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INTRODUCTION

This document is an appendix to the report title Intelligent Assets: Unlocking the Circular Economy Potential, written by Ellen MacArthur Foundation in collaboration with the World Economic Forum as part of Project MainStream (a partnership between the Foundation, the World Economic Forum and McKinsey). The report was originally presented at the Annual Meeting of the World Economic Forum meeting in Davos, Switzerland, January 2016.

The Intelligent Assets report studied the interplay between the value drivers of circular business practices and intelligent assets. It's goal is to shed light on the value creation opportunities that emerge from this interplay, and to give a directional perspective on potential opportunities in the medium to long-term. Key to this perspective was the series of case studies collected from contributing companies; a selection of these are presented in additional detail in this appendix.

The full report can be downloaded from:

<http://www.ellenmacarthurfoundation.org/publications/intelligent-assets>

PROJECT MAINSTREAM

The Intelligent Assets 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. MainStream is led by the chief executive officers of nine global companies: Averda, BT, Desso BV (A Tarkett Company), Royal DSM, Ecolab, Indorama Ventures, 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.

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**CASE
EXAMPLES**

Angaza

Pay-as-you-go Solar Energy

Angaza's pay-as-you-go (PAYG) platform facilitates the sale of solar-powered devices to end users in the developing world, laying the foundation for the creation of prosperous grid-free societies without the vast investments and resources associated with traditional power infrastructure.

Angaza is a Bay Area-based start-up founded in 2010, and currently has 13 employees. Currently the sole focus of the business is on companies providing solar energy solutions for emerging markets. The footprint is already wide, with customers in East and South Africa, India and Pakistan, and there are plans to expand into new markets such as South America.

BUSINESS MODEL

Angaza's business model is a combination of usage monitoring systems and micro-financing. Its PAYG platform supports manufacturers who want to sell their products in emerging markets where access to capital and cash is very limited. The PAYG-ready products can be delivered to end users (consumers or small businesses) in return for only a small down payment; the embedded technology then monitors energy use or time used, and automatically deactivates the product if the pre-paid usage/time is expended and another payment isn't made. The users can pay for additional use via a web or mobile application. After the payments have exceeded a defined retail price, the customer can use the product free of any further charge. Angaza says that the PAYG platform has been able to boost their clients' sales by 400–500%.

SOURCES OF VALUE CREATION

Knowledge of the condition of the asset, in this case whether a device is being used or not, allows Angaza's customers to charge the users of their product for usage rather than the product itself. This means that the user can obtain a solar-powered reading light without having to pay the retail price (ranging from USD 10–12 for simple reading lights to USD 50–100 for solar home systems), but are charged on a weekly basis with unlimited use, or per kWh of usage. The effect of this model is substantial in underdeveloped areas where access to a reading light can mean the difference between a university degree and a stagnant life in poverty.

The Angaza model increases the utilisation of the asset (by enabling users to afford to use them) but also has the potential to extend the use cycle of the asset by, in the case of products with transmitting Global System for Mobile communications (GSM) chips, leveraging data for predictive maintenance purposes.

There is an indirect, more profound consequence of increased utilisation from the proliferation of available solar energy: it could potentially allow developing regions to leapfrog to a grid-free, renewable-powered society without the massive infrastructure investments that would be required to get power to rural parts of developing Africa using a conventional grid. Considering the vast resources needed to build up such a grid, solutions such as the PAYG platform play an important role in powering the circular economy.

OUTLOOK

It is easy to conceive other product segments where the PAYG platform could be viable. Angaza says 'anything with a measurable flow [such as electrons or water] is interesting', and is currently working on a solar water pump and clean cooking stove. The long-term goal is to develop a complete catalogue of renewable energy devices managed by the PAYG software – further contributing to lifting people out of poverty and helping them to lead empowered and healthier lives.

Arup IoT in Construction and Infrastructure

Arup has been a leader in providing resource-efficient solutions in the construction sector for decades. To enable circularity of buildings and infrastructure constructions, Arup is increasingly exploring Internet of Things (IoT) solutions to facilitate predictive maintenance, and envisages a future where IoT has disrupted ownership structures and assets can be looped faster, effectively making buildings flexible, upgradeable, and more resource productive.

Arup is an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services in the built environment. Founded in 1946 in London, Arup now has over 92 offices across Europe, North America, Africa, Australasia and South East Asia, and employs over 12,000 people globally.

SOURCES OF VALUE CREATION

Arup's core mission – 'we shape a better world' – resonates with the circularity of assets in the built environment, and circular economy principles are becoming increasingly important in its business. As a business partner focusing on helping clients find solutions to challenging problems, Arup is actively introducing IoT to increase resource productivity in construction and infrastructure projects. Two examples provide evidence of IoT-enabled circular benefits – and an indication of what's yet to come.

Arup challenged the proposed scheme to replace the over 50-year-old Forth Road Bridge, which spans the Firth of Forth in Scotland, with a bigger bridge. Eventually, it was decided to retain the old bridge for light traffic, and build a smaller new bridge (i.e. Forth Replacement Crossing). The consumption of a large amount of material resources was avoided by keeping the old bridge, which was essentially cascaded to a new form of use. At the same time, this resulted in significant project cost savings.

Arup have developed a simple to operate, advanced and fully integrated structural health monitoring system (SHMS) to be installed on the Forth Replacement Crossing. This will give advance warning of structural problems and allow targeted inspection and intervention to ensure the smooth operation of the bridge, and prolong its service life. Comprising approximately 1,000 sensors, integrated to comprise a resilient real-time event-driven system, the SHMS will store data in two independent servers, to be accessed using an advanced relational database system, which ensures correlation of data and the automatic generation of reports. This sophisticated IoT-enabled monitoring system will provide

knowledge of the new bridge's condition, enabling predictive maintenance which will extend the bridge's use cycle.

In a recent project, the construction of a sewage sludge treatment facility, Arup used building information modelling (BIM) software to develop a detailed '3D' model of the facility that not only helped design the plant in a resource-effective way, but also means the facility could potentially become a 'material bank' in the future. The '3D BIM' model provides transparency about material composition in the facility, enabling replenishment at decommission. There is potential to develop the '3D BIM' model into an operation and maintenance tool to assist in prolonging the asset service life.

