Sustainability and diversity in the global automotive industry

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Abstract: This paper argues that the automotive industry has reached the end of a prolonged period of technological monoculture that allowed and necessitated the kind of monolithic industrial structure, business models and operational practices currently in evidence. Using multiple micro-case-studies and examples from around the world, this paper will further argue that the future will be one characterised by technological diversity in which the solutions for automobility will vary according to spatially-specific requirements, embedded capabilities and strategy. Alongside this emergent diversity is considerable scope to dismantle existing barriers to entry to the sector and for new entrants to unleash innovative business models. These developments speak to the agenda of local economic revivalism under the rubric of cluster initiatives and similar policies. The contemporary economic crisis brings a unique historical opportunity to break the existing path dependency of the industry and thereby create a more sustainable form of automobility.

Keywords: industrial ecology; economic diversity; path dependency; business models; sustainability; automotive technology management.

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1 Introduction

The global automotive industry has been thrown into an era of eco-austerity, an unprecedented combination of severe economic privation combined with an unrelenting requirement to achieve vital environmental performance targets. Much of the old industry, the production locations, the brands, the products and the companies are likely to disappear over the next few years but the question of what type of automotive industry emerges in its stead remains unanswered.

Using multiple micro-case-studies and examples from around the world, the paper will further argue that the future will be one characterised by technological diversity in which the solutions for automobility will vary according to spatially-specific requirements, embedded capabilities and strategy. Alongside this emergent diversity is considerable scope to dismantle existing barriers to entry to the sector and for new entrants to unleash innovative business models. Even the ongoing rescue of the existing automotive industry initiated by national governments around the world from mid 2008 is (somewhat contentiously and partially) being tied to the introduction of 'greener' vehicles; but seen in a longer perspective there is a unique historical opportunity to break the existing path dependency of the industry and thereby create a more sustainable form of automobility.

We forecast some time ago (Nieuwenhuis and Wells, 1997; Wells and Orsato, 2005) that the industry would cease to be sustainable because of fatal flaws in the business model and an inability to embrace the technologies needed for sustainability. The relevant question now is what emerges in the place of the old industry and, in this regard, the paper argues that there will not be 'one best way' or a single solution. In turn, this gives considerable scope in the policy arena, but makes forecasting future 'winners' extremely problematic.

The paper is organised in the following way. First, an account of the ways in which industrial ecology can serve as a metaphor for social and economic organisation is given. It is then argued the automotive industry has been characterised by globalisation and a form of technological monoculture but also that the characterisation of the automotive industry as uniformly global has always been empirically flawed at many levels. In the third section, an account is provided of the crumbling away of this quasi-monolithic structure as a result of economic and environmental pressures. In the fourth section, the argument is then advanced that a more sustainable industry is likely to emerge premised on diversity to meet locally specific characteristics.

2 Industrial ecology, diversity and sustainability

Industrial ecology is an approach to understanding industrial systems as if they were ecological systems. Since the founding article from Frosch and Gallopoulus (1989), the concept of industrial ecology has found growing resonance with academics, practitioners and policy-makers looking for a basis upon which to instigate the transition to ecological sustainability. It has resulted in two broad lines of inquiry. The first is life cycle analysis and related methodologies that seek to enumerate all of the physical and material inputs and outputs required for a product over its 'life cycle' of birth (creation or manufacture), life (or use) and death (or disposal). The second is eco-industrialism wherein sectors or spatially-concentrated industrial activities are analysed in terms of their physical

inter-linkages. The definitive work on the industrial ecology of the automobile is that of Graedel and Allenby (1998).

In a wide-ranging review about the scope of studies within industrial ecology, den Hond (2000, p.60) noted:

> "Industrial ecology is both a vision, a research field and a source of inspiration for practical work. Its proponents aim to contribute to sustainable development by closing materials cycles and realising a fundamental paradigm shift in the thinking concerning industry-ecology relations."

