FUTURE JOBS

IRELAND 2019

Preparing Now for Tomorrow's Economy

Ireland's Industry 4.0 Strategy 2020-2025

Supporting the digital transformation of the manufacturing sector and its supply chain

Minister's Foreword

This Industry 4.0 Strategy is a key output of Future Jobs Ireland, the Government's new economic pathway to ensure that Ireland is well placed to prosper in a rapidly changing global economy.

Manufacturing is a central pillar of our economy employing over 227,000 people with 85% of that employment outside Dublin. Ireland has successfully established a global reputation in manufacturing sectors such as Pharmaceuticals and Chemicals, Food and Drink, Medical Devices, Computers and Electronics, and Engineering. However, the emergence of a new wave of advanced ICT technologies is spurring a radical transformation across the sector. Such is the scale of this transformation that it is often referred to as the fourth industrial revolution or Industry 4.0.

Firm adoption of Industry 4.0 will be critical to maintaining a competitive manufacturing base into the future which will drive national productivity gains and underpin sustainability of high-quality jobs and export-led economic growth. However, firms of all sizes will face challenges in developing and adopting Industry 4.0 strategies. In 2019, Future Jobs Ireland acknowledged these challenges and signalled Ireland's ambition, not just to respond, but to embrace the opportunities offered.

The Industry 4.0 Strategy builds on Ireland's industrial capabilities built over the decades, including a thriving community of indigenous supply chain SMEs and the presence of world-leading software and ICT industries.

As the technologies driving the Fourth Industrial Revolution are developing so rapidly, research and development (R&D) will play a key role in ensuring that Ireland is at the forefront of Industry 4.0. To ensure that Ireland stays ahead of the curve, we have already invested in a number of research centres, including the SFI funded research centres CONFIRM and I-Form and the Irish Manufacturing Research Centre funded by Enterprise Ireland and IDA Ireland.

To ensure coherence across these centres my Department is establishing a new coordination mechanism Future Manufacturing Ireland as part of this strategy. The role of FMI will be to ensure the publicly funded centres develop the full breadth of capability required to support companies in this time of rapid and complex change and to make it easier for companies to access the expertise that they need.

One of Ireland's advantages in the Industry 4.0 transition is the depth of world class manufacturing and ICT expertise located here. Government programmes that support clusters, such as the Disruptive Technologies Innovation Fund funded under Project Ireland 2040, will bring this expertise together to develop innovative solutions and new business opportunities, as well as ensuring the widespread adoption of new technologies.

A key policy concern is the effect that digitalisation will have on employment. It is expected to reshape the skills that will be required from the workforce of the future. The Government will ensure that the education and training system responds to those changing skills needs. The Industry 4.0 Strategy will also support Ireland's Climate Action Plan as digital technologies can lead to more efficient and flexible production processes with increased resource efficiency in terms of both energy and materials.

Through this Strategy, the Government is responding to the scale of the transformation presented by digital technologies with an ambitious plan that will help ensure that by 2025 Ireland will be at the frontier of the fourth industrial revolution and at the forefront of Industry 4.0 adoption.

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Minister for Business Enterprise and Innovation
December 2019

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Executive Summary

The vision underpinning this strategy is that by 2025 Ireland will be a competitive, innovation-driven manufacturing hub at the frontier of the fourth industrial revolution and at the forefront of Industry 4.0 development and adoption.

Future Jobs Ireland 2019 acknowledges the impact that advanced digital technologies, such as artificial intelligence, robotics and big data and analytics will have on Ireland's economy and manufacturing base. With its focus on the quality and sustainability of jobs and the productivity of the enterprise base, Future Jobs Ireland signals Ireland's ambition, not just to respond to the challenges, but to embrace the opportunities presented by these new technologies.

New digital technologies have already begun to transform global manufacturing value chains, supply chains and business models, redefining sources of competitive advantage for both firms and national economies. Digitalisation of manufacturing refers to the use of digital technologies, data and applications to deliver advancements in manufacturing-related operations (including the broader value chain of manufacturing activities) and to enhance the performance of manufactured products (and related services) in both established and emerging sectors. The family of technologies underpinning digitalisation includes: cloud computing; advanced sensors; high-performance computing; advanced automated and autonomous systems; robotics; artificial intelligence; machine learning; augmented/virtual reality; blockchain; big data; and digital fabrication (including 3D printing), among others. The boundaries of manufacturing therefore are being reconfigured as digital capabilities and firms that were traditionally outside of manufacturing, become part of emerging value networks.

Ireland has a strong manufacturing base employing 227,000 people in key sectors such as Pharmaceuticals and Chemicals, Food and Drink, Medical Devices, Computers and Electronics, and Engineering in 2018 [1]. Industry 4.0 therefore presents both opportunities and challenges for enterprise policy in areas such as employment, productivity, competitiveness, and sustainability. There will be new cross-cutting opportunities for manufacturing firms arising from Industry 4.0 product and service innovation including enhanced business models (through the provision of a range of data services to customers) and the development of more functional products. These underpinning capabilities can potentially strengthen the competitiveness of Ireland's manufacturing base.

Process innovation built on digital technologies can also lead to more efficient and flexible production processes with increased resource efficiency (both energy and materials). Industry 4.0 adoption will therefore contribute to the climate action agenda as set out in Ireland's Climate Action Plan 2019.

A key policy concern however is the effect that digitalisation will have on employment. It is expected to reshape the skills that will be required from the workers of the future, driving significant disruptions in the labour market. In Ireland it is projected that overall there will be growth in manufacturing employment over the next five years, but only under the assumption that manufacturing in Ireland remains internationally competitive. Industry 4.0 capability will be a critical driver of that competitiveness, underpinning productivity growth and innovation in new goods and services across the value chain.

International benchmarking exercises have signaled Ireland as a leading country in terms of readiness for the future of production. A number of key features have been identified in the Irish enterprise base that could help position Ireland as a leader in Industry 4.0 if appropriately leveraged, including our existing industrial capabilities, the presence of world leading software and ICT industries and the relative proximity of firms which facilitates collaboration.

However, firms of all sizes face challenges in developing and implementing Industry 4.0 strategies including: investing in RD&I and access to demonstrators; challenges around technology adoption including the availability of technology roadmaps and expertise, interoperability and standards and identifying common opportunities and new value chain partners; and finally challenges internally around deployment including firm capability, skills gaps and technology implementation and integration costs.

While the Industry 4.0 transformation will be led by firms, the presence of enabling conditions that facilitate the development of new technologies, as well as their diffusion and absorption, will play a key role in the digital transformation. This strategy therefore sets out a clear vision and goals for Industry 4.0 in Ireland and the strategic actions that will help to achieve those.

A Vision for Industry 4.0 in Ireland

The vision underpinning this strategy is that by 2025 Ireland will be a competitive, innovation-driven manufacturing hub at the frontier of the fourth industrial revolution and at the forefront of Industry 4.0 development and adoption.

Manufacturing firms, and their supply chains, will be employing Industry 4.0 technologies to support productivity, international growth and sustainable employment. Firms will be exploiting opportunities offered by Industry 4.0 technologies by:

- adapting their methods of manufacture to improve productivity and enable enhanced customisation and made to order products;
- competing in new markets based on innovations in goods and services;
- developing new business models;
- better integrating supply chains;
- building competitive advantage through the development, adoption and strategic use of relevant standards.

Ireland will excel at providing the opportunities to develop skills and capabilities of the current and future workforce required for Industry 4.0.

Ireland will be globally recognised for the development and deployment of new Industry 4.0 technologies building on our strengths in RD&I.

A strong collaborative culture will be a key driver of Industry 4.0 in Ireland, and will support the digital transformation across sectors, value chains and supply chains, and will position firms in Ireland at the global forefront of the Industry 4.0 transformation.

The Industry 4.0 ecosystem will be underpinned by a strong and balanced policy, legal and regulatory framework.

Goals of Ireland's Industry 4.0 Strategy

1. To stimulate firms to adopt and build capability in Industry 4.0 technologies.

2. To stimulate firms to harness the new opportunities enabled by Industry 4.0 technologies.

3. To become a global leader in RD&I which underpins Industry 4.0.

4. To facilitate the current and future workforce to develop the skills to deliver the Industry 4.0 transformation and exploit the new opportunities arising in manufacturing and supply chain firms through Industry 4.0 technologies.

5. To establish a world class business environment for Industry 4.0 which is underpinned by an appropriate regulatory, legal, standards, and internationally connected ecosystem.

Strategic Actions

The strategy has been structured around six themes:

1. Future Manufacturing Ireland

2. Awareness and Understanding of Concepts

3. Exploring and Planning

4. Implementation of Firm Level Industry 4.0 Strategies

5. Framework Conditions

6. Implementation of Ireland's National Industry 4.0 Strategy

Theme 1: Future Manufacturing Ireland

To achieve Ireland's goal of becoming a global leader in RD&I underpinning Industry 4.0, the Department of Business, Enterprise and Innovation (DBEI) will establish a new coordination mechanism - 'Future Manufacturing Ireland'. The role of Future Manufacturing Ireland will be to develop the breadth of capability required across publicly funded research centres in a coherent and coordinated manner and to ensure that this capability is promoted to firms of all sizes. This new coordination mechanism will ensure maximum alignment of activities across the system, avoiding unnecessary duplication and fragmentation of effort.

