Genome Insider S2 Episode 6: Back to the Future! A Sorghum Story

An assortment of sorghum varieties. (Roy Kaltschmidt, LBNL)

ALISON: Hey! I'm Alison Takemura, and this is Genome Insider, a podcast of the US Department of Energy Joint Genome Institute, or JGI.

So there's this plant that the DOE is very interested in using to produce biofuel and bioproducts. Step into a field of this plant, and, oh my goodness, it is just so. tall. Full disclosure, I'm about 5 feet and a half inch, but really. This plant is towering.

JOHN: It's literally like going into a forest where the canopy, the leaves are way above your head. And it's actually quite cool, even in Texas below that canopy.

John Mullet, biologist at Texas A&M University. (Texas A&M AgriLife Research)

ALISON: That's John Mullet.

JOHN: I'm a professor in the Department of Biochemistry and Biophysics at Texas A&M University.

ALISON: John's also a member of the DOE's Great Lakes Bioenergy Research Center, and he's part of this massive DOE effort to study this canopy-creating bioenergy crop called sorghum. Now, sorghum is a cereal crop, like wheat or oats, and sorghum grain — at least in the US — is mostly fed to animals. But the sorghum that we're talking about today is not that. It's not that kind of sorghum. The DOE studies a type of sorghum called bioenergy sorghum or biomass sorghum. And it's much better suited as a bioenergy feedstock because it can be grown on marginal land, with little water, and the whole plant — the stalk, the leaves, all of it — can be used to make biofuel and bioproducts.

Now, it's important to point out that the more a bioenergy crop grows and the more biomass it makes, then the more energy that you can get out of it. And these bioenergy sorghums — well, they really know how to grow.

William Wheeler, a postdoctoral associate working on the DOE-supported ROOTS project, stands next to a field of bioenergy sorghum this summer. The plants are about three months old and have another three months of growing to do. (Brock Weers)

JOHN: Sorghum plants, at the end of the season could be 16 to 18 feet tall.

ALISON: And that's just in about 6 months!

So, in thinking about sorghum, I wondered: what does it smell like to stand in a field of this stuff?

JOHN: Sorghum smells… Oh, that's great. actually reminds me of why I went into plant science. I just love the smell of plants.

When you mow your grass in the volatiles that are released, I just always thought that was very pleasant. And that is true of sorghum, too. So, sorghum, especially when its stems are full of sugar. It just has a very sweet smell. In fact, if you were in the field, in that part of the season, people often chop down a portion of the stem and it's like all completely filled with sucrose. But yeah, sorghum smells like a typical grass. Smells great.

ALISON: Sorghum stems are actually kind of like sugarcane.

JOHN: They accumulate lots of sugars, sucrose, starch, and monosaccharides. And that's really good for a bioenergy crop. Those sugars are readily converted into biofuels or jet fuel or bioproducts.

ALISON: The comparison to sugarcane made me curious; could you have a piece as a snack?

JOHN: Absolutely. Sure. Just like sugar cane. Hey, just peel off the outside of the stem. And oh, yeah, it’s great, great refreshment when you're out in the field.

ALISON : All that sugar is what makes this kind of sorghum such a good feedstock for biofuels.

John and his team were among the first to develop bioenergy varieties of sorghum. But they’re still trying to do more. If John could, he’d point a magic wand and enhance all of sorghum’s most valuable features, in order to make it into the ideal bioenergy plant. But that’s just not possible. So, he actually has to work with sorghum’s parts list: the genes that sorghum has and how they’re regulated, when they turn on and off. He can then use that information to actually make better varieties for biofuels and bioproducts.

John’s work in sorghum isn’t just about what’s going on above ground, though. The plant’s deep roots could be an unexpected part of what makes sorghum so well suited for our bioenergy future.

But before we get to the future of sorghum, let’s dig into its past. First question: Where did sorghum come from?

JOHN: Sorghum is native to Africa. And Africa has gone through many millions of years of drying, and then conditions that are maybe more favorable.

ALISON: And evolving in those harsh conditions made it astonishingly drought tolerant. There’s a story that sorghum’s abilities even caught the eye of a founding father.

