Government Office for Science

Foresight

The future of manufacturing: international perspectives - workshop report

Future of Manufacturing Project: Evidence Paper 1

Foresight, Government Office for Science

The future of manufacturing: international perspectives - workshop report

By

Arup

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This review has been commissioned as part of the UK Government's Foresight Future of Manufacturing Project. The views expressed do not represent policy of any government or organisation.

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Overview

The UK Government Office for Science has undertaken a two-year Foresight project examining the **Future of Manufacturing** to help ensure policy decisions are resilient to future uncertainties.

As part of this programme, a series of three international workshops were held to gather European, US and Asian perspectives on the future of manufacturing to the year 2050. The objective was to identify common themes and differences, and inform the UK understanding of the international context.

The three workshops each convened over 20 industry experts, policy makers and academics with expertise in relevant areas of study.

The workshops provided a high-level cross-industry platform for delegates to share regional insights into key drivers of change and their potential implications in terms of future risks, challenges and opportunities. Delegates were also asked to provide suggestions as to what actions are needed in the short term to support the manufacturing sector in light of their discussions about the long term.

This report captures the results of the three workshops, which took place in **Berlin** (27th February 2013), **Washington DC** (7th March 2013) and **Singapore** (13th March 2013).

All three workshops were hosted by the UK Government Office for Science, with facilitation provided by the Arup Foresight + Innovation, who have also written this report.

The workshops all followed the same agenda to allow common themes and differences to be identified:

9.00	Welcome and Overview
9.30	**Drivers of Change**
10.50	Coffee Break
11.10	**Drivers of Change (cont'd)**
12.30	Networking Lunch
13.15	**Clustering and Implications**
14.50	Coffee Break
15.00	**Actions**
16.00	Close

Executive Summary

The three international workshops staged in Europe, the US and Asia revealed a remarkable degree of consensus as to what the big issues are for manufacturing over the next few decades. The most striking thematic meme relates to **sustainability** in its broadest sense, encompassing social (education, skills, employment, diversity, age and gender balance) and economic aspects (decoupling value from negative environmental impacts), in addition to the environmental focus. Much emphasis was placed on **resource efficiency** and **waste minimisation** in all workshops, in the context of the environment. However the discussion did probe much further into radically new models of production and consumption, exploring concepts and approaches including nanotechnology, biomimicry, industrial symbiosis and the circular economy.

The discussions in Europe and Asia suggest that increased **automation** and use of **robotics**, coupled with focussed efforts to increase productivity and drive efficiency gains, will likely see a reduction in the numbers of certain jobs in manufacturing. However, it is likely that new higher-skilled employment opportunities will emerge in manufacturing in high value areas such as software development and related “manu-services”. Humans will also be needed to design and maintain automated systems.

A third strand that merits a mention here is **Big Data**, and the advanced analytics and capabilities that can be expected as software and computing power further develops. Many organisations are already using analytics to manage a growing wealth of data encompassing everything from supply chains and manufacturing processes, to consumer behaviour. However, there is huge potential for harnessing the power of Big Data as these become yet more sophisticated.

Finally, there was much reference to new models of **distributed manufacturing**, enabled by additive manufacturing techniques such as **3D printing** and emergent niche micro-manufacturing capabilities. It was recognised that these trends could radically transform manufacturing as a sector. The most interesting discussion around this issue took place during the Singapore workshop. Intriguing questions were asked about what should happen when the consumer becomes a producer, in terms of health and safety, quality control, copyright and intellectual property. On this subject, as with all these major themes, there are more questions than answers at this point in time as we look out to the year 2050.

This series of regional workshops hosted by the Government Office for Science surfaced a great many insights across a plethora of themes and issues. These are reported on in the ensuing pages.

European Perspectives

European Perspectives

The "**Future of Manufacturing: European Perspectives**" event was held at the end of February 2013 in Berlin. A dinner at the British Ambassador's Residence preceded the workshop at the British Embassy the following day.

The following countries were represented at both the dinner and workshop: Finland, Germany, Greece, Italy, the Netherlands, Spain, Sweden and the UK. The 25 delegates provided a mix of academic, private sector and public sector representation.

Derek Flynn, Paul McCaffrey and Sejal Mahida participated from the UK Government Office for Science. They were joined by Professor Steve Evans (Director of Research in Industrial Sustainability, Institute for Manufacturing, University of Cambridge), a member of the Lead Expert Group, who advise the project team.

Dinner:

British Ambassador's Residence
Tuesday, 26th February 2013

Workshop:

British Embassy, Berlin
Wednesday, 27th February 2013

Project Team:

Derek Flynn, Deputy Head of Foresight, Government Office for Science
Paul McCaffrey, Project Leader, Foresight, Government Office for Science
Sejal Mahida, Project Manager, Foresight, Government Office for Science
Marcus Morrell, Lead Facilitator, Arup
Cornelius Schneider, Co-Facilitator and Scribe, Arup

Dinner Conversation

A fascinating dinner conversation, designed to prepare participants for the workshop the following day, was held at the British Ambassador's Residence and chaired by Malcolm Scott (Consul-General in Düsseldorf and Director-General of UK Trade & Investment in Germany).

Discussion covered a broad range of topics from resource efficiency to ways to address skills shortages. It was seen as critical that governments and industry find ways to introduce children to basic engineering concepts from an early age. Inés Gurbindo, Director of Manufacturing at MTorres, gave the example of a corporate initiative that engages the children of its employees in a competition to design and construct mechanical objects using Lego bricks. It was concluded that strategic engagement with youth needs to start at primary school and continue through secondary school to university.

With regards to medium- to long-term employment in the manufacturing sector, it was agreed that even if there is a move to greater automation within the sector, there would still exist significant opportunities for employment. A great many services will continue to be required to support automation such as logistics management, plant maintenance or marketing.

There was much discussion around the need to build complementary networks across Europe that bring together large manufacturers, SMEs, suppliers of services, academia and government to create self-supporting ecosystems supported by quality infrastructure. This would form reinforcing regional networks for future development of the manufacturing sector. Other critical factors mentioned were population growth, the ageing workforce, managing complexity and Big Data, and the need to attract more female employees.

It was acknowledged that innovation is often very slow, and that revolutions happen less than evolutions. While the conversation was impressively diverse, it was on reflection perhaps more relevant to the next decade or two. For example, there was considerable discussion relating to shorter term issues such as youth unemployment and rising energy prices.

"We should be buying our sons and daughters 3D printers!"

Dr Carsten Reise,

Fraunhofer Berlin /TUBerlin, Germany

Dinner Quotes

A number of interesting comments were made by delegates during the dinner. Here are some highlights:

“How can we connect good and highly focussed education systems to counter loss of manufacturing jobs?”
Professor Reijo Tuokko, Head of Department of Production Engineering, Tampere University of Technology, Finland

“The synergies between Information Communications Technology (ICT) and production technology offer huge potential for innovation and the evolution of manufacturing.”
Bernd Schimpf, President, Wittenstein AG, Germany

“Triple bottom line reporting in the developed world could become a competitive advantage over economies with an abundance of resources and cheap labour.”
Gereon Uerz, Group Research Future Affairs, VW, Germany

“We should bring back mass production to inner cities where the highest unemployment rates are found.”
Professor Engelbert Westkämper, Head of Department, Institute of Industrial Manufacturing and Management Universität Stuttgart, Germany

“Regional networking generates 25% cost benefit for manufacturing.”
Professor Engelbert Westkämper, Head of Department, Institute of Industrial Manufacturing and Management Universität Stuttgart, Germany

“Sustainable and integrated business is the future for the manufacturing sector.”
Professor Steve Evans, Director of Research in Industrial Sustainability, Institute for Manufacturing, University of Cambridge

Drivers of Change

The following day, participants engaged in workshop activities to build on topics that were initiated during the dinner discussion.

During the morning the delegates were divided into five groups, each representing one of five focal domains: Social, Technological, Economic, Environmental, Political. The five sub-groups were given 15 informational cards, each representing a single Driver of Change. A list of these cards is given in the Appendix to this report (page 100).

We defined a Driver of Change as a trend or issue likely to have a significant impact on the future of global manufacturing and on society more broadly.

The 5 groups assessed the pre-selected drivers in order to identify which they believed to be most impactful on the future of global manufacturing. They were also invited to fill out blank cards with any additional drivers they believed to be important. They were asked to choose 12 drivers that together represented the most compelling and impactful drivers to the year 2050.

After this, one person per group was asked to stay with their STEEP domain, while the rest of the participants were asked to move to another STEEP category of their choosing. They then followed a similar process, reducing the number of cards from 12 to 8.

A third rotation followed, during which sub-groups filtered out 3 of their 8 cards, to leave 5. The 25 prioritised cards (i.e. 5 per STEEP category) were then summarised by volunteer rapporteurs in a plenary session.

A Driver of Change is “a trend or issue likely to have a significant impact on the future of global manufacturing and on society more broadly”.

The pre-filled cards were researched and produced by Arup in collaboration with the Government Office for Science.

Drivers of Change

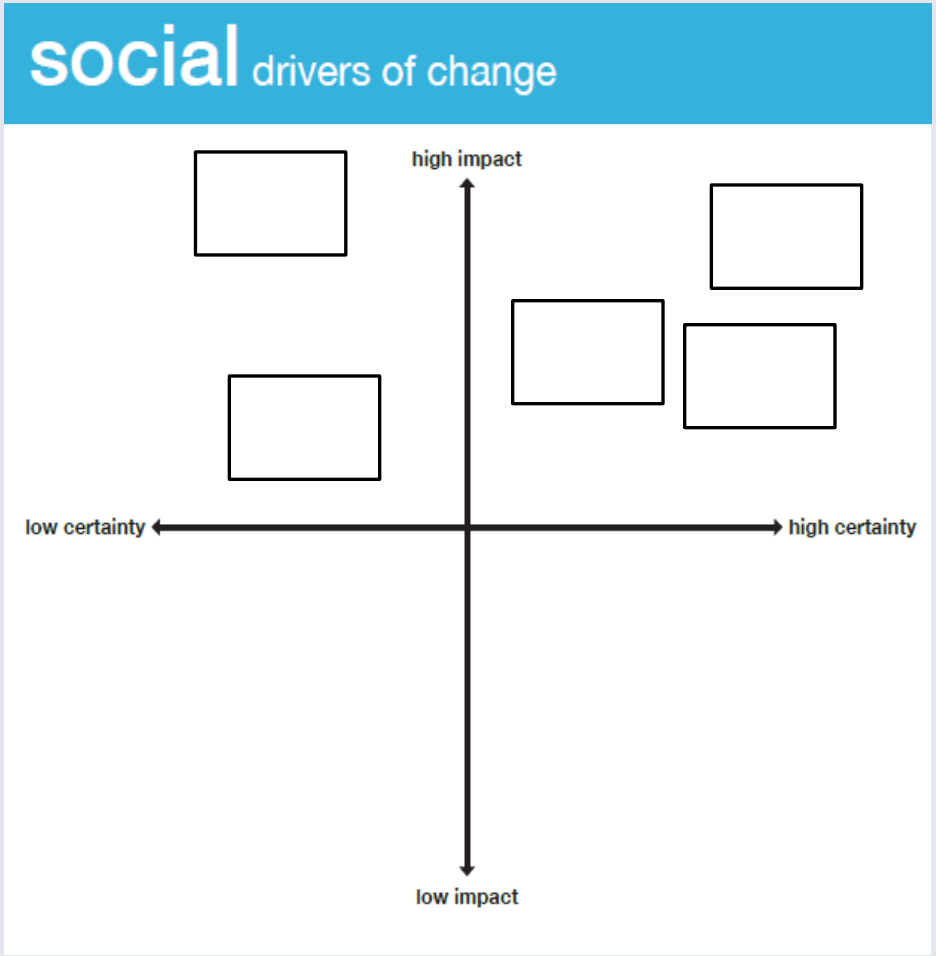
Drivers of Change

Drivers of Change

Delegates were then asked to map their five chosen drivers onto a matrix plotting perceived levels of certainty against likely impact (relative to each other).

An exemplar matrix is shown here with a sequence of five cards representing chosen drivers of change.

The 25 chosen drivers are reported in the following pages.



European Drivers of Change

Social

1. Urbanisation
2. Access to Information
3. Clash of Classes
4. Education and Diversity
5. Demographics

Technological

1. Research & Development
2. New Materials
3. Mass Customisation and Personalisation
4. Urban Production
5. Big Data

Economic

1. Human Capital
2. Manu-Services
3. Collaboration and Coopetition
4. New Markets and Competitors
5. Circular Economy

Environmental

1. Climate Change
2. Environmental Effectiveness
3. Environmental Efficiency
4. Consumer Environmental Pull
5. Supply Chain Disruption and Resilience

Political

1. Education
2. Global Governance Regulations
3. Asianisation
4. Smart Specialisation
5. Resource Conflicts

KEY: Red = pre-selected Drivers of Change; Purple = slightly modified titles; Black = new drivers completed by delegates

Drivers of Change: Social

The five prioritised drivers of change chosen within the Social domain were as follows. Note that the most impactful drivers are listed first:

1. **Urbanisation** (*high certainty, high impact*)
   The United Nations projects that around 70% of the world's population will be living in cities and towns by 2050 (up from 50% currently). The trend raises important questions for the manufacturing sector as many factories and plants are currently located outside urban centres.

