Towards a sustainable industrial system

With recommendations for education, research, industry and policy

This paper builds on discussions at an International Manufacturing Professors' Symposium in Cambridge UK in July 2008 and the subsequent UK Manufacturing Professors' Forum. Leading professors from the fields of design, production, operations management and service science gathered with thought leaders from industry and professional organisations to attempt to chart the route to a more integrated and mature understanding of sustainable industrial systems.

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Towards a sustainable industrial system: accelerating the contribution of education and research

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Executive summary

Our industrial system has been responsible for raising the quality of life of peoples around the world. It is becoming increasingly clear however, that the current system is creating unintended and serious consequences for the environment at a global level. Change on a significant scale is required urgently.

Some businesses are already engaged in reducing their impact through the introduction of new products, processes and business models. Academics concerned with the industrial system have a responsibility to study these emerging models, to interact with them and to synthesise and spread the knowledge.

Whilst it is important to address the impact of each product of the industrial system and to pursue aggressive reduction of the effects of specific activities, we must also examine the operation of the whole system. Only in this way can we hope to bring the benefits of industrialisation to those who have not yet experienced them without exceeding the limits of our planet.

This paper presents cases where industry is already taking action, and argues that:

- dramatic improvements can be made by deploying existing expertise at the level of individual businesses
- relying on technology alone to make the industrial system sustainable is a trap to be avoided
- collaborative engagement of academics is essential to tackle the challenge of reorganising the industrial system

Teachers and researchers, consumers and producers, and practitioners and policy-makers all have the opportunity to shape a future industrial system.

What such a system will look like is still unclear and the journey uncertain. This paper does not provide all the answers but offers a platform for informed debate. The case studies highlight examples of changing industrial practice that illustrate the scale of potential improvement. It considers the implications of these examples and makes recommendations for education, policy, research and practice.

Contents

1 Background

It is now widely accepted that manufacturing industries are having a major influence on the deterioration of the global environment. Some experts suggest the industrial system can account for 30% or more of greenhouse gas generation in industrialised countries. Businesses, governments and consumers are beginning to react, but the complexity of the problem and diversity of views, make it difficult to identify widely acceptable courses of action. This confusion occurs at a time when the window of opportunity for action is rapidly closing.

The academic community has the opportunity, indeed arguably the responsibility, to contribute to the discussion and to the formulation of courses of action. Whilst climate change and environmental experts have made substantial contributions, there are major opportunities for academics concerned with the design and operation of the industrial system to use their particular expertise.

This paper therefore seeks to highlight opportunities for the academic community to contribute to the development of sustainable, global industrial systems. It does not provide all the answers but hopefully provides a platform for an informed debate about the future shape of these systems, and identifies possible routes to achieve them.

2 The wider context

Industrial systems have been instrumental in improving prosperity for many, helping to free them from the daily struggle for food and shelter. The first industrial revolution was national and created changes that were highly visible at a national scale; the implications for the planet as a whole, however, were virtually invisible. Few predicted that industrialisation would create the unintended consequences that are now evident, consequences that result from exceeding sustainable levels of raw material extraction, emissions and waste. Whilst the benefits for some centres of affluent industrial production are apparent, so also are the growing consequences for the planet, its ecosystems and the natural capital on which future prosperity and indeed human survival depend.

A few pioneering thinkers[1] have concerned themselves with the impact of industrial systems but they were constrained by the existing knowledge of environmental systems and their limited ability to model impacts of changes in production and consumption. (How much oil is available? How many trees can we cut down every year? How much mercury can be released into this river? How will the growth of greenhouse gases in the atmosphere affect the complex systems of the planet's climate?). Over recent decades, international scientific research and information technology have transformed both the extent of our knowledge base and our ability to anticipate and analyse the likely future consequences of developments.

The Intergovernmental Panel on Climate Change (IPCC) and other organisations have pointed to the social and environmental consequences of current industrial activity, but lack expertise in the structure and nature of the industrial system. The opportunity and responsibility to act lies with those who are directly concerned with the industrial system, including industrialists, policy makers and manufacturing and business academics.

The delay between actions and planetary effects can often be decades or more. Yet economic and investment decisions by producers and nations, and our behaviour as consumers, are still largely dominated by concerns over local issues and short-term thinking. By the time large scale effects become so evident that they demand urgent action the social and economic costs can have escalated dramatically.

Today, as a global community, we face serious challenges where demand for resources is outstripping supply and where emissions and waste have accumulated to levels that endanger our current quality of life. Processes of economic decision making and governance must shift towards long term analysis and evaluation, incorporating whole life-cycle social and environmental impacts.

When the global price for oil rose to record heights in 2008 (before the economic crisis) it was clear that the effects of a rapid escalation of the oil price to $150 per barrel had not been adequately anticipated or planned for. The negative consequences for national economies, car-dependent cities, global and national production and distribution systems, community and individual life styles, became suddenly apparent. We are also learning how complex and tightly linked our financial systems are. The call for resilience in our financial, industrial and natural systems is becoming louder, and will require new ways of thinking – as Einstein is quoted as saying "The thinking it took to get us into this mess is not the same thinking that is going to get us out of it."

