Insights into ecodesign practices amongst the world's largest carmakers

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Abstract
Significant environmental impacts occur throughout the lifecycle of passenger vehicles. The mountains of crushed end-of-life vehicles in wrecking yards and the city smog due to internal combustion engines are but two of the visual evidences of the necessity to reconsider the un-sustainability of car-based mobility. Because industrial designers assist manufacturers in creating and enhancing these automotive products for the consumer market, they are co-implicated in the ensuing environmental crisis. This paper seeks to know what the world's largest passenger vehicle manufacturers are doing to address the adverse ecological effects arising from their products. To gain insight into automakers' activities, their latest annual reports on environmental sustainability and corporate citizenship were consulted. These documents were analyzed to gain insights into the product-based strategies by which these producers attend to their responsibilities in progressing a sustainable environment and society. The design approaches collated in the paper are intended to enable and inspire industrial designers to envision solutions that are more sustainable to produce and to consume, by learning from the successful case studies of others in the industry.

Keywords
Sustainable design, industrial design, corporate social responsibility, automotive design, environmental reports

1 Introduction
That automobiles generate both positive and negative impacts throughout their lifecycle is unquestionable. They help us to move around with ease and speed, enable us to travel wide and far, and provide a means for transporting our cargo; indeed modern life wouldn't be where it is without the automobile. However, like any manufactured product, cars require at every phase of their cradle-to-grave lifecycles significant amounts of energy inputs as well as other resources, while at the same time emitting wastes in various forms.

2 Background
2.1 Corporate reporting of sustainable activities
Heightened consumer awareness on the ecological consequences of manufactured goods has risen in the last few decades. In particular this consciousness has been accentuated by the visually evident pollution of the global landscape and the unpredictability of weather patterns attributed to climate change. It has thus become important that manufacturers' public image and reputation be perceived as one that is behaving responsibly or ethically as a global citizen, and that is abiding by the rule of

law and upholding the moral standards of society. Large manufacturers, especially those with global operations, now find themselves rather compelled to publicly disclose the ways by which their corporate activities and outcomes affect the environment and society. Expectedly the more positive accomplishments would be highlighted and the not-so-positive would be glossed over, potentially leading to consumer deception or 'greenwashing'[1] (Laufer, 2003).

These voluntary 'sustainability reports'[2] help global manufacturers display transparency and accountability about their environmental and social pursuits to internal and external stakeholders (Train4CSR, 2008), as well as demonstrate compliance with the environmental regulations in the jurisdictions in which they operate. At the same time the reports present beneficial opportunities for manufacturers to reflect on how sustainability aspects could be better integrated into their processes, and how they could engage better with the community.

There are innumerable formats by which manufacturers could communicate their commitment to sustainability. Some publish comprehensive stand-alone environmental reports while others merely insert a few pages on corporate citizenship into their comprehensive annual report[3]. Global standards and guidelines[4] are now available to ensure that organizations discuss uniform points in their sustainability reports.

2.2 *Industrial design and sustainability*

In a consumer society, manufacturers are praised and patronized for well-designed products, and censured for those which undersatisfy consumer expectations. Often industrial designers are the creative minds that conceived and developed these products, be they commercial successes or market failures. Typically it is the role of the industrial designer to enhance the aesthetics, functionality, ergonomics, and usability of the product, and consider its marketability and manufacturability. The automotive industry has traditionally drawn on the creative expertise of industrial designers in styling the visual appearance of the vehicle.

Unfortunately far too many products are ill-conceived or short-lived and end up being thrown away in landfill. Modern manufacturing industry, and industrial design by extension, has been accused of fostering a culture of premature product obsolescence, whereby products are intentionally not built to last and made to look outdated in the manipulated public mind in order to assure continuance of production and sales (Packard, 1960). Therefore, while industrial designers are partly to blame for the environmental crisis that ensues from lack of producer/product responsibility, they are also in a special position to influence the positive environmental qualities of the product in the first place.

Often the negative impacts of products are made visible by the solid waste that the products turn into at the end of their useful lives. However, these impacts are already built into the product much earlier before they are discarded. For instance, when the designer fails to consider how the products will consume energy, water or other resources throughout their lifetime, or how they could be transported and

[1] Greenwashing is a marketing strategy whereby consumers are mislead into believing that a company's products or services are environmentally responsible, in an attempt to cover up corporate activities which are not actually sustainable.
[2] Sustainability reports are invariably known as environmental report, integrated triple bottom line (TBL) report, corporate social responsibility (CSR) report, or corporate citizenship report.
[3] Inclusion of CSR information and policy in annual reports is mandated by law in Denmark and in France.
[4] One of the most prevalent standards for sustainability reporting comes from the Global Reporting Initiative (GRI), used by over 4,000 organizations from 60 countries. The standardized GRI Indicator Protocol Set specifies the company's performance using criteria encompassing environment, human rights, labour practices, society, economics and product responsibility.

distributed within minimal space configurations, or how they could be easily maintained and repaired, then the adverse consequences become designed into those products, whether accidentally or simply by poorly considered design thinking.

There is now a wide range of trade publications and academic literature that showcase various strategies that industrial designers could use to mitigate the overall lifecycle impacts of manufactured goods, ranging from the design of processes to the design of product outcomes. For instance, an ecodesign manual has been published by the United Nations Environment Programme (Brezet and Van Hemel, 1997), which was further developed and promoted by the Industrial Designers Society of America (Belletire et al., 2012) and recently made into a software application known as the Okala ecodesign strategy wheel app. This app expands the original 8 strategies and 33 sub-strategies of the UNEP manual into 47 sub-strategies. These strategy tools acknowledge that the biggest leaps towards environmental betterment lies in strategic innovation, or radical design revolutions rather than incremental design evolutions.