Subsequently, it can be argued that industrial ecology has been rather more adept at closing materials cycles than promoting a fundamental paradigm shift in industry-ecology relations and, in part, this is due to the narrowness of the metaphor (Wells, 2006; Wells and Darby, 2006).

Here, the emphasis is on the ways in which industrial ecology can serve as a metaphor for social and economic organisation, rather than the relatively narrow and empirical use to which this theoretical framework is usually put (Ehrenfeld, 2003). Industrial ecology as a metaphor gives rise to issues such as transitions in eco-industrial systems and to questions of resistance and resilience, adaptation and succession. Applied to the automotive industry, it is argued in the following section that this has been characterised by globalisation and a form of technological monoculture, leading to a broad uniformity in product design, business model and consumer expectations of automobility.

In the analysis of natural systems, diversity has three main meanings. It can be applied to the variety of types within one species, the diversity of species within a given ecosystem (and ultimately in the world as a whole) or it can be applied to the diversity of ecosystems and subsystems around the world. In broad terms, diversity is seen as a healthy or beneficial characteristic for an ecosystem, although it is also clearly evident that certain ecosystems by their very nature support a much greater level of diversity than others – compare the Amazonian rainforest with the Arctic tundra. Conversely, the loss of diversity is seen as both an indicator of ecosystem damage and a contributor to further decline. Diverse ecosystems are characteristically robust because diversity enables resistance and resilience at the ecosystem level, even where at a species level these qualities may not exist. Resistance is the ability to withstand exogenous forces for change, whereas resilience is the ability to recover from the impact of such forces.

Of course, the identification and measurement of diversity in human socio-technical systems is not scientifically grounded in the way that ecosystem analysis can be grounded in genetics. Hence, the characterisation of the form and degree of diversity in the automotive industry is inevitably contentious and cannot simply be mapped onto biological concepts. Moreover, in human socio-technical systems there may be overwhelming economic and political pressures to retain a certain socio-technical solution even when the forces for change are also powerful. In this respect, the industrial ecology metaphor is not intended to be taken as a precise analogy, but as a source of insight and inspiration from which underlying principles may be taken. In this paper, the themes that diversity is healthy and beneficial, and that diversity arises out of a more precise fit to local circumstances, are taken as guiding concepts to assist our understanding for the future of the automotive industry. Hence, the approach taken in this paper reflects that of using industrial ecology as a guidance device, which in turn is

underpinned by a broader understanding of industrial ecology as articulated by Isenmann (2003, p.30):

> "…Industrial ecology's philosophy of nature includes at least a specific epistemological interest in nature (orientation to nature), a particular comprehension of nature (nature as a model) and a certain treatment of nature (learning from nature). This set of characteristics comprises metatheoretical aspects (epistemological interest in nature), as well as theoretical (comprehension of nature) and practical ones (treatment of nature)."

Using industrial ecology as a metaphor, as in this paper, is not intended to provide precise metrics. This paper takes the stance identified by Ehrenfeld (2004, p.827) that:

> "Related to the normative perspective… industrial ecology is a new paradigm that can offer a conceptual base for finding solutions to what have been intractable problems. As paradigms, objective notions like the ecological metaphor take on prescriptive or normative clothing as they become pragmatic responses to solution-seeking actors… The other half of the metaphor refers to industry. The field is focused on understanding the industrial basis of production, a characteristic of modern societies. Understanding the industrial systems of modern societies is held to be critical to designing new forms of production that are more sustainable."

