Redesigning the Industrial Ecology of the Automobile

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sustainable business

Summary

This article explores the potential of industrial ecology to inform the redesign of an existing industry: that which is concerned with the production, sale, and support of automobiles. In so doing, it brings together the concepts embedded in industrial ecology with issues of economic scale, product design or technology, process technology, and the way in which new combinations of these features can result in an alternative structure for the automotive industry that has the potential to enhance sustainability performance. In so doing, the article advances the general argument that the economic, technical, and spatial organization of production and consumption are co-determined in a manner that collectively shapes the industrial ecology of an industry. In contradistinction to the prevailing industry, the article then advances the concept of micro factory retailing as an alternative framework for the industry that would result in significantly different performance in terms of industrial ecology.

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Introduction

Since the founding article from Frosch and Gallopoulos (1989), the concept of industrial ecology (IE) has found growing resonance with academics, practitioners, and policy makers looking for a basis upon which to instigate the transition to ecological sustainability, particularly in North America. Nested within industrial ecology, eco-efficiency has been seen by some as the means by which breakthrough innovations in technology could allow quantum improvements in resource utilization—although others may see it as incrementalist. Eco-efficiency is the formalization of a "doing more with less" approach for business: a term used, for example, by the World Business Council for Sustainable Development (WBCSD), the Organisation for Economic Cooperation and Development (OECD), and the United Nations Environment Programme (UNEP) to describe an approach to the development of sustainable business and sustainable production, particularly through innovation (Ryan 2004; WBCSD 1996, 2001a, 2001b; OECD 1998).

Although there is still no agreement even about the factor by which resource productivity should be increased in order to maintain the carrying capacity of the planet (see, for instance, Reijnders 1998; Ryan 1998), IE has rapidly emerged as the scientific stream with the potential to help both advanced and emerging economies to escape the Malthusian trap of environmental limits to growth. But although industrial ecology has proven to be a useful analytical tool in terms of indicating *what is* (i.e., the measurement and delineation of the problem to be solved), it has been far less useful—or at least has not been deployed as much—in terms of guiding decisions over *what might be* (i.e., as a prescriptive tool to guide innovative strategy).

In this article we present some ideas and a proposal as to why IE, as constituted so far, has been theoretically limited and limiting. We argue that there is nothing new about the social sciences adopting the theories and concepts of the physical sciences. In organization studies, for instance, the use of the so-called organizational ecology or population ecology perspective is a didactic example of such attempts (see Orsato 2001a; Baum 1996). No matter what criticisms such attempts have faced (see Young 1988, for instance), there still seems to be a residual sense that in transplanting "proper" concepts and techniques from the natural sciences to sustainability-related studies improves the legitimacy of the disciplines within the social sciences. Despite this, we would argue that IE has been highly selective in its treatment of the science of ecology and its use of metaphor or analogy. If other aspects of the science of ecology are embraced, then a rather different approach to IE emerges—one in which issues such as diversity and scale suddenly become important. Ultimately, though beyond the scope of this one article, there must be linkage between the essentially micro concept of industrial ecology and the macro concept of the *distributed or decentralized economy*.[1] An intermediary concept that might help bridge these micro and macro levels is that of *organizational fields* (DiMaggio and Powell 1983).[2]

Analytically, the concept of *organizational field* encompasses the context in which organizations are embedded. The concept of organizational field was coined by DiMaggio and Powell (1983, 148) as "a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products." The idea of an organizational field differs slightly from the definition of industry or sector, because it also includes institutional elements that can influence the structuring process of firms and industries that are not recognized in classic definitions of industrial sectors. The concept includes both objective and subjective factors that shape the context in which innovations might occur. The organizational field has since been used by the so-called institutional theorists and emerged as a critical locus of study bridging the organizational and societal levels.

Given the concrete conditions of the automotive industry explored in this article, industrial ecology appears inadequate to the task of the co-determination of social, environmental, and economic conditions for sustainability, despite the field's robust foundations and subsequent development. In particular, this article seeks to demonstrate that industrial ecology could be enriched by consideration of the question of economic scale and industrial organization within and between firms in a sector. In order to give the expanded notion of a decentralized industrial ecology content, we provide several examples of our concept of micro factory retailing (MFR) in the automotive industry. In this concept, the production and retailing functions are combined on one site, resulting in multiple small-scale facilities serving local or regional markets.

Few can doubt that the contemporary automotive industry is one of the most obvious manifestations of the difficulty of reconciling environmental, social, and economic goals (Graedel and Allenby 1998; Tukker and Cohen 2004). The sheer scale and complexity of the sector make for an emotive and highly political policy arena, and again in this article we cannot do full justice to the sector. Notwithstanding these comments, we hope that those familiar with the automotive industry, and indeed those who are not, will recognize the totality of the vision we present and equally the real power of industrial ecology as an organizing theoretical framework for the redesign of entire sectors of economic life.

