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High school teachers participating in a teacher workshop at the McCall Outdoor Science School. *Photo courtesy of MOSS.*

# Teacher professional development for energy literacy

The USDA-NIFA, through NARA, supports programs to educate K-12 students and increase their level of bioenergy literacy. Curriculum units have been developed for middle and high school students that explore alternative energy development and use. The Imagine Tomorrow competition provides high school students opportunities to develop and showcase biofuel projects. Classes at the University of Idaho's McCall Outdoor Science School (MOSS), a NARA affiliate, connect K-12 students to bioenergy concepts and projects.

Elevating the level of bioenergy literacy through programs that interact directly with K-12 students is only one part of NARA's education strategy. Another way to promote bioenergy literacy to K-12 students is to provide learning opportunities for K-12 educators so that they have the tools and knowledge to include bioenergy instruction in their classrooms.

Members affiliated with NARA's Education team recently published a journal article that describes two different formats used to help K-12 teachers build bioenergy literacy. The article was published in the Journal of Sustainability Education.

View Teacher Professional Development for Energy Literacy: A Comparison of Two Approaches here.

## Webinar format

One format used a series of monthly webinars to instruct high school teachers. The twenty-six teachers who participated in these webinars coached student teams for the Imagine Tomorrow competition and were located within the four-state NARA region (ID, WA, MT, OR). The goals driving this approach were to increase the quality of the Imagine Tomorrow experience and projects and to provide an opportunity for scientists, most were NARA researchers, to share their research directly with teachers.

The questions guiding the webinar series included:

- What resources exist for teaching bioenergy resources?
- What is the NARA project doing to advance bioenergy in the Pacific Northwest?
- How can these ideas contribute to my students' projects for the Imagine Tomorrow competition?

The breadth of subjects covered included an overview of the NARA project, bioenergy-based teaching tools, biofuel supply chains, lignin co-product development, and air emission impacts. Each researcher presented for 20-30 minutes with a similar amount of time provided for teacher questions.

## Face-to-face format

The other format delivered an onsite workshop that spanned four consecutive days and was conducted at the McCall Outdoor Summer School campus in McCall ID. Seventeen teachers attended the workshop while an additional twenty teachers participated online through a "blog" format that generated a total of 15 updates.

The workshop topics explored the technology and sustainability issues associated with using forest residuals to produce biojet fuel and co-products.

The overarching questions guiding this workshop included:

- Is this a good idea?
- How do we know?

As with the webinar format, multiple NARA researchers provided presentations. Unlike the webinar, however, those who physically attended the workshop took part in multiple hands-on learning activities that could be duplicated with their students. The hands-on activities included measuring the amount of biomass available from slash piles and simulations that helped describe the conversion processes used to generate chemical products from wood residuals. In addition, the teachers assumed the role of varied stakeholders to discuss the projected benefits and concerns resulting from a wood residual to biojet and co-product industry.

## Assessing each format

A series of interviews and surveys were conducted with teacher participants and presenters to evaluate the effectiveness of each format. Initial feedback indicates that the webinar approach attracted a broader geographic participation and allowed teachers to better connect the lessons directly to the Imagine Tomorrow student projects and to their local communities.

The face-to-face approach allowed more in-depth exploration of subjects and provided hands-on exercises for teachers to take back to their classrooms. The direct interaction between presenter and teacher was mutually beneficial for both parties. In addition, the intimate nature of the workshop allowed the workshop facilitators and instructors to understand the particular needs and goals of the teacher participants. The NARA education team plans to present a follow-up paper that describes the classroom outcomes resulting from teacher participation later this year.

Both approaches provided timely research information and inquiry-based lessons that could transfer to the classrooms. They both delivered concepts connected to the Common Core and the Next Generation Science Standards.

Due to the NARA project's broad mandate to investigate a range of subjects relating to the technical, environmental, social, economic, and educational aspects connected to an emerging wood-based biofuel and co-product industry, the NARA project functioned as an good case-study to use for a cross-interdisciplinary approach to enhancing bioenergy literacy. The NARA website provided useful content for these workshops in the form of relevant primary and secondary literature, newsletters, videos, and knowledge databases and educational resources.

Danica Hendrickson, curriculum director at Facing the Future, introduces curriculum units to high school teachers. *Photo courtesy of MOSS.*

# Putting "sustainability" in energy education

Research performed by NARA members contributes to an understanding of how to develop a sustainable wood residual-to-biojet fuel and co-product industry. Sustainability in this case refers to economic, social and environmental sustainability. Techno-economic, biomass supply and logistics, and community impact analyses are being developed to gauge economic sustainability; a community asset assessment model and outreach activities evaluate social sustainability; and research relating to soil, wildlife and air emission impacts contribute to evaluating environmental sustainability. The triple bottom line of economic, social and environmental sustainability research was highlighted last fall at NARA's annual meeting.

Presentations relating to NARA's sustainability research can be viewed here.