3 Globalisation and the automotive industry

Historically, it can be argued that the automotive industry has displayed since the 1920s an increasingly dominant technological base in the form of the all-steel body technology pioneered by E.G. Budd and the internal combustion engine, that in turn gave rise to a characteristic business model premised on the innovations of Alfred Sloan and grounded in the privileged position given to manufacturing economies of scale (Nieuwenhuis and Wells, 2007). In this very broad sense, there certainly was 'one best way' because this system extinguished virtually all other technical configurations for the automobile. It was also spatially expansive, in that the expansion of markets was enabled by, and further reinforced, manufacturing economies of scale (Batchelor, 1994; Nieuwenhuis and Wells, 2007; Raff, 1991). Hence, the adoption of the Budd body technology system can be identified as the critical distinguishing feature propelling rationalisation and concentration in the production system as a whole, resulting in the decimation of hundreds of craft producers in the industrialised nations. This techno-centric vision of the history of the automobile sees the innovations in lean production from Toyota, or indeed those characteristic of distinct vehicle manufacturers such as Honda or BMW (see Freyssenet et al., 2003; Womak et al., 1990) as essentially variants or refinements of this basic business model rather than radical departures.

In this respect, then, the globalisation of the automotive industry can be seen as the creation on a world scale of a particular form of path dependency (David, 2007; Nelson and Winter, 1982). In line with the dominant position given to the core technologies that constitute the automobile, so-called socio-technical landscapes (Smith et al., 2005) were created that supported and enabled this form of motorisation. Such landscapes included the design and deployment of the road infrastructure, the provision of facilities to refuel cars, the framing of legislation regarding the use and performance of cars (most notably of course regulations regarding exhaust emissions and safety) and the creation of a vast

supportive network in terms of the insurance industry, police, maintenance and repair garages and ultimately the spatial structure of communities that increasingly came to reflect car ownership and use. Even cultural attitudes to transport and mobility have been somewhat conditioned by the set of possibilities presented by the automotive industry (Staley, 2008; Urry, 2007). The question is whether remaining economies of scale in distribution and marketing, and in terms of socio-political influence, will remain as effective barriers to significant change. There are strong forces to resist change and these forces should not be discounted yet. For policy-makers it is evident that the economic power of the existing automotive industry remains compelling because of the contribution to employment, wealth creation and the balance of payments in many countries – a factor that may explain why the industry had been able to subvert attempts at CO_2 regulation in Europe for many years. The basis of lock-in for the prevailing incumbents includes the tangible and fixed features such as fuel stations for petrol and diesel, legal requirements and regulatory regimes (for example, around permitted emissions of toxic chemicals), crash impact standards, vehicle sizes and definitions (over for example what actually constitutes a car). It also includes aspects of popular culture and public acceptance, as well as the gradual embedding of a vast support infrastructure to support vehicles in use, again in many cases built on the assumption of all-steel bodies and internal combustion engines. Hence, for the automotive industry, this support infrastructure includes franchised and independent garages, insurance companies, emergency services, vehicle recycling facilities, educational and research capacity oriented towards steel use or internal combustion technology and much more. Then, at the cultural level, in films, books and music the image and role of the car has come to be (largely) defined around the dominant technology: it is what people have come to expect a car to be (Grushkin, 2006; Walker, 2005). Not least, this means that any alternative technology is compared with the performance of the contemporary car even where a like-for-like comparison is not necessarily helpful or indeed appropriate.

All of these factors can be said to underpin the continued dominance of the core technologies that constitute the contemporary car. Under these circumstances, it might usefully be asked whether any alternative could possibly disrupt the domination of the core technologies. The forces of inertia simply outweigh the impetus for and benefits of change.

Over time, there has arguably been a process whereby the industry has, on various metrics, become more a single global entity (Sturgeon et al., 2009). Previously closed national markets have progressively (if incompletely) opened their borders to trade and inward investment under the rubric of the World Trade Organization. Trading groups such as the European Union (EU) have sought to create single markets from previously distinct national markets. Trading flows between nations have increased, albeit dominated by some very large key flows such as from Japan to the USA or from the EU to the USA. Companies have invested more widely in non-domestic production locations, either for market access to the established markets (principally the EU and the USA) within emergent economies or for lower-cost production locations from which to serve other markets.

