Genome Insider S2 Episode 9: Creating an Energy Market for Miscanthus

Miscanthus giganteus, here at UC Davis, is both an ornamental and a potential biofuel feedstock. (Roy Kaltschmidt/Berkeley Lab)

ALISON: Hey! I'm Alison Takemura, and this is Genome Insider, a podcast of the US Department of Energy Joint Genome Institute, or JGI. I want to introduce you to a plant, which has led sort of two very different lives in the US. This plant, originally from Asia, is a tall, bushy grass, known by its genus name Miscanthus. Miscanthus was first an ornamental plant.

ERIK: I think it started in the 1870s. A New York nurserymen went to Japan and purchased some varieties of one with a white stripe called variegatus, and one with a horizontal yellow stripe called zebrinus.

ALISON: That's Erik Sacks, a plant breeder and geneticist at the University of Illinois Urbana-Champaign..

ERIK: And he shipped them back to the US. And they're still for sale today in the nursery industry. Those very two varieties,

ALISON: These grasses are surprisingly pretty, like a bit of avant garde art in your garden. And Erik says, Miscanthus only got more popular. Another nurseryman,

ERIK: that nurserymen, Aksel Olsen,

ALISON: He procured a variety, called Miscanthus giganteus, which can reach a staggering 4 meters (or 13 feet) tall. Not that Axel himself had to spend much energy on getting the plant.

ERIK: He didn't go to Japan. He just purchased the plant and had it shipped.

Miscanthus sinensis 'Zebrinus' has stripes like a zebra. (Wikimedia)

ALISON: How? Because of an ingenious marketing ploy.

ERIK: There was a very large nursery trade in the Yokohama area, and there was a very large nursery company called the Yokohama nursery company, and it would have a beautiful color-illustrated catalog in English. And for this amount of gold, you can get this much pieces of whatever you wanted!

ALISON: Including Miscanthus. Most varieties of Miscanthus are actually found in China. But because of the thriving nursery trade between Japan and the US and Europe at that time — the late 1800s, early 1900s — most of our ornamental Miscanthus are from Japan.

And we have a lot of ornamental Miscanthus. You can find them at nurseries and garden centers, often called by their common names, “silver grass” and “Maiden grass.” The names are probably allusions to the gorgeous silvery tassels that it has when it flowers.

Dan Rokhsar, geneticist at UC Berkeley and the lead of the Computational Genomics group at the JGI. (Courtesy of the UC Berkeley)

But this, this is just one side of Miscanthus. Here’s Dan Rokhsar, a geneticist at UC Berkeley and the lead of the Computational Genomics group at the JGI, to tell us about how Miscanthus has substance as well as beauty.

DAN: The reason we're interested in it is because it grows extremely rapidly.. It's a perennial grass that produces an enormous amount of biomass.

ALISON: And it doesn’t need prime agricultural land to do it; it can grow on marginal land, with little fertilizer and little water.

DAN: Without really taking care of it, we can generate a lot of biomass and then that biomass could be converted directly into energy by burning it or through conversion into fuel. And so the idea is to create a sustainable bioenergy source using this plant.

ALISON: But it’s going to take a lot more than a fancy illustrated catalog to bring Miscanthus to the bioenergy market. To meet this challenge, scientists are investigating what farmers need, what helpful governmental policies might look like, and how unlocking Miscanthus’ basic biology could make the plant a hot commodity.

The full color catalog from the Yokohama Nursery Company in Japan allowed nurserymen to order Miscanthus. (Biodiversity Heritage Library)

First, let me just run you through what Miscanthus has going for it as a bioenergy crop. It’s tall, it’s productive, it’s perennial — so it’ll come back year after year. It has thick, dense roots, and they’re able to sequester carbon in the soil, which means..

MADHU: The resulting biofuels that we would get would be negative carbon compared to gasoline. So this would be more than 100% cleaner than gasoline.

ALISON: That’s Madhu Khanna, an environmental economist at the University of Illinois Urbana-Champaign. With Erik and Dan, she’s a member of the Center for Advanced Bioenergy and Bioproducts Innovation (or CABBI), one of four DOE Bioenergy Research Centers. Madhu actually leads CABBI’s effort to understand the economics of deploying efficient bioenergy crops. She’s also intimately familiar with Miscanthus’ challenges, particularly for farmers, the people who would be growing this energy crop.

MADHU: There are a number of barriers that will affect farmers’ decisions about adopting it, one of which is that there are significant establishment costs.

