CITIES IN THE CIRCULAR ECONOMY:

THE ROLE OF DIGITAL TECHNOLOGY

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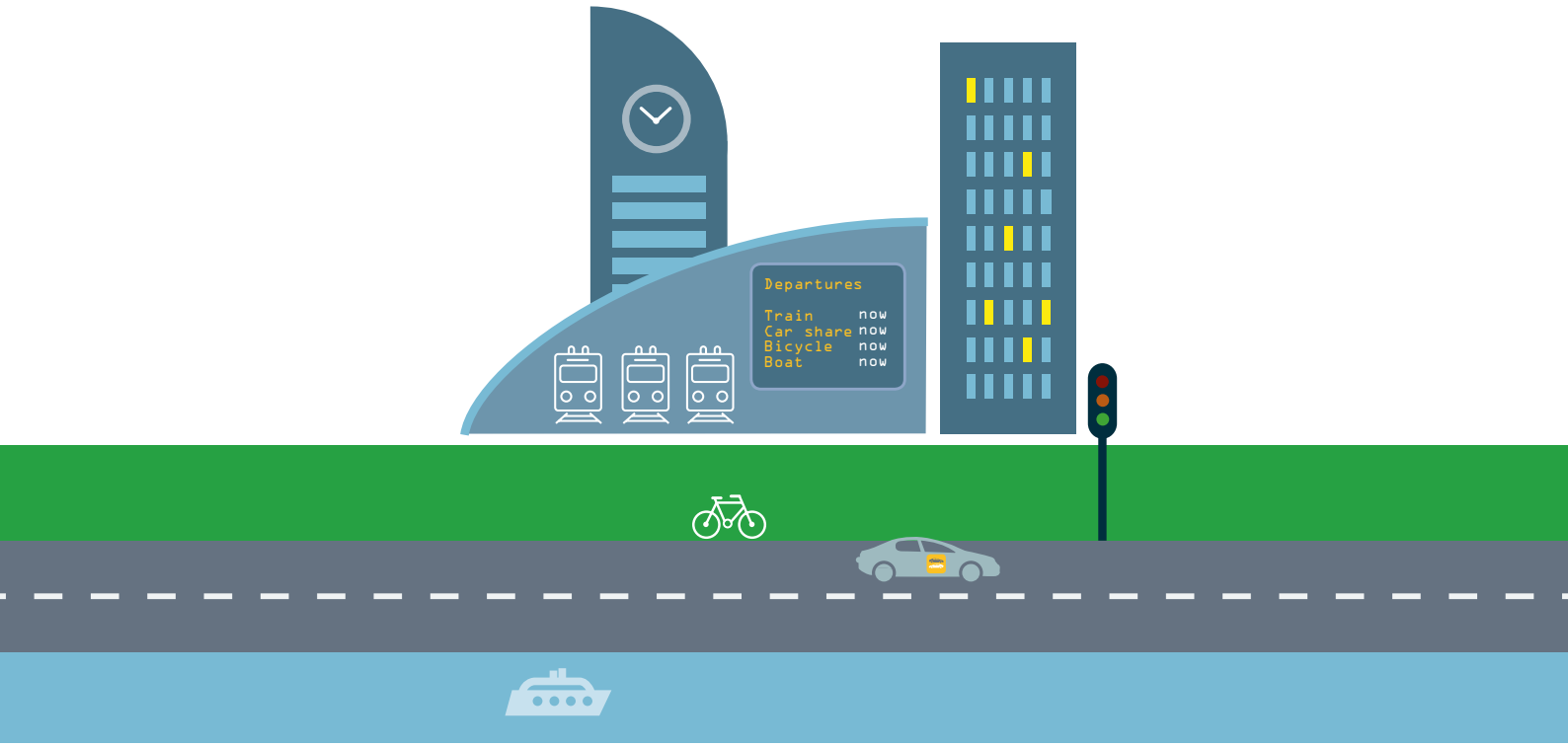

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INTRODUCTION

At the heart of creativity, innovation and growth, urban environments could become hotbeds of circular economy activity, enabling closed loops of biological nutrients and the recirculation of durable materials.

The Ellen MacArthur Foundation (the Foundation) was created in 2010 to accelerate the transition to a circular economy, one that is restorative and regenerative by design. A circular economy relies on three principles:

1. Designing systems that work, eliminating waste and pollution
2. Keeping products at their highest value and in use
3. Regenerating natural resources and restoring finite materials to be used again

With its stated vision to accelerate the transition towards a circular economy, the Foundation directs its activities towards the most catalytic actions and actors. As such, the Foundation focuses on cities due to their role in shaping the global economy, with 54% of the world's population living in urban areas and accounting for 85% of global GDP generation. Cities are also aggregators of materials and nutrients, accounting for 75% of natural resource consumption, 50% of global waste production, and 60-80% of greenhouse gas emissions. This combination of factors creates a unique context for the transition to a circular economy both in terms of challenges and opportunities.

