Amy Cannon, John Warner, Natalie O'Neil

0:05
Welcome everyone to our Green Chemistry Education webinar. We are very happy to have you here gathering with us virtually from all over the world. Today's presentation will feature Dr. John Warner, our Co-founder and also a Co-founder of the field of Green Chemistry.

0:24
My name is Amy Cannon, I'll be your host today. I'm the executive director and Co-Founder of Beyond Benign, a non-profit organization dedicated to Green Chemistry Education. The name of this webinar series has been updated to reflect the time that we're currently in. Green Chemistry Connections is something that I believe all of us are striving for at the moment.

0:50
In a time where we are all having to distance ourselves, it becomes so much more important that we try to connect as best we can. So, today's webinar is also being brought to you in celebration of the 50th anniversary of Earth Day, which is near and dear to my heart. Earth Day back in 1988 was the day that began my path to Green Chemistry. It was my first time researching a sustainability issue, actually ozone depletion, which theses brilliant scientists down the road from us here at MIT had cutting-edge research coming out right at that time.

1:24
I created a booth as part of an Earth Day fair at my Junior Senior High School. From that day on I knew I wanted to save the world; I just didn't realize it at the time that my passions for this space would bring me to Green chemistry. So, I'm so happy today to celebrate Earth Day with you and talk about this topic. This topic that is addressing and solving sustainability issues. All these sustainability issues that I began studying and learning about all those years ago, but addressing these issues at the molecular level. So, with that, happy Earth Day!

2:03
We are thrilled to have so many folks from different countries, different backgrounds joining us today. At Beyond Benign, we work across the continuum from K-12 to Higher Ed and Industry as we prepare and support scientists and citizens to address sustainability through Green Chemistry. We see education as central to achieving a sustainable society and we need to work together to properly train and prepare students, educators, and professionals to face today's challenges and tackle sustainability issues. I know we have K-12 teachers, college, university, faculty, students, along with industrial scientists and leaders joining us today. We all have central roles to play as we build a sustainable future together.

2:51
This webinar is being brought to you by Beyond Benign, where our mission is to foster a Green Chemistry Education community that empowers educators to transform chemistry education from cradle-to-career for a sustainable future. Building this community is now more important than ever. Thank you for being part of this today and we hope you stay engaged and involved. So, please do sign up for our newsletter, which you can see on our homepage, on the bottom of our homepage, to be notified about any upcoming

webinars and opportunities in K-12, college, university, and professional education. If you like what you hear today and would like to contribute, please do so by using the donate link on our homepage.

3:37
I also wanted to take a brief moment before we begin today to thank so many of our sponsors and partners. These companies, foundations, and organizations have been essential in advancing Green Chemistry Education, and we really can’t thank them enough for their continued support.

3:59
So, reviewing some logistics briefly before we get started. We are broadcasting live from our homes and recording this session. All attendees are in listen-only mode, and all lines are muted. If you have a question, please type it right into your question/chat box on the control panel for our moderators to view. We have a fabulous set of moderators today, our two program managers: Natalie O'Neil, our Higher Education Program Manager, and Janie Butler, our K-12 Program Manager. After John's presentation we will respond to as many questions as we can. The recording will also be posted in the link that you can see here, and we'll also make sure we put it in the chat box too and any supporting documents. You will actually receive a link to the recording in your email inbox tomorrow as well.

4:56
For those of you who participate in social media, please connect us with us through Twitter or Facebook. We'd love to hear some live tweeting going on. If you're joining us as part of a virtual class or event, let us know in the chat box or in social media. And also let us know where you're joining us from across the globe. I know there's lots of people joining us from many different countries. In fact, we have our fabulous Juliana Vidal here joining us all the way from Brazil to help with the conversation on social media during this webinar. So, please reach out to her throughout the discussion today and thank you for joining this webinar and being part of this community. So, now finally on to the main event! We're thrilled to have John speaking with us today on this 50th Anniversary of Earth Day! I'm going to introduce John and then we'll hand the controls right over to John.

5:53
So, Dr. John Warner is one of the Co-Founders of the field of Green Chemistry, writing the defining book “Green Chemistry Theory and Practice”, and also the 12 Principles of Green Chemistry with Paul Anastas over 20 years ago now. He's a Co-founder and Director of Innovation and Industrial Training here at Beyond Benign. He's a Co-founder and President of the Warner Babcock Institute. He's a Distinguished Professor of Chemistry at Monash University in Australia. He's received so many honors and awards throughout his career. Most notably as an industrial chemist, he received the Perkin Medal, the highest award in industrial chemistry. As a professor, he was honored in the Oval Office with the Presidential Award for Excellence in Science Mentoring for bringing women and underrepresented minorities into the chemical enterprises. As an inventor, he has nearly 300 patents. He's worked with over 100 multinational companies. 15 of his inventions have been assigned or licensed to various companies. His inventions have served as a foundation for new companies in asphalt paving, hair color restauration, photovoltaics and ALS drug therapies. He's been named a Lemelson Invention Ambassador. He's also done extensive work with government agencies, supporting and advising agencies in Massachusetts, California, the US Federal

Government, the European Union, in the state of Victoria, and Australia. He's received the Reinventing Government Citation from vice-president Gore, helping to create the Presidential Green Chemistry Challenge which still remains today. The German Ministry of Economic Affairs in TU, Berlin, recently created the John Warner Center for Green Chemistry startups in Berlin. He's received the American Institute of Chemists Northeast Division Distinguished Chemist of the Year. He's a fellow of the American Chemical Society, the Royal Society of Chemistry and the Royal Australian Chemistry Institute. Utne Reader called him "one of the 25 visionaries changing the world" and ICIS named him "one of the most influential people impacting the global chemistry enterprises" and that he is. So, with that, I am happy to hand the controls over to John and, take it away John!

8:23

Thank you Amy and thank you Beyond Benign for organizing this webinar, and thank everybody for coming and joining today on Earth Day for its 50th Anniversary Celebration. I hope that everybody is safe, health, and happy and your family is managing and weathering the COVID-19 realities of today as best as we can. Hopefully as we share some time together this little bit of a silver lining that we have opportunities now to be more with our families and to be able to gather together like things like this. So, thank you.

