White paper

# You can save the planet with design & engineering simulation

## Towards design-for-recyclability and sustainable manufacturing

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# Executive Summary

Manufacturing processes today span everything from aerospace to automotive, energy generation to oil & gas, and electronics to shipbuilding. Yet, all these contribute to emissions and environmental pollution as well as intensive use of our world's precious energy and water resources. With a burgeoning human population on planet Earth, limited natural resources, and endangered species and habitat, the need for sustainability has never been more critical in the history of humanity. Both global warming and the possibility of an environmental catastrophe appear to be an existential threat to life on planet earth, or at least an irreversible consequence to mankind's poor stewardship of our unique ecosystems in the last century.

Computer-aided engineering (CAE) and design simulation emerged from NASA in the 1960s and has risen on the back of the developments in digital computing to be a $5Bn/y industry today, fueled by advances in 'Moore's Law'. Since its inception, CAE has been driving efficiency, quality, and productivity in asset intensive manufacturing processes through the creation of what the industry now calls 'digital twins': virtual physics-correct representations of real components, products, subassemblies, and systems. However, the advent of the worldwide web, the Internet of Things, and the generation of 'Big Data' and AI (Artificial Intelligence) to optimize both manufactured products and processes has meant that latterly digital transformation can take product quality, manufacturing productivity, and ultimately sustainability to the next level. We have reached what is now frequently called Industry 4.0 with the next big wave in manufacturing being autonomy across factories, facilities, transportation, farming, mining, cities, and even nation states.

CAE today is proven to reduce waste at the conceptual design stage; reducing physical prototyping, delivering right-first-time customized solutions, fueling the renewables revolution. Ultimately, it brought design-for-recyclability to the fore for the highest business ROI (Return on Investment) possible in product development, and then even through to the complete product lifecycle of full recyclability in what is increasingly being called the 'circular economy'. CAE is both a source of simulation data and a glue to the 'digital thread' needed to deliver manufacturing cost savings, productivity improvements, and ultimately quality products designed with the intent to meet all environmental challenges today from the starting idea.

This white paper assesses the extent of the sustainability challenge facing mankind and our planet today, and examines the underlying factors. It then looks at how these factors can be effectively addressed at source for the manufacturing industries we all rely on to deliver our consumer products and the quality of modern living we all expect, to illustrate what smarter-by-design really means in a world crying out for sustainable engineering solutions.

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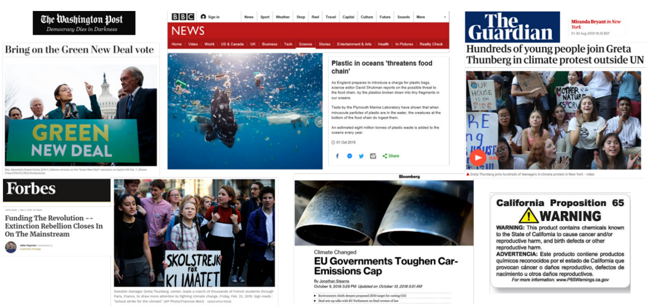
## Climate change, the ‘climate emergency’ and ‘extinction rebellion’ activism

Whether it’s killer smogs in Delhi or Beijing, droughts and floods in sub-Saharan Africa, forest fires in California, Australia or the Amazon – the green lungs of the world are disappearing at an alarming rate of four times the size of Wales every year. These issues have all come to the fore recently in ever more shrill 24 hour news cycles. And when we contemplate plastics polluting our oceans or shrinking ice sheets in West Antarctica with receding glaciers in our major mountain ranges, what appear to be ever increasing ‘climate events’ and their devastating consequences to both mankind and our environment; something is not quite right. The Swedish schoolgirl environmental activist, Greta Thunburg – virtually unheard of over a year ago – was recently able to lobby the United Nations in New York and to grab huge media attention worldwide in association with the ‘Extinction Rebellion’ protests that she instigated. Whether haranguing the world’s leaders in New York gets the desired result or not, increasingly we are seeing the rise of Green political parties in Europe and the emergence of ‘Green New Deals’ in America as politicians scramble to respond to the sustainability agenda. Environmental concerns over the sustainability of our unique and beautiful planet with its complex interconnected ecosystems are not new, but they have clearly moved from a fringe topic to be a political priority in the developed world over the last decade or so (1, 2). The advent of environmental direct-action over the last year or so is a consequence of huge public concerns over climatic changes happening in the last century and the scientific research now showing the extent of global warming. And we can expect ever more stringent environmental legislation to come as a result from our legislators and parliaments around the world to combat this issue.




Our global mainstream media is increasingly highlighting environmental and sustainability concerns

But what exactly is ‘Sustainability’? The concept is arguably as old as we humans in our families and tribes reusing our nearby resources to survive from year to year; but it has emerged in our time to take its present form because of the Environmental Movements in the 1970’s. The best definition is that taken from a seminal United Nations Report on ‘Our Common Future’ in 1987 by the Norwegian politician Gro Harlem Brandtland (3) who wrote that:

> **“Sustainable Development is the development that meets the need of the present without compromising the ability of future generations to meet their own needs.”**
>
> **Gro Harlem Brandtland**

The UN’s response to Brandtland’s work was the subsequent Kyoto Protocols in 1997 and the Paris Environmental Agreements in 2015. These accords made all the world’s major nations agree to restrictions in harmful so-called ‘greenhouse gas’ emissions (mainly CO2), along with timetables for countries to move towards ‘sustainable’ energy sources in the future. Sadly, the protocols have not been entirely successful as several nations have flouted them. But they have created impetus and a framework for change, and they are still driving momentum for change today that activists are harnessing.

## The earth and sustainability – how bad is it really?

In a presentation at HxGN Live in June 2019, President & CEO of Hexagon, Ola Rollén, delivered a sobering keynote to the audience describing the unprecedented sustainability challenges facing humanity and our beautiful blue planet which is itself a complex equilibrium system (2). He presented some shocking statistics - including the fact that one million species on our planet are in survival jeopardy today. Indeed, since the dawn of time we have killed off over half of the species on our planet including 80% of all sea and land mammals. By 2050 we will have trawled all fish from our oceans if we continue to fish at the levels we do today. In the last 120 years alone, we have lost 1,000,000,000 hectares of forestry from the face of the earth; that’s about the full land mass of Canada.

A big factor in the current ecological crisis on planet earth is the increasing world population of humans and the sustainability challenge that a growing population inevitably poses given finite natural resources and a thrust towards Western living standards across the world. In 1804 the world’s population passed 1,000,000,000 people for the first time. It took another 123 years to reach 2 billion, and then the planet’s population rose to 3 billion people by 1960, 4 billion in 1974, and it has now peaked at 7.7 billion today. By 2050 it is estimated that the world will be inhabited by 10 billion humans and we will have an even bigger global middle-class market of consumers. The world’s human population has risen dramatically but we’ve not scaled sustainably especially when one considers that we are reaching so-called ‘Peak Oil’ in a key natural resource exploitation and one-third of all agricultural produce each year goes to waste.

Across the world we emit approximately 100 million tonnes of $CO_2$ each day into the atmosphere and this is projected to double by 2030 unless we reverse our behavior (2). We are emitting so much $CO_2$ that a 'Doomsday Limit' will be reached by 2050 - according to Rollén - where it will be hard to correct for the emissions we make. Of the 36 Billion tonnes of $CO_2$ related greenhouse gases we emit each year, nearly 35% comes from energy production (for electricity), 25% from agriculture, 20% from industrial emissions, 14% from transportation and 6 % from buildings. In the USA alone, 68% of total energy production $CO_2$ goes up into the atmosphere and is not recovered or recycled. Rollén states that 71 out of the 100 top polluters in the world today are companies or corporations; only 29 are countries.