The *Real* Scope of Industrial Ecology

In a broad review of studies within industrial ecology, den Hond (2000, 60) noted that

> 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 realizing a fundamental paradigm shift in the thinking concerning industry-ecology relations.

The basis of our contention is that industrial ecology has been better at examining existing industrial systems than at identifying the conditions for paradigm shift toward industrial sustainable development. To some extent, the analytic tools are still under development, as with approaches such as materials flow analysis and life-cycle assessment, among many others (Brunner 2002). It appears that IE as a practice lends itself to incremental improvements via waste minimization, through materials substitution, emissions reduction, and other remedial actions, highlighting the key environmental "hot spots" of a process (Bringezu 2003). The focus on industrial systems as a whole, rather than just products or just individual factories, is certainly a great strength for IE, but the basis of analysis continues to be materials and the transformation processes used to change them into useful products and services. Hence the strong appeal of contributions that offer a "quantum leap" in resource efficiency performance, the so-called *Factor X* debate (see Reijnders 1998; Ryan 1998; von Weizsacher et al. 1997), and hence on to the notion of eco-efficiency (Schmidheiny 1992). This line of argument also underpins the idea of natural capitalism as advanced by Lovins and Lovins (2001).

One of the most overt manifestations of IE is embedded in the concept of industrial symbiosis, with the Kalundborg eco-industrial park in Denmark as its quintessential example (Tibbs 2000, 1993). It is not surprising that this concept has captured the imagination and support of policy makers and politicians eager to redress the ravages of industrial decline (Kirshner 1995); the eco-industrial park suggests a win-win scenario of economic and environmental gains (Esty and Porter 1998; Porter and van der Linde 1995). Following on from a long line of thematic economic development areas, such as science parks, technology parks, biotechnology parks, and enterprise zones, the eco-industrial park offers the tantalizing promise of both economic efficiency and environmental regeneration.

The spatial dimensions may be at the micro or eco-industrial park level, but for others, more sense can be made at the aggregated city or regional level (Kincaid and Overcash 2001). Still, the eco-industrial park idea, however flawed it might be (Roome, 2001), does encourage one vital consideration: the environmental cost of transporting materials and components. According to Clift (2001, 8) in an analysis of "mad cow" disease (BSE or bovine spongiform encephalopathy) and foot-and-mouth outbreaks in Britain: "Whether we are looking at animals or potted dairy produce, the point is that unnecessary transport carries not just goods, but risks and impacts."

We certainly acknowledge that with a complex industrial product—and they do not get much more complex than a car—it might be extremely difficult to arrange for "local" supply lines into a factory. Therefore, in seeking to redesign the industrial ecology of the automotive industry, we need to be mindful of how such a project would attain spatial form.

The concern for efficient interorganizational relationships and linkages evident in IE is to be found increasingly in other aspects of the business literature, most notably the growing concern with supply chains or networks. In this literature, the fundamental argument is that the competitiveness of a company at the head of a supply chain (i.e., facing a customer; a vehicle manufacturer is a classic example) depends upon the ability to manage the rest of that supply chain to maximum effect (Burgess et al. 2002). The focus on "value stream mapping" and "supply chain agility" therefore reflects the view that competition really takes place not between individual enterprises, but between extended supply systems centered on those enterprises.

Clearly in the automotive industry, our area of particular expertise, with over 70% of the ex-works[3] value of the vehicle bought from external suppliers, this argument holds some force and is reflected in the high corporate status now accorded to procurement strategists. Furthermore, the conventional business literature since the 1990s has shown a huge interest in "lean production," generally with its emphasis on the elimination of waste (Womak et al. 1990). Again, this concern with waste reduction and efficiency has been extended into the supply chain management arena in terms of logistics (Jones et al. 1997) and, increasingly, green supply chains (Thierry et al. 1995; Angell and Klassen 1999; Guide and van Wassenhove 2002), reverse logistics, and remanufacturing (Seitz and Wells 2003).

Nonetheless, if sustainability in the automotive sector is to be studied—and indeed, as we argue in this article, to be pursued by industrial ecologists—we need to expand the scope of IE studies and consider the automotive sector as a whole. As Graedel and Allenby (1998, 78) point out, studies concerning the environmental impact of automobiles should

> [c]onsider the extraction from their reservoirs of the materials that are used, what happens to them (and the environment) during product manufacture, how the use of the product or systems affects the world within which the use occurs, and, finally, what happens to the product or system and its materials once it is obsolete or the consumer disposed of it.

Clearly, such a study requires an analysis of environmental impacts happening in all phases of the product life cycle. Initial steps in this direction have already been taken, both for the industry as a whole (Keoleian et al. 1997a) and for individual components (Keoleian et al. 1997b)—sufficient at least to challenge the sustainability of the contemporary automotive industry. This analysis also begins to suggest limits within the contemporary logic of the automotive industry (see also the comments by Tukker and Cohen 2004), limits that define the scope for eco-efficiency to render the industry more sustainable. One of those key limits, we will argue, is the primacy of least-cost manufacturing economies of scale.

