Perfecting Motion® — Tribology and the Quest for Sustainability

Episode 6 – Sustainable Use of Plastic Waste in the Production of Fuels and Lubricants

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Neil Canter:
Good day to all, this is Neil Canter, your podcast host for "Perfecting Motion – Tribology and the Quest for Sustainability." In Episode Five of our series, we had examined steps being taken to improve the sustainability of the internal combustion engine. We know that internal combustion engine-powered vehicles will continue to be used on roads in the US and globally for at least the next 25 years. One step that can be taken is to identify, in terms of making things more sustainable, is to develop more sustainable fuels to utilize materials that we no longer are using and are treated as waste. Plastics that are no longer used fits in this category. So, think about it, we use plastics in all aspects of our lives. Materials have become indispensable, whether we use them in plastic bags, plastic bottles, trash bags, cups, utensils, shower curtains, et cetera.

So, I challenge all of you listening to this podcast to think about this and look around your house, apartment, office, as well as your kitchen, bathroom, and living room, and identify all the types of plastics you are using. The Environmental Protection Agency (EPA) reports as of 2018, 35.7 million tons of plastic waste was generated in the United States, which represented 12% of all municipal solid waste. Plastic waste is also becoming a growing problem in polluting our oceans. According to NOAA (The National Oceanic and Atmospheric Administration), at least 8 million metric tons of plastic waste ended our ocean in 2010, and this issue continues to grow. As a result, we are seeing some of this waste wash up on beaches around the world. So, as we move forward to our road to sustainability in the tribology and lubrication field, we also need to figure out ways to find and use materials that can be reused and recycled. What better way to do this than to take advantage of the large quantity of plastic waste available. As a chemist, I can envision a connection between plastic waste and fuels and lubricants, which both are organic materials. So, the question arises about how fuels and lubricants can be made from plastic bags, plastic bottles, and other plastic materials. For answers, we are pleased to have Professor Dion Vlachos from the University of Delaware, who is working with researchers to take plastic and plastic waste and convert it into fuels and lubricants.

Dion, welcome, and thank you very much for joining us. Let me start here as we know that there has been a lot of recycling going on with plastics in reducing plastic waste and we try to do it every day, at least I do. We seem to see this plastic problem, but how effective is recycling and how much progress has been made in reducing waste through it?

Dion Vlachos:
Hello, good day to all and thank you for having me, Neil. We do recycle in order of about 15 percent of all plastics today, so it is a small fraction of all the plastic waste. Most of that goes today into incineration. We effectively burn the plastic to generate more energy after the plastic has a lot of additives from the manufacturing. So, this generates a lot of emissions that end up in the atmosphere. The incineration we do today is not very effective. There is also something called mechanical recycling. What we do is we take the plastic bottles and cut them down into small pieces and process them.
In doing that, we degrade the quality of the plastic. So, when we try to reuse some of that together with new material, the quality degrades. Typically, what we do is we use low quality type of products, so this methodology is also not very effective, and that is why it is not being used as widely. The idea is to look into other means of doing the recycling and this new emerging kind of field is called chemical recycling. For the most part, this recycling is not done commercially today, but there is tremendous interest in the US and globally in developing new effective, efficient, scalable applications that can be applied to the larger problem. So, that is what we are looking at the University of Delaware and many other research groups.

Neil Canter:
So, what led you to think about taking the various types of plastic and trying to convert it into fuels and lubricants?

Dion Vlachos:
This is a huge problem for the US and globally. The impact it has on the environment and health is not even well understood, so there is an urgent need to take a step forward in solving this problem. We have been having a lot of interest in what we call a circular economy, which takes all sorts of waste streams, renewable potential feedstocks like trees and agricultural waste and convert these things into useful materials. Our experience over the last 10 plus years has been focusing on lignocellulosic biomass and agricultural waste like Corn stover that is left on the field that could be a tree or processed from the backyard and try to make it something useful. We have a lot of experience studying what are useful products and what the market really needs, and lubricants is one of these products that has a huge market. It is a multibillion-dollar industry even though going forward with electrification, lubricants are used all over in tractors, airplanes, in everything, so this is a growing market. It has what we call value added, which means for every dollar you spend on plastic waste to collect and clean it, you can make $100 out of the product you make. This makes the value proposition of the product quite attractive. We are very interested in identifying potential opportunities in the market that can be viable and the economics look good. Lubricants is one of these areas that we have identified as being very promising

Neil Canter:
In looking at a lot of different plastics, why did you focus on what are called polyolefins? For those who do not know what polyolefins are, think about a soda bottle that could be a high-density polyethylene soda bottle that might be two liters or something you might pick up in the grocery store. Why did you think about focusing on the polyolefin side of the plastics?

