time.

Another area of innovation was in ultraviolet (UV) printing inks where the drying process was carried out by UV radiation instead of heat from a heat setting oven. UV-cured inks did not result in any harmful emissions, facilitated instantaneous drying, and gave a high gloss. They were particularly suitable for printing on plastic and cardboard materials. Although they were more expensive, UV-cured inks required only 50% the energy that was needed for printing with conventional inks. They also resulted in a substantial improvement in printing speed due to the faster drying process. These advantages had resulted in UV-cured inks being the fasted growing market segment in the early 1990s.

Beginning already in the late 1970s research and development began to be focused on the development of water-based inks. Initially these efforts had been spurred by cost considerations, because the oil crisis had resulted in substantial price increases for mineral oil inks. In the 1980s, when solvents contained

Figure 1

Technical Processes in Printing: An Overview

The most important printing techniques used in the 1990s were lithography, gravure, flexography, and screen printing. During centuries they all had been derived form letterpress.

Letterpress was a process invented by Gutenberg for the world's first printing press he had developed in Germany some six centuries ago. The letter's image area was raised above the non-printing area and was inked by rollers and pressed into contact with the paper. Letterpress ink dried slowly through oxidation only, except in newspaper production where dried by absorption by the paper and could be accelerated by the application of heat.

Lithography used a flat printing plate with an image area that was receptive to ink and non-printing areas that were wetted by water and chemicals to repel ink. Litho printing was dominant in many applications as it was more economical than letterpress. The inking system, however, was fairly complex. Specially formulated heat setting inks to facilitate instant evaporation were used on lithographic web offset presses. Newspapers printed on lithographic machinery did not need heat driers as the ink was absorbed by the paper.

In the *gravure method* the image was recessed into a plate surface and the depth of the cut and the number of ink cells determined the quantity of ink that was transferred to the paper. Different thicknesses of ink were applied to give a range of tones. Gravure was very popular for printing magazine, brochure and directory printing, because as the cylinder plates had a long life and achieved fast print speeds on a variety of surfaces. Digital controls and laser and electron beam engraving were replacing hand engraving of plates. Large and small establishments used gravure as the method of printing as it gave consistently high quality in high or low production volumes.

Flexographic printing, which was derived from the rotary letterpress printing process, was a rapidly growing technique that had become one of the main methods for printing on packaging materials such as plastic, film, polyethylene bags, corrugated containers, as well as newspapers. It used photopolymer plates and fast drying inks or ultraviolet (UV) cured pastes. The advantage of flexographic printing was that it was accurate, fast, economical and gave good print quality.

Screen printing used a porous stencil through which ink was squeezed onto the underlying substrate that could be of any material, i.e. paper, metal, plastic, textiles, etc. The mesh through which the ink was squeezed ranged from fine to coarse and could be made of fabric or metal gauze, which determined the thickness of ink that was deposited on the material. Screen printing was very versatile as almost any type of ink could be used and color could be applied without restriction. Its limiting factor was the relatively slow rate of production. However, new types of equipment were being introduced to improve the rate of output.

in mineral oil inks became the focus of environmental regulation, the research efforts into water-based inks were increased, since without any doubt water was the safest solvent. Water-based printing inks initially presented several problems. They resulted in higher printing costs, because their formulation was more complex and they required more heat to dry. Initially, they also resulted in a loss of gloss and a tendency of the paper to be warped or distorted by the water. However, these problems were subsequently solved. By 1993 new resins had been developed that overcame most of the problems associated with water-based inks such as lower printing speeds, higher heating costs, and degraded paper quality. Another important innovation had been new waterborne flexographic inks for use in food packaging, allowing the use of the flexographic printing method with its distinct cost advantage over conventional printing methods in this environmentally sensitive application.

Fundamental changes were also occurring with respect to the use of alcohol in the printing process, which might ultimately lead to waterless printing without the need for a fountain solution containing VOCs. Fountain solutions were used in offset printing to render non-image areas unreceptive to the ink. They were water-based and contained a dampening aid whose role it was to reduce the water's surface tension. Traditionally, the most effective dampening aid had been isopropyl alcohol (IPA), a VOC that evaporated quickly, and thus facilitated short ink drying times and high printing speeds. However, as VOCs they were also subject to stringent environmental regulation. A further disadvantage was that they were dangerous substances, because they were skin irritants and could explode. To address these problems, manufacturers innovated in two directions: The first had been to reduce the percentage of IPAs in the fountain solution without adversely affecting its performance. A second, more promising direction had been the development of an alcohol-free, non-VOC substitute that allowed to bring emissions down to zero, maintained the fountain solution's performance, and reduced dampening costs by 30% to 50%.

Another way to eliminate VOC emissions in offset printing was to substitute the fountain solution as a whole and print waterless, a relatively new technology that required no alcohol or any other form of costly and environmentally hazardous dampening system in the pressroom. With certain applications, waterless printing could thus result in substantial cost savings. The technology's future prospects were very promising: According to industry experts, at least 10% of web-offset printing was expected to be performed waterless by 1996.

Another area of innovation had been the cleaning agents used for removing inks from printing presses and production equipment. Due to their high VOC-content they were subject to strict regulation. A possible substitute had been developed in 1992 in the U.S. It was more expensive than conventional, VOC-based cleaning agents, but this disadvantage was partly offset by its advantages in terms of easier application, reduced health hazards, and eliminated risk of explosion.

As a result of the huge number of different printing ink ingredients and the variety of different processes where inks were used, printing inks were enormously complex products. This made it very difficult for legislators to set sensible regulations, and created the potential for costly and useless requirements. A good example for such a mistake was the German Bundes-Immissionsschutzgesetz under which coldset printing processes were subject to an approval procedure concerning air emissions to get an operating license, despite the fact that coldset printing could not even result in any air emissions because coldset inks dried by absorption in the paper and not by evaporation.

INDUSTRY STRUCTURE

ln the 199Os, the commercial environment for ink manufacturers was influenced not only by environmental laws and regulations, but also by the influence of technical changes and by a recession which had severely impacted the printing industry. This had intensified problems for ink manufacturers as well as many of their customers, some of whom, having invested heavily in new printing presses during the boom years of the 1980s, were in serious financial difftculties because of slack demand.

