Manufacturing 2075

Materials Future

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Manufacturing 2075 - Overview

By Dr Konstantinos Georgarakis, Senior Lecturer in Low Energy and Novel Casting, Cranfield University

Influence the future

What Manufacturing 2075 is about? It is about pro-actively thinking of the future; it is about preparing for the future and influencing the future. It is about building on our country's heritage in science and technology to understand and address the long term future needs of the society. It is about developing the inspiration and the ability to shape the future.

In the inaugural Manufacturing 2075 event in December 2016 we addressed the topic of "Manufacturing on the Moon" as a key future challenge and aspiration of the mankind.
In this year's symposium we focused on "Materials' Future". The symposium was structured on Keynote Talks given by prominent representatives from academia and industry presenting technological advancements, future challenges and strategic views related to Materials and Manufacturing that will help us influence the future.

Group-work in though-provoking workshop sessions generated ideas for addressing future challenges. The symposium featured the **"Future Technology Exhibition"** showcasing state of the art technologies by leading companies and innovative research by Cranfield's Manufacturing Research Centres related to Composite Materials, Additive Manufacturing, Welding and Laser Processing, Surface Engineering and Nanotechnology, Bulk Metallic Glasses and Sustainable Manufacturing Systems, Through Life Engineering Services, Manufacturing Informatics and Cost Engineering. We also invited students from local schools to hear their thoughts on how life will change in the next 50 to 100 years and have them challenge us over our ideas.

Materials have underpinned the evolution of our civilization over the centuries. There are good reasons why the ages of civilization development of the past are named after the type of material which determined the peoples' life most. Nowadays, we are using science driven advanced materials to build our transport systems, produce energy, communicate, produce medicine and improve human wellbeing.
In our fast changing societies, future developments within the next 60 years will be enabled by the innovation in a wide range of materials. These may include nanomaterials, materials for energy, biomaterials, metamaterials, 2-D materials, carbon-based materials, non-equilibrium materials, magnetic materials, electronic and superconducting materials as well as materials that have not been yet explored or discovered. Control and manipulation of materials structure at the atomic scale will enable the manufacturing of customized materials with properties and engineering performances designed for specific applications.

Progress in Materials and Manufacturing will reinforce the efforts on tackling global challenges such as the threat from climate change. Harvesting energy from renewable sources (including solar, wind, thermal and kinetic power) will become more efficient and energy from nuclear fusion may become a viable option in the second half of this century. Sustainable manufacturing processes and materials with low energy footprint will play a key role in future developments. Challenges related with security, as well as the earth's growing and ageing population will be receive more attention and innovative technological and societal solutions will be developed.

Analysis of big data and improved speeds of data transmission may be enhanced by Space-Based System Technologies.

How life would look like in 50 or 100 years? Well, it is not a simple mind exercise. It is about planning for the future. Developing skills and understanding how education should be shaped. Identifying research directions and technology drivers to serve the future societal needs and promote human well-being. We hope you will enjoy this report and we look forward to seeing you at Manufacturing 2075 on December 5th 2018, to discuss the challenges and perspectives of "Digital Engineering".

"In our fast changing societies, future developments within the next 60 years will be enabled by the innovation in a wide range of materials."

Dr Konstantinos Georgarakis
Senior Lecturer in Low Energy and Novel Casting, Cranfield University

Manufacturing in space

ALM and Advanced Manufacturing: Our Future in Space and on Earth

Dr Makaya said that space travel has specific considerations, including weight, what can be manufactured in space, and recycling of goods. "We cannot depend on cargoes of new materials all the time, but will have to manufacture in space."

> "When you take topology optimisation to its limit, some designs look like alien life forms,"
>
> **Dr Advenit Makaya**
> Advanced Manufacturing Engineer,
> European Space Agency (ESA)

ALM and Advanced Manufacturing:

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ESA is looking at 3D printers using in-situ resources and power optimisation for the Moon, Mars and potentially further. Also printing of living cells, organs and blood in human settlements. "Doctors cannot be flown out to treat patients. They must be medically self-sufficient for the duration of the exploration," said Dr Makaya. Tommasso Ghidini at ESA has started new research on printing human cells and ultimately organs in a space settlement.

Additive manufacturing will be very important for space. Ihe International Space Station has polymer 3D printers for making replacement plastic parts. Back on Earth, parts that are currently additively manufactured (AM) for the space industry include injectors, chambers / nozzles and monolithic thrusters. AM structures have been shown to both reduce the weight and improve the thermal properties of a nozzle, via its lattice structure. A platinum thruster by Airbus was the first AM process in the world to make a working space thruster using an AM technique and wasted no platinum.

ESA and partners have used **topology optimisation** design and make brackets for attaching components to satellites, to only put material where it is needed, to reduce weight. "When you take topology optimisation to its limit, some designs look like alien life forms," said Makaya referring to generative design of parts. Another bracket is additively made using a lattice design with hundreds of small struts, reduces weight but this introduces challenges of reliability with so many supports.

Technology harmonisation roadmap

ESA has created a roadmap to develop additive manufacturing for space. It involves more than 700 experts and stakeholders, 26 countries and 390 companies are represented. The roadmap involves 30 types of parts and assesses their technology development across six aims, from design to processing and standardisation (see diagram).

ESA realises that additive layer manufacturing is just one technology that can help achieve what is required in space, so it has developed an Advanced Manufacturing Cross Cutting Initiative to map all the components and disruptive technologies that can reduce weight, reduce cost and lead times, including those such as friction stir welding, materials processing, assembly processes and electronic materials. It has now produced a compendium that lists all the activities that ESA thinks are needed to develop advanced manufacturing technologies for space. A national delegation will take proposals from companies that want to contribute their capabilities to the ESA programme.

In the UK, ESA has an Advanced Manufacturing Test laboratory at Harwell near Oxford, that is dedicated to identifying and developing early stage advanced manfuacturing technologies. It also has an AM benchmarking centre at the MTC near Coventry, where industry can come to get advice, research and produce AM processes that are suitable for space applications. Examples of parts the benchmarking centre has verified include an **IBDM Ring.**

The objectives were to improve the incumbent IBDM ring in terms of mass, cost and environmental impact (life cycle analysis).

There is now a European Cooperation for Space Standardisation proposal that is developing a framework for AM made hardware (ECSS). A working group started work in Q4 2017.

