COLLABORATIVE PROJECT

MODULARITY IN ICT

This paper sets out to understand how modular design can enable the ICT sector both to innovate, reduce its dependence on virgin resources and extend the lifespan of its products. It was found that modularity can act as a lever towards circularity in the ICT sector if certain key parameters are met to avoid potential adverse effects.

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ANTEA GROUP

Tristan Steichen
Senior Consultant
tristan.steichen@anteagroup.com

ORANGE

Mikko Samuli Vaija
Lead Life Cycle Analyst
samuli.vaija@orange.com

Elisabeth Bêche
CE Project Manager
elisabeth.beche@orange.com

Jean-Manuel Canet
Senior Manager
jean-manuel.canet@orange.com

WITH ADDITIONAL CONTRIBUTIONS FROM:

- DLL Group: Sabine Hagevoort & Sjoerd van der Zee
- Granta Design: Luca Petruccelli
- HP: Ngozi L. Lawanson, Susan F. Dixon & John Ortiz
- iFixit: Thomas Opsomer
- Orange: Birte Kurbjeweit & Philippe Tuzzolino

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WHAT CIRCULAR ECONOMY CHALLENGE DID THE CO.PROJECT SEEK TO ADDRESS?

The purpose of this Co.Project was to evaluate whether modularity is the correct design decision to enable greater circularity within the ICT sector.

WHAT WAS IN SCOPE OF THE CO.PROJECT?

Specifically, the Co.Project project attempted to:

1. Explore what is meant by 'modularity' in the context of design and manufacturing of electronic products
2. Determine whether a shift to modular design principles could enable a transition to increased circularity within the ICT sector, taking into account the loops described in the butterfly diagram

INTRODUCTION

Modular design, or "modularity in design", is a design approach that subdivides a system into smaller parts, which can be independently created and then used in different systems. A modular system can be characterised by functional partitioning into discrete, scalable, and reusable modules; rigorous use of well-defined modular interfaces; and the use of industry standards for interfaces[1].

Such a design approach is an attempt to combine the advantages of standardisation - where high volumes normally equal low manufacturing costs, - with those of customisation - where products or services are tailored to accommodate specific individuals.

Modular design is not a new concept for manufacturers and there are well known examples on the market today. In the automobile industry, vehicles are designed with some level of modularity, e.g. engines and wheels that can be interchanged between different types of cars or trucks in order to reduce the diversity of component production. Although this type of modularity is not always visible to the consumer, the financial benefits to the manufacturer are clear. An example of modularity more obvious to consumers exists in the furniture industry, where products are designed and sold to customers with the intent of being customised (personalised) according to specific needs. As an added benefit, parts (or modules) of the furniture may be replaced or amended if needed.