Theme 1: Future Manufacturing Ireland	Strategic Actions	Responsibility
Strategic Action 1	Establish a new coordination mechanism, Future Manufacturing Ireland, to ensure coherence and optimal delivery of RD&I supports across centres with a dedicated focus on advanced manufacturing/Industry 4.0.	• DBEI, EI, IDA, SFI

Theme 2: Awareness and Understanding of Concepts

These actions aim to help firms develop awareness of the opportunities and challenges arising from Industry 4.0, and the supports and expertise that are available to support firms.

Theme 2: Awareness and Understanding of Concepts	Strategic Actions	Responsibility
Strategic Action 2	Raise awareness and understanding amongst manufacturing firms and their supply chains of the concept of Industry 4.0 and the potential business benefits and opportunities to be derived from engaging in Industry 4.0 activities.	• EI, IDA, SFI, NSAI, LEOs
Strategic Action 3	Support the activation of enterprise-led Industry 4.0 clusters including through the use of the Regional Innovation and Technology Clusters Fund.	• EI, IDA, SFI, NSAI
Strategic Action 4	Provide clear communication and guidance to firms at all stages of their Industry 4.0 journey, mapping where current digital capability and technical expertise may be found, and signposting public supports available for supporting the Industry 4.0 transformation.	• EI, IDA, SFI, NSAI, LEOs

Theme 3: Exploring and Planning

The actions aim to support firms to undertake 'hands-on' exploratory work on Industry 4.0 technologies and systems, and to help firms to develop their own Industry 4.0 roadmaps and strategies for implementation.

Theme 3: Exploring and Planning	Strategic Actions	Responsibility
Strategic Action 5	Provide access to firms to Industry 4.0 demonstrators to allow them to experiment with individual Industry 4.0 platform technologies and the integration of Industry 4.0 digital technologies in configurations simulating those in manufacturing and supply chain firms.	• EI, IDA
Strategic Action 6	Provide support to firms to develop Industry 4.0 pilots in-house that would also act as exemplars to other firms.	• EI, IDA
Strategic Action 7	Provide access to external expertise to support firms: • to evaluate the value capture opportunities, implementation challenges and financial costs and estimate the potential return on investment of Industry 4.0 technology adoption. • to develop firm-level Industry 4.0 related roadmaps, including: technology; standards adoption; skills; regulation; and investment roadmaps.	• EI, IDA

Theme 4: Implementation of firm-level Industry 4.0 Strategies

The actions are aimed at providing supports to firms that want to invest in Industry 4.0 capabilities and strategies and focus on: access to finance; skills development; and support for the development of Industry 4.0 consortia.

Theme 4: Implementation of firm-level Industry 4.0 Strategies	Strategic Actions	Responsibility
Financial Support for Implementation		
Strategic Action 8	Utilise existing State programmes to support firms to invest in implementation of Industry 4.0, including: • Direct to firm RD&I grant support through the agencies. • The Future Growth Loan Scheme.	• EI, IDA • Strategic Banking Corporation of Ireland (SBCI), DBEI, DAFM
Strategic Action 9	Develop options for the establishment of an accelerated capital allowance scheme to incentivise firm investment in Industry 4.0 capital.	• DBEI
Skills Development		
Strategic Action 10	Support the development of strategic leadership and management skills in Industry 4.0.	• EI, IDA, LEOs, DES, NSAI
Strategic Action 11	Provide direct supports to firms to upskill their existing employees in adopting Industry 4.0 technologies, systems and standards.	• EI, IDA
Strategic Action 12	The Regional Skills Fora will be available to facilitate engagement between enterprise and the Education and Training system to respond to identified needs.	• DES
Strategic Action 13	Utilise the expertise and supports in the public RD&I system to upskill firm employees in Industry 4.0.	• SFI, DES, IDA
Strategic Action 14	Assess the skill requirements for Industry 4.0 and signpost to appropriate provision.	• DES, DBEI, SFI
Firm Consortia for Implementation		
Strategic Action 15	Provide industry-led-consortia with opportunities to compete for funding focused on deployment of Industry 4.0 technologies through for example the Disruptive Technology Innovation Fund and Regional Enterprise Development Fund.	• EI, DBEI

Theme 5: Framework Conditions for Industry 4.0

Framework conditions are a critical part of the business environment for Industry 4.0, supporting established firms and start-ups and attracting new Industry 4.0 investment to Ireland. Given the pervasiveness of the digital transformation across our economy and society there are a broad range of framework conditions that need to be in place to support an inclusive and sustainable transition. These include, for example, connectivity, trust and security, data privacy and digital literacy.

These framework conditions will be addressed in the Government's forthcoming National Digital Strategy. This strategy addresses those framework conditions where we have identified specific Industry 4.0 measures. Two of the most important framework conditions relate to 'RD&I' and 'skills' and these are addressed under Themes 1 and 4 respectively. The other conditions concern standards and international connectedness.

Theme 5: Framework Conditions	Strategic Actions	Responsibility
Standards Development		
Strategic Action 16	Provide support for SMEs and publicly funded researchers through existing funding allocations to engage at international Industry 4.0 standards fora.	• EI, NSAI, SFI, LEOs
International Connectedness		
Strategic Action 17	Develop a plan for Ireland to engage more strategically in international activities and RD&I collaborative initiatives around Industry 4.0, so as to add to our capabilities, increase our profile in Industry 4.0, and shape the future agenda and opportunities arising.	• DBEI, FMI and relevant agencies

Theme 6: Implementation of Ireland's Industry 4.0 Strategy

This action sets out how the implementation of the strategy will be monitored and overseen.

Theme 6: Implementation of National Industry 4.0 Strategy	Strategic Actions	Responsibility
Strategic Action 18	Establish an Industry 4.0 Stakeholder Forum to oversee implementation of the Strategy and report on an annual basis to the Minister for Business Enterprise and Innovation.	DBEI with relevant Government Departments, agencies and external stakeholders.

1. Introduction

1.1 Enterprise Policy Context

Internationally it is recognised that the diffusion of an advanced wave of ICT technologies will transform the global industrial base. These new digital technologies have already begun to transform global manufacturing value chains, supply chains and business models, redefining sources of competitive advantage for both firms and national economies. For Ireland, with its strong manufacturing base, this presents both opportunities and challenges in key policy areas such as employment, productivity, competitiveness and sustainability. 'Ireland's Industry 4.0 Strategy' sets out a vision to position Ireland at the forefront of this fourth industrial revolution thereby helping us to sustain our competitive manufacturing base and achieve our broader economic and enterprise goals.

Emerging from a severe recession, Ireland has experienced 6 years of economic growth and is now approaching full employment. The manufacturing sector has been a strong contributor to national growth, accounting for approximately 11.6% of Ireland's increase in employment between 2012 and 2018. Furthermore, exports of goods by companies in the manufacturing sector and supported through our development agencies were 19% greater in 2018 than in 2012 [1]. However, in their 2018 Economic Survey of Ireland, the OECD highlighted that reviving productivity will be crucial to ensure Ireland's future economic dynamism and to maintain high living standards. In addition, they highlighted the need to shift our focus from job numbers to the quality and sustainability of jobs.

Ireland has recognised the need for this change in policy direction and the Government's 'Enterprise 2025 Renewed' sets out a strategy for Ireland to realise the vision of becoming the best place to succeed in business, delivering sustainable employment and higher living standards [2]. The strategy is aimed at continued targeting of export-led growth, underpinned by innovation and talent, to deliver increased competitiveness and productivity. It also aims to deepen our resilience so that we can anticipate and respond to external shocks such as those associated with Brexit as well as developments in international trade and taxation.

Building on this, Future Jobs Ireland 2019 signals Ireland's intent to place a priority on quality and sustainability of jobs and raising productivity levels across the economy, particularly in the small and medium enterprise (SME) sector [3]. Implementation of these actions will be bolstered through investments outlined in priority 5 of the Project Ireland 2040 National Development Plan [4]. Both Enterprise 2025 Renewed and Future Jobs Ireland 2019 highlight that digital technologies are becoming increasingly disruptive and pervasive.

Indeed, digitalisation of enterprise is increasingly recognised as a significant opportunity for driving productivity and growth in economies internationally. The EU for example has placed digitalisation of industry as a key component as it develops a long-term vision for the EU's industrial future: it recognises digital transformation is at the core of the next industrial revolution and that boosting the uptake of digital technologies along and across industrial value chains and promoting firm growth is key to Europe's growth and competitiveness [5].