8:53

I want to start my presentation by just beginning with a disclaimer that I don't claim to have any gifted insight. I don't claim to have all the answers to any questions or anything like that. I am not so presumptuous to think that I have any better view of the universe than anybody else does. So, if I come off sounding presumptuous at any point, that is an accidental affectation of how I'm talking. Because the way that I look at it is, I've lived my life just like everybody else has. I've been a professional chemist for about 35 years. The first decade of my professional life I was an industrial chemist working at the Polaroid Cooperation and then subsequently I've been on Dow Sustainability External Advisory Council and I worked with Cefic in the European Union for the Green Chemistry Boot Camps. The second decade of my life I was an academic - a full professor of chemistry, a full professor of plastics engineering, director of biochemistry. We created the world's first Ph.D program in Green Chemistry at the University of Massachusetts. Subsequently, I've been working with Beyond Benign, in these other universities. As an entrepreneur, I founded the Warner Babcock Institute for Green Chemistry with Jim Babcock, and then subsequently had other spin out from our technologies, Hairprint, Collaborative Medicinal Development, Collaborative Aggregates, and Ambient Photonics. And then throughout these 35 years, I've had the opportunity to interact with different government agencies. With the Presidential Green Chemistry Challenge in the U.S. here, but also with Massachusetts, California testifying to congress a couple times and then the Strategic Advisor at the EPA in Victoria.

So, the way I look at this is that, through my life I've had the opportunity to see how we do chemistry, how we teach chemistry, how we invent chemistry, and how we manage chemistry. For me, if we were truly going to have a sustainable future, we're going to have to make changes in all the aspects of the chemical enterprises, not just in one. And this is about how we can work together. Yes, the professional chemists are central to this because we're the ones that are inventing the new technologies, but we can't do it alone; we need to have help, we need to have collaborations. And so, I thought what would be useful for today's presentation is to give some thoughts about the duality of chemistry being the central science, so to speak, of all this; but then the reality that we chemists can't do it alone, and how to think through these thoughts. Chemistry, as we know, has done some really amazing things for us, society! We've got a lot to be proud of; when we think of the agricultural progress that's been made over the years. I found this graph that shows an 82% increase in global food production since 1990. The way that this has been accomplished it’s through the invention of chemical things, like pesticides! And it should not be ironic to anybody that, as we've gotten 82% increase in global food production, we've got the 78% increase in the pesticide usage across the world. So, we can see this and that's a lot to celebrate, but as far as increasing the distribution of food to the world's hungry. But of course, there's the negative aspects too. We open up the newspaper, turn on the radio, look on the internet, and we hear about these reports about pesticides in our food supply, the hazards of these things, and the toxics of these things. There’s the good and there's the bad. When it comes to electronics, again we've done some amazing things in electronics! If you look just in the microelectronics industry, there’s this thing called Moore's Law that is talking about the production of the number of transistors on integrated circuits. Since 1970, you can see this amazing increase in the science and the development of miniaturization, and the faster and faster speeds.

13:11
I'm sure everyone on this webinar has heard the line that our cellphones have more computational power today than the Apollo space mode promotion, and I mentioned. So, there's amazing things that we can celebrate! But of course, there's the negatives, the e-waste problems that we are being inundated with. When it comes to energy, there's many advances. I just decided to illustrate in photovoltaics. You can see that in the world’s photovoltaics and solar research, the efficiency of devices is going through the roof. The developments are amazing! But of course, from the other aspects of energy, we all know about IPCC, and the climate change and the predictions of CO_2 and global warming. You open up the newspaper, you turn on the radio, you look on the internet… There’s the good and there’s the bad. When we talk about pharmaceuticals, check this out here: The SEER Cancer Statistics review shows that since 1975 the survivability, once diagnosed with cancer, has increased over 50% for the 10-year survivability. It’s amazing stuff that's happening in the pharmaceutical sciences! But of course, you open up the newspaper, turn on the radio, look on the internet, and we hear about pharmaceuticals in the environment, the hazards, the problems with this getting into our waterways, in our lands. With materials, it’s kind of interesting when you think of it. Right now, there’s a very hot topic about finding out plastics in the environment and materials and everything. We’ve got to remember that there is a massive amount of global population that is in an economically distressed scenario, where the offering of lightweight inexpensive plastic has actually been a game-changer for survivability. And it's an interesting and somewhat poignant reality that in 1990 the global production of plastics actually began to outpace the global production of steel. And so, while there is a lot to be proud of and to celebrate, you open up the newspaper, turn on the radio, look on the internet, and we hear about plastics in the ocean, in the environment, and things like that. So, it's interesting that, the chemical sciences, when we think about the impacts in the service and society, we in science think about matter. We wrestle with this concept of “the duality of matter”, that matter has a wave aspect to it and a particle aspect to it. And it's interesting to recognize that, when it comes to chemistry

and service to society, there's a duality; there are some positive attributes that are happening and there's some negative attributes that are happening. And if we're going to have a sustainable future, then somehow we need to rationalize this dichotomy. So, we're blessed to have so many wonderful movements, so many wonderful philosophies, so many wonderful programs, cradle-to-cradle, resilience, natural capitalism, the circular economy, responsible care, limits to growth, biomimicry, the UN SDGs, the European Green Deal, Alliance to End Plastic Waste, Green Chemistry… There's just so many approaches that we look at all these and we say: "How do I fit in? What is my role to play?"

16:38

The most important thing that I think we need to recognize, is that the truest… When you look at all approaches to sustainability, when you look at all of the problems that have happened in the past, one of the things that seems to me to be a recurring theme is: The absence of a respect of diversity always leads to trouble. And what we need to do is not be competition, not be looking at one being a successor to another and one movement being better than another; and recognize that they all have important roles to play, and every individual in society is going to match up to some other than the other because their particular skills will be in sync to this. What we need to really do is map out; all this stuff all fits together. I love this quote from, personal here, Mahatma Gandhi: "The difference between what we do and what we are capable of doing would suffice to solve most of the world's problems." This is something that we need to recognize is that, we're capable of doing a lot of things, either socially or through technology. We need to unlock this human potential and find out that's only going to happen through collaborations and cooperations with one another. So again, remember my disclaimer. I don't claim to have any gifted insight. I am not a specific definitions word person. So, please as I use different words, don't get hung up on what specific semantics I'm using. Hopefully we focus on the concept here that I'm presenting, and this is a work in progress, so I'll probably evolved the way that I phrase these things. But try to kind of put together: "What is this whole process?" We start with natural resources, we extract from natural resources, and we make molecules and ingredients. Then we take these molecules and ingredients and we use the tools of synthesis to make materials and components. Then we manufacture products using those materials and components. Then we hope that the highest form that we can have of sustainability is to maintain a system in which these products stay in use or in re-use. And then when that fails, we have to go back to the materials and components, using what people refer to sometimes, as mechanical recycle. When that has problems, we go back to molecules and ingredients with a term that I use, molecular reprocessing. And then at the end of the day, we have to go all the way back to the natural resources and what could degradation and biodegradation achieve. What's interesting is, if you look at this process, each one of these verticals have different skill sets and different types of needs required for us to really push to a sustainable world.