Summary

Makaya said one of the big side effects with space manufacturing was space debris and its effects. ESA had to research areas like parts decay, re-entry into Earth's atmosphere and debris impacting on the ground.

Issues for space components that ESA faces include:

- "Demisability": how products will degrade, a new materials property for space
- Direct inputs for the re-entry simulation software
- Specific Heat Capacity, specific enthalpy, thermal expansion, density, thermal conductivity
- = Leading to "Design-for Demise" for space parts

Carbon in transportation

The World Economic Forum says "failure of climate change mitigation and adaptation" is the No. 1 disruptive risk to society."

Benoit Gauthier,
Team-X – Technology Roadmapping and Planning, AirbusCo-founder of Smart Carbon Alliance

The good carbon

A circular approach to curbing GHG emissions in the transportation industry for a sustainable future

Key themes

- **World faces planetary crisis on climate change**
- **Cutting carbon emissions in all sectors is "behind schedule"**
- **New propulsion can accelerate the future of mobility, creating new business opportunities**
- **Gauthier's approach is the potential of carbon-based nanomaterials to reduce carbon consumption in aerospace**
- **Move from "the Good, the Bad and the Ugly carbon" to the Smart Carbon.**

The World Economic Forum says "failure of climate change mitigation and adaptation" is the No. 1 disruptive risk to society.

Benoit Gauthier takes the view that there are grades of carbon – good, bad and smart – based on how the carbon is used, and industry needs to move to high value, smart carbon to transform to preserve the environment.

All industry sectors are too slow at cutting greenhouse gas emissions (GHG), including transportation. Aerospace should lead the way, Gauthier's presentation said.

New methods of low carbon manufacture and propulsion will generate business opportunities and sustainable growth.

Gauthier suggested that "good carbon" has been used to fuel the first three industrial revolutions, bringing us to the point of "Industry 4.0", or manufacturing with cyber physical systems.

Aviation GHG is currently only 2% of anthropogenic CO_2 emissions" (IPCC AR5) but is poised to increase to 15% of global emissions by 2050. Also aviation contrails increase the aviation industry's effect on GHG, by trapping heat that would otherwise escape from the Earth, which contributes to global warming.

Climate change is increasingly affecting the aviation industry. Effects include flight cancellations due to high temperatures and airport exposure to rising sea levels.

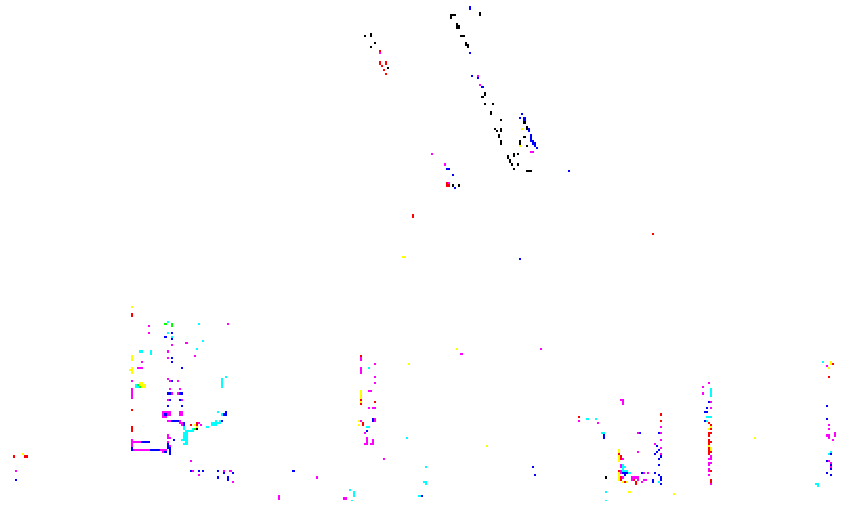
The global aviation industry has set ambitious CO_2 reduction targets. Its target of 1.5% fuel efficiency per year has been exceeded, and it plans to reduce Co_2 emissions from aviation by 50% by 2050 (2005 baseline).

What are the solutions?

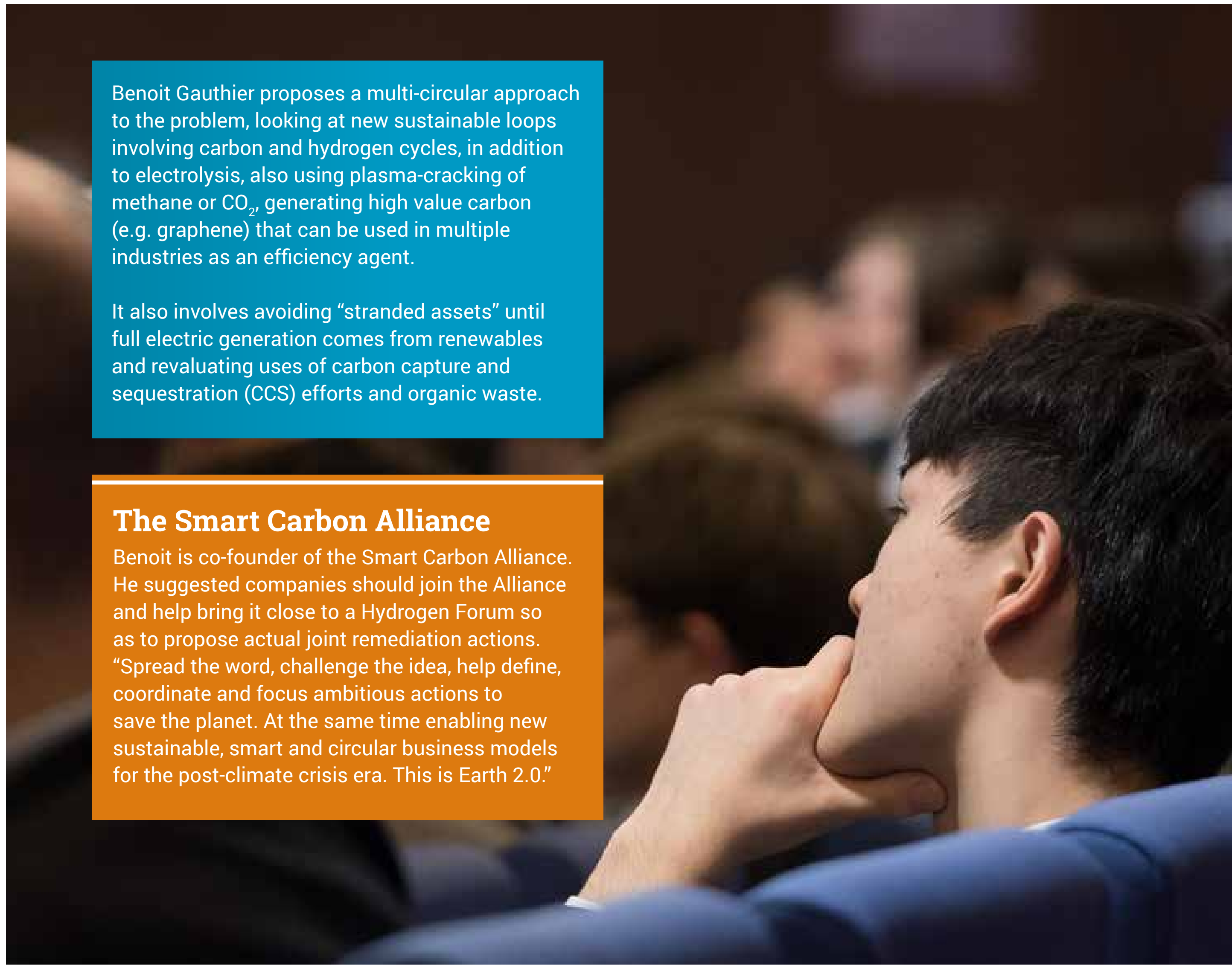
To avoid environmental catastrophe, Gauthier advocates the **electrification of transportation**.