ALISON: These are the costs of planting. The process starts with the underground storage stems Miscanthus has. To the uninitiated, they look kind of like sweet potatoes. They're called rhizomes. And if you cut them up and plant them in the ground, lo and behold, you'll get new shoots of Miscanthus. But that process? It's expensive.

Rhizomes aren't like seeds: they're not easy to collect because they have to be dug out of the ground, they're much heavier to ship, and they have to be kept moist, because they'll die if they dry out. They're also harder to plant because they're bigger, so farmers have to dig deeper into the soil.

MADHU: It also takes two to three years to get fully established to be able to provide maximum yield. So during that time, farmers are not earning an annual income like they would with annual crops.

ALISON: Though, if the farmers had some marginal land they weren't planning to grow anything on, they could use that without a financial loss. Still, there are other barriers to growing Miscanthus.

Madhu Khanna, environmental economist at the University of Illinois Urbana-Champaign. (Courtesy of the University of Illinois)

MADHU: Additionally, with row crops (ALISON: a.k.a. annual crops), farmers have crop insurance. And so if there is a bad year, they know that they will be covered for the downside risks. But for energy crops, like Miscanthus, there is currently no crop insurance program. And so farmers would lose their crop insurance for the row crops, and not be covered in case of any weather-related or other risks associated with energy crop production.

ALISON: Ouch. But, Madhu's not finished.

MADHU: Additionally, because it's a perennial, it requires farmers to make a long-term commitment to keep their land under Miscanthus for 15 years or more. And, and so, as opposed to annual crops, they cannot frequently rotate with other crops depending upon changes in market conditions.

ALISON: In other words, Miscanthus is a double-edged sword for farmers: it's easy to grow once established. But it's almost too good. Once it puts down those dense roots, it's really tough to dig up. So, once farmers choose to plant Miscanthus, they're basically stuck with it. Of course, the hope is that they can sell it. But unlike the relatively stable market for the pretty ornamental varieties of Miscanthus, the market for bioenergy Miscanthus can have tectonic shifts. That's why, Madhu says, you need long-term contracts for Miscanthus.

MADHU: So that there is an assured market and a guaranteed price that farmers can hope to get if they want to convert their land from annual crops to Miscanthus.

ALISON: If there's policy uncertainty or, as Madhu puts it, an “unwillingness of the market” to make long-term contracts, then that can make it very risky for farmers. So, of all these factors, what does Madhu think farmers need most in order to grow Miscanthus?

MADHU: I think the most important thing is to have a market for it. And in order to develop a viable market, we need to have assurance of policy that is going to create a demand for renewable energy and bioenergy in particular. And there needs to be some certainty, long-term certainty that the policy will be implemented.

ALISON: Madhu mentions that we’ve had the Renewable Fuel Standard, which was passed in 2005. It says, OK, we, the US, by 2022, will produce 16 billion gallons of next-generation biofuels. These will be made from plant cellulose, so we can use grasses like Miscanthus. And we’ll make that 16 billion gallons each year, which is about a tenth of the fuel that we use annually.

But sadly, that policy has not been successfully implemented: we’re producing less than 15% of what that policy had aimed for. And we’re not using any energy crops, including Miscanthus, to make biofuels commercially — at least, not yet.

There’s still hope, though. Future policies could be better designed to reach bioenergy goals. For instance, they could take into account bioenergy’s climate benefits.

MADHU: Currently, there is, really limited to no markets for paying farmers for the carbon sequestration as well as just the carbon credits they generate by producing bioenergy. And so that's another incentive that could be provided in the future to take this to market.

ALISON: While scientists think about how to improve the value of Miscanthus in the market using economic and policy incentives, they’re also tackling the problem using their knowledge of Miscanthus’ biology. They’re trying to make Miscanthus hardier, so it can grow on poorer land, and withstand floods, droughts, heat, and cold. Erik, who told the story about nurserymen, Miscanthus, and Japan at the top of the episode, he’s gone to extreme climates, hunting for these kinds of tough traits in Miscanthus.

Erik Sacks, plant breeder and geneticist at the University of Illinois Urbana-Champaign. (Courtesy of the University of Illinois)

ERIK: Even though most of these are from the tropics, Miscanthus goes all the way up to approximately 50 degrees latitude in eastern Russia, where it's very, very cold hardy.

ALISON: Just how cold hardy? Erik has an illustrative story.