In this process, the contemporary car and its associated business model can be understood to arise from intersecting innovations in product design, process design and marketing and distribution frameworks (Batchelor, 1994; Nieuwenhuis and Wells, 2007; Raff, 1991) in the early 1900s:

- the standardisation of parts, the detailed division of labour into short, repetitive work cycles, high levels of vertical integration and the moving assembly line producing in large numbers to give manufacturing economies of scale pioneered by Ford for the Model T (from 1908 onwards)
- the all-steel body architecture developed by Budd that allowed complete enclosure of the vehicle body and for paints to be baked onto the body
- the organisational and market, branding and sales innovations developed by GM from 1920 onwards with the 'M' divisional structure, the concept of multiple brands grouped under single ownership, the use of credit finance to purchase cars and the annual model change cycle to keep up demand for new cars.

As an ensemble, these organisational and technical innovations resulted in an industry with characteristically large capital costs (in equipment and per-model) that allowed and necessitated mass production to result in low per-unit prices in the market. These low prices expanded the market, but also excluded those vehicle manufacturers who did not adopt the business model. As a result, car production factories became large and centralised, with increasingly distant markets accessed via long distribution linkages and dispersed franchised dealerships.

4 The crumbling monolith: economic and environmental pressures on the vehicle manufacturers and the mainstream automotive industry

Freyssenet et al. (2003) rightly challenge the totalising concept of globalisation advanced by proponents of lean production as a universal solution to corporate profitability (Womak et al., 1990). The automotive industry has long been subject to forces for fragmentation and diversity because in broad terms places tend to have distinct cultures of automobility that more or less conflict with the industrial logic of standardisation and manufacturing economies of scale (Edensor, 2004). Indeed, it has been argued by some that car cultures are neglected forces that are both shaped by and help shape the characteristic form of automobility (Hagman, 2003; Wright and Curtis, 2005). For some, this means the industry is more regional in character than global (Rugman and Hodgets, 2001). Meanwhile, others such as O'Brien (2002) have advanced the argument that industries that seek to impose a global uniform structure are less able to be sustainable because they lack a fit to local cultural differences and therefore fail to connect properly with either consumers or workers. For more critical theorists with a focus on labour relations, such as those working within the GERPISA tradition, there is rather more emphasis on differences between vehicle manufacturers and national variants of structure and organisation. This 'varieties of capitalism' approach has yielded useful insights (Mikler, 2008, 2009). Not least, this work has shown that corporations vary in significant ways according to the national economic systems in which they are founded and have their main operations, which is suggestive that the quest for sustainability will not result in a uniformity of solutions either.

One of the key issues confronted by vehicle manufacturers over recent years has been the fragmentation of established markets in terms of the brands, models and variants offered to consumers. Strategies such as modularisation and cell-based assembly can be understood as mechanisms to cope with increasing variety (Miyake, 2006; Morris and

Donnelly, 2006). As Table 1 shows for the case of the UK, the general trend since the early 1990s has been for the number of models, body styles and variants on the market to grow substantially, with the number of variants doubling in the space of ten years. This type of fragmentation has been partly enabled by, but also rather negates the value of, so-called platform strategies wherein apparently different models share the same underlying architecture. While analysts such as Maxton and Wormold (2004) have identified economic and business reasons why the automotive industry needs to change, this paper augments that perspective with sustainability issues as key sources of change.

Table 1 Brand names, models, body styles and variants on the UK market: 1994 to 2008

Year	*Brand names*	*Models*	*Body Styles*	*Variants*
1994	54	205	300	1,303
1995	56	211	309	1,580
1996	57	218	321	1,624
1997	53	225	318	1,611
1998	54	231	382	1,637
1999	52	240	332	1,759
2000	57	262	357	1,931
2001	58	260	351	2,042
2002	57	263	387	2,472
2003	56	257	370	2,743
2004	62	351	397	3,042
2005	54	323	376	3,155
2006	63	356	415	3,219
2007	64	344	397	3,323
2008	59	304	366	3,291

Source: Wells and Morreau (2008)

In addition, at the global level there remain enduring differences between national markets both large and small, Table 2 illustrates a few of the more obvious of such differences. These differences also undermine the scope for standardisation and point towards the divergent ways in which automobility is made manifest in different locations.

