One Cool CATalyst_ Robert Bake...Works to Convert CO2 to a Fuel

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SPEAKERS

David Staley, Robert Baker, Eva Dale

E Eva Dale 00:00

From the heart of the Ohio State University on the Oval, this is Voices of Excellence from the College of Arts and Sciences with your host, David Staley. Voices focuses on the innovative work being done by faculty and staff in the College of Arts and Sciences at The Ohio State University. From departments as wide ranging as art, astronomy, chemistry and biochemistry, physics, emergent materials, mathematics and languages, among many others. The college always has something great happening. Join us to find out what's new now.

D David Staley 00:32

Robert Baker is an assistant professor in the Departments of Chemistry and Biochemistry at The Ohio State University College of Arts and Sciences. He earned his bachelor's and master's degrees at Brigham Young University, and his doctorate at the University of California, Berkeley. He's received the Air Force Office of Scientific Research Young Investigator Award and the Department of Energy Early Career Award. He specializes in ultra fast soft X ray spectroscopy, nanomaterials and highly selective catalysts, and catalytic reaction studies. And we'll find out today what those terms mean. I am pleased to welcome Professor Robert Baker to Voices from Arts and Sciences.

R Robert Baker 01:13

Thank you, David.

D David Staley 01:14

All right. So help me with that term. Did I say it right?

R Robert Baker 01:17

Yeah. Spectroscopy, I'm teaching my kids to get that one right, too.

D David Staley 01:21

Well, tell us, tell us what this means, what is ultra fast soft X ray spectroscopy?

R Robert Baker 01:26

Well, you know, so, spectroscopy is really how light interacts with matter. And so it's the idea of using light as a tool to understand, you know, how electrons move in a material, and how this eventually leads to, you know, very desirable things like converting sunlight to fuels or sunlight to electricity.

D David Staley 01:44

So light as a tool, explain what that means.

R Robert Baker 01:47

You know, light can be used to excite a process, or light can be used to actually study a process. And so, in our lab, we do both. So you know, the goal is that, you know, sunlight would become the dominant source of energy that the planet uses.

D David Staley 02:01

So walk us through, what is, in your lab, how we're using light as a tool, and what sorts of processes.

R Robert Baker 02:08

So one of the reactions that's really important for the future is CO2 conversion. So CO2 is the,

D David Staley 02:14

Beacause of climate change,

R Robert Baker 02:15

That's right

D David Staley 02:16

Concerns about co2 in

R Robert Baker 02:17

That's right

D David Staley 02:18

And presumably from sunlight? the atmosphere.

R Robert Baker 02:18

Fossil fuel, when you burn a fossil fuel, it goes to carbon dioxide. And this is starting to pile up in the atmosphere. And this creates a couple of problems, one is, you know, CO2 is not that good for the atmosphere. And the other is that we're running out of fossil fuels. And so to really close this loop, it would be wonderful to take CO2, and actually put it back as a feed stream to a chemical reaction, so convert CO2 to a fuel. But you know, this takes energy. And the question is, where's this energy going to come from? That would be, that would be the best option. That's right.

D David Staley 02:22

So, and this is something that you're working on, you're in your lab,

R Robert Baker 02:50

That's right,

D David Staley 02:51

That's your process.

R Robert Baker 02:53

That's right.

D David Staley 02:53

David Staley

So explain, explain how this is going to how this is going to operate?

R Robert Baker 02:57

Well, you know, this is incredibly complex. So there's lots of parts to it. But, you know, the very early parts is that you have a catalyst, a material, which will absorb light, and then turn that energy into the energy of some electrons. And then these electrons have to do work. And hopefully, that work is to convert CO_2 into some chemical which we want to use. But there, it's you know, there's a lot of pathways that can go and a lot of places that it can diverge. And so we're trying to track these down.

D David Staley 03:23

What could we be converting CO_2 into? What's the what's the hope here?

R Robert Baker 03:27

Well, you know, the hope would be an alternative fuel, something that you could put in your gas tank and drive your car off

D David Staley 03:33

Like a solid fuel?

