European Strategic Research Agenda

JOINING



Prepared by the Joining Sub-Platform

2014

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Executive Summary

Background

'Horizon 2020', a financial tool for implementing the Innovation Union flagship initiative (European Commission, 2011), has spotlighted manufacturing as one of the areas for stimulating the economy and supporting the Europe 2020 Strategy. In order to support this, the growth and competitiveness of manufacturing in Europe needs to be addressed. In 2003 the European Technology Platform 'Manufuture' was implemented to provide input from industry regarding strategic direction for research and innovation in manufacturing.

Moving ahead to Horizon 2020 or H2020, Manufuture has identified Joining as a key enabler to manufacturing, and therefore, strategic direction should be developed. Joining is recognised as a core element of innovative and sustainable manufacturing. This has stimulated the creation of a Sub-Platform with the purpose of developing a coordinated strategic approach in the field of Joining.

"The value added by manufacture and application of Joining technology in Europe amounted to around EUR 65 billion in 2010. Over 1.25 million employees were connected with this added value within Europe in 2010" (Moos 2013).

Mission

The mission of the Joining Sub-Platform is:

To develop a competitive, innovative and sustainable Joining competence that utilises advanced techniques and products, to add value to manufacturing, generating economic growth and skilled jobs for the benefit of EU stakeholders

This Strategic Research Agenda (SRA) has been created to support this mission and give considered and appropriate technical direction to its implementation, given the grand challenges identified by the European Commission.

Joining spans a wide range of techniques and materials. It can be defined as:

Creating a bond of some description between materials or components to achieve a specific physical performance.

Main Objectives of the Sub-Platform

- Support the European 2020 Strategy in addressing the grand challenges, through mechanisms such as the growth of innovative and sustainable production.

- Catalogue the key priorities for research and innovation in Joining through the creation of a Strategic Research Agenda, and ensure this is aligned to the agenda on a European, industrial and academic level.

- Ensure that the Joining topic receives the appropriate amount of focus and support given its importance within manufacturing.

- Characterise the challenges that are faced across the manufacturing industry and identify opportunities for accelerating the exploitation of Joining.

- Compliment the step-change research and innovation developments identified by the 'Manufuture' technology platform.

- Develop industrial commitment in Joining through engagement initiatives through targeted interaction with companies from a variety of industry sectors.

- Collaborate with Factories of the Future Private and Public Partnership (EFFRA, 2012).

- Recognise and provide action towards reacting to the structural changes that will evolve across Europe resulting from global megatrends.

- Evolve the perception of Joining to be recognised as a core element of competitive, innovative and sustainable production.

Recommendations

As a key enabler to manufacturing, Joining will require significant research and innovation in order to align itself with developments in current, new and emerging markets, technologies and materials. Following the analysis in this report, the table below provides top level detail of the three main areas where Joining research and development is necessary.

Table: The three main areas of industry need in Joining research and development.

Area 1: General Areas for Development	
High value, cost effective and agile, Joining techniques	Design for Joining and the reduction of Joints
Joining that is optimised for new materials, structures and manufacturing processes	The utilisation of increased ICT in the stability and capability of Joining
Joining technology optimised for product re-use and recycling	Approaches suitable for high volume, high productivity manufacture
New Joining approaches offering cost, quality and/or performance benefits	Improved efficiency and waste reduction in Joining technologies
Identification of alternatives to scarce or harmful substances in joining and coatings	Development of Business models around joining in production (process selection, global market enablers for winning business within Europe)
Prevention of musculoskeletal health problems in welders by developing future concepts and designs of work, work places and means.	Development of recommendations or guidelines clearly indicating alternatives in the companies' working methods to improve welder's postures and position when welding.
Preserve know-how and grow intelligence of Joining through creating an increased understanding of the processes and their potential through training and education within industry and academia.	

Area 2: Associated Technologies	
The advanced automation of Joining, from thin to thick section, in the manufacturing chain	Modelling and simulation of Joints, structural integrity evaluation and life extension
Pre and post Joint processes e.g. heat treatment	Inspection methods tailored to Joining applications and in-situ condition monitoring
Joining technologies for repair and re-use	Joining to enhance performance in extreme conditions, including surface engineering
Development of flexible cells for manufacture (process technology, flexible tooling, towards mass customisation)	Quantification of energy usage to enable optimised joining processes
Area 3: Specific Joining Requirements	
Dissimilar materials Joining	Development of affordable environmental, thermal and erosion resistant coatings
Joining composites, multi-phase and coated materials	Joining of crack susceptible and highly alloyed materials including for high temperature applications
Joining multiple sheets and complex structures	Development of low temperature sealing joints
Low distortion and low heat input Joining	Miniaturised and thin section Joining, soldering and adhesive bonding
Low electrical resistivity and low thermal conductivity Joints	Joining ultra-high specific strength materials
High productivity, high performance, thick section Joining	Development of hybrid Joining processes
Joining of speciality materials with enhanced properties	High performance joining of non-metallics

1. Background

The 'Europe 2020 strategy' (European Commission, 2010) highlights the significant realities left by the economic and financial crisis experienced across Europe. These unfortunate circumstances exposed a number of truths including high levels of unemployment and debt across Europe. Europe 2020 wanted to learn from this crisis and address the grand challenges ahead in order to achieve a stronger and more sustainable future for Europe. For this, a strategy for smart, sustainable and inclusive growth was outlined in 2010, and one where several flagship initiatives were initiated to highlight a number of key actions for Europe.

'Horizon 2020', a financial tool for implementing the Innovation Union flagship initiative (European Commission, 2011), has spotlighted manufacturing as one of the areas for encouraging growth in the economy, particularly in the area of exports. In order to support this, the path to the sustainable competitiveness of manufacturing in Europe needs to be understood. Therefore, the 'Manufuture' Technology Platform was implemented to develop strategy regarding research and innovation in manufacturing.

The Manufuture Technology Platform has identified Joining as an enabling technology to manufacturing. Joining is recognised as a core element of innovative and sustainable manufacturing, therefore, a strategic direction for Joining should be developed. This has stimulated the creation of a Sub-Platform with the purpose of developing a strategic approach in the field of Joining.

As identified by Manufuture's new vision (Manufuture Implementation Support Group, Working Draft, 2012), in order for Europe to remain competitive, particularly when developing economies with modernised production methods and enhanced technical capabilities are emerging, retaining localised manufacturing is key, and one where Joining plays an important role.