Finally, and again, only thinking in terms of the existing technology paradigm for the automotive industry, the main powertrain source (petrol or diesel internal combustion engine) is being modified to meet the demand for lower CO_2 emissions (see for example, Murphy, 2008a; 2008b). The viability of different solutions depends somewhat on where those solutions are deployed because of the differences in the ways in which automobility is experienced in those locations.

Despite some convergence, regulatory regimes for cars around the world remain differentiated. Some markets have specific safety tests not found in other markets, others distinct cycles for the testing of emissions. Even more pronounced are the differences in the fiscal regime imposed on new car sales and features such as annual taxation. The more recent interest in regulating CO_2 emissions has resulted in similar global diversity (ICCT, 2007) and is likely to generate more in the future (Ryan and Turton, 2007;

Sperling and Cannon, 2007). Thus, even in the EU where the quest for a single market has been ongoing for many years, there are differences in simple measures such as the rate of value-added tax applied by governments on new car purchases and differences in the definition of vehicle taxation segments and categories.

Table 2 Existing regional differences in automotive markets: some examples

Region/country	*Main distinguishing feature*	*Comments*
Japan	Kei class of micro-cars	Unique to Japan for many years. Segment defined by law in terms of physical dimensions and engine size.
Japan	High initial quality; low longevity	Cars sold on high initial quality, e.g., paint finish; 'shaken' test system and high annual renewal costs force out older cars, many of which are exported as used vehicles.
USA	Low initial quality; low price; limited technological innovation.	Cars sold 'off the lot' with emphasis on discounting; large V8 engines with three or four-speed automatics, power steering and soft handling.
USA	Light truck segment	Unusually dominant in the USA, with up to 50% of all new passenger vehicle sales in this category; SUVs, pick-ups and crew-cab variants. Some brands (e.g., Jeep, Hummer, GMC) exclusively in this segment.
Europe	Car-derived van segment	Used in light commercial applications, cars with a van-style body.
Europe	High quality and longevity with high rates of innovation.	Premium car brands, e.g., Mercedes, BMW, Audi able to support added cost of technical innovation; emphasis on car performance and driver involvement.
Europe	Hatchback designs and diesel engines	Both largely found in Europe rather than elsewhere in the world.
India	Three-wheelers	Also found in other Asian markets including China; used as small commercial passenger vehicles in large numbers; often based on scooter engines.
Thailand	Pick-up trucks	Widely used as multipurpose vehicles including passenger and light commercial applications; otherwise personal transport often via motorcycles.

Source: Author

5 Fragmentation and diversity

If natural ecosystems are examined it is readily apparent that, under natural circumstances, specific and distinctive ecologies develop in specific places in response to the more or less unique environmental characteristics of those places. Hence, differences in climate, latitude, topography, geology, etc., give rise to unique flora and fauna that result in a sustainable ecosystem. If this metaphor is applied to the automotive industry, it can be seen that the 'solutions' for sustainability are liable to be many and varied

according to the specificities of place. Indeed, the character of the problem of sustainability varies from one location to another, as does the potential for solutions. The dimensions of these specificities include physical characteristics as with natural ecosystems, but are not confined to these. Other dimensions include economic level and the distribution of wealth, the extent of automobility, the structure of the built environment, relative locations of work and residence, available alternative modes of travel and many other features that collectively constitute the culture of automobility in a place.