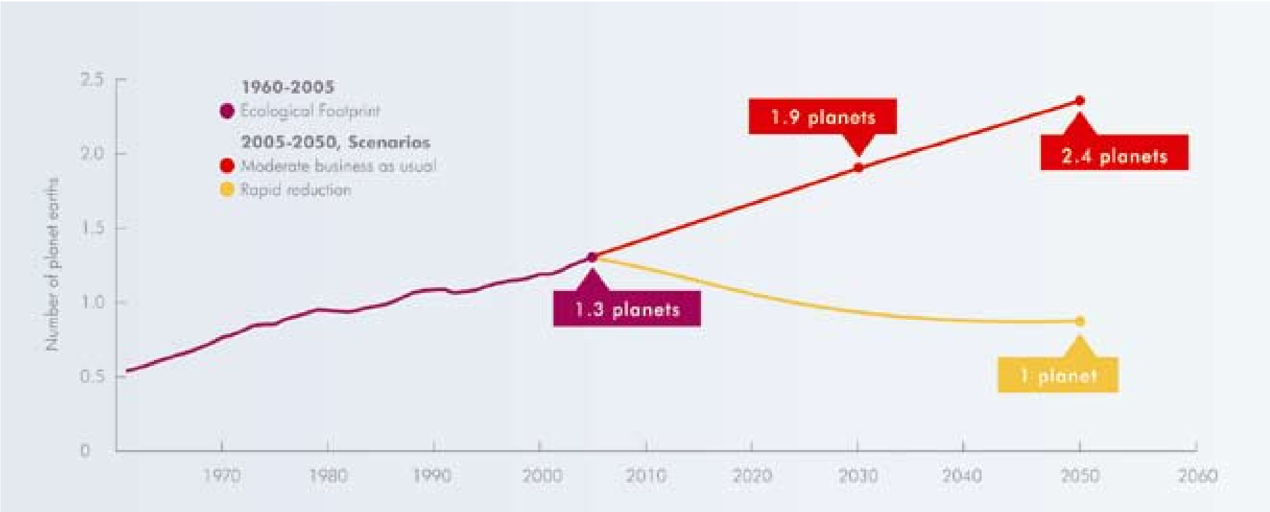
Global warming – and the consequent effects of increasing atmospheric concentration of greenhouse gases – presents even greater challenges for social and economic systems, with the potential for devastating consequences. The short time 'window' for action to reduce greenhouse gas production has been widely elaborated by scientists and economists. The revolutionary transition to a new 'low carbon economy' which has to be achieved in just a few decades is already the subject of global concern. Even if the most optimistic outcomes of global action come to pass, the effects of global warming will continue for the rest of this century, presenting unparalleled challenges for existing systems and the infrastructure of production, distribution and consumption.

The very latest analysis – a key input to the Climate Change Conference in Copenhagen in December 2009 – explains the level of change needed to achieve varying degrees of CO_2 levels[2]. The European Union defines 'dangerous climate change' as 2˚C; which is 50% probable at 450ppmv CO_2. At this level of warming 30% of species will become extinct and a billion people will suffer water stress. To achieve 550ppmv (likely 3˚C rise) we would need to peak CO_2 emissions in 2020 and thereafter reduce at 9% each year for 15 years. When the French installed all of their 40 nuclear power plants their overall CO_2 emissions reduced by just 1% per annum.

The other significant challenge to current industrial systems is equity – intergenerational equity (as in the classic

[1] Including Rachel Carson, EF Schumacher, Barry Commoner, Paul Ehrlich and Meadows et al

[2] Anderson & Bows. 2008



A graphical representation of humanity's ecological footprint, showing we are currently using 1.3 planets to provide the resources we use and to absorb our waste. This could increase to nearly two planets' worth by 2030 and nearly two and a half by 2050, if no action is taken. (Source: www.globalfootprintnetwork.org)

definition of sustainability) and global equity. We extract materials at a rate that will not allow future generations to match our lifestyle. Some critical resources will run out within 10 years[1]. What we produce from that extracted material is not equitably distributed on a global scale. Industrial development has not freed all global citizens from lives of poverty and hardship; access to food, clean water, shelter and other fundamentals of improved prosperity still elude over one billion people. The world is still struggling to shift from the historical 80:20 breakdown where 20% of the world's richest consume 80% of the resources.

It is estimated that the richest live a lifestyle that would need four planets to support, while in total humanity is using the equivalent of 1.3 planets to provide the resources we use and to absorb our waste. This means it now takes the Earth one year and four months to regenerate what we use in a year. Clearly this profligate lifestyle cannot continue.

Technology alone cannot be relied upon to break the link between growing consumption and growing impact on the planet. Dramatic changes are required to our systems of consumption and of production, with changes to patterns of living in a low-carbon economy. This will place industry and business systems at the centre of the next industrial revolution.

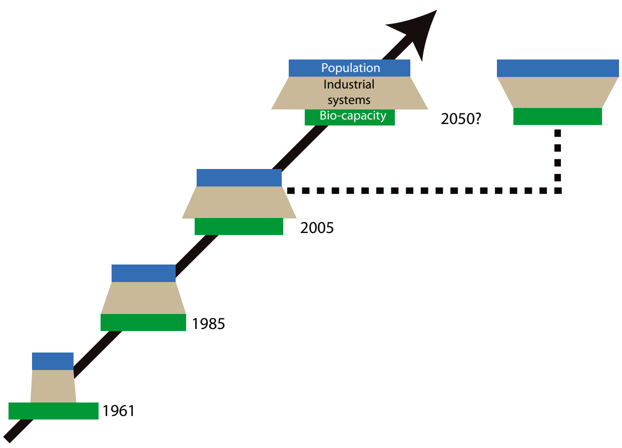
The industrial system is not just part of the problem it has to be part of the solution.

[1] Resource Efficiency Knowledge Transfer Network, March 2008

3 The scale of the challenge

Our current industrial system takes natural capital (mined and grown materials) and turns it into the 'stuff of the world'. While each organisation is incentivised to be efficient at its own activity, the efficiency of the total system at converting material into valuable end product is below 10%, with over 90% of extracted resources failing to reach the customer. In a world with an infinite supply of both raw materials and sinks for waste, such system inefficiencies could be irrelevant. Today it is increasingly evident that the world is finite, its ecosystem is complex, and we are operating close to the boundary. Systems that perform at 10% efficiency, that only extract one use from a preciously extracted material, that use enormous quantities of water and energy are not well-designed systems.

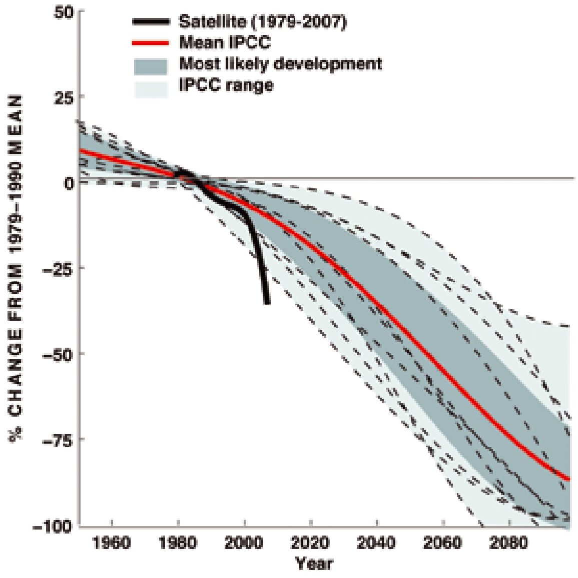
Some countries use up to four times their 'share' of the ecosystem, while others use a quarter. Together, humanity uses the equivalent of 1.3 planets to provide the resources we use and absorb our waste[1]. Within this context, the industrial system is expanding, and whilst this improves the living standards of ever more people it compounds the stress already placed on the planet's resources. With a growing population and a rapidly expanding industrial system, it is clear the current system cannot be sustained indefinitely.



