UCI University of California, Irvine

Future of Smart Manufacturing in a Global Economy

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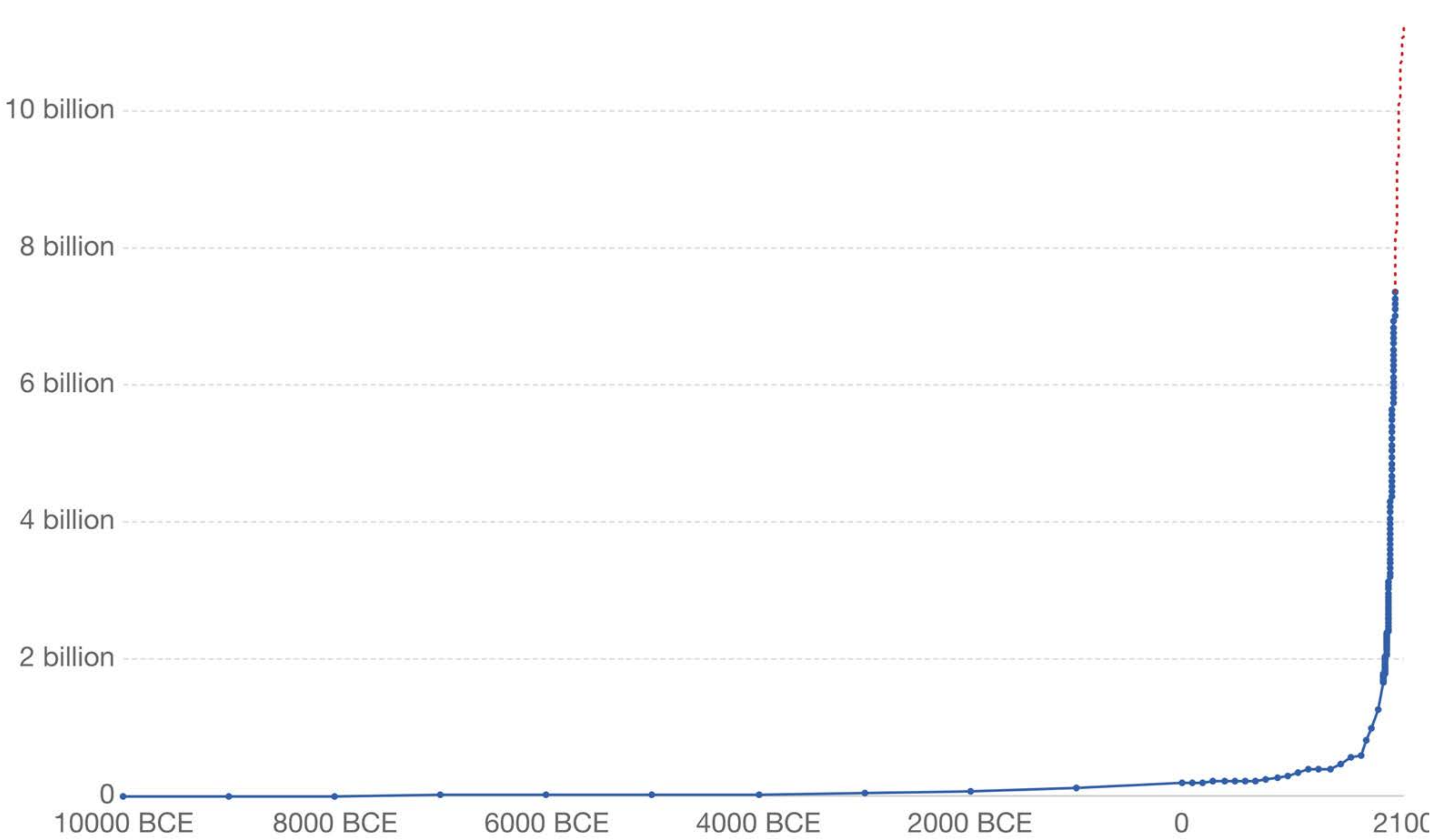
2018 ASIA PACIFIC WORKSHOP
Broadcom Foundation
May 7, 2018

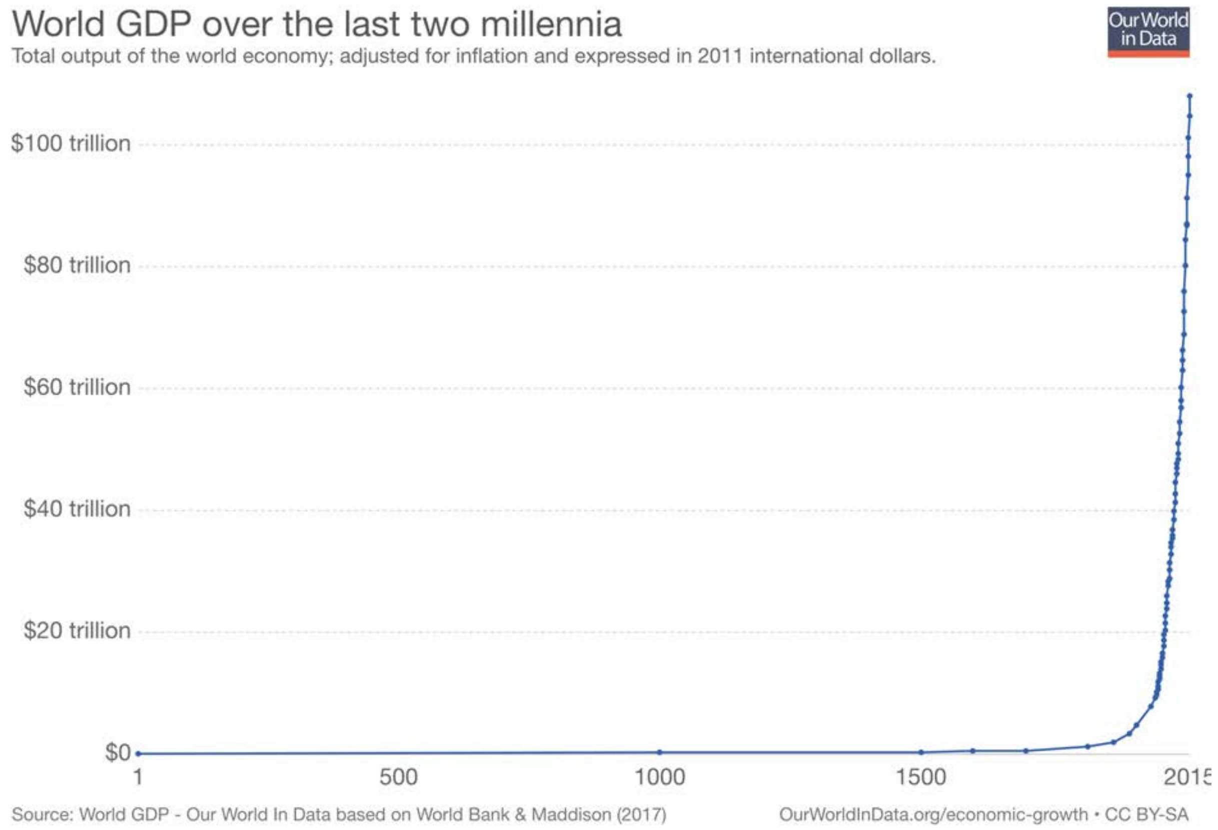
Outline

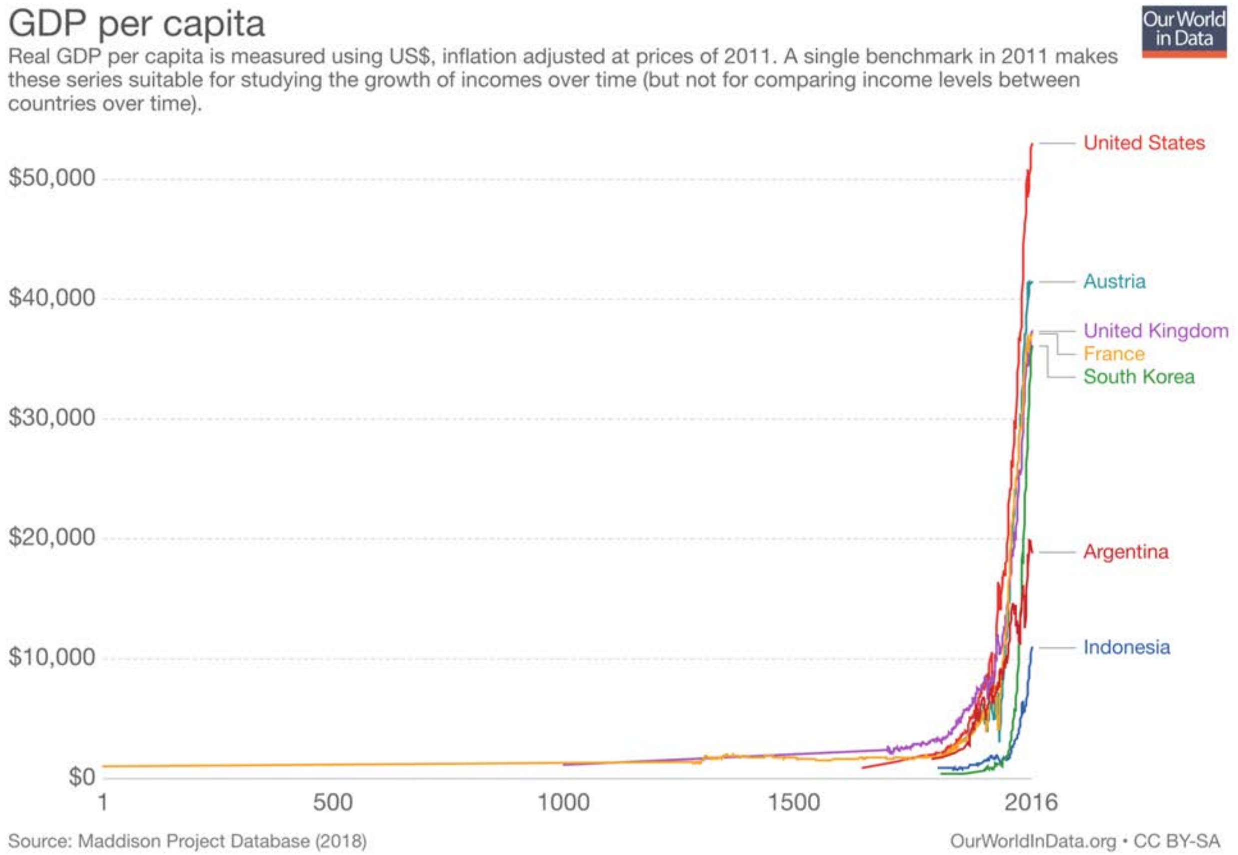
- Context and trends
- Industry 4.0
- Manufacturing in the 21st Century
- Ideas for the Future
- Conclusions

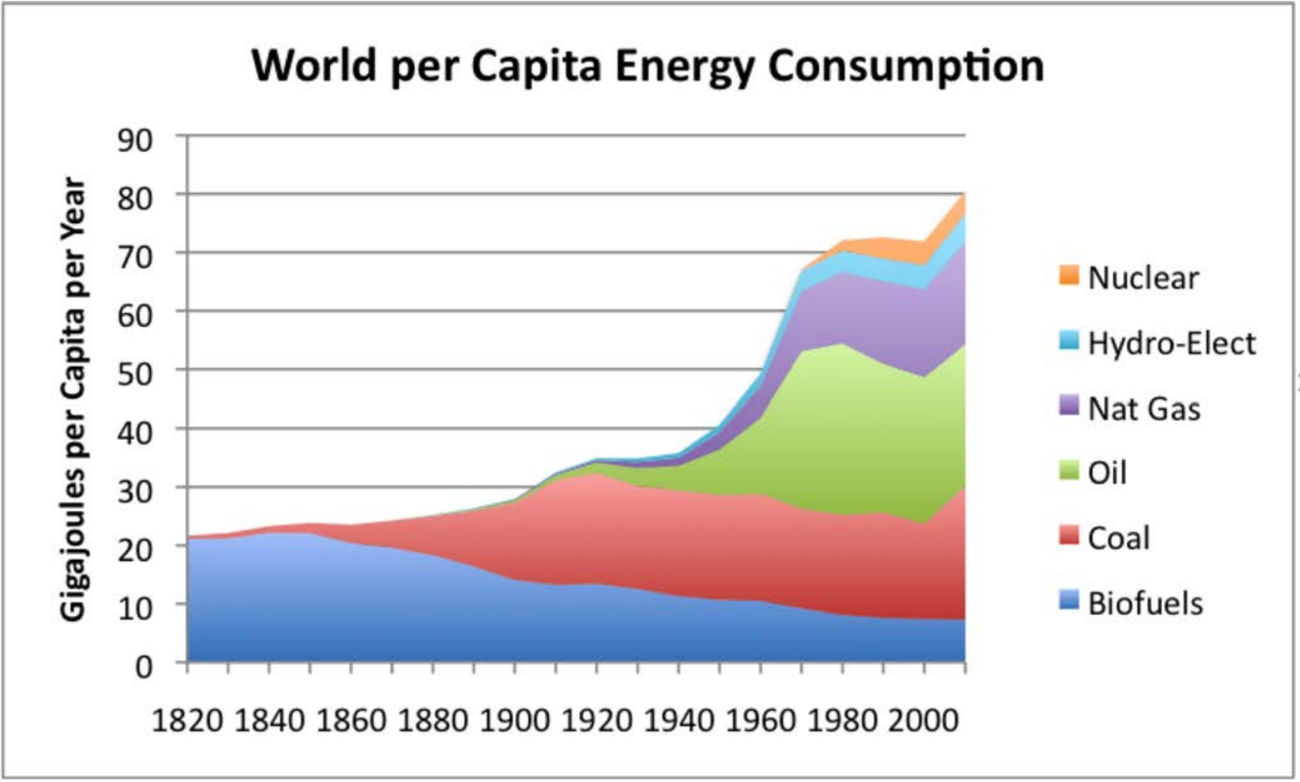
World Population over the last 12,000 years and UN projection until 2100



