

Rocky Mountain Research Station

Science You Can Use Bulletin



January/February 2016 | Issue 17

Burgeoning Biomass: Creating Efficient and Sustainable Forest Bioenergy Technologies in the Rockies, Part II



Pelletized biochar. Photo: Nate Anderson

Forestry operations in the western U.S., including thinning for hazardous fuel reduction, leave behind a staggering amount of wood waste. Much of this waste is non-merchantable tree stems, branches, and tops. These materials, called forest residues or “slash,” are usually yarded into large piles and burned for disposal. In the bark-beetle-affected areas of northern Colorado alone, it is estimated that there is a backlog of 120,000 piles of woody biomass slated for burning. Not only

is this a waste of a potential resource, pile burning can exacerbate air quality problems and increase greenhouse gas emissions. It also leaves long-lived burn scars on the forest floor. If slash could be economically transported, processed, and used by a bioenergy facility, it could be transformed into energy and marketable products rather than burned for disposal. This may be a more environmentally and socially appealing alternative to open burning.

SUMMARY

Woody biomass could be used to generate renewable bioenergy and bioproducts in the western U.S. and has the potential to offer environmental and societal benefits. The purpose of the Rocky Mountain Research Station-led Biomass Research and Development Initiative (BRDI) project is to research and develop technologies, approaches, and new science that will help to make this possible. Part one of this series (September/October 2014) addressed the economic and environmental challenges of the biomass supply chain, from the site of harvest to the bioenergy facility—from “cradle to gate.” This issue of the Bulletin is focused on the supply chain from the conversion facility to end use, covering material processing, conversion, end use, and disposal—from “gate to grave.” It features important research on life cycle assessment of products from forest biomass, economic feasibility of conversion operations, and social acceptance of woody biomass energy. It provides details about the marketable uses for biomass co-products, like biochar and activated carbon. These contributions, combined with the material covered in part one, have the potential to facilitate biomass utilization as a feasible renewable energy option to offset fossil fuels, reduce our long-term carbon emissions, and address many significant forest management challenges.

Woody biomass has the potential to offer environmental and societal benefits. When used for renewable energy, it can reduce our dependence on fossil fuels, increase energy security, decrease forest insect and disease outbreaks, lower our long-term carbon footprint, and help reduce severe wildfire hazards. However, there are social, economic, and environmental barriers to be overcome. This Science You Can Use Bulletin is the second in a two-part series highlighting research of the Rocky Mountain Research Station (RMRS) Biomass Research and Development Initiative (BRDI) project, funded by the National Institute of Food and Agriculture (NIFA). The project aims

to develop technologies, approaches, and new science to address the technical, environmental, social, and economic aspects of woody biomass utilization. The first issue (September/October 2014) focused on research to optimize the efficiency of the biomass supply chain from “cradle to gate”—that is, from the site of harvest to the bioenergy facility. This issue picks up where the fall 2014 issue left off and features research from project investigators Nate Anderson, Debbie Page-Dumroese, and Dan McCollum of RMRS, Tom Elder of the USFS Southern Research Station, and Rick Bergman from the USFS Forest Products Laboratory, as well as research

from collaborators Robert Campbell of the University of Montana, Karl Englund of Washington State University, and Tyron Venn of the University of Montana and the University of the Sunshine Coast, Australia. It highlights RMRS-BRDI research related to the use of woody biomass from “gate to grave”—from the gate of the conversion facility, covering material processing and conversion, to the disposal of end-use products. It features important research on conversion technology, economics, life cycle assessment, and social acceptance of woody biomass energy.

BIOMASS: GATE TO GRAVE

The Gate to Grave segment of the supply chain includes steps to convert processed forest biomass into valuable products that are delivered to end users who drive the demand for bioenergy and bioproducts.

