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Are you ready for the sustainable, biocircular economy?

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Abstract With the effects of the climate crisis becoming more extreme, and in view of the urgent need to achieve sustainable development goals, managers, companies, and entire industries must embrace the sustainable, biocircular economy, enabling all stakeholders as well as our planet to thrive in this inevitable future. This article clarifies the emerging concept of sustainable biocircularity by showcasing best-practice applications, with examples from policymakers, civil society organizations (CSOs), companies, and others working together to bring vital transformational change. We present five guiding EARTH principles (ecology, authenticity, resilience, transformation, and holism) to help ensure the transition to a sustainable, biocircular economy benefits organizations and society at minimal cost to the environment. We next introduce the five stages required to develop a successful transition to sustainable biocircularity. Here we highlight how an integrated, systems-based STOP (skills, technologies, opportunities, and problems) road map can enable organizations to conduct strategic analysis and decision-making across each of the five stages, thus helping to achieve that transition. We demonstrate how the guiding principles, the five stages, and the road map are intertwined and stress that companies must understand and embrace each of these in order to thrive in this new environment. Finally, we provide a biowashing checklist to help ensure this transition is truly sustainable, just, and authentic.

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1. Time to act now for a biocircular future

The need to transition to a low-carbon society is paramount; should we fail to do so, the consequences for the planet and for society will be disastrous. The current United Nations sustainable development goals are due to be met by 2030, but the most recent Intergovernmental Panel on Climate Change (IPCC) report states we have less than 7 years to avoid the worst impacts from rising temperatures. The report pulls no punches. It emphasizes the need for urgent action to avoid total catastrophe for the planet and its inhabitants, highlighting how many people are already suffering the worst effects of the climate crisis, as evinced by the devastating extreme weather events of 2022, including fires, hurricanes, and floods. To ignore the IPCC's warnings would mean unprecedented increases in temperature, increases in sea levels, and record heat waves, leading to famine and population displacement. Miami, Shanghai, San Francisco, Mumbai, Honolulu, Bangkok, and Boston will all be permanently flooded if net-zero global emissions are not achieved by 2050.

One way to help achieve the transition to a low-carbon society is to transition from a fossil-fuel-based economy to a sustainable, biocircular one. Businesses need to go beyond traditional management thinking and consider sustainability, circularity, and the use of renewable biological materials in place of fossil fuels such as coal, oil, and natural gas. A sustainable, biocircular economy would provide opportunities to address the climate crisis and biodiversity loss while simultaneously increasing productivity and competitive success. Done properly, it would be a win-win for firms, for society, and for our planet.

Sun et al. (2018) argued that future sustainability research should explore more closely the relationship between business and the environment and identify those businesses that foster sustainable innovation. This article addresses these issues by exploring successful innovations within a sustainable, biocircular economy.

2. What is a biocircular economy?

Put simply, a biocircular economy is an economy powered by nature (Centre for International Forestry Research, 2021). It is a new blueprint for industrial economies emphasizing the use of biologically derived, or bio-based, renewable materials from agricultural, forestry, and marine waste and residues, which either go unused in normal production processes or are discarded. Bio-based materials are used instead of fossil fuels and fossil-fuel-based materials. The biocircular economy focuses on minimizing waste, sharing resources, and keeping products "alive" as long as possible, particularly through resale or reuse (Todeschini et al., 2017). Thus, biocircular thinking must occur throughout the entire lifecycles of products (Buxel et al., 2015).

What sorts of materials and products count as bio-based? Think of clothes made from milk that would have gone to waste, of biodegradable plastics made from bacteria, leftover soy, or discarded timber, or of using waste mushrooms and bamboo for multiple different products (e.g., mycelium lamps, bamboo crockery and cutlery), materials (e.g., mushroom or bamboo leather), and packaging. Another example is discarded timber and residues from the willow tree, which are highly versatile. Innovative new processes extract "bioactives" for use in healthcare, including salicin, a natural pain reliever and antiinflammatory. The remaining willow pulp is then used to make biodegradable food packaging.

Making the switch to biocircularity has enormous potential for industries as diverse as agriculture, energy, and pharmaceuticals. In the US, the bioeconomy is already valued at $1 trillion dollars, or 5% of gross domestic product (GDP; Cumbers, 2020). In the Eurozone, it was worth €2.4 trillion in 2017, employing 17.5 million people, 8.9% of Europe's labor force, with total value added representing 4.7% of the region's GDP (Piotrowski et al., 2019). Over 60 countries have bioeconomy-related strategies—including the EU, Japan, South Africa, the UK, and the US (IACGB, 2020).

