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Global Expert Mission USA Composites 2018

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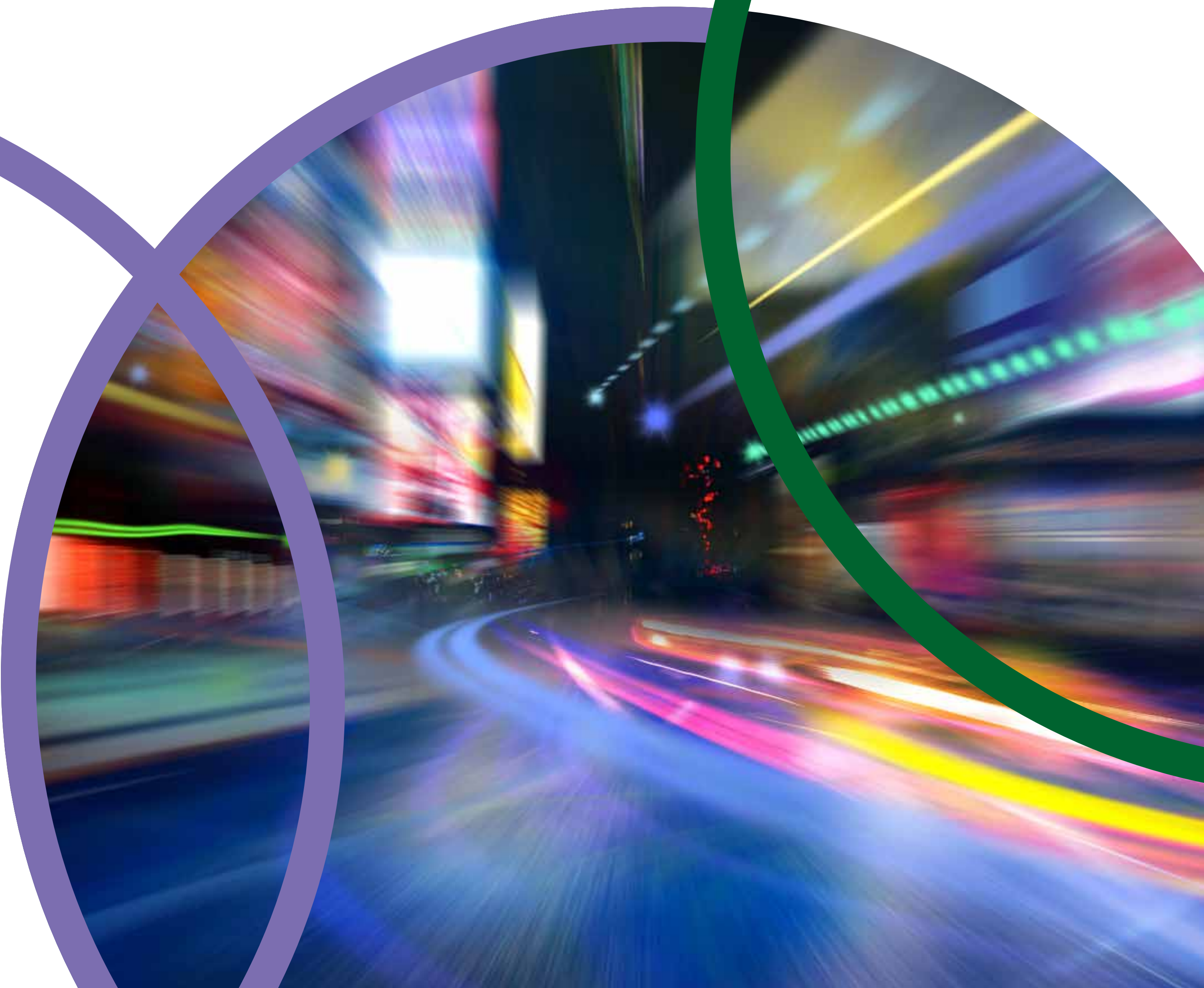

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Welcome

Innovate UK's global missions programme is one of its most important tools to support the UK's Industrial Strategy's ambition for the UK to be the international partner of choice for science and innovation. Global collaborations are crucial in meeting the Industrial Strategy's Grand Challenges and will be further supported by the launch of a new International Research and Innovation Strategy.

Innovate UK's Global Expert Missions, led by Innovate UK's Knowledge Transfer Network, play an important role in building strategic partnerships, providing deep insight into the opportunities for UK innovation and shaping future programmes.

The Composite Materials Expert Mission travelled to Dallas, Tennessee and Alabama in October 2018 and in this publication we share the information and insights gathered during the delegation's time in the US.

1. Overview of the US Composites Sector

Figure 1 and Figure 2 provide details of the global composites market and Figure 3 and Figure 4 provide details of the North American composites market, all compiled by Lucintel. The American Composites Manufacturers Association (ACMA) which is the trade association for the composites industry in the US is currently working to deliver its own data on the US market.

Figure 5 and Figure 6 provide details of the UK composites market, compiled from data gathered for the Composites Leadership Forum and presented in a similar format to the Lucintel data. It should be noted that the Lucintel and CLF data have not been compiled in the same way and the timescales used are not exactly the same, so any comparison only provides an indication. In Figure 2, Figure 4 and Figure 6, the horizontal axis denotes the percentage share that the sector has within the global market, the vertical axis denotes the percentage that sector has of the global growth and the size of the bubble denotes the size of the market for that sector in 2021 (2020 for UK). These graphs provide a useful indication of a country's strength in certain sectors.

Focusing in on the US market initially, it can be seen that in 2016 the market was worth $24.8 billion and will grow to $32.9 billion by 2022, providing an overall compound annual growth rate of 4.8%. ACMA states that glass fibre is the reinforcement most commonly used, but they do not yet have all the data for the market broken down by material types.

Listing the industry sectors by order of size with the largest first gives:

- Transportation
- Aerospace and defence
- Construction
- Electrical and electronic
- Pipe and tank
- Consumer goods
- Marine
- Wind energy.

Although the wind sector has the largest compound annual growth rate (CAGR) of all the industry sectors, it can be seen that the value of the sector is tiny. Figure 4 provides a much better picture of the future strengths of the US market. This clearly shows that the US dominates the global aerospace composites market and will also claim a large share of future growth. The US will also do well in the global marine market, although the size is relatively small. However, the transportation market is also of interest as this is large and the US will also capture a large share of global growth.