NARA's Education team develops tools and experiences to help prepare a future workforce to participate in a biofuels industry. The programs and lesson plans designed for K-12 students not only include traditional topics on energy use and efficiency, but also feature elements that encourage students to consider the social, economic and environmental considerations involved with energy choices. A journal article recently published in the Journal of Sustainability Education, describes curriculum units produced through Facing the Future (FTF), a NARA affiliate organization, that promote global sustainability education. The journal article also demonstrates how these curriculum units are incorporated into present day K-12 classrooms.

Read Global Sustainability: An Authentic Context for Energy Education here.

## Curriculum units developed through the lens of global sustainability

The curriculum units described in this journal article are titled *Fueling our*

*Future: Exploring Sustainable Energy Use*. Two editions are available to accommodate either middle or high school students. Each edition features nine lessons that progress from fundamental energy science to a study of global energy issues and case studies reflecting NARA's research. Since the first publication in 2014, educators from eleven countries purchased over 270 curriculum units. The lessons contained within these curriculum units focus on global sustainability and encourage critical thinking, collaboration, communication, creativity, and the integration of multiple concepts and views.

The final test, or performance-based assessment (PBA) for these curriculum units, has students work independently and collaboratively to answer the driving question: What are the most sustainable biofuels that can be produced in the Pacific Northwest? To answer this question, students evaluate the sustainability of the entire supply chain used to produce biofuels and consider the perspectives of the multiple stakeholders affected. The students conclude their lessons by writing a personal position paper on biofuel development in the Pacific Northwest.

The curriculum units were developed and tested with contributions from multiple sources including education and content experts, many were NARA researchers, as well as an international set of teachers who specialize in varied disciplines like history, social studies and science. Another NARA affiliate, University of Idaho's McCall Outdoor Science School (MOSS), pilot tested the curriculum and contributed valuable feedback for the development.

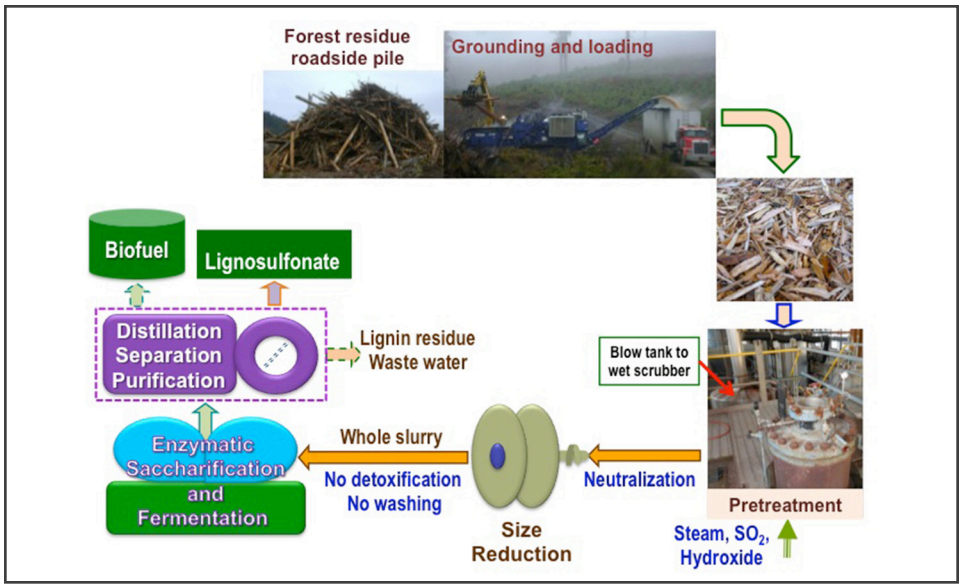
## Future work

Further curriculum refinement is underway. Facing the Future plans to use the bioenergy assessment tools developed by NARA to gauge the bioenergy literacy gains made by those students who receive the lessons. This assessment should identify lesson segments with the greatest literacy impact and help shape the production of further lessons.

Initial feedback is promising. While using FTF's curriculum, 86% of educators reported that their students are more engaged and 91% of educators reported an increase in their students' critical thinking skills. Of these educators, 93% reported an increase in their own knowledge of global issues. Listed below is a comment received by FTF from an educator who is using the lessons in her classroom:

"I love that this was so well integrated and there was such a variety of ways students learned about topics. The activities with visuals, extensions, and links to extensions and additional information were very helpful. Also, the PBA was excellent, my students really got into it especially because so many of them have family members that work for Boeing."

Future curriculum units are being developed for elementary students.




Schematic of mild bisulfite pretreatment process. Courtesy of Junyong Zhu at USDA Forest Service, Forest Products Laboratory.

# Wood-to-alcohol conversion technology suitable for a pulp mill retrofit

Building a biorefinery to convert wood residues into chemical products like biojet fuel is expensive. The projected capital investment exceeds $850 million. An alternative, and potentially less costly approach, is to retrofit existing wood-based facilities and establish a distributed supply chain where various stages of the conversion process are conducted at separate facilities.