Dion Vlachos:
There are two main reasons. First, is a practical one. About 56 percent of plastic waste we make today is polyolefins. Particularly there are two molecules—polyethylene and polypropylene—which are used in everyday consumer things that you mentioned like in plastic bags, trash bags, et cetera. They are the majority of plastics. So, that is rule number one, as we need to tackle the biggest problem at hand. Second, this is some of the hardest molecules to recycle. From a science point of view, these are the least understood, least developed, and most challenging molecules. In comparison, if you look at the PET (polyethylene terephthalate) type of molecules, which we have in soft drinks, there are already technologies out there that are recyclable. They need to be improved, however, there is already progress being made in some of those molecules. Though, polyolefins is the hardest molecule to recycle, so we thought this is the area where we would have the most impact.

Neil Canter:
Just to clarify, polyethylene and polypropylene are basically hydrocarbon-based. There is no other functionality which makes them relatively inert and difficult to break down. Polyethylene terephthalate, which is a polyester material, has what is called an ester group—which is more vulnerable to break down because of hydrolysis as it can be vulnerable to water from that standpoint.

In generic terms, can you discuss what you and your team are trying to do by taking polyolefins and converting them into fuels and lubricants?

Dion Vlachos:
If we go with the chemical technology, the most common thing that comes to mind is to hit the map at high temperatures. They said Greeks invented the word pyrolysis, which basically means no air—just keep tapping on the material and you break it down. Because of the strength of carbon-carbon bonds in these molecules, we need to go to five, six, 700 degrees centigrade, which is some really high temperatures. At this point, all the bonds start breaking down and what you form are primarily light gases like methane—think of that as propane gas on your grill and the value of this thing is not very high. We have too much actually in the United States, as we called it shale gas, which is extracted by a process known as fracking and today we produce too much of that. So, there is not much in the market or having too much supply. The pyrolysis is very high energy and involves a good amount of carbon dioxide and a lot of emissions supply this energy. The idea here is to introduce a catalyst, which is a material that takes something at low temperatures and does a little magic and converts that into a new product. By changing the pathway, the thing that opens up a new highway like you go up on the East Coast of the United States, up and down with a completely new seven lane highway. So, that is what the catalyst effectively does. The key question now becomes what is the right catalyst for that? As a result, we looked into the refinery operations that cracked large molecules, similar to the ones we have in the plastic. That is a process called fluid catalytic cracking, as we try to break the molecules down and they (the refineries) take on the bottom of the barrel of the crude oil and they try to crack and make more gasoline and jet fuel for the airplanes. We tried this and it did not work using a variety of different known materials from the refineries. It did not work because we deal with solids and the idea is to hit them up so we can melt. Though, this thing now becomes kind of a snake that is moving around in a melt and coming in contact with a solid material or a new catalyst that can actually not produce the writing of molecules, but these materials have to have new functionality or groups, some traits of personality we like that is able to do multiple things at once. For one thing, what we do is we remove hydrogen from the molecules during a process called dehydrogenation. This creates the double bond

and becomes much more active. So, you can go on and develop another kind of group and they start doing cracking. And then you put on another one and you begin to isomerize, which means it becomes branched. This branching is what we need in lubricants, as the good lubricants do not have straight molecules, though, they have a lot of branching, and eventually we need to finish the product by taking these carbon-carbon double bonds and convert them into single bonds and then the mulch becomes stable, and you can use them for a long time. That process is the reverse of the very first one, which is called hydrogeneration. As a result, you have four or five different functionalities that we need to impart in the materials and that can become challenging in how to discover those.

Now the new thing we have done is to think carefully about how to bring all these functionalities together. For example, think about the opera and how we orchestrate the music using multiple instruments. This is what catalytic materials do to produce fuels and lubricants.

