World Resources Institute

Sustainable Enterprise Program
A program of the World Resources Institute

BAYERISCHE MOTOREN WERKE AG (A)

In the late summer of 1990, the German government invited industry commentary on a proposed policy to make automobile manufacturers responsible for the final disassembly and disposal of their products, as well as for ensuring that most of each vehicle is recycled. Commonly known as product "take-back" requirements, such legislation is potentially revolutionary for manufacturers. The obligation to assume stewardship for a product long after it has been sold necessitates changes in product design, materials use and disassembly techniques that would have been unthinkable even ten years ago. Moreover, establishment of a reverse distribution network to collect discarded products requires a significant investment in apparently non-productive assets.

At BMW AG, it was the task of the recycling group (T-RC) to determine the company's response to the draft legislation, which was called "Draft: The Federal Government's Policy on the Reduction, Minimization, or Utilization of Scrapped Vehicle Wastes." Dr.-Ing. Horst-Henning Wolf and Dr.-Ing. Harald A. Franze would assume primary responsibility for developing BMW's proposals to the German Environment Ministry (BMU, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit).

The contents of the draft legislation came as no surprise to BMW. Years earlier, Klaus Töpfer, head of the BMU and the federal government's champion of the legislation, visited BMW's corporate headquarters in Munich. Chairman Eberhard von Kuenheim, Wolf, Director of T-RC, and Franze, head of T-RC Development, briefed him on BMW's environmental program and the current vehicle recycling situation: due to a mushrooming diversity of materials used in vehicle manufacture, vehicle recyclability was declining. This trend increases the costs of dismantling and disposing of vehicles. The viability of the vehicle recycling industry, composed of dismantlers who separate and sell vehicle components, and shredders who process and reclaim component and body materials, was becoming increasingly tenuous.

Wolf and Franze had followed both the legislative and recycling industry developments carefully. As Wolf headed off to the Research and Engineering Centre and Franze back to his office, each wondered about the implications for BMW, the economics of recycling and how, if at all, the company should alter its operations and political strategies.

The Vehicle Recycling Industry

Approximately 4,000 dismantlers and 44 shredders recycle almost 95% of Germany's scrapped vehicles. In 1989, the network processed 2.1 million vehicles. The dismantling operation is a time consuming and very manual process of unscrewing things and requires relatively unskilled labor. Dismantling requires little capital investment other than property and manually operated tools. Companies serving this market are widely dispersed throughout Germany and tend to be fairly small and undermanaged. In contrast to dismantling, the shredding operation requires large machines to rip apart metal, a significant capital investment which limits the number of participants in the market. Both shredding and dismantling companies have relationships with remanufacturing and metals companies in order to ensure markets for their outputs. (See **Exhibit 1** for a complete illustration of the parts and materials flow of spent vehicles through the recycling network).

In a typical auto disposal situation, the final owner transports the old jalopy to a dismantler and negotiates a price for disposal. The make and condition of the model determine the residual value of the vehicle's parts and materials. The better the make and condition, the greater the residual value and the lower the cost. Depending on the value of the vehicle and its condition, the owner may pay the dismantler, the dismantler may pay the owner, or there may be no exchange of money. Dismantlers are under no legal obligation to accept used vehicles. BMWs typically fetch DM 200-300 from dismantlers, as high-value components and metal can be sold to reprocessing and scrap metals companies.

Dismantlers pull apart spent vehicles and separate and sell used, valuable components. Components are frequently remanufactured and reconditioned. The reconditioning is done by some dismantling companies, a number of dedicated remanufacturing companies and most vehicle manufacturers. These used parts—e.g. catalytic converters, batteries and gearings--are sold at a fraction of the cost of new parts. Dismantlers also sell used polymer components to polymer suppliers which grind them up and sell the recycled polymers. Finally, they typically drain operating fluids, compact the vehicle and transport the remaining hulk to vehicle shredders.

Shredder companies, most of which are owned by major steel companies, use large shredding machines to process the remaining car hulks. They purchase the hulks from the dismantler, rip the vehicle hulk into fist-sized pieces and then use a variety of magnetic, air and aqueous separating machines to sort ferrous and non-ferrous metals that have resale value in metal markets. The ferrous scrap is sold to steel mills; the non-ferrous to specialized metal companies. Automotive Shredder Residue (ASR, known throughout the industry as "fluff") is a by-product of this separation process. Comprised of plastic, foam, rubber, glass and dirt, ASR cannot be recycled in mixed form and hence has no economic value for shredder operators. In order to complete the material disposal cycle, shredders must pay for the transport and disposal of ASR, either by landfill or incineration.

In total, dismantlers and shredders recoup nearly 75% of the material from a used or wrecked vehicle; ASR, the remaining 25%, presents the waste management challenge. (See **Exhibit 2**). ASR accounts for 400,000 tonnes of solid waste--75% of total shredder waste and 65% of Germany's industrial annual solid waste stream. **Exhibit 3** indicates the magnitudes of ASR and total shredder waste streams in EC countries. However, a number of current trends within the industry indicate that the challenges to the existing recycling network may be growing.

Improvements in materials technology, particularly in polymer technology, are enabling vehicle manufacturers to optimize the performance of individual components and simultaneously reduce the weight of the vehicle. (See **Exhibits 9-12** for an indication of the increase in plastics use.) Weight reduction improves fuel efficiency and handling. However, the proliferation of these materials makes disassembly a more complicated and costly process. The end result is an increase in the ASR percentage of vehicles, which reduces the residual value of the car, and increases the amount of material to be disposed in landfills or incinerators.

As the costs to the network of disassembling and disposing of vehicles increase, it must pass on the costs to the final owner. At some point, the owner will refuse to pay the fee, and may seek to illegally or improperly discard the vehicle, at no cost to him/herself. Hence, the decrease in vehicle recyclability not only weakens the dismantling industry, but may exacerbate Germany's solid waste problem. More ASR could find its way into environmentally sensitive areas; more vehicles into the Black Forest.

A second disconcerting aspect of the recycling industry is that only 10% of the dismantlers currently operating in Germany have been certified for operation by the BMU. Most of these operations do not have leachate systems required for operations dealing with hazardous waste (i.e., waste oils and operating fluids), while others require significant remediation efforts in order to obtain certification. If requirements were enforced, most dismantlers would have to make significant outlays of capital to comply or close down.

The German Solid Waste Situation

Like many other countries, Germany is afflicted with the dual pressures of increasing per capita waste generation, and a populace that is increasingly intolerant of traditional methods of waste disposal. So while the amount of garbage is on the rise, economically viable disposal options are on the wane. The pinch is particularly acute for large generators of industrial waste, such as the shredders that produce ASR. Germany's two most popular disposal methods--landfill and incineration--are getting prohibitively expensive for such generators, who are then forced to develop more creative solutions.

Current Practices

Germany utilizes three disposal methods to process its annual municipal and industrial waste stream of 90 million tonnes.[1] Landfill operations handle approximately 50%, resource recovery (waste-to-energy) incinerators 35%, and recycling just 15%. See **Exhibit 4** for a comparison of waste disposal practices in the United States, Japan and Germany.

Until recently, Germany was among the world's largest waste exporters. East Germany and the North Sea were the main disposal grounds for German waste. For instance, in 1988, West Germany exported 2.1 million tons of garbage to East Germany. However, BMU and the Bundestag, the German Parliament, recently enacted legislation banning exportation of waste and entered an agreement with the EC to eliminate ocean disposal as a management option.[2] Germany will now be independently responsible for its own waste.

Landfill Disposal

Land disposal is the oldest and best-known method of solid waste management. In recent decades, the "not-in-my-backyard" (NIMBY) movement, a collective reference to grassroots, local initiatives that oppose new landfill development, has made new facility sitings extremely difficult for waste management companies and local municipalities. Nevertheless, many experts still believe that it is the appropriate approach. If population density is low, space is available, no groundwater or surface water sources will be threatened, and waste content is largely biodegradable, landfill disposal may be the safest and most efficient waste management approach.[3]

Landfill siting, design and technology have progressed significantly during the past two decades. In the past, siting decisions had more to do with convenience than the hydrologic setting and potential environmental impacts. Typical disposal areas were wetlands, marshes and spent mines, all of which are environmentally sensitive areas, and design and technology were afterthoughts. As a consequence, many landfill sites have been closed by regulatory authorities due to the adverse effects that operations have had on water and soil quality.

Environmental Impacts. Past problems, such as litter, odor, and rodent population, have given way to the more serious problems of leachate and methane generation.[4] Leachate is produced when water from rain or waste permeates the landfill, becomes acidic through various interactions with garbage content and dissolves elements and compounds from other wastes. Once a landfill's capacity to contain water is exhausted, leachate can escape into nearby surface waters and underground aquifers, contaminating ecosystems and drinking water. Leachate can contain toxic

---

[1] Organisation for Economic Co-operation and Development, The State of the Environment (Paris, France: OECD Publications, 1991), p. 149.

[2] Newsday, Rush to Burn: Solving America's Garbage Crisis? (Washington, DC: Island Press, 1989), p. 87.

[3] H.A. Neal and J.R. Schubel, Solid Waste Management and the Environment: The Mounting Garbage and Trash Crisis (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1987), p. 37.

[4] P.R. O'Leary, P.W. Walsh, and R.K. Ham, "Managing Solid Waste," *Scientific American*, Vol., 259, No. 6, December 1988, p. 40; C. Pollock, *Mining Urban Wastes: The Potential For Recycling*, Worldwatch Paper No. 76 (Washington, DC; Worldwatch Institute, April 1987), pp. 14-15.

metals, such as cadmium, and polychlorinated biphenols, both of which pose threats to public health.[5] Once contamination has occurred, affected areas, especially aquifers, are very difficult to remediate.