The introduction of new printing materials required completely new approaches. Reformulations of printing inks had become necessary to comply with all the technical and environmental changes. Ink manufacturers had to take into account the effect of national and international laws on their customers, as well as the increasing emphasis on the recycling of every printed matter. Printing inks had to be made easily removable during recycling and the solvents used during printing had to be recoverable.[1]

Product

Product Description

Printing inks were used for printing with printing machines. Modem printing inks were derived from the original, century-old formulations, which had been a mixture of soot and burnt oils mixed with resins and gums from natural sources such as trees, resulting in a typically black drawing ink.

Printing inks were to be distinguished from writing inks which were very fluid and contained virtually no pigments as these would clog a pen's nib. Ball point pens also did not use printing inks, using instead a thick, dyed, nonaqueous paste that dried almost immediately on contact with the paper. Printing inks were highly complicated chemical compounds consisting of a variety of pigments. During several dispersion processes these compounds were made into specially formulated varnishes in order to suit particular methods of printing.

I. ICC Key Note Market Reports 1992, 6.

Typical varnishes were made from resins dissolved in petroleum spirits, alcohol, or linseed oils, which had been thickened by high temperature heating. Ink containing carbon black was used by newspapers as it rapidly soaked into the upper layer of the paper and, unlike many other printing inks, did not require additional drying agents.

Every printing process had its own requirements for inks and the choice of which ink to use depended on a variety of factors such as the nature of the substrate to be printed on, type of application, drying speed, the need for color, and the type of printing process itself. Colored inks, which were essentially based on a mix of yellow, magenta (red) and cyan (blue), were used extensively by the printing industry for illustrative and decorative work. Black, called a non-color. was the standard for most remaining inks,

Ink formulations were designed to ensure the ink adhered to a wide variety of surfaces such as paper, board, glass, metal, plastic, wood, or textiles. The various printing techniques could only work with particular types of ink which ranged from fluids to pastes. There were also many different inks for different types of equipment. Plasticizers were added to give flexibility to the ink and adhesives were added to bind the ink to the substrate, such as paper, plastic or others. Wetting agents and waxes were used to make the ink resistant to abrasion. Catalysts were added to facilitate quicker drying. Alternatively, solvents were added which evaporated on contact with the substrate, or water emulsions which were heat dried when employed, or other drying methods such as ultraviolet radiation were used.[2]

Substitutes

Despite a fairly large number of actual and potential substitutes, printing inks as well as printing in general did not face any serious substitution threats. The long expected negative impact of electronic media such as electronic mail, voice mail, data on compact disc, and so on did affect the printing industry, but not to the extend which had often been predicted.[3]

2. ICC Key Note Market Reports 1992,4.

3. Commission of the European Communities, 1991/92. 8-24.

Likewise, laser and ink jet printing was gaining rapidly in popularity as the cost of equipment fell and reliability improved. However, these techniques were not considered to be suitable for high volume applications where conventional printing remained paramount. There niche was in business areas where high quality repetitive printing was required in relatively short production runs.[4]

Production Process

Similar to paint manufacturers, printing ink manufacturers were primarily formulators. They determined the optimal combination of at least 1,500 different raw materials which satisfied the user's printing needs and supplied that formulation to their customers. The manufacturing process aimed at providing a uniform mix and sizing of component materials and basically consisted of four steps. First was a premixing step where pigments, adhesives and solvents were combined to produce a paste of homogeneous composition. In a dispersion process the pigment particle size was then reduced. The material was subsequently thinned with additional solvents, oils and resins and then, in a final step, once again dispersed.[5]

Economies of Scale

Given the large variety of different formulations and an extreme customer orientated small-batch production process, economies of scale were modest. However, in an industry where R&D constituted a main source of competitive advantage, larger companies which could fund these activities were sometimes said to be favored over small firms.[6]

Entry or Exit Barriers

There were two important entry barriers in the printing ink industry: Strong supplier-customer relationships which often had been developed over generations. The other entry barrier was the manufacturer's know-how concerning the large variety of printing ink formulations mentioned before.

4. ICC Key Note Market Reports 1992, pp. 3.
5. Huber-Gmppe 1989, pp. 7.
6. ICC Key Note Market Reports 1992, 3.

As in the allied printing and publishing industry, a main exit barrier was constituted by the highly specialized fixed assets.

Buyers

Buyer Description

Virtually every industry was a customer for printing inks, but the main sectors of demand were from the publishing, printing, and packaging industries.

The publishing industry - newspapers, books, and magazines - represented a huge market for the specialist printers in this activity. In recent years newspaper printing had been transformed by the adoption of electronic technologies at every stage of the process from the origination of text and pictures to the final product.

Commercial printing covered a multitude of industries such as the production of directories and catalogues, financial, legal and business forms, timetables, advertising material, or reference manuals, which were fundamental to commercial life. Commercial printing represented a large market for the printing ink industry and many of the companies involved had specialized in this segment.

The packaging industry was another major customer for printers. It was the most resilient to recessions. The food and drink industries used a wide variety of packaging materials such as paper, cardboard, plastic, metal, glass, and wood. The ink had to adhere to, and be consistently legible on all these materials even in the most extreme conditions. Inks and varnishes were as varied as the packaging materials, some were aqueous based, some contained alcohols, and, for volume printing on plastic surfaces, solvent-containing inks were used. Particular care was taken over wrappings and inks used with certain types of food, because of the fear of possible contamination.

Distribution Channels

The main distribution channel for printing was directly by the company itself. Beyond that there were few print ink wholesalers. The main reasons for direct distribution were the necessary close relationships between the ink manufacturer and the printer due to research and delivery requirements, risks associated with storing inks, and the high transportation costs.[7]

Bargaining Power

printing ink manufacturers generally had low bargaining power. Thus, many of the newly developed environmentally friendly inks of the early 1990s were initially more expensive than conventional inks, but were not able to fetch higher prices in the market.

Suppliers

The primary suppliers to the printing ink industry were producers of synthetic chemicals. Multinational chemical and petrochemical firms such as BASF, Hoechst, Bayer, Ciba-Geigy, Sandoz, ICI, and Dow Chemical were important suppliers to the industry throughout the world. More recently, because of the more intensive use of biodegradable ingredients such as soy oil, producers of the underlying agricultural products had become critical suppliers as well.