As well as electric urban mobility, that could be Google or Uber concepts with autonomous, self-driving cars, Airbus is researching Urban Air Mobility, including drone transportation such as the Volocopter and CityAirbus, public drone transportation. These all have technology, infrastructure and regulation challenges.

One solution is E-FanX, an electric powered aircraft.



In November 2017, Airbus, Siemens and Rolls-Royce teamed up in a major regional electrical aircraft project, E-Fan X. This hybrid-electric technology demonstrator is set to take flight in 2020.



Benoit Gauthier proposes a multi-circular approach to the problem, looking at new sustainable loops involving carbon and hydrogen cycles, in addition to electrolysis, also using plasma-cracking of methane or CO_2, generating high value carbon (e.g. graphene) that can be used in multiple industries as an efficiency agent.

It also involves avoiding "stranded assets" until full electric generation comes from renewables and revaluating uses of carbon capture and sequestration (CCS) efforts and organic waste.

The Smart Carbon Alliance

Benoit is co-founder of the Smart Carbon Alliance. He suggested companies should join the Alliance and help bring it close to a Hydrogen Forum so as to propose actual joint remediation actions. "Spread the word, challenge the idea, help define, coordinate and focus ambitious actions to save the planet. At the same time enabling new sustainable, smart and circular business models for the post-climate crisis era. This is Earth 2.0."

Advanced materials research Henry Royce Insitute

Keeping an eye on advanced materials

Professor Philip Withers, Regius Professor of Materials, University of Manchester

Key themes

- £235 million Royce Institute devoted to advanced materials research
- Aims to join up world-class but fragmented and siloed advanced materials expertise in the UK
- Key challenge is to develop "materials systems", combing experimental models, big data and computational tools
- Facilities for SMEs to research and work, encourages growth
- Outcomes must be for the good of society and the economy

Professor Withers explained that the new £235 million Sir Henry Royce Institute (SHRI) is an international flagship for the accelerated discovery and development of new materials systems for economic and societal benefit.

It is organised around four thematic areas:

- Device materials such as 2D materials, atom level devices
- Energy materials inc nuclear materials
- Health and Soft Solids, inc biomaterials and devices and
- Structural materials, inc researchon advanced metals manufacturing

The SHRI has several underlying objectives. A key objective is that the work should benefit society and the UK economy. One objective is to develop "materials systems". Withers said "Only very rarely do we invent a completely brand new material, but there are many opportunities to design and develop a wide range of new materials systems."

The UK has "islands of excellence" in a wide range of material science, from nanofibres and spark plasma sintering to hard coatings and printing devices. The aim of SHRI is to join them up into a coherent and effective research eco-system able to accelerate computationally led discovery and maturation of materials systems. Currently the landscape looks more like a game of snakes and ladders.

Withers said part of the SHRI difference is the combination of using computational tools, digital data and experimental tools to accelerate new material development. The availability of powerful computational algorithms and material simulation today is making a huge difference to materials research. One benefits the other, so that optimising the centre / a company's "experimental make capability" can accelerate computational design.

The future

Solutions for the future involving advanced materials include:

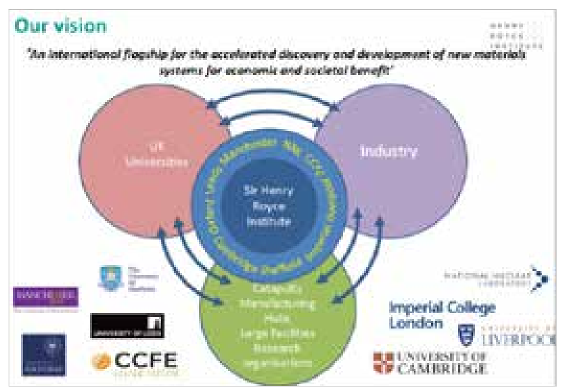
Greener travel: Royce is developing materials and coatings able to run hotter that are stronger and lighter.

Clean, CO_2 free energy: Royce (Manchester/CCFE) is developing materials to withstand extreme temperatures and environments for fusion energy.

Water purification: Graphene-oxide membranes developed at the NGI can sieve common salts out of salty water and make it safe to drink.

Energy storage: Royce (Oxford lead) looking at new more robust and effective battery materials for transport and to store renewable energy to balance power supply.

Biomedical materials: Royce (Manchester) making artificial tendons to improve quality of life for aging population.



Extract from Professor Wither's presentation

Processing materials

Manufacturing 2075 Advanced Materials Processing: Looking to the Future

Professor Helen Atkinson CBE,

Pro-Vice-Chancellor - Aerospace, Transport, Manufacturing

Professor Atkinson started by setting out the economic and environmental impact of metal processing.