Neil Canter:
Thank you. That shows an eloquent way of explaining it for those who are not that terribly technical in terms of understanding how this is made. In fact, what you are talking about in hydrocracking and hydrogenation are steps that are taken, not just to make fuels and that sort of thing, but also to make base oils currently to make Group II and Group III base oils. Those are base oils that many of our listeners are familiar with from the lubricant world because of what the industry has done, so using similar processing to what is done to make conventional base oils.

How far along have you gone in making fuels and lubricants using this technique. What types of fuels, lubricants or base oils have you made in terms of what you are doing in this process?

Dion Vlachos:
This is a very good point. For example, the markets are evolving with the move towards jet fuels and electrification in the future. As we previously discussed, lubricants will be here to stay for quite some time and it is important to have new technology that is tunable, if possible, that can make gasoline, jet, or diesel. Diesel is another one of the fuels because the tracks are too heavy for batteries that are going to go for longer time than cars without electrification. So, diesel and jet fuel, particularly for airplanes, and lubricants we believe are important markets to target. In fact, we can produce various fractions or have countries change the fraction of what we make. In terms of base oils, we have properties between Groups II and III with our group of experts, but they know that we can do hydrotreating and convert this into different grades. As good engineers and chemists, we can change with other lubricants and additives. So, we can tune these quite a lot, but the catalyst is critical here to tune in what we make.

Neil Canter:
It sounds like you have a lot of flexibility depending on the catalyst and the conditions you use, whether you are making diesel, jet fuel, and even making base oils. Conceivably, you could do that because all those are of interest to our listeners from that standpoint. From the perspective of raw materials in terms of doing that, obviously polyolefins make up a lot of it. Can you handle mixtures of different plastics and types of polyolefins in the process? How flexible is the raw materials situation. Could you take waste by going to a landfill and take out the plastic and just it put into your system and make beneficial products or are you still working to that goal?

Dion Vlachos:
This is a very important point in terms of the practicality and the needs. Currently, we have treated virgin materials. Even the materials you can buy have several additives like antioxidants and such, though they are not pure materials. A bottle cap uses plastic bags, bottles from the lab, more real word materials and the technology works almost equally well. Again, these additives do change a little bit with the performance, but this is something we work our thinking for the most part. Mixed plastics, mixed polyolefins, even polyolefins with PVC getting to the real-world things of the landfill, which we have developed technology to treat that.

Neil Canter:
For our listeners, PVC is polyvinyl chloride that is used in things such as garden hoses and tubing. It is probably one of the most widely used plastics.

Dion Vlachos:
We have not taken to the landfilled material yet. The technology needs to be developed further, so we are not able to go into the landfill and be treated. But we can treat industrial quality and if we have only polyolefins today in the recycling can, we can treat that today. As a result, there are more steps that need to be done in terms of separating problematic elements or fractions from the land field that need to be separated. But you are not just fitting in a chemical reactor, so that part still needs to be developed.

Neil Canter:
In terms of polyvinyl chloride or PVC, what about the chlorine element of it as that obviously from my background can be hazardous and difficult to deal with under high temperature or dispose of. And, of course, is not that sustainable. How do you handle that?

Dion Vlachos:
Yeah, so this is a very good point. We look at PVC because it is a very problematic plastic. This chlorine element kills the catalyst to start. If you consider polyolefin together with PVC, the argument process dies. The very first thing we need to treat towards the real landfill is PVC. If we add it to the reactor, it is going to kill everything. Also, this high temperature produces HCL. This is very acidic, corrosive and dangerous. So, what we try to do is selectively remove the PVC, capture it in in the media, so this does not go into the catalyst. But we have discovered some very interesting aspects in that a little bit of PVC can help the catalytic process itself. What this means is that we do not need to purify the PVC 100 percent. So much more needs to be done, but it looks very promising.

Neil Canter:
For those who are not familiar, HCL is hydrochloride. When you add water to it is hydrochloric acid—it is very acidic, very corrosive, very dangerous. How far along are you with commercialization of this type of technology or even technology in the field in general, not just what you are doing but with other colleagues and people are doing in this area? How soon or how quickly are we going to see this type of approach where we are going to get fuels and lubricants out of plastic waste?