OUTLOOK

Arup sees the IoT monitoring of construction projects as a lever to not only enable predictive maintenance, but also facilitate the development of performance-based business models in a sector where the longevity of assets has traditionally been an obstacle. For instance, the steel in railways could in the future be owned by steel manufacturers who, pressured by lower demand for new products, instead provide 'steel as a service'. By using intelligent assets to track both ownership and condition, they would be able to retain the asset while optimising its performance. Similarly, if buildings are designed more intelligently including designing out waste, and the condition and ownership structure of its components are fully transparent, it would be possible to more frequently loop certain components (e.g. interiors, building services, façades etc) to accommodate changing needs or upgraded technology. In this sense, the resource productivity of constructions could be optimised from a life-cycle point of view.

Auscott Limited

Irrigation Management and Cotton-Bale Tracking

Auscott's IoT-based irrigation management and cotton-bale tracking systems provide company management with a holistic view of field and resource dynamics, empowering them to effectively maximise yield as well as regenerate natural capital.

Founded in 1963 by the J. G. Boswell Company of California, Auscott Limited is one of Australia's leading grower-processors of cotton with 220 permanent employees and company operations on approximately 40,000 hectares in the Namoi valley, Macquarie, Murrumbidgee and Gwyder valley regions in New South Wales.

Auscott is a vertically integrated agribusiness with production, ginning, classing, marketing and shipping capabilities for both its own production and that of other Australian cotton growers. However the core of the Auscott business model is cotton production. The company, like many other Australian cotton growers, employs sophisticated IoT-based irrigation and cotton-bale tracking systems to assist them in achieving world-class yields (approximately twice the global average).

SOURCES OF VALUE CREATION

Auscott's IoT-based irrigation management system enables scarce water resources to be monitored and tracked across the water cycle. From on-the-field sensing to predictive weather data, the system takes the entire water cycle into account, resulting in optimised irrigation application and direct yield or field productivity increases resulting from reduced 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.

Knowing the real-time condition of the water cycle on the field allows Auscott to increase field utilisation. The condition of the field (or asset)

entails knowledge of the moisture content in the soil, of the volume of water in the on-farm storage facilities, of the water height in the canal systems and of the amount of water available from nearby river systems, and information from weather forecasts. The IoT-enabled real-time monitoring of the water cycle on the farm, combined with weather data, allows for optimal irrigation application which results in increased asset utilisation or in agricultural terms, field productivity.

In addition, the company also uses IoT technology to track cotton bales from the field all the way to the manufacturer. The cotton-bale tracking system uses plastic module wraps embedded with RFID tags to track the cotton modules from the specific, GPS-derived location where they are picked. This allows managers to monitor cotton quality variability within every square metre of their fields. Simultaneously Auscott's John Deere cotton pickers continually monitor yield per hectare. Combined quality and yield data are then overlaid with other biological and geographical information such as Plant Cell Density (PCD) maps or elevation maps, allowing managers to optimise Nitrogen, Phosphorous, and Potassium (NPK), pesticides, herbicides and irrigation application as well as farming practices such as crop rotation, and even labour and machinery use. This optimisation of resource application increases asset utilisation (field productivity).

BURBA

Bottom Up selection, collection and management of URBA waste

The BURBA prototype, an intelligent waste management system, was designed to increase the feasibility of optimising waste collection routing, reducing costs associated with fines on overflowing bins and incentivising certain waste disposal behaviour in specific areas. The prototype system is able to identify individual containers, users, single marked items or waste categories using RFID and LBS technology.

The BURBA prototype was developed as part of a European Union-funded pilot project, which ended in early 2014. The project was a collaboration between five different companies based across Italy, Spain, Portugal and China, the Polytechnic University of Milan and a total of three municipalities across Italy, Spain and Poland.

OPERATIONAL MODEL

The prototype system enables the real-time monitoring of the condition of waste containers. RFID and LBS technology inside the intelligent waste containers measure data such as temperature, humidity, weight and volume on demand or at specifically timed events such as disposal events. This data is then relayed and managed from a virtual private network.

The BURBA prototype's 'user'- or 'disposer'-based identification tags and tracking mechanisms allow for more tailored waste disposal activities. The prototype uses an app to inform the user about the location of specific bins in the area, making it easy for citizens to correctly dispose of their waste. Encouraging correct disposal behaviour could both increase the quantity of materials recovered and reduce misallocated waste streams.

SOURCES OF VALUE CREATION AND LESSONS LEARNED

Knowledge of the location and condition of waste containers (where and how full they are at a given time) facilitates the optimisation of the waste collection system, which increases the feasibility of launching materials/assets into additional use cycles. By increasing waste collection capabilities, a system such as BURBA's is expected to lead to not only an increase the volume of materials looped or cascaded into additional use cycles but also enables waste management to operate on a more granular level, enabling the engagement of more sophisticated sorting and recycling processes.

Since the project finished in early 2014 however, there have been no further plans to scale the prototype. The high costs to scale to a municipality level have been suggested to be a major prohibitive factor. These high costs are due to a range of factors. Firstly, the intelligent waste containers themselves can cost up to ten times the price of a more

traditional waste container. Furthermore, the prototype's battery and locking mechanisms require periodic maintenance efforts requiring the municipality to invest in associated skills training and the deployment of regular maintenance initiatives. In addition, to scale the BURBA prototype a municipality would require customised waste container production, which would require additional investment and the appropriate collaborations with a manufacturer. In its current state of development, considerable technological investment is thus required before the prototype would be ready to be applied as a system in the first few municipalities. It is likely, however, that with increasing scale, the cost to produce an intelligent container would go down considerably, making the system cheaper for other municipalities to adopt, hence increasingly its feasibility.

OUTLOOK

In addition to the logistical benefits of connected bins, data collected by these bins could potentially also be analysed to help local authorities understand the waste disposal behaviour of citizens and businesses. This information could be used to optimise infrastructural elements (e.g. the placement of bins). 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 could 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.

Cisco

Europe's first SmartROAD

The Hamburg Port Authority (HPA) in collaboration with Cisco is pioneering the Smart Port concept through the implementation of Europe's first 'smartROAD'. The smartROAD Proof of Concept aims to improve infrastructure condition, resource management, traffic flow and environmental management using an IoT approach with real-time data and analytics.

