INTELLIGENT ASSETS:

UNLOCKING THE CIRCULAR ECONOMY POTENTIAL

ELLEN MACARTHUR FOUNDATION

2016

The circular economy is an economic and environmental imperative but there is a huge gap between a big concept and a practical reality. The Internet of Things is the "glue" that links the trillions of items we consume each year globally, with the changes in everyday consumer behaviour, product recovery, material separation and remanufacturing that we need.

Mike Barry
Director, Plan A, Marks & Spencer

PREFACE

The exponential growth of digital connectivity has had a sweeping impact on our society in the last decade. It is widely understood that this increase in connectivity – and the technological innovation it spurs between people, products and systems – can create significant new sources of value for citizens and economies, whilst also creating new challenges for regulators and policy makers. Understanding and harnessing the potential of this "Fourth Industrial Revolution" for society, the economy and the environment is the theme of the 2016 Annual Meeting of the World Economic Forum. This report on intelligent assets – a key feature of the fourth industrial revolution – and how they can be paired with Circular Economy principles is, consequently, both an important and a timely contribution to the new economics agenda.

As we look to the next decade, the prevalence of connectivity, through the Internet of Things and the creation of 'intelligent assets', will accelerate. The question remains: how can these technological advances be harnessed to enable smarter economic growth, resource and food security, and an improved infrastructure? The Internet of Things is already increasing efficiency in our current linear 'take, make, dispose' economy. Could it also, however, enable a less resource-dependent *circular economy* that is restorative and regenerative by design? And, in turn, could embedding *circular economy* principles in smart connected systems and devices significantly bolster the opportunity? These are the questions we asked ourselves, and experts across the field, when writing this report.

This report illustrates opportunities for innovation and creativity across a spectrum of industries and sectors: it looks at how we manufacture and use electronics and advanced equipment, how we create our energy infrastructure, how we build and transform our buildings, and how we produce food. It assesses how smart cities might evolve to become a focal point for the transitions to follow. There are profit opportunities for companies to play for but perhaps more importantly, there's an opportunity for society to redefine its relationship with resources.

This document aims to provide the rationale for these opportunities that the intersection of the circular economy and smart connected devices could unlock for your business, city or region. While open questions remain to be explored, we believe the perspective shared here offers a compelling vision for intelligent assets in a circular economy. We invite you to add your voice to this conversation, and look forward to engaging with the first movers and leaders to act on this opportunity.

This report is the product of Project MainStream, an initiative that leverages the convening power of the World Economic Forum, the circular economy innovation capabilities of the Ellen MacArthur Foundation, and the analytical capabilities of McKinsey & Company. We are grateful to all the businesses and institutions that engaged with us to create this report, and to the Project MainStream Steering Board for its continued collaboration on the transition towards a circular economy.

Dame Ellen MacArthur
Founder, Ellen MacArthur Foundation

Dominic Waughray
Head of Public-Private Partnership, World Economic Forum

CONTENTS

There exists a great opportunity for aligning IoT innovation with a circular economy.
Carlo Ratti

FOREWORD

It could be that the early part of the 21st century is seen as the era when system-wide connections changed the economy and our way of life more profoundly than we realised at the time.

Intelligent Assets **delivers a landmark study of the opportunity and challenges ahead. It draws upon the important combination of circular thinking and connectivity, canvassing the views of a number of highly-regarded stakeholders on how to achieve a circular economy at scale.**

If new business models are designed correctly, they can be built at lower cost, offering improved quality of service while using fewer resources. This is an opportunity that must be seized by both businesses and governments to propel us into a new era of sustainable maturity.

While the principles of a large-scale circular economy are being embraced in industrialised countries, no greater potential for circular operating models can be seen than in emerging markets. The opportunity to transition towards new modes of industrialisation is profound. This has the potential to improve billions of lives while minimising intensive use of natural resources. We must manage our rapidly growing global population with this in mind.

It is vital that key stakeholders continue to work together to develop concrete proposals that meet the challenges posed in this report. This document will be a vital reference point for future collaboration if we are to deliver on the real promise of sustainable innovation.

Cisco and Philips are proud to be global partners of the Ellen McArthur Foundation, contributing dedicated resources and impassioned advocacy for the design of circular business models. Both our companies embrace circular values in our strategies, pioneering new technologies and solutions that we hope will shape our industries and build a more sustainable global future.

Frans van Houten
Chief Executive, Royal Philips

Chuck Robbins
Chief Executive, Cisco Systemss

PROJECT MAINSTREAM

This report was written under the umbrella of Project MainStream, a multi-industry, global initiative launched in 2014 by the World Economic Forum and the Ellen MacArthur Foundation, with McKinsey & Company as knowledge partner. MainStream is led by the chief executive officers of nine global companies: Averda, BT, Desso BV (a Tarkett company), Royal DSM, Ecolab, Indorama, Philips, SUEZ and Veolia.

MainStream aims to accelerate business-driven innovations and help scale the circular economy. It focuses on systemic stalemates in global material flows that are too big or too complex for an individual business, city or government to overcome alone, as well as on enablers of the circular economy such as digital technologies.

DISCLAIMER

A team from the Ellen MacArthur Foundation produced this report in collaboration with the World Economic Forum. The Ellen MacArthur Foundation takes full responsibility for the report's content and conclusions. While the contributors listed in the acknowledgements provided significant input for the development of this report, their participation does not necessarily equate to endorsement of the report's full content and conclusions.

SUPPLEMENTARY INFORMATION AVAILABLE

Extended versions of select case studies are available from the Ellen MacArthur Foundation website. www.ellenmacarthurfoundation.org/publications/intelligent-assets

ENHANCED DIGITAL CONTENT AVAILABLE

The digital version of this report contains audio tracks with additional comments from selected contributors. Click on the symbols to listen.

.

IN SUPPORT OF THE CIRCULAR ECONOMY AND INTELLIGENT ASSETS

The coming profusion of smart sensors and connected technologies that makes up the Internet of Things will have a profound effect on our cities. Cities are already leading the way in reducing carbon emissions and deploying smart systems, and the circular economy is the next big opportunity that a city like London is best placed to drive forward. London already has a strong and growing low carbon goods and environmental services economy and I foresee the same opportunity presenting itself in the circular economy.

Boris Johnson
Mayor of London

We have tremendous challenges ahead of us. We have to improve the human condition around the world as the population grows, while at the same time learning to tread more lightly on our planet. The only way we'll meet them – and I'm confident that we will – is with a combination of technological progress, innovation, markets and goodwill.

Andrew McAfee
Co-Director, MIT Initiative on the Digital Economy; Author, The Second Machine Age

Truly circular economies arguably cannot exist without the Internet of Things. No amount of clever design ensures a complex system will remain useful and efficient over time. To be sustainable, a system must be responsive; actions and behaviours must be connected via data and knowledge. With the embedding of intelligence in almost every object, we can imagine systems that adapt and respond to change in order to remain fit for purpose.

Tim Brown
Chief Executive Officer, IDEO

The projected addition of high tens of billions of IoT devices in the next several years will dramatically intensify connectivity among individuals and various units, organic and inorganic. Future advances in systems integration on chips or stacked chips with nanoscale devices for both dense memory and fast logic, versatile biosensors, neuromorphic computing and deep machine learning capacity will rapidly increase the intelligence of machines, robots, equipment and connected things, thus helping to strengthen the circular economy. The growth of the circular economy will in turn enlarge the optimisation problems domain, generate immensely big data, identify new needs and call for more innovations in future electronics, thereby feeding each other in a continuously evolving and sustainable ecosystem for a better world for all.

Sung-Mo Steve Kang
President, Korea Advanced Institute of Science and Technology; *Chair,* Global Agenda Council on the Future of Electronics

For the SDGs [Sustainable Development Goals] and the search for sustainable growth models, the Internet of Things combined with big data and data analytics has the potential to turbocharge promising circular economy models, in part via the impact on the efficiency of use, maintenance and longevity of assets. This surely will advance us several steps towards growth models that allow for expanding prosperity while maintaining and augmenting the natural capital base of the global economy and our existence.

Michael Spence
Nobel Laureate; William R. Berkley *Professor in Economics and Business,* NYU

The Internet of Things and circular economy practices are mutually reinforcing – bundled together they present immense opportunities — for business and society at large — leading to systems that are resilient, decentralised, self-repairing and scalable without experiencing complexity problems. The natural world – life itself – is network based, and bio-inspired systems are already standard. Looking forward, the Internet of Things will provide information about what resources we have and what we are losing. With objects becoming increasingly self-aware, the sharing platform of the future could have assets making themselves available for use in real-time. Enhanced tagging and tracking capabilities, such as insect-inspired swarm intelligence, present enormous economic opportunities to plug leaks and make use of materials previously considered to be waste.

Janine Benyus
Co-founder of the Biomimicry Institute

Information is at the heart of ensuring that businesses around the world can make the right decisions to eradicate waste and use resources effectively. The internet of things, with its smart sensors and connected technologies, can play a key role in providing valuable data about things like energy use, under-utilised assets, and material flows to help make businesses more efficient. Their role in building a future with a more circular economy is critical and we are excited about the role technology will play in realising this vision.

Kate Brandt
Lead for Sustainability, Google Inc.

ACKNOWLEDGEMENTS

PROJECT TEAM

Ellen MacArthur Foundation
Andrew Morlet
Chief Executive

Jocelyn Blériot
Executive Officer;
Lead, Communications and Policy

Rob Opsomer
Lead, Project MainStream

Dr. Mats Linder
Project Manager

Anina Henggeler
Analyst

Alix Bluhm
Analyst

Andrea Carrera
Analyst

World Economic Forum
Dominic Waughray
Head of Public-Private Partnership,
Member of the Executive Committee

Nathalie Chalmers
Project Lead, *Circular Economy*
and Global Leadership Fellow

Wolfgang Lehmacher
Head of Supply Chain and Transport
Industries

James Pennington
Project Specialist, Circular Economy

Opinion Piece Contributors
Bernard Meyerson
Chief Innovation Officer, IBM

Carlo Ratti
Professor, Massachusetts
Institute of Technology

Frank Appel
Chief Executive Officer,
Deutsche Post DHL

Kenneth Cukier
Data Editor, The Economist

Neil Crockett
Chief Executive Officer,
The Digital Catapult United Kingdom

Nicolas Cary
Co-founder, Blockchain

Ricardo Abramovay
Professor, University of São Paolo

Rick Robinson
IT Director for Smart Data and Technology,
Amey

EXPERT INPUT AND CASE STUDY CONTRIBUTORS:

Angaza Design
Victoria Arch
Vice President of Global Strategy

ARUP
Rainer Zimmann
Waste Business Leader

Auscott Limited
Harvey Gaynor
Chief Executive Officer

Balbo Group
Fernando Alonso de Oliveira
Organic Products Manager

BURBA[1]
Carolina Launo
Ivo Maria Cassissa
Coordinators, European Project
and the Consortium.

CISCO
Matthew Smith
Global Head of Market Development,
Internet of Everything

Neil Harris
Head of Sustainability, Cisco Europe

Daniel Keely
Senior Manager,
Enterprise Business Group

Nalamati Laxman Siddharth
Business Analyst, Internet of Everything
Market Development

Darrel Stickler
Expert, Sustainable
Business Practices & CSR

Pauline Vogl
Project Manager,
Sustainable Business Practices

Circularity Capital
Jamie Butterworth
Co-founder

City of Copenhagen
Morten Højer
Chief Advisor on Climate
and Economy

Rikke Gram-Hansen
Senior Consultant,
Copenhagen Solutions Lab

Søren Kvist
Senior Consultant,
Copenhagen Solutions Lab

Courbanize
Gretchen Effgen
Vice President Business Development;
former Vice President Strategy and
Corporate Development, Zipcar

Delta Development Group
Owen Zachariasse
Manager,
Innovation and Sustainability

DIRTT
Julie Pithers
DIRTTbag

eBAY inc
Brian Bieron
Executive Director,
eBay Public Policy Lab

Ellen Macarthur Foundation
Ken Webster
Head of Innovation

Ashima Sukhdev
Project Manager

Enit Systems
Hendrik Klosterkemper
Chief Executive Officer

HP
John Ortiz
Director,
Product Stewardship, HP

IBM
Solomon Assefa
Director,
Research Africa

Mary Keeling
Manager Economic Analysis,
Smarter Cities, Analytics

Jad Oseyran
Circular Economy Lead,
Global Business Services

Imaflora
Patrícia Cota Gomes
Coordinator,
Forestry Market Projects

Innobasque
Carolina Rubio Miner
Programme Director

Libelium
Alicia Asin
Chief Executive Officer

David Gascon
Chief Technical Officer

Judy Curtis
Technology and Life Sciences

McKinsey Center For Business And Environment
Helga Vanthournout
Senior Expert

Dr. Martin R. Stuchtey
Director

Miniwiz
Johann Boedecker
Communications Director, Partner

Nutter Consulting
Melanie Nutter
Principal,
Nutter Consulting and former Director
of the San Francisco Department of
Environment

Onfarm Systems
Sarah Mock
Marketing

Philips
Markus Laubscher
Program Manager Circular Economy

Premise
Jonathan Doyle
Director of Field Engineering

Product Health
Tamara Giltsoff
Founder and Director,
Business Development

Provenance.org
Jessi Baker
Founder

Smart City Expo World Congress
Ugo Valenti Vazquez
Managing Director

Folc Lecha
Chief Press Officer

Spire
Theresa Condor
Vice President Corporate Development

Sunpower
Marty Neese
Chief Operating Officer

Marissa Yao
Director of Sustainability

TOMRA
Stefan Ranstrand
President and Chief Executive Officer

United Nations Conference on Trade and Development (Unctad)
Anne Miroux
Director,
Division on Technology and Logistics,
Head of the Secretariat of the United
Nations Commission on Science and
Technology for Development

University Collage London
Joanna Williams
Senior Lecturer & Director of
Communications,
Bartlett School of Planning

University of Lorraine
Eric Rondeau
Professor

Wired
Sophie Hackford
Director,
WIRED Consulting and WIRED
Education

PRODUCTION

Editor: *Ruth Sheppard*

World Economic Forum editor:
Fabienne Stassen

Design: *Graham Pritchard*

GLOBAL PARTNERS OF THE ELLEN MACARTHUR FOUNDATION

CISCO · Google · H&M · INTESA SANPAOLO · Kingfisher · PHILIPS · RENAULT · Unilever

1 Electronic Systems, Bottom Up selection, collection and management of URBAn waste (BURBA) project (funded by European Commission under the FP7, with contract number FP7 - ENV – 2010 - 265177).

EXECUTIVE SUMMARY

50bn

There will be 25-50 billion connected devices by 2020.

The impending digital transformation holds the potential to redefine the very basis of our materials-reliant industrial economy. Enabled by intelligent assets, a new model of development gradually gaining independence from finite resource extraction is emerging. Can pervasive connectivity become the new infrastructure: enable effective material flows, keeping products, components and materials at their highest value at all time, and thus in turn enabling the coming of age of the circular economy? Such a system would generate, on top of business advantages, multiple benefits for users and society as a whole. It would be a system where shared and multimodal transport help citizens to quickly and safely navigate to their destination, even during rush hour. A system where assets are able to signal the need for maintenance before breaking down, and in which farmers can monitor and regenerate areas of their land which are at risk of degradation, while at the same time providing abundant and fresh produce.

Early signs of this transformation are perceptible, as this report highlights, yet clarifying and scoping out the depth of change at play in the global economy is necessary to harness the full potential of this positive wave of development.

A rapid increase in the number of intelligent assets is reshaping the economy, and this development will create significant value. The number of connected devices is expected to grow to 25–50 billion by 2020, from around 10 billion today. A growing body of research indicates that this Internet of Things (IoT) offers a trillion-dollar opportunity, brought about by improved production and distribution processes and, perhaps more importantly, a significant shift in the way products are utilised.

As author James Bradfield Moody[2] puts it, the *"processors are starting to communicate beyond the confines of their device, and are sharing information that has never been shared, or even collected, before. This brings us to [a] big idea that will govern how we innovate in a resource-limited world – the convergence of the digital and natural worlds."*

Pairing this digital revolution with circular economy principles can indeed transform the economy's relationship to materials and finite resources, thus unlocking additional value and generating positive outcomes. The circular economy helps decouple economic value creation from resource consumption. Its four value drivers – extending the use cycle length of an asset, increasing utilisation of an asset or resource, looping or cascading an asset through additional use cycles, and regeneration of natural capital – can be combined with one (or several) of the three main intelligent asset value drivers – knowledge of the location, condition, and availability of an asset.

In this systemic change perspective, IoT becomes the new, virtualised infrastructure that governs assets use and movements along the value chain. Digital tools – such as exchange platforms allowing multiple useful lives and embedded product information – become as important as physical tools when it comes to determining and steering asset flows. The value created can extend beyond direct business benefits, and generate significant wider societal benefits. In mobility, for example, IoT-enabled apps helping drivers to find a parking space and avoid busy roads not only deliver a direct user advantages, but also reduce congestion and emissions, hence benefiting society as a whole.

Businesses are already exploiting the interactions between the circular economy framework and intelligent assets today, across several sectors, and with a focal point in cities. By breaking down structural barriers established over time between production and consumption or use, an IoT-enabled circular economy offers considerable opportunities for a multitude of sectors including manufacturing, energy and utilities, built environment and infrastructure, logistics and waste management, and agriculture and fishing. Both large incumbents and disruptive innovators are rethinking their models and value chains, indicating that the digital revolution is not a niche market but the underpinning of a new economy. With over 80% of global GDP generated in urban areas and multiple opportunities to optimise materials flows, cities are at the forefront of the upcoming transformation.

What is at stake is not incremental change or a gradual digitisation of the system as we know it, but a reboot: pervasive connectivity rolled out at scale has the power to redefine value generation, whilst helping emerging economies bypass heavy upfront investments and material-intensive solutions. For instance, an ecosystem of intelligent asset-enabled services could jointly open widespread access to reliable, grid-free renewable energy. Solar panels could be provided as a service to individuals and businesses without access to the capital to buy solar panels themselves, through weekly online payments. Battery health monitoring, predictive maintenance of panels, automated management of distribution systems and other IoT-enabled services could complement this model to avoid the massive investment in capital and resources needed to develop a centralised grid infrastructure.

Such a promising horizon entails redefined collaborative mechanisms between technology and the framework within which it operates. At the confines of innovation and regulation, creativity needs to be called upon in order to manage the complex questions raised by data circulation and capture, compatibility of systems and intellectual property. Several experts consulted have remarked that companies need to shift away from a protective approach and closed innovation, towards more open-source, collaborative data platforms. At the same time, the proliferation of sensing equipment in society raises important questions about data security and privacy. Addressing these challenges requires new rules of the game that will allow the fast-moving technology and market trends to evolve. Companies and policymakers would need a multi-stakeholder approach to create such conditions; if successful they could lay the groundwork for solving several of the core challenges for designing an economy that is truly restorative and regenerative.

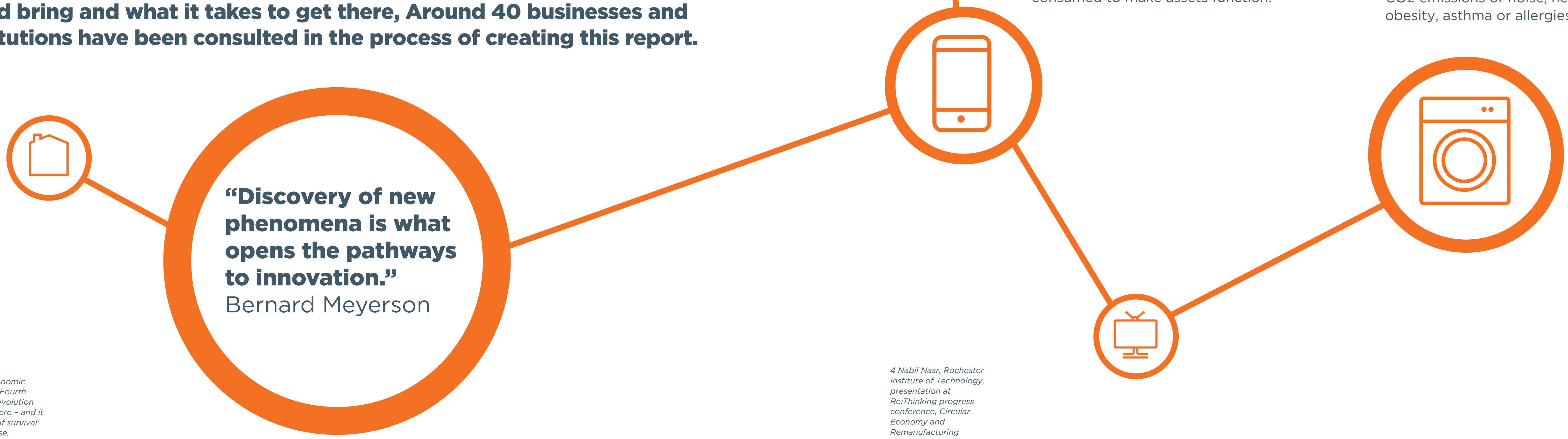
2 J. B. Moody, B. Nogrady, The Sixth Wave – how to succeed in a resource-limited world (2010).

INTRODUCTION

Digital technology is fast becoming a pervasive feature across a wide variety of products. Equipped with the ability to sense, store and communicate information about themselves and their surroundings, these 'intelligent assets' are posed to unlock tremendous opportunities for businesses and individuals. Will this development – by many regarded as the impending 'fourth industrial revolution'[3] – lead to an acceleration of the extractive, 'linear' economy of today, or will it enable the relative decoupling of resource consumption from economic development and accelerate the transition towards the circular economy? To what extent could intelligent assets contribute to capturing circular economy benefits? And importantly, what are the key challenges to address in order to realise the potential opportunity?

This report is the first of its kind to discuss these questions, by studying the interplay between the value drivers of circular business practices and intelligent assets. Its goal is to shed light on the value creation opportunities that are emerging from this interplay, and to give a directional perspective on potential opportunities in the medium to long-term. In doing so, it seeks to initiate a discussion inspiring businesses, innovators, and policymakers to explore the synergies that circular economy and intelligent assets can generate.

The report builds its arguments on aggregated insights from a collection of case studies and stand-alone opinion pieces from a wide range of thought-leaders – reflecting today's ongoing developments but also what the future could bring and what it takes to get there, Around 40 businesses and institutions have been consulted in the process of creating this report.



"Discovery of new phenomena is what opens the pathways to innovation."
Bernard Meyerson

3 World Economic Forum, The Fourth Industrial Revolution 'is already here – and it is a matter of survival' (Press release, 26 October 2015).

USEFUL DEFINITIONS

Although this report is not technical in nature, it discusses a number of technical concepts, some of which currently have somewhat different meanings depending on who is discussing them. The following definitions aim to clarify the terminology used in this report.

