Research the Resonates
Villanova CLAS Podcast
Episode 1 Transcriptions
Sustainability: Alternative Fuel Sources

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Guest 2 (DI): Diane Isaacs '19 MS
Guest 3 (CT): Claire Teahan '19 CLAS

JP: Simply stated, I'm really fascinated with the fact that the sun provides a tremendous amount of energy in the world we live in. And plants have found a way to harness sunlight and convert it to usable forms of energy in this process known as photosynthesis.

HOST: That's Jared Paul. He's an associate professor of chemistry at Villanova University. Much of his research focuses on electron transfer reactions. In other words, he's interested in the understanding what's happening at the chemical level in everyday natural processes.

JP: The photosynthetic process seems to be this beautiful, natural process to take water, remove the electrons and protons, and make fuels. So, looking to nature and what they're able to do, and then trying to find ways that we can do that in the laboratory can solve a lot of the massive challenges we have today.

HOST: This is Research that Resonates, a podcast from Villanova University's College of Liberal Arts and Sciences that takes you inside the labs and classrooms to learn from our distinguished faculty and students. I'm you're host, Chelsea Gerrard.

In our first mini-series, we're talking about sustainability. Villanova researchers are looking into some of the most pertinent issues affecting our planet today, including renewable energy, rising sea levels and climate change.

I met up with the folks in The Paul Lab to learn more about what impact their research could have on developing alternative fuels sources.

JP: So my name is Jared Paul. I'm an associate professor at Villanova University in the department of chemistry.

DI: My name's Diane Isaacs. I'm a second-year grad student in the master's program at the chemistry department here at Villanova.

CT: My name's Claire Teahan and I'm a senior at Villanova in the department of Chemistry.

HOST: Dr. Paul and his students are specifically looking at solar energy as a fuel source, which he explains is happening in nature all the time—through photosynthesis.

JP: Photosynthesis is the process where plants take energy that's emitted from the sun and convert it to a usable storable form of energy, such as sugars, carbohydrates. The way they do that is what's called reducing carbon dioxide. So, in order to reduce carbon dioxide, you need electrons and protons to combine into carbon dioxide—to make a sugar, and to make these storable energy forms. So, what photosynthesis has basically evolved to do, is take those electrons and protons from water, remove the electrons and protons from it, and give off clean oxygen.

HOST: That process is otherwise known as water oxidation.

JP: Our research is really interested in this process of taking the electrons and protons out of water to do useful chemistry. This is a very complicated process. It requires a lot of energy. There's a lot of byproducts along the way. So, it's not a simple process, and we're really interested in how do we do that efficiently.

HOST: The first step is to select a metal catalyst. The Paul Lab uses Ruthenium because it's easy to study and has proved to bind well with water and absorb light in the visible range. But what exactly is a catalyst?

JP: Basically, a metal catalyst is kind of your transient source of electrons and protons. So, basically the concept behind the catalyst is—the catalyst you can remove electrons and protons from it, and it becomes electron deficient. It wants electrons now. So, if water can come up to it and give its electrons back to the catalyst and make oxygen—now that catalyst is an electron source, which can then give them off again. So you want to basically be—and that process is known as oxidation and reduction—so you want a catalyst that can lose its electrons readily, that's being oxidized – but then also be readily re-reduced, so gain those electrons back. So, it's kind of this transient source that funnels off electrons and takes new electrons in. I think of it as kind of the central point in the water oxidation process and the idea of coupling it ultimately to making these storable fuel sources.

DI: The thing about the catalyst is there's a bunch of different things on it, and if you can modify that, you can modify it in a way that can help you better oxidize that water, so you require even less energy. We're just trying to find the way to make the most efficient catalyst possible.

HOST: That's Diane again. And one of the ways she says they are striving for efficiency is by experimenting with ligands—which is a molecule that they bind to the ruthenium.

DI: This ligand is what's actually attached through the ruthenium, so it's part of the catalyst. And the ligand is what you will modify to hopefully increase water oxidation to help you lower that barrier so you can make everything happen.

JP: A little bit on the ligands, real quick—so ligands are basically a scaffold that you can attach to ruthenium to give it some unique properties to help with things like the electron transfer process or moving protons around. So that's where our whole lab designs new ligands and thinks about new ways—and we collaborate with a lot of people who also send us ligands-- to try to makes systems that make that ruthenium more efficient to do what we want it to do. So, our chemistry… our ligands… we have the ability to dynamically change them. And what I mean by that, is we can through relatively simple changes in the environment—say changing a PH, adding an acid or a base, we change the structure of our ligand. And that ligand – changing the structure of it—is going to influence the properties of the metal, which might increase the ability to oxidize water, or might decrease the ability to oxidize water. So, our grand thought is, if we can find relatively simple ways to change the environment, we might be able to turn a catalyst on and off. So basically, creating an on-off switch for catalysis, where when you want to do the process you activate it and at some point, like a light switch, you flip it off and you stop doing that catalytic process. That's something that we're really interested in, and that's kind of our unique, or semi-unique, area that we're trying to kind of move into.

HOST: While Diane focuses on efficiency of the ligand, Claire is researching how they might be able to make the ruthenium a more efficient catalyst.

CT: My project is a little different from Diane's in that I'm looking at bimetallic complexes, so there's actually two ruthenium metal centers, as opposed to just one. The reason why I'm interested in doing this—is we think it can help with the stability of the compound because water oxidation requires that we reach a high oxidation state. And so, the idea is that if we have two metal centers, we can kind of like share that oxidation state and alleviate some of the strain on the compound and the catalyst as a whole.