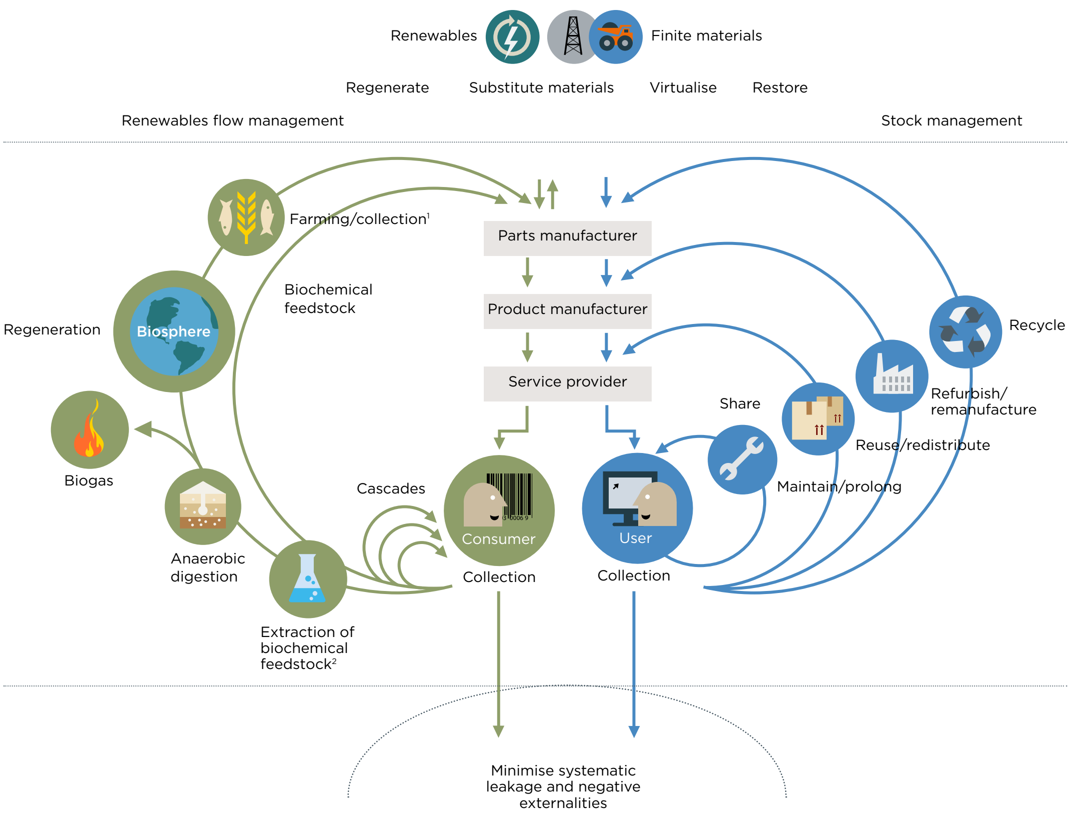
In both cases, modularity represents an opportunity for manufacturers to stand out from the competition and create value in innovative ways. Initially, the decision to 'go modular' in these cases was not necessarily driven by a desire to be more circular, but there is conceptual alignment between circular economy principles and modular design principles.

Consider the loops in the Ellen MacArthur Foundation's circular economy system diagram below, which shows the flows of technical nutrients through the circular economy paradigm.

As shown in the box to the right of the diagram, the loops of this butterfly diagram correspond to four different areas of value creation that can result from modular product design:

- Product life extension, as modular design is a potential lever to enable easier maintenance, reparability and refurbishment
- Creation of secondary component markets, as modular design requires the adoption of standardised components that can be reused in other applications
- Higher price for material waste streams, as modular design allows for easier separation of material inputs and, therefore, higher purity of after-use material streams.
- Reduction in dependency on finite feedstock, as modular design enables high purity after-use material streams, which improve the quality of recycling, allowing manufacturers to replace virgin materials with secondary materials.

1 https://en.wikipedia.org/wiki/Modular_design



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

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

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Outline of a circular economy

Before we can begin to evaluate the principles and benefits of modular design on circularity, we must start to establish a common understanding of the potential modularity offers, and how to measure, from a circularity perspective, the value created.

1. Product life extension:
   Products can be upgraded/maintained easily, and their lifespans extended
2. Creation of Secondary Component Markets:
   Full products and/or individual components can be refurbished for future use
3. Higher Price for Material Waste Streams and Reduction in Dependency on Finite Feedstock:
   After collection of equipment to be sent to recycling centres for separation, materials streams are separated for high purity recycling and higher recycling ratios

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PHASE 1: WHAT DOES MODULARITY MEAN FOR THE ICT SECTOR?

Modularity is the degree to which a system's components are designed with relatively independent functional units that can be combined. A modular structure consists of self-contained, functional units (modules) with standardised interfaces and interactions. "Self-contained" is understood to mean that the function is realised within the module itself. Replacing one module with another allows users to maintain or repair the same product (i.e. a manufactured or renewed product) with relative ease or create a new, higher quality variant of the product (i.e. increase its functionality).

Characteristics of modular design:

- Distinguishable – independent modules that can be easily separated from the rest of the equipment (e.g. a removable battery on a laptop computer)
- Defined purpose – each module has a defined function (e.g. a camera on a smartphone)
- Interchangeable – modules can be substituted for those with different functions that change the way the whole system operates
- Designed for disassembly – the ability to easily deconstruct the product to the level of the underlying modules without compromising its integrity, e.g. in the construction industry, concrete slabs can be used as a building foundation instead of poured concrete

Not all of these characteristics must be present for a given product to be considered modular; however, demonstration of more than one can certainly improve the degree of modularity and could have an improved impact on circularity.