R Robert Baker 03:34

Well, yeah, liquid fuel,

D David Staley 03:35

Oh, liquid fuel

R Robert Baker 03:36

A liquid fuel, yeah. But you know, this invariably involves doing carbon-carbon bond coupling. So you know, CO_2 has just one carbon in it. But gasoline is a string of many carbons long. And this is challenging chemistry.

D David Staley 03:49

And so how would you describe your efforts at this stage?

R Robert Baker 03:52

Well,

D David Staley 03:53

Is there room for optimism? Should we be excited by this?

R Robert Baker 03:56

So it sounds like, well, is anybody else working in this area? Or do you think of yourself as sort of the pioneer or sort of at the research forefront? Oh, yeah, there's, there's definitely room for optimism. So you know, we've recently shown that some rather very inexpensive Earth abundant materials, like copper and iron oxides, can couple carbon-carbon bonds from CO2, and, and the product would remake as acetic acid. And there's one hopeful step. There's a long way to go before you get the gasoline, still. Oh, I do like to think of myself as a pioneer, but not because we're leading the effort in CO2 reduction. I mean, this is a big field, and there are many, many people working in this field. So one of the challenges in my job is to find a way we can contribute that's unique. And so, the thing we're trying to do, which I think is unique, is we're trying to understand the details about how the electrons move in the catalyst. These are the very first steps in the process. They happen on a timescale which is femtoseconds

D David Staley 04:56

Femtoseconds?

R Robert Baker 04:58

Yeah, that's a hard number to even comprehend. So,

D David Staley 05:00

So is that faster than a nanosecond?

R Robert Baker 05:02

Oh, much faster. That's a million times faster than a nanosecond

D David Staley 05:06

A million times faster. All right. And so, when you work at those, that's presumably what's meant by ultra fast?

R Robert Baker 05:12

Ultra fast, that's right. So, so to put it in perspective, you know, so mathematically, Femto means 10 to the minus 15. But that's hard to comprehend. So there are actually more femtoseconds in one second, than there are seconds in 100 million years.

D David Staley 05:25

Wow, fabulous.

R Robert Baker 05:27

Right, so when we, when we look at how electrons move on this timescale, this is kind of almost outside of our comprehension.

D David Staley 05:33

So the nature of these reactions are occurring at this kind of speed, right?

R Robert Baker 05:37

That's right, the electron motion happens on this speed.

D David Staley 05:41

And so presumably, you have described some of the tools and things that you have, that can work at these sorts of speeds, how do you slow yourself down to these kinds of speeds?

R Robert Baker 05:50

Well, so, so we, we do it with the laser system. So it's kind of like fast photography, it's like, you know, the analogy that I like to give is the shutter speed on a camera. So if you have a, you know, a slow, a slow shutter speed, and a pitcher throwing a baseball, you'll just see one blur from the mound to the catcher's mitt. But if you want to actually resolve this process, you need a shutter speed that gets crisp snapshots. And so you know, on the timescale of electron motion, that shutter speed has to be femtoseconds. And so the way we control the shutter speed is we make in our laboratory pulses of light, that whose durations have only few femtoseconds, we convert that light into X rays, so that we can do fast, you know, very sharp time resolved X ray absorption measurements.

D David Staley 06:36

So you describe yourself as one of, of several pioneers, but you think of yourself as a pioneer, help us, describe for us what it's like to be on that sort of research frontier, to be a pioneer, what does that mean, in the sciences to be a pioneer?

R Robert Baker 06:52

Oh, well, you know, I think in one way, it means that you're, you're never comfortable, you're never quite sure what you're doing. And you're never quite sure what you're going to see.

D David Staley 07:01

So that's quite an admission, I think from from a scientist.

R Robert Baker 07:04

I try to be transparent about this, you know, you know, you get the graduate students who are really the ones doing the work. And you know, that, you know, they've invested a lot of time and effort to be here and to be doing their studies. And, you know, it implies a certain amount of trust, you know, in their advisor, you know, in the system in general. And so, you know, how you break this news to them, that we're really embarking in an experiment when we don't know what the results are going to be.