2. **Access to Information** (*high certainty, medium/high impact*)
   This driver relates to wider access to information via the internet and mobile devices. The online tools and platforms that anyone can use to share opinions, insights and experiences – collectively known as social media – will continue to enable greater access to information and opinions going forward, and this will translate into new social and consumer attitudes and behaviours.

3. **Clash of Classes** (*medium/high certainty, medium/high impact*)
   The gap between the richest and the poorest within many countries and regions is growing. Should this trend continue we may see a rise in social unrest and instability. Major societal tensions can bring about many challenges for manufacturers, in terms of security and the choice of plant location, for example.

4. **Demographics** (*high certainty, medium impact*)
   The global population is not only growing dramatically, but it is ageing due to an increase in life expectancy. As total fertility rates further reduce we will see a further increase in the proportion of the oldest people in many European countries and elsewhere. The elderly in the more economically advanced countries are enjoying better health for longer, thanks to advances in medicine and improved diets. People will also be asked to work for longer in order to mitigate looming pension crises, so employers will need to harness the abilities of an older workforce.

Drivers of Change: Social

5. **Education and Diversity** (*medium certainty, medium impact*)
   Education is key if manufacturers are to close the skills gap that exists currently. Engagement with young people needs to start in primary schools and must continue through to secondary school and into higher education. The Sciences, Technology, Engineering and Mathematics (STEM) will need to attract many more young people in the future.

"In engaging younger generations we should go back to producing things with our hands (as in "manu"facturing) and introduce young people to that at an early age."

Prof Heinrich Flegel
Director of Research Materials, Lightweight Design & Manufacturing, Daimler AG

Drivers of Change: Technological

The five drivers of change chosen within the Technology domain were:

1. **Research and Development** (*high certainty, high impact*)
   R&D is a key contributor to economic growth and drives competitive advantage. R&D budgets can be very significant in certain sub-sectors within manufacturing. In developing economies, however, a more frugal approach to innovation emphasises shorter launch cycles and innovation through commercialisation. Further R&D investment, particularly in virtual reality and additive manufacturing techniques, is seen as critical.

2. **New Materials** (*medium/high certainty, high impact*)
   Innovation will create additional demand and drive further productivity gains. Important areas for focussed innovation are additive manufacturing technologies (e.g. 3D printing) and in the development of new materials such as carbon fibre components and nanotechnology, or cost-effective recyclable materials.

3. **Mass Customisation** (*medium/high certainty, medium/high impact*)
   Mass customisation and personalisation is a new competitive frontier for manufacturing and service industries alike. The Trend will continue to unlock a massive increase in product customisation and personalisation, and without a corresponding increase in costs.

4. **Urban Production** (*high certainty, medium/low impact*)
   Advances in technology will bring about a shift towards localised urban production. For example, cleaner and quieter plant equipment will enable manufacturing activities in densely populated areas. Urban manufacturing could also foster greater levels of collaboration due to the proximity to suppliers, competitors, consumers and academic institutions.

5. **Big Data** (*high certainty, low impact*)
   Many organisations are already using analytics to manage a growing wealth of data encompassing supply chains and manufacturing processes. However, the analytics software and platforms available today are still very much in a development phase and there is huge potential for harnessing the power of Big Data as these become more sophisticated.

Drivers of Change: Economic

The five drivers of change chosen within the Economic domain were:

1. **Human Capital** (*high certainty, high impact*)
   This is a catch-all term describing the process of sourcing, training and retaining staff and workers. It encompasses recruitment, skills development and qualifications, and it also touches on employee benefits and remuneration (especially important in attracting more female workers). Finally it includes relations between employers and trade unions.
2. **Manu-Services** (*high certainty, high impact*)
   Manufacturing companies rely on a multitude of service providers to produce their goods. These include telecommunications and travel services to connect workers in global production networks, logistics providers, banks and IT service providers. In the UK, just 42% of manufacturing jobs are in production occupations, while the rest are in service-related and professional roles.
3. **Collaboration and Coopetition** (*medium/high certainty, high impact*)
   As products become more complex technically, manufacturers have sought to collaborate with an ever-wider network of suppliers and collaborators. Coopetition occurs when companies forge alliances across traditional boundaries, in order to share common costs for example. In terms of collaboration, cross-functional and multi-disciplinary networking will become more important in future.
4. **New Markets and Competitors** (*medium certainty, high impact*)
   The rate at which global demand for manufactured goods is increasing is accelerating, driven by the momentum of emerging economies. Millions of newly affluent people are reshaping and resizing the global middle class, which is likely to expand from 2 billion to over 5 billion by 2050.
5. **Circular Economy** (*medium/low certainty, high impact*)
   Advances in resource efficiency promise to cut use of materials and energy. An emerging "Circular Economy" will help stretch resources further, where waste outputs can be used as resource inputs elsewhere. New technologies and processes are increasing our ability to recycle more material goods, while design for reuse will help minimise waste.

Drivers of Change: Environmental

The five drivers of change chosen within the Environment domain were:

1. **Climate Change** (*high certainty, high impact*)
   While delegates were in broad agreement that climate change is happening, it was noted that there is still a lot of uncertainty as to how it will develop in the coming decades. As regulatory pressures to reduce greenhouse gas emissions in manufacturing increase, companies will seek to further reduce levels of carbon intensity. One way for manufacturers to reduce emissions is to change the mix of energy inputs to renewables, including by switching to hybrid or electric engines in manufacturing facilities.

2. **Environmental Effectiveness** (*medium/low certainty, high impact*)
   Environmental effectiveness refers to the ability of natural services such as water purification, groundwater recharge, preservation of biodiversity, shoreline stabilisation, pollination and the decomposing of waste. While many of these ecosystem services are seemingly free, the estimated equivalent value of just water-based services is over US$5 trillion per year. It may be that in future producers and consumers pay for these services in order to sustain them.

3. **Environmental Efficiency** (*medium/high certainty, medium/high impact*)
   There are only 1.9 global hectares of biologically productive space available per person on the Earth. Given that the average world citizen has an ecological footprint of 2.3 global hectares currently, it is clear that current levels of consumption is unsustainable. Industry will need to learn to do much more with fewer material resources, and find innovative ways to close resource loops such that little or no waste is generated.

4. **Consumer Environmental Pull** (*medium/low certainty, medium impact*)
   While it is uncertain whether society will push for greater sustainability, this Driver is nonetheless potentially highly impactful for manufacturers, especially those that sell directly to the end consumer.

5. **Supply Chain Disruption and Resilience** (*high certainty, medium/low impact*)
   Globalisation and the growing complexity of global supply chains have increased industry exposure to natural disasters such as heat waves, earthquakes or extreme flooding. Improved collaboration and networking could be one pathway to increased resilience.

Drivers of Change: Political

The five drivers of change chosen within the Politics domain were:

1. **Education** (*high certainty, high impact*)
   Education is fundamental to the future of manufacturing. Governments everywhere can play an influential role in elevating the profile of manufacturing, and encouraging young people to take up STEM subjects at school.

2. **Global Governance Regulations** (*medium certainty, high impact*)
   Government intervention in areas such as market deregulation or fiscal policy have a high impact on producers of goods. Should any government wish to support the manufacturing sector then more intelligent regulations and policy measures can be of great benefit.

3. **Asianisation** (*high certainty, medium/high impact*)
   Asia's economic and geo-political influence has waxed and waned over the past 5,000 years, but it has risen inexorably in recent decades. It is highly certain that Asian manufacturers will create employment for many millions of people in the coming years. What will Europe's answer be in the context of such growth?

4. **Smart Specialisation** (*medium certainty, medium/high impact*)
   Regional and local government bodies can foster and develop collaboration, cooperation and networking. Strategic intervention is required to build on regional strengths and specialisations that can thrive in the global marketplace.

5. **Resource Conflicts** (*medium/low certainty, medium/high impact*)
   With the world population rising, global consumption rates soaring, energy supplies rapidly disappearing and climate change eradicating valuable farmland, the stage is being set for persistent and worldwide struggles over vital resources.

Clustering and Implications

After lunch, delegates were asked to form sub-groups of 4-5 people, and choose up to 6 drivers from the prioritised list of 25 that they felt raise interesting questions about the future of manufacturing. These could be related drivers. However, they could be entirely unrelated – proving challenging or thought provoking when considered together.

Once delegates had clustered their chosen drivers together, they were asked to identify any risks, challenges and opportunities that their cluster might present over the coming decades to 2050.

Post-its were used to map these implications on to a timeline (opposite).

Clustering and Implications

Cluster 1 “Breaking the Link”

This cluster examines drivers which together inspire the title “Breaking the Link (Between Value and Material)”. The cluster looks at ways in which production can be optimised such that underlying resources are used hyper-efficiently. The long-term opportunity is a new business model that exploits the right balance between local and global. Businesses that can create value whilst simultaneously closing resource loops could take profit away from conventional business and eventually trigger opposing lobbying power.

Opportunities

1. **Short-term**: mass customisation value opportunity;
2. **Short-term**: legal framework to make local production and mass customisation easier;
3. **Medium-term**: short supply chain to create more value;
4. **Medium-term**: make customers happy by being more local and more innovative with materials;
5. **Medium-term**: happy customers means better business;
6. **Medium-term**: value keeps the customer;
7. **Medium-term**: profit from resources (e.g. a school pays for heating provided by waste heat from a local factory);
8. **Long-term**: supply-chain resilience to disruption;
9. **Long-term**: reduce counterfeiting risk;
10. **Long-term**: environmental effectiveness.

Selected Drivers:

- **Mass Customisation and Personalisation** (Tech)
- **New Materials and Additive Manufacturing** (Tech)
- **Urban Production** (Tech)
- **Environmental Effectiveness** (Env)
- **Supply Chain Disruption and Resilience** (Env)
- **Resource Conflicts** (Pol)

Short-term = 2020s
Medium-term = 2030s
Long-term = 2040s

Clustering and Implications

Cluster 1 "Breaking the Link" (cont'd)

Risks and Challenges

1. **Short-term**: material science is global but it needs to become more local by recognising and studying the greater value potential in local materials;
2. **Short-term**: the challenge is to help companies to pioneer these new business models (e.g. by investing in R&D);
3. **Medium-term**: there is a medium term risk around information security (i.e. personal data);
4. **Medium-term**: a cooperation challenge;
5. **Medium-term**: a communications challenge;
6. **Medium-term**: the research investment required to fund material science innovation;
7. **Medium-term**: political lobbying reducing the opportunity for manufacturers to broaden revenue sources (e.g. provision of energy);
8. **Long-term**: risk of susceptibility to local disasters (focussing on impact of regional disasters).

Clustering and Implications

Cluster 2 "Green Lean and Clean (GLC)"

This cluster of selected Drivers describes a step-change in technology that enables manufacturers to drive innovation in new, environmentally-friendly materials and products.

Opportunities

1. **Short-term**: people want to work in environmentally responsible companies;
2. **Short-term**: reduces risk exposure to a shortage of resources through recycling and resource efficiency;
3. **Medium-term**: more innovative products;
4. **Long-term**: environmentally benign business models lower cost of societal healthcare;
5. **Long-term**: stronger biodiversity.

Risks and Challenges

1. **Short-term**: lack of reliable or proven business models;
2. **Short-term**: step-change in technology required;
3. **Short-term**: economic risk;
4. **Medium-term**: supply chains could be overwhelmed resulting in disruption;
5. **Long-term**: local regulation versus a global market.

Selected Drivers:

- **Urban Production** (Tech)
- **New Materials** (Tech)
- **New Markets and Competitors** (Ec)
- **Environmental Effectiveness** (Env)
- **Environmental Efficiency** (Env)
- **Consumer Environmental Pull** (Env)

Clustering and Implications

Cluster 3 "European Manufacturing: Powered by People"

This cluster explores a people-centred vision of eco-friendly, localised urban manufacturing driven in part by customers with higher sustainability demands. As the rising cost of energy and materials and transport is balanced with the public good of quality jobs in manufacturing, the total cost equation will increasingly favour higher labour content than might be expected. This will encourage a more local production system.

Opportunities

1. **Short-term**: labour force mobility and impact on industry;
2. **Short-term**: continuous education and re-skilling by industry (facilitated by the Government);
3. **Short-term**: personnel fulfilment in manufacturing jobs and innovation;
4. **Short-term**: absorptive capacity to adapt and innovation cycles driven by human capital;
5. **Short-term**: better education and better environmental awareness among workers and consumers;
6. **Short-term**: more consumer demand for products using fewer resources etc;
7. **Medium-term**: improved work-life balance;
8. **Medium-term**: Audi over-55 production (silver line) and valuing experience;
9. **Medium-term**: strategic capability and leadership within industry enabling response to change and demand;

Selected Drivers:

- **Education and Diversity** (Soc)
- **Urban Production** (Tech)
- **Human Capital** (Ec)
- **Consumer Environmental Pull** (Env)
- **Environmental Effectiveness** (Env)
- **Education** (Pol)

Clustering and Implications

Cluster 3 "European Manufacturing: Powered by People" (cont'd)

10. **Medium-term**: peripheral vision of industry met by diverse people;
11. **Long-term**: use of ICT for learning and teaching, also to lower costs;
12. **Long-term**: critical challenges solved by the best brains (e.g. resource constraints);
13. **Long-term**: virtual solutions to resolve mobility and lifestyle issues.