19:42

So, in the manufacturing and recycling we can think of this as trying to maintain a closed loop. When we think of synthesis and molecular reprocessing, I refer to this as materials metabolism, and I'll talk about this a little bit more. Then when we get down to the to the end here, we're looking at regeneration and how can we have these extractive processes. Actually, ultimately have some regenerative ability within it. So, if we look at this whole thing from beginning to anything, how does this all fit together? Well in my way, and obviously nothing is cut and dry and there's overlaps all over the place. But in one way, the circular economy addresses on the product side of this equation, and Green Chemistry kind of addresses the molecular invention part of this. Obviously, like I said, there are aspects of Green Chemistry and use and re-use, apects of circular economy and natural resources. So, of course this isn't these perfectly well-defined boxes, but it's a useful way of kind of passing out how this fits together. So, let's go into each of these verticals a little bit more. I think it's useful to focus into each of the verticals.

20:52
The first one is use and re-use. Janine Benyus is another one of my personal heroes and the author of “Biomimicry” and the founder of the field of biomimicry. She does she have it right when she says that 3.8 billion years of evolution and life on Earth; the nature have figured things out and we humans have an opportunity to do this.

21:19
So, if we look at each of these verticals, we look at these verticals through the lens of the natural world. Some things that we can think about: So, when we think of use and re-use, for example, a hermit crab. A hermit crab as it grows, it leaves the little shell and it goes and finds a bigger shell. That shell is being re-used and it goes from hermit crab to hermit crab. We humans, what we try to do, is we try to make car parts and things that last for a very long time, stay in commerce as long as possible. Obviously something like a playground, we don't want that changing every day or every week, we want these to be durable goods, we want this to last for a long time. If we make something to be re-usable, something that’s now kind of like the hermit crabs shell… One way to think of this, one way that I proposed for us to think of this, is to differentiate the design product aspect of something and the molecular composition of something. When we use and re-use something, we conserve the molecular composition **and** we conserve the form. So, both the composition and the form are maintained. And we do this as much as we can because that keeps us at the highest state. But what ends up happening is, entropy ultimately rears its ugly head and says: “No, I'm not going to let you do that anymore!”. And things break. That's just the reality that we're stuck with. What happens when things start to break? We shift to the next vertical of the closed-loop concept in which, in nature one way of looking at this is, a bird will go get twigs and rocks and things like that and build a nest. A beaver will go find pieces of things in the forest and maybe cut down a tree to make a dam. We humans, when we try to re-use materials in different ways… Like with plastics? What we'll do with mechanical recycling of plastic? We will collect them, will sort them, will shred them, will melt them, will granulate them, so that we can keep plastics being recycled, and recycled, and recycled. When we do this vertical, what we're doing is conserving the molecular composition, but we are changing the form. The twigs on the ground are now about a nest in the tree, the bushes and the things on the ground are now a dam in the river, the plastics have been cut and shred for whatever they looked like before, they might had looked like a cup, they might had looked like something else, but they've been shredded and they’ve been turned into a different form, but the composition... The intent is to maintain that composition and of course that happens until it doesn’t; entropy rears its ugly head.

24:13

If you look at the molecular structure, if we look at polymers, every time we do mechanical recycling, there's the statistical chance that these materials start to break down; the molecular weight of the polymers start to get smaller, and the mechanical properties start to degrade. So, what happens? We have to shift to the next vertical, and that next vertical is what I refer to as materials metabolism. When we talk about materials metabolism, we're talking about large molecules being converted to small molecules and small molecules being converted to large molecules. We have catabolism and anabolism, and nature has evolved a spectacular way to do this in a dynamic equilibrium. I use as an illustrative example, if giving me my wife and my daughter Natalie, it's an older picture of her… What happens when we eat food? In nature, how does biology organized itself so that when we eat food, what do we do?

25:18

Well interestingly enough, if we were design by humans, if the biological system was designed by humans, what would we do? We would break down the protein, separate the amino acids, purify them, have a little truck, maybe store glycine, in one finger, and alanine in another… we would take the carbohydrates and put glucose over here, and ribose over here, then maybe throw some lipids here. But that's not what nature really does, right? What nature does is that, simultaneously, as we break down molecules, we form new ones! As we're eating, we're growing hair, we're growing fingernails, we're growing blood cells. Nature has figured out how to do these things at the same time. This is the materials metabolism of nature. But in this time here now, what we're doing is in these processes, the molecular composition is being altered and the form is being altered at the same time. So, both form and composition are being altered. Of course, what makes nature do things so much better than we humans is that, not only does nature couple the molecules; nature couples the energy, that all the sudden energy is also part of this thing! The amazing invention of ATP, adenosine triphosphate! Most metabolic transformations occur with these phosphate groups being energetically moved back and forth, the electron repulsion of these oxygens, this potential energy that we push energy up a hill, we push energy down a hill, we make molecules, we break molecules… Nature has figured out a way to couple these things, and we need to learn so much from nature. And then the last vertical, after we've done that, as we've got to look at: "Okay, well what happens at the end of this?" If it's going to go back to nature, how is it going to go back to nature and this regenerative cycle? Anyone who's inspired by nature, you can't help but be inspired by termites making termite mounds, and dung beetles doing the things that they do, and bees tracking… You're getting pollen, and wildlife eating their prey… This is an amazing circle of life kind of thing where nature has certainly figured this out, and as we get further away down to the left in this diagram, we find that we become as more, and more, and more unnatural. We look at the ways that we do our extractive technologies, and our extractive technologies on the right here don't look a whole lot like the things on the left.