Figure 1: Breakdown of the global composites market by sector

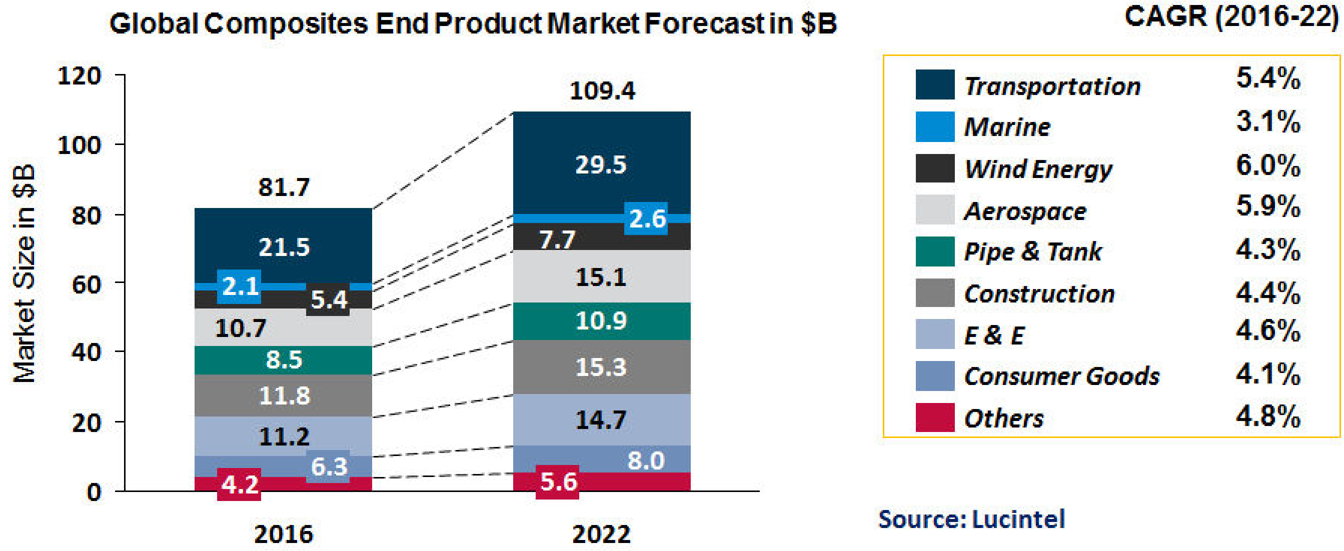


Figure 2: Sectoral share of global composite market and growth

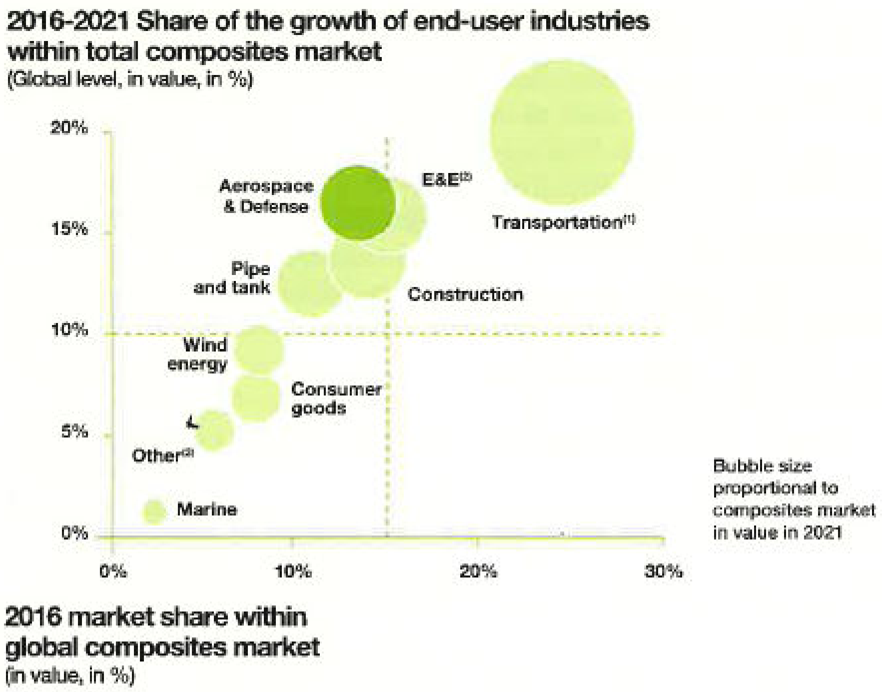


Figure 3: Breakdown of the North American composites market by sector

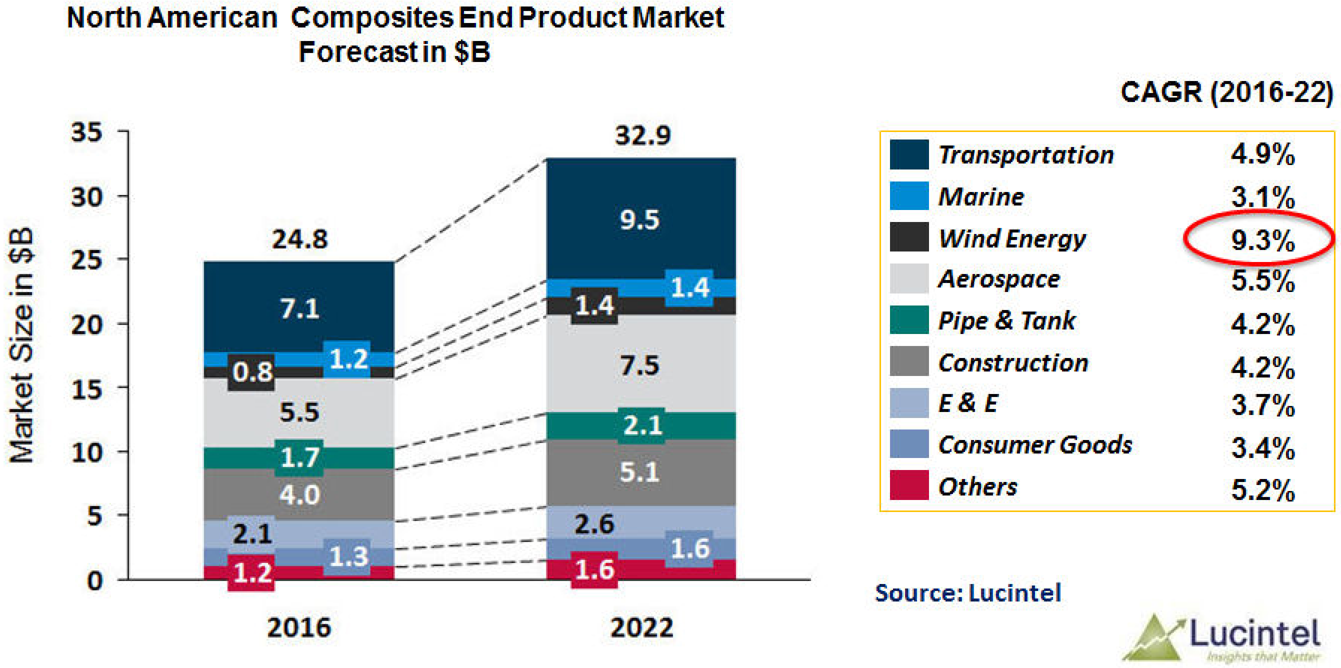


Figure 4: North American sectoral share of global composites market and growth

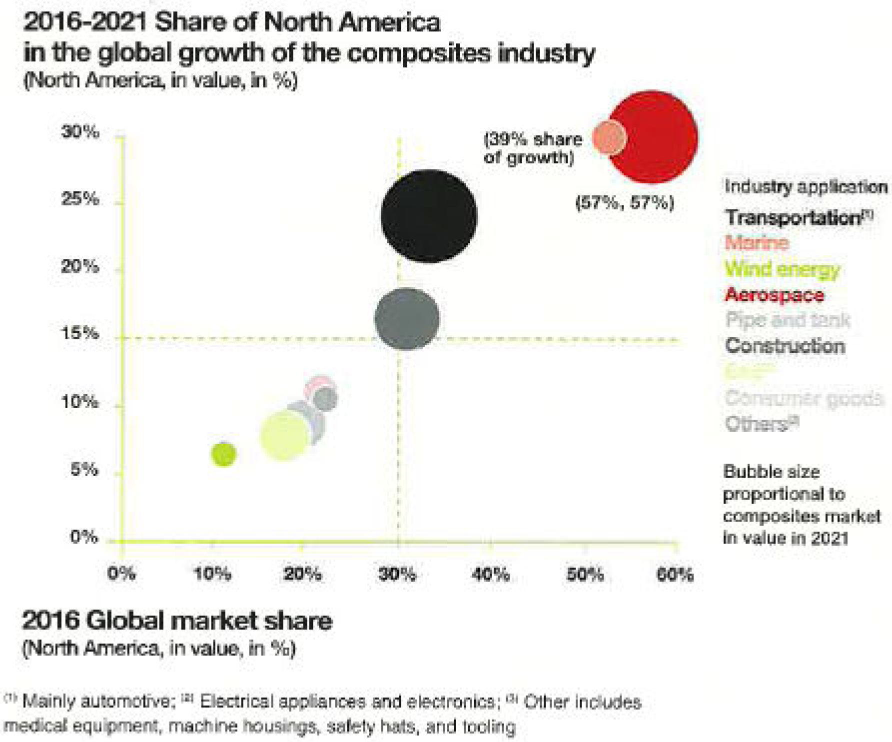


Figure 5: Breakdown of the UK composites market by sector

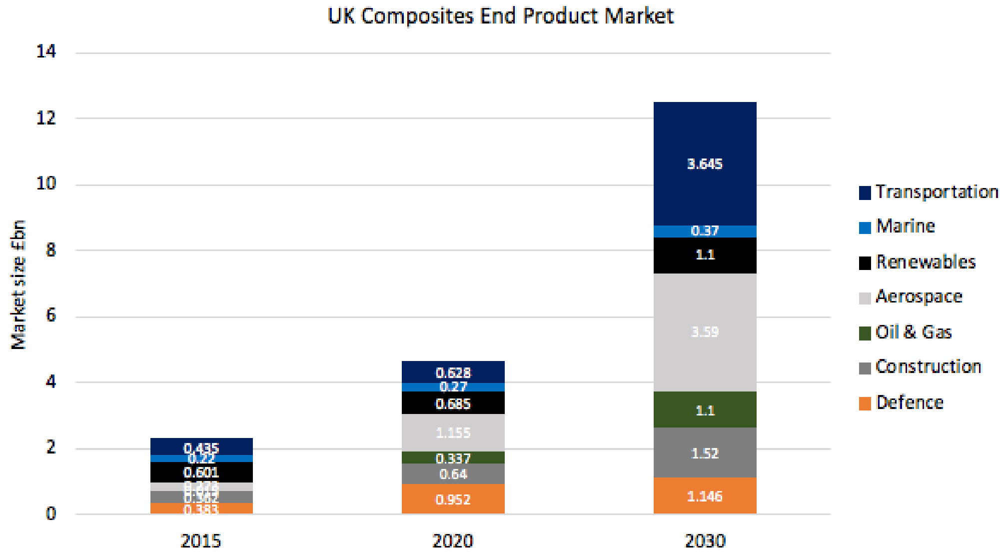


Figure 6: UK sectoral share of global composites market and growth

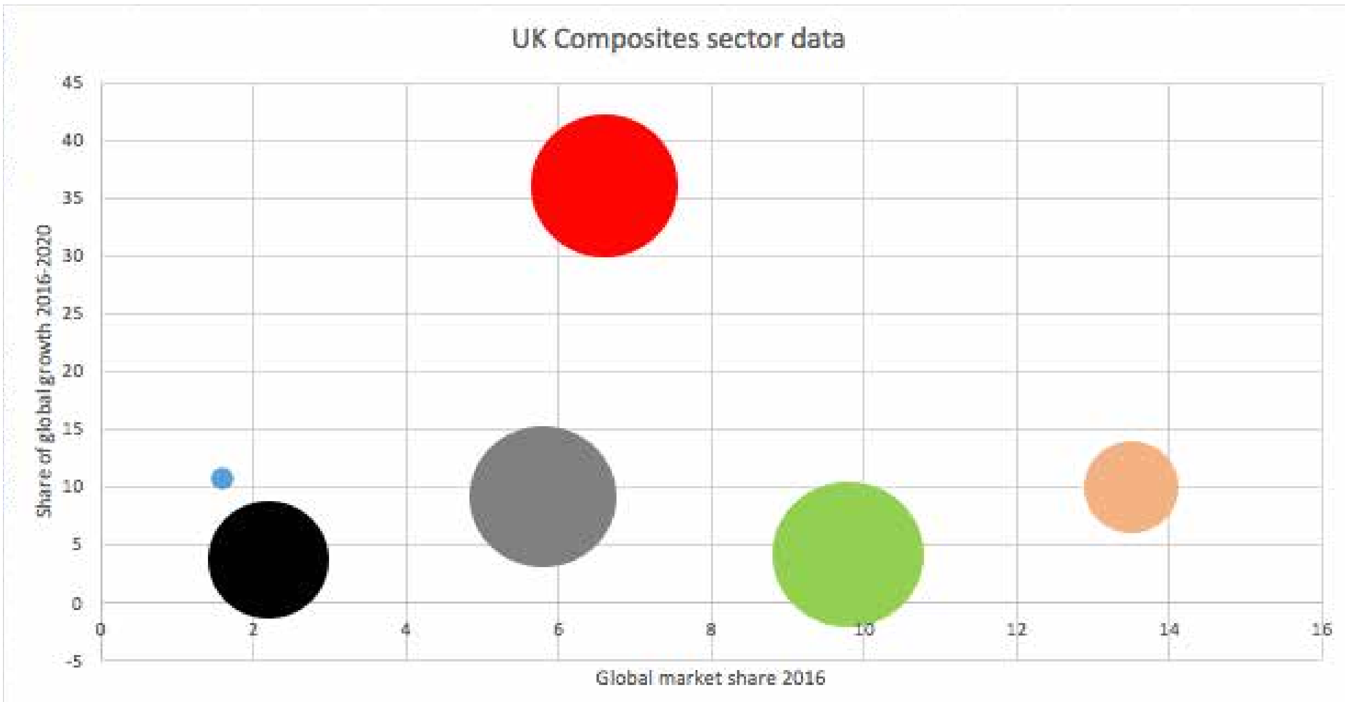


Table 1 compares data on the global, US and UK markets taken from Figure 1 to Figure 6. This shows two things:

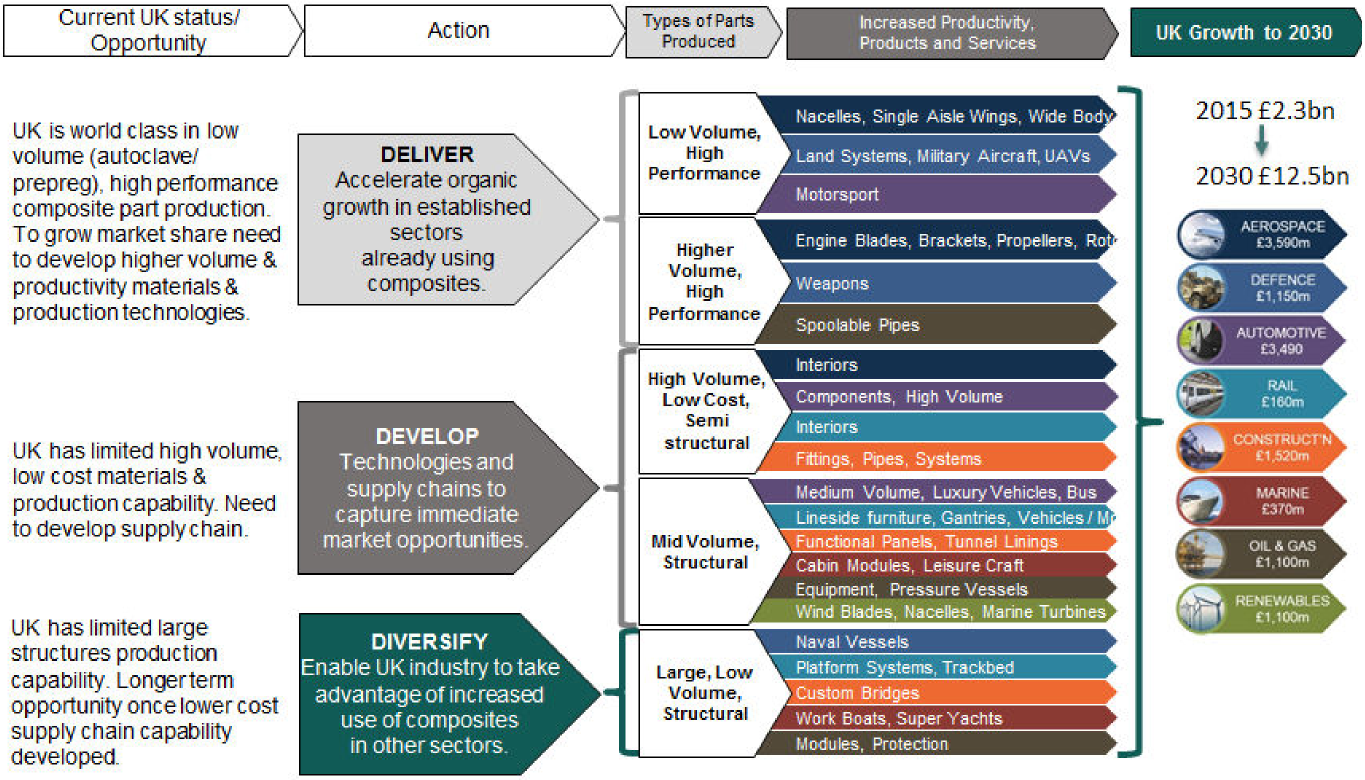
- The UK lags behind the US and the rest of the world in capability to deliver composite parts into the transportation sector. CLF data also suggests that the UK is not well-placed to capture future market share either. This suggests the UK could benefit from working with the US to develop strengths in this area.
- The US and UK share common strengths and aspirations to capture future market in aerospace composites. Collaboration in this area could be of mutual benefit.

Table 1: Comparison of the global, US and UK composite markets'

	Market size (Global and US 2022, UK 2020)	Industry sector market share in the region (Largest first and for 2020 UK, 2022 others)	Share of global growth (2015-20 for UK, 2016-22 others)
Global	$109.4 billion	• Transportation • Construction • Aerospace and defence • Electrical and electronic • Pipe and tank • Wind energy/consumer goods	• Transportation • Aerospace and defence • Electrical and electronic • Construction • Pipe and tank • Wind energy
US	$32.9 billion	• Transportation • Aerospace and defence • Construction • Electrical and electronic • Pipe and tank • Consumer goods • Marine	• Aerospace and defence • Marine • Transportation • Construction • Other • Pipe and tank • Electrical and electronic
UK	$6.1 billion	• Aerospace and defence • Renewables • Transportation • Construction • Oil and gas • Marine	• Aerospace and defence. • Oil and gas • Renewables • Marine • Construction • Transportation

Both of these areas for potential collaboration fit with the UK Composites Strategy, a schematic of which is provided in Figure 7. Collaboration in the transportation sector fits with the Develop part of the strategy and collaboration in the aerospace sector fits with the Deliver part.

Figure 7: Schematic of the UK Composites Strategy[1]



[1] "2016 UK Composites Strategy: Lightening the Load." https://compositesuk.co.uk/about/industry/uk-composites-strategy

2. Innovation Landscape

2.1 Relevant Policy

The National Science and Technology Council (NSTC) is the US body that coordinates science and technology policy across the diverse entities that make up the federal research and development enterprise. The NSTC consists of committees, with sub-groups, as shown in Table 2.

The sub-groups most relevant to the composites sector are the Subcommittee on Advanced Manufacturing (SAM) and the Material Genome Initiative. High-level details of their policy/strategy and relevance to composites collaboration are provided below.

Although NASA contributes to the NSTC sub-groups, given the relevance of the visit to the NASA Marshall facility to the mission, an overview of the NASA strategy, highlighting relevant points, is also provided below.

Table 2: NSTC Committees

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL (NSTC)

COMMITTEE ON ENVIRONMENT, NATURAL RESOURCES, AND SUSTAINABILITY (CENRS)		
AQRS: Air Quality Research (SC)	SWORM: Space Weather Observation, Research, and Mitigation (SC)	SOST: Ocean Science & Technology (SC)*
CSMSC: Critical & Strategic Mineral Supply Chains (SC)	Water-Energy-Food (TF)	SWAQ: Water Availability & Quality (SC)
IARPC: Interagency Arctic Research Policy Committee (IWG)*	SES: Ecological Systems(SC)	T&R: Toxics & Risk (SC)
SDR: Disaster Reduction (SC)	SGCR: Global Change Research (SC)*	USGEO: U.S. Group on Earth Observations (SC)
MMCWG: Methane Monitoring and Characterization Working Group (WG)		

COMMITTEE ON HOMELAND & NATIONAL SECURITY (CHNS)		
BDRD: Biological Defense Research & Development (SC)	Astronomical Assets and Data (IWG)	SCORE: Subcommittee on Special Cyber Operations Research and Engineering (SC)
CDRD: Chemical Defense Research and Development (SC)	NDRD: Nuclear Defense Research & Development (SC)	DAMIEN: Detecting & Mitigating the Impact of Earth-Bound Near Earth Objects (IWG)
D-IED: Domestic Improvised Explosive Devices (SC)	National Security Laboratory Research, Development, Test and Evaluation Facilities and Infrastructure (SC)	AUS: Autonomous Unmanned Systems (SC)
SOS-CBRNE Standards (SC)	CISR: Critical Infrastructure Security and Resilience (SC)	

COMMITTEE ON SCIENCE (CoS)		
IWGN: Neuroscience (IWG)*	PSSC: Physical Science (SC)	LSSC: Life Science (SC)*
SBS: Social and Behavioral Sciences (SC)	IWGMI: Medical Imaging (IWG)*	SMDIS: Strengthening the Medicolegal Death Investigation System (WG)
FTAC-RDRS: Research and Development Reporting Standards	TISTI: Topics in International Science, Technology, and Innovation (SC)	SFA: Subcommittee on Food and Agriculture (SC)

COMMITTEE ON STEM EDUCATION (CoSTEM)*	
FC-STEM: Federal Coordination in STEM Education (SC)	

COMMITTEE ON TECHNOLOGY (CoT)		
Social and Behavioral Sciences Team (SC)	SAM: Advanced Manufacturing (SC)*	MGI: Material Genome Initiative (SC)
Lab to Market (SC)	NITRD: Network and Information Technology R&D (SC)*	NSET: Nanoscale Science Engineering & Technology (SC)*

2.1.1 Strategy for American Leadership in Advanced Manufacturing

The most recent policy, and therefore support, for composites innovation within the US, has been driven by the NTSC's SAM, which in coordination with the National Economic Council has published the 2018 Strategy for American Leadership in Advanced Manufacturing[2] as an update to the previous manufacturing strategy[3].

The goals of the Advanced Manufacturing Strategy are shown in Table 3, with relevant text related to composites and collaboration identified in blue.

The fact that both materials development and additive manufacturing development are referred to in the same strategy encourages links between the two strands of development, which is not currently seen in the UK.

The UK and US share the need to focus on cost reduction, through the use of digital methods, for development and qualification of materials.

Both the US and UK recognise the benefits of public-private partnerships (UK evidenced through HVM Catapult) and wish to provide extra support to small and medium-sized manufacturers (SMEs in the case of the UK). The potential issue raised in the section of Table 3 that describes manufacturing innovation ecosystems is that public-private partnerships should be sustainable and not keep coming back for public funding.

The recognition that funding is needed for standards development to facilitate commercialisation is mirrored by the activities of the CLF, which has a working group focused on Regulations Codes and Standards. Composites UK maintains a dialogue with ACMA on activity in this area.

The importance given to technology transfer between the defence and civil sectors is something that is also recognised in the UK, but in the case of collaboration, may raise issues with regard to ITAR.

[2] Strategy for American Leadership in Advanced Manufacturing." A report by the Subcommittee on Advanced Manufacturing Committee on Technology of NSTC. Oct 2018. https://www.whitehouse.gov/wp-contentuploads/2018/10/Advanced-Manufacturing-Strategic-Plan-2018.pdf

[3] A National Strategic Plan for Advanced Manufacturing." NSTC Feb 2012. https://www.manufacturing.gov/sites/default/files/2018-01/nstc_feb2012.pdf

Table 3: US Manufacturing strategy goals. (Relevant text for composites/collaboration in blue)

Develop and transition new manufacturing technologies

1. Capture the future of intelligent manufacturing systems.
2. Develop world-leading materials and processing technologies.
    - 2.1 High performance materials
      Promote a materials genome and systems-level computational approach to material design, optimisation, and implementation to significantly reduce design time and cost in identifying, developing, qualifying, and scaling production of high-performance materials.
    - 2.2 Additive manufacturing
      Continue advancements in process control and process monitoring to secure additive manufacturing technologies as viable production alternatives. Measure and quantify the interactions between material and processing technology to better understand the relationship. Establish new standards to support the representation, presentation, and evaluation of additive manufacturing data to ensure part quality and reproducibility. Expand research efforts to establish best practices for applying computational technologies to additive manufacturing, including simulation and machine learning.
    - 2.3 Critical materials
3. Assure access to medical products through domestic manufacturing.
4. Maintain leadership in electronics design and fabrication.
5. Strengthen opportunities for food and agricultural manufacturing.

Educate, train, and connect the manufacturing workforce

1. Attract and grow tomorrow's manufacturing workforce.
2. Update and expand career and technical education pathways.
3. Promote apprenticeship and access to industry-recognised credentials.
4. Match skilled workers with the industries that need them.

Expand the capabilities of the domestic manufacturing supply chain.