The footprint of the industrial system has expanded several fold in the last 50 years, supporting an improved quality of life for an ever increasing population. The industrial footprint however now exceeds the globally available bio-capacity. If we are to live within our resources while still achieving acceptable living standards, our industrial systems need to undergo radical change.

[1] www.footprintnetwork.org

To live well – but within our means – experts predict that we must be able to deliver the 'stuff of life' using less than a quarter of current bio-capacity. For our industrial systems that means reductions of 75-90% in the use of carbon-based energy and similar scale reductions in resource use and material flows, while delivering the same value.



Actual loss of arctic sea ice revealed by satellite images, compared to models produced by the Intergovernmental Panel on Climate Change (IPCC). Chart by Dr Asgeir Sorteberg, Bjeknes Centre for Climate Change Research and University Center, Svalbard, Norway

As our knowledge and desire for change grows, the window of opportunity closes and delay is both dangerous and unnecessary. The Earth is coming under stress more quickly than predicted – for example, the Arctic sea ice is melting much faster than expected (see graph above).

Increasing numbers of businesses are trying to address these concerns, creating an explosion of new products, processes and business models which demonstrate notable reductions in environmental impact while maintaining value to customers. However, the knowledge is piecemeal, and the impact on the larger industrial system is currently very limited.

Significantly better performance of the industrial system as a whole is possible, but we have to reject the idea that 'less bad is good enough'. The scale and pace of change must be understood if we are to move quickly toward a system that operates within planetary limits. A deep understanding of those limits, and a shared mental model of a future 'sustainable industrial system' are urgently needed.

Academics have an important role to play in coordinated action to address these issues as educators of the staff of future industrial organisations. Research across the industrial system can explore and develop opportunities for radically new systems.

Scholars of the industrial system have the opportunity to study emerging business models, to take part in improving them, and to synthesise that knowledge to help others. Their shared understanding of the process of organising men, money, machines and materials into efficient configurations is a unique resource.

A moment of opportunity

The overriding task is to decouple quality of life from the resources (bio-capacity) needed to support it. In the industrial world the search for efficiency has a long history, finding new ways to deliver improved performance. Such decoupling is feasible, and is already happening in many places, but a greater, more coordinated and more innovative effort is required.

Significant changes to the way we think about the industrial system are needed in order to make it sustainable. We have to look creatively at rethinking the full cycle of designing, making and serving, at rapid innovation in the products of the current system as well as the development of new models for satisfying human needs and desires through different systems of production and consumption. We need step changes in performance of the system as a whole.

Some experts argue that it is possible to change our industrial system so that we:

- add the same value with 25% of the materials and energy previously required ('Factor4')
- make use of the 90% of discarded extracted materials
- use benign materials that can be reused again and again (so-called 'cradle-to-cradle')
- refurbish and reuse sophisticated long-lasting components again and again
- develop a system of global manufacture of a universal set of extra high value components, which could be assembled in a decentralised network with diverse, locally produced components and sub-systems
- build industrial systems that mimic and nurture the environment

Without advocating a particular target or technique, the common features of such thinking are that they deliver a step change in performance, that they do not rely on technology that is not yet available, and that they derive from changes to the whole industrial system.

Just as such changes to the industrial system require cooperation across all the parts of the system, the practice, study and teaching of 'sustainable industrial systems' requires cooperation between disciplines at an unprecedented level.

Priorities and opportunities

Examples of reductions of 40% or more in manufacturers' use of resources are becoming more common, suggesting that large scale change is possible. Indeed, 40% improvements in energy and resource efficiency in the industrial system are happening in less than five years, without the application of new technology. As a first priority we should be duplicating such improvements across industry, while at the same time seeking longer-term, resilient industrial systems.

In industrialised countries the industrial system itself can account for 30% or more of greenhouse gas generation. Reducing this by 40% over four years would be an enormous first step in tackling global warming and in decoupling quality of life from resources and impacts. The case studies that follow show industries that have:

- reduced the energy used to make their product by over 40% in five years
- reduced landfill waste by 100% (zero to landfill)
- reduced water consumption by over 70% in three years
- converted almost all (99%+) raw materials into end products with hardly any waste
- collected their product from customers and reused them for new customers
- designed buildings that need no central heating or air conditioning systems

These changes use new ways of thinking about the industrial system and do not rely on revolutionary new technologies for their performance. These companies continue to improve at dramatic rates – they have not run out of ideas. Thinking at the level of the industrial system offers ever greater opportunities.

No matter how rapidly the world moves to reduce the environmental footprint of our industrial system there will be a legacy of effects that will continue to challenge our future economic and social development. Climate change is a clear example of this. Global action to mitigate the effects of global warming will have to be accompanied by action to adapt to its continued effects. Shifts in weather patterns, extreme weather events, sea level rise and so on, will create significant challenges for the existing infrastructure of all human settlements, including established processes of production, distribution and consumption. The design of a low-carbon industrial system will need to address issues of adaptation; the resulting system needs to be more resilient in the face of significant climate-induced challenges.

Students of the industrial system have not systematically attacked resource productivity or resilience in the same way that they have tackled labour productivity or quality. In recent times the quality and lean revolutions have shown us a new, massively improved way of organising design and production and taught us new ways of seeing 'waste'. The levels of performance improvement seen in this shift must be emulated in a new search for resource efficiency.

A role for all of us

This is a moment of historical importance and excitement, and for unprecedented creativity and innovation: the beginning of the 'next industrial revolution', one that can provide sustainable prosperity for all. That moment cannot be delayed, as each year of living beyond our means takes us deeper into ecological debt and into a situation that becomes ever harder to resolve.

Teachers and researchers, consumers and producers, practitioners and policy makers all have the opportunity to shape a future industrial system; one that can deliver social and economic stability while still operating within the limits of the planet we all share.

4 Case study evidence

There are many examples of changing industrial practice. We have chosen a range of cases that illustrate the scale of potential improvement and cover a range of sectors and operational scales. We do not claim that these examples are either best practice or ultimately sustainable. Notwithstanding the significant levels of improvement the companies have achieved, each recognises that they are at the early stages of a long journey. In their different ways they have each looked into the future and identified a need to change, and targeted key aspects of their business for change.