Methane production has also emerged as an environmental concern. A colorless, combustible and potentially explosive gas, methane is produced naturally during the microbiotic, anaerobic decomposition of waste.[6] It has been known to kill vegetation adjacent to landfills by depleting soil of oxygen and nutrients. Recently, landfill methane generation has been implicated in the global warming debate.[7]

Current Landfill Operations. State-of-the-art landfills are far more sophisticated than their predecessors:

- The geotechnical and hydrologic characteristics of newer landfill sites are carefully assessed prior to choosing the site, so as to minimize potential contamination from leachate.
- Plastic and clay liners are used to retain seepage and recovery systems are used to capture and process leachate prior to emission into surrounding ecosystems.
- Landfill gas systems (LGS) are used to harness landfill methane for productive purposes. Methane is captured, cleaned and sold to nearby gas and power companies, defraying and in some cases covering landfill operating costs.[8] Recovered methane has the same energy capacity as natural gas--1,000 BTUs per cubic foot. Although only a limited number of LGS systems have been incorporated into landfill systems around the world, experience indicates that they supply a steady and reliable source of energy and will be widely adopted in the future.

Status in Germany. Similar to the situation in the United States, the landfill population in Germany has decreased rapidly over the past two decades. In Bavaria, landfill facilities have decreased by 99%--from 4,000 to 40--and there are plans to close the remainder within 5 to 10 years.[9] Some sources indicate that Germany will run out of landfill disposal capacity within the next 5 years.

The vast majority of German landfills are not "state-of-the-art," and the public and public officials have become increasingly concerned over their environmental impact. A recent BMU regulatory campaign has led to stricter content and emissions standards for a number of pollutants, most notably PCBs. Under the requirements, PCB concentration levels for wastes entering landfills will fall from 50 ppm (parts per million) to 10 ppm over a two year period. At that time, if PCB levels are above 10 ppm in waste shipments, the waste load will not be accepted and will be reclassified as hazardous waste. Hazardous waste disposal is on the order of three or four times as expensive as solid waste landfill disposal in Germany. ASR will likely be among the kinds of waste that will be

---

[5] PCBs are industrial toxins typically found in electronics equipment and hydraulic fluids. They are known to cause cancer, birth defects, skin disease and gastro-intestinal damage in humans. In the United States, they are listed as a "medium" cancer risk and subject to numerous layers of regulation and reporting requirements.
[6] The Global Tomorrow Coalition, The Global Ecology Handbook, ed. by Walter H. Corson (Boston: Beacon Press, 1990), p. 277.
[7] J. Raloff, "Are landfills a major threat to climate?", *Science News*, Vol. 131, March 7th, 1987, p. 150.
[8] I.P. Wallace, "Landfill Gas-Fired Power Plant Pays Cost of Operating Landfill," *Power Engineering*, Vol. 59, No. 1, January 1991, p. 27.
[9] Newsday, op. cit., p. 86.

turned away from landfills. See **Exhibit 5** for the current and projected costs of landfill disposal.

Incineration

Problems with landfill disposal have led to a search for new solid waste management options. Burning garbage, often to generate power, has been a prevalent secondary option in many industrialized countries, including Germany. As of 1987, more than 350 waste-to-energy facilities were operating in over 15 countries, more than half of which were in Western Europe.[10] Incinerators burn garbage at high temperatures and reduce waste volumes by nearly 90% (weight by 70%). However, concerns over negative environmental impacts, high costs of construction and maintenance, and potential obstruction of recycling programs have limited widespread reliance on incineration as a primary waste management option.

Environmental Impacts. Air emissions from the incineration process are the fundamental environmental concern. Burning chlorinated material, metal and plastic potentially emits dioxins and furans, metals and PCBs, all of which are toxic and pose significant human health threats.[11] Although most incinerator facilities have taken steps to control emissions, potential negative effects on human health are a constant concern for incinerator operators and local communities.

Disposal of the residual ash also poses problems. Although there are uses for ash as feedstock for cement and gypsum, or road bed, unused ash is often landfilled. However, unburned metals in the ash make it quite toxic, and have prompted a movement in the US and Germany to disallow landfill disposal of ash. German officials are considering reclassifying ash as hazardous waste.

Incinerator Operations. Depending on the BTU value of the refuse, garbage can be an excellent source of energy for electricity. Incinerators burn waste at temperatures of 700 to 1200 degrees centigrade and recoup energy in the form of steam, which is used either by power companies or nearby manufacturing facilities. Current designs are equipped with multiple pollution control systems to reduce harmful emissions. In conjunction with BMU, all German incinerators report emissions each day and plants are shut down when incinerators are out of compliance with standards for one hour.

Status in Germany. Incineration has emerged as a critical component of German waste management strategy. The German incinerator population has grown from 7 in 1965 to 47 as of 1988. All but one are resource recovery incinerators and collectively they handle 35% of Germany's solid waste stream.[12] German officials expect 20 more plants to come on line by 1995 (as many as 35 by 2000) and the percentage of solid waste that they process to rise to 50%.[13] However, the cost of bringing a new incinerator on-line ranges from DM 240--320 million. Current incinerations prices are, on average, twice the price of landfill disposal.

---

[10] Neal and Schubel, op. cit., p. 81.

[11] Certain dioxins, such as tetrachlorodibenzo-p-dioxin (known as "Agent Orange"), are among the most toxic molecules in existence, and have been proven to break down immune systems and cause birth defects.

[12]. L. Barniske, "Waste Incineration in the Federal Republic of Germany--State-of-the-Art Technology and Operating Experience as to Corrosion Problems," in Incinerating Municipal and Industrial Waste: Fireside Problems and Prospects for Improvement, ed. by R.W. Bryers (New York: Hemisphere Publishing, 1991), p. 9.

[13]. Newsday, op. cit., p. 86.

The Green Party, a political unit with a primary aim of advancing environmental quality, is strongly opposed to these plans and has vowed to work with local environmental groups to oppose new facility sitings. Unfortunately for the automobile industry, incineration may no longer be a viable disposal option for ASR. The BMU is concerned about the environmental risk of plastic incineration, and does not want to reduce incentives to recycle.

Materials Trends and Choices in the Automotive Industry

A Polymer Primer

Polymers are composed of long repeating chains of monomers--small molecular units consisting of carbon atoms linked to hydrogen, nitrogen, oxygen, fluorine, sulphur, bromine, or chlorine atoms--that are chemically modified to create plastics. For example, ethylene monomers are reacted to create the polymer polyethylene.

Polymers were first used by the automotive industry in the late 1950s. Early polymers such as polypropylene (PP) and polyvinyl chloride (PVC) were relatively inexpensive and unsophisticated, and were used for a limited number of applications such as interior trim. Plastics technology rapidly evolved toward higher value added "engineering" and "specialty" polymers. These materials are formulated to exhibit properties specifically tailored for individual application needs, such as strength or heat resistance.

Polymers are generally separated into two classes (see **Exhibit 6**):

- Thermoplastics consist of polymers that resemble intertwined bundles of spaghetti without direct connection between each polymer chain. (See **Exhibit 7**). Weak electrostatic forces hold the chains together. These forces can be strengthened by cooling or weakened by heating, making the polymer pliable under certain conditions. As a result, thermoplastics can be recycled under proper conditions. However, they experience some degradation in properties as a result of progressive reduction in molecular weight (chain length). Thermoplastics account for 85% by weight of all polymers produced.
- Thermosets, unlike thermoplastics, are linked together by chemical bonds. Due to their cross-linked structures, they are resistant to heat and many have great dimensional stability. Thermosets are not easily recycled, although numerous research efforts are underway.

Chemical suppliers alter the performance and quality of original polymer resins in order to customize polymers for specific functions in several ways:[14]

- Suppliers manipulate chain length and the degree of crystallization of the feedstock mix in order to adjust the properties of the final polymer or polymer blend.
- Processors use various additives, such as plasticizers for flexibility, lubricants for greater moldability, antioxidants for greater temperature stability and ultraviolet stabilizers for resistance to sunlight, and flame retardants.
- Fillers and reinforcements, such as fibers and hollow glass spheres, are added to increase

[14] James F. Carley, "A Plastics Primer," *Modern Plastics Mid-October Encyclopedia Issue*, p. 4.

strength and stiffness; chalk is added as a general filler to reduce cost.

- Certain polymers are mixed to create polymer blends or alloys, enabling the processor to achieve a wide range of physical and performance characteristics.

Advantages and Disadvantages of Plastics

Applications Qualities. **Exhibit 9** documents the increase in polymer use in the automotive industry. While they continue to be used primarily for interiors, such as dashboards and seats, plastics are increasingly used in critical components, such as fuel tanks and body paneling. Metals still comprise the bulk of the car (i.e., the chassis and engine block), but plastic content continues to grow. In addition to weight advantages over metal, proponents point to several additional advantages:[15]

- High corrosion and chemical resistance
- Greater ease and efficiency in manufacturing through reduced steps in production
- Reduced number of parts needed for a single component, as plastics can be fashioned incomplex shapes
- Greater versatility and adaptability to production changes and specific requirements
- Reduced energy consumption in manufacturing[16]
- Reduced expense on a volume basis

Critics charge that a number of plastics characteristics continue to make them unsuitable for many automotive applications:

- Low temperature stability
- Degradation under ultraviolet light
- Lengthy production time
- Lack of experience with polymers in critical applications
- Difficulty of achieving first class surface finish
- Current low level of recyclability

The drive toward acceptance in the automotive world has helped spur a corresponding effort by polymer manufacturers to engineer polymers for specific components and applications. According to Richard Dolinski, Vice President of Dow Chemical's Automotive Development Group, "one size does not fit all in the world of automotive materials, and that's as true of metal as it is of plastics. Both thermoplastics and thermosets serve us well. (We) use them when they are right for the application."[17] As a result, the number of polymers used in one vehicle has grown significantly; a typical vehicle contains more than 20 different polymers and alloys.

---

[15] F. den Hond and P. Groenwegen, "Innovation in the Context of Plastic Waste Management--The Automotive Industry," Report of the Commission of the European Communities, DG XII--Moniter-SAST Unit, Free University-CAV, Amsterdam, Netherlands, March, 1992, p.