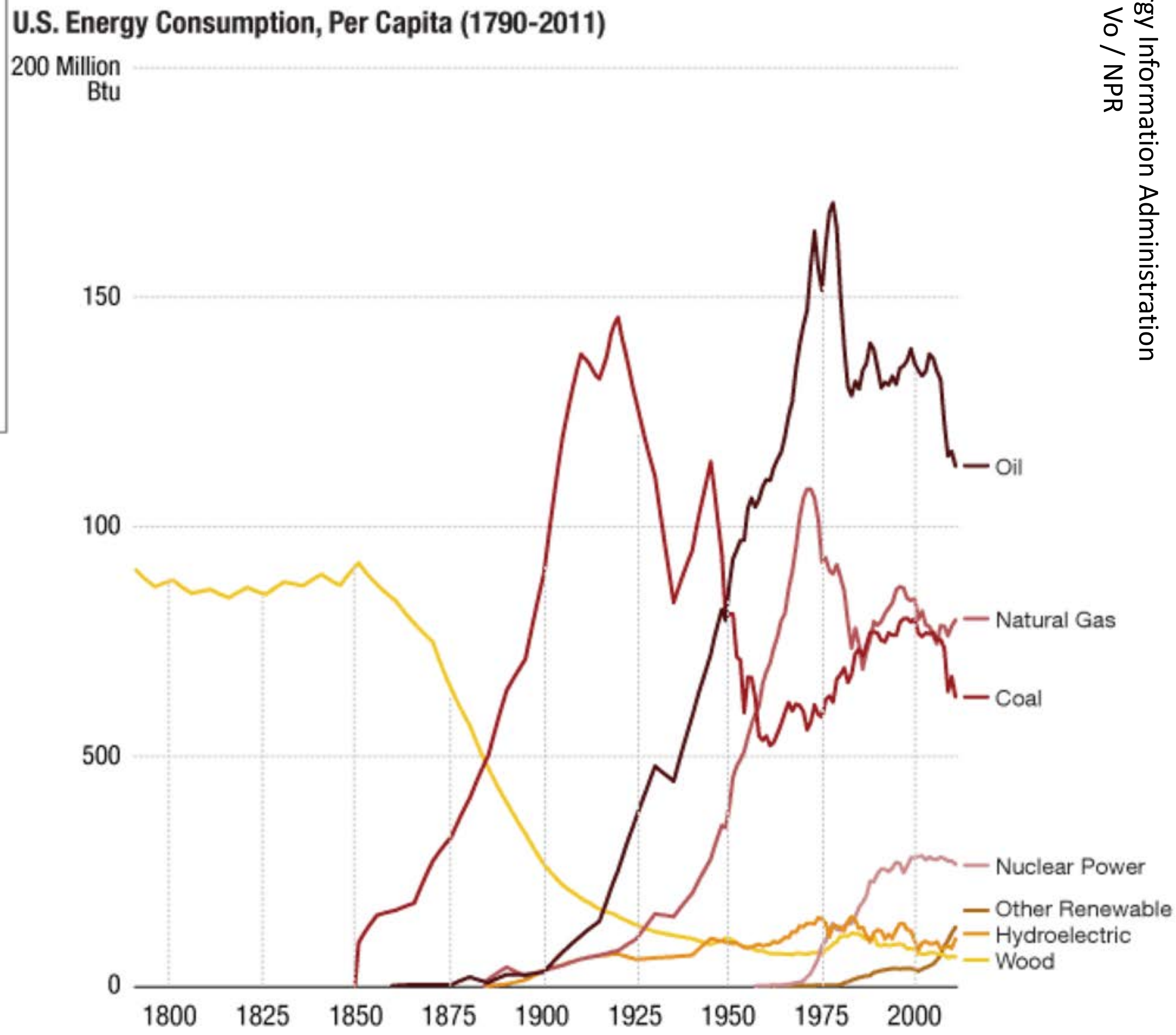
Source: World Population over 12000 years - various sources (2016), Medium Projection – UN Population Division (2015 revision)
OurWorldInData.org/world-population-growth/ • CC BY-SA


World GDP over the last two millennia
Total output of the world economy; adjusted for inflation and expressed in 2011 international dollars.
Our World in Data
$100 trillion
$80 trillion
$60 trillion
$40 trillion
$20 trillion
$0
1
500
1000
1500
2015
Source: World GDP - Our World In Data based on World Bank & Maddison (2017)
OurWorldInData.org/economic-growth • CC BY-SA


GDP per capita
Real GDP per capita is measured using US$, inflation adjusted at prices of 2011. A single benchmark in 2011 makes these series suitable for studying the growth of incomes over time (but not for comparing income levels between countries over time).
Our World in Data
$50,000
$40,000
$30,000
$20,000
$10,000
$0
1
500
1000
1500
2016
United States
Austria
United Kingdom
France
South Korea
Argentina
Indonesia
Source: Maddison Project Database (2018)
OurWorldInData.org • CC BY-SA



Source: OilDrum
http://www.theoildrum.com/node/9023

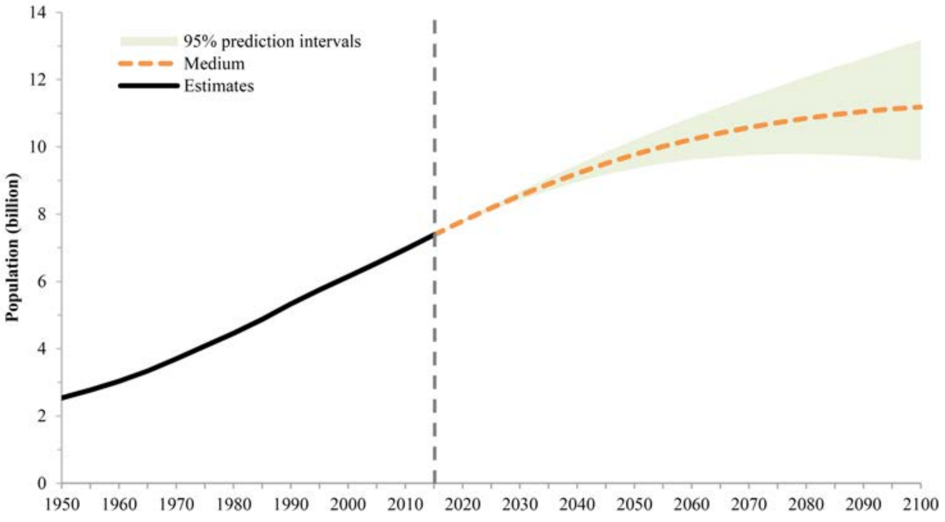


Source: U.S. Energy Information Administration
Credit: Lam Thuy Vo / NPR

Energy consumption growth

Global demographic shifts will drive the coming decades

Figure 2. Population of the world: estimates, 1950-2015, and medium-variant projection with 95 per cent prediction intervals, 2015-2100



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

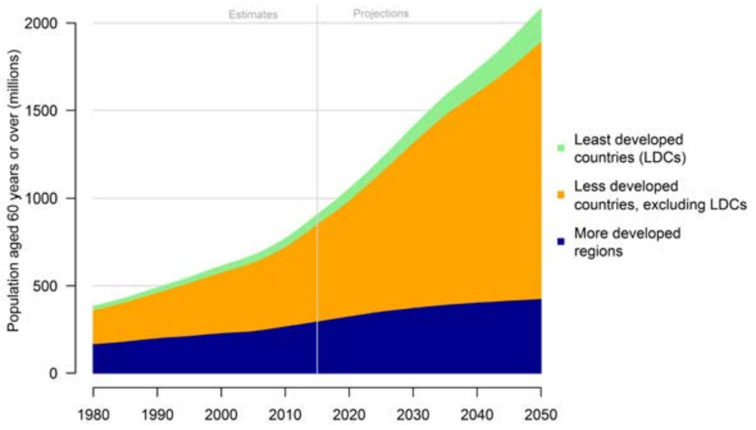
TABLE 1. POPULATION OF THE WORLD AND REGIONS, 2017, 2030, 2050 AND 2100, ACCORDING TO THE MEDIUM-VARIANT PROJECTION

Region	*Population (millions)* 2017	2030	2050	2100
World	7 550	8 551	9 772	11 184
Africa	1 256	1 704	2 528	4 468
Asia	4 504	4 947	5 257	4 780
Europe	742	739	716	653
Latin America and the Caribbean	646	718	780	712
Northern America	361	395	435	499
Oceania	41	48	57	72

Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

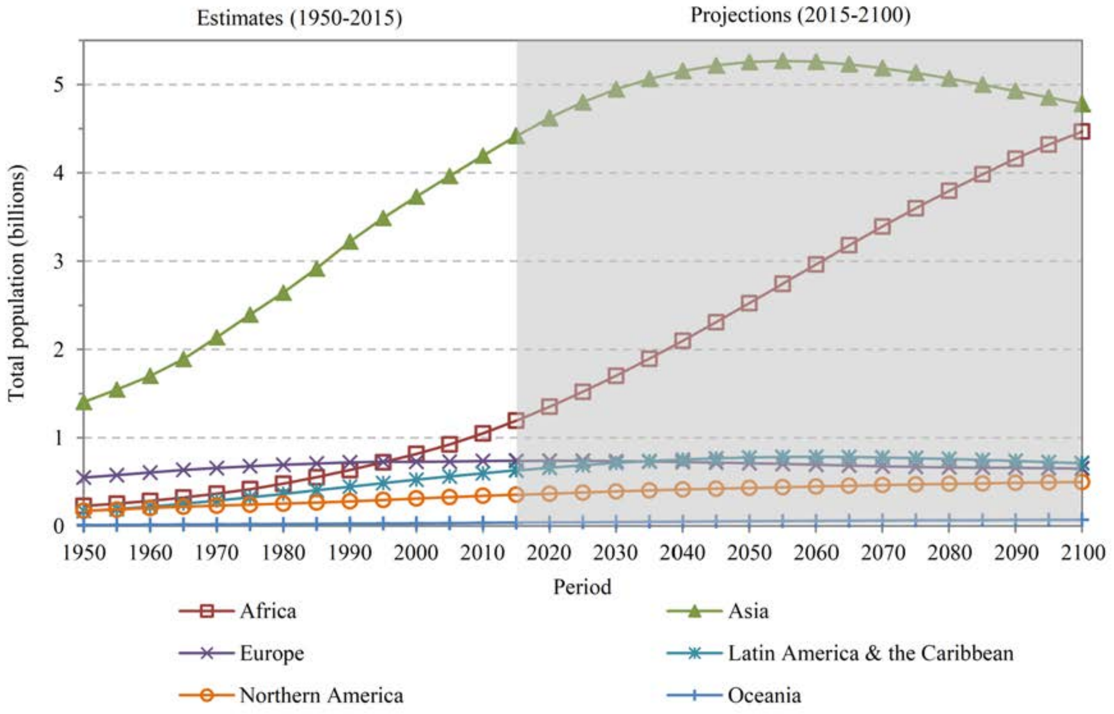
Figure 1.

Number of persons aged 60 years or over by development group,[1] from 1980 to 2050

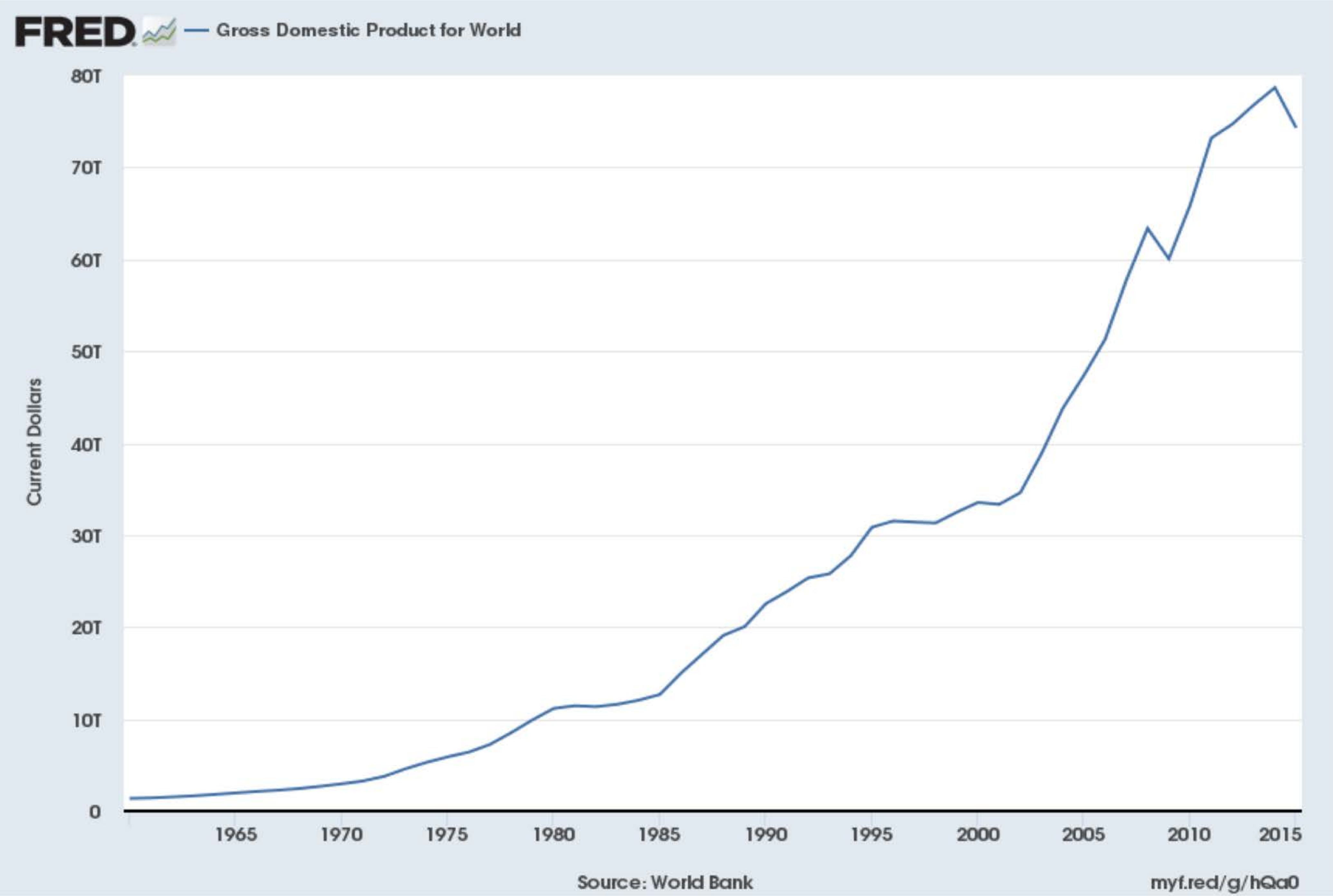


Data source: United Nations (2017). World Population Prospects: the 2017 Revision.