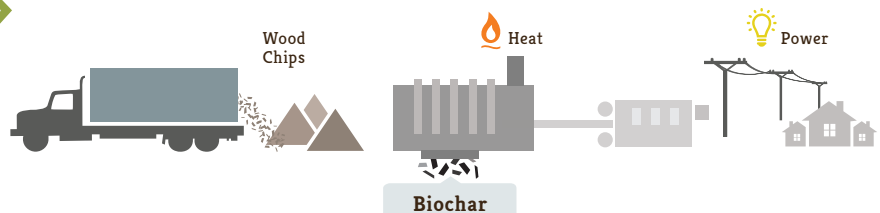
Social & Economic Context

Successful use of woody biomass for energy requires public support. Understanding how the public views woody biomass energy and related trade-offs is critical to future adoption of forest-based bioenergy.



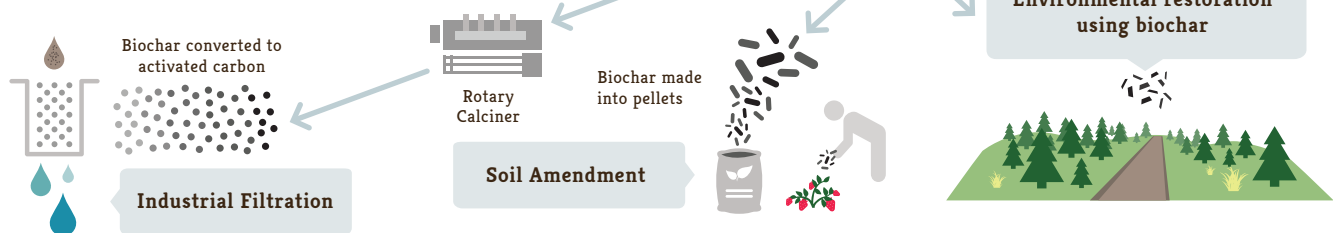
Biomass Conversion Produces Heat, Power, and Biochar

Conversion of biomass can yield: heat and power for manufacturing, power for the power grid, and a charcoal product called biochar, which has several uses in agriculture and industry.



Biochar: Multiple Marketable Uses

Biochar product revenues can enhance economic feasibility. Possible uses for biochar include soil restoration, farm and garden applications, and filtration, with or without activation.



Biomass conversion technology research and development—the Tucker RNG System

Most NIFA-BRDI projects include a commercial partner who works with agency and academic scientists to further research and develop new biomass technology. This project partnered with Tucker Engineering Associates, which designed and built the Tucker Renewable Natural Gas (RNG) System, a promising thermal biomass conversion technology. What makes a biomass conversion system promising? First, it must be concluding its research and development phase and moving toward commercialization. It also has to be technically feasible to operate in industrial settings, meaning it can operate continuously in a wide range of conditions. Finally, as a part of the conversion process it must create environmentally-sound, marketable products at competitive prices. Tucker Engineering Associates was selected as the commercial partner because their technology is “greatly improved from early trials and closer to commercial deployment than anything that we’ve worked on before,” says RMRS research forester and project director Nate Anderson.

The Tucker RNG technology turns wood waste—slash for example—into electricity, heat, and biochar, which is a charcoal co-product of the wood-to-energy conversion process. Woody biomass entering this system must first be pre-processed, usually by chipping, screening to smaller chip size, and drying to a moisture content of 10% or less. The dry wood chips then pass through an airlock and into

a high-temperature pyrolysis reactor in which little or no oxygen is present. The initial heating drives some gases off the wood, including hydrogen, carbon dioxide, carbon monoxide, methane, and other light hydrocarbons, which are collected as synthesis gas (“syngas”). The Tucker Unit cleans and further refines the syngas, producing an energy-dense renewable natural gas output. Unlike some similar systems, the Tucker RNG unit does not use gas to produce liquid fuel. The gas is funneled to a combination engine-generator (a “genset”), to produce electricity. As the conversion process continues, the remaining biomass fully carbonizes into a charcoal-like material called biochar. The syngas, biochar, heat, and power are all valuable products generated by the conversion process.