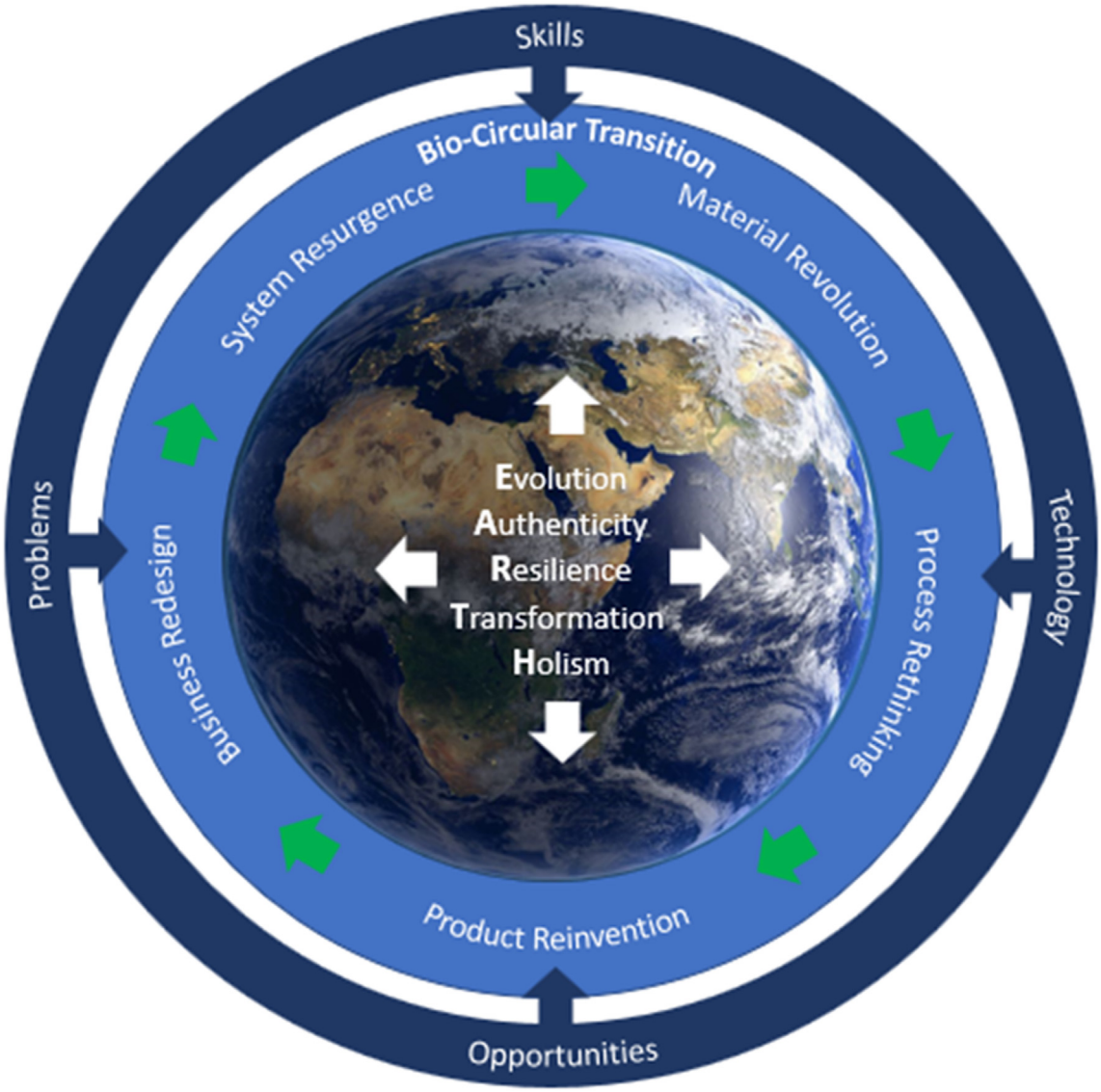
Many existing bioeconomy approaches focus on the positives of a switch to bio-based materials, but there are also fundamental risks. For example, the use of bio-based materials to produce biofuels has led to multiple environmental and societal problems, including hunger, land grabbing, and destitution, especially among indigenous peoples, with documented instances of poor and exploitative working conditions within the biofuel industry (Geary, 2012). Not only has the demand for biofuels pushed up the prices of basic foodstuffs, such as vegetable oils in the EU—indeed, prices had increased by 171% as early as 2017—but many foods are now consumed by cars and trucks; for example, 58% of EU rapeseed oil is used in transportation (Sihvonen, 2017).

Awareness of these significant risks can help companies switching to a bio-based approach to

succeed. If businesses switch to a bioeconomy strategy without also ensuring sustainability and circularity, they run the risk of biowashing while also undermining a transition that could work for everyone. Analogous to greenwashing, *biowashing* entails adopting cosmetic or performative aspects of the bioeconomy to enhance public image with little or no improvement to social or environmental outcomes. It is imperative companies avoid jumping on the bioeconomy bandwagon before considering the key principles that will make the bioeconomy work.