3 Methodology

Automobiles are amongst the largest and most visible products designed by industrial designers; as such their effects on society, be they good or bad, are easy to see. This research is interested in determining if ecologically sustainable industrial design strategies are employed in the manufacturing of passenger cars, defined as road motor vehicles with at least four wheels, intended for the carriage of passengers[5] and designed to seat no more than nine persons including the driver (UNECE et al., 2010). Passenger cars constitute over 78% of the annual worldwide production of motor vehicles[6].

Two databases were consulted to determine the world's largest producers of passenger cars: the 2011 OICA[7] World Ranking of Motor Vehicle Manufacturers, based on production volumes; and the 2012 IndustryWeek[8] IW1000, an annual ranking of the world's 1,000 largest publicly traded manufacturing companies based on revenues or sales volumes.

The OICA ranking listed 50 motor vehicle manufacturers from 13 countries; however, only 39 qualified as passenger car makers with their own brands.[9] This OICA shortlist was compared with the 1,000-company database of IndustryWeek. Twenty two companies were found to be common in both lists[10]. For the purposes of this paper, the study was limited to the Top 15. Together these 15 automakers manufactured 52,092,823 cars in 2011, or 86% of the world car production in that year (OICA, 2011); the contribution of each company including their subsidiaries is detailed in Table 1 and Figure 1.

[5] This UNECE definition includes taxis, ambulances, motor homes and 8-seater passenger vans.
[6] The remaining 22% is made up of buses, coaches, heavy trucks and light commercial vehicles for the carriage of goods.
[7] Founded in Paris in 1919, the Organisation Internationale des Constructeurs d'Automobiles (International Organization of Motor Vehicle Manufacturers) links the 35 national federations of vehicle manufacturers, assemblers and importers from around the world. Its permanent committees coordinate international motor shows and compile industry statistics and studies relating to the development and future of the automobile industry.
[8] First circulated in 1882 as the weekly Iron Review, the American trade publication IndustryWeek [ISSN 0039-0895] has been in business under this name since 1970 and from 2001 has been published monthly by Penton Media in Cleveland. Companies around the world with a majority of their business in the manufacturing industry are eligible to be included in the annual IW1000 list, which was launched in 1996.
[9] Three Chinese automakers did report a production of passenger cars, but their websites only show trucks, buses and commercial vehicles as their products, so they were deleted from the study. One Taiwanese manufacturer was making Toyota cars under license for domestic consumption; because it did not have its own marque nor original design vehicles, it was also excluded.
[10] It must be noted that the rankings in the two databases are dissimilar; the IW1000 data is based on vehicle sales while the OICA data is based on vehicle production. Moreover the IW1000 uses 2012 data, while the OICA is 2011.

Table 1. World's 15 largest producers of passenger cars.
Data source: www.oica.net

Rank	Parent Headqtrs	Company Group	Car marques including subsidiaries	2011 car production
1	Germany	Volkswagen AG	Audi, Bentley, Bugatti, Lamborghini, Porsche†, SEAT, Škoda, Volkswagen	8,157,058
2	USA	General Motors Co	Baojun^Δ, Buick, Cadillac, Chevrolet, Damas, GMC, Holden, Opel, Vauxhall	6,867,465
3	Japan	Toyota Motor Corp	Daihatsu, Lexus, Scion, Toyota	6,793,714
4	S Korea	Hyundai Motor Co	Hyundai, Kia	6,118,221
5	Japan	Nissan Motor Co	Datsun, Infiniti, Nissan, Venucia^Δ	3,581,445
6	France	Peugeot SA	Citroën, Peugeot	3,161,955
7	Japan	Honda Motor Co	Acura, Everus, Honda	2,886,343
8	USA	Ford Motor Co	Ford, Lincoln, Troller	2,639,735
9	France	Renault SA	Dacia, Renault, Renault Samsung	2,443,040
10	Japan	Suzuki Motor Corp	Suzuki, Maruti	2,337,237
11	Italy	Fiat SpA	Abarth, Alfa Romeo, Chrysler†, Dodge, Ferrari, Fiat, Jeep, Lancia, Maserati	1,804,523
12	Germany	Bayerische Motoren Werke AG	BMW, Mini, Rolls Royce	1,738,160
13	Germany	Daimler AG	Denza^Δ, Mercedes-Benz, Smart	1,443,419
14	Japan	Mazda Motor Corp	Mazda	1,103,632
15	Japan	Mitsubishi Motors Corp	Mitsubishi	1,016,876
			Total	**52,092,823**

†In 2011 Fiat became the majority shareholder of Chrysler. In 2012 Volkwagen became the parent company of Porsche.
^ΔThese marques are joint ventures: Baojun of GM + SAIC Motor; Denza of Daimler + BYD; Venucia of Nissan + Dongfeng.