Dion Vlachos:
It takes about 10 years from the initial invention to commercialization. First, you develop the technology and then you take it out of the lab into what we call a pilot plant. Then you try the ideas out at the larger scale and then try them in building the actual new plant. I think with the information technology, data

science, and other things such as high throughput, we are shortening this time down from 15 years to maybe half dozen years. To be realistic, even to get the approvals of the companies for setting up a new plant and build it in the design phase, et cetera, it can take about a year or two just to do this piece. For us, it will probably take a few years before we get there with this technology.

Neil Canter:
So, you can see maybe in 10 years by the end of this decade, we could have something commercial, and I agree as well. I see a lot of companies involved who make polyolefins and other polyolefin polymer resins very interested in doing this because of the pressures to reduce plastic waste. So, they are very much involved in this type of pressure as you mentioned, with the circular economy. We in the lubricant industry see this as very viable. We can use base oils and other lubricants and fuels from waste, which is a renewable, recyclable type of aspect. We could use it and recycle that and again reduce the amount of dependency we have on the current petrochemical stream, which is being, in my view, being phased out. I appreciate you giving us an update and probably will want to have you back at some point in a few years or so, as we keep doing this podcast, Dion, to get an update because as part of what we are doing is we are moving forward in sustainability. You are a sustainable aspect, in terms of what you and your team are trying to do, so I appreciate your time. Thank you very much and we look forward to hearing back from you as to how things are progressing.

Dion Vlachos:
Thank you so much for having me.

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Neil Canter:
As we continue discussing how plastic waste can be used to produce fuels and lubricants, I would like to first introduce some figures that were produced in a report published in February 2022 by the Organization of Economic Cooperation and Development, which is also known as the OECD. One of the objectives of sustainability is to develop a circular economy. We have talked about that throughout this podcast series where material produced can be recycled and reused repeatedly. The OECD report indicates that only about 1.2 percent of all plastic is being used in circular innovation. Currently, nine percent of all plastics used globally are recycled, and 22 percent are mismanaged. The OECD report really did not say what happened to the remaining 69 percent of plastics – presuming it is being used and dumped, unfortunately. Compounding the problem is that global plastic production doubled over the past 20 years to 460 million metric tons, which is about one trillion with a "T" pounds. Global production of recycled plastic in the same 20-year period did quadruple to 20 million metric tons, or about 64 billion pounds, but that is still less than 10 percent of total plastic production. In terms of global plastic waste generation, that has doubled over the past 20 years with two-thirds of the waste having been produced within the past five years and 40 percent of that waste coming from packaging. So, think about it when you are tearing up or putting a package together, and you have some waste plastic that you did not use, it is ending up in a waste dump somewhere.

Here are some other telling numbers: In the US, we produce about 221 kilograms, or about 487 pounds of plastic waste per year. Europeans are better as they generated about half the waste. One other critical issue that the OECD report talked about is microplastics. Leakage of microplastics in the environment is growing concern. These are materials that are smaller than 5 millimeters and smaller than two-tenths of an inch, and sources of microplastics include resin pellets, synthetic textiles, road markings and tires. Besides showing up in oceans and on beaches, microplastics are also showing up in the air. Recent studies indicate microplastics is all in our environments, so that makes it harder. In summary, plastics account for 3.4 percent of total global greenhouse gas emissions, which, of course, is something we are trying to reduce. Before I introduce our next guests to talk about the potential for converting larger quantities of plastic waste into fuels and lubricants, in terms of technology, plastics are lady petrochemical-based and come from crude oi. For those following the news, as we record this podcast in March 2022, the price of crude oil is now over $100 a barrel. I do not think I have to tell most of you listening what the price of gasoline or diesel is, in terms of how many dollars per gallon. So, let me bring in my guests: Doctor Robert Kennedy, Doctor Ryan Hackler, and Doctor Max Delferro, all from the Chemical Sciences and Engineering Division of Argonne National Laboratory. Thank you for taking time to speak with me.

Let me start first by asking what you and your colleagues are doing to try to convert plastic and plastic waste into fuels and lubricants. What led you to consider doing it and what steps have you taken to move the process forward?