JOHN: Benjamin Franklin, it was said, was traveling through Africa and saw this unusual drought tolerant cereal. And he brought it back to the US thinking it would be quite useful.

ALISON: OK, so unfortunately, no one can find records of that. But we do know that Ben Franklin really did espouse the virtues of sorghum, also known as broom corn.

We have hard evidence: A letter that he wrote to his sister-in-law in 1757:

DAVID as Ben Franklin: “I inclose you some of the Grain called Whisk Corn, or Broom Corn. .. The Grain is good for Bread, and for Fowls, Horses, &. makes excellent Thatch...”

“Pray try if it will grow with you.“

ALISON: Those early varieties, or genotypes, of sorghum that were introduced to the US were tall and used more of their energy on their growth rather than their grain.

JOHN: And it was through breeding that the breeders selected for short, genotypes that would produce a lot of grain, because that's an easy crop to produce, and there was a market for it for feed.

 Bioenergy sorghum, which produces copious amounts of biomass, grows near College Station, Texas. (Texas A&M AgriLife Research)

But now, when we need to produce a lot of biomass for bioenergy, then you want to go in the other direction. And my students would often say, oh, we're going back to the future. These are the original genotypes that were brought to the US.

ALISON: So how do you get a plant fit for the future to be more like how it was in the past? If you’re going for a really targeted approach, you start with trying to understand all of its genes: its genome.

JOHN: But there aren't that many people that are interested in the sorghum genome. And this is where DOE came in and said, we could use our capacity that we have at the Joint Genome Institute.

ALISON: That’s how John got involved with the JGI and the Great Lakes Bioenergy Research Center: to crack sorghum’s genetic code.

JOHN: And sure enough, we got a sequence out. It was just revolutionary, I mean being able to look up your genes or see, do whole genome analysis of transcriptomes and work out gene regulatory networks. And you can't do it if you don't have the foundational information about the genome, what are the genes, what are the gene families.

ALISON: They sequenced the sorghum genome — the species is called Sorghum bicolor — and it turned out to be about 800 million base pairs long — about a quarter of the size of the human genome. And it encodes about 34,000 genes.

But the team didn’t stop there. They also sequenced different varieties of sorghum, in order to help them link genes to different traits.

JOHN: They've been evolving for almost 50 million years.There's lots of diversity, lots of interesting, unique features and different types of genotypes.

ALISON: By sequencing different varieties of sorghum and comparing those genetic blueprints, John and his team found genes that influence how big sorghum plants can get and how much sugar they can store.

JOHN: It enabled us to move from guessing what the genes were that controlled various traits to being able to clone them out and understand how they work. It was tremendous.

So every time we go into any project now, we access JGI’s extraordinary capacity to help us do sequencing and analysis.

ALISON: Now that they’ve got all this information about sorghum’s genome, John and his team are unlocking molecular secrets. But one secret they’ve uncovered is visible to the naked eye: sorghum’s roots. One reason sorghum can produce so much biomass is because its roots go really deep.

JOHN: And so we wondered, well, just how deep do the roots go.

ALISON: They found that roots can go to about 2.4 meters, or 7 and a half feet deep. If I were to dig a hole that deep, and ask one of my favorite actors — and let’s be honest, just, people — Dwayne “The Rock” Johnson, to stand in it, even he would be in over his head. So, how does sorghum get its roots to go so deep?

JOHN: The trick that we've discovered that sorghum uses, is when it gets down in the soil profile, and soils can be quite dense; it's hard for roots to penetrate.

And what sorghum does is it just decreases the diameter of the root to below 0.5 millimeters to 50 microns in diameter, very small roots.

ALISON: Fifty microns is about the width of a fine human hair. So these roots get hairy.

JOHN: And they just penetrate in between the soil particles. And they go very deep. That way they can get water, they can get nutrients. And that's one of the reasons now we understand why sorghum, in response to a drought, will stop growing but it never dies. Because it's got its roots so deep in the profile.