Richard Tucker, president of Tucker Engineering Associates and Chief Technology Officer of RNG, with a Tucker RNG system. Photo: Nate Anderson

The Tucker RNG System is especially well-suited to applications where it can be used to reduce energy costs, process waste feedstocks, and produce heat and electricity for customers interested in green energy. It is scalable in size to meet a wide range of production needs, from mobile conversion units to larger,

permanent installations. Although using biomass from forestry and agricultural operations generally decreases total carbon emissions and lessens the environmental impact of the energy produced compared to fossil fuels, the Tucker RNG System can also use a wide range of non-renewable carbon-rich feedstocks, including coal, tires, and plastic waste, making it potentially useful in a wide range of applications. The system can reduce net carbon emissions by capturing and using heat and solid carbon (e.g., biochar) generated in the conversion process. Along with heat and electricity, the gas and biochar produced by the unit can be used to produce a variety of marketable products that can be shipped to distant markets, which is important to the forest industry in rural areas.

Making use of biomass: Tucker RNG system products

Synthesis gas

The main components of the syngas produced from woody biomass by the Tucker RNG System (in mole percentages) are carbon monoxide (45-50%), carbon dioxide (10 to 15%), hydrogen (15 to 20%), and methane (15 to 20%). This gas mix, which contains 500 to 600 Btu per cubic foot (about 50 to 60% of the energy content of natural gas), can be burned for heat or to generate electricity for the grid. The syngas can also be cleaned up, compressed, and stored as a gaseous fuel.

Making liquid hydrocarbon fuels out of syngas is an exciting possibility, but currently very much in the research phase for small-scale applications.

As part of the RMRS-BRDI project, Tom Elder of the USFS Southern Research Station has been working with the Louisiana State University Department of Chemical Engineering to develop methods to make liquid fuel out of the Tucker Unit syngas using different catalysts. He says, “These liquid fuels have many of the characteristics of gasoline and diesel.” However, developing the right catalysts is challenging. Each catalyst is composed for specific compositions and concentrations of gases coming from different conversion processes and feedstocks. In other words, if a catalyst is developed for Tucker RNG wood syngas, another would have to be developed for syngas produced by another conversion unit or from another feedstock, and catalyst development is time consuming and expensive.

Carbon products

Biochar is the solid end product of thermal conversion of biomass in the Tucker RNG System, and accounts for about 15% of the dry input feedstock mass, with the rest going into the syngas. It can be used as a solid fuel and burned like coal, or can be used as a soil amendment, and/or as a raw material for industrial sorbents to filter liquids and gases. According to Anderson, “It has pretty similar properties to coal, so it can be used pretty seamlessly as a coal substitute and burned in the same types of boilers for energy, or used as an industrial raw material.” Because biochar contains fewer or lower concentrations of sulfur and other impurities found in some coals, this use can reduce harmful emissions from coal-fired power plants; cleaner burning



A forest site being treated with pellets using a custom biochar pellet spreader mounted on a forwarder. Photo: Nate Anderson

biochar replaces some of the higher emissions coal.

Biochar has been shown to be beneficial as a soil amendment. Unlike wood, which decomposes when applied to soil, biochar is very slow to break down and while in place, it bonds tightly to water and soil nutrients. According to Debbie Page-Dumroese, an RMRS research soil scientist focusing on uses for biochar, “Using biochar, we can increase water-holding capacity of the soil by 20-30% depending on soil type,” which has obvious benefits for plants and crops growing in dry environments. Biochar also has many exchange sites for retaining soil nutrients that otherwise might get washed through the system with rainfall. Biochar can be applied directly to the soil surface where it works

“Using biochar, we can increase water-holding capacity of the soil by 20-30% depending on soil type,” notes research soil scientist Debbie Page-Dumroese.

its way into the soil profile and can remain for a very long time—hundreds or even thousands of years.