"The value added by manufacture and application of Joining technology in Europe amounted to around EUR 65 billion in 2010. Over 1.25 million employees were connected with this added value within Europe in 2010". Moos (2013)

A Joining Sub-Platform committee has been formed with a remit to on engage with industry and academia, characterising current and foreseeable challenges, and identifying new opportunities for exploitation within the field of Joining. This has led to the inception of a vision and strategy that assigns itself, not only to addressing the needs and opportunities of Joining technologies, but also the broader socioeconomic challenges that go beyond the technological needs of industry. Therefore, this document will present a working paper in the form of a Strategic Research Agenda (SRA) about the current status of Joining, its importance within industry and a set of recommendations for future action that will assist in supporting a competitive and sustainable manufacturing base for Europe.

An overarching link to Joining technologies and its broader alliances outlined herein provide identification towards the Factories of the Future PPP Consultation Document (EFFRA, 2012), a roadmap developed in line with the Horizon 2020 proposal from the European Commission.

Note: Following stakeholder consultation, a revised version of the consultation document is expected in January 2013. Emphasis has been placed not only on research requirements for advanced manufacturing processes where emerging innovative products and advanced materials need further development, but also on getting more from existing markets and approaches. Joining and associated technologies, equipment, materials and requirements are considered. This can be considered as preparation for, the carrying out of, and the monitoring, evaluation and assessment of Joints.

Weight reduction is one of the main factors for reducing carbon dioxide emissions, especially in the coming decades when conventional energy resources will be depleted.

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The implementation of light-weight designs requires targeted use of new and different materials. There is an unavoidable need to develop technologies to join these often dissimilar materials without destroying their specific properties.

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How can emerging innovative products using advanced or different materials be manufactured without Joining?

Figure 1 provides a representation of where the Joining Sub-Platform fits within the components of the aforementioned European agendas. The industry sector groups and the broad themes relevant to these sectors are those that encompass Joining as a key function.



Figure 1 Representation of where the Joining Sub-Platform fits within the components of the European agendas.

2. Definition of Joining

Joining spans a wide range of approaches, materials and techniques. It can be defined as:

Creating a bond of some description between materials or components to achieve a specific physical performance.

This bond can take many forms, for example fabrication of structures and the creation of wear resistant coatings, but can be described as being generated by one or more of the following effects:

- Thermal – This includes fusion and solid state techniques and other thermally affected Joining techniques. Examples include Joining based on the following: Arcs, brazing, electron beams, friction, lasers and electrical resistance.

- Chemical – A bond effected through chemical reaction. Examples include: Adhesive bonding.

- Mechanical – A joint generated through a mechanical mechanism. Examples include: Screw joining, riveting, clinching, and flanging.

3. Vision

The Joining industry is a challenging scientific and technological area on a global scale. The Joining Sub-Platform vision and its strategy will therefore, ensure that Europe continues to play a leading role in manufacturing, based on the enabling technologies of Joining. The vision will also look to accelerate the exploitation of Joining within Europe to a global level, and assist in addressing the European Grand Challenges, such as societal issues and the environment.

MISSION

To develop a competitive and sustainable Joining competence that utilises advanced Joining techniques and products, to add value to manufacturing, generating economic growth and skilled jobs for the benefit of EU stakeholders

VISION

- **The support of manufacturing through competitive and sustainable Joining techniques as a core element of modern manufacturing**
- **High value and flexible Joining processes that support new and existing business models**
- **Joining processes that are knowledge based through scientific understanding**
- **High performance Joining maintaining and developing structural and functional properties**
- **Joining technology distinguished as a sustainable, resource and energy efficient process that also serves the social agenda**
- **Improved productivity and efficiency of Joining processes**
- **Accelerated exploitation of Joining on a global level**
- **The development of Joining to support localised manufacturing through the expertise, and knowledge of skilled workers in Europe**
- **The development of training in the areas of Joining**
- **Joining contributing to wealth creation in industry, particularly in SMEs**

4. Objectives

The Joining Sub-platform has set an obligation for openness and transparency for all its activities, and to involve and represent a broad range of European-wide stakeholders. Therefore, a commitment to maintaining a long-term vision will be achieved through progressive routes and by continuous engagement with stakeholders.

The top level objectives of the Joining Sub-Platform are to:

- Support the European 2020 Strategy in addressing the grand challenges in the areas of:
  - Employment
  - R&D
  - Climate change/energy sustainability
  - Education
  - Fighting Poverty/social exclusion
- Catalogue the key priorities for research and innovation in Joining through the creation of a Strategic Research Agenda, and ensure this is aligned to the agenda on a European, industrial and academic level.
- Ensure that the Joining topic receives the appropriate amount of focus and support given its importance within manufacturing.
- Compliment the step-change research and innovation developments identified by the 'Manufuture' European Technology Platform. The five pillars of manufacturing are:
  - New added Value Products and Services
  - New Business Models
  - Advanced Industrial Engineering
  - Emerging Manufacturing Science and Technologies
  - Infrastructures and Education
- Collaborate as appropriate with Factories of the Future PPP (EFFRA, 2012).
- Develop industrial commitment and investment in Joining through engagement initiatives and targeted interaction with companies from a variety of industry sectors.
- Recognise and provide action towards reacting to the structural changes that will evolve across Europe resulting from global megatrends.
- Characterise the challenges that are faced across the manufacturing industry and identify opportunities for accelerating the exploitation of Joining.
- Evolve the perception of Joining to be recognised as a core element of competitive and sustainable production.

5. Current Position of Joining

Within the EU-27 manufacturing industry, a reported €5,812 billion turnover was achieved in 2009, of which €1,400 billion was added value, (Eurostat, 2009). In terms of contribution to employment and value added for the non-financial business economy this equated to one quarter of the total. Joining is a core element of innovative and sustainable manufacturing.

Joining is a significant source of value added in the manufacturing process. The field of Joining is not recognised as an industry, however, the world-wide economic significance of Joining and its components is significant. For example, it has been estimated that Joining, as an enabling technology, underpins one third US Cross Domestic Product, (American Welding Society, 2002) and one third of Canadian Cross National Product, (Suthey Holler Associates, 2006).

In Europe a survey conducted in 2013 reported a projected 908,000 people that are active in the field of Joining (Moos & et al, 2012). Adding people employed where Joining robots are involved, an additional 215,000 can be included, which provides a total estimated 1,123,000 people.