1. Increase the role of small and medium-sized manufacturers in advanced manufacturing.
    - 1.1. Supply chain growth
      Enhance outreach and education efforts consistent with how small and medium-sized manufacturers (SMMs) learn about and adopt innovations. Ensure that agency technology transition programmes focus on SMMs.
    - 1.2. Cybersecurity outreach and awareness
    - 1.3. Public-private partnerships
      Continue to use federal convening powers to ensure that all relevant parties, particularly SMMs, are fully engaged during the formative stages of public-private consortia and collaboratives.
2. Encourage ecosystems of manufacturing innovation.
    - 2.1. Manufacturing innovation ecosystems
      Public-private partnerships, driven by industry and with a focus on both commercial and defence manufacturing processes and products, can minimise the problem of an ecosystem tethered only to federal funding. Expand the creation and utilisation of manufacturing collaboratives and consortia for both technology and economic development. Create additional public-private partnerships focused on technologies critical to America's future competitiveness.
    - 2.2. New business growth and formation
    - 2.3. Research and development transition
      Coordinate across the agencies and federal technology transfer-related policy groups to identify technologies suitable for transition from lab to market within the US. Prioritise funding for research into measurement science and standards development to speed the transition of research and development to commercial practice.
3. Strengthen the defence manufacturing base.
    - 3.1. Disruptive dual-use capabilities
      Pursue dual-use technologies to spur innovation and technology development in the defence and commercial supply chains, contributing to economic stability, long-term growth, and a robust national defence.
    - 3.2. Buy American
    - 3.3. Leveraging existing authorities
4. Strengthen advanced manufacturing for rural communities.
    - 4.1. Advanced manufacturing for rural prosperity
    - 4.2. Capital access, investment, and business assistance

2.1.2 Materials Genome Initiative

The importance of the Materials Genome Initiative (MGI) is demonstrated by the fact that it has an NSTC sub-group. The original aim of the Materials Genome Initiative[4, 5] when it was launched in 2011 was to discover, develop, manufacture, and deploy advanced materials twice as fast, at a fraction of the cost. Table 4 provides an overview of the four key challenges and objectives to deliver this. Text shown in blue highlights particular areas of interest for collaboration.

The first thing to note is that the overall aim of this project aligns entirely with most of the work being carried out by the Composites Leadership Forum (CLF) in the UK. It is therefore unsurprising that much of the work to align experiments with computation to achieve this objective fit with the UK's composite requirements.

The second point to make is on access to materials data. For at least 20 years, the UK composites community has been calling for a materials database to allow designers access to data on composites to facilitate the uptake of composites across a broader range of sectors. There are a wealth of reasons why this has not gone forward in the UK, but none are UK-specific. The UK should learn lessons from what the US is doing in this area.

The final point is that the US is open to international collaboration in this area.

[4] https://www.mgi.gov/

[5] Materials Genome Initiative Strategic Plan." Dec 2014. https://www.mgi.gov/sites/default/files/documents/mgi_strategic_plan_-_dec_2014.pdf

Table 4: Strategic goals and objectives of the MGI

Enable a paradigm shift in culture

1. Encourage and facilitate integrated research and development.
    - Over a two-year period, increase the cumulative number of researchers who have participated in MGI projects by 50%. (DOD, DOE, NSF)
    - Hold regular, multi-agency principal investigator meetings, including industry, to build a stronger MGI community. (DOD, DOE, NSF)
    - Over a two-year period, add multiple foundation engineering projects (FEP) supported by federal government. (DOD & DOE)
2. Facilitate adoption of the MGI approach.
    - Work to define venues that promote interactions, transition and integration between academic and industry researchers, including students on MGI projects. (Subcommittee on MGI)
    - Over a two-year period, launch an incentive prize focused on demonstrating the use of MGI techniques to rapidly deliver new materials. (DOE, NASA & NIST)
3. Engage with the international community.
    - Continue to pursue opportunities for collaboration with international partners for discussions of materials science research and development, and build on strengths of existing international partnerships. (SMGI)

Integrate experiments, computation, and theory

1. Create an MGI network of resources.
    - Establish an information inventory, including contact information, for openly available codes, software and experimental capabilities for synthesis and characterisation, as a community resource. (SMG)
    - Establish a network of research groups focused on developing predictive software for structural materials. Document lessons learned and best practice for use in launching an additional network for other material and application areas. (DOE, DOD, NIST & NSF)
2. Enable creation of accurate, reliable simulations.
    - Across all TRLs, identify challenges for theory, modelling and simulation for different materials and associated cross-cutting methods and algorithms. Hold a workshop and report annually. Evolve focus to include, in the first four years, structural, magnetic, energy storage and electronic materials.
3. Improve experimental tools – from materials discovery through deployment.
    - Convene a multiagency workshop to assess the current state and future directions for characterisation tools that allow in situ and in operando assessments of materials properties, synthesis and processes. (DOD, DOE, NASA, NIST and NSF)
    - Multiagency workshops to identify major challenges for application of the MGI approach. In the first four years include lightweight metals, catalysts, batteries and energy storage, semiconductors and integrated circuits. (NIST, DOE, DOD & NSF)
    - Benchmarking studies to quantify time to market for a subset of material classes/applications. (NIST)
4. Develop data analytics to enhance the value of experimental and computational data.
    - Convene a path-finding workshop focused on the status of the computational tools for data analytics for applications emerging from materials science and engineering. (NIST)

Facilitate access to materials data

1. Identify best practice for implementation of a materials data infrastructure.
    - Multiagency workshops with stakeholders to establish the needs of the materials communities, identify barriers to creating a materials data infrastructure and methods to overcome. (DOD & NIST)
    - Foster ongoing discussion of best practice in data management plans used by participating agencies with the opportunity to leverage these for broader applications within the MGI community. (SMG)
2. Support the creation of accessible materials data repositories.
    - Develop and implement at least three materials data repository pilots to assess a range of models and initiate the definition of a materials data infrastructure model. (DOD, DOE & NIST)

Equip the next-generation materials workforce

1. Pursue new curriculum development and implementation.
2. Provide opportunities for integrated research experiences.

2.1.3 NASA Strategic Plan

An overview of NASA's Strategic plan 2018[6] is provided in Table 5. It can be seen that Advanced Materials are listed as a key focus area within the Exploration Research & Technology (ER&T) funding account, which funds research and development. This is expanded upon within NASA's Technology Roadmap focused on materials, structures, mechanical systems, and manufacturing[7] which details the composite requirements both from a materials and a structures development perspective.

The strategic plan also states that international partnerships are welcome in pre-competitive research and development. The UK is listed as a country with which they already have agreements, but they also state that these partnerships need to take into account external factors such as export control considerations; US foreign policy; national security policy; national space policy; and changes in government leadership or objectives in the US and abroad.

6. NASA Strategic Plan 2018." https://www.nasa.gov/sites/default/files/atoms/files/nasa_2018_strategic_plan.pdf
7 NASA Technology Roadmap TA12: Materials, Structures, Mechanical Systems and Manufacturing." May 2015. https://www.nasa.gov/sites/default/files/atoms files/2015_nasa_technology_roadmaps_ta_12_materials_structures.pdf

Table 5: Overview of NASA Strategic Plan 2018 with relevance to composite collaboration identified

Theme	Strategic goal	Strategic objective	Relevance to composites and UK collaboration
Discover	Expand human knowledge through new scientific discoveries.	1. Understand the Sun, Earth, Solar System and Universe. 2. Understand responses of physical and biological systems to spaceflight.	
Explore	Extend presence deeper into space and the moon for long-term exploration and utilisation.	1. Lay the foundation and market for America to maintain a constant human presence in low earth orbit. 2. Conduct exploration in deep space, including the surface of the moon.	Development of new capabilities such as crew transport, Space Launch System (SLS) heavy lift, and in-space habitation.
Develop	Address national challenges and catalyse economic growth.	1. Develop and transfer revolutionary technologies to enable exploration capabilities for NASA and the nation. 2. Transform aviation through revolutionary technology research, development and transfer. 3. Inspire and engage the public in aeronautics, space and science.	Over the next ten years - through the Exploration Research & Technology (ER&T) funding account - the Agency will advance revolutionary capabilities for both NASA mission challenges and national needs. NASA will invest in the following Exploration Campaign key focus areas: • Advanced environmental control and life support systems and in-situ resource utilisation. • Power and propulsion technology. • Advanced materials. • Communications, navigation and avionics. • Entry, descent, and landing. • Autonomous operations. • In-space manufacturing and on-orbit assembly. • Research to enable safe and effective operation in space environments. By carefully fostering international partnerships in pre-competitive areas, NASA supports the safe and efficient growth in global aviation important to the United States.
Enable	Optimise capabilities and operations.	1. Engage in partnership strategies. 2. Enable space access and services. 3. Assure safety and mission success. 4. Manage human capital. 5. Ensure enterprise protection. 6. Sustain infrastructure capabilities and operation.	NASA has over 800 active international agreements with more than 120 countries. While over half of these agreements are with the European Space Agency and partners in five countries (France, Germany, Japan, Canada and the UK), a large number are with partners around the world. Key external factors for partnerships include: export control considerations; US foreign policy; national security policy; national space policy; and changes in government leadership or objectives in the US and abroad.

2.2 Support Provided and Case Studies

2.2.1 Manufacturing Strategy

The extent to which the different federal agencies play a role in fostering the growth of advanced manufacturing through investments in research and development and in education and workforce development is shown below. Table 6 shows the parts of the strategy they contribute to and Table 7 shows the actual programmes they have established.

Table 6: Federal agencies investing in the US Manufacturing Strategy

Goals	Objectives	DoD	DOE	DOC	HHS	NSF	NASA	DOL	USDA	DOEd
Develop and Transition New Manufacturing Technologies	Capture the Future of Intelligent Manufacturing Systems	●	●	●		●	●			
	Develop World-Leading Materials and Processing Technologies	●	●	●		●	●			
	Assure Access to Medical Products through Domestic Manufacturing	●		●	●	●				
	Maintain Leadership in Electronics Design and Fabrication	●	●	●		●	●			
	Strengthen Opportunities for Food and Agricultural Manufacturing	●				●			●	
Educate, Train, and Connect the Manufacturing Workforce	Attract and Grow Tomorrow's Manufacturing Workforce	●	●	●		●	●	●		●
	Update and Expand Career and Technical Education Pathways	●	●	●		●	●	●		●
	Promote Apprenticeship and Access to Industry-Recognized Credentials	●	●	●		●	●	●	●	●
	Match Skilled Workers with the Industries that Need Them	●			●			●	●	
Expand the Capabilities of the Domestic Manufacturing Supply Chain	Increase the Role of Small and Medium-Sized Manufacturers in Advanced Manufacturing	●	●	●	●	●	●		●	
	Encourage Ecosystems for Manufacturing Innovation	●	●	●	●		●			
	Strengthen the Defense Manufacturing Base	●	●	●	●		●			
	Strengthen Advanced Manufacturing for Rural Communities								●	