Page-Dumroese and colleagues have been working with biochar produced by the Tucker RNG system in forest settings where it has been shown to be useful for enhancing tree growth and avoiding soil compaction in areas like skid trails. She reports, “We’ve seen tree growth increase by 25-30% in tree thinning experiments. About 80% of what we put out as carbon can be sequestered in the soil for the long term. Also, biochar in the soil reduces the bulk density, so it helps to remediate compaction and it helps to keep the soil aggregates together so that it doesn’t recompact.” She adds that biochar can also be used in mine reclamation, where it can bind heavy metals and add organic matter to the soil and prevent leaching into streams and groundwater, and along roadways or drainage ditches, where it can filter petroleum products out of road runoff. Her current work is focused on determining the appropriate biochar application rates in the field. “In most forests we don’t see a response until we get up to an application rate of about 3

“...Also, biochar in the soil reduces the bulk density, so it helps to remediate compaction and it helps to keep the soil aggregates together so that it doesn’t recompact,” adds Page-Dumroese.

tons/acre, and we can go as high as 10 tons before it starts to repel water or erode in a heavy rainstorm,” she says. “You can add the higher amounts to the coarse-textured soils because it works its way in faster.”

The biochar coming out of the Tucker RNG System is very powdery and can be difficult to work with, so researchers have been developing ways to turn the biochar into a product that can be applied using equipment similar to a fertilizer spreader. Karl Englund, a RMRS-BRDI project collaborator from the Washington State University Civil and Environmental Engineering Department and the Composite Materials Engineering Center, says “A pellet mill is perfect for turning this powder into something usable.” Englund is working on assessing the potential for using local materials that might be around after a forest operation, like slash and needles, and grinding them to mix with biochar as a binder and extender for the pellets. “Mobile pelletizing units are something we are interested in, which is why we are trying to use local materials,” he says.

The biochar produced by the Tucker RNG System can also be used as a renewable raw material for making activated carbon, which currently comes mostly from coal but can also be made from wood, coconut shells, and other biomass. To make activated carbon, biochar is “activated” with heat and steam or a strong base, such as potassium or sodium hydroxide, which increases the porosity and surface area of the material. There are a number of uses for activated carbon, but the most common is industrial filtration of liquids and gasses, including drinking water and emissions from power plants and vehicles.

Unfortunately, the low cost of other raw materials, specifically coal, makes it difficult for wood-based activated carbon to compete on price without premiums for renewable products or connections to wood waste streams. Biochar also has more variability than coal, and may not work well for some applications. On the positive side, markets for activated

carbon are well-established, whereas those for biochar as a soil amendment are still developing in the home gardening, agriculture, mining, and forestry sectors.

The sustainability of woody biomass products: Environmental, financial, and social considerations

Environmental impacts

When looking at the environmental sustainability of a product, it is useful to calculate all of the environmental impacts related to greenhouse gas emissions, energy balance, water and air pollution, toxicity, and other impacts from raw material extraction to manufacturing, distribution, use, and disposal—in other words, from “cradle to grave.” One way to do this is a life cycle assessment, which is similar to an economic cost-benefit analysis, but instead looks at environmental impacts. According to Rick Bergman, a Research Forest Products Technologist



Rick Bergman, with the USFS Forest Products Laboratory, collecting data to conduct a life cycle assessment of the Tucker RNG technology. Photo: Nate Anderson

at the USFS Forest Products Laboratory who is contributing to the project, “For new products it is useful to make a comparison with an existing product, like biochar versus coal.” Because biochar is rich in non-decomposing “fixed” carbon, using it as a soil amendment can reduce greenhouse gas emissions by sequestering carbon in the soil, keeping formerly labile carbon locked in the soil for hundreds or even thousands of years. Bergman and his FPL colleague Hongmei Gu found that when compared to electrical energy from coal-based syngas, wood-based syngas combined with biochar sequestration reduced greenhouse gas emissions by 87%.

