

## Analyze That episode transcript

### Polymer upcycling via reactive extrusion:

FTIR microscopy insights into blend compatibilization

*This transcript has been lightly edited for clarity, readability, and length. The content reflects the original discussion and technical intent of the speakers.*

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#### Host:

When we talk about recycling plastics, success isn't just about reuse, it's about whether the material still works. And I'm delighted to be joined today by Lucivan Barros and Ron Rubinovitz, both of whom are senior application scientists at Thermo Fisher Scientific. And they've joined me today to discuss polymer upcycling. Lucivan, Ron, welcome. I'll give you the chance to introduce yourselves. Lucivan, maybe starting with yourself.

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**Lucivan Barros:** Hello everybody. My name is Lucivan Barros. Thank you for having me. I'm the extrusion application scientist there at Thermo Fisher. And this role is very interesting, very dynamic. There's no two days that are the same. But what most fulfills me in this role is the ability, the possibility that I have to help customers, which can be industry or university, to understand better their application. So, it's a lot of learning. It's a lot of exchange of knowledge—very, very dynamic role

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**Host:** Great. And Ron?

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**Ron Rubinovitz:** So, my name is Ron Rubinovitz. Thanks for the opportunity to talk today. And my role has got a lot of overlap in functionality with what Lucivan was just describing. I work with the FTIR product line. So, in my role, I'll be talking to people, either potential customers or existing customers, about what FTIR technology and our products can do to help their analyses. And just like Lucivan was saying, no two days are the same. Because my product—probably Lucivan's also—is applied to such a wide range of applications, research, industrial subdivisions within those two categories, it's a

very interesting broad range of things to learn about, both from the customer as well as in both directions actually, because I can learn things from the customers, as well as them finding out things that people have done in the past successfully with FTIR. So it's a very rewarding job from that point of view and very dynamic. You never know what you're going to do today, that sort of thing.

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**Host: Great.** Thank you. I'd love to know as well, this sounds like a really specialized technical field. Can you both tell us what initially drew you to this field? How you got to where you are today?

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**Ron Rubinovitz:** So for me, I think what happened, I guess you could say that science is just kind of in my background. My dad was... an electrical engineer, my two brothers have computer related jobs. My grown kids have high tech or computer related jobs. So I guess it was just in my DNA that I was going to end up working in science.

But more specifically, when I was younger, I didn't really know about chemistry per se, but I knew there were scientists working on making new materials out of existing materials. And I thought that was a really interesting thing to do. And so I ended up with an undergraduate degree in chemistry. And in graduate school, I got exposed to optical spectroscopy, where you're learning very interesting and fundamental things about materials just by the way they interact with light. So that's kind of how I got into this position.

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**Lucivan Barros:** In my case, I've always been very interested in chemistry, physics, science in general, which led me to study material engineering for my bachelor's degree, which basically everything that you see around you, it's materials, right? So my undergrad program was very focused on metallic and ceramic materials, a little bit of polymers. And to compensate that, I started very early in college to do research in polymers because I knew I wanted to learn about polymers.

And then I found that polymers are a very interesting field. There's a lot of technology that comes from polymers and can be used in polymer fields. And later in grad school, I started with extrusion and processing of polymers. And this got me hooked on this field because I could understand how the process can influence the structure, morphology of the materials, and the final properties of the material as well. And also this field, we get to play with different analytical techniques—very interesting techniques, such as FTIR microscopy—and many other techniques, so we can have like an overview of the polymers.

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**Host:** Great. Well, I'm a geneticist by training, so I'm glad that DNA got a mention from Ron there in an episode about polymers and materials.

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**Ron Rubinovitz:** Happy to help. Yeah, thank you.

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**Host:** Let's turn to our topic now. I don't think there's anyone who doesn't know that we should think and worry about plastic waste and recycling. But let's splash that out a little bit. Why do we recycle? Why is it so important that we think about these topics?

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**Lucivan Barros:** Yeah, although this is a very challenging thing to do, the answer for this question is quite simple. It's just because we produce a lot of these materials. We have some data from 2023 that in the last 50 years, we produced over 8 billion tons of plastics. And 36% of this production was in the past 10 years.

So if you think about this number, it's like we produced 3 billion tons of plastics since 2013, which was like yesterday. So that's why we need to think about that. And today we have a rate of production of 4 million tons per year. And the data show that if you keep this rate, by 2050 we're going to have more mass of plastics in the oceans than mass of fish.

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**Host:** W That's unbelievable. What are the challenges to recycle more of these materials then to avoid them going back into the environment, back into the oceans?

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**Lucivan Barros:** Yeah, there are several challenges and there's a lot of scientists and researchers working on that in this exact moment. But for me, the most challenging thing is sorting out these materials because we have a wide range of plastics out there. So, making sure that these batches that we want to recycle are homogeneous, or at least know what's in them, it's very challenging—especially because these materials, they are very incompatible when it comes to thermodynamically. So each one is going to follow a different route of processing or recycling.

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**Host:** Yeah, really important point there that you say. You know, route of recycling: as a plastic consumer, you just worry about putting plastic in a recycling bin or taking it to a recycling plant. I don't think many people know how we actually recycle plastics. So if you could talk a bit on that, that'd be great.