The Unsustainable Paradigm of the Automotive Industry

The automobile constitutes an industrial product that engenders both considerable economic wealth creation and serious burdens on the natural environment. The industry has responded, to increasingly strict governmental regulation, to collaborative research and development (R&D) programs, and to voluntary agreements, by adopting cleaner manufacturing technologies and investing in environment-related research. Vehicle manufacturers are working toward increased levels of resource productivity. They have targeted energy and material conservation for both financial and environmental reasons (Knibb et al. 1998; Rogers 1993). Since the second half of the 1990s, most vehicle manufacturers have also started to release annual environmental reports containing detailed information about improvements in vehicle manufacturing, emissions reduction in vehicle use, alternative drive and fuel systems, and recycling strategies for end-of-life vehicles.

That improvements have indeed been made by car assemblers is not in doubt. The average environmental performance of most fleets has significantly improved in the last quarter of the twentieth century (Graedel and Allenby 1998), at least in terms of toxic emissions. (With respect to CO_2 emissions the industry has not performed as well, because the benefits of more efficient engines have been negated by increased vehicle weight, acceleration, and top speed [Wells 2003a].) Such improvements, however, have not alleviated the pressure faced by firms operating in the industry. Regulatory measures on air emissions have continuously intensified. During the 1990s, although the industry in Europe lobbied against the imposition of direct regulations on end-of-life vehicles (ELVs), the European Parliament approved a new Directive on ELVs in September 2000 (CEC, 2000).

Environmental issues have certainly become an important economic issue for the automotive industry.[4] The saturation of mature markets and consequent intensification of rivalry has resulted in an even more difficult situation for vehicle manufacturers. The markets for new cars in most Western European countries practically stagnated during the latter 1990s. The markets in most developing countries did not perform well, either—with the notable exception of China. The emerging economies faced economic and structural problems in the second half of the 1990s and, although these markets still remain areas for potential expansion, economic decline in this period produced poor performance in terms of car sales. In simple terms, car manufacturing was under pressure on both the economic and environmental fronts. At the same time as the profitability margins of car manufacturing were extremely low, the pressure to invest in product development and environmental protection has gradually risen.

Vehicle manufacturers have responded to the regulatory and market pressure, but the technological paradigm of car design and manufacture substantially limits the alternatives available to them. Most of their actions have been designed to reduce costs by reaching greater economies of scale in car production and sales. Platform consolidation, supply chain management, and modular assembly constitute the management initiatives in this direction most widely pursued among vehicle manufacturers. Additionally, the industry has sought cost savings through consolidation, with mergers and acquisitions, to create "multi-brand constellations" or groups that straddle the major markets of the world. Such rationalization practices have the potential to generate substantial cost savings in systems of design, component supply, production, and distribution and marketing. As a result, industry consolidation has assumed such a pace that many expect that by 2020 only six global corporations, each one producing around 15 million cars per year, will be competing worldwide (Eggleston et al. 1999; Feast 2000).

Although not seeking to deride or belittle the very real progress made by global vehicle manufacturers, it is hard to escape the conclusion that these companies are to some extent trapped within their own paradigm or mindset in a manner similar to that of industrial ecology—certain items simply do not get onto the agenda. As one of the "founding fathers" of industrial ecology—writing specifically about the automotive industry—notes, work still needs to be done to clarify the relationship between industrial ecology, sustainable development, and technology (Allenby 2002; Graedel and Allenby 1998).

Yet, our contention is that a vital missing ingredient is not information, as Allenby proposes, but the *structure of capital* and the *business model* that underpin "normal" practice. In our view, there is an intimate causal relationship between the structure of capital, the characteristics of product design, the manufacturing processes used to create those products, and the consumption patterns that result (Schmidt 2001). In the automotive industry, the large-scale core process technologies may be more (economically) efficient but they create products (and processes) that are less than optimum from an environmental perspective. Thus far, industrial ecology has concerned itself with process, and to a lesser extent with product design, in a multiple organization context. If our contention is accurate, then the neglect of capital structure is fatal. We explore this aspect by first re-examining the issue of economies of scale in the car industry and later proposing a radically new concept for the automobile system: micro factory retailing (MFR).

Economies of Scale in the Car Industry: Scale of What?

A critical issue is that of economies of scale, because if the MFR concept cannot be competitive with existing approaches then it will clearly not be sustainable. Economies of scale reside at three levels: plant, firm, and industry. They may also be internal or external (Cairncross 1966). The current approach to vehicle manufacturing involves the construction of large car plants able to manufacture and assemble all-steel cars in large numbers. Plant-level manufacturing (or technical) economies of scale are realized through specialized equipment (presses, welding lines, and holding jigs), linked processes (stamping and welding), labor specialization, and low per-unit ex-factory costs. In order to sell sufficient cars, geographically extensive markets are required—which in turn means long logistics chains and dense networks of retail outlets. To date, most vehicle manufacturers have not had to bear a great deal of the investment cost in the dealer network. Neither have they sought to capture a high proportion of the total lifetime revenue stream created by a car in use. Between the manufacturing plant and the customer are stockpiles of cars throughout the system, managed by long customer lead times.