Figure 3. Population by region: estimates, 1950-2015, and medium-variant projection, 2015-2100

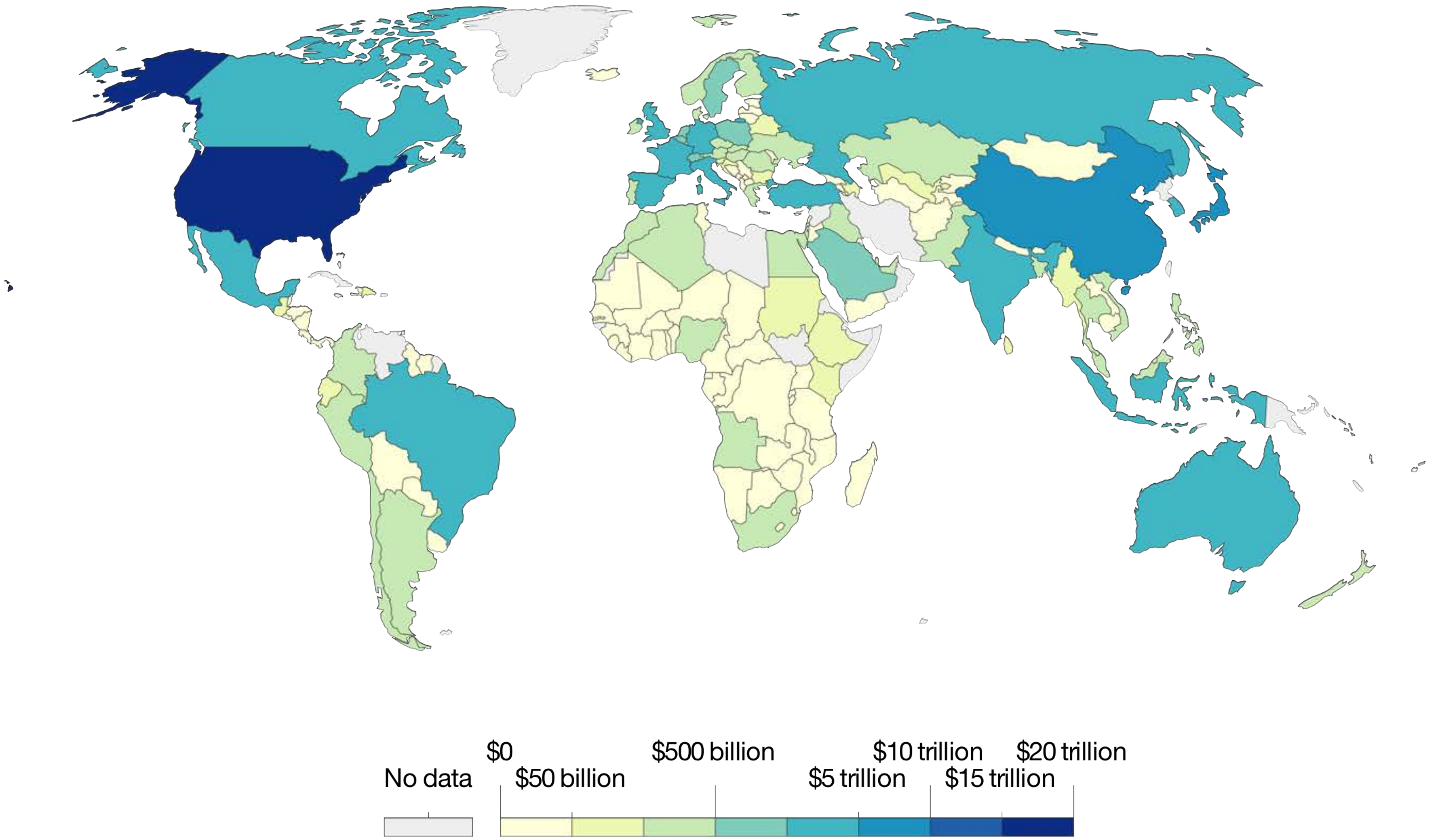


Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.


FRED
— Gross Domestic Product for World
80T
70T
60T
50T
40T
30T
20T
10T
0
Current Dollars
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Source: World Bank
myf.red/g/hQa0

Gross Domestic Product, 2016

Our World in Data



Source: World Bank – WDI

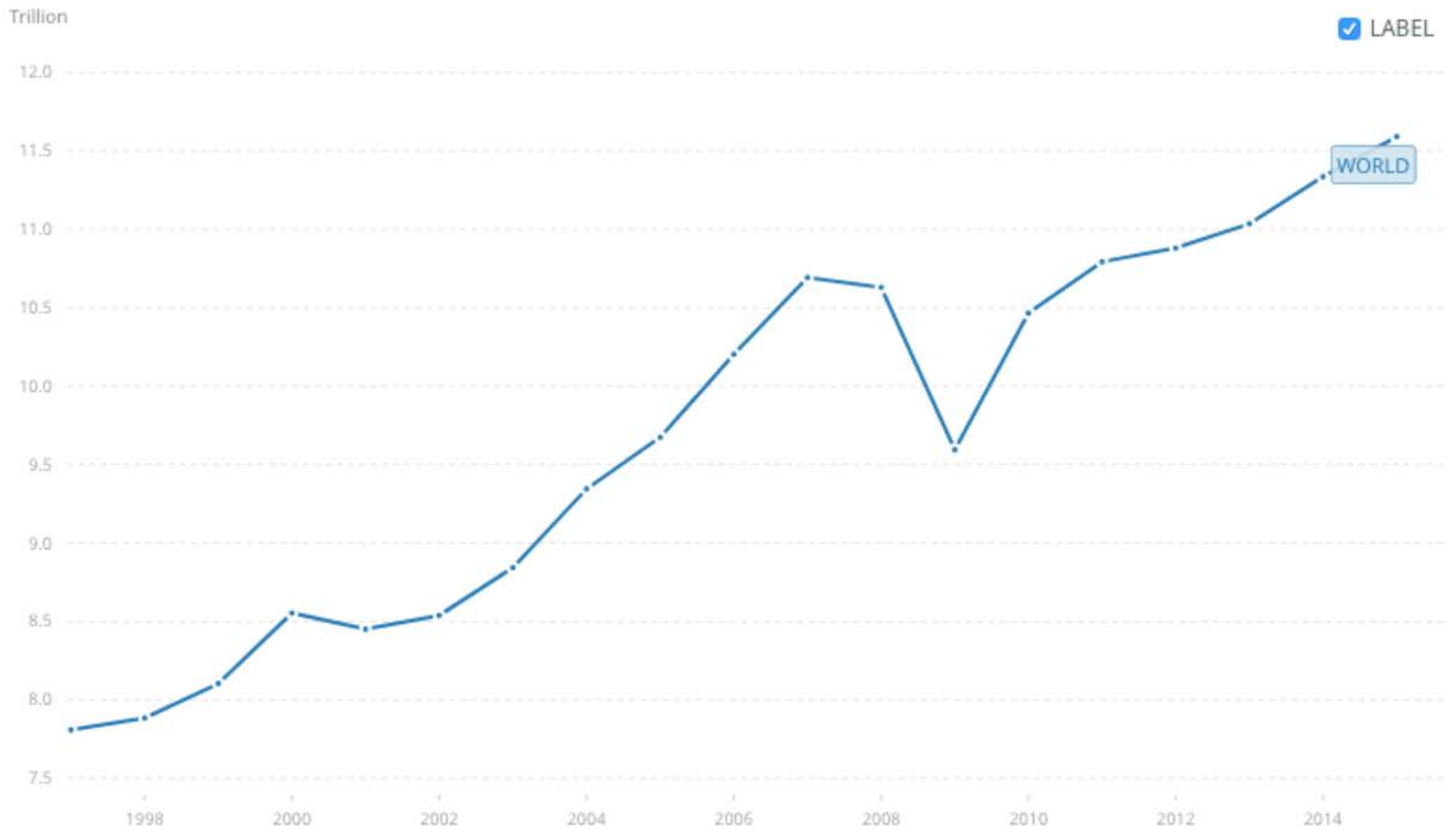
OurWorldInData.org/economic-growth • CC BY-SA

Manufacturing, value added (constant 2010 US$)

World Bank national accounts data, and OECD National Accounts data files.