The more the industry becomes fragmented (across as many variables as possible) the more it will fit with precision into the specific requirements of locality. Against this are set some forces tending towards centralisation and standardisation. In terms of product technologies this means that many species of automobility must co-evolve and co-exist around the world, each with a particular niche application. There can be scant doubt the available technologies from which to construct a car are burgeoning (Kelly, 2008; NAIGT, 2009). Indeed, the key policy question has rather become one of managing what is increasingly seen as an inevitable transition (Struben and Sterman, 2007) involving some difficult choices between vehicle configurations, powertrain systems, fuel types and the basic split of modes of transport in order to achieve a low-carbon mobility future (Staley, 2008).

The diversity potential of the future automotive industry can be seen at three levels, all of which are briefly outlined below. First, there is likely to be comparative diversity between different places where the basis for sustainable automobility may vary. Secondly, there is likely to be comparative diversity in the application of different technologies (or bundles of technology) for different applications. Thirdly, these two sources of diversity also give rise to the third level of diversity – that of the business model by which sustainable automobility might be delivered to the market.

5.1 Place diversity

The impact of place diversity applies not just to market forces or indeed the potential of localities with respect to sustainable automobility, but also to the impact of government policy on innovation, technology and industry. In general terms, governments at national and regional level have been much-galvanised over recent years by the 'cluster' concept advanced by Porter (2000a, 2000b). Applied to the automotive industry, this means that localities may pursue distinct forms of automobility that tie in with economic and industrial policy aims (Kamp, 2008).

Table 3 gives some examples of how distinct locations are following divergent forms of automobility. Of course there is much debate over the many forms of fuel and powertrain that might be employed and their relative economic, technical and environmental merit (Chanaron and Teske, 2007). Such debate is not denied here, but if anything only serves to illustrate the more general point that single solutions are unlikely to be forthcoming.

It may well be the case that the global financial crisis that has unfolded since mid 2008 will seriously undermine the capacity of some of these locations to pursue independent strategies. A case in point is Iceland, which has been profoundly affected by these financial traumas and may be unable to live up to the hopes that were previously held to become the world's first hydrogen economy (Árnason and Sigfússon, 2000; Solomon and Banerjee, 2006).

Table 3 Localities and diverse automotive industry technologies

Place	*Comments of the form of diversity*
California	Electric vehicles (project Better Place); hydrogen highways (fuel cell vehicles)
Denmark	Wind power electric vehicles (project Better Place)
Irish Republic	Electric vehicles (project Better Place and separate Renault-Nissan agreement)
Israel	Solar power electric vehicles (project Better Place with Renault-Nissan)
France	Nuclear power electric vehicles
Iceland	Geothermal hydrogen fuel cell vehicles
Vancouver	Hydrogen highway, fuel cell industry cluster
India	Tata Nano and MDI Air Car; CNG vehicles
Brazil	Sugarcane ethanol
Malaysia	Palm oil biodiesel
Republic of China	Petrol – electric hybrids
USA	Petrol – electric hybrids; plug-in hybrids
Germany	BMW hydrogen fuel cell ancillary; hydrogen internal combustion engine
Russia	CNG vehicles
Norway	Contemplating ban on sale of petrol and diesel new cars by 2015; hydroelectric vehicles

Source: Author

5.2 Application and technology diversity

The fragmentation of the UK market into a greater number of models and variants is but part of the process of application fragmentation that could be allied to technological diversity in a growing range of niches. In brief, it might be expected that cars will become less 'general purpose' in design. A feature of many emerging designs is their lack of fit with traditional market segments and government categories – for example vehicles that are part motorcycle, part car (e.g., the Carver, the Tango) or may just not sit happily within existing definitions (e.g., the MDI Air Car), but equally it can be envisaged that certain technology packages are best suited to certain applications. For example:

- city cars with permanent zero toxic emissions; possibly one or two-seat vehicles with reduced safety performance in impacts; pure battery electric vehicles or fuel cell or compressed air; probably lightweight body structures

- suburban cars with stop-start hybrid optimisation and part-time zero emissions; possibly narrow cars for enhanced land-sharing; commuter vehicles; possible car-train combinations

- station cars used within a specific area; designed for interior refitting; possibly battery-exchange electric vehicles
- long distance cars; possibly optimised petrol or diesel with emphasis on improved aerodynamics and efficient high-speed running; lightweight body structures; highway safety technology, e.g., collision avoidance systems, lane-keeping systems
- single person multipurpose vehicles; more than motorcycles, less than cars
- car-sharing cars; possibly modular designs able to be reconfigured easily with exchangeable body styles
- play, recreation and non-essential cars.

