Season 3, Episode 4: The Sustainable Materials Economy
Host: ESF President Joanie Mahoney
Guest: Dr. Chang Yoo

Chang Yoo: The reason we have lots of petroleum product with the chip prices because they have very well developed, finally processed by the boiling point. They can have gas, gasoline, diesel, aviation fuel and even plastic material from one crude oil. They don't waste any component. They use everything as a product.

Right now in the US, 40% of municipal solid waste are biomass waste. So we have great potential, not from harvesting the tree or grass or other materials. We can reduce the waste generation but also utilize it for the future fuels and material source.

Joanie Mahoney: Welcome. This is Joanie Mahoney who has the honor and privilege of being the president at SUNY ESF. And I'm back with another episode of our Campus Conversations, the podcast. And we're focusing this season on some of the tremendous research that happens here on the ESF Campus. And today I am very pleased to introduce Dr. Chang Yoo, who is a an assistant professor of chemical engineering and an associate editor for Frontiers in Chemical Engineering. Welcome.

Chang Yoo: Thank you, Joanie. Thank you for the nice opportunity. It's great to introduce my research and my collaboration at ESF with you.

Joanie Mahoney: Thank you. And your research is incredible. We have a lot of people in the audience that are scientists like you, but I hope that we're reaching other folks that fit the category of me, which is non-scientist and try to explain what it is that you're doing and why it can be so life-changing and beneficial for the planet. So let's just start with your biography a little bit.

Chang Yoo: So I studied my Bachelor and master in chemical engineering department in Hanyang University in Seoul, South Korea. So one of the motivation for me to come to US is because when I did my master, last project was about the separation of sugar and acid. Actually, it comes from biofuel production process. So originally I studied pharmaceutical separation, but I just expand my area and interest to biofuel.

Especially South Korea is the country doesn't have that much natural resources, so we have to import everything from the outside. And energy security is one of the big problems in that small country. So we try to figure out what will be the future resource, especially energy source. So that motivated me to come to US and study about the biofuel.

So my PhD is from Iowa State University and Iowa as you know is visible cornfield. Lots of biofuel produced from the corn ethanol and I got lots of training about the biofuel production, especially about the second generation biofuel. So currently when you go to the gas station, biofuel ethanol is from the corn or the grain fermentation. So it is great resource. We can blend with gasoline without any changing the engine or infrastructure. So it is really available for commercialization. However, one big issue with the corn ethanol is because of the food.

Joanie Mahoney: Right. There's an ethical problem about whether in the US we should be using food to power our vehicles when there's people around the world that are hungry.

Chang Yoo: And also it swing a lot by the weather and environment. Sometimes corn price goes up really high then it's not easy to consistently and sustainably feed this ethanol for the fuel purpose. So due to that, peoples move their direction to second generation biofuel, which is from the biomass. For example, once we harvest the corn, we can make the ethanol from corn but also we can get ethanol from corn stover which is left over on the field.

Joanie Mahoney: Okay. So we could have the corn as a food source and then have the biomass that's left be the product that you can study for how to create a biofuel from that. And so I was surprised when I was reading that biofuels are so old. In reading about your research, I understand that it was a 120 years ago that we had the Ford Model T, there was a version of it that used ethanol as the fuel source. So using biofuels is not new. Is that right?

Chang Yoo: Yes. So during the World War II we already faced this kind of shortage regarding the fuel and people develop lots of different technology, and one was the bio ethanol. So as you mentioned, Henry Ford already made the engine for ethanol only 1900 and then they use it for the car for a while. The only problem was at that moment petroleum was so cheap.

Joanie Mahoney: That is what I wanted to get to. Because why wouldn't we have stuck with it? And it's because petroleum has been so inexpensive and there's a lot of reasons it's inexpensive, right?

Chang Yoo: That is true. So we can think about the petroleum first. In general, my research field I can describe as a bio refinery. So the concept is from oil refinery. And the reason we have lots of petroleum product with cheap price is because they have very well developed refinery process. By the boiling point they can have gas, gasoline, diesel, aviation fuel and even plastic material from one crude oil. So they don't waste any component. They use everything as a product.

