# The Future of Sustainable Plastics

## A Global Energy Transition Series Report


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**SUMMARY REPORT**

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# About the Authors

**Dr. Nicola De Blasio** is a Senior Fellow leading Belfer Center research on energy technology innovation and the transition to a low-carbon economy. With more than 25 years of global experience in the energy sector, Dr. De Blasio is an expert in navigating the challenges of strategic development and technology innovation toward sustainable commercial success, at scale. This coupled with his insight on the impact of an institution's development and innovation activities on other facets of business strategy, such as environmental, social, operational, geopolitical, and governmental factors. Dr. De Blasio serves as an independent board member and adviser to various companies, start-ups, and non-profit organizations. He has worked across business, academia, government, and civil society to develop and implement new business opportunities and establish connections that support research, educational and convening opportunities. He spent 18 years at Eni, one of the world's leading energy companies, most recently as Vice President and Head of R&D International Development, where he was also responsible for the start-up group. He engineered the strategic alliances between Eni and the Massachusetts Institute of Technology – which also led to the creation of the Eni-MIT Solar Frontiers Center in 2010 – Stanford, Tsinghua, and other word leading universities. He was a visiting scholar at MIT with the MIT Energy Initiative (MITEI), as well as a member of the MITEI Advisory Board, its Executive Committee (2005-2015), and the Eni Award Committee. He began his career with Snamprogetti (Eni's Group) as a process engineer before becoming an economic feasibility study specialist.

**Phoebe Fallon** is a Senior at Harvard University studying Environmental Science and Public Policy. She is particularly interested in system-wide sustainability initiatives in the energy and waste management sectors. She is currently researching plastic and its potential as a feedstock for hydrogen production. Fallon is the co-author of the white paper "Avoiding a Plastic Pandemic: The Future of Sustainability in a Post-COVID-19 World" (2021), and a contributing author to the G20 report on Hydrogen, "Mission Hydrogen: Accelerating the Transition to a Low Carbon Economy" (2021).

**Dr. Blake Bextine** joined the Defense Advanced Research Projects Agency (DARPA) as a program manager in March 2016 and has served twice as acting Deputy Director of the Biological Technologies Office. He is interested in novel approaches to addressing issues facing agricultural biotechnology and food security, including nucleic acid-based anti-pathogen/anti-pest strategies and insect and plant transformation strategies for rapid trait selection. Additionally, Bextine has focused on the climate-conscious approaches to infrastructure development and waste elimination utilizing cutting-edge synthetic biology platforms. Bextine came to DARPA from the University of Texas at Tyler where he was Professor of Biology and Assistant Vice President for Research and Technology Transfer. Before he arrived at UT Tyler, Bextine was a Postdoctoral Fellow in the Department of Entomology at the University of California, Riverside. He received his PhD from Oklahoma State University, MSc in Entomology from Texas Tech University, and BA in Biology from the University of Northern Iowa. Bextine is a recipient of the University of Texas System Regents' Outstanding Teaching Award and has also won the UT Tyler President's Scholarly Achievement Award, the White Fellowship for Teaching Excellence Award, and multiple UT Tyler Researcher of the Year Awards. He received the 2014 USDA Partnership Award along with other members of the Zebra Chip research group.

**Alessio Lorusso** is the founder and CEO of Roboze, which develops the extrusion of the most precise material 3D printing tech for the most performing super polymers in the world. Lorusso built his first 3D printer when he was only 17 years old, inventing the beltless technology a few years later. Roboze, which is headquartered in Italy and Texas (with +100 employees), designs and manufactures the most accurate 3D printing technology in the world for high-performance super polymers and composites. These materials can be used for metal replacement in extreme condition applications such as those found in the aerospace and defense, energy, chemical, transportation (railway, EV, autonomous driving), and medical devices sectors. Roboze currently serves some of the major industry leaders in the world including Ducati, Redbull F1, Ariane, Bosch, Leonardo, Airbus, Collins, GKN, Shell, Baker, Conoco, Aramco, and many others. Lorusso was named 2019 Entrepreneur of the Year by Ernst & Young and is part of the Forbes 30 Under 30 Class of 2018.

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**Figure 1:** Nicola De Blasio (top left), Blake Bextine (top right), Phoebe Fallon (bottom left), Alessio Lorusso (bottom right)

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# Introduction

By Nicola De Blasio and Phoebe Fallon

"Material invented in the early 20th century, which has enabled modern life as we know it, and whose sustainable production and disposal are one of the major challenges of our century." Crossword lovers will undoubtedly recognize this clue for a seven-letter word.

But when we think of plastic, what does spring to mind? Plastic has become so ubiquitous in our daily lives that we do not give it much thought. Yet it has molded society in many ways that make our lives easier and safer, from clothing to chewing gum, from tea bags to whitening toothpaste, and from toys to plastic bags or bottles. Up to five trillion single-use plastic bags are consumed every year, and one million plastic water bottles are sold each minute globally. However, the lack of end-of-life considerations and high recycling costs have turned plastic into the victim of its success by creating a global environmental crisis. Plastic is at the center of society's debate on sustainability, even more so due to the COVID-19 pandemic, which turned plastic into a much-needed ally. While the overall impacts of the pandemic are still difficult to quantify, ramifications are sure to be felt for decades to come.

Providing secure, reliable, and affordable resources for all without causing devastating environmental consequences is perhaps the greatest challenge of the 21st century. But the pandemic has significantly altered dynamics and changed priorities. How has this impacted the quest for sustainability? How can we leverage the advantages of plastic without contributing to the world's environmental crisis?

These questions pose significant challenges but also open an opportunity to address sustainability at a systemic level through circularity and the transition to low-carbon alternatives to petroleum-based plastics. Today's plastic economy is highly fragmented. Not all plastics are equal, as they have different physical-chemical properties and lifespans. Furthermore, these differences are exacerbated by the lack of global standards and coordination across value chains, which has allowed the proliferation of different materials, labeling, collection schemes, sorting, and reprocessing systems, all hindering overall sustainability. Finally, innovation activities are also fragmented—the design of new materials is often disconnected from the development and deployment of after-use processes and infrastructure.

A new plastic paradigm is therefore needed. Achieving a long-term sustainable future for plastic will require integration along the entire value chain, from design to reuse, and the transition to a truly circular economy.  Requiring that a product's end-of-life is considered from the time it is developed and resources are reused instead of continuously added. In terms of innovation, this will also require an increased focus on composition in terms of smarter materials design to improve recyclability and the development of bio-based alternatives.

We discussed these challenges with two experts: Dr. Blake Bextine, Program Manager at the Defense Advanced Research Projects Agency (DARPA), and Alessio Lorusso, founder, and CEO of Roboze, a 3D printing company during "The Future of Sustainable Plastics" webinar, held at Harvard Kennedy School on April 28th, 2022 – as part of the Global Energy Transitions Talks series.

# Plastic Today

By Phoebe Fallon

The webinar began with a presentation of Dr. De Blasio and Fallon's report, *Avoiding a Plastic Pandemic: The Future of Sustainability in a Post COVID-19 World*. The report, published in January 2021, details the accumulation of plastic waste in the environment, the impact of COVID-19 on plastic use and disposal and recommendations for implementing a circular economy approach to the plastic value chain.

Since the inception of the plastic industry, more than 6.3 billion tons of plastic waste have been produced worldwide, the vast majority of which ends up in landfills. Plastic remains in the environment for hundreds of years, and even when degraded does not leave an ecosystem, but instead remains present as smaller pieces or particles. The structure of the plastic value chain is linear, which is one of the causes of the plastic waste crisis. The linear economy approach—also known as a take, make, waste value chain—is one in which raw materials are transformed into products that are then used until being thrown away as waste. This model creates value by manufacturing and selling as many products as possible at the cheapest cost possible and assumes that the planet's resources are infinite. As a result, it does not take into consideration any end-of-life issues.

To curb the amount of plastic discarded as waste every year, a new approach is needed. Achieving a long-term sustainable future for plastic will require integration along the entire value chain; from design to reuse, together with a transition to a circular economy. A circular economy is characterized by a value chain approach in which a product's end of life is taken into consideration from the moment it is developed, and resources are reused instead of being continuously added. In order to improve the plastic value chain and eventually transition into a circular economy for plastics, existing recycling processes need to be streamlined and improved.

Today's plastic economy is highly fragmented. To begin with, not all plastics are equal as they have different chemical and physical properties and lifespans. Furthermore, some are products by themselves (like water bottles) while others are parts of more complex products. For this reason, post-consumer plastic waste is usually very inhomogeneous and comprises a wide range of material, shape, color and size types requiring separation—a costly, time and energy-intensive process which often leads to lower quality materials. These differences are exacerbated by the lack of global standards and coordination across the value chain, which has allowed for the proliferation of different materials, labeling collection schemes, and sorting and reprocessing systems, all of which hinder overall sustainability. Furthermore, innovation activities are also segmented. The design of new materials is often disconnected from the development and deployment of after-use processes and infrastructure.

From an economic point of view, recycling is dictated by market demand, price, and regulatory considerations, and involves all stakeholders along the value chain. Consumers play a critical role since the way plastic products are used and disposed of has a significant impact on their quality and value post-use.

Due to the fragmented state of the plastic economy, the only widely adopted technology for the large-scale treatment of plastic solid waste today is mechanical recycling, also called chop-and-wash. In this process, plastics are sorted by material type, ground, washed, and then dried to produce recycled flakes. Due to the high temperatures used, progressive material deterioration becomes an issue. In general, the higher the temperature a polymer can withstand without losing its properties, the higher the quality it will have as a recycled material, but due to progressive deterioration plastics cannot be recycled infinitely. To mitigate this effect, the resulting plastic flakes are then usually blended with virgin plastic of the same type to produce materials with suitable properties for manufacturing. Recycling is dictated by market demand, price, and regulatory considerations, and these factors have prevented the wide-scale adoption of an alternative approach to chop-and-wash, which is chemical recycling.

Chemical recycling is a process encompassing various technologies and processes such as pyrolysis with a high tolerance to mixed and contaminated plastic waste streams. The goal of chemical recycling is to break the long polymer chains down into their original building blocks, or monomers, which can then be used as feedstocks for new plastics, fuels, waxes, or other valuable products. It yields materials of higher quality than those obtainable through simple mechanical recycling. However, this approach requires complex industrial processing equipment, and hence overall economics tend to be less favorable compared to the production of virgin plastic. As a result, this route is not yet deployed at an industrial scale globally. Both mechanical and chemical and recycling have drawbacks, and in some instances are not cost-effective when compared to the production of virgin plastic.

