NARA
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Grades 7-12 Biofuels Curriculum Released to Educators

One of the five NARA project goals is to increase bioenergy literacy among students, educators, professionals and the general public. For students and educators, NARA funds and participates in a number of programs targeted to K-12 and higher education students.

> View a listing of the student education opportunities provided by NARA

Developing and distributing curricula that translates NARA research to middle and high school students is one activity NARA promotes and funds. In late 2013, NARA's affiliate member Facing the Future, published a lesson plan entitled, "Fueling Our Future: Exploring Sustainable Energy Use". This publication encourages students to work through many of the issues that NARA is tasked to evaluate such as the environmental impacts and technological hurdles to use forest residuals to make bio-jet fuel. To date, over 200 copies have been distributed to educators.

> Read a review of *Fueling Our Future: Exploring Sustainable Energy Use*

In the March 2014 edition of Science Scope, NARA members Jennifer Schon, Justin Hougham, Karla Eitel and Steve Hollenhorst published a new lesson plan entitled "The Value of a Tree; Comparing Carbon Sequestration to Forest Products".

> Obtain a copy of *The Value of a Tree; Comparing Carbon Sequestration to Forest Products*

According to lead author Jennifer Schon, "This lesson incorporates STEM practices well and can be scaled up or down depending on available resources. The lessons offer teachers a unique opportunity to incorporate salient policy issues regarding biofuels with something they can likely access easily: trees."

This lesson plan encourages students to explore the varied ecosystem services that a tree provides such as habitat, materials, carbon sequestration, oxygen and energy. Student activities include identifying a tree to calculate the following:

- The height and circumference
- The amount of carbon stored and amount of carbon sequestered annually
- The amount of jet fuel that can be created from the tree carbon
- The distance a Boeing 747 can fly per kilogram of carbon

In addition, knowledge assessments are provided to measure student understanding before and after the lessons. Responding to the assessment component, the authors stress:

"There is no right answer when deciding whether to harvest a tree for lumber and use its slash for biofuel or to leave the tree for carbon sequestering. The important concept for them to understand is that there needs to be a balance and the answer is complex, with many layers involved."

NARA Research Impacts Lesson Content

Work led by NARA researcher Indroneil Ganguly found its way in the lessons. Dr. Ganguly's preliminary life cycle assessment for converting forest residuals into bio-jet fuel suggests that using bio-jet fuel instead of fossil fuel reduces net carbon emissions by 60%, and the avoidance of burning slash piles negates the carbon dioxide emissions associated with harvesting, collecting, chipping, and transporting the biomass to a chipping facility. This inclusion demonstrates how NARA research is being communicated directly to educators and their students.

Learn more about [Dr. Ganguly's work: Poster]

Learn more about [Dr. Ganguly's work: Video]

Entry into the Classroom

Several hundred middle school students, in various classroom settings, have used this curriculum during pretesting and the lessons have been refined based on their and the teacher's experience. The lessons can be modified to accommodate various learning levels and goals, and versions are available for middle and high school students. These lessons do a great job to incorporate STEM learning goals and standards and showcase a current real-world opportunity while asking questions and seeking critical thinking related to transportation fuel options and the student's natural environment.

Rotating reactor used at the USDA Forest Products Laboratory

Finding the "Sweet Spot" in Isolating Simple Sugars from Wood

NARA researcher J.Y. Zhu and his team are trying to solve a problem. They are refining a pretreatment method used to soften the wood and allow the simple sugars to be released. It is the simple sugars that are used to make alcohols, which are the building blocks to produce bio-jet fuel. Removing simple sugars from wood requires some pretty harsh treatments. Too harsh of conditions will result in altering the simple sugars into unwanted chemicals collectively called inhibitors. In this case, not only are the sugar molecules degraded, but the inhibitors created interfere with downstream processing steps necessary to ferment the sugars into alcohols and generate co-products. As the severity of the pretreatment is reduced, however, fewer simple sugars are released which decreases yield.

In a recently published paper funded by NARA, J.Y Zhu and his team evaluate how pretreatment temperature affects simple sugar yield and sugar degradation into inhibitors. They evaluate the inhibitor formation and simple sugar yield using two temperatures (165° and 180° C) for the SPORL (Sulfite Pretreatment to Overcome the Recalcitrance of Lignocellulose) pretreatment method. This pretreatment method relies on heat, chemicals and time, so to make up for the decrease in heat, they assigned a reaction time of 75 minutes for the 165°C temperature condition and 30 minutes for the 180°C reaction. By adjusting the reaction times, the "reaction severity" stayed relatively equal between the two conditions.