Internet of Things (IoT). The networked connection of physical objects. For simplicity, this term is used in this report to indicate all objects, systems and processes that are exchanging information through the Internet, instead of differentiating them by additional definitions (e.g. the Web of Things, Internet of Everything or Industrial Internet of Things).

Intelligent assets. Physical objects that are able to sense, record and communicate information about themselves and/or their surroundings. This definition incorporates IoT objects but also includes assets that are not continuously transmitting information, and things that do not feature wireless communication.

Asset. A physical object, such as a machine, building or material. Components of objects are also described as assets because they are frequently treated individually during or after a use cycle.

Resource. A flow or stock of materials or energy that can be transformed into assets or consumed to make assets function.

Performance models. A business agreement in which the customer pays for the use, or the performance, of a product rather than the product itself. The rationale is that there is no inherent benefit in owning the product. On the contrary, ownership can entail additional costs (upfront investment), risk (unpredicted repair, maintenance or obsolescence), and end-of-use treatment costs. Performance models go under several names with different specifics, e.g. service contracts or 'servitisation', leasing or asset centralisation. The emergence of IoT has also led to the popular notion of 'anything-as-a-service'. The term 'performance model' is used to encompass all these varieties in this report.

Remanufacturing. A process of disassembly and recovery of an asset at a product and component level. Functioning, reusable parts are taken out of a used product and rebuilt into another. By definition, the performance of the remanufactured component is equal to or better than 'as new'.[4]

Reverse logistics. The process of moving goods from their typical final destination to concentrate them at a central location, either for the purpose of capturing value (through reuse, remanufacturing, refurbishment, parts harvesting or recycling), or for proper disposal.

Negative externalities. Negative externalities can be defined as cost suffered by a third person or society as a whole resulting from an economic transaction, e.g. pollution including CO_2 emissions or noise, health issues including obesity, asthma or allergies.

4 Nabil Nasr, Rochester Institute of Technology, presentation at Re:Thinking progress conference, Circular Economy and Remanufacturing (14 April 2015).

1

RETHINKING VALUE CREATION – THE CIRCULAR PERSPECTIVE

Research to date has demonstrated that the circular economy is a clear value creation opportunity. It is an appealing and viable alternative to the linear 'take, make, dispose' model, and businesses are starting to implement circular principles into their operations. The circular economy aims to enable effective flows of materials, energy, labour and information so that natural and social capital can be rebuilt. This new economic model seeks ultimately to decouple global economic development from finite resource consumption.

AN OUTLINE OF THE CIRCULAR ECONOMY

The linear 'take, make, dispose' model, the dominant economic model of our time, relies on large quantities of easily accessible resources and energy, and as such is increasingly unfit for the reality within which it operates.[5] Working towards efficiency – reducing the resources and fossil energy consumed per unit of economic output – will not alter the finite nature of their stocks but can only delay the inevitable. A more fundamental change of the operating system is necessary.

The concept of the circular economy has attracted attention in recent years. It is characterised, more than defined, as an economy that is restorative and regenerative by design and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. It is conceived as a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields and minimises system risks by managing finite stocks and renewable flows. It works effectively at every scale.

The circular economy rests on three key principles, shown in Figure 1.[6]

BENEFITS OF THE CIRCULAR ECONOMY

Multiple research efforts and the identification of best practice examples have shown that a transition towards the circular economy can bring about the lasting benefits of a more innovative, resilient and productive economy.

Substantial net material savings: In the first two reports from the Ellen MacArthur Foundation, detailed product-level modelling was used to estimate the value of an 'advanced' circular economy scenario. Considering only the sectors of medium-lived complex goods (e.g. consumer electronics) revealed estimated cost savings of up to USD 630 billion annually in Europe after 2020. For the fast-moving consumer goods (e.g. food and beverages, clothing and packaging), the economic opportunity was estimated at more than USD 700 billion annually on a global scale, or materials savings of roughly 20%.[7]

Reduced exposure to price volatility: A natural consequence of net material savings would be a shift down the cost curve for raw materials. For steel, the global net materials savings could add up to more than 100 million tonnes of iron ore in 2025 if applied to a sizeable share of the material flow (i.e. in the steel-intensive automotive or other transport sectors, which account for 40% of demand). In addition, such a shift would move the steel industry away from the steep (increasing) right-hand side of the raw materials cost curve, thus likely reducing demand-driven volatility.[8]

Increased economic development: The study *Growth Within: A Circular Economy Vision* for a *Competitive Europe* estimated that a shift to the circular economy development path in three core industry sectors – mobility, food and built environment – would allow Europe to increase resource productivity by up to 3% annually. In addition, it would generate EUR 1.2 trillion in non-resource and externality benefits, bringing the annual total benefits for Europe to around EUR 1.8 trillion versus the current development scenario.[9] On a global scale – using different methodologies and performed across different sectorial and geographical scopes – multiple studies have consistently shown the positive impacts of the circular economy: growing GDP by 0.8–7%, adding 0.2–3.0% jobs, and reducing carbon emissions by 8–70%.[10]

Increased innovation and job creation potential: Circularity as a 'rethinking device' has proved powerful, capable of sparking creative solutions and stimulating innovation. An academic meta-study of the relationship between employment and the circular economy, conducted in the *Growth Within* report, found a positive effect on jobs in scenarios where the circular economy is implemented.

Increased resilience in living systems and in the economy: Land degradation costs an estimated USD 40 billion annually globally, without taking into account the hidden costs of increased fertiliser use, loss of biodiversity and loss of unique landscapes.[11] The application of circular economy principles, encouraging higher land productivity, less waste in the food value chain and the return of nutrients to the soil, will enhance the value of land and soil as assets.

TIME FOR A STEP CHANGE?

Despite the repeated demonstration of the benefits of the circular economy for businesses as well as societies, the introduction of some of its core practices – such as performance models – has to date been slower than expected given the sound business case. For good reasons perhaps: existing circular business models at scale demonstrate the importance of information and feedback-rich systems, and that it takes time and effort to get it right. Could the onset of intelligent assets perhaps provide the missing link to make a step change in the uptake of circular business models – removing barriers that prevent sharing, leasing and performance models from becoming the 'the new normal'? Could the digital revolution offer a blueprint of the infrastructure needed to keep materials in circulation – or could the infrastructure in fact even be fully virtualised? The match between the digital development and the circular economy does indeed seem promising.

PRINCIPLES

FIGURE 1 **THE CIRCULAR ECONOMY – AN INDUSTRIAL SYSTEM THAT IS RESTORATIVE BY DESIGN**

1

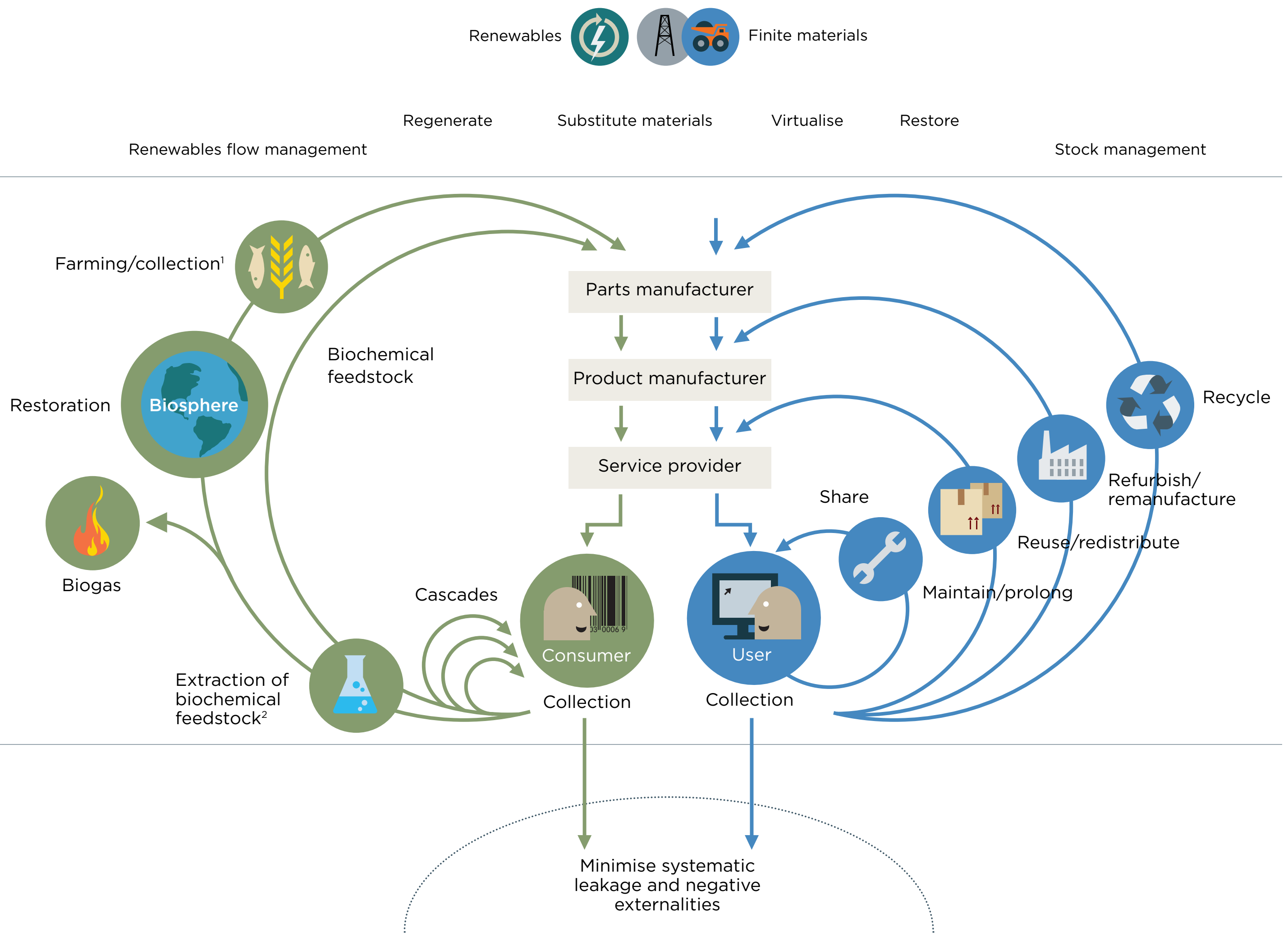
Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows – for example, replacing fossil fuels with renewable energy or using the maximum sustainable yield method to preserve fish stocks.

2

Optimise resource yields by circulating products, components and materials at the highest utility at all times in both technical and biological cycles – for example, sharing or looping products and extending product use cycles.

3

Foster system effectiveness by revealing and designing out negative externalities, such as water, air, soil, and noise pollution; climate change; toxins; congestion; and negative health effects related to resource use.



5 This fact is highlighted in the concept of 'planetary boundaries', which has received substantial attention recently. Goals 13–15 in the recently revised UN agenda for sustainable development take these boundaries into account. See for example W. Stephen et al., Planetary boundaries: Guiding human development on a changing planet, (Science, vol. 347, 2015); UN resolution, Transforming our world: the 2030 Agenda for Sustainable Development (25 September 2015).

6 For a broader discussion of these principles, see Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth Within: A Circular Economy Vision for a Competitive Europe (2015).

7 Ellen MacArthur Foundation, Towards the Circular Economy I (2012) and II (2013).

8 Ellen MacArthur Foundation, World Economic Forum and McKinsey & Company, Towards the Circular Economy III (2014).

9 Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth Within: A Circular Economy Vision for a Competitive Europe (2015).

10 For a more general discussion of the interplay between the circular economy, employment, education, money and finance, public policy and taxation, see the book The Circular Economy: A Wealth of Flows by Ken Webster, Head of Innovation at the Ellen MacArthur Foundation.

11 Ellen MacArthur Foundation, Towards the Circular Economy II (2013).

12 See Ellen MacArthur Foundation, Towards the Circular Economy I (2013).

13 Few companies have established what could be called 'circular' businesses at scale. The most prominent examples include CatReman, Rolls-Royce TotalCare, Philips Healthcare's performance contracts, and Ricoh's Managed Print Services, Most of which have developed their businesses for decades.

THE SOUL OF THE CIRCULAR ECONOMY

KENNETH CUKIER
DATA EDITOR, THE ECONOMIST, AND CO-AUTHOR OF THE INTERNATIONAL BESTSELLER *BIG DATA: A REVOLUTION THAT TRANSFORMS HOW WE WORK, LIVE AND THINK*

Almost everything we think about technology is wrong. It never just improves things – it usually ends up changing them. For instance, the electric light bulb wasn't just better than candlelight: it transformed the productive hours of work – and changed the economy irreversibly.

Likewise, the Internet of Things, powered by big data, has the potential to radically shake up business, the economy and society. Things that were products can become services. What was once a fixed cost may become a variable cost. Information that was impossible to know can now be tracked. And one of the greatest impacts will be in the 'circular economy', the idea that natural resources are used in an effective and sustainable manner.

To understand the potential, consider the French tyre company Michelin. The company wants to add sensors to its tyres, to understand wear over time. For customers this is great. They will learn when to rotate tyres or replace them – unique to their specific driving conditions. This saves money and improves safety.

But there is more to play for. Armed with usage data, the company is even better equipped to shift its business model from selling tyres to leasing them (which it began before sensors made this model even more attractive). After all, GE and Rolls-Royce don't sell jet engines but lease them with service contracts on the side – why not tyres too? The data collected by the sensors tell the company how the tyres can best be maintained.

The consequence of this shift in business model is profound. The tyre company now has a vital commercial interest in making tyres to last as long as possible, since the firm still owns them. And it has a new financial interest in using materials and processes that make recycling old tyres as efficient as possible.

Provided there is wise leadership, the circular economy will flourish.
Kenneth Cukier

Thus the technology that offered a benefit to consumers (cost savings and safety) and the bottom line of companies (new business models) has a society-wide benefit too, in terms of sustainability. These sort of 'triple play' wins – for consumers, companies and society – will become commonplace as the Internet of Things and big data increasingly become a part of everyday life. As such, the Internet of Things could become the 'soul' that animates objects in the circular economy.

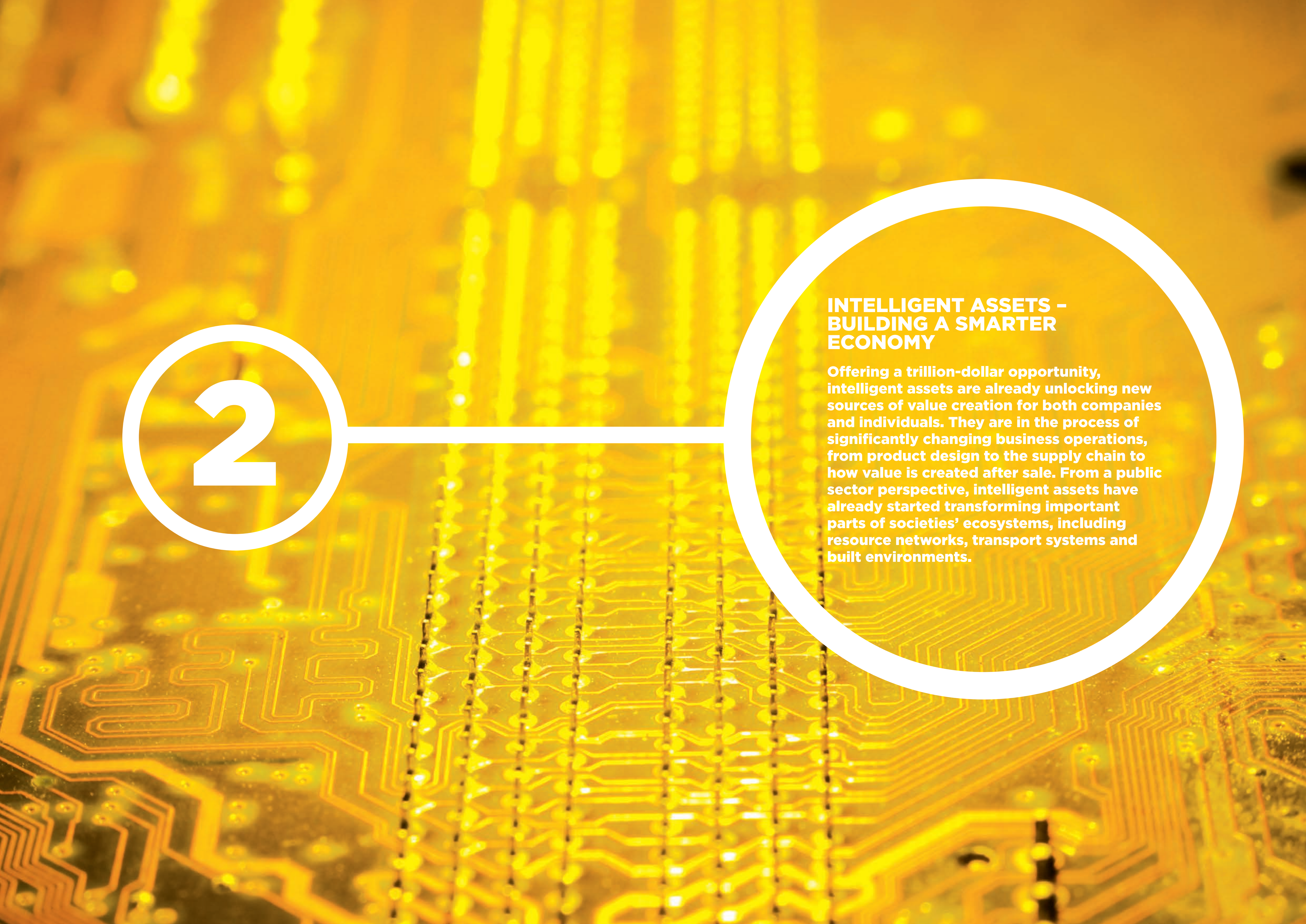
However, making this a reality requires overcoming obstacles that risk impeding the circular economy. Regulators will be suspicious of algorithms that offer probabilistic answers rather than certain ones, especially in healthcare but in cars too. Yet correlational answers that are not causal is precisely how machine-learning artificial intelligence algorithms work, which fuel the Internet of Things.

Moreover it is unclear who actually owns the data: the company that invested in collecting and analysing it, or the entity from whom the data was collected? Here, Europe and America may move in different directions, promising more heartburn on both sides.

What to do? As a first step, business leaders and policymakers need to take a more permissive approach. They need to find ways to fit Internet of Things technologies into existing regulatory frameworks rather than oppose it. The battles over Uber and AirBnB around the world show this won't be easy.

At the same time, both sides need to acknowledge a need for a new democratic and economic ethos of what might be called 'algorithmic transparency': the need for public scrutiny of how big data works in practice. The crises facing European car companies over the integrity of emissions tests show the importance of this new principle of democratic, capitalist accountability – the modern equivalent of audited company financial statements.

Provided government, the business community and civil-society institutions practise wise leadership, the circular economy will flourish. Without it, everyone will fail to reap the benefits of the Internet of Things and big data – and that is the biggest waste of all.



2

INTELLIGENT ASSETS – BUILDING A SMARTER ECONOMY

Offering a trillion-dollar opportunity, intelligent assets are already unlocking new sources of value creation for both companies and individuals. They are in the process of significantly changing business operations, from product design to the supply chain to how value is created after sale. From a public sector perspective, intelligent assets have already started transforming important parts of societies' ecosystems, including resource networks, transport systems and built environments.

A TRILLION-DOLLAR OPPORTUNITY

An estimated 10 billion physical objects with embedded information technology already exist today and many more smart cars, homes, cities, factories, energy systems, and other networks of connected devices are being built.[14] Many companies have already begun to integrate IoT technologies into their operations and projections for future penetration, while spanning a big range, all point towards significant growth. Research firm Gartner predicts that by 2020 'around 25 billion connected "things" will be in use' and their 'disruptive impact will be felt across all industries and all areas of society'.[15] A recent report by DHL and Cisco suggests that the number of connected devices and objects in 2020 will reach 50 billion.[16]

Similarly, future value projections come with a lot of uncertainty but show tremendous promise. McKinsey Global Institute predicts that the IoT will have a total economic impact of USD 3.9–11.1 trillion per year by 2025 (70% within business-to-business (B2B)), with customers capturing most of the benefits.[17] Research by Cisco suggests that the 'Internet of Everything' – the networked connections between people, data, process and things – will create an economic opportunity of USD 14.4 trillion for companies and industries worldwide during the next decade alone, corresponding to an opportunity to increase global corporate profits by about 21%.[18]

How these figures vary when different policy and investment trends are taken into account can be illustrated by recent research from Accenture which estimates that, under the current scenario, the IoT would add about USD 500 billion to China's cumulative GDP by 2030. However, by taking additional measures to improve industry's capacity to absorb IoT technologies and increase IoT investment, China could boost its cumulative GDP by USD 1.8 trillion by 2030. [19]

CHANGING THE WAY VALUE IS CREATED

McKinsey states that 'the ability to monitor and manage objects in the physical world electronically makes it possible to bring data-driven decision-making to new realms of human activity – to optimise the performance of systems and processes, save time for people and businesses and improve quality of life'.[20] As pointed out by Daniel Keely at Cisco, as assets become more intelligent they learn to communicate and collaborate amongst themselves, eliminating the need for human intervention. These advances in autonomous 'machine learning' technologies enable the automatic optimisation of a digitised process, which goes beyond providing decision support for asset owners or managers. Where physical interaction is still required, machine to machine (M2M) collaborative networks are able to deploy autonomous devices to attend to a problem (e.g. drones). These advances in IoT technology are likely to represent the next major step change in asset productivity.

As illustrated by the following examples, intelligent assets profoundly change the way value is created in a business environment as the information generated by a connected machine, device or product becomes a critical component of value creation. Firstly, with the rise of IoT solutions, variations can not only be minimised but also responded to. For instance, through real-time transmission of data regarding external factors (e.g. humidity or temperature) that impact the quality of a product in the manufacturing process, the product can be routed to a different stage of the process that is not adversely affected.[21] Secondly, recent IoT technologies enable products or machines to continuously create value even after they have left the supply chain. Through intelligent assets delivering information concerning their location, condition or availability, companies and end users can capture value in new ways throughout an asset's use cycle.[22] In addition, the manufacturer could use the information generated by the asset to further improve the product design. Finally, thanks to the ease of connecting people and things via mobile devices, the idea of sharing or leasing assets has become a significant economic opportunity for businesses and individuals across multiple sectors. A well-known example is Zipcar, which increases the utilisation of cars.