When looking at the global Joining equipment market, mainly governed by arc Joining equipment, in 2008 this market was worth $13.2 billion (BCC Research, 2008). The total global market size for automated/robotic Joining and related equipment for 2011 was $1.285 billion. Regional market sizes are provided in Figure 2 where Europe holds a 28% share of this total figure.

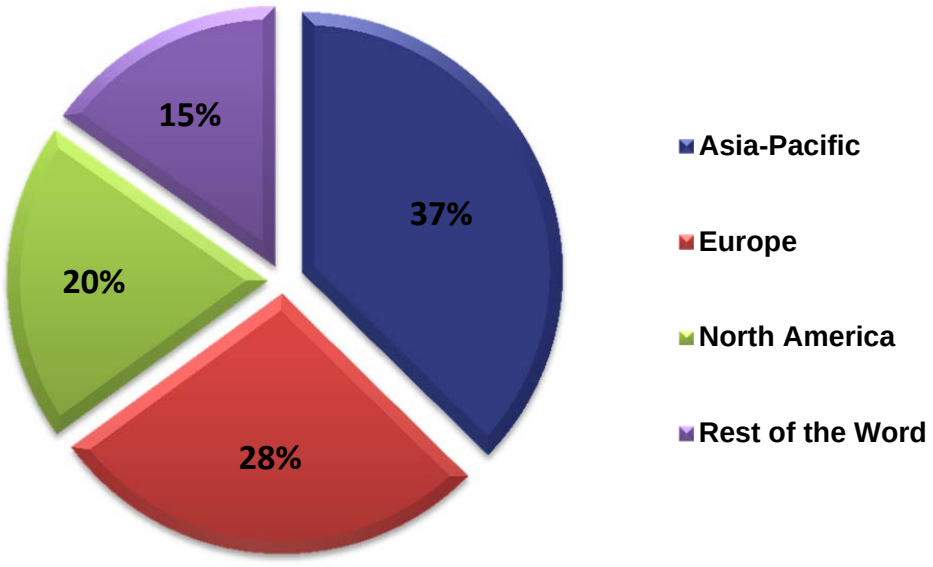


Figure 2: Regional market share for automated/robotic Joining and related equipment in 2011 (Figure reproduced using data from BCC Research 2008).

Given this significant presence of Joining and its component technologies in industry and the skilled trades, it is obvious that Joining performs a key function in manufacturing and production that contributes significantly toward economic sustainability.

The current social and technical trends are driving change to a more knowledge based society. The main resources in Europe for global competitiveness are the knowledge and skills of the people in both traditional and more contemporary manufacturing.

UK energy infrastructure data, which can be reliably used in reference to European wide trends, shows that for Joining in the engineering construction sector (on site fabrication) and the manufacturing supply chain (offsite fabrication of components) there are approximately 2500 people capable of high integrity Joining. However, these skills are declining at a rate of 6% per year, mainly due to retirement in an ageing workforce, and low numbers of new entrants taking skilled Joining as a career. It is such skills shortages that can result in a depreciated capability in European manufacturing. It is essential that employees in manufacturing are trained to understand the processes they are using, so that such processes are used to their potential, and are developed further.

According to the philosophy in the strategic research agenda entitled "Manufuture" (Report of the High Level Group, 2006), it is possible to utilise technologies in such a way that mass production processes can be brought back, for example, from Asia to Europe (Middeldorf & Jerzembeck, 2012). This would be realised in part through the development and implementation of Joining technologies. Developing sustainable global competitive advantage is the main component of European future economic strength and would deliver the desired high levels of productivity employment, and social cohesion. The current world class nature of the Joining competence in Europe should be supported by government as a component of such global competitive advantage strategy.

6. Global Megatrends

Megatrends influence the manufacturing of products, and therefore drive Joining technology. The trends considered in the following pages are those which influence Joining technologies the most and therefore where the development of Joining can have the most impact (Middeldorf & Jerzembeck, 2012).

- Demographic Change
- Globalisation
- Individualism
- Sustainability

6.1 Demographic Change

The economic centres in the world are exposed to different demographic changes (http://geocommons.com/datasets/7859/data). There are "young societies" who are driven to create and extend attractive working and development possibilities for the young generation. There are "ageing societies" such as Japan, Germany or Italy, in which the demographic development is leading to a dramatic shortage of specialist knowledge. Even in societies not suffering as much in this area, the average age of Joining experts is increasing significantly. Joining expertise is recognised as a field of increasing importance, where expertise capacity is decreasing.

Joining technology cannot be driven by automation alone, human interaction is a necessary component. In addition to modern automation techniques, Joining technology will still be directly applied by human beings in the long term future. In the wake of demographic developments, there will be different global requirement profiles for the deployment of welders. In particular, Joining technology application needs to be designed in a demographically appropriate way, especially regarding the cross-sectorial topic of Human Machine Interfaces. In conjunction with this the impacts on welders need consideration in order to ensure their health. Future advanced training concepts should be adapted to accommodate this trend because of the enhanced future need in Europe and on the global stage. The physical requirements of the different welding tasks regarding posture, muscle activity, comfort, use of ancillary equipment and related musculoskeletal disorder need to be evaluated to reduce the effect of harmful working conditions and its effects on welders.

6.2 Globalisation

One of the unique areas of Joining technology is the successful implementation of global training and certification systems in personnel qualification with the international recognition of welder qualification tests and global process standards in Joining (procedure qualification tests). Devices and facilities as well as filler materials and auxiliary materials for Joining are utilised all over the world, but must meet the respective regionally different conditions and statutory requirements.

Another area is that global systems for quality assurance are being carried out and refined with the corresponding qualification and certification systems in explicitly European and international structures and organisations; however there is a long way to go before full integration will be realised. Global communication standards and Web-based procedures and, to an increasing extent, Web-based training systems, are being utilised in this respect.

A large number of companies dealing with Joining and Joining technology are successfully operating in the international markets. The manufacturers of Joining systems, filler materials and process materials are strongly oriented to exports.

It can be stated that manufacturing and Joining technology in Europe are essential parts of global business. Joining technology development in European countries enables European companies to manufacture innovative products and to commercialise them globally.

6.3 Individualism

A general development towards the individualisation of society is well-known and is supported even further by the diverse utilisation of ICT enabled developments. For production technology, this individualisation entails an even stronger demand for "individualised products and services". Joining technologies will have to develop to respond to this need.

6.4 Sustainability

Sustainability is connected with trends in energy supply, environmental protection, transport and economics. The demand for sustainability is connected with market opportunity for cost reduction. However, these market opportunities can only be exploited by innovative production technology and by exploiting innovations in Joining technology.