Risks and Challenges

1. **Short-term**: unfavorable labour force mobility and impact on industry;
2. **Short-term**: increased workload has negative impacts on mental health and raises costs due to absenteeism;
3. **Short-term**: continuous adaptation of education system is required (new technologies etc) in order to sustain quality human capital;
4. **Short-term**: make more environmentally friendly products to meet customers' demands;
5. **Short-term**: lack of understanding future requirements of industry in relation to demand for skills;
6. **Medium-term**: demographic change and an ageing society will require the workplace to adapt;
7. **Medium-term**: a specialist highly skilled workforce trained in over-engineered solutions;
8. **Medium-term**: high labour and production costs due to 'best in class' human capital.

Clustering and Implications

Cluster 4 "Customised Local Value Creation"

This cluster of drivers describes specialist closed loop eco-systems of manufacturers, suppliers and service providers. Driven by the opportunity to re-claim value from products, local value creating systems will emerge that capture products as they end their first useful life in order to then process them and maximise value. These systems will increasingly include large elements of services delivered alongside the products.

Opportunities

1. **Short-term**: thinking global, working local;
2. **Short-term**: manufacturing and services are built around regional, local and urban needs;
3. **Short-term**: the circular economy can be fostered through localised smart specialisation, producing specialist products for a global market;
4. **Medium-term**: more employment of population, increased growth in GDP;
5. **Medium-term**: global education standards, creating demand;
6. **Long-term:** de-risk of social conflict;
7. **Long-term:** increased social equality.

Risks and Challenges

1. **Short-term**: property rights;
2. **Short-term**: trade barriers (political, economic etc);

Selected Drivers:

- **Collaboration and Co-opetition** (Ec)
- **Circular Economy** (Ec)
- **New Markets and Competitors** (Ec)
- **Supply Chain Disruption and Resilience** (Env)
- **Smart Specialisation** (Pol)

Clustering and Implications

Cluster 4 “Customised Local Value Creation” (cont’d)

3. **Short-term**: more competition hinders growing competition?;
4. **Short-term**: increased competition for resources locally;
5. **Medium-term**: cultural differences and obstacles;
6. **Medium-term**: productivity gains and impact on unemployment;
7. **Medium-term**: volatile markets.

Clustering and Implications

Cluster 5 “Made in Downtown”

This cluster describes green, urban production in a resource constrained future. Driven by pressures to use fewer materials and less energy in clean factories, and enabled by new manufacturing technologies for local manufacturing and ICT, the long-term opportunity exists to bring factories into a mixed-use environment closer to homes (‘downtown’). Eventually these local factories will deliver public goods by cleaning the air and water, for example, by utilising their capacity for co-ordination and technology management.

Selected Drivers:

- **Environmental Efficiency** (Env)
- **Urban Production** (Tech)
- **Circular Economy** (Ec)
- **Demographics** (Soc)
- **Resource Conflicts** (Pol)
- **Global Governance Regulations** (Pol)

Opportunities

1. **Short-term**: buying local;
2. **Short-term**: urban job creation (e.g. local craft jobs)
3. **Short-term**: stick with “old” materials by recycling;
4. **Short-term**: use existing logistics (e.g. shopping centres);
5. **Short-term**: CO2 reduction;
6. **Medium-term**: international agreement on CO2 mitigation;
7. **Medium-term**: China fragments;
8. **Medium-term**: link manufacturing with water/ energy/ waste supply;
9. **Medium-term**: set technical standards of manufacturing for equipment.

Risks and Challenges

1. **Short-term**: expensive real estate, floor space etc.
2. **Short-term**: competition/conflict for space in cities;

Clustering and Implications

2. **Short-term**: public acceptance in relation to having factories downtown;
4. **Short-term**: increased congestion (transport, logistics etc);
5. **Short-term**: some factories cannot be relocated to cities;
6. **Medium-term**: loss of economies of scale;
7. **Long-term**: depopulation of the countryside.

Actions

In the last hour of the workshop, delegates were asked to work on their own to identify answers to the following three questions:

1. What one business or investment decision should **private enterprise** be taking given the implications identified?
2. What one area of research can **academia** contribute towards?
3. What one thing should **governments** be doing in light of the implications identified?

Actions shown in blue relate to actions that involve collaboration across more than one sector.

Actions for Business

Note that the following actions are written verbatim, and that all actions are included despite similarities in certain cases. Actions are shown in order of popularity.

Corporate strategy:

- Enterprises should start with their best competencies and best fit in their regions in terms of customers, skilled people, suppliers. They should strive to be the best and have the best equipment and personnel in its core activities.
- Invest in R&D and people, and think more long-term.
- Undertake continuous market research into potential new markets.
- Adopt modern technologies (Big Data, additive manufacturing, cloud computing etc) to increase speed of business and flexibility.
- Invest in both incremental and radical innovation in facing new challenges.
- Customer engagement and integration through open innovation.
- Use R&D budgets to actively explore and experiment with new business models, using open innovation and other collaborative means where appropriate.

Sustainability:

- Enterprises should invest in R&D and develop their business model and business proposition towards “Greener Leaner and Cleaner”.
- Focus on “Green In” (materials and resources like energy and water), “Green Insight” (healthy employees committed to long careers; less resource consumption), “Green Out” (clean water, or green products such as children’s toys).
- Change financial and investment objectives towards sustainability and the real economy.

Capital equipment:

- Implement advanced manufacturing engineering into today’s processes and extend it.
- Foster better collaboration between technology suppliers and users of advanced manufacturing.
- Flexible capital equipment.

Actions for Business (cont'd)

Skills:
- Collaboration with academia and governments to identify the right skills.
- Support the continuous qualification and skills development of personnel.

Local and urban production:
- Move towards shorter, localised supply chains.
- Realise urban production and diversification through local production.

Ageing population and demographics:
- Provide products for the elderly.
- Develop attractive work environments generally, and provide ageing workforce-friendly workplaces specifically.

Labelling and transparency:
- Identify and agree industry-wide methods of assessing and communicating environmental aspects of consumer goods, so that consumers are empowered to make choices (e.g. improved environmental labelling).

Standards:
- Foster global standards for manufacturing professions, methods and tools.

Corporate social responsibility:
- Support less economically advanced regions in creating new markets, rather than exploit or destroy them.

Actions for Academia

Sustainability:

- Greener, leaner and cleaner: academia should cooperate more with business in collaborative Research, Development and Innovation (RD&I) – projects for clean tech solutions (technology and business).
- Resource availability: collaboration through roadmaps to reduce over-exploitation of resources (tangible and intangible).
- Maximising environmental effectiveness of industry, e.g. emitting clean air and water as 'waste' outputs.
- Sustainability (resources, energy).
- Evaluation criteria related to application and contributions for sustainable growth.
- Research models for low-cost environmentally-friendly manufacturing – i.e. which sectors?
- Technology and organisational processes to enable the 'cleaning' of manufacturing.
- Environmentally effective/ efficient manufacturing processes and materials.
- Native, local materials and putting them to new uses.
- Research into materials from renewable resources.

Technology:

- Technological research that reaches the market by pulling together efforts with industry.
- Establishing the production backbone/ production system connecting production with SAP (business development systems) and procurement for a collaborative environment globally and affordably.
- Identify the use cases for new technologies (e.g. additive manufacturing).
- Research focus on manufacturing engineering and advanced manufacturing.
- Develop personalised mass production technologies and value network organisation tools.
- Developing means for knowledge sharing and qualifying 'on the job'.
- Data management: find positive usage of the amount of current data collection.

Collaboration:

- Competitor and supply chain collaboration.

Actions for Academia (cont'd)

Academic curricula that's fit for purpose:
- Be creative in developing new curricula.
- Focus on provision of good, educated people (including mechanical engineers, material scientists etc).
- Skills much more business-oriented.

New business models:
- Explore business and technical solutions for selling "use" instead of selling "functionality".
- Create models for decentralised factories and value creation.
- Identify the use cases for new business models (e.g. urban production).

Multi-disciplinary approach:
- Rather than work in silos, academics should instead create multi-disciplinary research environments that work across disciplinary areas.
- Undertake cooperative research "on campus".

Long-term thinking:
- Risks and challenges: academia should start working on the challenging drivers.
- Academia should work more with individual and societal challenges.

General research focus:
- Greater focus on the environment, healthcare, energy, multicultural management and multi-disciplinary skills.

Actions for Government

Regulation:
- Governments must agree on a new global framework to regulate manufacturing (e.g. labelling processes).
- Set environmental and regulatory standards between nations.
- Cooperatively set up rules for global coopetition without effecting too much differing cultural habits (sic).
- Commercial barriers for products that do not comply with environmental issues or personnel protections.
- International regulatory regime: taxes, social and environmental.
- Green Lean and Clean: the Government/EU should set the targets for reducing emissions: ETS – 2020/2030.
- Framework to encourage market for ecosystem services.
- Create a framework for a production-friendly environment.
- Build legal and policy frameworks that enable and encourage eco-effective manufacturing.
- Framework conditions: facilitate standards at an international level.
- Define property rights serving open innovation and private patent rights.
- Protect intellectual property rights.

Education and training:
- Education, support and flexibility to adapt to new technologies and trends.
- Agree/align standards of education for a more global industrialised environment.
- Support technical education at schools and universities.
- Invest in education in relation to modern technology transformation.
- Investment in engineering education starting with primary school education.
- Invest more in high level education regarding manufacturing needs e.g. industrial engineering.
- Take leadership of the skills agenda in order to increase skills availability.
- Training: invest in training a highly skilled workforce.

Fiscal policy:
- Introduce a new taxation system.
- Taxation and legislation for attracting private sector for investments.

Actions for Government (cont'd)

General, overarching actions and activities:
- Understand long-term needs of industry and respond.
- To reduce boundaries of trade.
- Measures: GDP of value add of manufacturing.
- Policy statement: international agreement on Intellectual Property rights, the price of carbon, free trade, human rights etc.
- Provide incentives for companies to develop new processes and products through the use of regulations, legislation, education, taxation etc.

Regional and local development:
- Develop regions according to product manufacturing needs through education, services etc.
- Start with a nucleus of SMEs in a good region (of Great Britain, for example) with perfect conditions for enterprise.
- Put urban manufacturing on the agenda and set up lighthouse applications and cases.

R&D:
- R&D: invest in appropriate academia-industry research.
- R&D financing or credit in strategic sectors such as energy, automotive, environment and ICT.
- RDI support and financing; international agreement.

New business models:
- Governments must invest in furthering their own knowledge of new business models (e.g. eco-effective factories).
- Encourage provision of maternity and paternity arrangements to counter the demographic trend towards an ageing population.
- Procurement: pull demand where appropriate (e.g. public procurement of innovation).

European Perspectives: Conclusion

Certain key themes surfaced strongly throughout the workshop:

Local and regional manufacturing, including urban manufacturing: It was felt that European manufacturers would do well to shorten global supply chains in order to mitigate supply chain risk and improve the environmental footprint of operations. Local and regional clusters of businesses, services and academic institutions should support each other in striving towards common strategic aims (see driver “Smart Specialisation”). These manufacturing eco-systems could be encouraged through government incentives, fiscal or otherwise. Urban production is seen as a great opportunity in Europe (four of the five clusters included the driver “Urban Production”). In the future, specialist micro-manufacturing facilities may be located in or near urban centres in order to benefit from closer proximity to the workforce and to the end consumer. Urban manufacturing would also help tackle unemployment, as most of the unemployed live in urban centres.

The circular economy and new materials: The “Circular Economy” featured in the top five Economic drivers, and is closely related to several other chosen drivers, most notably “New Materials” and “Environmental Efficiency” (a proxy for resource efficiency). All of these drivers were examined as part of the clustering exercise. In addition, many of the actions across all three sectors relate to driving progress and innovation across a wide range of areas relating to long-term sustainability (resources, materials, waste etc).

Big Data and advanced analytics: Many organisations are already using analytics to manage a growing wealth of data, however this will increase as analytics software and platforms become more advanced. Big Data offers a great deal of potential. It can give manufacturers real-time insight into consumer behaviours and opinions, help identify opportunities sooner and get improved variants to market more rapidly.

Human capital and ageing populations: This topic was first touched on at the dinner in relation to the need to promote STEM subjects early in a child’s education, but it also came out during the workshop in terms of investing in human capital in the workplace. Ensuring that skills are maintained on the job is seen as extremely important. Employers must work hard in the future to attract and retain the best talent, and to ensure that the workplace is suitable for women and older employees.