The characteristics of a modular design give a finished product certain attributes that differentiate it from non-modular comparisons.

Using the examples provided (or other examples where modularity had a transformative effect on the way users engage with a product or product category), the potential benefits of modular products primarily include:

- Upgradability – the capacity to improve a product by altering the functionality of one or more modules
- Maintenance – the ability to isolate errors in individual modules and correct them, while maintaining functionality of the product as a whole
- Reparability – the ability to isolate faults in individual modules so that they can be repaired or replaced
- Recyclability – the ability to easily disassemble and separate the components of a product so the materials within them can be recycled

Preliminary analysis of existing modular equipment

As part of the first phase of this evaluation by the Co.Project team, several examples of equipment from different categories were analysed to determine their modularity, taking into account the benefits described above:

1. Upgradability, including software aspects
2. Maintenance and repairability
3. Recyclability

These product categories included smartphones, laptops, desktops, storage devices and multi-function printers. A few examples follow of where the benefits of modularity resonated:

- Upgradability is enabled in equipment such as desktops when the central processing unit (CPU), memory, hard drive and graphics cards (e.g.) can be easily replaced by the user, or accessories can be added to adapt to customised usage scenarios.

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- Maintenance and repairability of smartphones and tablets are demonstrated when key components (such as the battery or the screen / LCD – touch component), can be quickly and easily replaced by users with simple tools (e.g. a screwdriver) or without the use of any tool.
- Recycling is demonstrated when the different components from all product categories mentioned can be easily dismantled and separated, then transported to the appropriate channels for post-use handling.

In each of the examples reviewed, modularity has been partly integrated into the design of the product. Modularity enables the upgrading of equipment (e.g. adding memory), and/or increases the ability to maintain it over non-modular products (e.g. replacing modules or spare parts), thus promoting repairability.

PHASE 2: CASE STUDY RESIDENTIAL GATEWAY

In the second phase of the project a case study was carried out on two residential gateways (xDSL modems/wireless routers) in order to identify the potential benefits of modularity for ICT equipment and with regard to their environmental footprint mitigation. Both products share their design for the casing and electronic board; however, their Wi-Fi functions differ. On one product, the Wi-Fi function takes the form of an expansion card connected to the motherboard (i.e. mainboard) with a mini PCI-connector, which will be referred to as "modular" from now on.

On the other product, the Wi-Fi function's electronic components are soldered onto the motherboard and cannot be easily replaced.

As Wi-Fi is one of the key features of residential gateways, having this function designed on a replaceable sub-assembly can greatly enhance the product's lifespan thanks to a better repairability rate and upgradability.

As a first step, both products' manufacturing environmental footprints were assessed with the life cycle assessment (LCA) method and EIME[2] software.

The EIME software is able to provide environmental footprint results for several dozens of indicators with different sets, such as the ILCD2011 LCIA method.[3] For this study only five indicators were considered:

- ED: assessing the primary energy depletion
- GWP: assessing the greenhouse gas emissions
- RMD: assessing the raw material depletion (especially scarce metals such as gold, silver, platinum, etc.)
- WD: assessing the amount of water required for process and cooling
- WE: assessing the nitrogen and phosphorus-based substances emissions

It was found that the modular product manufacturing's footprint is higher for all five environmental indicators since additional electronic components are required for this design. Therefore, the modular design will always prove to be the worst case when it comes to its environmental footprint for similar lifecycle scenarios of both products (i.e. same life expectancy, repairability, upgradability, etc.).

Environmental benefits after taking the repair rate into account

In the second step of the study, the product distribution, the electricity consumption for usage and the end-of-life treatment were included. The lifecycle for both products was set to three years with the hypothesis being that a failure would occur on the Wi-Fi function at the end of this period. While the non-modular product is considered non-repairable, a portion of the modular design devices will be repaired (ranging

2 https://codde.fr/en/our-software/eime-en/eime-presentation

3 See report : Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods - EUR 25167 EN – 2012 – JRC Technical Reports

from 1 to 100%). Another three years' lifecycle was considered after this repair/second product manufacturing step.

The environmental footprint assessment was carried out using the same software and indicators selected for the first step.