D David Staley 07:27

Well, and that's, that's, that's a really interesting admission, I think, I mean, obviously, you know a lot you've, you know, you've won all these awards, and you have, you know, impressive degrees. But this is what it's like to be at the research forefront, that, that what the questions aren't clear, or the questions haven't been asked.

R Robert Baker 07:43

Right. Yeah, I think, I think it's a matter of asking the right questions. I mean, if it's a question that the, that you already know the answer to, then it's the wrong question. But you need to be very smart about this, hopefully, something where the answer can point us in the right direction. I mean, really, we hope that even though these studies are very fundamental, that in the end, we all help people know how to make a material, which will really solve some of these critical problems.

D David Staley 08:05

So in asking the kinds of questions that you're asking, I get the sense that sometimes you go down blind alleys, or sometimes they're failures, is failure, something that you're accustomed to? Is failure, something that's part of the enterprise? Is it a, is it maybe a positive thing?

R Robert Baker 08:21

Yeah, you know, failure is definitely part of the scope of work. But, you know, I like not to think of it as a failure, because if you're smart about it, and you have your eyes open, I think there's always something to be learned. And so, you know, I think looking back, often, what we learned that turns out to be most important, isn't what we're looking for, but something we discovered by having our eyes open along the way. So, you know, you could call it a failure, but in a way, it's just a different pathway to success, maybe.

D David Staley 08:45

Describe for us that thrill of discovery

R Robert Baker 08:49

You know, for me, this is why I do this job it, you know, there's nothing that compares with seeing it, you know, to really take the data and analyze it and realize that you're seeing how the electron is moving. I mean, you can't be the size of an electron, you know, and sit there on the atom and watch them orbit around you, but it's pretty close. And, and when you get the answer right, and, you know, you've made the measurement that shows how it's really happening. You know, that's a great feeling that that's very exciting.

D David Staley 09:13

So you've described some of the potential benefits or outcomes, not just scientific, but, but sort of practical outcomes, both in terms of the potential to reduce CO_2 levels in the atmosphere,

R Robert Baker 09:27

That's right

D David Staley 09:27

But also the possibilities for new kinds of fuels. Would you describe your work mostly as pure or applied research? Or is it some sort of combination of the two?

R Robert Baker 09:37

Oh, I think it's always a combination of the two, but we're on the very pure side of things. You know, we're really trying to understand the fundamental properties. And the most basic, you know, nature of electron motion and materials that can provide guidance, you know, and so, you know, in a way it's, you know, we have to, when we write proposals or trying to seek funding like this Department of Energy or Air Force award, make the case that, you know, these things really matter. And, you know, I think that they do, and I think the Department of Energy and the Air Force obviously think that they must, but yeah, I mean, we're, we're hoping to feed the stream of knowledge that will eventually produce the discovery.

D

David Staley 10:15

Did they fund you largely for the pure science? Or were they funding you as much for the applied possibilities?

R

Robert Baker 10:25

You know, I think that

D

David Staley 10:26

I'm asking you to get in the mind of your funders.

R

Robert Baker 10:28

The mind of my funders, well, you know, the, the programs which I'm in, so the condensed phase and interfacial molecular sciences program for the Department of Energy, they're under the basic Energy Sciences. So, you know, in their minds, they really want to understand the basic science that controls energy conversion. And, you know, I think the funding culture is changing, and it's getting, you know, harder, in some ways harder to become funded, but it, I think pushes researchers to be more creative, and, you know, think outside the box. And so, you know, these days, I think you have to make the case that what you're doing is going to lead to an important application. And so, you know, I do think of ourselves as applied. And, you know, I kind of think of my research program, you read the terms, the soft X ray spectroscopy, the nanoparticle catalysis and catalytic reaction studies, you know, so I think of our research program as being on a stool with three legs, one of which is measurements, and one of which is making materials, and one of which is testing them for their actual applications. And so I think if you take off any one of those legs, then you know, you potentially lose relevance in what you're doing. So we tried to stay balanced this way. Nanomaterials for highly selective catalysts. Yes. Okay. So this is, you know, so nanomaterials has been a hot topic for some decades now,

D

David Staley 10:50

Indeed.