Environmental Regulation

Environmental Risks

The printing ink industry impacted on a number of environmental media throughout all major steps of its extended value chain, beginning with raw material and suppliers to production and usage until the final disposal of the printed matter. There was strong pressure on printers to use less polluting water-based inks or inks with higher solid content. These inks, which were considered to be the most environmentally friendly, were becoming increasingly accessible to a wider range of printing processes.

The major environmental impact regarding printing inks were volatile organic compounds (VOCs). In the presence of heat and sunlight, VOCs reacted with nitrogen oxides in a photo-chemical reaction and formed ozone, a contaminant of the air. VOCs were contained in solvents in the ink and were released during production as well as during application (i.e. during the printing process itself). VOCs presented the largest problem during the printing process, where solvents evaporated when the print dried. This

7. Commission of the European Communities, 1991/92, 8- 18

was less of a concern during the production process, because most producers of print inks had already

Figure 2

Environmental Impacts: Printing Inks				
Stage **Media**	**Suppliers** Petrochemical Industry	**Production** Printing Ink Industry	**Usage** Printing Industry	**Final Disposal of Printed Matter**
Waste			Waste inks	Toxic waste (solved in the mid-1980s by eliminating toxic heavy metals from pigments)
Soil	Storage of raw materials	Storage of inks		
Water	Storage of raw materials	Storage of inks. cleaning of production machinery	Cleaning of presses with water	
Air	Storage of raw materials	Evaporation of solvents during production process; Cleaning of production machinery with solvent-based solutions	Evaporation of solvents and alcohol during the printing process; Cleaning of presses with solvent-based solutions	
normal typeface: small impact		underlined: medium impact		**bold: large impact**

adopted closed-loop systems, which allowed them to recapture part (or most) of their VOC emissions

Another source of VOCs in the printing process was the dampening aids used in fountain solutions. Fountain solutions were used in lithographic offset printing, where they were applied to the lithographic plate to render non-image areas unreceptive to ink. Traditionally, some 15% to 20% of a fountain solution consisted of VOCs. The amount of VOC emissions depended to a considerable extent on the degree of finishing: the more finishing, the larger the environmental problem since more solvents were required.[8]

VOCs also posed a problem during cleaning of printing ink production equipment as well as during cleaning of the printing press itself which was usually done with solvent-based detergents.

8. Association for the Promotion of Research in the Graphic Arts Industry (UGRA) 1992, pp. 2.

Another environmental issue was the disposal of waste ink, many types of which were classified as toxic waste. In many countries, the regulations for disposal of waste inks had become so strict that they had prompted ink manufacturers and printers to attempt optimizing the recovery of used inks.

Yet another environmental issue was energy efficiency. The production of mineral oil-based raw materials in the petrochemical industry used more energy than the production of renewable raw materials.

An additional potential risk - especially for suppliers - was the storage and transport of fluid ingredients such as solvents. Many fluids were flammable and in the case of an accident were potential threats to the air, soil, and water.[9]

Printing inks could also pose environmental problems when it came to recycling printed matter. In this case the type of ink played an important role: Not all inks had the same de-inking characteristics, which determined the output quality of recycled paper as well as the energy usage for processing.

Unlike the case until the early 1980s and because of the elimination of toxic metals such as cadmium and lead from pigments during the mid-1980s, the final disposal of printed matter was no longer a problem. They could easily be disposed of in landfills or burned.

Focus and Type of Regulation

Environmental regulations concerning the printing ink industry varied widely throughout the world. Whereas European, Japanese and American producers faced very strict regulations and standards, many companies based in Asia - primarily Korea and Malaysia - were not yet confronted with any legal restrictions.

Most current or proposed regulations in the early 1990s were performance standards or command and control instructions which focused on air-pollution (Germany's Bundes-Immissionsschutzgesetz, the E.C. 's VOC-Directive, US Clean Air Act Amendments). In addition, there were also a few instances of

9. Association for the Promotion of Research in the Graphic Arts Industry (UGRA) 1992, pp. 2.

Figure 3

Environmental Impacts: Printing Inks				
Stage / **Media**	**Suppliers** Petrochemical Industry	**Production** Printing ink Industry	**Usage** Printing Industry	**Final Disposal of Printed Matter**
Waste			**Waste inks**	Toxic waste (solved in the mid-1980s by eliminating toxic heavy metals from pigments)
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Air	Storage of raw materials	Evaporation of solvents during production process Cleaning of production machinery with solvent-based solutions	**Evaporation of solvents and alcohol during the printing process; Cleaning of presses with solvent-based solutions**	
normal typeface: small impact		underlined: medium impact		**bold: large impact**

voluntary or "gentleman's agreements:" In 1985, for instance, the Swiss printing ink industry agreed with the Ministry of the Environment to reduce solvent usage by 20% .[10]

10. Egger and Stall 1992, 43.

COMPETITION

In 1991, the United States of America was by far the largest producer of printing ink in the world, producing nearly 900,000 tons which represented some 45% of the world's production. The U.S. was followed by Europe with a 1991 production volume of over 600,000 tons and Japan with about 400,000 tons. The remaining 100,000 tons was accounted for by Australia, East Europe and some Asian states.

Germany

Competitiveness Overview

In 1992, the European Community accounted for nearly 90% of the total production of printing inks in Europe. Among its member countries, Germany was by far the largest printing ink manufacturer with a total production of over 250,000 tons representing an European production share of 40% and a world production share of 12.6%.[11] Other important European manufacturers of printing ink were the UK, France and Italy which together held a production share of almost 40%. The remaining 20% was split among the Netherlands, Belgium, Spain, and others.

Since the industry was primarily orientated towards the domestic market, its export quota was only 28 % , far below the German industry average. With DM464 million, the German printing ink industry had one of the largest positive trade balances in Europe.[12]

Leading Firms

The leading German printing ink manufacturer was thought to be Kast-Ehninger of Stuttgart. Kast was a subsidiary of BASF of Ludwigshafen, the second largest printing ink producer in the world, and held a European market share of approximately 15%. The second largest German firm was the Huber-Gruppe of Munich with a 9% European market share, followed by Gebr. Schmidt of Frankfurt with 8% and Siegwerk Druckfarben of Siegburg with 8% .[13]

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11. Commission of the European Communities, 1993, 6-20.
12. CEPE, European Confederation of Paint, Printing Ink and Artists' Colours Manufacturers Associations, 1993
13. Verband der deutschen Druckfarbenindustrie, Frankfurt, 1994.