The Foundation has been working with its global partner Google to explore the crucial role of technology in enabling key aspects of the transition towards the circular economy in cities.

Google believes in the democratizing effect of putting knowledge in the hands of everyone, so we are organizing the world's information and making it universally accessible. Google is committed to doing this in a way that has a positive impact on people and the planet. Google believes that a key enabler to making cities more restorative and regenerative is a circular economy powered by digital technology.

Digital technology can enable city leaders and citizens to extract, refine, and analyze data in ways that use information and networks to create cities that are circular by design. This paper explores the role that some aspects of digital technology can play in creating an urban system that is regenerative and restorative.

CITIES AND THE CIRCULAR ECONOMY

Challenges of the linear system

Cities are operating within a global economic system that is based on the linear 'take-make-dispose' model, and as such, urban economies mirror and amplify the challenges of this model.

A growing global population, largely concentrated in cities due to rapid rates of urbanization, and a rising urban middle class, has led to an increase in the demands and pressures on urban infrastructure, and an increase in the consumption of resources. Coupled with the lack of restorative or regenerative mechanisms, these pressures are leading to structural waste (and consequently lost economic opportunities) as well as negative impacts including greenhouse gas emissions, reduced air quality, and congestion.

A new way forward – a circular economy

To address the challenges of the linear economic model, the Ellen MacArthur Foundation, Google and many other partners have been promoting the transition to a circular economy. A circular economy is characterized as an economy that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, whilst distinguishing between technical and biological cycles. It is conceived as a continuous positive development cycle that preserves and enhances natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flows.

The concept of the circular economy is particularly relevant in the urban context as it offers designers, planners, policymakers, and businesses a framework to rethink systems: how we design and operate them in a manner that will preserve, restore and regenerate natural, social and financial capital.

A vision for a circular city

A circular city embeds the principles of a circular economy across all its functions, establishing an urban system that is regenerative and restorative by design. These cities aim to eliminate the concept of waste, keep assets at their highest utility at all times, and are enabled by digital technology. A circular city aims to generate prosperity and economic resilience for the city and its citizens, while decoupling this value creation from the consumption of finite resources.

A circular city will likely include the following elements:

Built environment

A built environment that is designed in a modular and flexible manner, sourcing healthy materials that improve the life quality of the residents, and minimize virgin material use. It will be built using efficient construction techniques, and will be highly utilized thanks to shared, flexible and modular office spaces and housing. Components of buildings will be maintained and renewed when needed, while buildings will be used where possible to generate, rather than consume, power and food by facilitating closing the loops of water, nutrients, materials, and energy, mimicking natural cycles.

Energy

Resilient, localized and distributed energy systems that allow effective energy use, reducing costs and reducing our impact on the environment.

Mobility

An urban mobility system that is accessible, affordable, and effective. A multi-modal mobility structure that will incorporate public transportation, with on-demand cars as a flexible

but predominantly last-mile solution. Transportation will be electric-powered, shared, and automated. Air pollution and congestion will belong in the past, and excessive road infrastructure will be converted to serve other needs of citizens. Central to vehicle design will be remanufacturing, durability, efficiency and easy maintenance.

Food systems

A system where nutrients will be returned to the biosphere in an appropriate manner, while generating value and minimizing food waste. Nutrients could be captured within the organic fraction of municipal solid waste and wastewater streams, and processed to be returned to the soil in forms such as organic fertilizer – used for both urban and rural agriculture. Through urban farming, the city will be able to supply some of its own food, reusing food waste and sewage in closed and local loops to produce vegetables, fruit, and fish.

DIGITAL TECHNOLOGY: ENABLING THE TRANSITION

Digital technology has enabled a fundamental shift in the way the economy functions, offering possibilities for radical virtualization, de-materialization and greater transparency on product use and material flows, all while creating new ways of operating and participating in the economy for producers and users. Through the collection and analysis of data on materials, people and external conditions, digital technology has the potential to identify the challenges of material flows in cities, outline the key areas of structural waste, and inform more effective decision-making on how to address these challenges and provide systemic solutions. It will also be critical for security of data and systems to be ensured.