European Perspectives

The following 25 delegates attended the workshop at the British Embassy in Berlin:

Prof George Chryssolouris, University of Patras, Greece, Dept of mechanical engineering and aeronautics, Vice Chairman of EFFRA
Alexander Dahm, Head of FAL and Integration A320 Family, EADS
Enrico Deiaco, Swedish Agency for Growth Policy Analysis
Professor Steve Evans, Director of Research in Industrial Sustainability, Institute for Manufacturing, University of Cambridge
Prof Heinrich Flegel, Director of Research Materials, Lightweight Design & Manufacturing, Daimler AG, and Chairman of Manufutures
Inés Gurbindo, Directora Industrial, Mtorres
Ulrike Hillemann, Science & Innovation Network, British Embassy in Berlin
Ulf Holmgren, Director and Head of Manufacturing and Working Life Division, VINNOVA - Sweden's Innovation Agency
Dr Günter Hörcher, Head of Research Strategy, Fraunhofer Institute for Manufacturing Engineering and Automation IPA
Pierfrancesco Manenti, Research Director, IDC Manufacturing Insights EMEA, IDC
Dr Detlef Pauly, IAATSCI (Industry Solutions) at Siemens
Antti Peltomäki , Deputy Director-General of the Enterprise and Industry Directorate-General, European Commission
Dirk Pilat, Deputy Director for Science, tech and industry, OECD
Bonifacio Garcia Porras, Enterprise and Industry Directorate-General, European Commission
Dr Carsten Reise, Fraunhofer Berlin / TUBerlin
Rendel Rieckmann, Deputy Head of FAL and Integration A320 Family, EADS
Bernd Schimpf, President, Wittenstein AG
Jeremy Schlickenrieder, Science & Innovation Network, British Embassy in Berlin
Malcolm Scott, Consul-General in Düsseldorf and Director-General of UK Trade & Investment in Germany
Professor Gunther Seliger, Fraunhofer Berlin / TUBerlin
Dr Javier Garcia Serrano, Head of Energy, Chemistry, Environment, Products and Services Department, Global Innovative Markets Directorate, CDTI
Professor Bas ter Weel, Head of Department of Labour and Education, Netherlands Bureau for Economic Policy Analysis
Professor Reijo Tuokko, Head of Department of Production Engineering, Tampere University of Technology
Gereon Uerz, Group Research Future Affairs, Volkswagen
Professor Engelbert Westkämper, Head of Department, Institute of Industrial Manufacturing and Management Universität Stuttgart

European Perspectives

Photo taken at the British Embassy, Berlin

US Perspectives

US Perspectives

The "**Future of Manufacturing: US Perspectives**" event was held on the 7th March 2013 in Washington DC. On account of a snow storm which hit the East Coast the day before the workshop, a dinner at the British Ambassador's Residence was cancelled. Several delegates were not able to fly in to DC to attend the workshop. Nevertheless, the event was attended by a good mix of academia, private sector and public sector representation. A total of 19 delegates attended.

Paul McCaffrey participated from the Government Office for Science. He was joined by the following Lead Expert Group members from the UK:

Professor Steve Evans, Director of Research in Industrial Sustainability, Institute for Manufacturing, University of Cambridge

Professor Anne Green, Institute for Employment Research, University of Warwick

Professor Alan Hughes, Director of the Centre for Business Research, University of Cambridge

Workshop:

British Embassy, Washington DC
Wednesday, 7th March 2013

Project Team:

Paul McCaffrey, Project Leader, Foresight, Government Office for Science
Marcus Morrell, Lead Facilitator, Arup
Callie Key, Co-Facilitator and Scribe, Arup

US Drivers of Change

Social

1. Demographics
2. Urbanisation
3. Social Attitudes Towards Consumption
4. Gender Equality and Changing Roles
5. Open Innovation

Technological

1. New High Impact Technology
2. Big Data, Modelling and Visualisation
3. Robotics and Automation
4. Customisation on Demand
5. Physical Infrastructure

Economic

1. Global Supply and Demand
2. Commodity Supply and Security
3. Economic Un/Certainty
4. Nation State vs. Multinational
5. Resource Efficiency

Environmental

1. Green Manufacturing: Materials
2. Green Manufacturing: Energy
3. Green Manufacturing: Water
4. Natural Disasters
5. Eco-transparency to Consumers

Political

1. IP Protection
2. Political Tolerance Towards Scientific Discovery
3. Public Opinion
4. Trade Blocs
5. Political Stability

KEY: Red = pre-selected Drivers of Change; Purple = slightly modified titles; Black = new drivers completed by delegates

US Drivers of Change

US Drivers of Change: Social

The five drivers of change chosen within the Social domain were (most impactful listed first):

1. **Demographics** (*high certainty, high impact*)
   National and global demographic shifts which encompass ageing populations (and the population of those within working age), immigration and emigration, and the gender balance. This driver also touches on black swan events that impact the global population such as pandemics.

2. **Urbanisation** (*high certainty, high impact*)
   The United Nations projects that 70% of the world's population will be living in cities and towns by 2050 (up from just over 50% currently). Different patterns of urbanisation in emerging markets will place new demands on manufacturers, exacerbated by the consumer habits of a growing middle class.

3. **Social Attitudes Towards Consumption** (*medium certainty, high impact*)
   Changing consumer attitudes and expectations, driven by raised environmental awareness and access to new technologies (e.g. 3D printing) and platforms (e.g. social media). These are likely to drive new patterns of consumer behaviour. However, these are very difficult to predict.

4. **Gender Equality and Changing Roles** (*low certainty, high impact*)
   There is a heightened awareness in most regions about the need to provide equal opportunities to both genders. Policies that are in place to correct imbalances are much less certain than the awareness of this critical issue.

5. **Open Innovation** (*high certainty, low impact*)
   More and more companies are tapping into the wider public's intellectual capital by crowd-sourcing innovative ideas and solutions. Manufacturers are giving creative consumers a direct say in, and rewarding them for, what gets developed, designed and made.

US Drivers of Change: Technological

The five drivers of change chosen within the Technological domain were:

1. **New High Impact Technologies** (*high certainty, high impact*)
   These are the emergent technologies that will have the greatest impact on manufacturing. These cover new materials and processes (e.g. bio-manufacturing, biomimicry and bio-design) and additive manufacturing techniques (e.g. 3D printing). This also relates to the "next big thing" technologies that we don't know about yet, the "unknown unknowns".

2. **Big Data, Modelling and Visualisation** (*high certainty, high impact*)
   This driver involves the utilisation of mined data to model design and manufacturing processes so that errors can be corrected before production starts. This will be enabled by the widespread use of sensors on machines and in products and goods (e.g. the Internet of Things), and by the increased use of visualisation and simulation tools.

3. **Robotics and Automation** (*high certainty, high impact*)
   This high impact driver speaks to the emergence of Artificial Intelligence (AI) and the increased use of automation and robots in manufacturing. Both will have implications for more flexible production in future.

4. **Customisation on Demand** (*high certainty, high impact*)
   Custom manufacturing is becoming more commonplace. Consumers will become more empowered as they are given more opportunities to request exactly what they want within a given price point. Additive manufacturing and rapid prototyping will democratise manufacturing even further.

5. **Physical Infrastructure** (*high certainty, high/medium impact*)
   Physical infrastructure refers to the basic systems and services such as water supply, drainage, transportation and power supply, that a country or organisation uses to work effectively. Discussion touched on the idea that the grid may not be needed in future to deliver energy.

US Drivers of Change: Economic

The five drivers of change chosen within the Economic domain were:

1. **Global Supply and Demand** (*high certainty, high impact*)
   This driver relates to future dynamics of global supply and demand for manufactured goods. This encompasses the economic development of emerging markets and the location of future production (i.e. on-shoring, re-shoring versus off-shoring). This will be influenced by the projected growth in the world's middle class population.

2. **Commodity Supply and Security** (*high certainty, high impact*)
   Commodity prices have increased sharply since 2000, erasing all the declines of the 20th Century. Prices of a range of raw materials are likely to remain high as global resource markets oscillate in response to surging demand and potentially volatile energy costs. In the background, supply of many resources will remain relatively inelastic.

3. **Economic Un/Certainty** (*medium certainty, high impact*)
   Future global uncertainty with regards to fiscal policy and the changing regulatory landscape.

4. **Nation State vs. Multinational** (*high certainty, medium impact*)
   This driver reflects future shifts in the relationship between nation states and large multinational corporations. How will governments regulate international markets (supply chains, access to commodities etc)?

5. **Resource Efficiency** (*high certainty, low impact*)
   The move towards greater resource efficiency and utilisation as raw and processed materials become more scarce. This also encompasses energy and water.

US Drivers of Change: Environmental

The five drivers of change chosen within the Environmental domain were:

1. **Green Manufacturing: Materials** (*high certainty, high impact*)
   As resources become more scarce and costly, manufacturers will need to reduce their usage of raw and processed materials through increased efficiency to the point where minimal or zero waste is sent to landfill.

2. **Green Manufacturing: Energy** (*high certainty, high impact*)
   This is a catch-all driver covering the carbon footprint of manufactured goods (including direct energy usage and embedded energy in products). This touches on the wider context of reliable access to affordable low carbon (or zero carbon) energy, and technologies and processes that drive energy efficiency gains.

3. **Green Manufacturing: Water** (*high certainty, high impact*)
   Sustainable manufacturing and the availability and reliable supply of clean, safe water.

4. **Natural Disasters** (*low certainty, high impact*)
   Climate change could bring about more frequent natural disasters. Regardless of the rate of increase, businesses will need robust strategies in place to optimise resilience to disasters such as floods, droughts, earthquakes and tsunamis.

5. **Eco-Transparency to Consumers** (*low/medium certainty, low/medium impact*)
   There is increasing pressure to communicate to the consumer product information relating to environmental costs and impacts. This trend will change business models, as consumers become more informed about the impacts that their consumer decisions have on the environment and society at large. New pricing signals will come into play, and disruptive efforts will bring about new, smarter customer-driven models that decouple value from the consumption of natural resources.

US Drivers of Change: Political

The five drivers of change chosen within the Political domain were:

1. **IP Protection** (*high certainty, high impact*)
   Intellectual Property protection will become more and more important to manufacturers in future. Countries are starting to become sources of their own innovation, and this will effect the location choice for many manufacturers.

2. **Political Tolerance towards Scientific Discovery** (*medium certainty, high impact*)
   As more innovation takes place, governments will have to adjust their risk tolerance with a view to allowing new scientific advances in scaled-up production. Policy responses will have to take safety and sustainability into account. This trend requires policy solutions that balance risk with the ability to protect people and planet.

3. **Public Opinion** (*high certainty, high impact*)
   Greater levels of transparency, combined with the rise in citizen journalism and vigilance (enabled by the internet, social media etc), will have a significant impact on manufacturers as they seek to mitigate risks relating to negative publicity and press coverage.

4. **Trade Blocs** (*low certainty, high impact*)
   Trade blocs are important as they guide investment decisions and drive markets and trade between nations. While this is not a major driver now, it is not clear which way these are going in future. This could be an area of high impact by 2050.

5. **Political Stability** (*medium certainty, medium impact*)
   The growing pains of emerging economies may spark future conflict, socio-political revolution and manifest physical change. We can, however, expect greater stability as emerging markets mature.

Clustering and Implications

Cluster 1 "Learning from Luddism"

This cluster examined divergent pathways to two future scenarios: utopian and dystopian. The outputs explore the relationship between people and technology, and the opportunities and negatives associated with increased usage of robotics and artificial intelligence.

Opportunities

1. **Short-term**: more jobs are created as customisation on demand scales up and "out" (ie. becomes widely available to all);
2. **Short-term**: more people become employed in more socially valuable areas (perhaps);
3. **Short-term**: new models lead to the redistribution of income;
4. **Short-term**: attentions turn to societal grand challenges and people-intensive welfare;
5. **Short-term**: greater value is placed on connections to people and place leading to new niche, localised products;
6. **Medium-term**: human genetic modification leads to longer working lives;
7. **Medium-term**: scaled-out technologies are available to more people;
8. **Medium-term**: demand from non-manufacturing sectors boost consumer spending;
9. **Long-term**: gerontocracy and the rule of the artificially augmented and aged few;

Selected Drivers:

- **Gender Equality and Changing Roles** (Soc)
- **Demographics** (Soc)
- **Robotics and Automation** (Tech)
- **Political Tolerance towards Scientific Discovery** (Pol)
- **Public Opinion** (Pol)

Short-term = 2020s
Medium-term = 2030s
Long-term = 2040s

Clustering and Implications

Clustering and Implications

Cluster 1 "Learning from Luddism" (cont'd)

10. **Long-term**: global equalisation of wages restores value of work;
11. **Long-term**: high income, opportunity in more sustainable locations (e.g. Portland, Oregon)
12. **Long-term**: all the things we don't want to do and previously gave to low-cost workers are now being done by automation.

Risks and Challenges

1. **Short-term**: fewer jobs for people;
2. **Short-term**: increased automation means that more income is appropriated by fewer people (robots don't earn wages!);
3. **Short-term**: the challenge to scale up technologies;
4. **Medium-term**: fewer manufacturing jobs;
5. **Medium-term**: the services economy is more important for jobs;
6. **Long-term**: social disintegration in manufacturing sector leads to dystopia;
7. **Long-term**: political legitimacy collapses as factories are attacked.

Clustering and Implications

Cluster 2 “Commodity Supply & Security”

This cluster explores manufacturing on demand and tracks the shift to a circular economy, in which waste outputs are used as inputs elsewhere in a closed-loop system.