Another leading firm was Hartmann Druckfarben, which was based in Frankfurt. This $81 million/year ink maker had been acquired in 1986 by Japan's Dainippon Ink and Chemicals (DIC), the world's largest producer of printing inks. Hartmann had previously been a subsidiary of BASF. West German antitrust law had obligated its divestiture after BASF's acquisition of the American ink and automotive coatings maker Inmont, which boosted BASF's German printing ink market share to more than 50% .[14]

In 1990 Sun Chemical (a division of Dainippon Ink and Chemicals) had signed a letter of intent with the East German Druck- und Lederfarbenfabriken Halle to set up a joint venture to produce printing ink for East Germany and other Eastern European markets using Sun's technology. Sun had been the first U.S.-based printing ink manufacturer to enter into such an agreement.[15]

Distinctive Environmental Regulation in Country

The most important law in Germany regulating VOC-emissions was the Bundes-Immissionsschutzgesetz, Bimschg (Federal In-mission Control Act) of 1974. Implementation of this law was required by the states according to recommendations in the Technische Anleitung (TA) Luft, a set of technical instructions on how to control air quality.' In strict legal terms, the TA Luft was only binding to administrative authorities. However, indirectly, it also had a binding effect on the printing and printing ink industries because of the approval procedures it contained.

The TA Luft was amended and updated several times, with major changes occurring in 1986 and 1991. Until 1991, its primary impact on the printing ink industry had been the requirement to receive formal approval for plants using more than 250kg solvents per hour. Manufacturers who exceeded this limit were allowed to demonstrate equivalent reductions at other facilities, providing them with flexibility as to where to reduce emissions most economically. The 1991 amendments to the TA Luft increased the stringency of requirements for printing processes, putting limits on air emissions of 0.50g/m^3.

14. "Dainippon Buys a European Printing Inks Maker." Chemical Week July 23, 1986, 7.
15. "Sun Ink Venture in East Germany." Chemical Week May 16, 1990, 48.

German printing ink manufacturers were also subject to the United Nations European Commission for Europe (ECE) protocol for reductions of VOCs which aimed at a 30% reduction in VOC-emission by the year 2000.

By 1994, there was still no directive from the European Community concerning VOC emissions besides the ECE protocol. All European Community directives were based on article 130s of the European Community Treaty, thus requiring each individual member country to devise its own method of implementing the directive. Industry representatives sometimes feared that this might lead to vastly different laws, followed by significant market distortions.[16]

The most important planned directive concerning the printing ink industry was the directive on "The Limitation of The Emissions of Organic Compounds." This draft included the obligation to install a solvent-management plan and set emissions limits for VOCs. Most relevant was its Annex IV which set specific VOC emissions limits for printing ink manufacturers.

The draft directive also defined a maximum of 5% organic solvent content for water-based printing inks. The European printing ink manufacturers association criticized this limit, contending that the aim should not be to eliminate the solvents, but rather to retain them as complete as possible in the inks.

The second directive on "Integrated Pollution Prevention and Control" was expected to affect the printing ink industry in two ways. By establishing cut-off limits for the most polluting substances for water, soil and air it was expected to lead to increased research into environmentally friendly water-less inks. It was also expected to lead to the increased use of closed-loop solvent recovery systems, because it required an integrated environmental protection approach to prevent polluters from shifting emissions from one media into another. Increased adoption of closed-loop solvent recovery system, in turn, was expected to lead to further development of monosolvent inks which were necessary prerequisites for solvent-recovery systems to be economically feasible.

16. "Developments of Printing Ink in the 1990s." Ink & Print 1993, 18.

A further feature of the directive on integrated pollution control was that it contained provisions for exempting manufacturers from certain requirements, if they committed to setting up an emission plan with fixed targets.

The United States

Competitiveness Overview

With a world production share of 42% and annual sales of $3 billion in 1992, the United States was the world's largest manufacturer of printing inks. [17] U. S . printing ink manufacturers were oriented towards their domestic market even more than their European counterparts. 98% of the American production of printing inks was geared towards the domestic market and only 2% was exported. [18]

Leading Firms

The largest U.S. producer of printing inks was Sun Chemical of Fort Lee, New Jersey. It had been acquired in 1987 by Japan's Dainippon Inc.,[19] an acquisition which had made Dainippon the largest printing ink and graphic arts supply company in the world.[20]

Flint Ink of Detroit, a privately held company, was North America's second-largest producer of printing ink, and the world's largest producer of newspaper ink. Flint Ink also produced chemical pigments for the printing industry. In 1991, Flint Ink had $510 million in sales.

Other leading U.S. manufacturers of printing ink were JM Huber of Edison, New Jersey, the Sakata Group of Elk Grove Village. Illinois, Superior Printing Ink of New York City, and U.S. Printing Ink of New Jersey.[21]

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17. Commission of the European Communities, 1993, 6-20.
18. "Flint Ink's Future Was Printed in Soybeans." Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3
19. ICC Key Note Market Reports 1993, 19.
20. ICC Key Note Market Reports 1993, 19.
21. "Flint Ink's Future Was Printed in Soybeans." Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3.

Distinctive Environmental Regulation in the United States

In the U.S., VOC emissions from printing inks were regulated since the passage of the Clean Air Act Amendments of 1977, which set standards for acceptable levels of ambient ozone. Similar to Germany's TA Luft, the law required the U.S. Environmental Protection Agency (EPA) to provide Control Technique Guidelines (CTGs). CTGs were guidance documents issued to the states to help in developing regulations on air pollutant emissions and recommended specific, reasonably available control technologies. Once finalized and issued, states in ozone non-attainment areas had 12 months tune to adopt the CTG's recommendations as regulations. CTGs only set minimum requirements and states and local agencies were free to issue stricter rules.[22]

CTGs contained so-called control strategies for efficient emissions reduction that affected three areas of the printing industry: ink manufacturing operations, controls for fabric printing operations, and controls for web offset printing operations. Most control strategies focused on add-on controls, process modifications. or reformulation or substitution of materials.

The American printing ink .industry was also subject to the 1990 Clean Air Act Amendments, which among others, specified

* permitting requirements for installations,
* annual emission fees,
* restrictions on 189 hazardous air pollutants and categories, as well as
* control requirements for VOC sources.[23]

There was also regulation concerning the waste ink problem. It included the Resource Conservation and Recovery Act of 1976 (RCRA), which defined solvents, solvent-containing inks, and other toxic materials as hazardous waste, and the Comprehensive Environmental Response Compensation and Liability Act of

22. "Sheetfeds Set for Eco-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.