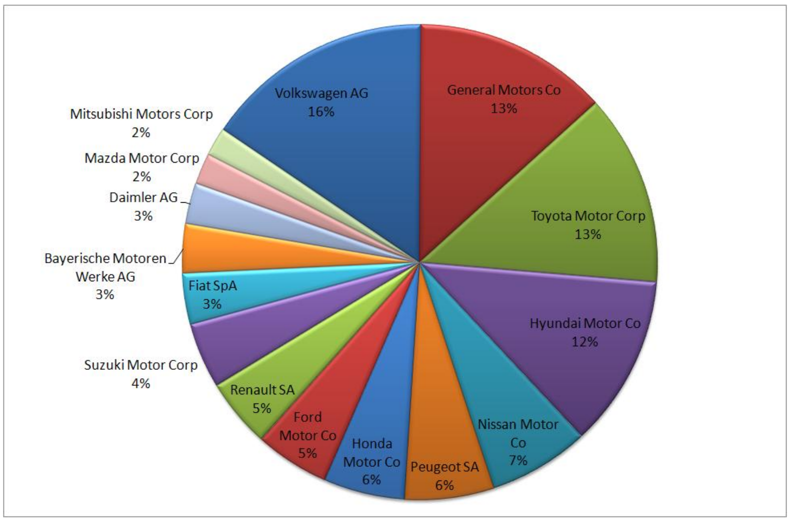

Figure 1. Share of passenger car production by Top 15 automakers.

The official website of each carmaker was visited to obtain their latest annual reports and sustainability reports, as well as gather updated corporate and product information. The collected data were then analyzed for ecodesign strategies used by the company. Excerpts of ecodesign approaches from the reports were cut-and-pasted into a large table, with the y-axis populated by the 47 ecodesign strategies (Table 2), and the names of the 15 manufacturers on the x-axis. Other data were obtained from studies by independent research groups.

Table 2. Okala ecodesign strategies[11] (Belletire et al., 2012)
based on UNEP Ecodesign manual (Brezet and Van Hemel, 1997)

1 Innovation
1.01 rethink how to provide the benefit
1.02 design flexibility for technological change
1.03 provide product as service
1.04 serve needs provided by associated products
1.05 share among multiple users
1.06 mimic biological systems
1.07 use living organisms in product system
1.08 create opportunity for local supply chain

2 Reduced material impacts
2.09 avoid materials damaging human or ecological health
2.10 avoid materials that deplete natural resources
2.11 minimize quantity of material
2.12 use recycled or reclaimed materials
2.13 use renewable resources
2.14 use materials from reliable certifiers
2.15 use waste by-products

3 Manufacturing innovation
3.16 minimize manufacturing waste
3.17 design for production quality control
3.18 minimize energy/water use in production
3.19 use carbon-neutral or renewable energy sources
3.20 minimize number of production steps
3.21 minimize number of components/materials
3.22 seek to eliminate toxic emissions

4 Reduced distribution impacts
4.23 reduce product and packaging weight
4.24 reduce product and packaging volume
4.25 develop reusable packaging systems
4.26 use lowest-impact transport system
4.27 source or use local materials and production

5 Reduced behavior and use impacts
5.28 design to encourage low-consumption user behavior
5.29 reduce energy consumption during use
5.30 reduce material consumption during use
5.31 reduce water consumption during use
5.32 seek to eliminate toxic emissions during use
5.33 design for carbon-neutral or renewable energy

6 System longevity
6.34 design for durability
6.35 design for maintenance and easy repair
6.36 design for reuse and exchange of products
6.37 create a timeless aesthetic
6.38 foster emotional connection to product

7 Transitional systems
7.39 design upgradeable products
7.40 design for second life with different function
7.41 design for reuse of components

8 Optimized end-of-life
8.42 integrate methods for used product collection
8.43 design for fast manual or automated disassembly
8.44 design recycling business model
8.45 use recyclable non-toxic materials
8.46 provide ability to biodegrade
8.47 design for safe disposal

4 Results & Discussion

In general all the 15 automakers demonstrated activities which could be considered as related to the 47 ecodesign sub-strategies. Some of the more notable ecodesign approaches used throughout the automotive lifecycle are discussed in this section.

4.1 Innovation

4.1.1 Rethink how to provide the benefit, provide product as service, or share among multiple users

Honda was one of the first automakers to include car-sharing in their business portfolio. From 2003 to 2008 the Honda ICVS (Intelligent Community Vehicle System), also known as Honda Diracc, operated in Singapore as a demonstration program funded through the Singapore Economic Development Board. 100 Honda Civic hybrids parked in 21 dedicated carports downtown were shared by 2,500 members. The movement of cars was tracked, allowing demand to be forecasted and car availability to be managed.

[11] The 47 Okala ecodesign strategies are not actually numbered; they are numbered in this study to facilitate referring to.

The parked car gets unlocked after the member taps his/her contactless smart card against the windscreen card reader, and an on-board control panel releases the ignition key after verification of the personal identification number.

In 2008 Daimler AG through its subsidiary Smart started the Car2Go car sharing business. Two-seater microcars (Smart ForTwo), 625 of which are purely electrically driven, are made available for hiring any time of day or night, without a contract, minimum charge or minimum rental duration. The per-minute usage charge includes the cost of fuel, tax, insurance, prepaid parking and maintenance. If there's an available Car2Go vehicle anywhere the user can rent it on the spot; alternatively smartphones or the Internet can help locate free cars. Currently over 260,000 customers are sharing 5,600 Car2Go vehicles in 18 cities in Europe and North America, and vehicles have been rented more than 5 million times. A Car2Go vehicle is rented every 4.3 seconds (Daimler, 2012).