[16] For example, in a comparison of energy requirements for fuel tank production, plastics need only 47% and aluminum 80% of the energy needed to create one steel fuel tank. L. Matysiak, "Design for Environment; An Analysis of German Recycling Legislation and Its Implications for Materials Trends and Corporate Strategies in the Automobile Industry," unpublished thesis (Cambridge, Mass: MIT, May, 1992), pp. 36, 42.

[17] A. Stuart Wood, "What To Do With Plastics, Cars When They're Junk?" *Modern Plastics*, June 1988, p. 62.

Recoverability. The downfall of increased plastics use is the resulting reduction in the recyclable content of today's vehicles. Metals experience little degeneration from use, have value in secondary metal markets and an established set of buyers. As a result, reprocessed metals can be used for critical applications. While metal recycling is efficient and profitable, it is often not a "closed loop" recycling system; metals recaptured from spent vehicles are not frequently reused in production of new parts.

The plastic recycling technology and end-markets are markedly different. Recycling of thermoplastics is easier, cheaper and more effective than recycling thermosets. Some industries currently recycle thermoplastics, including the automotive industry, in which recent studies have shown that old plastic parts can be recycled even after ten years of use.[18] However, there are several complications that have precluded recycling activities in the past:

- Polymers can be recycled only with homogeneous polymers. Plastics must be separated into like waste streams before any recycling efforts can be undertaken. The greater the number of polymers used in a vehicle, the greater the complexity and effort required to separate them. Although Hoechst Celanese, Eastman Chemical, Dupont and others have developed ways to separate polymers, alloys, composites and additives into monomer feedstocks for some polymers, the technology is not yet effective for many.
- Insufficient labeling of plastic parts has hindered efforts to separate and recycle parts.
- Polymers can be contaminated by commonly used substances, such as paint, glue and other connecting materials, and additives and fillers. While certain additional substances, such as ultraviolet stabilizers that help preserve quality, can improve the recyclability of polymer parts, others can degrade and hence limit the value of the recycled resin.
- Polymers degrade during the regranulation and remelting process, reducing their quality and checking the development of markets for recycled plastics (see **Exhibit 8**).

Recycled Plastics. According to polymer experts, there is not a clear distinction between virgin and recycled polymers in automotive applications. Despite the degradation that occurs in the regranulation and remelting process, recycled polymers are frequently mixed with virgin polymers for specific applications. In such mixes, recycled polymers are unlikely to be more than 10% of the mix. The lack of a supply of recycled polymers have limited their use. When they have been used in automotive applications, recycled polymers traditionally have been relegated to non-critical applications, such as noise dampening pads, which are hidden from view, or luggage compartment linings.

Industry Materials Trends

Environmental considerations in vehicle design and performance emerged as focal points for German vehicle manufacturers in the mid-1970s. Energy efficiency and emission levels came under regulation or voluntary agreement between BMU and vehicle manufacturers. What ensued was an industry-wide shift away from heavier metals toward lighter, high performance materials in an effort to meet fuel efficiency and emissions standards.

---

[18] Den Hond and Groenwegen, "Co-operation between Firms in the Automotive Branch and Strategies to Solve the Shredder Waste Problem," unpublished research paper presented at "The Greening of Industry: Research Needs and Policy Implications for a Sustainable Future" Conference, November 1991, Noordwijk, Netherlands, p. 5.

Over the past thirty years, net metal content of vehicles has dropped by 9.5% while plastic content has grown by 11% (see **Exhibit 9**). Iron, steel and other metals have been reduced in favor of aluminum and plastics. Although current prices may check aluminum growth rates, plastics content is expected to rise to 15% of vehicles in the coming years. In Germany, the automobile industry accounts for 7% of total plastic consumption.

BMW Materials Selection. BMW has been part of the industry-wide trend toward plastics. **Exhibit 10** shows the increase in the plastics content in each of BMW's major model series over the course of the last two decades. Plastics comprise 10-11% of BMW's current product line; glass, rubber, fabric and other non-recyclable materials 12.5--15% (see **Exhibit 11** for the weight and plastic content of each of BMW's models). **Exhibit 12** documents the polymers and quantities found in the current BMW 5-Series model. Franze predicts the plastic content of the company's product line will continue to experience growth through the 1990s.

The BMU and Vehicle Recycling

"Industry in the Federal Republic of Germany has taken on the commitment to employ its creativity, its expertise and technical know-how to continually develop environmentally favourable technologies. It recognises the need to incorporate environmental interests--right down to the question of managing the waste accruing from the products it manufactures--in its decision-making and planning activities. It regards environment policy as an indispensable component of an overall, future-orientated policy."[19]

--BMU, Environmental Protection in Germany

Environmental policy is beginning to reflect a new approach to waste generation and management in manufacturing industries. Increasingly, industries must examine the full range of environmental impacts associated with manufactured products, known as "life-cycle analysis." (See **Exhibit 13**).

BMU's approach to this type of regulation is based on the idea of voluntary, industry-driven regulation rather than the strict command and control approach practiced in the United States. Under the approach, BMU sets goals for pollution levels and industrial performance, and, in conjunction with regulators, industries create their own systems and implementation guidelines to achieve them. Although agreements between BMU and industry are voluntary, the agency can formally create and enforce regulations to achieve the desired outcome if "voluntarily-regulated" industries do not meet their objectives, such as:

New Waste Avoidance and Waste Management Act. In June 1988, the Bundestag passed *Actungesellschaft*, the "New Waste Avoidance and Waste Management Act."[20] The relevant provisions of *Actungesellschaft* are as follows:

---

[19] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Environmental Protection in Germany. Bonn, Germany: BMU Public Relations Division, 1992.

[20] Bundestag, Waste Avoidance and Waste Management Act, August 27th, 1986, *Article 14*, Bonn, Germany.

- Industry has the responsibility to minimize waste generation through waste avoidance and waste utilization.
- Waste utilization techniques should take priority over traditional waste disposal.
- The federal government has the authority to issue general administrative regulations on future requirements for waste management.
- BMU has the authority to issue statutory regulations regarding the avoidance or reduction of noxious substances in waste or to ensure the environmentally-compatible management of such waste or to promote the reuse or recycling of such waste. BMU can issue a *verordnung*, or voluntary agreement, between government and industry to engage a particular environmental problem.

Verpackungsverordnung. In conjunction with the BMU, the Bundestag passed a sweeping piece of legislation in 1991 targeting the role of packaging waste in the German solid waste stream. The decree gives consumers the right to return all packaging materials directly to the point of sale, with deposits possible on some items, and the assurance that the returned packaging will be materially recycled unless it is technically infeasible.

Vehicle Recycling Legislation. In August 1990, Töpfer and BMU issued "Draft: The Federal Government's Policy on the Reduction, Minimization, or Utilization of Scrapped Vehicle Wastes," a voluntary agreement with vehicle manufacturers to address growing concerns over waste from used vehicles. The provisions of the draft are as follows:

- Vehicle manufacturers or their agents must accept used vehicles from the final vehicle owner.
- This transaction must be free of charge to the final vehicle owner.
- In vehicle disposal, reuse and recycling of parts and materials should take precedence over other disposal methods (i.e., landfilling or incineration) whenever technologically feasible, economically reasonable and markets exist for parts and materials.
- In order to achieve the goal of recycling, manufacturers must provide facilities where dismantling can occur, and must develop the supporting technology to effectively separate reusable products from toxic waste streams and other unusable matter.
- New vehicle designs should reflect the goal of increased reuse and recycling of components and materials once the vehicles' useful lives are terminated.

The ultimate goal of the draft legislation is the implementation of a nationwide take-back system by the end of 1993 and a reduction in automotive shredder waste by 60% of current levels to just over 200,000 tonnes per year. Manufacturers have the option to work with the existing recycling network or develop their own system, so long as the goal is achieved. In order to ensure a market for recycled polymers, BMU also is considering the creation of a recycled polymer content requirement. For example, recycled polymers may be required to comprise 25% of a manufacturer's total plastic consumption.

Bayerische Motoren Werke AG

"We know it is important to react to developments with speed and agility. Equally, it is vital at an early stage to allow in our planning for possible future developments. After all, we are working today on cars that will not be on the roads for ten or even twenty years. Thus, we help to shape the future. A form of mobility not new to us is to imagine what is currently unimaginable."[21]

--Dr.-Ing. E.h. Eberhard von Kuenheim
Chairman, Board of Management

Headquartered in Munich, Germany, Bayerische Motoren Werke AG was founded in 1916 as a high-performance engine manufacturer. After initial success in the aircraft engine business, the company branched out into development of motorcycles and automobiles. It quickly developed a reputation within the automobile and motorcycle racing circuits as a top-notch manufacturer, prompting the company to concentrate more heavily on the private automobile market. Today, automobile related revenues account for over 90% of company sales.

The company is controlled by heirs of Herbert Quandt, who provided $1 million to BMW in 1959 to help the company through a difficult period. The 65% share controlled by the Quandts is now worth nearly $3 billion. Dr.-Ing E.h. Eberhard Von Kuenheim, BMW's Chairman, has held the position for two decades.

Business Strategy and Performance

Until the mid 1980's, when it entered the performance car market, BMW had a reputation for producing quality, functional automobiles. In 1980, the company sold 339,232 vehicles and 29,263 motorcycles, generating DM 6.89 billion in revenues and after tax profits of DM 160 million; domestic market share was 5.6%. Engineering improvements, new product introductions, a conscious shift into the upper bracket of the market boosted sales, and a 3 million vehicle domestic market boosted revenues and profits throughout the 1980's. Despite a tight worldwide market in 1989, BMW generated sales of 511,476 units, revenues of DM 20.9 billion, and annual growth of over 13% for the 10 year period; the company's share in the domestic market rose to 6.7%, accounting for 42% of revenues (See **Exhibit 14** documents BMW financial and production data).

Product Line. BMW had always been known for its craftsmanship and engineering, but its target market did not fully exhaust its abilities. From the 1950s through the early 1980s, BMW's product line was targeted at the small, functional car market. BMW's 2 and 3 Series models--small, two-door vehicles that sold very well--were the collective cornerstone of the company.