Three main fields in Joining technology development are influenced by the sustainability agenda. These three mechanisms are:

- New materials and fabrication technologies for sustainable energy generation. This is the need for a new energy infrastructure to support a sustainable and economically viable energy mix.

- New materials and fabrication technologies for the manufacture of sustainable products. These include fully recyclable products, lightweight construction in transport, design concepts for the mobility of the future etc.

- Sustainability in production and in Joining technology itself, i.e. combining higher energy efficiency with lower pollutant emissions in production .

7. Challenges and Opportunities for Joining

In order to ensure the future of Joining within Europe it is vital that the EU is significantly ahead in the development and exploitation of Joining processes. The underpinning knowledge to support this is also of significance and Europe needs to ensure this is secured for generations to come. This in turn will generate opportunities for increased business turnover and the number of jobs not only safeguarded but created.

The importance of the Grand Challenges highlighted by the EU are significant and the uniting of European industry, governments and institutes alike is required in order to bring together an understanding of the key areas of research and to guide the future direction of Joining technology development.

Responsibly driven economic growth is a prerequisite for societal sustainability, addressing the needs of the citizen and the environment and as such is deemed as a key enabler to the success of the EU Grand Societal Challenges (EFFRA, 2012).

Manufacturing needs to incorporate sustainability, from planning and design, to repair and recycling, and the end of a product life cycle. It is these aspects which have a direct influence on Joining technology. Only energy-efficient, environmentally favourable fabrication can create products that are needed by a sustainable EU economy (Middeldorf & Jerzembeck, 2012).

Outlined in the following sections are some of the key PESTLE drivers for individual industry sectors and some of the current industry products, within these drivers, that relate to Joining. Emphasis is then drawn down to technology development areas where Joining plays a critical part of overcoming the technical barriers seen in industry products. This technology development can therefore be used to address the drivers. **This is not an exhaustive list of technology areas.** Figure 3 provides a schematic of the process methodology used.

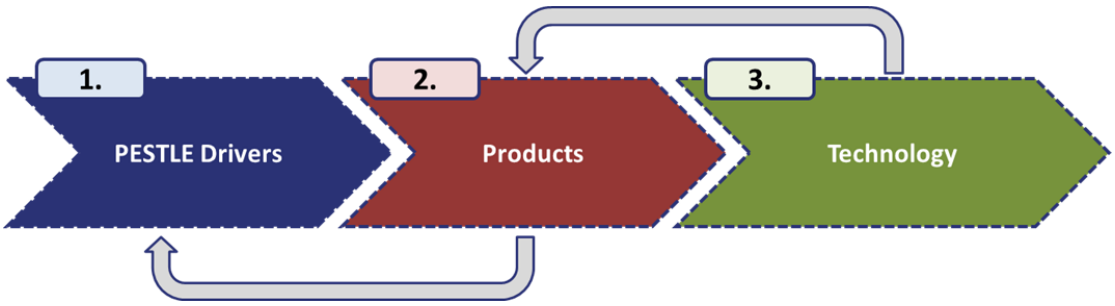


Figure 3: Schematic of the process methodology used for mapping the Joining themes.

Automotive and Road Transport

Drivers:

- **Light weighting, prompted by the need for fuel efficiency**
- **Reliability and quality**
- **Low carbon vehicles**
- **Reducing costs**
- **Recyclability and disassembly**
- **Regulatory and legislation requirements**
- **Improved crash performance**
- **Improved driveability (structural stiffness)**
- **Training and skills**



Industry Products Relevant to Joining:

Vehicle bodies

Light weighting is driving the need for optimum designs and this increasingly means using mixed materials within a structure such as vehicle bodies. Also, composites are becoming more desirable over metals due to their **reduced weight**, good corrosion properties, and ease of shaping.

Electric vehicles

The need for **lower cost** and **performance enhancement** is driving the need for improved processes, parts and materials such as battery and fuel cell technology, and the development of **high efficiency** electrical motors. Electric vehicles have different drivetrain constraints compared to traditional vehicles powered by internal combustion engines usually located at the front. This has led to motor and battery positioning requirements in electric vehicles allowing new construction philosophies to be used. Hence, there is now a requirement for a new approach to auto-body construction for electric vehicles.

Main Joining Technology Challenges and Opportunities:

Vehicle bodies:

- Dissimilar/hybrid materials Joining such as aluminium, steel, high strength steel, fibre composites, and plastics
- Joining composites
- Joining of coated high strength materials
- Automated aluminium spot welding
- Joining thin sheets
- Joining multiple sheets
- Joints between tubular structures

Electric vehicles:

- Low electrical resistivity joints
- Low heat input joints to avoid damage
- Joining packs of thin sheets
- Approaches suitable for high volume rapid manufacture
- Performance of joints in HP Hydrogen





Power

Drivers:

- **Security of supply**
- **Impact on the environment**
- **More efficient use of fuel**
- **Increased overall efficiency**
- **Decentralised energy production for local CHP, wind and domestic solar**
- **Volume manufacture for renewable energy sources**
- **Life extension**
- **Structural integrity/safety**
- **Standards for wind energy**
- **Reduction in manufacturing costs particularly in wave and tidal**
- **Government waste policies (waste to energy and nuclear decommissioning)**
- **More competitive market**



Industry Products Relevant to Joining:

Renewable Energy

Offshore Wind turbines

To reduce the **impact on the environment** from CO_2 emissions, there is a drive to achieve 20% of all power generated from renewable sources by 2020 within the EU. To meet these targets, there are plans to develop significant offshore wind energy farms. A significant number of wind turbines are therefore required, driving **volume manufacture** in all areas of the wind turbine structure, particularly in the turbine tower where thick section Joining technologies are required. Due to the relatively harsh offshore environment there is also a need for Joints to be part of the provision of corrosion protection and long term structural integrity.

Wave and Tidal Energy

To reduce **impact on the environment** from CO_2 emissions and to compliment the developments in wind power generation; there are a significant number of ideas for wave and tidal power generation systems. Many of these are no more than design ideas and only a few have made it to prototype. A number of European continents have significant coastline from which to harness energy produced from wave and tidal movements. In order to realise these designs and make the technology a viable compliment to wind energy, the need for **volume manufacture** and **reduction in manufacturing costs,** along with the **structural integrity** of Joints are all key drivers in the development of wave and tidal energy.