The EU have also established a 'Digitalisation of European Industry' (DEI) initiative [6]. The aim is to reinforce the EU's competitiveness in digital technologies and ensure that industry can fully benefit from digital innovations. The EU is now proposing to direct funds towards delivery of these digital ambitions and as part of the next long-term EU budget (MFF 2021-2027) through a number of initiatives:

- €15 bn for the cluster of policy challenges associated with 'digital and industrial' within the Horizon Europe Programme[1];
- The Digital Europe Programme[2], which would be a new €9.1 billion funding programme with the main objective being to boost Europe's digital transformation to the benefit of citizens and businesses; and
- A European Social Fund+ which will include support for upskilling and reskilling of the workforce to be ready for new digital and automation challenges.

In response to these developments, Government is developing a new 'National Digital Strategy' to progress and grasp the opportunities offered by digitalisation and respond to its challenges to maximise the well-being of our citizens as well as the productivity, competitiveness and sustainability of our economy. The strategy will cover a broad range of societal and economic areas including, infrastructure and security; data, privacy and regulation; education and skills; trust, wellbeing and inclusion; digital public services; innovation; the digital economy; and labour market changes.

Given the importance of the manufacturing sector and it's supply chain to Ireland's economy, and the likely disruption caused by new digital technologies, it is important that Ireland sets out its ambition to support firms to adopt digital technologies and its commitment to develop a globally competitive business environment for Industry 4.0.

1.2 Importance of Manufacturing to Ireland

There were 16,700 firms in the manufacturing sector in Ireland in 2017, with Irish-owned companies representing about 97% of this cohort [7]. SMEs account for a significant proportion of firms in the key sub-sectors of manufacturing and which are: Pharmaceuticals and Chemicals, Food and Drink, Medical Devices, Computers and Electronics, and Engineering. However, these key sub-sectors show different concentrations of large firms.

In 2018, Ireland's manufacturing sector was directly responsible for 227,052 jobs [8], with an estimated 182,000 additional jobs indirectly attributed to the manufacturing sector[3]. At 35%, Ireland reported the largest share of total Gross Value Added attributed to manufacturing amongst EU countries in 2017 (this compares with a Euro area – 19 countries - average of 17% recorded in this year) [9].
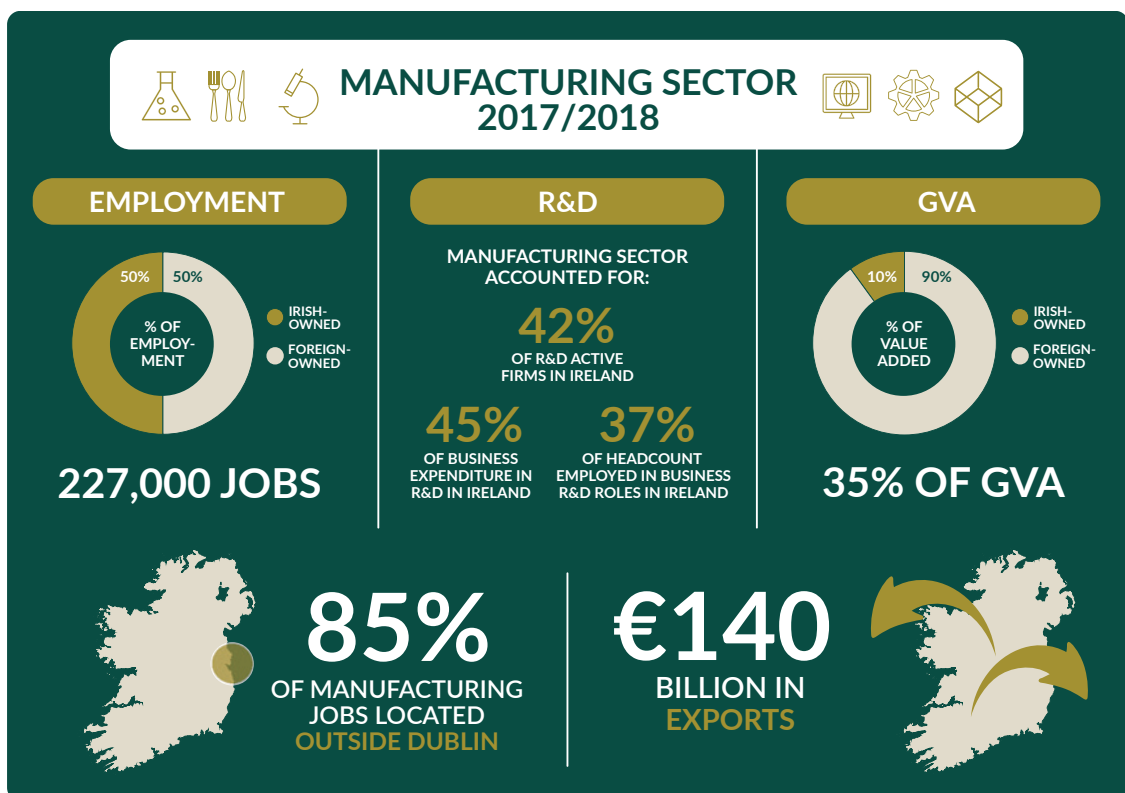

MANUFACTURING SECTOR 2017/2018

EMPLOYMENT

50% 50%
% OF EMPLOY-MENT
● IRISH-OWNED
● FOREIGN-OWNED

227,000 JOBS

R&D

MANUFACTURING SECTOR ACCOUNTED FOR:

42% OF R&D ACTIVE FIRMS IN IRELAND

45% OF BUSINESS EXPENDITURE IN R&D IN IRELAND

37% OF HEADCOUNT EMPLOYED IN BUSINESS R&D ROLES IN IRELAND

GVA

10% 90%
% OF VALUE ADDED
● IRISH-OWNED
● FOREIGN-OWNED

35% OF GVA

85% OF MANUFACTURING JOBS LOCATED OUTSIDE DUBLIN

€140 BILLION IN EXPORTS

Figure 1 Infographic illustrating the importance of the Manufacturing Sector to Ireland's economy in 2017/2018.

1. *Horizon Europe is the next EU Framework Programme for Research and Innovation.*
2. *The Digital Europe Programme, is a proposed new funding programme and is part of the "Single Market, Innovation and Digital" chapter of the EU's long-term budget proposal. It builds on the Digital Single Market strategy launched by the Commission in May 2015.*
3. *Wider economic impacts were estimated based on Type I and Type II multipliers for employment. Employment Multiplier of 1.8 for manufacturing exports from Indecon Study for DBEI in 2015 'Assessment of the Economic Impact of Exports on the Irish Economy".*

While foreign-owned firms account for nearly 90% of Value Added contributed by the manufacturing sector, Irish-owned firms accounted for 50% of direct employment in this sector in 2018, thus demonstrating the importance of both cohorts of firms to the economy [10].

As a small economy, with a limited domestic market, a high export orientation is one of the characteristics of the manufacturing sector. Exported goods from Ireland in 2018 were recorded at €140 bn [11]. Furthermore, there are many Irish-owned firms that are part of the supply chains of exporting manufacturing firms based in Ireland and therefore can be considered export enabling firms.

In 2017, 42% of R&D active firms in Ireland were in the manufacturing sector and these firms accounted for 45% of business expenditure on R&D in Ireland and 37% of head count staff employed in business R&D roles in Ireland [12].

It is clear from this data that the competitiveness of the manufacturing sector and its supply chain will be vital to the continued success of the Irish economy.

1.3 Industry 4.0

There is a paradigm shift occurring globally in the activities of manufacturing firms and their supply chains. This shift is underpinned by the adoption of a suite of advanced information communication technologies (ICT) which include: cloud computing; Internet of Things (IoT); high-performance computing; machine learning; big data and analytics; robotics; and digital fabrication.

The term 'Industry 4.0' has become internationally recognised as referring to the convergence of these technologies to enable the ubiquitous digital connection of machines, workpieces and IT systems within firms as well as stretching across value and supply chains. Critically the gathering and analysis of data from across these elements enables machine-based decision making.

Figure 2 highlights the underpinning technology associated with each of the three industrial revolutions to date as well as the predicted fourth industrial revolution underpinned by Industry 4.0 technologies. The figure emphasises the point that the fourth revolution will be based on disruptive change which will include, and go beyond, advances at the factory site. Industry 4.0 will impact on productivity through increased automation; more intelligent control of planning, logistics, maintenance and purchasing; optimised supply chains; improved traceability; and new delivery platforms.