Specifically, the following technologies have been identified as enablers of circular economy activity in cities:

- **Asset tagging:** Asset tagging technologies can provide information such as the condition and availability of products, components, or materials. In turn, this information can help extend the use of an asset, increase its utilization, loop or cascade it through additional use cycles, and also help regenerate natural capital. For example, prolonging the life cycle of a car by monitoring its usage patterns and condition through sensors can trigger alerts about problems as they appear, to allow for an easy and quick fix.
- **Geo-spatial information:** When combined with asset tagging, geo-spatial information can provide visibility on the flow of materials, components, products and people across the city (including patterns of optimal mobility routes, energy demand peaks and valleys, congestion, and waste generation). For example, the ability to visualize traffic and pollution information on base maps, layered with valuable insights from other sources (i.e. census data, material information data) allows experts to predict and plan targeted strategies to address issues of congestion and

pollution, but also allows citizens to understand and learn what that data shows in a format that is accessible and understandable.

- **Big data management:** Current computation capability allows us to overlay general patterns of human behavior on top of aggregated information received from asset tracking and geo-spatial mapping activities. For example, predicting energy consumption patterns at a local level, suggesting transport options that avoid peak hour traffic flows in real-time. Leveraging advanced processing capacities, computers now can perform complex and agile analyses that will help to determine and deploy the most effective resource solutions at an unprecedented speed and quality.
- **Connectivity:** The widespread and easy access to smartphone and application technology allows for increased connection between people, and between people and products leveraging asset tracking capabilities. This enables circular business models such as leasing and sharing platforms, reverse logistics, take-back systems, and distributed remanufacturing. For example, business models such as Uber, Airbnb or BlaBlaCars would not be feasible without an accessible app that connects assets on offer with those who would like to use them.

FROM VISION TO REALITY

In 2016, the Ellen MacArthur Foundation published Intelligent Assets: Unlocking the Circular Economy Potential, a report that analyzed the potential of digital technology in advancing the circular economy. The report identified the urban environment as a fruitful ground for solutions that combine the design and implementation of intelligent assets with key principles of the circular economy. Figure 1 outlines a vision of how digital technologies can enable circular material flows in cities.

Google is able to capture insights across cities, from the quality of the air people breathe to the amount of energy they use at home. The Google Cloud Platform allows for global scale data sharing and provides the foundations for collaborative projects between the public and private organizations, such as the Waze Connected Citizens Program. These technologies allow Google to integrate data sources such as high-resolution imagery, GPS movements, sunlight capture and intelligent sensors with a global user community to contribute to the circular city.

Examples of how Google's technologies are supporting the vision for a circular city are layered onto figure 1.