So the idea is instead of just targeting one biofuel, we try to maximize the use of biomass. We try to make different product with one single biomass. In that case, instead of just produce bio ethanol alone, may not meet the market competitiveness. But if we can produce ethanol plus some chemical or material then we can reduce the price of bio ethanol to make it more feasible in practical life.

Joanie Mahoney: So some of your research then is about what other things we can be doing with the biomass so that we have an ability to reduce that cost and compete more effectively with crude oil?

Chang Yoo: Yes. So let me explain this way. 1970, I mean, even nowadays, paper industry still make paper from the wood. So wood has about 40 to 50% tog cellulose mainly used for the paper making. But once you look at the plant cell of the wood, actually another 10 to 20% are the sugar, which is not the cellulose but another sugar. It means we can provide that one to certain microorganism. They can ferment it and make it to ethanol or a bioplastic.

Also, wood has about 20 to 30% another biomolecule which name is lignin. So this lignin, the lot of lignin is actually make some rigidity and then protect the sugar in the plant cell from the insect and outside of microorganism attack. But it actually it is covering the cellulose and then protect the wood from the outside. But if we use the biomass for the paper making, this will make the color. When you recall the old 1989 is some paper has brown it's color because lignin is still remain in the paper and that one reduce the quality of paper.

So people tried bleaching and they remove all the lignin out from the plant cell wall and they sell it as a copy paper with a white color. But at that time this lignin was discarded just as a waste.

Joanie Mahoney: And then what are you finding that you can perhaps use that waste product?

Chang Yoo: So early 2000 when people tried to make the biofuel more economically feasible. First approach is starting with those other sugars beside the cellulose. We call it as a hemicellulose. And these sugars are not consumed by general yeast but many microbiologists engineer the microorganism and now many engineered microorganism can consume and then produce ethanol as well. But it wasn't sufficient enough to make it in market.

So still 20 to 30% are lignin. What can we do with this lignin? And they look at the chemical structure of lignin. Interestingly, this lignin is composed of aromatic compound which we can easily see from the petroleum. So if we can properly fractionate and then chopping to the monomer, we can replace the lots of petroleum chemicals and also we can apply for the fuel additives.

So that is the idea we start to think about the lignin utilization. And currently I'm doing corporal project with multiple ESF faculty and outside. One is I'm working with Gyu Leem in chemistry. He's the photocatalytic scientist. So his idea is capturing the visual light and then convert it to the energy with catalyst. So the target is trying to convert this lignin, which is automatic polymer to buno aromatic compound which can replace lots of petroleum chemicals.

Joanie Mahoney: And that's with Dr Leem here at ESF in the chemistry department. And so that is part of what I wanted to talk about is the sheer number of collaborations that you have. So let's just back up and say you have discovered that in addition to being able to make fuels from this biomass, there are other things that we can do. And you've reached out to partners to look at what that is. You mentioned bioplastics and I know that that is something that is also coming out of our chemical engineering department research. Where do you intersect with the bioplastics? Is the material for the bioplastic residual or is it the same thing and you're both using the same thing? You're looking toward energy and they're looking toward packaging.

Chang Yoo: Actually, they are from the same biomass. For example, currently we are trying to converting some agriculture residual and carbohydrate part, so sugar part, we still want to ferment and make the bioplastic. But the left over lignin also use it for the blending or composing material with bioplastic. So eventually what we want to do is completely utilize the biomass from one single component like the oil refinery. We do not want to utilize one single component in biomass. Always we want to think about all the component together.

Joanie Mahoney: The criticism around electric cars is because if you're using electricity produced by a dirty source, then it's not all it can be. Where is that analogy appropriate in the biomass world? Where are we in being able to say that using biomass is green? What's your expectation about whether we will get to that as really a truly a green energy source?

Chang Yoo: Actually, that's great question. Because when I study my PhD, no one mentioned about the green energy and the environmental friendly material and solvent. Everybody just mentioned about the cost and the price. Is it market available or not? But now people changing their mind. So previously we only say, instead of petroleum, if we use the biomass, the resources is green that is sufficient enough. Now we know. Department of Energy clearly mentioned, not only the starting material or the processing involving any solvent, any energy and water use, they are counted as a environmental credit. If we can reduce and then remove the petroleum enough, then we can say this is green. But even if you use the biomass, too much toxic chemicals and energy input is required. We cannot say this is green fuel, green material anymore.