28:04

And so, what's going on? Well, in this case here, it's useful to see that we're altering composition and we're conserving the form. It seems to contradiction, but when you really get down to it, you see what I mean? It's the composition is being changed while the form is being held. But this isn't the end of the story! If we look at this map and we say, okay, where does everything fit on this map? I would argue that if we spend a great deal of time mapping everything out, we would look at this and be very satisfied. Well, this looks pretty sustainable. Yeah, we got some problems. But what's on this picture here looks really good! Well, the problem is, not everything is on this picture yet. Because what happens is when we extract, we have leakage; when we synthesize, we have leakage; when we manufacture, we have leakage; when we use and re-use, there's leakage. Leakage, leakage, leakage… This thing is leaking like a sieve! These things here are not in the loop! These are things that are falling out of the loop. And we as humans, yes, we can describe the system the way we hoped and wanted it to be, but there's always going to be the inevitability of things not going the way we would like them to go. In those cases, we've got to ask ourselves: "How do we address this?"

29:27

So essentially when we look at this, going to the right I would argue is leaning more towards behavioral modifications; product design adopting behavioral changes. As we go to the left, we're talking about technology innovations that are compatible with nature. Clearly this is not cut and dry and there's overlap in both directions, this isn't an absolute here. But the point is, we are not going to get to where we want to go just by doing behavioral changes in society; we need technology that's going to help us. And we're not going to get there with just technology; we need behavioral changes that help facilitate the technologies and steering direct what technologies need to be created. So, at the end of the day, there's got to be some way to put this behavioral stuff and this technology stuff together.

30:22

What's interesting for my perspective is that if we map out these things, conserve form, conserve composition, alter form, alter composition, alter form, alter composition, conserve and alter there, the vertical here, the materials metabolism vertical, we're altering both the form and the composition. So, from a design stuff ethic we've got the most degrees of freedom, the most design opportunities in this space. So, it's absolutely critical that we address these issues and find ways to use the tools of chemistry along with all the other things. Of course, I have a bias here, this is kind of what Green Chemistry is all about, the 12 Principles of Green Chemistry, and the acknowledgements that, for us to truly have sustainable innovations in Green Chemistry, we need to have things that are more environmentally benign, but we also have to go beyond benign and we have to look at how things perform and what things cost. Only if we have safety, performance, and cost do we have what I feel is successful sustainable Green Chemistry. And this can only happen through massive collaborations with a great group of people. Let's look at this in a little bit more focused area. Let's image there's a field somewhere. We humans get together, we decide we're going to make a pond. We dig a hole, we fill it up with water, we put in some fish, we put in an animal and a couple of trees. We come back a little bit later and everything is dead. We are not just smart enough to figure out this thing again, the 3.8 billion years in the millennia of trial and error, of nature, of creating these delicate balances and dynamic equilibria of materials and energy. Something that we are struggling to do, but it's not impossible. Over the last few decades, with time, we figure it out. Yeah, here is a pond. It's Amy and Natalie at a pond. It's little bit older this picture. This pond works because it wasn't designed by us, humans. It evolved through the millennia, so the birds, the bees, the bugs, and the bunnies all figured it out how to this dynamic equilibrium to successfully coexist. We have started to scratch the surface of this. Here is the metabolic pathways that have been mapped out in the organic cells, and you can see the complexity here. And one can look and say: "Oh my God, this is so much to understand!”. We've really only scratched the surface, but we've demonstrated that we can do this; that we can understand how dynamic equilibrium and nature can be supported and sustained. So here we are now at 2020, there’s the factory in China, there’s the factory in Asia, there’s the factory in Europe, there’s the factory in South America, there’s the factory in North America. We've got the electronics industry, we've got the pharmaceutical industry, the cosmetics industry, the textiles industry. And here we are in 2020 trying to find a way to weave them all together, to have some kind of a balance, to have some kind of a circularity here so that we can share resources and share ways to do things. But man, is it hard! And the reason that it's hard is that these things, unlike nature that coexists together, these things were designed completely in isolation of each other. They were not aware of each other as the pharmaceutical industry did what it did, and the electronics industry did, and this factory was built… There was no, at the design stage, trying to understand how things fit together. And so now here we are! Scratching our heads saying, “How can we do this? And although it's difficult, it’s not impossible because there's one thing that connects all of the things on this slide: Chemistry. And if we can work together, chemists and non-chemists, to find aspects of each of these different things and find how can we make them sit together, we can pull this off. So, if we look at this loop here, and we look at the circularity of the system of natural resources, manufacturing, distribution, use, and collection. This is a loop. The problem with a closed loop is, it presupposes that everything we want is in that loop. And yeah, I think we need a few more inventions here. So, where would invention fit on a closed loop? So, me being the twisted person I am, I see a little twist in this diagram and essentially have put in a Mobius strip here and I said: Okay, so we have the materials ecology with a materials go but we have to superimpose on this, what I call the intellectual ecology, the basic research, applied research, development, scale up, commercialization… These have to work together in an intimate relationship with each other. We need to be learning from the people on the front line of making products and the people that are inventing and creating behavioral changes and all that. So, the materials ecology and the intellectual ecology… It's not like a mini Venn diagram. It's not like a spoked wheel. I love the Mobius strip analogy because the Mobius strip is intimately in contact to each other at all points. And so, it's useful to think of it from this perspective.

35:54

Again, my disclaimer of my presumption here… I don't claim to have the answers, but here are some observations I’ve made about looking at what I call materials metabolism and nature's mechanisms that we can learn from. If you think about it, we humans, oh my goodness! We have such a non-sustainable way of looking at chemistry and materials… Listen to our language: “We break bonds, we make bonds, force things to do what we want them to do”. It’s almost as if you can imagine, as my iPhone comes off of the assembly line, you can hear the molecule screaming “No!”. They want to go back to where they were before we force them to do what we want them to do.