Since 2010 the car lease service 'Mu by Peugeot' has been operating in over a hundred cities in France, England, Germany, Spain, Italy, Belgium and Switzerland. Mu hires out Peugeot cars, vans, scooters, bikes, electric vehicles and hybrids, as well as such accessories as roof boxes, bike carriers, GPS navigators, or DVD players. In 2011 Peugeot's sister company Citroën started C-Zero Multicity Carsharing in Berlin, making available 100% electric vehicles and charging stations with 100% renewable energy sources. In 2012 Citroën Multicity branched out into the peer-to-peer car-sharing industry (PSA, 2012).

Volkswagen started their 'Quicar: Share a Volkswagen' project in 2011. Operating in 62 stations in Hanover, Quicar makes 200 VW Golf BlueMotion city cars available for short-term hire 24/7 to its 5,000 customers. The Quicar Plus service is for longer rental periods, with a wider selection of models, from compact cars to convertibles, station wagons, people movers, and vans (Volkswagen, 2012). In the same year BMW, Mini and Sixt launched their DriveNow joint venture, where over 1,000 premium cars are shared by some 60,000 customers in Berlin, Munich, Cologne, Düsseldorf, and San Francisco (BMW, 2010).

In 2012 General Motors partnered with RelayRides, the world's first peer-to-peer car sharing site, allowing GM car owners to rent out their idle cars on a short-term basis. Using the existing OnStar system on GM vehicles, car renters could unlock cars with their mobile phones (GM, 2012).

Fiat, in collaboration with the Italian Ministries of Education and Environment, launched "Fiat Likes U" in 2012 to orient university students towards eco-friendly driving; city cars and mini multi-purpose vehicles equipped with Eco:Drive[12] are available for sharing free-of-charge for all students in 8 major Italian universities (Fiat, 2012). At around the same time, Renault Twizy Way in Germany and France allowed Renault customers to share Twizy plug-in electric quadricycles; booking was conveniently done through smartphones and the vehicle charging stations were linked with the public transport system (Renault, 2011).

Toyota uses its 1,200 dealerships across Japan as venues for its Rent A Car business, making available Toyota hybrid cars, passenger cars, mini vans, RV, vans, trucks and minibuses with free 24-hour roadside assistance. In 2012 it trialed the Ha:mo (Harmonious Mobility) urban transport system in Toyota City, with two elements: Ha:mo Navi smartphone apps for searching for commuting routes or alternatives, and Ha:mo Ride, a sharing service using 30 Toyota COMS single-occupant

[12] Fiat Eco:Drive explained in Section 4.5.1of this paper.

ultra-compact electric vehicles for short-distance city travel. Customers earn eco-points if they use the Ha:mo park-and-ride facilities in train stations or use public transportation. Toyota recently signed a memorandum of understanding with the City of Grenoble, the Agglomeration Community of Grenoble Alpes Métropole, car-sharing service operator Cité lib, and Électricité de France to deploy in 2014 70 Toyota COMS for zero-emission 'last-mile' car sharing in the French Alps. Toyota also added 30 Scion iQ EV all-electric city cars and 16 RAV4 EV all-electric crossover utility vehicles to the University of California Irvine (UCI) Zero Emission Vehicle Network Enabled Transport (ZEV-NET) fleet. Commuters to UCI and area businesses can rent a battery-powered vehicle from the Irvine Transportation Center to the university campus.

Ford Deutschland recently announced its Ford2Go nationwide car sharing program, wherein 50 participating Ford dealers across Germany would be offering customers in their towns a wide range of over 500 shared vehicles, including Ford Transit Connect vans and fuel efficient Ford Ka city cars.

4.1.2 Design flexibility for technological change

This strategy is achieved by having flexible automotive platforms that can accommodate different fuel engines or electric vehicle technology. For instance, it is typical for cars produced for the Brazilian market to be 'flexible-fuel', or capable of running on any ethanol blend from E20 (a mixture of 20% ethanol and 80% gasoline) to E100 (100% ethanol). There are also many cars in Europe and South America that are 'bi-fuel' or 'dual-fuel', meaning that their engines can run on two different fuels, commonly gasoline and LPG (liquefied petroleum gas) or CNG (compressed natural gas), which are stored in separate tanks.

4.1.3 Mimic biological systems

This strategy was only found in concept cars. In 2005 Mercedes Benz showed to the world their Bionic prototype car. The sloping nose and trim silhouette of the exterior were modeled directly after the yellow boxfish (*Ostracion cubicus*), a tropical coral reef species that was found to be surprisingly aerodynamic given its boxy frame. The MB Bionic has 65% lower drag coefficient than other vehicles in its class, reducing fuel consumption by 20%. The chassis and structure of the car are also biomimetic, having been based upon how trees grow with minimal stress concentrations (Daimler, 2012).

BMW's GINA (Geometry in *N* Adaptations) concept car, released in 2008, uses fabric as a skin that allows drivers to change the shape of the car at will, unlike rigid structures. Electro-hydraulic devices move metal wires and carbon fibers to achieve different fabric forms and to reveal different parts of the car, such as when accessing the engine. This 'living design' emulates the morphology and functionality of living bodies (BMW, 2010).

Nissan's BR23C (Biomimetic Robot Car), also unveiled in 2008, is an accident-avoiding robot whose behavior has been patterned after bees, which apparently don't collide into each other. The BR23C uses laser range finders to mimic the compound eyes of bees, to stake out 180 degrees in front of the car, the area for its 'safety shield'. The movement of fish travelling in schools was also mimicked in the Nissan EPORO, another collision-free robot car. EPORO cars run on electricity and use algorithms to move in harmony and in solitude. The crash-prevention technology in these robots is similar to those already being implemented in Nissan and Infiniti cars, like intelligent brake assist, forward collision warning, and lane departure prevention (Nissan, 2012).