Joanie Mahoney: And is some of your research working toward making it more green?

Chang Yoo: Yes. So I have one project called it as deep eutectic solvent. So the solvent itself is combined with two different material or three different material without any water or solvent. So solid with certain ratio they're starting to chemically has a hydrogen bonding and become the solvent. And this one has very close to ionic liquid, another strong solvent for many industrial application use.

This one has similar advantage and property with this ionic liquid. However, ionic liquid is too expensive and toxic. So instead of that, we want to use a clean resources to combine and synthesize the solvent. For example, we can use a sugar powder and some amino acid or other aromatic compound just blend together and then heat it up as a solvent. And since the solvent resource are all from nature, we can say this is a greener solvent.

So the final goal of this green solvent application is replacing the petroleum source as much as we can. Also, this solvent provide better biodegradability. So end of life once we use and then dispose to somewhere, it shouldn't be toxic to our environment.

Joanie Mahoney: So the world and the funders, the Department of Energy are looking at the whole life of the process and not just can we use a biomass in place of a fossil fuel to drive our cars down the road? I know you said you were focused on cost because we have to be. If it's prohibitively expensive, then we're not going to get there. So the thing that you just said is heat. I'm curious how you are getting the heat to do the process to get you to the biofuels.

Chang Yoo: So currently people define the heating source with different way. I mean, generally in the industry people use steam heating. So it still need the energy from the electronic resources. It can be from the coal or the nuclear power. So we cannot say that it's clean. So instead of replacing the energy source right now, people develop the technology, reduce the energy input.

Joanie Mahoney: That's what I was wondering. Are we moving to where it's less intensive amounts of heat and energy that you need for the process?

Chang Yoo: Yes.

Joanie Mahoney: Good.

Chang Yoo: So few way. One is by the solvent development, so improve the effectiveness of solvent and reduce the energy requirement for the conversion or as I mentioned before, photoelectric chemistry can bring more clean and room temperature reaction. So generally biomass conversion need hundred or several hundred degree temperature to convert it. But what if we can get the energy source from the sunlight and then convert it to the energy source.

Joanie Mahoney: So we know fossil fuels are bad, but is the process of turning crude oil into the gasoline for the car more efficient or less efficient than creating the biomass fuel out of the byproducts of the corn?

Chang Yoo: So the efficiency, no doubt the petroleum is more efficient. But the thing is after we produce, how can we capture all the carbon dioxide and release the carbon? In terms of efficiency alone still I can say the petroleum resource is better.

Joanie Mahoney: So there's a healthy future for your research program, right? Because we still have a ways to go. I was reading about your work with recycling the solvents and what we do with the waste today. I think I read somewhere in your research that it said eight bushels of corn can make 21.6 gallons of ethanol. So if you had 450 pounds of not corn anymore because we're using the corn as a food source, but the residual material from the corn plant, how much of that is left that needs to be composted or buried? Are you using most of the material?

Chang Yoo: When you look at the chart somewhere in the EPA or Department of Energy, right now in the US, 40% of municipal solid waste are biomass-based waste.

Joanie Mahoney: 40% of municipal waste is biomass?

Chang Yoo: Yes.

Joanie Mahoney: That's high.

Chang Yoo: So that's really high. So we have great potential, not from the harvesting the tree or grass or other materials, we can reduce the waste generation but also utilize it for the future fuels and material source.

Joanie Mahoney: We have great partnerships with paper manufacturers and there's a whole department here that understands the science of making paper and recycling paper. But at some point the fibers become unusable and historically that's been waste. But you're able to use those fibers to study where we can create biofuels.

Chang Yoo: So that is one of project currently we are doing with multiple ESF faculties supported by New York State DEC. We are doing the project which is recycling and virilise the waste fiber from paper recycling facility. So what happen is when we recycled the paper, after use a certain cycle, the fiber lengths is short and then cannot recycle as paper anymore. And as you said, it will be just landfills as waste. But the idea is still the chemical is structurally cellulose is still there. So instead of just landfills and decompose, we just bring it as energy source.