Bergman and Gu also looked at the sustainability of the Tucker RNG System. Based on their analysis, the Tucker unit produced 2.54 megajoules of bioenergy for every 1 megajoule of fossil fuel energy that was input into the system. “Therefore,” says Bergman, “the Tucker RNG unit is an energy efficient system that can provide renewable energy.” In general, locating the unit close to biomass sources reduces the fossil fuel emissions from hauling woody biomass and makes the system more energy efficient. More specifically, some energy generated by the Tucker RNG system is currently unused but could be used for feedstock drying, further reducing fossil fuel use and increasing efficiency and sustainability of the whole system.

Financial analysis

The key to making utilization of woody biomass profitable is in the multiple and diverse uses to which woody biomass can be put, according to Dan McCollum, a research economist at RMRS. “Think of it as a portfolio. Not

all woody biomass has to be used in the same way. One product’s demand for woody biomass may be limited. But the very same material can be used for an entire portfolio of products.” Some uses of woody biomass can produce multiple value-added products at the same time. What that means, McCollum says, “is an individual product does not necessarily need to be profitable by itself, as long as the combination of outputs is profitable and/or reduces a company’s cost of production.” A sawmill is a good example. Heat can be used to kiln dry wood products, syngas can be used to produce electricity for on-site processes or the grid, and biochar can be sold to various markets. The mill’s overall cost of production can be reduced by replacing inputs that were previously purchased with co-products from pyrolysis and by using waste biomass as feedstock.

KEY FINDINGS

- Small-scale thermochemical biomass conversion technologies can effectively provide heat, power, and bioproducts.
- Biochar, a solid co-product of woody biomass conversion, has the potential to be used in forest road rehabilitation to mitigate and prevent soil compaction. Other biochar uses include restoration of damaged soils.
- When compared to energy from coal syngas, wood syngas combined with biochar sequestration reduces greenhouse gas emissions by 87%.
- Biomass energy is an attractive concept to some segments of the public, but its price may still be a barrier to adoption.
- Factors that are likely to increase the profitability of woody biomass conversion operations include developing new markets for bioenergy and bioproducts, diversifying product lines, and increasing the efficiency of the conversion system, such as using waste heat for production processes.

An analysis of the financial performance of a mobile conversion unit used to produce biochar from sawmill residues done by Anderson and others showed a very wide range of potential results—from being significantly in the red to significantly in the black over a 10-year project period, with the financial outcome being most sensitive to labor costs and the market price of biochar. Factors that are likely to increase the profitability of such operations included increasing the efficiency of the conversion system for higher output, further developing the markets for biochar and associated products, operating these conversion technologies in areas with high wood-waste disposal costs, and using the produced waste heat or syngas instead of fossil fuels to heat buildings and kilns.

Social acceptance

Does the public support using woody biomass as renewable energy? Energy from biomass is more expensive than that from natural gas, but its use offers ancillary benefits to local communities, including less air pollution from open pile burning, reduced wildfire risk, creation of local jobs, and localized energy self-sufficiency. Tyron Venn, associate professor of forest economics, and Rob Campbell, PhD student from the University of Montana, conducted surveys in Montana, Colorado, and Arizona to measure the tradeoffs that residents of the Rocky Mountains may be willing to make to use this renewable energy source. They found that the majority of the respondents were concerned about smoke from wildfires and open pile burning, and also thought that local job creation should be considered when managing



public forests. Almost three-quarters of the respondents indicated that they supported higher amounts of woody biomass harvest from public lands to generate renewable energy, with more people favoring smaller-scale woody biomass plants as opposed to larger plants. Only 41% of respondents, however, were willing to pay higher monthly energy bills for biomass energy, with the average respondent willing to pay about \$1-\$2 per month extra. In the end, it appears that while biomass energy is an attractive concept to some segments of the public, the price of that energy may still be a barrier.