14 HBR, Internet of Things: Science Fiction or Business Fact? (2014).

15 Gartner, Gartner Says 4.9 Billion Connected 'Things' Will Be in Use in 2015 (11 November 2014).

16 DHL and Cisco, The Internet of Things in Logistics (2015).

17 McKinsey & Company, The Internet of Things: Mapping the Value beyond the Hype (2015).

18 Cisco, Embracing the Internet of Everything To Capture Your Share of USD 14.4 Trillion (2013).

19 Accenture, How the Internet of Things Can Drive Growth in China's Industries (2015).

20 McKinsey & Company, The Internet of Things: Mapping the Value beyond the Hype (2015).

21 Lopez Research, Building Smarter Manufacturing With the Internet of Things (2014).

22 Deloitte Review, The more things change: Value creation, value capture, and the Internet of Things (2015).

IoT can play a critical role in solving impeding resource management issues encountered by decision-makers in the face of mass global urbanisation [...] The resource productivity increase potential is particularly significant in developing countries.
Anne Miroux

ENABLING BETTER RESOURCE EFFICIENCY FOR SOCIETIES

Beyond the business landscape, intelligent assets have already started transforming significant parts of societies' ecosystems, including resource networks, transport systems and built environments. As recent research suggests, for public sector players, the ability to generate information though connected devices represents a USD 4.6 trillion opportunity, as a result of increased productivity, new forms of cost savings and revenues.[23]

A recent joint study by the Global e-Sustainability Initiative and Boston Consulting Group estimates that IoT-enabled solutions – increasing the efficiency of the transmission, distribution and use of power – could reduce greenhouse gas emissions by 9.1 billion tonnes by 2020, representing 16.5% of the projected total in that year.[24]

In an interview with McKinsey & Company, Cisco's former chief globalisation officer Wim Elfrink predicted that, over the next decade, IoT systems in a city environment could achieve a 50% reduction in energy consumption as well as an 80% improvement in water usage.[25] According to Intel, city authorities will spend USD 41 trillion on infrastructure upgrades for IoT in the next 20 years in order to reduce their dependency on fossil fuels and define a more sustainable urban environment through real-time feedback of resource use.[26]

As one of the world's leading 'smart cities', Barcelona has implemented IoT technologies to improve its resource use. The city is, for instance, saving USD 58 million a year through connected water management, and USD 37 million from connected street-lighting solutions reducing costs by one-third.[27] In the United Kingdom, Thames Water is in the process of implementing a 'smart water pilot'. It aims to create a single view of Thames Water's operating systems, while enabling more efficient water sourcing and the remote monitoring of assets.[28]

23 J. Bradley, C. Reberger, A. Dixit, V. Gupta, Internet of Everything: A USD 4.6 Trillion Public-Sector Opportunity (Cisco, 2013).

24 Boston Consulting Group & Global e-Sustainability Initiative, GeSI SMARTer2020: The Role of ICT in Driving a Sustainable Future (2012).

25 McKinsey & Company, The smart-city solution (2012).

26 Intel, Green Cities: San Jose implements Intel IoT solutions, available at: http://intel.ly/1nxhL5b

27 World Economic Forum, Are you ready for the Internet of Everything (2014).

28 Accenture, Accenture to Help Thames Water Prove the Benefits of Smart Monitoring Capabilities (2014).

OPEN INNOVATORS AND DATA SHARERS ARE THE IOT'S FUTURE MARKET LEADERS

NEIL CROCKETT
CHIEF EXECUTIVE OFFICER,
THE DIGITAL CATAPULT, UNITED KINGDOM

The shape and form that the IoT market will take in the United Kingdom – although of course difficult to predict – will be game-changing. What we can say with a high degree of certainty is that we are only just scratching the surface of opportunities presented by these emerging technologies. Looking forward, our future technological means can be summed up with being able to 'sense everything we can sense'. More critical than developments in sensing technologies, however, is our ability to relay, interpret and enhance decision-making upon generated data.

In the race to harness the value at stake, a whole range of new market leaders will emerge. Leading players will be those who manage to redesign their value creation and business processes, harnessing insights from data that IoT models generate. The coming years will see new, systematic, whole-life IoT models emerge – models that could dramatically change the way we produce, own, use, repair, and trade assets.

Looking forward, IoT platforms that enable us to track our assets all the way along supply chains are emerging. This type of technology will start to allow us to establish and certify the pedigree of an asset (e.g. the circularity of the asset), putting us in a position where we can begin to create policy and tax incentives around how assets are being designed, utilised and managed along supply chains and across asset use cycles. Furthermore, these policy and tax incentives could eventually be implemented in real time. Smart waste management systems, for instance, incentivising waste separation by civilians through a reward system, have the potential to become standard practice.

A lot of the technologies required to achieve an IoT marketplace already exist today, but the question of how to most effectively scale them up and capture the value potential they offer requires concerted, cross-disciplinary, organisational and even sectorial efforts. A successful transition involves three major factors:

Firstly, the need for large-scale interoperability demonstrators is key. It is essential to deploy test beds facilitating open-source interoperability creation, and they should also assist real-life collaboration using best practice tools aimed at creating systematic approaches to IoT.

Secondly, there is great synergistic value in open innovation that needs harnessing. Businesses, government and innovators will eventually realise that it is more profitable to collaborate than innovate as individual entities. Moving away from the existing, siloed approach to one of open innovation will enable IoT value creation above and beyond what we are seeing today. An effective market environment is one where challenges are opened up to the best innovators and researchers, emerging as well as incumbent, using collaborative approaches with clearly defined problems and challenges.

And finally, increased data sharing will allow organisations to more effectively overcome challenges and profit on IoT opportunities. Because IoT value resides mainly in the variety and volume of data, organisations sharing data on assets and resources, whether IoT or not, will again find synergistic value creation opportunities.

While circular economy business models can yield increasing asset and resource productivity, IoT plays an important role in making data available and turning that data into useful knowledge. It is truly a question of being able to maximise the use of data. Since both the IoT and circular economy perspectives imply systems thinking and cross-sector collaboration, market leaders in this space will be those who most successfully collaborate, share and use an open approach to innovation.

MACHINE DECISION-MAKING IN A CIRCULAR ERA

BERNARD MEYERSON
CHIEF INNOVATION OFFICER, IBM;
CHAIR OF THE WORLD ECONOMIC FORUM
META-COUNCIL ON EMERGING TECHNOLOGIES

Contrary to popular belief about the 'hockey stick' development of the IoT market, the progression of the market has been quite constant over the last ten years. Historically, there has been a relatively steady generation of applications coming online and growing in scale with industrial companies capturing significant value through monitoring systems and processes.

Recently, consumer-facing applications have been gaining much public attention, although they are not necessarily high value. Applications that merely monitor systems and pass on knowledge obvious to the consumer – such as a refrigerator telling you when you are out of milk – are not what make IoT revolutionary. The real value lies with applications that enable the discovery of new phenomena, which is what opens pathways to innovation.

Cognitive systems make correlations between what might be second-, third- or fourth-order events that are impossible for humans to observe, yet critical. For instance, rather than a fridge telling consumers when they are short of milk, the same set of capabilities can be applied in a system that collects energy usage, storage and generation data from all across the electrical grid, and uses this to calculate how to best utilise, and minimise, local generation capacity. Furthermore, countless examples of IoT developments within the healthcare sector already have profound impacts on the quality of life we experience as humans. Robotic helpers in homes for elder care, customised treatment protocols for diabetics, advanced cancer treatments, and IoT-sourced real-time health data, all benefit from ever more sophisticated and intelligent systems being integrated on a global basis via the IoT.

Advancements in discovery capabilities over the coming decade will also make circular economy business models more and more viable. These models will experience ever more efficient asset utilisation and resource productivity through sustained data acquisition and process optimisation, leading to broad progress in the design and development of less capital-intensive assets while still achieving all required business outcomes.

Concurrent with value arising from these discovery-based IoT outcomes, momentous security concerns arise, as increasingly connected systems are by definition more vulnerable to cyber threats. By virtue of integrating your system into the global web, it is imperative for one to take a vigilant approach to securing both IoT application development and execution environments.

In the extreme, one can simply isolate systems from all networks. Isolating systems associated with potentially high risk to the public, such as nuclear power plants, may be the way to go, but generalising that practice would also preclude obtaining the insights and ultimate value possible from engagement with the knowledge ecosystem available via the IoT. Whole sectors of the economy would be prevented from harnessing the value generated through the discovery of new phenomena as unveiled by interconnectivity, data access, and resultant learning.

As we enter the 'cognitive era' we are seeing the emergence of hybrid decision-making, where cognitive systems and their users cooperate to discover information and synthesise solutions surpassing human decision-making capabilities in the face of complex system problems. Future innovators will surely use this emergent capability to implement the inherently complex circular economy principles and many other intractable challenges.

3

PAIRING THE CIRCULAR ECONOMY & INTELLIGENT ASSETS

The interplay between circular economy and intelligent asset value drivers provides a fertile ground for innovation and value creation. Circular economy value drivers include extending the useful life and maximising the utilisation of assets, looping assets, and regenerating natural capital. Intelligent asset value drivers include collating knowledge about the assets' location, condition, and availability. A broad range of opportunities emerges when these value drivers are paired. While it is impossible to predict all possibilities going forward, there are already numerous conceivable ways in which this interplay could drastically change the nature of both products and business models.

Both IoT and the circular economy are about exploring connections and feedback. IoT seeks to make assets of all kinds more intelligent and the circular economy to mobilise assets to decouple resource use from economic development. Their visions are complementary but, for these models to thrive, it is critical to find smart, effective ways to maximise the utilisation of assets and keep them in the inner loops of their possible cycles (see page 17). Intelligent assets are already presenting solutions to many resource challenges faced by circular economy innovators. The feedback-rich nature of circular economy models might conversely make them particularly suitable to help extract value from the large amount of data generated by intelligent assets.

To understand the value creation opportunities created by the interplay between circular economy value drivers and those of intelligent assets, it is useful to think in terms of an 'interaction matrix' (Figure 2). In this matrix, using one (or several) of the intelligent asset value drivers together with one (or several) of the circular economy value drivers unlocks new value. The interaction matrix presents examples of a range of conceivable opportunities, and offers a framework to accommodate an even larger number of yet inconceivable ones.

FIGURE 2
INTERACTIONS OF CIRCULAR ECONOMY AND INTELLIGENT ASSET VALUE DRIVERS AND EXAMPLE OF VALUE CREATION OPPORTUNITIES

	INTELLIGENT ASSET VALUE DRIVERS		
CIRCULAR ECONOMY VALUE DRIVERS	Knowledge of the **location** of the asset	Knowledge of the **condition** of the asset	Knowledge of the **availability** of the asset
Extending the use cycle length of an asset	• Guided replacement service of broken component to extend asset use cycle • Optimised route planning to avoid vehicle wear	• Predictive maintenance and replacement of failing components prior to asset failure • Changed use patterns to minimise wear	• Improved product design from granular usage information • Optimised sizing, supply, and maintenance in energy systems from detailed use patterns
Increasing **utilisation** of an asset or resource	• Route planning to reduce driving time and improve utilisation rate • Swift localisation of shared assets	• Minimised downtime through to predictive maintenance • Precise use of input factors (e.g. fertiliser & pesticide) in agriculture	• Automated connection of available, shared asset with next user • Transparency of available space (e.g. parking) to reduce waste (e.g. congestion)
Looping/ cascading an asset through additional use cycles	• Enhanced reverse logistics planning • Automated localisation of durable goods and materials on secondary markets	• Predictive and effective remanufacturing • Accurate asset valuation by comparison with other assets • Accurate decision-making for future loops (e.g. reman vs. recycle)	• Improved recovery and reuse / repurposing of assets that are no longer in use • Digital marketplace for locally supplied secondary materials
Regeneration of natural capital	• Automated distribution system of biological nutrients • Automated location tracking of natural capital, such as fish stocks or endangered animals	• Immediate identification of signs of land degradation • Automated condition assessment, such as fish shoal size, forest productivity, or coral reef health	

29 For a wider discussion of these circular economy value drivers, please see Ellen MacArthur Foundation, *Towards the circular economy I* (2012) and *II* (2013).

30 It should be noted that use cycle extension is in some instances not always preferable over substitution. In sectors experiencing rapid performance improvements – e.g. more energy efficient cars or fridges – it might make more sense from a life cycle assessment perspective to change products more often. Nevertheless, using IoT to monitor product health will of course support decision-making about when to exchange an old device for a new one, and do something productive with the discarded unit. In this view, extending the length of a product's use cycle could rather be described as optimising product's use cycle.

31 While ecosystem services are still viewed as 'externalities' and therefore do not show up on businesses balance sheets, they play a crucial role in value creation. Preserving and rebuilding the long-term resilience of agricultural systems and fish stocks – and the system services provided by the larger biological system in which agriculture and fishing are anchored – are the foundation for creating sustainable value from natural resources and related assets (e.g. in the food, textiles and beverage industries).

CIRCULAR ECONOMY VALUE DRIVERS

Four key circular economy value drivers for generating asset and resource productivity can be identified.[29] Their value creation potential mainly results from extending the use cycle length and count, increasing asset utilisation, while reducing the creation of new products from virgin materials and producing less waste – especially structural waste including negative externalities.

Extending the use cycle length of an asset. Keeping products, components and materials in use for longer means that the need to produce more assets from new resources is reduced, while the value added through manufacturing is retained.[30] This can be achieved by designing products that are more durable and easier to upgrade, repair or maintain, and deploying predictive maintenance to prevent irreversible failures that would end an asset's use cycle. This value driver also implies reducing consumption of a finite resource, fuel or fossil-based energy.

Increasing the utilisation of an asset or resource. Maximising the utilisation of assets by either sharing them among users (peer-to-peer sharing of privately owned assets or public sharing of a pool of assets) or enabling greater asset or resource productivity in operations. In this report, the definition also includes designing out negative externalities – which implicitly enhances the utilisation of finite resources – as well as increasing access to and utilisation of renewable resources.

Looping or cascading an asset through additional use cycles. Moving end-of-use assets or resources from one use cycle to a new one. Looping includes i) reusing the asset as is with a new user; ii) remanufacturing or refurbishing the asset before entering a new use cycle; iii) recycling materials to replace virgin resources in making new assets. Cascading assets or resources could either mean moving them to secondary markets or into lower-value uses.

Regeneration of natural capital.[31] Preserving and enhancing the long-term productivity of natural systems such as soil, oceans, forests and wetlands. This includes returning biological nutrients and carbon to the land, avoiding topsoil erosion and the leaching of nutrients from one system to another, replenishing lost nutrients and soil layers, as well as managing maritime stocks in such a way that they are able to maintain a healthy population.

INTELLIGENT ASSET VALUE DRIVERS

Broadly speaking, intelligent assets can supply three main forms of knowledge about assets and resources that enable value creation in a business environment[32] (see Figure 2):

Knowledge of the location of the asset. Asset tracking – determining the location of an asset, either in real time or based on connected checkpoints – is a significant enabler of sharing models. It is also an important opportunity for users to bring down the costs of logistics and other operations, and use their resources more effectively. This is especially important for businesses that have mobile, high-value assets deployed across multiple locations, since operational performance depends on balancing resource utilisation, rapidly redeploying resources, and keeping assets in service.[33] Tracking assets can also greatly facilitate auditing, helping companies comply with accounting standards at a much lower cost.

Knowledge of the condition of the asset. The collection[34] of sensor data that monitors an asset's condition – the technical or biological performance or state of an asset, including specific responses to environmental conditions – enables users and/or suppliers to use defined thresholds or rules to initiate actions or notifications that allow for condition-based (predictive or preventative[35]) maintenance, repair, decommissioning, or change of use pattern.[36] Knowledge of the condition of an asset includes recording the use pattern of the asset, as well an asset's material composition and its potential change[37] during the use cycle – as for example recorded in embedded product inventories.[38]

Knowledge of the availability of the asset. Data on an asset's availability – including whether an asset is idle but also the supply/demand dynamics for an ensemble of assets – allows for the increased sharing of assets among different users as well as the development of new business models that promote the shift towards a more service-oriented economy. Availability also includes knowledge about asset ownership, and in energy systems availability includes knowledge about usage and demand of energy at a given location and a given point in time.

32 The distinction made to identify (one or more of) the three main intelligent asset value drivers can also be found in other publications including: DHL and Cisco, *The Internet of Things in Logistics* (2015), HBR, *Internet of Things: Science Fiction or Business Fact?* (2014), and in a number of articles published by the IBM Big Data & Analytics Hub or SAP Solutions.

33 Deloitte, *The Internet of Things Ecosystem: Unlocking the Business Value of Connected Devices* (2014).

34 This collection of asset status/health data has been possible through process control systems for more than 30 years, but has been limited to 'asking' the asset about its condition. IoT increasingly enables assets to instead communicate when appropriate what they need to remain safe and efficient.

35 For the purpose of this report, the term 'predictive' maintenance has been used consistently to also include 'preventative' maintenance.

36 Jim Crosskey, *Using the Internet of Things to detect asset failures before they occur* (IBM big data & analytics hub, 2 June 2015).

37 This includes both intended change (e.g. upgrades) and unintended change (e.g. wear and damage).

38 Sometime referred to as 'product passports', embedded product inventories refer to any digitised information about an asset's material composition, history, or condition.

KEY BARRIERS AND ENABLERS

The circular economy is an inherently feedback-rich system, and innovation will depend on the provision of new information for designing business models as well as physical products. Going forward, there is little doubt that the information generated by probing the circular economy–intelligent assets interplay will be able to enhance the information feedback loops and drastically change the way products are made, used, paid for, and looped back into the value chain. However, for the full value potential provided by the interplay between the circular economy and intelligent assets to be realised, a number of barriers and key enablers need to be addressed.

DATA SECURITY AND TRUST

Since much of the value created by the interplay between circular economy and intelligent assets lies in the ability to collect and interpret data, it is crucial to address concerns about how innovators, companies and government agencies use, share and protect personal data. Moreover, as intelligent assets' capabilities expand, mechanisms need to be developed to prevent potential criminal activity that could harm private individuals as well as businesses. Stakeholders, including policymakers, research institutions and industry players need to work together on challenges related to the management of IoT systems in order to foster innovation, while minimising security risks.[39] Experts including Neil Crockett, Nic Cary and Sophie Hackford, highlight the lack of a legal infrastructure that ensures trust and security over personal data as a major hurdle for IoT market development. Further developing and harnessing security innovations (e.g. through blockchain technology) is imperative to nurturing IoT technology development and generating trust within the IoT market.

INTEROPERABILITY OF INTELLIGENT ASSETS AND IOT NETWORKS

McKinsey & Company estimates that 40% of the total IoT value creation potential requires a fully functioning digital ecosystem in which there is seamless data sharing between assets and networks from different industry players.[40]

As pointed out by Neil Crockett of the Digital Catapult United Kingdom, most of today's intelligent assets have been designed in closed innovation processes and therefore work largely in silos. In this 'pre-standards phase' of the IoT landscape, devices or networks created by different manufacturers or technology companies are often unable to integrate or run on a common operating system.[41] As a result, companies today mainly use sensor data for anomaly detection and control but not for optimisation, prediction or discovery. More sophisticated sensing and analytics technologies could unlock value sources such as performance data for predictive maintenance, or workflow data to optimise operating efficiency, and companies and industries seeking to tap into this potential would benefit from developing infrastructure horizontally rather than creating vertical stacks of integrated products.[42]

FLEXIBLE BUSINESS MODELS THAT CAN RESPOND TO PRICE VARIABILITY AND THE RAPID EVOLUTION OF TECHNOLOGY

To date many IoT systems require significant upfront capital investment, while at the same time lack a clearly defined return on investment in what are still often untested and immature technologies. To add complexity to the investment decision, industrial IoT components need to be built with maintenance and updates in mind because industrial systems need to be continually modified and maintained to meet changing requirements.[43] Reorienting the business strategy to allow for this rapid evolution of technology could be an important step towards making operations more circular. Companies are also likely to benefit from identifying their partners within the intelligent asset/circular economy ecosystem, and determine whether they want to join a partner's platforms or develop their own. The development of joint lighthouse projects, where technologies and processes are tested and findings are shared, could benefit the development of intelligent assets on a broader scale.[44]

Failing to reap the benefits that the Internet of Things and the circular economy present, is the biggest waste of all.
Kenneth Cukier

Resilient IoT market evolution can be informed through biomimicry – the study and emulation of life in our natural world. The way in which natural systems access, store, and share information about themselves can – and should – be considered in order to design intelligent assets that harness maximum asset and resource productivity.
Janine Benyus

39 World Economic Forum and Accenture, Industrial Internet of Things: Unleashing the Potential of Connected Products and Services (2015).

40 McKinsey & Company, The Internet of Things: Mapping the Value beyond the Hype (2015).

41 IBM, Device Democracy (2015).

42 Jessica Groopman, Interoperability: The Challenge Facing the Internet of Things (Altimeter Group, February 2014).

43 Chris Murphy, Internet Of Things: What's Holding Us Back (InformationWeek, 5 May 2014).

44 World Economic Forum and Accenture, Industrial Internet of Things: Unleashing the Potential of Connected Products and Services (2015).

4

INNOVATORS TODAY SHOW WHAT TOMORROW'S BUSINESS ECOSYSTEMS COULD LOOK LIKE

A rapidly growing number of businesses is harnessing the synergies between circular economy and intelligent asset value drivers. These businesses are present in a wide range of sectors, including manufacturing, built environment and infrastructure, energy and utilities, agriculture and fishing, and logistics and waste management, as well as smart cities. They include large incumbents as well as disruptive innovators. The solutions created by these businesses unlock not only direct value for the customer or end user, but could profoundly change the resource productivity of societies by forming new ecosystems of services that eliminate negative externalities or the need for some resources altogether.

Previous research has highlighted that digital technology is a core enabler for circular economy business models.[45] In a similar way, pairing IoT-enabled innovation with circular economy principles can help identify new value creation potential. Looking at the ongoing digital revolution using the combined lenses of intelligent assets and circular economy reveals that numerous businesses (and cities) are already unlocking value in this realm – for instance optimising capacity utilisation, implementing predictive maintenance, and automating sales and inventory management. The examples given in Figure 3 are by no means exhaustive, but show that businesses are already active in most of the matrix's intersections. Some are familiar multibillion-dollar corporations; others are emerging innovators.

This chapter introduces promising innovations (and their resulting benefits) in five industrial settings: materials and manufacturing; energy and utilities; built environment and infrastructure; logistics and waste management; and agriculture and fishing. Individual case examples are discussed for each setting, and a broader perspective is then applied in order to explore the wider opportunity that follows from a transition to a more circular economy. In addition, the opportunities emerging in the context of smart cities are explored.