This article provides managers with a framework for strategic decision-making (Figure 1) as they guide their firms toward sustainable biocircularity. It is a systems-based framework that highlights the drivers and innovation opportunities in management practices and technologies. First, we present five EARTH principles (ecology, authenticity, resilience, transformation, and holism) to ensure the bioeconomy transition benefits organizations and society without destroying the environment. Next, we introduce the five stages of biocircular transition and provide the STOP road map to help navigate these stages. The principles and road map are intertwined, and companies need to embrace both to succeed. The guiding EARTH principles can help managers embrace the key concepts, ensuring a successful transition to a biocircular economy, and the STOP road map provides the tools to ensure that the stages of the biocircular transition are realized. Finally, we

Figure 1. Biocircular future framework



Note: The biocircular future framework identifies the key issues for managers, companies, industries, governments, and civil society organizations to consider as they evaluate, plan, and implement their biocircular transitions.

present a biowashing checklist (Table 1), a practical tool that firms can use immediately to evaluate and design their biocircular transition efforts, thus avoiding the pitfalls of biowashing.

3. The guiding EARTH principles

The move toward more sustainable economic and social systems is replete with unintended consequences and token initiatives. To avoid these pitfalls, we developed five guiding EARTH principles to transition to a biocircular economy. They each involve changing the mindset and culture of organizations, and they require collaboration and cooperation with a broad range of stakeholders. They compose the ethos of the organization.

3.1. Ecology

First, organizations need to adopt ecological thinking, developing norms and values that put the preservation and nurturing of ecosystems at the heart of decision-making (Sun et al., 2018). This is the foundational element for the other principles. This process will require significant organizational change. First, organizations need to ensure managers understand bio-based alternatives and their value cascade. This means prioritizing the production of high-value products, such as pharmaceuticals, before using materials to produce lower value goods, such as bioenergy.

In parallel, managers must consider the ecosystems of their bio-based materials. Ecosystems consist of varied and complex resources that must be integrated into bioeconomy planning. Under bioeconomy planning, the resources, waste, and relationship characteristics of the ecosystem, whether urban or rural, guide the development of economic activity. For example, there is enormous potential to design bespoke, distributed production facilities that integrate with local environmental and social systems. These facilities can optimize use of natural resources for each ecosystem and generate employment and economic wealth for communities. For instance, German company Prolupin harvests food ingredients from a plant called lupine, and these are used to make vegan meat and dairy alternatives. Lupine can be grown on the poor, sandy soils of the coastal region of Mecklenburg, Western Pomerania in Northern Germany, and as a nitrogen-fixing plant, it enriches the soil more than other crops. Previously lupine had been used as animal feed, and margins were unattractive. But the company's innovation in extracting food ingredients from lupine means it can provide farmers with higher margins than those for rye, the traditional crop for this soil.

3.2. Authenticity

The next EARTH principle focuses on avoiding the mistakes of the past and ensuring sustainable, biocircular practices are achievable—which means avoiding biowashing. Pretending to be green or just focusing narrowly on the use of bio-based materials will damage not only the planet but also the company's reputation and bottom line. Companies must authentically apply sustainable principles rather than merely trying to appear sustainable (Baldassarre & Campo, 2016). We urge such companies to use the biowashing checklist (Table 1) and to work with ecology experts to ensure their use of bio-based materials is managed appropriately.

For example, IKEA faced criticism from multiple sources in 2021 when the environmental civil society organization (CSO) Earthsight found the furniture giant was sourcing timber from Russian suppliers practicing illegal logging in protected forests. Initially the company denied the reports, but after investigating and working with certification bodies and key stakeholders, it placed a temporary ban on timber from the Russian Far East and from Siberia. These supply-chain challenges are not over for IKEA (2022), which owns huge swathes of forest in Eastern Europe, but the company has recognized the importance of addressing the issues with honesty and authenticity, working with local stakeholders to develop solutions.

Beyond avoiding deliberate attempts to use biocircularity as hollow marketing, companies should take active steps in creating credibility and be willing to correct course when necessary. The internal and external transparency of new biocircular processes is at the heart of a good-faith transition effort. When clear maps of processes are made available to internal and external stakeholders, along with the physical and human resources involved, this creates a sense of confidence and spurs conversations that can identify problem areas. The involvement of independent third parties in this design and evaluation effort is fundamental. Finally, without clear performance metrics linked to sustainable, biocircular goals, it would be impossible to assess the success of the transition. Clear metrics openly shared with stakeholders are another key element of an authentic effort to transition.