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**Lucivan Barros:** Sure. There are three main ways to recycle these materials. The first one is incineration. We basically burn all these materials, and we try to eliminate this waste from the environment and try to recover a little bit of the energy that was spent to produce them in the first place.

But the downside here is that we generate a lot of unwanted byproducts, such as ash or emissions.

Second is mechanical recycling. Maybe this is the most cost effective and the simplest one. So we basically shred all of these materials, we heat them up, melt them, and then we mix and shape them, remold them into a new product. The downside here is that we lose a lot of the mechanical properties of this material. So, we are degrading the final properties of the final product—and we call this downcycling. So we are degrading the properties.

And third is chemical recycling. So through a chemical reaction, we basically convert this plastic back to the raw materials and use these raw materials to remake our new plastics. But this is very energy-consuming, and we need a lot of further processing for that.

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**Host:** Can we be smarter with this?

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**Lucivan Barros:** Yes. And I feel like the whole world is trying to solve these issues. There are very interesting technologies out there. For example, we can create smart materials—materials that are really degradable, materials that can convert themselves back to ketones or aldehydes once they are back into the environment and not leaving any microplastics behind. But we're still on baby steps on this technology.

So we need to improve the mechanical and overall properties of these materials. Another way to do that is what we call upcycling. So when you aim to create a product that is equal or greater value than the original, we can do that by incorporating all this waste into new polymers, into new materials. This waste is going to act as filler to improve the mechanical properties, or to use for another purpose.

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**Host:** So we've spoken a little bit about the why, but let's transition into the how. How can this be done in practice? What analytical techniques or instruments are required to do this work?

**Lucivan Barros:** In simple words, we need to mix this waste of plastic into new polymers, new plastics. But these, we need to use some strategies. What do I mean for that? They need to be compatible.

The mixing of these materials should be homogeneous, and the mix also should get rid of any agglomeration because all of these factors will influence the final properties and the quality of the final product. And remember, we want to upcycle. We don't want to downcycle.

And for that, we can use twin screw extruders.

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**Host:** Can you explain what twin screw extruders are? And is that all we need to solve this challenge or do we need other techniques as well?

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**Lucivan Barros:** Extruders, they are polymer processing instruments. So basically, the machine consists of a barrel. And inside this barrel, we have two screws that rotate. And these screws are going to apply pressure, dispersive, and distributive mixing in the material. And the material is fed continuously into the barrel.

And the material is going to be pushed through the die.

It would be nice that this is the only thing that we need to recycle polymers. But we need to think about the material itself. So the process alone is not enough. We need to play with the material.

As I mentioned before, a large part of these materials are not compatible thermodynamically talking. So besides the effective mixing, which is the role of the extruder machine, we need to make sure that this fine morphology, this mixing, is kept after the process is done.

For that, we need to move to reactive extruder. Reactive extrusion process is when we perform a chemical reaction inside extruder. So we basically use extruder as a chemical reactor, but the advantage here is that this is a continuous process.

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**Host:** And in practice, what do you have to consider in the upcycling process?

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**Lucivan Barros:** OK, so Ron and I worked on a project together about upcycling of polypropylene. For those who don't know, polypropylene is used on your yogurt cup or

the cap of your water bottle. So we have this waste of polypropylene—polypropylene that was used—so we need to reuse that.

OK, I know that polypropylene is a low cost. We also know that polypropylene is easy to process. So we should take advantage of these characteristics.

So we can simply incorporate this waste into a high-performance polymers—polymers that are more difficult to process or more expensive, but polymers that have great mechanical properties, for example.

So then we use waste of polypropylene and polyamide, which is a nylon, and mix them together. The issue here is that they are incompatible. Again, they don't like each other. They're going to segregate. So we need to compatibilize. So we add a compatibilizer agent to make them more mixable.

And there are some factors that we need to consider for success. For example, time. How long do we need this mixing to be done inside extruder? What's the composition between polypropylene, polyamide, and compatibilizer agent? What is the temperature? What's the aggressiveness of mixing that is needed? And those things that we need to consider.

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**Host:** Now you've explained that incredibly casually, but in practice, how long would that actually take you?

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**Lucivan Barros:** That would take long because this is research, right? And we need to perform a detailed study, vary all of these composites, all of these factors that I just mentioned.

So that's why I would recommend a lab scale machine, which is small machine that you can play with. It gives you lot of flexibility to experiment several process conditions, especially when you don't have a lot of material.

You don't want to use an industrial-sized machine because these machines are so big and they produce hundreds and hundreds of pounds per hour. You don't have material, and they are very hard to set up.

So having a small extruder, a lab scale, extruder drives innovation because you have a lot of flexibility and possibility to test all of these process conditions, to have the best process conditions at the end.

**Host:** Yeah, that sounds way more feasible. When it comes to chemical changes in the material, how do you verify that the process was effective?

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**Lucivan Barros:** Yeah, for that we need to evaluate the final material after the extruders, to try to understand how all of these process parameters that I mentioned before, and the formulation, worked for this process.