The potential for technological and application diversity is huge. A recent review identified over 350 potential sources for biodiesel alone (Basha et al., 2009) and there can be no doubt that in this one area of automotive technology alone there is a rapid rate of change (Demirbas, 2009). The possibilities in terms of body structure design are becoming ever-wider, particularly with novel plastics and adhesive systems and with multimaterial body designs. In many instances, these technologies are better suited than conventional steel stamping and welding for low-volume applications. Hitherto, these alternatives have been excluded from the market by virtue of high relative cost compared with conventional technologies; but as the environmental pressures grow then the viability of these niche applications will also grow, further undermining the high volume side of the industry.

5.3 Business model diversity

An interesting feature that cannot be explored at depth here is that novel technologies (in terms of both those technologies that constitute the car and the production technologies associated with it) along with application-specific design concepts can often be best realised via novel business models (Lovins and Lovins, 2001; Wells, 2008). As with the alternative technologies, this form of diversity is identifiably emerging. Here, four examples are briefly outlined: Better Place, Riversimple, Gordon Murray Design T25, and the MDI Air Car. It is evident that none are (yet) changing the world and that if the case of TH!NK is anything to go by, the attempt to pursue radical business concepts alongside innovative technology is fraught with hazard (Orsato et al., 2008), but these cases can be thought of as outliers of the sort of changes that might befall the mainstream automotive industry.

Of the four examples, Better Place (http://www.betterplace.com) is arguably the most developed of the innovative business models and is currently having the largest impact. In brief, Better Place is an electric car mobility concept in which the company acts as a mediator around the core technologies of battery recharging and battery swapping. Project Better Place (as it was originally named) was founded by an entrepreneur named Shai Agassi and collaborates with partners to set up large-scale electric recharge grids, made up of cars, batteries, charging points, exchange stations and renewable energy stations (Williams, 2008).

Better Place has signed agreements with several countries and regional or urban authorities to install the required infrastructure, including Israel, Republic of Ireland, Denmark, Australia, Ontario, Japan, Hawaii and others (see Proctor, 2008, 2009). The company has worked closely with Renault-Nissan – the main supplier of battery-swappable or rechargeable electric vehicles. While none of the projects has yet come to fruition, work is underway with initial vehicles expected in some instances by 2010.

A quite different vision is offered by Riversimple (http://www.riversimple.com). In their words the company stance is:

> "We believe that business can be a powerful force in addressing the greatest issues that face humanity. However, it cannot be business as usual. The business must be driven by a profound purpose, must be democratic in structure, must seek to give back to society more than it takes and must be highly flexible and responsive to changes in its environment."

The Riversimple approach has five key elements:

- Super-lightweight vehicles, constructed from carbon composites, with network electrics managed by ultra-capacitors (so-called electric network hybrid vehicles).
- Open source design and development. Riversimple will invite the community to help develop its vehicles.
- A service concept – the cars are leased not sold. This aligns the interests of the manufacturer with the interests of the consumer and of the environment – everyone wants cars that have a long life span with maximum efficiency and minimum materials usage.
- Distributed manufacturing – the economies of scale of carbon composites frames are very different from those of steel-bodied vehicles. Riversimple vehicles are likely to be produced in small factories producing 5,000–10,000 vehicles per year. This allows for considerable local variation in the car.
- Broader ownership – the corporate structure of Riversimple is designed to ensure that all stakeholders in the enterprise have a fair say and share in the benefits of a successful business.