Toyota is collaborating with researchers to study insect optics that would help create better night driving technologies. The low-light seeing abilities of the dung beetle (*Onitis alexis*) provided biomimetic inspiration for a video-camera algorithm which brightens dark pixels when capturing night scenes, then sharpens the picture edges, and finally smoothes out the 'noise' and enhances the detail from the digital images (Toyota, 2012).

4.1.4 Use living organisms in product system

Natural systems can be successfully embedded into factory working processes and conditions. In 2003 Ford Motor Company started the revitalization of its historic flagship factory complex, the contaminated River Rouge truck assembly plant in Dearborn. This involved onsite 'phytoremediation' using big bluestem and green ash plants to break down polycyclic aromatic hydrocarbons and to neutralize toxins in the soil. The factory's 42,000 square-meter roof was transformed into a 'living roof', the largest installation of its kind in an industrial building in the USA, planted with succulent groundcovers and other species to reduce storm water runoff, to absorb carbon dioxide and to restore native habitat to the site. Skylights and an air delivery system shower abundant natural daylight and fresh air into the factory floor (Ford, 2012).

Using living organisms in cars, however, is only conceptual at the present time. In 2010 Mercedes Benz unveiled the Biome car, grown from genetically modified seeds and powered by plant juice. The ultralight 'BioFibre' material from the seeds, claimed to be stronger than steel but lighter than plastic, gets knitted to shape the car's chassis, interior and wheels. Biome uses a futuristic fuel called BioNectar4534, which isn't stored in a tank but rather in the car's BioFibre. Because the Biome is made of organic matter, it biodegrades in compost heaps at the end of its life (Daimler, 2012).

4.2 Reduced material impacts

4.2.1 Avoid materials damaging human or ecological health

All the 15 automakers had demonstrated success in complying with international laws regarding use of hazardous materials in the automotive industry. REACH[13] (Registration, Evaluation, Authorization and Restriction of Chemicals) (EU, 2006) is the most important of these legislative acts. Automakers and every company who delivers parts, materials or accessories to them must register each substance used into the International Material Data System (IMDS[14]) database, which compares the material against the REACH and the Global Automotive Declarable Substance List (GADSL[15]). Articles or objects containing 'substances of very high concern' (SVHC[16]) must be made known. Many automakers issue guidance manuals to help their component suppliers

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[13] The REACH legislative act is considered the world's toughest law on chemical regulation and affects industries globally. It requires all manufacturers, importers and marketers of any of the 143,000 chemicals in the European Union to register the properties of their substances with the European Chemicals Agency (ECHA) and submit health and safety data, as well as replace the most hazardous ones with safer alternatives.

[14] The IMDS is the automotive industry's global data repository for material content of various components used in vehicles. The IMDS includes the black and black and gray lists of prohibited and declarable substances, which are of concern to human health, environmental safety and recycling.

[15] The GADSL provides a definitive list of substances in the automotive value chain that require declaration due to their being a significant risk factor to human health or the environment. Substances designated as 'Prohibited' are forbidden from being used in certain applications or should be used in quantities less than regulated threshold limits.

[16] SVHC include those which are carcinogenic; mutagenic; toxic for reproduction; persistent, bioaccumulative and toxic (PBT); or very persistent and very bioaccumulative (vPvB). Articles or objects in which SVHC are present at >0.1% mass of the object must also be declared to the ECHA.

enter material data into the IMDS; this process helps identify SVHC presence and to initiate the search for safer alternatives.

In addition to legislation, some companies have highlighted hazardous material reduction into their own manufacturing standards. For instance, the BMW Group Standards GS 93008-1, GS 93008-2 and 93008-4 detail specific requirements to suppliers regarding banned and declarable substances in materials, components and processes. Daimler has the DBL8585 standard which sets general requirements on hazardous materials, dangerous goods and negative substances. General Motors Worldwide Engineering Standards GMW3059 controls restricted and reportable substances for parts. Nissan's NES M0301 engineering standard deals with restricted use of substances; Volkswagen's VW 91101standard contains worldwide material restrictions. Ford has its Restricted Substances Management Standard, while Mazda publishes its Management Standards for Environmentally Hazardous Materials.

4.2.2 Use recycled or reclaimed materials

Recycled content is present in 15-20% of the plastic parts in a BMW car; these can be found in under body paneling, rear shelves, fuel tanks, wheel housings, boot ventilation, and central console mount. The flock compound insulation for the rear parcel shelf is made of 80-90% recycled polyurethane foam (BMW, 2010).

Vehicles carrying the Renault eco² signature contain significant proportions of recycled plastic in relation to the car's total plastic content: Laguna had 16% (33kg); New Scénic 34%; Twingo 9% (15kg); Clio 10% (19kg); and New Mégane Hatchback uses 23 kg of recycled plastic (Renault, 2011).

General Motors converted 365km of containment boom from the 2010 Gulf of Mexico oil spill into 45 tons of plastic resin that were used to make a year's worth of air deflection baffles for the Chevrolet Volt. The baffles were made of 25% boom material, 25% recycled tires from the GM proving ground test facility, 25% plastic shipping aids, and 25% mixture of postconsumer recycled plastics and other polymers (GM, 2012).