Incineration is sometimes also considered a recycling option since proponents claim that it allows for energy recovery in the form of heat. While the process might be convenient for the treatment of mixed waste because it avoids the need for sorting, it does not allow for recovery and reuse. Furthermore, since carbon is a major building block of plastic, simple incineration is a source of greenhouse gas emissions and potentially other hazardous substances. Incineration is therefore an example of a linear economy approach and not a recycling option for a sustainable plastic economy.

Thus far, the strategy to address the challenges associated with plastic production and use has been mainly based on the "three Rs" approach: Reduce, reuse, and recycle. And although any measure to curb the environmental impacts of plastic is a step in the right direction, a systematic change is needed. With this in mind, our recommendations for the plastic value chain are as follows.

- **Increase the recyclability of plastics.** This can be done by redesigning products to be easily recycled and reused. For example, instead of combining many types of plastic in one product which makes recycling more difficult and expensive, redesign productions so that manufactured goods are made of only one type of plastic. A classic example of this is a water bottle—instead of three types of plastic (bottle, cap, and label), it could be designed with one. Limit the number of specialized plastics and additives and introduce extended producer responsibility to create incentives for plastic products to be easily recyclable.

- **Enhance existing recycling systems.** Improve and harmonize existing collection and recycling systems and instate a better infrastructure to accommodate the proliferation of bioplastics. This can be done, for example, by increasing access to industrial composting plants. Mandate recycling targets and percentages of recycled materials and new products.

- **Decarbonize plastic production.** Switch to low carbon energy sources such as renewable energy or green hydrogen while substituting petroleum-based plastics with more sustainable materials such as bioplastics. In addition, continue to conduct life cycle analyses on new products to ensure their overall sustainability.

- **Develop new public-private partnerships.** Foster government support for research and development, either through investment mechanisms or private public partnerships. Align incentives, for example, by requiring producers to address the negative externalities of plastic waste, such as ocean cleanup. On a larger scale, develop global partnerships that combine technical and regulatory factors to harmonize value chains.

- **Demystify the plastic sector for consumers.** Ensure that local communities and the public at large have an appropriate appreciation for the critical role they play. Educate consumers on plastic life cycles and incentivize sustainable practices as the way that plastic products are used and disposed of has a significant impact on their value and quality post use.

To date, technological factors, economic considerations, but also consumers behavior have hindered the sustainable use of plastic and created a global environmental crisis. New geopolitical forces—such as the challenges of development and climate change—are reshaping the playing field and stakeholders around the world will need to decide their role in this transition. The transition to a sustainable future for plastic must encompass every aspect of the value chain; from production, to consumption, to disposal, and be based on a circular economy approach to ensure meaningful and overall positive effects.

# Sustainability and Sustenance: DARPA's Approach to Circularity

Revised Transcript of Blake Bextine

During his presentation, Dr. Bextine discussed the ReSource Project, which is a military logistic support program aiming to provide a versatile and durable system that converts single-use packaging along with other waste into critical materials such as lubricants, adhesives, fibers, potable water, and edible macronutrients.

The U.S. military produces a very large amount of refuse, much of which happens to be plastic. However, Dr. Bextine observed that in many instances, plastic pollution was addressed by collecting waste in one location, such as an ocean or beach, and depositing it in a different location. Solving half of the problem by removing plastic from the environment does not address the underlying issue of what to do with plastic waste, and this is the problem DARPA began to address.

There is a longstanding military problem, which is providing food and other critical materials to deployed soldiers on the front lines or in challenging locations to reach. Dr. Bextine's group aims to address this problem while also diminishing the military's contribution to the plastic waste crisis by "taking that burden and turning it into higher value products at the end of the logistical chain". Dr. Bextine identifies reduced logistics as a main contributor to climate change events.

"If we can lower the amount of plastic that's being used, reuse it in a more beneficial way, and then also reduce sort of the movement of materials around the globe, I think we can help in a lot of different ways," Bextine explained.

Deployed soldiers are provided with meals ready to eat (MRE), which come in a package that contains foods individually packaged in three plastics that are multilayered, meaning that it is difficult to break down. However, this packaging contains more caloric value than the food that is contained within it.

The ReSource program leverages the molecular biochemistry of plastic to strive for value in the form of food products and caloric intake. This requires the physical release of the chemical structures of plastic. “One of the beautiful things about plastic is that it’s made of these long-chained hydrocarbons that fold back on themselves and don’t allow water access” Bextine explained. This reduces catalytic, enzymatic, and biological activity—but if these structures are opened, there may be a molecular method to breaking polymers down.

Rather than reshape existing plastic into new materials, this program focuses on changes to plastic at the molecular level. The goal is to open polymer structures using enzymatic or catalytic activity to break polymers into small eight to fourteen-carbon chains. These carbon chains would be valuable once broken down for petroleum, oils, or lubricants, but are also potential building blocks for new products.

Dr. Bextine has focused on the process of building up products using synthetic biology. According to Dr. Bextine, some microbes can “take[the] eight to fourteen carbon structure, use that as an energy source, and then develop proteins, fats, and carbohydrates in different ways in cellular material” that could be harvested and recapture the original value of plastics.

There are many use cases to produce macronutrients from waste plastic. In addition to providing sustenance to armed forces, there are also applications in disaster relief. In locations where aircrafts can land but lack sufficient runway to takeoff, large quantities of aid materials are not able to be brought. In these instances, the technology behind the ReSource program could fit in a CONEX box and be delivered via drop from a large aircraft flying over a disaster zone. Once it was delivered, trash could be put in one end, and foodstuffs would come out as a result. For use by the military, there would be a smaller, portable model. This could be placed in the back of a truck and travel to suit the user’s needs.

The ReSource program is still considering a few health and safety concerns before this solution can be deployed at scale. Waste plastic can contain toxins that will need to be removed before the macronutrients are created, and the FDA will need to approve their final product. An additional—but perhaps even more important—concern is the taste of the food which is being produced. The deliverable of this product will need to be healthy and edible, two qualifications which are still being perfected.

**The Role of DARPA in Innovation Cycles:**

When tackling challenges, DARPA uses the following framework:

"What are you trying to do? Think about how it's done today and what are the limitations of how we're doing it. What's new about your approach? If you're successful, who's going to care? And then think about the procedural things. What are the risks? Where are you going to have failure points and how can you mitigate that? How much is it going to cost to do the work that you need to do? How long will it take?" Dr. Bextine explained.

DARPA's project management approach centers on transparency and accountability by using midterm and final exams as well as monthly check-ins for budget and fund use.

This approach is being leveraged on many active projects, which include alternative sources to rubber "developing some synthetic biology increase in rubber [and] latex production in natural plants that are North American and developing an industry that may alter our need for utilization of international rubber sources." A second project that was recently completed is called the Engineered Living Materials, or ELM program. The ELM program leverages mycelia, the vegetative structure of fungal growth which develops belowground to create insulation, plastic and foam alternatives—as well as fabric.

DARPA uses its framework to develop innovative solutions to modern problems while maintaining accountability and mindfulness.

To that end, DARPA recently funded work to take the current output product and collaborate with a 3D printing platform to create more dynamic food products. Rather than create gummy bear-consistency shapes, a 3D printer might print a structure such as "an apple that would have a skin" to enhance the experience of eating this product.

The current waste stream of the military is usually dealt with via incineration. While there have been some attempts at gasification using pyrolysis and similar approaches, these methods can be arduous and cost-ineffective. Dr. Bextine explained that the “current state of the art in the breakdown of plastic and turn it into new materials is also very large, energy-intensive” but that at ReSource, “we wanted to get away from that.”

The state-of-the-art methods of breaking down plastic to turn it into new materials is currently energy intensive. The ReSource program aims to avoid these pitfalls by salvaging valuable molecules from plastic waste and leveraging microbes rather than fossil fuels to recover energy out of the system to feed back into operation. The production of food from plastic waste is a two-pronged solution, simultaneously addressing the plastic waste crisis and potential food scarcity within the military and, on a larger scale, in disaster relief scenarios.

The ReSource program tackles challenging problems using the principles of circularity to turn plastic waste into a valuable asset.

# 3D Printing and the Future of Plastic: Spotlight on Roboze

Revised Transcript of Alessio Lorusso

Roboze wields incredibly precise 3D printers, but its business has expanded beyond the services it renders to alter the supply chains of its clients. Roboze provides its clients with 3D printers to print what they need when they it onsite rather than manufacture in bulk and transport it to their factory locations. Point-of-use, on-demand manufacturing, allows for local production and eliminates waste as well as emissions. As CEO Alessio Lorusso explains, "[We are] really helping companies in replacing traditional methods and in bringing back manufacturing back to the point of use, back to Europe and back to America".

At this juncture, Roboze employs more than 120 individuals between Italy and America. Roboze is based in the south of Italy and Houston, Texas. To date, Roboze has deployed more than 500 printers in 28 countries in the world, and their customers printed over 50,000 parts in the last two years.

Roboze is using its printers to create a series of micro-factories printing necessary parts quickly, when needed, and close to the point of use. There are currently over 25 of these micro factories in existence, and by the end of 2022 there will be an additional 20. Roboze aims to enhance the efficiency of manufacturing and thereby avoid waste material, carbon emissions related to shipping, and additional resource use associated with a fragmented supply chain. Lorusso outlined the business model behind microfactories as follows: "We will print parts when needed, where needed, and deliver parts close to the point of use."

"3D printing can be part of the solution to reduce the $CO_2$ emissions related to mass manufacturing and irresponsible use of resources. But 3D printing can also become part of the problem if we don't act today to avoid [it]." To avoid becoming another unsustainable company in the future, Roboze is leveraging green, innovative solutions in the near term to ensure that 3D printing remains a sustainable alternative to traditional manufacturing.

To this end, Roboze encourages financial sustainability coupled with environmentally sustainable decisions. In practice, this entails a business model wherein customers are incentivized to ship parts that have reached the end of their life cycle back to Roboze. Roboze will then recycle the parts and "provide materials back to clients at a fraction of the cost." This incentivizes circular material use, as well as on-demand production and manufacturing close to point of use. It solves the problem that Lorusso identifies as a slippery slope: "If we don't care today, we are going to be part of the problem tomorrow."