36:40

Lynn Margulis, amazing biologist, wrote this book “Symbiotic planet” and I love her philosophy that evolution isn't about the survival of the most dominant prey, the fittest; it's the survive of the most compatible. And I think we need to take this kind of cue from our materials. I do this jokingly, when I say we need to put our molecules on a couch and say: “What do you want to be?”. If the molecule looks up at us and says: “I want to be a paint”! Well, it's going to be a heck of a paint, right? If it wants to be a paint, it’s not going to fade, it’s not going to chip. If we force the molecules to do what we want, those molecules are going to fight us back. But what I mean by this is, instead of forcing the molecule, we play the role of the discovery; we look at the molecular topography, the electron density, the lipophlicity, and we try to figure out how to make these things work. That's where it's at! Put the ego aside a little bit, try to be a little bit more “learning from nature”. And so, I've come up with these five mechanisms of nature that I want to quickly go through. The first mechanism that I've noticed is triggered change. Think about this for a second. We eat our breakfast, we eat our lunch, eat our dinner. The enzymes and the chemistry inside of us stomach digests it. Do you ever think, a hamburger looks kind of like us! Why does our stomach digest the hamburger and not digest itself?

38:13
Well, the reason, the way that this works, is that we have triggered chemistry! The enzyme pepsinogen, that essentially gets clipped, and a blocking group gets removed from it, and the active form happens. In nature a triggered event happens to control before and after. Think about neurotransmission. I scream at you: “AH!”. You get scared, you jump. What happens when that happens is, you've got neurotransmission in which, coming on the forward side of a neuro junction, you've got the signal coming down, you've got neurotransmitters passing through the junction, binding to the receptors to induce the change that goes down and propagates to your neuron. Whoa, how does this calm down? If this is flooding the gap, we're going to stay screaming and yelling, and with the arms up overhead all the time. The way nature has triggered the cessation of this impulse is that the acetylcholine which is the neurotransmitter, is broken down by acetylcholinesterase in two parts that are now inactive. That inactivity stops that from happening. Nature changes things by triggering. We think of an analog response; we turn up the volume on a radio, it’s loud. This isn’t a very natural way of things happening. Think about a solid; ice isn’t 20% melted at one temperature and 50% melted at another… No! It's a solid, it's a solid, it's a solid, then it melts and then it goes on further again. If we use this kind of transition, we use this lens at looking at our products. We look at these triggered events; we’re talking about in one state stability, performance, and another state, product stability.

39:59
We need to do this for biodegradation in the environment. Here I have my milk carton. We want to make a biodegradable milk carton. The problem is that, what we don't want, is when the milk carton is in the refrigerator, we don't want it breaking down and leaking then; we want it to break down when we want it to break down. So maybe we need triggered degradation. We don't need an analog response; we need a triggered response. A very quick example of using this technology, one of the commercialization’s we did at Warner Babcock Institute for Green Chemistry is Collaborative Aggregates, the spin-out company that is commercializing asphalt pavement technology. All the roads in the United States and in the world, the sun and the air oxidize the surface rendering it all nasty, so we have to repave. Well, that repaving… A lot of that old stuff gets accumulated in landfills; we don’t have an opportunity to reuse them. What this technology allows us to do is to use high levels of recycled content, circle economy, lower processing temperature, carbon and climate, it’s non-toxic, environmentally safe, Green Chemistry, that self-healing, and repairing biomimicry. These two products are the *Delta S* which goes into the pavement, and the *DeltaMist* which gets sprayed on it. This is an example of triggered chemistry.

41:29

Collaborations is another very interesting mechanism in the materials metabolism. A lot of organizations will do a skills assessment; you go, you take a test and some people: “I'm good at math! I'm going at communication!” An unwise organization will take these poor people and say: “Oh, you, that's not good at communicating, go take a workshop! Become better at it!”. “You! You're not good at math! Go, take a workshop!” Everyone goes to doing stuff. Everyone's unhappy and sad, because they do math because they love math. They don't communicate because they don't want to communicate. A smart organization doesn't force people to improve deficiencies. They recognize that people should do more of what they love. They're doing what they love, they're going to do better at it. So, they collaborate and then everybody's happy; they're doing what they wanted, and they are helping each other out through collaboration. We chemists have never really figured that out. We make these “Island of Dr. Moreau” molecules where we put all the functionality on a molecule, when all what we simply wanted was a simple molecule. What happens when we do some chemical derivatization? A covalent derivatization of a molecule? What we do is, we're really mitigating intermolecular forces between the molecules and the environment. Nature doesn't do it this way. Nature makes collaborations.

42:40

A membrane has all kinds of different components to it, the lipids, the proteins, the carbohydrates. If we can learn from that, instead of changing the molecules, form collaborations, what I call noncovalent derivatization, gives us an opportunity to be more natural. Look at tree material and cellulosic material. Cellulosic materials are amazing collaborations. You've got the cellulose fibers, the hemicellulose components, and the lignin; all collaborating together to make these structures. My example that's successful out of the Warner Babcock Institute is the spin-out company Collaborative Medicinal Development that's taken this material that's not very bioavailable, and using noncovalent derivatization and other mechanisms, increase the bioavailability. We’ve got three phase clinical trials on *clinicaltrials.gov* for Motor Neuron Disease, ALS, and Parkinson's Disease. We’ve been only able to do this using this kind of philosophy.

43:58

The third one is alignments. Lavoisier started chemistry back in the 1700s. So, we've been at this for a long time; 250 or so years. We humans have designed systems to heat things under high temperature, apply high pressure, use all these harsh solvents. Look out at nature! Biological design outperforms what we do, but also outperforms how we do it. In nature, everything is at room temperature, ambient pressure, using water as the solvent, and biological systems. Why? Well a thermometer is a molecular speedometer. If you think about it, as we heat something up, molecules move faster; as we cool something down, molecules move slower. The way this works, when we learn chemistry, we learn that the geometries of electron density around molecules are important to understand because only specific trajectories form the reactions that we want to have happened. So, molecules will 99.999% of the time bump into each other and not produce chemistry. However, once in a while the right trajectory happens. When we heat things up, put things under high pressure and solvate things in solvents, all we're doing is increasing the collisions. All collisions! The good ones and the bad ones. The epiphany that I had is that, there's almost never a reactive collision in nature! Almost never in nature two molecules bang into each other and violently react. What happens in nature is, they first use the same orbital field, the same regions of electron density that control reactivity also control orientation. So, they snuggle up to each other, then they react. That's an opportunity we need to think about. The spin-out company from Warner Babcock, Ambient Photonics, created this technology by making a self-assembled system, much like an Escher drawing, with a semiconductor, the chromophore, the electrolyte, have this continuity that facilitates electron transfer. This is a really exciting technology that is not for outdoor use, but for indoor low-light use to power devices, the internet... It's a very exciting technology.