Our consumption of difficult-to-biodegrade products increases year on year - we typically produce 1,000,000 plastic bottles a day in the world and less than half are recycled (2). We typically buy 1,000,000 plastic bottles a minute. By 2029 more than 5 trillion plastic bottles will have been made and disposed of, and 8 million tons get into our oceans every year. Rollén reported that we ingest 70,000 microplastic particles per year into our bodies. Indeed, our addiction to single-use plastics is contributing to a mountain of plastic waste that we recycle in Europe and North America and then our governments ship the waste that cannot be disposed of half way around the world for either landfill or, increasingly, ending up in illegal burning of plastics in developing countries with lax environmental regulations. Recently China and Malaysia have refused to accept such western world waste anymore. What is also quite sad is that the top ten nations responsible for polluting the oceans with plastic are all in east Asia.

Whatever one's political viewpoint, it is self-evident that we need to reach sustainable usage of the world's natural and recycled resources, especially with a rising human population. The impact of consumerism in the developed and developing world alone, increased urbanization, and an addiction to single use fossil fuels, is creating a huge problem that humanity needs to address in the 21st Century if we and our planet are going to survive in a form we are all comfortable with. Indeed, it is stating the obvious to say that a large number of Asian, North American and European cities are at risk from sea levels rising if global temperatures increase significantly because they are located on low lying coastal plains.

## Sustainability in manufacturing; a road less travelled, a journey worth taking

At the end of the Second World War, Japan's industrial base was crushed; manufacturing machines were broken, and engineers had to work with very few materials on production lines that were prone to shortages in the post-war depression. American academics like Professor Edwards Deming came to Japan and encouraged Japanese manufacturing industry to adopt a wholesale embracing of 'Total Quality' methods in their factories. Slowly, over two decades, Japan pulled its manufacturing base up to be one of the best in the world. Japanese industry invented the term 'Just in Time Manufacturing' that caused their industries to become world class. Indeed, the Japanese word kaizen - that represents total quality manufacturing - means incremental performance improvement within existing manufacturing processes, and it soon led to better products in Japanese factories such that by the 1960s their productivity was twice that of equivalent Western European and North American factories, with minimal waste and high quality. 'Just in Time Manufacturing' was rechristened as 'Lean Manufacturing' in the 1980s by western academics as it came back into the Western World and was widely adopted. Factories then moved towards automation in the late 20th Century and we are now seeing a shift towards autonomy in the 21st Century.

President & CEO of Hexagon, Ola Rollén

Like all manufacturing industries globally, suppliers of consumer and industrial products are being forced increasingly to embrace sustainability criteria in their product development processes whether they want to or not, because of the quadruple pressure points of declining natural resources, governmental legislation, societal pressures and consumer choice. According to Rollén (2), most companies today want business growth and many talk of sustainability (however it is defined). But all definitions are grounded in the same notion, that we're overwhelming the earth's resources and creating more waste than we can handle. Indeed, some argue that we will need 3-4 planet earths by 2050 if we continue consuming at the levels we are doing today. So, is there any good news? Well, continued economic growth according to Rollén doesn't have to be at the expense of the planet. Every company today wants to boost its efficiency, its productivity, and quality outcomes via 'Smart Factories' and 'Smart Manufacturing' processes as companies embrace the looming autonomy challenges of the 21st Century. And if they can achieve those outcomes at scale, not only can they sustain growth for their businesses, but also for the planet that we all share. In effect, sustainable manufacturing will lead to fewer natural resources being used, less waste through perfect quality products, and less pollution through zero or no emissions. It actually makes good business sense to embrace sustainability as Rollén correctly observes.

To achieve sustainability in all industries, design & manufacturing engineers who make the commodities we all rely upon, will need to increasingly design sustainable processes, products and value chains. Hence, sustainable development in the context of engineering design means we need to embrace four context levels: Planet, Society, Business, and Technology (1). Sustainable design therefore needs to address problem definitions, synthesis of potential solutions, analysis of possible solutions, and then improvements to the final solution, all in the context of a solution that meets both the needs of people and all specific contextual constraints with respect to the planet and prosperity. Sustainable design engineers in the 21st Century will therefore have to consider and meet constraints on energy usage, water, food, health, and other basic human needs as part of sustainable manufactured product design processes. Once sustainable engineering is achieved, we will see, for instance, rapid startup of Industrial factories and facilities at lower cost with safe, efficient and environmentally friendly operations and longer lifespans. It also will mean that buildings and the built environment will have optimized resources by design, that is, less rework and projects delivered on plan, on time, and on budget. In the Mining Industry for instance, sustainable engineering will mean minimal environmental impact, safety is prioritized, and communities consulted, and operations will be run at maximum efficiency. In Agriculture and Farming, sustainability will mean that inputs are optimized at source, and farmers will produce higher crop and livestock yields with less waste, and at lower cost.

Science and technology underpins our modern world in ways that the average person on the street may not fully appreciate; appearing in the form of advanced modes of transportation for both people and goods, new means of power generation to maintain our global economy, advances in healthcare to improve the quality of our lives, the creation of new chemical compounds and materials never seen or used before by mankind, and breathtaking new pieces of electronics and telecommunications equipment. The consumer products industry, across the world in particular, has been operating very much on a disposable commodity basis for many years and especially in the 20th Century. Indeed, many products require high levels of energy to manufacture, they can involve exploitation of low-paid labor in the developing world, and they are conceived with little thought for recyclability and sustainability in mind with respect to the global environment. And, increasingly, only the big multinationals can make these products economically with ever thinner profit margins. Consumer product manufacturers, however, will have to embrace the latest advances in the fields of technology and engineering to be more environmentally friendly and sustainable in the 21st Century. I believe that opportunities and legacies for sustainable design in manufacturing will emerge as science, technology and engineering will be the agent for solving many of the energy and environmental problems we face globally this century.