Table 7: Federal agencies' manufacturing and related programmes

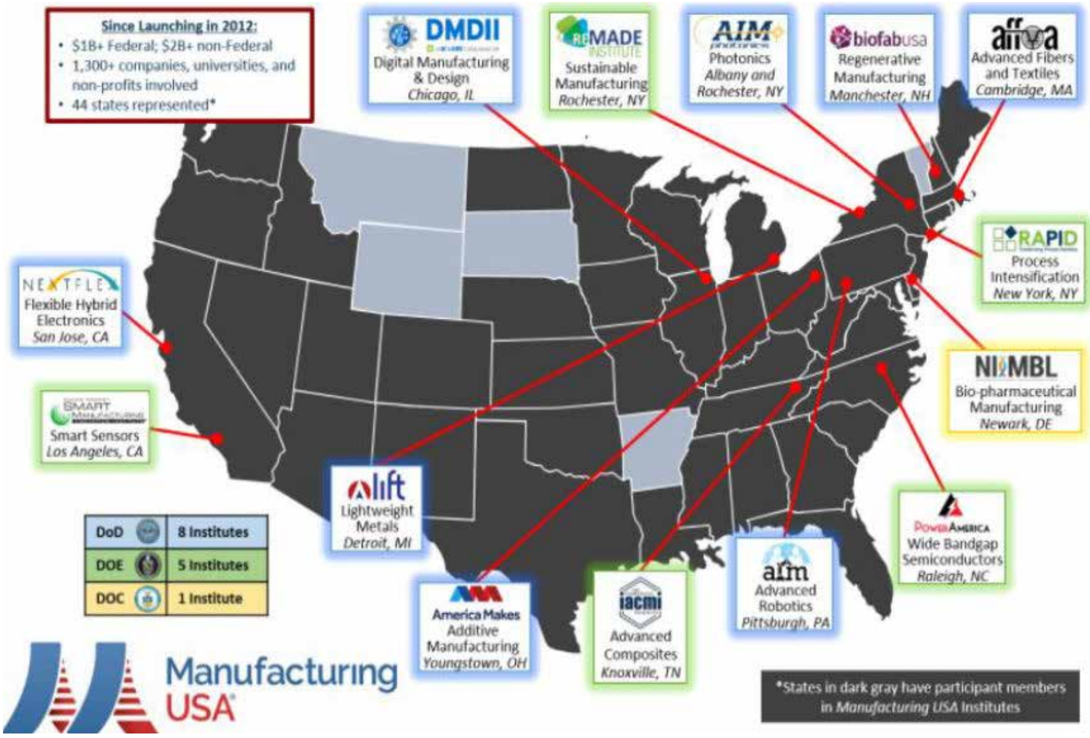
Agency	Manufacturing and Related Programs	
DOC (NIST & ITA)	• Manufacturing USA • Manufacturing Extension Partnership • Additive Manufacturing • Smart Manufacturing Systems • Robotics for Smart Manufacturing • Advanced Materials Measurements • Standard Reference Materials	• Materials Genome Initiatives • Physical Measurements • Biomanufacturing • ITA Global Markets • ITA Industry & Analysis • ITA Enforcement and Compliance
DoD	• Manufacturing Technology Programs • Manufacturing USA institutes • Defense Industrial Base Modernization	• Industrial Base Analysis and Sustainment Program • Defense industrial base scale-up • Defense Production Act Title III
DOE	• Clean Energy Manufacturing Institutes • High Performance Computing for Manufacturing • Lab-Embedded Entrepreneurship	• Energy Innovation Hubs • Manufacturing Demonstration Facility at Oak Ridge National Laboratory • Critical Materials Hub
HHS/FDA	• Advanced Research and Development of Regulatory Science for Continuous Manufacturing • Centers for Innovation in Advanced Development and Manufacturing	• Bio-Medical Advanced Research and Development Authority • Medical Countermeasures Advanced Development and Manufacturing
NASA	• Game Changing Technology Program • Advanced Exploration Systems Program, In-Space Manufacturing Project	• Advanced Manufacturing Technology Project • National Center for Advanced Manufacturing
NSF	• Engineering Research Centers • Industry/University Cooperative Research Centers • Advanced Manufacturing • National Robotics Initiative 2.0	• Secure and Trustworthy Cyberspace • Cyber Physical Systems • Cellular and Biochemical Engineering • Designing Materials to Revolutionize and Engineer our Future
USDA	• Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program • Business and Industry Guaranteed Loan Program • Biofuel Infrastructure Partnership • Rural Utility Service	• Rural Business-Cooperative Service • Research grants • Small Business Innovation Research • Support for export-related activities and marketing, including USDA BioPreferred Program

Of particular interest to composites are Manufacturing USA (listed as DOC), the Manufacturing Demonstration Facility at Oak Ridge National Laboratory (DOE) and the NASA programmes (listed in the next section).

Manufacturing USA was launched in 2012 by the Obama administration as the National Network of Manufacturing Innovation and renamed in September 2016. It consists of 14 manufacturing innovation institutes (Figure 8) that represent public-private partnerships focused on developing advanced manufacturing product and process technologies, facilitating their commercialisation, and developing workforce skills around advanced manufacturing technologies.

In 2017, Manufacturing USA institutes had 1,291 members. These included 844 manufacturing firms; 297 educational institutions, including universities, community colleges, and other academic institutions; and 150 other entities, including federal, state, and local government, federal laboratories, and not-for-profit organisations. Of the manufacturers, 549 (65%) were small businesses with 500 or fewer employees, and 295 (35%) were large manufacturers. The Institute for Advanced Composites Manufacturing Innovation (IACMI) is the institute that focuses on composites. As detailed below, the headquarters of this institute are at Oak Ridge National Laboratory.

Figure 8: Manufacturing USA institutes



2.2.2 Institute for Advanced Composites Manufacturing Innovation (IACMI)

The Institute for Advanced Composites Manufacturing Innovation (IACMI) was the fifth Institute in Manufacturing USA and is supported by the US Department of Energy's (DOE) Advanced Manufacturing Office (AMO) and the investments of industrial, state, university, and other partners. The DOE Office of Energy Efficiency and Renewable Energy (EERE) and AMO issued a Funding Opportunity Announcement (FOA) to create the Clean Energy Manufacturing Institute (CEMI) for Composite Materials and Structures. The focus of the Institute is on "innovative composites manufacturing approaches to meet cost and production targets that lower the energy consumption, greenhouse gas emissions and address end-of-life issues [that] will accelerate realisation of life cycle energy efficiency target fibre reinforced polymer composite applications" in vehicles, compressed gas storage and wind turbines.

IACMI receives $70 million federal funding over five years and $178 million non-federal support ($58 million from states and $120 million from industry over five years). This funding runs until May 2020.

IACMI is based at several locations:

Headquarters: Oak Ridge National Laboratory[8], Knoxville, TN. Has:

- Carbon Fiber Technology Facility[9] (see Figure 9).
- Manufacturing Demonstrator Facility[10] (see Figure 10).

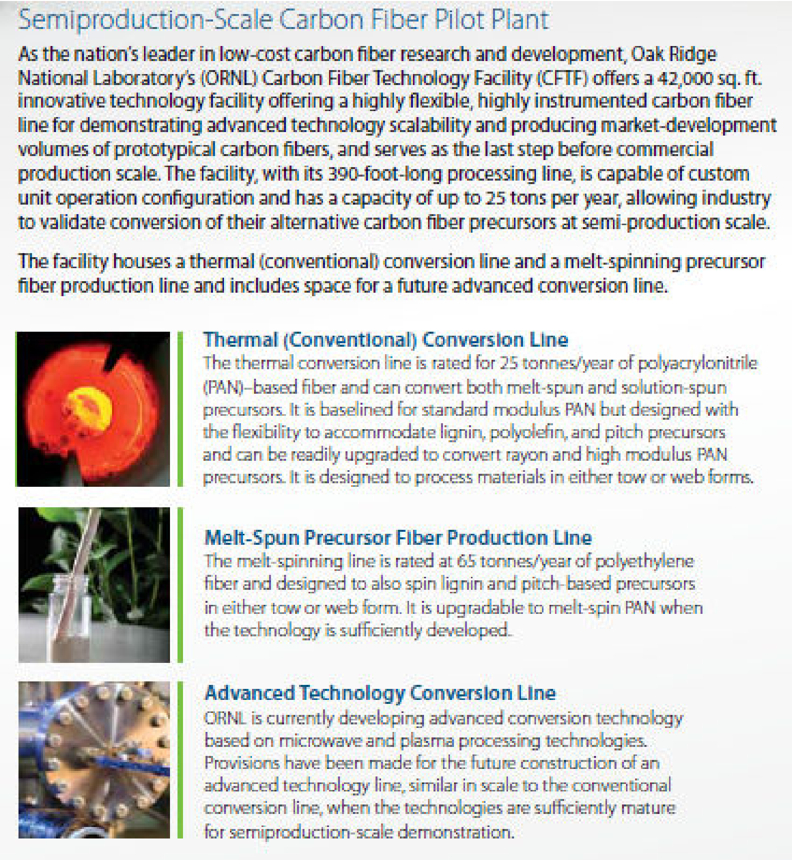
Satellite hubs:

- University of Tennessee, Knoxville, Fibers and Composites Manufacturing Facility, TN (see Figure 11).
- IACMI Scale-Up Research Facility (SURF), Detroit, MI (see Figure 12).
- Michigan State University Composites, Lab: Lansing, MI.
- University of Dayton Research Institute's, Composites Laboratory: Dayton, OH.
- Composites Manufacturing, Education and Technology Facility (CoMET) at the National Renewable Energy Laboratory's National Wind Technology Center: Boulder, CO.
- The Indiana Manufacturing Institute at Purdue University: West Lafayette, IN (see Figure 13).

Affiliates:

- Composite Protoyping Center, Long Island, NY.
- Composite Recycling Technology Center, Port Angeles, WA.

Figure 9: Oak Ridge Carbon Fibre Technology Facility[9]



Semiproduction-Scale Carbon Fiber Pilot Plant

As the nation's leader in low-cost carbon fiber research and development, Oak Ridge National Laboratory's (ORNL) Carbon Fiber Technology Facility (CFTF) offers a 42,000 sq. ft. innovative technology facility offering a highly flexible, highly instrumented carbon fiber line for demonstrating advanced technology scalability and producing market-development volumes of prototypical carbon fibers, and serves as the last step before commercial production scale. The facility, with its 390-foot-long processing line, is capable of custom unit operation configuration and has a capacity of up to 25 tons per year, allowing industry to validate conversion of their alternative carbon fiber precursors at semi-production scale.

The facility houses a thermal (conventional) conversion line and a melt-spinning precursor fiber production line and includes space for a future advanced conversion line.

Thermal (Conventional) Conversion Line

The thermal conversion line is rated for 25 tonnes/year of polyacrylonitrile (PAN)–based fiber and can convert both melt-spun and solution-spun precursors. It is baselined for standard modulus PAN but designed with the flexibility to accommodate lignin, polyolefin, and pitch precursors and can be readily upgraded to convert rayon and high modulus PAN precursors. It is designed to process materials in either tow or web forms.

Melt-Spun Precursor Fiber Production Line

The melt-spinning line is rated at 65 tonnes/year of polyethylene fiber and designed to also spin lignin and pitch-based precursors in either tow or web form. It is upgradable to melt-spin PAN when the technology is sufficiently developed.

Advanced Technology Conversion Line

ORNL is currently developing advanced conversion technology based on microwave and plasma processing technologies. Provisions have been made for the future construction of an advanced technology line, similar in scale to the conventional conversion line, when the technologies are sufficiently mature for semiproduction-scale demonstration.

