MATERIALS
BIOPLASTIC

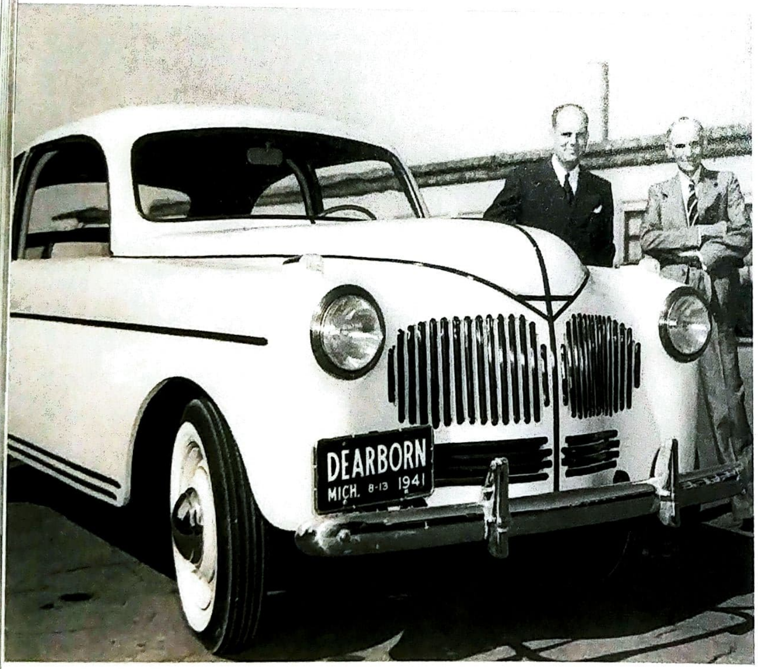
From the Stone Age to the Iron Age to the Steel Age, we delineate society's epochs by their primary material for fabrication. Ours could be called the Age of Plastic. Globally, we produce roughly 310 million tons of plastic each year. That is 83 pounds per person, and plastic production is expected to quadruple by 2050. The material is everywhere, from clothing to computers, furniture to football fields, and almost all of it is petro-plastic, made from fossil fuels. In fact, 5 to 6 percent of the world's annual oil production becomes feedstock for plastic manufacturing. But the polymers that make up plastic exist everywhere in nature, not just as fossilized forms, and experts estimate that 90 percent of current plastics could be derived from plants or other renewable feedstock instead. Such bio-based plastics come from the earth and many can return to it, often with lower carbon emissions than their fossil fuel–based kin.

The Greek verb *plassein*, the root of plastic, means "to mold or shape." What affords plastics their malleability are polymers—substances with chainlike structures, made of many atoms or molecules bound to one another. Most have a backbone of carbon, linked with other elements such as hydrogen, nitrogen, and oxygen. We can synthesize polymers, but they also occur naturally all around and inside us; they are part of every living organism. Cellulose, the most abundant organic material on earth, is a polymer in the cell walls of plants. Chitin is another abundant polymer, found in the shells and exoskeletons of crustaceans and insects. Potatoes, sugarcane, tree bark, algae, and shrimp all contain natural polymers that can be converted to plastic.

Although petro-plastics now dominate the market, the material for the earliest plastics was plant cellulose. In the nineteenth century, playing billiards was de rigueur for the well-to-do in the United States and Europe, and the balls that adorned billiard tables were 100 percent solid ivory. The market was voracious; elephants were slaughtered by the thousands for their tusks, each the source for merely a handful of billiard balls. The trend prompted public outcry, while driving up costs for the billiards industry. Billiards player and tycoon Michael Phelan issued a challenge: $10,000 in gold to anyone who could develop an alternative to ivory. The offer prompted printer and tinkerer John Wesley Hyatt to begin testing possibilities. He developed a substance from the cellulose in cotton, dubbed "celluloid." Celluloid turned out to be less than ideal for billiard balls—Hyatt never got the money—but it was just right for products such as combs, hand mirrors, toothbrush handles, and movie film.

Henry Ford also played with the possibilities of bioplastics, establishing a significant research and development program focused on constructing car parts from soybeans. In 1941, Ford unveiled his soybean car, but he could not overcome rock-bottom fossil fuel prices or the all-consuming focus of World War II. In addition to being the maiden bioplastic, celluloid sparked the invention of Bakelite, Leo Baekeland's petroleum-based plastic—the first of its kind. Along with the emergence of the petrochemical industry, Bakelite ushered in a petro-polymer explosion in the early twentieth century. Suddenly, it was possible to create products of various sizes and shapes—high in durability, low in weight—and to do it on the cheap.