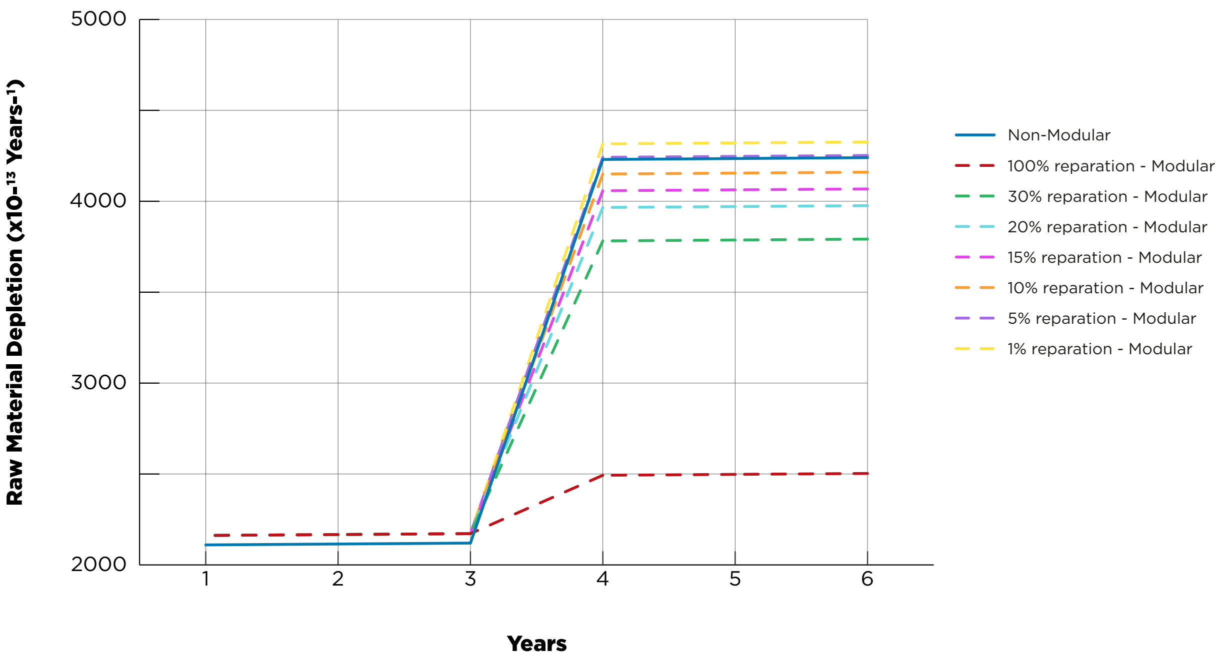

Figure 1: RMD indicator environmental footprint for non-modular and modular designs

It was found that in the first three years the non-modular design's footprint is always lower. In the second part, however, the focus is on which modular design curve will cross the non-modular design curve. This will determine the repair rate to be achieved for the modular design in order to obtain environmental benefits. As different environmental impacts are related to different components or processes, the crossing modular curves are different for each indicator. Figure 1 shows that for the RMD indicator at least 5% of modular product has to be repaired.

Environmental benefits of refurbishment

The third step assessment was carried out using Granta Design's BoM Analyzer[4] and ResCoM[5] report, using the inventories created for the modular and non-modular designs. Granta Design's BoM Analyzer tool model was validated against the previous LCA running the same analysis and obtaining comparable results. It was used to speed up the analysis and investigation of several refurbishment scenarios. In this step two options were included for the refurbishment centre: close to customer (i.e. Europe with shipment by truck) and far away from customer (i.e. Asia with shipment by plane).

4 http://grantadesign.com/products/mi/

5 The prototype report was developed by Granta in the context of the EU - FP7 project ResCoM (http://www.rescoms.eu/). It allows a fast track LCA evaluation of closed loop remanufactured products across multiple life cycles by inputting few key variables.

The aim was to establish how many times the product has to be refurbished in order to achieve environmental benefits. The following hypotheses were used for refurbishment rates:

- Non-modular design (Wi-Fi on motherboard): 85% (baseline) or 95%
- Modular design (Wi-Fi on expansion card): 85%, 95% or 100%

For an 85% refurbishment rate of the non-modular design it was found that:

- If the modular design's refurbishment rate is 85%, there is no break-point;
- If the modular design's refurbishment rate is 95%, there is a break-point, at the second refurbishment;
- If the modular design's refurbishment rate is 100%, there is a break-point, at the first refurbishment.