The European penchant for small cars, however, led most of the other German companies to focus on the same market. Volkswagen AG, Ford-Werke AG and Adam Opel AG--significantly larger multinational corporations with more diversified product lines--provided BMW's main competition down-scale. Mercedes-Benz, the flagship German manufacturer, competed in the upscale performance market.

In 1986, BMW invaded the upper-intermediate performance luxury car segment (a market

[21] BMW, *1990 Annual Report*, Munich, Germany, p. 6.

dominated by Mercedes-Benz) with the introduction of its new 7 Series luxury sedan, which became Europe's top-seller in the over $50,000 category. "We had to get away from the boxy look of our cars and create a model that people would want to look at and caress," explains chief designer Claus Luthe, who oversaw the design of several more expensive, adventurously-designed vehicles.[22] The company found success beyond its expectations in the intermediate luxury segment of the market with its 5 Series, introduced in 1988. BMW believes that its new 1990 3 Series will solidify BMW's position in the performance luxury market. According to von Kuenheim, "for almost 30 years, Mercedes-Benz had the monopoly in luxury vehicles. To their surprise, we've now ended that monopoly."[23]

The 3, 5 and 7 Series vehicles remain BMW's main products, together accounting for over 90% of all vehicles produced by the company. In the future, BMW intends to introduce new models or engines annually and make substantial engineering improvements throughout its operations.

Research and Development. BMW's design and engineering focus manifests itself in the company's commitment to extensive research and development and is reflected in continuous improvement in its product line. For example, according to BMW personnel, the new 325i model is larger, 13% more powerful, and 11% more fuel efficient than its predecessor, yet at $29,900, costs only 4% more than its predecessor in the 3 series line.

Over the course of the next five years, the company intends to spend DM 6.4 billion (approximately 3% of anticipated revenues over the same period) on research, development, engineering improvements and automation. Work was recently completed on a DM 960 million Research and Engineering facility in Munich-Milbertshofen which will serve as BMW's design and engineering headquarters and house 4,500 employees. The facility consolidates design, engineering development and manufacturing planning into a single site.

The company has also announced its intention to spend about DM 800 million annually to acquire companies (especially in the electronics industry) that have technological capabilities directly related to the automobile industry. The company, for example, recently gained controlling interest in DesignWorks USA, a California-based engineering design firm that BMW has used in the past to "audit" its internally-developed designs.[24]

Market Position. In the past decade, BMW's responsiveness to new market opportunities and demands has paid off--sales have grown at better than 10% annually since 1986, well above the industry growth rates. Most of its success is due to its expansion into the performance luxury car segment. It has also gained some advantage through its ability to produce semi-customized vehicles in an efficient manner, holding marginal costs down.[25] The company's European market share is 2.8% and world market share is 1.7% (See **Exhibit 15**).

[22] P. Fuhrman, "The Company Behind the Image," *Forbes*, November 27th, 1989, p. 89.
[23] Fuhrman, op. cit., p. 89.
[24] These figures based on an exchange rate of DM 1.6/US $ 1.
[25] The production line at the Regensburg plant is responsible for the 3 basic models of the 3-Series (sedan, convertible and station wagon), each with some 40 types of stylistic choices, each with different component options, and each customized for over 10 different countries. BMW estimates that completely identical vehicles are produced, on average, four months apart.

Forbes notes the unique position BMW has garnered among vehicle purchasers--"BMW flourishes by selling to people who feel they are flaunting their affluence less ostentatiously and more intelligently than if they were driving similarly priced cars of other makers."[26] The typical BMW buyer wants performance and luxury, and is willing to pay for it. The company has been able to fill this need by tapping its engineering strengths to achieve attractive styling without sacrificing handling and agility.

Despite its past success, BMW, along with Mercedes and other European performance luxury car producers, faces a significant challenge from lower-priced Japanese competition. A majority of Japanese manufacturers have created subsidiaries in order to penetrate the European market. Honda's Acura, Toyota's Lexus, Nissan's Infiniti and Mitsubishi's Diamante units and new models from Mazda, each with high customer satisfaction ratings and on average lower prices, have found good success in the North American and Japanese markets, and are set to challenge in the European market. Von Kuenheim is skeptical of their ability to do so: "building luxury cars and a luxury image requires more than scissors and glue. Just because Toyota and Nissan are introducing cars that look like BMW and Mercedes doesn't mean they will succeed as we have."[27] Regardless, the market segment that was once controlled almost exclusively by Mercedes-Benz has become one of the most competitive within the automotive market.

BMW executives are concerned about the company's ability to sustain its competitive position. "Our real problem," asserts von Kuenheim, "is not whether we can sell $60,000 cars or $90,000 cars. It is whether we can be competitive with workers who have the highest wages, the shortest working time, the most benefits, and the longest holidays."[28]

BMW and Environment Stewardship

In 1972, a series of houses were built adjacent to BMW's Munich plant, which employs over 14,000 people, in order to address housing needs of the athletes and spectators of the 1972 Summer Olympic Games in Munich. When the Olympic Flame was extinguished, the houses were offered for sale, and many BMW plant workers took up residence. Residents in the housing complex became concerned about noise and emissions from the plant. In response, BMW appointed an *Umweltreferent* (environmental specialist) to analyze current operations and reduce local impacts.

BMW's environmental program has since expanded, and BMW views both its engineering and environmental initiatives as being compatible. As one trade publication described it, "BMW's reputation still hinges on great handling, but its research efforts indicate that the company is also well aware of its responsibilities to provide environmentally sound, economical, and safe automobiles."[29]

---

[26] Fuhrman, op. cit., p. 89.
[27] Fuhrman, op. cit., p. 89.
[28] A. Taylor, "BMW and Mercedes," *Fortune*, August 12th, 1991, p. 62. According to von Kuenheim, autoworkers in Germany earn $ 8.37 to $ 11.16 (as compared to $ 16.58 to $ 19.42 in the US), but the level of benefits (unlimited medical care, free education for workers' children, and bonuses) they receive more than doubles their wages. They work 37.5 hour work weeks (as compared to 40 hour work weeks in the US) and have 6 weeks vacation (as compared to 4).
[29] Bill Siuru, "Fast Lane," *Mechanical Engineering*, October 1989, p. 66.

Components Remanufacturing Program. In the mid-1960s, BMW initiated a program to recondition and remanufacture high-value, used components for resale as used parts. The company found that used engines could be remanufactured and sold to buyers at 50 to 80% of the cost of new engines, with an acceptable profit above the costs of disassembly, logistics and labor. BMW expanded this program to an additional 1,700 individual parts, including starters, alternators, transmissions, waterpumps, final drive gearings and various electronic components. According to BMW spokespeople:

> "It is no coincidence that this high-value recycling is referred to as High-Tech recycling: Using the most advanced technologies such as ultrasound cleaning or numerically-controlled grinding systems, each original BMW exchange part and component is carefully overhauled, reconditioned and tested according to strict quality standards."[30]

The company offers the same warranty condition on its remanufactured parts as it does on new parts. There is currently a substantial waiting list for these parts. In 1989, the company reprocessed 18,000 engines, 280,000 waterpumps, 20,000 transmissions and 9,500 electrical systems.

The ecological benefits of the program were largely an afterthought. The program prevents a significant portion of material from entering the waste stream. Engines, for example, may provide the best example: of a single engine that enters the reconditioning process, 94% of the engine is reconditioned, 5.5% is remelted for reuse, and the final 0.5% is landfilled.

BMW and Recycling

Recycling and Pollution Prevention in Production. Throughout the 1970s and 1980s, the company developed pollution prevention strategies for its production processes and implemented a number of programs:

- Production waste (used oils, gases, glass, plastics, etc.) is separated and reused as an integral part of production activities. Used oils are reformulated and reused in new products, gases are collected and fed into manufacturing and paint units, and glass and plastic scraps are returned to suppliers.

- BMW requires its suppliers to take back homogenous plastic waste from all production facilities. BMW collects plastics scrap, and suppliers pack, transport and reuse it.

- Water, primarily used in cleaning operations, is used and reused six times before it is disposed as effluent.

Dr.-Ing. Manfred Heller, who heads the Konzern Umweltschutz (TSU, environmental protection staff), claims that efforts like these allow the company to re-use 80% of its waste. The remaining 20% is landfilled, incinerated or treated as special waste. While these efforts have cost BMW DM 10 million in new equipment, he estimates that the company has saved over DM 70 million through

---

[30]. Company Information.

reductions in materials procurement and disposal costs.

Post-Consumer Component Recycling. In collaboration with its component manufacturers and dealer network, BMW initiated a recycling program for catalytic converters in April 1987 in order to reuse the precious metals content. Six ounces of platinum and one ounce of rhodium are used in each catalytic converter to reduce vehicle emissions, but, at the end of the converter's life, the metals can be reused. The dealer network recoups catalytic converters from customers and ships them to BMW's production facilities, where the components are ground up and the metals recovered. Customers receive credits to their accounts to be used in the purchase of spare parts.

Post-Consumer Vehicle Recycling. In June 1990, the company's Board of Management added BMW's recycling group T-RC as a formal department housed within the TSU. The T-RC informally began in 1985 when various employees initiated meetings to discuss vehicle and polymer recycling out of personal concern and interest. T-RC is comprised of 10 people, representing materials, development, planning, production, logistics and finance disciplines. Dr.-Ing. Horst-Henning Wolf, the group's director, reports directly to Bernd Pischetsrieder, head of Technik (Production Division) and a member of the board.

In that same month, the company established a pilot disassembly site within its Landshut facility, the company's remanufacturing plant. The goals for the program are to study dismantling and shredder techniques and economics for BMW vehicles.