ERIK: I was visiting a station near Lake Khanka, where we were collecting...

ALISON: There’s a research station there, and they were with the station manager.

ERIK: It was a beautiful autumn day, we were in like shorts and short sleeves and stuff. And he’s like, Oh, yeah, that lake — which is like one of our great lakes; it's huge! It's huge! And part of it’s in China, part of it’s Russia. And he’s, ‘Oh yeah, that gets two meters of ice on it in the wintertime.’ And you know, these rhizomes are only primarily in the top six to eight inches of the soil. So they're frozen solid. How do they survive that?

ALISON: Figuring that out could set the stage for a more cold-tolerant variety of bioenergy Miscanthus. Another strategy is thinking about the big, bulky rhizome. Miscanthus is really good at moving fixed carbon into the rhizome. But..

Steve Moose, plant geneticist at the University of Illinois Urbana-Champaign. (Courtesy of the University of Illinois)

STEVE: Maybe we don't want it to be so good. Maybe leaving it in the stalk, then you can actually harvest it right above ground,

KANKSHITA: And find a balance where it still stays perennial. But at the same time, the stalks have a little bit more oomph in it for other purposes.

ALISON: Quick introduction: You just heard, in this order, Steve Moose, a plant geneticist at the University of Illinois Urbana-Champaign, and Kankshita Swaminathan, a plant geneticist at the HudsonAlpha Institute for Biotechnology, a JGI partner.

Steve and Kankshita are also thinking about tweaking the types of compounds that Miscanthus makes. Because if they can get Miscanthus to make more valuable molecules, maybe they can tip the economics in Miscanthus’ favor.

One class of those molecules? Lipids. Making up oils, lipids are..

STEVE: ..very energy dense, they can be used right in a biodiesel or jet fuel application.

ALISON: Another potential avenue is creating ‘base chemicals’ in Miscanthus, which are used as the building blocks to other, more specialized chemicals.

STEVE: And they're often petroleum-derived, that's their current source, but they could be bio-derived.

ALISON: There’s ongoing efforts to make these base chemicals in microbes, but scaling up might just be easier in plants.

STEVE: The plant side, it might be more challenging to get them to make these special things. But if we can, the scaling is very fast, I mean, just grow it, you know, and it's just growing a crop.

And so if you add value to it, you'll change that equation on the farm, right, if the farmer is going to get paid more for it, because there's more value to share through the system, the farmer gets a little more of it.

ALISON: Then, maybe you don't need subsidies, or other incentives to get farmers to grow Miscanthus. Instead, maybe…

STEVE: They'll be begging for it. If they hear their neighbors making more money than they are, they're going to want to be in on it.

ALISON: That would be a game-changer for bioenergy. Of course, it's a long road to get Miscanthus to that point.

Kankshita Swaminathan, plant geneticist at the HudsonAlpha Institute for Biotechnology, a JGI partner. (Courtesy of the HudsonAlpha Institute for Biotechnology)

KANKSHITA: A lot of basic biology has to come together first, before we can, really build all the dreams. For example, Steve mentioned, we're trying to make lipids in, in these grasses. But right now, the tools that we have, are limited, because our understanding of the biology of the plants are limited.

ALISON: Kankshita and other scientists still have lots of questions: How do you funnel some of Miscanthus' carbon into lipids instead of where it would normally go, into more plant biomass? How do you make sure the plant doesn't mind that major shift in its metabolism and still continues to grow like gangbusters?

KANKSHITA: And this is where I think genome biology, gene function plays a big role. And JGI has enabled a lot of the science.

ALISON: In fact, JGI has helped Kankshita and colleagues get a genome sequence of Miscanthus. It was published in late 2020. But that effort was more than a decade in the making. And the story took some unforeseen twists.

It all started in 2007 with none other than the petroleum company BP. BP, then branding itself as 'Beyond Petroleum,' was interested in bioenergy. So in 2007, they created the Energy Biosciences Institute (or EBI, for short). BP had pledged 10 years of funding for the project, and they selected UC Berkeley, the University of Illinois Urbana-Champaign, and Lawrence Berkeley National Laboratory to lead it.

Steve and others pitched the idea of Miscanthus as a biofuel of the future to BP. And BP, through EBI, decided to pursue it.

STEVE: Then we had to quickly build a team that had to have the right expertise. And, you know, and that's where Dan really came in, you know, he's a leader in the sort of the technology and the analysis of genomes.