These cases are a first step in creating a library of such cases, for use by all industrial academics and practitioners. If you want to add your own example please email David Morgan (dcm32@cam.ac.uk) for a proforma. A web site for sharing examples and best practice is currently under development: www.ifm.eng.cam.ac.uk/sis/

VITSŒ: timeless designs that encourage reuse

VITSŒ manufacturers and distributes high quality furniture around the world. Its key product is a universal shelving system (the 606) that won multiple awards for design excellence and is part of the collection at the Museum of Modern Art in New York City.

Vitsœ was originally founded in Frankfurt, Germany in 1959. In 1995 Vitsœ moved all aspects of the company and production to the UK and since then, sales at Vitsœ have risen year on year by 20%. Vitsœ focuses on generating steady growth by constant, incremental improvements to the quality of both product and customer service, which the company is able to control fully by selling direct.

What trigger is the company responding to?

The cost of most consumer products has dropped significantly in today's markets, ensuring that little value is attached to the products, allowing them to become disposable (repair being unavailable or uneconomic). Trends in fashions also increase the disposability of consumer items, leading to significant amounts of wasted resources.

What was the response?

Vitsœ's differentiated position has been to ignore high fashion, creating timeless, robust products that favour simplicity and flexibility. Vitsœ creates furniture that lasts longer and concentrates on reuse not disposal. All new components are designed and manufactured to be compatible with the original system. The designs use non toxic material and create very little waste during production. Vitsœ has invested in reusable packaging for its suppliers and for shipping products to its customers. By pursuing this position, Vitsœ has minimised the impact of its activities on the environment.

Bottom line benefits

By encouraging the user to buy only what is needed, the customer relationship is established on the principle of long-term value. More than half of Vitsœ's customers are existing customers who are adding to, rearranging or reinstalling their furniture, which may have been bought as long ago as 1960. Customers buy Vitsœ's furniture because they can reuse it, rearrange it and take it with them; they understand that they are making a genuine lifelong investment.

Wider lessons

Vitsœ has not received any incentives, tax breaks, grants or loans to support its desire to take a longer-term view of the design and support for its products; and yet they have survived almost 50 years in the market.

Brandix: factory goes green

Sri Lanka's Brandix Group, which exports clothes to international retailer Marks & Spencer, has redesigned a 30-year-old factory to meet 'green' factory standards. This facility was awarded the Platinum Certificate in the LEED rating system of the US Green Building Council.

What trigger is the company responding to?

M&S found that their customers expected them to address their environmental impact as part of 'business as usual' operations. This meant committing to work with their suppliers to combat climate change, reduce waste and safeguard natural resources.

What was the response?

A reduction of carbon emissions by 80%, an energy saving of 46%, a reduction of water consumption by 58% and zero solid waste to landfill has been achieved.

Tarred roads have been replaced with paving blocks to greatly reduce heat build up around the factory, which in turn prevents heat flow into the factory and helps save on air conditioning.

The building management system is an intelligent control center that controls carbon dioxide and humidity levels in the modern air conditioning system ensuring an optimum working environment.

The use of natural light is critical to lowering heat and reducing energy consumption. The windows use special glass material channelling sunlight into the plant's workspaces, without the accompanying heat. LEDs provide light to the sewing machines at needle point, supplementing the natural light provided by the skylights. This has helped to reduce total electricity consumption by 10%. The factory's steam boilers and steam distribution systems have been redesigned and a brand new super-efficient air conditioning system installed. All of these modifications have reduced total energy consumption by 46%.

The green areas in the gardens have been increased substantially. The plant's new rainwater percolation pits allow water to soak back into the ground helping to replenish the natural water table. The plant's roof has been redesigned to harvest rainwater, collecting about 115 cubic meters per day, which is recycled for all use

except drinking water. Subsequently, a tertiary filtration system and a disinfection process allow the used water to be recycled again for toilet flushing and gardening. The overall result is a reduction of 58% in total water consumption.

An electrically-powered car is used for delivery of samples between plants and for short haul of stock within the factory, sourcing its energy from the plant's windmill.

The factory recycles and reuses 100% of the solid waste produced. Even canteen waste is composted to contribute to biogas generation. This biogas is then used to power the gas burners in the kitchens.

Bottom line benefits

- 30%-40% reduction in operating costs
- Heath and safety of building occupants
- Enhanced occupant comfort

Wider lessons

The adoption of best practices and global standards has not only benefited Brandix qualitatively, but has also brought a considerable benefit to both top and bottom line performance, through effective cost and waste management and higher productivity.

Philips: designing for green

As a world leader in healthcare, lifestyle and lighting, Philips integrates technologies and design into people-centric solutions, guided by validated customer insights and its brand promise of 'sense and simplicity'. Products range from TVs and MRI scanners to colour-controllable LED lights and home defibrillators. Design is seen as a key differentiator for Philips products and a sound record on sustainability as a further essential aspect of its brand image.

What trigger is the company responding to?

Since its founding Philips has understood that the simultaneous pursuit of business interest together with socially and environmentally sound behaviour is critical to success. Philips has been working to minimise the environmental impacts of its products, processes and services since 1970. In the early 1990s, during a wide ranging restructuring of the business, sustainability was identified as a key part of the business moving forward.

What was the response?

In the early phase of the company's response to 'green issues' packaging reduction, weight reduction and simplifying product architectures (resulting in lower assembly times) were successful. This improved the credibility of the environmental effort because it resulted in direct financial benefits.

In 1994 Philips began to set a series of measurable environmental targets. At the same time, Philips introduced the EcoDesign process which deals with all aspects of product creation.

This has lead to the Philips Green range which contains products that perform 10% better than competitor products on at least one of the six key measures: energy efficiency, packaging, hazardous substances, weight, recycling and disposal, and lifetime reliability.

Philips are committed to generating 30% of total revenues from green products over the next five years (up from 15% in 2006) and intends to double investment in green innovations to €1 billion by 2012. It also hopes to further increase the energy efficiency of operations by 25% by 2012.

Bottom line benefits

Philips overtly promotes its green range and seeks to gain competitive advantage through the design and marketing of greener products, reaching customers not previously addressed by Philips. As a market leader in green products, Philips is also likely to be best placed to derive benefits and avoid problems associated with any future eco legislation.

The focus on the efficiency of the business operations has also lead to reduced energy consumption and reduced costs.