These sustainability methods leverage plastic and its recyclability as an alternative to metals which must be mined, refined, transported, manufactured into parts and transported again. While recycling plastic does decrease its carbon footprint, it nonetheless comes from petroleum. Looking to the future, Lorusso declared that "Roboze is committed to invest millions in a couple of years in creating biopolymers and biocomposites for high performance" to replace the petroleum-based polymers currently in use. Today, biopolymers are deployed in relatively simple use cases, such as disposable cutlery. But Lorusso believes that with invention and investment, biopolymers can replace petroleum-based plastic in industrial uses. This will decrease the creation of virgin plastic and reduce plastic waste.

Roboze is a prime example of a company leveraging innovative solutions and a circular business model to incentivize reducing, recycling and reusing plastic. Further, they have an eye towards future endeavors to reduce their reliance on plastic by using an alternative material. Sustainable business takes many forms, but conscious choices made financially feasible are a cornerstone of circularity.

# Q&A Session Transcript

After the speakers' presentations, the audience had the opportunity to ask questions, moderated by Dr. Nicola De Blasio. The revised transcript is included below.

**De Blasio: Dr. Bextine, can you please describe how the process of going from plastic waste to food works in a little more detail?**

**Bextine:** The way we approach DARPA projects is, I would say that we give guardrails. We have a concept that we want to execute on, and we realize that we have a lot of talented, smart, ingenious people out there that have good ideas. We go in with an idea of how we would like to do it. In my case, I really wanted something that would use synthetic biology through the entire process. That way, you have a way to really conserve energy and put yourself in a good position to be successful. But then as proposals come in, we make evaluations and determine different ways. And like I said at the end, we want to mitigate some of those risks, so you want to take multiple shots on goal, not to use too many cliches here.

What we've been really looking at is different approaches for breakdown. There are catalytic approaches that we have some of our researchers doing things that are activated by very low energy targeted heat approaches. We actually had an interesting outcome on one of them. The program's been up and running for about a year, and I have a colleague, Eric Van Gieson, who's running a program called PPB. He's rethinking personal protective equipment in sort of a new biology focused way, and as part of that they are producing some new materials that looking at it are going to produce new problems for us because these materials are going to be even more difficult to break down. And he gave a talk, and had somebody from the WHO that brought up the fact that during COVID we've been producing 42 million tons more plastic trash just from medical waste, and I think that was on a weekly basis. Whatever it was, it's way too much. And turned it to us and said, "Hey, can you start to break down your stuff?" And it turns out all the plastics we're working with are the medical waste plastics.

And so using that sort of physics based approach, I think we have a low energy good outcome approach that breaks some of those materials down. It also happens to decontaminate, which is a nice piece to it. But we have a lot of different ways. We've also been looking at microbes. So because now we're at a point where we've had dumps in place with plastic there for about 50 to 70 years, we've started to see evolution come up with approaches for breaking these materials down. We have opportunities to harvest microbes that break down the materials. We can also take the enzymes out of those microbes and utilize them. We have insects that have eaten some of these plastic materials, developed gut microbiomes. So we have some sort of microbiome consortium type concepts. So there's different ways to handle the problem.

On the buildup, as long as we can get down to sort of a center of the wheel sort of molecule, we can take that a lot of different directions for use. So we can start to use cellular outcomes from microbes or even higher organisms like fungi or insects potentially and make 3D printing material that Alessio can put into what he does.

**De Blasio: You mentioned that you go down to change the plastics' eight to fourteen carbon structure. You then feed these to the enzymes, so you don't use them directly to create food, correct?**

**Bextine:** No. There's a middle man in that which is the microbes. And we have individual microbes. We can do synthetic biology to make them more efficient in their use. We could also use directed evolution. So basically growing them over and over on a new source so that they learn to utilize it more efficiently. But essentially what we're doing is sort of tailoring a carbon source to a microbe or a microbial community, and then the utilization and harvesting of that carbon and the energy contained within those carbon bonds can be utilized for upcycling into other carbonic structures like other carbohydrates, fats, or protein structures if we have nitrogen available and things like that. Just using microbes to ultimately produce what you need.

**De Blasio: And then Alessio, could you add to that and explain how and if one could actually 3D print an apple that you could actually eat?**

**Lorusso:** Well, Nicola, not yet. No, I'm joking. Our 3D printers today work, of course, with our super polymers and composite materials, which of course comes from oil. This is not a problem today, but it will become a problem tomorrow if we don't act to let our technology be prepared to be sustainable, because of course 3D printing is more sustainable compared to massive production because we don't need to produce millions of parts and we don't need to store those parts for years in warehouses. 3D printing uses just the resources it needs to create the products, first of all.

And talking about metals, and especially CLC machine metal, of course we don't need to create waste of materials because we use just the material needed for the part. So 3D printing is more sustainable compared to mass production, manufacturing matters like CNC machining, injection molding and the other stuff. But the technology is becoming more and more adopted in the world. So a moment will arrive where 3D printing will become part of the problem if we don't create a supply chain behind the recycling of the printed parts and if we don't create today the right conditions for this technology to be adopted to become a real sustainable manufacture for the long-term.

So our goal today is to create a supply chain method and a business model which allows our customers to send back the parts at the end of the life cycle and to send back all the scraps, little scrap but still scrap, like super structures, and all other things involved in the 3D printing process. Because it's not true that 3D printing is a zero-waste process of manufacturing. That's not true. Even 3D printing creates some waste. So, we need to care about that.

Our model behind the recycling allows our customers to be sure that all the scraps and all the 3D printed parts at the end of the life cycle will be recycled into new materials. We want to incentivize them to care about this by offering the new recycled material to them, the circular economy material, at a fraction of the cost of the initial one. Of course, we all know that after recycling polymers lose some mechanical properties, but there are still an enormous amount of applications where thermal properties, chemical resistant properties are required, and you don't need that level of mechanical performance, even within the same customers. The goal is to democratize more and more the usage of high temperature and high performance technopolymers and incentivize the circular economy program we put in place. While we do this, we need to invest today to create the biopolymers and the biocomposites in two, three, four years from now. It's not easy. It's not easy, because super polymers and composite materials like carbon fibers, PEEK materials, et cetera are the result of years, decades of inventions around the world. So today we all need to be concentrated in developing the future generation of biopolymers and biocomposite polymers that come from nature, because I firmly believe that nature has all the answers. We just need people to replicate what nature did in the last thousands of years in a laboratory into industrial scale. This will require time and will require huge investment, but if we don't act today, we'll still be victims of oil for the next 50 years. We cannot do that. We need to invest today.

**De Blasio: How quick are these processes? Blake, how quickly can you break the plastic down and then feed it to the enzyme? And then we have a question for both of you about how you could combine both programs in the value chain, where you go in maybe not for a war but just for the fettuccine Alfredo and you start to break down all the plastic and you 3D print everything you need.**

**Bextine:** A big problem that we have in utilizing biology for most approaches ends up being the time that it takes, because biology when compared to chemical approaches like pyrolysis is going to be much slower. And then the other problem is always consistency and replication. Biotic organisms can be finicky, constrained by physics. So where you have temperature issues, things like that, humidity, pH, are are pieces of that that we have to get consider.

But the speed, largely on the front end of the system, of breaking down the plastic where we've used the catalytic based approaches with a small amount of energy, we're able to almost instantly break down the materials in a matter of minutes. And then on the biological part of the process it's much slower but we're looking at approaches to potentially increase that time either through genetic manipulation or the directed evolution approach. It's early stage research so we have ways to go, but what we're trying to do is sort of lower that bar of entry so that some of these other approaches can be de-risked a bit.

On the back end, looking at the growth of the microbes, one touch point that we have in thinking about the microbial system that we use for making biological cement that ultimately leads to a cement alternative, that usually grows on the order of four hours for large amounts of material. So we do have some ways that we can accelerate the production. And the goal in the program... And most of the time in a DARPA program when you put the broad agency announcement out, if people don't think you're a little crazy, then you're probably pitching at the wrong level of what you want to do. But we are really looking at having a continuous system that can in the smaller footprint device support 10 individuals over like 10 days, and so something that continually puts that in. Now, a lot of that's dependent on the amount of material that you have to put in on the front end.

In the larger format we're looking at something that could sustain a large group of people in the order of a hundred for a 30-day period of continual production. Those are hard metrics to hit, honestly. We're looking good, I think we'll get there, but we've got to set the bar high so that we can really push the researchers to do something incredible.

**De Blasio: Alessio, how fast can you 3D print?**

**Lorusso:** Well, I don't want to give numbers because without the world context they are not useful, but what I can say is that we can print in hours what today is produced after three, four weeks. This is because today, to produce some parts by sensor machine or by injection molding you need to put in place the entire process. You need to create the molds, you need to do the first, the second, the third, the fourth interaction, and at the end of those interactions probably you discover that the way you designed the part is not the best and you need to start again. So we do today in hours what, until yesterday, has been done in weeks.

But what we can do more and what we do more every day is to have hundreds of printers today in the world that can print simultaneously hundreds of parts. So in my opinion, 3D printing will never be as fast as traditional manufacturing because the concept behind 3D printing was different from the beginning. So if we pursue the goal of realizing the 3D printing technology capable of printing or producing and they have the same productivity of an injection molding, that's not the right direction in my opinion. 3D printing must ensure us the same level of performance, reputability, and consistency of traditional manufacturing methods, and in my opinion, the business model needs to ensure us the scalability of the production. In our business model we have hundreds of microfactories in the world that we can control, and with one click 50 machines start to produce the same parts in different locations in the world. In my opinion, the business model is the real key to scale the productivity of the technology. The technology must be reliable, must be consistent, must create reputable result and performing parts while the business model should create the right scalability.

**De Blasio: Could each of you say a few words about the cost of the processes that you're suggesting?**

**Bextine:** The ReSource project is still in its super early stage so there is currently no cost other than the research funding that we're providing.

**Lorusso:** It's still expensive in my opinion. And we really need to be careful about this. 3D printing is not cheaper. Probably it's not more expensive than traditional manufacturing methods, if of course we compare apples with apples. So if we talk about the same parts numbers, it's not more expensive but it's still expensive. The way to create a more affordable technology and to democratize the technology more and more, in my opinion, is the sustainability. I firmly believe that sustainability is the key to democratize the technology, because in our business model, the more parts are printed by our 3D printers by our customers, the more recycling we can do and the more materials we can offer to our customers at  cheaper price.

This, in my opinion, is the key to democratizing the technology, because all base polymers are expensive, because there are expensive processes to create them. PEEK material is one of the most expensive polymers in the world, but it's one of the best performing polymers in the world. So, we need to find a balance. We need to democratize the use of these super polymers while exercising care about the recycling of those super polymers and create a mechanism where we can offer these materials as circular materials to the same customers, and to other customers, to new customers in order to democratize more and more the technology.