ALISON: Dan and his team, including Berkeley bioinformaticist Therese Mitros, were then leading the effort to sequence sorghum, another potential bioenergy feedstock. We explored sorghum in a previous episode of Genome Insider, so check it out in the show notes!

Back to the team Steve was building around Miscanthus: another early recruit was Kankshita.

She was really skilled, and one example was her ability to extract Miscanthus DNA. Steve says that Dan definitely took notice.

STEVE: I mean, at one point, he wouldn't let anyone else make it. If I remember right.

ALISON: The team made steady progress for years, but by 2015 the Miscanthus data they had still wasn't enough to put together the genome. Unfortunately, this is when BP decided to call it quits! They dissolved EBI, about three-quarters of the way through their original commitment. Why? Well, it's unclear, but BP did have the Deepwater Horizon oil spill disaster in 2010, and that might have been a contributing factor.

Still, even though BP's institute was finished, the team wasn't ready to completely call it quits.

KANKSHITA: We had this group that enjoyed working together.

ALISON: So they pushed on, slowly and without much money. But something else good came out of EBI's demise: former international competitors suddenly became collaborators.

KANKSHITA: During the EBI days, there were competitors, but when EBI ended, so did other funding in other places, and so everybody had this, half-finished effort. In some ways, I actually see that as a positive thing, because then all these groups really came to the table. And we met at the plant and animal genomics meeting, sat around the table and said, Okay, this is what I have, this is what I can contribute.

ALISON: It allowed everyone to pool their knowledge and keep chipping away at the elusive Miscanthus genome. Then, in 2017, the researchers caught a break. That year, the Department of Energy formed CABBI, the DOE Bioenergy Research Center that I mentioned earlier. CABBI provided institutional support to jumpstart Miscanthus research.

KANKSHITA: That really enabled us to then finish the job we had started.

ALISON: One of the benefits of the published Miscanthus genome is that it'll help speed up Miscanthus breeding programs: scientists will be able to survey the genetic map and apply the gene editing tool CRISPR so that they can cut the 10-year breeding cycle in half. But Kankshita and Steve weren't making as big of a deal about the recently published genome as I would've expected...

KANKSHITA: I know, but we have something better, which is why I think we're both (laughter)...

ALISON: OK, Kankshita explained it to me this way. The first genome came from a variety of Miscanthus that they knew had a less complex genome. Still, it was hard enough putting the genome puzzle together, even when that puzzle was as simple as possible.

Scientists are working on increasing the value of Miscanthus grasses, so that farmers can reap economic rewards from growing it. (Courtesy of Erik Sacks)

But now, wielding newer technology, Kankshita and the rest of the Miscanthus team have something bigger in the works. They've put together more complete genomes of multiple Miscanthus species from different parts of their range in Asia. CABBI scientist Therese Mitros at UC Berkeley, working with the JGI Plant Program at HudsonAlpha, is leading the analysis of those genomes.

So, why is Kankshita so excited about them? The genomes provide Kankshita and her colleagues just a much better foundation to understand how Miscanthus operates.

KANKSHITA: I'm looking at this as a biologist, absolutely enamored and amazed at what the technology was just you know, 5-10 years ago to what it has become and the ability of these groups to really weave this thing together. To me, it's a piece of beauty. (laughter)

ALISON: By peering into the genome, Kankshita can see Miscanthus' potential. The genome's a map that'll allow scientists to take a grass that's often just used to dress up a landscape and develop it into a carbon-sequestering, bioenergy powerhouse.

ALISON: This episode was directed and produced by me, Alison Takemura, with editorial and technical assistance from Massie Ballon, David Gilbert, and Ashleigh Papp.

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And if you're interested in hearing about cutting edge research in secondary metabolites, also known as natural products, then check out JGI's other podcast, Natural Prodcast. It's hosted by Dan Udwary and me.

That's it for now. See ya next time!
Additional information related to the episode:

JGI Science Highlight: A Grass Model to Help Improve Giant Miscanthus
Miscanthus publication: Mitros T et al. Genome biology of the paleotetraploid perennial biomass crop Miscanthus. Nature Communications. 2020 Oct 28. doi: 10.1038/s41467-020-18923-6
JGI Blog: Rethinking Agriculture from an Ecosystem Perspective featuring former CABBI Director Evan DeLucia in 2018
CABBI also featured in JGI podcast Genome Insider S2 Episode 6: Back to the Future! A Sorghum Story
Miscanthus genome v7.1 on Phytozome
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