46:06

Synchronicity is my next mechanism. Again, go back to this concept of large molecules and small molecules. One thing we do when we learn chemistry… Unfortunately, we think of chemistry as a series of soliloquies. This molecule reacts to this molecule to form this and this. It's almost as if it were The Shakespearean play with, some players come on the stage, they would leave; the next player, starting material come, they disappear, and the product forms. That's not really the way to think about it. Well, the way we have to really think about it: Imagine you're sitting in your chair and I'm going to play Richard the Third for you. You're watching a play of Richard the Third, but just for the heck of it, I'm all for going to put Hamlet, and Macbeth, and King Lear, and Romeo and Juliet. You're sitting there and your head is exploding! You're trying to watch five plays at the same time! "I can't do this! I can't watch it!". The dichotomy of activity is almost impossible to watch.

46:59

In a cell, it's not five reactions; it's not 50 reactions; it's not 500 reactions. Thousands of reactions happen at the same time in nature. How did nature figure out to do things synchronously? Here's the way of thinking of it: Here's another picture of Natalie when she was younger, you can see these toys that she's gotten her hands. Everyone's familiar with this type of toys. You can make different objects and different things with these things. It's kind of interesting to say that once you introduce a new shape a new thing, it's a game changer, for as far as how we're trying to do things. But what's really interesting is, these blocks are reversible, right? After Natalie has played all day, Amy and I can disassemble it, put it in the box. When she wakes up in the next morning, start all over again. Really kind of beautiful model, of course, these are reversible. But the problem is if we use our hands to put this thing together; we want to make these things, so we make it. But chemistry doesn't work that way. We can't see chemistry. We can't touch chemistry. We can't force chemistry to do what we want it to do. It's almost like, imagine taking these pieces, putting these pieces in a box, shaking the box up, and hoping that that comes out. Of course, we're going to have all kinds of different things going on. We can't control that. Nature does!

48:19

Let's think of it this way. What's happening here, it's these snaps. They will bump into each other; they will stick together. What if we put velcro in it? Velcro would stick it together, but what's interesting is velcro doesn't compete with the snap. It's synchronous, but the technology is noncompetitive. And a button can go at the same time and not compete. We can now imagine making devices, making things. If we have this orthogonal noncompetitive chemistry, we can start imagining doing some pretty crazy things, and this isn't as insane as you might think. Look at my daughter's cheek there. What do you want to do it? You want to pinch that cheek? Why does the cheek deforming go back to normal? The protein elastin! Elastin deforms and repeats. Beautiful, pretty! Love to talk to you more about it, but I want to get through this presentation.

49:14

Let's use our molecular microscope so to speak and hold in on this molecule. The amino acids in these proteins are kind of like these blocks. Carbon, carbon, nitrogen is stuck together. The peptide linkages, the condensation things, where the nitrogen and the carbon are condensed in the loss of water, well, that's kind of like these snaps. The hydrogen bonding between some of these things, that's kind of like the velcro. The covalent cross-linking, the desmosine units, well, that's kind of like the button. Nature has figured this out! The technology that has been spun out called Hairprint is based on this kind of synchronicity. When an insect goes and when tries to grow a shed to fix a skeleton, it turns dark and black in a couple hours. It's a tyrosinase oxidative cascade. What we realized, we didn't grind up dead bugs to do that, we found that velvet bean has the similar process. We take an extract from velvet beans and we're able to color hair. It restores the original color hair. You have color hair like mine, and you go you get back to the color you had 30 years ago. If someone's was black, it gets black, if someone's was light brown, it gets brown… Just like a finger has a fingerprint, a hair has a haiprint. This product has been commercialized for the last four years. It's an example of synchronicity. How do you have the chemistry to happen, penetrate, and stay in. This is an example for that. The last example is diversity and I make the statement: If the chemical enterprises had embraced diversity 50 years ago and had welcomed different perspectives, I don't know that would be here worrying about so many things now. Someone would have said: "You're doing what?". But because we have this isolationist approach is why were in the position that we're in. But I'm talking here not about human diversity, which is probably even more important, but I'm talking about molecular diversity. When we do any kind of synthesis, we take petroleum out of the ground, we do some single functionalization, some port near there would be getting the oil, and then we unleash organic chemistry to make highly functionalized molecules. Well, truth be told, the petroleum a hundred million years ago were those highly functionalized molecules. So, what we really do is, we take a plant, we bury in the ground for a hundred thousand years, we rip off all the functional groups, take it out of the ground, we put them back on. People have been trying forever to sidestep these hundred thousand years of fossilization. Even Thomas Edison talked about this. Why is it so hard? Well, the reason it's hard is while it's easy to synthesize, my faith easy… It's not easy, but it's possible to make things by obeys. The difficulty is to purify it at scale. That's where we've got to start thinking different. Everyone wants to have you know… Look at how we make things! We 50, 60 years ago when we decided our manufacturing process feeds, we specified things because it was easy to purify the oil product. We get 99.999% pure material and so we designed our products to be dependent on that purity. But that locked us into a narrow set of operating conditions. So, when we want now bio-based replacement: "Oh, but it has to be 99.99% pure". But does it? Does it really? Nature doesn't use high pure material. Nature uses Gaussian distributions of diversity of molecular structure. It embraces this molecular diversity.

53:10

If you think of something like a reindeer. When the weather is hot it has a high body temperature, the fluidity of itself is a certain fluidity. But down in the cold, thin kind of cells have the same kind of fluidity.

If we humans try to design this, we would make all this gradation of molecules, but in the way nature works, it's a distribution of materials of different isomers, of different molecular weights, and at high temperature, one group kicks in, and then at the low temperature another group kicks in… And nature adapts through molecular diversity.

53:38
So, if we can accept how materials naturally form in nature, lignin and cellulose like to be together, maybe we should be inventing materials instead of paying money to separate them. Maybe we should keep them together when we recycle materials. We find that certain materials like to come together. Maybe we should be designing materials to embrace those affinities for one another. If we can do that, and we can do it a reproducibly a commercial scale, now all the sudden we can start pulling some things off; the manufacturing cost becomes pretty effective, and you've got a higher value material to boot.