## Design & engineering simulation (CAE) for sustainability

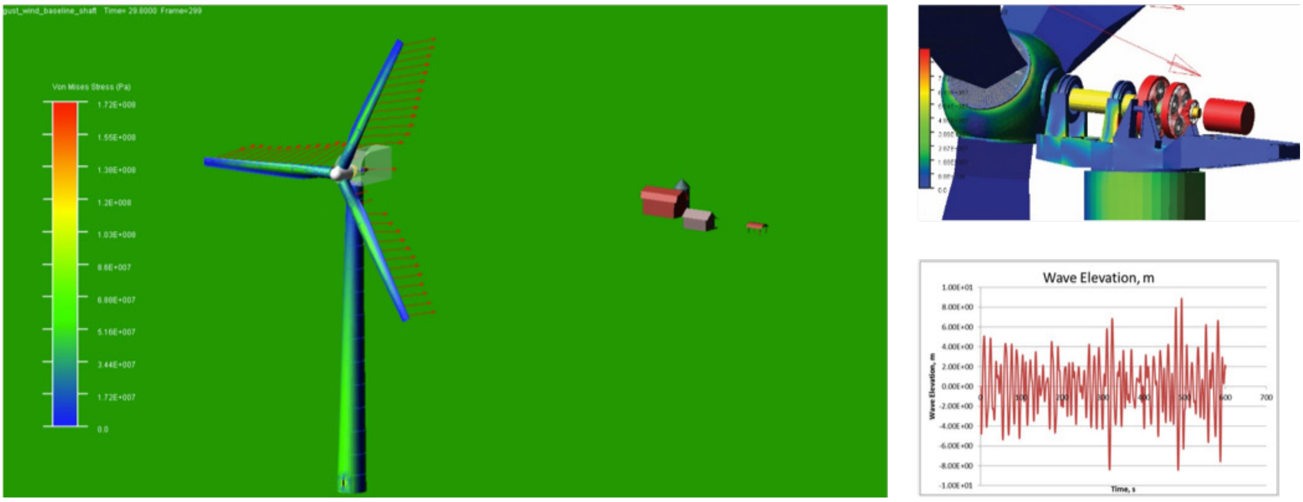
Since its nascent use over 50 years ago, Computer Aided Engineering (CAE) has by its very predictive nature been at the forefront of more efficient and high-quality product development. It has also been leading the way in developing new environmental technologies for renewable and clean energy sources and recycling, and companies like MSC Software (part of Hexagon AB since 2017) have been global pioneers. We see this repeatedly because CAE engages with research & development design processes so that better and more efficient products can be designed with fewer (and sometimes no) prototypes being built during the manufacturing process. This means less material waste, low scrappage rates and lower energy usage. In short, CAE helps to design products 'right-first-time' and 'fit-for-purpose' in each and every industry it is applied to. CAE is also 'upfront' in every product design and manufacturing process (and concurrent throughout the process) in the world. This means it can be used to design out undesirable performance features and to avoid negative environmental impacts at the early conceptual design stage when ROI is highest. And CAE can conceptualize as yet untested manufacturing processes and new products so it is therefore a very cost effective and safe way to test 'what if..' scenarios without hazardous consequences to both people or the environment. This century will bring opportunities for new socially conscious, environmentally friendly, sustainable, high-tech engineering products and companies all producing outputs conceptualized and designed in PLM (Product Lifecycle Management) software driven by CAE simulations.

Today, CAE design & engineering impacts all of the main infrastructure industries in the world - energy, water, food, and health. It is well known that CAE boosts efficiency, productivity and quality outcomes in all of these sectors because it deals with fluid flow, heat transfer and materials (mass) transfer as well as electrical and magnetic effects. CAE can impact environmental sustainability across all industries in four main areas:

- Energy Generation
- Transportation
- Farming, Food & Water Management
- Materials – Mining, Metals, Plastics, Fossil Fuels, and Next Generation Materials

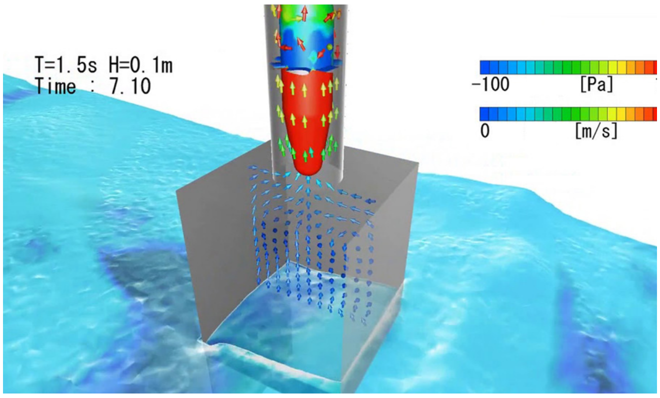
## Energy generation, management, storage and sustainability

Electricity generation and electrical storage, deployment and use are essential to the developed and developing world's quality of living. In both the developed and developing world, we frequently generate air pollution through our political choices. Some countries subsidize fossil fuel companies and even prioritize high carbon emission energy sources over renewables because it is cheaper, and it allows them to gain national GDP growth over the environment impact locally such fuels have. A phrase we are hearing more and more in the sustainability debate is 'carbon neutral'. Carbon neutrality essentially means cutting $CO_2$ emissions at source or by so-called 'carbon capture' methods - like sequestering of $CO_2$ gas in rocks underground, planting more trees to capture carbon - or by using renewable sources like solar/wind/wave power generation and management. What is interesting is that the cost of renewables – wind and solar power generation in particular – has been plummeting of late and getting close to that for fossil fuels. However, the 'elephant in the room' with respect to the energy industries is nuclear power generation (via nuclear fission). Nuclear power actually generates near zero carbon emissions, but Green




Adams simulation solutions for wind energy manufacturers

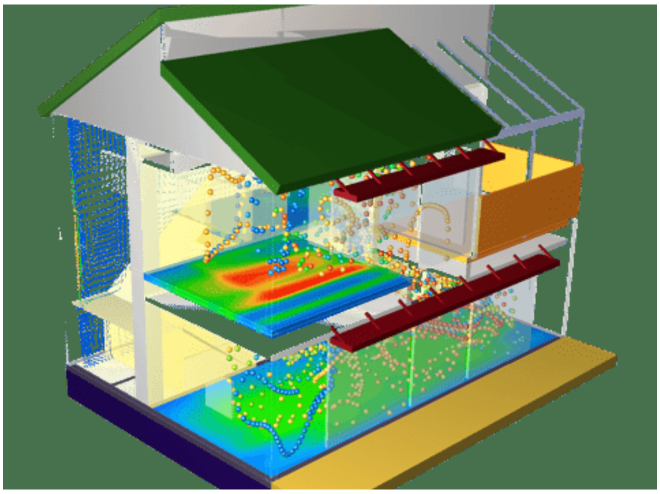
politicians hate it because of its long-term impact after accidents and nuclear spill emissions like those at Six Mile Island, Fukushima and Chernobyl which metaphorically hang over the debate and have negative impacts lasting hundreds of years. Nuclear fusion power is conceptually possible as an alternative and it is known to be 'clean', but it has been promised for over 30 years and as yet no viable approach has emerged. It could still come to humanity's rescue though this century.




Seawater wave power generation wave simulation in the scFLOW CFD software of a wells turbine

If one examines CAE applications in the Power Generation and Renewables Energy sector over the last twenty years, we can quickly see that design and engineering simulation has been in the vanguard of new technologies because of its cost-effective predictive abilities. MSC Software products have been helping to design radically new and innovative energy generation processes, as well as traditional power plants and nuclear reactors.

CAE has been used to simulate renewable technologies such as wind and wave turbines, plus zero emission solar panels have been designed for optimal structural, acoustic, fluidic, manufacturing and mechanism design. In short, CAE simulation has resulted in leaner power generation operations and reduced carbon footprints by right-first-time conceptual design. As the cost of scalable sustainability keeps decreasing in real terms, improving energy facilities and usage of CAE in Oil & Gas processes will also have a major impact on environmental sustainability.