Opportunities

1. **Short-term**: Big Data and open innovation to measure and communicate environmental impacts to customers;
2. **Short-term**: the ability to collect and understand huge amounts of information about customers;
3. **Short-term**: experimentation at a local level and scale up where appropriate;
4. **Short-term**: identify where opportunity costs are zero;
5. **Medium-term**: ability for bigger companies to “lock in” market via personalisation;
6. **Long-term**: reduce market barriers to entry on account of open innovation;
7. **Long-term**: circular economy minimises waste.

Risks and Challenges

1. **Short-term**: resolving privacy issues and ownership of personal data;
2. **Short-term**: quality standards for Big Data and analytics providers;
3. **Short-term**: promoting open innovation while protecting intellectual property rights;

Selected Drivers:

- **Open Innovation** (Social)
- **Customisation on Demand** (Tech)
- **Big Data** (Tech)
- **Resource Efficiency** (Economic)

Clustering and Implications

Cluster 2 “Commodity Supply & Security” (cont’d)

4. **Medium-term**: up-cycling technology and infrastructure;
5. **Long-term**: market coordination;
6. **Long-term**: chicken and egg – innovating the business model versus the infrastructure required to do this;
7. **Long-term**: commodity price volatility.

Clustering and Implications

Cluster 3 "Innovation Ecosystem for Green Manufacturing"

This cluster of drivers point to resilient models of production and consumption in a new ecological age, with a focus on innovation in material science in the long-term. Driven by changing attitudes to consumption and a concern for resource and energy efficiency (and enabled by ICT connectivity), manufacturers increasingly interact with users and other businesses and government in a desire to deliver exactly the value that the customer desires. Personalisation of products is just a first step on this pathway.

Opportunities

1. **Short-term**: policy to phase out coal-based energy plants creates pull for new green technology;
2. **Medium-term**: expert green technologies and services;
3. **Medium-term**: new economies of production and consumption (e.g. customisation on demand);
4. **Medium-term**: China's middle class "thickens" and the green market prospers;
5. **Long-term**: replacement of scarce materials (e.g. Rare Earths replaced by green materials);
6. **Long-term**: development of novel bio-materials and bio-processes;
7. **Long-term**: higher demand for green technologies.

Selected Drivers:

- **Open innovation** (Social)
- **Social Attitudes Towards Consumption** (Social)
- **Customisation on Demand** (Tech)
- **Resource Efficiency** (Economic)
- **Green Manufacturing: Materials** (Env)

Clustering and Implications

Cluster 3 "Innovation Ecosystem for Green Manufacturing" (cont'd)

Risks and Challenges

1. **Short-term**: increased poorly designed regulation stifles innovation;
2. **Short-term**: lack of manufacturing skills;
3. **Short-term**: policy to phase out coal-based energy plants, which creates an energy supply shortfall;
4. **Short-term**: access to capital;
5. **Medium-term**: health and safety risks (e.g. from customisation on demand, lax attitudes by consumers of 3D printing technology);
6. **Long-term**: IP commons protection (e.g. China looks the other way). This could result in a breach of national security.
7. **Long-term**: failure to find replacements for scarce materials.

Clustering and Implications

Cluster 4 "The Next Frontier: Mobilising Skills"

This cluster examines a gap which this break-out group perceived in the workshop discussions so far, which is future skills. The cluster explores the mobilisation of new skills in pushing progress forward towards the next frontier for manufacturing.

Opportunities

1. **Short-term**: use of nanotechnologies in manufactured products (is this well enough understood?);
2. **Short-term**: empowering supply chain with new technologies;
3. **Short-term**: increased individual data collected (e.g. airlines watch behaviours and patterns of travel to extract maximum revenue based on your preferences);
4. **Short-term**: attracting and retaining the best global talent;
5. **Short-term**: political tolerance towards scientific discovery becoming more "open";
6. **Medium-term**: mobile, transnational workforce;
7. **Medium-term**: individualised pricing (through "Big Data" analysis);
8. **Medium-term**: genetic manufacturing (also a risk);
9. **Long-term**: customisation of products and services;
10. **Long-term**: overcoming gender inequalities (in STEM subjects);
11. **Long-term**: manufacturing in space.

Selected Drivers:

- **Demographics** (Social)
- **New High Impact Technology** (Tech)
- **Big Data, Modelling and Visualisation** (Tech)
- **Commodity Supply and Security** (Economic)
- **IP Protection** (Pol)
- **Political Tolerance towards Scientific Discovery** (Pol)

Clustering and Implications

Cluster 4 "The Next Frontier: Mobilising Skills" (cont'd)

Risks and Challenges

1. **Short-term**: cyber-espionage;
2. **Short-term**: ethics and the acceptability of products;
3. **Short-term**: disparities in national IP protection policies and enforcement;
4. **Short-term**: data security;
5. **Short-term**: acceptance of data mining is reversed;
6. **Short-term**: geographic concentration of commodities;
7. **Short-term**: scarcity of spectrum;
8. **Medium-term**: educating future innovators;
9. **Medium-term**: encouraging STEM skills;
10. **Medium-term**: genetic manufacturing;
11. **Medium-term**: vulnerability of the cloud;
12. **Medium-term**: data storage;
13. **Long-term**: birth rates below replacement levels;
14. **Long-term**: understanding implications of data security and cyber-espionage;
15. **Long-term**: scarcity of raw materials.

Actions for Business

Education and Skills:
- Business should invest (through grants, apprenticeships and other job training programmes, guest lecturers etc) in order to prime the pipeline for STEM disciplines (particularly in middle high school and college).
- Similarly, businesses should invest in "talent pipeline partnerships" with education partners to offer opportunities for STEM students to interface directly with entrepreneurs and intrapreneurs early on, and have their product or business concepts evaluated by them.

Long-term outlook:
- Businesses shouldn't look to quarterly returns as a basis for measuring return on investment or performance; instead they should be more patient with the capital that is invested in the manufacturing sector.

Manifesting a positive vision:
- Businesses should take the initiative and invest in American manufacturing, and stop using uncertainty as an excuse!
- The private sector should create a new golden era of American technological and manufacturing innovation by taking bigger investment risks (as did the Victorians) and by backing the most promising entrepreneurial activity.

Corporate Social Responsibility:
- Greater emphasis on sustainable practices, welfare of employees and customer satisfaction.
- Customer participation in development of products to include concerns about risks, but also to shape those concerns.
- Businesses should collaborate to develop, gain acceptance for and enforce ethical standards.

Coopetition:
- Identify opportunities to work on pre-competitive or translational R&D together with competitors and invest heavily in it (ie. two companies should work together, then go apply new knowledge in their own markets).
- Create an active risk-pooling approach to long-term credentials related to supply chains, talent and resources (sic). For example businesses can invest in "commons" for skills building, share supply chains to reduce risk, or invest in platform research.

Actions for Business (cont'd)

Other actions:

- Private enterprise should be involved in foresight, and conduct a strategic planning event to consider their business plans in light of future threats and opportunities.
- Certify manufacturing clusters and provide tax incentives and vouchers for workforce development, joint R&D, export initiatives and standards development.
- More corporate spin-outs.

Actions for Academia

Industry collaboration:

- Reach out to industry and understand their problems and challenges (via faculty, industry fellow rotations etc).
- Universities need to do more outreach to the manufacturing sector, and find out their real research and technology problems (particularly SMEs).
- Encourage/support student internships as a requirement.
- Recruit professors and teachers from private enterprise – bring the employers (manufacturers) into the classroom on a consistent basis to create better connectivity between academia and enterprise.
- Train and educate students based on what enterprises need for their workforce.
- Develop more technologies that will defy economies of scale (with industry).
- Create a more accurate definition of what constitutes manufacturing and innovation and what the right metrics are to measure both.
- Promote a new understanding of what manufacturing is through the adoption of new classifications/ understanding /data sources (input-output view).
- Provide incentives for high-impact research.

Curricula and training:

- Rethink STEM curricula and pre-requisites to increase attractiveness/ reduce drop-outs.
- It doesn't matter what actions academics take as long as they take an active interest in its further development, deployment and utility of this research into the future of manufacturing.
- Formal cross-cutting training in entrepreneurial skills.

Technology

- Identify and develop concepts for radical new technologies (e.g. molecular construction of whatever is needed would fix many of the problems identified), that can scale down and still be competitive.

Actions for Academia (cont'd)

Intellectual Property

- Revision of university IP policies in order to attract more businesses to collaborate (e.g. Penn State's new IP policy).
- Models of technology transfer (e.g. management of IP) that encourage competitive market structures (e.g. socially responsible licensing).

Innovation

- Leverage Big Data and advanced computing and tools to simultaneously advance scientific understanding and commercialisable innovation (e.g. understanding how the brain works and iterating with improving AI/advanced computing – ie. two-way feedback between scientific discovery and technological advance).

Actions for Government

Education:

- Education incentives for STEM disciplines for individuals, schools and private enterprise so they are linked in a way that each cog in the chain becomes a stepping stone; and so that individuals are incentivised to study STEM disciplines by schools that specialise in STEM as it relates to manufacturing.
- Encourage private enterprise to commit to an investment in individuals graduating from schools.
- Stimulate rewarding STEM career paths (ie. the demand side, not supply).
- Promotion of STEM skills alongside others (for broader perspectives), through improved careers support to individuals.
- Invest more in STEM education from primary school through to university to create a capable workforce.

Incentivising innovation

- Certify manufacturing clusters and provide innovation vouchers for workforce development curricula, joint R&D initiatives, trade missions and standards development.
- Credit mechanisms for entrepreneurial activity (government collateral and loan agreements).
- Create incentives for innovation that balance flexibility and risk in addressing public well-being, safety and environmental quality.
- Create a “Special Innovation Zone” framework for experimentation (quick permitting, geographic zones, funding tied to experiment objectives, access to pilot market.
- Create one-stop portals at the local level for permits and licences.

Regulation:

- Regulation design through partnerships, bringing prospective customers and firms into temporary regulatory agreements, matching consumption with jobs.
- Regulate smarter: review all major regulations impacting the manufacturing sector.
- Eliminate regulations that are barriers to a manufacturing economy.

Actions for Government (cont'd)

Other actions:

- Develop a policy framework to encourage solutions to energy security and future proofing (e.g. build new nuclear and new gas storage capacity in UK now, develop renewable mix and invest in interim solutions such as shale gas).

- Increase incentives for competitive markets (as opposed to monopolistic ones), in addition to tougher anti-trust legislation and the formation of collaborations across region, patent pools, incentives for social corporate responsibility.

US Perspectives: Conclusion

While there were fewer US delegates at the workshop in Washington DC than expected, due to weather conditions, the outputs were extremely impressive. It may be that this reflects the deep thinking that has recently taken place in the US around the future of American manufacturing by organisations such as the National Academy of Engineering. In any case, their focussed minds produced some intriguing insights. Among the themes that surfaced most strongly are the following:

The future shape of the global economy and regulatory behaviours of governments. Several of the drivers of change chosen within the Economic domain point to a great deal of uncertainty in relation to the future dynamics of the global economy. Patterns of global supply and demand are changing rapidly, as regions such as the US and Europe attempt to reinvigorate their manufacturing sectors. There are unanswered questions around future attitudes of governments towards trade, protectionism and the activities and ownership models of powerful private sector multinationals.

Innovation in manufacturing: this is a very clear meta theme that was present throughout the workshop discussions, encompassing technological and scientific exploration and experimentation, collaboration, education and skills development. Open Innovation was included in the 25 prioritised drivers, and was picked in two of the clusters. Political tolerance towards scientific discovery was also chosen in several clusters. Finally, many intriguing actions were identified to incentivise innovation across business and academia. For example, one idea is for the Government to set up a "Special Innovation Zone" framework for experimentation. Under which business could benefit from fast-tracked permitting or pilot markets.

Social attitudes, behaviours and expectations: several prioritised drivers related to the societal aspects that touch on, or are impacted by, manufacturing. Social attitudes towards consumption, selected as a high impact Social driver, was seen to be critical in shaping demand for manufactured goods in future. Eco-transparency to the consumer was also identified as a key driver – implying that consumer relations will be a two way process, with the onus on manufacturers to be more transparent about the ecological footprint of their products and operations. Customisation on demand will also take the relationship with the end consumer to a much deeper level than exists currently.