The manufacturing and processing of metals to form components has an economic worth to the European Economic Area of £1.3 trillion. Metals production consumes about 5% of global energy use and is responsible for annual emissions of more than 2 gigatonnes of CO_2.

There is a strong move to develop alloys with higher performance, better manufacturability and lower cost. “We need manufacturing to become more flexible to reduce material consumption and reduce waste of high value materials,” she said.

Strong applications for advanced materials

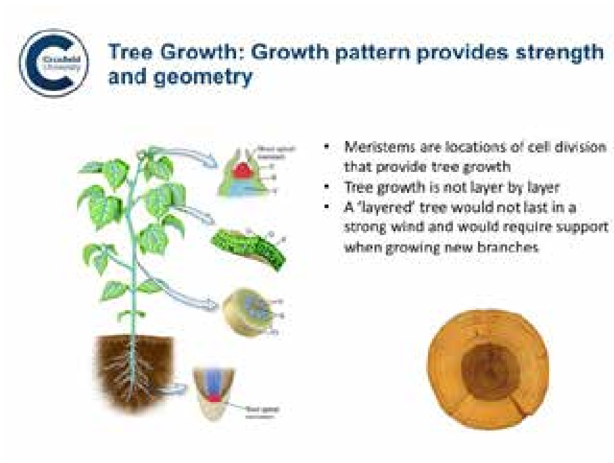
- Light weight system solutions for transport industry
- New steels for nuclear industry
- Net Shape aerospace components
- Additive repair of high value components
- Materials tailored for orthopaedic applications
- Primary metal suppliers for automotive, aerospace, land-based turbines

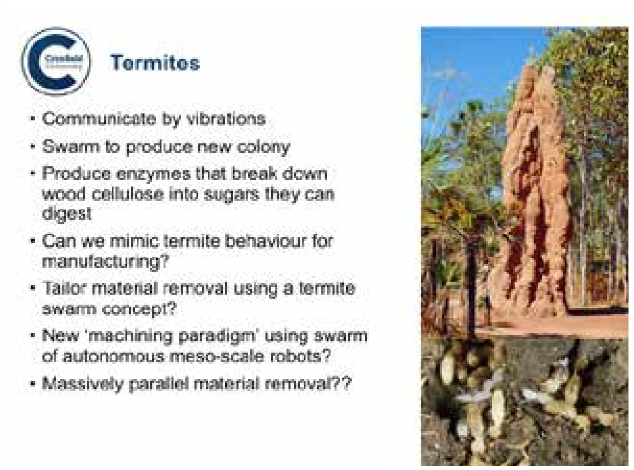
One of Atkinson's research fields is Advanced Composites Processing. Some of this research is about improving the performance of joining and fastening solutions for new composite materials, i.e. which types of fastening technology work best

Research areas for fastening include the evaluation of low cost fastener technologies and embedding metallic fasteners in carbon SMC.

One area applicable to manufacturing is the development of smart joining strategies including:

- Design for fast disassembly and repair
- Dis-bondable adhesives through biomimetic application and MEMS device incorporation for dis-bonding through local heating
- Dis-bonded surface is undamaged ready for repair





Extract from Professor Atkinson's presentation

Intelligent composites

There is a substantial research focus on intelligent composites, designed with multifunctional nanomaterials (especially graphene), smart polymer structures and high performance fibres.

A rising field of engineering is self-healing materials, which have applications in aerospace, defence, construction and more.

Smart polymer structures can self-repair. Repair can be activated by local heating. They would be capable of local area damage detection followed by a local area "healing process".

More sophisticated **multi-materials** are being designed for industry now such as Metal/Ceramic/Composite materials. The interface of these, where they join, is a key challenging area.

For the **intelligent design of composite materials**, factors involved include embedding sensors through graphene composite grading, local area damage detection, and interfacing smart coatings and dissimilar materials with composites. Sensors are essential for features like self-healing.

Prof. Atkinson also said that real-time monitoring of material condition was increasing, where embedded sensors can be used for applications such as **damage identification** through potential reciprocity gap.

Digital manufacturing

Atkinson highlighted the challenges for digital manufacturing. One is the speed of adoption of Model-Based Definition/Enterprise (MBD/E).

Model-based definition is designing an assembly with a complete 3D digital data set for components and assemblies. CAD can allow the insertion of essential engineering information such as dimensions, Geometric Dimensioning and Tolerancing, notes and other product details within the 3D digital data set. The 3D digital data set may contain enough information to manufacture and inspect product without the need for engineering drawings.

She suggested manufacturing will be far more efficient with fully automated 3D MBD/E deployment to external supplier operations and the adoption of minimum technical data annotations for different stages of the product life cycle. This can lead to significant reduction of rework and manufacturing non-conformance

Foresight report: biomimetic manufacturing

Will the next generation of manufacturing innovation be enabled by imitating biological systems in production environments? This was posited in the 2013 UK government report, "The Foresight Report: The Future of Manufacturing"

Already new furniture companies are "growing" chairs and tables from wood and bamboo, into designed shapes.

Should additive manufacturing proceed in layers or could other approaches be applied to mimic tree growth?

Atkinson showed a scenario of data communication similar to a virus outbreak. Can we share the digital twin with everything a part touches, creating a data 'outbreak', with computerised part information spreading like a (benign) disease?

And for something truly futuristic….
Can we mimic **termite behaviour** for manufacturing? A new 'machining paradigm' using swarms of autonomous meso-scale robots.

Refer to Professor Atkinson's presentation for more on digital workflows, degrees of automation and collaborative automation.

> "The manufacturing and processing of metals to form components has an economic worth to the European Economic Area of £1.3 trillion."

New digital manufacturing technoloigies

The changing face of UK manufacturing

> "It removes the human from even designing and executing the manufacturing process, so their creative capacity can be targeted more at advancing the actual technology"
>
> **Professor Sam Turner,** CTO, HVM Catapult

Intelligent composites

Professor Turner said for "digital manufacturing", people talk about cyber physical systems, but it is really the integration of a suite of systems, the coming together of large amounts of data through higher connectivity, and the intelligence we can derive from those. Essentially about being more flexible and agile in the products we are making.

The future of the aerospace industry is divided into two broad camps, aeroengines and aero-structures.