In a study of Larimer County, Colorado residents, McCollum, along with Colorado State University researchers Maryam Tabatabaei and John Loomis,

found further evidence of social acceptance. Respondents were asked to choose between the status quo level of forest treatment and two alternatives providing an increased level of harvest and removal of beetle-killed trees at additional cost. The difference between the alternatives was in how residual materials from harvest were handled. In Alternative 1, residual materials would be burned on-site, as is currently the predominant method of disposal. Alternative 2 specified that residuals would be moved off-site and used to produce biochar. Payment for the additional harvest would be in the form of a dedicated tax for forest treatment operations. Average willingness to pay was \$411 per household per year for Alternative 1 and \$470 per household per year for Alternative 2, over and above

“Our focus has largely been on product development and research and development of the conversion systems themselves,” says project leader Nate Anderson, “the next step is to scale up... [w]e are looking at the set of conditions under which the system is likely to be commercially viable.”

the cost of the status quo. The message of these results, according to McCollum, “is that the public perceives excess woody biomass in the forest to be a problem and is tolerant of forest thinning as a way of dealing with that problem. Few details were provided to respondents on the benefits of biochar, other than as a way to avoid on-site burning of residual material. Even so, there was some evidence of willingness to pay for those additional benefits indicating recognition of some social benefit to making use of woody biomass.”

What is next?

Thus far, “Our focus has largely been on product development and research and development of the conversion systems themselves,” says Anderson, “the next step is to scale up.” In this case, that means shifting the focus to upscaling all aspects of the project, from the economic and ecological analyses, to the size and deployment of the Tucker RNG units, to biochar application in the

Choice Set 1		Expected outcomes over 10 years		
Attribute		Strategy A	Current Strategy	Strategy B
Homes powered with wood in my state		20,000 homes	20,000 homes	30,000 homes
Unhealthy air days in my community		5 days per year	10 days per year	10 days per year
Large wildfires in my state		15 large wildfires per year	12 large wildfires per year	6 large wildfires per year
Forest health in my state		10% healthy forests	20% healthy forests	30% healthy forests
My household's monthly energy bill		\$400 (\$4,800 annually)	\$100 (\$1,200 annually)	\$120 (\$1,440 annually)
I would choose (select one only)		☐	☐	☐

Excerpt from a survey designed to measure tradeoffs associated with energy from woody biomass. Credit: Robert Campbell and Tyron Venn

field. For example, biochar was initially applied by hand to relatively small forest plots, but its application is now being up-scaled by project collaborators designing a mechanical biochar spreader that can be driven on skid trails, log landings, or roads for larger-scale industrial application to forest soils. Moving forward, many of the scientists involved in the RMRS-BRDI project are also involved with the Biomass Alliance Network of the Rockies and Waste-to-Wisdom—two large integrated NIFA-funded projects with the goal of further developing bioenergy and bioproducts from forest biomass.

Commercial deployment of the Tucker RNG system needs to add up financially for the technology to have a future. “Now, we are looking at the set of conditions under which the system is likely to be commercially viable,” says Anderson. “Areas with high electricity costs, like Hawaii and Alaska, are great targets for these systems, as are areas with high waste disposal costs, like parts of Europe, and places that put

price premiums on green energy, like California. Many people are interested in deploying these systems in off-grid parts of Africa and Asia. Places that have municipal, agricultural and industrial biomass waste streams are also good candidates.” Overall, the net value of biomass conversion must be improved by a combination of better processes and better market conditions, and, as with any commercial venture, finding cheaper, better ways of operating. Also, says Anderson, “It is really helpful if people appreciate and are willing to pay for the non-market benefits of renewable energy, like better air quality and reduced wildfire risk. Then, the benefits are monetized in ways that help these technologies get adopted.” More broadly, in many areas land managers implementing treatments on the landscape for timber harvest, restoration, and fuel reduction struggle to find markets for the biomass that used to go to hog fuel and pulpwood for paper manufacturing. Finding markets for woody biomass remains a challenge,