The 100% refurbishment target seems quite difficult to achieve, as it would imply having to reduce to zero all the losses along the reverse logistic chain (i.e. not a single product unreturned by customers, lost or damaged in transport). However, an increase of the refurbishment rate by 10% due to modularity would seem plausible.

In this BoM Analyzer tool assessment, the option with air transport considers, a 10,000 km trip to the refurbishment centre in the instance an operation can only be carried out by the manufacturer's factory, located in Asia for example. It was found that, in this scenario, the results are uncorrelated in a negative fashion: the highest refurbishment rate achieves the worst environmental footprint. In other words, the environmental benefits of the refurbishment process will never be great enough to offset the huge energy consumption of air transport.

In addition to these two assessments which focus on refurbishment centre location, another study was done to find out whether refurbishment operations carried out by customers would be beneficial.

For this case, the current design of the residential gateway needed to be altered allowing the customer to repair/upgrade some parts, without exposing the entire motherboard or other critical parts. In order to mimic this feature, the modular product's design was modified, to allow "fool-proof" part replacements by the customer:

- A hatch was added on the lower casing (additional plastic part)
- Longer Wi-Fi antenna cables to compensate for the adverse Wi-Fi card emplacement (easy customer access but not best for radio purpose)

For this assessment three different designs for the "fool-proof" feature were modelled: light design, average design and heavy design. The modular product will require more plastic and cable length than the non-modular one (i.e. higher environmental footprint for manufacturing and shipment from factory). However, for the refurbishment step, only the Wi-Fi sub-assembly has to be shipped to the customer's home instead of the entire product. This assessment's results are displayed in Figure 2.

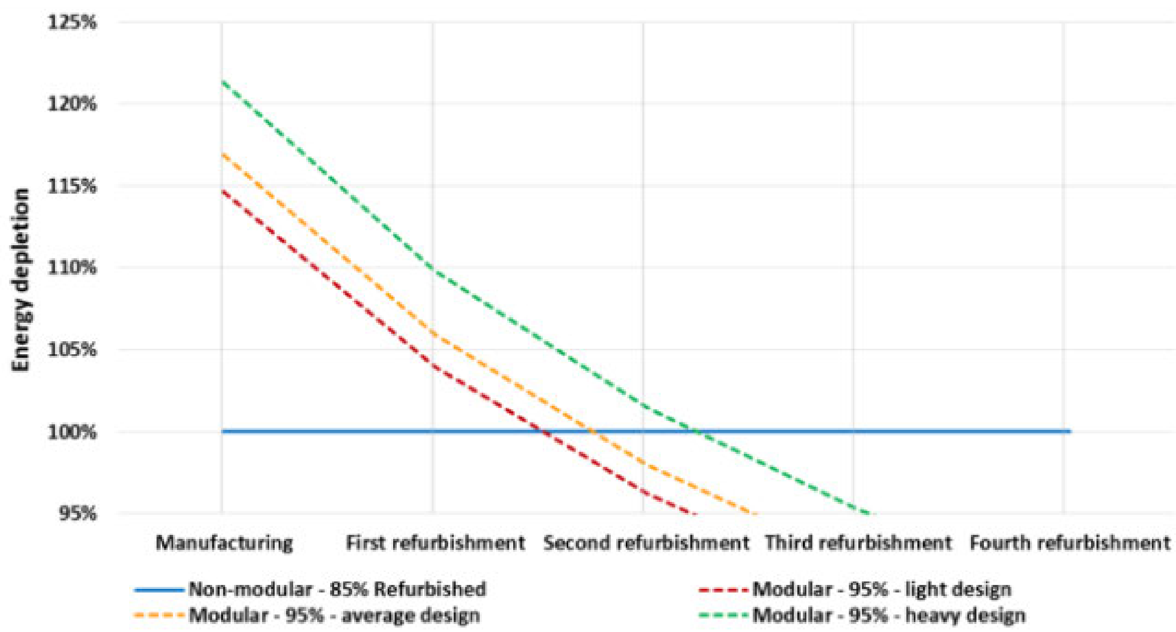

Figure 2: Modular and non-modular designs environmental footprint (device refurbished by customer)

The figure above shows that the ability to achieve environmental benefits with a device refurbished by the customer is strongly related to the design. In this example, the light and average designs reach the break-point at the second refurbishment, whereas the heavy design will require three refurbishments.