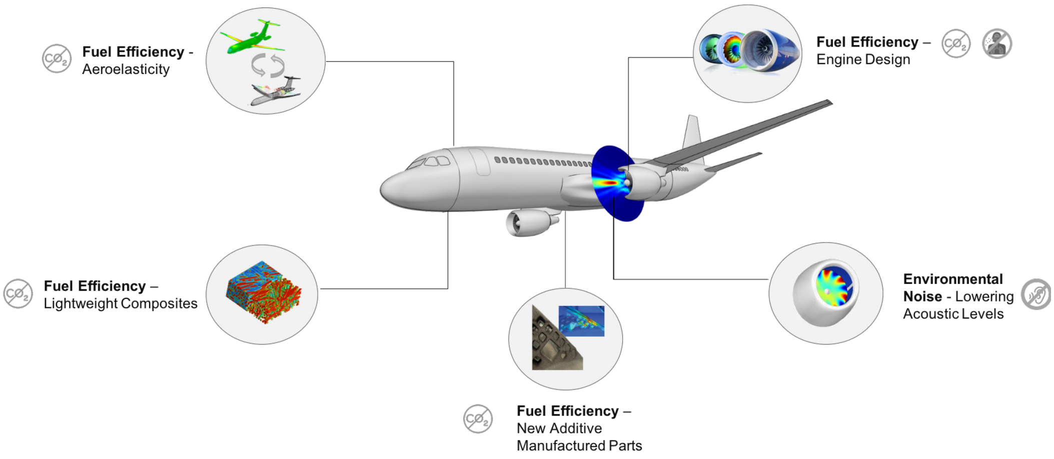
MSC Software products have been helping to design radically new and innovative energy generation processes

## Transportation and sustainability

Present forecasts for aerospace industry trends indicate that there will be 34,000 civil aircraft in the world by 2036, a 60% growth on today with 40% being replacement aircraft. This demand in air travel is being driven generally by more affluence in Asia. We are also seeing a major thrust towards the electrification of automotive engines and powertrains with the global drive towards electric vehicle design, manufacture and deployment by companies such as Tesla.

## Towards next generation sustainability in aircraft design with CAE

The new Airbus A350-1000 and Boeing 787 Dreamliner are some of the most technologically advanced passenger



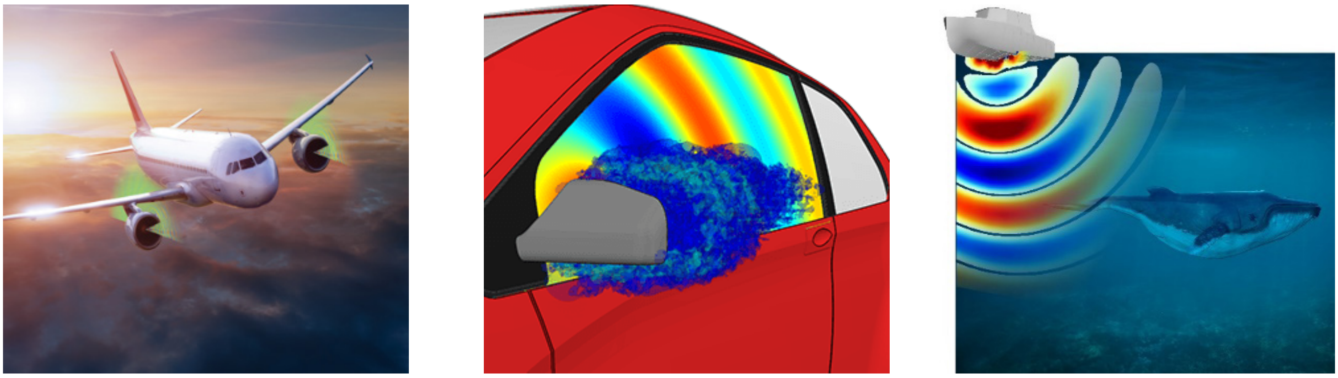

aircraft in the world and these next generation aircraft have been extensively designed by CAE. They are also eco-friendlier than their predecessors. The A350's wings actually structurally deform during flight especially at altitude where the aircraft slightly transforms its flaps to fine-tune its center of gravity depending on its weight at that point in time as fuel is consumed. Doing this process, it optimizes its flight lift-to-drag ratio and decreases fuel consumption over conventional planes significantly. The Airbus' engines will be the most powerful ever, generating a maximum thrust of 97,000 lbs (over a quarter of the thrust of the NASA Space Shuttle)! The net effect will be that its range of 8,000 miles means it will be able to travel from London to Perth Australia in one flight as we are starting to see. In addition, optimal fan performance in the design of the aircraft's engines, coupled with other efficiency improvements conceptualized by CAE simulations mean that the A350-1000 will use 25% less fuel than any other commercial aircraft. This will reduce its carbon dioxide emissions and overall traveler carbon footprints significantly. Moreover, the engine's acoustics are 40% lower than other aircraft engines in its class thus minimizing acoustic pollution – all thanks to CAE. Boeing and Airbus aircraft airframes won't be made of aluminum. Instead, exotic new titanium composite materials are being employed that are stronger and lighter. These will have an added benefit that the atmosphere inside the cabin can be more humid than ever before so that passengers will breathe air with a density and humidity typical of that at 6,000 feet rather than 40,000 feet thus leading to less hair static and itchy, skin rash than ever before!

Aero engines are some 50% more efficient than 30 years ago. Commercial airlines are forecast to use about 97bn gallons of jet fuel this year, a record. bio-fuels currently offer the best option because they have the capacity to reduce the carbon footprint anywhere between 50-80% when you compare them to fossil fuels. One route is to get rid of fuels completely, or perhaps combine them in electric hybrid engines. It's not an option for huge long-haul airliners but for smaller aircraft covering perhaps 1,000 miles electrification is a really good opportunity as it offers the possibility of a carbon neutral flight for a limited range. There are multiple improvements being made: better aircraft aerodynamics, changes to ways aircraft taxi on runways, use of lighter materials, improvements to airspace use to allow more straight-line flying and reduce holding patterns. It is worth noting that electric battery powered (and hybrid) aircraft engines together with aircraft that have solar panels on their wings which result in low emissions are being designed by CAE tools today before they are flight tested. Additive manufacturing of specialist parts, particularly in defense applications, is becoming ever more common. Internal parts of many aircraft can be 3d printed with lightweighting in mind, but increasingly we will see more critical as well as non-critical parts being additively manufactured especially with more sustainable materials and even natural fibers.

Acoustic pollution along with light pollution are arguably starting to become public health issues (7). The Actran product from Hexagon MSC has been used to simulate exotic materials, like composites and other new materials, and their acoustic impact for years. CAE simulation can be used to assess drive-by noise for trucks, trains and cars, and in Green Building Codes for acoustic sustainability. FEA (Finite Element Analysis) simulation techniques have addressed sustainability issues in the analysis of mechanical structures for noise and vibration in terms of passenger comfort to provide generative design for eco-friendly lightweight structures. They have also been used to optimize manufacturing processes with the goal of reduced waste and environmental impact and extension of product life via durability and total cost of ownership simulation in order to support development of smart connected autonomous ecosystems.

## Sustainable cars on our roads because of CAE

The automotive industry is going through unprecedented changes due to tighter emission regulations and emerging massive dual disruptors of electric vehicles and autonomous mobility. In the European Union alone, we will see new $CO_2$ regulations in 2020 where emissions target of 95g of $CO_2$ / km will be in place for all new passenger car fleets, a 27% reduction compared to today. This target will be coupled to an excess emission premium for manufacturers failing to meet the emissions standard of 95€ for every g/km of excess emissions per vehicle. In Denmark, the government is banning internal combustion engine cars totally by 2030. Major cities like London have banned all diesel engine cars from the city center already to minimize dangerous