New cross-cutting opportunities for manufacturing firms will arise from Industry 4.0 product and service innovation including new business models (through the provision of a range of data services to customers) and the development of more functional products (by embedding digital functionalities such as GPS and connectivity to the Internet of Things). These underpinning capabilities will also strengthen the competitiveness of Ireland's manufacturing base.
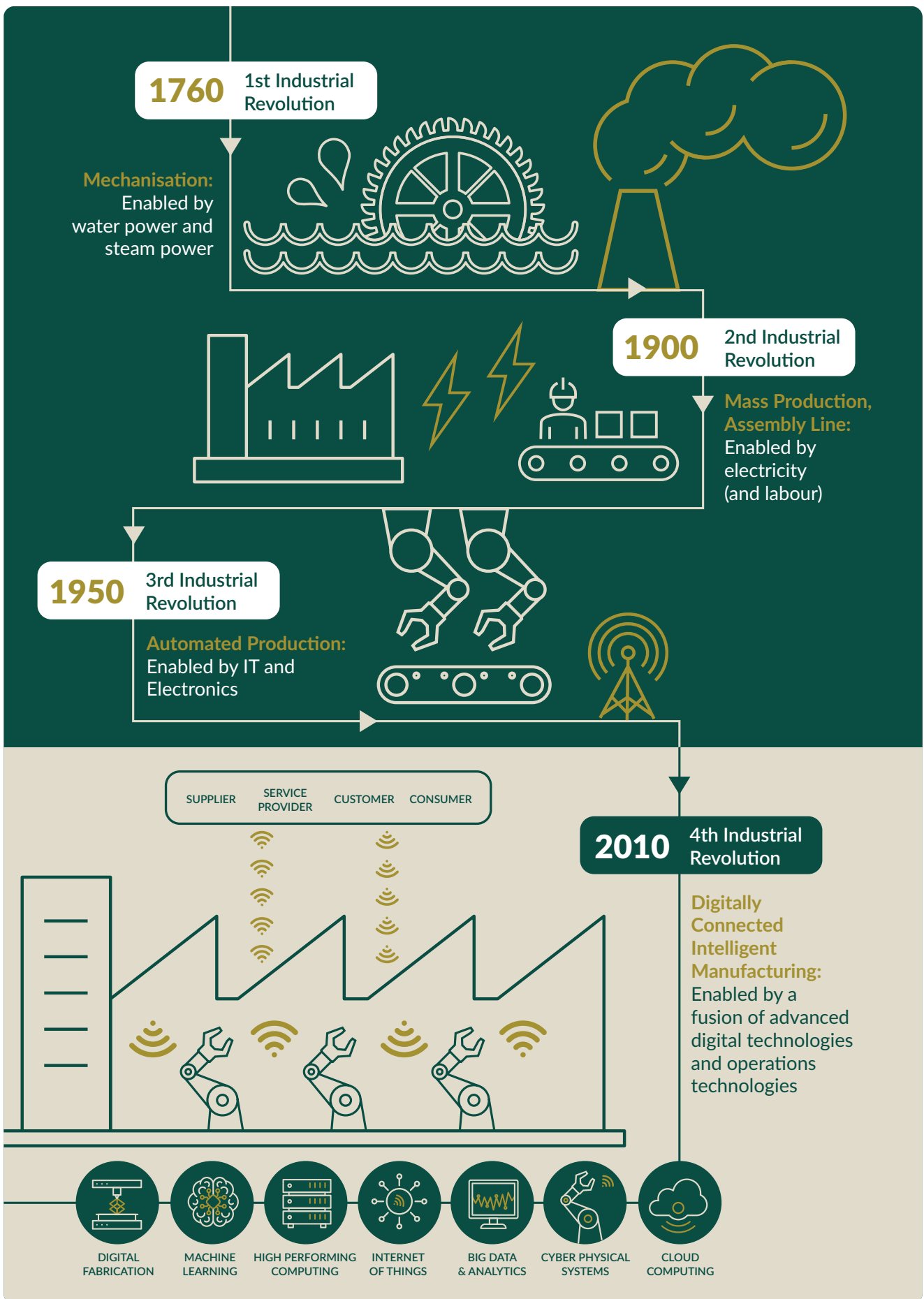
1760 1st Industrial Revolution

Mechanisation: Enabled by water power and steam power

1900 2nd Industrial Revolution

Mass Production, Assembly Line: Enabled by electricity (and labour)

1950 3rd Industrial Revolution

Automated Production: Enabled by IT and Electronics

SUPPLIER SERVICE PROVIDER CUSTOMER CONSUMER

2010 4th Industrial Revolution

Digitally Connected Intelligent Manufacturing: Enabled by a fusion of advanced digital technologies and operations technologies

DIGITAL FABRICATION MACHINE LEARNING HIGH PERFORMING COMPUTING INTERNET OF THINGS BIG DATA & ANALYTICS CYBER PHYSICAL SYSTEMS CLOUD COMPUTING

Figure 2 Illustration of the technology advances underpinning Industrial Revolutions to date, and the predicted 4th industrial revolution.

Impact of Industry 4.0

Increased Productivity

From a firm perspective, the adoption of Industry 4.0 technologies can drive productivity gains in manufacturing through for example:

- increasingly autonomous automation of the production process through cyber physical production systems (CPPS)*, in which the connection of hardware and software systems enables the implementation of data driven manufacturing activities. Such systems can use streams of data to learn and adapt to new demands which leads to more efficient and agile systems.
- simulation and modelling which supports increasingly intelligent control across elements of a firm including, maintenance, planning, purchasing and logistics. In high volume production facilities for example, such as in the pharmaceutical and chemical, and computer & electronics sectors, the ability to predict when equipment is likely to fail will realise significant savings in down time, and thus drive up productivity.
- enabling generation, collection, transmission, storage and complex analysis of huge volumes of data which supports intelligence-based decision making in areas such as R&D and design.

Furthermore, the Industry 4.0 phenomena encompasses a sophisticated digital relationship between manufacturing firms and their supply chain, partners and customers allowing for real time information and feedback, thus supporting for example:

- optimised supply chain operations and enhanced inventory management through digital integration of cross-firm operations, which will have significant importance for example in sectors such as the food and drink sector where raw materials may have limited shelf life and in sectors with high value individual parts such as the medical device sector.
- improved traceability of raw materials/supplies which will support for example accelerated regulatory compliance in sectors where this is important such as the medical devices, food and drink, and pharmaceutical and chemical sectors through translation into opportunities for accelerated regulatory compliance processes.
- more efficient goods and service delivery through use of digital business platforms** (leading to a reduction in the number of intermediaries involved).

*   *Cyber physical systems (CPPS) are based on embedding ICT systems in physical objects and interconnecting them.*

** *A digital business platform is an adaptable technology layer that fits into a firm's IT landscape to connect software, apps, devices and people.*

New Business Opportunities

There is also a variety of new business opportunities for firms arising from adoption of Industry 4.0 technologies which include for example:

- new business for manufacturing firms based on the ability for customisation and made to order products. As manufacturing firms will need to procure a more diverse range of material and parts in accordance with their customer orders, it may be preferable to have suppliers located nearby to minimise delivery times. Thus, the uptake of more customised production by manufacturing firms may also embed the local supply chains as well as open-up opportunity for the introduction of supply firms not currently located locally.
- Increased customization is leading to changing market expectations. New business services models are emerging based on embedding digital functionalities in physical products and wrapping data-based services around these products to support the development of entirely new markets. Understanding the 'user experience' and 'user environment', through the real time data achievable via Industry 4.0 will therefore be increasingly important for manufacturing in Ireland to realise the opportunities of product/service convergence. A product built with 'smart' parts can alert both the manufacturer and customer if maintenance is required, supporting a preventative measures approach. These type of business models will have particular relevance to the engineering, medical device and electronic and computers sectors and such diversification of business activities will open-up opportunities for firms, even if high volume production activities are located elsewhere.

1.4 Rationale for an Industry 4.0 Strategy

From a macroeconomic perspective, Industry 4.0 offers the potential for significant economic growth, with the EC estimating that digitalisation of manufacturing could add €110 billion per year to Europe's industry base [6]. It is also recognised that Industry 4.0 adoption will drive significant disruptions in the labour market, though estimations of the impact on global jobs vary widely from large net job losses to net job gains [16], [17].

For Ireland, it is estimated that despite the displacement of jobs through adoption of digital technologies in the manufacturing sector, there will be positive workforce growth in this sector over the 5 years 2019-2023 [18], under the assumption that manufacturing operations in Ireland remain internationally competitive over this timeframe.

Crucially, process innovation built on digital technologies can lead to more efficient and flexible production processes with increased resource efficiency (both energy and materials). Industry 4.0 adoption will therefore contribute to the climate action agenda as set out in Ireland's Climate Action Plan 2019.

The table below outlines some of the potential impacts of Industry 4.0 in relation to increased productivity and new business opportunities.

Process Industries	
Pharmaceuticals and Chemicals	**Pharmaceuticals** • Personalised healthcare is driving a shift towards more targeted products. • Information-based medicine and innovative monitoring and delivery mechanisms are being developed. • Flexible batch-manufacturing processes and patient data capture and analysis are becoming key enablers. **Chemicals** • Digitalisation is enabling the streamlining of complex processes and operations. • Value-added data services around chemical products are being developed (e.g. apps for providing technical recommendations to clients).
Food and Drinks	• directly with farmers and food manufacturers. Farmers and food producers are thus becoming retailers. • Product customisation is being enabled through the ability to adapt nutrient content to particular categories of customers.

Product Manufacturers	
Medical Devices	• MedTech products are moving towards end-to-end solutions for better care at lower prices, including connected health and drug delivery through data capture. • Personalised healthcare and customisation of medical products are being developed including combination products and diagnostics.
Computer and Electronics	• The Computer and Electronics Sector is becoming a key enabling sector for Industry 4.0, providing intermediate goods to other industrial sectors and making their products and services knowledge intensive.
Engineering	• Digitally enabled flexible batch-manufacturing processes will be required to address increased product customisation trends.