MANAGEMENT IMPLICATIONS

- Opportunities to use woody biomass from treatments include combustion for heat and power, and are evolving to include biofuels and bioproducts applications.
- Biochar can be used to facilitate forest soil restoration by improving soil properties and minimizing further compaction. New equipment is available to make this possible over large areas.
- Using biomass for energy is most economically feasible when treatment sites are close to markets, in areas where current energy costs are high, and when the public supports renewable energy.
- Small-scale woody biomass conversion systems can produce heat and power, as well as other products, at a wide range of facilities and are becoming more commercially viable as technologies improve.
- New opportunities are emerging for biomass utilization and biochar use closely tied to forest restoration and management.

but conditions are improving with the commercialization of new technologies and the expansion of bioenergy, biofuels, and bioproducts manufacturing.

FURTHER READING

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To provide scientific information to people who make and influence decisions about managing land. The US Forest Service RMRS Science You Can Use Bulletin is published regularly by:

Rocky Mountain Research Station (RMRS)

US Forest Service
240 W Prospect Rd
Fort Collins, CO 80521

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SCIENTIST PROFILES

This issue picks up where the fall 2014 issue left off and features research from project investigators Nate Anderson, Debbie Page-Dumroese, and Dan McCollum of RMRS, Tom Elder of the USFS Southern Research Station, and Rick Bergman from the USFS Forest Products Laboratory, as well as research from collaborators Robert Campbell of the University of Montana, Karl Englund of Washington State University, and Tyron Venn of the University of Montana and the University of the Sunshine Coast, Australia



Nate Anderson is a Research Forester with the Rocky Mountain Research Station, where he studies forest resource management and economics. His recent work is focused on the use of forest biomass for bioenergy and bio-based products. Nate received his PhD in Forest Resources Management from the SUNY College of Environmental Science and Forestry.

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Debbie Page-Dumroese is a research soil scientist with the Rocky Mountain Research Station. Deb has a PhD in Forest Soils from the University of Idaho. Her research efforts relate to soil productivity during harvest operations. She is a principal investigator for the North American Long-Term Soil Productivity study and a world-wide study examining forest management and below ground processes.

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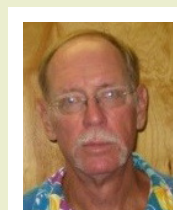
Dan McCollum is an economist at the Rocky Mountain Research Station studying people and natural resources, including non-market values of goods and services and how local economies and communities are affected by economic activity resulting from resource management. Dan has a PhD in Economics from the University of Wisconsin.

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Rick Bergman is a research forest products technologist with the Forest Products Lab in Madison, Wisconsin. He earned a PhD in Forestry and Life Cycle Analysis from the University of Wisconsin. His research focuses on life-cycle analysis of wood building materials and bioenergy resources to quantify critical emissions and environmental impacts.



Tom Elder is a research scientist with the Southern Research Station of the USDA Forest Service. His research emphases are biomass characterization and conversion to bioproducts and bioenergy, concentrating on gasification, pyrolysis, and catalytic upgrading of the products.

SCIENTIST PROFILES cont.



Robert Campbell is a PhD candidate in the College of Forestry and Conservation at the University of Montana. He has a Master's degree in Applied Economics from Oregon State University, where he focused on environmental and resource economics. His research interests pertain to the valuation of non-market environmental goods.



Karl Englund received a BS and MS degree in Wood Science at West Virginia University and a PhD in Civil Engineering from Washington State University. His research focuses on processing composites and utilizing waste materials as feedstocks for composites and biofuels. Much of his work involves collaboration with government agencies, non-profits, and industry.



Tyron Venn is a Senior Lecturer in Economics at the University of the Sunshine Coast, Australia. His research is focused on supporting economically efficient natural resource management and policy, including wildfire, invasive species, and water and utilizing forest biomass for energy. Tyron earned his PhD in Economics from the University of Queensland.