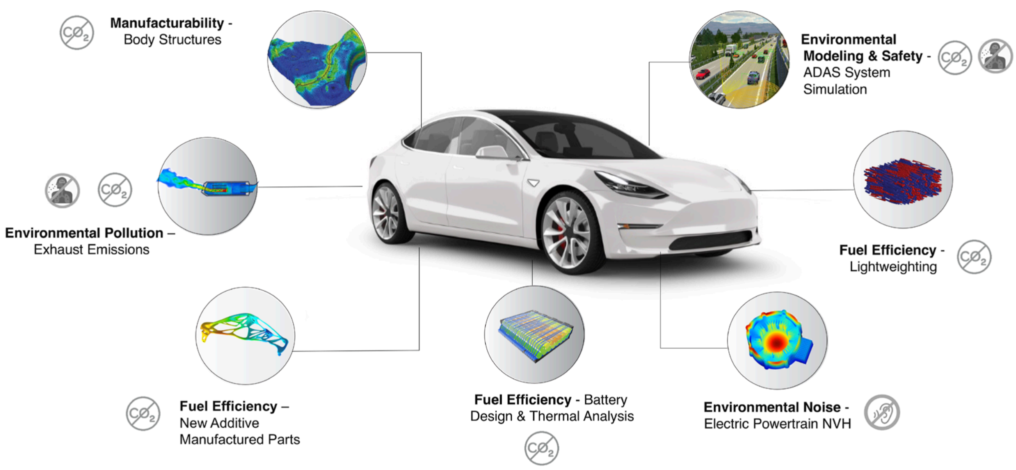
Aeroacoustics in aircraft (l) drive-by wing mirror noise (m) and hydro-acoustic ship hull whale (r) simulation

particulate emissions. Norway will phase out conventional cars by 2025, followed by France and the United Kingdom in 2040 and 2050 respectively. India has said that no new gasoline or diesel vehicles will be allowed by 2030 (if economical).

In order to achieve emission reduction targets in Europe, the electrification of powertrains for all OEM (Original Equipment Manufacturer) vehicles will be required. Indeed, the advent of electric powertrains inside cars will remove considerable complexity in manufacturing with ensuing sustainability benefits. It has also been calculated that around 20% of the world's electricity generation goes into running motors of some form or other. And with the drive towards electrification of cars and ground transportation this will become higher. Hence, thermal effects in both motor design and the electronics driving motors will become ever more important.

Typically, a conventional internal combustion engine in a car has 1,400 parts yet an electric vehicle powertrain will only have 200, so in principle manufacturing will be easier. Electric vehicles are projected to be 54% of all new car sales in 2040 (5). All sorts of lightweighting technologies are being employed as standard in the manufacture of production cars on our road today. Composites were once the preserve of Formula 1 race cars but are becoming ever more common in saloons. And, of course, the major disruption that autonomous vehicles will bring to the ground transportation industry in the next 5 to 10 years will also inevitably lead to sustainability benefits such as near zero emissions, better acoustics and longer vehicle lifetimes and more usage because most self-driving cars will be electric.

In terms of automotive sustainability today, extensive exhaust and drive-by environmental noise CAE predictions and coupled fluid-acoustic simulations of exhaust silencers are being simulated around the world as well as particulate emissions modeling. Simulation can quickly and accurately simulate modern composites and additive manufacturing components dealing with NVH (Noise, Vibration and Hardness) simulations. It is worth noting that electric cars are not a panacea for environmental problems associated with transportation – in many ways they just move pollution source from internal combustion engine exhaust tailpipes to power station exhaust stacks! And we still have major challenges with fast charging networks for all the new car electric batteries that will be needed. Moreover, will our power generation grid systems cope with the new demands of everyone charging overnight? And electric vehicles still suffer from 'range anxiety' in the minds of consumers – the concern that the vehicle will run out of power away from a recharging point due to the number of miles possible under a single charge.

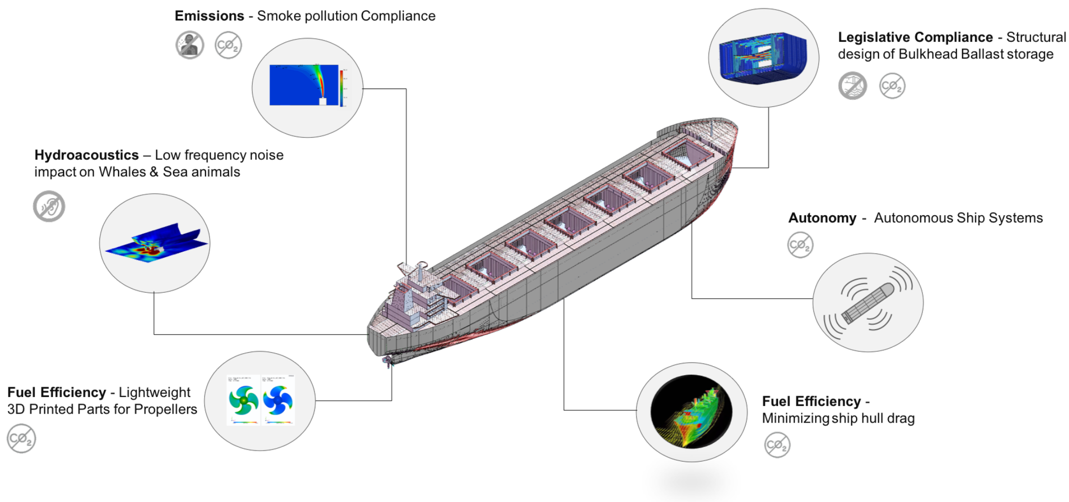


## Sustainable shipping on the high seas thanks to CAE

It is a little-known fact that nearly 90% of all the goods in the world are transported across the planet on container ships and $CO_2$ emissions from international shipping make up ~2% of the world's total greenhouse gas emissions today. Work is going on in the world today to reduce the carbon footprint of all ships by 30% by making ships more energy (fuel) efficient via better ship hull and propeller design, more bio friendly engines, and also reducing underwater noise to preserve marine mammals.

Certain supermarket products that we take for granted, like palm oil for instance, where 85% of the world's production comes from SE Asia, can be extremely damaging to the environment due to changes in land cultivation practices. Palm oil comes inside nearly 50% of all our supermarket purchases – both inside food stuffs and non-food stuffs like shampoos. By and large its cultivation is not sustainable and growing palm trees in SE Asia has denuded tropical forests and the habitats of endangered orangutans and pigmy elephants.

The food industry is a complex network including farmers, grocers and supermarkets as all having visible elements. It also includes manufacturers of agrochemicals and

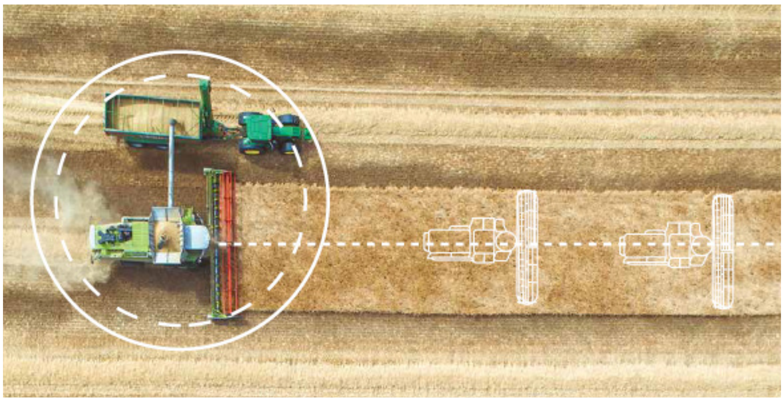



## Farming, food, water management and sustainability

As we have already seen, sustainability is the balance between human activity and the environment such that development can take place without disrupting the ability of natural resources to replenish themselves. It is therefore quite surprising to find out about the total environmental impact of our food chain when we track a food item's journey from the farm to our plates. Almost one-quarter of all the world's greenhouse gases come from agriculture and forestry with changes in cultivated land use having a major impact on our planet over the last 100 years. In South America, huge swathes of rain forest have been cut down to make way for cattle farming to satisfy the needs of meat eaters across the world. Indeed, since the 19th Century when engineers came up with viable ways of long distance refrigerated transportation of perishable goods, we have seen a huge growth in food supply chain distances across the world. Refrigerated transportation alone has grown by nearly