Table 1. The biowashing checklist

Ecology	
Identify natural ecosystems that will be affected by the transition.	□
List resources that will see increased use.	□
List resources that will see decreased use.	□
For each resource, develop a preliminary assessment of positive and negative impact on the environment.	□
For each resource, develop a preliminary assessment of positive and negative impact on society.	□
Authenticity	
Develop a detailed flow chart of the new process(es).	□
Involve external, independent experts in designing and monitoring the new system.	□
Devise appropriate measures of the effects of the new process(es):	
- For the organization;	□
- For the natural environment; and	□
- For the social systems involved.	□
Set up appropriate systems to monitor the impact of the transition.	□
Develop clear and transparent processes to provide data access to external and internal stakeholders.	□
Resilience	
Map the potential risks of the transition:	
- For the organization;	□
- For the natural environment; and	□
- For social systems involved.	□
Develop plans to mitigate risk:	
- For the organization;	□
- For the natural environment; and	□
- For social systems involved.	□
Transformation	
Internal obstacles to transformation:	
- Develop a map of the areas in the organization that will be actively involved in making the change.	□
- Develop a map of the areas in the organization that will be affected by the change.	□
- For each internal stakeholder identified in the previous two points, list potential negative and positive consequences.	□
- Identify internal stakeholders who might be resistant to the change.	□
- Devise possible ways to mitigate internal resistance without compromising the goals of the transformation (i.e., involve internal stakeholders).	□
External obstacles to transformation:	
- Develop a map of external stakeholders who will be actively involved in the change.	□
- Develop a map of external stakeholders who will be affected by the change.	□
- For each external stakeholder identified in the previous two points, list potential negative and positive consequences.	□
- Identify external stakeholders who might be resistant to the change.	□
- Devise possible ways to mitigate external resistance without compromising the goals of the transformation (i.e., involve external stakeholders).	□
Holism	
Identify potential conflicts between the EARTH principles. (For example, what will the company do should the transparency required by the authenticity principle entail disclosing information about potentially vulnerable ecosystems or populations?)	□
Develop tools to address challenges that arise in any trade-offs.	□
Brainstorm possible unintended consequences of the transition.	□

3.3. Resilience

Our third EARTH principle is developing resilience, the ability to withstand shocks and to address conflicting and often paradoxical goals. A business's move toward biocircularity will have significant effects on the resilience of the company, on the natural environment, and on the social systems involved. At the operational level, companies will need organizational flexibility and supply-chain agility to address high environmental uncertainty and product complexity in the emerging bioeconomy (Srinivasan et al., 2021). The effectiveness of new or unfamiliar biomaterials as well as new processes will need to be tested in comparison with current technologies. The procurement of biomaterials, for instance, might be subject to different types of disruptions compared with that of traditional materials.

Companies in the oil and gas industry, for example, have been heavily criticized for failing to move to renewable energy; however, Finnish company Neste—formerly, Neste Oil—embraced the transition early by focusing on biocircularity.

Stating publicly that dependence on nonrenewable resources must decrease dramatically, the company pivoted its business by developing new technology in 1996 to generate biofuels from waste fats (Neste, 2021). Now two-thirds of Neste's profits come from its renewable products business, in contrast to 2% for the French oil company TotalEnergies (formerly Total; Reed, 2021).

Beyond the resilience of individual companies and supply chains, a sustainable, biocircular economy should improve the resilience of the natural and social systems it relies upon. Environmental and social resilience contribute to the resilience of individual businesses that are dependent on the resources that the environment and society provide. For example, agriculture is particularly vulnerable to changes in natural systems and requires a high degree of resilience. Traditional mineral fertilizers cause pollution, having a detrimental impact on soil fertility, production yield, and quality. Italian agricultural company Acqua & Sole's technology transforms agricultural waste into high-quality fertilizer while causing none of the pollution associated with traditional fertilizers. The company operates on the principle of interconnectedness between nature and human activity and has "renaturalized" its operations by replacing insecticides with ducks and cultivating hundreds of hectares of biodiverse habitats. The area has returned to the same biodiversity it had 1,000 years ago. Cultivating a resilient environment supports the surrounding community in withstanding natural shocks, such as extreme weather events, into the future (Hermann et al., 2021).

3.4. Transformation

This principle recognizes that transitioning to a sustainable, biocircular economy involves a total transformation not only within businesses but of entire industries. To survive, humanity needs to transform how it thinks about and engages with products, alongside reevaluating ideas of ownership, of consumption, and of what is valued within society (Sekerka & Stimel, 2011). Governments and consumers are already incentivizing and encouraging this transformation, and this will only increase in the future. Organizations that recognize and prepare for these changes will be in a strong position to develop their networks and to embrace the transformation. In Ireland, where agriculture is the largest indigenous industry, value creation in the industry has historically favored large processors and retailers. For example, less than 10% of the cost of a chicken goes to the farmer, 35%—40% to the processor, and over 50% to the retailer (Campbell, 2011). The biocircular economy has the potential to transform the structure of the industry so producers can realize the full value of their products. One example is the Agri Bio Circular (ABC) Economy initiative led by the Irish biowaste company College Group. Scientists and life-cycle researchers there are working with farmers to extract phosphorus from farm waste, to be used in several valuable products, such as fertilizer and char. This bidirectional relationship between primary producers and other stakeholders offers opportunities for companies to work with farmers struggling with economic and environmental challenges by helping them diversify and add value to their products.