Cisco Systems, Inc., founded in 1984, is an American worldwide leader in IT headquartered in San Jose, California, that designs, manufactures, and sells networking equipment. Cisco has a turnover of around USD 50 billion and 70,000 employees worldwide.

As a proof of concept, the SmartRoad project provides real-time data on the condition of the movable infrastructure of the Kattwyk Lifting Bridge. Structural sensors are used to measure stress experienced by the wires, inclination of the bridge supports and bridge vibrations. Knowledge generated on the condition of the asset in question enables the technical maintenance department to precisely and predictively plan maintenance and repairs. Moving towards zero unplanned maintenance hours and the ability to maintain the asset at its highest possible value directly extends the use cycle of this asset.

The IoT system connects all structural sensors used – strain gauges, tilt meters, and accelerometers – and their associated systems, to a highly secure network infrastructure using LoRa, a low-powered wireless technology. Data is processed by analytics software, and findings are made available via a centralised, integrated dashboard.

Cisco

Smart+Connected Personalised Spaces

Cisco's Smart+Connected Personalised Spaces solution assists businesses to increase their utilisation of desk and office space by dynamically allocating workspaces to employees. The system can reduce real-estate costs while enhancing employee productivity by using a personalised platform to combine unified communications, web technologies, digital signage, media technology, and the ability to integrate with diverse building systems.

Cisco is a world leader in networking solutions with over 70,000 employees worldwide. The Smart+Connected Personalised Spaces solution has currently been introduced in English and Korean but is programed to be easily adaptable to various languages regions.

BUSINESS MODEL

With increasing energy and real-estate costs, the demand for flexible work environments where desks and offices can be reserved and used when needed is rising. Cisco's Smart+Connected Personalised Spaces solution satisfies this demand by making space available for reservation and use as needed. This allows for cost reductions for clients through improved utilisation of expensive real estate and the existing information and communication technology (ICT) infrastructure.

The solution is sold to clients in a one-off package. After sale a consultative service is offered where the implementation details are tailored in line with the office space layout and client's work requirements.

SOURCES OF VALUE CREATION

Cisco's IoT-enabled solution allows the user to know the real-time availability (supply and demand dynamic in terms of real-time occupancy/reservation status) of a workspace, enabling increasing utilisation of that workspace. The value creation potential was estimated to be as high as ~50% reduction in workspace facilities cost per employee, ~75% increase in number of employees accommodated and ~35% savings on real-estate costs.

In addition to this, the system enables knowledge on the condition of workspace attributes, such as workspace energy consumption data (e.g. lights, HVAC, blinds). This knowledge is estimated to create a further value of ~7-8% savings on energy costs.

Smart+Connected Personalised Spaces is enabled through a set of core technologies. It combines unified communication, web technologies, digital signage, and an integrated network architecture built onto a common platform. A web-based application allows end users to reserve cubicle and office space. In addition availability can be monitored and spaces reserved in-house, using Cisco's interactive media experiences platform, on digital signage set up at convenient locations throughout the workspace displaying the real-time occupancy status. Cisco's built-in systems such as HVAC (heating, ventilation and air conditioning), lighting and occupancy sensors are interfaced through a building gateway. This enables the users' personal lighting and temperature preferences to be automatically updated once they have checked in at a designated workspace.

This whole system can be administrated and managed through one portal, allowing managers to easily add, modify, and delete workspaces and services; automatically receive trouble tickets if issues arise; and produce trend reports about usage across locations, spaces, and services.

Delta Development Park 20|20 and Schiphol Trade Park

Delta's innovative products of service (PoS) leasing model moves away from selling elevators to the provision of 'vertical transport' service coupled with maintenance contracts. Through the help of IoT this business model allows for predictive maintenance and longer use cycle of the company's assets.

Delta Development Group is a privately owned real-estate development and investment company founded in the Netherlands in 1988, with offices in Germany, France and Italy. With a strong backbone in commercial real estate the company has a proven track record in the field of high-quality project development and value-adding asset management. Delta's current portfolio stands at over EUR 800 million.

BUSINESS MODEL

Delta's latest project is the development of the Park 20|20 and Schiphol Trade Park, a fully serviced office park that comprises approximately 89,000 m² of office space, 1,400 parking spaces, a 18,000-m² hotel with conference centre and 3,700 m² of facilities, including a supermarket, athletics track, and a variety of restaurants.

The project includes Delta's PoS leasing model - all elevators in the trade park are part of a leasing agreement. At the end of the lease, the client has the option to either purchase the elevators or Delta will reuse the assets in a different setting. For Delta the fixed service contract provides stable cash flow and due to the continued maintenance of the asset, market value exceeds book value at the end of the first contract period through the maintained (or improved) quality of the asset.

SOURCES OF VALUE CREATION

Within this business model, IoT plays an enabling role in creating value for both the asset owner and asset leaser. The IoT capabilities translate elevator use and parts/components maintenance data into information that allows the asset owner, in this case Delta, to provide building occupants with ongoing quality assurance and uninterrupted usability through predictive maintenance. The asset leaser benefits from reliable vertical transport with zero asset down-time.

Predictive maintenance, paired with ongoing quality assurance and improvement, extend the use cycle of the asset and increases asset utilisation. The longer lifetime of the asset allows the asset owner to loop the elevator through several use cycles. After the first contract period comes to an end, the subsequent use periods of the elevator result in above market revenue generation on the asset with further revenue generation from a new series of service contracts.

Real-time data generated on the use of the elevator means that parts approaching failure could be repaired or replaced, therefore maintaining or enhancing the quality of the elevator. In sum, the ability to monitor the condition of multiple assets in different locations increases the company's effectiveness in the entire management of the PoS portfolio (i.e. predictive maintenance and looping assets across multiple use cycles). IoT data that identifies used elevators that can be reused in a different setting enables Delta to cascade its products and maximise revenue through multiple use cycles.

Enit Systems

The Enit Agent

The ENIT Agent is a clip-on IoT solution that enables manufacturers to increase the efficiency and extend the use cycle of energy-related assets within their industry plants. Combining an open software and standardised hardware approach, the ENIT Agent is able to adapt to changes in the system, while prolonging the use cycle of different components of that system.

Enit Systems is a young, innovative start-up founded in 2014 with the support of the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany. After more than five years of extensive research and EUR 10 million of capital investment the team launched the ENIT Agent, which has become an attractive solution for clients from the German Mittelstand² as well as major players in the plastics and metal industries.