And at the same time we need to develop high performance biopolymers which replicate the same mechanical performance, thermal and chemical performance, maybe one day of these all base polymers. It's not easy. It's not easy, of course. But in my opinion, today, we start to have the right tools and there is a huge commitment today even from customers in adopting these super polymers. They are more open mind today than ever before. So this is the perfect moment to invest massive resources in this because I firmly believe that biopolymers and biocomposite will be the future, will be way more cheaper than all base polymers.

**Fallon: Nicola, could you also speak to maybe the relative costs of mechanical versus chemical recycling to the best of your knowledge?**

**De Blasio:** Well, in a way it's an easy answer. The fact that chemical recycling is not being done today shows that it's definitely more expensive, but it also relates to the fact that if you compare virgin plastic to recycled plastic, sometimes the virgin plastic is still cheaper, especially when all prices are low. But I think to the point that Blake and Alessio made, it's important to keep in mind that we do this cost analyses without considering a lot of the externalities that we don't factor into fossil fuel use. So it's like comparing apple with pears sometimes.

**Bextine:** I was also going to mention... One of the questions that came up was about breaking some of these molecules down. Currently pyrolysis breaks us down into the single carbon or ethanol space and so what you end up with is a large energetic cost there. And if you sort of use the logic that we're approaching ReSource with, you have to develop those molecules back up two carbons at a time, and every time you reassemble, you utilize energy. So in the pyrolysis example, you're using a lot of energy and then building something up is going to utilize more energy. And so our approach was really to break things down into, I guess what in the business world would be like the minimal viable product that we could get out of that breakdown process and try to conserve as much energy as possible.

I think to Nicola's point, some of these alternative approaches haven't scaled yet because we don't know sort of where the bounds are. And so with projects like ReSource, we're looking into that and looking at the risks that come from it and seeing where they go. When I think about some of these technologies and how they're going to scale, DARPA, the agency that I work for, has always been very thoughtful about how do you produce something, that's one thing, how do we make the impossible possible? And then on the other side of it, at what point do you start getting it into the market so that it can be useful.

Concrete is a good example where traditional methods of concrete are known throughout the world. We've been doing it for a long time. I think the Romans made some pretty good concrete back a few generations ago and it still stands. So it's a well-known, well-tried, very true process. So when you come in with something new, and in this case, I guess that we're on the right side of the carbon equation, people want to be on that but they don't want to spend 50 times, a 100 times the cost to do something on a large project.

So what we have to do is try to push towards scale, where the scale of our biological approaches or our alternative approaches, like Alessio was talking about, can actually meet the market demand while also being cost effective. And then, I think, if you're within the same order of magnitude, then people would want to use the more bio-friendly approach. But for all of these types of things, we have to get there, we have to get it to scale, and that takes a lot of work and a lot of time. So whatever we can do to push that will make the world a whole lot better place.

**De Blasio: Alessio, what is the optimal batch size for 3D printing per unit cost?**

**Lorusso:** Very, very, very nice question, and the answer is, it depends. It can be 100, can be 1,000, can be 10,000. The real question is, when do you need these parts? Do you need them Monday morning at 8:00 AM or you do you need them on a monthly basis. The real thing is how many parts do I need in this specific moment, because you can have the need to have probably 10,000 parts per year but you don't need the 10,000 parts Monday morning at 8:00 AM, you need 1,000 parts per month.

So the real question is, how can I produce these parts in a smarter way? How can I produce my parts on monthly basis instead of producing all these parts in just one shot with traditional manufacturing methods and wait one year to use my parts? This is the real question. The timing is the most important thing, because if you need parts and you need these parts split in a year, the most sensible thing could be probably, even if the number seems to be high, produce this part with 3D printing so you can produce just in time on monthly basis avoiding warehousing costs, production costs set up costs and all the things involved.

**De Blasio: Blake, have you tried the food coming out of the ReSource process?**

**Bextine:** Technically, on a presentation to the public, no, because it hasn't been through FDA approval, so no. What we do is we break that plastic material down into those smaller carbons. That's sort of a slurry of DCAs that are the middle part of that process. And then what we ultimately do is grow that into what looks like a granola bar that is made of cellular material. But this is just one approach.

We also have been able to take the cellular material at the end and we can actually separate out parts of that so we can pull oils out specifically. So we've been looking at lubrication needs, machines, and things like that as one of our endpoints. We even have some pretty cool ways that we can get the microbes to excrete that fatty acid material and we can collect that. And if we use molecular biology, we can tailor that to specific chain lengths in fatty acids so you get different capabilities there. We haven't used any of it in practice officially. It smells good, I can tell you that.

If you think about yogurt production that's made by a microbe, that's sort of the end product that we can hope for. I don't know how old everybody there is but it's also how beer is made, so we might be able to make some additional products out of the system.

# About DARPA

For sixty years, DARPA has held to a singular and enduring mission: to make pivotal investments in breakthrough technologies for national security.

The genesis of that mission and of DARPA itself dates to the launch of Sputnik in 1957, and a commitment by the United States that, from that time forward, it would be the initiator and not the victim of strategic technological surprises. Working with innovators inside and outside of government, DARPA has repeatedly delivered on that mission, transforming revolutionary concepts, and even seeming impossibilities into practical capabilities. The ultimate results have included not only game-changing military capabilities such as precision weapons and stealth technology, but also icons of modern civilian society such as the Internet, automated voice recognition and language translation, and Global Positioning System receivers small enough to embed in myriad consumer devices.

DARPA explicitly reaches for transformational change instead of incremental advances. But it does not perform its engineering alchemy in isolation. It works within an innovation ecosystem that includes academic, corporate, and governmental partners, with a constant focus on the Nation's military Services, which work with DARPA to create new strategic opportunities and novel tactical options. For decades, this vibrant, interlocking ecosystem of diverse collaborators has proven to be a nurturing environment for the intense creativity that DARPA is designed to cultivate.

DARPA comprises approximately 220 government employees in six technical offices, including nearly 100 program managers, who together oversee about 250 research and development programs.

DARPA goes to great lengths to identify, recruit, and support excellent program managers—extraordinary individuals who are at the top of their fields and are hungry for the opportunity to push the limits of their disciplines. These leaders, who are at the very heart of DARPA's history of success, come from academia, industry, and government agencies for limited stints, generally three to five years. That deadline fuels the signature DARPA urgency to achieve success in less time than might be considered reasonable in a conventional setting.

Program managers address challenges broadly, spanning the spectrum from deep science to systems to capabilities, but ultimately, they are driven by the desire to make a difference. They define their programs, set milestones, meet with their performers, and assiduously track progress. But they are also constantly probing for the next big thing in their fields, communicating with leaders in the scientific and engineering community to identify new challenges and potential solutions.

Program managers report to DARPA's office directors and their deputies, who are responsible for charting their offices' technical directions, hiring program managers, and overseeing program execution. The technical staff is also supported by experts in security, legal and contracting issues, finance, human resources, and communications. These are the people who make it possible for program managers to achieve big things during their relatively short tenures.

At the Agency level, the DARPA Director and Deputy Director approve each new program and review ongoing programs, while setting Agency-wide priorities and ensuring a balanced investment portfolio.

DARPA benefits greatly from special statutory hiring authorities and alternative contracting vehicles that allow the Agency to take quick advantage of opportunities to advance its mission. These legislated capabilities have helped DARPA continue to execute its mission effectively.

# About Roboze

Roboze designs and manufactures the world's most accurate 3D printers for producing parts with super polymers and composite materials to replace metals in industries with extreme working conditions.

The main goal is to shape a new paradigm in digital manufacturing: Roboze Distributed Manufacturing that connects demand with supply, creating a distributed production model, which allows producing avoiding waste, reducing shipments and CO2 emissions, and bringing production back to the point of use.

Roboze is replacing metal parts, helping companies to cut costs, time, and emissions. Roboze produces parts using super polymers and composites through its patented 3D printing technology leveraging a customer-centric business model utilizing subscription and manufacturing as a service marketplace.

The Roboze ecosystem is re-shaping the manufacturing industry and revolutionizing the world of 3D printing with the most precise technology for the highest performing super materials, producing parts, on-demand, just-in-time, and locally through its distributed manufacturing network that allows companies to reduce costs and time by shortening the steps in their supply chain and digitalizing their inventory.

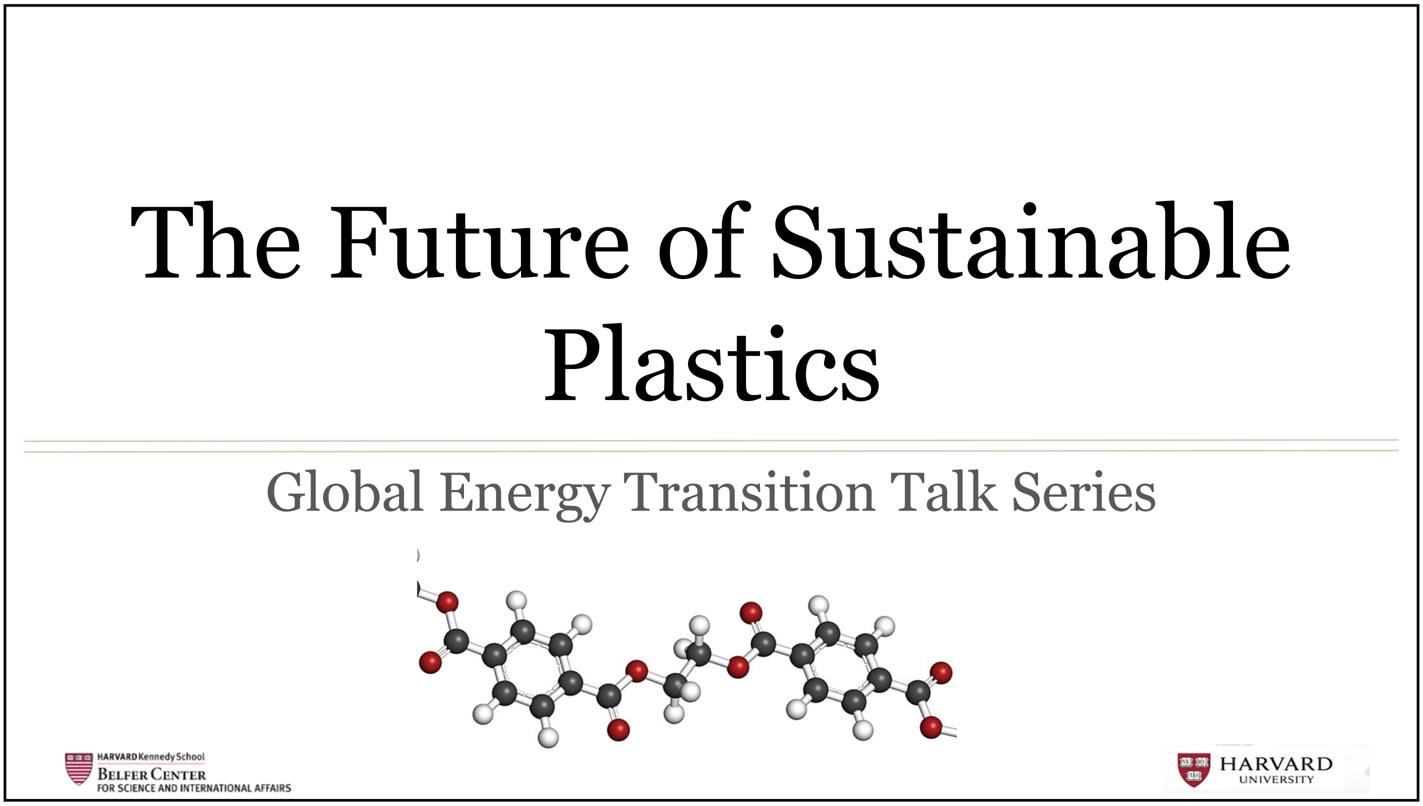
Roboze has already demonstrated in the past its attention and commitment to the research and development of solutions that can reduce the environmental impact of manufacturing, but without sacrificing performance—starting with overturning the delocalized production model by proposing a new production paradigm, Roboze Distributed Manufacturing. In this method, specialized 3D printing centers with Roboze systems, distributed all over the world, produce parts wherever and whenever needed, reducing transport and waste, up to programs of Circular Economy for the recovery of processing waste and disused parts to be reintroduced on the market for the benefit of end users and above all the environment.