US Perspectives

The following 19 delegates attended the workshop at the British Embassy in Washington DC:

Philip Auerswald, Associate Professor, School of Public Policy, George Mason University, and senior fellow at the Kauffman Foundation
Will Barton, Head of Manufacturing, UK Technology Strategy Board (*UK*)
Dr. David S.C. Chu, President and Chief Executive Officer, Institute for Defence Analyses
Dr. Mark Claydon-Smith, Head of Manufacturing, UK Engineering and Physical Sciences Research Council (*UK*)
Dick Elsy, Chief Executive Office of the High Value Manufacturing Catapult (*UK*)
Professor Steve Evans, Director of Research in Industrial Sustainability, Institute for Manufacturing, University of Cambridge *(UK)*
Stephen Ezell, Senior Analyst, Information Technology and Innovation Foundation
Kim Frankovich, Vice President Sustainability, Solo Cup Company
Professor Anne Green, Institute for Employment Research, University of Warwick *(UK)*
Professor Alan Hughes, Director of the Centre for Business Research, University of Cambridge *(UK)*
Sreenivas Ramaswamy, Engegement Manager at McKinsey & Company, Fellow at McKinsey Global Institute
Annabelle Malins, British Consul General (*UK*)
Dr Steven McKnight, Assistant Director of the Engineering Directorate, National Science Foundation (NSF)
Egils Milbergs, Executive Director Washington Economic Development Commission
Dr Michael Molnar, Chief Manufacturing Officer National Institute of Standards and Technology (NIST)
Brian Raymond, Director of Technology and Policy, National Association of Manufacturers
Rebecca Taylor, Vice President, National Center for Manufacturing Sciences
Walter D. Valdivia, Fellow, Governance Studies, Center for Technology Innovation, The Brookings Institution
Dr Katie Whitefoot, Senior Program Officer for Manufacturing, Design, and Innovation for US National Academy of Engineering

US Perspectives

Photo taken at the British Embassy, Washington DC

Asian Perspectives

Asian Perspectives

The "**Future of Manufacturing: Asian Perspectives**" event was held in Singapore. A dinner at the British High Commissioner's Residence preceded the workshop at the British High Commission the following day.

The following countries were represented at both the dinner and the workshop: China, India, Indonesia, Japan, Malaysia, Singapore and South Korea. Delegates provided a mix of academic, private sector and public sector representation.

Professor Sandy Thomas and Paul McCaffrey participated from the Government Office for Science. They were joined by the following Lead Expert Group members from the UK:

Dr Hamid Mughal, Executive Vice President of Manufacturing Engineering & Technology, Rolls Royce

Prof Chris Lowe, Director of the Institute of Biotechnology, University of Cambridge

Dinner:

British High Commissioner's Residence
Tuesday, 12th March 2013

Workshop:

British High Commission, Singapore
Wednesday, 13th March 2013

Project Team:

Sandy Thomas, Director, Foresight, Government Office for Science
Paul McCaffrey, Project Leader, Foresight, Government Office for Science
Marcus Morrell, Lead Facilitator, Arup
Marlon Kobacker, Co-Facilitator and Scribe, Arup

Dinner Conversation

A dinner was held at the British High Commissioner's Residence, hosted by the High Commissioner, His Excellency Antony Phillipson. The conversation during the meal covered a great many contextual drivers from population growth and the rising cost of labour, to the potential for future economic disruption brought about by local or regional natural disasters. There was much discussion about sustainability in the context of increasing consumption, resource scarcity, climate change and the need for energy security.

In terms of opportunities, there was a healthy disagreement as to what sustainable or green manufacturing might mean or what shape it will take over the coming decades. Components include resource efficiency, waste minimisation and clean energy.

Cheryl Chung (Centre for Strategic Futures, Singapore), speculated that we may witness a new industrial revolution that takes us from mass production to mass customisation. If society starts printing their goods in future, who then becomes the manufacturer?

It was encouraging to hear far-sighted speculation around the longer-term future for manufacturing. This touched upon concepts such as the circular economy and industrial symbiosis, biomimicry and the invention of processes to grow materials – all of which pointed to some very exciting prospects for the sector despite the challenges ahead.

We also heard about country specific challenges. Andrie Budiman (Nestle) described rampant population growth in Indonesia and the pressure to increase productivity as economic growth slows its pace. Shyam Takale (Bharat Forge Ltd*),* explained that India's biggest challenge going forward is the provision of adequate infrastructure. Rapid development in India's urban centres is getting ahead of infrastructure, and this needs to be addressed.

"In the context of this discussion, this is certainly Asia's century."

Prof. Chris Lowe

Director of the Institute of Biotechnology, University of Cambridge

Dinner Quotes

A number of interesting comments were made by delegates during the dinner:

“In the context of upscaled mass customisation and personalisation, who will be the winners and who will be the losers?”
Cheryl Chung, Lead Strategist, Centre for Strategic Futures (CSF), Prime Minister’s Office, Singapore

“We need an ecosystem of manufacturing in Asia, with shorter supply chains.”
Francis Hiew, Managing Director, Spirit Aerosystems Malaysia Sdn Bhd

“The need to reduce CO2 emissions by more than 70% is a significant challenge and will fundamentally change the nature of manufacturing.”
Prof Yasushi Umeda, Department of Mechanical Engineering, Graduate School of Engineering, Osaka University, Japan

“It will not be enough optimising manufacturing resources in future. We will need a radical rethink; an “out of the box” approach to create new solutions.”
Dr Hamid Mughal, Executive Vice President of Manufacturing Engineering & Technology, Rolls Royce, UK

“The gap between the big conglomerates and small players is too huge.”
Dr Byeongwon Park, Team Leader, Centre for Strategic Foresight, Science and Technology Policy Institute (STEPI), South Korea

“In 2050 many of the challenges in manufacturing will be the same as we have now. However, resource scarcity will become a greater challenge. How will we design products that reduce material use and optimise performance? Virtual material design and virtual process design is where the work will surely be realised.”
Dr Lim Ser Yong, Executive Director, SIMTech, Agency for Science, Technology and Research (A*STAR), Singapore

“Sustainability will become a more important factor over the coming decades. Ecological manufacturing will be the way of the future. Integrating waste streams into useful resources is the way forward.”
Dr Moonjung Choi, Director of Technology Foresight Division, Korea Institute of Technology Development

Asian Drivers of Change

Social

1. Ageing Population
2. Decreasing Job Numbers
3. Workforce Mobility
4. Consumer Expectations
5. Throw Away Culture

Technological

1. Increased Computational Power
2. New Manufacturing Techniques
3. Biotechnology
4. New Materials
5. Increased Automation

Economic

1. Generation of Knowledge
2. Rising Consumption
3. Business Model
4. Trade Blocs
5. (nil)

Environmental

1. Climate Change
2. Waste Management + Recycling
3. Resource Depletion
4. Sustainable Manufacturing
5. Tipping Points

Political

1. Resource Conflicts
2. Trade Blocs
3. Producer Responsibility
4. Government Industrial Policy and Leadership
5. Global Governance

KEY: Red = pre-selected Drivers of Change; Purple = slightly modified titles; Black = new drivers completed by delegates

Asian Drivers of Change

Asian Drivers of Change: Social

The five drivers of change chosen within the Social domain were (most impactful listed first):

1. **Ageing Society** (*high certainty, high impact*)
   The global population is ageing due to an increase in life expectancy. As total fertility rates further reduce we are seeing an increase in the proportion of the oldest people. The elderly in more economically advanced countries are enjoying better health for longer, thanks to advances in medicine and improved diets. It is expected that we will see an increase in productive life, and that the elderly will retire later in life. This will certainly be the case in countries with high dependency ratios.
2. **Decreasing Job Numbers** (*high certainty/ high impact*)
   Increased automation and use of robotics, coupled with focussed efforts to increase productivity and drive efficiency gains, will likely see a reduction in the numbers of certain jobs in manufacturing. However, it is likely that new employment opportunities will emerge in manufacturing in areas such as software development, data analytics and related “manu-services”. Humans will also be needed to design and maintain automated systems.
3. **Workforce Mobility** (*medium certainty, high impact*)
   Skilled operational and managerial employees are expected to be in short supply particularly in the ageing economies of Europe and Japan, while talent pools continue to develop in developing economies. These labour market shifts may create an additional impetus for companies to look to regions such as Asia and South America for skilled workers.
4. **Consumer Expectations** (*low certainty, high impact*)
   Consumers are increasingly better informed about the products they consume, thanks largely to improved access to information. They are also willing and able to go anywhere for the best price, most convenience and desired functionality.
5. **Throw Away Culture** (*high certainty, medium impact*)
   It has been estimated that in the UK as many as 80% of new products are discarded after a single use and that 99% of the materials used in their production are discarded within the first six weeks. This is exacerbated by planned obsolescence in industrial design, which seeks to design a product with a limited useful life.

Asian Drivers of Change: Technological

The five drivers of change chosen within the Technological domain were:

1. **Increased Computational Power** (*high certainty, high impact*)
   Future developments in computational power will improve manufacturing systems and processes. Tangential to this is the improvement in digital infrastructure and software. Advances in Big Data and the Internet of Things will likely unlock opportunities to mine data for knowledge and insight.

2. **New Manufacturing Techniques** (*medium certainty, high impact*)
   New future technologies as well as emergent technologies such as rapid prototyping, additive printing that help provide a response to the question “how can we move particles/products resource-efficiently and as fast as possible?”

3. **Biotechnology** (*high certainty, high impact*)
   Biotechnology, or the use of living systems and organisms (or derivatives thereof) to develop or make products, will uncover new areas of scientific discovery in future. Engineers will start to manufacture things differently and much innovation can be expected, especially in areas such as material science and waste mitigation.

4. **New Materials** (*high certainty, medium impact*)
   Innovation creates additional demand and drives further productivity gains. One important area for future innovation is in the development of new materials such as carbon fibre components and nanotechnology, for example.

5. **Increased Automation** (*medium/high certainty, medium/low impact*)
   The cost of automation has fallen considerably in recent decades and has delivered substantial productivity gains. This also contributed to the fact that manufacturing employment in advanced economies fell by 19% in the 10 years to 2008. Automation in developing economies is looking attractive as wages continue to rise.

Asian Drivers of Change: Economic

The five drivers of change chosen within the Economic domain were as follows. Note that this sub-group was not able to reach consensus on a fifth driver in the final round of the exercise.

1. **Generation of Knowledge** (*high certainty, high impact*)
   A limited number of talented individuals will be in high demand in future decades. This driver relates to the education of the future workforce, and the training required to ensure that workers are adequately skilled.
2. **Rising Consumption** (medium/*high certainty, high impact*)
   Millions of newly affluent people are reshaping and resizing the global middle class, which is likely to expand from 2 billion to over 5 billion by 2050. Much of this growth will take place in urban centres. Markets will become increasingly stratified, to reflect different income levels.
3. **Business Model** (*medium certainty, medium impact*)
   New business models will be created in future, driven by new ways of conducting R&D and by innovative patterns of production and distribution. For example, as products and processes become more complex technically, manufacturers may collaborate with an ever wider network of partners, including competitors.
4. **Trade Blocs** (*low certainty, high impact*)
   There is considerable uncertainty around the future of the world's trade blocs. New patterns of economic integration may impact manufacturing, in terms of access to markets, regulation and Intellectual Property protection.
5. (nil)

Asian Drivers of Change: Environmental

The five drivers of change chosen within the Environmental domain were:

1. **Climate Change** (*high certainty, high impact*)
   This is a generic all-encompassing driver that covers anthropogenic climate change linked to fossil fuel use and deforestation. It also touches on carbon offsetting, carbon management (including carbon pricing), taxation (especially in aerospace) and carbon capture and storage.
2. **Waste Management + Recycling** (*high certainty, medium/high impact*)
   It is fairly certain that manufacturers will be required to minimise waste in future. Most waste management strategies prioritise waste reduction and prevention over reuse and recycling; while final disposal in landfill or by incineration is a last option.
3. **Resource Depletion** (*medium/high certainty, medium impact*)
   Growing competition for increasingly scarce resources will fundamentally alter many country and company strategies and will likely serve as a catalyst leading to significant material science breakthroughs. We may even start mining raw resources from asteroids in future (a company in the US, Planetary Resources Ltd, is seeking to do exactly this)!
4. **Sustainable Manufacturing** (*high certainty, medium/low impact*)
   As regulatory pressures to reduce ecological footprints and greenhouse gas emissions in manufacturing increase, companies will seek to further lessen environmental impacts, and improve energy productivity and carbon intensity. One way for manufacturers to reduce emissions is to change the mix of energy inputs to renewables, including by switching to hybrid or electric engines in manufacturing facilities. Other solutions include industrial symbiosis, where clusters of diverse entities share common services and resources.
5. **Tipping Points** (*low certainty, high impact*)
   Scientific observations indicate that historically the planet's climate has changed in abrupt steps rather than through smooth transitions. This evidence suggests that the current generation of climate models is unable to warn us about these ‘tipping points’ or positive feedback loops. Climate scientists suggest that there are as many as 15 tipping points in the biospheric system, any of which could potentially lead to run-away climate change.

Asian Drivers of Change: Political

The five drivers of change chosen within the Political domain were:

1. **Resource Conflicts** (*high certainty, high impact*)
   With the world population rising, global consumption rates soaring, energy supplies rapidly disappearing and climate change eradicating valuable farmland, the stage is being set for persistent and worldwide struggles over vital resources.
2. **Trade Blocs** (*high certainty, high impact*)
   Depending on the level of economic integration, trade blocs can fall into different categories such as preferential trading areas, free trade areas, customs unions, common markets and economic and monetary unions. While trade will always happen, the degree to which nation states trade choose to follow an export led strategy and/or protect certain sectors is uncertain.
3. **Producer Responsibility** (*high certainty, medium/high impact*)
   Extended producer responsibility laws, requiring companies to take back products at the end of their useful life, are likely to become more commonplace as resources are further constrained.
4. **Government Industrial Policy and Leadership** (*medium certainty, medium/high impact*)
   This driver relates to the degree to which a country promotes and/or protects domestic industry using mechanisms such as tax and R&D incentives, intellectual property protection and branding.
5. **Global Governance** (*low certainty, high impact*)
   Further regulatory pressure to combat climate change and reduce carbon emissions levels is likely. This will affect all manufacturing sectors but most especially steel, chemicals and refined energy products. Global consensus on this issue is uncertain. However, this is a potentially highly impactful driver.