The essence of lean production, adopted by the industry from the 1990s onward in order to resolve problems of inefficiency, has been to seek compliance of the supply base and the vehicle distribution network with the demands of the vehicle manufacturing process, thereby reducing stock levels in the system—not to optimize the system as a whole. Such activities do not mean increased efficiency arising from increased scale, but merely the ability to use quasi-monopoly power to extract profit from weaker suppliers.

Firm-level economies of scale are more broadly based and can be summarized as managerial, marketing, financial, and risk reduction advantages. Collectively, these mean that in the long run output increases faster than inputs as the scale of production expands. According to Rhys (2001), economies of scale in the automotive industry at plant level can reach up to 2,000,000 units per annum for pressed steel panels, 1,000,000 units per annum for engine castings, and 250,000 units per annum for final assembly. The major (nontechnical) economies of scale lie outside the plant level, most notably R&D, where 5,000,000 units per annum is regarded as optimum.

Despite many measures, traditional manufacturing and distribution face problems (Wells and Nieuwenhuis 2000). The high capital costs with very "lumpy" investment in plant and models inherent in all-steel body technology are high-risk. As has been noted in economic theory, economies of scale "arise because large, specialized machinery and equipment are useful *only* when the volume of output that a firm can sell justify its employment" (Lipsey 1980, 222, italics added).

The resulting oversupply leads to discounting and rapid erosion of residual values in cars already sold. At the same time, the introduction of a new model can often lead to long delivery times for customer-ordered cars. The inflexibility of manufacturing leads to inability to adjust output to demand and difficulties in switching from one model to another—responding to increasingly violent market fluctuations is difficult with existing technology. The reliance on continued sales of cars as the main source of revenue is increasingly untenable in developed markets, where costs rise as shorter model lifetimes lead to lower per-model volumes. Thus, high break-even points in manufacturing (where plants have to run at 85% of capacity or more to be profitable) lead to over-supply and the need to maintain extensive logistics lines to a large number of sales outlets.

Finally, the environmental costs of production, particularly (but not only) with respect to the paint shop, can no longer be ignored. Overall, *high* economies of scale in the car industry make sense only for situations in which the demand for cars is high, requiring quasi-full capacity of production. As we have stated earlier, this is simply not the case for the auto industry today. Hence, one critical environmental failing that is rarely recognized is that of waste through overproduction. Seen from the perspective of the whole automobile system (i.e., encompassing all components of the value chain), overproduction can be seen as one of the greatest (economic and environmental) inefficiencies of the system—indeed, this is an issue that the ecological efficiency school of thought would do well to consider.

A New Industrial Ecology for Automobiles: Micro Factory Retailing

We make no claims here that our concept of MFR is the answer—that is, that it will make the automotive industry ecologically and economically sustainable. Indeed, the logical conclusion of our analysis that economic activity needs to be embedded in locality and context means that there can be no prescriptive, generic solutions. Diversity means just that—a multiplicity of solutions that might all coexist in time and possibly space. We do not assume uniformity of demand across geographic space: quite the opposite. We propose that flexibility in small-scale manufacturing is one means of satisfying diverse demand. Moreover, our understanding of the significance of organizational fields is that there are huge impediments to any process of change that might lead from the automotive industry as currently constituted toward something like the vision we have for MFR. To give some illustration of the ways in which the automotive industry could be transformed through a redesign based on industrial ecology, we here outline the basic concept of MFR—though other accounts could also be consulted (Nieuwenhuis and Wells 2003; Wells and Nieuwenhuis 2003).

Micro Factory Retailing as an Ideal Type

The concept of micro factory retailing (MFR) is in essence a business model for the automotive industry in a distributed economy. The MFR concept is not an account of an existing business. It is an ideal type, a vision, a view of what might be rather than what is, a hypothesis that could be tested by the tools of IE. MFR is an attempt to provide an individual understanding of how a specific industry could try to meet the many and varied demands of sustainability. As such, MFR represents a radical reshaping of the relationships between product technology, process technology, business organization, and the purchase and use of cars. We cannot claim that the analysis applies to other sectors or products, though it might. At least for the automotive industry, if new patterns of production and consumption are to emerge, MFR might be one means of achieving these new patterns. Despite these qualifying comments, the MFR concept is grounded in reality; it is based upon the reality that parts of the MFR concept are already in evidence in the industry today—albeit not in one single place. In the examples we give later we highlight the features each case contributes to the MFR concept.