60% in the last forty years. And of course, keeping proper temperature control of food transporters is essential to prevent food spoilage but can be energy intensive.

farm machinery, food processing and catering, as well as distribution systems. The problem in shifting from the mass-market model to a sustainable model arises because of the rigidity of these dependent intermediaries. Many companies are trying to reposition themselves as eco-friendly but a traditional farmer is more likely to care about the sustainability of their crops as opposed to big corporates because they have an attachment and respect for the land that they have been cultivating perhaps for many generations. With farming, we need to talk about the socio-economic aspects of farming as well as the ecological and economical ones. These are interdependent factors and



are the three pillars of sustainability. There is no economic development without social development and no social development without environmental protection. Ironically, the biggest disadvantage to sustainable food chains is not agricultural but economical. Food yield per acre has increased since big businesses started taking interest in agriculture, although, one may argue that this is taxing the land for resources. At the same time, it is true that growing urban populations cannot survive on strictly 'sustainable' food sources. And foods labeled as 'sustainable' are often costlier, but blindly scaling such operations is also difficult. According to the US National Agricultural Research, Extension, and Teaching Policy Act of 1977 (6) sustainable agriculture is defined as an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- Satisfy human food and fiber needs
- Enhance environmental quality and the natural resource-based upon which the agriculture economy depends
- Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls
- Sustain the economic viability of farm operations
- Enhance the quality of life for farmers and society as a whole

With the advent of smart farming methods in the last 25 years, and in particular, monitoring of huge amounts of data in the farming supply chain, including cold chain logistics and continuous temperature and humidity data, means that farmers can optimize farming inputs and outputs which drives yields higher while lowering costs and producing less waste.

Finally, for the first time in history, more than 50 percent of the world's population lives in urban areas and by 2050 it has been estimated that nearly 70 percent of all people will live in cities. With population growth exploding, cities are faced with increasing pressure on their aging infrastructure. One of a city's most important pieces of critical infrastructure is its water system. Water systems are often overlooked; yet they are critical components of energy management in smart cities, typically comprising 25 to 50 percent of a city's total energy spend. Indeed, some commentators have said that because of water shortages, wars will be fought in the 21st century over one of the most precious natural resources on the planet – water. Smart Water Apps like those from Hexagon can provide high-quality maintenance and services of a city's water resources even as the population grows and demands on the water network increase. These Apps provide up-to-date analytics on data and infrastructure that let city planners identify and respond to customer requests quickly. This gives the city operational and strategic advantages such as increased quality of the services provided, at the same time reducing cost of network operation and maintenance and reducing the number of incidents and remediation time.

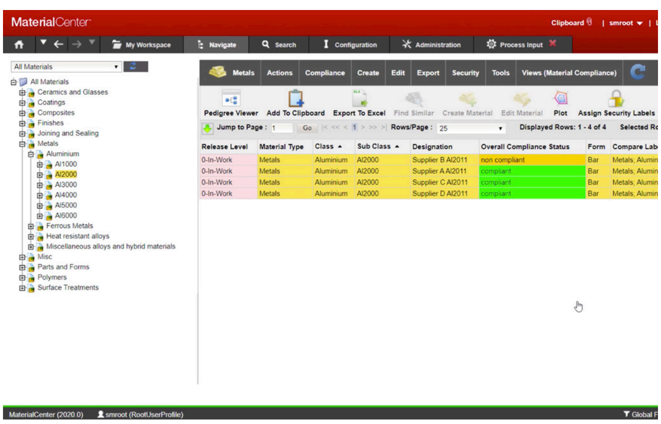
## Living in a material world with sustainability

Material resources on our planet are under immense pressure because they are finite, and quite simply, we humans are overmining and under-recycling according to Victoire de Margerie from the World Materials Forum (5). She has identified several bottlenecks today citing the concern that 60% of the world's known cobalt resources are used to help make electric batteries non-inflammable but they are sourced from the Democratic Republic of Congo in Africa, one of the world's most unstable countries. With no other land based alternative sources today, we only have 25 years of known reserves left in the world. As a consequence, in Europe off Portugal today, trials of subsea mining of cobalt nodules is being carried out as a way of relieving this security-of-supply dependency – but with other consequential environmental concerns on the impact to the seabed ecosystem this type of mining brings. When we consider Smartphones, there are 2.7 billion units in the world today, a tenfold increase over 10 years ago (5). All smart mobile phones today use rare earth metals for their screens and 90% of all rare earth production in the world is controlled by China. Many nations see this as a national security concern. The market leader, Apple, from America has therefore created a generous buy-back smart phone program to aid in recyclability of its phones but also to ensure that it has access to enough rare earth metals so that it doesn't become a business risk. Sustainability is therefore becoming an economic and security driver in some industries and application areas.

Every single CAE simulation in the world today requires good material properties to produce accurate results. Sustainability in engineering simulation predictions therefore requires proper material utilization and optimization throughout a manufacturing process. And every CAE simulation should require a fully traceable simulation supply chain with trackable components throughout the product's lifecycle and its circular economy from conceptual idea to its recycling. To address materials

sustainability, there is a need for a comprehensive materials solution that covers virtual material development, virtual materials testing, advanced (multi-scale) and standard material modeling serving all major FEA codes, inclusion of the effects of additive manufacturing, addressing automatic fiber placement and the effect of defects, ensuring digital continuity and a material-centric digital-twin, embracing artificial intelligence, and finally ensuring materials compliance and sustainability. A typical example would be providing a complete solution for the current and future needs of aerospace materials data & process management for the complete materials workflow as a single point of entry for all materials related activities. This guarantees simulation fidelity, reduced data loss and the elimination of tedious manual data management activities and yields 10x productivity gains

In terms of sustainability and compliance of materials, companies like iPoint GmbH in Germany, a pioneer in the digital circular economy, offer sustainable materials management and simulation solutions as part of an Integrated Computational Materials Engineering (ICME) solution. iPoint Systems also permits a direct integration of environmental compliance check, and comparison of the properties of both physical and simulation data sets. Material environmental and social compliance is a complex landscape and a critical aspect for many organizations. Direct integration of iPoint's Compliance Application (iPCA) with MSC Software's MaterialCenter 2020 has led to robust and immediate environmental compliance checks providing the unique capability of combining in-house corporate materials for accelerated environmental compliance checks and is a unique capability combining corporate materials management and compliance with the latest information on legislation like REACH and RoHS which permits comparison of properties from both physical and simulation data. The combined integrated offering provides material engineers, design engineers, CAE analysts, and compliance specialists the full capabilities needed in their respective domain of expertise with access to information needed from the other disciplines. This frontloading approach allows users to make decisions for a more responsible material design at a very early stage in the product creation process – the precondition for a truly circular economy and sustainable supply chains.