ALISON: And that’s not just a good thing for sorghum. Plant roots add carbon to the soil. Plants are like straws sucking CO_2 out of the atmosphere as if it were a giant milkshake.

Some of that fixed carbon goes into building the roots, and some of that carbon leaks out into the surrounding soil. And that's fabulous. Because around the world..

JOHN: Soil carbon levels have depleted significantly by 50 percent or more over the last 100 years, especially in annual cropping systems.

ALISON: So, more carbon in the soil helps the soil hold more water and nutrients. It makes the soil more fertile.

Towering bioenergy sorghum gets harvested at the end of the season. (Texas A&M AgriLife Research)

And what's more, the deeper those roots go, the less likely their carbon is to be recycled back into the air. Instead, the carbon gets sequestered in the soil. And with today's carbon-drenched atmosphere, well, that's exactly what we need.

JOHN: It sequesters a lot of CO_2, so that can help mitigate climate change.

ALISON: John and his team recently did a study on sorghum. And they asked, ok, how much carbon can sorghum make into root biomass, and they compared that result to corn. So corn can produce about three-and-a-half tons of roots per acre. But...

JOHN: ..sorghum plants will produce about seven dry tons of biomass in their root system per year.

ALISON: That's about double what corn can make. So sorghum roots are a surprisingly effective all-natural carbon capture system.

There're some new capabilities that John is also super excited about right now. He's working with the Environmental Molecular Sciences Laboratory, aka EMSL, that's E-M-S-L, a DOE user facility at Pacific Northwest National Laboratory, in Washington state.

JOHN: And EMSL is now helping us in collaboration with the collaboration of my group, Amy Marshall-Colon at the University of Illinois and Kankshita—

ALISON: That's Kankshita Swaminathan—

JOHN: at HudsonAlpha.

ALISON: That's the HudsonAlpha Institute for BIotechnology in Huntsville, Alabama. It's a DOE-funded partner institution. Both Amy and Kankshita are members of another DOE Bioenergy Research Center, the Center for Advanced Bioenergy and Bioproducts Innovation, or

CABBI, that's C-A-B-B-I for short.

JOHN: And EMSL has technology for doing single cell laser capture microdissection.

ALISON: That's a powerful technology that lets scientists capture individual cells and look at what genes they express inside.

JOHN: And that is really essential if we're going to do engineering on a cell specific or tissue specific basis.

ALISON: An example is engineering certain tissues to store more plant oils that could be used for bioenergy.

JOHN: So there's lots of technology. But all of this traces right back to the Department of Energy's investment in this area.

DOE has done a fantastic job at setting up the large scale ecosystem for genomic research, which is really accelerating what we can do with bioenergy sorghum.

And it certainly has made the science and the research that we've been able to do much more exciting, because we can get access to the information that's required to do the work.

ALISON: But now let's turn our gaze to the future. How do we get to commercial scales of sorghum production, that enable biofuels and bioproducts, and sequester carbon, all at the same time? The next step, John says, is biorefineries. They're kind of like oil refineries: they take raw materials and they make fuel or other valuable chemicals — but biorefineries don't use fossil fuels: They use plants!

JOHN: So the engineering that is being done on the crop itself, improving that, that's been coming along for years. There's lots of knowledge that's built up in terms of how to harvest, how to convert that material, how to separate it into various valuable products.

ALISON: Petroleum is also used to make all kinds of products besides fuels — like solvents, plastics, et cetera — so we want to replace those, too.

U.S. Senator Debbie Stabenow of Michigan visits the Alpena Biorefinery. (Office of Senator Stabenow)

JOHN: The next phase that's going to happen is biorefineries being built out. And then products will flow. You know, 25 years from now, people won't think anything about it. They'll just be a bunch of biorefineries that are doing two things: they're generating products that'll displace what fossil fuels currently produce for us. At the same time, they'll be mitigating the climate, putting CO_2 into the soil and capturing it at the biorefinery and sequestering it. Yeah, given 25 years, this system will be built out to a large extent. And it'll just be part of the energy and bioproduct infrastructure. It's a big transition. So I don't underestimate the challenge. … But the technology is available, the science is being produced, and that transition will happen.