In conclusion, the modular design's drawback is the additional material required during the manufacturing phase. However, the environmental impact of this additional material can be offset through the lifecycle within an acceptable period of time, if the repair/refurbishment rate increases by at least 5 to 10% above non-modular design. The logistic model (i.e. refurbishment centre location and transport modes) and the design modifications (i.e. additional material required to design a modular product) are two key parameters to achieve at the offset.

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KEY LEARNINGS

Referring to the white paper issued in October 2016, **modularity appears to represent a lever toward circularity in the ICT sector;** however, some **key parameters must be considered** to avoid potential adverse effects (i.e. more environmental pollution resulting from modular design):

- Context of use and specifically the collection use/reverse logistic conditions, according to the geographies where the product will be in use
- Pace of evolution of the different technologies embedded in the product
- Availability of spare parts/modules
- Potential involvement of customers/users to replace the modules

Besides, regarding rare materials - which are at stake in the ICT sector, the key point is the **technique used to fasten sub-assemblies or components which contain a high concentration of rare materials.** The fastening technique will indeed determine the possibility of recovering rare materials at the recycling stage.

NEXT STEPS FOR CO.PROJECT MEMBERS

Now that modularity effects have been assessed on ICT with simple case studies it could be worthwhile to seek European projects such as Celtic-Plus to expand the scope.[6]

WHAT NEXT RESEARCH QUESTIONS OR EXPLORATION TOPICS HAVE EMERGED FROM THIS CO.PROJECT?

In this Co.Project we mainly focus on hardware modularity and did not tackle the software modularity aspects. Adding software modularity for a residential gateway's environment can add flexibility (specific roadmap by service), reduce test cost for new deployments, help the development of new business by allowing running code from partners (trusted environment) and open the device with the capability to run any application from an application store. These positive effects might also benefit the product's lifespan or to reduce the amount of material required for a similar service.

TO FIND OUT MORE, PLEASE CONTACT:

Elisabeth Bêche
Co.Project Lead
elisabeth.beche@orange.com

Joe Murphy
Co.Project Facilitator
Joe.murphy@ellenmacarthurfoundation.org

6 https://www.celticplus.eu/

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ELLEN MACARTHUR FOUNDATION

The Ellen MacArthur Foundation was created in 2010 to accelerate the transition to a circular economy. The Foundation works across five areas: insight and analysis, business and government, education and training, systemic initiatives and communication. In its business and government programme, the Foundation collaborates with its Global Partners (Danone, Google, H&M, Intesa Sanpaolo, Nike, Philips, Renault, Solvay, Unilever), Core Philanthropic Partners (SUN, MAVA, Players of People's Postcode Lottery) and its CE100 network (businesses, universities, emerging innovators, governments, cities, affiliate organisations) to build capacity, explore collaboration opportunities and develop circular business initiatives.

ABOUT THE CE100

The Circular Economy 100 is a pre-competitive innovation programme of the Ellen MacArthur Foundation, established to enable organisations to develop new opportunities and realise their circular economy ambitions faster. It brings together corporates, governments and cities, academic institutions, emerging innovators and affiliates in a unique multi-stakeholder platform. Specially developed programme elements help members learn, build capacity, network and collaborate with key organisations around the circular economy.

ABOUT COLLABORATIVE PROJECTS (CO.PROJECTS)

Co.Projects are opportunities for formal pre-competitive collaboration between CE100 members. They are driven by members, for members and their focus can range from research initiatives to pilots and toolkits. Co.Projects leverage the CE100 network with the aim of exploring opportunities and overcoming challenges which are commonly and collectively faced by organisations making the transition to a circular economy, and which organisations may not be able to address in isolation. making the transition to a circular economy, and which organisations may not be able to address in isolation.

DISCOVER OTHER ON-GOING CHALLENGES

ACCESS THE CO.PROJECT INSIGHTS LIBRARY