Max Delferro:
We started work on this problem more than five years ago when probably few people at the time were really thinking about the plastic accumulation problem. If you think about plastics, they were discovered more than 90 years ago. From a scientific and technological point of view, we spent 90 years to make this plastic resistant, inert, and very cheap. But only just recently, we really started to think about what we can do with these plastics, and we really need to develop new science and technology to really tackle this problem. But what we are learning from a scientific point of view, which we really need to thank and acknowledge The U.S. Department of Energy for initial funding and helping us to work with big and private companies to help transfer this technology from the lab to the market.

One of the big problems of plastics is that we have too many kinds of plastics. If you know, there is seven numbers with a symbol that the general audience think that plastics is recyclable, which is not true. We have only technology right now to recycle, for example, Number One and Number Two, and there are plenty of opportunities from a scientific, interventional point of view to really tackle the other numbers: three, four, five, six and seven. With our group, we really started to think about particularly polyolefin and what we can do, for example, with HDPE, LDPE, and LLDPE that account roughly 50 percent of the total plastics on the market.

Neil Canter:
For the audience’s standpoint, HDPE is high-density polyethylene, LDPE is low-density polyethylene and LLDPE is linear low-density polyethylene.

Robert Kennedy:
I would also note that with polyolefins, we are also looking at polypropylene.

Neil Canter:
My guess, guys, is those two, and you talked about it earlier, that those two make up the bulk of the polyolefins that are out there right now being used?

Ryan Hackler:
Right. I do want to point out, Neil, based on the numbers you were talking about previously, that the plastics that we are targeting—these different types of polyethylene and polypropylene—they contribute to a vast amount of those single-use, plastic waste that you were talking about that people use one time for a type of packaging, whether it is food, clothing, shipments, something like that and then immediately dispose of.

Max Delferro:
In our Center, which is composed of collaborators from Argonne, Northwestern University, Ames Laboratory, University of California at Santa Barbara, University of South Carolina, University of Illinois, and Cornell University, we are looking at catalytic methods to deconstruct plastic waste to make a new product that has an economic value that is higher than the starting material.

Neil Canter:
I assume that is what you mean by the term "upcycling"?

Max Delferro:
That is correct. Upcycling is a pure, economic value. We want to make plastic waste as a new and clean feedstock.

Neil Canter:
Right, so instead of recycling, which people generally talk about, upcycling is moving to a more value-added type of product?

Max Delferro:
Correct. With the help of my previous Argonne colleague, Doctor Ali Erdemir, we thought we could transform plastic waste, particularly polyolefin in tribological oil such as polyalphaolefin, because the chemical structure after the construction of using our catalytic method really assembled the polyalphaolefin, particularly polyalphaolefin 10 and polyalphaolefin 4 internally. Robert and Ryan really discovered this catalytic method and optimized the condition to obtain very high yield of almost more than 90 percent yield of liquids from plastic waste.

Neil Canter:
Thanks, Max.

I would like to ask you guys, Ryan and Robert, to talk about the challenges of doing this and how does this catalyst work in a generic way to break down what Max had indicated, which I agree with, as a chemist, is a very indirect material—polyethylene and polypropylene are highly inert.

Ryan Hackler:
Yeah, so I just want to take a step back just so that we can make it clear to the audience in explaining what it is that we are dealing with—as a material—and what we are aiming to do. So, as you mentioned from the onset, Neil, that plastic is a petrochemical derived material. You have crude oil that you can process and refined to create a feedstock that can ultimately go towards plastic that we can then use for various types of applications. What we are trying to do is essentially take that spent material, as you guys had mentioned, has 90 almost 100 years of development and research into as an energy-rich material and rather than spinning the wheels and recycling it into the same material, create a higher value by essentially extracting that material and create a new product. So, what we are talking about

here with lubricants, for example, for our process is one of the more straightforward applications but as we move forward, we hope to look at different types of hydrocarbon-based materials, so this can include waxes, cosmetics, detergents. So, one of the things we are looking at from the beginning is lubricants. What we are trying to do here is take what is essentially trash. It is a real world, post-consumer plastic that someone had used to carry their lunch that Amazon had used for shipping containers. There is any number of real-world variables for something that is a reach feedstock that we can process, but also taking into account the different types of contaminants and additives that you should expect from this type of material. So, anything from, say, a candy bar has dyes, metals and metal oxides to show maybe advertisements, the nutritional value—all these different types of components that are needed but ultimately contribute to a very sophisticated, complex material that ultimately at the end of the day, we are saying we want to process it into a much more straightforward, more precise and more narrowly defined material.