ALISON: John's actively working on making this a reality. And, it makes me hopeful.

JOHN: I've been working with collaborators to put together the next generation of biorefineries. And we're looking for people who are interested in making investments to put things together in this new way.

ALISON: These biorefineries will have a little extra something special. Now, I hadn't heard of this before, but John was really excited about it: the use of human-made carbon sequestration technology at the biorefinery. This add-on feature would actually capture and sequester carbon dioxide that's produced as a byproduct, before that carbon can escape to the atmosphere.

JOHN: I have to say it's the new carbon capture and sequestration technologies that look very promising, coupled with sequestering CO_2 in the soil at the front end,

ALISON: i.e. when it's growing in the field, which sorghum is very good at doing...

JOHN: ...you end up with a carbon negative crop. Ten years ago, I never thought that would happen. But now it's possible.

We're really at the point where we're transitioning, you can see that the economics is already very good…. I'm very optimistic about the future in this area.

ALISON: And this transition to biofuels and biorefineries isn't just something that helps the country and the world by reducing greenhouse gas emissions. John says the changes will also revolutionize small communities.

JOHN: We'll build out a sector that will certainly help rural economies.

ALISON: These'll be communities in the Midwest, where there are already some 75 plus biorefineries, and these'll be communities in the South and in the Gulf Coast, where they'll take the place of oil refineries.

JOHN: That's economic development. Once you have biorefineries in place, then the feedstocks that have to be produced will be produced in those rural communities, they'll be fed into the biorefineries, and it will diversify the economies. So there's lots of benefits in terms of rural economy development that will happen, in addition to diversifying the sources of energy and securing them for the future.

One thing about that, maybe people don't always recognize that, once you have set up a biorefinery system based on bioenergy crops, it's sustainable forever. I mean, it's not like an oil field that will run out of oil. If it's able to produce these crops, over and over and over again, it's sustainable. So let's solve the problem and move on, right?

ALISON: This episode was directed and produced by me, Alison Takemura, with editorial and technical assistance from Massie Ballon, Ashleigh Papp, and David Gilbert, who also pitched in with an impersonation of Ben Franklin.

DAVID: My name is Benjamin Franklin. I was born the 17th day of January, 1706.

ALISON: Thanks, David.

Genome Insider is a production of the Joint Genome Institute, a user facility of the US Department of Energy Office of Science. JGI is located at Lawrence Berkeley National Lab in beautiful Berkeley, California.

A huge thanks to John Mullet, biologist at Texas A&M University and member of the U.S. Department of Energy Great Lakes Bioenergy Research Center, one of four DOE Bioenergy Research Centers across the country. You know, I wonder how I can become an investor in one of those biorefineries that John was talking about…

JGI allocates a third of its resources to supporting these DOE Bioenergy Research Centers. Another one, the Joint Bioenergy Institute at Lawrence Berkeley National Lab, is collaborating with JGI on a number of sorghum projects, including one to sequence mutants generated with fast neutron radiation, in order to find safe sites that can be engineered using CRISPR-Cas9 technology.

I know we didn’t get to talk about it in this episode, but we wanted to give a quick shoutout to JGI’s other sorghum collaborations. For example, we’re helping UC Berkeley's Peggy Lemaux study drought tolerance through a five-year, multi-institution project funded by the DOE Office of Biological and Environmental Research, called Epigenetic Control of Drought Response in Sorghum, or EPICON for short.

Do you want to dive deeper into the research that JGI enables? If so, then join us at the JGI Annual Genomics of Energy & Environment Meeting, August 30th through September 1. It's virtual and free and open to anyone who’s interested: from students to researchers to biology enthusiasts. Reserve your spot now by going to our website usermeeting.jgi.doe.gov.

And because we’re a user facility, if you’re interested in partnering with us, we want to hear from you! We have projects in genome sequencing, synthesis, transcriptomics, metabolomics, and natural products in plants, fungi, algae, and microorganisms. If you want to collaborate, let us know!

Find out more at jgi.doe.gov forward slash user dash programs.

That’s it for now. See ya next time!