Hydropower

Due to other renewable energy sources which lead to a fluctuating input to the grid, pump storage hydropower plants are more and more attractive again. In contrary to the past, when these power stations had a cycle time of about one year, nowadays loading and unloading occurs several times a week (if not days). Beside the application of advanced high strength steel, which is sometimes challenging to weld due to limited toughness and increased hydrogen susceptibility, fatigue is an additional challenge to consider in service conditions.

Solar

There is a drive towards **decentralised energy production,** moving a portion of the power production, albeit relatively small, from the more traditional sources to local domestic supply. Domestic solar panels provide a solution to this.

Volume manufacture, improved efficiency and **product longevity** is driving the need for improved manufacturing processes, new designs and materials, and long term protection systems.

- Local CHP (**C**ombined **H**eat and **P**ower) – moves toward **decentralised energy production** and **more efficient use of fuel** are driving the development of fuel cell systems using domestic gas supply to generate household heat and power, which create new material and geometry Joining challenges.

- Biomass & waste to energy plant – **government waste policy** is driving the need to maximise the recovery of energy from domestic, agricultural and industrial waste. Government incentive schemes make this attractive to companies to develop power plant for burning waste. However, the often corrosive nature of the gases (e.g. chlorine induced corrosion), produced from sometimes unknown combinations of municipal waste, has driven the development of new coatings for the protection of fire-side boiler components in co-fired power generation applications.

Nuclear Power Plant

Nuclear plant

In the power sector the current need to reduce the **impact on the environment** requires a radical shift in the electricity generation mix on a global scale. The “business as usual” option is not sustainable because energy security, affordability and environmental impacts resulting from carbon emissions are all a factor.

Nuclear power is currently the only option that can globally deliver low carbon base load electricity at competitive prices. The fuel cost component of nuclear energy is lower than fossil fuel generation and is less vulnerable to sharp increases in fuel prices and, as such, offers more stable electricity pricing in a more **competitive market**.

A number of challenges with new build projects have led operators to seek options for assessment of existing aging plant, including Joints to allow **life extension**.

Decommissioning and waste disposal

Every nuclear nation will require a **waste and decommissioning strategy** albeit with implementation often protracted over several years or decades. The favoured deep repository **waste disposal strategies** require secure encapsulation ensured for tens of thousands of years leading to a requirement for remote and reliable methods for thick section Joining.

Fossil Fuel Plant

Fossil fuel power generation plant

The need to reduce **impact on the environment** and **increase efficiency** is driving the fossil fuel power generation sector to improve heat rate/efficiency/output through the use of higher temperature plant and waste heat recovery. To increase temperature, new grades of creep strength enhanced steels are being employed leading to the development of appropriate Joining procedures. There is also a requirement for operators to significantly **extend the life** of existing plant, including the Joints involved, as well as have adequate repair procedures in place when Joint failures occur in service.

Main Joining Technology Challenges and Opportunities:

Offshore Wind Turbines

- Thick section Joining for pylons
- Joining methods for higher volume, thick section
- Joining of composites to metal for turbine blades
- Aluminium coatings for splash zone corrosion protection
- In-situ condition monitoring of joints in wind turbine components (tower, blade, nacelle)

Wave and Tidal Energy

- Joining of tubular structures
- Joining for higher volume thick section
- Use of composites and Joining of composites to metals for weight reduction
- Corrosion protection coatings



Solar

- Coatings for PV cells
- Joining of light weight structures
- Composites for light weight structures

Local CHP (**C**ombined **H**eat and **P**ower)

- Joining technologies for mass production
- Joining of fuel cell components
- Ceramic Joining technologies

Biomass & waste to energy plant

- Sprayed coatings for biomass plant components
- Joining technologies for repair
- Joints between tubular structures
- Joints between dissimilar materials
- Life assessment and extension of Joints

Fossil fuel power generation plant

- Joining of creep strength enhanced ferritic steels
- Post weld heat treatment
- Joints between dissimilar materials
- Life assessment and extension of Joints
- NDT of Joints in complex pipe work

Nuclear plant

- Specialist repair
- Specialist NDT of Joints
- Structural integrity & life extension of Joints

Decommissioning and waste disposal

Joining processes for thick section waste encapsulation containers.





Aerospace

Drivers:

- **Life cycle cost**
- **Improved performance**
- **Improved buy-to-fly ratios**
- **Life extension**
- **Materials performance**
- **Manufacturing cost reduction**



Industry Products Relevant to Joining:

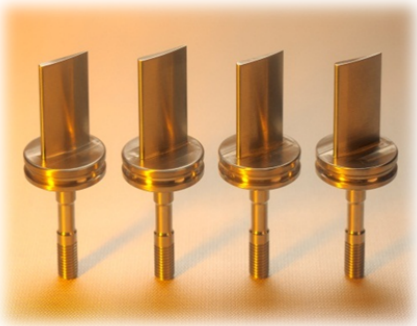
Airframes

Recent twin aisle and very large aircraft designs have incorporated 40-50% composite material in their fuselage and wing structures for **reduced weight** and increased **fuel efficiency**. The use of more carbon fibre composite means the increased use of titanium alloys because of the need for metal-composite joints with low corrosion risk. Improving the Joining of the metallic, composite and metallic to composite joints is critical in future aircraft design, including the next generation of higher volume single aisle aircraft.

Engines

In order to produce the more **efficient** lean burn engines, the industry is demanding higher operating temperatures from current materials. This puts demands on the Joining techniques for the high temperature superalloys, and on the heat resistant coatings. The use of carbon fibre fan blades in recent engine designs also adds the need for cost effective metal to composite joints for leading edge erosion protection.





Main Joining Technology Challenges and Opportunities:

Airframe

- Cost effective Joining process adoption, for example, solid state and power beam Joining and adhesive bonding.
- Alternative spot Joining techniques
- Cost effective high performance Joining for near net shape manufacture
- High performance curing of composites and further development of out of autoclave composite processing
- Joining composites to metals



Engines

- Development of affordable environmental, thermal and erosion resistant coatings
- Cost effective additive manufacture for near net shape manufacture (as per airframe above)
- Joining of high temperature materials for aero engines
- Dissimilar materials Joining
- Joining composites to metals





Construction and Engineering

Rail, Heavy Duty Vehicles and Ships

Drivers:

- **Light weighting prompted by the need for fuel efficiency**
- **Larger ships to reduce freight costs and passenger cruising costs**
- **Through life cost reduction, but with continuing pressure on first time purchase price**
- **Recyclability and disassembly**
- **Regulatory and legislation requirements e.g. reduce damage to the sea by developing effective but non-harmful anti-fouling coatings for ship hulls.**
- **Reduce maintenance costs and increase availability using 'smart' sensors and approaches**
- **Training and skills**

Industry Products Relevant to Joining:

Light-weighting is driving the need for optimum designs, and this increasingly means using mixed materials within a structure. For ships more high strength steel is being used and, as ships become larger, this places an emphasis on the Joining of thick section high strength steel while ensuring good toughness and fatigue performance.