54:15
The last example I have for this is parley ocean plastics and Adidas. I was blessed to have the opportunity to work with them back in 2015, I found myself on the center stage of the United Nations General Assembly talking about Whale Wars, and parley confiscated up a bunch of this ocean debris, and we had to find a way to separate the nylon from the polypropylene, pull out the pigments, extrude it to a specific dimension...

54:44
We actually built the first extruder to make this happen and standing beside me on the board of directors of Adidas, we introduced the 2016 running shoe made out of ocean plastics. The point here is, if someone said: "Okay, take this and make it indistinguishable from virgin high-purity material", that's never going to pencil up. You know, it's got to be better off just getting the higher purity virgin material and my nature would never do that.

55:15
So, we need to really rethink this whole process. I hope this is useful to think of these different mechanisms in nature that we might be able to do. I'll leave you with, over the last decade at the Warner Babcock Institute, we've filed nearly 280 patents, we've got healthcare technologies, biomimicry technologies, circular economy technologies, reduced toxicity technologies, reduced carbon technologies, water technologies using this mindset. This isn't just a hypothetical "gee wiz", this is something that really does work. And I feel that we need to, as a society, embrace this just a little bit more if we're going to do this. And it's going to require collaboration. Everyone in the chemical enterprises, everyone in the non-chemical enterprises need to look at how we do, how we teach, how we invent, and how we manage chemistry and find a way for us all to work together. I couldn't be more optimistic.

56:16
I just look around at the people that are on this webinar, the people that I meet every day… We're going to do this! We just got to figure out how to do it efficiently and do it sooner than it's going to take. Thank you very much for taking the time to listen to me. I really appreciate the opportunity, and I hope you're all well. Thank you.

56:36

Thank you so much, John. That was fabulous. I'm going to share my screen again. And thank you so much for your sharing your vision. We're so happy to answer any questions that have come in. I know that if you have any additional questions, please type them into the control panel right in that chat question box. I know that Natalie and Janie have been working hard to pull them together. So, I'm going to ask Natalie O'Neil, our Higher Ed Manager, to help read some of the questions. We will stay on and answer some of these questions.

57:16

Great. Thanks, Amy and John. There have been lots of questions coming in and lots of congratulations in terms of a great presentation. Everyone is really enjoying it overall. The first question that we do have coming in is: You covered a lot of things here John, but what is it that we could really focus on to make the biggest impact? Is it plastics? Is it solvent? Is there one thing that you could tell us to focus on?

57:41

That's a great question. It's funny, I get asked this question a lot. And my first reaction is, I could never be so presumptuous to say: “This is more important than this or that”. Everyone has a different take, but I actually do think there is one thing that is more important than anything else. And that's education. At the end of the day, if we see that we're not really training our chemists and chemical engineers giving them the tools to do what we're talking about here… The way we teach chemistry is kind of the same as it has been for the last several decades. So, you've got an organization like Beyond Benign that is promoting education and Green Chemistry throughout K-12 to Higher Ed and arguably that's the most important thing we can do, because if you give the chemists, the chemical engineers, and the designers of products the tools that they need, everything they do will get better. And so, if we focus on the individuals, not focus on the stuff, not focus on them, just look at the people, look at the skills and the people, not only are we supporting an economy and allowing people to find good jobs to do things that are important and necessary, but I believe that people will do the right thing given the given the right tools. So, the first job all of us have in my opinion, is to focus on education and trust people to do the right thing given the skills that they need.

59:12

We appreciate that response, John. The next question is: If I'm not a chemist, how do I play a role in all of the things that you've talked about? So, if education is important and you're talking about Green Chemistry education, but I'm not a chemist. How do I get involved here? Oh, thank you, thank you, thank you. That's a really, really, really good point. It's funny. If I go to some party or group of people that I am hanging out and someone says to me, “What do I do?” Oh my God, when I say I'm a chemist it’s like I’m a conversation stopper… They usually look at their shoes, it’s like they all hated chemistry in high school. We have developed this bad relationship between society and the field of chemistry and… Think of the implications of that! The politicians we vote for, the products that we buy, the news that we listen to say: “Oh, I have nothing to do with the chemical enterprises”. We abdicate a certain connectivity to the reality of our existence. To appreciate Bach or to appreciate Beethoven, you don't need to know how to play the violin. To appreciate someone playing basketball and doing a cool move in basketball, you don't have to know how to play basketball to appreciate the artistry and the skill.

1:00:40

When it comes to chemistry, it’s kind of the same thing. We all are either going to benefit from the cool things that chemistry can do or we’re going to suffer from the negative things that chemistry can do. To say: “Well, that’s just not what I do” is probably a mistake. So, looking at how are we educating the next generation of students; how are we communicating what it is that we want, need, and desire; how are consumers interacting with retail, interacting with NGOs… This is something that is anticipatory requirement of people in society. If you sit on the sidelines and don't become engaged in the conversation at some level, then you deserve what you get it at some level. We need to help each other; we need to be part of this. And If chemists keep doing what chemists have always done in isolation, well, they're going to keep doing what they've been doing in isolation.

1:01:39

We need to break these barriers down and recognize that it’s kind of pretty cool. So, I feel like that comes into the next question that came in about: “What can we do to reduce toxics in the environment?” Well, the first thing is to develop an awareness of what is in your products. There are a lot of organizations that will give you information of… Right now, we don't often do this, but in a hypothetical world where you, standing in a grocery store, standing in a store, looking at a shelf of all different products, recognize it, as your hand reaches… And you grab one kind of shampoo instead of another kind of shampoo. You are making a decision at that moment to support either something that is good for human health and the environment, or is less good the human health and the environment. But if you don't participate in that process, if you don't think about that, figure that in, and find some ways of doing that, then that’s not cool. So, you know, I don't want to endorse any specific mechanism to communicate with society, but there are websites, there are many different programs. The thing is to take it upon yourself to learn how to access this information, to figure out which ones are the ones that are appropriate and trustworthy, and make some decisions based on what that goes on your purchasing on this information. If you're buying, your preferences in purchasing will change the preferences in manufacturing, which will change the preferences in research and development.