Table 1. Example of international Industry 4.0 trends and drivers in key Irish manufacturing sub-sectors. [14]

opportunity to realise a competitive base of manufacturing and supply chain firms into the future which will drive national productivity gains and underpin sustainability of high-quality jobs and export-led economic growth. Advances in Industry 4.0 technologies through research, development and innovation (RD&I) activities, and expertise in the integration of Industry 4.0 technologies in manufacturing and supply chain firms, also offers supply, service and consultancy provision opportunities to new and existing ICT and manufacturing technology firms.

Framework conditions that support Industry 4.0 activities will be critical in enabling existing firms in Ireland to transform, in nurturing start-ups, and in making Ireland an attractive location for new foreign direct investment (FDI) targeting Industry 4.0. opportunities. However, the corollary of this is that if existing firms do not invest in Industry 4.0 they will find it difficult to remain competitive and this could pose a real threat to Ireland's economy.

Industry 4.0 has the potential to make other locations, previously considered too costly for manufacturing operations, more viable from a cost-benefit perspective thus increasing competition for Ireland for existing and new FDI. Furthermore, there are significant technical challenges related to the integration of Industry 4.0 technology into existing manufacturing systems, which may tempt new investments related to Industry 4.0 towards green field sites. Such impacts would in turn have negative implications also for indigenous supply chain firms in Ireland.

To harness the opportunities and mitigate threats, manufacturing and supply chain firms in Ireland need to not only engage in Industry 4.0 but have the ambition to become recognised leaders in global value and supply chains.

International benchmarking exercises have signaled Ireland as a leading country in terms of readiness[4] for the future of production [19], [20], and a number of key features have been identified in the Irish enterprise base that could help position Ireland as a leader in Industry 4.0 if appropriately leveraged [14], including:

- the industrial capabilities built over decades;
- the disproportionate share of top global firms in a few manufacturing sectors (both process industries and product manufacturing);
- the thriving community of indigenous supply chain SMEs;
- the high export orientation of Irish-based manufacturing firms which has allowed the country to develop strong expertise in global supply chain management and develop an outward looking perspective;
- the presence of world-leading software and ICT industries; and
- the relatively close proximity of firms to each other which is an advantage for developing consortia.

Firms will themselves need to determine the changes and opportunities that are best for their businesses and as transformation implies digital interaction beyond the boundaries of firms, single firms cannot unilaterally complete the transformation. Thus, it is necessary that firms adopt a collaborative approach to Industry 4.0.

However, given the risks associated with engaging in Industry 4.0, there is a concern that many firms may not invest in the technologies, skills or organisational changes required for their transformation. While some of the more advanced firms have embarked on the journey, many other firms possess little knowledge of the opportunities Industry 4.0 presents, how they might go about engaging in an Industry 4.0 agenda, nor the threat inaction poses.

The strategy identifies the important role the State has in the development of a supportive ecosystem of relevant skills, RD&I supports, standards development, international connectedness, policy, legal and regulation. The State, through the enterprise development agencies, will also act as a catalyst for consortia development aimed at capitalising on Irelands potential to be at the forefront of Industry 4.0 arising from the key features of our enterprise base, as were outlined above.

1.5 Structure of Ireland's Industry 4.0 Strategy

The following section presents:

1. **A vision for Industry 4.0 for Ireland;**

2. **The goals for the strategy;**

3. **A set of strategic actions.**

This strategy has been informed by a study commissioned by The Department of Business, Enterprise and Innovation (DBEI), which highlighted that a primary focus for Ireland at this point should be on supporting the diffusion of Industry 4.0 technologies across a large base of firms including those with low absorptive capacity [14].

Furthermore, this strategy recognises that there are a number of existing initiatives and schemes in place in Ireland that can be leveraged towards achieving the strategy goals. All the strategic actions will commence over the first twelve months of the strategy.

2. Vision and Goals

2.1 A Vision for Industry 4.0 in Ireland

The vision underpinning this strategy is that by 2025 Ireland will be a competitive, innovation-driven manufacturing hub at the frontier of the fourth industrial revolution and at the forefront of Industry 4.0 development and adoption.

Manufacturing firms, and their supply chains, will be employing Industry 4.0 technologies to support productivity, international growth and sustainable employment. Firms will be exploiting opportunities offered by Industry 4.0 technologies by:

- adapting their methods of manufacture to improve productivity and enable enhanced customisation and made to order products;
- competing in new markets based on innovations in goods and services;
- developing new business models;
- better integrating supply chains;
- building competitive advantage through the development, adoption and strategic use of relevant standards.

Ireland will excel at providing the opportunities to develop skills and capabilities of the current and future workforce required for Industry 4.0.

Ireland will be globally recognised for the development and deployment of new Industry 4.0 technologies building on our strengths in RD&I.

A strong collaborative culture will be a key driver of Industry 4.0 in Ireland, and will support the digital transformation across sectors, value chains and supply chains, and will position firms in Ireland at the global forefront of the Industry 4.0 transformation.

The Industry 4.0 ecosystem will be underpinned by a strong and balanced policy, legal and regulatory framework.

2.2 Goals of Ireland's Industry 4.0 Strategy

The Industry 4.0 transformation will be led by existing and new firms, both indigenous and foreign-owned. However, given the economic importance of manufacturing to Ireland and the global paradigm shift that is currently underway in the sector the Government has a role in working with industry to adapt the business environment to the Industry 4.0 transformation. This strategy has five policy goals that describe the key outcomes that the Government wishes to achieve through implementation of the strategic actions.

These goals are:

1. To stimulate firms to adopt and build capability in Industry 4.0 technologies.

2. To stimulate firms to harness the new opportunities enabled by Industry 4.0 technologies.

3. To become a global leader in RD&I which underpins Industry 4.0.

4. To facilitate the current and future workforce to develop the skills to deliver the Industry 4.0 transformation and exploit the new opportunities arising in manufacturing and supply chain firms through Industry 4.0 technologies.

5. To establish a world class business environment for Industry 4.0 which is underpinned by an appropriate regulatory, legal, standards, and internationally connected ecosystem.

3. Strategy by Strategic Actions

Strategic Actions that aim to deliver on the goals of the strategy have been developed under the following 6 themes:

Theme 1: Future Manufacturing Ireland

Future Manufacturing Ireland will support Ireland's goal to become a global leader in RD&I in Industry 4.0 by developing the breadth of capability required across publicly funded research centres in a coherent and coordinated manner and by ensuring that this capability is easily accessible to firms of all sizes.

Theme 2: Awareness and Understanding of Concepts

The actions aim to help firms develop awareness of the opportunities and challenges arising from Industry 4.0 and the supports and expertise available.

Theme 3: Exploring and Planning

The actions aim to support firms to undertake 'hands-on' exploratory work on Industry 4.0 technologies and systems and to help firms to develop their own Industry 4.0 roadmaps and strategies for implementation.

Theme 4: Implementation of firm-level Industry 4.0 Strategies

The actions are aimed at providing supports to firms that are willing to invest in implementing Industry 4.0 strategies and focus on: access to finance; skills development; and support for the development of Industry 4.0 consortia.

Theme 5: Framework Conditions for Industry 4.0

Framework conditions are a critical part of the business environment for Industry 4.0, supporting established firms and start-ups and attracting new Industry 4.0 investment to Ireland. Two of the most important framework conditions relate to 'RD&I' and 'skills' and these are addressed under Themes 1 and 4 respectively. This theme addresses standards and international connectedness.

Theme 6: Implementation of Ireland's Industry 4.0 Strategy

This action sets out how the implementation of the strategy will be monitored and overseen.

Theme 1: Future Manufacturing Ireland

The State recognises that the public RD&I system has a variety of roles to play in supporting the Industry 4.0 transformation.

These include:

- achieving excellence and critical mass in research that underpins Industry 4.0 and ensuring that there is a strong pipeline of researchers to work, in both public RD&I organisations and enterprise in Industry 4.0 relevant activities;
- training of people to develop the skills needed to deploy Industry 4.0 technologies;
- developing basic R&D-related technology, near-to-market demonstrators and pilot lines;
- fostering firm collaboration; and
- provision of technical advisory services to support firms at the different stages of their Industry 4.0 journey.

The Government is already investing in RD&I activities related to Industry 4.0, with 'Advanced and Smart Manufacturing' and 'ICT' identified as priority themes on which to focus competitive public funding for RD&I [21] and significant public investments have been made in a number of key RD&I centres with a dedicated focus on advanced manufacturing/Industry 4.0, including:

- Irish Manufacturing Research: funded through the Enterprise Ireland (EI)/IDA Technology Centre programme, it is an independent legal entity with a focus on nearer to market RD&I Industry 4.0 activities, including additive manufacturing and with plans to extend activity in collaborative robotics and augmented/virtual reality.
- Confirm: a Science Foundation Ireland (SFI) funded research centre based within the HEI system, with a focus on research and technology development in the area of smart manufacturing.
- I-Form: an SFI funded research centre based within the HEI system, with a particular focus on additive manufacturing, combined with the use of digital technologies in manufacturing.