Neil Canter:
So, how do you go about that, as I assume you started off with virgin material. In other words, fresh polyethylene and polypropylene. How does it work in generic terms, and how does the catalyst you guys have developed work to chop it up and spit out something that is maybe more fluid because fuel and lubricant is fluid, whereas polylethylene and polypropylene, of course, is solid?

Robert Kennedy:
The process that we are doing is what is called hydrogenolysis, so that is olysis cleaving with hydrogen, so we are using hydrogen to help break the bonds in the plastic to make shorter and shorter molecules. And so what we are really trying to do here with the supported metal catalysts that we are using is use metal and hydrogen and the contact with those two with the polymer to break the polymer into shorter and shorter pieces, but do so in a way that we are selectively getting to molecular weight ranges where we are making things that are usable as lubricants.

Ryan Hackler:
Yeah, this goes back to what Max was mentioning that for our process, particularly, not only are we creating these liquid products that we hope to use for lubricant applications, but we are trying to do so in a way that is as efficient and economically favorable as possible. We do not want to be producing methane, ethane, all of these gases that we cannot utilize for this type of lubricant application. We are trying to basically convert as much of the plastic material that we harvest towards specifically this one type of product, in this case a lubricant.

Neil Canter:
Plus, if you are going to do methane, that is defeating the purpose from a sustainability standpoint. Methane, as you guys know, is a very potent greenhouse gas, more potent than carbon dioxide. Methane is the main component of natural gas for listeners out there who do not what it is.

So, tell us how you have come along in terms of structuring the metal catalyst to hone on a particular type of material, whether it be a fuel or a lubricant type thing or some sort of base intermediate to make it? How are you coming along with doing that, at least with the virgin material, and then how, of course, are you doing it or if have you gotten to the point of looking at plastic waste where you have taken a hodgepodge of stuff and throw it in with your catalyst to see what comes out?

Ryan Hackler:
I think Max and Robert can talk more about this, but to preface this discussion, I think it is important for maybe the audience to know what chemically is distinct between something like a fuel to a lubricant product to a wax or anything like that. So, the fuels, be it the things we put in airplanes or cars, or any of these types of motor applications, these are usually much thinner liquids, so if you obviously are using gasoline, this can range from essentially a hydrocarbon species where the carbons constitute anywhere between six, seven, eight carbons upwards to 10, 11, 12, depending on what it is exactly, whereas lubricants have a larger range for how many carbons constitute that material, so lubricants can range from C 20s, C 30s, C 40s, and so on, and they can be distinct based on their structure compared to, say, like waxes. So, one of the biggest distinctions apart from the size of the molecule is how they are shaped and how they connect to each other, and so knowing that we basically adopt different strategies, depending on what type of products we are aiming at. If we are looking for smaller molecules, we might have to change either the parameters of our process or change the catalyst itself so that we selectively get either a smaller product or a larger product, or even a differently shaped product.

Robert Kennedy:
Just to give a sense of scale, the plastics that we are talking about those will then be thousands to millions to billions of carbons in one molecule of the plastic.

Neil Canter:
Thank you, Robert. I appreciate that from our audience's standpoint. What are you doing in terms of getting to a distribution of carbon atoms, whether it be for fuel or lubricants, that would be comparable to what is already out there made safely from crude oil?

Max Delferro:
Yeah, this is the beauty of our technology and catalyst that is also a little bit different from other systems. Polyolefin or polymer plastic, in general, are a very broad distribution of chains called PDI or polydispersity as a large polydispersity and what we discovered, particularly the system that Ryan and Robert have developed, we are now able to make a very narrow distribution of product and that is very important, for example, for tribological application. In fact, we are working, for example, with Chevron Phillips to transfer this technology and test our tribological liquids now in-house for possible application and partnership with us.