BUSINESS MODEL

The ENIT Agent is a clip-on IoT device that enables its user to understand, manage and maintain complex, decentralised energy systems such as industry plants. It allows for a comprehensive read-out of the billing meter as well as a full integration of the system's sub-meters and therefore eliminates the need to replace some of the client's older assets. The device has been developed to overcome two major barriers to effective resource management, the cross-sector integration of data and the implementation of multifaceted management algorithms.

The ENIT Agent enables industry clients to optimise production processes on the basis of real-time information, to reduce resource inefficiencies and to increase utilisation through improved monitoring of machine performance as well as predictive maintenance. In addition to the hardware Enit Systems offers a service giving clients access to specialist advice when it comes to decision-making processes.

SOURCES OF VALUE CREATION

The ENIT Agent is able to communicate with all types of energy technology equipment (solar panels, inverters, cogeneration plants, electricity meters) as well as with various other systems including those used in industrial automation and building automation. The client is given a web access point via which the energy flows in the operation can be traced in real time, revealing where predictive maintenance is required and savings potentials exist. On average, the ENIT Agent saves companies 5-20% on energy costs.

The ENIT Agent's high level of compatibility with present and future equipment from different manufacturers increases the product's integration and therefore extends the use cycle of these clients' assets. Through predictive maintenance based on real-time information of the location and condition of all assets connected to the system, utilisation of those assets can be significantly increased.

The ENIT Agent acts on an innovative networking layer that brings together the various worlds of industrial control technology, network control technology and proprietary control systems. The information derived from raw energy datasets within the system can be used to support decision-making processes in controlling (e.g. the energy costs per product type), process monitoring (e.g. the impact of process brakes such as maintenance), and supply security.

OUTLOOK

While the ENIT Agent offers a high level of interoperability, there is room for improvement. The open software invites other app developers to add languages of components that have not yet been integrated (or are currently being developed). To accelerate this process Enit Systems is currently developing new apps in cooperation with different plant operators. The aim is to integrate the deeply specialised production knowledge of the German Mittelstand into the development of energy management software, while allowing clients to exchange information and learn from each other.

There is also an ambition to create software that enables machine-to-machine (M2M) communication and therefore minimise the need for human intervention in IoT value creation. The database approach developed by Enit Systems is 50 times more efficient than existing products in similar settings and therefore opens up great opportunities for non-industrial applications, including buildings, micro-grids, combined heat and power plants and photovoltaic systems in the private sector.

² Germany's mid-sized manufacturers, collectively known as the Mittelstand, are often praised as a group for providing the backbone of the world's fourth-largest economy.

HP Instant Ink

Launched in early 2014, HP's Instant Ink service provides printing as a service to individuals and small businesses around the globe. The model uses connected printers to send customers replacement cartridges, along with post-paid envelopes for returning used cartridges, before the customer runs out of ink. The model successfully demonstrates a component recovery and recycling programme – or looping of assets through additional use cycles – both Business to Business (B2B) as well as Business to Consumer (B2C), in the consumer electronics sector.

HP is a global information technology company headquartered in Palo Alto, California with approximately 50,000 employees worldwide. HP brings together a portfolio that spans printing, personal computing, software, services and IT infrastructure at the convergence of the cloud and connectivity, creating secure, context-aware IoT solutions.

BUSINESS MODEL

IoT-enabled servitisation models are not a novel development at the enterprise level in the electronics sector. IoT-enabled monitoring of printers and computers for instance is standard in large IT management service contracts currently provided by both HP and Ricoh. Recent technological developments are, however, enabling performance models to trickle down to small- and medium-sized enterprise (SME) customers where previously the tracking and logistics were prohibitively costly. With its Instant Ink service, HP is pioneering the 'IT as a service' model further, taking it to consumer electronics level, a category notoriously difficult in terms of component recovery and reverse logistics.

Subscribers to the service 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. In this way the user never has to run out of ink. Empty cartridges are collected through a network of what the company calls their 'planet partners' – shipping companies and electronics retailers based all over the world – and returned to HP where they are entered into a 'closed-loop' recycling programme. Within a year of the launch Instant Ink was already approaching a million subscribers.

SOURCE OF VALUE CREATION

One of the key value drivers behind the IoT-enabled service model is the ability of the company to build stronger customer relationships through delivering a reliable and convenient service. In addition, it is estimated

that the programme's customers also benefit from up to a 50% reduction in their ink costs. Improved convenience, saved time and reduced ink costs all lead to a very high program customer retention rate. HP's 'closed-loop' recycling programme effectively loops assets through additional use cycles. Cartridge design and durability is improved to enable the business model, which HP has reported is eliminating up to 67% of waste associated with the number of pages printed. Additionally, printer use data helps inform system designs, including packaging and replenishment algorithms to minimise waste, while feeding data into future product designs, to improve serviceability, durability, and customer satisfaction.

OUTLOOK

HP is already looking at ways to extend the Instant Ink service, and increase IoT-generated knowledge of not only the quantity of ink in the printer but also of the operational condition of the entire machine. Such a development would enable the manufacturer to aggregate complete information on the printer's condition (this model could also prove feasible for other consumer electronic devices such as computers, coffee machines etc.). Not only would this approach add value associated with the predictive maintenance model but, when data on the composition and real-time condition of assets become abundant, it could significantly influence product design. The insights provided by the operational information could be applied to further inform the design of more productive and long-lasting future products – both by extending their use cycle (making them more durable and easier to maintain) and by enabling further looping (improving their design for remanufacturing, disassembly and effective asset recovery).

IBM Digital capabilities to enable the Circular Economy: Circularity Insights as a Service

IBM has recently developed a reuse optimisation tool, “Circularity Insights as a Service”, to support product managers to optimise the reuse of products, components and materials. The tool integrates and analyses the relevant data sets around the product specs, journey and market data, to enable a more informed decision making process. This results in increased resource productivity as well as financial and environmental benefits.

IBM is the world's largest IT and consulting services company, originated in 1911 and currently operating in over 170 countries. The corporation focuses heavily on innovating in research and development to shape society at large.