R

Robert Baker 10:58

You know, so the question is, you know, what this can actually offer and in the area of energy conversion, it's the idea of kind of like designer materials, so can you really control on the nano, and then the molecular scale, the properties of the material to have it do what you want it to do?

D David Staley 12:05

And nano scale here means what?

R Robert Baker 12:08

Oh, small, few nanometers. So you know, a nanometer is ten to the minus nine. So there's a billion nanometers in a meter. So if you take a meter stick and chop it into a billion pieces, that's the size of the particles that we're working with.

D David Staley 12:22

And why does why does that matter? In other words, working at that scale, what does that, what does that do to materials? Or what are the, what are the implications?

R Robert Baker 12:30

Well, you know, we don't notice features on that size. But molecules are even smaller, molecules are on the order of a tenth of a nanometer. So this is the scale where molecules start to notice the features. And so if you want to take CO2 and convert it to something useful, or any feedstock biomass, or any feedstock and convert it to useful chemical product, these are the properties of the material, which the molecules will notice them and will control how they act.

D David Staley 12:55

Chemists have always worked at small scales, though,

R Robert Baker 12:58

Right,

D David Staley 12:58

Isn't that true? Or is there something different now with nano scale enterprises?

R Robert Baker 13:03

Well, you know, they have always worked at small scales. But it's, I think, what's improving is our ability to control properties on the scale and our ability to see them. So we haven't always been able to directly measure these properties. And then this gives rise to the ability of okay, can we even control these properties? And I think that's what's new about nanoscience.

D David Staley 13:25

And catalytic reaction studies. What does that what does that refer to?

R Robert Baker 13:30

So this is the application leg of the stool. So,

D David Staley 13:32

I see.

R Robert Baker 13:33

You know, where we are on the spectrum, this is the applied end. So if we make a material, or, you know, study a material that seems to have very favorable, you know, properties in terms of harvesting energy and converting it, you know, sending these electrons down the right pathway, then we want to see, you know, does this really work? And so we put it in the beaker, we, you know, connect the solar simulator to it. And we actually run the reactions and look at the performance of these materials.

D David Staley 13:59

You had mentioned "we", you talked about graduate students, for instance, doing, doing a lot of the work presumably, in your lab,

R Robert Baker 14:06

That's right, they're the ones who do the work.

D David Staley 14:08

So well, and I'm curious to know about, about your lab, we're obviously using an audio medium, could you describe for us in words, your lab, what we would see if we were to go into your lab, what we would hear, the sort of people that would be there and the sorts of activities they do?

R Robert Baker 14:24

We also, yeah, you would, you would see very active students, but under, during the time that an experiment is happening, you would hear the sound of silence. And that's

D David Staley 14:34

Really?

R Robert Baker 14:35

And that's by design. You know, we talk about how short is a femtosecond and how do we control these pulses of light to measure something so precisely, the distance that light travels in that short amount of time is less than a micron.

D David Staley 14:49

And a micron is?

R Robert Baker 14:50

A micron is a millionth of a meter.

D David Staley 14:52

Oh my goodness.

R Robert Baker 14:53

And so, if there's anything on the table where we run these measurements, that shaking, even if it's shaking a micron, this, now blurs the image to us that you know the time resolution blurs.

D David Staley 15:04

So it's not just silence, people have to be still.

R Robert Baker 15:07

We don't, we don't want anything vibrating. And so although there's a lot of pumps running in the background, these are all mechanically isolated the best we can so that by the time you reach the table where the measurements happening, it's vibration free. So you know, so this equates to really silent.

D David Staley 15:22

And no cell phones or anything of that nature.

R Robert Baker 15:26

You know, I think the cell phones are all right, the issue with the cell phones is no cell phone signal down in the basement,

D David Staley 15:31

Ah, of course, yes, maybe by design.

R Robert Baker 15:33

That's right, we go down into the basement where, you know, nothing interferes.

D David Staley 15:36

And describe how, how your lab or indeed any sort of scientific lab works in terms of, when you say graduate students doing work. Who else is in the lab? Undergrads?

R Robert Baker 15:49

Yeah, we also have undergraduates who work in the lab, that's one of the great things about Ohio State University is there's a lot of, you know, really talented undergraduates, you know, they're highly motivated. So, you know, I just finished teaching a class last week, and a number of undergraduates are chomping at the bit to get into the research lab. And so, you know, I think this is an important part of the job is to give them that training and that experience.