Wider lessons

Philips has recognised the business opportunity and long term necessity of addressing green issues, and aims to embed sustainability in all it does in terms of design, research and development. By integrating this into the way it operates, sustainability becomes not an additional cost, but part of business as usual and a means to gain long term competitive advantage.

Xerox: managing documents not printing copies

Xerox is a global document management company which designs, manufactures, sells and supports printers, multifunction systems, photo copiers, digital production printing presses, and offers related consulting services and supplies. Founded in the USA in 1906, Xerox is famous for its invention of the plain paper copy and the laser printer.

What trigger is the company responding to?

Xerox has been recovering used equipment since the 1960s. In the late 1980s and early 1990s there was a drive to develop a more formal system to maximise the profitability of using recovered equiment in remanufacturing operations. In parallel, Xerox began its 'Waste-free Products and Factories' initiative in 1991.

What was the response?

The company shifted its operation from a product based system (selling a photocopier plus maintenance) to one in which it provides a service (selling the ability to produce copies). The service model is intended both to improve customer experience and to incentivise and enable Xerox to address the minimisation of waste throughout the design, make, use and end-of-life stages.

Xerox has produced toner which requires less mass per page, and their High Yield Business Paper can utilise 90% of a tree, whilst typical paper uses only 45%. Modular product design, wide product compatibility across models, integrated return logistics, ease of assembly and disassembly and the development of hi-tech quality assurance methods has allowed reuse of over 90% of components and remanufacturing of products.

The 'Waste-free Products and Factories' initiative passed a major sustainability milestone by diverting more than 900,000 tonnes of electronic waste from landfills around the world.

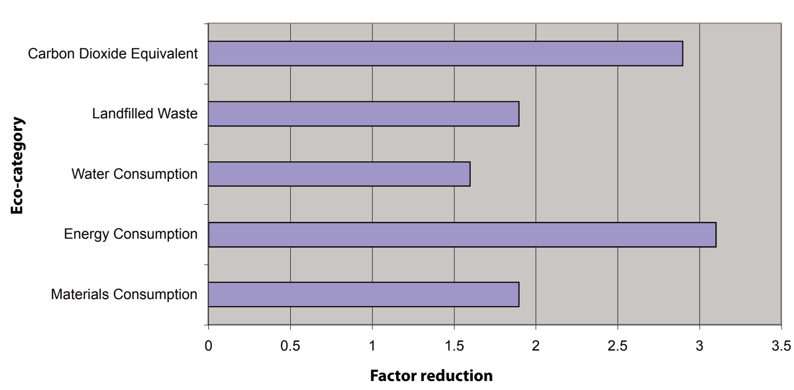
Bottom line benefits

The remanufacturing of products can lead to significant eco-efficiency gains (see chart), reducing the resource consumption and waste production of Xerox as a business. Parts that enter local repair programmes in the UK are reported to result in annual savings of $4million.

Wider lessons

By bringing the product under their control Xerox have the opportunity and the motivation to deal with both through-life and end-of-life issues. Some analysts suggest that the strength of the Xerox remanufacturing-based business model is inherent in the type of products they produce – the products are large, robust, easy to disassemble and valuable when remanufactured. The company has made a substantial investment in developing the systems and technologies which support a resource-efficient, service-based business model.

Eco-efficiency gains from remanufacturing of DC265 modular copiers



Toyota Motor Europe: leaning on production

Toyota Motor Europe operates nine manufacturing facilities within the Greater Europe area. These range from the two oldest, Burnaston and Deeside UK (1992), to the newest in St Petersburg, Russia (2007). These plants operate a comprehensive range of processes for engine and transmission manufacture and full vehicle assembly operations.

What trigger is the company responding to?

Environmental protection is one of Toyota's 'Guiding Principles', first issued in 1992, and further documented in the Toyota Earth Charter. Using these documents as a blueprint for action and applying their management tools, including The Toyota Way and The Toyota Production System, each region developed a series of five-year action plans. These plans set challenging targets to continually reduce environmental impact and were disseminated to all levels of each plant. Toyota Motor Europe (TME) are now part way through the 4th five-year action plan.

What was the response?

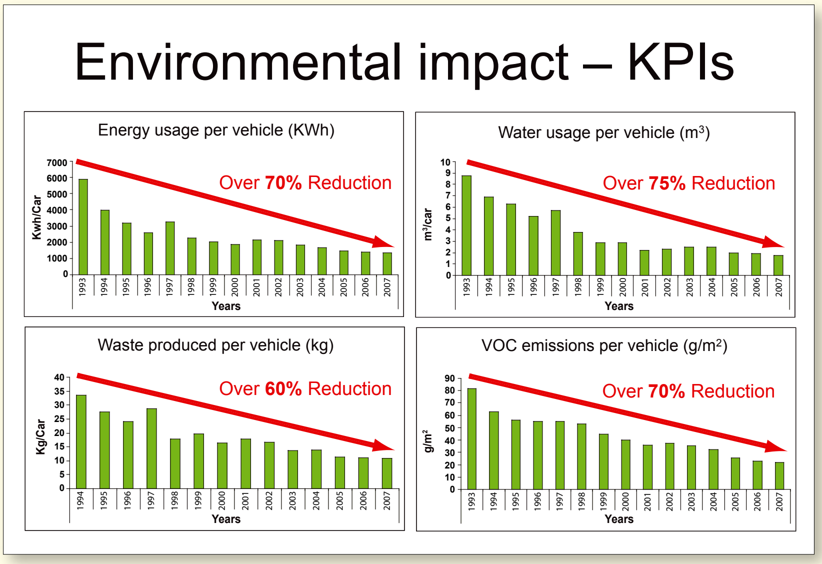
Taking the global aim of zero emissions and a roadmap towards the ultimate eco car as inspiration for the manufacturing companies in Europe, TME developed their own vision 'Towards the ultimate eco factory'. This vision was based upon a strong foundation of legal compliance and risk reduction, with special focus on four major key performance indicators: energy/CO_2, water, waste and air emissions (Volatile Organic Compounds – VOC). These represent the most significant manufacturing plant environmental impacts.

Bottom line benefits

By adopting these principles the European manufacturing environmental impact was significantly reduced. In many areas significant cost savings have also been realised. Toyota UK (TMUK) demonstrates this continual improvement since 1993 (see graphs below).