Read [Using low temperature to balance enzymatic saccharification and furan formation during SPORL pretreatment of Douglas–fir]

Lower Heat Reduces Inhibitor Formation

Identifying high temperature as a cause for inhibitor formation was based on the theory that sugar degradation into inhibitors from hemicellulose requires more energy (think heat) than the heat necessary to allow for effective simple sugar yield. As it turned out, the pretreatment set at 180°C at 30 minutes produced approximately double the concentration of inhibitors as the conditions at 165°C for 75 minutes, yet the sugar yield efficiency for both conditions was the same. In addition, the change of temperature did not have a significant affect on lignin removal. Designing an efficient pretreatment option with lower temperature not only helps reduce inhibitor formation, but will also allow for greater flexibility in using existing infrastructure that can handle the lower temperatures in the pretreatment process.

Background Information Regarding Pretreatment

Carbohydrates, often referred to as monosaccharides, or in laymen terms, simple sugars, are the molecules from wood that are used to make bio-jet fuel. Removing intact simple sugars from the wood material is a challenge because first, they are tightly bound together in the form of polymers called cellulose and hemicellulose and because second, these polymers are surrounded and protected by a complex molecule called lignin. The combined structure containing cellulose, lignin and hemicellulose is called ligno-cellulose.

Removing the simple sugars from ligno-cellulose involves two steps. The first step is called pretreatment which separates the lignin, hemicellulose and cellulose. The second step is enzymatic hydrolysis, in which enzymes, that break the bonds in cellulose and hemicellulose, are added to the pretreated wood and thus release the simple sugars.

See where pretreatment and enzyme hydrolysis occur in the NARA supply chain

There are a number of methods used for pretreatment. These methods rely on an input of energy and/or chemicals to disrupt the interaction of lignin, hemicellulose and cellulose.

Read a description of various pretreatment technologies evaluated by NARA

NARA will Select One Pretreatment Process

NARA has evaluated four pretreatment options and will decide on a single option within the next month. Some parameters that affect the choice of pretreatment options will be sugar yield, inhibitor formation, scalability, capital and operations costs, air emissions, and adaptation to existing facilities. Selecting a single pretreatment option is a significant NARA milestone and allows NARA researchers to create a comprehensive techno-economic analysis and a life cycle assessment that is based on a single conversion technology.

Photo courtesy of Ponsse

Forest residues, machines and soil: how do they mix?

Transporting the forest residues located in slash piles out of the woods requires vehicles and equipment to roll and vibrate over bare ground. This activity can cause soil compaction and disturbance, which can lead to adverse soil erosion and limit plant growth.

Numerous studies and harvesting policies have been initiated to lessen the impact of soil compaction and are based on the harvesting methods and equipment used at the time. As new harvesting methods and equipment are developed, a reassessment of their impact on the soil is warranted. New equipment is being developed for ground-based harvesting on steep slopes that offer an alternative to expensive cable harvest systems.

An article recently published in Forest Science, and partially funded by NARA, evaluates how forest-thinning operations on steep slopes affects the soil. For their study, authors Rene Zamora-Cristales, Paul Adams and John Sessions, evaluated thinning operations on two sites with steep slopes (greater than 50%) and similar soil types. Both thinning-operations used the same harvester equipment that cut and delimbed trees in a single downhill pass; however, one operation employed a skyline cable system to take out the harvested material and the other used a harvester-forwarder. Both the harvester and the forwarder were fitted with band tracks to provide improved traction. The soils on both sites were similar. The trails created represented 10% with the harvester-forwarded and 15% with the harvester-cable. The soil moisture levels were at ~30%.

Read *Ground-Based Thinning on Steep Slopes in Western Oregon: Soil Exposure and Strength Effects*

Study Results

Once thinning operations were complete, soil exposure and strength were estimated on the trails created by the thinning and harvesting equipment. For soil exposure, the harvester-forwarder operation resulted in over two times the soil exposure than the the harvester-cable operation with 7% of the sample points recording soil exposure verses 3%. For soil strength, a single harvester pass caused soil strength to increase by 19-34% in the upper depth classes (25-200 mm). A second pass using the forwarded increased the soil strength to 33-40% greater than undisturbed soil. Soil strength can affect forest productivity. Higher soil strength can limit tree and vegetative root penetration. These measurements were biased and recorded the soil strength of soil under the track ruts where the maximum compaction occurred. Total trail soil strength did not exceed 15%. It is interesting to note that approximately 30% of the trails created were covered with slash. Comparing the soil strength on trails with and without slash cover showed a 14% decrease in soil strength for slash-covered trails. This information suggests that the slash cover helped buffer the effects of compaction by dispersing the vehicle weight.

Forest Residual Harvest Implications

Evaluating the soil conditions after timber harvest on step slopes provides a baseline of data that can be used to evaluate the affects of transporting forest residuals from a harvesting operation on steep slopes. In addition, this study indicates that residual slash cover can affect the severity of soil compaction and may influence how slash piles are managed and transported relative to the sequence of harvesting operations. The authors acknowledge that further site evaluations could also provide a better understanding to how the changes in soil strength can affect water retention and erosion on steep slopes.

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