Here the aero-structures camp is talking about new "manufacturing platforms" that can simultaneously building wing structures in situ using multiple hybrid technologies, including additive, subtractive, composite layups. Laying down metallic and composites together.

With engines and turbines, smart materials are essential. In making discrete components from different materials to be assembled with tight tolerances, the information exchange to see and control the functionality of those materials is the role for digital.

Extract from Professor Turner's presentation

Automation

Is not just about automating the assembly process but gathering data from that process. Why?

- **Control your processes better and**
- **Verify that processes are validated as they are made, increase in-line verification.**

Connectivity: Turner said this is about both "connectivity in factories and connectivity within supply chains, to help reduce price points". Finding out the best place for humans in the manufacturing loop. Humans are dexterous, creative and have knowledge – in these roles they offer better value than automated systems.

Turner talked about a range of new and digital manufacturing systems including **augmented reality**, laser and optical guiding systems for e.g. showing where to drill holes at precise depths, and execute assemblies, and more.

Collaborative robots that work alongside humans. The smart workbench, used by Meggitt, where the interface guides the operator by gating each operation. This helps with flexibility where people are doing assemblies of different products and in training.

Digital twins

Freeing up humans' creative capacity
We use already CAD and modelling to design components, moulds, tools and factories. What is new with digital twins is that we will use machine learning where the system will tell us, based on a core CAD model, the best way to produce that component. Turner said "It removes the human from even designing and executing the manufacturing process, so their creative capacity can be targeted more at advancing the actual technology. All this technology on the shop floor may move in to the manufacturing engineering rooms, this will accelerate the pace of change and free up further creative capacity."

AI and additive

Sam Turner said the Catapult has engaged with a partner working in artificial intelligence, who advocates additive manufacture because it does not waste anything, goes straight "from the art to the part". What can't we do this in forging, casting and machining?

Feature recognition technology. By creating simple rules for feature recognition software and what tool paths are possible, industry has developed some AI tools that are practising feature recognition already, "so AI is already starting to replace manufacturing engineering knowledge. But the bit they have not got right yet is material science. By combining machine learning techniques with the existing knowledge and physics based models about how materials will behave under forming technologies, will be the greatest advance."

Industrial strategy grand challenges
The IS grand challenges are: Artificial intelligence (AI), clean growth, future mobility and an ageing population Prof Turner went on to summarise HVMC work in the following areas. Refer to his presentation for more details:

Electrification, including the Faraday Challenge, a £246 million commitment over the next four years on battery development for the automotive electrification market. HVMC has helped to convene the automotive industry and Automotive Council in this area.

HVMC is shaping national strategy through technology demonstrators. It provides SME support, through transformational demonstrators e.g. **Factory 2050** at the AMRC in Rotherham.

Hubs and spokes – to spread the message via other learning centres.

Digital twins for product acceleration, Connected supply chains, Robotics, AI, Visualisation, Connectivity, additive manufacturing are all areas the Catapult is working in.

Composites

Consultation with the UK composites supply chain has shown that the UK has the opportunity to grow its current £2.3bn composite product market to £12bn by 2030.

Professor Turner also mentioned the Made Smarter Review, a plan to make the UK a global leader in industrial digitalisation by 2030

Made Smarter has big potential for economy and industrial efficiency:

- **£455 billion** positive impact for UK manufacturing of faster innovation and adoption of IDTs over 10 years
- Net gain of **175,000** jobs across the economy
- More than **25%** industrial productivity gain by 2025
- Reduce carbon emissions by **4.5%**

> The expertise is lacking in both the field of industrial IT and training to put these new systems in place."We have to make sure that those with the knowledge can convey it to more people."
>
> **Dr Giuseppe Dell'Anno**, Chief Engineer, National Composites Centre

Future-proofing UK composite manufacturing

Dell'Anno said the NCC and Catapult centres were all about "real work on the factory floor", but this needed to be optimized by digital tools to detect and minimize waste and reduce cycle times.

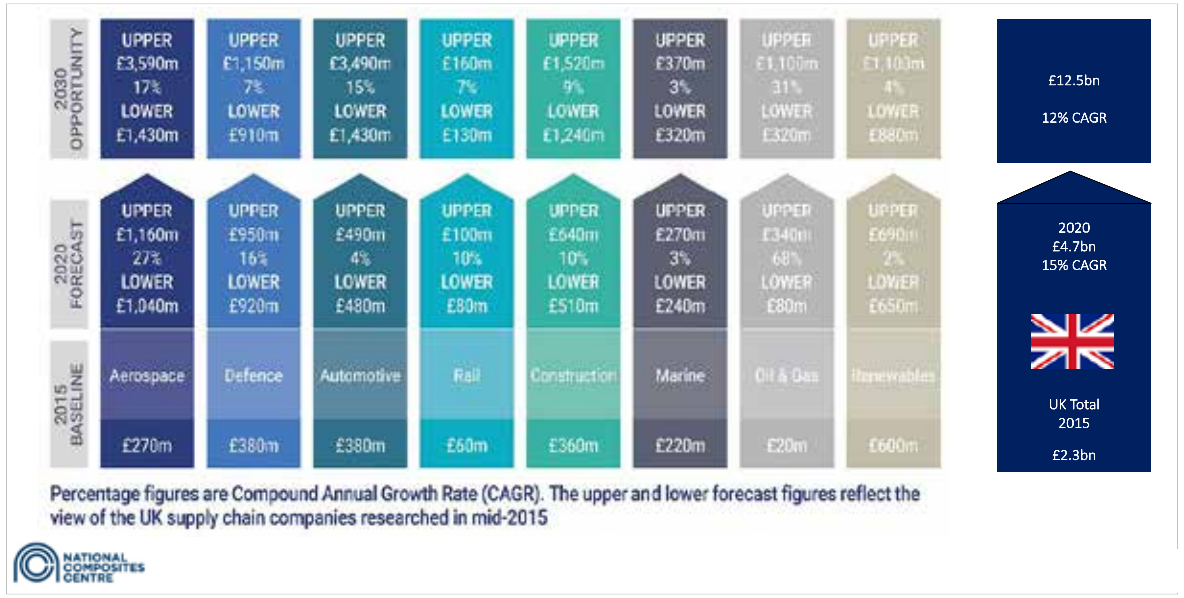
Why should digital manufacturing be important for composites?