These activities are complemented by a large number of publicly funded Principal Investigators as well as other relevant publicly funded research centres in technologies that underpin advanced manufacturing and are therefore also contributing to the Industry 4.0 agenda. Other publicly funded centres of expertise whose work supports advanced manufacturing include: Tyndall National Institute (microelectronics and photonics); NIBRT (bio-processing) Irish Centre for High-End Computing (HPC); other SFI Research Centres such as AMBER (materials), CURAM (medical devices), Lero (software) and SSPC (pharmaceuticals); and other EI/IDA Technology Centres including PMTC (pharmaceuticals), CEADAR (AI, data analytics), MCCI (microelectronics). The Enterprise Ireland supported Technology Gateway Network also works on technologies related to advanced manufacturing and their capabilities complement those listed above.

IDA is also planning to establish an Advanced Manufacturing Centre (AMC) which would coordinate with and complement existing centres. The AMC is in response to the identified needs of Ireland's discrete manufacturing industry base. It will provide a collaborative environment focused on the acceleration of development and integration of core Industry 4.0 platform technologies and will serve the entire Irish-based manufacturing sector and supply chain.

The Government also has an objective to ensure coherence and coordination among publicly funded RD&I centres and to develop the full breadth of capability across the public RD&I system required to support the Industry 4.0 transformation. DBEI will therefore establish a new coordination mechanism - 'Future Manufacturing Ireland' (FMI) - to help ensure such coherence. This new coordination mechanism will ensure maximum alignment of activities across the system, avoiding unnecessary duplication and fragmentation of effort.

Theme 1: Future Manufacturing Ireland	Strategic Actions	Responsibility
Strategic Action 1	Establish a new coordination mechanism, Future Manufacturing Ireland, to ensure coherence and optimal delivery of RD&I supports across centres with a dedicated focus on advanced manufacturing/Industry 4.0.	- DBEI, EI, IDA, SFI

Theme 2: Awareness and Understanding of Concepts

Firms in Ireland are at different stages in their engagement with Industry 4.0 and these differences exist between sectors but also between firms in the same sectors.

There is still a need therefore to raise awareness and understanding of:

- technologies that underpin Industry 4.0;
- challenges and opportunities that Industry 4.0 can present across their operations, innovation agenda, business models and value chains;
- the impacts of product/service convergence and customisation arising through Industry 4.0 in relation to strategic design, service design and product design.

The innovation and enterprise agencies will work together to disseminate knowledge on how sectors and firms nationally and globally are adopting Industry 4.0 technologies. They will drive awareness and understanding of Industry 4.0 related topics across firms with little knowledge of the concept, but also to firms at the various phases of the digitalisation journey, with content tailored accordingly. They will employ a variety of mechanisms such as Industry 4.0 focused seminars and use-cases.

Best-practice sharing and knowledge development through peer-to peer learning is also a key mechanism that can be exploited. Bringing together manufacturing and supply chain firms, ICT providers and researchers around Industry 4.0 agendas will encourage positive spill-overs and knowledge diffusion. Funds will be made available through the Regional Innovation and Technology Clusters Fund to support such cluster activity. Through this fund, EI will support Institutes of Technology to activate Industry 4.0 enterprise-led clusters, focusing on bringing together a large base of firms including those with low Industry 4.0 absorptive capacity.

Difficulty in accessing knowledge and expertise can be a barrier to the diffusion of new technologies, particularly for SMEs. Ireland's innovation and development agencies will therefore map where Ireland's digital capability and technical expertise can be found and signpost the supports for Industry 4.0. They will also leverage their continuous interaction with industry and existing expertise (both solution providers and public research organisations) to facilitate connections between the relevant actors.

Theme 2: Awareness and Understanding of Concepts	Strategic Actions	Responsibility
Strategic Action 2	Raise awareness and understanding amongst manufacturing firms and their supply chains of the concept of Industry 4.0 and the potential business benefits and opportunities to be derived from engaging in Industry 4.0 activities.	• EI, IDA, SFI, NSAI, LEOs
Strategic Action 3	Support the activation of enterprise-led Industry 4.0 clusters, including through the use of the Regional Innovation and Technology Clusters Fund.	• EI, IDA, SFI, NSAI
Strategic Action 4	Provide clear communication and guidance to firms at all stages of their Industry 4.0 journey, mapping where current digital capability and technical expertise may be found, and signposting public supports available for supporting the Industry 4.0 transformation.	• EI, IDA, SFI, NSAI, LEOs

Theme 3: Exploring and Planning

Given the breath and complexity of Industry 4.0 technologies, and in particular the challenges of integration with existing operating systems, exploring and planning is a critical part of the Industry 4.0 journey.

Internationally the use of demonstrators is a proven tool to help firms with their own Industry 4.0 strategies. Demonstrators include for example virtual reality showcases, test-beds[5], and pilot lines[6]. They are small scale technology infrastructures established to show how technologies might work in industrial environments. Demonstrators can help demystify Industry 4.0 by allowing decision makers to 'see and feel' digital technologies in a setting that they can relate to. Access to demonstrator facilities also provide firms the opportunity to:

- carry out hands-on experimentation;
- independently evaluate new digital technologies;
- identify and address potential technical challenges in implementation including issues associated with integration of Industry 4.0 technologies into legacy systems;
- assess the use of existing, updated or new standards;

- evaluate the value capture opportunities and assess the capability, expertise and financial costs that would be required for implementation, thus helping in developing estimates for return on investments;
- aid in the development of roadmaps for implementation.

It is also important to understand the shifts and convergence that may occur from manufacturing to manufacturing service provision, where Industry 4.0 can utilise data capture for the continuing re-design and customisation of products and the design and development of new service offerings.

Through their RD&I programmes, IDA and EI will provide their clients with the opportunity to access demonstrators and to develop in-house demonstrators. These supports will also provide firms with the opportunity to access external expertise to aid in the exploring and planning phase of their Industry 4.0 journey.

Future Manufacturing Ireland (FMI) will have a role in ensuring that Industry 4.0 demonstrator capability in the publicly funded research centres is aligned with the needs of industry while avoiding unnecessary duplication in activity.

Theme 3: Exploring and Planning	Strategic Actions	Responsibility
Strategic Action 5	Provide access to firms to Industry 4.0 demonstrators to allow them to experiment with individual Industry 4.0 platform technologies and the integration of Industry 4.0 digital technologies in configurations simulating those in manufacturing and supply chain firms.	- EI, IDA
Strategic Action 6	Provide support to firms to develop Industry 4.0 pilots in-house that would also act as exemplars to other firms.	- EI, IDA
Strategic Action 7	Provide access to external expertise to support firms: - to evaluate the value capture opportunities, implementation challenges and financial costs and estimate the potential return on investment of Industry 4.0 technology adoption. - to develop firm-level Industry 4.0 related roadmaps, including: technology; standards adoption; skills; regulation; and investment roadmaps.	- EI, IDA

5.   *A testbed is a platform for conducting rigorous, transparent, and replicable testing of scientific theories, computational tools, and new technologies. The term is used to describe experimental research and new product development platforms and environments.*

6.   *A pilot line is a pre-commercial production line that produces small volumes of new technology-based products or employs new production technology.*

Theme 4: Implementation of firm-level Industry 4.0 Strategies

As set out above, Industry 4.0 will have a disruptive impact on the manufacturing sector over the coming years. By supporting firms to implement Industry 4.0 strategies the State will help to build knowledge across sectors, encourage spillovers between firms and ultimately enable firms in Ireland to compete internationally, thereby securing our manufacturing base.

Supports will be provided to firms that are willing to invest in Industry 4.0 through:

- direct and in-direct financial support for implementation;
- skills development;
- facilitating Industry 4.0 consortia for implementation.

Financial Support for Implementation

To implement Industry 4.0 strategies firms will need to invest in physical and intangible assets, including infrastructure and human capital.

Firms can leverage the existing IDA and EI RD&I schemes for direct grant supports. These schemes will provide support for in-house physical and intangible assets[7] including supporting costs related to in-house employees and external expertise involved in implementation of Industry 4.0. Clients of the agencies will be made aware of the opportunity to avail of the RD&I grant support schemes to support Industry 4.0 implementation.

Finance options that provide competitive rates over longer periods can encourage firms to strategically invest in implementation of Industry 4.0. The Future Growth Loan Scheme will support longer term credit to firms[8] for funding investments in physical and intangible assets, personnel costs and additional overheads and operating costs.[9] Furthermore, the rationale and viability for an accelerated capital allowance scheme for Industry 4.0 will be explored. Such a scheme would allow for the cost of capital equipment and intangible assets for Industry 4.0 to be deducted at a faster rate than the standard capital allowances tax structure thus increasing cash flow in firms and providing an incentive for firms to invest in Industry 4.0.