BUSINESS MODEL

After the first use cycle of an asset, it is normally challenging for businesses to effectively quantify the value of their assets in circulation. To be able to effectively know the real potential value of reuse of a product, component or materials, various data sets need to be integrated and analysed. Only then the optimal reuse option of a product can be made, whether to refurbish it, remanufacture it, harvest some key components or recycle the materials. The more we know about the product, components and materials specs, their state, their location, their accessibility and the market demand across the various product layers as well as the relevant regulations, the more we are able to pull value out of the reuse options.

The relevant data sets that feed into the reuse optimisation model include product related data: the engineering and design specs, the components list and accessibility, and if needed the materials, their accessibility and characteristics. Furthermore, IoT is enabling data by better tracking of the state, location and availability of assets making planning more accurate. And finally, data on the market status can be assessed through capturing demand data as well as the legislation constraints that might exist and limit the reuse options. The applicable data sets in the appropriate data model for the industry and product category will feed into the forecasting and optimisation model, to enable real time based insights around optimal reuse.

The model will also cope with variable business objectives such as maximise profit margins, maximise revenue, or minimise inventory. For instance, suppose a medical equipment manufacturer wants to define the most financially lucrative use of a returned equipment that they would like to retire from their portfolio. How would managers decide between refurbishment or upgrading to sell it in a secondary market or harvesting parts or recovering critical materials for their supply chains? Optimising such a decision would require detailed consideration about the geographic location of the asset, what condition it is in and information about the market price for components and materials of the asset as well as the resale price of the equipment as a whole. By compiling

and making such information available on demand, the Reuse Selection Tool enables individual businesses to build a business case for looping and cascading assets into further use cycles and potentially diverting them from landfill.

OUTLOOK

The IBM Circular Economy (IBM CE) core competence team is working closely with the Watson IoT unit to define how to bring the quality of insights to the next level, bringing more value to their industrial sector clients. A suitable performance based business model will of course be favourable to secure returns. Jad Oseyran, from IBM notes that “IoT technology development will enable further the move to a performance based model as well as provide more information on an asset’s location and the state which it and its components are in”. In addition, the cognitive capabilities of Watson could prove valuable to complement the current advanced analytics capabilities of the model by leveraging vast amount of unstructured data (like documents containing text or pictures, regulation or technical design documents).

The IBM CE team is currently exploring opportunities within the construction industry because of its asset-intensivity as well as the diversity of the industry’s products and suppliers. The data model and the analytics engine of the reuse selection tool can however also be adapted to a multitude of other industries across the economy. Preferable candidates are asset intensive industries with a service or performance model, seeking to ensure more secure product returns. Other initial target industries are electronics and industrial machinery.

Libelium

IoT Management Platforms in Agriculture

Libelium, in partnership with companies including Elmitel, BioMachines and Dolphin Engineering, develops and manufactures a tailored Internet of Things (IoT) Smart Agriculture management platform to enable services that allow growers to observe, measure, and respond to the environmental conditions, diseases and pests that affect their agricultural production, making crop and farm management more effective and assets more productive even when used at small scale.

Libelium is a Spain-based technology company, founded in 2006 and with currently 45 employees in Zaragoza. The company designs and manufactures hardware and software development tools for wireless sensor networks and specialises in Smart City, environmental and water quality monitoring, and smart agriculture applications for customers around the globe.

BUSINESS MODEL

Libelium believes that for the Internet of Things to create maximum value, it requires an open platform capable of dealing with different technologies, communication protocols and sensor databases. Three years ago the company launched Waspnote – the first wireless sensor hardware platform to be open, horizontal, modular, and accessible – to enable IoT developers to design and deploy sensor applications in settings that range from smart cities to intelligent agriculture.

In partnership with Elmitel, BioMachines and Dolphin Engineering, Libelium has developed sensor networks and cloud solutions that allow for acquisition, storage, and processing of data to improve agricultural processes. So-called precision agriculture enables growers to take action at the field level by matching farming practices to crop needs and thereby reduce the amount of pesticides, fertilisers, and water used, while boosting yield. For growers, return on investment comes from gains in efficiency (workload), and savings on fertiliser, irrigation and phytosanitary costs.

SOURCES OF VALUE CREATION

Sensor nodes are deployed across agricultural fields and plantations to monitor several combinations of environmental parameters including temperature, humidity, photosynthetically active radiation (PAR), and soil water potential. Moreover, the sensors help detect disease development in crops by providing data on the condition of the agricultural asset. Through the connection with a cloud-based system, the information generated by the nodes allows growers to not only monitor variables that affect their crops in real time, from any location, but also to identify the appropriate level of activity (e.g. hydration, fertilising, pest prevention measures) required to increase their production. Because the fieldwork is managed remotely from a PC, smartphone or tablet, information regarding the real-time condition of the asset is crucial for defining the right actions in the different areas, at the right moment. The ability to share

information globally facilitates international cooperation in addressing problems and finding solutions collaboratively.

The knowledge regarding the real-time location and condition of crops allows the grower to improve field productivity by preventing excessive use of resources such as water and pesticides. A decrease in the use of pesticides not only reduces risk to the workers' health, but also reduces risk of harming plants, soil and affecting the groundwater, in the long term. Some of the technology applications include a function for predictive spraying advice in real-time alerts, allowing the grower to protect his crops from pests and fungal diseases –therefore increasing utilisation of biological assets – rather than treating the symptoms with even more chemicals.

The interoperability and connectivity of the open hardware platform with other developers' applications is key for the success of precision agriculture. Sensor nodes feed data into a cloud system and the grower can access and visualise information on a PC, tablet, or smartphone. Through the integration of decision support systems growers are alerted when they need to take action and guided through the process of identifying the most appropriate measures to increase production outcomes.

OUTLOOK

The open hardware platform developed by Libelium has already been used in over 50 settings in areas including smart cities, logistics, farming, deforestation, healthcare and environmental protection. The potential for future applications is unlimited, as long as cooperating developers continue to design technological solutions to connect with the system to create a new ecosystem of business opportunities around data generation, storage, and analysis.

OnFarm Systems and Capay Farms IoT Management Platforms in Agriculture

OnFarm Systems synthesises agricultural data into effective agricultural management decision-making. The OnFarm platform integrates data from sensors produced by over 40 companies, and data from public and manual sources, allowing their clients to optimise the management of a multitude of technical and biological resources used in modern agriculture.