New trade routes will require much more shipping travelling through Artic waters. This too will place a premium on ensuring that fabrication techniques will provide good toughness in arduous, low temperature conditions.

Joining Technology Challenges and Opportunities:

- Dissimilar/hybrid materials Joining such as aluminium, steel, high strength steel, fibre composites, plastics
- Joining of composites
- Joining thicker sections, including high strength steel, whilst ensuring good toughness.
- Low distortion Joining techniques to reduce costs, including rework, and improve fuel efficiency. This is particularly important as weight saving is leading to thinner sections, which are more susceptible to distortion.

Construction and Engineering and the Modern Built Environment

Drivers:

- **Through life cost reduction, but with continuing pressure on first time purchase price**
- **Regulatory and legislation requirements, e.g. reduced energy requirement of buildings in use**
- **Reduce maintenance costs and increase availability using 'smart' sensors and approaches**
- **Training and skills**

Industry Products Relevant to Joining:

Infrastructure

This includes **new build** and **maintenance/ repair**. In the case of buildings, **retrofitting** and the associated Joining requirements is very important to improve energy efficiency as only 2% to 3% of the building population is built new each year.

Time to build and commission on site

This is becoming an increasingly important issue. There is a need to minimise this time, for example to avoid disruption to rail or road services. This is driving a greater **trend to off-site manufacture**, which means that the requirements for on-site Joining are also changing.

Main Joining Technology Challenges and Opportunities:

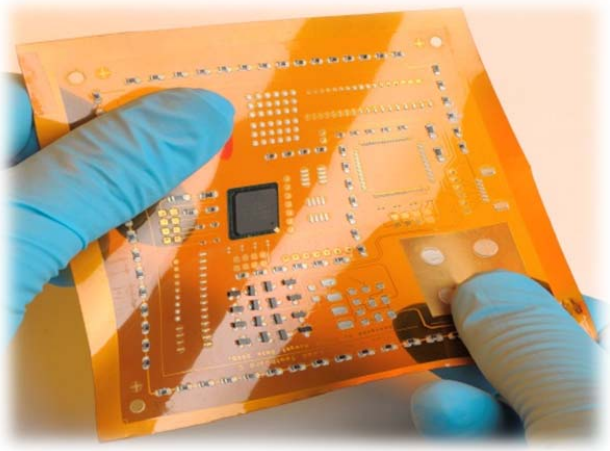
- Dissimilar/hybrid materials Joining such as aluminium, steel, high strength steel, fibre composites, and plastics
- Joining thicker sections, including high strength steel, whilst ensuring good toughness.
- Low distortion Joining techniques to reduce costs and the need for rework.
- Reliable, easy to use repair techniques are required
- Joining of composites.



Nanotechnology Electronics, Photonics, and Sensors

Drivers:

- **Lower cost manufacture**
- **High density products**
- **Reliability and quality enhancement**
- **Higher power operation of product**
- **Higher temperature product operation**
- **Multi-function devices (e.g. electronic, mechanical and photonic)**
- **Environmental legislation**



Industry Products Relevant to Joining:

Displays

- Industry wants to implement organic flexible electronics and displays which are driven by a need for ***lower cost***, enhanced product design and ease of manufacture. Protective packaging, materials and joints, is a significant problem for the industry and is restricting commercial exploitation. This is due to moisture and oxygen entering and damaging the displays.
- There are known problems with how to join LED displays to an assembly and extract the heat fast enough at suitably low cost.
- Environmentally friendly design and assembly is increasing due to legislation requirements.

Circuit boards

There is a need for an understanding of how to recycle circuit boards. This is driven by environmental legislation and the benefits that can be achieved, but also by design-for-disassembly. The automotive industry is already looking into this by limiting the use of levels of metal within components. Computer companies are already designing laptops for easier disassembly. This is driven mainly by legislation, which is becoming more demanding with time.

High Temperature Electronics

There is an increasing need to operate electronics above 200°C for engine management and downhole oil and gas applications. This brings about the need for new Joining technologies as adhesives and soldering are no longer suitable.

Sensors

There are current issues of how to make sensors work in more extreme heat environments, particularly with exotic materials e.g. engine management systems where sensors need to be closer to the engine where it is hotter to provide a quicker response. This is been driven by the need for increased performance, safety and reliability.

Computers and Mobile Devices

There is increasing demand for making smaller and smarter mobile and computer type products. This is putting pressure on materials and Joining technology. These devices may contain tens of thousands of joints.

Electronic systems

- An increased use of batteries in automotive and consumer products is resulting in a need for smaller, more electrically/thermally efficient packaging and assembly technology. Development and thermal management of, for example, lithium based batteries.
- Thermal management of electronic systems - Increased use of power and optical devices are resulting in a need for improved cooling techniques in ever smaller areas – at low cost.
- Nano-scale Joining needs more integrated and higher reliability systems with 100% yield manufacturing and testing procedures.

Main Joining Technology Challenges and Opportunities:

Displays

- Developing low temperature sealing joints to protect displays

Circuit boards

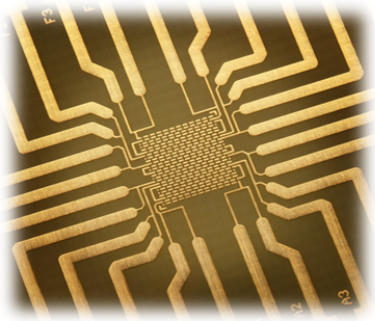
- Joining of the heat track of the circuit board connections on circuit boards.
- Miniaturise soldering and bonding
- Sealing

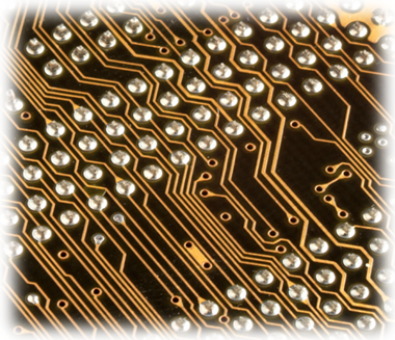
Computers and Sensors

- Joining related to replacing toxic components

Electronic systems

- Joining copper to aluminium
- Low resistance joints
- Polymer Joining





Medical

Drivers:

- **Regulatory requirements**
- **Cost**
- **Personalisation/Customisation**
- **Consumer medical products**
- **Ageing population**
- **Obesity**
- **Device life extension**
- **Miniaturisation**
- **Stratified Healthcare**



The main drivers in the medical sector for the development of new products or processes are ***safety*** and, due to the high ***regulatory requirement***, an 'easy' route to market. Despite the medical sector being perceived as a high value sector, ***cost*** is also a major factor.