FIGURE 3
BUSINESSES ALREADY OPERATING IN THE CIRCULAR ECONOMY – INTELLIGENT ASSETS INTERACTION MATRIX

INTERNET OF THINGS VALUE DRIVERS

	KNOWLEDGE OF THE **LOCATION** OF THE ASSET	KNOWLEDGE OF THE **CONDITION** OF THE ASSET	KNOWLEDGE OF THE **AVAILABILITY** OF THE ASSET
EXTENDING THE USE CYCLE LENGTH OF AN ASSET	bam, waze	angaza, DELTA, PRODUCT HEALTH, FANUC, UNION PACIFIC, PHILIPS, ARUP	OPOWER, BBOXX, ENIT SYSTEMS, sensity, PHILIPS
INCREASING **UTILISATION** OF AN ASSET	Brambles, BMW, JOYGLOBAL, Google, UBER, waze	enevo, ONFARM, Honeywell, Johnson Controls, CISCO, tado°, nest, GE	angaza, zipcar, Honeywell, Johnson Controls, CISCO, UBER, paybyphone, STREETLINE, BBOXX
LOOPING/ CASCADING AN ASSET THROUGH ADDITIONAL USE CYCLES	PROVENANCE, TOMRA, hp, spire	IBM, TOMRA, bam, ARUP, DELTA, PRODUCT HEALTH, amey	IBM, PHILIPS, CISCO, PREMISE
REGENERATION OF BIOLOGICAL NUTRIENTS TO THE BIOSPHERE	spire, PLANET LABS, libelium, ARRAY OF THINGS	spire, JOHN DEERE, ONFARM, AGCO, libelium	

45 The Ellen MacArthur Foundation, Towards the circular economy I (2012).

MANUFACTURING OF ELECTRONICS AND ADVANCED EQUIPMENT

MAKING, USING AND REUSING STUFF

Performance contracts, predictive maintenance, and remanufacturing are already well-established (circular) practices in some sectors of the manufacturing industry. Intelligent assets are helping these feedback-dependent operations perform better and with increased flexibility – making them accessible to a broader range of companies and consumers. In addition, the unprecedented amount of information generated by connected assets is enabling designers to translate feedback data into product improvements. Finally, complexity and material demand in various production processes is being drastically reduced through the ability to virtualise product features via cloud technology.

Imagine a world in which all high-value assets belong to their manufacturer, who is incentivised to maintain and improve them on an ongoing basis. Not only your car, but computer, washing machine, lighting system, fridge – they all have the inbuilt ability to securely communicate with their manufacturer, sending real-time information about their use patterns and the condition of different components on the basis of which they are maintained, updated or replaced and recycled/cascaded into a different use cycle. With a growing number of businesses incorporating both intelligent assets and circular economy principles into their strategies and operations, the need for human intervention to maintain, reuse or recycle materials is being minimised.

MORE PRODUCT CATEGORIES, BETTER PERFORMANCE MODELS

Manufacturing – particularly of advanced, expensive equipment – has been a focal point of circular economy studies for many years as it offers one of the biggest potentials for economic and environmental impact of any sector. Material savings alone in the European Union could amount to USD 630 billion in an advanced circular economy scenario.[46] These savings stem from a combination of the main three circular value drivers: *extending the use cycle* (due to predictive maintenance), *increasing utilisation* (due to reduced unplanned downtime and increased overall equipment effectiveness), and *looping or cascading the asset* (due to improved information of the condition and use history of individual components).

Performance-based business models – where a supplier retains ownership of the product and the customer pays on a per-use (or performance) basis – provide the supplier with a fixed contract revenue stream while offering incentives to maintain, simplify and increase the reliability and productivity of the product. Done right, it also reduces total asset costs, while increasing profitability and customer service value. The retained ownership can enable, but is not critical for, the taking back of products after use and refurbishing/remanufacturing them before taking them to market again.

The business case for such circular models is quite intuitive for advanced equipment; its manufacture is resource intensive and therefore expensive, and products are often robust enough to be repaired or refurbished either throughout or at the end of use cycles. It should therefore be no surprise that the pioneers in the field began their operations long before the circular economy was established as a concept. Most notably, Rolls-Royce's 'power-by-the-hour' model for airline engines was incepted in 1962 and pioneered the performance-based business model.[47] Caterpillar founded its Cat Reman business line in 1973 and is still a well-respected example of remanufacturing operations.[48]

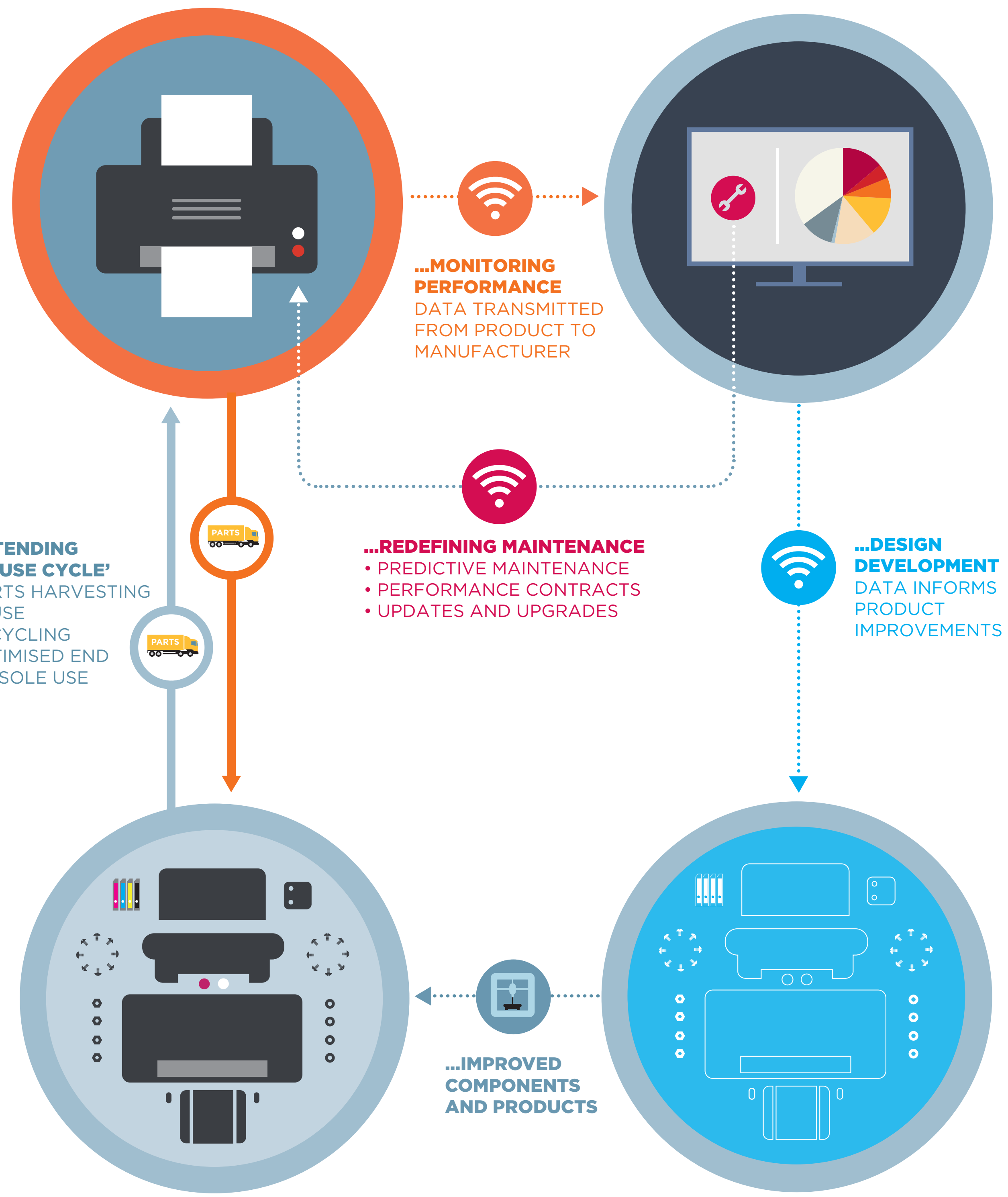
While Rolls-Royce and Cat Reman are proving that circular business models can work without IoT, intelligent assets have the potential to significantly improve the user's and/or supplier's ability to service and repair products in a predictive maintenance scheme. Comprehensive real-time data is key to effective predictive maintenance, enabled by knowing the condition (such as engine health), and therefore IoT technology is currently revamping the way giants such as Rolls-Royce or Philips conduct their operations/services. Information and communications technology (ICT) players such as Cisco and IBM are also active in this field, helping clients move towards maintenance schemes supported by data monitoring and predictive analysis. For example in the healthcare industry, Cisco and Philips point out that decisions regarding the replacement of medical equipment at hospitals are currently based mainly on the equipment's age and estimates of utilisation. With sensor technology revealing the actual condition of the equipment, such decisions could be made on a case-by-case basis, which would save resources. The data would

46 Ellen MacArthur Foundation, Towards the Circular Economy I (2012).

47 Rolls-Royce, Rolls-Royce celebrates 50th anniversary of Power-by-the-Hour (30 October 2012).

48 Caterpillar, Happy birthday Reman (2013).

INTELLIGENT ASSETS TRANSFORMS THE WAY WE MAKE, USE, AND REUSE STUFF BY...



also enable more flexible performance contracts benefiting both the hospital management and equipment's manufacturer. Fanuc – a computerised numerical control (CNC) systems and industrial robot company, and a partner with Cisco – accesses data streams from its robots located around the world via the cloud. Apart from streamlining the spare parts supply chain, such shared information could also greatly enhance machine learning among the robots.[49]

As indicated above, predictive maintenance in performance contracts is not a novel development at enterprise level. However, recent technological development increasingly enables performance models to trickle down to small and medium-sized enterprise (SME) customers where previously the tracking and logistics were prohibitively costly.[50] Notably, this development can be seen in consumer electronics and IT equipment, a product category notoriously difficult in terms of component recovery and reverse logistics. HP launched its 'Instant Ink' service in early 2014, providing printing as a service to individuals and small businesses. Subscribers pay a monthly fee based upon the number of pages they print, and the connected printer notifies HP when the cartridge is about to run dry and signals to deliver a new one without the subscriber having to interact. HP collects empty cartridges to include them in its 'closed-loop' recycling programme. Instant Ink is approaching a million subscribers and HP reports that the design enables elimination of up to 67% of waste associated with the number of pages printed, and a very high customer retention rate. In fact, as John Ortiz of HP notes, the ability to build stronger customer relationships is one of the key values unlocked by an IoT-driven, circular performance model, and it could very well be applied to other types of electronic products such as personal computers.

KNOWING WHEN TO REUSE, REMANUFACTURE OR RECYCLE

To date, reverse logistics and remanufacturing have been subject to several risks, including the fluctuating demand and supply of used products/components, and the widely varying condition of the returned components. Ideally an enterprise would choose the next use cycle for each returned product – e.g. sell for scrap value, recycle, recover components through parts harvesting, remanufacture, or reuse – by taking into consideration a combination of factors regarding the product's condition as well as the current market situation. Only with the ability to collect large quantities of product and customer data, and an analytical model to make sense of it, does such a decision-making model become feasible.

IBM has recently developed a prototype, comprehensive analytics tool called the 'Reuse Selection Tool', to help product managers choose the next, optimal use cycle for a product. The company has defined a range of inputs that include product engineering and material data, modularity and reuse potential data, regulations and financial data such as market price and cost of remanufacturing, but also crucially the supply and demand data at various product taxonomy levels. Feeding the model granular data of a product's use history and the condition of different components, combined with a set of macroscopic financial data, enables the product manager to decide on a per-unit basis whether to remanufacture, recycle or scrap. Although IBM has developed its prototype tool primarily for electronic equipment, Jad Oseyran of IBM notes that the company is exploring opportunities within the construction industry since it presents an interesting opportunity with its asset-intensive and diverse products. Furthermore, the data model and the analytics engine of the reuse tool can be adapted to other industries.

Moreover, IBM is investigating whether recent developments in cognitive computing (the simulation of human thought processes in a computerised model as pioneered by the Watson system) could be integrated into the Reuse Selection Tool to structure and interpret data in a meaningful way.[51] Jad Oseyran comments that although recent technological advances, including those in cognitive computing, are not essential to achieve the transition towards the circular economy, they can be a key enabler in the future.

REDEFINING DESIGN

When data on the composition and real-time condition of assets becomes abundant, product design can be transformed. For Rolls-Royce, aggregation of IoT-generated information on an engine's condition provides insights into more productive, durable and long-lasting engine design opportunities, while the servitisation model provides incentives to apply these insights. In a similar way, HP is looking to apply its IoT-generated data to inform its product design processes. In sum, the augmented information generated by intelligent assets contributes to improving future product generations – both by extending their use cycle (making them more durable and easier to maintain) and enabling further looping (improved design for remanufacturing and design for disassembly).

Moreover, IoT could drastically increase resource productivity by virtualising all but the core physical function of equipment. As suggested by Cisco's Daniel Keely, processing, analysis and visualisation functionalities within a medical scanner could be moved to a secure cloud service, making upgrades simpler and in turn driving further use cycle extension. The broader set of cloud data that will be made available could potentially be leveraged by designers and engineers to further improve the machine, provided the data is mined in a secure way.

49 See, for example: http://www.cisco.com/web/strategy/manufacturing/connected-machines.html

50 For instance, IoT-enabled monitoring of printers and computers is standard in large IT management service contracts (provided by, for example, HP or Ricoh).

51 IBM estimates that 80% of all data generated today is unstructured and very difficult for humans or traditional algorithms to intepret. See http://www-01.ibm.com/software/data/infosphere/warehouse/unstructured-data-analysis.html

ENERGY AND UTILITIES

CREATING A SMARTER ENERGY INFRASTRUCTURE

A surge in innovative and disruptive business models in the energy sector is currently under way. Developed markets are seeing a proliferation of intelligent assets to optimise energy use in many settings, from homes to street lighting. In addition, IoT technology is enabling distributed energy systems, particularly in developing markets. New businesses are emerging that enable off-grid renewable energy as a service at affordable prices. Such new business models could be crucial in giving broader access to renewable energy sources to many more end users. Moreover, these models could make it increasingly viable for developing markets to build entirely distributed energy systems and avoid the significant resource and capital costs tied up in a centralised energy system.

Imagine all individual households, factories and public buildings in your city generating their own electricity from renewable sources, which can be stored in different batteries, including the ones in your car or at home – reducing your electricity bill by up to 25%. All of those energy-generating entities in your area are connected through a grid, allowing them not only to be self-sufficient but also to contribute to the grid stability of the whole region. Or imagine that each community in a developing country has access to affordable solar-powered energy, giving people the comfort of electrical light and appliances, and enabling them to better educate themselves and increasingly participate in global economic activity.

Next to food and water, energy is arguably the most vital human need in a modern society. Despite ongoing improvements in energy efficiency that bring down per capita consumption in developed economies,[53] significant sources of structural waste associated with energy systems still need to be addressed. In energy production and distribution, substantial losses are associated with power grids, and the emergence of (small-scale) renewable energy generation is challenged by problems of distribution and storage, particularly in remote locations.

OPTIMISED ENERGY CONSUMPTION BY SMARTER DEVICES AND BETTER INCENTIVES

Using intelligent assets to improve efficiency in energy consumption is a recognised and growing practice.

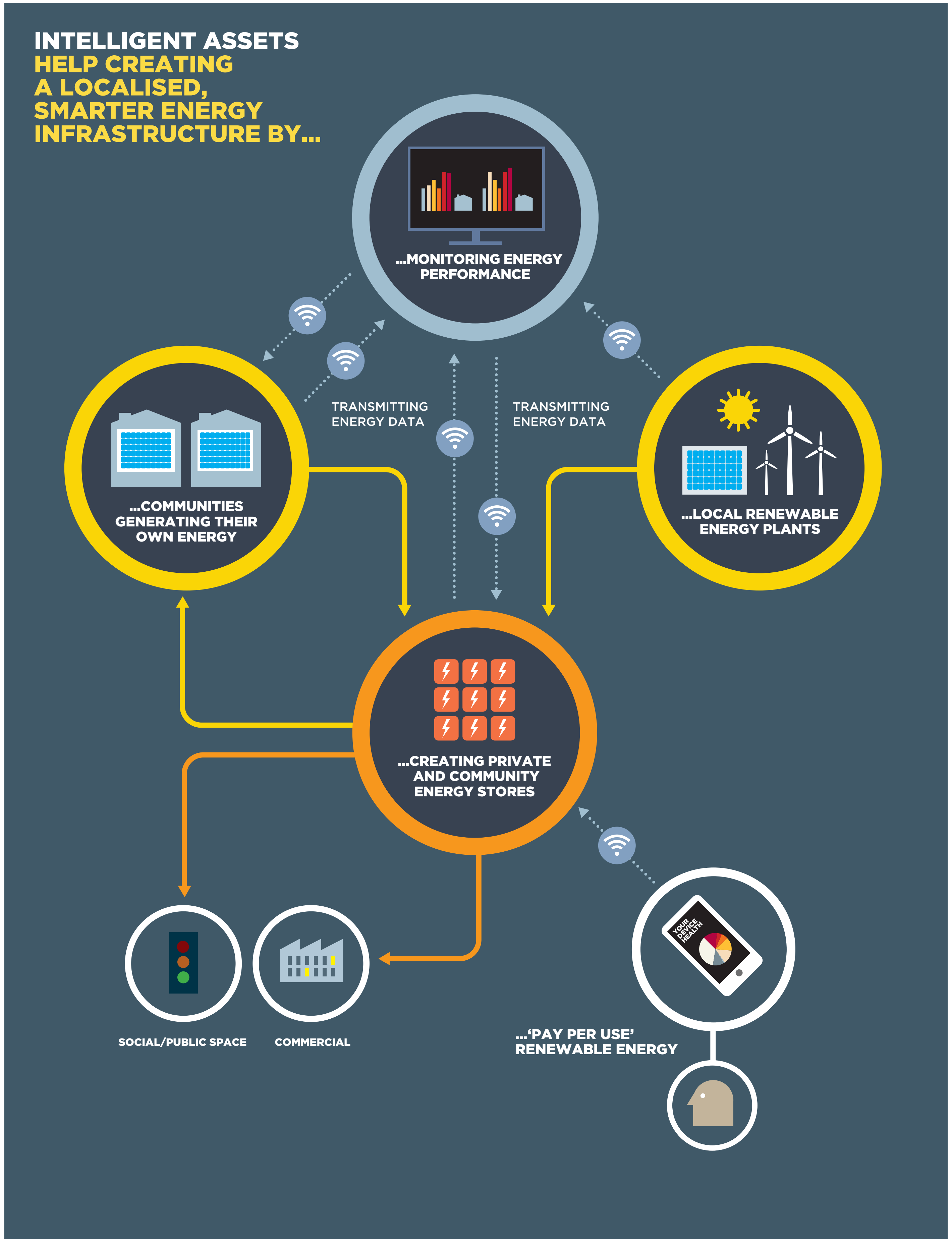
- Cisco uses an IoT-enabled system called Cisco Energy Management (CEM) to accurately measure and manage energy use (and CO2 emissions) at their manufacturing facility in Malaysia, with a goal of reducing energy consumption by 20%.

- Philips provides 'lighting-as-a-service' to their customers, continuously optimising power consumption as they have live and reliable data on the use patterns of their customers, and can therefore enhance the light installations.

- GE recently announced its 'energy-as-a-service' platform, aiming to take 10–20% off customers' energy bills as well as enable better distribution for utilities.[54]

- Silicon Valley-based Enlighted provides an IoT-based energy service system, claiming it saves their clients 60–70% on lighting and 20–30% on heating/cooling, while the IoT infrastructure additionally enables further smart solutions.[55]

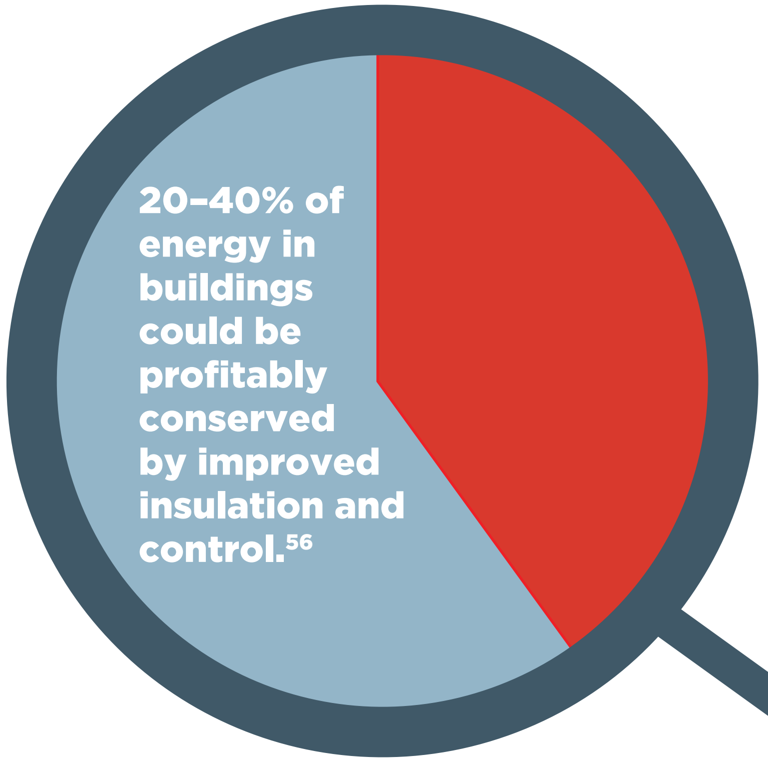
Philips CityTouch is a similar service for cities, providing connected outdoor light points and management software. Authorities can change light intensity remotely depending on natural light and street conditions, replace individual components based on actual burning hours rather than on assumptions, and reconfigure installations to adapt to changing environmental factors. In the same vein, California-based Sensity Systems uses sensors in its large-scale instalments (e.g. in airports) to both monitor use



53 IEA, *World energy outlook* (2014).

54 Carl Weinschenk, *GE's Current offers energy-as-a-service* (Energy Manager Today, 8 October 2015).

55 Alan Murray, *For companies, big energy savings are linked to the 'Internet of Things'*, (Fortune, 15 September 2015).

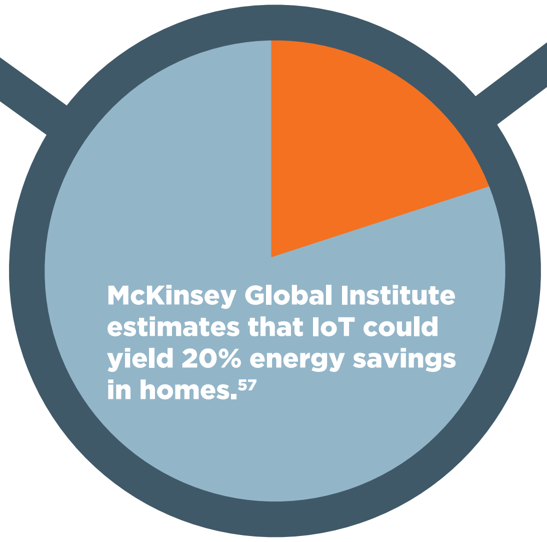


patterns and automatically adjust power to the individual LED lights depending on the number of people beneath them.

The above examples also provide resource-productive knock-on effects. For instance, Philips CityTouch increases the ability to manage heterogeneous use cycles of different asset components in detail, and can *loop* assets back into production at the end of their use cycle. In addition, the cloud-based service uses exactly the amount of remote computing power needed, eliminating the need for in-house servers. Philips estimates that such a set-up leads to at least 30% less energy consumption in computing.