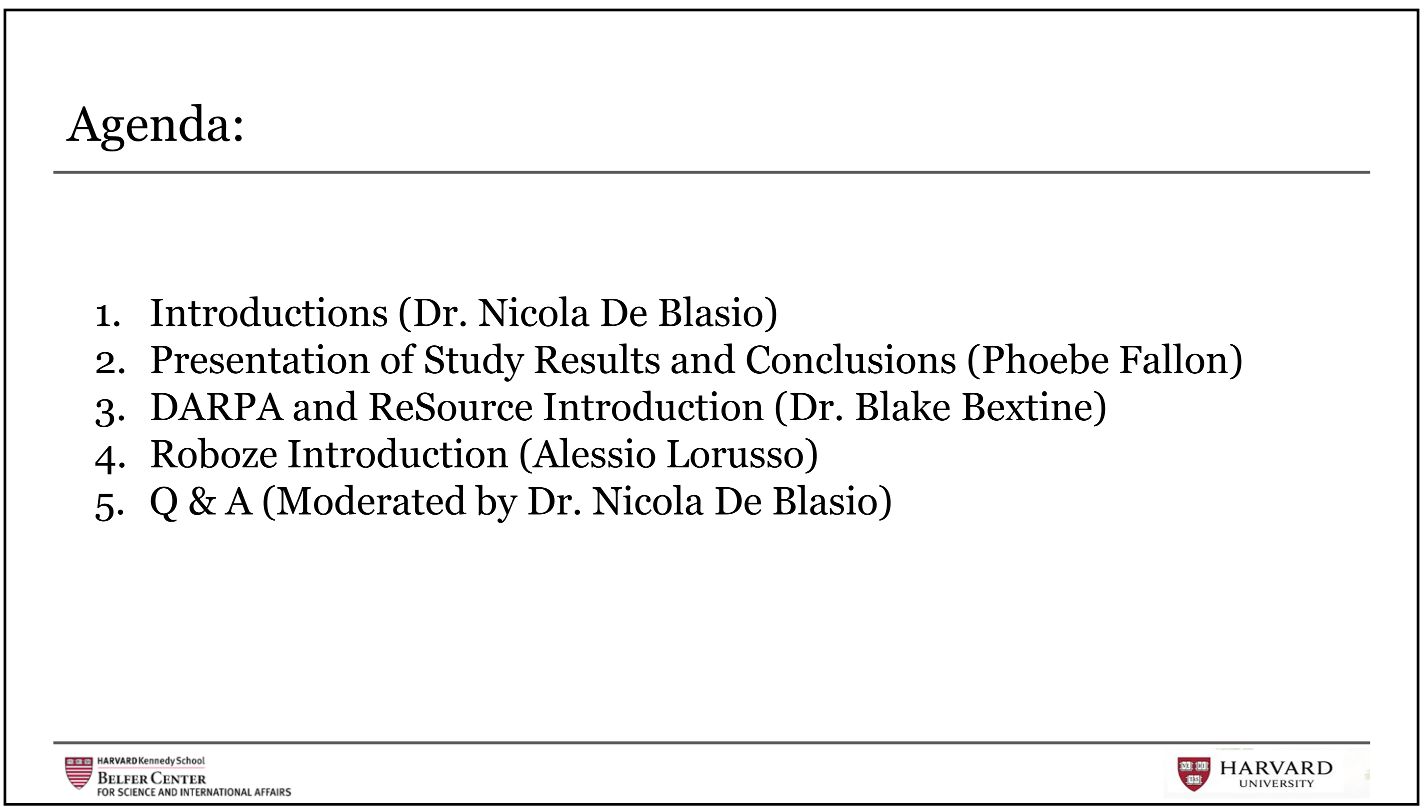
Today Roboze strengthens its commitment and invests in a facility that will host new materials science, chemistry, and nanotechnology laboratories. The goal is to rapidly advance in the development of alternative materials to petroleum-based superpolymers by favoring the use of bio-based reinforcing matrices and fibers. The challenge lies in finding new materials and technologies that can, on the one hand, reduce the generation of carbon dioxide (responsible for the greenhouse effect), and on the other hand, achieve the properties of the super polymers available today in the replacement of metal parts.

The first result is Roboze Bio-based PA, polyamide for high-performance 3D printing composed of a matrix reinforced with natural bio-based fibers. With the same specification and performance, but with 60% lower CO2 emissions than a carbon fiber-reinforced petroleum-based PA, this new PA will enable manufacturing companies to move closer to their sustainability goals and contribute to a better future for the planet.

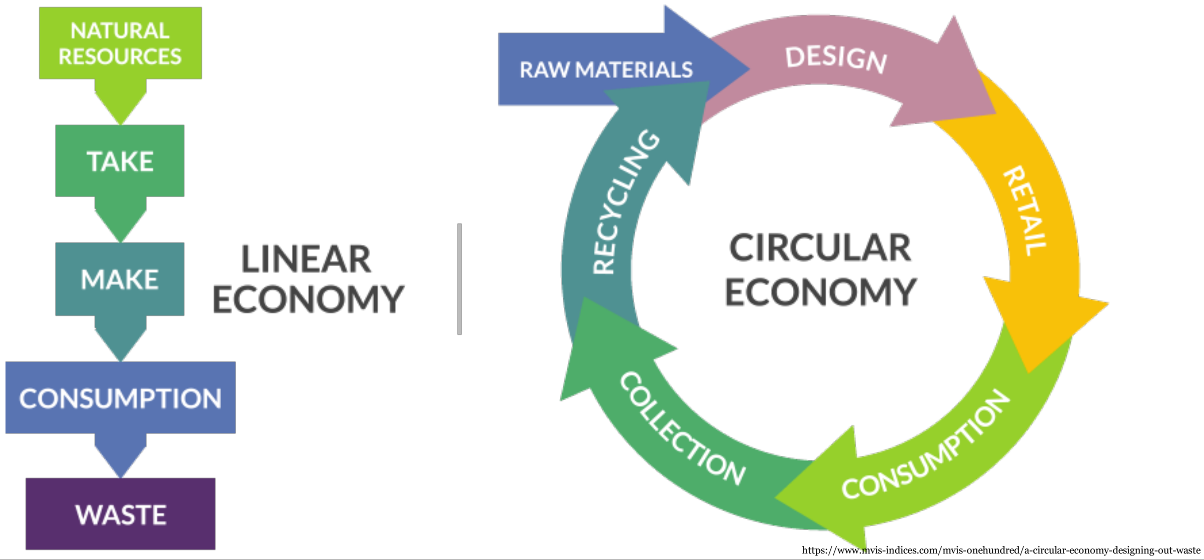
Roboze solutions have been already chosen by global leaders like GE Global Research, Airbus, Ducati Corse, Dallara Automobili, Bosch, and many others. Today Roboze is an Italo-American reality with Headquarters in EMEA and USA and more than 120 employees.

# Appendix 1: Fallon's Slide Deck



# Circular economies present a valuable opportunity to decrease waste and increase product sustainability



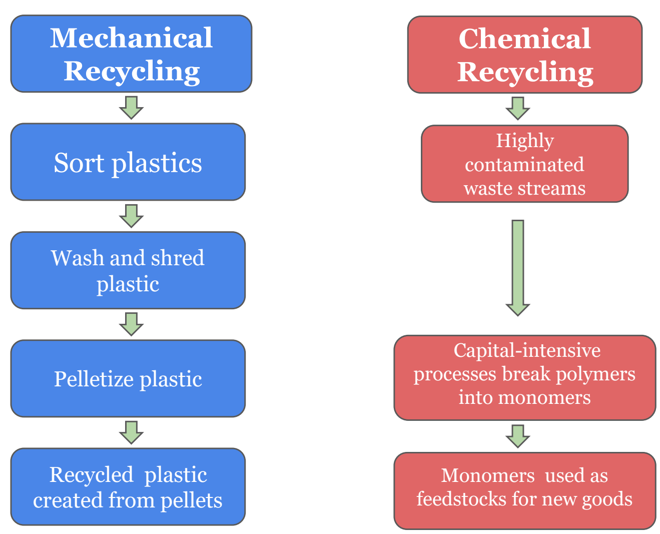

https://www.mvis-indices.com/mvis-onehundred/a-circular-economy-designing-out-waste

HARVARD Kennedy School BELFER CENTER FOR SCIENCE AND INTERNATIONAL AFFAIRS

HARVARD UNIVERSITY

# Plastic value chains are fragmented, and recycling processes inefficient and expensive

- ❖ Labelling, collection, sorting and reprocessing vary based on location
- ❖ Post-consumer plastic waste is inhomogeneous
- ❖ Mechanical recycling is widely used, but leads to progressive material degradation
- ❖ Alternative recycling methods are capital-intensive, preventing widespread adoption
- ❖ Recycling is market-driven, and price of recycling is often higher than virgin materials

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## Recommendations

- **Increase recyclability of plastics: Redesign** products to be easily recycled and reused. **Limit** the number of specialized plastics and of additives. Introduce **extended producer responsibility** to create incentives for plastic products to be more easily recyclable.
- **Enhance recycling**. Improve existing collection and recycling systems. Build infrastructure tailored to recycling bioplastic. **Mandate recycling targets** and percentages of recycled materials in new products. **Incentivize recycling** for consumers.
- **Decarbonize production.** Switch to **low carbon energy sources**, while substituting petroleum-based plastics with more sustainable materials. **Conduct life cycle analyses** on new products to ensure their overall sustainability. Build demand for bioplastic through policies, like renewable plastic standards, starting from high value products.