License : CC BY-4.0

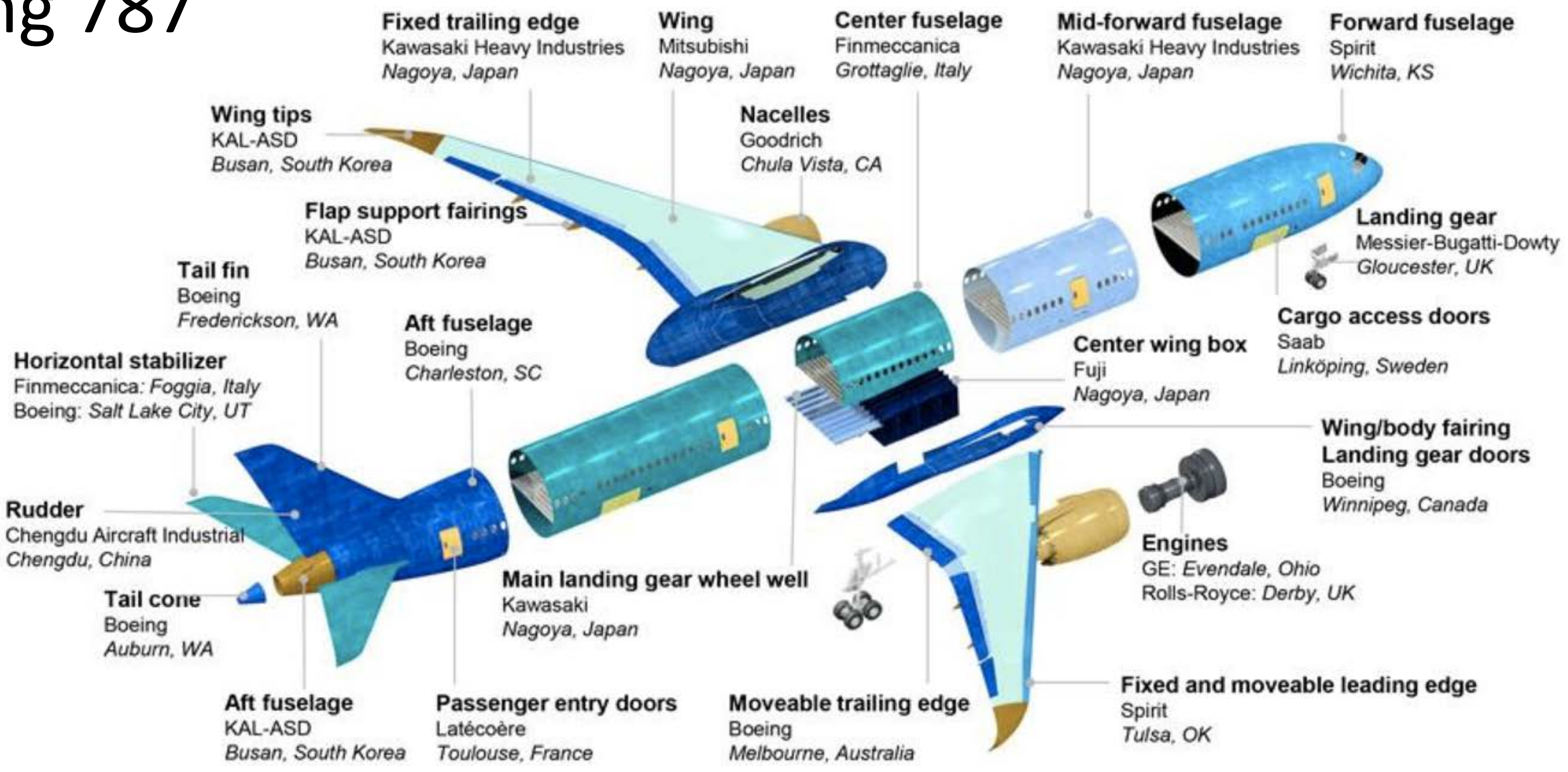
Line Bar Map Share Details



1960 - 2016

Manufacturing Supply Chains are Global

Boeing 787



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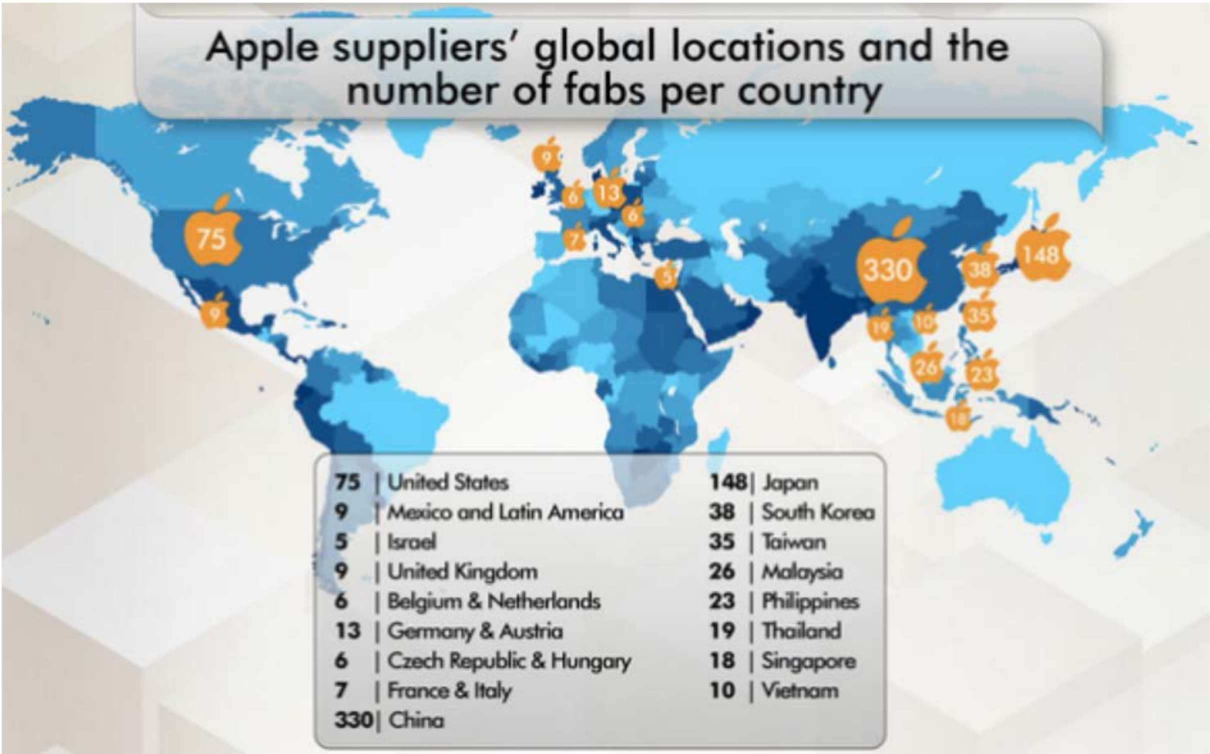
A major case study in complex innovative product development and manufacturing

https://www.pmi.org/learning/library/innovation-challenges-complex-projects-boeing-dreamliner-10050

Apple iPhone



Apple iPhone 7 32GB (A1778)

Cost Summary	
Direct Material Costs (Component Costs)	$215.80
Conversion Costs (Assembly / Insertion / Test Costs)	$5.00
Total Cost (Direct materials and manufacturing)	**$220.80**

Itemized Components	Manufacturer Name	Description	Total Cost
Apps Processor			
System-on-Chip	TSMC (Apple)	Apple A10, Quad-Core 64-Bit ARM Based CPU, Hexa-Core GPU, 16nm FinFET	$26.90
Baseband / RF / PA			**$33.90**
Baseband	Intel Corp	Baseband Processor, Multi-Mode	
RF Transceiver	Intel Corp	RF Transceiver, Multi-Mode (Qty:2)	
RF Front End			
Antenna Switch Module	TDK Corp	Antenna Switch Module, w/ Filters	
Antenna Switch Module	TDK Corp	Antenna Switch Module, w/ Filters	
Envelope Tracking	Qorvo Inc	Envelope Tracking IC	
FEM	Broadcom Ltd (Avago)	FEM	
FEM	Skyworks	FEM	
FEM	Skyworks	FEM	
PAM	Broadcom Ltd (Avago)	PAM	
PAM	Broadcom Ltd (Avago)	PAM	
PAM	Qorvo Inc	PAM	
PAM	Skyworks	PAM	
Battery			
	Huizhou Desay	Li-Polymer, 3.8V, 1960mAh	$2.50
BT / GNSS / WLAN			**$8.00**
BT / WLAN	Universal Scientific Industrial	BT / WLAN Module	
GNSS	Broadcom Ltd	GNSS Receiver	
Front End		BT / WLAN & GNSS Front End	
Cameras			**$19.90**
Front FaceTime		7MP BSI w/ Fixed Lens	
Rear		12MP BSI, w/ AutoFocus, & Optical Image Stabilization	
Display			**$39.00**
Display / Touchscreen Module		4.7" 1334x750 LTPS IPS LCD, w/ In-Cell Touch	
Electromechanicals			**$16.70**
Taptic Engine		Taptic Engine	
Other Electro-Mechanicals		Antennas, Connectors, Microphones, PCBs, Speakers, etc.	
Glue Logic			**$1.30**
	Lattice Semiconductor	FPGA - iCE40 Ultra, 40nm	
Mechanicals			**$18.20**
Enclosure		Enclosure, Main, Bottom - Machined Aluminum	
Other Mechanicals		Hardware, Labels, Insulators, Shielding, vents, etc.	
Memory			**$16.40**
NAND	SK Hynix	32GB NAND	
SDRAM	Samsung Semiconductor	2GB LPDDR4 PoP	
Power Management			**$7.20**
PMIC - Main	Dialog Semiconductor	PMIC - Main	
PMIC - RF	Intel	PMIC - RF	
Others		Other PMICs, Transistors, Diodes, etc.	
User Interface			**$14.00**
Audio codec	Cirrus Logic	Audio Codec	
Audio Amplifier	Cirrus Logic	Audio Amplifier (Qty:3)	
NFC	NXP	NFC Controller	
Others		Interface Ics, discretes, passives, etc.	
Sensors			
Barometer	Bosch Sensortec GMBH	Barometric Pressure Sensor	
e-compass	Alps	Electronic Compass	
Other Sensors		Accelerometer, Gyroscope, Touch ID Fingerprint sensor, ALS/Proximity sensor, etc.	
Box Contents			**$11.80**
Lightning Cable		USB to Lightning	
Lightning to 3.5mm Audio Adapter		Audio Adapter, Lightning to 3.5mm Jack	
Headset w/ Lightning Connector		Headset, Stereo, w/ Lightning Connector	
Charger		Wall to USB Type A Jack, 5V, 1A	
Boxes and Literatures			

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Summary of Key Drivers

- Population growth and demographic changes
- Global economy, supply chains, trade, and talent flows
- Intense and growing competition
- Economic prosperity under sustainability constraints

What is Advanced Manufacturing?

"Advanced manufacturing is a family of activities that

- depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or
- make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology.

It involves both new ways to manufacture existing products, and the manufacture of new products emerging from new advanced technologies."

President's Council of Advisors on Science and Technology
Report to the President on
Ensuring American Leadership in Advanced Manufacturing

How will (smart) manufacturing landscape change in the coming years?

Key Related Terms

- Industry 4.0
  - European vision
  - Fourth Industrial revolution
- Smart Manufacturing
  - US based Smart Manufacturing Leadership Coalition (SMLC)
- Cyber-Physical Systems (CPS)
- Internet-of-Things (IOT)

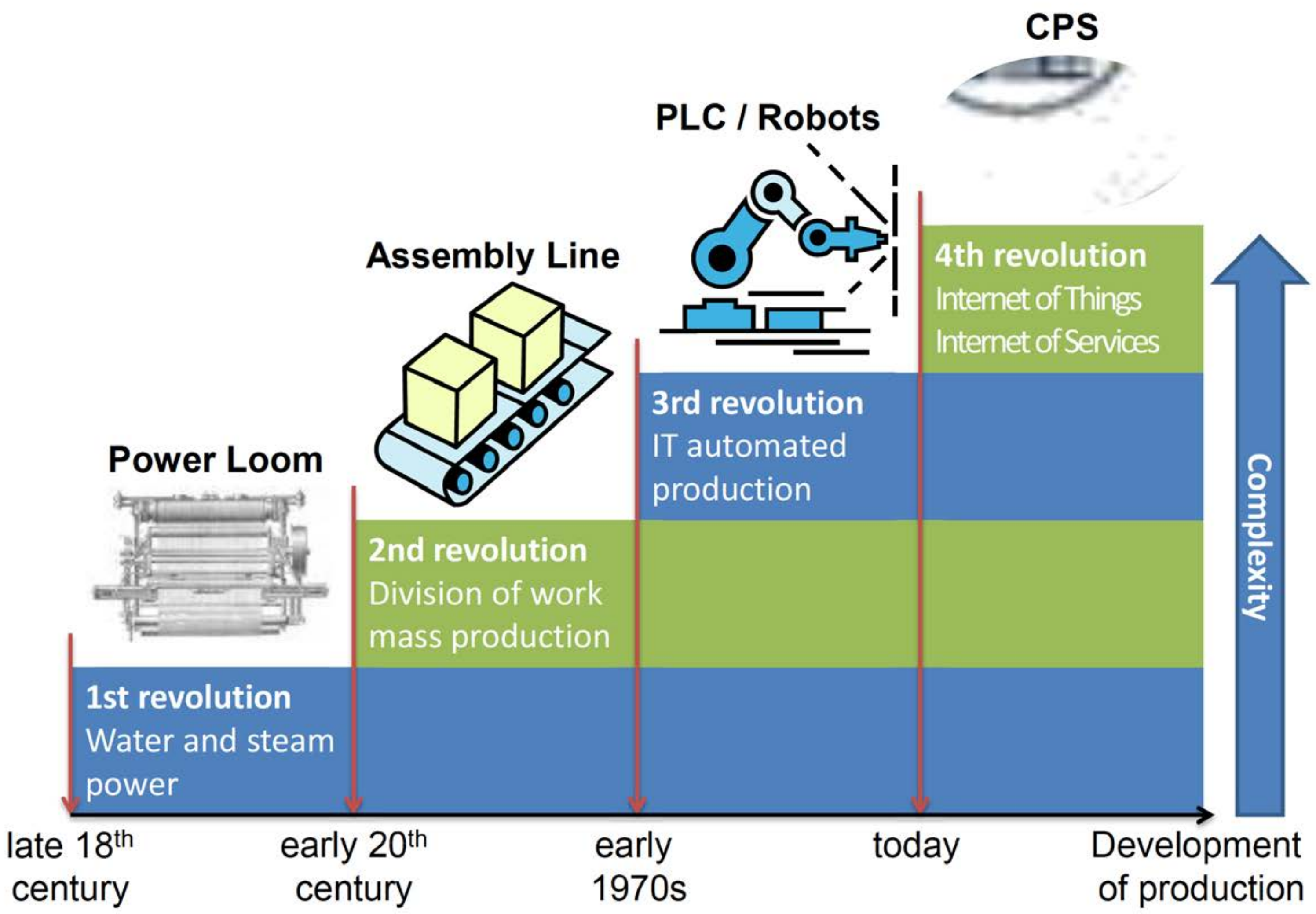


Fig. 1. Four industrial revolutions.

