MANUFACTURING FOR NATURE'S CIRCULARITY:

How Industry Circularity Definitions Differ from Nature and Why it Matters

NATURAL FIBER WELDING®

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INTRODUCTION

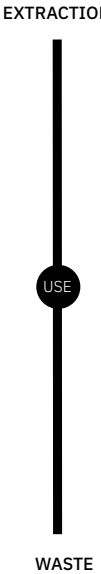
Current industry definitions of circularity default to incrementally extending the useful life of materials as much as possible, focusing on repair, reuse, and recyclability, but often without rigorous and comprehensive sustainability in mind. Much effort (read: money) has been spent on plastic recycling as an example of an "infinitely recyclable," circular economy. Yet, since mass production of plastic began in the 1950s, it is estimated that only 9 percent of plastic ever produced has been recycled. In that time the amount of new plastic material produced has and continues to increase at an alarming rate. Production growth is not being replaced by recycled material for both technical and economic reasons.[1] If current rates of virgin plastic material production continue, by 2050 plastic production could account for 10–13 percent, and by some measures approaching 20 percent, of the global carbon budget needed to avoid a 1.5° C global increase from preindustrial temperature levels.[2,3]

The economics of plastic recycling have never been feasible because of the lack of infrastructure and the large amount of energy required for both mechanical and chemical recycling. New plastic material is simply more economical to produce than recycled plastic. (The oil, gas, and plastic industry has, apparently, known this from the beginning.)[4]

The flow of fossil fuel–based virgin plastic must be slowed — and fast. Some propose slowing plastic production growth by, for example, mixing mycelium or other biomass with plastic to incrementally reduce absolute plastic production demand. The reality is that these "bio" plastic approaches lack unit economics to scale with sufficient capital efficiency and with necessary speed to have a global impact. Moreover, mixing biomass with plastics (and/or with bioplastics) is not circular and firmly falls into the linear economy model.

Looking to Earth's natural circularity as the gold standard, humanity can choose to demand manufacturing, design, and end-of-life practices that are in alignment with the highest standards of true circularity. In this paper, we provide background on the current industry definitions of circularity, discuss how nature's circularity differs, and explain Natural Fiber Welding's (NFW's) approach to show how to build truly circular products. By using abundant, renewable plant material from the beginning and using only natural and bioneutral inputs, at NFW we design and manufacture naturally circular materials that are durable, functional, and beautiful. Most importantly, the all-natural approach and focus enables circular product design that is the key link to enable circularity that scales to global proportions.

LINEAR PRODUCTION MODEL



INDUSTRY DEFINITION OF CIRCULARITY

The concept of a circular economy was developed in response to the resource intensive and unsustainable linear model of "take-make-dispose." In a linear economy, material and energy are extracted from Earth and disposed of in a landfill or, at best, incinerated for a modest amount of energy recovery. Unfortunately, the linear model often excludes accounting for issues such as toxic microplastic pollution that can happen during product use and/or disposal. The toxic, high carbon realities of plastic production compounds sustainability problems for any future "plastic circularity."

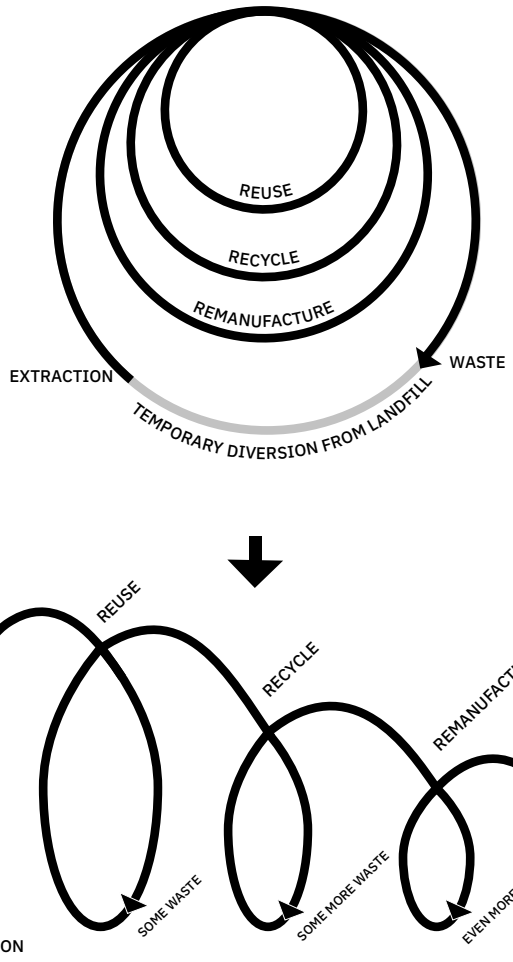
Current industry and academic definitions of the term "circular economy" vary widely in their scope and key details. These definitions typically focus on the reuse and remanufacturing of material to keep it in the production loop as long as possible. One representative definition follows:

> "The concept of circular economy conceives of a production and consumption system with minimal losses of materials and energy through extensive reuse, recycling, and recovery."[5]

Korhonen, et al. reviewed other definitions in a 2018 paper, in which they argue that the circular economy is an "essentially contested concept."[6] This means that the goals and objectives of a concept are generally agreed upon, but the definition, units of measurement for success, and even appropriate methods of testing are generally not. There is much more to say on this topic. For the purposes of keeping this part of the discussion compact, we recommend two other articles that review circular economy definitions: Johansson and Henriksson, 2020, and Harris, et al., 2021.[7,8] These two articles offer further reviews of circularity literature and analyze circularity within the context of environmental policy[7] and review assessment methodology for circularity.[8]

In the chorus of voices seeking to define and verify circular economy efforts, voluntary industry initiatives or certifying organizations are some of the loudest and may often be more marketing than substance. While these organization's models have been key in driving policy frameworks for the circular economy, in a recent analysis by the Changing Markets Foundation, the effectiveness of these organizations at actually reducing material and energy consumption was scrutinized and found to be ineffectual.[9] While we commend these organizations for the pioneering work attempted thus far, it is clear that much more must be done to define, measure, and critique purported progress.

INDUSTRY CIRCULARITY MODEL



Additionally, organizations like ISO and ASTM are seeking to standardize circularity definitions, metrics, and practices to aid in the transition to a circular economy, while currently there are none. One large problem with the prevailing models of circularity: they are hardly circular. While there are loops representing reuse, redistribution, and recycling in both biological and technical materials, the models also include inputs through mining and extraction from limited natural resources. More importantly, they also include outputs to the atmosphere through biogas, incineration for energy recovery, and landfill, while the latter two are given asterisks "to be minimized" with very limited technical and economic data to define standards that must be achieved.

Moreover, other sustainability metrics, like the relatively large and stubborn carbon footprint of recycling plastics[3] and avoiding the release of toxic microplastic pollution[10,11] are often ignored.

The vast majority of efforts to create a circular economy add a few loops to the line at best. However, a looped line — even with a lot of loops — is still a line. Current definitions assume that recycling technical materials, especially plastics, with the necessary yield to be considered circular, is both economically and physically feasible.

In almost all cases, sufficient efficiencies do not exist.[12] This is most apparent when looking at the magnitude of recent investments into virgin plastic production versus the magnitude of investments into viable "circular" (plastic) systems.[13,14]

The question is: How can we define a circular economy without using a true circle?

Our answer: *We shouldn't.*

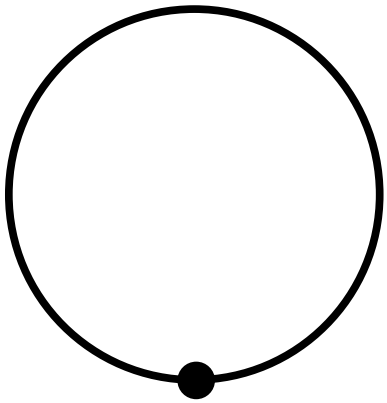
NATURE'S CIRCULARITY

Natural processes, and especially photosynthesis, demonstrate circularity and abundance that has no productivity equal. At Natural Fiber Welding, all of our technologies are designed to fit within nature's abundant, circular systems. We believe the closest humanity can come to true circularity — that is comprehensively sustainable — is to design our ecosystem of materials and products within the natural circular economy that already exists at large scale and is powered by the sun.

Biogeochemical cycles developed over billions of years to support complex ecosystems by converting energy from the sun and matter into a coherent system of biologically available forms. During the cycle, energy and matter are transferred between different reservoirs, namely: the biosphere, the atmosphere, oceans, and the geosphere (rock, sediments, and soil). Virtually all elements undergo some form of biogeochemical cycle. Certain elements, i.e. atoms like carbon and nitrogen, are both abundant and have the appropriate chemistry such that they have become essential and form the organic building blocks that make up life (e.g. sugars, lipids, proteins, and nucleic acids).[16,17]