We can do mechanical testing. We can do rheological analysis. But we can also look into the molecular level as well and check if the chemical bonds were formed or not with techniques like FTIR, which Ron is the expert in. And that's what Ron did in this project, and I'll let him explain.

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**Host:** Ron, before we talk about FTIR that was used in this study, can you tell me a little bit about the technique itself?

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**Ron Rubinovitz:** Yeah, of course. So FTIR stands for Fourier Transform Infrared Spectroscopy, and it's a molecular vibrational technique, which means that by shining light on a sample and seeing how the light interacts with the sample, we're going to get information about the molecular bonds of the sample. So it's very chemical specific.

And for example, big applications: just identification of materials. So for polymers, it's a very good tool. You can readily tell the difference between many different types of polymers, or even polymer classes, with FTIR.

And it's a non-destructive technique, which is also very useful because once I'm done testing it with FTIR, it can be tested with other techniques as well. And as I'll mention later on, what you can also do is apply FTIR microscopy to a sample. So you can get down to smaller sizes than you would with a conventional FTIR spectrometer.

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**Host:** Great. And how can we assess or verify that we have the expected changes in the material? How does FTIR fit into this?

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**Ron Rubinovitz:** Yeah, so good question. As I mentioned, we were going to use FTIR microscopy because what we want to do is get some insight into the pellets that are being produced here.

Those are the pellets that were provided to me. We basically had two types of pellets: pellets that were made with the compatibilizer, and pellets made without the compatibilizer. And everything else we tried to make as similar as possible.

And as Lucivan described, we anticipated that the use of the compatibilizer would help with the mixing. We'd get a much better dispersion in the blend, or homogeneity. And what we wanted to see with the FTIR is: can we tell the difference between those pellets? Can we see different domains or regions within the pellets, of the polyamide and the polypropylene?

So that was what was done with the FTIR microscopy. There's a capability called attenuated total reflectance, or ATR microscopy, where you can measure. In our case, we got down to about 10 micron spatial resolution. So we would measure a section of the pellet and then we would move on to the next one.

So I don't have to do that manually. I can just set up the microscope to make measurements across a desired surface area, and then we can see the spectra that were obtained.

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**Host:** And how did you know the reactive blending works in the upcycling example link?

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**Ron Rubinovitz:** Yeah, good question. So what happened here was, we weren't sure before we started the study how the size of the domains would relate relative to the FTIR spatial resolution.

But what did happen was when we looked at a pellet that was made with the compatibilizer, we saw elements of the polyamide features as well as the polypropylene features. So the two of them have very distinct spectra and peaks that are very unique to each other.

So we could see, when we looked at the compatibilizer sample, that no matter where we looked on the sample, the ratio of the polypropylene features to the polyamide features, or vice versa, were pretty much consistent across the range.

When we looked at a pellet that was made without the compatibilizer, we saw much, much larger variation as we moved across the surface. This is sort of enforcing what we learned about hardness testing or physical testing and rheological testing. We could actually see that the blending was much more effective with FTIR by doing that.

And of course, once that's done, those ratio values—I don't have to look at each spectrum one at a time and look at it because there's hundreds of spectra that are being collected—these are used to construct chemical maps where the colors are indicative of

the intensities of the ratios. Or we can just export out the spectra ratios and then do a simple statistical analysis of those numbers to see the range and standard deviation.

So that way we can objectively compare the compatibilizer pellets with the non-compatibilizer pellets as well. And also, if one was going to try to do some process optimization, one would have an objective way of saying, well, we can see that we're making much more consistent material, making this change, for example.

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**Host:** Like anything, cost and efficiency come into this. What are the advantages of this testing in those terms?

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**Lucivan Barros:** Yeah, I can take that. So this process allows us to recycle waste polymers and have a final material with properties as good, at least as good as new polymers. But that's advantage.

Now we have a product made with 50% of used materials. So we are saving energy. We are removing these materials from the environment. And also, we have less expensive materials at the end of the day.

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**Ron Rubinovitz:** Yeah. And I would, if I can add, I think this was already mentioned. But I think it's a point worth repeating that when we recycle, the whole value of recycling is important, of course, as a way of handling all this waste polymer in the environment.

But it's only going to be really effective if we can produce materials that have value going forward in manufacturing. And this is a way of doing that.

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**Lucivan Barros:** Yeah, correct. And that's why we can use the results of these kinds of studies with mechanical, rheological, spectroscopy testing and make intelligent decisions to process parameters adjustment and make the best product in the best way.

For example, we can use this data to adjust and fine tune temperature, screw design, feed rate, or even the formulations for overall efficiency. And as Ron said, we need to have enhanced material at the end of this process.

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**Host:** Yeah, thank you both. I think if our conversation had a core message, it'd be that understanding what's in our upcycle materials helps ensure that they meet standards,

protect people and environments by giving them a viable path for plastic waste recycling. So thank you both for your insights today.

That's all for our episode on polymers. There will be more episodes to come in the Analyze That series. Thank you to Ron and Lucivan

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**Lucivan Barros:** Thank you.

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**Ron Rubinovitz:** Thank you.