Thoben et al, Int. J. of Automation Technology 2017

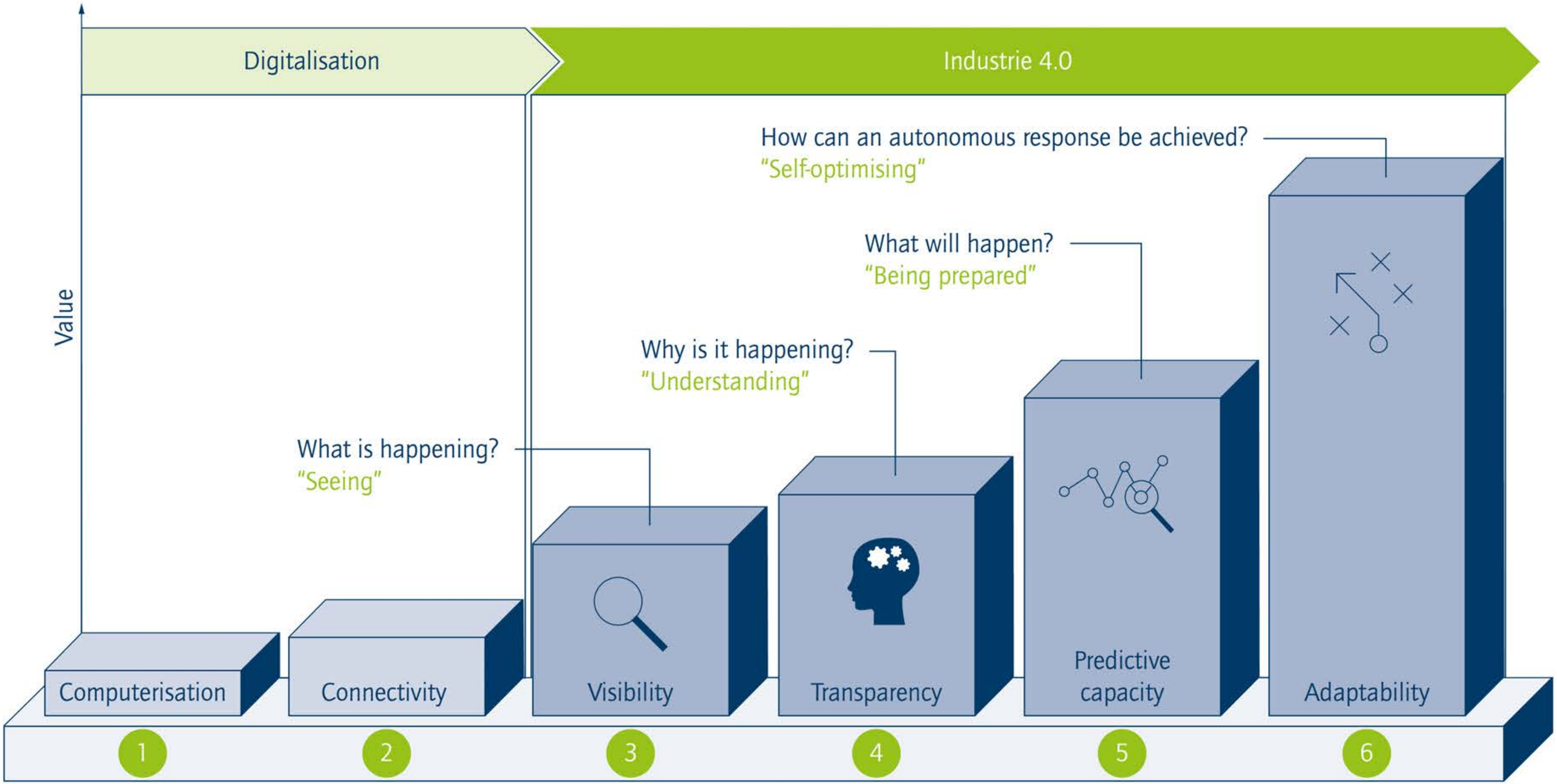
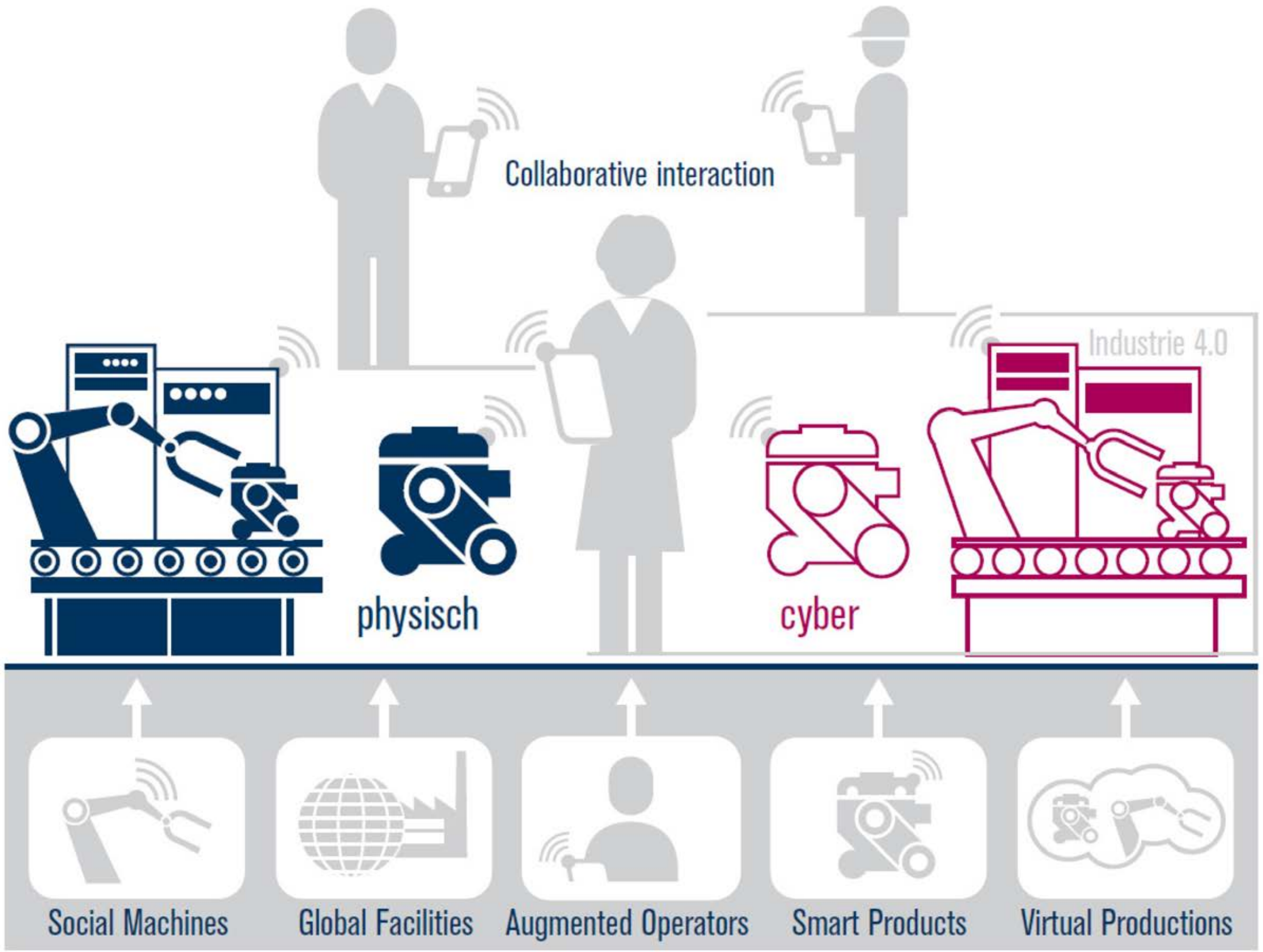


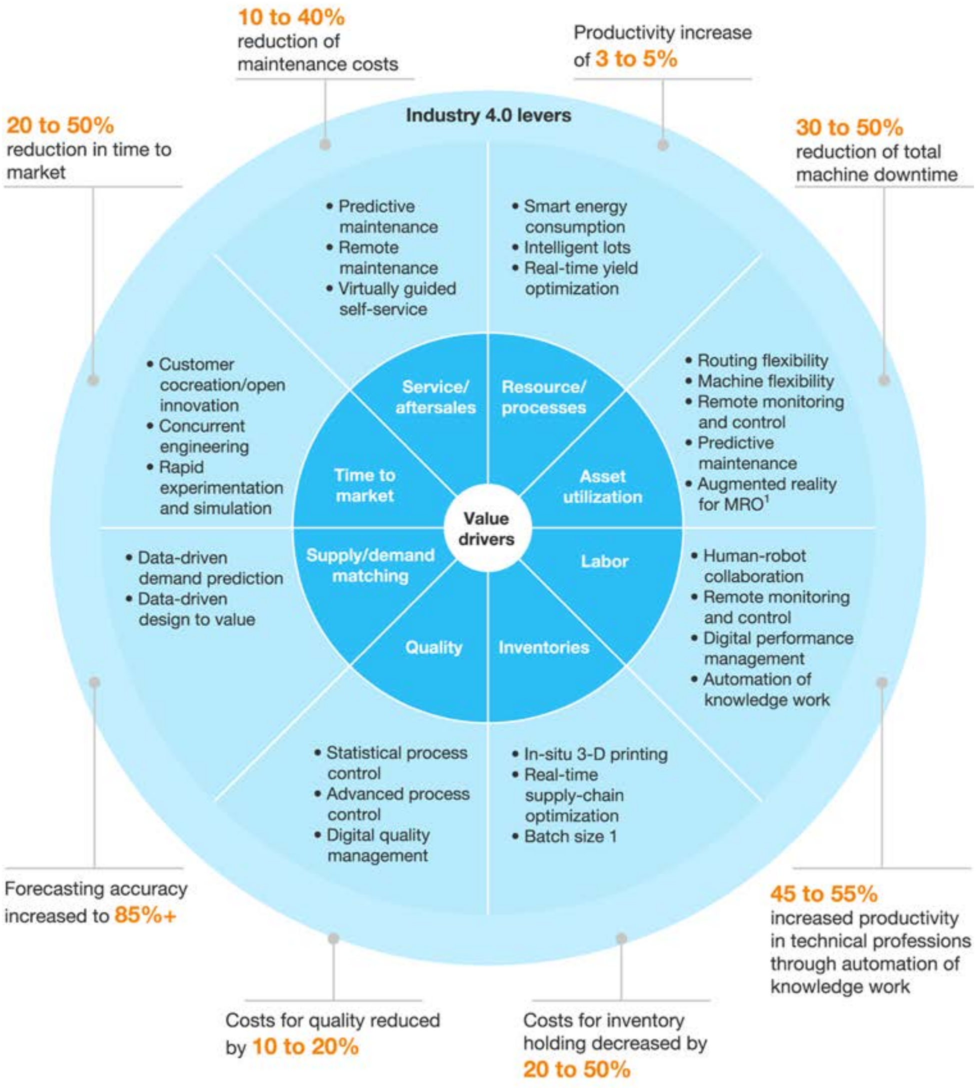
Figure 5: Stages in the Industrie 4.0 development path (source: FIR e. V. at RWTH Aachen University)



Source: Final report of the working group Industrie 4.0 [1]

Fig. 2. CPS Vision of Industrie 4.0.

The McKinsey Digital Compass maps Industry 4.0 levers to the 8 main value drivers.



[1]Maintenance, repair, and operations.

Source: "Industry 4.0: How to navigate digitization of the manufacturing sector," McKinsey Digital, 2015
McKinsey&Company

Source: McKinsey

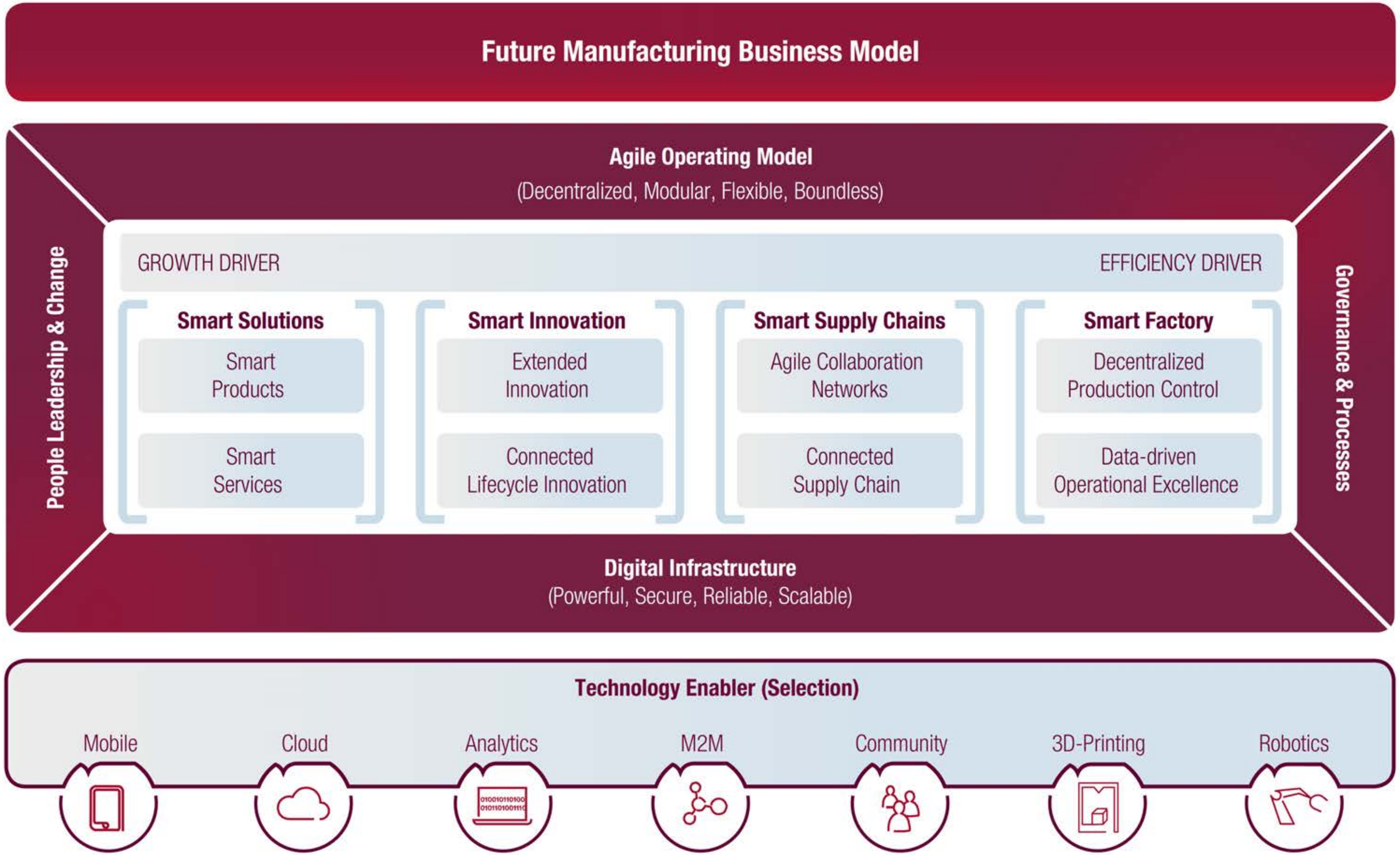
Nine Technologies Are Reshaping Production

Advanced robots	• Autonomous, cooperating industrial robots, with integrated sensors and standardized interfaces
Additive manufacturing	• 3D printers, used predominantly to make spare parts and prototypes • Decentralized 3D printing facilities, which reduce transport distances and inventory
Augmented reality	• Digital enhancement, which facilitates maintenance, logistics, and SOPs • Display devices, such as glasses
Simulation	• Network simulation and optimization, which use real-time data from intelligent systems
Horizontal and vertical system integration	• Data integration within and across companies using a standard data transfer protocol • A fully integrated value chain (from supplier to customer) and organization structure (from management to shop floor)
The Industrial Internet of Things	• A network of machines and products • Multidirectional communication among networked objects
Cloud computing	• The management of huge volumes of data in open systems • Real-time communication for production systems
Cybersecurity	• The management of heightened security risks due to a high level of networking among intelligent machines, products, and systems
Big data and analytics	• The comprehensive evaluation of available data (from CRM, ERP, and SCM systems, for example, as well as from an MES and machines) • Support for optimized real-time decision making

Source: BCG analysis.
Note: SOP = standard operating procedure. CRM = customer relationship management. ERP = enterprise resource planning. SCM = supply chain management. MES = manufacturing execution system.