Carbon in particular has received a lot of attention because there are two forms of carbon, carbon dioxide (CO_2) and methane (CH_4), that are emitted from human industry into the atmosphere at high rates and are the primary carbon motifs contributing most significantly to the anthropogenic climate crisis. (It is worth noting that ethane, fluorocarbons, and other emissions matter as well.) At the same time, in its different forms and reservoirs (e.g. soil organic matter or large forests) carbon is an essential nutrient in global biodiversity and ecosystem health.[18]
If we look to a forest and trees as an example of natural circularity, we can follow individual elements as minerals are taken from the soil, CO_2 is pulled from the air, and molecules are organized into plant material — all powered by sunlight. After the lifetime of the tree is done, it falls and begins to decompose back to the soil in the timescale of years, even decades. Sunlight now provides energy for

NATURE'S CIRCULARITY



NATURAL WASTE CONTRIBUTING TO CONTINUATION OF CYCLES

photodegradation, and fungi and bacteria biodegrade lignin and cellulose that make up the tree. Insects and microorganisms continually biodegrade the tree into CO_2 and new lipids, nucleic acids, and proteins to build themselves up. Microbial metabolism uses the energy from molecular bonds to mineralize nutrients from the tree into forms that other plants or organisms can use in the soil. Just as water cycles through the biosphere, the nutrients of life cycle out from a vast "ocean" of diversity.

The elements are returned to the forms they came from and begin the cycle again. This is circularity in its truest sense.

Humanity has long understood, at least innately, nature's circularity and worked in harmony with it. Indigenous conceptions of materials were inherently circular. Textile production was a matter of material origin, the wearer's need, and appropriate design and manufacturing to suit. Making high quality, durable goods from regionally specific, all-natural ingredients,

repairing them as often as possible, and eventually returning to the earth safely was the only option. And this thoughtful approach works quite elegantly, we think, even today.[19]

HOW NATURAL FIBER WELDING DEFINES CIRCULARITY

At Natural Fiber Welding (NFW), we are not willing to compromise the definition of circularity already found in nature. Anything less is simply not sustainable when one considers how even "small" concessions are amplified at the scale of billions of consumers. NFW's patented, high throughput technologies create materials that are designed for recycling and reuse at scale. We believe working with brand partners to design products made from natural materials at their highest utility and value, with long lifetimes and no mixing of incompatible plastics, is the only sustainable way to address circularity. Simply put, nature's example for true circularity is to use interchangeable nutrients, and NFW designs to fit within this natural system definition.

NFW accepts the reality that "Everything you make returns to the earth as food, or poison."[20] We fit within nature's circularity by: 1) starting with *only* nutrient and nature neutral inputs (e.g. plant fibers or minerals) so our materials can be safely returned to the same environment they came from, and 2) manufacturing so that our products are nourishing as they decompose to the same elements from which they began, and then safely build again the same molecules we used for production. We use the term "bioneutral" to describe our do-no-harm approach to materials science and manufacturing.

At NFW, we choose to work with plants, rather than plastic. We specialize in reformatting ingredients from nature directly into high-performance materials. This no compromise approach sets NFW apart in the material space both in terms of philosophy and practice. Plastic production relies on breaking down molecules to unnatural forms and using toxic plasticizers and additives. Then, all too often, this man-made waste "leaks" into the environment, unintentionally or otherwise, with negative consequences that span many timescales. At NFW, we acknowledge the inevitability of some amount of waste. However, with thoughtful design, waste can "feed" rather than "poison" the environment. This is a different end-of-life approach than the majority of industrial plastics and additives produced by the current generation of petrochemical and biochemical manufacturers that operate today.

While we emphatically commend industry partners who are transparent in their quests for circularity (see this article from Patagonia,[21] for a great example), we know we can help designers go further and do better. By drawing on lessons from Earth's cycles, we can transform natural elements into a different biogeochemical reservoir (let's call it, consumosphere?), but with intentional design, the energy and matter can be transformed back to the same elements as before and become part of Earth's natural biogeochemical cycles again. Or rather, we believe it doesn't have to leave the cycle at all.

CONCLUSION

At NFW, we firmly believe that we can be a part of nature's circularity through forming and shaping naturally abundant plant fibers to replace — not simply reduce — plastic in the material industry. Additionally, we believe this model offers the only truly sustainable and scalable solution capable of meeting humanity's wants and needs in material production. While current definitions and examples of circularity in the technical cycle don't follow nature's example of circular materials, NFW has shown that we can manufacture and design naturally circular materials that are durable, functional, and beautiful. NFW is already in-market with global brands and some of the most valuable and influential brands are currently developing products on the NFW platform. With nature's circular design in mind, we can achieve the highest levels of sustainability. Join as we journey towards circularity in its truest sense.