23. "Printing Industry Works on Air Pollution Control. " Pittsburgh Business Times & Journal January 28, 1991, vol. 10, no. 25, 3.

1980 (CERCLA), commonly known as the Superfund law, which was intended to facilitate the cleaning up of hazardous waste sites and, where possible, to impose liability for cleanup on responsible parties.[24]

24. "Waste Ink: The Burden was Shifting." Graphic Arts Monthly January, 1991, vol. 63, no. 1, 116.

EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

Product Effects in the Printing Ink Industry

Due to new environmental laws and scientific results, the list of chemicals that was not approved for use in inks because of health or environment concerns was much longer than the list of chemicals that was approved. This limitation increased the challenge that ink manufacturers faced: To devise formulations that met all technical requirements and were environmentally safe. Ink research in the 1980s had solved for the most part problems such as toxic metal contamination and flammability. More difficult was the reduction or elimination of VOCs and the problem of proper post-production waste ink disposal in accordance with regulations.[25]

Although the printing ink industry had come a long way in making inks and coatings more environmentally friendly, users and the public at large still continued to have many misconceptions about how safe they were to use and dispose of. Because many of the ingredients that went into inks were derived from petrochemicals, they tended to be immediately suspect. But while they might be considered hazardous and had to be handled in certain ways, they were not necessarily toxic.

By 1994, almost no inks contained lead or other toxic metal compounds anymore. Surplus inks, however, were still disposed of in approved landfills or, preferably, used as fuel in cement kilns or similar incinerating programs.[26]

To address environmental problems manufacturers had developed a number of different inks. The most frequently discussed alternatives to conventional petroleum-based inks were soy-based-, UV-cured, and water-based inks.

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25. "R&D Choices: Printing Inks." Graphic Arts Monthly April 1992, vol. 64, no. 4, 94.

26. "Inks Aren't the Problem: The Ink Industry had Come a Long Way Toward Eco-Responsibility." Folio: The Magazine for Magazine Management April 1, 1992, vol. 2 1, no. 4, 101.

Soy-Based Inks

Considerable confusion surrounded the use of soybean oil as a substitute for petroleum oil in printing inks. Letterpress and lithographic inks had traditionally been made with vegetable oils. Only after World War II, with the development of high-speed printing presses, had fast-drying petroleum-based inks become the standard. By the 1990s, however, there was, once again, a move towards printing inks that were based on vegetable oils. An initial driving force behind the development of soybean inks had been rising petroleum costs.

Responding to the energy crisis in the late 1970's, the American Newspaper Association began looking for a vegetable-oil ink, hoping that its price would be lower and more stable than that of petroleum inks. Soybeans were already domestically grown in the United States at that time, and thus the choice for a vegetable oil was a natural one. By 1986 a first soy-based newspaper ink had been developed, and one year later, in 1987, Sun Chemical's General Printing Ink Division introduced the first commercial soy-oil ink to the market. All major ink makers soon introduced similar soy inks. By the early 1990s, one-third of all U.S. newspapers were printed with soy-based inks, including half of the nation's dailies[27] and about 3% of the U.S. soy oil production was used to manufacture printing inks.[28]

In the U.S., soy-based inks soon gained in acceptance because of their environmental compatibility combined with their good performance: American printers had noted better results on older presses, an easier clean-up between runs, a greater stability on the press, and better compatibility with recycled papers. Soy-based inks did not rub off the paper as readily as petroleum-based inks, and soy-based colored inks produced intense, clear colors on the paper.[29]

On the other hand, the slow drying speed of soy-based ink was a primary source of complaints that was voiced by some printers, particularly those in sheetfed operations. The ink films applied in sheetfed

27. "Flint ink's Future Was Printed in Soybeans." Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3.

28. "Einsatz nachwachsender Rohstoffe in Druckfarben." Farbe+Lack July 1992. vol. 98, no. 7, 509.

29. "Soy-Based Inks: US and Western European Consumption Would Double by 1995, Market Could Approach $ 800 Million." Industrial Bioprocessing November, 1991, vol. 13, no. 11, 4.

printing were generally heavier than those applied in news and forms printing, and a greater variety of substrates was used Both the thickness of the film and the inability of some substrates to allow penetration and absorption adversely affected drying times. These difficulties were even more Pronounced in high-speed heatset offset printing. Because heatset inks dried primarily by evaporation, the high boiling range and low vapor pressure of soya oil, even at minimum substitution levels, could create drying problems, requiring printers to slow down their presses or increase oven temperatures and resulting in increased fuel consumption, a rise of paper degradation, and a loss of ink g1oss.[30]

For these reasons, European manufacturers maintained that soy oils were unsuitable for heatset inks. They also asserted that soy oil was more aggressive to the production facilities and thus had an adverse effect on printing press lifetime.[31] Soy-based printing inks were also more expensive than conventional inks. Color newspaper inks made with soybean oil cost about 5% to 10% more than petroleum-based inks and black soybean inks could cost up to twice as much as petroleum inks, making them very price uncompetitive.[32]

petroleum-based inks contained 25-40% VOCs, compared to only O-4% for soy-based inks. Reduced VOC emissions and lowered worker exposure to toxic chemicals thus were the principle environmental advantages of soy inks. However, the major VOC problems occurred during the drying process in heatset printing, whereas no drying was needed in coldset printing where the ink was completely absorbed by the paper. Since soy-based inks presented major problems in heatset operations, their adoption did not really solve the VOC-problem.

Other ecological benefits that had been claimed by some soy ink proponents - better biodegradability, the creation of less toxic waste, and less hazardous de-inking sludges - were also questioned by many ink makers from Europe, as well as from the petroleum industry. These critics maintained that soy oil

30. “Soy Oil Inks.” Graphic Arts Monthly March 1992, vol. 64, no. 3, 116.

31. “Werbung fur Druckfarben mit nachwachsenden Rohstoffen?” Verband der deutschen Druckfarbenindustrie. 1994.