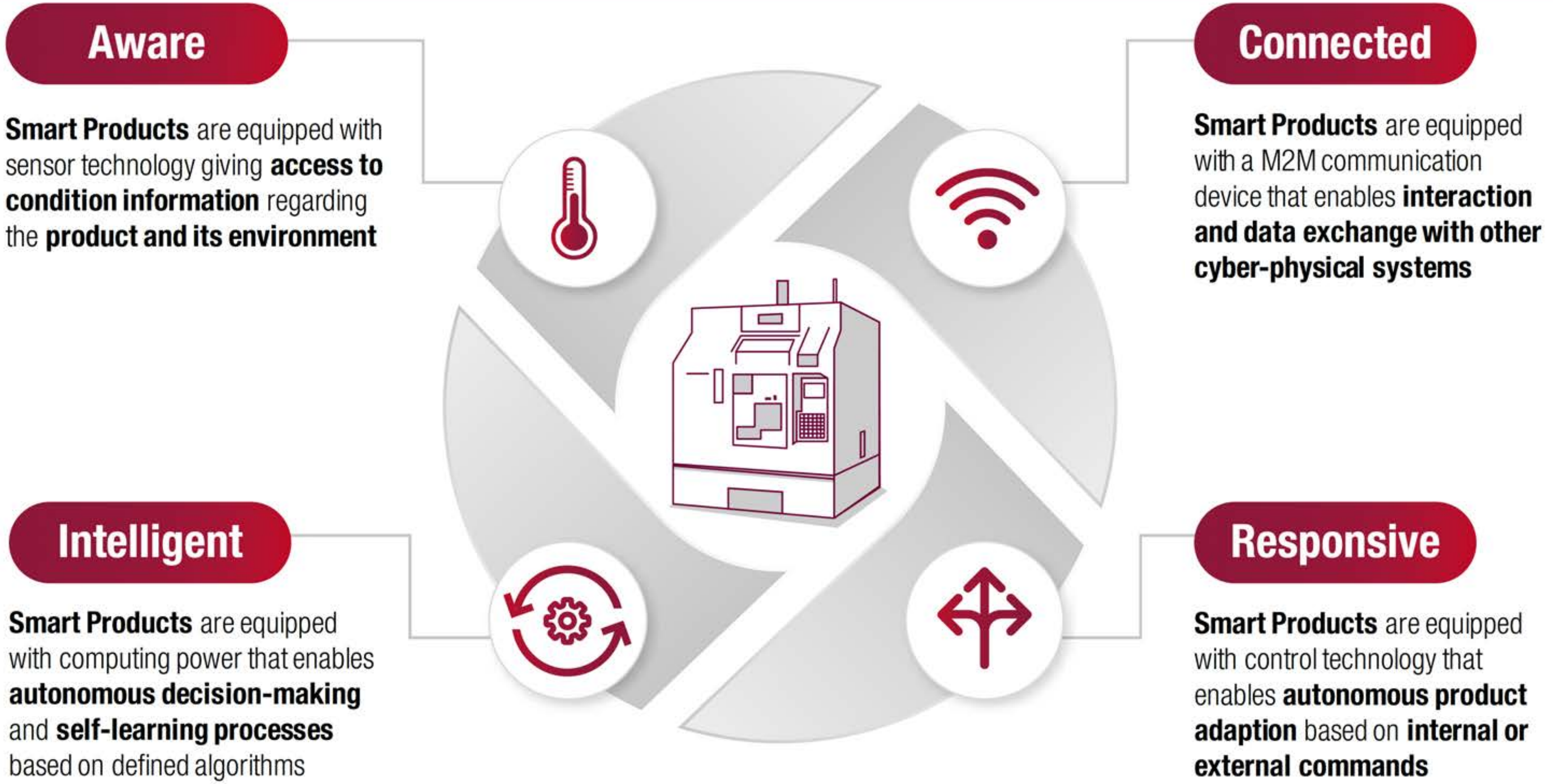
Source: BCG

The Capgemini Consulting Industry 4.0 Framework



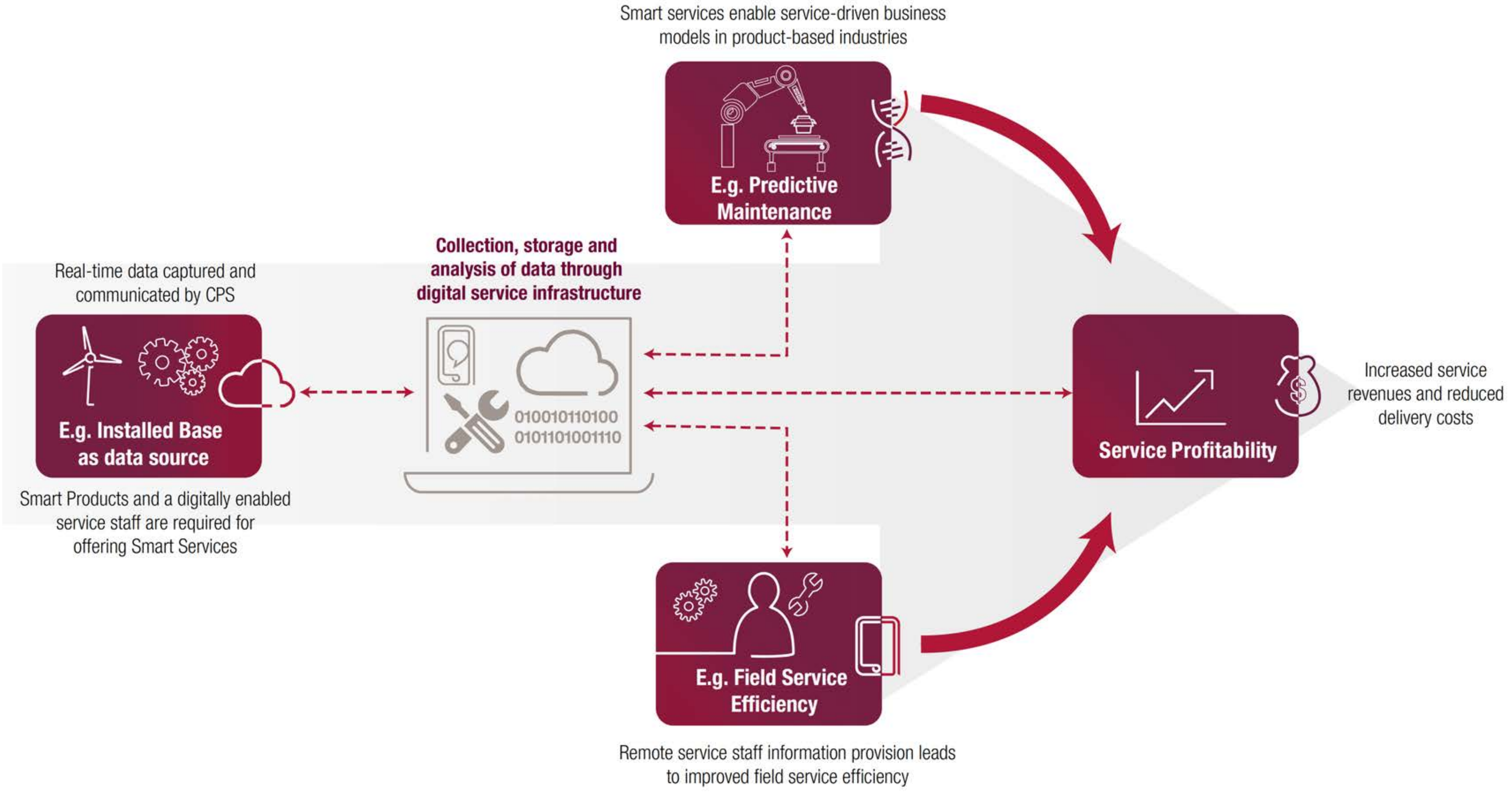
Source: Capgemini Consulting

Figure 1 - Defining characteristics of Smart Products



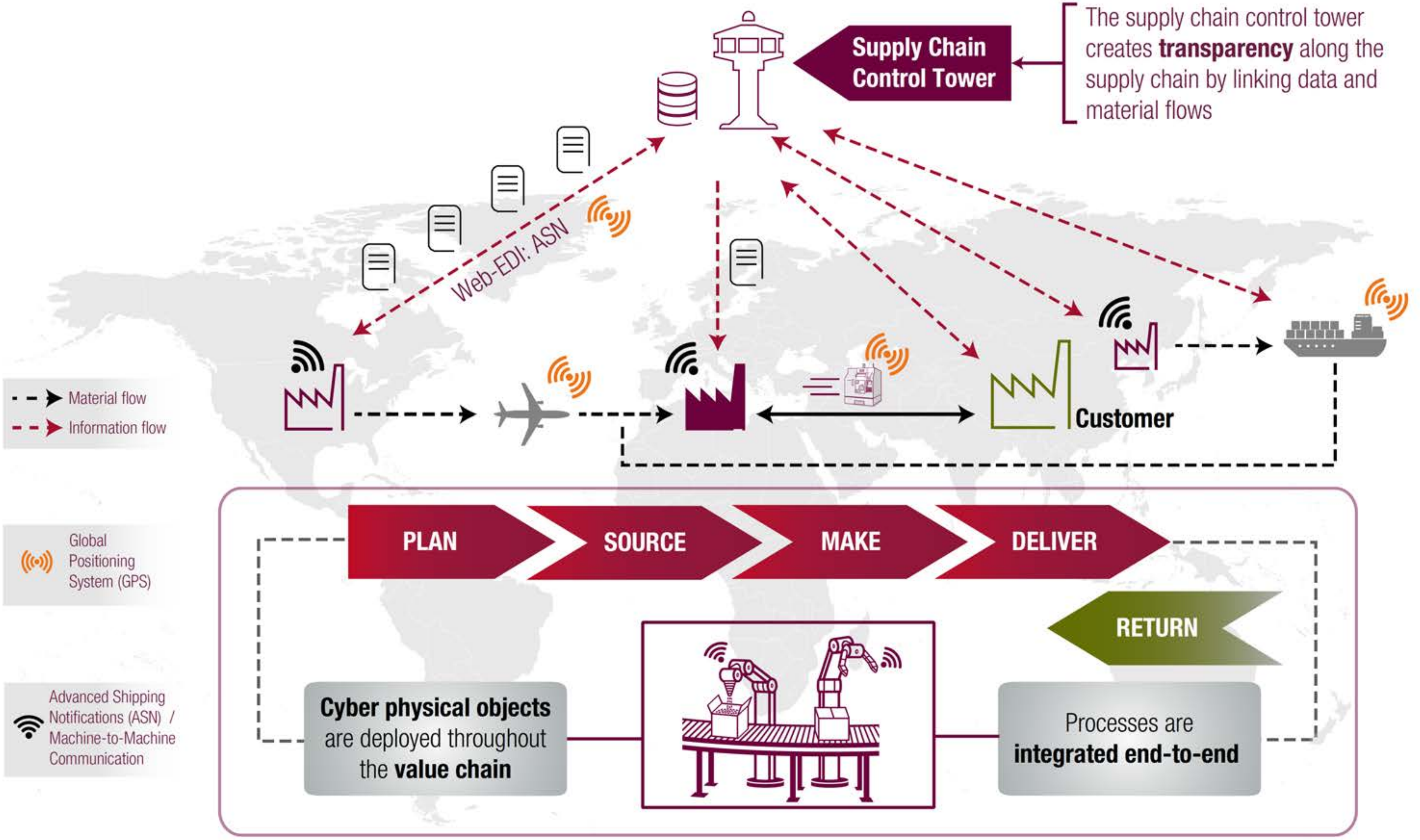
Source: Capgemini Consulting

Figure 2 - Value creation through Smart Services and remote service delivery



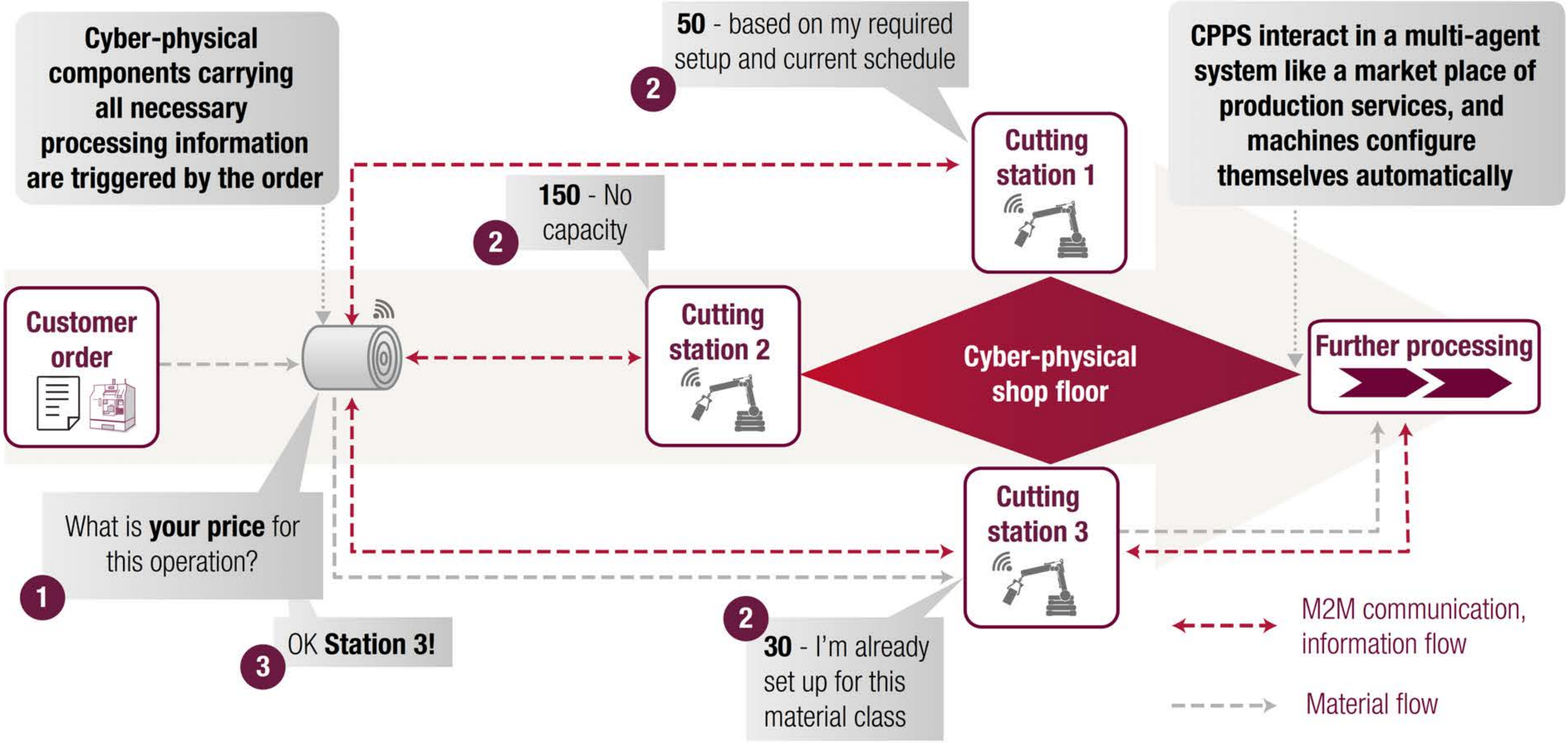
Source: Capgemini Consulting

Figure 8 - Basic structure of a Connected Supply Chain



Source: Capgemini Consulting

Figure 10 - The market mechanism enabling Decentralized Production Control



Source: Capgemini Consulting

Figure 12 - Business impact: Smart Factory

Smart Features	Functionality	Influence on Key Success Factors: Process cost	Batch size	Lead time	Product quality
Decentralized production control	Flexible production planning & control	●	●	◑	○
	Automated machine configuration	●	●	●	◑
Integrated data bases and advanced analytics	Detection of in efficiencies	[●]	◑	◑	◑
	Prediction of quality issues	◑	○	◑	●

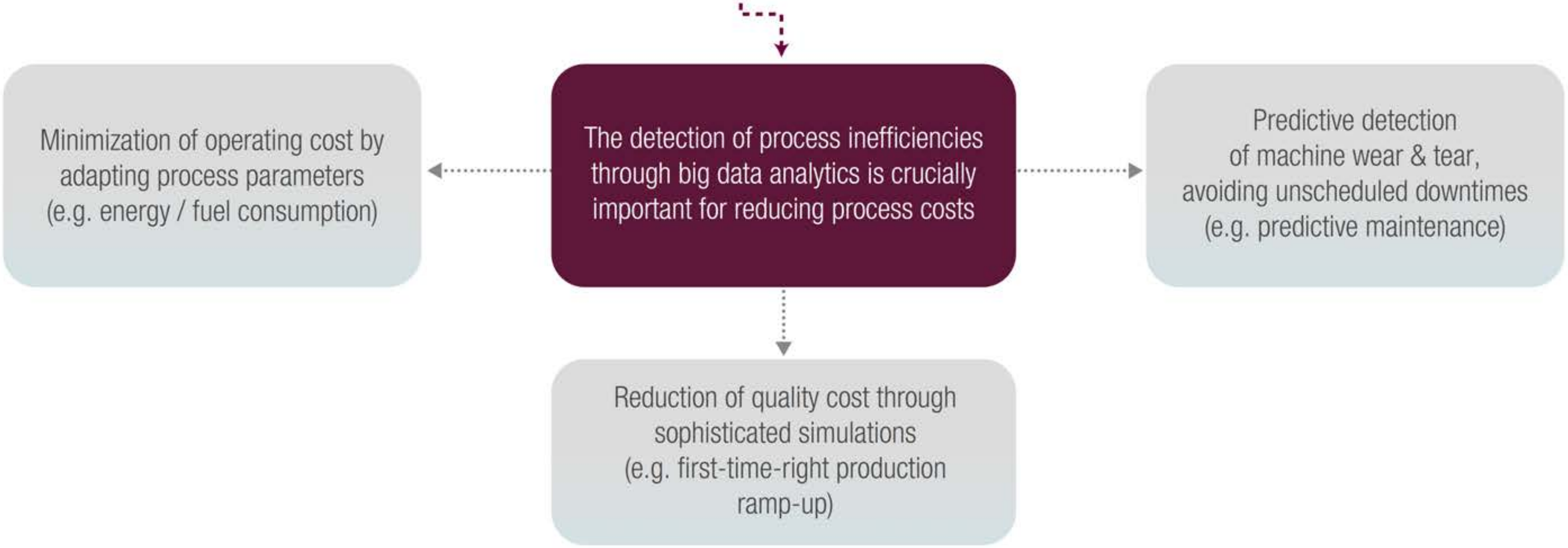


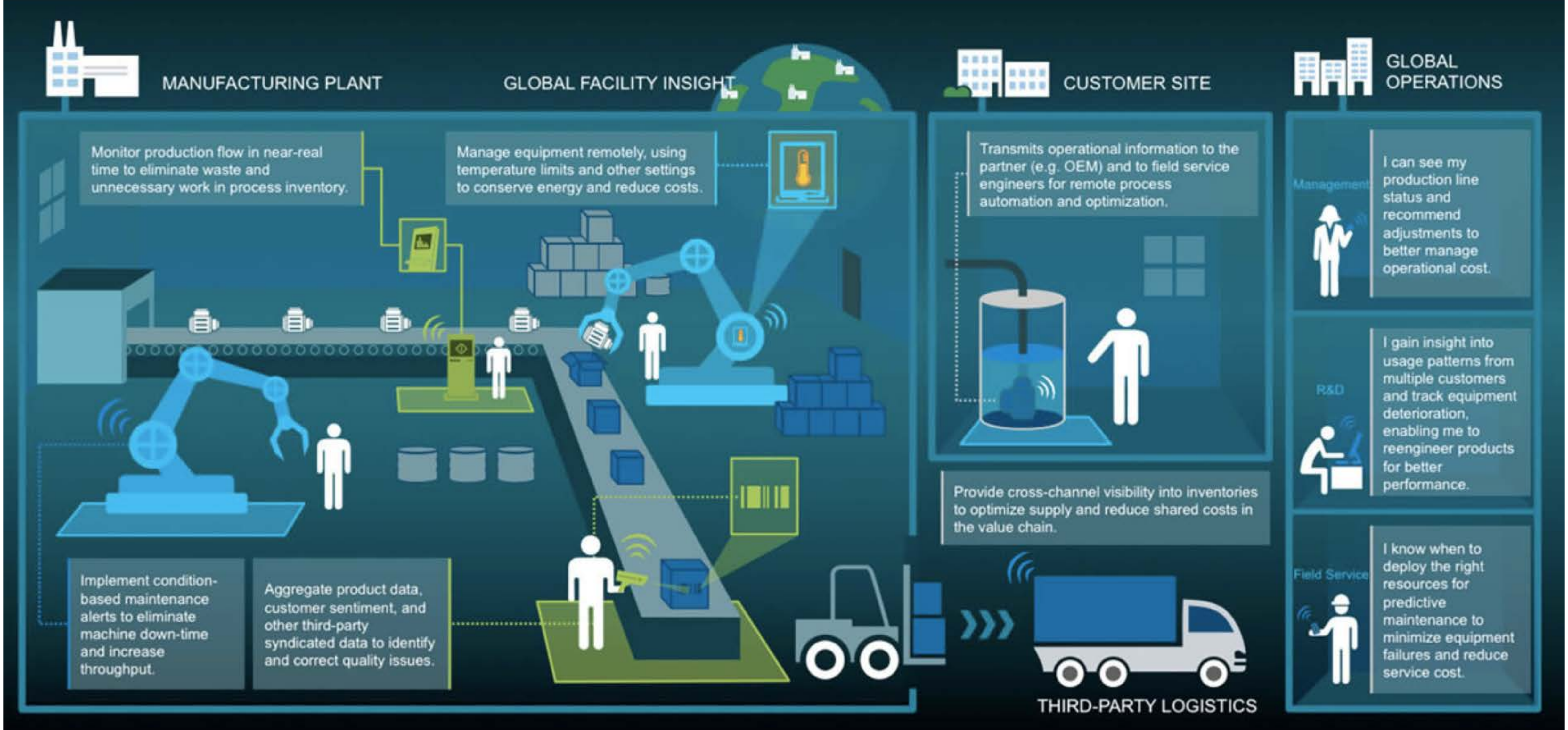
Figure 13 - Assessment of Technology Enablers' importance for realizing the value drivers of Industry 4.0

	Mobile	Cloud	M2M	Advanced Analytics	Community Platforms	3D printing	Advanced Robotics
Smart Products	●	●	●	●	○	○	○
Smart Services	●	●	●	●	○	◑	◑
Extended Innovation	○	●	○	●	●	○	○
Connected Lifecycle Innovation	●	●	●	●	◑	○	○