HOST: What's high oxidation versus low oxidation?

CT: I guess it all has to do with adding and removing electrons from a compound. So, when you remove an electron from a compound you increase your oxidation state. So, when you remove one electron, you're at a plus one oxidation state, but for water oxidation you need like plus four, plus five. So that's really high and that can affect the stability of a compound. So, the idea is that if we have two metal centers, it won't be quite as difficult to get to such a high oxidation state.

HOST: So, can you describe your interest in this area of study and how you've seen this area of research evolve?

CT: When people ask me about my research I find it can be complicated to explain, but then, looking back through everyone's different levels, I've realized that you can explain this research to really anyone—just at a different level. So, I think when I was in elementary school, I mean you learn that fossil fuels are bad, and like renewable energy. And then as I was in middle school I could specifically look at—there's different types of renewable energy—there's water energy. Water can be a renewable source of energy. The sun. The wind. And then, when you get to high school you understand that, you know, there's a lot of science behind this, and you start to learn the specifics. I can remember learning about solar panels. So, now, just the renewable energy I learned about when I was in elementary school and middle school – I'm still looking at renewable energy now, in my inorganic research lab. It's just on a much more specific and more scientific level. Now I'm looking specifically at water oxidation and catalysts for that process so that we can make solar energy more efficient, and therefore make renewable energy a more realistic option.

HOST: I asked Diane the same question—why is she interested in water oxidation?

DI: That's a very good question. I feel like this is all part of a bigger thing that you can couple it with something else, and then so you can use this as a reusable fuel. So maybe we're not exactly at the part where we're harvesting the sunlight, but if we can find some way to couple that with this, then we have a source where we can now store that solar energy, rather than just have the solar energy while the sun's shining. What about all those times when the sun's not shining at night or during the day if it's cloudy, and just trying to be able to find a way to get rid of those fossil fuels the best we can.

HOST: If we're able to create a catalyst that's successfully and efficiently moves the electrons and protons so that we can create energy, how is the light no longer an issue?

JP: So the way to think about it again, is when the sun's shining you can be generating electrons and protons and they can be moving around and basically generating – or well they can be just moving electrons around. That's how conventional solar cells work. Light shines, moves electrons around a circuit, and you're getting power. When the light stops shining, however, you stop moving electrons around. So what you need to do is have a way of basically an electron source for the night, when the sun's no longer shining. So conventionally you know we buy that from the power companies whether it be through nuclear power or burning different fuel sources and oil heating, natural gas, etc, etc. 'Cause that works twenty-four-seven. So, the idea is, if we can take those electrons and protons through something like water and put them in a storable fuel that we can burn at a later time when the sun's not shining, we can have energy throughout time. Now there's a lot of questions as to what that storable fuel is. You can imagine if you take simple protons and put electrons into it, you get hydrogen, which is a terrific fuel source. You can imagine if you can develop a catalyst that takes carbon dioxide and you put electrons and protons into it you could make sugars, you could make methane, you could make methanol. So, there's chemists/scientists around the world that are working on all these different processes. They're very very complicated. We've chosen to focus on one area in particular, and that's the water oxidation process. The beauty of water is if you can find a way to remove the electrons and protons from water and do useful chemistry, the only byproduct is oxygen, which is clean.

HOST: So, what's next for the research, and can you just paint me a picture of where you guys are and where you'd love to see yourselves go?

CT: I'll start and then you can add. I guess an exciting development in our lab is we now have an oxygen probe that allows us to measure whether or not we're making oxygen, which is something we haven't had before. So, in the event that you do make a catalyst, we couldn't study the creation of oxygen, I guess. So, now this is like a new piece to our tool box that Diane has been looking a lot into and figuring out how it works. So now, once we make compounds that have a site for our water to bond and that are potential catalysts, we can actually see how good they are at doing their job or how much oxygen they can realistically make.

DI: So like Claire was saying, we have the oxygen probes, so now we can measure oxygen evolution and I've been playing around with that trying to figure it out. And now we've got it figured out. We're going to use what we're calling as a control to make sure that our system's actually working and we can compare it to other papers because people have made this before and show that our numbers are similar to them, our set-up is valid, and from that we can go and test our own catalysts. One of the other members of our lab is going to be making some interesting ligands that we haven't had before and from what we can tell from the literature, no one else has used before—that we're really interested in testing their catalytic ability of—to see if that would provide an even higher catalytic ability.

HOST: Developing alternative fuels sources is ultimately an interdisciplinary undertaking. Before we can harvest the sun's energy, we have to understand the chemistry behind it. And that's where chemists, like Dr. Paul, Diane, and Claire come in. Their research is an integral part to developing sustainable solutions. It's inspiring work. But Dr. Paul says his real inspiration is his students.

JP: My big goal here has been to work with undergraduate students and masters students and train them, and train them in cutting edge areas of chemistry. Villanova provides us a real wonderful opportunity to do that here – to do real, relevant chemistry while we're training students. I always joke that my goal is not to win a Nobel Prize someday, but it's to train the next Nobel Prize winner in organic chemistry, or chemistry in general, whatever field they choose. So my real inspiration has been to get students involved in research, to get them doing real world, important chemistry, tackling significant issues, and using that for their own growth so they can go on and do wonderful things and really benefit our future.

HOST: Thanks for listening to Research that Resonates. Check out all our episodes on sustainability, as part of our first themed miniseries.