Figure 10: Oak Ridge Manufacturing Demonstrator Facility[11]

Additive Manufacturing

ORNL is collaborating with equipment manufacturers and end users to advance state-of-the-art technologies and revolutionize the way products are designed and built. Drawing on its close ties with industry and world-leading capabilities in materials development, characterization, and processing, ORNL is creating an unmatched environment for breakthroughs in additive manufacturing or 3D printing.

[8] https://www.ornl.gov/cftf

[9] Oak Ridge Carbon Fiber Technology Facility brochure. https://web.ornl.gov/sci/manufacturing/docs/brochures/2017-CFTF-brochure.pdf

[10] https://www.ornl.gov/mdf

[11] Oak Ridge Manufacturing Demonstrator Facility brochure https://web.ornl.gov/sci/manufacturing/docs/brochures/2017-MDF_brochure_update_sml.pdf

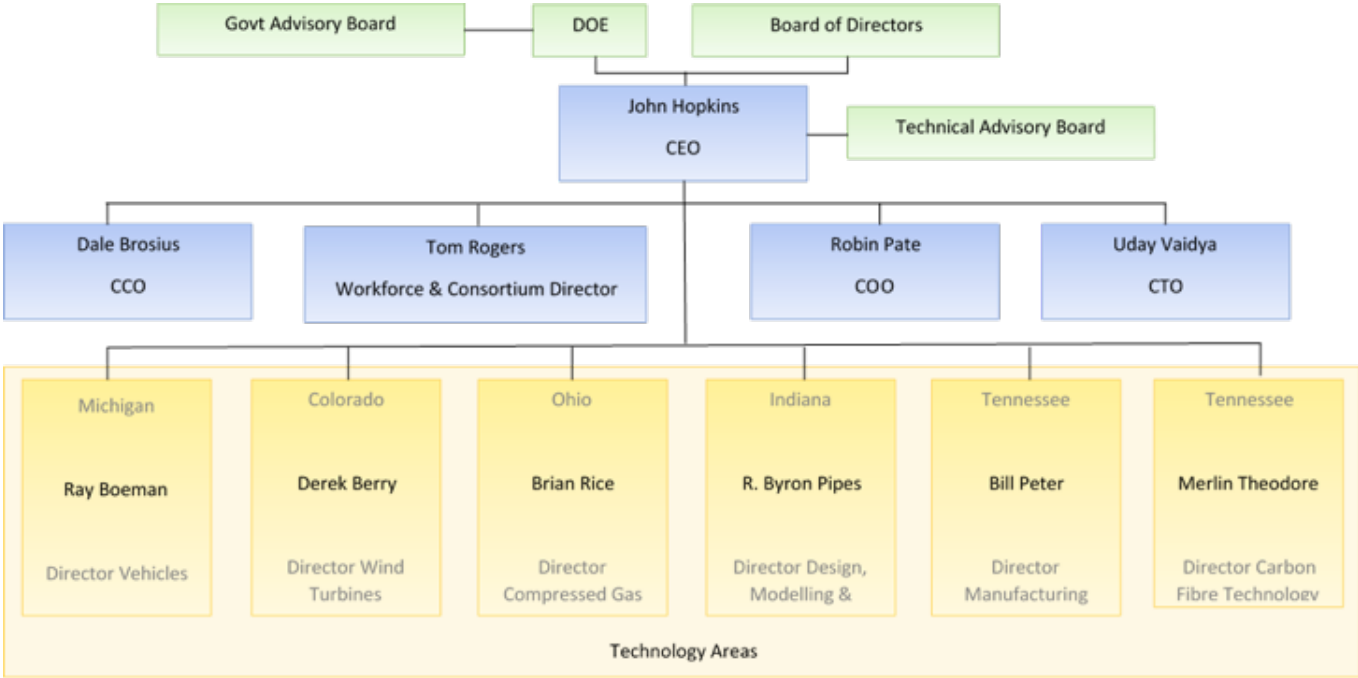
Figure 11: IACMI FCMF, University of Tennessee Knoxville

Figure 12: IACMI Vehicle Scale Up Facility, Detroit, MI

Figure 13: IACMI Indiana Manufacturing Institute at Purdue University

The senior management team for IACMI are shown in Figure 14.

Figure 14: IACMI Senior management



IACMI targets and focus areas are shown in Figure 15. IACMI has also developed a roadmap[12] to ensure it achieves its technical and economic targets.

Figure 15: IACMI Targets and focus areas

Companies that wish to work with IACMI become members and then either pay directly to access the equipment and know-how or pull together collaborative projects either with or without funding (see next section). Examples of projects undertaken within IACMI are shown in Figure 16, Figure 17 and Figure 18.

[12] IACMI roadmap. https://iacmi.org/technology-roadmapping/

Figure 16: IACMI Automotive case study

Novel composite products and processes enabling high-volume, lightweight automotive parts

Project partners including an OEM, material supplier, tier one supplier, academia and national laboratory work together to optimise carbon fibre production enabling high volume manufacturing of lightweight automotive components. The invention of unique chemistry and development of novel products and processes led to achievement of OEM specifications and demonstrated viability. Ford Motor Company, the project lead, is currently reviewing opportunities for broad implementation. Other project partners include Dow Chemical Company (Midland, MI), DowAksa (Farmington Hills, MI), Oak Ridge National Laboratory (Oak Ridge, TN), The University of Tennessee, Knoxville, Purdue University (West Lafayette, IN), and Michigan State University (East Lansing, MI).

Figure 17: IACMI Recycling case study

Automated preform manufacturing equipment for recycling scrap pre-preg

The Composite Recycling Technology Center (Port Angeles, WA) leads a team pioneering ways to automate processing of carbon fibre scrap and remanufacture it into new consumer products. This automation is essential so that the 50 million pounds of carbon fibre scrap produced annually can be processed in high volumes, fulfilling the enormous potential for energy savings and carbon reduction and creating a global composites recycling industry. At the Automotive Lightweight Materials Summit in Detroit in August 2017, the team demonstrated the manufacture of an automotive seatback made from recycled carbon fibre composite using tooling supplied in partnership with IACMI. Other project partners include: The University of Tennessee, Knoxville and Oak Ridge National Laboratory (Oak Ridge, TN).

Figure 18: IACMI Case study in the wind sector

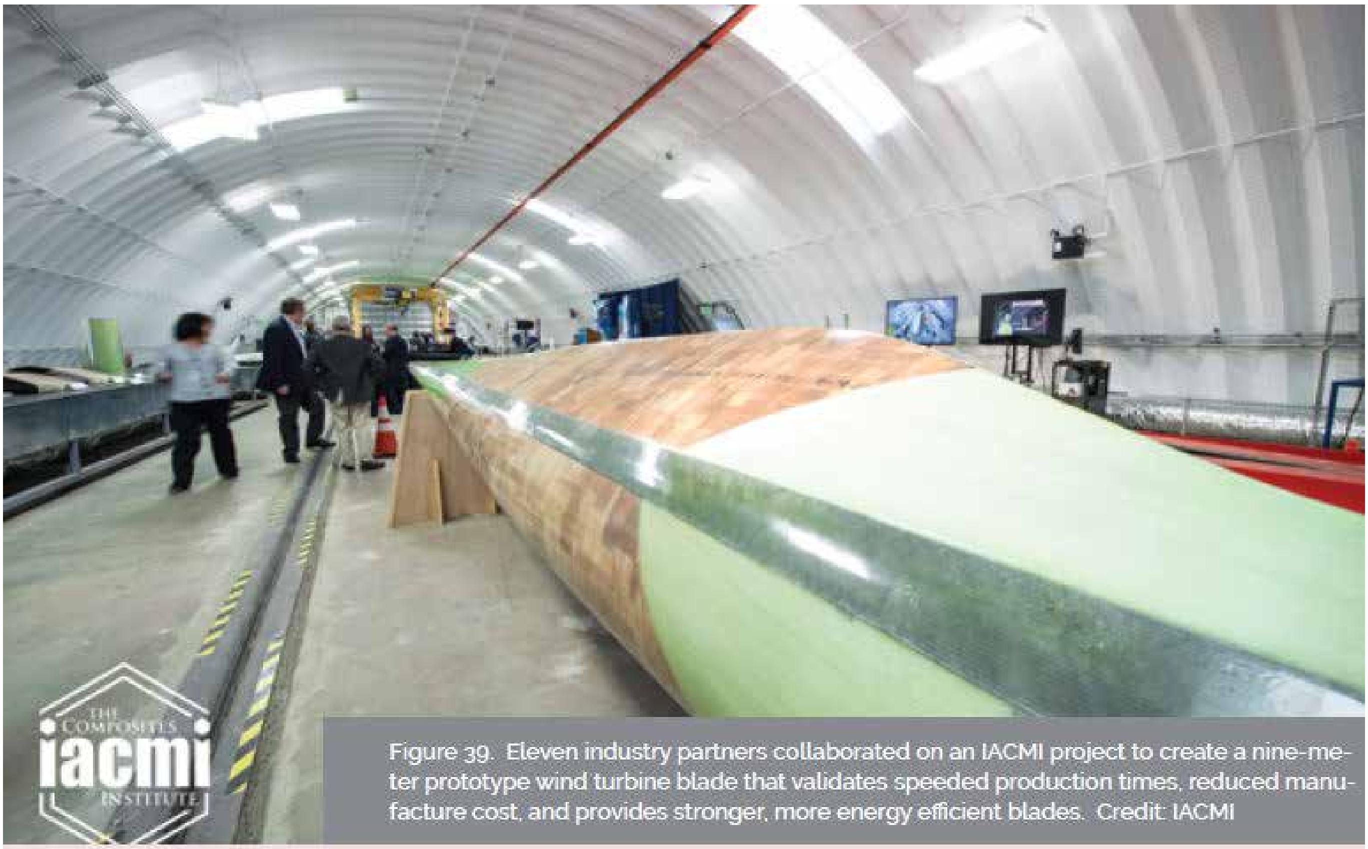


Figure 39. Eleven industry partners collaborated on an IACMI project to create a nine-meter prototype wind turbine blade that validates speeded production times, reduced manufacture cost, and provides stronger, more energy efficient blades. Credit: IACMI

IACMI Team Combines Technologies to Create Prototype Nine-Meter Wind Turbine Blade

IACMI unveiled an innovative nine-meter wind turbine blade prototype. The turbine blade was fabricated at IACMI's Wind Technology Area in the Denver, Colorado area. Commercialization of the wind blade prototype created could speed production times, reduce manufacture cost, and provide stronger, more energy-efficient blades for the United States.

The new blade, molded on tooling supplied by TPI Composites, Inc., features innovations such as impact resistant components and continuous fiber reinforced thermoplastic parts. The blade was produced via pultrusion with the first textile PAN fiber made at Oak Ridge National Laboratory's Carbon Fiber Technology Facility.

This prototype was nominated for the Combined Strength Award at CAMX 2017, the nation's leading composites conference with more than 250 education sessions and more than 8,000 attendees.