Agile Collaboration Networks	○	●	○	◑	●	●	●
Connected Supply Chain	●	●	●	●	○	○	○
Decentralized Production Control	◑	◑	●	●	○	●	●
Data-driven Operational Excellence	◑	●	●	●	○	○	○

Technology Enabler relevancy: Technology Enabler is of little importance for realizing this value driver ○-◑-● Technology Enabler is crucial for realizing this value driver

Source: Capgemini Consulting

Internet of Things in Manufacturing



Source: Microsoft

IoT Applications

- The application of IoT is projected to generate $1.2 to $3.7 trillion of value globally by 2025, in four primary forms:
  - operational efficiency;
  - predictive and preventative maintenance;
  - supply chain management;
  - inventories and logistics.
- Factory floor efficiency will have the largest impact
  - Increasing productivity by as much as 25 percent.
- IoT + data analytics + machine learning

Source: McKinsey

Predictive Maintenance

- Using sensors to monitor machinery in real-time, thus “transforming the maintenance model from one of repair and replace to predict and prevent.”
- Example: Ford placed IoT sensors on production equipment:
  - Downstream machines can detect if work pieces from an upstream machine deviate from specifications
  - Possible problems in upstream machines that can be identified and fixed.
- Example: Toyota reduces the burden of recalls by
  - Knowing exactly which machine produced each component of each vehicle
  - Enabling it to track and isolate the problems much more rapidly.