Economies of Scale with Micro Factory Retailing

Rather than seeking to match the high-volume, low-unit-cost approach of traditional manufacturing and distribution, MFR refutes this logic by placing small factories within the markets they serve—and so eliminates the distinction between production and retailing. This approach negates or sidesteps most of the benefits of scale associated with the traditional industry and allows the capture of external (industry-wide) economies of scale. For example, traditional manufacturing requires an extensive distribution network, incurring substantial fixed and variable costs. Compared with this, the fixed costs for MFR are probably an order of magnitude lower. Perhaps more important than the simple investment cost comparison are the many strategic possibilities that flow from MFR (Wells 2001a). The "classical" advantages of the small-scale firm are well known, and include features such as improved worker loyalty and commitment and faster response to market changes. It is less well-established whether an entire industry made up of small-scale firms offers economic and, particularly, environmental advantages.

The MFR concept is not just normal car manufacturing on a small scale; it necessarily requires and enables radically new automotive technologies and production processes. Despite this, the idea of using the factory as the point of sale is not entirely new to the automotive industry and there are parallel lessons on the competitive advantages of small scale to be learned from other sectors such as steel minimills, specialty chemicals, and microbreweries that have already experienced some aspects of MFR in action (Johanasson and Holapa, 2003). In other sectors, such as computers (for example, Dell Computers), consumers deal directly with the factory, a practice likely to become more prevalent with Internet shopping.

Micro Factory-Related Examples from the Automotive Industry

Research into the MFR concept has identified several instances within the automotive industry where the approach, or parts thereof, have been tried. It is interesting to note that thus far the larger suppliers to the automotive industry, be they materials companies or component suppliers, have not attempted direct involvement in such schemes—perhaps because of fear that they would appear as competitors to their customers, the vehicle manufacturers. Rather, most of the examples discussed briefly below come from those who are outside the industry or on its periphery in various ways, with one notable exception. The examples reveal several ways of thinking about product technology, manufacturing process, industrial interlinkages, scale, and business models that go beyond "fire and forget" production. In each case, the aspect of new thinking that the example shows is highlighted. Thereafter, there is a discussion on possible metrics to capture the industrial ecology benefits and costs of scale.

This section draws on several recent examples that combine innovative car designs, innovative manufacturing approaches, and new business models in various ways. They either were deliberately conceived in terms of small-scale production and retailing, or have aspects that could be articulated in such an approach.

One version or approach was the TH!NK.[5] The basic design concept was a two-seat city battery electric vehicle with a thermoplastic body for urban commuters and utilities (Wells and Nieuwenhuis 1999). The TH!NK factory in Norway had a design capacity of 5,000 units per annum. The wider business plan included the use of Internet sales and mobile service delivery to obviate the need for dealerships. Furthermore, the intention was to supply potential new markets such as California by locating "cloned" factories in the markets.

Another approach is that embodied in the Ridek concept[6] (Wells 2003b). The Ridek consists of two parts: a motorized deck (or "Modek") that combines the chassis with the power train in one integral unit, and a self-contained body module (or "Ridon") that is mounted on the motorized deck via four fixing points. Under the proposed business model only the Ridon would be purchased and owned by the consumer. The Modek would be owned by the municipal authority, which would have to retain sufficient numbers of Modeks to allow the units to be exchanged as required. Modeks would then be rented or leased out to consumers, but could be serviced, repaired, maintained, or upgraded at a central urban facility.

OScar, alternatively, is a United Kingdom-based entrepreneurial start-up company that is seeking to bring to market a vehicle concept based on the Amory Lovins "Hypercar."[7] It combines a carbon-fiber body structure with a fuel cell power train to create a lightweight zero-emissions vehicle. At present it is at the early stages of development, but explicitly embraces the idea of micro factories to deliver the concept. One of the most interesting aspects of this particular project is the use of "open source" design (Wells 2001b).

Even the vehicle manufacturers themselves have shown potentially radical ideas—an example being the GM AUTOnomy.[8] Designed by a small team within GM, the brief was essentially to reinvent the automobile in light of the fuel cell and drive-by-wire.[9] In essence the GM AUTOnomy has certain similarities to the RIDEK concept outlined above. The vehicle is split, with a running chassis upon which a body can be mounted. The chassis contains the fuel cell and all related power train components, as well as the physical and electronic docking points for the body. With drive-by-wire there is scope for the redesign demonstrated by the Hy-wire concept vehicle (GM 2003).

Motor Development International (MDI)[10] is the company formed to bring to market the ideas of the inventor of the compressed air engine, Guy Negre (Wells 2002). The technical concept and business plan have generated much controversy in the automotive industry, and doubts over both remain.

The core of the MDI approach is to grant licenses to third parties that in effect take on an MDI franchise for a defined territory in return for the investment needed to create the factory to serve that territory. MDI has designed a standardized or modular factory that includes office space and a showroom, because in the MDI concept the point of manufacturing is also the point of retail and service/maintenance delivery.

Table 1 seeks to provide a summary of the social, economic, and environmental aspects of the examples that could become the basis for a MFR approach to the automotive industry. The next section explores the advantages of MFR from an industrial ecology perspective.

Micro Factory Retailing as Applied Industrial Ecology

It is worthwhile to consider how far this rethinking of a major industry fundamentally changes the terms of comparison and performance in business, social, and environmental terms.