Some practical examples of TMUK's activities and achievements:

- Zero waste to landfill – achieved in 2003 (two years ahead of target)
- Waste water recycling – 100,000 tonnes of water saved per year
- CO_2 reduction within the boiler house (4,500 $TC0_2e$ per year below 2004 levels)
- Decoupling of CO_2 emissions with increasing production volumes since 2003
- 25% reduction in energy use per vehicle in paint booths



Wider lessons

TMUK and a plant in France, were selected as two of five global Toyota 'sustainable plants' which serve as best practice development models for the Toyota organisation. These plants focus on achieving leading environmental performance, increasing the use of renewable energies and ensuring the plants are in harmony with their local surroundings. Toyota also contributes to a wider audience by sharing information and activity with a wide range of interested parties.

Swepac International AB: longer-lasting soil compactors

Swepac International AB is a small manufacturer of soil compactors in Sweden. They have a wide range of products with various motor options and machine sizes.

What trigger is the company responding to?

About 90% of its customers are rental companies so the end user rarely owns the product. Several of its competitors have a strategy of developing cheaper products and making their profit on spare parts. Swepac's strategy is to have products of good quality, lasting for a long time and needing little maintenance. Its products are scheduled to be refurbished after three years, and then returned to Swepac after five to six years of use, when they are fully reconditioned and sold.

What was the response?

Swepac initiated an ecodesign project, involving an industrial designer, to redevelop the products and the range of services they offer. The ability to use the products as part of their rental service offering was a prerequisite for the design, which also included considerations such as maintenance and weight.

From an environmental perspective it was important that the compactors should be designed to facilitate maintenance. For example, the products' hydraulic system does not need to be opened during its lifetime, unless it needs to be repaired. This avoids the possibility of oil leakage during maintenance.

Another design change involved choosing materials to keep the product looking new, as studies had shown that users were more careful when handling products that looked pristine. A different material was used to make the cover and the product was left unvarnished as the varnish had a tendency to wear off. The need to recycle products at the end of their life also influenced the choice of materials.

Bottom line benefits

The company sees environmental performance as a key selling point for its customers. It also wants to be ready for future demands on environmental performance. The new design facilitates maintenance and refurbishment and the products look fresh. The company has won design awards.

Wider lessons

It is important to consider the design of a product, including product architecture and choice of materials, when optimising technical solutions in relation to the business model and product's use. In Swepac's case design changes made the product easier to maintain and look more attractive. The ecodesign project was seen as a key factor in the company's success.

Old and new designs for Swepac's soil compactor

Adnams: beer with less carbon

Adnams is a publicly owned brewery based in East Anglia in the UK. They produce traditional British ales which are sold throughout the UK in pubs and retail outlets. Adnams aims to make sure their impact on society is a positive one, expressing the company's values in ways which combine social and business benefits with long-term sustainable success.

What trigger is the company responding to?

With volumes increasing and the footprint of the organisation struggling to fit within the confines of its Southwold base, important decisions regarding the production and distribution of their products needed to be made. Ageing production equipment needed to be replaced and a new out-of-town distribution centre was required – it was important that these decisions reflected the values of the company.

What was the response?

The distribution centre was built largely with low carbon materials with excellent insulating properties (e.g. lime and hemp, glulam beams, turfed roof, minimal steel) and also incorporated solar heating and rainwater recovery systems. These measures, plus building location and ventilation design helped to avoid the need for cooling systems to preserve the product. The new production equipment was chosen with quality and efficiency as key priorities – for example 100% of the process steam is reused which means that 90% of the heat from one brew is used to make the next brew.

Bottom line benefits

The new production equipment reduced gas bills by 31% (despite rising volumes) and uses over 60% less water per pint produced. Although the distribution centre cost 15% more than a standard building, electricity bills have been reduced by £49,000 pa compared to an equivalent 'standard' unit and uses 58% less gas and 67% less electricity per square metre than the old centre. The company also worked with their supplier to reduce bottle weight by a third, and has historically used high yield local crops to reduce pesticide use and transport of raw materials. As a result of these wide ranging efforts, Adnams were able to participate in a Tesco promotion involving low carbon products. In conjunction with the University of East Anglia CRed carbon reduction scheme and the Carbon Trust, they leveraged their efficient operation to produce a beer which emitted 25% less carbon than previously (see figure). With a small amount of offsetting (0.004p per bottle), the East Green beer was certified as carbon neutral to the distribution centre.

	High emissions scenario pre-2006 gCO_2 eq per bottle	High emissions scenario post-2006 gC02 eq per bottle
Barley production	43g	43g
Malting process	19g	19g
Brewing process	81g	66g
Transport	39g	31g
Bottling process	66g	54g
Bottle manufacture	334g	219g
TOTAL	583g	432g
tC_e	$159gC_e$	$118gC_e$

Pre and post-2006 emissions per bottle. Post 2006 figures show benefits of new process equipment and reduction in bottle weight

Wider lessons

Adnams' efforts have not been concentrated on one particular area but across every aspect of the production and distribution of products and have included working with others where the company did not possess the expertise or ability to make changes. Adnams' values mean that even when an investment was revenue neutral or slightly negative, they were prepared to back it because they believed it had benefits. These may not show up on the balance sheet, but contribute to the long term sustainability of the organisation.

Navistar and Castrol: chemical management system

The Navistar Diesel Engine Plant in Melrose Park, Illinois, employed 1,200 people in a 1.5 million square foot manufacturing facility as of 1997. Castrol are worldwide producers and marketers of synthetic and conventional motor oil and lubricants.

What trigger is the company responding to?

In the eighties Navistar was experiencing difficulties through a combination of foreign competition and an economic downturn. In the Melrose engine plant downsizing meant focusing on their core business, reducing costs and improving operational controls.

What was the response?

In 1985, the organisation was approached by a Castrol representative with a novel concept: to make Castrol the sole supplier of coolants for the plant. In return, Castrol would accept a flat monthly fee – at a rate below Navistar's current monthly coolant bill. In addition, Castrol would perform many of the routine monitoring tasks which Navistar staff were struggling to complete, such as testing and maintaining the coolant systems throughout the plant.

Though the chemical management system (CMS) provided Navistar with a variety of benefits, the initial champions of the programme, the plant chemists, saw it as an opportunity to refocus their limited resources on activities aligned closer to the company's core business – production, quality control, health and safety. In addition, Navistar stood to benefit from the stable chemical costs and assistance in reducing environmental discharges.