4.2.3 Use renewable resources

Plant fibers are increasingly being used by European carmakers, either by themselves or as composites. These natural materials have high stiffness-to-weight ratio, are 30-40% lighter than glass, lower in cost, and can suitably replace glass fibers in reinforced plastic composites. Mercedes Benz E-class vehicles had door panels with jute (*Corchorus capsularis*), sisal (*Agave sisalana*) or flax (*Linum usitatissimum*). Sisal and cotton (*Gossypium hirsutum*) are used for the rear panel shelves of the C-class, and hemp (*Cannabis indica*) for the inner door panels of S-class. Chevrolet Impala uses flax for trim panels. Kenaf (*Hibiscus cannabinus*), flax and hemp are utilized for the inner door panels and seat backs of General Motors' Opel Astra and Opel Vectra. Kenaf can also be found in Toyota sedan package shelves. BMW 7 series cars use 24kg of renewable materials, including flax and sisal in interior door liners (Saxena et al., 2011).

Toyota uses bio-based plastics in seat cushions for the Prius, Corolla, Matrix, RAV4, Lexus RX 350, and Lexus HS250H, as well as for scuff plates, cowl side trims, luggage compartment liners and trim upholstery, carpeting, tool box areas, floor finish plates, and package trays (Toyota, 2012).

4.3 *Manufacturing innovation*

4.3.1 Minimize manufacturing waste

While factories in any industry aim to both avoid waste and to recover all manufacturing waste for recycling or reuse to achieve 'zero-waste' production, an amount of non-recyclable waste is still generated, which gets classified as 'waste for disposal'. In the automotive industry the leader in waste elimination is Subaru[17]; in 2004 its Indiana (USA) plant became the first manufacturing facility in the USA to achieve zero-landfill status. All Subaru vehicles are made in zero-landfill factories, where use of materials is maximized and 100% of the manufacturing waste goes to either recycling, composting, electricity generation or waste material auctions (Subaru, 2012).

As the world's largest car manufacturer, General Motors operates 103 landfill-free facilities globally, more than any other automaker. Of the production waste generated – including scrap metal, paint sludge and shipping materials –97% is recycled or reused while 3% is incinerated to generate energy (GM, 2012). Six[18] of the eight US plants of Daimler have been certified as 'zero waste to landfill' facilities (Daimler, 2012). Ten of the 14 North American plants of Honda are landfill-free (Honda, 2012).

At the Fiat Group, waste sent to landfill was only 0.2% in 2011 (Fiat, 2012). Kia Motors of the Hyundai Group sent only 0.9% of its 2009 waste to landfills; its Sohari (South Korea) plant has not been generating any landfill waste since that time (Kia, 2012). Mazda has also gone zero-landfill since 2009: 37% of scrap metal and casting sand go back to in-plant recycling, while 63% is recycled externally (Mazda, 2012). Suzuki Motors has already achieved its zero-landfill target since 2001 (Suzuki, 2012). Nine of Toyota's 14 factories in North America divert 100% of their waste away from landfills (Toyota, 2012).

The BMW Group reports that in 2011 its disposable waste per manufactured vehicle was 10.09kg, a 5.1% improvement to the previous year. One of the waste avoidance measures implemented was the non-waxing of vehicles for extra surface protection, and instead wrapping horizontal surfaces (bonnet, roof, luggage compartment door) with a reusable protective foil, and only for around 10% of vehicles destined for 'risk markets' (BMW, 2010). Ford Motor Company's record follows closely: 10.3kg landfill waste per vehicle it built in 2011 (Ford, 2012). Among other measures, Ford is working with global suppliers to use more eco-friendly packaging, improving its production processes, and enabling its employees to actively suggest ways to help the company achieve its waste elimination objectives.

At the Volkswagen Wolfsburg site, the reduction of the width of steel coils for the car body parts resulted in significantly less waste; this and other materials optimization measures resulted in a new VW Golf that took 15% less production waste than the previous model, as well as saving 73,000 tons of steel (Volkswagen, 2012).

4.3.2 Minimize energy/water use in production

BMW pioneered powder-based clear paint technology which doesn't require any water or solvents and doesn't produce waste water. Water for the shower tests in the passenger, luggage and engine compartments, as well as for washing new cars, gets reconditioned and recycled, leading to 80% water savings. At the BMW USA paint shop

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[17] Subaru, the automotive division of Fuji Heavy Industries, ranks #22 in world passenger car production, and is not included among the automakers in this study.

[18] These Daimler USA factories make trucks and buses, not passenger cars.

water reduction at the phosphate bath and e-coat processes saved 36 million L/yr, or about 30% of consumption (BMW, 2010). Less water usage meant less wastewater treatment needed.

4.3.3 Use carbon-neutral or renewable energy sources

The electricity requirement of several automaker facilities are supplied from renewable sources, either partly or fully, aiding in reducing their carbon footprints. Wind turbines supply some or all of the energy needs of Nissan in Sunderland (England), BMW in Leipzig (Germany), Ford in Genk (Belgium) and in Dagenham (England); and Renault in Tangier (Morocco).