In composites manufacturing there is a lot of craftsmanship, requiting the skilled opertors and heads and hands.

Dell'Anno pointed out, like other speakers, that highly integrated systems enabled processes to be customised, giving customers what they want and

Artificial intelligence was about learning and to transform more data into information that we can actually use. He said, "Artificial intelligence will replace the famous "extra pair of eyes" we need and define "where good lives" and identify the patterns than in our heads would automatically.

Challenges: All of the Catapult plan requires the right IT infrastructure, a framework of software and hardware that need to be planned thoroughly before we even begin to capture and analyzing data and producing things. The expertise is lacking in both the field of industrial IT and training to put these new systems in place."We have to make sure that those with the knowledge can convey it to more people."



This translates into:

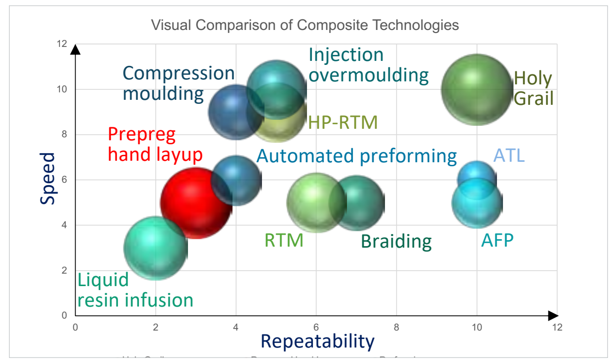
- Speed, in the NCC's case reduced cycle times
- Speed in terms of translation of the invention to commercialization, "that my invention sees the light of day."
- Repeatability in terms Improving the quality of what we do, reducing the waste and getting it right first time
- Design complexity to have automated systesm that are more robust and tolerate more complex designs

Technologies and processes

Which technologies have the potential to be the prominent composite manufacturing technologies in 20 years?

The NCC is assessing the landscape of composite manufacturing techniques to assess which can be more efficient. Assess them for speed, repeatability and design complexity.

Take the basic **pre-preg hand laminating** as the baseline process (red bubble). It scores:
5 out of 10 in speed
3 out of 10 in repeatability
10 out of 10 for design complexity (a larger bubble)



Extract from Dr Dell'Anno presentation

We are aiming for a 10/10 score for speed, repeatability and complexity for the best process (Holy Grail).

The composite processes are:

- Prepreg hand laminating (baseline)
- Automated Tape Laying
- Automated Preforming
- Automated Fibre Placement
- Braiding
- Resin Transfer Moulding
- Liquid Resin Infusion
- High Pressure RTM
- Compression Moulding
- Injection Overmoulding

Some already have very high repeatability, such as automated tape laying and automated fibre placement. These techniques have high capability but they are not as fast as they could be.

Some processes are very fast, like High Pressure RTM. "We have made parts using HPRTM for the automotive industry at the NCC with a takt time of less then four minutes." But he said, we don't have tools today to predict the repeatability of this process with the right level of confidence.

For productivity, Dell'Anno said remove the technologies that are dependent on manual preforming. "It doesn't matter how quickly you can impregnate your vari-forming resin if your preform takes four hours." At the moment manual preforming is the bottleneck, and the greatest challenge.

Automation has made us 15 times faster in preforming (NCC has reduced 2 hours to 8 minutes, based on an omega panel made at the NCC when we commissioned the HPRTM process). But for companies like Jaguar Land Rover to even consider the process it needs to further reduce 8 minutes to one minute, or 120x improvement in cycle time from the baseline, "which is remarkable and very challenging," said Dell'Anno.

The rest of his presentation looked at concepts like:

The instrumented worker

The concept involves applying sensors to a manual task, tracking hand movements, using cameras and pressure mats. This addresses fact that we are never going to replace a human, and find ways to address the flaws in their performance. This tool itself can teach the worker when he's doing it right.

Further improvements include: Machine learning: Can reduce the speed of the cycle time by automating the decisions that operators typically have to take during the mfg process. and

Surrogate model: loads of preliminary testing to experimentally validate points across a surface which is then used by the integrated system to identify the optimal position once a set of variables are defined.

Seminconductors and Gallium Nitride

Future challenges for the manufacturing of GaN devices

Professor David Wallis, Department of Engineering, University of Cardiff
Department of Materials Science and Metallurgy, Cambridge

David Wallis's presentation examined the potential of Gallium Nitride (GaN) devices.

Little-known GaN is a compound of Gallium and Nitrogen and is effective in a wide range of band gaps, from infrared to ultraviolet. This makes it an excellent semiconductor. GaN is found in many household products including laptop displays, low energy light bulbs and LED headlights.

It also has numerous high value electronic applications including electric vechicles and data centres.

The UK has established the first compound semiconductor cluster in the world.

Manufacturing GaN

The biggest manufacturing challenges for GaN are to:

- Make GaN devices cheaper and
- Improve their performance and reliability

GaN is 1000x less sensitive to defects that other semiconductors. It is a superior material to GaN substitutes for conducting, but is more expensive.

To manufacture GaN cost effectively, it is joined onto large area silicon (Si) substrates, which allows manufacturing in existing Si foundries in the UK. IN the case of companies like Plessey, these often had:

- Fully depreciated buildings and equipment
- Increased automation
- Increased yield and throughput

This has led to reshoring of semiconductor manufacturing from Asia.

Part of the value of GaN semiconductors is in the chip/wafer scale packaging. Much more of the value of the whole LED is the high value die (the GaN component) compared with the low value package than on a conventional LED package.

Wallis's presentation goes into more technical detail on GaN's chemical and thermodynamic properties.

Summary

- GaN LED market » £26bn/year
- GaN Electronics Market » £1bn/year

Future Manufacturing Challenges for GaN include:

- Further reduce device cost, Increase market acceptance, Find new markets and Engineering challenges to enable exploitation of GaN performance

What is the UK doing to advance semiconductors?

Established a Compound Semiconductor Cluster in South Wales, developing a complete ecosystem. The cluster covers research, prototypes, through to applications. It is a >£300m investment in buildings, equipment, people and research projects.