Bottom line benefits

Castrol's fee was no longer linked to the amount of fluid sold and so there was a financial incentive for them to improve chemical use efficiency at the plant. This resulted in a reduction in coolant usage of more than 50%, and a reduction in coolant waste of more than 90%. But the benefits were not limited to chemical volume. Navistar experienced less production downtime and improved product quality. Potential production, health and environmental problems were identified and resolved more quickly, before they became significant. Compliance reporting was much easier, given the chemical tracking data provided by Castrol. Overall, the opportunity for each company to focus on their core business produced superior performance and profitability.

Wider lessons

CMS is a business model in which a customer engages with a service provider in a strategic, long-term contract to supply and manage the customer's chemicals and related services. Through this model the link between production and profit is broken – a company no longer makes more money by selling more stuff. Thus profitable business can be maintained whilst selling less. The approach requires a deep level of trust between the organisations involved. The tender needs careful attention in order that the environmental, operational and compliance goals of both organisations can be aligned.

5 Implications for how we think about the industrial system

The case studies presented suggest that significantly better performance of the industrial system is possible without relying on the development of 'step change' technologies. Instead change is achieved through innovative thinking and careful planning. The examples range in scope; some address individual aspects of the industrial system in which they operate e.g. Production (Toyota), others address the wider system of manufacturing[1] which can include product design, production, materials flow and the business model (Xerox, Vitsoe).

Whilst it is important to address the impact of each aspect of the industrial system and pursue aggressive reduction in the impact of specific activities, we must also examine the operation of the whole system. Efficiently manufacturing products that are inefficient in use, for example, is not enough. This approach can even result in substantially negative outcomes when efficiency gains or cost reductions result in increases in consumption (the so-called Rebound Effect).

The greatest opportunity to reduce the impact of the industrial system on the planet arises when we consider the whole system. The optimisation of any individual component of the industrial system – be it the design, manufacture, delivery or recovery of products, materials and services – is inherently constrained by the other aspects of the system.

Not every system will be able to reconfigure its business model or 'green' its existing manufacturing process – this is why the whole system must be considered when addressing the environmental implications of the business. Only by using this broader frame of reference can we access change on the scale the planet requires.

Here a new shared understanding and mental model of a future industrial system is urgently needed. Many researchers and academics have already contributed valuable new ways of thinking about our industrial system[2] (see box opposite) but many of these paradigms have not been adopted and integrated into the way we study, teach and consult on industrial systems. All manufacturing scholars should consider how their work can contribute to creating a sustainable industrial system – whether by building upon existing approaches or by conceiving completely new ideas. This implies we must each gain a better understanding of how our current work – whether in production technology, supply chain, innovation or strategy – impacts on the shape of the industrial system. With a better understanding of the interactions between the ecosystem, the industrial system and our own specialist knowledge, we can begin to explore changes to our teaching, research and practice.

Technology development is essential to achieve significant changes to resource efficiency but considerable potential also lies in applying existing practices and knowledge to a broader view of the industrial system. In parallel with technology-based research we should broaden the boundaries of the systems we operate in and integrate elements/variables to achieve system-wide improvements. In particular we should include externalities such as environmental impacts, the end-of-life phase, the use phase and social implications into our perspective. These perspectives are not well represented in our current understanding and teaching of industrial systems, and the manner in which we do research, teach students and inform industry is not yet fit for the challenge to create a sustainable industrial system.

System thinking

The design of sustainable industrial systems requires 'system thinking'. This implies:

- a better understanding of the relationship between the industrial and ecosystems
- a better understanding of customer value
- new mental models to reflect the need for 'closed loop' cycles for components and materials (where materials are not lost to the system), networked-distributed production, system resilience and learning from biological examples
- increased sharing between disciplines
- new systems of education, training and research
- much closer collaboration between consumers, industry and policy makers

Systems thinking provides the foundation for a proactive approach to the design of industrial systems. Industrial practice has already embarked on a period of significant change; industrial education, research and policy must accelerate to support that change and enable further experimentation. The evidence that we have seen from the case studies demonstrates that dramatic improvements can be made at the level of sub-systems, such as factories or businesses. In parallel, however, it will be necessary to develop the understanding and capabilities necessary to enable changes in the whole industrial system.

[1] Manufacturing is defined as the full cycle of activities from understanding markets through product design, production and end of life management issues.

[2] e.g. Ehrenfeld, Graedel and Allenby, McDonough & Braungart, Robèrt, Anderson, Lovins, Manzini

Existing models of industrial sustainability

A few pioneers (such as Ehrenfeld, Graedel & Allenby, McDonough & Braungart, Robèrt & Lovins) have proposed mental models to help us understand what sustainability is, how it impacts upon the current industrial system and how the industrial system may have to change. Each of these models emphasises different aspects.

The Natural Step framework developed by Robèrt defines a sustainable society as one where nature is not subject to systematically increasing concentrations of substances extracted from the Earth's crust; to systematically increasing concentrations of substances produced by society; to systematically increasing degradation by physical means and, in that society, people are not subject to conditions that systematically undermine their capacity to meet their needs. The framework also emphasises back-casting from the desired end-point (a sustainable society and industrial system) to create a programme of change.

The twin concepts of living within the planet's means, and of moving from a linear industrial system to a closed loop system (where no materials are ever lost to the system) are shared with many of the other models.

The Industrial Ecology model is championed by Graedel and others. Based on a comparison between industrial and natural ecosystems, Industrial Ecology seeks to position the industrial system within the ecosystem and to emulate that system's ability to use all its wastes as raw material for other life processes. In Industrial Ecology practice we already see many manufacturers using waste from others for their own processes.

McDonough & Braungart proposed a **cradle to cradle model** as a specific form of Industrial Ecology, whereby they separate all materials into either 'biological nutrients' or 'technical nutrients'. Biological nutrients can be decomposed and allowed to re-enter the natural system, while technical nutrients should be kept within the industrial system and used multiple times. McDonough & Braungart have proposed a number of techniques which can be used to define, measure and implement cradle-to-cradle operations.

The relationship between people, products and the industrial systems that develop and deliver those products is explored by Ehrenfeld who defines sustainability as 'the possibility that humans and other life will flourish on Earth forever'. In his work **Sustainability by Design** he proposes a set of root causes of unsustainability – including the consumption culture and a poor understanding of the complex interactions between people, products and planet – and seeks a balanced approach to achieve significant change while holding onto the best of current systems.