Industry Products Relevant to Joining:

Orthopaedics

Due to the ***ageing population and increasing levels of obesity***, extending the life of orthopaedic implants is a current driver. The industry is also looking at **smart implants** and the use of **new materials**, other than commonly used titanium or cobalt chrome. Implantable sensors are a current key topic although issues remain around how they are inserted into the device and still function in such a challenging environment. This prompts challenges such as how wireless signals can be generated if titanium encapsulation of electronics is used. The use of Carbon fibre re-enforced PEEK and other composites is increasing.

The production of biocompatible coatings for implants, that allow the integration of implants into the human body, remains an important field which is entering production.

Diagnostics

There is a need for Joining in microfluidics, where small intricate channels in devices require fluid flow. For example, reduction of leakage of liquids from solvent reservoirs and infectious agents from devices is a key topic in diagnostics, as is blood handling.

Implantable diagnostics for measurement of diabetes are being developed. Many types of adhesive are limited for long term implantation, therefore there is a need for other materials.

Cardio-vascular

Cardio-vascular implants need to be reliable and long lasting. Therefore, there is a need for high integrity joints in products, such as pacemaker batteries.

Main Joining Technology Challenges and Opportunities:

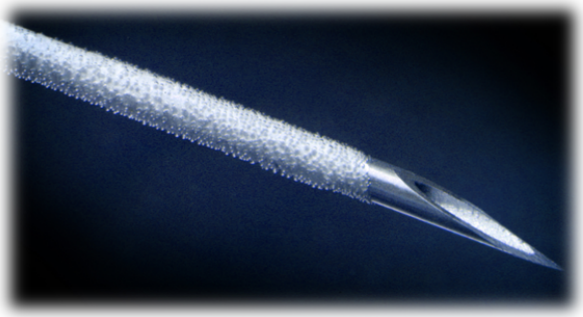
The medical sector represents a large market opportunity and is extremely diverse. Joining issues arise in every sub-sector from wound care (peel ply processes, dissimilar materials Joining, sensors etc.) through to implantable neurological devices that require very high integrity electronic wire bonds for example.

Orthopaedics

- Improved Joints for increased life of orthopaedic implants
- Improved implants other than hip joints (i.e. knees, small bone replacements)
- Smart implants
- New, higher performance materials

Diagnostics

- Polymer Joining (especially dissimilar materials)
- Adhesives
- Lasers
- Ultrasonic Joining





Cardio-vascular

- Thin section Joining of mixed materials for catheters
- Joining of advanced materials such as shape memory and super-elastic metals

Other Related Joining Technology

- Joining polymers
- Joining of foils to polymer products
- Fabrication of electronic packages into implantable metal products (laser Joining, ceramic sealing and prototype design)
- Joining of super-elastic alloys to steel
- Improved Joining of textiles
- Joining of super-elastic alloys to polymer products
- Fabrication of sensors into catheter products, i.e. polymer to metal Joining

Oil and Gas

Drivers:

- **Increasing complexity in exploration and production (higher risks)**
- **Deep water**
- **Arctic (LNG)**
- **Extreme environments**
- **Enhanced recovery – oil sands & shale gas**
- **Subsea and downhole technologies**
- **Structural integrity and corrosion management**
- **Joining of clad pipe**
- **Test methods and procedure development**
- **Fatigue performance**
- **Inspection, monitoring and maintenance**
- **External scrutiny (regulations and compliance)**



Relevant areas to Joining and Joining related technologies:

Exploration & Production Facilities

Exploration and production is being driven towards areas where it is more technically challenging to extract oil and gas. For example, there are *deep water developments*, such as the Gulf of Mexico, South East Asia, offshore Brazil and West Africa. The main problems are the *extreme depths, high pressures,* and the *high temperatures* of the fluids and gases when they are extracted. Also, most of the fluids and gases extracted are sour and therefore highly corrosive. This means that there are special requirements placed on Joining and Joining needs in this industry, and high costs due to the requirement for going into deeper waters, further away from shore requiring expensive vessels to cope in these extreme environments.

Products:

- Structural integrity and performance of Joints in ***floating production storage and offloading (FPS and FPSO)*** *vessels*
- Design and performance of Joints in ***oil rig jacket structures***
- Long-term integrity and loading conditions for *risers &* ***deepwater risers*** (flexible)
- Servicing and maintenance of ***processing and refinery plant***
- Reliability and maintenance of ***subsea and downhole equipment***

Main Joining and Joining related technologies:

- Joint fatigue improvement in Oil shale extraction due to higher temperatures and corrosion
- Joining where LNG is involved – working with liquid at -164^{o}C
- Joint quality inspection and acceptance criteria
- Joining of steel of different grades and thicknesses
- Coatings for corrosion mitigation

Transmission, Storage & Process

Safe and reliable transmission, storage and process are crucial to the ongoing success of the oil and gas industry. Safety and best practice are paramount reducing operational costs and this is achieved through the effective use of advanced technologies and techniques.

Products:

- Structural integrity and performance of ***pressure vessels*** ranging from simple tanks to complex manifolds – weld repairs & coatings
- Design and performance of structural components such as ***tubular joints, mechanical connectors and foundation piles***
- Operation and maintenance of ***refineries and plant***

Main Joining technology Challenges and Opportunities

- Joining of steel of different grades and thicknesses
- Development and qualification of weld repair procedures
- Development and qualification of weld inspection procedures
- Inspection & repair of storage tanks
- Coatings for corrosion mitigation
- Pressure equipment directive (PED) for Joining

Pipeline Integrity Management

Pipelines are a crucial part of the energy-delivery system, and the oil and gas industry and its supply chain invests heavily to ensure that pipelines continue to meet the needs of the 21st-century global energy industry.