The Competition

Other German manufacturers have undertaken initiatives to study the ASR problem, and some have taken differing approaches to the solving it.[31]

Adam Opel AG. 1989 was a very successful year for General Motor's German affiliate. The company generated DM 20.8 billion in revenues as production rose 11% to nearly 1.25 million vehicles and net profits rose 10% to DM 1.1 billion. (See **Exhibit 16** for complete financial, production, and market share data for the German market). Opel's share of the German market was 16.1%. The company has undertaken some preliminary investigation into vehicle dismantling and reuse of plastic components. Opel has been using plastic components since 1979 and has conducted preliminary research into plastics reuse. It currently uses a small percentage of recycled polymers in its bumpers, and sees new applications in air-cleaner housings, floor mats and sound-proofing materials.[32]

Ford-Werke AG. Ford maintained its German market share of 10.1% and earned profits of DM 362 million. Ford is concentrating on developing new plastics recycling and automated sorting technologies, and labeling plastic components.

---

[31] All production data from Ward's Automotive Yearbook (Detroit, MI: Ward's Communications, 1990); all financial data from Moody's Investors Service, Moody's International Manual 1991, Volume 1 (New York: Moody's Investors Service, Inc., 1991).
[32] "Leading-edge Engineers Design for Recycling," *Machine Design*, January 24th, 1991, p. 13.

Mercedes-Benz AG. Mercedes' produced almost 260,000 units and earned DM 1.4 billion in profits on sales of DM 56.3 billion. Mercedes-Benz is interested in testing vehicles for disassembly, but does not advocate recycling and reuse of polymer components. Mercedes-Benz feels the best use of waste plastic is a modified form of waste-to-energy incineration called metallurgical recycling. Using newly designed melt reactor technology, the manufacturer intends to strip high-value parts, drain operating fluids, compress the hulk and feed it into a melt reactor, which can reach temperatures of 2000 degrees Celsius. Steel is melted, heavy metals and plastics are gassified, and useful energy is created. Throughout the process, emissions are collected and fed into an optimized gas purification system in order to further combust or eliminate the environmentally undesirable content. Mercedes' first metallurgical recycling facility is scheduled to open in 1992, and subsequent additions to its network will be based on the results of that operation.[33]

Volkswagen AG. VW produced and sold nearly 3 million vehicles, generating revenues of DM 65.3 billion and profits of DM 1 billion. Like BMW, Volkswagen has been actively involved in examining and addressing environmental issues. Internally, it is considering using partial recycled content for its parts and is experimenting with recycling bumper materials to be used in new components, but is still in the test phase. VW also labels all its thermoplastic components. Externally, VW prefers the idea of a number of regional dismantling and recovery centers, licensed by the company and the government, to handle the dismantling of all its spent vehicles.

Cooperation

In 1974, the Verband der Automobilindustrie e.V. (VDA, the German automobile association) established the Forschungsvereinigung Automobiltechnik e.V. (FAT) to study automobile recycling. The group initially focused on metals and plastics recycling techniques and works with the plastics, glass, rubber and other industries to develop techniques and technologies for recycling. In 1989, each of the five major German automobile companies--Adam Opel AG, BMW AG, Ford-Werke AG, Mercedes-Benz AG and Volkswagen AG-- joined the effort, renaming the consortium PRAVDA. PRAVDA presents the views of the automobile industry on vehicle recycling to regulators and the public.

BMW's Options

Wolf and Franze sat down later that afternoon to analyze the relevant options available for its take-back and recycling strategy. While they believed that BMW had the ability to reuse certain recycled polymers, they questioned whether recycled polymers would uphold BMW's stringent performance standards. If recycled materials were to reduce quality or throughput, Pischetsrieder, von Kuenheim and the remainder of the Board of Management would not likely support their plan. Wolf concentrated on the take-back infrastructure, while Franze examined what role, if any, use of secondary materials should play in manufacturing operations.

Wolf, after consultation with Franze, outlined the following options available regarding the take-back infrastructure:

[33] Den Hond and Groenwegen, op. cit., p. 21.

Option 1: Fight the Regulation. BMW could argue that the proposed regulation would severely hamper the industry's costs of operations and, since PRAVDA was already attempting to address the same issue, the regulation was both burdensome and unnecessary.

Option 2: Create an Independent National Take-Back Infrastructure. The company could create its own take-back infrastructure in order to handle disposal of all BMW vehicles. In such a network, all BMW vehicles would be transported to the company's pilot dismantling and reconditioning site at Landshut. BMW dismantlers would remove and pelletize polymer components, and dispose of the remaining ASR through landfill, incineration or an external plastics supplier. This would not only ensure the recovery and return of "remanufacturable" parts to BMW reconditioning operations, but through the development of model-specific dismantling techniques, the company could cut dismantling times by 35% and reduce processing costs.

Option 3: Modify the Existing National Take-Back Infrastructure. BMW could work with the existing scrap vehicle processing infrastructure in order to ensure its continued viability. The company could develop model-specific recycling techniques and disseminate them to existing dismantlers.

That afternoon session produced the following options for BMW's secondary materials strategy:

Option 1: Take-Back Processed Vehicles and Landfill ASR. BMW could opt to ensure the take-back and proper disposal of its spent vehicles by funding landfill disposal of the remaining ASR. In this case, dismantlers and shredders would make no change to operations, but BMW intervention would ensure their economic viability. BMW would continue to use virgin polymers in new vehicle production.

Option 2: Take-Back Processed Vehicles and Incinerate ASR. Akin to Mercedes-Benz, BMW could argue that the most efficient use of recycled plastics is waste-to-energy incineration. Vehicle hulks would continue to be processed for used metals, but polymers and other materials, such as foam, carpet and glass, would be gassified in melt reactors to recoup energy.

Option 3: Recycle Plastics for Use in Other Industries. BMW could recover plastics from its vehicles to become feedstock for other industries. If BMW were to establish markets for its used plastics, dismantlers would have an economic incentive to undertake plastic component dismantling. Recovery of plastics would lower disposal costs, thereby reducing the economic burden on the shredder industry.

Option 4: Use Recycled Polymers in BMW Vehicles. BMW could use recycled polymers for certain of its plastic components in order to help create a market for recycled plastics. While it might not be practical to implement a "closed-loop" recycling system at the present time, they could use recycled polymers for specific applications.[34] In order to evaluate this option, they would need to develop an approach to evaluate when the substitution of recycled polymers for virgin materials made economic sense. At Franze's suggestion, they chose a number of components to examine,

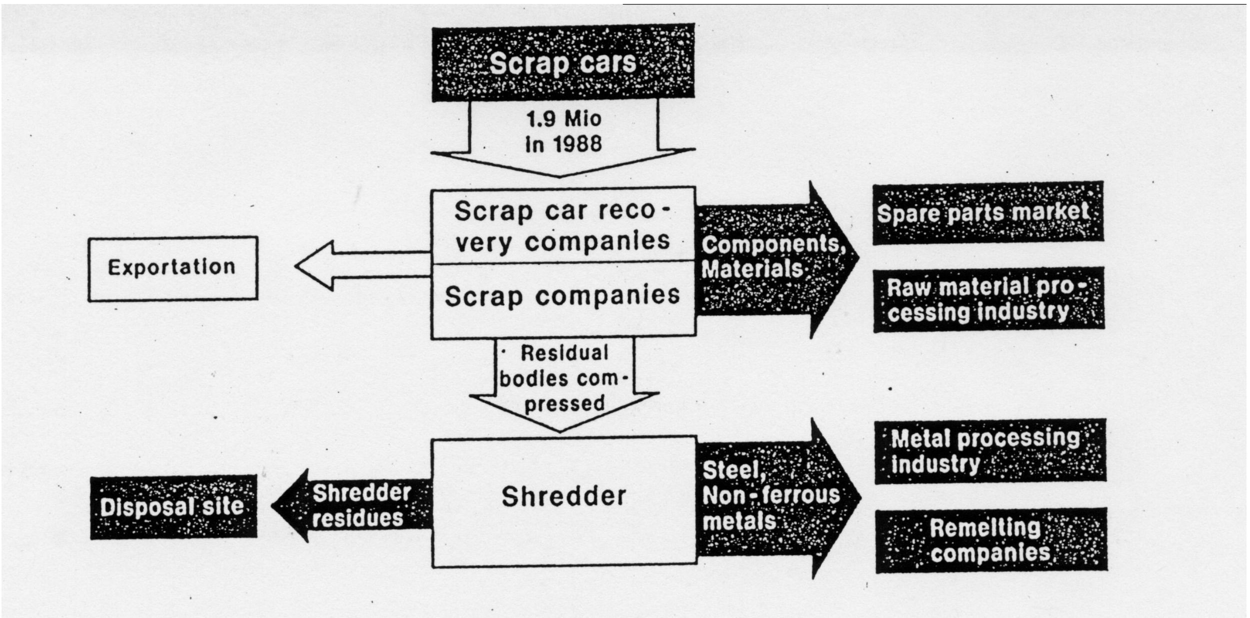
[34] In a "closed-loop" system, end-waste materials are recovered and fully utilized in new products.

including the bumpers on the new 3 series, in order to determine material flows and costs, recycling costs, and recycling logistics.

Option 5: Incorporate Design for Environment (DFE) Methodology. In order to meet the current demands of the draft legislation, BMW could alter product and process designs to reduce, reuse and recycle waste. For example, they could incorporate greater amounts of additives and stabilizers in the polymer mix, label plastic components, design for use of recycled instead of virgin polymers, minimize component size and simplify disassembly. DFE could enhance the vehicle's recyclability and minimize negative environmental impacts of future disposal.