Embeddedness

One potential avenue for theoretical development is to bring in the concepts to be found in the debate on the decentralized economy and on the phenomenon of "relocalization." The work on eco-industrial parks represents one basis for understanding the character of localization. Our first starting point for this analysis is that of Schumacher (1973) that, quite simply, "small is beautiful." By changing spatial scale it is possible to redefine the terms of competition, and indeed to redefine the fundamental purpose of business. Again, this is a debate that is too long and contentious to enter into fully in the context of this article, but the premise from which we start is to deny the old adage that "the purpose of business is business" or even, in contemporary parlance, to maximize shareholder value. Rather, the purpose of business is to bring wealth creation, useful products and rewarding work to the community in which it is based (Schuman, 1998).

With this combined product-service function and social applicability, the MFR factory becomes the location for repair, spare parts, and in-use modification (e.g., external panel refresh, powertrain upgrades, refitting of interior trim) that allows the manufacturer to benefit directly from profitable aftermarket activities. The factory becomes the center for trade-ins, used vehicle sales, and end of life vehicle recycling and hence becomes the embodiment of product stewardship within the local community.

The MFR concept clearly resonates with social and political objectives by creating local employment and wealth creation in high-value manufacturing activities. Those purchasing the product or service would know that there would be direct local economic benefits and, equally, there would be fewer concerns over, for example, exploited labor in far-off locations. The MFR concept further embodies the growing desire to increase the use of skilled labor and reduce fixed investment in order to reduce cost, increase flexibility, and increase social cohesion. Related to the previous point is the fact of lower social impact of any plant closures, as a smaller plant would be closed in each location. Given that sustainability does not and cannot mean the ossification of social or economic structures, it is incumbent upon those advocating a different future to consider the adaptability of the business solutions they propose: adaptability is a key facet of the MFR approach.

Customer Focus

The issue of customer focus or satisfaction is not normally within the ambit of industrial ecology. Still, in order to be sustainable a business must be commercially viable, and the way to achieve this is to deliver customer satisfaction superior to that from rival approaches. The MFR concept offers a mechanism to deliver this superior customer satisfaction in many different ways. For example, the consumer will benefit from a reduction in depreciation of the vehicle. In existing systems this depreciation is created by a combination of product wear, overproduction, and the step-change introduction of a new model. Alternatively, customers can be taken around the plant, can meet the people who will make their car, and can thereby feel closer to the product (a practice already used to sell prestige vehicles

Table 1 Social, economic, and environmental aspects of micro factory retailing (MFR) illustrated by the selected examples

Example	*Social*	*Economic*	*Environmental*
TH!NK <www.think.no>	High-skill, long-cycle-time assembly work; local capital start-up prior to Ford purchase. Employment for small rural town.	Break even at 5,000 units per annum. Replicate the factory for output expansion. No dealerships. Internet sales, mobile service delivery.	Battery electric-power car. High aluminum and plastic content in vehicle. No paint shop.
Ridek <www.ridek.com>	Combined public and private ownership. System can contribute to traffic management.	Production envisaged at urban scale, one plant per city. Smaller, independent producers could make the upper vehicle structure.	Battery electric-power vehicle. Environmental benefits from traffic management contribution.
OSCar <hugospow@compuserve.com>	No intellectual property rights. Small-scale factories with enriched work environment.	Avoids R&D economies of scale through Internet-based open source design. No dealerships.	Carbon fiber, fuel cell vehicle. Possible for customized designs of high eco-efficiency. No paint shop. Material leasing as a means to reduce reliance on physical production to add value.
GM AUTOnomy	Retains core skills and workforce of major companies. Allows local value-added employment.	Retains economies of scale in most aspects other than final assembly.	Fuel cell vehicle. Electronic systems allow many secondary environmental advantages.
MDI Air Car <www.theaircar.com>	Allows workers to have a variety of functional roles in assembly, sales, administration, and so forth.	Production envisaged at a regional scale. No dealerships or distribution system. Franchise system to buy factory kit enables low-cost market entry.	Compressed air (zero emissions) vehicle. No paint shop.

in Europe). Information on customer life-styles, aspirations, and mobility-needs goes directly to the factory, to inform product development, because the factory has daily dealings with those buying, servicing, and repairing their cars. The inherent production flexibility of MFR is the practical basis upon which new levels of customer care can be built. MFR makes possible flexible response, shorter lead times, and late configuration, which in turn yield shorter times to market and quick responses to customer orders. Again, the existing industry is trying to achieve build-to-order responsiveness but is crucially handicapped by existing production structures such as long logistics lines from the factory to the geographically dispersed retail outlets.

MFR might address the customer requirement for high levels of product variety required for success in the market in two ways. First, through modular designs and the inherent flexibility of low-volume technologies, any one MFR unit could produce a range of vehicle configurations, though clearly there are practical limits. This is analogous to the variety of output found in many commercial vehicle factories. Indeed, it is possible that products could be reconfigured on a temporary or semipermanent basis if such a feature were designed-in at the outset. Second, it could be envisaged that multiple MFR sites could provide different product categories. In the MFR approach there is no conflict of interest between production and retailing. The vehicle manufacturer can have direct control over the retail business and captures a greater share of the downstream value chain.