32. “The Media Business - A New Ingredient for Many Papers: Soybean Ink.” The New York Times March 23, 1992, Section D, 8.

was no more easily biodegraded than petroleum on paper, and that much of the toxicity of printer's waste was due to the pigments and resins used in ink formulations, regardless of the carrier. In contradiction to the American standpoint, Europeans stated that soy-based inks did not have better de-inking qualities than petroleum-based inks. Moreover, while there might be reduced VOC emissions from using soy-based inks, these were not significantly less than those emitted from inks formulated from modern saturated petroleum oils, which, according to German, E.C. and American law, were not hazardous either.[33]

Soy-based inks were appropriate for use with letter-press and lithographic presses, but not for gravure presses. Therefore, newspapers were the biggest market for soy-based inks, particularly in color printing. However, European associations noted that the use of soy-based products in the U.S. to a large extent was the result of political pressure from the domestic soy industry, as evidenced by the Vegetable Ink Printing Act, which required that 40% of all lithographic federal printing be done with vegetable inks.[34]

UV-Cured Inks

Traditionally, high-gloss clear coatings, used on the covers of books and magazines, had required various types of volatile petroleum solvents. Driven by environmental regulations, as well as by cost considerations, ink manufacturers in the early 1990s began research on ultraviolet curing alternatives. By 1993, most of the conventional inks in high-gloss clear coatings segment had been replaced by ultraviolet (UV) cured inks.

UV-cured inks consisted of specialized resins and solvents, so-called liquid acrylic monomers, and certain additives that, when subjected to high-intensity UV light, solidified. The "drying" process was thus carried out by UV radiation instead of applied heat from a heat-setting oven.[35] Since no solvents were emitted during the process, it was pollution free. Nonetheless, the process also had some negative effects

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33. "Werbung fur Druckfarben mit nachwachsenden Rohstoffen. Verband der deutschen Druckfarbenindustrie. 1994.

34. "Shades of Green: Environmentally-Friendly Inks and Dyes." Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

35. ICC Key Note Market Reports 1993, 21.

on the environment. Not only did UV-cured inks contain carcinogens,36 but de-inking was a concern with UV inks and coatings as it was difficult to break them down with conventional techniques. However, his drawback could be overcome by adopting the so-called flotation process for de-inking (see below). [37]

UV-cured inks were increasingly being used for high speed printing, where they were not only advantageous from an environmental standpoint, but also highly cost-effective. They required only half the energy used by conventional inks requiring heat set ovens which more than offset their initial price disadvantage. In terms of cost effectiveness, there were few alternatives to UV inks for high-gloss clear coatings printing .[38]

As a result, UV-cured inks were gaining in sheet-fed printing, packaging, as well as narrow and wide width flexography. With expected growth rates of 10% to 15% in the 1990s.[39] radiation reactive inks had become the new segment leader in growth. Manufacturers said that 25 years of research into their development and potential end uses was finally paying off. Economic considerations, as well as pressure form environmental regulations, had led to innovations that led to distinct competitive advantage to their developers.

Water-Based Inks

Some twenty years ago, even before the development of soy inks, water-based inks had emerged as an alternative to petroleum-based inks. Ink manufacturers began experimenting with water-based inks even before the oil crisis of the 1970s. Pressure from increasingly strict environmental regulations subsequently prompted the industry to try them as a means of eliminating petroleum solvent altogether, initially only with limited success. Substantial research work subsequently allowed to considerably

36. “The Greening of an Industry: Printers and Consultants Develop Environmentally Friendly Printing Products.‘ Folio: The Magazine for Magazine Management July 1990, vol. 19, no. 7, 29.

37. “Inks Aren’t the Problem: The Ink Industry has Come a Long Way Toward Eco-Responsibility.” Folio: the Magazine for Magazine Management April 1, 1992, vol. 21, no. 4, 101.

38. ICC Key Note Market Reports 1993, 23.

39. “Shades of Green: Environmentally-Friendly inks and Dyes.” Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

improve the qualities of water-based ink, allowing printers to shift from solvent-containing to water-based inks wherever the required printing process allowed it.[40]

Compared to solvent-containing inks, water-based inks produced brighter colors.[41] However, the raw materials they required were more expensive than those used to make petroleum-based inks. Initially, they also required more heat to dry, did not print as well or had as much gloss, and the water tended to distort the paper causing waviness in the printed product.[42] A further disadvantage was that water-based inks were not always compatible with existing printing processes and required modifications such as additional heat drying facilities.

In the early 1990s, printing ink manufacturers succeeded in developing new resins for water-based inks to be used in high speed web printing presses. New waterborne systems were also formulated for gravure and flexographic inks to be used in food packaging. The new resins overcame most of the problems associated with water-based inks such as their lower printing speeds and high heating costs.

Since they did not contain any organic solvents, water-based inks were not only non-hazardous, but also non-flammable. However, problems associated with their de-inking initially constituted a drawback. Probably the most popularly used de-inking method was the flotation process which relied on the fact that oil-based printing inks, being less dense, floated to the top if mixed with water, where they could be collected. Because water-based inks did not contain any oils they were impossible to use with the flotation process.[43] After considerable research conducted by a group of U.S. manufacturers, this drawback was removed in 1993 by developing an additive to the flotation process that allowed newspapers that had been imprinted with water-based inks to be recycled to standard commercial levels.[44]

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40. Huber-Gruppe: Dr. Reismann. Personal communication to the author.

41. “Flint Ink’s Future Was Printed in Soybeans.” Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3.

42. “Inks Aren’t the Problem: The Ink Industry had Come a Long Way Toward J&-Responsibility.” Folio: The Magazine for Magazine Management April 1, 1992, vol. 21, no. 4, 101.

43. ‘Ink Market Segments Had Flat Year: Printing Ink Manufacturers.” Graphic Arts Monthly March, 1993, vol. 65, no. 3, 96.