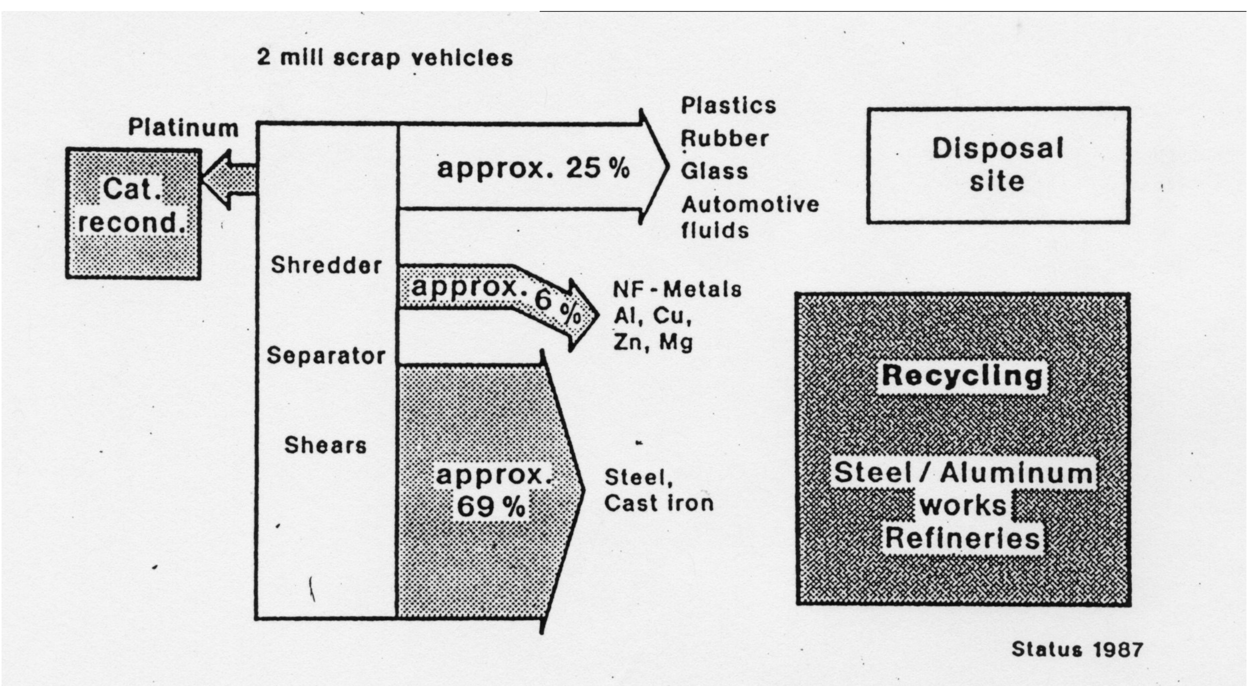
Wolf and Franze were supposed to meet with Pischetsrieder later that week. He would want an analysis of the problem, including the volumes of waste and disposal costs facing the recycling industry and BMW independently, and what factors BMW must be considered when using secondary materials. Ultimately, he would also want to know what strategy BMW should pursue in response to the draft legislation and what system, if any, the company should advocate. With options before them, they thought carefully about BMW's future actions.

Exhibit 1: Flow Chart for the German Recycling Network



Source: Company Information

Exhibit 2: Material Flow in Scrap Vehicle Disposal



Source: Company Information

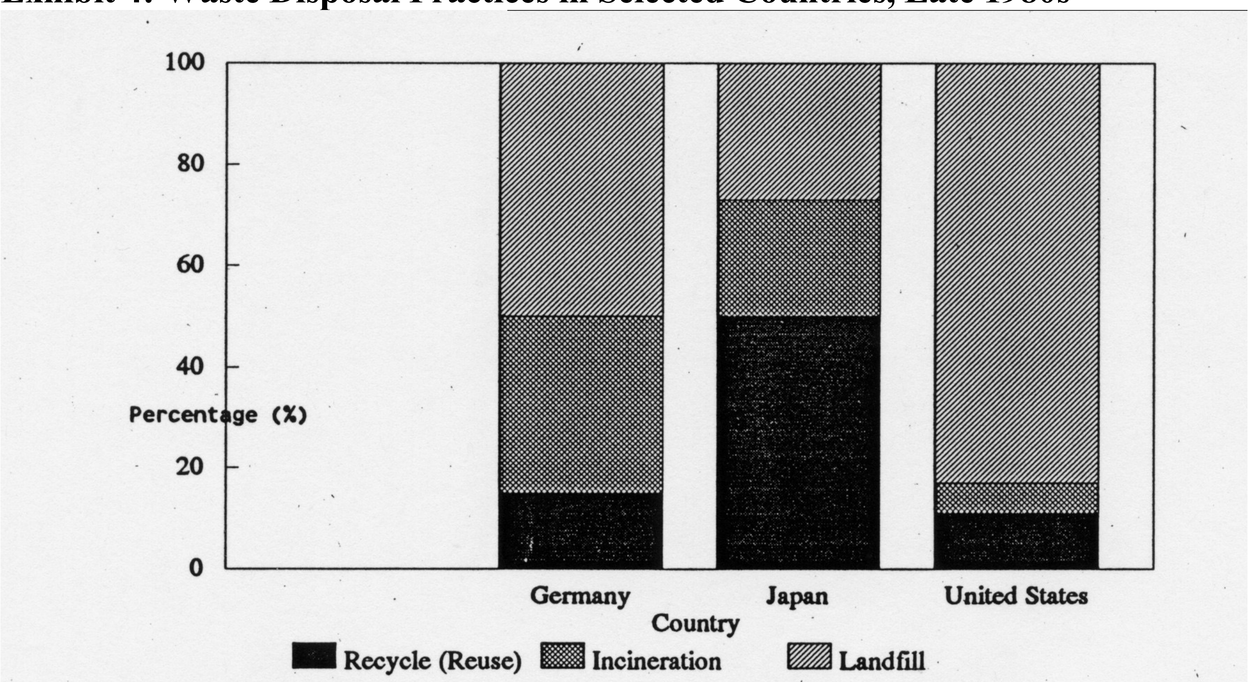
Exhibit 3: Shredder Waste in Selected European Countries

Country	Vehicles Processed (000s)	ASR (000s tonnes)	Total Shredder Waste (000s tonnes)	ASR as % of Shredder Waste %	Total Industrial Waste (000s tonnes)	ASR as % of Industrial Waste %
Germany	2,100	400	530	75.5%	61400	0.65%
UK	2,000	465	720	64.6%	50,000	0.93%
France	2,000	398	475	83.8%	50,000	0.80%
Italy	1,500	300	N/A	N/A	43,700	0.69%
Netherlands	450	115	140	82.1%	17,300	0.66%
Denmark	75-90	10	40	25.0%	1,600	0.63%

Note: Differences in amounts of ASR reflect differences in approaches to waste management.

Source: Den Hond, CEST, VDA, Author Estimates, OECD reports.

Exhibit 4: Waste Disposal Practices in Selected Countries, Late 1980s



Source: Corson, p. 270.

Exhibit 5: Landfill Disposal Prices – Current and Project

Year	Costs (DM/Tonne)
1987	30
1988	40
1989	60
1990	120
1991*	200
1992-1993*	400-600
1994-1995*	500-1800

* Projected

Source: Company Information, Author Estimates

Exhibit 6: The Hierarchy of Plastics

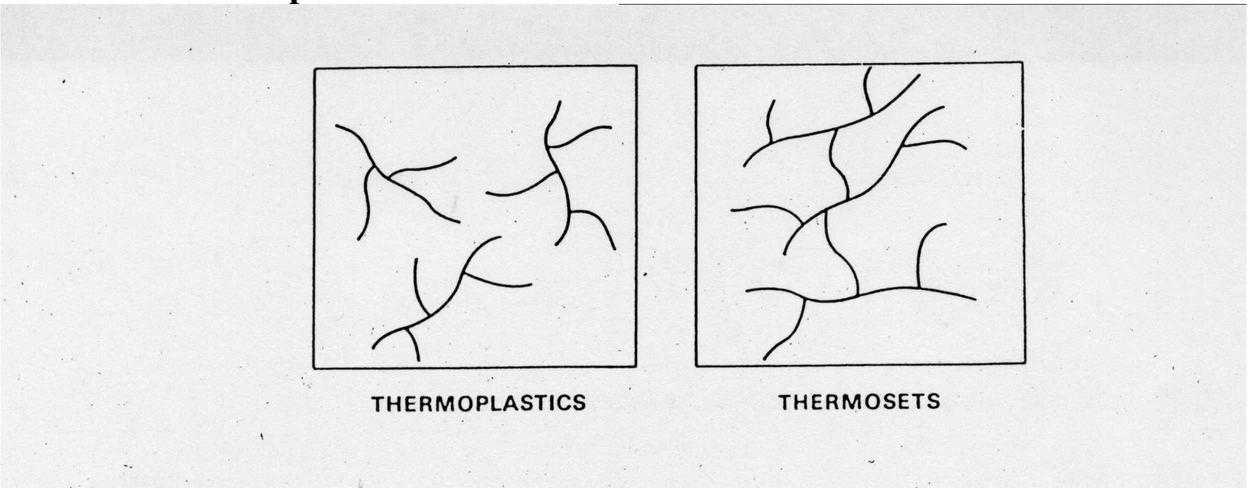
Plastics group	Typical member	Representative properties[a] Material cost, ¢/cu. in.	d, Specific gravity	E, Flexural modulus, 10^3 p.s.i.	E/d	Flexural strength, 10^3 p.s.i.	Notched Izod impact strength, ft.-lb./in.	Deflection temperature (264 p.s.i.), °F
THERMOPLASTICS								
Commodity	Low-density polyethylene (LDPE)	1.40	0.92	40	43	1.6	no break	<100
	Polypropylene homopolymer (PP)	1.53	0.90	200	220	7	0.8	130
	Crystal polystyrene (PS)	2.2	1.05	430	410	12	0.4	180
	Rigid polyvinyl chloride (PVC), pipe grade	1.9	1.3	400	310	13	1.0	155
Intermediate								
	Polymethyl methacrylate (PMMA)	4.0	1.18	380	320	14	0.4	180
	Acrylonitrile-butadiene-styrene terpolymer (ABS), high-heat	5.2	1.07	350	330	11	4	230
	Cellulose acetate butyrate (CAB)	5.5	1.18	150	130	4	3	150
	Thermoplastic olefin elastomer (TPO)	4.0[b]	0.93	10	11	5	no break	n.a.
Engineering								
	Acetal (polyoxymethylene)	7.9	1.42	400	280	13	1.4	230
	Nylon-6/6, 30% glass fiber	9.4	1.3	1000	770	30	3	350
	Polycarbonate (PC)	9.4	1.2	340	280	13.5	5	270
	Polyphenylene sulfide (PPS)	12[b]	1.3	550	423	14	0.4	275
Advanced								
	Liquid-crystal polymer	40	1.35	1800	1300	19	3	650
	Polytetrafluoroethylene (PTFE)	45	2.17	80	37	1.7	3	100
	Polyetheretherketone (PEEK)	110[b]	1.31	560	430	16	1.6	320
	Polyethersulfone (PES)	25[b]	1.42	360	250	18	1.4	395
THERMOSETS								
	Alkyd polyester	3.7	1.2	540	450	12	0.3	80
	Epoxy, general-purpose	6.0	1.25	350	280	16	0.6	350
	Phenolic, general-purpose	2.7	1.5	1200	800	10	0.3	370
	Urea-formaldehyde, black	3.4	1.5	1400	930	10	0.3	270

a: Most properties have ranges, sometimes wide, that depend on grade. This table gives middle-of-range values from the Resins and Compounds chart in the Data Bank. Cost figures are based on bulk prices as of May 1988.

b: - Costs of these materials ranged as much as two-fold.