Clustering and Implications

Cluster 1 "Oxymoron WALL.E"

This cluster examines green manufacturing, and asks the question: is the concept of sustainable manufacturing an oxymoron, given that manufacturing consumes resources?

Opportunities

1. **Short-term**: new products and services;
2. **Short-term**: potential for extracting maximum value from processes and products;
3. **Short-term**: meet consumer demand with minimum product complexity;
4. **Short-term**: new drivers and competitive advantages;
5. **Short-term**: technology leadership;
6. **Short-term**: holistic systems approach;
7. **Short-term**: industrial symbiosis;
8. **Short-term**: new partnerships and collaborations;
9. **Short-term**: new resources (e.g. recycled, additive, biological etc)
10. **Short-term**: maximise product performance through artificial intelligence;
11. **Short-term**: design for sustainability;
12. **Short-term**: international collaboration;
13. **Short-term**: recycling in the informal sector will shrink;
14. **Medium-term**: influence leadership behaviours;
15. **Medium-term**: business opportunities in the after-sales market;

Selected Drivers:

- **Consumer Expectations** (Soc)
- **Robotics and Automation** (Tech)
- **New Manufacturing Techniques** (Tech)
- **Waste Management and Recycling** (Env)
- **Sustainable Manufacturing** (Env)
- **Producer Responsibility** (Pol)

Short-term = 2020s
Medium-term = 2030s
Long-term = 2040s

Clustering and Implications

Cluster 1 "Oxymoron WALL.E" (cont'd)

16. **Medium-term**: biomimicry;
17. **Long-term**: taking an ethical and/or green lead;
18. **Long-term**: becoming employer of choice;
19. **Long-term**: Big Data of product lifecycle management makes money.

Risks and Challenges

1. **Short-term**: value proposition unclear hence capital for investment difficult to obtain;
2. **Short-term**: business model customised to local need lacks global appeal;
3. **Short-term**: adaptable and dynamic business models;
4. **Short-term**: government policy;
5. **Short-term**: cost, capacity and capability to recycle;
6. **Short-term**: technologies do not keep pace with evolving demands;
7. **Short-term**: variable approaches to meeting environmental obligations;
8. **Short-term**: rising trade blocs;
9. **Short-term**: very short product life-cycle making investment unviable;
10. **Short-term**: planned obsolescence;
11. **Short-term**: health warnings attached to more consumer goods and products;
12. **Medium-term**: variable global standards;
13. **Long-term**: trade barriers ("tit for tat");
14. **Long-term**: international conflict;
15. **Long-term**: technology fads and saturation.

"We cannot keep digging more and more materials from this Earth's limited resources. We may need to create and even grow materials in future."

Dr Hamid Mughal

Executive Vice President of Manufacturing Engineering & Technology, Rolls Royce

Clustering and Implications

Cluster 2 “Resource Breakthrough”

This cluster explores the challenges and opportunities arising from contemporary throw-away culture, resource depletion and shifting consumer behaviours and expectations.

Opportunities

1. **Short-term**: R&D;
2. **Short-term**: education in sustainability – consumer needs vs. wants;
3. **Short-term**: a better government-industry partnership to find solutions;
4. **Short-term**: change in consumer behaviour towards less consumption;
5. **Short-term**: improved waste management and recycling;
6. **Short-term**: investment in new manufacturing techniques;
7. **Short-term**: new models of collaborative consumption (e.g. car-sharing);
8. **Medium-term**: symbiotic industrial partners (“my waste is your resource”);
9. **Medium-term**: new business model for managing waste across industries;
10. **Medium-term**: new value chain in manufacturing to minimise waste;
11. **Medium-term**: new social norms;
12. **Long-term**: increased effort to find new clean energy sources;

Selected Drivers:

- **Consumer Expectations** (Soc)
- **New Manufacturing Techniques** (Tech)
- **Business Model** (Ec)
- **Resource Depletion** (Env)
- **Waste Management and Recycling** (Env)
- **Government Industrial Policy and Leadership** (Pol)

Clustering and Implications

Cluster 2 "Resource Breakthrough" (cont'd)

13. **Long-term**: environment-driven immigration provides access to new talent;
14. **Long-term**: new industries emerge around new energy sources;
15. **Long-term**: nodes of resource for decentralised production;
16. **Long-term**: new game-changing energy source discovered.

Risks and Challenges

1. **Short-term**: growth in throw-away culture;
2. **Short-term**: huge amount of waste;
3. **Short-term**: getting buy-in to fund R&D;
4. **Short-term**: resource depletion;
5. **Short-term**: increased taxation on resource consumption;
6. **Medium-term**: price volatility;
7. **Medium-term**: resource protectionism;
8. **Medium-term**: social unrest;
9. **Medium-term**: resource conflict;
10. **Long-term**: resource-based political power;
11. **Long-term**: industry having to keep up with consumer demand;
12. **Long-term**: can government regulations keep up with new business models?;
13. **Long-term**: environmental refugees.

"We have to think about sustainable manufacturing now to move forward."

Osamu Kobayashi

Director, Japan Science and Technology Agency, Singapore Office

Clustering and Implications

Clustering and Implications

Cluster 3 "Producers in Society"

This cluster uncovers the implications of the shift towards greater responsibility for producers in ensuring that their goods and products produce minimal waste.

Opportunities

1. **Short-term**: development of new materials (coming soon to Japan!);
2. **Short-term**: corporations providing public services;
3. **Short-term**: new concept of production;
4. **Short-term**: development for standards in Asia;
5. **Short-term**: linking corporate and public partnerships;
6. **Medium-term**: new business models towards personalised production;
7. **Medium-term**: increased small-scale production (e.g. in the home);
8. **Medium-term**: redundant labour moves into entrepreneurism;
9. **Medium-term**: new production processes lead to growth in new jobs;
10. **Medium-term**: people can communicate better with corporations;
11. **Long-term**: waste management industry.

Selected Drivers:

- **Decreasing Job Numbers** (Soc)
- **Business Model** (Ec)
- **Resource Depletion** (Env)
- **Producer Responsibility** (Pol)
- **Government Industrial Policy and Leadership** (Pol)

Clustering and Implications

Cluster 3 "Producers in Society" (cont'd)

Risks and Challenges

1. **Short-term**: high levels of pollution;
2. **Short-term**: damaged ecology;
3. **Short-term**: social unrest (inflation and joblessness);
4. **Short-term**: failure of government leadership (leads to corporate free-for-all);
5. **Short-term**: education and training;
6. **Short-term**: governments increasingly protectionist;
7. **Short-term**: regulating what gets produced in the home (e.g. weapons?);
8. **Medium-term**: business models stagnate in industrialised Asia;
9. **Medium-term**: poor enforcement of regulation e.g. waste or pollution;
10. **Medium-term**: disaffected consumers;
11. **Medium-term**: driving recycling over consumption of energy;
12. **Long-term**: pollution from the recycling process.

Clustering and Implications

Cluster 4 "Ageomics"

This cluster focuses on the ageing population, and looks at the ways in which technology can improve human performance in the elderly in a resource constrained future.

Opportunities

1. **Short-term**: home working "silver surfers"
2. **Short-term**: more workforce
3. **Short-term**: new industry/sector creation
4. **Medium-term**: "in-silico" design for new manufacturing (no waste);
5. **Medium-term**: computational power applied profoundly;
6. **Medium-term**: super computing and modelling;
7. **Medium-term**: mechanism for neurodegenerative disorders;
8. **Long-term**: DNA computing;
9. **Long-term**: robots for older people;
10. **Long-term**: understanding of the brain;
11. **Long-term**: human performance enhancement (biology + computer).

Risks and Challenges

1. **Short-term**: neuro-degenerative disorders;
2. **Short-term**: taking care of the elderly;
3. **Short-term**: waste and pollution control;

Selected Drivers:

- **Ageing Population** (Soc)
- **Increased Computational Power** (Tech)
- **Biotechnology** (Tech)
- **Rising Consumption** (Ec)
- **Waste Management and Recycling** (Env)
- **Resource Conflict** (Pol)

Clustering and Implications

Cluster 4 “Ageomics” (cont’d)

4. **Short-term**: understanding ageing (e.g. revealing protein structures);
5. **Medium-term**: physical and chemical enhancement;
6. **Long-term**: biological enhancement;
7. **Long-term**: biological age mitigation.

Actions for Business

R&D investment
- Invest in new manufacturing processes and the development of new products (e.g. automation, IT analytics, Big Data and the Internet of Things).
- Should start to invest in the future of manufacturing by paying attention to computational technology.
- Investment in R&D to provide best value over the life-cycle of the product.
- Companies in developing countries have the opportunity to leap-frog technology and devise new concepts for new factory design or new business models unencumbered by legacy infrastructure or technologies, for example.

Sustainable manufacturing
- Invest in ways to reduce waste and minimise resource usage.
- Educate consumers to participate in or otherwise support sustainable manufacturing (recycle, focus on needs vs. wants).
- Look into ways to turn waste into resource.
- Companies should consider sustainable manufacturing to decrease environmental pollution; and increase social responsibility.
- Businesses need to have an agenda that addresses resource depletion and catalyses action plans.
- Think about alternative directions to take in order to reduce exposure to resource risk.
- Private enterprise should make plans for sustainable manufacturing over a longer planning time horizon.

Training and skills
- Co-invest with government and academia to train personnel at all levels of competence.

Ageing population
- Private enterprise to take broader social responsibility with respect to the labour force and ageing population in partnership with governments.
- Invest and realise new business opportunities like sustainable manufacturing and “ageomics” (business models focussed on the elderly and their needs) – methodologies and enabling technologies will come after such decisions are taken.
- Survey the needs of elderly customers and invest in these areas.

Actions for Business (cont'd)

Resilience

- Build resilience into business models against external shocks.
- Firms need to develop forward-looking mechanisms to cope with uncertainty, facilitate adaptation and participate in the provision of systemic solutions.

Other

- The private sector should work more with stakeholders like the government, academia and the general public (e.g. through open innovation).
- Base the choice of manufacturing location decisions on customer interaction and "total business cost" and not on unit cost. What cost should be taken care of through advanced manufacturing technologies?

Actions for Academia

Industrial support
- Academia should increase interaction with industry to better understand in the true sense what industry's needs are and then decide on appropriate curricula for relevant courses.
- Rebalance the research agenda towards wealth creation and "less pure" academic research, and more applied research to support industry during the challenging years ahead.

Sustainability
- Improve their understanding of the needs/challenges in manufacturing and focus research on critical global socio-economic and environmental challenges.
- Research clean renewable energy solutions and clean technologies.
- Learn and apply lessons from nature in developing more sustainable forms of production (e.g. biomimicry).
- Develop a systems approach to waste management and use of resources (ie. what waste outputs can become resource inputs?). What is the best optimised system?
- Support R&D in material science to develop new functions to minimise waste.
- Academics should think about research into new materials with the view that these materials might help reduce waste and increase recycling.

Skills and training
- Train the student to be ready for the future, and to be agile and resilient in the manufacturing sector.

New pedagogy
- Establish open source models of knowledge sharing and new curricula.

Biotechnology
- Research into biotechnology (e.g. mechanism of ageing).
- Basic research into the field of information technology and biotechnology.
- Improve our understanding of the human brain (function and dysfunction) and possible application for this knowledge.
- Investment in life sciences and biotechnology to address ageing, waste and new materials (including biomaterials).

Actions for Academia (cont'd)

Other

- Conduct research into machine assistance for the elderly, to augment the workforce.
- Generate future visions of manufacturing (as many as possible in workshops like this one) and identify potential enabling technologies to help manifest each vision.
- Research 'meso-science' – the manipulation of meso-structures will be the common challenge for the future of manufacturing.

Actions for Government

Manufacturing
- Governments should initiate a national programme on the future of manufacturing.
- Consider how regulations and fiscal structures will change under new models of production and consumption (e.g. decentralisation of manufacturing through 3D printing and collaborative consumption).
- Provide incentives for manufacturing firms to actively engage in the development of solutions to critical grand challenges (e.g. the environment, unemployment etc) and use government mechanisms (e.g. education, R&D, infrastructure) to facilitate these tasks.
- Government should promote manufacturing to all age groups as a worthwhile and rewarding career aspiration.

Sustainability
- Government should facilitate and lead collaboration between business and academia, to identify and act upon steps towards sustainable manufacturing.
- Government can introduce more comprehensive and rounded policies on waste and environmental management.
- Introduce policy measures to increase environmental protection.
- Comprehensive industrial policies implemented to drive sustainable, innovative manufacturing.
- Encourage common understanding and consensus-making on issues like global sustainability and social equality.