A circular economy focuses on "purposeful restoration and regeneration" (Todeschini et al., 2017, p. 761), eliminating waste, keeping products "alive" for as long as possible, and, at the end of their lives, reclaiming or repurposing them. Such an economy helps regenerate natural systems. A paradigm shift to a circular economy means companies will develop new design practices emphasizing durable products that can be more easily taken apart and refurbished. This also leads to the development of more sustainable "take-back" systems for these more durable products.

For example, several companies, such as Rejoue in France and Jiminy Eco Toys in Ireland, supply locally made, nontoxic, and plastic-free toys while also repairing, refurbishing, cleaning, and redistributing preloved toys that would otherwise have a short lifespan. And recently, advocates for economic circularity have looked beyond ownership and called for collaborative consumption models (Batista et al., 2018). Just look at Swedish company Ihopa, the "Spotify of products." It provides a subscription sharing service for otherwise expensive, bulky, and seldom-used products.

3.5. Holism

Finally, the principle of holism is the glue for the other principles. *Holism* means embedding systems thinking into individual and organizational decision-making. Within the academic literature, researchers have argued for decades about the need to recognize the interconnections between the environment, economy, and society (e.g., Gladwin et al., 1995). This is a challenging shift because it means businesses must look at complex systems and not discrete issues. But companies can avoid the pitfalls of biowashing only through recognizing these systems holistically and as

interconnected, and they can succeed in implementing circular, bioeconomy strategies only if these prove sustainable for humanity and for the planet. Practicing holism provides decision-makers with a multilevel perspective of the sustainable, biocircular economy. It is central to changing the system. This means creating strategies and practices that take into consideration the organization, its supply chains, and its networks, as well as society and the environment. Holistic thinking requires a relational approach (Sekerka & Stimel, 2011) for developing new connections across the entire value chain, including nontraditional relationships with governments, academics, and CSOs as well as suppliers and consumers. Organizations that consider the biocircular economy as a complete, holistic system will develop the necessary mindset and organizational culture to embed the other four principles.

We are already seeing how the biocircular economy can provide the framework for a just transition to more sustainable industrial systems, as it transforms the economic and social fabric of communities and regions. In Lapland, Finland, fashion and textile company Infinited Fiber is transforming a defunct paper plant into a new factory to produce regenerated textile fiber, an alternative to cotton made of waste textiles, which will be sold to large customers such as Inditex, Patagonia, and H&M Group. The factory will bring 270 direct jobs to this northernmost region of Finland and is expected to generate 800 indirect jobs. The campus will provide new, highly skilled employment, drawing both local and international workers, with the aims of rejuvenating community life in the area and of generating high-value products, all the while preserving rather than exploiting local ecosystems.

4. Navigating the stages of biocircular transition: The STOP road map

In order to make the transition toward biocircularity, we suggest organizations view the EARTH principles as the guiding ethos through which their company operates. By adopting such an ethos, they will then be in position to implement the different stages of their sustainable, biocircular evolution and to use the STOP road map to pursue opportunities and to avoid pitfalls. The STOP road map focuses on:

- Skills—ensuring people have the right biocircular skills to inform their decision-making, behaviors, and actions;
- Technologies—understanding the technologies that can assist in a successful transition to biocircularity;
- Opportunities—identifying the right opportunities and staying aware of new products and services, potential supply bases, and consumer markets; and
- Problems—pitfalls and trade-offs to watch out for.

With this road map, a company can focus on transforming not just its business but its business model. As illustrated in Figure 1, we identify five stages of business transition toward a sustainable, biocircular future, from Stage 1: Material Revolution to Stage 5: System Resurgence. In the next section, we discuss each stage and detail how skills and technologies can support firms seeking to take advantage of opportunities and to address problems at each stage. All the while, companies must embrace an ethos that revolves around the guiding EARTH principles.

4.1. Stage 1: The materials revolution

The first stage in moving to a sustainable, biocircular business model is to substitute nonrenewable materials with biological alternatives. As fossil-fuel-based materials become more expensive to source, the replacement of nonrenewable materials with bio-based alternatives will have the double advantage of cost-effectiveness and risk mitigation. For example, by 2060, global demand for plastic is forecast to be 1.2 billion tons (OECD, 2022). Traditional plastics are fossil-fuel-based, so companies have begun to look to plant-based feedstocks to create bioplastics.

4.1.1. Skills

New technical skills in biotechnology and in chemical engineering are required for the separation and conversion of molecules to develop high-value products from bio-based materials. Research institutes are rapidly gaining expertise in extracting and developing novel materials from biological resources and, in doing so, providing the next generation of scientists with research-led training in bioeconomy technologies. The Shenzhen Institute of Synthetic Biology in Shenzhen, China, runs joint training programs with 23 universities to provide industry-focused master's and doctoral courses to students from all around the world. Companies in the material development space will

need to invest in the development of these technical skills as the bioeconomy grows.