44. ICC Key Note Market Reports 1993, 23.

Given higher raw material costs, the Price of water-based inks was higher than the price of conventional petroleum-based inks. In several applications this initial cost disadvantage was fortunately offset by other economic advantages. In the packaging industry, for instance, where they were used on flexible substrates including both paperer and plastic film, water-based inks had made great inroads, because the flexographic printing process that was generally employed with water-based inks was less expensive than the conventional offset process with petroleum-based inks.[45]

As a result, sales of water-based printing inks were expected to grow substantially. In the U.S., for instance, they were estimated to grow at an annual growth rate of 6.3%) reaching some 246 million pounds of ink by 1995 to represent a share of 10.3% of the 2.38 billion pounds market total.[46]

New Petroleum-Based Inks

particularly in Europe, where soy-based inks had never received the attention they had attracted in the U.S., petroleum-based inks continued to be the focus of substantial research and development efforts. By the early 1990s spurred by strict environmental regulations and customers who were demanding environmentally safe printing inks, the trend in Europe was towards the use of highly refined petroleum. These oils combined the well-known qualities of conventional petroleum-based inks with the added advantages of non-toxicity. One manufacturer even pointed out that they were edible.[47] Their non-toxicity thus provided easier storage, a safer printing process, and an improved public acceptance. In 1993, highly refined petroleum oils were more expensive than conventional oils, but industry observers expected this price differential to be at least reduced, if not eliminated, with continued innovation efforts .[48]

45 “Shades of Green: Environmentally-Friendly Inks and Dyes.” Chemical Marketing .Reporter September 20, 1993, vol. 244, no. 12, SR14.

46. Chem Systems. In: “Shades of Green: Environmentally-Friendly Inks and Dyes. ” Chemical Marketing Reporter September 20, 1993, vol. 244, no. 12, SR14.

47. A. Miiller AG: Hauser, in: “Die Sensation auf dem Drucketmarkt.” Amriswiler Zeitung March 24, 1992.

48. “Shades of Green: Environmentally-Friendly Inks and Dyes.” Chemical Marketing Reporter September 20, 1993, vol. 244, no. 12, SR14.

Production Process Effects in Printing Ink Production

In the early 1990s, printing ink manufacturers and printers in most industrialized nations were subject to newly enacted environmental laws which regulated organic solvent discharges and waste generation resulting from both printing ink production and printing ink application, i.e. the printing process itself. The laws also affected working practices concerning the exposure of employees to potentially harmful carcinogens. Strict controls and enforcement frequently made it impossible to operate from old premises which had been adapted over the years on an ad hoc basis, necessitating investments in premises as well as new processing equipment in order to comply with regulations which were certain to become even stricter in future years.

Once again, volatile organic compounds and recycling were the main environmental issues. Regulation had led to considerable change and innovation for printing ink manufacturers as well as printers themselves.

Solvent-Recovery Systems

To comply with regulations restricting the release of VOCs contained in petroleum solvents for use in heatset inks, most heatset printers employed devices on their driers that catalytically incinerated the solvents .[49] Realizing that incineration was at best a suboptimal solution involving the elimination of VOCs, which themselves represented a costly raw material, manufacturers soon began to research technologies that would allow them to not only comply with regulations, but also to re-use the VOCs. One such technology that was successfully employed by many printing ink manufacturers involved a closed loop system that recovered and then redistilled the evaporated solvents into holding tanks for subsequent re-use in printing inks. This technology could only be used for production processes involving one single kind of solvent, so-called monosolvent processes, because separating different VOCs was economically unfeasible. Frequent re-use of solvents also posed a threat of introducing contaminants to the manufacturing process which might negatively affect printing ink quality.

49. “Shades of Green: Environmentally-Friendly Inks and Dyes.” Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

There were several solvents which could be economically recycled without adversely affecting product quality, The most popular one was Toluene, a solvent that was primarily used for gravure inks. Recycling of toluene in a typical gravure production process allowed to reduce solvent input by about 20% and toxic waste by nearly 5%, for a total production cost reduction of 8%.[50] In addition, the risk of explosion was reduced and hence the cost of insurance. Closed loop VOC systems not only allowed the producer to comply with regulations and protect the environment, but also resulted in improved economic efficiency.

Cleaning Solutions

Another area where printing ink manufacturers had to confront environmental issues was machinery cleanup. To remove excess printing inks, oils, and other inputs from production equipment, manufacturers frequently employed cleaning agents which contributed to air pollution because they contained up to 100% volatile organic compounds. One method for printing ink companies to lower their VOC emissions from machinery cleaning was to better train employees on the proper use of solvents.[51]

However, by the early 1990s, an American Control Technique Guideline draft (CTG) called for cleaning agents to contain only 30% VOC, with the remaining 70% consisting of soap and water. Users initially feared that the low VOC content cleaning agents required by the CTG would lead to increased costs, slower drying times, and reduced cleaning ability. Cleaning agent producers were able to quickly innovate and develop solutions that addressed these concerns, There were also less risks associated with storing the modified cleaning agents.

A particularly innovative cleaning agent was introduced in 1992 by an American supplier in Palmer, Pennsylvania. It was composed of non-volatile compounds with properties similar to conventional volatile solvents. It did not contain water, but could be mixed with water and thus was compatible with water-

50. Kast-Ehninger/BASF Druckfarben: Hagmann. Personal communication to the author.

51. "Water, Water Everywhere. . . .But Not a Drop in the Ink." Graphic Arts Monthly November, 1991, vol. 63, no. 11, S14.

based cleaning processes. This cleaning agent did not only address the VOC problem during cleaning processes, but was said to be also very reasonably priced.[52]

Re-Use of Inks

The re-use of inks was also a concern for the printing ink industry, although the diversity of inks as well as imperfect separation processes continued to pose problems. It was impossible for printing ink manufacturers to re-feed inks stemming from de-inking processes from paper recycling into their production processes. However, printing ink manufacturers often took back unused or leftover printing inks from their customers and either re-used them or had them disposed of. Reuse of printing inks was only possible if they were pure and could be clearly identified. Given the ever increasing number of different printing inks, this had become very difficult. This fact, combined with more stringent environmental regulation concerning the final disposal of printing ink, had made manufacturers wary of accepting unused inks. Instead, they suggested ink recycling systems to their printer customers which fed waste ink back into the printing process as a more efficient solution of this problem. An example for such a system will be presented below.

Production Process Effects in Printing Ink Application

Fountain Solutions

Fountain solutions were applied to the lithographic plate to render non-image areas unreceptive to ink. Since printing inks were oil-based, the fountain solution was water-based and contained a dampening aid whose role it was to reduce the surface tension of the water. More than half of all VOCs emitted from the pressroom stemmed from isopropyl alcohol (IPA), which had been used as a dampening aid since the 1950's. In the early 199Os, anticipation of future regulations, coupled with concern for the environment and employees, prompted a number of printers to demand IPA substitutes.[53]

52. "Sheetfeds Set for Eco-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.