Models creating transparency about usage have also begun to appear in the residential space. For example, Nest Labs' smart thermostats build a heating schedule around their users' routines and can be controlled remotely to maximise comfort, while minimising energy consumption. A similar company is the start-up Tado°, which uses sensors that react to the presence of people in order to calibrate heating.

Another important area for optimisation is the large number of SMEs operating complex, distributed energy systems such as industry plants. The German company ENIT Systems offers a connected clip-on device, the ENIT AGENT, that helps its user to understand, manage and maintain these decentralised systems by overcoming the typical interpretation challenges posed by the different technologies. The ENIT AGENT creates full transparency of energy usage and saves companies 5–20% of energy costs. In addition, it eliminates compatibility problems between the old and new components in the system, thereby allowing for better maintenance and longer use of the different machines. Furthermore, the open software invites users to add applications to the system, and the ambition is to include M2M communication and further improve the energy distribution. Connecting both energy-generating and consuming devices could also help businesses to increasingly provide their own energy.



Intelligent monitoring systems can also be used to create energy saving incentives. Basing its business model largely on established behavioural psychology principles, OPower is incentivising individual consumers to reduce their energy bill by providing the company with personalised energy reports that compare their usage data with a large database of other users. Utilities such as E.On in Europe and Dominion in the US similarly offer detailed reports and connected power switches to help customers reduce their consumption. This type of precise use data from intelligent assets coupled with behavioural feedback could have interesting wider applications, e.g. for municipalities to create incentives for citizens to reduce excess resource use, or to plan for effective utility infrastructure upgrades.

56 Energy Statistics and Balances of Non-OECD Countries; Energy Statistics of OECD Countries, and United Nations; Energy Statistics Yearbook; http://www.iea.org/stats/index.asp

57 McKinsey & Company, The Internet of Things: Mapping the Value beyond the Hype (2015).

For intelligent assets to create value in the circular economy the development of an open and global payment protocol is required. The technology behind the Bitcoin blockchain has the potential to enable the billions of internet devices that will negotiate with each other to unleash market forces, to bring down the costs of goods and services for all market forces to bring down the costs of goods and services for all.
Nic Cary

DISTRIBUTED RENEWABLE ENERGY IN DEVELOPING MARKETS

On the energy production side, large-scale renewables such as wind and solar power have seen impressive improvements in efficiency and cost reduction over the last decade. Making these assets more intelligent is one driver behind their improved efficiency. GE, for instance, makes wind turbines that automatically change gear according to wind conditions, and more recent solar panels are able to optimise their angle to the sun. Using IoT technology to monitor the *condition* of these capital-intense assets also creates more accurate knowledge about their real value at any point in time, which is an important lever to attract investors.

The use of intelligent assets has also begun to emerge in smaller-scale energy generation systems. SunPower, a US-based, integrated solar energy service provider, says it is making important strides in the IoT space, introducing 'smart' solar panels that are connected to other devices in the home, enabling energy consumption to be matched to generation – e.g. optimising the timing of energy-intensive activities such as laundry, refrigeration or dishwashing, with power generation. Cateva, a start-up supported by Siemens, has developed an energy management tool that allows homes outfitted with photovoltaic systems to rent out part of their battery power to network operators.[58]

So far, the growth of solar power has been most prominent in developed markets, and has been deployed largely without the help of intelligent assets. A number of companies are now using IoT to take solar power to developing markets where cheap, and preferably renewable, power is in desperate demand.[59] The company BBOXX offers combined solar power and storage kits to developing markets. Not only can they be remotely controlled and monitored, but knowledge of their location also facilitates service and maintenance in regions where infrastructure and location mapping can be poor. Since storage is often the limiting factor in solar power systems, ProductHealth has developed a connected device that helps users monitor battery health with their phone or computer. The algorithm warns the user of destructive use cycles based on readings of voltage, current and temperature. In addition, BBOXX as well as Sun King provide cheap solar panels or solar-powered devices, such as radios and reading lights, which can facilitate dramatic improvements to the users' standard of living and education.[60] Through collaboration with companies such as ProductHealth and Angaza, these products are intelligised and connected.

Although comparatively cheap, the solar devices offered in regions such as Sub-Saharan Africa are often too expensive for their target users. Angaza therefore offers a 'pay-as-you-go' platform that allows users to receive the product for a small down payment and to pay for the usage (usually on the baseis of number of weeks or kWh). Payment is made via a web or mobile interface, and the connected device knows when to switch on and off depending on the user's account balance. When the full cost of the product has been paid, the new owners can use it as much as they wish.[61]

The implications of using intelligent assets for energy generation and storage can be tremendous. Not only does it bring power and increased living standards to millions of people, their use could potentially allow regions currently devoid of grid infrastructure to prioritise distributed energy systems (e.g. micro-grids or even off-grid) over developing a grid infrastructure from scratch, avoiding huge capital expenditure sand resource consumption. According to Marty Neese at SunPower, the promise of IoT applies to developed markets as well – where the proliferation of solar and wind energy sources, which are approaching price parity with conventional, centralised energy sources, will have a drastic impact on the demands for energy distribution systems. Coupled with the increasing range of business models and technologies to improve efficiency and optimise energy distribution in (local) smart grids, the emerging ecosystem of intelligent devices will make this option increasingly viable.

58 Siemens, Swarm Solution for Energy Users (2015).

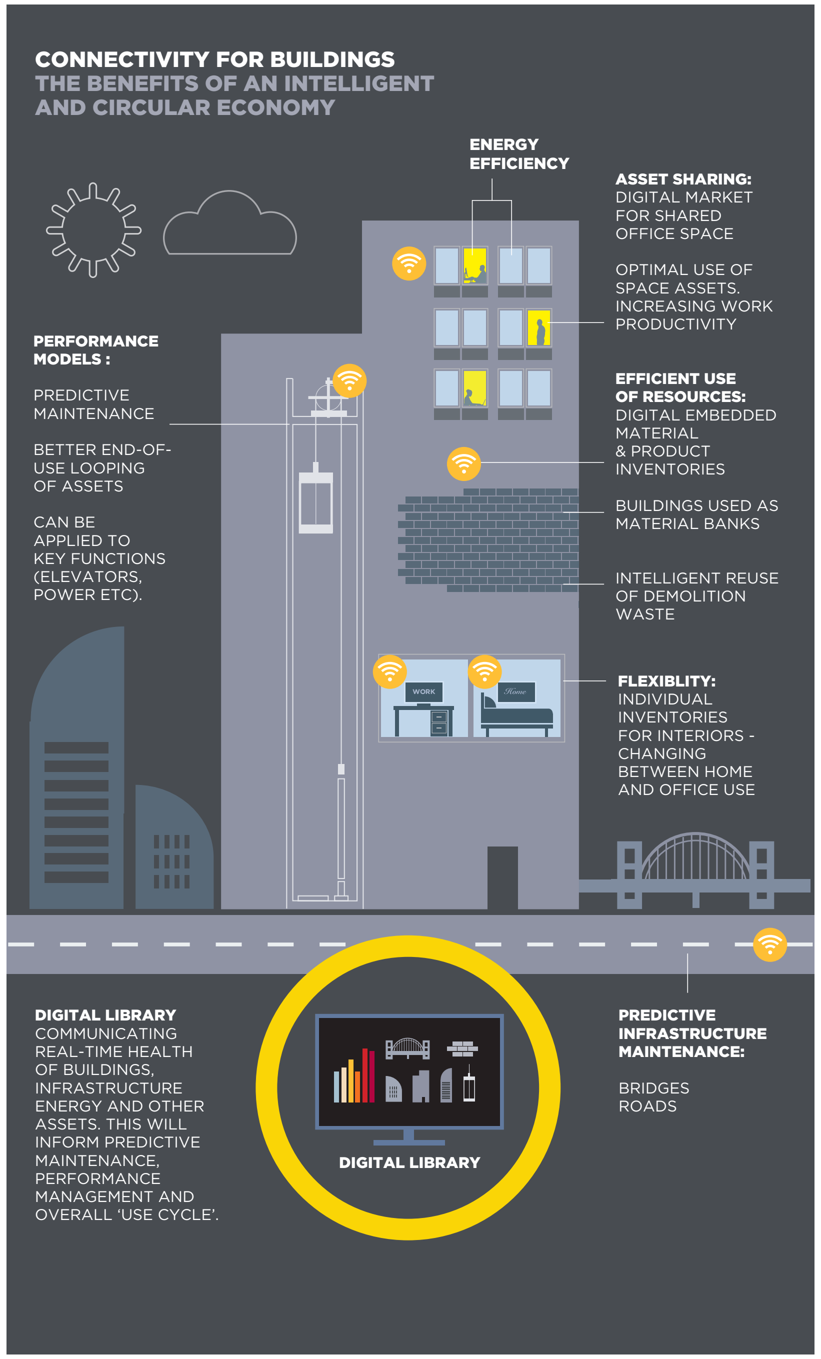
59 It is estimated that 1.3–1.5 billion people lack access to grid power. Estimates vary by source; see for example http://www.iea.org/topics/energypoverty/

60 Even a seemingly trivial thing such as being able to read after dark can mean the difference between getting into college and not. Education in developing regions is one of the crucial drivers for their accelerated development out of poverty, a fact that was also acknowledged by the committee for the Nobel Prize in Physics when giving the 2014 award to the inventor of the blue LED – the last component needed to produce white LED light. See http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/press.html

61 Similar models are growing in popularity in developed markets as well. SunPower predicts that so-called 'Power purchase agreements' – where the customer pays for the power generation rather than the assets – could further boost proliferation of solar power in developed as well as developing markets. The business model also aligns well with SunPower's ambition of being circular in their entire value chain, being able to take back and loop components and materials when they are decommissioned.

BUILT ENVIRONMENT AND INFRASTRUCTURE

BUILDING CONSTRUCTIONS THAT REMEMBER & COMMUNICATE



The incorporation of intelligent assets into the built environment goes beyond improving energy efficiency. It is reshaping both asset utilisation and material management within the sector. Connected buildings and building components are starting to enable the wider use of performance contracts and predictive maintenance schemes, while at the same time dramatically increasing the potential for improved asset utilisation through sharing. The future is likely to entail a built environment that is flexible and modifiable and which, through its interconnectivity, can feed the wider system (the city or the traffic grid) with information that enhances both traffic management and urban planning.

Imagine a world in which all roads, bridges, public spaces, sports facilities, office buildings and private homes represent the biggest valuable materials deposit for the built environment. In this world these assets are connected to a digital library, revealing up-to-date condition of the assets' components to not only enable predictive maintenance and performance models, but also to be a platform for a secondary materials market. Imagine how the connectivity of constructions could pave the way for closing the material loops for the largest source of waste in modern society.

The construction process is fragmented with misaligned incentives among contractors and can create up to 15% waste by volume.[62] Based on 2009 data, an estimated 54% of demolition waste in Europe is landfilled[63] and most recycling occurs in low-value applications.

A key reason for the value degradation of building material is the lack of knowledge of material composition or value. In addition, the utilisation of buildings is poor, resulting in inefficient resource use.

An estimated 55–65% of total office space is not used even during office hours.[64]

Structural waste is prominent also in infrastructure; every instance of unplanned maintenance for roads, bridges and other important infrastructure constructions causes large disruption and, despite road infrastructure being hugely oversized, congestion occurs regularly.

The road system is taking up 50% of the built environment space while peak traffic only covers 10% of the roads.[66]

Intelligent assets have begun to be incorporated into the built environment. Building service providers and construction companies are already using IoT to optimise the energy efficiency of buildings and larger communal systems (such as street lighting). Large building service providers, such as Johnson Controls and Honeywell, use IoT to help the tenants of their buildings to reduce the cost of their energy bills, while enabling utilities providers to better plan their energy production and avoid wasteful peaks.[67]

CHANGING HOW MATERIALS ARE MAINTAINED AND REUSED

In a more novel approach, intelligent assets are now increasingly being deployed to address the sources of waste and resource inefficiencies at several stages across an asset's use cycle. Knowing the *location* of building components as well as their condition gives asset owners unprecedented monitoring capabilities, enabling both new business and financial models. These models enable *extended use cycles* of buildings as well as improved potential to *loop or cascade* building components and materials in new use cycles at the end of the building's (or component's) use. For example, the automatic embedded product inventories generated by Dutch company BAM's building information management software allows multiple stakeholders to treat the constructions as a 'resource bank', enabling the assets to be returned when a building is decommissioned. IBM and Delta Development are collaborating on incorporating connected sensors into the new Schiphol Trade Park, which will provide an extremely rich flow of data that can be used to optimise resource use, predictive maintenance, reuse and functional design.

The infrastructure space is also seeing the introduction of connected sensor devices. Arup, for example, has supported the installation of an intelligent monitoring system in Hong Kong to enable predictive maintenance for roads and other key infrastructure constructions. Moreover, Arup recently projected a new bridge for heavy traffic over the Firth of Forth, Scotland, which will be equipped with more than 1,000 sensors to monitor its condition through a simple-to-operate, advanced and fully integrated structural health monitoring system.[68] Cisco and the Hamburg Port Authority have recently launched the 'smartROAD' proof of concept study, a pilot

62 Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth Within: A Circular Economy Vision for a Competitive Europe (2015).

63 European Commission, Service contract on management of construction and demolition waste (2011).

64 Norm Miller, Workplace Trends in Office Space: Implications for Future Office Demand (University of San Diego, 2014); GSA Office of Government-wide Policy, Workspace Utilization and Allocation Benchmark (2011).

65 Land dedicated to streets and roads, parking, service stations, driveways, signals, and traffic signs. See S. Heck and M. Rogers, Resource revolution: How to capture the biggest business opportunity in a century (Melcher Media, 2014).

66 Centre d'études sur les réseaux, les transports, l'urbanisme et les constructions publiques (CERTU), http://www.certu.fr

67 See https://buildingsolutions.honeywell.com/en-US/solutions/; http://www.johnsoncontrols.com/content/us/en/products/building_efficiency/case_studies2.html

68 As a side effect, this design choice avoided demolishing the existing 50-year-old Firth Road bridge, which could instead be repurposed for lighter traffic (thereby avoiding the need for a resource-intense new bridge). Future installations of monitoring devices on the old bridge could potentially enable predictive maintenance that would extend its lifetime even further.

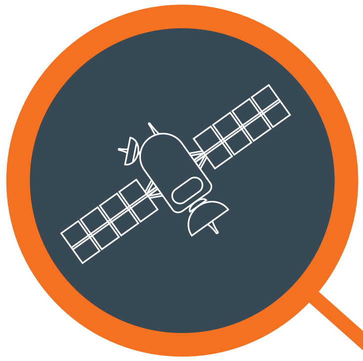
aiming at improving aspects of infrastructure, including resource management and traffic flow, through the use of sensor technology and analytical tools. The first phase of the project focuses on monitoring the health of the infrastructure while subsequent phases are planned to monitor and optimise traffic flows and lighting.

Miniwiz, a company that turns post-consumer waste into high performance material, explains that despite the distance left to cover before intelligent assets provide granular information about the stocks and flows of building materials, such information could enable a harmonisation of design of new assets with the availability of local materials. Enabling design software to 'scout' the market for available resources could allow design decisions to be based on what materials are locally available. As such, the IoT-enabled transparency of material flows could facilitate the emergence of local, secondary material markets, similar to the Scottish Material Brokerage Service.[69]

PROLIFERATION OF PERFORMANCE MODELS AND ASSET SHARING

Intelligent devices also increasingly allow for the use of performance models in the built environment. For instance, Delta Development has introduced a 'Products of Service' leasing model for elevators in the new Park 20|20 and ongoing Schiphol Trade Park project. Data transmitted by the elevators enables predictive maintenance and better end-of-use looping or cascading of the assets, and lets Delta act on its incentive as product owner to maximise the elevators' utilisation and quality. More IoT-based monitoring is likely to proliferate performance models and further shift asset ownership and management within the built environment. As Rainer Zimmann at Arup points out, there is a clear business case for extending the performance model to more types of building components, including facades and interiors, or even materials. It is not inconceivable that materials manufacturers, facing reduced demand for raw materials, could shift towards providing, for example, 'steel-as-a-service' to railways, provided the right monitoring system is available.

Knowing the *availability* of a specific space, for example an office, can significantly increase its *utilisation* if this knowledge is used to enable sharing between users. Cisco's 'Smart+Connected Personalized Spaces' solution helps businesses increase the utilisation of desk and office space by dynamically allocating workspaces to employees. The system can reduce real-estate costs by up to 35% and enable an office space to accommodate 75% more employees. By connecting all office-related functions to the same platform, including lighting, heating, ventilation, air conditioning and IT devices, an additional 7–8% of energy costs can be saved as the devices only need to be switched on when an office space is occupied. Cisco estimates that the personalisation of the workspace enabled by this connectivity also improves workforce productivity. System managers can follow up on usage data across locations, spaces and services, and continually improve utilisation of the workspaces.



As the built environment becomes more sensitised and connected, more flexible use patterns and resource management could emerge. One conceivable scenario is one in which buildings' use cycles become *shorter* – but where modular design, performance-based use of components and granular embedded product inventories allow for cheap repurposing and a faster turnover of usage. More frequent repurposings of buildings enable both a more flexible adaptation to market demand and an opportunity to gradually upgrade and transform the building with state-of-the-art technology. Julie Pithers of the modular interior supplier DIRTT agrees that this scenario is likely, and adds that one could eventually see a home market when buildings are tailored to specific needs without having to include the average need of the next inhabitant. Hyper-flexible interiors that 'remember' their history could be exchanged on a large online market – at a fair price since their age, condition and therefore value is known – allowing families of five to move into properties that previously housed a small firm or studio, and vice versa. IoT-enabled local sourcing of materials for new buildings – as mentioned by Miniwiz – could be further reinforced by the faster turnaround of building materials.

69 The Scottish Material Brokerage Service began operating in January 2015. It has two aims: (i) to deliver collaborative contracts for waste and recyclable materials from Scottish local authorities and other public bodies of sufficient scale to help them achieve better value for money, and reduce risk from price volatility; (ii) to create the business conditions for investment in domestic reprocessing by providing certainty in the volume and duration of supply of valuable materials. See www.zerowastescotland.org.uk/brokerage

LOGISTICS AND WASTE MANAGEMENT

GETTING THE RIGHT STUFF TO THE RIGHT PLACE

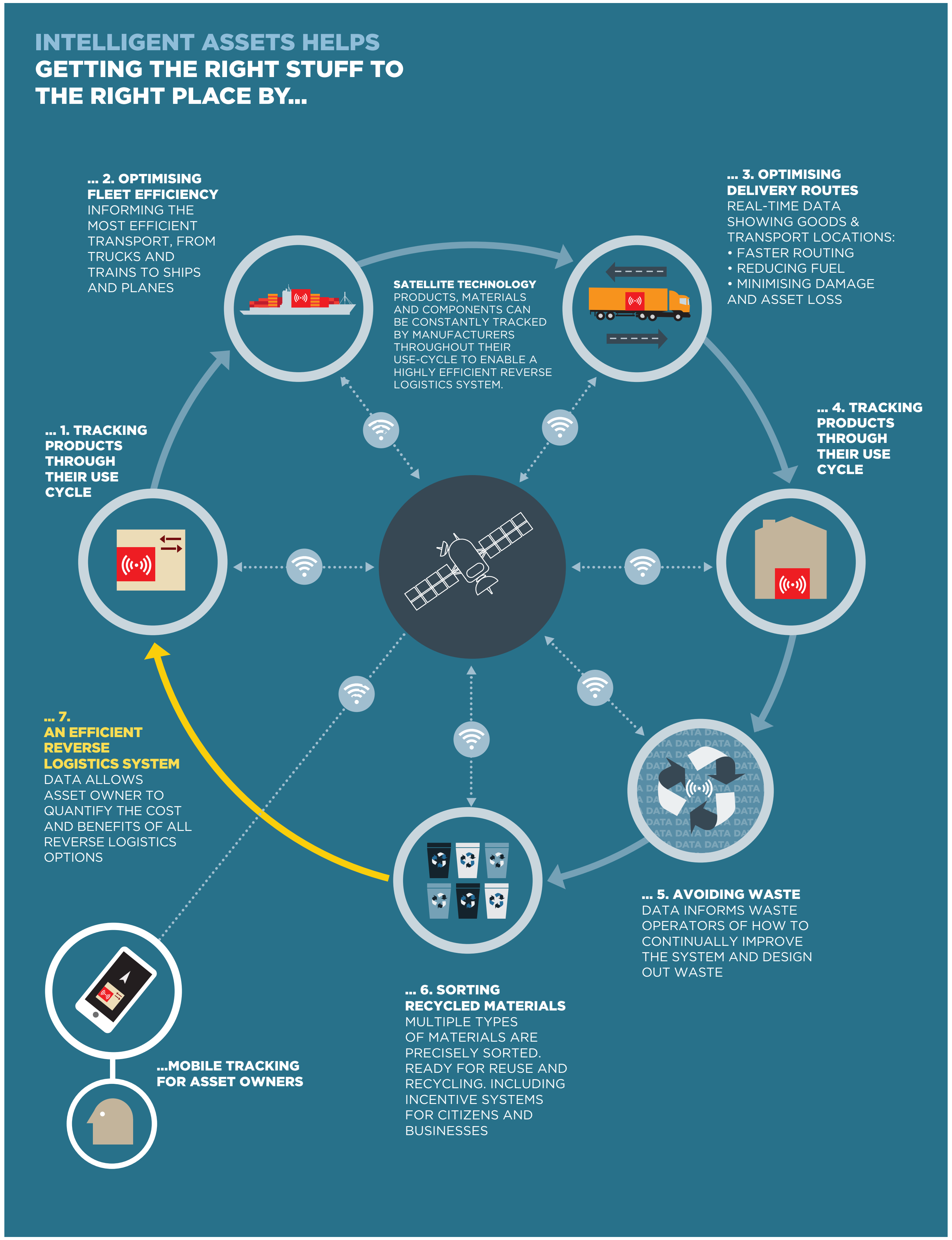
The latest developments in sensor technology and connected IoT systems mean that companies can now track almost any kind of asset, almost anywhere in the world in real time. Even though asset tracking has been standard practice in the logistics sector for some decades, new technologies are now increasing asset and resource productivity by enabling reverse logistics programmes as well as real-time route optimisation. Similar developments are seen in waste management where, in addition to real-time waste collection route optimisation, new systems are able to precisely sort and recycle multiple types of materials as well as monitor and incentivise waste disposal behaviour. Such progress could potentially reshape the way assets and resources are reused and recycled across industries, unlocking material value by providing transparency in reverse logistics and materials separation operations.