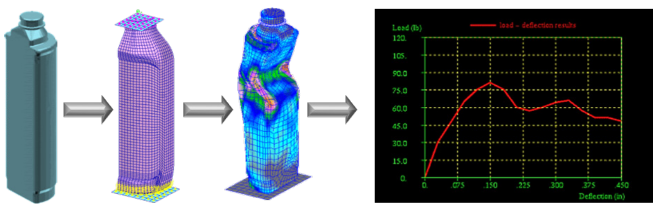


Direct integration of iPoint's Compliance Application (iPCA) with MSC Software's MaterialCenter 2020

## Packing up excessive packaging

It is safe to say that materials are everywhere in the world that we inhabit, and we see a wide variety in every product we touch and use, both natural and man-made materials. But who hasn't lived in the developed world and not felt dismay at some point or other standing in a queue at a supermarket checkout with an array of consumer products in your basket or trolley while contemplating the huge amount of packaging and shrink wrapping that our food and goods come in today? Or after an online purchase from Amazon that results in a bulky package arriving the next day at your front door in a cardboard box packed with paper, padded out with foam, and then sealed in multiple plastic bags? Something makes you think that consumer packaging has all gone too far. We are clearly using up the world's resources in packaging that is single-use, non-biodegradable and not recyclable. Perhaps we in the developed world are hapless consumers - or more likely - mindless in the use of natural resources for peripheral consumer products while satisfying our desire for the consumption of 'things' that we discard in short order soon after purchase.

The packaging industry today has many billion-dollar brands that manufacture of millions or even billions of products per year. It is going through major challenges to reduce material consumption while increasing package strength. Manufacturing throughput impacts company profitability massively and efficient and reliable processes are needed.



Virtual prototyping of manufacturing using CAE simulation

Mechanical processes such as conveying, pressing, forming and filling are paramount. The equipment used may be "one-of-a-kind" and goals may include optimized filling, conveying and secondary packaging processes. It is also expensive to test/compare different concepts and to tune "in service" for best performance and reliability.

Virtual prototyping using CAE simulation is emerging as a key strategic initiative within successful packaging companies to meet these challenges and improve competitiveness. CAE modeling enables packaging engineers to quickly and accurately run comprehensive virtual tests to optimize package designs, filling and conveying processes, and even simulate shipping and shelving. CAE in the packaging industry improves product performance with respect to filling and conveying and it accelerates design cycles while reducing cost. In effect, it helps to meet environmental sustainability for everything the packaging industry manufactures as it can help reinvent packaging processes with the environment as the key priority through predictive innovations.

## It's all about actionable data

Digital transformation is a big topic today in the manufacturing industries and with thought leaders, and data is often at the center of these discussions. The use of data generated during manufacturing operations is key to enabling unprecedented levels of manufacturing productivity, but we need to remember one thing: not all data is created equal. Analysts predict that 163 zettabytes of data will be created per year worldwide by 2025. But it's expected that less than one percent of that data will be stored. This will be due in part to limitations in storage infrastructures, but mostly it's because we simply don't need all this data.


Improve quality and productivity with Hexagon and MSC's Smart Factory solutions

Any manufacturer should always ask two questions about the data they create:

- What data do we need?
- How do we use this data productively?

The move towards Industry 4.0 has forced manufacturers to start using actionable information more effectively and here are three ways data can be used intelligently to cut manufacturing cycle times, enhance products, and drive sustainability:

## 1. Connect data throughout the product lifecycle

Siloed departments are a major productivity block in companies. In many manufacturing organizations, CAE design and engineering, production, and quality are not communicating as effectively as they could or should be. Data produced by these different functions becomes siloed, causing missed opportunities to drive greater process efficiency, improve products, and reduce resource wastage. Consolidating data infrastructures is a good place to start, or at the very least integrating the multiple management systems in use. More advanced organizations are using cloud-based data handling. Not only does this provide an infrastructure capable of handling big data, it also offers the visibility and accessibility required to ensure all necessary stakeholders get the data they need. Connecting systems through the Internet of Things (IoT) enables real-time insights into different departmental operations, driving greater collaboration and quick response decision-making. Among the plethora of data created by the different departments, big data analytics ensures you're quickly identifying patterns in the relevant data and are able to capitalize on the right opportunities/ quickly identify the most crucial areas for improvement.

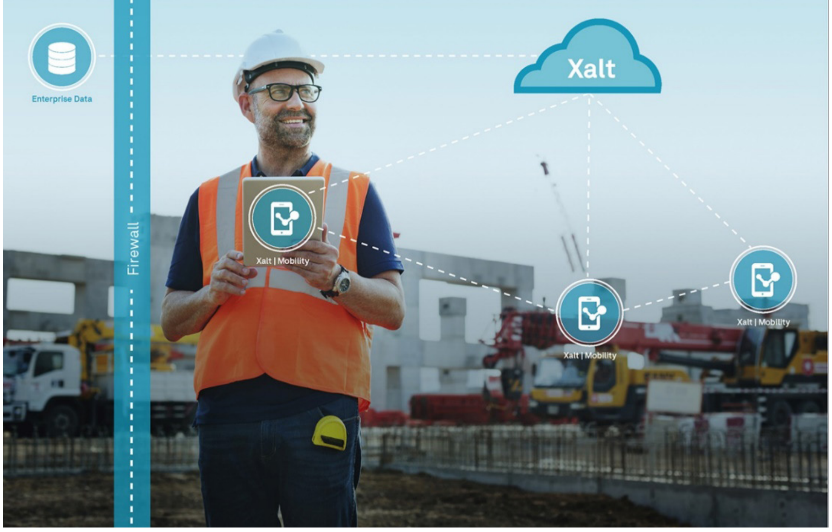
With IIoT, machines not only interact to share data but can alert users of crucial real-time information, for example if the machine is in need of maintenance or it is operating outside of prescribed parameters (like temperature range). With machine learning, systems can self-regulate and fix themselves without the need for operator intervention. Such connectivity makes data analysis much more effective. With a holistic picture of the product lifecycle, you can see where bottlenecks are appearing in the process and how different operations might be interacting ineffectively. What's more, with greater connections comes more detailed simulations. Whether you're creating digital twins or simulating the end-to-end process, this can provide game-changing levels of insight to predict outcomes and drive efficiencies.

## 2. Build data into the aftermarket

Before the advent of Industry 4.0 technologies, it was very difficult for manufacturers to keep track of a product once it had been sold. Aftermarket services relied heavily on obtaining a customer's perception of the product's condition and quality. Manufacturers can now equip the products themselves with IoT sensors to deliver information that will enhance customer support capabilities. This could simply involve remotely monitoring a machine to know when maintenance or an upgrade is required. But more mature operations will enable machine learning, with systems able to identify when they need repair work. Clearly, data insights such as these present a clear opportunity for manufacturers to evolve their support services and enhance customer loyalty to their business.

## 3. Increase data visibility in the supply chain

For large manufacturers and OEMs with suppliers all-round the globe, uncertainty in supply chain management can be a major problem. Your internal teams and major vendors might give you good insight into pain points, but it's delving into the data that will enable you to make connections across the supply chain, track any interacting issues, and hone in on what's most significantly impacting the bottom line. Rather than exhaustive communication via web or phone, the combination of IoT and big data



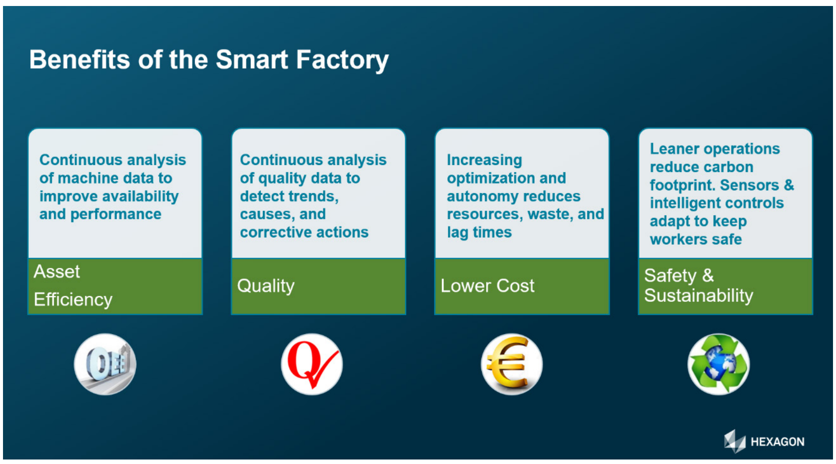

allows for automated end-to-end monitoring of products from creation through shipping. And the typical logistical blind spots during shipping are removed. Instead of relying on reports from key checkpoints during the journey, data can be exchanged in real-time to help manufacturers manage inventory and track location, enabling them to take fast proactive measures if there are potential delays. Sophisticated sensor technology can also provide insight into the condition of the goods themselves. This is a level of data connectedness that goes beyond typical current infrastructures, with potentially thousands of supply chain touch points for large organizations. It will take a good deal of integration and strong governance to reap the benefits of the actionable information available here, but if achieved the levels of efficiency and waste reduction would be game-changing.