53. "Inks Aren't the Problem: The Ink Industry had Come a Long Way Toward Eco-Responsibility." Folio: the Magazine for Magazine Management April 1, 1992, vol. 21. no. 4, 101.

Most dampening aids which were subsequently developed were also VOCs, but could be used in lesser concentrations in the fountain solution, causing less VOC emissions. Thus, while fountain solutions had previously required up to 15% IPA, now only between 1-4% of the new dampening aids were necessary.[54] There were even substitutes available that had zero VOC content: FFC International of Lancaster, Pennsylvania, a company founded by two former press operators, had introduced a zero-VOC alcohol product in 1992.[55] The IPA substitutes not only reduced VOC emissions, but were also cost effective. Even though they cost some 5% to 10% more than IPA, they allowed an estimated average savings of 30% to 50% in overall dampening costs estimated, because so much less of them was required.

Waterless Printing Technologies

Another way to eliminate VOC emissions in offset printing was to substitute the fountain solution as a whole and print Waterless, a relatively new technology that required no alcohol or any other form of dampening system in the pressroom. This technology had been developed during the late 1980s, particularly in Japan, where the so-called Toray waterless plate in printing processes was used.[56] Because the process required no fountain or dampening solutions, its users were automatically in compliance with environmental regulation concerning water pollution and VOC-emissions.

A further advantage of the waterless printing process was that it produced much higher print quality. Waterless inks could be used in a much greater film thickness, resulting in stronger colors, higher saturation levels, and greater gloss. They also tended to be more rub- and scratch-resistant than conventional inks. With the absence of water, much less ink was absorbed into the paper; it literally stood on the surface of the page, which was the reason for the intense colors and higher gloss and saturation levels that were achieved with waterless inks. Waterless printing was particularly useful for printing on surfaces that were not compatible with water, but could also be used on many other surfaces.

54. "Sheetfeds Set for F&-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.

55. "Sheetfeds Set for Em-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.

56. ICC Key Note Market Report 1993, 25.

A final advantage of water-based inks was that they were said to be used more easily on recycled papers .[57]

As with any new technology this one also had its initial problems. Principally, over-heating of the plates was expected to be solved with the introduction of new inks and improved cooling system inks. Ink manufacturers such as Dai Nippon's U.S. subsidiary Sun Chemical had already invested considerably in the research and manufacture of waterless inks. Because they did not require any costly dampening systems, waterless printing could result in substantial cost savings. Therefore the future prospects for this technology were very promising: Industry experts expected that at least 10% of the web-offset segment would be waterless by 1996.[58]

Ink Recycling

Waste ink management was a complicated issue because of the confusion concerning the intent and content of many environmental regulations. It was also unclear whether the printer or the printing ink manufacturer was responsible for the disposal of waste inks stemming from the printing process. Three disposal options were commonly discussed:

* Resource recovery, a method which transformed waste inks and similar materials into a supplemental fuel;
* Incineration, in which high-temperature burning reduced inks to a safely disposable ash; and
* Stabilization, in which wastes were solidified and disposed of in approved landfills.

In each of these cases, major disadvantages lay in both the bulk of the waste material going into the waste stream, and in the general public's antipathy to the processes involved. Waste inks had commonly been disposed of by the printing ink manufacturer, and not by the printer who had generated it. Theoretically, however, it was more sensible to have the printer himself deal with the waste ink, because transportation

57. "Shades of Green: Environmentally-Friendly Inks and Dyes." Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

58. ICC Key Note Market Report 1993, 25.

costs would be saved and some direct pressure would be exerted on the printer to minimize the amount of waste ink he generated.

Letting the printer himself deal with the waste ink was not necessarily costly. A Swiss printing firm discovered that it could actually save money by recycling into its own production process a considerable amount of the waste ink it generated.[59] Prior to its recycling program, the company had generated 3,000 kg of waste ink per year, which had been collected in cans and was returned to the ink manufacturer in a labor intensive process that also posed considerable risks to the environment in case of spillage. This motivated the firm to search for methods to re-use its waste ink. After several field trials, it finally discovered that new printing ink could contain up to 5% of waste ink without negatively affecting print quality. The only equipment needed to re-feed waste ink into the printing process was a stirring machine to mix old and new inks which cost about SFr43,000 ($30,000). The new system led to considerable savings in transportation and disposal costs which resulted in a return on investment of three years. Moreover, the environmental aim had been reached by reducing the waste amount by 90%.

59. Zollikofer AG: Stihl. Personal communication to the author.

APPENDIX

Table 1

Ingredients of Printing Inks		
Ingredients	**min %**	**max%**
Pigments	5	30
Solvents	20	70
Adhesives	15	60
Wetting agents. waxes	1	10
Source: Gebr . **Schmidt.**		

Table 2

World Production of Printing Inks			
Country or area	**1990** (1000 tons)	**1991** (1000 tons)	**1991** (%)
USA	863.7	893.1	42.8
Japan	386.1	386.9	18.54
Europe[2]	624.3	642.3	30.78
E.C.[2]	575.8	595.4	28.54
Germany	244.8	262.9	12.6
Others[2]	155.2	164.2	7.87
Total	2029.3	2086.5	100
Calculated from data provided by the Commission of the European Communities, 1990/91, 8-35; UN Statistical Year Book; Statistisches Bundesamt.			

Table 3

European Production of Printing Inks				
	Volume (1000 tons)			Value (1000 ECU)
Country	**1990**	**1991**	**1992**	**1992**
Austria	9.7	9.7	11.9	45,298
Belgium	30.9	27.0	28.2	101,590
Denmark	8.0	7.7	10.0	43,334
Finland	9.3	8.6	8.5	26,709
France	66.7	63.0	67.0	314,000
Germany	244.8	250.0	269.0	981,711
Italy	74.4	65.4	69.3	239,916
Netherlands	22.3	29.5	25.8	117,000
Norway	6.2	6.4	6.2	24,700
Portugal	3.8	3.7	--	--
Spain	31.6	21.3	22.7	78,100
Sweden	11.6	14.3	12.6	48,905
Switzerland	--	12.8	21.4	163,477
UK	92.6	119.8	132.5	573,000

Source: UN Industrial Statistic Yearbook 1991; CEPE, European Confederation of Paint, Printing Ink and Artists' Colours Manufacturers Associations.

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