Advancements in tracking technologies embeddable inside product material will lead to a shift in thinking from product flow optimisation in the supply chain to material flow optimisation.
Eric Rondeau

Imagine a world in which you can track any of your business's assets on your tablet, no matter whether they're on land, at sea or in the air, or how fast or slowly they are moving. Risk of damage and delay would be minimised and global demand for resources, including food, materials or pharmaceuticals, could be met faster and more cost-effectively. Every product would come with a digital identity that reveals material components or ingredients, manufacturing processes and producers, making every aspect of the supply chain transparent and allowing you to make well-informed choices about what to buy. Imagine your waste collecting company receiving real-time data about the amount and type of materials in public and household bins, allowing them to pick up on demand and to connect with manufacturers to redistribute used or unwanted products and materials.

OPTIMISING THE ROUTE

Incipient satellite technology – enabling new forms of data collection from intelligent assets as well as through observation of the Earth – is changing how humans understand and manage materials and energy. Emerging business models in this field exploit enhanced tracking capabilities to unlock value in the logistics sector through new route optimisation capabilities that essentially increase utilisation of assets. For instance, San Francisco-based Spire uses its privately owned nano-satellite constellation to provide a platform for globally tracking just about any asset, from trucks and trains to ships and planes, enabling intelligence generation for global production and trade. This enhanced visibility means that damage or loss of assets can be minimised. For example, the shipping arm of a large commodity company uses Spire's technology to oversee its global fleet, enabling the client to minimise fuel consumption, determine optimal routing mid-voyage and reduce waiting time in ports. This kind of information about global supply chains also has knock-on effects in a variety of areas,



such as facilitating industry decision-making around sourcing and supply, giving consumers increased transparency about the origin of goods, and providing visibility into global economic activity, growth and risks.

In a similar way, the information generated by mobile devices could provide decision-makers with the data required to optimise resource management on a global scale. Premise, a California-based data analytics platform, services organisations such as the World Bank and the Gates Foundation by leveraging both existing satellite-based telecommunications networks and the proliferation of mobile phones[70] to measure economic, political and social trends in real time. The company is attempting to develop the mechanisms required to track persistent and ongoing resource security issues around the world – food, water, electricity, medical services and connectivity – to serve as a cost-efficient crisis prevention system for decision-makers and ultimately facilitate enhanced resource management around the world.

GETTING STUFF BACK

When it comes to getting a product to market, asset tracking is already very advanced. Logistics giants like DHL or FedEx are able to determine the exact location and trajectory of every single parcel in their logistics chain. However, the application of these best practices to the reverse supply chain – the inbound flow and storage of assets and related information – has so far been very limited (to a large extent because of prohibitive costs[71]). Knowing the *location and condition* of assets and resources is a key enabler behind most reverse logistics programmes, and the proliferation of cheap, connected devices could help extensive tracking systems become the norm in the reverse cycle. Businesses that know where their assets and materials are, even after they left the supply chain, are better equipped to quantify recovery value on a product-specific level, enabling the *looping and cascading* of assets across multiple use cycles.

One challenge of reverse cycle operations is that a collected product is often grouped with other similar second use-cycle products, which might differ in value depending on how they were treated and maintained throughout their first use cycle. Industry experts indicate that if an asset is aggregated or 'pooled' with other used assets and in this process the information on its individual quality is lost, it can get significantly undervalued. Increased transparency regarding the history, real-time location and condition of a product resulting from improved intelligent asset tracking could enable managers to reduce asset and resource value loss and increase the profitability of reverse logistics models. In addition, the ability of an intelligent asset to communicate its real-time *location* and *condition* means that reverse operations can be accurately timed, facilitating system optimisation capabilities.

An emerging ecosystem of innovators is aiming to deliver cheaper, more sophisticated IoT-enabled solutions for better asset tracking. For instance, UK-based Provenance uses blockchain technology to help businesses and their customers gather and keep track of data along and across the multiple use cycles of their assets. By tracking items geographically and revealing qualitative and quantitative product-related information, the Provenance system can identify assets that are not in use so they can be collected and launched into additional use cycles. According to Provenance, the model has the potential to assist the intelligent assets market to overcome existing interoperability challenges by laying the foundations for an open, secure global registry for all material items.

Getting assets back through reverse logistics can be challenging due to regional regulations.[72] For multinational companies operating in a number of different markets, the web of trade policies relating to the import, export and handling of 'waste' or used products can be onerous to navigate, and can discourage them from setting up reverse supply chains. For instance, Brazil, China and Russia do not have legal standards that distinguish remanufactured products from used products, and therefore they do not permit their importation.[73] In an attempt to overcome such barriers, governments such as those in Denmark, Finland, the United Kingdom and the United States are currently investigating how to adjust existing regulation;[74] IoT technologies could help in the effort to amend these regulations. The online trading platform eBay, for instance, notes that embedded IoT technology (which could store and transmit the history, composition and present state of repair of a product) could help overcome logistical hurdles, such as those involved on delivery and cross-border compliance.

Another intriguing innovation in this space is IBM's Reuse Selection Tool (also see the manufacturing section of this chapter). This platform will be able to compile and analyse IoT data about an asset's location and condition, allowing users to quantify the cost and benefits of various reverse logistics options, including reusing, remanufacturing or refurbishing. Optimising resource use in real time could be instrumental in enabling aspiring businesses to maximise profits in the inherently complex area of reverse logistics operations.

70 Premise estimates that by 2020, there will be an estimated 6.1 billion Android smartphone users globally.

71 Deloitte, The hidden value in Reverse Logistics Point of view (9 January 2014).

72 In the case of the UK see for example DEFRA discussion paper, Clarifying the application of the definition of waste to re-use and repair activities (2014).

73 UK All-Party Parliamentary Sustainable Resource Group, Remanufacturing: towards a resource efficient economy (2014).

74 UK All-Party Parliamentary Sustainable Resource Group and All-Party Parliamentary Manufacturing Group, Triple win: the social, economic and environmental case for remanufacturing (2014). See also: Ellen MacArthur Foundation, Delivering the circular economy: A toolkit for policymakers (2015).

COLLECTING AND SORTING, TURNING WASTE INTO RESOURCE

Intelligent assets are also augmenting capabilities in waste management and recycling. Sensing technology is, for instance, beginning to be used in this sector to achieve higher recycling yields through more precise sorting activities, as well as allowing operators to optimise waste collection routes and incentivise citizen and business waste disposal activities.

Tomra, a multinational corporation that creates sensor-based solutions for optimal resource productivity, uses its technology to establish state-of-the-art recycling through both reverse vending and waste separation, thereby helping its customers to improve their resource productivity by recovering materials through precise sorting processes during production. These services give insights into the composition of multiple types of materials, enabling both improved *utilisation* and *looping* (in this case recycling) of resources across additional use cycles. Tomra states that these improved processes helped mitigate some 22 million tonnes of CO_2 in 2014.[75]

Intelligent assets are also increasing the feasibility of optimising waste collection routing, reducing costs associated with fines on overflowing bins and incentivising certain waste disposal behaviour in specific areas. For instance, Amey, a UK-based infrastructure support provider, is currently developing a programme that uses intelligent bins capable of monitoring their capacity in real time, allowing optimal waste collection routing and the avoidance of fines. Looking forward, a system like Amey's intelligent bin network may be complemented with user-based identification tags allowing for more. The BURBA prototype, for instance – an EU-funded project whose name stands for 'Bottom Up selection, collection and management of URBAn waste' – uses such 'user' or 'disposer'-based tracking mechanisms. The prototype uses an app to inform the waste disposer about the location of specific bins in the area, making it easy for users to correctly dispose of their waste. Encouraging correct disposal behaviour could both increase the quantity of materials recovered and reduce misallocated waste streams (a major cost for recycling facilities).

In addition to the logistical benefits of connected bins, data collected by these bins can also be analysed to help local authorities understand the waste disposal behaviour of citizens and businesses. This information can be used to firstly optimise infrastructural elements (e.g. the placement of bins). Radio-frequency identification (RFID) or mobile user-based recognition at the point of disposal, together with data collected in the waste treatment plant, could also assist local governments in launching successful incentives to reduce waste volume and improve recycling rates. These include, for example, more directed information and capacity-building programmes, the introduction of differentiated collection taxes or fees based on performance, or 'good' behaviour reward schemes.

Sorting technologies such as those provided by Tomra can also reduce structural waste early in the value chain. In the mining industry, for example, up to 50% of the run-of-mine – raw materials coming directly from the mine to be delivered to the preparation plant – could be rejected by precise sorting at an early stage, which could save large amounts of structural waste in materials transport. Tomra describes how an Australian mining client who currently spends approximately 25% of its product value on road transport alone can, by installing pre-transport sorting, substantially reduce vehicle and fuel costs. Similar reductions of structural waste are experienced in the food-processing industry where optical sorters can analyse up to 45 tonnes of product per hour. Tomra is currently sorting around 180 different foods for its clients, assisting them to reduce food waste by approximately 5–10% and to maximise their yield.

75 Tomra investor presentation (21 October 2015). https://www.tomra.com/en/investor-relations/

IOT AND LOGISTICS PLAY A CRUCIAL ROLE TO ENABLE THE CIRCULAR ECONOMY

AN INTERVIEW WITH FRANK APPEL
CHIEF EXECUTIVE OFFICER,
DEUTSCHE POST DHL GROUP

What would a compelling vision of an IoT-enabled economy look like for you in ten years' time?
I believe that we will see a more circular economy in ten years' time. To design value chains with regenerative products, materials and energy and with zero waste, we have to rely on enablers such as the IoT, a global political framework with the right incentives and circular logistics with return solutions. In a future circular economy, products and materials become smart, being connected to the IoT. Integrated chips and sensors can ensure that life-cycle information relevant for the reuse of products and materials is collected and stored. The products will communicate with users, collectors and remanufacturers to ensure they are returned and reused after their first life cycle. Additionally, condition monitoring of sensitive goods during transport, storage and use will expand product lifetime.

How do you see your organisation fitting into this vision?
Both IT and logistics play a crucial role when it comes to enabling the circular economy. An optimised flow of products and materials has to be ensured on a digital and physical level. Logistics enables products and materials to be recovered and reused in an effective manner. The more information on the products' life cycle and residual value provided through the IoT, the more efficient the return logistics network can be. At the same time transparency on assets' locations through IoT technology increases network efficiency, with the management of swap bodies being just one example. Expanding the vision of the circular economy to our business means establishing a seamless logistics network with integrated return and processing and the provision of materials and products for the next life cycle.

Another area of great potential for synergies from IoT and logistics is the focus of the circular economy on renewable energy and designing out waste. Smart, communicating vehicles sharing traffic and network information can further increase logistics' efficiency – another area of our current innovation activities.

What do you think are the major hurdles and barriers to achieving this vision?
In dialogue with our customers, e.g. from the technology sector, we see the great potential of the circular economy. But what holds us back from implementing this system at full scale? Some key hurdles are the lack of consumer demand and the existing boundaries for returning products. This includes, but is not limited to, access to return points, the low residual value of returned products and complexity due to regulations on cross-border shipping.

If you could design an action plan for overcoming these hurdles and challenges what would your first three steps be?
First, we have to enhance our network (on both a digital and physical level) to improve the return and reuse of products and materials. This task is already on Deutsche Post DHL Group's agenda.

Second, collaboration of companies within and across different sectors is essential, including manufacturers, IT, logistics and recycling organisations. The Ellen MacArthur Foundation's CE100 programme (which we are a member of) offers a great platform for this collaboration.

Third, enabling the transition towards the circular economy should be on the political agenda. I am glad to see that the European Commission is already working on identifying related actions. Looking at our customers' and our own commitment to a sustainable and responsible business approach, I am confident that we will see a more significant transition of our economy in the near future.

AGRICULTURE AND FISHING

INTELLIGENT NATURAL CAPITAL

Intelligent assets are reshaping humans' ability to manage the Earth's natural capital. IoT-driven insights into the complex dynamics of natural resources are enabling conventional agricultural systems to significantly increase asset productivity while simultaneously enabling the regeneration of land. Crop production and wild catch fishing are two industries starting to develop new ways of unlocking the value created by combining circular economy and intelligent asset value drivers. Further technological and system advancements have the potential to expand on these solutions and enable these sectors to increase global food production while minimising resource use and environmental damage.

In the first half of 2015 alone, venture investment in so-called 'agtech' start-ups reached USD 2.06 billion; this figure was close to the USD 2.36 billion raised during the whole of 2014, a record year in itself.[77]

Imagine a world in which agricultural producers – through the ability to monitor and manage their crops and livestock more effectively – will meet the increasing global demand for food without having to transform more ecosystems to farmland. Imagine local farmers being able to reduce pesticide, fertiliser and water use to regenerate their land, while at the same time producing more fresh produce. Imagine the world's oceans rebuilding their richness of fish and other living creatures as a result of satellite tracking of fishing activities and the subsequently improved enforcement of international regulation.

An expected 60–70% more food is needed by 2050 to feed the world's growing population and meet the demands of a growing middle class.[76]

INTELLIGENT ASSETS ON LAND

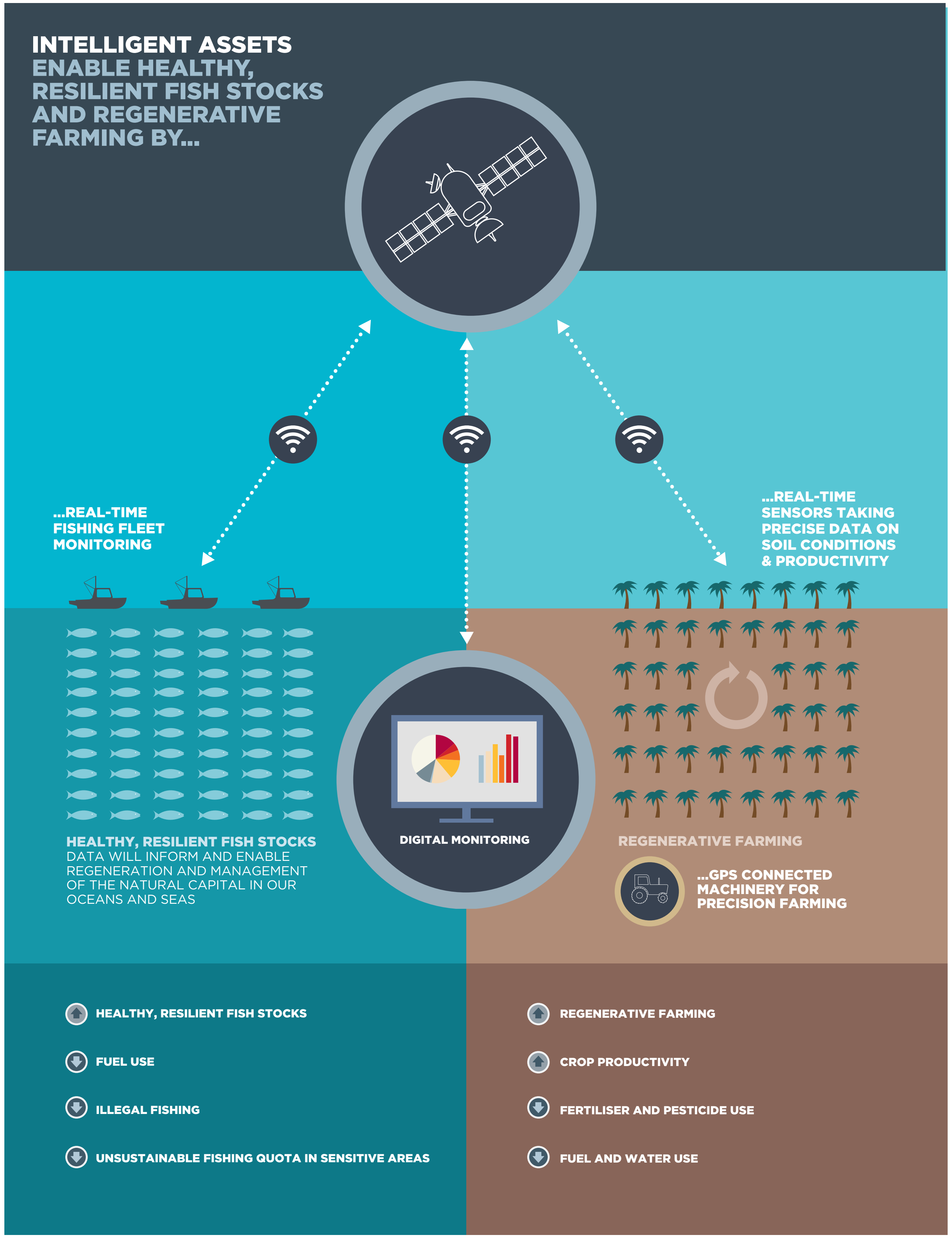
Sensing technology and so-called precision agriculture are transforming the agricultural sector, helping to overcome land and resource productivity challenges. Farming today is increasingly becoming a high-tech profession with farmers being supported by sophisticated management software, helping them monitor, for example, soil nutrients, moisture content, pest and disease control, yield per square metre or nutrient content. Venture investment figures show the enthusiasm about future value creation opportunities associated with these applications.

While over the past decades productivity in industrial agriculture has continuously increased on a per square-metre basis, it has come at the expense of additional input factors (e.g. fertilisers, pesticides and fuel). However, the recent development of sensor technology and cloud-based management systems enables farmers to greatly enhance asset productivity by generating the same or increased output with less input. As illustrated by the examples below, real-time IoT-enabled knowledge about the *location* and *condition* of their assets allows managers to optimise resource applications and improve the input/output ratio, as well as reduce soil compaction costs and other negative externalities associated with farming activities.

The Spain-based company Libelium, together with a large number of hardware and software partners, develops open source sensor platforms and cloud solutions that allow their clients to observe, measure and respond to the environmental conditions, diseases and pests that affect their agricultural production. This so-called precision agriculture enables growers to take action at the field level by matching farming practices to crop needs, and thereby reduce the use of pesticides, fertilisers and water, while boosting yield. Similarly, California-based start-up OnFarm developed data-feed management decision tools that allow clients such as Capay Farms to effectively organise,

76 On a caloric basis. FAO, World Food and Agriculture to 2030/2050; FAO Expert Meeting on How to Feed the World in 2050.

77 Louisa Burwood-Taylor, Moving to Mainstream: AgTech Gathers $2.06bn in the First Half of 2015, (AgFunderNews, 31 July 2015); Steve Lohr, The Internet of Things and the Future of Farming (New York Times, 3 August 2015)



analyse and synthesise the data provided by a large number of on-site sensors from up to 40 different suppliers, and combine it with external data, such as weather forecasts and water table readings.

Large agricultural players may choose to develop IoT-driven management systems themselves. Auscott Limited, one of Australia's leading cotton grower-processors, has developed sophisticated, customised IoT-based irrigation and cotton-bale tracking systems that help the company achieve world-class yields (approximately twice the global average). Auscott combines real-time monitoring of its water cycle on site, river-based sensing, satellite-based remote sensing and weather information. This approach allows optimised water usage and field productivity by reducing water wastage (run-off or evaporation) and soil erosion. This development is highly valuable in the semi-arid region in which Auscott operates – the company estimates that every 1% of water saved is worth AUD 200,000, while a 1% yield decrease (due to eroding soils) would cost AUD 675,000 annually. In addition, to ensure best practices and quality control, Auscott's cotton-bale tracking system uses plastic module wraps embedded with RFID tags to track the cotton from the exact GPS-derived location where it is harvested. This allows managers to monitor cotton quality variation within every square metre of their fields. Simultaneously, Auscott uses John Deere cotton pickers that continually monitor yield per hectare as they harvest the cotton. The quality and yield data can then be combined with topographic and plant density information to optimise irrigation and the application of NPK fertilisers (nitrogen, phosphorous and potash or potassium), pesticides and herbicides, as well as farming practices such as crop rotation, and even labour and machinery use.

NATURAL CAPITAL REGENERATION

The evolution of connected sensors and digital management platforms could also help farmers to *regenerate their natural capital* by improving the ability of their land to maintain or even replenish nutrients and topsoil. Maintaining or improving soil structure involves many factors, including achieving a healthy level of microbial activity, high levels of organic matter and reversing or preventing soil compaction. These factors are often interrelated and have positive effects for soil water and nutrient-holding capacity, and ultimately reduce soil degradation.

However, the regeneration of natural capital in conventional industrial agriculture is not easily achieved and sometimes requires drastic actions, such as the reduction of overall yields in the short term, combined with more long-term changes.

78 Land degradation assessment (FAO, 2015), http://www.fao.org/nr/land/degradation/en/. This statistic does not take into account the hidden costs of increased fertiliser use, loss of biodiversity and loss of unique landscapes.

The Food and Agriculture Organization of the United Nations estimates that land degradation costs an average of USD 40 billion annually worldwide.[78]

As pointed out by such practitioners as the Balbo Group in Brazil, a regenerative agricultural system needs to begin with the right design principles – intelligent assets are not a plug-and-play solution. The challenge is to measure the right things. According to Fernando Alonso of the Balbo Group, there is a risk that the information collected by the sensors prompts the farmer to optimise for short-term productivity rather than long-term regeneration, since what's best in the long term could be difficult to deduce from the data.

Yet, as illustrated by the following examples, connected sensors can significantly improve a farmer's ability to understand what is needed to maintain topsoil health and avoid degradation – an important development towards land regeneration.

- Sensors monitoring soil nutrient content allow farmers to observe and manage nutrient threshold levels and determine if and when intercropping, crop rotation or other management practices are required to prevent irreversible soil degradation associated with loss of nutrients.

- IoT enables high accuracy of data on pest levels and a shift from a preventative full pesticide application approach to directed treatment of infected specimens – either by spraying only when necessary or quarantining or destroying the affected crops before the damage spreads – which reduces pesticide use as well as the risk of 'super bugs' evolving. Libelium notes that sensing technology has been crucial to move towards a balanced and resilient viticulture, as documented in customer case studies in vineyards in Europe.

- IoT-based knowledge prevents and helps reverse soil compaction. Compacted soil impedes root growth and limits the ability of the plant to take up nutrients and water, which could eventually lead to irreversible land degradation. For instance, Auscott uses machinery equipped

with GPS devices that allows them to follow specific traffic pathways with approximately 2 cm precision and substantially reduce soil compaction. Although the associated yield benefits are difficult to allocate to one specific farming practice, Auscott's Chief Executive Officer Harvey Gaynor describes how moving to controlled traffic systems can increase dryland grain farming yields by around 16% on either side of each wheel track.

- The Balbo Group has georeferenced all sugar cane rows on its farms using GPS, allowing equipment such as harvesters, harvesting trucks and tractors to be automatically piloted when inside them, improving yields by ensuring that heavy equipment does not crush crops.