OnFarm Systems is an IoT and data management start-up founded in 2012 in Fresno, California. The company currently has 11 employees and serves hundreds of agricultural clients, primarily specialty crop growers, predominantly in California and the Pacific Northwest. This case describes the OnFarm platform at work at Capay Farms, the tenth largest almond/walnut producers in the United States.

BUSINESS MODEL

The OnFarm platform collects and updates much of their clients' data every 15 minutes (currently processing more than 50 million sensor readings per month). In the agricultural sector, this is virtually equivalent to real-time monitoring. But the core of the OnFarm platform is not the volume of data, rather the ability to make good use of it through a software platform that gathers and synthesises this data to provide effective support for decision-making.

The OnFarm platform allows Capay Farms to effectively organise, analyse, and synthesise the data provided by their vast network of on-site sensors, combined with external data such as weather forecasts and water table readings. This allows the client to run a leaner, more resource-productive business since the use of input factors such as water and fertiliser can be planned more accurately.

While OnFarm charges a yearly subscription fee for their platform, the lion's share of unlocked value is captured by the client. Capay Farms currently monitors well depths, water flow and soil moisture levels to guarantee that groundwater levels are healthy, plants are getting the water they need for best crop health and production and that no water is wasted. Electric power use is monitored along with soil moisture levels to determine whether irrigation can be delayed or rescheduled to avoid the pumps being used during periods of high demand on the state power grid.

SOURCES OF VALUE CREATION

Knowing the real-time condition of the components that decide the productivity of the field – the 'asset' – allows the user to increase its utilisation. Example of such conditions include moisture content in the soil, weather conditions, and fertiliser applications, the movement of which is monitored through the soil profile to ensure fertiliser is being used by trees and is not being leached outside of the rooting zone. Increased utilisation comes from an unprecedented accuracy in the deployment of inputs such as fertiliser, pesticides and irrigation applications, and thus a decrease in excessive use.

Careful monitoring of the condition of individual areas of land unlocks an avenue to carefully regenerate biological nutrients in the bio-cycle and restore, rather than degrade, land and soil quality. For instance, increased knowledge of water resource flows can lead to a reduction in water loss and leaching of nutrients. In principle, knowing in detail the condition of soil and land could help the farmer to precisely manage production and rest periods that can help rebuild the soil layers and regenerate the land. Although there are not yet any established such uses of the platform, it is an area OnFarm plans to investigate.

In addition to regeneration, enabling the intensification of productive land and the retiring of marginal land is also enabled through OnFarm's technology. Growers know that some parts of their fields are less productive than others, and by providing compelling data on whether or not an area is prohibitively unproductive, OnFarm provides the financial incentive needed to alter management practices.

The core enabling technology for the OnFarm platform is the ability to read and synchronise data in real time from a large number of diverse sources. There are any number of technologies that assist in the capture of agricultural data, from in-field and on-machine sensors to aerial vehicles (including satellites, airplanes, and UAVs) to farmers' observations and public sources (mainly research carried out by the USDA/Cooperative Extension Service and National Weather Services). The hardware that collects this data is generally owned/leased by 'OnFarm Ready' partner companies, who deliver hardware technology, imagery, equipment, and weather forecasting that can aggregate massive amounts of data for analysis. The information is available through one management system, on any device, at any time and yet accessible only to participants with permission.

Philips CityTouch Public Lighting Services

The Philips CityTouch model uses intelligent assets to provide optimised street lighting services to cities around the world. The model extends the use cycle of street lights, enables specific lighting components to be reused at the end of a use cycle, and provides additional knock-on benefits such as increased efficiency in energy consumption in cities such as Los Angeles, Buenos Aires, London and Rotterdam.

Philips has been in the lighting industry for over 120 years, and over this time has developed a keen focus on street lighting. Six years after the original CityTouch incubator initiative within Philips, the CityTouch model is operational in over 500 different cities in 33 countries. The company plans to expand the model through entire Latin America, the Middle East and South East Asia in 2016.

BUSINESS MODEL

The CityTouch (lighting management) system for outdoor lighting offers user-friendly web applications to manage streetlights and analyse lighting data, making cities not only more resource efficient but also making them better places to live. The CityTouch platform either connects every street light directly via the cellular mobile network or through a local radio frequency network. All the data generated is stored and processed on the CityTouch lighting management platform, where the system direction and optimisation takes place. Customers pay an annual service fee per connected lighting asset for the management of the whole end-to-end solution from controls hardware to machine-to-machine connectivity and software applications.

SOURCES OF VALUE CREATION

By connecting outdoor light points and management software, the model allows operators – typically city authorities – to change light intensity remotely depending on natural light and street conditions, replace individual components based on actual burning hours rather than scheduled replacement based on assumptions, and reconfigure installations to adapt to changing environmental factors.

Combined, the system allows managers to optimise asset use time and predictively maintain their system, extending the use cycle of the assets. By increasing the ability to manage heterogeneous use cycles of the different asset components in detail, the model enables the looping of assets or asset components through additional use cycles.

The model also produces positive knock-on effects that lead to new sources of value for users of Philips CityTouch. For instance, when a light goes out completely or a specific component fails, the system's integrated auto-fault notification alerts the operator and enables managers to optimise maintenance logistics and processes on a system-wide level, saving not only employees' time and resources but reducing citizen inconvenience by identifying and fixing the lighting fault more quickly. Another effect is that the ability for managers to remotely dim or turn off lights when they are not required, leads to increased energy efficiency. Traffic density information can be applied for dynamic dimming schemes to better balance safety versus energy saving. Energy is also saved through the use of a cloud-based service. The cloud uses exactly the amount of remote computing power needed and eliminates the need for in-house servers, which is estimated to lead to at least 30% less energy consumption in computing.

Premise

Tracking Macroeconomic Trends

Premise is a San Francisco-based, global company with a network of nearly 30,000 contributors in 34 countries. Premise indexes and analyses millions of observations captured daily through their global network of contributors - to whom they have paid out nearly USD 3 million for their contributions in the past two years.

Premise is a data and analytics platform that measures economic, political and social trends in real time with a mission to improve people's communities and livelihoods around the world by increasing economic and societal transparency.