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## Recommendations

- **Development of new public private partnerships.** Foster government support for **research and development**—both through investment vehicles and private public partnerships. **Align incentives**, for example by requiring producers to address the negative externalities of plastic waste, such as ocean clean-up. **Develop global partnerships** that combine technical and regulatory factors to harmonize value chains.
- **Demystify the plastic sector** and ensure that local communities and the public at large have appropriate appreciation for the critical role they play. **Educate consumers** on plastic lifecycle and **incentivize sustainable practices**, as the way plastic products are used and disposed of has a significant impact on their value and quality post-use.

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# Appendix 2: Bextine's Slide Deck

## Leveraging biology for national security

Blake Bextine, PhD
Program Manager
Biological Technologies Office
Defense Advanced Research Projects Agency

The Future of Sustainable Plastics
Harvard Kennedy School, Belfer Center for Science and International Affairs

28 April, 2022

DARPA

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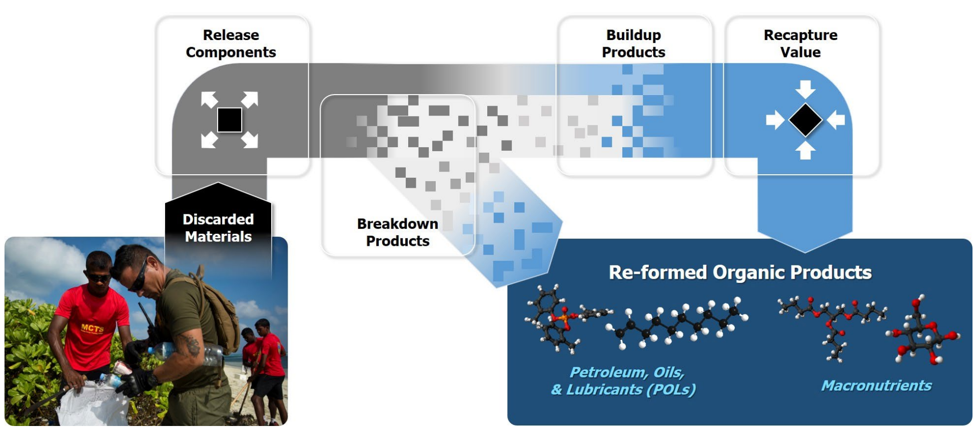
## Burden to Benefit

ReSource

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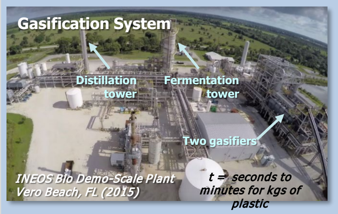
## Limitations of Logistical Support and Waste Elimination

### Current Practice

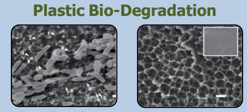
- Logistic support has a large **human cost** in contested environments
  - Established bases have food delivered and prepared onsite (i.e., "catered war")
  - Each supply run puts warfighters at risk
- Much waste is **simply burned**, without even an attempt at energy recapture

### State-of-the-Art

- **No ability** to produce valuable materials when & where needed
- Waste elimination is **difficult and hazardous**
  - Incinerators (<100 in the US) eliminate waste and produce electricity
  - Gasification facilities (~300 globally) convert single-stream solid waste to "synthesis gas" (CO, $H_2$)
- **Some ability** to bio-degrade common plastics back into precursors




Plastic Bio-Degradation



*Ideonella sakaiensis* PET attachment | *Ideonella sakaiensis* pitting of PET

*t = months to years for kgs of plastic*

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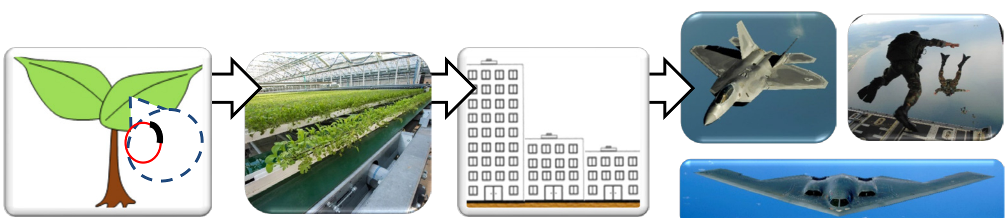
3

## STTR: Reliable alternative natural rubber products




**Envisioned Alternative Natural Rubber PIPELINE**

### Approach

- Implement molecular circuits for enhanced rubber biosynthesis
- Utilize modern cultivation techniques of alternative rubber plants
- Improve the amount and quality of alternative natural rubber during collection
- Identify and address issues associated with alternative natural rubber extraction and/or processing

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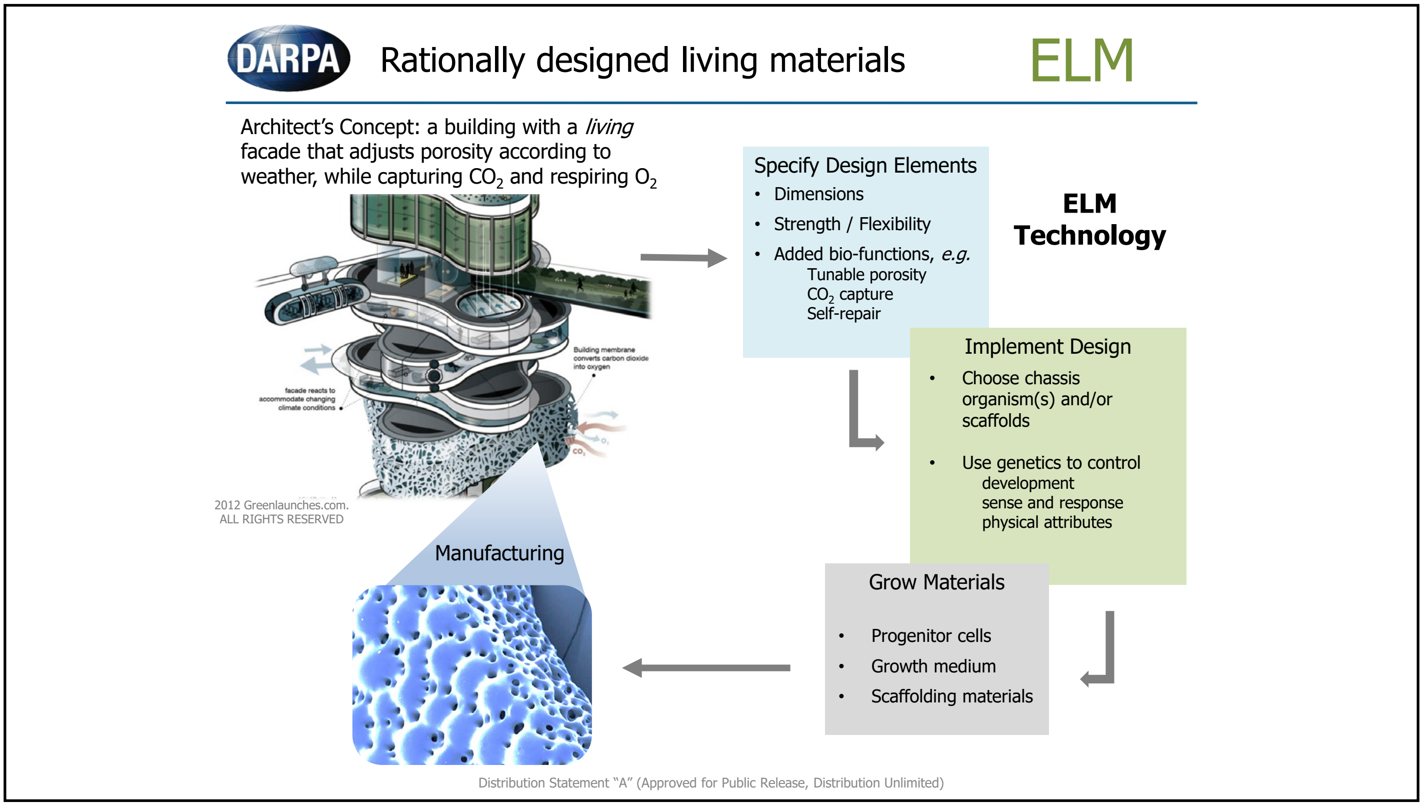
4