Ford uses roof-mounted photovoltaic panels at its factories in Michigan (USA) and in Bridgend (Wales); Fiat subsidiary Ferrari have them too at its Modena (Italy) site. BMW uses some 70 solar collectors to heat the water for its paint shop in Rosslyn (South Africa). Daimler's solar energy systems operate facilities in several locations in Germany, Canada, and USA, with over 45,000 m^2 of roof surface for CO_2-neutral electricity generation (Daimler, 2012). The Volkswagen site in Tennessee (USA) has a 263,000 m^2 solar park, with 33,600 photovoltaic panels (Volkswagen, 2012). Volkswagen subsidiaries SEAT in Catalonia (Spain) and Bentley in Cheshire (England) have their workshop roofs decked with more than 20,000 solar panels each. All six manufacturing sites of Renault in France are solar-powered, with the panels collectively spanning 450,000 m^2 (Renault, 2011). General Motors has solar arrays in its Opel-Vauxhall facilities in Rüsselsheim and Kaiserslautern (Germany). The largest rooftop solar installation in the world is at the General Motors plant in Zaragoza (Spain), with 85,000 lightweight panels over a roof area of 190,000 m^2 (GM, 2012).

Naturally occurring methane or landfill gas help to power the manufacturing facilities of Nissan in Aguascalientes (Mexico), Ford in Michigan (USA), Volkswagen in Tennessee (USA), and BMW in South Carolina (USA). In the USA General Motors is the largest corporate user of landfill gas as a replacement for natural gas, with seven of its facilities using landfill gas (GM, 2012).

4.3.4 Minimize number of production steps

BMW's MINI marque uses an integrated painting process that, compared with conventional methods, requires one less layer of paint. Omitting the filler layer means less solvents emitted; enameling becomes unnecessary, so less energy intensity; and less operations means less demand for water and energy (BMW, 2010).

4.4 Reduced distribution impacts

4.4.1 Develop reusable packaging systems

BMW and its suppliers have jointly designed returnable shipping containers, helping reduce the cardboard, wood and other packaging waste per vehicle (BMW, 2010). All Nissan production sites in Japan have achieved a 100% recovery rate for their waste in 2010; one of the measures taken was to utilize reusable and collapsible plastic and steel containers for shipping parts to and from their operational sites, instead of wooden pallets and single-use cardboard boxes (Nissan, 2012).

4.5 *Reduced behavior and use impacts*

4.5.1 Design to encourage low-consumption user behaviour

Newer Fiat models are fitted with Eco:Drive, a software application co-developed by Microsoft and Fiat to collect and process data about fuel consumption, CO_2 emissions and driving characteristics while the car is being driven, enabling drivers to analyze their driving data and receive advice on techniques for ecologically responsible driving. Reducing CO_2 emissions by 15% saves an average of €160 yearly. Fiat 'ecoDrivers' can share their driving experiences and practices on the 'ecoVille' online community (Fiat, 2012).

Renault's DrivingEco^2 approach is to educate drivers on saving fuel as a means of curbing greenhouse gases, through such driving behaviour strategies as maintaining constant speed, thinking ahead to avoid brake pedal use, and regularly checking tire pressure. Since 2009 Renault has partnered with Key Driving Competences NV to design innovative eco-driving training courses for company fleets and private individuals (Renault, 2011).

4.5.2 Reduce energy/material consumption during use

Toyota Motor Corporation offered four of the most fuel-economical cars[19] in 2013: Scion iQ mini-compact, Toyota Prius Hybrid midsize, Prius c Hybrid compact, and Prius v station wagon. Volkswagen Group had the two most fuel-thrifty small station wagons (Audi A3 and Jetta SportWagen). The other most fuel efficient cars are Honda CR-Z (two-seater); Chevrolet Spark (subcompact); and Ford C-MAX Hybrid FWD (large) (US-DoE and US-EPA, 2013). These hybrids can go as far as 21 km/L combined city and highway driving, while the fuel-economizing petrol cars ranged between 14 and 16 km/L.

4.5.3 Seek to eliminate toxic emissions during use

Off-gassing of toxic chemicals is behind the typical 'new car smell'. Tests by The Ecology Center (2012) among 200 of the most popular vehicles for the 2011 and 2012 model years found that these chemicals contribute to some acute and chronic health problems. Using x-ray fluorescence analyzers, toxic chemicals were found in steering wheels, dashboards, armrests and seats. The Honda Civic came out as the least toxic car, followed by the Toyota Prius, Honda CR-Z, and Nissan Cube. The Honda Civic was found to be free of brominated flame retardants in all interior components; its fabrics and trim were PVC-free; and only low levels of heavy metals and other metal allergens. In contrast the most toxic car, the Mitsubishi Outlander Sport, had seats and center console with bromine- and antimony-based flame retardants and chromium[20] treated leather, as well as lead in excess of 400 ppm in seats.

[19] Not including electric vehicles.

[20] These 'chemicals of primary concern' – bromine, chlorine, lead, cadmium, mercury, hexavalent chromium and heavy metals – are believed to cause allergies, birth defects, impaired learning, liver toxicity, and cancer. Overheating of plastics in dashboards increase the concentration of volatile organic compounds (VOC) – responsible for 'sick house syndrome' – and degrade chemicals into more toxic substances.

4.6 System longevity

4.6.1 Create a timeless aesthetic, foster emotional connection to product

BMW's design is 'timeless and distinct', claiming to 'avoid fads and fashions'[21]; its classic twin-kidney radiator grilles and characteristic long hood shape with short overhang are signature elements that connect BMW models across generations.

The popular small compact cars of BMW subsidiary MINI are iconic British cars; their distinctive two-door configuration, 'bulldog' stance, chrome-plated radiator grilles and exhaust pipes, classic positioning lights and fog lamps in the front apron, and low centre of gravity and short wheelbase that deliver the legendary go-kart feeling have hardly changed since Alec Issigonis designed them in 1959 for the British Motor Corporation. MINI cars are so strongly connected with their owners that 243 MINI car clubs exist in 43 countries[22].