The model is building a widespread human-directed and machine-refined sensor network to track persistent and ongoing resource security issues around the world - food, water, electricity, medical services, and connectivity access. The model leverages the proliferation of mobile phones - in five years' time there will be an estimated 6.1 billion Android smartphone users, accounting for 70% of the world's population - tasking contributors to collect images and data on specific areas of interest in return for a fee. The expected result, an infrastructure capable of serving as an economic early warning, crisis prevention system for key decision-makers, ultimately enabling enhanced resource management around the world.

Product Health Monitoring Batteries

Product Health supports the distribution of off-grid solar power and distributed energy storage by providing a near real-time monitoring system for battery health. Product Health's Smart Battery Dashboard warns owners and operators of batteries of asset misuse or failing assets and supports optimisation of the battery's use cycle.

Product Health is a UK-based start-up founded in 2013. It originated from the venture capital firm Synergy Energy, and although there are only around a dozen employees, the company has already expanded across Europe, Sub-Saharan Africa and Bangladesh.

The monitoring system can be applied to other product types and could in the future propel development of distributed energy systems as well as performance models for a large variety of products. The technology is an enabler for the service economy because assets can be protected and maintained remotely, allowing people to rent products or pay for use. This shift is widely visible in the developing economies, where power systems and home devices are paid for by installments.

BUSINESS MODEL

Product Health acknowledges that the world still has 1.4–2 billion people without access to power. In developing markets, especially the Sub-Saharan region, the quickest route to power is often through a solar panel charging a battery, which could be used for charging phones, pumping water, or heating food.

Batteries are however very sensitive to usage patterns (how the battery is charged and discharged) and can degrade quickly if used in the wrong way, making them often the weakest link in a distributed energy system. Product Health monitors battery health and performance in real time using embedded IoT technology, provided crucial information for battery producers, distributors and users to optimise resource productivity. One of Product Health's key clients is BBOX, a solar home system manufacturing and distribution company.

SOURCE OF VALUE CREATION

Product Health bases its model on knowledge of the condition of the asset (the battery initially). Its web-based dashboard provides alerts that guide usage and maintenance of the asset,

ultimately helping to extend the use cycle of the battery. Knowing in advance if a battery is being misused, is failing or has reached the end of its life reduces waste and the cost of failures.

Monitoring hardware, including sensors and a communication hub, collects data on the voltage, current and temperature of the battery. The raw data is translated into intelligence that can be acted on, working with proprietary algorithms. The service can detect the state of charge, battery health, and estimate the battery capacity.

The algorithms and battery knowledge has been developed in collaboration with Oxford University's Energy & Power Group (EPG).

OUTLOOK

The type of technology provided by Product Health has been used for some time for large capex assets. One of the key differences in Product Health's offerings is the application of this technology to consumer-level products. Apart from batteries, there is of course an opportunity to introduce the same technology to other asset classes; Product Health is currently considering creating solutions for refrigerators, water pumps, and sanitation systems.

According to Product Health, another potential consequence of the technology is to enable a shift towards performance models for additional product types. Intelligising assets with elements such as the battery monitoring system is key to enable businesses to retain remote ownership and control of their products, and derive further asset value from predictive maintenance, well-timed decommissioning and looping, and a rich set of data to inform future design decisions.

Provenance Tracking Material Items

Provenance enables businesses to increase understanding of their material world. Provenance uses the blockchain as a platform to help businesses and consumers keep track of materials and associated data through asset use cycles. The model has the potential to lay the foundations for an open, secure register for all material items.

Provenance is a UK-based technology company that has been in operation since 2013, working with a beta group of 150 SME product-making businesses that span five countries.

BUSINESS MODEL

Provenance tags physical assets with digital information, connecting them to the blockchain, an open-access, highly secure data system. These assets (ranging from wood and fabric to gemstones) can then be tracked securely as they change hands and transform, along even very complex chains of custody.

Provenance technology is provided as software-as-a-service and charged to clients on a 'per transaction' basis with some basic set-up costs, for example whenever an asset is added to the blockchain or transferred to another user.

SOURCES OF VALUE CREATION

Knowledge of the location of the asset or resource allows materials to be physically tracked throughout use cycles enabling looping and cascading of an asset through additional use cycles. By geographically tracking products in an open, accessible system, assets on the Provenance platform that are not in use and ripe for reuse, remanufacture, or refurbishment can be identified and launched into additional use cycles. For example a bicycle can be registered on the blockchain using Provenance tools by a bike builder, using the embossed frame number as the reference. The bike owner can then receive a digital passport when purchasing the bike that contains the build date, the materials

used and a digital signature to say it was indeed manufactured by the said producer. Repairs and replaced parts can be logged by the owner as they use and maintain or upgrade the bike. If the owner wishes to sell the bike, new buyers would have access to an immutable, digital history for the bike and could then reuse components as appropriate or for those components they are not using the full details could be made public.

The Provenance model is made possible by blockchain technology. The blockchain is a distributed, verifiable ledger of transactions, which emerged in 2008 as an innovative platform for the decentralised currency Bitcoin. Provenance uses this technology to track real-time, verified transactions where assets are exchanged. Any type of data can be committed to the platform – location, status, certification – and will remain part of an immutable history of that asset. The Provenance model and blockchain technology simultaneously allow for the interoperability of data and secure anonymity for its users. All data that is uploaded to the platform, although pseudo-anonymous, can easily (through access to decryption information) be accessed and combined with any other data uploaded to the register if permission is granted. The analytics possible on data aggregated from, for instance, various subdivisions of a supply chain, or cross-sectorial data aggregation, have the potential to add enormous value through improved material flow decision-making capabilities.

Spire

Satellite-Based Maritime and Weather Tracking

Spire belongs to a new generation of companies that are commercialising the use of satellite data and, equipped with privately owned nano-satellite³ constellations, are revolutionising how humans understand and manage Earth's materials and natural resources. Making just about any point on earth observational from an array of space sensors, will have far-reaching consequences on how businesses and policy makers are able to manage the earth's stocks and flows of resources. Spire's satellite constellation collects data on a global basis and provides value by specifically listening to the earth's oceans and extremely remote areas, that cannot be served by other technologies. Spire collects and analyses near real time data relating to asset tracking, weather, and climate.

Spire is a privately owned, satellite-based maritime and weather tracking start-up founded in San Francisco in 2012. The company has experienced rapid growth with a focus on operational execution (8 satellites launched to date with a rolling manufacturing and launch schedule), a strong communication infrastructure (20 global ground stations as of December 2015), and extensive knowledge of market and customer demands. The company has over 80 employees across San Francisco, Glasgow, and Singapore, with clients spanning government and private sector entities in Asia-Pacific, Europe, and the Americas.