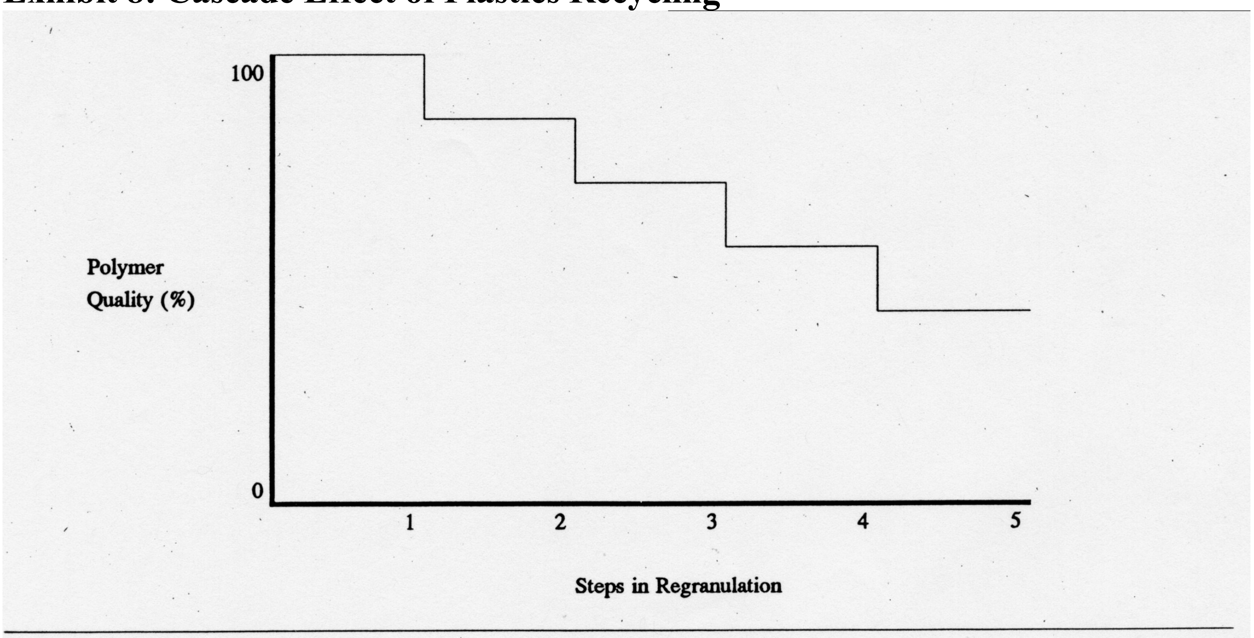
Source: Company Information

Exhibit 7: Thermoplastics and Thermosets



Source: Curlee, pg. 14

Exhibit 8: Cascade Effect of Plastics Recycling



Source: Company Information

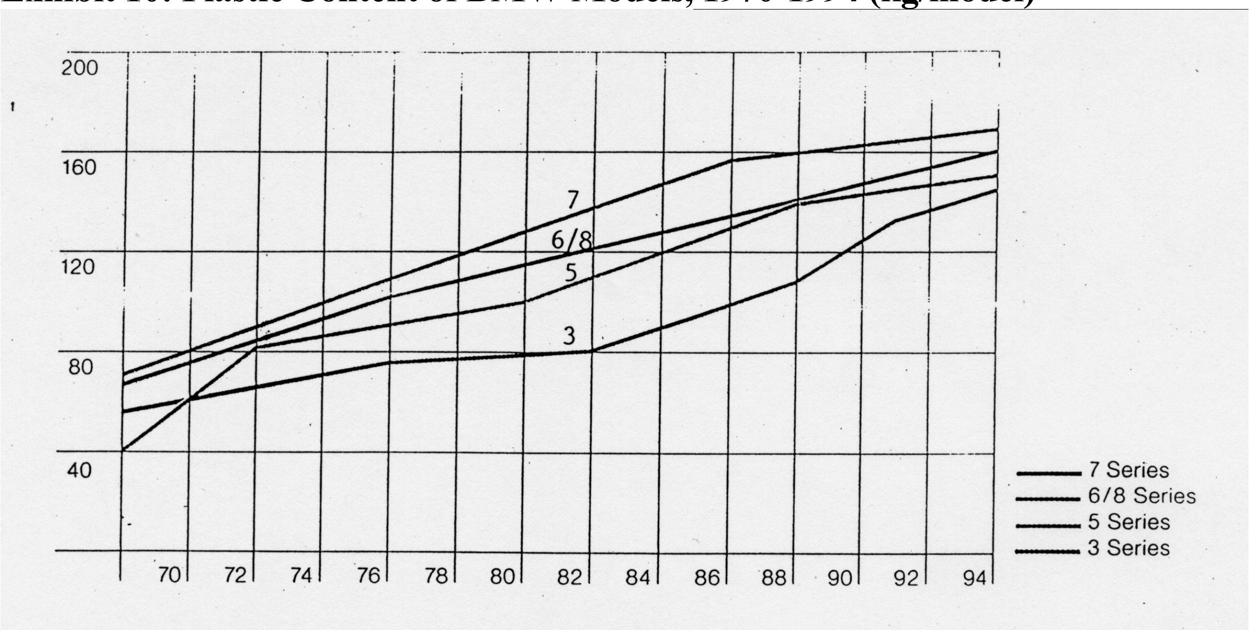
Exhibit 9: Materials Choice in Automobiles, 1965-1995

Material	1965	1985	1995*
Steel, Iron	76.0%	68.0%	63.0%
Lead, Zinc, Copper	4.0%	4.0%	3.0%
Plastics	2.0%	9.0%	13.0%
Aluminum	2.0%	4.5%	6.5%
Other Non-Recyclables (fabric, rubber, glass)	16.0%	14.5%	14.5%
Total	100.0%	100.0%	100.0%

* Projected

Source: Weber, p. 144

Exhibit 10: Plastic Content of BMW Models, 1970-1994 (kg/model)



Source: Company Information

Exhibit 11: BMW's Product Line – Weight and Plastic Content

Model	Weight (kg)	Plastic Content (kg)	Plastic Content/Weight (%)
3 series	1,050-1,250	130	11.3
5 series	1,350-1,475	150	10.6
6 series	1,450-1,650	170	10.9
7 series	1,550-1,750	160	10.3
8 series	1,750	170	9.7
Average	1,350-1,500	155	10.5

Source: Company Information, Author Estimates

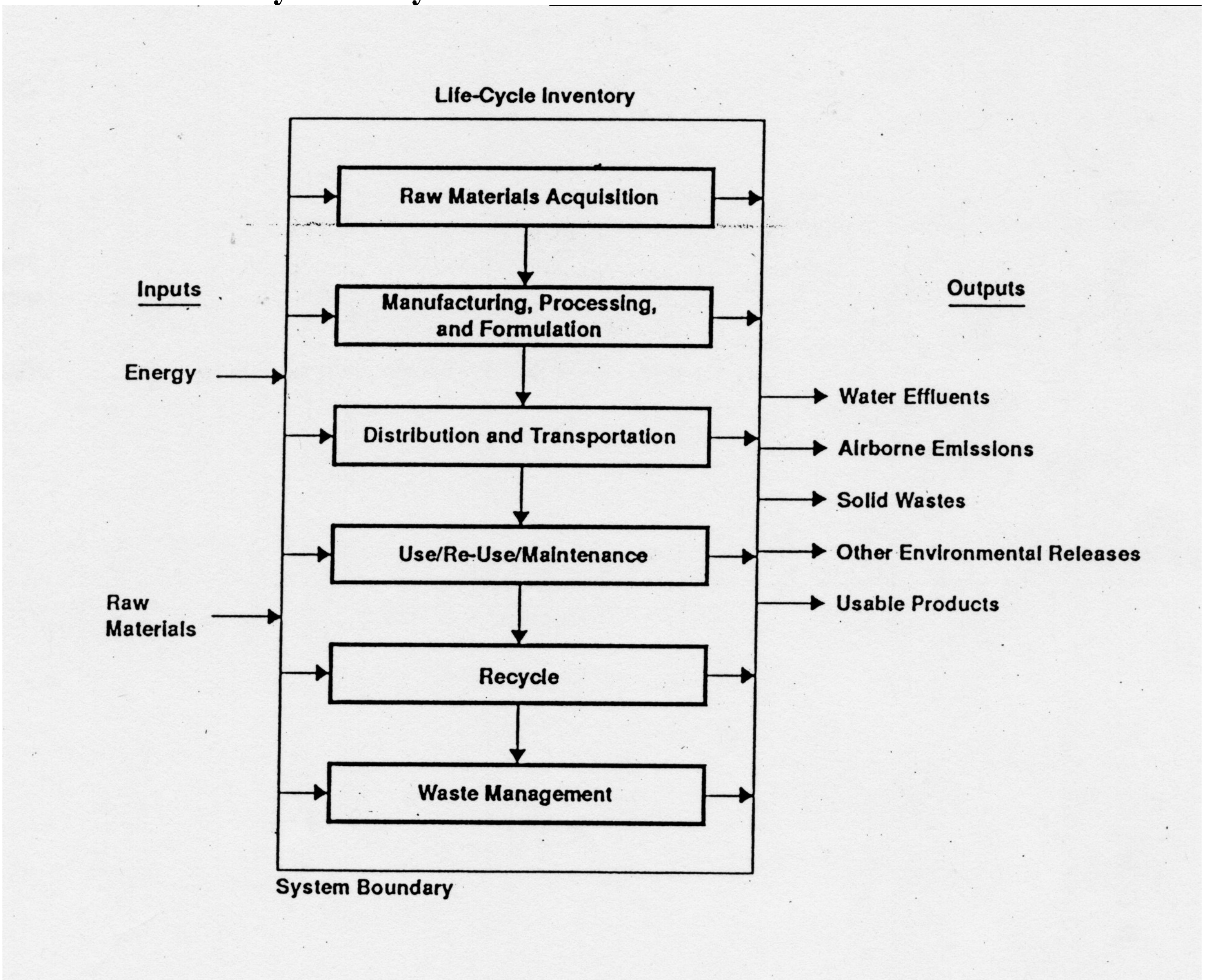
Exhibit 12: BMW 5 Series Plastic Content by Polymer, Application