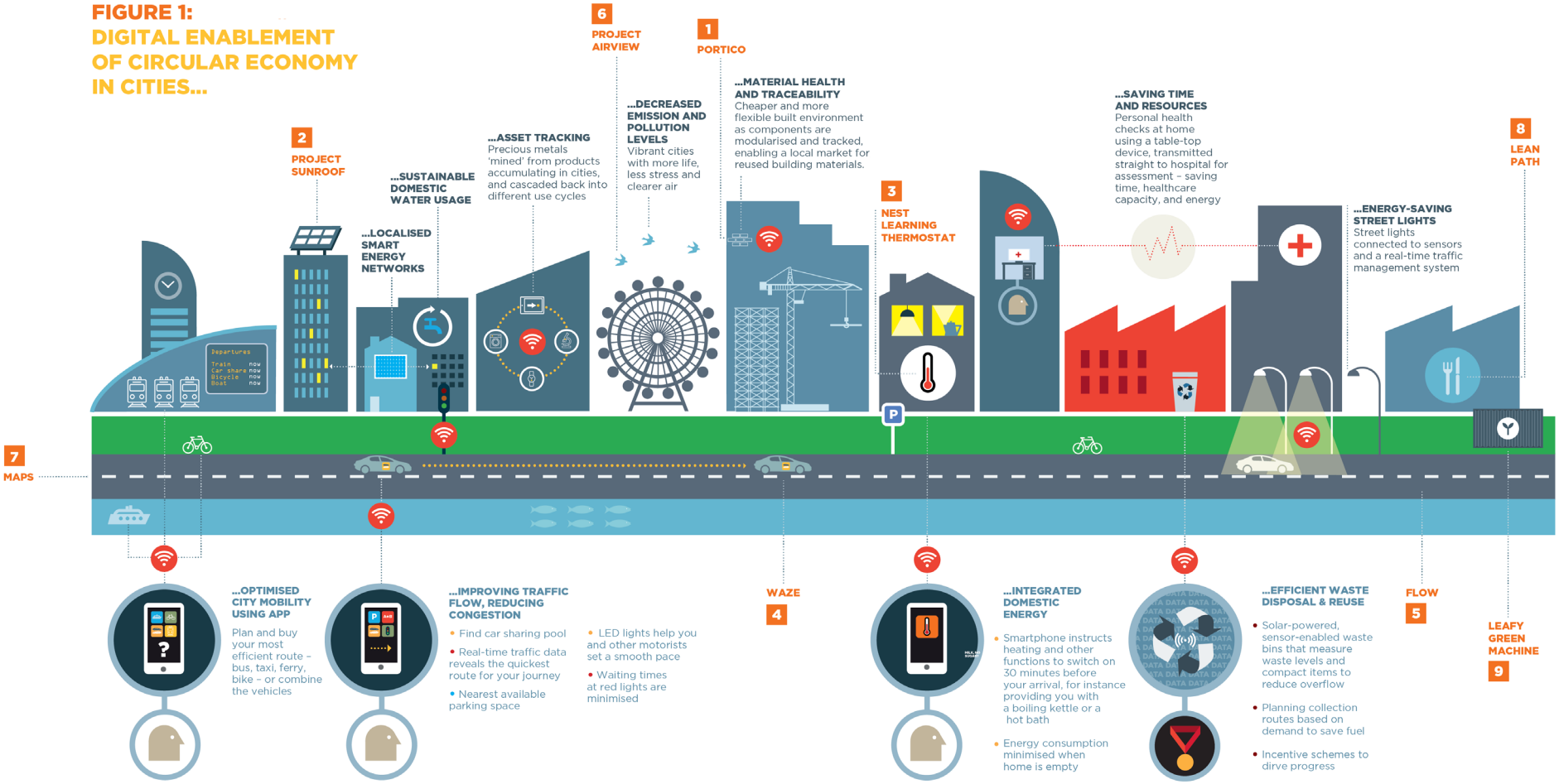

Figure originally from Intelligent Assets: Unlocking the Circular Economy Potential, and adapted for this paper.

Portico. **Portico** is an online web application, developed in partnership with the Healthy Building Network (HBN). Portico creates a direct communications channel between project teams and product manufacturers and their supply chains. Portico saves time and money by making it easier to get information about products and enabling increased use of non-toxic building products that promote human and environmental health and information transparency. Portico uses third-party standards to deliver quality data for ingredient disclosure, chemical screening and assessment and optimization. Materials that are optimized for health are safer for workers and building occupants and much easier to perpetually cycle, reducing the use of virgin materials. To date, Google has used Portico on more than 195 office projects in 20 countries with over 1,500 project team members.

Project Sunroof. This online tool based on Google Earth's 3D imagery helps individual homeowners explore whether they should go solar by analyzing everything from high-resolution aerial mapping and 3D modeling of residential roofs to sun positions, historical weather patterns, shadows cast by nearby objects, and typical electricity consumption. Sunroof's **data explorer tool** also enables solar viability reports to be run at the state, county, city, and zip code levels. This feature aims to provide a source of information for community members, researchers, and policymakers to help them make the case for solar deployment in their community. Sunroof's data coverage includes 67 million buildings covering every state in the U.S., with approximately 60 million U.S. buildings and 7 million buildings in Germany analyzed.

Nest Learning Thermostat. Nest, an Alphabet company, offers the Nest Learning Thermostat designed to reduce energy consumption, measure energy savings, and make it easy to understand energy savings results. Data from buildings is used to validate the heating and insulation performance of the built environment for our cities and homes. Putting a smart digital platform behind HVAC systems saves money and reduces the impact on the environment, using a unique algorithm that takes into account occupancy patterns, house characteristics, and how climate change affects the heating and cooling of buildings. Since launching, the Nest Learning Thermostat has helped consumers save more than 13 billion kWhs of energy. That's enough to power 20 million refrigerators for a year.

Waze. Waze is an interactive mapping application designed to reduce traffic congestion. It has 80 million active users who contribute to editing mapping and traffic information. It has developed a series of partnerships designed to solve complex problems through data. Through the Connected Citizens Program - a free, two-way data exchange - nearly 400 municipal and emergency partners are empowered to harness real-time insights to improve congestion and make better informed planning decisions. For example, as the host of the Olympic Games, **Rio worked with Waze** and its Map Editor Community to prepare for one of the world's largest traffic events. During the games, the city used new API (Application Programming Interface) with Waze to automatically update the Waze map with road closures resulting in 24-27% decrease in congestion during morning commute.

Flow. **Flow**, a company within Alphabet's Sidewalk Labs, builds digital tools for cities to enable a more efficient, equitable, and sustainable transportation system. For example, by using

technology to stitch together available parking, the time drivers spend circling and the amount of land devoted to parking can be reduced. Further, digitization of traffic, parking, roads and lights creates a rich platform to help maintain, plan and navigate the flow of people across a city. The outcome for cities is smarter planning, more transparency and much more accurate investment appraisal for infrastructure products.