Creating service business models from manufacturing

Balaji Srimoolanathan, Strategy Manager, Aerospace Technology Institute

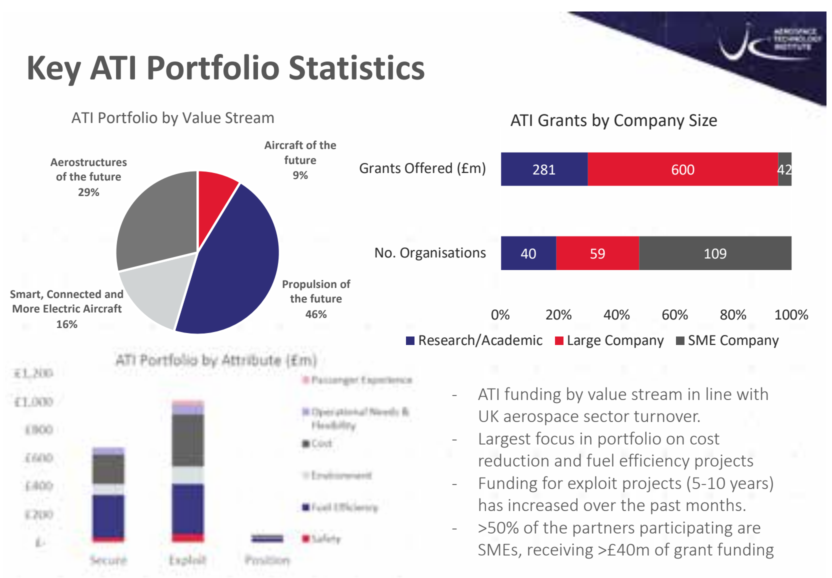
Through-life engineering services technology strategy for UK aerospace

More companies will have servitisation models their manufactured products in the future.

The Aerospace Technology Institute (ATI) was established to oversee a £3.9 billion investment programme to grow the UK's aerospace industry.

ATI is exploring aircraft, aerostructures and propulsion technologies of the futre, and smart, connected and electric aircraft.

Srimoolanathan explained Through-life Engineering Services or TES. "These comprise the design, creation and in-service sustainment of complex engineering products with a focus on their entire life cycle, using high-quality information to maximise their availability, predictability and reliability at the lowest possible through-life cost." TES is akin to servitisation but involves a deeper analysis of the technology and business models that servitisation can deploy.



Extract from Balaji's presentation

Srimoolanathan explained Through-life Engineering Services or TES.

"These comprise the design, creation and in-service sustainment of complex engineering products with a focus on their entire life cycle, using high-quality information to maximise their availability, predictability and reliability at the lowest possible through-life cost."

The ATI set out to develop a complete view of Through Life Engineering Services (TES) capabilities and technologies in the UK aerospace sector to inform its technology strategy – to ensure the UK is well positioned to take advantage of the opportunities in through-life services that are enabled by technology and to understand the opportunities for R&D.

Several near-term opportunities can be addressed through supply chain companies capturing product performance / operational knowledge to improve product design and reliability.

The ATI has created a framework for understanding the technologies and capabilities required to deliver potential service offerings. It enables companies to assess where they are on their servitisation journey from a knowledge, tools and technology perspective.

Where TES is specific to materials

- Design for Through-life and No Fault Found, focusing on CAD modules for life studies, new materials and "machines that never die".
- Methods to minimise incipient damage/defects in manufacturing to extend life by reducing residual stress, micro cracks, thermal damage and through compound in-service degradation science.
- Metal and composite repair technologies especially for novel materials and new components that cannot be repaired today. For metallic, inspection and deposition technologies to relieve stress, and the capability to machine and re-inspect.
- Analysis of surface quality and product life, including interface design for life and high performance, and maintaining ultra-precision features over time.

Next steps for the ATI

The ATI TES strategy identifies the opportunities of transitioning to through-life engineering services, and the technologies and capabilities required to enable the transition. The Institute will continue to work with the sector to disseminate the strategy and to encourage the sector to shape and submit relevant TES technology projects.

Workshop summaries

Session one

Trends and challenges in manufacturing new materials

Facilitator: Professor Krzysztof Koziol,
Head of Enhanced Composites & Structures Centre

Note Taker: Dr Sameer Rahatekar,
Research Lecturer in Manufacturing

A key theme of discussion was the manufacture of "single use" products by micro robots.

A team of small robots could make custom-made clothing for a specific function for that day or a period of time, saving the manufacture of many outfits that are never worn. Also, materials for space – both to help space travel and materials for use and manufacture in space.

The session discussed new materials around four themes: the digital world, energy sector, engineering, and transportation. The group looked for the properties future materials must possess in each of these sectors.

Digital: In the digital world materials will have embedded security features. Materials "with no power output" or low resistance, where data centres do not generate a lot of heat and CO_2 emissions.

Data storage, especially with quantum computing, is a huge area for the future. The team looked at the best materials for storing data. Graphene and nanomaterials, where much faster data transfer rates are possible. Layering materials, like semiconductors, in the design of future transistors and future devices.

Also looked at sensing, bridging the physical and virtual worlds. Assessing the parameters that we might expect from materials in the digital world.

Engineering materials: Focused on lightweight and high performance. Materials that push the boundaries of performance, moving towards the carbon nanotube performance of 100 pico pascals or 50x stronger than the materials we use at the moment. Through-life materials, where we do not want to service them – potentially self-maintaining properties.

Smart materials that can change their features to suit a particular requirement. be adaptable to their environment and multi-functional. "Can we control the age of these materials, because we may want some materials to age at a different rate to others," Prof. Koziol asked.

The group looked at health, safety and sustainability – new materials must comply with safety and other standards.

Energy: Subjects discussed included:
Generating energy in every household, using the materials that can enable this shift to domestic energy. Piezoelectric and photovoltaic (solar) cells. Manipulating materials for energy generation in domestic settings. Storing energy and how. Gravity and new materials – thinking far into the future about transportation.

Also multifaceted materials that change their structure from what we expect them to do.

Transportation: Energy harvesting with energy farmed from different propulsion systems, most likely electric propulsion. Lightweight, strong materials will be critical for transportation.

Hybrid materials that display different properties in layers of the same material, and how to engineer these hybrid materials for structural and e.g. conductive applications.

Another aspect debated was materials made at the source of need rather than unnecessary or wasteful movement in long supply chains.

The group discussed some parameters for how these themes would take effect and formed better ideas of how these would be deployed in the future.