DARPA
Rationally designed living materials
ELM
Architect's Concept: a building with a *living* facade that adjusts porosity according to weather, while capturing $CO_2$ and respiring $O_2$
Building membrane converts carbon dioxide into oxygen
facade reacts to accommodate changing climate conditions
2012 Greenlaunches.com. ALL RIGHTS RESERVED
Manufacturing
Specify Design Elements
• Dimensions
• Strength / Flexibility
• Added bio-functions, *e.g.*
Tunable porosity
$CO_2$ capture
Self-repair
ELM Technology
Implement Design
• Choose chassis organism(s) and/or scaffolds
• Use genetics to control
development
sense and response
physical attributes
Grow Materials
• Progenitor cells
• Growth medium
• Scaffolding materials
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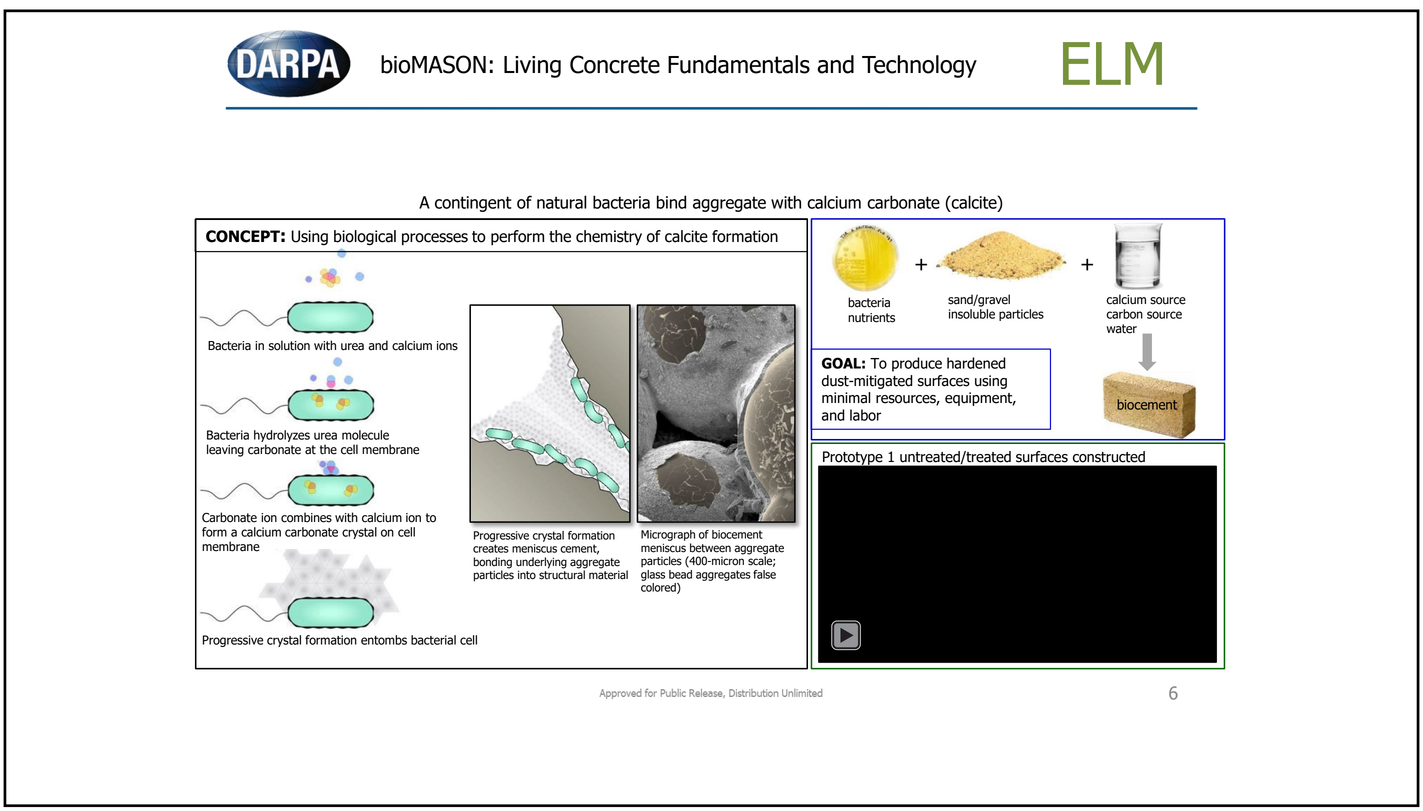
DARPA
bioMASON: Living Concrete Fundamentals and Technology
ELM
A contingent of natural bacteria bind aggregate with calcium carbonate (calcite)
**CONCEPT:** Using biological processes to perform the chemistry of calcite formation
Bacteria in solution with urea and calcium ions
Bacteria hydrolyzes urea molecule leaving carbonate at the cell membrane
Carbonate ion combines with calcium ion to form a calcium carbonate crystal on cell membrane
Progressive crystal formation entombs bacterial cell
Progressive crystal formation creates meniscus cement, bonding underlying aggregate particles into structural material
Micrograph of biocement meniscus between aggregate particles (400-micron scale; glass bead aggregates false colored)
bacteria nutrients
+
sand/gravel insoluble particles
+
calcium source carbon source water
biocement
**GOAL:** To produce hardened dust-mitigated surfaces using minimal resources, equipment, and labor
Prototype 1 untreated/treated surfaces constructed
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6

DARPA

ELM

## bioMASON Prototype 3 Deployment – Yuma, AZ

130′ x 130′ control and treated surfaces 48-hours post-install


Approved for Public Release, Distribution Unlimited

7

DARPA

## DARPA's mission

Breakthrough Technologies for National Security

**Precision Guidance & Navigation**

**Communications/Networking**

**IR Night Vision**

**Stealth**

**Radar Arrays**

**UAVs**

| 1960s | 1970s | 1980s | 1990s | 2000s | 2010s |
|---|---|---|---|---|---|

**Microelectronics**: VLSI, CAD, manufacturing, IR, RF, MEMS

**ARPAnet/Internet**

**Information Technology**: timesharing, client/server, graphics, GUI, RISC, speech recognition

**Materials Science**: semiconductors, superalloys, carbon fibers, composites, thermoelectrics, ceramics

New capabilities require a healthy ecosystem across Service S&T, universities, and industry

DARPA's role: pivotal early investments that change what's possible

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## The Heilmeier Catechism

DARPA operates on the principle that generating big rewards requires taking big risks. But how does the Agency determine what risks are worth taking?

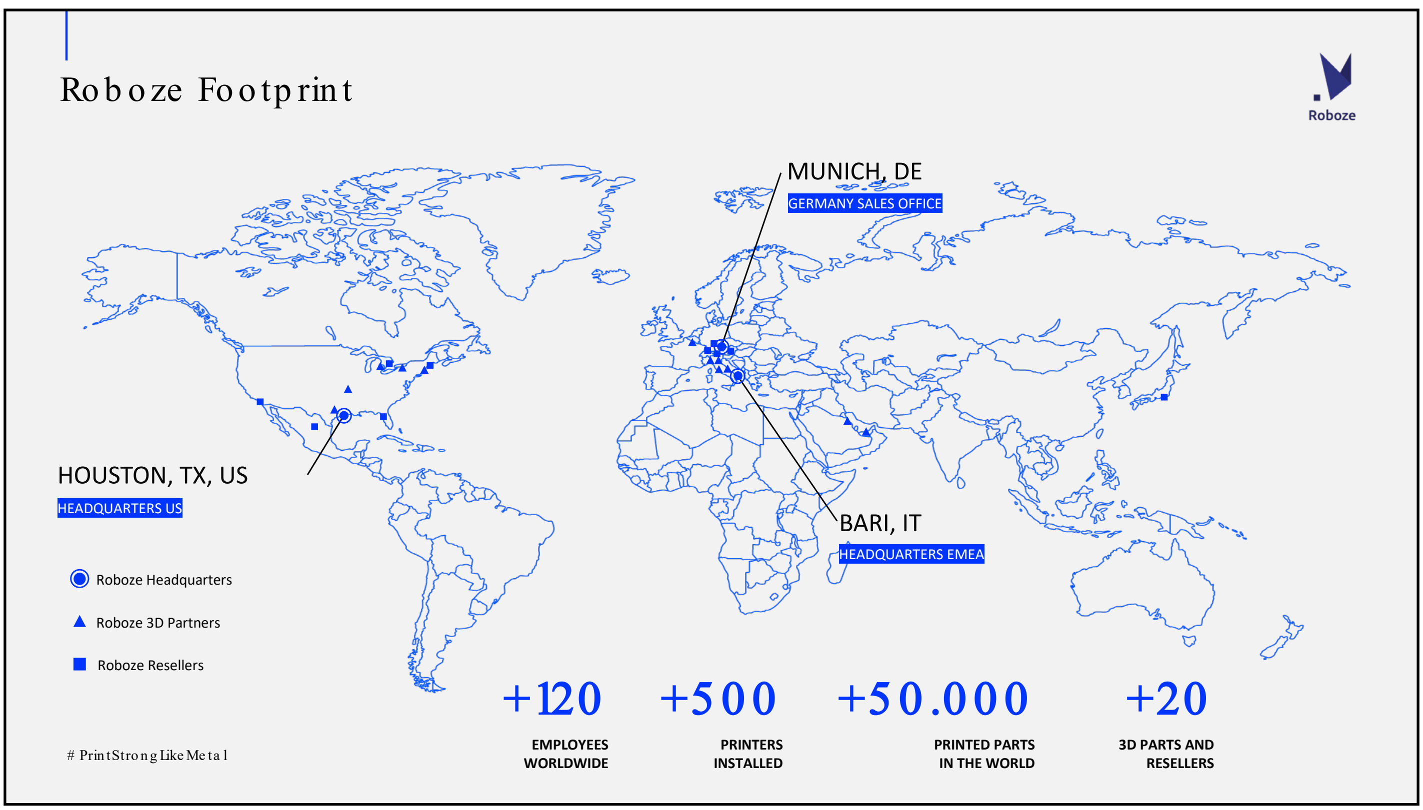
George H. Heilmeier, a former DARPA director (1975-1977), crafted a set of questions known as the "Heilmeier Catechism" to help Agency officials think through and evaluate proposed research programs.

1. What are you trying to do?
2. How is it done today, and what are the limits of current practice?
3. What is new in your approach and why do you think it will be successful?
4. Who cares? If you are successful, what difference will it make?
5. What are the risks?
6. How much will it cost?
7. How long will it take?
8. What are the mid-term and final “exams” to check for success?



www.darpa.mil

# Appendix 3: Lorusso's Slide Deck

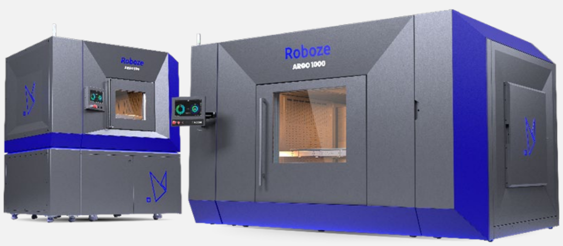
The most precise 3D printers for the most performing super materials

## Roboze Business Vision

Roboze

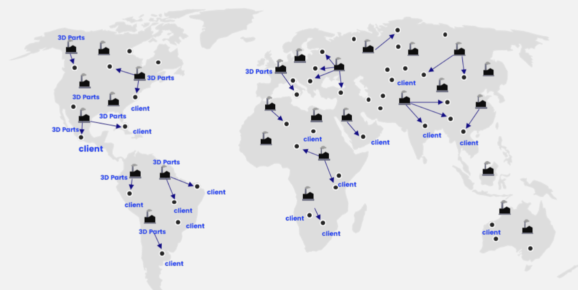
**Roboze 3D Printers**

Industrialize production



**Roboze 3D Parts**

Receive parts on demand



# PrintStrongLikeMetal

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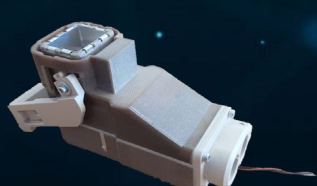
LOCCIONI

### ELECTRICAL MOBILITY

Bosch uses several Roboze 3DPrinters to print a variety of parts, including complex HV (High Voltage) connectors for electric vehicles

>70% costs saving

20,000 coupling and uncoupling cycles per year



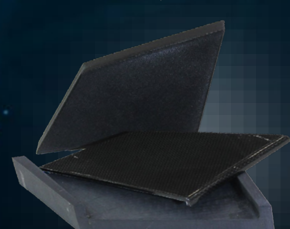
LEONARDO

### AVIATION

Leonardo Aerostructures, leading Italian aerospace company, uses Roboze technology to print metal replacement moulds for carbon fiber hand lay up process.