Products:

Research, support and guidance in several key aspects of ***pipeline*** design and maintenance, including: materials selection, pipeline Joining, corrosion mitigation, installation and inspection planning.

Main Joining technology Challenges and Opportunities:

- Joining of steel of different grades and thicknesses
- Quality inspection for welds
- Complex Joining for high strain areas
- Pipelines during their lifetime will be deformed due to being built on ice i.e. complex Joining for high strain areas
- Joining of pipe flanges
- Joining of composites for pipe metals (liners for metal pipes where the flanges require Joining)
- Joining and performance of Fibre reinforced plastics
- Joining undersea pipelines to avoid failure and very damaging hydrocarbon release

8. Joining Technology Development Areas

Joining technology has to be considered over the entire product life cycle, i.e. product design and development, production, maintenance, repair, recycling and waste disposal. Joining technology is, therefore, a core element of modern production that will play an important role in the future of manufactured products. As a key enabler to manufacturing, Joining will require significant research and innovation in order to align itself with developments in current, new and emerging markets, technologies and materials. Drawn down from the Sector based analysis, the table below outlines the three main areas for Joining research and development.

Table: The three main areas of industry needs in Joining research and development.

Area 1: General Areas for Development	
High value, cost effective and agile, Joining techniques	Design for Joining and the reduction of Joints
Joining that is optimised for new materials, structures and manufacturing processes	The utilisation of increased ICT in the stability and capability of Joining
Joining technology optimised for product re-use and recycling	Approaches suitable for high volume, high productivity manufacture
New Joining approaches offering cost, quality and/or performance benefits	Improved efficiency and waste reduction in Joining technologies
Identification of alternatives to scarce or harmful substances in joining and coatings	Development of Business models around joining in production (process selection, global market enablers for winning business within Europe)
Prevention of musculoskeletal health problems in welders by developing future concepts and designs of work, work places and means.	Development of recommendations or guidelines clearly indicating alternatives in the companies' working methods to improve welder's postures and position when welding.
Preserve know-how and grow intelligence of Joining through creating an increased understanding of the processes and their potential through training and education within industry and academia.	

Table (Contd): The three main areas of industry needs in Joining research and development.

Area 2: Associated Technologies	
The advanced automation of Joining, from thin to thick section, in the manufacturing chain	Modelling and simulation of Joints, structural integrity evaluation and life extension
Pre and post Joint processes e.g. heat treatment	Inspection methods tailored to Joining applications and in-situ condition monitoring
Joining technologies for repair and re-use	Joining to enhance performance in extreme conditions, including surface engineering
Development of flexible cells for manufacture (process technology, flexible tooling, towards mass customisation)	Quantification of energy usage to enable optimised joining processes.
Area 3: Specific Joining Requirements	
Dissimilar materials Joining	Development of affordable environmental, thermal and erosion resistant coatings
Joining composites, multi-phase and coated materials	Joining of crack susceptible and highly alloyed materials including for high temperature applications
Joining multiple sheets and complex structures	Development of low temperature sealing joints
Low distortion and low heat input Joining	Miniaturised and thin section Joining, soldering and adhesive bonding
Low electrical resistivity and low thermal conductivity Joints	Joining ultra-high specific strength materials
High productivity, high performance, thick section Joining	Development of hybrid Joining processes
Joining of speciality materials with enhanced properties	High performance joining of non-metallics
Corrosion behaviour (particularly of dissimilar joints)	High strength and ductility of joints

9. The Future of Joining

When looking into the future of the development of production, manufacture and other operations, involving Joining technologies, there is an industry need for emphasis on the following topics:

Product development and production will have to deal, in the future, with demands at a different and new scale, allowing new products to be even lighter, smaller, with increased lifetime and additional features. The utilisation of new material and new production processes will also lead to new functionalities, not only to serve wider markets, but also new markets. In both situations Joining will be a key enabler, not only in addressing new product demands and sustainability, but also in a new globalised marketplace.

The various Joining processes are in continuous competition for applications and market share, which has led to a positive effect on the development of Joining technology. In the future, Joining technology must, to a greater extent, contribute to accelerating capital-intensive production methods where higher productivity and more flexible production methods are required. Globally acting production companies require that the technologies used should be flexible in a way that production can be focused and customised to target markets. It is also expected that the production of the future will be even more network-oriented than now. The knowledge sharing and collaboration represents the logical way for Europe to gain a competitive edge. Joining technology is an extremely networked area, due to the fact that it is a cross-sectorial technology and requires interdisciplinary strategies which include all aspects of Joining technology.

Joining technology as a core element of modern production

Global competitiveness and sustainability are the main objectives when strengthening European development into a smart and sustainable economy that will deliver high levels of employment, productivity and social cohesion. In this quest for strengthening the European position, setting the pace of development of modern production standards is essential. Joining technology will be one of the core elements of this, and contributes in the following ways:

- ***Joining is knowledge-based:*** Joining processes are increasingly based on and driven by knowledge and science. Due to its diversity and its complexity, Joining technology has become a high-technology process. Also, as a truly cross-sectorial technology, Joining relies on knowledge from other disciplines. Successful knowledge management in Joining technology leads to the continuous shortening of development times and offers constant opportunity for the raising of quality, reliability and productivity.

- ***Joining is adaptive:*** Joining processes need to be highly adaptable through capability and stability in changing conditions. Intelligent regulation systems and process tools need to be developed to ensure stable processes. New Joining tasks, such as those resulting not only from the product development and product variants but also from the utilisation of new materials and structural characteristics, are put into effect using adaptable Joining processes. For example, the increased use of lasers for a variety of Joining applications from batteries to medical applications.

- ***Joining is sustainable:*** A sustainable society is based on well-known thematic topics; climate change and global warming, the scarcity of resources, the environmental burdens caused by the production and processing of raw materials, distinctly discernible demographic changes, progressive urbanisation, increasing mobility, the economic imbalance between industrialised, threshold and developing countries and the worldwide need for investment in the infrastructures. Joining technologies are, and must be developed as, sustainable solutions, oriented to resource and energy efficiency, serving the social agenda (Middeldorf & Jerzembeck, 2012)

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Links **Manufuture:** http://www.manufuture.org/manufacturing/
European Commission Technology Platforms:
http://cordis.europa.eu/technology-platforms/individual_en.html

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Further updates will be provided at **http://www.joining-platform.com**