4.1.2. Technology

Novel materials derived from waste resources such as waste product cellulose or agricultural, marine, and forestry waste are already showing up in sophisticated materials and in manufacturing technology. Skills and technology are developing in tandem, with universities and industry collaborating. For example, the Smart Cell project at Tokushima University in Tokushima, Japan is developing CRISPR genome-editing tools, which are applied to plants to increase the production of high-value biomaterials.

4.1.3. Opportunities

Drawing on the EARTH principle of ecology, sustainable, biocircular thinking can optimize the use of resources whether through inventing new materials or by repurposing of waste materials. For example, in Brazil, sugar cane was historically burned to produce bioenergy, but thanks to a major project funded by the Brazilian and UK governments, this waste product can be used to create high-value chemicals that can be incorporated into a range of products, from familiar items like air fresheners and fabric softeners to potentially life-saving medicines.

4.1.4. Problems

Failure to observe the EARTH principles can cause severe harm, as we have witnessed with the fossil-fuel industry, which has historically exploited communities and ecological systems to extract resources. To avoid repeating the same mistakes, companies must apply the principle of holism and ensure key stakeholders, such as communities, are at the center of sustainable biocircularity. By supporting local entrepreneurship, firms and research institutes can leverage local knowledge to catalyze innovation. In one example, when it began a bioeconomy project with Kenyan farmers, the Stockholm Environment Institute quickly found that the farmers were already adopting sustainable, biocircular sourcing strategies, including using agroforestry waste for animal feed and construction, which could be developed and scaled up to provide alternative income sources.

4.2. Stage 2: Rethinking processes

In this second stage, the focus shifts to production, and especially to the technologies that enable the rethinking of production processes and the reuse of waste in product lines. These typically consists of chemical, physical, and biological technologies (including catalytic conversion) that enable efficient use of bio-based materials. For example, in the fashion industry, enzymes from microorganisms are used instead of harmful chemicals in processes such as textile bleaching, dyeing, and finishing. This not only makes the fabric stronger and longer lasting but considerably reduces toxic waste pollution from textile processing.

4.2.1. Skills

Rethinking processes requires training workers to operate new technologies and to follow new procedures, along with developing entrepreneurial skills to explore how current processes can be adapted to biological materials and to identify potential new processes. In Australia, the Tasmanian government and its local university have partnered with nearby firms to develop novel bioeconomy process skills. Successful projects include a 2018 venture between Norske Skog and Australian company Circa Group to support production of a new bio-based industrial solvent called Cyrene. Producing Cyrene required Circa Group to develop significant new knowledge and skills in a prototype plant in Tasmania. Cyrene is now used globally in the manufacturing of products as diverse as paint, pharmaceuticals, and plastic.

4.2.2. Technology

In many cases, a sustainable, biocircular transition can happen with minimal disruption to manufacturing processes. Leveraging the technical and entrepreneurial skills developed, it is possible to identify process technologies that can be reconfigured to use biological materials, including large-scale process technologies such as biorefineries as well as small-scale manufacturing equipment. Dell is both embracing the materials revolution and rethinking its processes, working with suppliers to source bio-based materials as substitutes for specific polymers, with new materials slotting into existing manufacturing processes, minimizing investment in new equipment or staff training.

4.2.3. Opportunities

Rethinking processes can also be the beginning of a broader business transition. In Italy, the Gela and Venice biorefineries run by energy company Eni became the first to convert to bio-based resources,

processing waste vegetable and food materials rather than virgin materials. This not only saved costs but meant that the refinery no longer relied on virgin palm oil as a feedstock, enabling Eni to fulfill its pledge to eliminate it from its processes by 2023. Eni stands as an exemplar for others in the energy industry, having blazed a trail in embracing the EARTH principles.

4.2.4. Problems

Process technology costs, combined with the costs of upskilling staff, can be high for smaller firms. In a 2018 European survey, 73% of small and medium-sized enterprises (SMEs) cited access to finance as a barrier to bio-based processing innovations. This challenge can be mitigated by government investment, as is indeed happening worldwide. As of 2020, there were 60 countries pursuing bioeconomy policies and 19 dedicated country or regional bioeconomy strategies, including in the US, Latvia, Italy, and South Africa, many of which provide venture capital funding for bio-based startups and SMEs, such as South Africa's Bio-Innovation Venture Capital Fund.

4.3. Stage 3: Product (re)invention

The third stage involves the reinvention of existing products along with the emergence of new products. Product reinvention is where existing products are used for new purposes. For example, by-products such as whey from cheese production can be used to create bioplastics rather than ending up as a polluting waste. Products should be resilient and developed using life-cycle assessment (LCA) principles (Buxel et al., 2015). Ensuring authenticity is crucial to preserving buy-in from consumers and to avoiding biowashing.