And couple of my colleague in the department trying to convert it to the bioplastic with microorganism. And my team is working on chemically modified surface on the fiber and use it for the waste water treatment. So what happened is PFAS is a well-known toxic chemical in these days because once we produce the Teflon, it regenerate lots of PFAS waste.

Joanie Mahoney: And that's what we call the forever chemicals.

Chang Yoo: Yes, it just forever accumulates in the human body and then that is the reason why 2017 or '18 there was a big issue with the DuPont facility produces and then release these PFAS in the river and then people get the diseases from the PFAS. So this one is very unique structure, very rigid and then it's not easy to decompose. And even the concentration in the water is very low. So it's not easy to catch it.

Joanie Mahoney: So you can use this waste product from the paper mills to get the PFAS out of the water.

Chang Yoo: You're right.

Joanie Mahoney: That is fascinating. And that's part of the research that you're doing? Was this a surprise or was this something you were aiming to do?

Chang Yoo: No, people are already doing with pure cellulose. But our idea is instead of cut the tree and then make the cellulose for the material, why not we just virilise the waste from the industry for waste water treatment? And another advantage is after we catch it, the question is how can we dispose it? So this catched material, we can just put everything in the furnace and incinerate together. Then we don't need to worry about the second contamination. So once we incinerate, it doesn't generate any toxic chemical. Only PFAS is decomposed in the furnace.

Joanie Mahoney: Okay. So the PFAS that we all think of as forever chemicals and they're in the water and there's nothing we can ever do, turns out your research is making it possible for us to get them out of the water. And then if you incinerate a PFAS it goes away?

Chang Yoo: So it will be decomposed and then at least it won't exist as the chemical structure as is anymore. So many people are working on break the PFAS, but the chemical structure is so hard. So people need lots of energy and the chemical and catalyst to break it. But in this case, yeah, we can just burn everything in the furnace.

Joanie Mahoney: That is very encouraging and that's one of the common themes about the conversations I get to have with faculty at ESF, is you leave encouraged because you hear so much on the news about all the doom and gloom about the damage we've done to our environment and some of these issues sound impossible to fix, they're completely intractable. And then I sit with faculty at ESF and you hear, oh, we're finding solutions and we can make these things better. And what we need to do is make sure that we are supporting your research.

All right. So switching gears a little bit. There are tons and tons of waste already in landfills before you came along and were working alongside some of your colleagues to find beneficial use. There's biomass 40% in these municipal waste facilities. There's an awful lot of plastic too. Are you able to use some of the petroleum based plastic waste in your research?

Chang Yoo: Actually, that's very interesting question because people are facing that challenging and the people has lots of different direction for solving that problem. For example, one of my projects is waste plastic collecting it and then combined with biomaterial and then make as a composite. Because if we just dispose and then break down to the small particle again and then regenerate the plastic, need lots of purification. When you look at the video for the recycling facility in California, actually still most of them are by hand. They are not using the machine for the sorting the plastic and the glass and with better materials.

So the problem is it cost too much and it's not easy to cover the large quantity of municipal waste. So the idea is, okay, then instead of sorting everything, we can just collecting some part and then purify but not completely purify. So make it as blending again as a high temperature, melting it and then make the composite to cover lots of different materials.

Joanie Mahoney: So you're saying some biomass, some plastic trash can be combined into a composite that's lighter weight than had you been using pure plastic but capable then of using as a material in Boeing 787? Which is happening now. We have a policy where we don't have single use plastics and people being aware and using less plastic is a good start but there's so much already out there. And if you can scoop that all up together and use it on things like a jet airliner and it makes it more aerodynamic and then I would imagine it then since it's lighter will use less jet fuel and there's another environmental benefit, make it more fuel efficient until we figure out how you're going to make us some biomass jet fuel.

Chang Yoo: So production of jet fuel, generally we need certain carbon lengths longer than gasoline. So for that technology, people generally use instead of ethanol fermentation, break it to the hydrocarbon with thermochemical method. The problem is, to make the hydrocarbon from the biomass, need lots of energy and also catalyst is expensive. People normally use platinum or some palladium, like very expensive rare chemical catalyst. And what I'm doing right now is replacing this expensive catalyst to copper or nickel, which is also abundant.