This project was a partnership of 11 industry partners, including Arkema, Inc. (King of Prussia, PA); Johns Manville (Denver, CO); TPI Composites Inc. (Warren, RI); Huntsman Polyurethanes (Auburn Hills, MI); Strongwell (Bristol, VA); DowAksa USA (Farmington Hills, MI); Chomarat North America (Anderson, SC); Composites One (Arlington Heights, IL); SikaAxson (Madison Heights, MI); Creative Foam (Fenton, MI); and Chem-Trend (Howell, MI). Additionally, the project was supported by Oak Ridge National Laboratory (Oak Ridge, TN); the Colorado Office of Economic Trade and Development; and others.

2.2.3 Funding Model

A primary objective of IACMI is to research and accelerate the advancement of composites manufacturing technology by the private sector, applying research to manufacturing challenges. IACMI accomplishes this by awarding and coordinating the development of technical projects to support these goals. Projects must be led by IACMI's industrial members and include the participation of one or more IACMI core partners within the five technology areas (i.e. vehicles, wind, CGS, composite materials and process, and design, modelling and simulation).

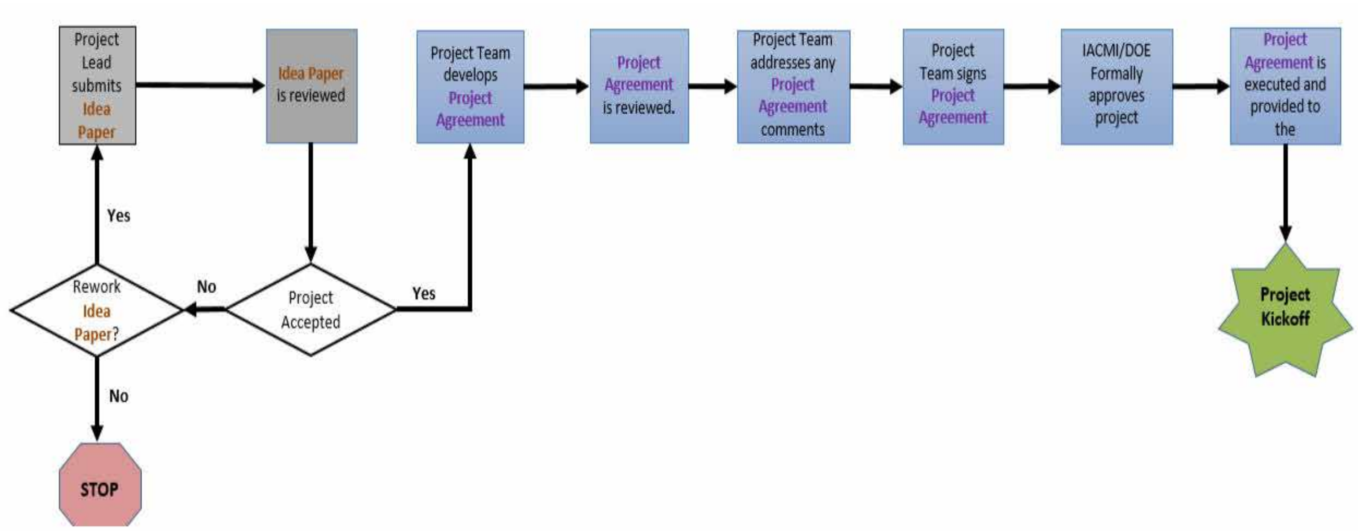
The IAMCI Request for Proposal Document[13] serves as an open call document, meaning that project ideas can be submitted to IACMI at any time. There is no limit on the number of proposals an applicant can submit if each describes a unique, scientifically distinct project. All project partners must become IACMI members.

The types of project that are funded and the project development process are shown in Table 8 and Figure 19 respectively. The idea paper shown in Figure 19 is only two pages and helps IACMI determine whether the proposal fits with their strategy and/or roadmap.

Table 8: IACMI types of project and funding requirements

Project type	IACMI Funds (/$1000)	Cost share required (IACMI Fund: Industry)	Duration
Enterprise	> $600	Minimum 1:1 (50% industry contribution is cash)	Up to 3 years
Technical collaboration	> $600	Minimum 1:1 (Large industrial entity (>500 employees) leads. 50% of contribution is cash)	Up to 2 years
Topic-specific	NA	Minimum 1:1	Up to 1 year

Figure 19: IACMI project development process



The fact that IACMI is funded by DOE is important as in 2017 the US and UK governments entered into an agreement on Scientific and Technological Cooperation. The Executive Agents for this agreement are the US Department of State and the UK Department for Business Energy & Industrial Strategy (BEIS). An Implementation Agreement is being prepared by the US Department of Energy and the UK BEIS to be signed; the UK has proposed an amendment which includes composites. This paves the way for collaboration in areas funded by DOE and BEIS (through Innovate UK).

[13] IACMI Request for Proposals Document. https://iacmi.org/projects/#6338b512192e125d7

2.2.4 Materials Genome

The MGI was not referenced by anyone met during the mission, so very little information has been gained about the funding mechanisms it uses. However, the two case studies below demonstrate that some of the work being performed and associated with this initiative is definitely composite related.

Figure 20: Composite-related case study taken from the MGI Strategic Plan

Air Force Research Laboratory Foundational Engineering Problem in Composites

Fully realizing the potential of advanced polymer matrix composites (PMCs) in aerospace systems is limited by the lack of integrated simulation tools that capture enough detail to adequately represent the complexity of these high-performance materials in system designs. Specifically, the ability to link the chemistry of PMC processing with mechanical performance, particularly the load response and damage evolution for high-temperature PMCs, is hindering applications. The current design process typically relies on repetitive analysis and testing to incrementally build confidence in composite performance. This process results in overly conservative or inadequate component designs for complex structures and requires more time and higher testing costs.

The Air Force Research Laboratory's Materials and Manufacturing Directorate is leading a collaboration among General Electric, Lockheed Martin, Autodesk, Convergent Materials, University of Dayton Research Institute, and University of Michigan to develop the integrated materials engineering computational tools needed to model the complexity of PMCs across different spatial and temporal domains. This new work integrates high-fidelity processing and mechanics simulation tools for high-temperature PMCs into the composite material design, qualification, and certification processes. The resulting tools can be used for designing prototypical components such as an airframe wing box and an engine bypass duct to demonstrate reduced cost, time, and risk in using PMC materials. Additionally, reduced conservatism in designs and accelerated transition to next-generation materials will enable performance improvements and significant fuel savings for new aircraft.

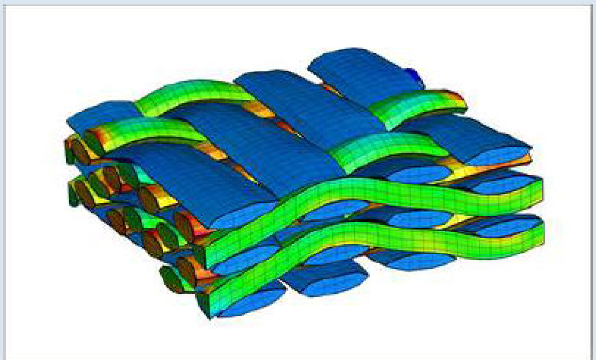


Image courtesy Air Force Research Laboratory

Figure 21: US-Comp a NASA-led composite-related project within MGI

Institute for Ultra-Strong Composites by Computational Design (US-COMP).

US-COMP is a NASA Space Technologies Research Institute (STRI) awarded in 2017 to a partnership of 11 universities, two companies, and the Air Force Research Laboratory. Led by Professor Greg Odegard at Michigan Technological University, the institute is funded at $15 million over 5 years.

US-COMP will serve as a focal point for partnerships between NASA, other agencies, industry, and academia to: (1) enable computationally-driven development of CNT-based ultra high strength lightweight structural composite materials within the Materials Genome Initiative (MGI); and (2) expand the resource of highly-skilled engineers, scientists and technologists in this emerging field.

2.2.5 NASA

NASA has been involved in composites research since the late 1960s. In the mid-to-late 1990s, significant effort was focused on the development of composite cryotanks for fuel storage and launch systems. These efforts have continued at various levels and in support of various programmes. The Space Launch System (SLS) provides new impetus for the development of lighter-weight tank systems and other components.

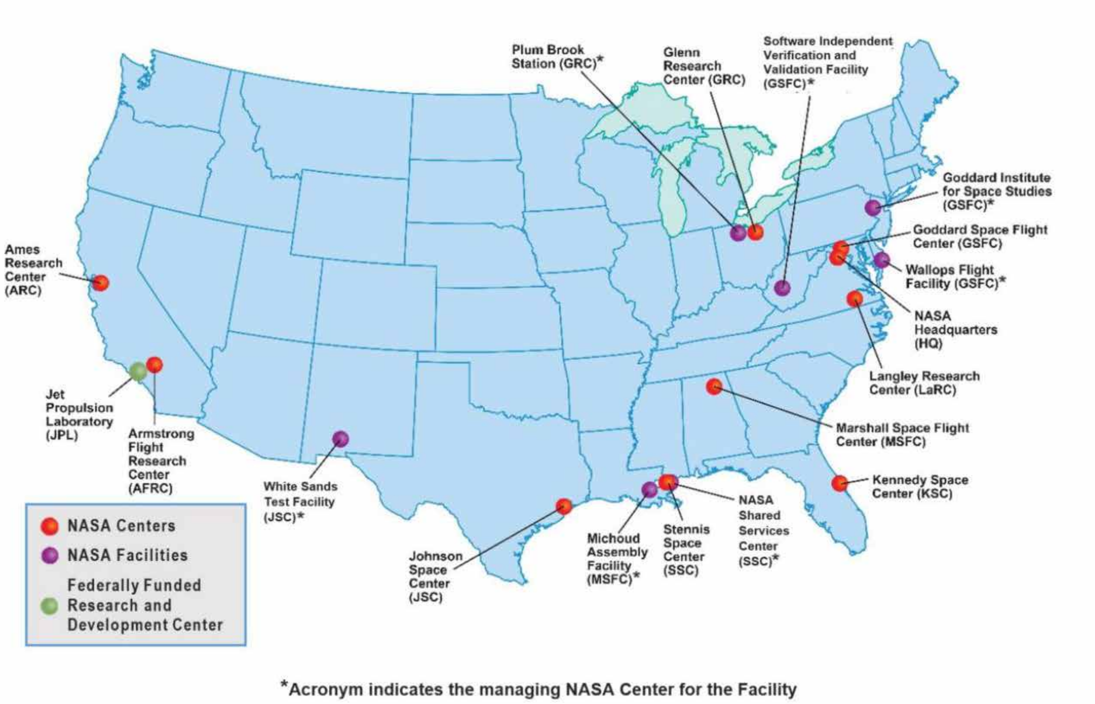
NASA established a Composites Community of Practice (COP) to prioritise and address common challenges. The first thrust of the COP was the management of, and shared access to, composites metadata. By 2016 the COP had grown to over 200 participants.

An Advanced Composites Consortium (ACC) began operation in January 2015. The purpose of the consortium is to foster collaborative R&D related to composites technologies with multiple partner teams. The goal of the coordinated effort is to conduct a technology gap assessment to guide national R&D efforts aimed at structural certification and continued airworthiness. The projects will be cost-shared with a 50/50 match requirement. The founding members include NASA and the FAA from the government and industry partners including Boeing, GE Aviation, Lockheed Martin, United Technologies Corp, and the National Institute of Aerospace (NIA). The NIA has been selected as the consortium integrator.