Project Air View. Project Air View partners with the Environmental Defense Fund (EDF) and Aclima to measure air quality using air sensor equipment mounted on Google Street View cars, producing maps with information on nitric oxide (NO), nitrogen dioxide (NO2), black carbon and other pollutants emitted from cars, trucks and other sources that can affect our health and our climate. This street-level data show how pollution can change block by block, enabling the development of targeted strategies to address the problems. The project is currently measuring and mapping air quality in communities in the San Francisco Bay Area, Los Angeles, and Central Valley regions.

Maps. Travelers or commuters can navigate more efficiently and reduce their personal carbon footprint by using Google Maps to get where they're going by walking, biking, or using public transportation. Travelers can avoid vehicular emissions altogether by choosing the bike or walking icon in Maps and getting customized turn-by-turn directions incorporating bike and pedestrian routes. Maps offers transit info for more than 6,000 public transit agencies and three million transit stations in 20,000 cities and towns in 64 countries—which adds up to more than one billion kilometers' (621 million miles) worth of transit results per day.

LeanPath generates data around food waste. The mechanized scales currently measure pre-consumer food waste in the kitchens of 129 Google cafes around the world. This data helps the Google Food Team evaluate pre-consumer kitchen waste and more accurately order the appropriate portions of food, which results in wasting less food upfront. By applying this technology, Google cafes globally avoided 1,549,551 lbs of food waste in 2016 alone.

Leafy Green Machine. Google partnered with Freight Farms in purchasing the Leafy Green Machine to pilot an urban agriculture innovation and grow food on site at the Bay Area campus. The controlled environment machine is built inside a repurposed shipping container, and uses patented high-efficiency LED lighting system, vertical growing, and controlled temperature, nutrients and water instead of dirt. It can efficiently grow herbs and vegetables all year round using approximately 95% less water than growing greens in the ground. With harvest to kitchen only steps apart, we minimize energy from transportation, refrigeration and packaging. Exploring solar power will take this project to the next level of optimization.

CONCLUSION

Over the past few years we have witnessed three parallel trends unfolding and shaping our economy. The first is the digital revolution, powered by the enormous advances in technological capabilities, their prices and accessibility for daily use. The second is the circular economy

transition, powered by the understanding that we need to rethink our economic activities to accommodate future prosperity in a resource constrained world. The third is the global trend of urbanization, which will bring over 75% of the global population into urban centers by 2050, in search of new opportunities, employment, and a better quality of life.

The combination of the first two trends has a revolutionary potential to address the challenges created by the third. The circular economy provides a compelling economic framework for effective resource utilization and a strong economic rationale for doing so, while digital technologies are crucial to embed and enable circular economy principles and practices into the everyday workings of cities.

The circular economy model, enriched with the synergies of technology is a powerful and potentially highly productive combination. A 2015 study conducted by the Ellen MacArthur Foundation, on the circular economy potential in Europe, suggested that the lion's share of economic opportunity highlighted is directly linked to advances in digital technology. Such advances, in the form for example of tracking systems and mobile apps, whether as a key driver or a convenience factor, allow for a considerable jump in asset utilization rates as well as material flow optimization, the benefits of which add up to EUR 900 billion annually by 2050.

A more recent report looking into circular economy opportunities in the Indian market estimates that applying the circular economy principles in the construction sector and cities could lead to an annual benefit of USD76 billion by 2050 and a positive impact on quality of life. In this case too, the circular economy transition will be powered by digital technology. The rate of growth in current and new cities in India, and emerging economies more generally emphasizes the urgency for action, and the significant opportunity to incorporate principles of the circular economy into new urban development from the outset, to avoid the linear lock-ins that are challenging the transition in the developed world.

Google is helping to power the circular economy with digital solutions that will accelerate the transition towards more prosperous, livable cities. City leaders and citizens can leverage existing technology in the Google portfolio to extract, refine, and analyze data in ways that use information and networks to create cities that are circular by design. A rich dataset of traffic flow, sunlight exposure, mapping, parking, air quality, and material characteristics is being built every day and there could be huge value gained from targeting that data towards redesigning the flow of people, materials, and information in our cities.

The challenge of transition and the need to accommodate the rapidly growing population in a world of finite resources is so enormous that no actor can address it alone. It will require collaboration within and between all sectors of society: governments, the private sector, academia, non-government organizations and the public. Powering the circular economy by providing digital solutions and closing the information gap is probably the best investment that technology companies of our time can make.