And also reduce the energy input by process development. We try to figure out how to reduce the energy input for the conversion of the biomass. So biomass itself can be converted to the hydrocarbon theoretically, but the main challenge right now in technically is because of energy and cost input. So our team is working on how to make it more efficient.

And another thing is you mentioned plastic. Go back to that question. Plastic alone can be recycled by the some chemical method. Biomass can be converted to biofuel and hydrocarbon fuel. But actually recently lots of papers reported, once it is blended with a certain ratio, it has a synergytical effect. So even the product yield is higher than single conversion of each of them.

Joanie Mahoney: Interesting. So some plastic, some biomass, the composite is greater than the sum of the two parts?

Chang Yoo: Yes. So that question is, do we really need to sorting all the waste or can we just manage a certain blend ratio, maybe just convert everything together? Still this is early stage, but people noticing this synergetical effect and then trying to develop the process with this blending material than the single material.

Joanie Mahoney: It has to start somewhere. And again, I'm just always fascinated by the kind of work that's being done here at ESF that you know is informing the next steps and the next steps. I want to switch gears to a couple different topics. One, is you've been working with high school students locally. How are you doing that?

Chang Yoo: When I got the NSF funding, I realized that one of the mission in NSF is outreach and then helping those STEM student and then also especially under represented student. So I talked with my two colleague. One is Dr. Leem in chemistry at ESF and Dr. Jane in SU. Both of them also has a NSF project and we had the same mission. So we tried to discuss how to recruit the student and then develop the program.

So first year we just develop the program as a pilot testing with six high school student from FM School area and we invite them and then introduce two days about what is the biomass, what is green energy and how we convert it? And it was really success. First student brought lots of great feedback to us and especially two student decide to have research experience with us further. So we did two year project with the high school student and even they published the high school journal articles.

Joanie Mahoney: Oh my gosh, that's incredible. What a great outreach program for us at ESF that you've folded this into your grant.

Chang Yoo: What we realize is students are already interested. I'm looking for interesting topic for their future. The problem is how can they expose this opportunity and how can they get this information?

Joanie Mahoney: A lot of these conversations I've had with faculty remind me of career day when I was in elementary school and what do you want to be when you grow up? This was never an option. So you grew up in South Korea and you saw firsthand the issues this small island had without its own natural resources, you said, and energy was an issue. How did you end up specifically studying what you're studying? Did you have a mentor along the way that was interested in this area of research or was this all organic to you?

Chang Yoo: The lucky thing for me is when I did my master study, I was not just focusing on my research alone, I was browsing the opportunity for any other research topic. I attended actually one seminar and then during the seminar the invited speaker was from US. And then that speaker talk about the future biofuel and it really inspire me, okay, this is the direction I want to study further.

Joanie Mahoney: That was the spark?

Chang Yoo: Yeah.

Joanie Mahoney: And you were already a master's candidate at that point?

Chang Yoo: I was a second year master student. So I had to decide, should I go with the same topic for my PhD or should I change the gear and finding something more interesting? And that was the point I decide, okay, I want to go to the biofuel. So that inspire us a lot and that is the reason why... Back to the outreach program. After first year, we got the interaction with the student and they get the feedback. What we realize is with the three faculty at ESD, we have limited capability to cover the high school student. So even if we expand 20, 30 student still we cannot cover the entire area, even the Syracuse area.

So what we did in the second year, actually last year, we did was we developed some material student can do at house or in other place. So we did this outreach in second year hybrid. So student here from local area we invited but we also recruit seven to eight student from Texas Rio Grande Valley, which is the border of the US. And we just recruit to one faculty there and then we do her help. We remotely, we send all the material to there and student just open the box and then put all the material and then doing the same thing with us with the Zoom.

So we just introduce everything with lecture and then they followed by the Zoom. And then eventually at the end we can just get together with Zoom again and present what they learned during the program.

Joanie Mahoney: Wow. Zoom has been like magic for people. It's extended our reach so much and we've now begun to understand how we can do things like that. And people have talked about how it doesn't translate as well in a STEM education because it's so hands on. And then did you also participate in a cohort of students focusing on water?

Chang Yoo: Oh yes. After that event, we had a chance to talk with our COE solution team and then they-

Joanie Mahoney: So, we have a center of excellence in partnership with Clarkson University in Healthy Water.