60% weight reduction

>60% costs saving



DUCATI CORSE

### MOTOR SPORT

Ducati Corse uses several Roboze 3DPrinters and super polymers to print durable and strong end use parts on track

97% reduction of time from design to validated functional part

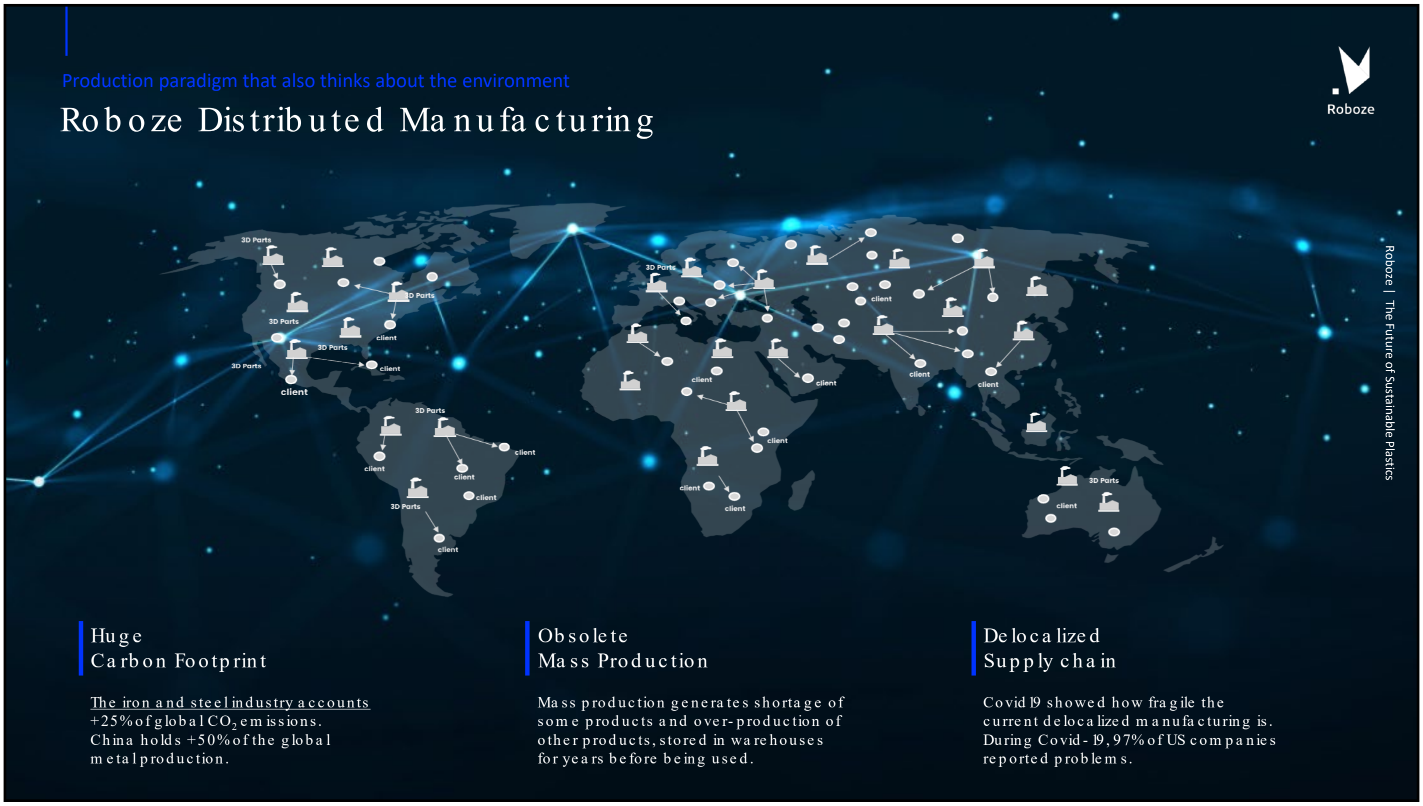
MEDICAL COMPANY

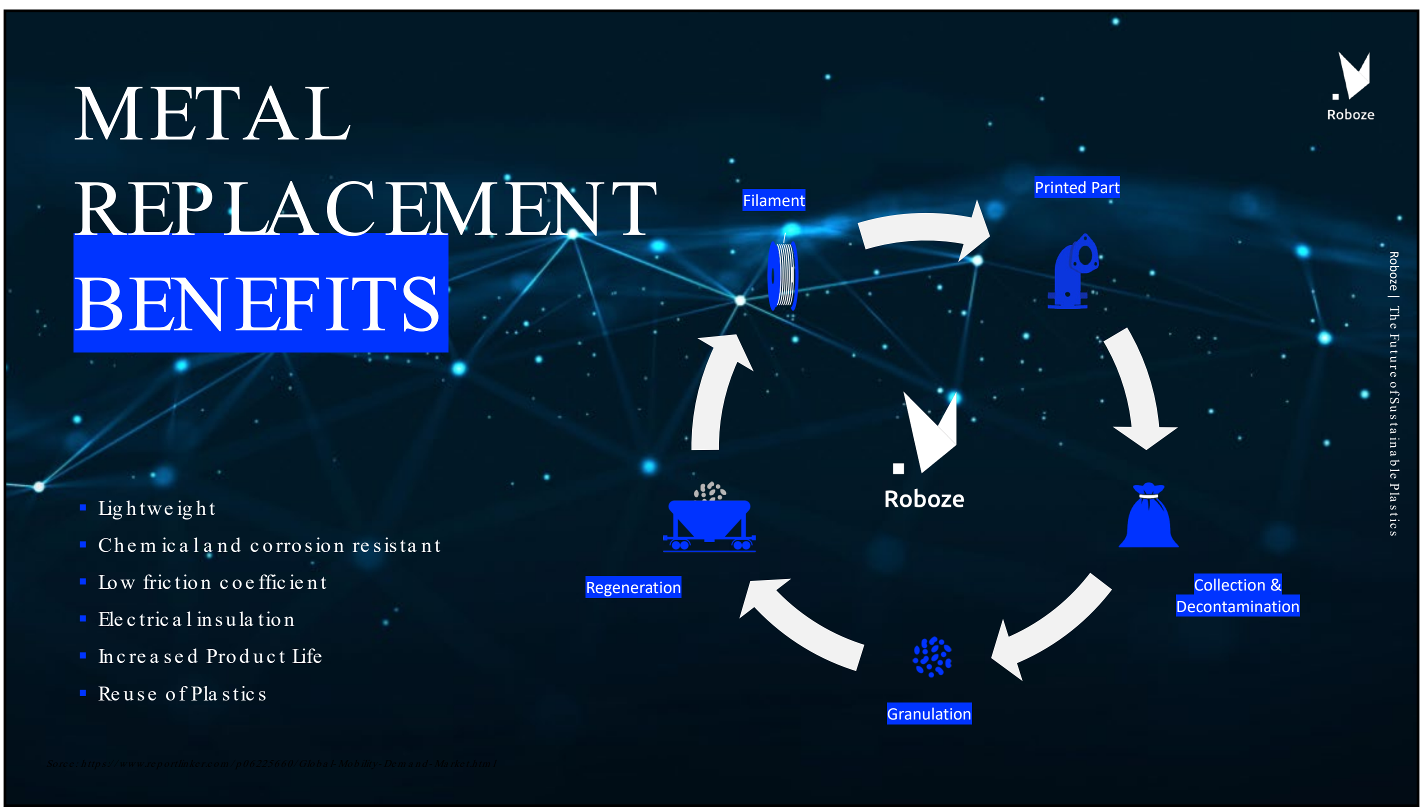
### MEDICAL DEVICES

Application: Prothesis Part

- 70% number of parts

>87% costs saving (compared to previous method)


Production paradigm that also thinks about the environment
Roboze Distributed Manufacturing
Roboze
Roboze | The Future of Sustainable Plastics
Huge
Carbon Footprint
The iron and steel industry accounts +25% of global $CO_2$ emissions. China holds +50% of the global metal production.
Obsolete
Mass Production
Mass production generates shortage of some products and over-production of other products, stored in warehouses for years before being used.
Delocalized
Supply chain
Covid 19 showed how fragile the current delocalized manufacturing is. During Covid-19, 97% of US companies reported problems.


METAL
REPLACEMENT
BENEFITS
Roboze
Roboze | The Future of Sustainable Plastics
Lightweight
Chemical and corrosion resistant
Low friction coefficient
Electrical insulation
Increased Product Life
Reuse of Plastics
Filament
Printed Part
Collection &
Decontamination
Granulation
Regeneration
Roboze

Technology and business model to impact the ecological footprint

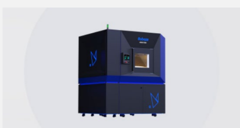
# Roboze Commitment

## Sustainability of 3D Printing

- **-41%** air cargo
- **-37%** ocean container
- **-25%** trucking freight

**- 67%÷71%** greenhouse gas emissions by using recycled plastic resins

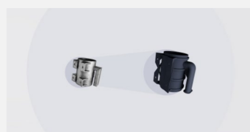
Bioplastics are key component to bringing the plastics into the **circular economy**



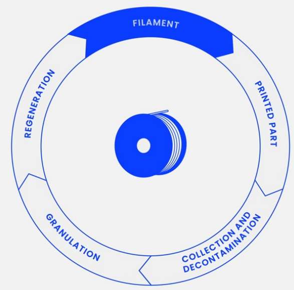
## Sustainability of Metal Replacement

**Rare earths** have environmental impacts (acidification, solid waste generation, gross primary energy footprint, toxicity)

Polymers have **up to 600% of longer lifespan** due to improved **corrosion resistance**



## Sustainability of Material Recycling

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