Pulp mills are well suited for use in a wood residual-to-biojet fuel supply chain. They are generally located in areas rich with woody biomass and have the transportation, storage capacity, and permit assets established. In addition, pulp mills are engineered to break down large amounts of wood material using chemicals and heat to isolate cellulose for paper production. This process is similar to the pretreatment phase, a process that exposes cellulose for enzymatic hydrolysis to simple sugars, used to produce biojet fuel from wood biomass. Because of the similarities shared between these two processes, it is likely that a pulp mill's infrastructure could be used for pretreatment with minimal modifications.

NARA evaluated multiple pretreatment processes including wet oxidation, dilute acid and mild bisulfite with the intent of selecting the best process for industrial use. Multiple considerations were investigated, and the mild bisulfite pretreatment protocol was selected.

The mild bisulfite pretreatment protocol was developed at the USDA Forest Service, Forest Products Laboratory and Catchlight Energy, both NARA affiliates. One of the advantages to the mild bisulfite process is that it uses sulfite chemistry, which is similar chemistry employed at pulp mills. Another advantage is that it was designed to operate at a relatively low temperature (145°C), which is compatible for a typical pulp mill's plumbing.

Recently, NARA researchers conducted a 50 kg pilot scale evaluation of the mild bisulfite process using conditions most adaptable for a pulp mill. The results were published in Bioresource Technology.

> Read Using sulfite chemistry for robust bioconversion of Douglas-fir forest residue to bioethanol at high titer and lignosulfonate: A pilot-scale evaluation here.

## A 70% ethanol yield

For this experiment, a 50 kg sample (oven-dried) of ground Douglas-fir residuals was used. This sample was taken from a larger sample collection labeled (FS-10) which is used as a "forest residual" reference sample for NARA's conversion experiments. FS-10 was collected from roadside slash piles in southwest Oregon. The roadside slash was ground and screened with 1.75-inch mesh to remove oversize particles and a 1/8-inch mesh to remove fines. The screen accepted materials labelled FS-10 was then dried to a 15% moisture content.

The experiment described in this publication was designed to replicate a commercial-scale conversion process that could be performed at a typical wood pulp mill. The FS-10 forest residuals were loaded "as is" without additional processing.

A dilute sulfite solution at low pH was produced containing calcium hydrogen sulfite ($Ca(HSO3)2$) and free sulfur dioxide ($SO2$). This was done by "bubbling" sulfur dioxide into a calcium hydroxide solution. The total $SO2$ loading was only approximately 25% of that used for sulfite pulping. This process, combined with the 145°C temperature maintained for four hours, provided the "pretreatment" step that could be conducted at a typical pulp mill. The entire slurry at the end of pretreatment had a solids content of ~25%.

The slurry was diluted to 16.7 weight percentage of total solids, brought to a pH of 6.2, and hydrolytic enzymes were added to release the simple sugars from the cellulose and hemicellulose. After pre-hydrolysis (~24 hours in laboratory due to lack of mechanical mixing), yeast was introduced to the hydrolysate and used to convert the simple sugars into ethanol.

As mentioned, this experiment was designed to replicate a commercial scale wood-to-alcohol conversion. It is important to note that no additional processing steps such as washing or detoxification were applied to the pretreatment slurry. The pretreated FS-10 whole slurry was directly used for enzymatic saccharification and fermentation after neutralization. The buffer used in this laboratory experiment can be eliminated for commercial practice. Under these conditions, an ethanol yield of 282 liters per ton of FS-10 forest residue was achieved which reflected a 70% theoretical yield based on the content of glucan, mannan and xylan in the FS-10 sample.

## Commercial grade lignosulfonate

Alcohols are not the only commercial product generated by this process. A highly sulfonated lignin product (lignosulfonate) was produced as a byproduct. Total lignosulfonate yield was 130 kg per ton of forest residuals. Lignosulfonates are used for a wide range of applications. They are added to improve the quality of concrete and plasterboard and applied to dirt roads as a dust suppressant. In 2001, the U.S consumption of lignosulfonates exceeded 400,000 metric tons. The lignosulfonate generated from this experiment shared comparable properties with commercial lignosulfonate. This result suggests that commercially viable lignosulfonate can also be produced under these pilot scaled conditions.

## From pilot test to real world

NARA is assessing the viability of retrofitting operational and idle pulp mill facilities as viable conversion sites. Tools have been developed to rank regional sites based on physical assets and social acceptance, and applied to the NARA region.

NARA's Education and Outreach teams are working with partners and regional stakeholders to assess potential sites across the supply chain where retooling of existing facilities can occur to convert forest residuals to alcohols, and/or biojet fuel, and co-products like lignosulfonates.

The authors conclude their study by stating, "This study demonstrated that underutilized woody biomass such as forest residuals can be efficiently converted to biofuel and bio-products using mature pulping technologies with proven commercial scalability." Their work provides a solid technical basis for potential retrofits.

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