D David Staley 16:09

So they have to apply or otherwise demonstrate merit to be able to work in your lab.

R Robert Baker 16:15

Sure. I mean, there's a limited number of positions. But you know, there's, there's a lot of, you know, really talented students here. So, you know, we, you know, I think the chemistry and biochemistry department does a really wonderful job of bringing many of these students into the research lab.

D

David Staley 16:29

And what are undergraduates doing in your lab? What would what would a typical undergraduate be doing?

R

Robert Baker 16:34

Okay, so I have, I have three undergraduates who have been working with me recently. And one of them is on his way to UC Berkeley for graduate school. And another is on her way to Caltech for graduate school, you know, so they're on, you know, bright futures in research.

D

David Staley 16:49

Because they were in your lab, I'll bet.

R

Robert Baker 16:51

Well, you know, they must have liked the experience, which I'm very proud of. So yeah, I mean, they've been working on this CO_2 reduction project that I tell you about, you know, Skylar, who's on her way to Caltech has been, you know, one of the forefront in my research group at trying to understand how CO_2 can convert to acetic acid, and what are the properties of the catalysts that make this possible.

D

David Staley 17:11

Wow. So undergraduates are essentially conducting research in your lab?

R

Robert Baker 17:16

Oh, definitely, definitely. Yeah, I mean, it would be hard to do without the work that they do.

D

David Staley 17:20

And graduate students, presumably, they are doing a different kind of work. I would, I would guess,

R

Robert Baker 17:25

That's right.

D

David Staley 17:25

David Staley 17:25

From the undergrads

Robert Baker 17:26

Well, so they've made a commitment. So you know, once they finish their coursework requirements, you know, they're, you know, life is really centered around doing the research that will build their PhD dissertation. So they're, you know, full time, their full, full time in the research laboratory.

David Staley 17:41

And doing what sorts of tasks?

Robert Baker 17:43

Oh, so they're the ones who, you know, run the soft X ray spectrometer, in fact, you know, I have to say, they're even the ones who built it.

David Staley 17:50

Oh, no, kidding.

Robert Baker 17:51

That's right. So, you know, this is not a commercial instrument. This is something which we, you know, designed and constructed ourselves. And, you know, I have graduate students who, who had the capability to, you know, envision how this would come together and actually put it together.

David Staley 18:04

And presumably, this is part of their research portfolios. This is what, their dissertation topics?

Robert Baker 18:10

That's right. Yeah. So they'll write a dissertation on this research. I mean, you know, one of the things that I'm really proud of is the ability to have them build and operate and maintain this, I think that makes them just extremely valuable. You know, when they go into industry, or maybe take an academic position in the future. They're the ones who can't just push the go button, but they put it together, they're the ones who will be called when it goes down. I think they're really in high demand.

D David Staley 18:33

Well, so you have graduate students, postdocs, presumably,

R Robert Baker 18:36

I've had postdocs work in my group that's right.

D David Staley 18:38

Postdoc, someone who already has their PhD and comes to work with you for,

R Robert Baker 18:43

Additional experience, that's right.

D David Staley 18:45

And so you have undergraduates. So what exactly does Robert Baker do in his lab?

R Robert Baker 18:50

Yeah, you might wonder if you know if the PI is really needed, but,

D David Staley 18:54

The Principal Investigator.

R Robert Baker 18:55

The Principal Investigator, that's right. So that's my role it's the Principal Investigator. In a way, my role is to provide guidance and to facilitate all this. But, you know, we also have to obtain the funding to support these students. And so we, you know, we conceptualize a lot of these ideas and make the case that these can really work. And I have to say, you know, I always joke with my students about when I'll cease to be needed. But, you know, they still come to me for the most difficult problems in the lab. And I haven't been out of the lab so long that I can't roll up my sleeves and still do my share the research.