1:03:46

In my opinion sometimes we overuse this concept of “voice of customer”. Organizations won't do something because they say: “Well, we don't hear the voice of customer”. I like to use, big Disney fan, so I use the Disney analogy of The Little Mermaid. The Little Mermaid doesn't have a voice. Prince Eric wants her to say: “I love you”. She's not saying, she clearly loves him, but she cannot articulate it. And because she cannot articulate it, the idiot doesn't know that she loved him. This is the way it has to be with society. We need to articulate to industry what we want, because we have a hard time. “Okay, if there's no voice of customer we shouldn't do it.” Well, let's create that voice. Let’s make it loud; make it very, very loud.

1:04:44

On that kind of front in terms of industries, have you been able to identify pairs of industries that would be particularly potential chemically symbiotic? One day, there's a great magazine article did a story... One day, I'm wearing a hard hat, I’ve gloves and boots, holding a shovel and I'm taking an asphalt. I'm in a steaming pile of asphalt with my gloves on, crumbling the asphalt, looking how it breaks. And as I'm doing this my cellphone rings and it's clinicians in Finland that are doing a cognition study of an Alzheimer's drug that we're working on. They're talking about the cognition with us. Now, most people would look at that and say: "Wait a minute! Asphalt pavement…. Neurobiology… That doesn't seem to go together." But my model of Alzheimer's is an organic polymer wrapped around an inorganic particle; we have a small molecule that slipped into the interface to control how it aggregates. What is asphalt? Organic polymer wrapped around an inorganic particle; we have a small molecule that slipped into the interface to control how it aggregates. At the molecular level, they're kind of the same thing. A molecule doesn't know what industry it belongs to; a molecule it's just a molecule. When you say, "what two things are related?", to my way of thinking the harder question is "what two things aren't related?" We have myopic view because our education system puts us in all these little boxes: "I'm a chemist. I'm a biologist. Oh, I'm not a chemist. I'm an organic chemist. I'm not an organic chemist, I'm a synthetic organic chemist. I'm not a synthetic, I'm heterocyclic synthetic..." We spent all this time looking at how to categorize, subdivide, and put each other in little tiny boxes that we forget: Nature doesn't do this. If we can realize that it is an illusion these separations, and that the pharmaceutical industry, the cosmetics industry, the petroleum industry, NGOs promoting worker health and safety… There's more in common than we're finding. We need to, instead of looking at how we're different, start identifying how we're similar. If you imagine the fractal view as we get closer, and closer, and closer to our products. Once you get down to the carbon atoms, the nitrogen atoms, the oxygen atoms, everything starts to look the same.

1:07:27

I think maybe we have time for one more question. This one is about our current situation and what we're going to come out of COVID-19. Is there a way that we could really start kicking off this global economy? How can we make sure that we stop negative chemistry being used as an excuse to rebuild the global economy?

1:07:48

That's a great question and I want us to start by saying that there is an assumption that there's some epic battle of good and evil going on. That industry has the solutions and it's choosing not to use them. And while there are some cases where this may be so, the vast majority, we don't have the solutions invented yet. Here we are, the 50th Anniversary of Earth Day. If we all woke up this morning and every consumer said: "I am only going to buy safe, nontoxic, sustainable, technologies." If every retailer said: "We will only sell safe, nontoxic technologies." If every manufacturer said: "We will only make safe, nontoxic…" We can't do it! We haven't invented them yet! I would argue that 65% or more of the technologies do not have viable alternatives invented yet. So, a sustainable future is not just a demand issue; it's a supply issue. As we do behavioral changes to get people to demand these things, we also need the technologies to meet these demands. That's why education is so critical to K-12 and university. I kind of again, silver lining here, I know the age that I am, and the demographics that I represent. A lot of people that I've interacted with never would do Skype, never would do Zoom, would never do these video things. "Ah, I'm a face-to-face kind of person" and all of a sudden they're realizing: "Hey, this isn't as bad as I thought!". And maybe one thing that's going to come out of this is some of these conferences where hundreds of thousands of people get on airplanes to fly to some little city, and all the "amazing impacts" that has on the environment, and on global climate and things like that. Maybe people will start rethinking this better.

And once they realize they can communicate better, maybe research collaborations will be even more facile. Instead of a group in Australia competing with a group in England, who's competing with a group… And everyone wants to get faster, and keep secret of this, keep thinking of this… Maybe recognizing the centrality of these issues, maybe through various media sources, we can lower these competitive things, which sometimes are healthy. But most of the time these kinds of competitions are very unhealthy and useless. And so maybe seeing just how vulnerable we are as a species, and how every one of us, every one of us humans, is being affected in responding to this COVID-19 in very similar ways, then maybe there's this hope that this gives us all a reason to take step, pause, stop looking at our differences, look at our similarities and be better at collaborating and doing science. It's a hope and I believe it.

1:11:06
Absolutely! Natalie, what's that it for now? I know we're running way over of our time here. But that's we are running way over our time and we have a ton more questions, so we may have to expand our kind of green chemistry connection series here and get you guys back on the line so you can answer more questions, because we have a ton of audience members that have more questions that would loved ti be answered. That would be a great thing to do is to schedule another time and just have a conversation, answering different questions. I'd be happy to do that anytime you'd like.

1:11:41
Great. All right, we're definitely going to be doing a lot more of these because we see these as great touch points to bring people together. So, we'll be happy to get that out. If you registered for this webinar and attended, you'll receive the information about that as well. So, in closing, our recording and supporting documents; you saw the note in the chat box there too. You can see a direct link where the recording will be posted along with supporting documents. Please join us next time, next week, actually. We have a Higher Ed webinar, which we're going to be talking with Dr. Ettigounder Ponnusamy from MilliporeSigma, and our very own Irv Levy on a DOZN 2.0 tool. It's an open access tool for evaluating greener labs. And so we're talking about that and there's also a tool to use in the academic setting, virtual academic setting.

1:12:42
We can give you a direct link there in the chat box, they might have already done that as well. I also just wanted to point you to, from our homepage you can also directly access a curated list from Janie and Natalie who are our moderators today, a curated list of virtual Green Chemistry resources that can be useful for both K-12 and Higher Ed during this time, during this unprecedented time when we're all have to think about ways of learning and teaching online and virtually. So, in closing, a huge thank you to John. Thank you so much for sharing your vision with us and all of your passion and dedication to this space. And thank you to all of you who joined in or tuned in for this webinar from all over the world. So, thank you so much for being part of this community. Be well, and Happy Earth Day! Looking forward to next time.