Like so many fossil fuel alternatives, bioplastics were sidelined until the oil crisis of the 1970s rekindled some interest. With the advent of green chemistry in the 1990s, alongside rising oil prices, commercial bioplastic production began in earnest. Today, a wide variety of bioplastics, with various recipes, properties, and applications, are in production or under development. Most are used in packaging of one kind or another, but they also are finding their way into everything from textiles to pharmaceuticals to electronics. Those that are "bio based" are derived, at least partially, from biomass. However, bio-based plastics may or may not be biodegradable. Polyethylene (PE) shopping bags made from sugarcane or corn are not. But bioplastics such as



The first and only bioplastic car was unveiled by Henry Ford in 1941 in Dearborn, Michigan. The car was inspired by the growing shortage of metal due to the war, as well as by the idea of combining industry with agriculture. He already had established the Soybean Laboratory in Greenfield Village at the time, and had made the fuel for the car from hemp oil. The frame was tubular steel, the body was plastic, the windows were acrylic, and it was powered by a conventional 60-horsepower engine. The finished car weighed 1,000 pounds less than its conventional, all-steel counterpart. Though it was created in part to aid the war effort, most car manufacturing ceased for the duration of the war and the bioplastic car was never revived.

RANKING AND RESULTS BY 2050

#47

4.3 GIGATONS REDUCED CO2	$19.2 BILLION FIRST COST	DATA TOO INDEFINITE TO BE MODELED

polylactic acid (PLA), like you might find in a disposable cup, and polyhydroxyalkanoates (PHA), which can be used for sutures, are both bio based *and* biodegradable under the right conditions. (PLA degrades only at high temperatures, not in the ocean or home compost bins.) Research on bioplastics continues to push the bounds of their feedstocks, formulations, and applications. Finding the right sustainable feedstock and avoiding petrochemical-intensive agriculture is essential.

In contrast to petro-plastics, bioplastics can reduce emissions and sequester carbon. This is especially true when feedstocks draw on waste biomass, like what is left over from pulp and paper or biofuel production. To maximize climate benefits, bioplastics' entire lifecycle should be considered—from growing feedstock to end-of-life disposal. Beyond decreasing greenhouse gases, bioplastics offer other benefits petro-plastics do not. Some have technical advantages, such as thermal properties ideal for 3-D printing. Those that are biodegradable at low temperatures may help address the world's plastic trash crisis, particularly in rivers and seas. Currently, a third of all plastics end up in ecosystems, while just 5 percent are successfully recycled. The rest are landfilled or burned. If current trends continue, plastic will outweigh fish in the world's oceans by 2050.

Perhaps the biggest problem facing bioplastics is that they are not conventional plastic. Bioplastics cannot be composted unless separated from other plastics, and few will compost in the garden bin. They require high heat to be broken down or special chemical recycling. If bioplastics are intermixed with conventional plastics, conventional recycled plastic is contaminated, rendering it unstable, brittle, and unusable. Without source separation and appropriate processing, bioplastic is all dressed up with nowhere to go in most municipal waste streams except into the dump.

And yet, a swift transition is possible: DuPont, Cargill, Dow, Mitsui, and BASF are investing in bio-based polymers because they believe they have a strong platform for expansion. Because bioplastics are a replacement technology—something that can be swapped in for existing materials—they benefit from the demand for plastic worldwide. At the same time, the biggest challenge for bioplastics to overcome is the fossil fuel–based plastics industry. When oil prices are low and because economies of scale are often lacking, bioplastics struggle to compete beyond niche markets. Petro-plastics also have the benefit of pipelines and tankers for more centralized production. To realize advantages, the distance between feedstock production and bioplastic manufacturing has to be proximate. Bio-preferred programs and targeted plastic bans can also support the growth of biopolymers and the evolution of the plastic industry.

IMPACT: *We estimate the total production of plastics to grow from 311 million tons in 2014 to at least 792 million tons by 2050. This is conservative, with other sources estimating over 1 billion tons if trends continue. We model the aggressive growth of bioplastics to capture 49 percent of the market by 2050, avoiding 4.3 gigatons of emissions. While technical potential is even higher, this solution is constrained by limited biomass feedstock available without additional land conversion. The cost to produce bioplastics in this scenario is $19 billion over thirty years. While the financial costs are currently higher for producers, they are dropping quickly.*