4.7 Transitional systems

4.7.1 Design for reuse of components

The European End-of-Life Vehicles (ELV) Directive requires that 85% of the car's mass[23] must be reused, either as parts or as materials (EU, 2000, 2005). For instance, BMW recovers reusable parts such as engines, transmission systems and other large components, which are reconditioned and made available as used spare parts. When developing new vehicles, BMW engineers ensure that each component is designed for easy recovery (BMW, 2010).

4.8 Optimized end-of-life

4.8.1 Integrate methods for used product collection; design recycling business model

Under the ELV Directive, it is the responsibility of the car manufacturer to take back their products upon end-of-life. In practice the last owner of a vehicle that has reached its end of life must return the car to a dismantler known as an authorised treatment facility (ATF), which will issue a certificate of destruction (CoD) to enable the owner to deregister the vehicle and to avoid further taxation. The ATF siphons off operating fluids, triggers the pyrotechnic devices (airbags and seatbelt tensioners), removes reusable components, and shreds the rest of the materials. In the UK, end-of-life vehicles can also be collected from homes free-of-charge[24]; dismantlers provide a valuation of the vehicle and reward the car owner with an amount that is based on the daily market prices for used parts and scrap metals. BMW Group was the first car manufacturer in the world to create an End-of-Life Vehicle Recycling Network (BMW, 2010); they take back BMW and MINI vehicles from their last owners regardless of age and whether they had been serviced by a BMW or MINI dealer.

[21] According to http://www.bmwusa.com/Standard/Content/Innovations/Design/SignatureElements.aspx
[22] See http://www.miniworld.co.uk/clubs/international-clubs.
[23] The European target is to reuse and recover at least 85% of end-of-life vehicle weight by 2006, and 95% by 2015. The ELV Directive has been in force in all EU member states since 2000.
[24] Dismantlers will not charge for disposal of end-of-life vehicles only if the vehicle still includes its engine, body, chassis, transmission drive, catalytic converter, wheels, and must not contain waste.

5 Conclusion

Most of the 47 Okala ecodesign strategies have been found to be present in the annual reports of the 15 carmakers, in one form or another. Only very few[25] were not mentioned in the corporate literature and websites.

It was encouraging to find eleven of the world's largest automakers engaging in ventures that present alternatives to owning a car. Several promoted car sharing, which has some obvious environmental benefits: one shared vehicle can take off 9 to 13 vehicles off the road (Martin et al., 2010), thereby freeing the carriageways from congestion, reducing the demand for parking spaces, and increasing the intensity of use of vehicles which otherwise would have been idle and fast depreciating.

All automakers now offer a range of cleaner motoring solutions in their product portfolio, either as battery electric cars, hybrid cars, plug in hybrids or alternative-fuel vehicles running on LPG, CNG or agrifuels. At the same time they are improving the overall efficiency of their conventional petrol vehicles, using such technologies as turbo charging, direct injection, and cylinder deactivation (US-DoE and US-EPA, 2013).

European legislation is certainly helping improve the environmental sustainability of the global automotive industry. The ELV Directive not only fosters extended producer responsibility at the vehicle's end-of-life but also compels designers and engineers to consider 'design for reuse/recycling/recovery' strategies in order to minimize waste and optimize resources. Higher landfill fees motivate integration of recyclability aspects during the early design phase; indeed the best way to reduce waste management costs is to refrain from creating waste in the first place. Almost all the car manufacturers have achieved zero-landfill status. Use of PVC and bromine in interiors of new cars is declining[26], so cars are becoming less toxic for drivers and passengers.

Laws also influence consumers to reassess their mobility behavior; road congestion charges, carbon taxes, and increasing fuel prices in several cities make car drivers rethink whether to drive the private car or take public transport. At the same time, many incentives exist to encourage ecologically compatible mobility choices. Carpooling makes drivers eligible to use high-occupancy express vehicle lanes. Purchasing 'greener cars'[27] entitles one to federal income tax credits and other benefits.

It could be argued however that industrial designers have little to do with the environmental improvements achieved by these automakers. Certainly engineers, scientists and technologists can claim to be the brains behind the improvements in manufacturing processes, engine efficiency, construction durability, zero-waste-to-landfill, and other technical aspects. However, industrial designers have great potential in contributing to carbon-neutral and emission-free mobility solutions. Radical design thinking can be used to improve the consumer experience during car sharing, to promote sustainable mobility attitudes and behaviors, among others. Designers can oppose planned obsolescence in automotive styling if they commit themselves to such activism, and instead offer designs which have optimized longevity. The 47 Okala ecodesign strategies offer multiple starting points by which designed solutions could become more responsible and sustainable.

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[25] For instance, there were no evidences found of '3.21 minimize number of components/materials'; '4.24 reduce product and packaging volume', or '7.40 design for second life with different function'.

[26] The Ecology Centre found that the interiors of 17% of new vehicles are PVC-free, 60% are bromine-free. Manufacturers have begun replacing PVC with polyurethanes and polyolefins which are easier to recycle and have less harmful additives.

[27] In Norway the Consumer Ombudsman banned the words 'green', 'clean' or 'environmentally friendly' from all car advertisements, reasoning that all cars pollute, even fuel-efficient ones.

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