In sum, ubiquitous sensing allows farmers to better understand the complex causal effects of specific operations and resource applications. This can have important implications for better understanding, optimising, and scaling emerging practices such as permaculture and holistic land management.[79]

INTELLIGENT ASSETS AT SEA

About 30% of the tuna and tuna-like species (including 97% of the highly valued Pacific bluefin tuna) and nearly two-thirds of other straddling stocks and stocks of other high sea fishery resources are estimated to be overexploited or depleted.[82]

In 2010, fish accounted for 16.7% of the global population's intake of animal protein and 6.5% of all protein consumed.[80]

Intelligent assets could also enable better maintenance and the regeneration of natural capital in oceans and seas, which is significant partly because fish play a critical role in global food security.

Many of the most valuable marine resources, however, are already depleted.[81]

One of the major challenges for marine fish stock policy development and management is illegal, unreported and unregulated (IUU) fishing.[83] Advancements in space technology, intelligent assets and analysis networks are enabling monitoring and surveillance in areas that previously proved impossible to monitor. Companies like Spire are providing real-time satellite sensing services that notify concerned authorities about IUU fishing activities. Data provided by Spire and institutions such as the European Space Agency are enabling independent organisations to establish fisheries monitoring and surveillance platforms using an integrated data approach, such as the one created by the Satellite Applications Catapult. The technology merges an array of data, including biological information on expected fish migration routes, historical fishing information and satellite data, to determine and communicate illegal fishing activities to authorities.

Advancements in satellite data availability will not only contribute to the reduction of illegal fishing activities and the associated immediate stock rebuilding effect, but could also provide international policymakers with the monitoring and enforcement tools they require to establish more comprehensive international fish stock management legislation, potentially leading to achieving the long-term regeneration and sustainable management of the natural capital in our oceans and seas and the associated food security and bottom-line opportunities.

79 See, for example, on permaculture: https://www.permaculture.org.uk/knowledge-base/basics; and on holistic land management: http://savory.global/institute

80 FAO, The State of World Fisheries and Aquaculture. Opportunities and Challenges (Rome: FAO, 2014).

81 Addressing this challenge is one of 14 themes of the FAO Millennium Development Goals; see FAO, Fisheries, aquaculture, oceans and seas (2015)

82 J.-J. Maguire et al., The state of world highly migratory, straddling and other high seas fishery resources and associated species (FAO, 2006).

83 According to the European Commission, illegal, unreported and unregulated fishing (IUU) depletes fish stocks, destroys marine habitats, distorts competition, puts honest fishers at an unfair disadvantage, and weakens costal communities, particularly in developing countries.

DIGITAL DEVICES TO BOOST SOCIO-BIODIVERSITY

RICARDO ABRAMOVAY
PROFESSOR AT THE UNIVERSITY OF SÃO PAULO

Valuing the activities of populations that live in the forest and depend on it for their livelihoods is one of the most important ways of strengthening the mega-diversity of the Amazon and other important Latin American areas. Up to now these regions have been characterised by an economy of destruction and not by any form of natural knowledge economy. An economy based on the knowledge of nature, however, can only flourish if it supports itself on the practices of those whose production systems are already part of the forest's living dynamics. It requires the participation of at least three central actors: the traditional populations that inhabit territories with rich socio-biodiversity, the companies that purchase their products and the consumers themselves.

But how would it be possible to establish effective contact among worlds so far apart? The answer lies partly in being able to communicate the origins and journey of these products – and here intelligent assets can be critical enablers. Brazil's biggest bread-producing industry, Wickbold, will soon be including a QR code on its packaging that will enable the consumers of its products to know the story of the Brazil nuts in their bread: where they come from, who took part in their production and other information about the threats to protected areas and how to address them. In other words, digital technology creates transparency on what benefits sustainably produced food are creating, enabling a fairer valuation on the market.

Indigenous groups, riverside communities and those who live in extractive reserves are being trained to enable them to include the relevant information in digital devices so that the industry can offer its customers information about the socio-environmental bases of what they are consuming.

This initiative already enjoys the participation of several Brazilian companies and will be the starting point for expanding the system. It is a fine example of how digital technology can draw peoples with very different lifestyles closer together and can strengthen the feeling that the prosperity of all depends on our ability to value the activities of those who exploit the standing forest in a sustainable way.

SMART CITIES FOCAL POINTS TO IMPROVE RESOURCE PRODUCTIVITY

With 60% of the world's population expected to be living in urban areas by 2030, cities are focal points for both consumption and (structural) waste. Consequently, they provide a fruitful ground for solutions that combine the design and implementation of intelligent assets with key principles of the circular economy. These solutions are driven both by businesses and entrepreneurs – forming synergistic ecosystems of services that increase asset and resource productivity – and policymakers, who are in the position to make large-scale infrastructure investments, design regulation and use sensor-generated data to create incentives for more effective resource use.

60% of the world's population are expected to be living in urban areas by 2030.

Imagine you are meeting friends for dinner in a nice restaurant in the city centre. But you're running late; it's rush hour, the roads are busy and you have no idea where to park your car. Now imagine you're in a city where an app aggregates real-time traffic data and reporting from drivers to show you the quickest route, and LED lights downtown help you and other motorists set a smooth pace so that the car you picked up from the city's sharing pool gets there as swiftly as possible and waiting times at red lights are minimised. Finally, another smartphone app guides you to the nearest available parking space.

The average private car spends 15% of its driving time in congestion and 20% looking for a parking space. Improving transport flows and introducing intelligent parking systems will reduce congestion and therefore emissions.[84]

If your friends convince you to stay for another drink, you can top up your parking meter directly from your mobile, while real-time transport displays inform you about available buses, trams or trains you can take to get home. Because the temperature has dropped, your phone will ask the heating system in your house to warm up 30 minutes before your arrival. Lights will switch on and the kettle will boil hot water for a cup of tea just seconds before you approach your front door.

84 Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth Within: A Circular Economy Vision for a Competitive Europe (2015).

The US Environmental Protection Agency found consumers could reduce energy usage by 10–30% using schedules and temperature settings of programmable thermostats.[85]

Yet despite the heated house and hot drink, you are feeling ill the next day. Imagine you stay home and do a health check remotely using a table-top device that analyses a blood sample and sends the results to your hospital. If needed, a prescription can be sent directly to your local pharmacy within minutes. Not only will you save time, but the hospital will also save important resources and be able to devote more attention and space to seriously ill patients.

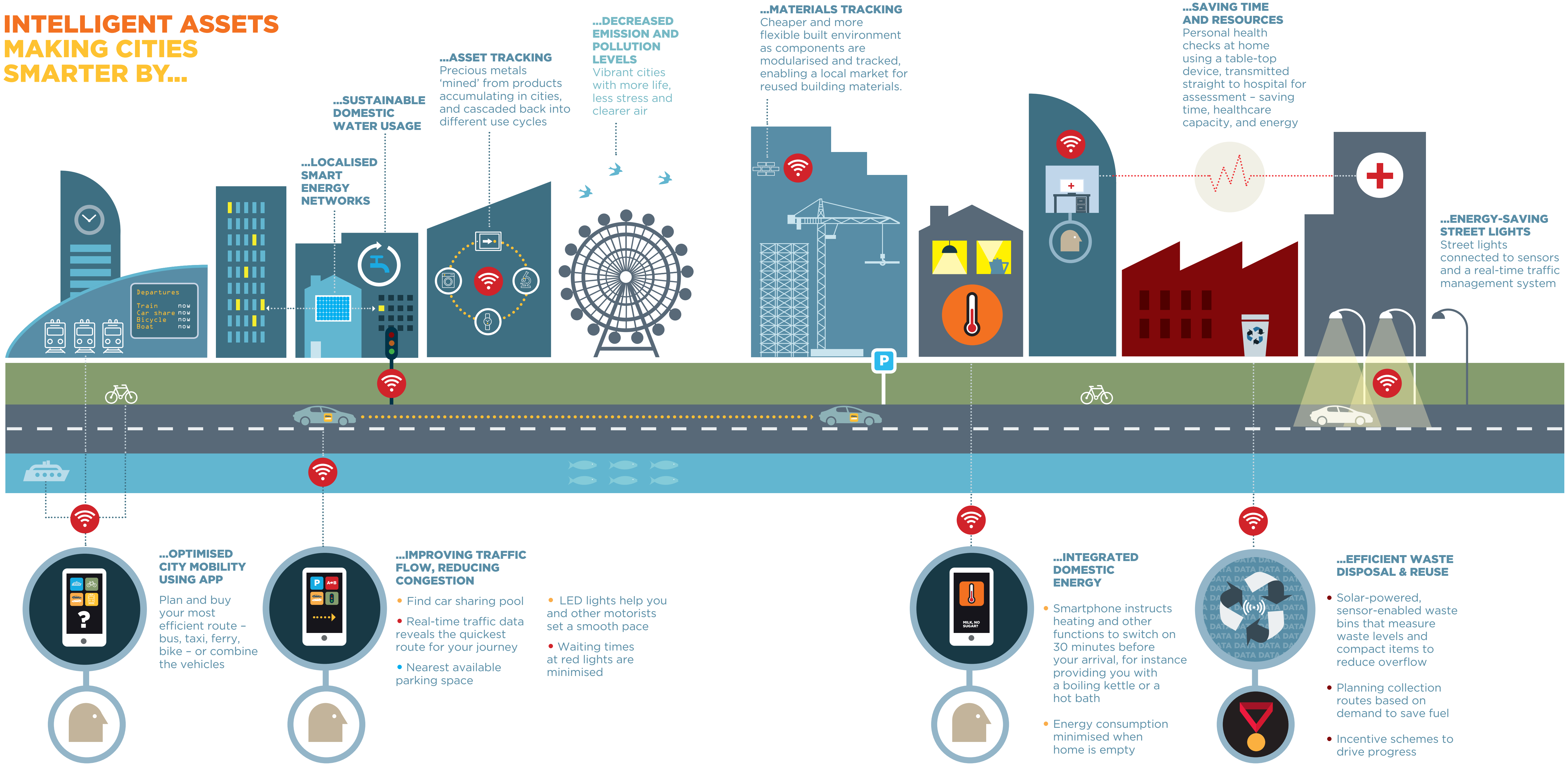
Berg Insight estimates that the number of patients using connected home medical monitoring devices will grow by 44.4% each year to reach 19.1 million by 2018.[86]

A CIRCULAR ECONOMY PERSPECTIVE CAN UNLOCK THE TOTAL VALUE OF SMART CITY SOLUTIONS

Cities are focal points for material flows, productivity and consumption. With some 180,000 people moving into cities every day, they are home to 54% of the world's growing population, a number expected to increase to 60% – five billion people – in 2030.[87]

Cities consume 75% of natural resources globally. They produce 50% of global waste and 60-80% of green house gas emissions.[88]

At the same time, since cities function as concentrators of materials and nutrients, they are the perfect stage for designing out structural waste as well as capturing residual value in secondary material streams. In areas such as energy, waste management, built environment and healthcare[89], connected devices can help increase resource productivity while dramatically freeing up capital and time – and help city authorities to develop an urban planning approach built on circular principles. Smart city solutions can help governments achieve many of their core objectives, including improved health services, minimised waste and resource use, sustainable domestic water usage, decreased emission and pollution levels and the improved flow of transport systems. A circular economy perspective can help unlock the value intelligent assets can potentially bring to the urban environment. Intelligent assets can add value by providing guidance through every stage of the development and implementation of smart city solutions, and by widening the arena for their application.



85 Martin LaMonica, Will smart home technology systems make consumers more energy efficient? (The Guardian, 22 January 2014).

86 Berg Insight, mHealth and Home Monitoring (2014).

87 HBR, How Smart Cities Save Money (and the Planet) (2012); WHO, Global Health Observatory (GHO) data (2015); McKinsey and Company, How to make a city great (2013).

88 UNEP, Cities and buildings – UNEP initiatives and projects (2012)

For example, with 9% of global electricity, 10% of gasoline and 13% of solid waste flowing through 27 of the world's biggest megacities alone, urban environments provide enormous potential for mainstreaming the idea and the broader application of 'closed loop' thinking. Cities could aim to use intelligent assets to close the resource loop through, for example, improved recycling, asset sharing, as well as the deployment of asset tracking technologies.

Albeit limited in how much additional resource productivity they enable individually, the ecosystems of smart city solutions could together revolutionise the way resources are used and consumed in cities. Benefits are wide-ranging for citizens (reduced time and monetary investment, improved health, less stress), entrepreneurs (space for innovation), the public sector (lower resource use, reduced costs) and the environment (reduced emissions and pollution, and increased utilisation and longevity of assets).

In the transport example outlined above, asset tracking paired with mobile technologies enable multiple car-sharing models such as Zipcar, DriveNow or Car2Go. The proliferation of these models means that a larger number of people can reach their destination with fewer assets and less time invested. The driving pattern of shared cars encourages electrification since they would often be parked in designated bays that could feature chargers, and the sharing pattern incentivises the design of cars that are more durable and easy to repair. Apps such as Parker reduce both the driving time looking for a parking space and the associated energy consumption. Apps such as Waze help drivers minimise their total driving time by real-time route planning. Intelligent traffic lights further reduce congestion and lead to smoother driving with less wear on vehicles. All in all, the impact on resource productivity in this example could be massive.

Overcoming humanity's greatest resource challenges requires a comprehensive, integrated understanding of technology and data [...] Nowhere else is this clearer than in cities.
Melanie Nutter

Transport is only one of the urban systems in which intelligent assets can unlock value synergistically. Asset tracking means that products are reused or cascaded back into a different use cycle rather than discarded. In that way, resources would remain in the city's ecosystem for longer (or ideally forever) and waste, as well as costs for sourcing new resources or raw materials, would be reduced to a minimum. A future city could source its share of the USD 21 billion worth of gold and silver that goes into the electronics manufactured each year from its own waste. Its lifts, escalators, fridges, lighting and heating systems, desks, chairs, phones and laptops could be owned and tracked by their manufacturer, who will either maintain and improve them or take them back and reuse them when your company decides it wants to get new ones or move to a different location. And the family housing could be much cheaper because the construction company owns and tracks the materials to reuse or sell at the building's end of life.

PIONEERS IN SMART CITY TRANSFORMATION

Just as a city's ecosystem of producers and consumers creates vast amounts of structural waste (e.g. congestion, emissions, health issues) and waste (e.g. food waste, packaging, sewerage) so can an ecosystem of solutions based on smart, connected devices gathering large-scale data address these problems. Even though transformation will happen to a large extent through new B2B or B2C solutions, governments and city planners can play an important role by providing a long-term perspective and investing in large-scale solutions (for example through public-private partnerships). Arup estimates that the global market for smart city solutions and the additional services required to deploy them will amount to over USD 400 billion by 2020.[91] Although transforming a metropolis that has evolved organically for hundreds of years into a smart interconnected ecosystem no doubt represents a difficult challenge, some cities across Europe have already achieved significant results by implementing smart city solutions. A few examples:

In **Helsinki** city authorities are aiming to 'unlock the ecosystem of mobility' and render car ownership obsolete by offering citizens a 'mobility as a service' app. This will enable users to plan and purchase their most efficient journey – whether by bus, taxi, ferry or bike, or a combination of these – at a cheaper price with greater flexibility. The government has recognised that multimodal transport infrastructure is critical to the success of this initiative. A key element of connectivity is Helsinki's public bike hire service and cycling infrastructure with lanes totalling 1,000 km in length.[92]

In **London**, where heat comprises nearly 50% of the city's energy demand and causes about 30% of its carbon emissions, authorities are aspiring to establish connected and mutually reinforcing heat and electricity networks to create integrated energy systems at a neighbourhood, district and ultimately city level, delivering secure, affordable and low-carbon energy to citizens and businesses. Smart city technologies and platforms will play an important part in achieving this vision by enabling effective integration and operation of heat and power systems and their associated infrastructure to improve their ability to deliver benefits to both energy companies and consumers. For example, the creation of Virtual Energy Plants using smart technologies and platforms could increase the flexibility of energy systems by coordinating and controlling multiple generating plants in different locations so that they operate as one plant.

The consultancy Rambøll has recently assessed the socio-economic value of '**Copenhagen Connecting**', an IoT-based strategy concept to improve the city's quality of life and resource effectiveness. The report found that the currently developed smart city solutions are estimated to create annual socio-economic benefits of EUR 590 million through 11–32% optimised car traffic flow, 2.4 million car hours saved, EUR 1.7 million in fuel reduction, 5.5 million m3 reduction in water use, 180,000 tonnes reduction in CO2 emissions, and a 50% reduction in stolen bike rates.[93]

In the United States cities have started to use IoT technologies to tackle waste problems on streets and in public areas. For instance, **San Francisco** has installed solar-powered, sensor-enabled waste bins that measure waste levels and compact items to reduce overflow. The bins share the data with local authorities, allowing them to enhance efficiency by planning collection routes based on demand. The use of this system can reduce operational costs by 70–80%.[94]

In South America, cities are also stepping up their game. Already 37% of streetlights in **Lima** are connected to a real-time traffic management system. Moreover the city is currently exploring how to deploy IoT solutions to make its infrastructure and economic activity low carbon in areas ranging from energy and transport to buildings and local ecological systems.[95] In **Mexico City** city officials have started looking at technology that would allow buildings to absorb nearby smog, creating a cleaner, safer city atmosphere, while **Rio de Janeiro** has invested in an integrated operations centre that hosts connected software, allowing for real-time monitoring of meteorological, crime, traffic and emergency data, as well as live camera feeds.[96]

89 Philips, How the Internet of Things is revolutionizing healthcare, http://www.philips.com/a-w/innovationmatters/blog/how-the-internet-of-things-is-revolutionizing-healthcare.html

90 C. A. Kennedy et al., Energy and material flows of megacities (PNAS, vol. 112, 2015).

91 Arup for the UK Department for Business, Innovation and Skills (BIS), Global Market Opportunities and UK Capabilities for future smart cities (2013); Will Knight, Driverless Cars Are Further Away Than You Think (MIT Technology Review, 22 October 2013).

It is imperative for cities to adopt circular systems to conserve global resources, reduce waste streams and emissions. For this reason circular economy (and circularity of resource flows) should be a founding principle for smart city planning.
Joanna Williams

A plan for converting data into useful information to achieve specific city resource management goals is key to best-practice smart city strategy.
Morten Højer

With about 30 village dwellers moving to a city every minute, **India** is urbanising at an unrivalled rate. City authorities have recognised that to address the resulting challenges of that movement, India's cities need to become a magnet for investment. With the announcement of transforming 100 cities into smart cities, the government is laying the foundation for improved security, water management and energy use.[97]

COLLABORATION AND DATA SHARING ENABLE THE CREATION OF A SMART AND CIRCULAR CITY

Public sector data is one of the single largest sources of information in Europe with an estimated market value of EUR 32 billion, with EUR 56 billion of additional gains if barriers were removed and the data infrastructure was improved.[98] As pointed out by Neil Crockett of Digital Catapult United Kingdom, 'increased data sharing will enable organisations to more effectively overcome challenges and profit from IoT opportunities'. The reuse of public data for smart city solutions could enable innovative and universal applications and services, while creating new business opportunities, jobs and greater choices for consumers.[99] To capture the full potential that smart city solutions can offer, city officials have the important role of both fostering the development of IoT-enabled applications in everything from urban planning to healthcare, while at the same time creating enabling conditions for a thriving ecosystem that embraces the core principles of the circular economy.

92 Citie, The City as Connector: lessons from Helsinki (19 May 2015).

93 Rambøll, Copenhagen Connecting Pre-Feasibility analyse (2013).

94 Bigbelly, Los Angeles Ninth Council District Expands Installation of Bigbelly Smart Waste and Recycling System (29 September 2015).

95 Boyd Cohen, The Smartest Cities in the World (FastCompany, 20 November 2014). http://www.fastcoexist.com/3038765/fast-cities/the-smartest-cities-in-the-world

96 Cisco, Critical Infrastructure: How Smart Cities will transform South America (2014).

97 Casey Tolan, Cities of the future? Indian PM pushes plan for 100 'smart cities' (CNN, 18 July 2015).

98 Graham Vickery, Review of recent studies on PSI reuse and related market developments (European Commission, 2011).

99 For a more extensive description of these policy instruments, please see Ellen MacArthur Foundation, Delivering the circular economy: a toolkit for policymakers (2015).

SPAWNING CIRCULAR INNOVATION *BIG DATA TO OPEN DATA*

CARLO RATTI
PROFESSOR OF THE PRACTICE AND DIRECTOR, SENSEABLE CITY LAB, MASSACHUSETTS INSTITUTE OF TECHNOLOGY; FOUNDING PARTNER, CARLO RATTI ASSOCIATI

Big data today is getting really 'Big'. According to a well-known quantification by Google's Eric Schmidt, every 48 hours we produce as much data as all of humanity until 2003 (an estimation that is already three years old). A lot of this data is produced in cities, through 'sensing' – the ability to measure what happens around us and to respond dynamically. New means of sensing are suffusing every aspect of urban space, where 'intelligent assets' reveal their visible and invisible dimensions. IoT also offers new ways to analyse and measure cities. Learning more and more about our cities puts us in a historically unique position to make more informed and intelligent decisions about resource use that affects almost every aspect of our lives – such as energy, waste, food distribution, healthcare, education and traffic. Therein exists great opportunity for aligning IoT innovation with circular economy principles.

To harness the vast range of opportunities offered by the spread of intelligent assets, the citizen must be involved in the process of managing resource use within cities. Citizens hold the ultimate control of their day-to-day activities and how they influence their surroundings, and IoT tools have the potential to give them the possibility to better understand and manage this influence. Mobile phone platforms are becoming key IoT enablers and hold great potential for unlocking circular economy value in this space.

In order for us to scale up the opportunities by the interplay between intelligent assets and circular principles, it is critical that an increasing number of people – users and developers of IoT – are involved by making big data and information public. In other words, big data should become open data to have a big impact on our lifestyle and cities.

FROM IDEAS TO ACTION

The surge in intelligent assets is expected to irreversibly transform industries and societies, and when paired with circular economy principles, this transformation has the potential to unlock tremendous value opportunities. However, for the full potential of these value opportunities to be realised, both private and public stakeholders must play an important role in addressing a number of technological, policy and business-related issues. As technology develops, there is a growing need for innovators and regulators to work together to leverage the richness of data generated while at the same time ensuring the privacy and integrity of organisations and individuals. Looking ahead, intelligent assets deployed in concert with circular principles could play a crucial role in facilitating the transition towards an economy that is truly restorative and regenerative.

Taken together, the value creation opportunities emerging in the sectors discussed in chapter 4 indicate that the synergies created there could indeed be major contributions to the acceleration of the transition towards the circular economy. However, the examples and expert perspectives presented in this report converge on the need to overcome several challenges to capture the full value at stake: reducing the costs of complexity and enabling interoperability; making technologies more transparent and accessible to the customer/user; and ensuring the security and privacy of data. If they don't address these challenges, businesses and other stakeholders could miss out on capturing the full value creation potential presented by recent technological development. For example, while 73% of companies across all sectors are already investing more than 20–30% of their technology budgets in big data analytics and a majority expect to increase spending in that area in the coming years, in 2013 businesses missed out on an estimated USD 544 billion, or 47%, of the total value created by IoT during that year.[100]

Since much of the potential highlighted throughout this report lies in the evolution of new business systems that reinforce restorative or regenerative practices among independent stakeholders, there is also a risk that a stalling development of innovation or data-sharing platforms prevents the more 'circular' benefits. Since circular business models and innovation need an extensive flow of information, limiting this flow may also limit resource management solutions to increase efficiencies. That is, IoT will no doubt increase the resource efficiency of assets and processes, but it is less clear to what extent it will be able to foster system effectiveness and propel the development of circular business models. As pointed out by several experts, the right enabling conditions for open innovation and data sharing are key to this development.