Neil Canter:
Chevron Phillips is a major producer of polyolefins, as well as lubricant alpha olefins used to make a well-known lubricant material used in lubricants called polyalphaolefins or PAOs. So, I would imagine, Max, all of those are in play at this point?

Max Delferro:
Yeah, and it is very interesting as we did not know at the beginning when we started to discover this new process and new technology, the tribological properties of this liquid from plastic waste are really matching the tribological properties of synthetic oil. In addition, we also did a lifecycle analysis, going back to your point before about clean energy. If we can make synthetic oil from plastic waste, we could save roughly 70 to 80 percent of CO_2 emissions and this could have a big impact.

Neil Canter:
That obviously is huge. Now have you done any scaling up at this point or you are leaving that to your partners to scale up. Where are you in terms of the scale-up process?

Ryan Hackler:
Right now, in the live quantities we have taken virgin polyethylene, virgin propylene, as well as started diving into mixed virgin polyolefin waste. We have even done some forays into bubble wrap post-consumer, bubble wrap from shipping companies such as Amazon and we have been able to convert this into these liquid lubricant products that, as Max was saying, as a base oil from our initial investigations have been comparable to polyalphaolefins to the some of these higher end synthetic lubricants. One of the things that Robert and I are doing right now, as we transition from the lab scale, is we are looking to start a company and go towards the kilogram scale to have a lot of investigative power to really implement this, to scale, to have as a product that we can sell to consumers.

Neil Canter:
I would imagine you are going to look at other polymers, as well as other mixtures. Obviously, the ultimate answer here is to take what is being dumped at a particular municipality and mix it all in, and then put it into a reactor and do it?

Robert Kennedy:
Yes, that would be the ideal. To your earlier question, what we have found is that by tuning the catalyst design and the conditions of the reactor, we can tune from the high end of fuel molecular weights up to the highest end of lubricant molecular weights and get a very low dispersity, very narrow molecular weight range of products and then we can tune and control that with our process. As a result, we can hit the viscosities and molecular weight ranges that might be needed for different applications.

Neil Canter:
One of the things I discovered, Robert, in a technical paper you sent me was indication you may be doing something with alkylated aromatics, which for the audience are intermediates used in things like surfactant production. Where are you with that in making an aromatic out of it?

Robert Kennedy:
We are all collectively part of a U.S Department of Defense (DoD) funded center called the Institute for Cooperative Upcycling of Plastics and one of our teams out at UC-Santa Barbara, which Max mentioned earlier, is working on making alkyl aromatics, and so they have found that by working in low hydrogen concentrations they can get to directly forming dialkylaromatics, which is a benzene ring that has two long alkyl chains off of it and is a structure that is very valuable and currently made through a very energy intensive process, so this might be a way to very directly make those chemicals that are in demand with a much less energy intensive process.

Neil Canter:
Obviously, all that is in play here of these products: fuels, lubricants, and surfactants, if you are talking about alkylaromatics, can all be recycled and used repeatedly. That is where the plastic is going eventually into a circular economy, which is truly exciting.

Neil Canter:
What does the future look like for plastics?

Max Delferro:
I will say this is an exciting time for scientists and engineers in this area. Clearly one technology cannot solve the plastics problem. We need several technologies to really come up with a solution. I think we will do it. I do not know when, but I think it is going to be in the very short term.

Robert Kennedy:
I would say we are already starting to see a couple of products coming online such as advanced recycling plastics that are polyethylenes, which is being made by converting plastic waste into ethylene and then repolymerizing. So, I think that is going to be the first major product we are going to see hitting the market. But what you are looking at with what we are working on here in the Institute for Cooperative Upcycling of Plastics and other centers like this is really looking at what are the advanced higher value chemicals that need to be made, if we are going to wean ourselves off of petroleum that need to be brought back into the supply chain and how do we get to those from plastic feedstocks.

Neil Canter:
I think you have got a lot of people out there who are anxious and impatient about it, with the price of gas where it is right now, which I think is going to help spur this thing along. I do not like to say this is a positive development because a lot of people are hurting paying gas, but this may be the way to spur this thing to happen.