D David Staley 19:25

Well, and it sounds to me, if I may, it sounds like what you've, what you have there is a, is like a

Well, and it sounds to me, if I may, it sounds like what you've, what you have there is a, is like a small business or small enterprise and you essentially function as the CEO. Is that, is that a fair analogy? Anything in your background prepare you for that sort of role, anything in your training that prepares you for that?

Robert Baker 19:36

You know, I've thought of this analogy before, it's, you know, I didn't anticipate how many different hats, you know, one would need to wear to work in this position. And, you know, I think that's one thing that keeps it exciting, you know, it's never the same day to day and you're always being pushed out of your comfort zone to learn new things. But yes, you're providing guidance, you're marketing your results, you're, you know, obtaining funding. Yeah, so I think it's a lot like a small business and you know, s research enterprise. No, not so much. I think it's just, you know, being very excited about what you do, and being willing to learn new things and try to make it work and, you know, have talented people around you, like we do at Ohio State to make this all possible.

David Staley 20:21

Well, and to be clear for everyone, this is hardly exceptional, a lot of science, this is how science gets done any longer

Robert Baker 20:27

It is.

David Staley 20:28

These laboratory enterprises.

Robert Baker 20:30

That's right.

David Staley 20:32

You, as I said in the introduction, won a Department of Energy Early Career Award. Tell us about the work that led to that award.

Robert Baker 20:41

So this research is funding us to use the ultra fast, soft X ray spectroscopy that we've been discussing, to look at the properties of catalysts that will allow it to split water into hydrogen and oxygen.

and oxygen.

David Staley 20:54

And why would we want to do that?

Robert Baker 20:56

Well, you know, hydrogen, and oxygen would be a beautifully clean and renewable energy source. And, you know, the Department of Energy is keenly aware of this. But you know, the process is not so easily done. And, you know, there are still questions about why the efficiency can't be higher, or why we can't do this process on a material which is Earth abundant, we could potentially do this on platinum. But there's only so much platinum, you know, in the earth could we do on something as as cheap and Earth abundant as rust? This would this would really be transformative.

David Staley 21:28

So hydrogen is obviously you're talking about hydrogen fuel cells?

Robert Baker 21:31

Right.

David Staley 21:31

But the challenge is, how do you produce the hydrogen?

Robert Baker 21:34

How do we produce the hydrogen

David Staley 21:35

For the fuel cell?

Robert Baker 21:36

That's right. Interestingly, you know, many people know that hydrogen is a clean fuel source, but they don't realize that most of the hydrogen that, you know, we use actually comes from a fossil fuel. So methane is the source of most of the hydrogen we use. And you know, it'd be wonderful to replace that with water.

D David Staley 21:53

Just replace it with water.

R Robert Baker 21:54

Just have water produce the hydrogen.

D David Staley 21:56

So tell us what your next research interest is going to be or what's next after these projects?

R Robert Baker 22:03

Well, I think that these projects, in a way teach us the direction we should go, you asked me originally, you know, how do you experience failure. And you know, I tried to not see it as failure, but as clues about what we should really be looking at. So,

D David Staley 22:16

It's a nice way of thinking of it.

R Robert Baker 22:17

Over my first four years, we've definitely seen things which weren't anticipated. One of the things we're really enthusiastic about is we set out to study how electrons move in materials. But it turns out that you can't really decouple the motion of the electrons from the motion of the nuclei, these happen in sync with each other. And in a way they guide each other. And this

D David Staley 22:36

The nuclei being the neutrons and protons in an atom.

R Robert Baker 22:39

That's right. So like I gave the example of rust. So you know, the scientific term for rust is hematite. This is just a fancy name for iron oxide. And it turns out that this could potentially split water. And it does but with a very, very low efficiency. And one of the things that we've learned recently is that the way that the nuclei, the iron atoms and the oxygen atoms in rust move, they push the electrons in undesired locations. So can we actually go back and try to control this better? I think this is one of the directions I'm very excited about.

D David Staley 23:13

Robert Baker. Thank you.

R Robert Baker 23:14

Yeah, thank you very much. Appreciate it.

E Eva Dale 23:16

Voices is produced and recorded at the Ohio State University College of Arts and Sciences Technology Services Studio. Sound engineering by Paul Kotheimer, produced by Doug Dangler.