References

1. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782. https://doi.org/10.1126/sciadv.1700782

2. Hamilton, L. A., Feit, S., Muffett, C., Kelso, M., Rubright, S. M., Bernhardt, C., Schaeffer, E., Moon, D., Morris, J., & Labbé-Bellas, R. (2019). Plastic and Climate: The Hidden Costs of a Plastic Planet. Center for International Environmental Law. https://www.ciel.org/plasticandclimate/

3. University of California - Santa Barbara. (2019, April 15). Plastic's carbon footprint: Researchers conduct first global assessment of the life cycle greenhouse gas emissions from plastics. ScienceDaily. Retrieved May 2, 2022 from www.sciencedaily.com/releases/2019/04/190415144004.htm

4. L. Sullivan, How Big Oil Misled The Public Into Believing Plastic Would Be Recycled. NPR (2020), (available at https://www.npr.org/2020/09/11/897692090/how-big-oil-misled-the-public-into-believing-plastic-would-be-recycled).

5. Haupt, M., Vadenbo, C., & Hellweg, S. (2017). Do We Have the Right Performance Indicators for the Circular Economy?: Insight into the Swiss Waste Management System: Circular Economy: Do We Have the Right Indicators? Journal of Industrial Ecology, 21(3), 615–627. https://doi.org/10.1111/jiec.12506

6. Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. Journal of Cleaner Production, 175, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

7. Johansson, N., & Henriksson, M. (2020). Circular economy running in circles? A discourse analysis of shifts in ideas of circularity in Swedish environmental policy. Sustainable Production and Consumption, 23, 148–156. https://doi.org/10.1016/j.spc.2020.05.005

8. Harris, S., Martin, M., & Diener, D. (2021). Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy. Sustainable Production and Consumption, 26, 172–186. https://doi.org/10.1016/j.spc.2020.09.018

9. Changing Markets Foundation, "License to Greenwash: How certification schemes and voluntary initiatives are fueling fossil fashion" (Changing Markets Foundation, 2022), (available at https://changingmarkets.org/portfolio/fossil-fashion/).

10. Lim, X. (2021). Microplastics are everywhere — but are they harmful? Nature, 593(7857), 22–25. https://doi.org/10.1038/d41586-021-01143-3

11. Carrington, D., & editor, D. C. E. (2021, December 8). Microplastics cause damage to human cells, study shows. The Guardian. https://www.theguardian.com/environment/2021/dec/08/microplastics-damage-human-cells-study-plastic

12. Geyer, R., Kuczenski, B., Zink, T., & Henderson, A. (2016). Common Misconceptions about Recycling. Journal of Industrial Ecology, 20(5), 1010–1017. https://doi.org/10.1111/jiec.12355

13. Plastic Recycling was a Myth. We're Living the Consequences. (2022, May 5). Time. https://time.com/6173859/plastic-recycling-big-oil-damage/

14. Portfolio Earth. (2020). Bankrolling Plastics | The Banks that Fund Plastic Packaging Pollution. Portfolio Earth. Retrieved May 5, 2022, from https://portfolio.earth/campaigns/bankrolling-plastics/

15. Brusseau, M. L. (2019). Chapter 6 - Ecosystems and Ecosystem Services. In M. L. Brusseau, I. L. Pepper, & C. P. Gerba (Eds.), Environmental and Pollution Science (Third Edition) (pp. 89–102). Academic Press. https://doi.org/10.1016/B978-0-12-814719-1.00006-9

16. UCAR Center for Science Education. (2011). Biogeochemical Cycles. https://scied.ucar.edu/learning-zone/earth-system/biogeochemical-cycles

17. Falkowski, P. G. (2001). Biogeochemical Cycles. In S. A. Levin (Ed.), Encyclopedia of Biodiversity (Second Edition) (pp. 552–564). Academic Press. https://doi.org/10.1016/B978-0-12-384719-5.00013-7

18. McDonough, W. (2016). Carbon is not the enemy. Nature, 539(7629), 349–351. https://doi.org/10.1038/539349a

19. Adisa-Farrar, T. (2021, October 19). Regenerative Design: Textile Systems. https://slowfactory.earth/courses/regenerative-design/

20. Slow Factory. (2022, April 20). Sustainability Literacy. What Is Sustainability Literacy? https://slowfactory.earth/sustainability-literacy/

21. Ram, A. (2021, March 10). Our Quest for Circularity - Patagonia. Patagonia. https://www.patagonia.com/stories/our-quest-for-circularity/story-96496.html