R&D support and incentives
- Governments should establish policies which are of a global standard and which will enable companies to operate on a level playing field and compete globally, using incentives for boosting R&D and innovation.
- R&D investment money to be put into specific research areas (e.g. new materials and resources).
- Develop coherent medium and long-term policies that incentivise R&D and the application of sustainable manufacturing technologies.

Partnership and collaboration
- Promote the partnership between government, private enterprise and academia.

Actions for Government (cont'd)

- Government should give subsidies to encourage the private sector to undertake high risk/challenging research which may or may not lead to successful outcomes.
- Supervise and guide private sector investment.

Skills and training

- Governments should invest in human resource development (education, training etc) because if Schumpterian creative destruction leads to decline in industry and mass structural unemployment, then there will be a lot of social issues to address downstream.

Ageing population

- Create user-friendly IT infrastructure for the elderly.
- Revamp thinking about the elderly and reframe their age in terms of experience. Invite them back into the workplace to enhance the workforce and guide existing workers on processes. The aged can add value to existing processes.

Other

- Open up the space for policy experimentation, especially around uncertain and complex problem areas.
- Policy making about tax, investment and organise activities around technology foresight.

Asian Perspectives: Conclusion

Certain themes surfaced very strongly throughout the workshop. These are summarised as follows:

Resource depletion and sustainability: this meta theme clearly captured the most interest among participants. “Resource Depletion” (Environment), “Resource Conflicts” (Politics), “Rising Consumption” (Economic) and “Throw Away Culture” (Social) were all selected as impactful drivers of change. There was also much discussion about the solutions to such large pressures and challenges. Improved waste management was seen as a crucial response, in addition to focussed research into material science and biotechnology. Other opportunities in this area, as highlighted in the Resource Breakthrough cluster exercise, include better government-industry partnerships and the development of new models of collaborative consumption.

Trade blocs: it is interesting that “Trade Blocs” was chosen as both an Economic and Political driver. This reflects significant uncertainty around the shape of global trade in the years to come, future access to markets and the regulatory changes that may come into force. Government Industrial Policy and Leadership, chosen as one of the five Political drivers, suggests that there is considerable uncertainty as to whether Asian governments will steer a leadership course in terms of future policy.

Automation and increased computational power: this was another thread that connected much of the day’s discussion. “Increased Automation” was chosen as a technological driver, and it was agreed that manufacturing in Asia would likely see a decrease in job numbers on account of it. As the sector develops, more emphasis will be placed on specialist knowledge (“Generation of Knowledge” was selected as an Economic driver) and efforts to enable workforce mobility.

Ageing society: this also came out strongly. It was chosen as one of the five social drivers, and the cluster entitled “Ageomics” centred on the ways in which technology can enhance quality of life and performance in the elderly. It informed some of the actions for business and government.

It was interesting that “Natural Disasters” was not chosen in the end (it was de-selected in the third round), nor was the driver entitled “Environmental Refugees” (de-selected in the first round), given the environmental and extreme weather events that have occurred in Asia in recent years.

Asian Perspectives

The following 24 delegates attended the workshop at the British High Commission in Singapore:

Andrie Budiman, Vice President, Head of Operations Performance, Nestle Indonesia (Indonesia)
Junko Chapman, Fellow, Centre for Research and Development Strategy (Japan)
Dr Moonjung Choi, Director of Technology Foresight Division, Korea Institute of Technology Development (South Korea)
Eddie Choo, Strategist, Futures Group, Ministry of Trade and Industry (Singapore)
Cheryl Chung, Lead Strategist, Centre for Strategic Futures (CSF), Prime Minister's Office of Singapore (Singapore)
He Daxing, Deputy General Engineer of the Beijing machine tool research institute (China)
Francis Hiew, Managing Director, Spirit Aerosystems Malaysia Sdn Bhd (Malaysia)
Osamu Kobayashi, Director, Japan Science and Technology Agency, Singapore Office (Singapore)
Dr Melvyn Kuan, Head, Strategy and New Initiatives, National Research Foundation (Singapore)
Prof Lam Khin Yong, Chief of Staff, Nanyang Technology University and Co-Chair of the Advanced Remanufacturing and Technology Centre (Singapore)
Kwa Chin Lum, Head of the Centre for Strategic Futures (CSF), Prime Minister's Office of Singapore (Singapore)
Prof Li Jinghai, Vice President of Chinese Academy of Sciences (China)
Dr Lim Ser Yong, Executive Director, SIMTech, Agency for Science, Technology and Research (A*STAR) (Singapore)
Prof Low Teck Seng, Chief Executive Officer, National Research Foundation (Singapore)
Prof Chris Lowe, Director of the Institute of Biotechnology, University of Cambridge (UK)
Dr Hamid Mughal, Executive Vice President of Manufacturing Engineering & Technology, Rolls Royce (UK)
Dr Ng Hsiao Piau, Head (Programmes), National Research Foundation (Singapore)
Dr Byeongwon Park, Team Leader, Centre for Strategic Foresight, Science and Technology Policy Institute (STEPI) (South Korea)
Shyam Takale, Executive Vice President and Director Engineering, Bharat Forge Ltd (India)
Karen Tan, Deputy Director (Physical Sciences and Engineering Directorate), National Research Foundation (Singapore)
Prof Sandy Thomas, Head of Foresight, Government Office for Science (UK)
Prof Yasushi Umeda, Department of Mechanical Engineering, Graduate School of Engineering, Osaka University (Japan)
Dr Yuan Like, Associate Professor, Department of Foresight and Evaluation Research, Chinese Academy of Science and Technology for Development, Ministry of Science and Technology (China)
Soh Xiaoquing, Head, Technology and Capabilities, Future of Manufacturing Group, Economic Development Board (Singapore)

Asian Perspectives

Photo taken at the British High Commission, Singapore

International Perspectives: Conclusions

Conclusions

In conclusion, there are several areas of differences that are worth mentioning in comparing the three regional workshops. The European workshop expressed strong interest in **urban manufacturing, local supply-chains and supportive eco-systems**. As Professor Westkämper pointed out at the dinner, studies have found that regional networking generates 25% cost benefit for manufacturing. Other issues seen as important from the European perspective are **education and skills**, and the **circular economy**.

The workshop in Washington DC looked at the most diverse set of themes and drivers. They were perhaps unique in having most interest in **intellectual property** protection. Greater emphasis was also placed on **collaboration across business, academia and government** in re-energising American manufacturing. Innovation was a dominant theme, as well as **gender equality** and **quality infrastructure** (interestingly). Also worth noting is that **natural disasters** was chosen by the Americans as a priority driver, but not by the Asian delegation.

The Asian context is very different from that of the US and Europe. Asia has witnessed many years of sustained growth and with it a significant increase in quality of life and consumption. Their perspective is therefore markedly different. While sharing the recognition that sustainability is of fundamental importance to the future of manufacturing in Asia, the discussions pointed to a special interest in **governance and leadership** in the context of **resource depletion** and conflict mitigation. The Asian delegation also took a more focussed look at the impact of an **ageing population**, and at the damaging effects of **throw away consumer culture**. It is interesting to note that urbanisation wasn't a priority driver from the Asian perspective, yet it was for the Europeans and Americans.

In terms of commonalities, there were five areas of shared focal interest: **sustainability (with emphasis on resource efficiency)**, **education and skills**, **automation**, **big data** and **new models of distributed manufacturing** (the latter enabled by additive manufacturing techniques such as 3D printing, and emergent niche micro-manufacturing capabilities). These interests teased out some fascinating tensions. For instance, there's the tension between automation and jobs. **Unemployment**, triggered by increased **automation** was cited in all workshops as an area of concern. What skill sets will future manufacturers require? They may be radically different than current requirements. In future we may see more biologists, nano-technologists and neuro-scientists working along software developers and data analysts. Other tensions arise from the trend towards **distributive manufacturing** and **3D printing**, which will challenge manufacturers in relation to health and safety, quality control, ownership and IP protection.

Conclusions

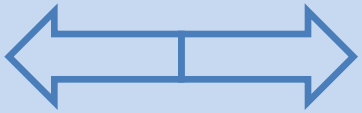
Three specific areas of systemic tension, all of which featured in all three workshop discussions, are illustrated here.

Sustainability

The transformation to a more sustainable model is an overarching challenge for all manufacturing sub-sectors, and it is an aspiration that wraps around three interesting points of systemic tension that surfaced in all three workshops:

Investment in automation

As automation costs come down and labour costs continue to rise, we are likely to see more automation in manufacturing. AI will scale-up and impact in the longer-term.

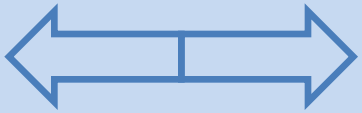


Investment in people

Factory workers are arguably more flexible than robots, in that they can easily be re-trained. Not all manufacturers will value this, as labour costs increase. Instead there will be a need for highly skilled employees.

Global supply-chains

Global supply-chains allow manufacturers to source best value for money, however there are risks inherent in managing extended, complex supply-chains.

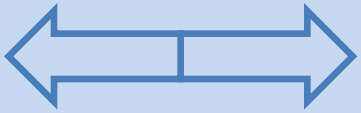


Local supply-chains

Localised supply-chains mitigate risks such as exposure to high transport costs or currency fluctuations. They are arguably more sustainable environmentally socially and economically. However, finding the right partners can be very challenging.

Distributed manufacturing

Micro-manufacturing, additive and home or community based manufacturing are clear trends. However, they pose significant challenges in terms of health and safety, quality control and IP as consumers become producers.



Traditional manufacturing

Traditional manufacturing, ie. non-distributive, does not expose manufacturers to these challenges. It may also be easier for manufacturers to implement industrial symbiosis.

Conclusions

As illustrated by the wealth of suggested actions for governments in all regions, there is a great deal that the public sector can do to support manufacturers in providing value. Here are some of the key action areas:

- Bring about agreement on global framework conditions to **regulate manufacturing** and **set sustainability standards** and targets;
- **Incentivise R&D spending** in specific areas such as technology, energy and material science;
- **Promote and facilitate innovation** (and enable open innovation), for example through the adoption of special innovation zones or provision of incentives
- **Intellectual property rights protection**.
- Promotion of **strategic partnerships** between the government, academia and industry (and within industry);
- Raise profile of **STEM subjects** from primary school through to tertiary education;

It was clear that businesses can do a great deal to enable a brighter future for manufacturing. Many of the actions from the workshops pointed to collaboration with academia in addressing skills shortages, including:

- Setting and communicating **the skills agenda** (Europe, US)
- Informing **curricula design** and in delivering teaching (US)
- Providing **apprenticeships** for young people (US)
- Supporting the continuous qualification and **skills development** of personnel (Europe, Asia)

“Unsurprisingly there was considerable discussion about **R&D investment** going forward. However, it is surprising that few business actions related specifically to collaborative R&D opportunities with academia. The onus, it seems, is on academic institutions to reach out to industry more (see highlights in blue on pages 32, 59 and 88).”

There was strong consensus that academia can support manufacturers most by researching subject areas including into **clean energy**, **resource efficiency**, **material science innovation** and **technological advancement** (including in the area of biotechnology and nanotechnology).

Appendix

Drivers of Change Cards

Here is a list of the pre-selected drivers of change that were given to delegates to work with in each workshop. All three workshops used this same list of drivers as a starting point for their discussion with regards to prioritising drivers under each STEEP category.

The research that went in to identifying and defining each pre-selected driver was carried out by Arup in collaboration with the Government Office for Science. Arup undertook desk research and mined their own horizon scanning database of trends and issues. They also analysed a wide number of reports, including the Government Office for Science's Certainties and Uncertainties report following a workshop with Lead Expert Group members in December 2012.

Social	Technological	Economic
Population Distribution	Biomimetics	Circular Economy
Ageing Society	Decarbonisation	Collaboration and Coopetition
Energy Demand	Techno-reliance	Onshoring vs Offshoring
Urbanization	Physical Infrastructure	Commodity Prices
Skills Shortages	Deindustrialisation	Trade Unions
Collaborative Consumption	Research and Development	China Trade
Public Perception	Big Data	Shipping
Consumer Expectations	Internet of Things	Brand Value
Workforce Mobility	New Materials	Access to Finance
Gender Equality	Robotics	Cheap Labour
DIY Consumers	Rapid Prototyping	Mitigation vs Adaptation
Throw Away Culture	Mass Customisation	Currency Fluctuations
Open Innovation	Increased Automation	New Markets
Social Media	Artificial Intelligence	Manu-services
User-centricity	Digital Infrastructure	Hidden Costs

Drivers of Change Cards

Environmental

Consumption Localization
Ecological Footprint
Resource Depletion
Tipping Points
Natural Disasters
Long Term Persistence
Environmental Refugees
Ecosystem Services
Motorisation
CO2 Storage
Diversity
Green Manufacturing
Heat Islands
Deforestation
Polluted Waters

Political

Resource Conflicts
Trade Blocs
Producer responsibility
Asianization
Corruption
Global Governance
Sovereign Wealth
Intellectual Property Protection
Terrorism
Taxation
Foreign Direct Investment
Waste Minimisation
Public Opinion
Nanohazards
Peak Oil

For further details on the Drivers of Change cards that were presented to workshop participants, please contact Marcus Morrell at marcus.morrell@arup.com.

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