Source: ITIF

Supply Chain Integration

- Firms are likely to see significant improvements in operational efficiencies as intelligent devices connect machines on all the factory floors across a supply chain.
- Example: BMW concept of “connected supply chain”.
  - Upstream Tier 1 and 2 suppliers IoT-enabled their production equipment
  - Track and communicate production machines’ operational status

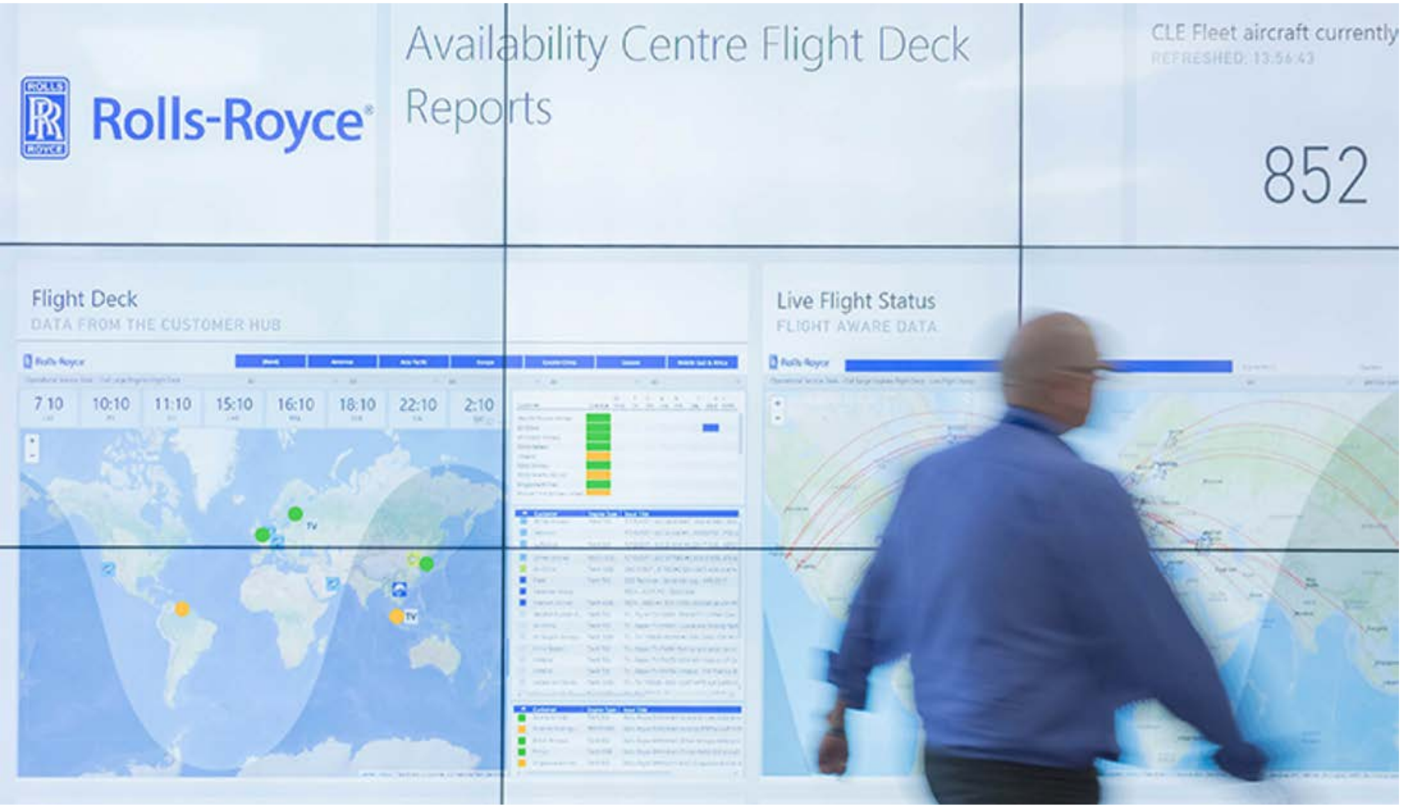
https://automotivelogistics.media/intelligence/bmw-shaping-self-steering-supply-chain

Inventory Optimization

- IoT can facilitate inventory optimization.
- Example: “iBins” system from Wurth USA
  - intelligent camera technology to monitor the supply boxes
  - wirelessly transmit the data to an inventory-management system
  - automatically reorders supplies as needed.
- IoT-enabled autonomous transport vehicles and robots
  - Factory floor operations
  - Materials transport
  - Logistics systems.

Source: Wurth, McKinsey

Example: Rolls Royce Aircraft Availability Center



Source: Rolls Royce

- Thousands of sensors in each Rolls-Royce engine track everything from fuel flow, pressure and temperature to the aircraft's altitude, speed and the air temperature.
- Data instantly fed back to Rolls-Royce operational centers.
- Civil aircraft availability center continuously monitoring data from 4,500 in-service engines.
- Providing customers with valuable aftermarket services, e.g, showing airlines how to optimize their routes

Andrew Ng on AI in Manufacturing

"AI technology is well suited to addressing the challenges facing manufacturing, such as variable quality and yield, inflexible production line design, inability to manage capacity, and rising production costs. AI can help address these issues, and improve quality control … shorten design cycles, remove supply-chain bottlenecks, reduce materials and energy waste, and improve production yields."

https://medium.com/@andrewng/revitalizing-manufacturing-through-ai-a9ad32e07814

Issue of Standards

The Alliance for Internet of Things Innovation

Towards the future

Circular Economy

OUTLINE OF A CIRCULAR ECONOMY

PRINCIPLE

1

Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows
ReSOLVE levers: regenerate, virtualise, exchange

PRINCIPLE

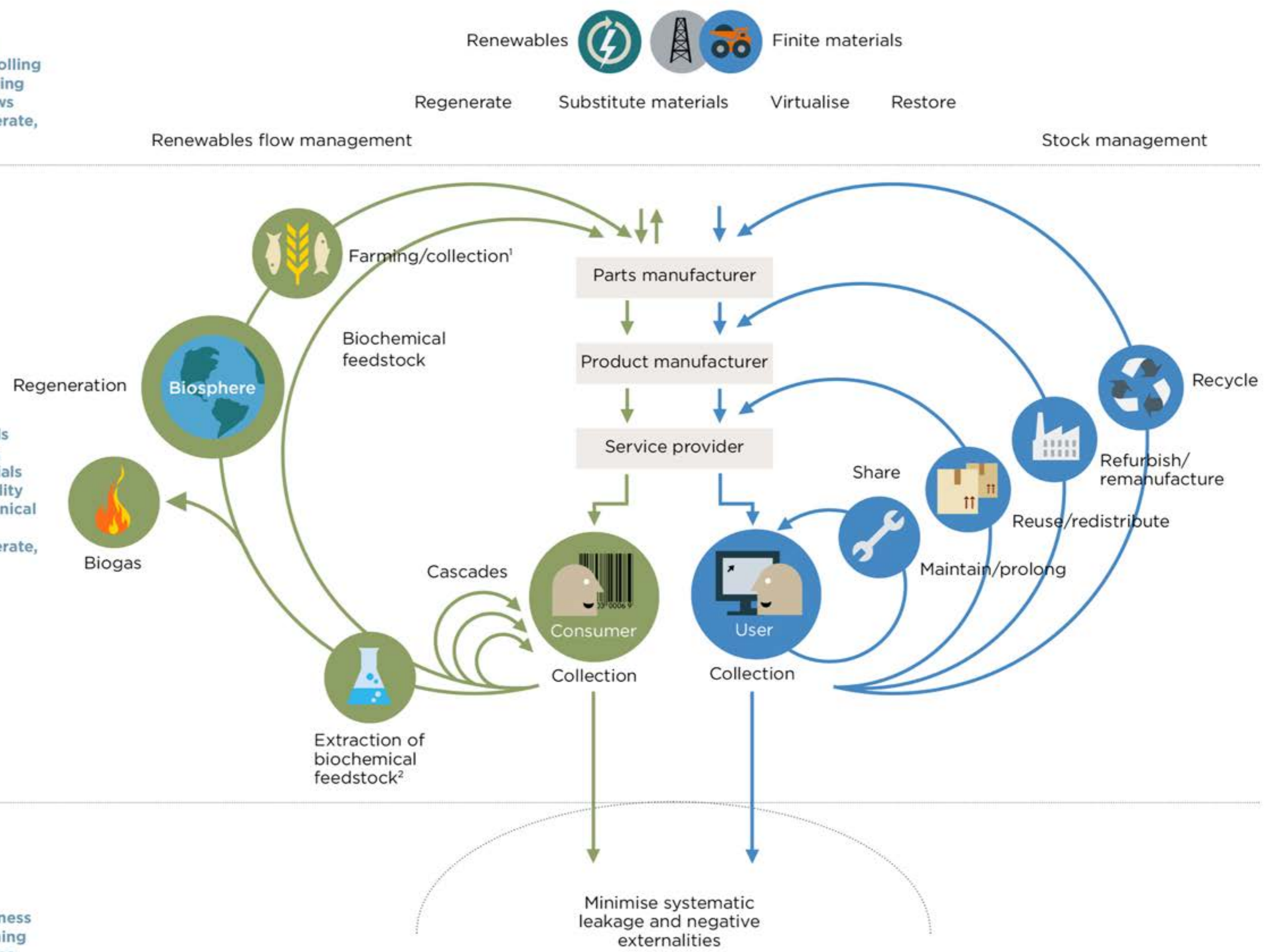
2

Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles
ReSOLVE levers: regenerate, share, optimise, loop

PRINCIPLE

3

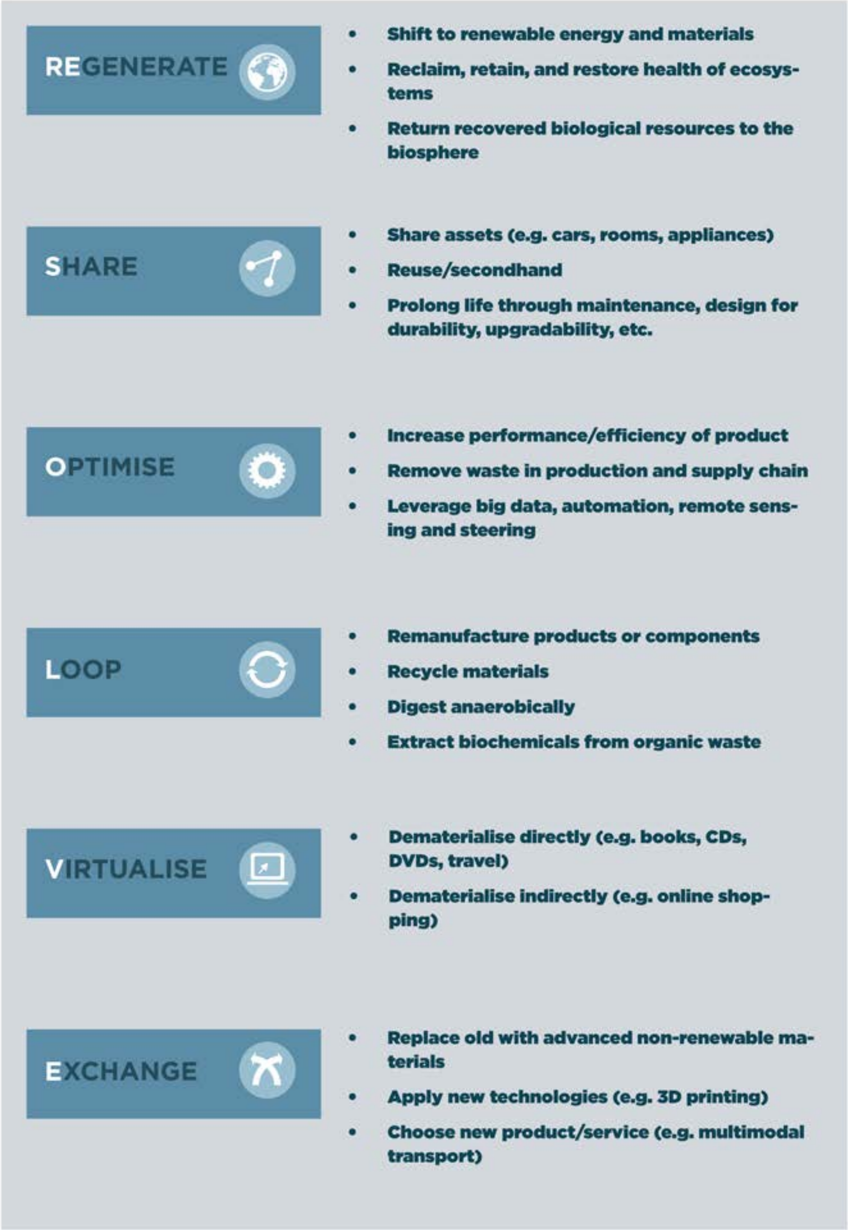
Foster system effectiveness by revealing and designing out negative externalities
All ReSOLVE levers



1. Hunting and fishing
2. Can take both post-harvest and post-consumer waste as an input

Source: Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment; Drawing from Braungart & McDonough, Cradle to Cradle (C2C).

Figure 2: The ReSOLVE framework: six action areas for businesses and countries wanting to move towards the circular economy



SOURCE: Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015). Based on S. Heck, M. Rogers, P. Carroll, Resource Revolution (2015).

Smart manufacturing technologies can impact some of these areas and enable circular economy

Much larger role for materials, natural resources, and energy

It will take more than technology

Key role for policy and regulations

Future of Manufacturing

What should/will manufacturing look like in 20 years?

- Sustainable manufacturing for a low carbon future, e.g., circular economy
- Affordable and economic goods and services
- Secure and reliable products, production, logistics, and distribution
- People and jobs: human-centered

UC Irvine is a Leader for the Future of Manufacturing

- Member of two Manufacturing Innovation Institutes:
    - Clean Energy Smart Manufacturing Innovation Institute (CSEMII)
    - Reducing EMbodied-Energy And Decreasing Emissions (REMADE) Institute
- Institute for Design and Manufacturing Innovation (IDMI)

CLEAN ENERGY SMART MANUFACTURING INNOVATION INSTITUTE™

REMADE INSTITUTE

UCI IDMI Institute for Design and Manufacturing Innovation

Conclusions

- Industry 4.0 and smart manufacturing will remain at the center of manufacturing revolution for the coming decade or longer
- Enormous challenges and opportunities in manufacturing ahead
- Technological progress will be critical
- But it must be human centered and aimed at societal prosperity and long term sustainability

Thank you!

Comments/ideas/questions?

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