Theme 4: Implementation of firm-level Industry 4.0 Strategies	Strategic Actions	Responsibility
Financial Support for Implementation		
Strategic Action 8	Utilise existing State programmes to support firms to invest in implementation of Industry 4.0, including: - Direct to firm RD&I grant support through the agencies. - The Future Growth Loan Scheme.	- EI, IDA - Strategic Banking Corporation of Ireland, DBEI, DAFM
Strategic Action 9	Develop options for the establishment of an accelerated capital allowance scheme to incentivise firm investment in Industry 4.0 capital.	- DBEI

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7. Such as computerised information (software and data-developed or acquired) and innovative property.
8. Loan terms of between 8-10 years will be available.
9. The standard capital allowances tax structure allows deduction of equipment costs from profits proportionally over 8 years.

Skills Development

Digitalisation is driving changes in the skills profile required in the current and future workforce of the manufacturing ecosystem.

As described earlier, the impact of Industry 4.0 will be pervasive across the manufacturing sector and the supply chain. Leadership teams will need to understand the potential benefits, opportunities and challenges to enable them to build and drive a vision for Industry 4.0 in their firms. Managers will also need to:

- develop an understanding of the opportunities and challenges in integrating Industry 4.0 technologies across the nodes of the manufacturing ecosystem and how best to address them;
- be able to identify capabilities missing in the organisation that are needed to implement Industry 4.0;
- lead and support existing employees to transition to new work environments and roles.

Manufacturing and supply chain firms will also require employees across their firm operations to develop new skills to successfully implement an Industry 4.0 strategy. EI and IDA currently provide direct support for training and this will be accessible to firms for Industry 4.0. Initial upskilling could be achieved for example through bespoke, industry-defined modules of about two days of duration as 'quick-win' mechanisms, in particular to demonstrate immediate value in upskilling.

However, given the rate of advancement in technology, upskilling and reskilling will be required to develop skills that are complementary to new technologies. This is recognised in the 'Supporting Working Lives and Enterprise Growth in Ireland' policy [22]. Through this policy, Government will provide targeted support for employees and employers in the Irish labour market and it will complement employer-based and State initiatives underway, through targeted support and investment. One such example is the 'Explore' programme which is focused on lifelong learning for upskilling experienced employees in manufacturing to support them to keep pace with technological change.

Education and Training Supports: Responding to the Challenges of Industry 4.0

The education and training system has already begun to respond to the challenges of Industry 4.0 and existing programmes are being leveraged to deliver the skills required at all levels within firms.

At management level there are a number of programmes available such as EI's Management Development Programme, Innovation for Growth, and the Tailored Management Company Support - all of which are accessible to both indigenous and foreign-owned firms; the LEOs Management Training Programme and a number of management development programmes provided by Skillnet Ireland and via the Springboard+ programme. These programmes will provide firms with the opportunity to develop the strategic leadership and management skills required to deliver on Industry 4.0 implementation strategies.

Furthermore, programmes developed by the Department of Education and Skills (DES) and it's agencies have been leveraged to meet the new skills needs arising from Industry 4.0 such as Springboard+ and the Original Equipment Manufacturing Apprenticeship and Manufacturing Apprenticeship Programmes. Also, the new ICT Skills Action Plan plans for a pipeline of ICT professionals that will underpin the ICT skills for Industry 4.0 [24].

To support individual firms to develop and implement training plans that meet their specific needs, the 'Regional Skills Fora', established by DES, acts as a single contact point with employers in each region allowing them to connect with the range of services and supports available across the education and training system. Work is already ongoing through the 'Regional Skills Fora' and the 'Skills for Growth Initiative'* to give employers the necessary tools to identify their skills needs, including those related to Industry 4.0. Once skills needs are identified, the Regional Skills Fora will facilitate engagement between enterprise and the Education and Training System to respond to these needs.

At postgraduate level, the SFI Industry Fellowship programme, for example, will support employees to spend time in academic environments participating in collaborative RD&I, receiving training and developing new skills in Industry 4.0. In addition, the Irish Research Council Enterprise Partnership Scheme will support the placement of postgraduate or postdoctoral researchers into firms to work on Industry 4.0 activities: the upskilling element occurring through the knowledge transfer from the Industry 4.0 experts to firm employees.

Moreover, the Industry 4.0 focused SFI centres (I-form and Confirm), have targets set for the number of PhD graduates to be directly supported by the centres, and these centres are also developing masters programmes in Industry 4.0 related areas and recruiting a high number of postdoctoral researchers. These graduates and postdoctoral researchers will be highly skilled in technical areas under the Industry 4.0 umbrella and will be key to producing a pipeline of specialist skills in Industry 4.0 for enterprise.

*Skills for Growth is a package of supports for employers to help them understand and plan for their skills needs.

Furthermore, expertise in Industry 4.0 is being developed in the public RD&I system and this training and education will be a primary channel for knowledge transfer between the public RD&I system and firms. Training to support upskilling of employees in line with future production skills also forms part of the proposed activities of the planned Advanced Manufacturing Centre (AMC).

Industry 4.0 will have a significant impact on existing roles in the manufacturing sector and its supply chain. New engineering roles will thus require a hybrid set of competencies in future graduates, combining mechanics, electronics and software. The future workforce will also require an evolved set of ICT skills such as: proficiency in new computerised modelling and simulation tools and data analytics for manufacturing design roles; proficiency in the use of real time planning tools that will be required in operations management; and cybersecurity competencies which are becoming more important in production and supply chain management as processes and machines become increasingly interdependent, and as data flows increasingly expand beyond the boundaries of individual firms and countries. Finally, skills related to leadership and strategic management in Industry 4.0 will be essential in the future workforce.

Ireland already has the advantage of having a relatively high-skilled workforce. Building on the success of Ireland's ICT Skills Action Plan 2014-2018, the ICT Action Plan 'Technology Skills 2022 - Ireland's Third ICT Skills Action Plan - represents a collaborative effort by the Government, the education system and industry to meet the goal of 'making Ireland the most attractive location in the world for ICT skills availability' [23], [24].

However, to ensure that the third level system will produce future graduates with the appropriate hybrid mix of ICT and engineering skills as required for Industry 4.0, there is a need to understand the skills requirements for enterprises engaging in Industry 4.0. The recent reform of the funding model for Higher Education, that includes better alignment of funding to the skills needs of the economy, will ensure continuing responsiveness of the system to identified skills needs including those relating to Industry 4.0.

Theme 4: Implementation of firm-level Industry 4.0 Strategies	Strategic Actions	Responsibility
Skills Development		
Strategic Action 10	Support the development of strategic leadership and management skills in Industry 4.0.	• EI, IDA, LEOs, DES, NSAI
Strategic Action 11	Provide direct supports to firms to upskill their existing employees in adopting Industry 4.0 technologies, systems and standards.	• EI, IDA
Strategic Action 12	The Regional Skills Fora will be available to facilitate engagement between enterprise and the Education and Training system to respond to identified needs.	• DES
Strategic Action 13	Utilise the expertise and supports in the public RD&I system to upskill firm employees in Industry 4.0.	• SFI, DES, IDA
Strategic Action 14	Assess the skills requirements for Industry 4.0 and signpost to appropriate provision.	• DES, DBEI, SFI

Firm Consortia for Implementation

This strategy recognises the strong rationale for the State to support consortia of firms to collaborate on Industry 4.0 challenges. One of the key defining features of the Industry 4.0 transformation is the digital connectedness beyond the boundaries of individual firms and countries and towards connection along global value and supply chains. Collaborations within sectors, across existing supply chains and between different sectors can lead to greater productivity gains (through process innovations, economies of scale, mutual learning and spillovers) and to new business models.

One of Ireland's advantages in the Industry 4.0 transition is the depth of world class manufacturing and ICT expertise located here. Consortia would provide an opportunity to bring together these two sectors to develop solutions and new opportunities in the global manufacturing value and supply chains. Areas that could be addressed include: technical challenges posed by integrating digital technologies into legacy systems; development of technology roadmaps for specific application development[10]; development and implementation of sectoral roadmaps; validation; determining how supply chain firms can integrate new digitally-enabled systems; interoperability and technical standards; data standards; regulation; and security.

Consortia of firms might also prove useful in addressing implementation challenges in highly-regulated sectors and could also focus on addressing the cultural and human challenges associated with Industry 4.0 deployment in firms.

The agencies will stimulate Industry 4.0 networking activity and consortia development including through the EI Regional Innovation and Technology Clusters Fund. Once consortia are well established with a shared Industry 4.0 agenda, opportunity for accessing funds to support the implementation activity of industry-led consortia will be available through competitive processes such as the Regional Enterprise Development Fund and the Disruptive Technology Innovation Fund. RD&I supports will also be available through EI, IDA and SFI for any collaborative projects that might emerge from the consortia.