The MFR concept is well-placed to take advantage of the possibilities offered by the Internet, which becomes the main medium by which customers order vehicles, spares, and accessory components, as well as book service appointments.

Environmental Impact

In any industry or activity there is a choice to be made between concentrating and dispersing that activity, and which is better for the environment. With fewer, larger plants there are various efficiencies (equivalent to economies of scale) in processes, that will mean lower per-unit burdens in terms of, for example, energy consumption, water pollution, and other performance variables. It is still the case that a large facility can also mean that for the locality in which it is placed there are very real environmental consequences both with normal operations and with catastrophic events.

Table 2 suggests issues that could be identified and measured using the tools of industrial ecology to provide a comparison between traditional, centralized manufacturing plus distribution and the MFR model. For example, it seems important to include the environmental burden of the distribution and retail system (both construction and use) for traditional car manufacturing. Table 2 therefore provides an overview of how traditional car manufacturing might be compared with MFR in order to establish the relative merit of each in terms of sustainability: that is, in terms of economic, social and environmental measures. This is by no means straightforward, as the two are not directly comparable across all aspects of the industry. In table 2, a centralized industrial structure is a characterization of the existing automotive industry defined by a system in which the manufacturing operations are concentrated in a (relatively) few large plants that in turn serve spatially-extensive geographic markets via long (even global) logistics lines for the finished product. In contrast, a decentralized structure means an approach to manufacturing, retail, and service delivery whereby the unit of production and delivery is located with the (local or regional) market that it serves, resulting in multiple small plants and comparatively shorter logistics lines for the finished product.

Compared with traditional car manufacturing, the MFR approach makes low-volume production viable. Low-volume production often utilizes technologies other than the all-steel body, pressed, welded, and painted. Therefore the MFR approach enables the traditional paint-shop, one of the environmental hot spots in car manufacturing, to be abandoned. It is not, therefore, a case of "like for like" comparison whereby some features of the system can be held constant (say, the use of the all-steel stamped unitary body) whereas others are varied and tested. The co-determination of the unsustainable features of the automotive industry suggests that a systemic resolution of those problems requires similar co-determination.

Table 2 Preliminary comparison of the environmental impact of centralized versus decentralized, micro factory retailing (MFR) manufacturing

Indicator	*Centralized*	*Decentralized MFR*
Plant and buildings construction. Ideally these need to be calculated on a per-car basis, discounted over the expected lifetime of production. Capital cost (financial) comparison.	Single large plant: land use, building materials, construction methods required (e.g., large foundations for press shop), transport of materials to site, disposal of waste materials. *Plus* construction cost of the distribution system: ports and railheads, dealerships, distribution compounds, national marketing offices.	Sum total of multiple individual MFR facilities, making allowance for "brownfield" sites and reuse of otherwise derelict land. Also making allowance for social benefits of distributed employment. No requirement for dedicated vehicles and infrastructure for distribution and sales.
Plant and buildings use burdens. Again calculated on a per-car basis. Environmental cost comparison of running the plant and distribution system, for example, in terms of energy use, water use, material use.	Single large plant assuming all traditional car technology using traditional processes. Again need to include environmental burden of distribution and retail facilities.	Sum total of multiple individual MFR facilities. Some manufacturing burdens are higher (e.g., initial energy used on an aluminum vehicle) but can be recovered in the in-use phase.
Logistics of complete vehicles on a per-car basis. Environmental cost comparison.	Outbound movement of complete vehicles via road, rail, or ship from factory to dealerships. Average trip length and type in terms of energy use, noise, other emissions.	Reduced outbound logistics due to proximity to the market. Avoided environmental burden due to lack of infrastructure for finished vehicle logistics.
Logistics of parts and materials. Environmental cost comparison.	Inbound movement of parts and materials. Might be longer range than MFR due to desire to purchase least cost, hence generating larger burdens.	In general, with multiple MFR sites more movements of parts from supplier to assembly site must be expected.
Vehicles in use. Environmental cost of running a vehicle. Would also require a financial cost comparison for consumers.	Metrics well established for contemporary vehicles on a per-mile basis with an assumed lifetime (say 150,000 miles).	If MFR enables economic production of alternative technology, then the in-use phase should show benefits in terms of, for example, energy consumption, reduced air emissions.
Product longevity. Note that in some manifestations of MFR there is potential for repeated refurbishment of the vehicle.	Divide all the other parameters by the total miles or years in use. It is therefore necessary to forecast product longevity.	If MFR allows greater longevity though either design features (materials, technology) or the business model (product service systems) then the manufacturing burden is amortized over a longer useful life.
Recycling, reuse and disposal. Environmental and economic cost of recycling. Note sensitivity of economic recycling to distance traveled by recyclate.	With centralized production there is the extra environmental cost of collecting and aggregating used components and vehicles via reverse logistics.	MFR burden might in total be reduced, but will still occur with respect to components and subsystems that have become obsolete.