Emerging satellite data-based business models such as Spire's are harnessing value at the interplay between the circular economy and intelligent assets by increasing understanding of our material and resource flows around the globe, enabling the looping and cascading of assets through additional use cycles, and increasing asset utilisation and the regeneration of biological nutrients to the biosphere. Although it is likely that these developments will lead to value creation and innovative business models in multiple sectors ranging from logistics and waste management to agriculture and forestry management, Spire's services are employed in two main areas.

First, the logistics sector is exploiting enhanced tracking capabilities to unlock value through improved route optimisation that increases the utilisation of assets. Spire's nano-satellite constellation provides 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. The data collected by Spire leads to improved logistics and routing capabilities while at the same time building on industry-wide, or cross-industry collaborations and change. Moreover, 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 their global fleet, enabling them 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.

The second area where Spire is providing value creation services is in the wild-catch fisheries sector. Traditionally, shared wild-catch fisheries have been difficult or impossible to manage sustainably. The extreme vastness of fish stock habitat areas, the number of interested fishing parties and the immense fishing capabilities of modern-day fleets, all lead to large levels of uncertainty around who exactly is extracting how much of these resources⁴ and the failure of most international management cooperation attempts.

Space-based monitoring and surveillance of marine regions that to-date have only been observable by boat contribute crucial data for the successful management of 'shared fish stocks' – which are some of the most highly valued stocks in the world. Efforts to combat Illegal, Unreported, and Unregulated (IUU) Fishing are being transformed through the use of satellite data fusion and analysis. This is an economic and humanitarian issue as well as environmental one. In 2010, fish accounted for 16.7% of the global population's intake of animal protein and 6.5% of all protein consumed,⁵ yet many of the most valuable marine resources are already depleted⁶ and IUU has imposed worldwide economic losses of an estimated USD 20 billion.⁷

With satellites able to regularly monitor previously 'hidden' areas and resources, fishing activities can be better monitored and regulated, and concerned authorities can be notified about IUU fishing activities. Being able to effectively prevent IUU activities and ensure adherence to fishing quotas is expected to encourage international management cooperation since affected parties can be assured claim to any future benefits resulting from an agreement to reduce fishing today, thereby leading to the effective regeneration of depleted fish stocks.

³ The term Nano Satellite commonly refers to a satellite under 10Kgs.

⁴ 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 coastal communities, particularly in developing countries.

⁵ FAO, *The State of World Fisheries and Aquaculture. Opportunities and Challenges* (Rome: FAO, 2014).

⁶ Addressing this challenge is one of 14 themes of the FAO Millennium Development Goals; see FAO, *Fisheries, aquaculture, oceans and seas*, <http://www.fao.org/post-2015-mdg/14-themes/fisheries-aquaculture-oceans-seas/en/>

⁷ <http://www.nmfs.noaa.gov/ia/iuu/faqs.html>

TOMRA

Reverse Vending and Automated Materials Processing

TOMRA's market-leading sensing technology is already enabling state-of-the art recycling through reverse vending as well as waste separation. When deployed in processing industries such as mining or food, it can further optimise utilisation of materials and eliminate waste.

TOMRA is a leading provider of sensor-based solutions for collection and sorting in the recycling and material processing industries. Founded in 1972, TOMRA currently has more than 2,200 employees and leading positions in all its markets around the globe.

BUSINESS MODEL

TOMRA has two main business segments: collection (mainly through reverse vending) and sorting (in recycling of, e.g. household waste and EEE, and production in the food and mining industry); and sorting, which became a significant business in the mid-2000s and is now 40% of sales.

In short, TOMRA's value proposition is to help clients improve their resource productivity by recovering materials – both through reverse vending of consumer packaging and sorting at a recycling facility – and by increasing the utilisation of resources through more precise sorting during production processes. While sensing technology used by TOMRA has been in use for decades in the recycling, food and materials processing industries, recent market growth has led to rapid growth in TOMRA's business model.

The resource productivity potential enabled by TOMRA's solutions is substantial; TOMRA claims that they helped mitigate some 24 million tonnes of CO₂ in 2014. If their and similar technologies percolate into new segments, this number could be multiplied several times.

SOURCES OF VALUE CREATION

TOMRA's collection and separation systems are based on knowing the condition of the assets (in this case their material composition). A range of spectroscopic technologies, including VIS, near-IR, X-ray and colour identification, are used to identify the materials. The data is coupled with decision-making algorithms that can separate objects based on their spectroscopic fingerprint.

Based on the sensing, TOMRA enables its clients to loop or cascade assets through additional use cycles (improved materials recycling using high purity sorting to avoid downcycling), and increase utilisation of the assets through either finding use for discarded material streams or designing out waste in the (reverse) logistics chain. The latter value driver can be further detailed using the following examples:

- TOMRA's reverse vending machines can optimise routing of pick-up trucks by communicating their load and location to a GPS-based route-planning programme.
- In the mining industry, up to 50% of the run-of-mine could be rejected at an early stage, saving large amounts of structural waste in materials transport (as an example, an Australian mining client spends 25% of its product value on road train transports, which could be reduced by pre-transport separation).
- In the food processing industry, granular sorting of feedstock (~180 foods currently implemented) does not only prevent discarding of entire batches due to a few bad units, but also to select in detail the optimal use of units from the same batch (e.g. raw potatoes, crisps, fries, meal, etc.).

OUTLOOK

The intelligent assets responsible for sensing and sorting of different materials could, when applied together with real-time data sharing, be used to inform manufacturers about potential product improvements, improve the ability to 'close the loop' in materials recycling, and prevent waste from being produced in the first place. While this has not yet been mainstreamed, some intriguing hypothetical examples can be mentioned:

- Optimising process parameters at food or materials processing plants or incinerators based on knowledge of composition, and also giving customer pricing power based on quality of supplier feedstock;
- Determining optimal use of waste streams based on composition by balancing material/caloric value against cost of processing – e.g. selecting between anaerobic digestion and incineration for an organic waste stream;
- Analysing municipal waste batch composition to differentiate collection tariffs, which (combined with directed information programmes) could significantly improve policy compliance as well as reduce waste generation.