Riversimple launched their first vehicle on 16 June 2009 in London as a proof of concept. As yet, the initial market location is not known. As with Gordon Murray Design (discussed below), Riversimple has a founder who was originally rooted in motor sport engineering, but has come to use that expertise in sustainable automobility. Interestingly, this is also the case with MDI, also discussed below.

Gordon Murray Design was established by Gordon Murray, an extremely successful designer of racing cars and the Mercedes-McLaren F1 road car. After a long career in this area, he set up Gordon Murray Design in order to run an independent design engineering business and one of the key projects is the T25. The T25 is conceived of as a super-efficient city car with a traditional but optimised and small-scale petrol engine. In this case, the business model is essentially to lease the product and the associated production process as a package to third parties, who would then put it into production.

The MDI Air Car (http://www.mdi.lu/english) has been around for nearly ten years now, in various iterations and name changes and the promise has always exceeded the

reality. In this respect, caution is obviously needed when assessing the significance of this company and the underlying business model. In the case of MDI, the business model is one where a franchise for an area is allocated. The franchisee would then get a modular factory that also combined retail and service functions and would then be able to produce the vehicles designed by MDI under the terms of the franchise. The relative merit of the compressed air system in environmental or cost terms is much debated, but the business model has not received much attention. In essence, it is a variant of what has been termed micro factory retailing (Wells and Nieuwenhuis, 1999) that combines the previously distinct functions of production, retailing and post-sale service.

To what extent do these alternatives embody realistic prospects for long-term and substantial change?

6 Conclusions and policy implications

Ultimately, the extent to which diversity increases in the global automotive industry into the future is unknown. In broad terms, there is always a shifting dynamic balance between the demands of the production system for standardisation, repeatability and hence low cost and the demands of the market for differentiation. It is certainly the case that the demand for differentiation is not unlimited and high levels of differentiation may be a luxury that can no longer be afforded.

This paper has, however, sought to show that there are strong grounds for expecting diversity of markets, of technologies and of business concepts which are likely to be an enduring feature of the automotive industry for a long time to come. Indeed, the central argument is that diversity in these senses arises inevitably out of attempts to derive forms of automobility better suited to distinct places and to distinct requirements.

In the policy arena, these changes offer some interesting potential benefits, but also some key challenges. Resources spent sustaining the existing industry, particularly through times of economic hardship, make short-term political sense but may not actually contribute to the kind of substantive and rapid change in the industry that would usher in a new era of sustainability. Rather than expending public funds seeking to support an increasingly moribund traditional automotive industry, governments at national and local levels could tie together strategies for greener urban areas, sustainable mobility, innovation, carbon reduction, local economic development and macro-economic concerns such as improved balance of international trade by supporting the development of radical business concepts. All too often, policy has focussed on the development of the actual technology along with suitably delineated 'technology pathways' with the assumption that the translation into a viable business is unproblematic. It is, therefore, important that the policy arena and funding for R&D programmes includes a strong element in which the business or social viability of technology deployment is addressed. It cannot be assumed that the mainstream automotive industry will be willing or able to bring to market technologies that do not fit their business model, or that the results will be the most appropriate for the location concerned. Policy-makers need also to focus on three key aspects. First, they need to act as intermediaries that can bring together the different constituencies and parties involved in the emergent automotive industry, including for example the electricity suppliers, innovative businesses developing new ownership and use concepts and public bodies that can accelerate the uptake of alternative vehicles.

Second, policy makers need to pursue an enabling, open-system approach to technology and infrastructures that does not exclude smaller companies. Third, it will probably be necessary to rethink much of the categorisation and regulation of the 'car' to allow industry to escape from the confines of the rules that govern vehicle performance. A world of diversity is in this sense much more challenging for policy-making, but also in the end offers much greater potential. Far from being redundant in a globalised business world, national level policy takes on a renewed significance in this era of diversity.

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