4.3.1. Skills

Product reinvention skills include technical skills in sustainable, biocircular product development, marketing skills to communicate the value of those products, and supply-chain-management skills to develop innovations with suppliers. For example, Irish energy company Bord Na Móna previously relied on the carbon-intensive fossil fuel peat to produce energy and horticultural fertilizer. As extracting peat became politically and economically difficult, the company was forced to develop new ways to generate revenue, and its employees had to develop entirely new skills. Bord na Móna transformed its product into a service by repurposing peat bogs as tourist attractions, marketing them as "bog parks," and it retrained its managers and marketing employees to support the parks' development and operation.

4.3.2. Technology

New product technologies can enable product reinvention for firms that follow sustainable, biocircular principles. For instance, the vegan leather industry has seen huge growth as consumers have turned away from animal products. The industry has faced challenges, however, as vegan leather is typically made from nonrecyclable plastic derived from petrochemicals, leading consumers to question its authenticity. New York-based startup Bucha Bio addressed this by developing a bacterial nanocellulose that can be used to make a biodegradable vegan leather substitute. The company was the first to successfully commercialize nanocellulose in this way.

4.3.3. Opportunities

Public-private innovation partnerships, such as Europe's largest, Climate-KIC, are creating opportunities to develop sustainable, biocircular products. Climate-KIC offers businesses and entrepreneurs training, coaching, and it offers financial support through the Climate Launchpad incubator, which has supported sustainable, biocircular companies. One of these is the Swedish company Lixea, which converts wood waste into renewable chemical compounds and packaging. Similarly, the Malaysian government offers a range of support for bioeconomy-focused businesses, including its BioNexus awards and Bioeconomy Community Development Programme. Successful new companies include Bioalpha, producing halal health supplements, and PureCircle, which makes food supplements from the stevia plant.

4.3.4. Problems

Companies seeking to reinvent their products must embrace the EARTH principles, particularly authenticity and ecology, to ensure new products are biocircular and to avoid accusations of biowashing or of overhyped marketing. Not all bioplastics, for example, are easily biodegradable or compostable. Many coffee cups and pieces of cutlery marketed as compostable are not suitable for home composting and will only biodegrade in an industrial composter. Taking an alternative, innovative approach to tackling catering waste, some companies, such as Biobite and Twiice, are now combining technological innovation with marketing skills to develop edible coffee cups and cutlery made from wafers and biscuits, which are being marketed across the food service industry to restaurants, caterers, and cafés.

4.4. Stage 4: Business redesign

The journey toward a fully circular, bio-based business model requires rethinking the structure and operations of the organization and its entire value chain. Relationship-management skills will be at the fore in this stage, to develop the relationships and networks necessary to create partnerships with new organizations and industries. Innovation remains center stage as companies consider how biological materials, products, and processes can lead to improved resource efficiency and to the development of new products, energy, and services. During this process, which is enabled by the changes enacted in the previous stages, the business model of the firm is redesigned to center around the sustainable, biocircular economy.

4.4.1. Skills

Change management, systems thinking, and leadership skills are essential to ensure business actions and impacts are linked to global sustainability frameworks while maintaining economic viability, particularly in industries with high environmental uncertainty (Srinivasan et al., 2021). Responding proactively to multiple economic and environmental challenges in the industry, Irish dairy producer Glanbia, for example, is seeking to transform its existing carbon-intensive business model to a low-carbon, high-value model. Through the AgriChemWhey project, it has worked with the pharmaceutical industry to develop an entirely new value chain, converting waste and by-products from dairy processing into biochemicals used to create pharmaceutical products, such as vaccines and biodegradable plastics.

4.4.2. Technology

We have seen already (in the Material Revolution and Rethinking Processes stages) that innovative technologies can support the more operational aspects of the sustainable, biocircular transition, but rethinking how technology is used can also support the redesign of business models. One example is smartphones. Smartphones require expensive and scarce raw materials, and manufacturers have been criticized for practicing planned obsolescence by deliberately producing products with materials that do not last. Dutch social enterprise Fairphone has historically addressed the latter problem by producing durable phones and sending replacement parts to customers free of charge. These phones employ an innovative design that allows the customers to repair their phones themselves. Now Fairphone is taking a holistic view of the supply chain, tackling the issue of scarce raw materials through sustainable biocircularity, partnering with Italian company Covestro to source bio-based plastic phone cases made from waste cooking oil.

4.4.3. Opportunities

Firms frequently engage in partnerships to support innovation and to influence policy on environmental issues (Wassmer et al., 2017). In line with the EARTH principle of holism, interconnections across value chains and nontraditional relationships are essential to successful business redesign. Public-private partnerships make it possible for innovative companies and entrepreneurs to capitalize on bioeconomy opportunities, partnering with nontraditional stakeholders to explore ways of doing business that benefit all. The BiomassWeb project in sub-Saharan Africa was funded by the German government, working in partnership with universities in Germany and Africa, alongside local farms, processers, and communities in Ghana, Nigeria, and Ethiopia, creating biomass value webs that maximize food security and value for farmers. One innovation to spring from this effort is the use of waste cassava peels as fertilizer to maximize nutritional value and yield from crops, including mushrooms and bamboo.