Alright guys, thank you, and I appreciate your time very much. I wish you well and as we move forward with this podcast, we may check in with you again to see where you are and the progress you have made in overcoming some of these challenges.

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CONTRIBUTORS

Dr. Neil Canter is an STLE Fellow and an STLE Certified Metalworking Fluids Specialist (CMFS)™, with more than 35 years of experience working in the lubricants industry. He received his doctorate in chemistry from the University of Michigan in 1983 and his bachelor's of science in chemistry from Brown University in 1978. Canter runs his own consulting company, Chemical Solutions, specializing in commercial development, marketing, product development and regulatory support for the lubricants industry. Canter is a member of STLE, the American Chemical Society (ACS), and the Society of Automotive Engineers (SAE). He is a contributing editor responsible for writing the monthly Tech Beat column in STLE's TLT magazine. He is also a member of STLE's Metalworking Fluid Education & Training Committee, STLE Education Committee, and the program chair for the STLE Philadelphia Section.

Canter recently assumed the position of STLE Advisor – Technical Programs and Services. Besides providing technical and commercial support, he is also the host of STLE's new podcast series: "Perfecting Motion: Tribology and the Quest for Sustainability."

Dionisios (Dion) G. Vlachos is the Unidel Dan Rich Chair in Energy Professor of Chemical & Biomolecular Engineering, a Professor of Physics and Astronomy at the University of Delaware, the Director of the University of Delaware Energy Institute (UDEI), of the UD node of the manufacturing institute RAPID, and the Catalysis Center for Energy Innovation (CCEI), an Energy Frontier Research Center (EFRC).

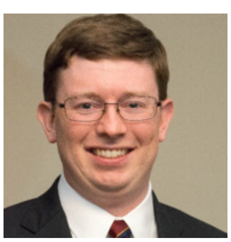
Dion obtained a five-year diploma in Chemical Engineering from the National Technical University of Athens, Greece, in 1987, and his master of science and doctorate from the University of Minnesota in 1990 and 1992, respectively. He spent a postdoctoral year at the Army High-Performance Computing Research Center in Minnesota.

Vlachos' research focuses on circular economy and waste derivatization, multiscale modeling and simulation, distributed (bio)chemical manufacturing, process intensification and novel catalytic reactors, renewable fuels and chemicals, catalyst informatics and in silico materials prediction, and kinetic modeling. He is a pioneer of the multiscale modeling field and the introduction of fundamental research in biomass.

Massimiliano "Max" Delferro is a chemist and group leader of the Catalysis Science Program in the Chemical Sciences and Engineering Division at Argonne National Laboratory. Max's work focuses on plastics recycling and the development of cleaner, safer solutions that benefit industries and individuals around the world. He is also a principal investigator of the Inorganometallic Catalyst Design Center, an Energy Frontier Research Center funded by the U.S. Department of Energy. Max earned his doctorate in organometallic chemistry from the University of Parma, Italy in 2008. He is a member of the American Chemical Society (ACS) and has served as the president and program chair of the Catalysis Club of Chicago since 2016.

His research interests include the synthesis and characterization of multimetallic single-site hydrogenation/dehydrogenation catalysts to atomic layer deposition, polymer recycling and upcycling, additives for tribological applications, and supported organometallic catalysis for C- H and C-C transformation.

Ryan Hackler obtained his bachelor's of science in chemistry at Western Washington University in 2014 and doctorate in Chemistry at Northwestern University in 2019. His work as a postdoc at the Argonne National Laboratory focuses on the synthesis and characterization of ALD-prepared thin films and nanoparticles for heterogeneous catalysis.



Robert Kennedy received his bachelor's of arts in chemistry at Charleton College in 2009 and doctorate in inorganic chemistry at Northwestern University in 2017. He was recognized with the Impact Argonne Award from Argonne National Laboratory for notable achievement in innovation – polymer recycling and was a recipient of the 2020 PSE Excellence Award: Programmatic Scientific Achievement from the Physical Sciences and Engineering Division at Argonne National Laboratory for developing a new catalyst for upcycling polyethylene plastic wastes into higher-value products with Argonne colleagues Max Delferro, Magali Ferrandon and Ryan Hackler. He also holds a US patent for catalytic upcycling of polymers.