Today, one of the biggest challenges that manufacturers face is to capture factory data and evaluate it during the test process. They want to keep record of the information of pre-test, actual test and post-test processes easily and systematically and then create complex relational information between these data. To meet this need, an engineering lifecycle management (ELM) tool within a data and process management system that focuses on capturing and managing the data all the way from the test data to the consumption of this data by the CAE products and various end users is needed. ELM will provide multiple methods to capture your data and has a web-based interface that allows you search and compare validate this data and apply multiple levels of security access to make sure users only see data that they are authorized to see. ELM tool also ensures that your data comes from a consistent, approved source and completely traceable processes. It is built on top of a framework because that allows direct integration with your custom CAE package in solution to perform simulations and ICME computations directly through the web environment. ICME and CAE integration also allows engineers to compare physical test data with virtual test data within a single tool and help them ultimately select the material that best suits their application. Using material center as a process engine, we have the ability to automate virtual test, report generation, and many other activities straight out of the browser.

Test data lifecycle is generally formed in a few stages. First, a stage to generate electronic data begins with manufacturing specimen preparation. For instance, a roll of carbon fiber is purchased from a supplier, a composite is then constructed through wet or prepreg, the test specimens are created in accordance to desired specifications then actual testing is performed on the specimen. Afterward, the test data is then captured in an electronic format. This data is often reduced verified and then published and distributed across an organization. Within the system, users can create a custom relational data model or ELM tool already provides a sample schema to use. So when you view a material you can view all the test data associated with it. Mc mapping engine also allows you to import many test data at once.

As a conclusion, with engineering lifecycle management tools, engineers are able to keep track of all the test stages and capture the information from them. With this ability, they now can make better tests and fully understand what is happening during the test process of their products. Engineering lifecycle management tools are thus saving from the time, cost and extra efforts to better test the prototypes.

Today CAE generates petabytes of data with simulations and as it becomes more pervasive, even more data will be generated. The single biggest technology challenge businesses and manufacturing face is putting the data they generate to work because data creation is outpacing our ability to use it. Think about the 25 billion devices connected to the Internet today and the expectation that this number will more than double by 2025 – it means the gap between data creation and usage is just going to get bigger and bigger. This "Data Leverage Gap" is what Hexagon excels at.




Benefits of the Smart Factory

## Manufacturing digital sustainability

Digital technology has a part to play in sustainable manufacturing and many organizations are starting to experiment with this. Examples include the use of virtual CAE design and 3D modelling which enables an organization to bring a design to life through predictive software without the need for wasteful physical prototypes. The use of CAE software to model packaging in different forms to see how it will stand up to different circumstances, such as heat and humidity or vibration on bumpy roads is another example. The use of "digital twins" when designing production lines so that different situations such as increases and decreases in orders can now be tested up front. This can be combined with virtual commissioning where digital production lines are tested for faults so that these can be eliminated before physical production lines are activated.

The use of digital technology to enable product and order customization so that customers can be more flexible about their orders. This leads to higher satisfaction, less waste and fewer returns. This type of technology is especially important in the automotive industry, but it also has considerable use elsewhere, such as in fashion where customized garments can be created and shipped in as little as two weeks. Hence, the use of digital technology to enable small production runs, which can be used to trial products and gain customer feedback before scaling up, reducing waste from failed products. Indeed, the creation of simpler products with fewer raw ingredients and simpler supply chains through a combination of a better understanding of consumer preferences and usage patterns, and more efficient design processes is more sustainable.

In summary, better sensors, manufacturing machines that can communicate to one another with everything connected to the internet will allow for a better understanding of end-to-end manufacturing value. These uses of technology can and will promote sustainability of course; but they have other more direct business benefits as well in terms of lower costs, the ability to go faster to market, and the ability to personalize products. In this optimized but increasingly real world, fast R&D and fast manufacturing are combined with better productivity, lower wastage levels and improved energy saving and higher product quality.

## Summary and conclusions

Mankind is waking up to the fact that our planet has finite resources and the rapid industrialization of the 20th Century has produced immense environmental challenges this century. Engineering and technology will play a major part in solving the problems that our children and grandchildren will face as we seek to have sustainable global economic growth rates in all countries. Given our present dependency on, and high consumption rates of crude oil, most known quality Petroleum resources today should be depleted by 2030 and we will be looking at shales and other lower grade carbon-based fuels. Moreover, various doomsday scenarios for global warming due to the effects of greenhouse gases should affect us by the end of this century. Even if, as is likely, corrections in energy usage and fuel consumption take place, and more eco-friendly and sustainable energy sources emerge and are developed in the next 25 years.

Manufacturing industries in the world today are manifesting a drive towards improving what is known as Product Lifecycle Management (PLM). This is effectively the time it takes to make a saleable product from conceptual idea to design, prototyping, tooling, manufacture, utilization and the product's ultimate retirement. In the automotive and consumer products industries in particular this shortening of time-to-market invariably leads to cost savings and lower priced products to consumers who generally get ever higher functionality. Advances in computer software have made this possible with various computer-aided engineering tools now being able to virtually design, "test" and optimize products before the first physical prototype is even constructed, thus saving companies time and money.

In the 21st Century sustainability is becoming an overriding priority in the globalized economy across all industry sectors and manufacturing operations. Social, environmental, and economic trends are driving the sustainability agenda. And this convergence of existential need and technological opportunity will require sustainable engineering design solutions to improve product performance, product quality, product manufacturability and ultimately product and material recyclability. Computer-aided engineering (CAE) simulation when done well will result in minimal waste in manufacturing production which means no recalls, no scrappage and no rework. Sustainable design, thanks to CAE simulation, will therefore help to drive economic benefits for all users, as well as address mankind's ever-growing environmental concerns for our planet and its finite resources. CAE helps to save on fuel consumption, reduce production waste with better quality assurance, decrease food waste, monitor and curb environmental pollutants and drive for zero carbon emissions. It's good economic sense to do sustainable engineering and we believe that our children and grandchildren will thank us for it. In conclusion, the need for environmental sustainability will significantly alter the nature of manufacturing design processes worldwide this decade by embedding sustainability related concepts of design exploration into the early design phase for products and processes in all industry sectors.

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Hexagon is a global leader in sensor, software and autonomous solutions. We are putting data to work to boost efficiency, productivity, and quality across industrial, manufacturing, infrastructure, safety, and mobility applications.

Our technologies are shaping urban and production ecosystems to become increasingly connected and autonomous – ensuring a scalable, sustainable future.

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