Chang Yoo: You're right, yeah. And they were looking for the outreach opportunity as well. So we volunteered. We have connection with the high school. So why not we can try with the water research. September we invite few students for the pilot program again as we did for another program. And then yeah, we successfully invite six student from the local high school student and they did a great job for the first outreach program with us for the water purification and how water... I mean, waste water can be treated with variety of technologies.

Joanie Mahoney: Will they get exposed using the fibers and positively charging them and trying to get the PFAS out of the water or is that a little bit advanced for the students?

Chang Yoo: No, because of the PFAS itself has some safety issue, we have limitation for the location and device for the PFAS capturing. So when we introduce any material for the high school kids or any other public, we try to make everything nontoxic.

Joanie Mahoney: Yeah, good idea.

Chang Yoo: So they can generally see and then they can learn the theory, but we do not use the same toxic material [inaudible 00:34:01] purpose.

Joanie Mahoney: Thank You on behalf of the college. But I will say, there's some irony in PFAS being too unsafe for us to use with high school students and meanwhile we're all ingesting them every day. And we hope maybe that won't be the case forever if we can figure out how to get them back out of the water. So before we finish, this area of research is just so interesting and it's broad and the potential exists. You could pull a thread and spend the rest of your professional career on some component of it, but you seem to have your hands in a lot of those different places. How are you able to just logistically be part of so many different teams and so much that's going on?

Chang Yoo: Yes. 40% of my position is about teaching and I do 20% service as well. Research is my major lore, but research is not everything. But good thing is we are doing the cluster hire. And what I learned when I work in Oak Ridge National Lab is I don't need to be the expert for everything. I can just use my strengths and then finding the right collaborators. Then we can make greater product within... I mean, more efficiently.

Joanie Mahoney: Yeah. That is such a good lesson for early career faculty to hear that are getting research programs up and running is you don't have to have the expertise in every part of it. Bring your expertise to the team and make something bigger with that collaboration.

Chang Yoo: Recently actually, I got email from our party this morning. They will officially award $2.5 million project to us. I mean, we are the part of the project, but they will award this one to us. And this project originally we proposed last year as ESF team. So we had a chemist, we have a chemical engineer and then construction engineer and then techno economic analysis and the life cycle analysis expert. And we couldn't get the funding last year because we were not strong enough in technical part. Luckily I was in another team. That team has very strong chemistry and engineering but they do not have any construction engineer. So this year once we applied funding, I just proposed to both team, why not we just combine and make the greater team? So we work with the University of Tennessee, actually this is leading institute and University of California and Clark Atlanta University with ESF.

So four university make great team from the chemist, engineers, economist and then construction engineer. And then we got this $2.5 million project from the Department of Energy.

Joanie Mahoney: That's fantastic. So in addition to being such an incredible researcher and teacher, you also have to be a networker because you have to find colleagues at institutions around the country. And in your case, around the world. You have some international collaborations that you're part of.

Chang Yoo: Yes. So last year, luckily I have one visiting scholar from South Korea. And after a few months he realized that our unique ESF education system will be beneficial for his university. So this professor is from in Inha University in South Korea and he's in the Department of Polymer Engineering and he tried to connect their program with us. So we got the MOU last year and actually we got the first visiting exchanges student from Inha University in our program this semester. And also we got the MOU with them for the two plus one master program. So study two year in Inha University and one year in our department. Then they can get the degree from both university.

Joanie Mahoney: That's fantastic. And again, it is such a benefit to the college as a whole to have you out there doing that kind of work. And before we say goodbye, I just want to thank you for stopping and taking time and talking about this. I find your area of expertise to be fascinating. I find it to be the source of a lot of hope that we're going to make things better. If there's something we can be doing to support your work, I hope you'll call on me. Thank you so much for sitting and talking to us today.

Chang Yoo: Thank you so much for the opportunity. And yeah, it's great for me to introduce my research and also introduce the collaborative work with the rest of ESF faculty with me.

Joanie Mahoney: Yeah, you definitely highlighted the work of some other ESF faculty. So thank you.

Chang Yoo: Thank you.

Joanie Mahoney: We'll see you soon.