Plastic Type	Weight (kg)	% of Total Plastic
Polyurethane (PUR)	31.2	20.9
Polyamide (PA)	17.8	11.9
Polyethylene (PE)	16.4	11.0
Polycarbonate Blends	14.8	9.9
Polypropylene (PP)	14.3	9.6
Unsat. Polyester (UP-GF)	14.1	9.5
Polyvinylchloride (PVC)	10.6	7.1
A-B Styrene (ABS)	9.4	6.3
Phenylene Oxide (PPO)	6.3	4.2
Polybutylene (PBT)	5.6	3.8
Polyoxymethylene (POM)	3.5	2.3
Polymethyl Methacrylate (PMMA)	1.9	1.3
All Others	3.1	2.1
Total	149	100.0

Plastic Consumption by Subsyste	Weight (kg)	% of Total Plastic
Interior Trim	86.5	58.1
Body	22.7	15.2
Electrical Componentry	17.2	11.5
Chassis	12.5	8.4
Transmission/Engine	10.1	6.8
Total	149	100.0

Source: Company Information

Exhibit 13: Life-Cycle Analysis



Source: SETAC, p. XIX

Exhibit 14: BMW AG Financial and Production Data, Selected Years

		1989	1988	1987	1986	1985	1984
Net Sales	DM Million	20,957.8	19,883.7	17,656.7	14,994.3	14,246.4	12,931.6
% Change	%	5.4	12.6	17.8	5.2	10.2	12.6
Export Share	%	58.5	59.8	65.9	65.7	65.0	61.1
Production--Automobiles	Units	511,476.0	484,121.0	461,340.0	446,438.0	445,233.0	431,995.0
Production--Motorcycles	Units	25,761.0	23,817.0	27,508.0	32,054.0	37,104.0	34,001.0
Sales--Automobiles	Units	510,968.0	486,592.0	459,502.0	446,109.0	440,732.0	4,342,665.0
Sales--Motorcycles	Units	25,549.0	24,205.0	27,811.0	31,731.0	36,320.0	33,912.0
Investment	DM Million	1,508.7	1,309.1	1,643.4	1,821.8	941.5	669.2
In tangible/fixed assets	DM Million	1,416.7	1,254.9	1,541.2	1,735.0	906.5	663.8
In subdiaries	DM Million	92.0	54.2	102.2	86.8	35.0	5.4
Depreciation	DM Million	1,233.3	1,231.0	1,145.6	948.9	751.6	707.9
Fixed Assets	DM Million	4,272.3	4,019.1	39,964.2	3,486.9	2,592.0	2,410.6
Current Assets	DM Million	5,860.5	5,344.8	4,661.5	4,564.3	3,980.6	3,496.0
Subscribed Capital	DM Million	790.6	750.0	750.0	750.0	600.0	600.0
Reserves	DM Million	2,868.0	2,516.0	2,328.5	2,141.0	1,320.3	1,160.1
Shareholder Equity	DM Million	3,851.6	3,453.5	3,266.0	3,059.8	2,070.3	1,910.1
Long-Term Liabilities	DM Million	1,312.5	1,195.7	1,161.1	1,125.9	1,268.4	1,183.0
Long-term Capital	DM Million	5,164.1	4,649.2	4,427.1	4,185.7	3,338.7	3,093.1
Balance Sheet Total	DM Million	10,132.8	9,363.9	8,625.7	8,051.2	6,572.9	5,906.6
Expenditure on Materials	DM Million	12,727.6	11,880.9	10,260.3	8,606.6	7,890.8	6,915.0
% of Production Value	%	60.5	59.4	57.8	57.1	55.1	53.6
Expenditure on Personnel	DM Million	4,126.6	4,000.2	3,586.4	3,173.7	2,918.5	2,792.5
% of Production Value	%	19.6	20.0	20.2	21.1	20.4	21.7
Taxes	DM Million	587.5	615.5	551.0	706.8	731.5	692.7
Net Income	DM Million	386.0	375.0	375.0	337.5	300.0	329.6
% Change	%	2.9	0.0	11.1	12.5	-9	14.4
Workforce at Year End		57,087	56,981	54,861	50,719	46,804	44,692
Wage Earners		35,212	35,524	34,185	31,883	30,170	29,524
Salaried Employees		18,457	18,157	17,522	15,822	13,918	12,677

Source: BMW AG, Annual Reports

Exhibit 15: BMW AG Market Share Data, Selected Years

	1989			1988			1989 vs. 1988
Market	Total Market *Units*	BMW Sales *Units*	BMW Market Share %	Total Market *Units*	BMW Sales *Units*	BMW Market Share %	Change in Market Share %
Austria	276,100	9,600	3.48	253,300	8,700	3.43	+0.04
Belgium	439,800	11,900	2.71	427,000	11,300	2.65	+0.06
France	2,274,300	30,600	1.35	2,208,100	31,600	1.43	-0.09
Germany	2,831,700	191,000	6.75	2,803,700	180,200	6.43	+0.32
Great Britain	2,300,900	48,900	2.13	2,233,900	42,900	1.92	+0.09
Italy	2,362,100	27,700	1.17	2,187,100	23,700	1.08	+0.09
Netherlands	495,700	10,400	2.10	481,300	11,600	2.41	-0.31
Spain	1,072,000	11,000	1.03	992,600	9,200	0.93	+0.09
Switzerland	320,200	13,100	4.09	320,200	14,100	4.40	-0.31
Major European	12,372,800	354,200	2.86	11,907,200	333,300	2.80	+0.06
Canada	987,600	4,300	0.44	1,050,700	5,000	0.48	-0.04
United States	9,867,400	64,900	0.66	10,610,100	73,800	0.70	-0.04
North America	10,855,000	69,200	0.64	11,660,800	78,800	0.68	-0.04
Australia	444,000	4,800	1.08	403,600	2,700	0.67	+0.41
New Zealand	83,900	700	0.83	71,100	600	0.84	-0.01
South Africa	221,300	18,700	8.45	230,500	17,500	7.59	+0.86
Japan	4,403,800	33,100	0.75	3,732,000	26,900	0.72	+0.03
World	28,380,800	480,700	1.69	28,005,200	459,800	1.64	+0.05

Source: BMW AG, Annual Reports

Exhibit 16: Financial, Production and Market Share Data for Selected German Firms, 1989

		Audi AG	Adam Opel AG	BMW AG	Ford-Werke AG	Mercedes-Benz AG	Volkswagen AG
Financial Data							
Sales	*DM Million*	12,215.1	20,805.8	26,515.4	19,806.2	56,367.0	65,362.2
Profit	*DM Million*	114.0	1,123.8	558.0	362.2	1,492.0	1,038.1
Book Value of Assets	*DM Million*	4,855.6	9,038.6	20,688.7	7,824.5	27,118.0	56,871.4
Book Value of Equity	*DM Million*	1,143.7	2,664.0	5,370.6	1,440.7	4,052.0	11,505.8
Profit/Sales	%	0.01	0.05	0.02	0.02	0.03	0.02
Sales/Assets		2.52	2.30	1.28	2.53	2.08	1.15
Profit/Assets	%	0.02	0.12	0.03	0.05	0.06	0.02
Assets/Book Equity		4.25	3.39	3.85	5.43	6.69	4.94
Return on Book Equity	%	0.10	0.42	0.10	0.25	0.37	0.09
Production Data							
Production	*Units*	421,243	989,385	511,476	633,340	536,993	1,463,991
% Change from 1988	%	-1.22	+10.48	+5.65	+4.02	-3.02	+6.7
Sales/Market Share Data							
Domestic Market Sales	*Units*	158,100	455,700	191,100	284,800	259,600	619,100
Domestic Market Share	%	5.6	16.1	6.7	10.1	9.2	21.9
% Change from 1988	%	-1.1	+0.8	+0.3	+0.1	-0.8	-0.3
European Market Sales	*Units*	380,000	1,454,400	381,700	1,559,500	433,300	1,335,200
European Market Share	%	2.8	10.8	2.8	11.6	3.2	9.9
% Change from 1988	%	-0.1	+0.4	+0.1	+0.4	-0.2	0.0
North American Market Sales	*Units*	23,200	N/A	69,200	N/A	79,800	155,100
North American Market Share	%	0.5	N/A	1.6	N/A	1.8	3.6
% Change from 1988	%	0.0	N/A	-0.1	N/A	0.0	+0.1

Source: Moody's International Manual, vol. 1, 1991 (NY: Dun & Bradstreet Corp., 1991);
Ward's Automotive Yearbook, 52nd Edition, 1990
(Detroit, MI: Ward's Communications, 1990)