In support of the Space Launch System (SLS), the Composite Cryotank Technology Development (CCTD) project objective was to design, build, and test large prototype cryotanks for use in future launch vehicles. Two composite tanks, one 2.4 m and one 5.5 m in diameter, were built using automated fibre placement (AFP) and were tested at NASA Marshall Space Flight Center (MSFC) in 2014. Both NASA Langley Research Center (LaRC) and MSFC (NASA Centres shown in Figure 23) have installed new robotic ATP systems. Both systems have working envelopes of approximately 12 ft x 12 ft x 33 ft.

Figure 22: NASA's Composite Cryotank Technology Development (CCTD) Project

Figure 23: NASA facilities



3. Conclusion

Table 9 shows the many opportunities and interest in collaboration identified during the Expert Mission.

Table 9: Summary of opportunities for US-UK collaboration in composites

US Funding	Suggested Topics	Potential Sub-topic	Funding availability 2019	2020	2021	2022	2023
IACMI (DOE)	Materials	Carbon fibre – pitch and PAN specification, development and validation (via part production).	✓		?		
		Resins – pull-though interesting technology, including bio & recyclable.					
		Nanotechnology – graphene and nano carbon fibre.					
		Intermediates – 3D woven and prepreg from recycled material.					
		Ceramic matrix composites.					
	Simulation	HVM Catapult work with IACMI Purdue on simulation of manufacturing processes, materials data, effect of defects.					
	Additive Manufacturing	3D printing for low cost, fast tooling.					
		HVM Catapult to learn from IACMI's integrated offering to deliver multi-material additive manufacturing capability.					
	Sustainability	Development of a supply chain for recycled composites.					
		Development of new intermediates for recycled fibres.					
	High Volume Part Production	All high volume applications.					
Michigan State		Automotive lightweighting applications.	Michigan State/APC funding				
NASA	AFP/ATL processing			? NASA Annual Budget			
	Thermoplastic composites						
	Graphene in composites		? $250m NASA Matls & Manuf				
MGI	Open access materials data. End-to-end process & performance simulation & correlation		?				
NIST	Standards for Composites in Construction		✓ $11m				
ACMA	Market Data Standardisation		✓ ongoing work				

Barriers to collaboration include differences in regulations between the US and the UK, such as REACH in the case of resin development and ITAR restrictions in the case of technologies which are dual-use. However, improved understanding of new ITAR restrictions would provide new routes to collaboration through working on non-defence related applications first.

Legislation

- ITAR: The US Manufacturing Strategy recognises the importance given to technology transfer between the defence and civil sectors, but this brings problems in US/UK collaboration with regard to ITAR. This issue was mentioned by UK mission participants in several meetings. An expert in this field from RUAG stated at one of the networking meetings that the US is trying to work to ensure this process does not create too many barriers and that there may now be ways around ITAR by ensuring that when a technology is dual-use, the application developed initially is civil.
- REACH: A common theme in the conversations with resin suppliers Huntsman and Dixie, was REACH regulations acting as a barrier to supply into Europe and therefore potential inward investment. They were particularly interested in seeing what happens to the UK chemicals sector once Brexit has finalised. Both businesses highlighted this as a potential opportunity for the UK to differentiate ourselves in this area. Not necessarily by lowering the requirements of chemicals regulation, but by making the regulations 'smarter' and more applicable to chemical innovation. In the short term, these worries about REACH may make US-based resin suppliers reticent to work with UK-based consortia.

Interestingly, in the short term, Wessex Resins had an alternative view on the REACH issue. They currently work with US-based suppliers, take their resin technology and make it REACH-compliant before selling it in Europe. This is a business model that works for them.

IP

- The US is adept at protecting their IP and ensuring optimal benefit to their company and the US. This can restrict UK/US collaboration because UK companies and funding bodies do not want to spend money on development only to find they are restricted in using the output. If any UK/US collaboration scheme is established, Innovate UK must provide support to ensure collaboration agreements are clear and fair.

Given that the mission had a focus on materials, it is worth expanding on the opportunity for research in this area in particular. The opportunities described in Table 9 can be summarised as follows:

1. Fibres: There are two distinct opportunities. The first is for companies in the UK such as Cygnet Group to work on the development of the carbon fibre line itself. Companies/organisations in the US interested in this include LeMond Composites, Oak Ridge, UAMMI. The second is for organisations such as GKN in the UK to work with carbon fibre producers in the US to specify the properties and price-point required for the fibre they are producing. In this high-value area, IP needs to be carefully managed in any collaborative research project.
2. Matrices: There was a general feeling that there are more innovative resin/matrix companies in the US than in the UK and hence a multitude of collaboration opportunities have been identified as shown below. However, Composites UK is quick to point out that there are some innovative UK-based resin companies (e.g. Wessex Resin, Bitrez, Alchemie, Applied Polymer Developments) which should not be ignored. REACH can be both a barrier to US companies wanting to engage in the UK and an opportunity when UK companies work with US companies to convert their products to be compliant.

   Opportunities identified:

   o Development of bio-based products using several routes.

   o Using anhydride curing agent to reduce part shrinkage.

   o Recyclable resins.

   o Use of urethane acrylates for cryogenic applications.

3. Nanotechnology: Opportunities exist for NASA, which wants to investigate the use of graphene, to collaborate with the likes of Versarien, Haydale, Thomas Swan and SHD. Huntsman is also developing long-chain nano-carbon fibre that may be of interest to UK companies.
4. Intermediates: Sigmatex has had interest from SpaceX in new materials development, and ELG has the opportunity to work with the likes of SHD, IACMI and Scott Bader in the production of pre-preg from recycled carbon fibre.
5. Ceramic Matrix Composites: Axiom is already working with NCC and Rolls-Royce on the use of CMC materials.

Annex 1
List of UK Participants

Composites UK
Department for International Trade (DIT)
DIT, British Consulate General Atlanta
DIT, British Consulate General Houston
EPSRC Future Composites Manufacturing Research Hub
Formaplex
GKN Aerospace
Innovate UK
Knowledge Transfer Network (KTN)
National Composites Centre (NCC)
Sigmatex
UK Research & Innovation (UKRI) USA
Victrex

Annex 1
List of US Participants

ACMA

Advanced Technology International

ARM Automation

Axiom Materials

Boeing

Cimarron Composites

Colorado State University

The Composites Consortium

Delaware University

Dixie Chemical Company

Dynetics

ELG Carbon Fibre

Eurolink

GE Aviation

Government of Ontario Canada

Hitco Composites

Huntsman

Huntsville Madison County Chamber

IACMI

Louisiana State University

Madison County Commission

Maher & Associates

Michigan State University

MVP

NASA HQ

NASA Marshall Space Flight Center

National Renewable Energy Lab

Nexolve

Oak Ridge National Lab

Owens Corning

Rice University

RUAG Space USA Inc

SHD Composites

US Space and Rocket Center

University of Alabama in Huntsville

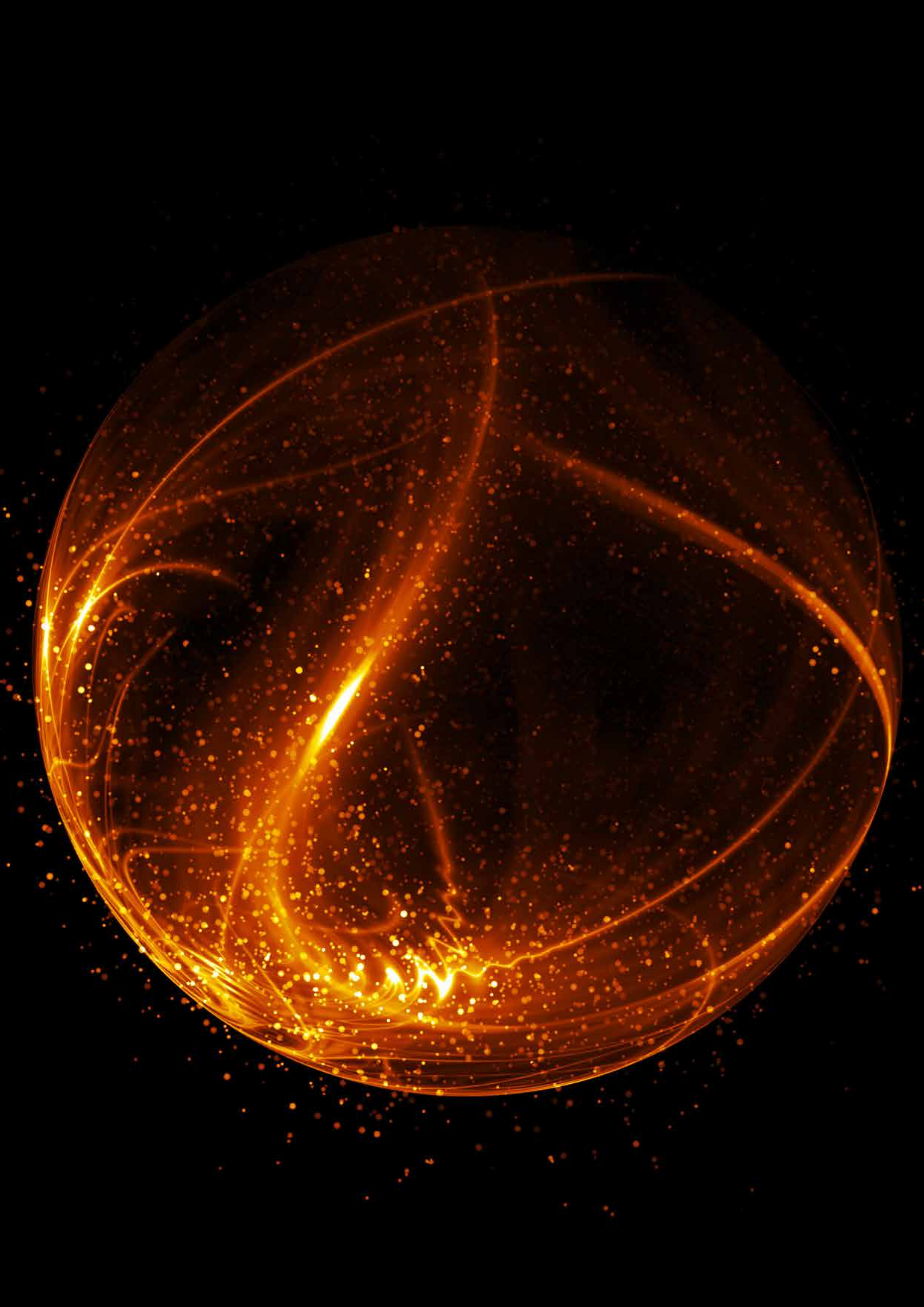
University of Dayton Research Institute (UDRI)

University of Tennessee

University of Tennessee Knoxville

Utah Advanced Materials & Manufacturing Initiative (UAMMI)

Wessex Resins & Adhesives



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