Session two

Future challenges in materials supply chain

Summary given by
Mark Russell, General Manager at Holism-Properties LLC and Director of Operations at TIL/Quodonics International

Facilitators: Dr David Rickerby,
Assoc. Professor in Surface Engineering

Dr Hamed Yazdani Nezhad,
Lecturer in Composite Engineering

In their summary on the workshop, Mark Russell summarised:

The supply chain is about getting material to where it needs to be. Material will have to be transported, that is a given, so the group looked at the things that will affect the supply chain. The key themes were:

- Politics and human behaviour
- Globalisation
- Sustainability
- Historical legacy
- Specialisation

Politics: Making sure that by the time we reach the future state, the provision of STEM and more equal gender and racial diversity should be a given. By 2025 everyone should be receiving the training they need, so that those who want to be trained in each area get the training.

Mark raised the concept of "good citizens". He said one thing he has learned in his manufacturing career is how to be a good citizen. "If you are a good citizen in everything you do in engineering, you are actually doing the best you can on this Earth," he said.

Human behaviour: If we can change human behaviour we can change other elements of business and the supply chain and how we manufacture. Sustainability, therefore, is affected by politics.

Globalisation and localisation: The group discussed where to locate manufacturing. He said some companies are developing flexible manufacturing plants that swap machines for other machines depending on what they need to manufacture that day. This can be taken further to contract manufacturing. There are hubs in the UK that are the key manufacturing points for certain products because those sites are the most capable for that product. Completely different Enterprise Resource Planning (EPR) set ups, with security in place, would be needed to manage these differently. The choice of whether to make one product from your own plant and use a contract manufacturer for another product.

Some industries, like defence or nuclear, have only certain places where they could manufacture the product, limiting the flexibility. The influence of 3D printing was discussed, where local plumbers and building suppliers could print parts on demand. In this case the new the supply chain challenge is how to get the right materials to the right place to support that.

Sustainability: The key theme here will be the circular economy. The "cradle to cradle" concept: many times people have looked at the whole lifecycle of a product, from the cradle to the grave. In the circular economy the grave becomes a cradle for another industry. The team looked at how both industry and the environment would support the circular economy approach.

Historical legacy: Mark said often there are legacy systems with legacy materials that are still needed or wont be replaced. Many old buildings in cities still have steam heating systems, installed 100-or more years ago. These still need support today because the owner wont rip apart the entire building just to replace the heating system.

Sessions three and four

Future lifestyle changes: A day in 2075 – two groups

Facilitators: Dr Paul Jones, Senior Fellow in Surface Engineering and Nanotechnology and **Dr Sue Impey**, Senior Lecturer in Surface Engineering

Note Takers: Cynthia Adu, Researcher in Sustainable Manufacturing and Dr Gustavo Castelluccio, Research Senior Lecturer in Manufacturing

36 students/teachers from Bedford Modern School (20) and Kimberley College (16) and 56 students/teachers from Bedford School in Lecture Room 1.

Paul said many ideas were put forward by the students and most did not require much coaxing to prompt these ideas.

Several themes were discussed:

- The world is shrinking: Transport, communications, social media. This has an affect on culture. Will the world develop with less cultural variation and we are all more or less the same, in language and also in what tools and equipment we use and what items we need.
- 3D printing / additive manufacturing (AM) was a big source of debate. Today we are making useable things using AM. In the future we could "print" food and personal medicine. Food may change the way it looks in order to be printable. How would the material be supplied? Factories that make powders that are either piped to the home or delivered using drones.
- Augmentation and the idea of large-scale augmentation of the human body. The group discussed how people might voluntarily choose to have prosthetic or bionic limbs, to enhance performance, or eyes with infra-red sight capability, for example. There were ethical considerations and the group discussed if ethics of today will match those of tomorrow.
- The environment: A big topics. Growing populations will need more food. Printing could supply food on demand but not the raw materials. Biofuel, that requires stock, will lose popularity as a greater premium is placed on food crops. Someone suggested growing more food using hydroponic systems – algae is already being harvested for fuel and food.
- Entertainment. Will this change due to augmented reality, will people stop going out on day trips? Will family events be the same as today?

The students had to leave Sue Impey's session 10-mins in, but they agreed to complete their future state ideas separately. Two students summarised what the group had had time to discuss and thanked Cranfield University for organising the conference.

Highlights for the students were the lecture theatre discussions on **artificial intelligence, digital twinning and augmentation**. James said the discussion of the future development of engineering especially in manufacturing was interesting.

Other students said the day had prompted ideas that they would normally not discuss and that it was really interesting to consider how life might be in the future and it prompted thoughts on, for example, resource sustainability.

Professor Rajkumar Roy summarised Manufacturing 2075, 2017 conference

"Today has been about thinking of future manufacturing systems and the materials we will need. We need those materials because life is going to change, change for the better. Life will become more complex, because we will improve our capability as human beings. We will need lots of support and technology to help us do what we want to do, which is why we need manufacturing to transform by 2075.

You have heard about humans creating new materials artificially, and biology will give a lot of inspiration. A tree converts six basic elements in new materials to build onto itself. This helps us think about how we can grow new materials.

Think about, when we actually travel to new planets, how we will manufacture products in that new environment. Manufacturing on the Moon and on Mars will become real by 2075.

Another truth for the future is that a large part of the world is going to consume more technology.

Today, only a small proportion of the world's population consumes technology and expensive consumer products, perhaps 10% to 20%. That number will grow and by 2050 I hope it will be over 50 per cent.

On the other side, resources are limited. Unless we can create new ways of manufacturing products and new materials, we will not be able to support the needs of the higher population that consumes technology. Our thinking must go into developing new materials.

We heard about gallium nitride, a relatively new material. How can we make these faster, and cheaper, so that it is widely affordable for the benefit of the many. That has to be our challenge."

Manufacturing in the future will be impacted by organic and disruptive technologies and systems, new materials, changing lifestyles, values and political and social developments.

We need to start imagining the future now to ensure we can answer the challenges thrown up by the future manufacturing landscape. Research, education and skills development will play key roles in meeting these changes.

Manufacturing 2075 is a globally-focused forum to discuss very long-term manufacturing challenges and to start thinking now about how we might address wand influence them.

Our collective views can shape the direction of research, ensure tailored, timely practical solutions and support innovation in education models.

Manufacturing 2075 – 5 December 2018

www.manufacturing-2075.org.uk

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