4.4.4. Problems

In redesigning a business, transparency across the entire business and supply chain is essential to avoiding the problems of the fossil-fuel-based economy, such as environmental harm and exploitative work practices. Unilever, for example, is trying to source palm oil and fossil-fuel feedstock for its personal care products in a socially and environmentally sustainable way. Now the British consumer goods manufacturer is partnering with US firm Geno to develop bio-based biotechnology alternatives to palm oil, a holistic approach that will support the EARTH principles of authenticity and resilience while protecting fragile ecosystems.

4.5. Stage 5: System resurgence

The final stage on the road to a fully sustainable, biocircular economy will see whole industries rethink their inputs, processes, and outputs within the wider context of social and ecological

sustainability. We will witness the creation of alternative, restructured, and reimagined industries that go on to forge nontraditional partnerships. At this stage, we will have a carbon-neutral economy with businesses and consumers using bio-based materials for the entirety of their (now expanded and extended) useful product lives. Only within this stage will the guiding EARTH principle of transformation come into play. Although humanity has not achieved this stage yet, examples of system resurgence that will scale in the future are fast emerging.

4.5.1. Skills

A relational approach is invaluable in supporting change management in organizations (Sekerka & Stimel, 2011). For companies embracing the sustainable, biocircular economy, relational skills such as effective communication and conflict resolution ensure effective alignment and management with nontraditional stakeholders, such as nongovernmental organizations, governments, and the media, creating new industries and systems. Companies and stakeholders are creating multistakeholder innovation hubs centered around a sustainable, biocircular value chain. Bringing together people across industries and sectors facilitates the transfer and development of knowledge and skills driving innovation. For example, the multistakeholder Dairy Nexus project in Scotland, focusing on bioeconomy innovations, includes dairy farms, biorefineries, and laboratories, and provides coworking spaces to facilitate cross-disciplinary knowledge exchange and innovation.

4.5.2. Technology

Technological innovations can support industrial transition through inclusive, multistakeholder engagement, with technology empowering all actors. The wearable electronics industry is transforming rapidly, with consumers expecting more biocompatibility and biodegradability from these devices, which have multiple applications across sectors from healthcare to defense to leisure. For example, using new technology, a bio-based material called silk fibroin can be extracted from waste silk to create material that, when used for wearable electronics, is more flexible, performs better, and is more cost-effective than traditional silicone materials, which could lead to significant structural changes across the wearable technologies sector.

4.5.3. Opportunities

In line with the EARTH principles of transformation and holism, there is enormous potential for whole industry transitions from a fossil-fuel-based economy to a sustainable, biocircular one that benefits multiple stakeholders and supports rural regeneration. For instance, in the small town of Lisheen in rural Ireland, the National Bioeconomy Campus has brought new economic opportunities and social connections to this former mining region. Since 2015, the campus, once the site of a lead and zinc mine, has grown to incorporate multiple biocircular pilot projects, a digital innovation hub, a diverse organizational network, and soon, a multipurpose bioprocessing plant.

4.5.4. Problems

Companies can ensure a just transition to the sustainable, biocircular economy by partnering with nontraditional stakeholders. The Amazon rainforest in Brazil has been ravaged by deforestation and its Indigenous inhabitants subject to land grabs. Partners including the CSO Forest Trends and the Brazilian Academy of Sciences are leading a bioeconomy strategy, called Amazon 4.0, which regards Indigenous peoples as crucial to bioeconomy development. The project focuses on products that support forest conservation and employment for Indigenous communities, including Brazil nuts, cacao, and art. In conjunction with the new government in Brazil, the project could lead to the regeneration of multiple systems within the forest.

5. The biowashing checklist

Drawing on the foundation of the guiding EARTH principles, and using the STOP road map to navigate the stages for transitioning to a sustainable, biocircular economy, we have developed a biowashing checklist. Firms can use the STOP road map to support the elements of the checklist, identifying the skills and technologies required to make the most of opportunities while also addressing potential problems in each category.

6. Conclusions

The transition to a sustainable, biocircular economy provides opportunities for firms to thrive, while allowing them to address the climate crisis and biodiversity loss. Businesses that succeed in the transition will create skilled jobs, be competitive in bio-based industries, engage new consumer markets, consume more sustainably, regenerate failing industries, and enrich communities. They can succeed by following the EARTH principles, using the STOP road map to navigate the stages for successful biocircular transition, and using the

biowashing checklist. Firms and industries that begin this journey now will be ahead of the curve and able to work together to bring about the urgent societal, ecological, and economic transitions required. By embracing the sustainable, biocircular economy, companies can play a pivotal role in the transition to a just, resilient, and ecologically sustainable society for all. With the climate crisis already linked to millions of deaths every year, this change cannot come quickly enough.

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