How should the key challenges be addressed? And where could this interplay lead if the challenges are adequately addressed? While there is of course no 'one size fits all' answer, this chapter outlines a series of questions and enabling activities to help private and public decision-makers to begin addressing challenges that could prevent them from capturing the full value at stake while driving the shift towards the circular economy.

100 Accenture and GE, Moving toward the future of the Industrial Internet (2015); Cisco, Internet of Everything (IoE) Value Index (2013).

NICOLAS CARY
CO-FOUNDER, BLOCKCHAIN

The greatest barrier to the acceleration of IoT is a broken financial trust and security model. You cannot have the circular economy and a network of intelligent assets without the widespread adoption of a global open financial protocol for value transfer. Current payment rails are antiquated, proprietary, slow and expensive. They also exclude billions of people and are fraught with fraud and risks. Thanks to the development of blockchain (the technology behind the crypto currency bitcoin), we now have the opportunity to democratise the financial system and let people who do not know or trust each other complete an economic transaction without relying on an intermediary.

IMAGINE A WORLD IN WHICH ALL PEOPLE CAN TRUST EACH OTHER

Let's step into the future a little. Imagine a world in which a Berber guide in the Saharan desert can instantly send a payment, to anyone in the world, at near zero cost. Imagine a world where your intelligent refrigerator detects you are running low on eggs and automatically orders them from Amazon with expedited drone shipping. Your fridge escrows the funds with a geolocational trigger, and when the drone arrives the payment is instantly done. Or better yet, imagine a world where you are running late for a flight and the Heathrow Express is severely delayed. Well, good news, you can order your self-driving, self-repairing and materially refurbished car, and pay it a surcharge fee to negotiate with all the other self-driving cars on the road to get out the way, automatically.

Unfortunately, before this can happen we have to completely reinvent the way payments work, and leverage a recent, critical innovation in computer science known as the bitcoin blockchain. Credit cards and other payment systems are Jurassic and inflexible channels for the age of the Internet. For example, online fraud is widely reported to be outpacing growth in e-commerce. This should not be a surprise to anyone who has studied the security model. Centralised data storage, combined with a 90-day settlement period for credit card payments, creates honey pots that attract hackers. Last year, hundreds of financial institutions were compromised in increasingly large breaches of personal and financial data. Traditional centralised security models no longer work. In addition, credit cards take a base fee and 2–3% of every transaction. Sadly, over four billion people can't even get credit cards and legacy-banking systems simply cannot scale to support an intelligent asset development where micro transactions will dominate the vast majority of volume.

The future financial system will be designed differently, leveraging decentralisation as a core principle in risk mitigation. In this world, anyone on earth will be able to participate in creating economic value on the Internet, using a financial protocol that allows individuals and machines to manage their own funds. The blockchain is a game-changing innovation because now, for the first time in history, a bitcoin wallet holder can transact with any other bitcoin wallet holder on earth, without having to rely on an intermediary. A few thousand lines of computer code can now do what banks have done for thousands of years, not to mention forex markets, clearing houses and merchant processors (all of which drive friction and cost in transactions today).

The technology behind the blockchain has the potential to reshape not just the flow of capital but also the efficiencies of supply chains. As a shared, secure record of exchange, the blockchain can track not only the transaction but what went into a product and who handled it along the way. With blockchain all bitcoin transactions can include a small referenceable amount of data, which means in a world of Internet-enabled devices, container ships, trains and trucks can record and capture any relevant details like location and elemental conditions and ensure that supplies are properly managed along their journeys. This data can then get captured and broadcasted to the bitcoin blockchain – the world's largest and most secure distributed computing database. A system that can create true transparency helping everyone study the provenance of goods and raw materials – a spreadsheet in the sky.

FRICTIONLESS AND TRANSPARENT

For intelligent assets to create value in the circular economy, we need frictionless payments as well as billions of Internet devices negotiating with each other, unleashing market forces to bring down the costs of goods and services for all. Supply chains will be transparent and the quality of our food, healthcare and products will be improved. As an industry, we have a lot of technical work to accomplish, specifically focused on scaling transaction capacity. We also need to build better software and experiences that allow people to more easily get used to interfacing with digital currency. On public awareness, we need to do a much better job of educating policymakers, influencers and general consumers about this groundbreaking technology.

ASKING THE RIGHT QUESTIONS

As much as connected, intelligent assets represent the technological answer to many present and future challenges, posing the right questions is key to steering the exploration of opportunities in the most beneficial direction for both businesses and society. This section outlines a series of questions for businesses and policymakers seeking to capture the value presented by the interplay between circular economy and intelligent asset value drivers. The scope of these questions is not limited to a specific industry or geography and aims at demonstrating ways in which institutions and individuals can begin to translate ideas into action.

Future market share will be captured by business models able to successfully leverage IoT-enabled transparency to exhibit circular economy activities.
Rick Robinson

QUESTIONS FOR BUSINESSES

1. How would the adoption of circular economy value drivers and the use of intelligent assets affect your industry? For example, if your industry shared pre-competitive data generated by intelligent assets, how much value could be created through increases in asset and resource productivity?
2. Could intelligent assets help you deploy new business models in accordance with circular economy value drivers?
3. Would the generation of detailed product information throughout the use cycle result in any design changes?
4. What value could you recover from assets you have sold in the last five years – and could information generated by those assets change this value?
5. Could data generated by your assets enable you to introduce (or improve) a reverse cycle programme in your business (including reverse logistics, remanufacturing/refurbishing and recycling)?
6. What financial model changes are required for your company to move from selling products to providing performance contracts?

QUESTIONS FOR POLICYMAKERS AND THE PUBLIC SECTOR

1. What would a programme to support education, collaboration and innovation in the interplay between circular economy and intelligent assets look like?
2. Could you in any way support markets in overcoming the interoperability challenge for intelligent assets?
3. Could public procurement guidelines be designed to encourage circular business models enabled by intelligent assets?
4. Can your institution facilitate the sharing of big data between industry stakeholders while maintaining data privacy and security? Is there a need to oversee current legislation?
5. Could knowledge generated by intelligent assets enable your institution to develop incentive schemes for businesses and individuals to become more resource productive (e.g. reduce waste, improve waste disposal behaviour, reduce energy and water resource demand, improve transportation flow)?
6. How could innovation, and privacy and data protection, flourish at the same time?

A CALL FOR CIRCULAR POLICY

NURTURING INNOVATION, CAPTURING VALUE

RICK ROBINSON
IT DIRECTOR, SMART DATA AND TECHNOLOGY, AMEY

The rise in IoT applications could significantly improve global market transparency, fundamentally changing the way consumers, government organisations and businesses make purchasing and investment decisions. More informed decisions would be made with increasing ease, a phenomenon that could dramatically shift consumer demand towards more resource-productive business models and shape them in ways we do not yet fully understand. Through this increased transparency, demand for circular products and services would grow, generating enormous market potential for products and services as well as entire business models designed to capture this demand. Models that successfully leverage IoT-enabled transparency to exhibit circular economy activities and establish a competitive advantage – through instrumenting the performance and impact of resources, supply chains, production processes and distribution networks – would succeed by capturing market share.

These changes in market transparency and the shift from the linear to the circular economy are unlikely to be driven by existing consumer demand alone, however. Consumer and business purchasing decisions are driven by many other factors – such as value for money; the quality of the end product; its ease of use; immediacy of purchase and association to brand values. To accelerate the shift – and perhaps to drive it to the extent required – both national and local policy initiatives are required to incentivise the development of the market.

Writing about the communities in which many of us live and work, in her book *The Death and Life of Great American Cities*, Jane Jacobs explains that 'private investment shapes cities, but social ideas and law shape private investment'.

An expressed governmental commitment to the circular economy, through the use of mechanisms, such as procurement practices, planning and development policies, industry regulations and tax regimes would shape the market to deliver on these goals. When a local authority or government institution expresses such a commitment, subsequent spending and investment in everything from new property developments to consumer purchases to the provision of waste services, catering or parks management will incorporate circular economy goals, challenging IoT users and developers and driving innovation as part of the competitive market process, having an enormous effect on the shape of the broader market.

Looking at today's IoT landscape, it can be argued that the market is in one way or another set to experience large growth looking forward. Whether this growth effectively captures the potential value creation possibilities posed by the circular economy - fuelled by increased consumer preferences for more resource-effective products and services - will be determined by whether the public and private sectors can agree on market shaping policies and practices that are effective in steering investment in circular economy solutions. Such solutions need to create transparent value for citizens and consumers, while offering sufficient opportunity for profit to attract private sector investment and IoT innovation. That will be politically, socially, economically and financially challenging dialogue; but it is a dialogue that we desperately need to succeed in order to stimulate the development of the circular economy at a pace that will make a difference.

SETTING THE RIGHT ENABLING CONDITIONS

A converging theme in the opinion pieces featured in this report is the challenge of enabling open, yet secure data sharing that fosters innovation and generates trust between stakeholders. The most significant challenge for businesses is to successfully move towards more open innovation, gradually shifting from the traditionally protective approaches focused on centralising data to maintain control, while ensuring adequate trust and security. The greatest policy challenge is to create an environment where businesses are able to innovate openly while at the same time ensuring organisations' and individuals' integrity with a strong legal framework.

ACTIONS FOR BUSINESSES

Employing both intelligent assets and circular economy principles requires a number of new capabilities for businesses to obtain a competitive advantage in the new economy emerging from the digital revolution. Below are some actions that – once a plan has been formulated – could help businesses capture the opportunities presented in this report.

Develop technical capabilities. Businesses will not only need the right sensing and interpretation technology but also the capabilities to filter, connect and make sense of the generated information in order to create mechanisms that support decision-making processes in the most beneficial way. Value is created from this information over several stages (i.e. data is *created, communicated, aggregated, analysed* and *acted upon*[101]) and businesses and customers alike ideally need to be able to extract value from all stages to optimise asset and resource productivity and make processes more circular. The choice exists between developing such capabilities in-house and outsourcing them – leading to a number of difficult decision points for organisations, but also to the possible emergence of new service sectors.

Adapt financing models. Circular business models enabled by intelligent assets could disrupt several financial aspects of businesses, including capital structure, accounting and valuation. Better transparency of asset inventories will lead to more accurate valuation of those assets, and would influence the supplier-customer owner incentives. Future balance sheets could therefore look very different. Performance and sharing models are just two examples of business models changing customers' and suppliers' need for capital – which could in turn disrupt capital markets.

Develop flexible business models. Within the emerging IoT landscape, business models capable of swiftly adapting to rapidly changing environmental and economic variables, such as commodity prices, inventory levels, and supply and demand patterns, will be future market leaders. The IoT enables real-time profitability optimisation, and businesses need to adapt their strategies and operations to allow more flexible and quicker responses to rapid changes in markets among competitors.

Develop skill. Investing in state-of-the-art hardware and software tools that create and aggregate big data is worth little to businesses unless they also have the right skills to translate this wealth of information into the right designs or decisions. Moreover, developing circular business models requires a broad set of capabilities in areas such as design, engineering, logistics and procurement. Companies need to invest in both recruitment and training activities to build the right skills among staff to understand and harness the new opportunities.

Develop collaboration platforms. Open innovation will not automatically lead to synergistic value creation and increased profits for everyone. The interoperability challenge is one that can only be overcome through the creation of collaborative environments where businesses, universities and innovators converge to solve problems in an open environment. Collaboration platforms along and across value chains, without constraints caused by competitiveness concerns, are therefore important catalysts for harnessing the potential in the interplay between circular economy and intelligent asset value drivers. For large businesses, internal collaborations may be just as critical to coordinate innovation.

ACTIONS FOR POLICYMAKERS AND THE PUBLIC SECTOR

Successful policymaking involves a tailored approach to problem-solving and setting goals specific to a region, which is arguably also a requirement for capturing value resulting from the interplay between circular economy and intelligent assets. Many policymakers face the challenge of creating an appropriate regulatory environment around a technological innovation that effectively ensures stakeholder trust and security while encouraging innovation. Sophie Hackford at WIRED Consulting explains how technologies, and the entrepreneurs leveraging them, are accelerating away from the capabilities of existing legal infrastructure to manage risks effectively, and that this development provokes alternative ways of providing a more effective regulatory system. Lessons learned from other fields, such as biotechnology or geoengineering – where the creation of 'guiding principles' for stakeholders to abide by was preferred – could prove useful.[102] On the other hand, sensitive issues like data privacy and security require a robust legal framework with adequate enforcement mechanisms. The key challenge for policymakers lies in stimulating (open) innovation while ensuring data security and generating trust for those who are directly and indirectly linked through intelligent assets. To address this, and other challenges related to enabling progress in the circular economy–intelligent assets interplay, they could consider instruments in the six categories outlined below.[103]

Large-scale interoperability demonstrators are key to harnessing value.
Neil Crockett

Information and awareness. These policies aim to change the ingrained patterns of behaviour of individuals and companies by providing them with broad or narrowcast information campaigns, or changing the curriculum or educational approach in schools, universities and continuing education. Since both circular and IoT-related innovation requires the private and public sectors to cooperate across traditional sectorial and functional silos, an understanding of the economic potential and the necessary practicalities is crucial and often lacking. To improve individuals' and societies' ability to engage with technology, many countries have started national initiatives, such as the US 'digital promise', created to spur the research, development and adoption of breakthrough technologies in all areas.[104] Similar programmes could be designed to create awareness of the limits of the linear economy and alternative, circular ways of doing business.

Collaboration platforms. These platforms can take the form of collaborations with some degree of government support, such as industrial symbiosis arrangements or R&D collaborations between academic and industry players. An important role of policymakers is to incentivise businesses to overcome interoperability hurdles by fostering cross-industry collaboration, including providing safe sharing environments (e.g. 'test beds') where multiple stakeholders can come together to solve existing problems. The demonstrator platforms set up by Digital Catapult United Kingdom are examples of a government-funded organisation stimulating open innovation through the creation of 'test beds'. These bring together businesses, universities and innovators to solve key challenges to growth in the IoT market while fostering circular practices.

Business support schemes. Government financial support such as grants, capital injections and financial guarantees all fall under this category, alongside the levers of technical support, advice, training and the demonstration of best practices. Possible solutions range from brokering traditional investment through public-private partnerships to using more innovative solutions including crowdfunding, as well as providing sufficient funding for research and education to support innovation from the circular economy–intelligent assets interplay. Finally, governments can create investment stimuli for models created by pairing circular economy principles with intelligent assets by underwriting some of the risk involved. An example of this is Innovate UK – a government-funded body providing R&D funding for specific projects. Its mission statement is to fund, support and connect innovative businesses to accelerate sustainable economic growth. It has already funded IoT projects regarding both security and smart cities, and circular economy business models.[105]

Public procurement and infrastructure. The public sector can step in to provide purchasing power that is lacking in the private sector due to entrenched customs and habits among companies and citizens or market failures, and which prevent IoT-enabled circular economy activities taking off. An early example is 'Copenhagen Connecting' – an initiative by the Danish city of Copenhagen. It plans to use smart data in traffic lights and lighting to create a more efficient traffic system that will increase safety for all road users and reduce traffic. When fully implemented, the initiative is estimated to yield economic benefits of roughly USD 735 million.[106]

Regulatory frameworks. The application of government regulations to mandate or stimulate circular economy activities enabled by IoT technologies, or prohibit or discourage non-circular practices, can either change existing regulatory instruments or create new legal frameworks. However, given differences in

101 M. E. Raynor and M. J. Cotteleer, The More Things Change: Value creation, value capture, and the Internet of Things, (Deloitte Review, Issue 17, 2015).

102 Innovations like the blockchain technology present another alternative to conventional regulation as the system secures itself by nature.

103 For a more extensive description of these policy instruments, please see Ellen MacArthur Foundation, Delivering the circular economy: a toolkit for policymakers (2015).

104 See http://www.digitalpromise.org

105 See http://interact.innovateuk.org/ for funding completion for research on IoT security and for feasibility studies into circular business models.

106 Ministry of Foreign Affairs of Denmark, Copenhagen Wins Smart City Award (26 November 2014).

the speed between the development of new policies and new technology and associated security issues, it is practically impossible for policymakers to implement effective policy targeted at specific issues. Instead, policymakers should focus on creating a secure, enabling environment. One example is to allow the development of an IoT-enabled information infrastructure that could make it easier to differentiate between resources and 'waste' in cross-border trading, which would in turn help governments control resource flows and build material backbones. A second example is establishing data privacy and security frameworks to create trust and confidence in the IoT market. At the moment the IoT is such a new technology that no such data privacy regulations exist; however many governments have started addressing this issue, such as the US Federal Trade Commission, which urges companies to adopt best practices to address consumer privacy. [107]

Fiscal frameworks. These instruments include different types of taxes and government subsidies. They can be applied to the market to either encourage circular economy activities enabled by IoT technologies, or discourage non-circular activities. For example, getting rid of (sometimes) indirect subsidies for raw material extraction or fossil fuels could further incentivise performance models. As illustrated by the Ex'Tax Project, shifting the taxation structure from labour to natural resource use could further incentivise circular practices as well as potentially create hundreds of thousands of jobs.[108]

LOOKING AHEAD

Intelligent assets form a powerful disruptive trend affecting most industries. The technology is already a market reality and will continue to grow, yet whether this growth will effectively capture the value creation opportunities offered at the interplay with circular economy value drivers will be determined by whether public and private stakeholders manage to successfully design and implement the enabling conditions required to overcome the challenges discussed above.

Looking ahead with a broader perspective, one can envisage staggering benefits, though it remains an open question to what extent and how fast this potential will be harnessed. Below are just a few possible outcomes that could be realised if intelligent assets were to be further designed, developed and deployed in concert with circular principles.

Enable material backbones. In the study *Growth Within: A Circular Economy Vision for a Competitive Europe*, one key recommendation for Europe is to develop a 'material backbone' – a system to optimise the circulation of materials and minimise the need for virgin resources – to strengthen its competitiveness. Intelligent assets – in particular asset-tracking solutions – could be instrumental in realising that vision.

Optimise stocks and flows. The ability of intelligent assets to monitor the flows of both technical and biological materials means that the question of optimising stocks and flows – a cornerstone in achieving the circular economy[109] – is no longer theoretical. It would be facilitated through combining an increased access to assets and multiplying the number of users per unit (e.g. through sharing platforms) with refining reverse logistic solutions enabling restoration through remanufacturing, and an increased transparency of the complex flow of residual and raw materials.

Reveal and quantify the cost of externalities. A major barrier for the transition towards the circular economy is the hidden cost of negative externalities. Sensing technology is already tracking detailed flows in, for example, food production systems, and in the future the extension of these applications could reveal the source of externalities, such as greenhouse gas emissions or ecosystem service destruction, in detail. This would not be a complete solution but a key step towards setting an accurate and fair price on these externalities.

As the global economy, and our living environment, become increasingly permeated by technology and intelligent assets, it is important for businesses and regulators to develop a more structured and system-based approach to the role they play in improving resource effectiveness, and with it people's quality of life, while at the same time safeguarding personal privacy and security. A first step towards creating and capturing value through the interplay between intelligent assets and circular economy principles involves increased cooperation between stakeholders within and across sectors (as well as between public and private sectors). If companies and policymakers manage to identify and articulate the opportunities presented by the circular economy – and integrate them in their strategies or policies – the synergies created together with intelligent assets could indeed be instrumental for solving several of the core challenges of designing an economy that is truly restorative and regenerative.

107 Federal Trade Commission, FTC Report on Internet of Things urges Companies to Adopt Best Practices to Address Consumer Privacy and Security Risks (27 January 2015).

108 The Ex'Tax Project, New Era. New Plan: Fiscal reforms for an inclusive, circular economy (2014).

109 See Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth Within: A Circular Economy Vision for a Competitive Europe (2015).

ABOUT THE ELLEN MACARTHUR FOUNDATION

The Ellen MacArthur Foundation was established in 2010 with the aim of accelerating the transition to the *circular economy*. Since its creation the Foundation has emerged as a global thought leader, establishing circular economy on the agenda of decision makers across business, government and academia. The Foundation's work focuses on four interlinking areas:

Education - Inspiring learners to re-think the future through the circular economy framework
The Foundation is creating a global teaching and learning platform built around the circular economy framework, working in both formal and informal education. With an emphasis on online learning, the Foundation provides cutting edge insights and content to support *circular economy education* and the systems thinking required to accelerate a transition. Our formal education work includes comprehensive Higher Education programmes with partners in Europe, the US, India, China and South America, international curriculum development with *schools and colleges*, and corporate capacity building programmes. In the informal education arena our work includes *Re-thinking Progress*, an open house educational event, and the *Disruptive Innovation Festival,* a global online opportunity to explore the changing economy and how best to respond to it.

Business and Government - Catalysing circular innovation and creating the conditions for it to flourish
Since its launch, the Foundation has emphasised the real-world relevance of its activities and understands that business innovation sits at the heart of any transition to the circular economy. The Foundation works with *Global Partners* (Cisco, Google, H&M, Intesa Sanpaolo, Kingfisher, Philips, Renault, and Unilever) to develop *circular business initiatives* and to address challenges to implementing them. In 2013, with the support of its Global Partners, it created the first dedicated *circular economy innovation programme*, the *Circular Economy 100*. Programme members comprise industry leading corporations, emerging innovators (SMEs), affiliate networks, government authorities, regions and cities. The CE100 provides a unique forum for building circular capabilities, addressing common barriers to progress, understanding the necessary enabling conditions, and piloting circular practices in a collaborative environment.

Insight and Analysis - Providing robust evidence about the benefits of the transition
The Foundation works to quantify the economic potential of the circular model and to develop approaches for capturing this value. Our insight and analysis feed into a growing body of economic reports highlighting the rationale for an accelerated transition towards the circular economy, and exploring the potential benefits across different stakeholders and sectors. The Foundation believes the circular economy is an evolving framework, and continues to widen its understanding by working with international experts including key thinkers and leading academics.

Communications - Engaging a global audience around the circular economy
The Foundation communicates cutting edge ideas and insight through its circular economy research, reports, case studies and books disseminated through its publications arm. It uses new and relevant digital media to reach audiences who can accelerate the transition, globally. In addition, the Foundation aggregates, curates, and makes knowledge accessible through *Circulatenews.org*, an online resource dedicated to providing up to date news on and unique insight into the circular economy and related subjects.