The Natural Capitalism model, as espoused by Hawken, Lovins & Lovins, draws a picture of the 'next industrial revolution' being based on four strategies – 'radically increased resource productivity, redesigning industry based on biological models with closed loops and zero waste, shifting from the sale of goods to the provision of services, and reinvesting in natural capital'. They argue that the growing scarcity of natural resources will act as the catalyst for the next industrial revolution in a similar way that the scarcity of human resources drove the logic of the first industrial revolution.

Many authors envisage the transformation of existing product-based production systems to systems based on a combination of products and services (or services that provide access to products). The concept of such **product service systems** is closely aligned with other business models which reduce material consumption by increasing the information-density of products (where the market value comes to reflect the information, rather than the material content of the product). In most information-intensive products the information content provides some additional service function; for example, the value of a mobile phone derives from its communications and other information services and such information systems now constitute a substantial part of the value of many other products, from domestic appliances to automobiles. In general the services or information added to a product contribute to its dematerialisation – reducing the amount of material required per unit of value.

This is not an exhaustive list of industrial sustainability models and some of these pose sigificant challenges still to be addressed. For example, a system based on returning all products to their constituent materials (to be returned to the system) would still require significant, and ultimately prohibitive, levels of energy for the process of capturing and reusing those materials.

These models come from pioneers attempting to map a new territory; for those who are beginning their own exploration of this new territory every map is an aid, no matter how incomplete or flawed.

6 Planning for tomorrow

Our vision is a sustainable industrial system that delivers high value to its growing base of customers around the globe, while using, at most, a quarter of the current resources.

Such a system would be very different to today's global industry – less homogenous with different business models and different relationships, creating different products and services. It is not at all clear what such a system would look like, indeed there may be very different industrial systems working alongside one another.

The urgency for change is now feeding through from scientists into mainstream government, business and academic thinking. The rate of change is likely to increase and we can observe many businesses quietly tackling parts of the challenge.

The path to a sustainable industrial system is difficult to plot – we are simply too naïve in our understanding of the relationship between industry and ecosystem and we lack sufficient experience to plan the whole journey.

This offers a rich ground for academia over the coming decades, indeed we might expect that the deliberate design of an industrial system becomes a specific skill, requiring education and research to match.

The immediate need is for rapid changes to existing systems and it is possible to observe a pattern from some of the pioneering manufacturers. These suggest that academia must improve its understanding of how industry impacts the ecosystem, must seek out new collaborators in a deliberate programme of problem-solving research and education, must explore a variety of new mental models to describe the industrial system and must collectively gather and learn from practice.

Based on this each of us can make informed choices about whether and how to change our own teaching and research to support the delivery of well informed students and new knowledge.

Recommendations for educators

- Every manufacturing and engineering design course must have a substantial component of teaching that explains climate change and resource productivity, and explains how the industrial system interacts with the social and environmental systems of the planet.
- All qualifications to be 'time lapsed', so that practicing engineers and manufacturers are encouraged to renew their knowledge. Part of that renewal would include specific components on sustainable industrial systems and biological systems.
- Universities to cooperate urgently in developing teaching material that is locally appropriate.
- Creation of a virtual and real International Summer School for teachers of the Sustainable Industrial System, in order to significantly accelerate the development of faculty capability.
- All topics taught to manufacturing and engineering students should be looked at in terms of their contribution to sustainability, and all student projects should include at least some discussion on sustainability impacts.
- Encourage interaction with environmental scientists and policy students on the positive role that the industrial system can play in making modern society more sustainable. These students would benefit greatly from learning the improvement, problem-solving and innovation skills that manufacturing and engineering design students gain.
- Measure and improve the total energy and material used to deliver our education (per student) and engage faculty staff and students in improving that.
- Team up with any local manufacturers who have experience in improving resource productivity – providing them with student resource and providing academia with teaching resource.

Recommendations for researchers

This is not intended as a specific research agenda on the topic of sustainable industrial systems; the focus is on how research might change.

- Encourage large, problem-solving research (e.g. the human genome project) where we avoid duplication of research effort if possible, and agree to tackle specific topics.
- Develop the new field of 'design of sustainable industrial systems'.
- Investigate which models of new industrial systems can deliver the radical changes required.
- Work with local industry on problem-solving projects, preferably with other disciplines and preferably with ambitious targets for improvement, that cover the whole industrial process.
- Agree on formats for making research available to other researchers and practitioners in a manner that encourages its use in practice. Current journals do not achieve this.
- Agreement on standards for measuring and assessing progress toward sustainability, to encourage transparency in both academia and industry in reporting results.
- Build tools to help industry calculate what the best performance of a whole system might be.
- Build a database of good examples and share globally.

Recommendations for industrialists

- Find out what is possible today without radical change and implement this quickly – don't be content with less than 10% improvement.
- Identify your largest two to four environmental impacts and engage with existing communities and universities who might know how to tackle these.
- Join with universities and/or unions and/or governments in benchmarking your performance against similar companies and against best possible targets.
- Pester your government to change policies so they reward the positive activity of doing more with less.
- Work with customers, suppliers, competitors, governments and others to promote system-level change.
- Investigate radical change of the industrial system and your potential role in it.

Recommendations for policy makers

- Funding of technological innovation and sustainable innovation should not be separate.
- Understand what the current 'best-in-class' performance is for all products and systems, so that we know how near (or far) the majority of products and systems are from this.
- Demand best-in-class products and manufacturing practices from suppliers (such as Japan's 'Top Runner' scheme). This works for both government procurement and, through legislation, for consumer products and systems.
- Support and reward significant reductions in energy and resource use.
- Facilitate industry cooperation delivering system-level change.
- Ensure that the full energy and resource 'shadow' for all products and services are available to producers and consumers.
- Support massive re-education of the existing workforce, as they are best placed to deliver immediate change.
- Recognise that a low-carbon economy is fundamentally different and support efforts to explore these differences.

Conclusions

Industrial systems have evolved through competition and technological change, always seeking to do more with less than the competition and so survive into the next generation. This Darwinian metaphor is compelling and often useful, yet it fails to capture our uniquely human ability to predict and plan. Only humans, and by implication also our industrial systems, can see a future peril that has never been seen before and prepare for it.

We argue that those industrial organisations that predict and plan for a sustainable future are likely to survive into the next generation. Learning how to use significantly less material and energy to create the same or better customer value, while creating little or no waste is not only a sensible long-term strategy but a compelling argument in today's volatile world. Such businesses will be resilient to some of the forces bearing upon them. The moment for significant action is now.

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