Theme 4: Implementation of firm-level Industry 4.0 Strategies	Strategic Actions	Responsibility
Firm Consortia for Implementation		
Strategic Action 15	Provide industry-led consortia with opportunities to compete for funding focused on deployment of Industry 4.0 technologies through for example the Disruptive Technology Innovation Fund and Regional Enterprise Development Fund.	• EI, DBEI

10. *Corporate technology roadmaps of the intended audience might be needed so as to ensure industrial engagement. Alternatively, initiatives could run in the opposite direction, using demonstrators to drive the development of corporate technology roadmaps, especially among SMEs.*

Theme 5: Framework Conditions for Industry 4.0

The State has a critical role to play in improving the business environment or framework conditions for Industry 4.0. Given the pervasiveness of the digital transformation across our economy and society there are a broad range of framework conditions that need to be in place to support an inclusive and sustainable transition. These include, for example, connectivity, trust and security, data privacy and digital literacy.

These framework conditions will be addressed in the Government's forthcoming National Digital Strategy. However, this strategy sets out the framework conditions that are particularly relevant to Industry 4.0 and where Government has identified specific policies that will play an important role in fostering Industry 4.0 in Ireland. These are:

- RD&I;
- Skills;
- Standards;
- International connectedness.

Strategic Actions for framework conditions related to RD&I and skills have already been addressed under Themes 1 and 4 respectively, and in this section Strategic Actions are set out for developing the remaining key framework conditions for Industry 4.0.

Standards Development

It is the digital interconnectedness across all elements of the manufacturing ecosystem that is the truly revolutionary aspect of the fourth industrial revolution. This interconnectedness will extend between firms and across borders and thus it is imperative that firms in Ireland operate systems that are interoperable with systems in other firms and locations.

Addressing Industry 4.0 system integration challenges requires understanding of relevant standards and awareness of international developments in this area. Furthermore, taking an active or driving role in standards development can be used as the basis for achieving technology leadership or competitive advantage.

Through, it's 'Telecoms Standards Initiative', EI provides support to companies in the internet, telecommunications and mobile sectors to facilitate their participation in standards activities. Furthermore, the National Standards Authority of Ireland (NSAI) have established an Advanced Manufacturing Technologies Committee which is dedicated to standards in new and emerging technologies in manufacturing. It is made up of subcommittees that are national mirror committees to the International Organization for Standardisation (ISO) and European Committee for Standardisation (CEN) committees that are developing standards in the area. Members of the subcommittees represent industry, academia and Government and the objective is to work together for Ireland, to influence the development of international standards in new and emerging advanced manufacturing technologies.

To further support this objective, firms and publicly funded researchers in Ireland will be encouraged to engage nationally and internationally on Industry 4.0 standards development. In addition to having the opportunity to influence the development of standards in this area, engagement at international fora will also help raise Ireland's profile in Industry 4.0 and subsequent national dissemination of global developments in standards will help firms in Ireland to stay abreast of the advances and opportunities in new and updated standards.

Theme 5: Framework Conditions Strategic Actions Responsibility	Strategic Actions	Responsibility
Standards Development		
Strategic Action 16	Provide support for SMEs and publicly funded researchers through existing funding allocations to engage at international Industry 4.0 standards fora.	- EI, NSAI, SFI, LEOs

International Connectedness

As outlined in section 1.1, Industry 4.0 is high on policy agendas internationally. At the European Union level there is an increasing focus on funding, co-ordination and co-operation of Industry 4.0 related activities.

EU Programmes supporting Industry 4.0 technology development and deployment include for example:

- the RD&I funding programme 'Horizon 2020'[11] which has identified 'Digitalisation of Industry and Services' as one of the focus areas for support for market-creating innovation and highly integrated activities; and
- European Regional Development Funds which can be used towards capacity building in Member States, including funding for experimental/demonstrator facilities.

Furthermore, as part of the next long-term EU budget (MFF 2021-2027), the European Commission (EC) has proposed:

- €15 bn for the cluster of policy challenges associated with 'digital and industrial' within the Horizon Europe Programme;
- The Digital Europe Programme[12], which would be a new €9.1 bn funding programme with the main objective to boost Europe's digital transformation to the benefit of citizens and businesses; and
- A European Social Fund+ which will include support for upskilling and reskilling of the workforce to be ready for the new digital and automation challenges.

A 'Digitalisation of European Industry' (DEI) initiative has been established by the EC and is aimed at taking a comprehensive approach at European level to avoid fragmented markets and to reap the benefits of digital evolutions.

As part of its approach the EC are:

- helping to co-ordinate national initiatives;
- focusing investments in EU's public-private partnerships;
- investing in a pan-EU network of digital innovation hubs;
- setting up large-scale pilot projects to strengthen Internet of Things, advanced manufacturing and technologies;
- looking to adopt future-proof legislation that will support the free flow of data and clarify ownership of data generated by sensors and smart devices as well as reviewing rules on safety and liability of autonomous systems; and
- preparing EU skills agendas that will help give people the skills needed for jobs in the digital age.

Manufacturing in Ireland is deeply embedded in global value and supply chains and to support the goals set out in this strategy Ireland will leverage European and international initiatives in a number of different ways:

- raising our international profile as lead innovators and influencing the agenda at an international and EU level;
- leverage international infrastructure and capabilities[13] – for example through access to demonstration facilities in the network of Digitalisation Innovation Hubs being established across the EU;
- ensuring that Ireland influences the development of, and, is prepared for future standards;
- supporting leading edge public RD&I through collaboration and mobility;[14]
- engaging in international research collaborations that add to our capabilities, knowledge and talent pool in Industry 4.0 and provide networking and collaboration opportunities for firms in Ireland to raise their profile in global value and supply chains.

Theme 5: Framework Conditions	Strategic Actions	Responsibility
International Connectedness		
Strategic Action 17	Develop a plan for Ireland to engage more strategically in international activities and RD&I collaborative initiatives around Industry 4.0, so as to add to our capabilities, increase our profile in Industry 4.0, and shape the future agenda and opportunities arising.	• DBEI, FMI and relevant agencies

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11. *Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. The EC have indicated that more than €6 billion will be earmarked for digital R&I in the programme.*

12. *The Digital Europe Programme, would be a new funding programme and is part of the "Single Market, Innovation and Digital" chapter of the EU's long-term budget proposal. It builds on the Digital Single Market strategy launched by the Commission in May 2015.*

Theme 6: Implementation of Ireland's Industry 4.0 Strategy

This Strategy has identified a comprehensive suite of direct interventions and framework policies to help us achieve our vision that by 2025 Ireland will have a competitive, innovation-driven manufacturing sector and supply chain that is at the forefront of Industry 4.0 development and adoption. Government departments and enterprise agencies will be required to ensure a coherent system of support and to maximise the impact of public investment. The Industry 4.0 transformation will be led by firms and the State will work closely with the enterprise sector and their representatives to calibrate the system of supports in response to new and emerging challenges and opportunities.

To ensure oversight of the Strategy, DBEI will establish an Industry 4.0 Stakeholder Forum to liaise with representatives of the manufacturing sector and relevant strategic partners. The Forum will provide advice and guidance to DBEI and its agencies on the implementation of the Industry 4.0 strategy and inform future policy development.

The Forum members will include representatives from the manufacturing value chain, Industry 4.0 experts, HEIs, industry bodies, relevant state bodies and the FMI project manager.

The Forum will operate for the period of the strategy to 2025 and will meet 2-3 times a year.

The role of the Industry 4.0 Forum will be to:

1. Provide expert views, feedback and inputs on the objectives outlined in the Industry 4.0 strategy and the implementation of the actions;
2. Review progress towards the goals of the Industry 4.0 strategy on an annual basis;
3. Help guide coherent policy development by advising on alignment and linkages with other relevant policy initiatives and enterprise developments;
4. Provide direction on new opportunities and challenges arising from Industry 4.0;
5. Promote Government Industry 4.0 initiatives among their own stakeholders.

The secretariat will be provided by DBEI and the Forum will submit an annual progress report to the Minister for Business, Enterprise and Innovation.

It is acknowledged that there are no indicators currently in use that accurately reflect Industry 4.0 adoption in the manufacturing sector and its supply chain. However, the EC has developed a framework for reporting on the digital transformation of businesses, which utilises: indicators; surveys; real-time data; and policy analysis methodologies. This 'Digital Transformation Scoreboard' (and associated report) could be used as a source of information for the annual review. The review could also avail of the EC annual review of 'Progress in National initiatives on Digitalising Industry' as an input to benchmarking and tracking of international Industry 4.0 activities. Furthermore, the review should look to take account of new indicator data and measurement approaches that may have emerged since the publication of this strategy.

Theme 6: Implementation of Ireland's Industry 4.0 Strategy	Strategic Actions	Responsibility
Strategic Action 18	Establish an Industry 4.0 Stakeholder Forum to oversee implementation of the Strategy, and report on an annual basis to the Minister for Business Enterprise and Innovation.	DBEI with relevant Government Departments, agencies and external stakeholders.

13. *International collaboration enables the sharing of specialist facilities and infrastructures that would not be feasible (or desirable) to have in place in every country.*
14. *Mobility also helps to maintain a strong inward and outward flow of researchers including short-term visits and periods of longer duration.*

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