Other advantages might follow. The MFR plant does not require a large, flat dedicated site with extensive support services. A conventional modern car plant occupies several square kilometers of land that, by virtue of the unique requirements of car manufacturing on this scale, requires dedicated service infrastructures for water, electricity, holding compounds, and so forth. Compared with this, MFR requires a classic light industrial facility and could even be used in small "brownfield" sites (i.e., those that had a previous and now defunct use, and that are in need of industrial regeneration).

Another interesting aspect is that the factory can undergo a transition over time from an essentially new car production focus to one more involved in service and repair. That is, the factory does not depend absolutely on the continued sale of new cars. This helps to mitigate the tendency to overproduction, with all manner of associated environmental and market benefits. The environmental cost of overproduction is never included in IE analysis, but we believe it to be crucial in the long term. Finally, the micro factory retailer can work as a point of collection of end-of-life vehicles, with the option to become a dismantling facility. This can certainly facilitate reuse and recycling of materials.

Emerging Economies

One of the initial stimuli to the work undertaken in industrial ecology was the basic concern that it would be impossible for the planet to support a standard of material consumption attained by highly industrialized countries if the emerging economies attained the same level. In other words, emerging economies desperately need development, but the terms by which this is achieved must be different—this is the essential message of the Brundtland Report, after all (WCED 1987). In addition, emerging economies suffer from chronic undercapitalization, high levels of national debt, and surplus labor. The MFR approach makes some contribution to these issues. For example, the approach is conducive to the creation of products that are appropriate to the prevailing local conditions. Furthermore, the low capital intensity and high labor intensity implied are ideal for the structural conditions in many emerging economies, while simultaneously providing for a reduction in expensive imports. It is interesting to note that through the duplication of MFR sites substantial investment savings could be realized by means of the multiple ordering of machines and equipment and the use of a standardized layout.

Organic Incremental Growth

Investments in assembly capacity can be incremental, either by adding (subtracting) more units or by the expansion (contraction) of existing units—and thereby supply can expand or contract in line with the market. A chronic problem with industries that have sought ever-increasing economies of scale is large fluctuations in supply relative to demand. Each additional capacity increment is very large, so the industry comes to be characterized by poor capacity utilization and low margins. Conversely, each MFR unit would have an investment cost well below that of a traditional manufacturing plant—although the cumulative investment cost for the same production capacity may be higher. The incremental expansion of capacity can also have a geographic component in that new plants can be added to develop new market territories.

Moreover, new products can be introduced incrementally, on a factory-by-factory basis and high product variety will become possible. The overall financial risk associated with new product introduction will be much lower than with contemporary approaches. This is another dimension to business flexibility that in turn underpins adaptability—the ability to respond effectively to changes in the external operating environment.

Concluding Remarks

In this article we aimed to provide an expanded perspective of industrial ecology. We did so not only by analyzing the current automobile industry but also by providing an alternative business model—micro factory retailing—which we believe is more sustainable in economic, social, and environmental terms. The brief empirical accounts presented here provided a flavor or sense of the many shapes that the automotive industry could adopt in the future, and in so doing redesign the entire industrial ecology of the automobile.

As this article intrinsically suggests, technical concepts alone are insufficient because they fail to take into account the possibilities and limitations of the industry as well as the whole organizational field within which companies exist. In this respect, even though the MFR type is largely hypothetical, it provides a strong basis for the evaluation of future alternatives that combine environmental dimensions with those of business and society. Undoubtedly, the tools of industrial ecology will be of great use in the evaluation of such alternative shapes.

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Notes

1. The concept of "distributed economies" is still under development. It is, in fact, an emerging research area that has mainly been explored by the International Institute for Industrial Environmental Economics (IIIEE). (For details, see IIIEE 2005.)
2. Because the concept has been broadly explored elsewhere by institutional theorists, we limit ourselves to use of the concept to indicate an appropriate level of analysis in industry-wide research. Additional information about organizational field and institutional theory can be found in IESBS 2001, Tolbert and Zucker 1996, and Scott and Mayer 1994.
3. Ex-works = factory gate prices, before distribution and retailing costs are taken into account.
4. For an overview of the end-of-life vehicle issue in Europe during the 1990s, see work by Orsato and colleagues (2002).
5. For a detailed account of the evolution of the TH!NK enterprise, see Chapter 10 of Orsato (2001b). See also <www.think.no> (Accessed August 03, 2004).
6. <www.ridek.com> (Accessed August 03, 2002).
7. <www.hypercar.com/index.html> (Accessed August 03, 2004).
8. <www.gm.com/company/gmability/adv_tech/600_tt/650_future/autonomy_050103.html> (Accessed August 03, 2004).
9. Drive-by-wire is the electronic control of systems such as steering and brakes that have traditionally been controlled by mechanical linkages.
10. <www.theaircar.com/> (Accessed August 03, 2004).

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