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A Review of Four Publications on the Sustainability and Potential of Plastic Alternatives

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Plastics and sustainability: towards a peaceful coexistence between bio-based and fossil fuel-based plastics by Michael Tolinski

Sustainable plastics: environmental assessments of biobased, biodegradable, and recycled plastics by Joseph P. Greene

The new plastics economy: rethinking the future of plastics by the World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company

Current attention to marine plastic debris and discussion of the role of plastics in the circular economy have prompted increased attention to plastic waste management. Several books and recent reports grapple with these topics. Ever since the invention of the thermoset Bakelite, plastics have been playing an increasingly important role in our society. A wide variety of fit-to-purpose plastics were developed over several decades, and the inaptness of modern waste management to deal with such variety has put severe stress on our environment, as laid out in "*The New Plastics Economy"* reports composed by the World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company [1, 2] (referred to as MacArthur reports hereafter). However, as much as the MacArthur reports capture the evolution of economic cycles of plastics, heavily focusing on their end-of-life management and suggesting future strategies for use, they seem to

underemphasize an emerging bio-based plastics platform. Additionally, a quantitative yet practical synthesis for industrial developers/practioners is missing. To fully grasp emerging trends for decision making at the industrial level, next to limiting ourselves to a circular economy framework, we recommend *"Plastics and Sustainability"* by Tolinski [3]. This work effectively structures the spectrum of modern plastics according to two contrasts: bio-based versus petroleum-based, and biodegradable versus non-degradable. Together with "*Sustainable Plastics: Environmental Assessments"* by Greene [4], it is an excellent resource to learn the environmental advantages of bio-based, biodegradable and recycled plastics, and their potential to replace conventional plastics. *Greene* promotes the sustained and ecological profits associated with bio-based and recycled plastics by detailing their function, by providing current, relatable examples and by performing life cycle assessment. Primarily because of the extensive life cycle inventory data included, Greene's book is well suited for consultation by researchers and environmental engineers. Following a similar format, yet less technical, *Tolinski* discusses the environmental benefits mainly for bio-based and biodegradable plastics. Both authors underpin the distinction between the motivation for biodegradable plastics, which are designed to solve the waste concern, and the motivation for biobased plastics, which could successfully reduce the inherent carbon intensity of the life cycle. Nonetheless, both books only briefly touch on the disadvantages of newly invented, biobased plastics, such as high cost, a limited number of reuse cycles (if any) and a poor after-use economy. These disadvantages, more prominently discussed in the MacArthur report [1], might strongly discourage decision makers/investors, hampering mass production. The aforementioned report successfully captures the majority of recent recycling research and activities (i.e. curbside collection, mechanical recycling, dematerialization, etc.) that take part in the current plastic economy. The report identifies the weaknesses of the current plastics economy and proposes

treatment methodologies to ensure the "*creation of an effective after-use plastics economy, drastic reduction of the leakage of plastics into natural systems (in particular the ocean) and other negative externalities; and the decoupling from fossil feedstocks*" [1, pg. 7]. *Greene* and *Tolinski* successfully introduce the concept of plastics sustainability to environmental scientists and engineers, while economic benefits of this concept on a global level are comprehensively demonstrated by the McArthur reports [1, 2]. Complementary, the different writings present social, environmental and economic improvements of sustainable plastic materials compared to conventional plastics, in a concise style. This work resonates strongly with the results concluded from work described in the scientific literature [5-8].

Greene and the *MacArthur* reports underlined the problem of the current open-loop recycling technology producing low-quality material that is useful for only one cycle. All three writings employed diverse literature and industrial reports in pursuit of an effective solution for "*moving the plastics industry into a positive spiral of value capture, stronger economics, and better environmental outcomes*" ([3], pg. 15). The MacArthur reports explicitly draw attention to those current issues in the plastics economy that were underemphasized in Greene's and Tolinski's work. For example, it pointed out that the current collection systems, which have been thought to be effective, leak millions of tonnes of plastic waste annually, citing the work of Jambek et al. [9]. The plastics escaping from after-use collection systems have a significant negative effect on marine ecosystems – "*ocean litter is known to have affected at least 267 species worldwide*" ([3], pg. 25) – and the economic activities (~$13 billion ([1], pg. 14)) that depend on them. The MacArthur report underscores a shift in attention to the current major dilemma of modern plastics, "*plastics leaking (escaping) from after-use collection systems and the resulting degradation of natural systems, particularly the ocean. Although not the focal point initially, evidence of the*

looming degradation of marine ecosystems by plastics waste, particularly plastic packaging, has made plastics leakage a priority topic" ([1], pg. 6). Evidently, any kind of modern waste treatment after proper collection is much better than plastic debris leaking to the ocean, because once leaked, this pollution is very difficult to remove ([3], pg. 29). The newest MacArthur report [2], suggests strategies for intensifying recycling and closing material cycles, assuming increased after-use demand reduces spilling. Additionally, new design efforts could reduce the need for small format plastic items, decreasing the pollution potential. In the work of these three authors, neither present day recycled plastics nor biodegradable plastics were identified to be a permanent solution for the issues regarding the current plastics economy. The most effective way to treat leakage of plastics is to "*make plastic packaging 'bio-benign' when it does (unintentionally) leak into the environment*" ([1], pg. 18). Or at least, further research and investments should be done to establish more closed-loop recycling, which is "*recycling of plastics into the same or similar-quality application*". The MacArthur reports emphasized that the concept of a closed-loop recycling system inspires investors and scientists to spend more effort in improving collection technologies, and stated that "*creating a working economy for after-use plastics would offer a direct economic incentive to build collection and recovery infrastructure*" ([1], pg. 18).

These complementary works, although not focused on the fundamental science or mechanical properties of pristine, recycled, or bio-polymers, dive into important environmental issues with respect to modern plastics and they propose potential routes toward sustainable materials. Given the recent shift in attention from climate change to oceanic pollution, future plastics should synergistically combine the advantages of bio-based feedstocks, which reduces carbon footprints, with a biodegradability effectively tailored to oceanic environments. Each of the highlighted writings approach the plastic spectrum from a different angle, both managers, investors, policy

makers and scholars can find value in the cited works as a guideline when analyzing potential alternatives of plastics in relation to their sustainability, applicability and economic performance.

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