

Extension, Engagement, and Technology Transfer

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A report for
The Waste to Fuels Technology Partnership
2019-2021 Biennium: Advancing Organics Management in Washington State



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Extension, engagement, and technology transfer with regional organics management stakeholders and the organics value chain

The goal of the Waste to Fuels Technology partnership is to promote the efficient recovery of energy, nutrients, and other saleable products from organics that are normally considered wastes. Even when renewable energy is not generated, the utilization of recovered products can reduce overall energy inputs, therefore reducing the need for carbon-intensive energy sources. The application of these next-generation technologies and processes depends on adoption by industry and municipal partners, and upon the purchase and use of the generated products (compost, biochar, etc.). Outreach efforts, therefore, targeted stakeholders related to both organics management and product use.

Building relationships across the organics management and value chain

The team made a number of presentations during the biennium related to the Waste to Fuels Technology (WTFT) partnership – though several opportunities to present were cancelled due to COVID-19-related disruptions, after spring 2020, the remainder of presentations were given utilizing remote, digital technologies. Presentations included discussions of the biorefinery concept, composting, anaerobic digestion, pyrolysis, biosolids, and nutrient recovery. These targeted presentations and interactions offered more than 1,448 opportunities for live interactions with stakeholders, including those who work in the organics management industry, purchasers and users of organic residuals, others working on sustainable organics management at non-profits, county and local governments, students, and other Washington residents. WTFT presenters are in **bold** here and in other listings throughout the chapter:

- **Hills, K. and M. Brady.** Compost Demand: The Role of Agriculture & Other Users. Washington Association of County Solid Waste Managers meeting. Leavenworth, WA (in-person and virtual). June 15, 2021. Attendees: 29
- **Bronstad, E.** It's Garbage CAN, not Garbage Cannot: Energy, Fertilizer, and Other Amazing Things from "Waste." Presentation to Pullman High School, May 10th, 2021. Attendees: 28
- **Stacey, N. and D.P. Collins.** The Elasticity of Biochar Across the Farm: Nutrient Capture, Compost Feedstock, and Soil Amendment. Western Nutrient Management Virtual Conference. March 3, 2021. Estimated attendees: 30
- **Yorgey, G.G.** An Overview of Greenhouse Gas Emissions and Climate Mitigation Opportunities in Washington State, with Examples from Large-Scale Agriculture.

- Washington Climate Assembly, <https://www.waclimateassembly.org/>. January 16, 2021. Estimated attendees: 75
- **Collins, D.P., N. Stacey, T. Tea, A. Bary, and L. Myhre.** 2020. Biochar feedstock influences compost pile temperature and available nitrogen. US Composting Council, Charleston, SC. Attendees: 70
 - **Stacey, N.E.** and C. Villa. Biochar: Production and Elasticity of Use on Farms. Tilth Alliance Virtual Conference. November 9-10, 2020. Estimated attendees: 50
 - **Bronstad, E.** Detecting Volatile Organic Compound Emissions from Compost Facilities. Pacific and Mountain West Nutrient Cycling, Soil Health and Food Safety Virtual Conference. October 29, 2020. Estimated attendees: 20
 - **Brady, M.** A Regional Economic Model of Municipal Compost Supply and Agricultural Demand with an Application to Western Washington. Pacific and Mountain West Nutrient Cycling, Soil Health and Food Safety Virtual Conference. October 29, 2020. Estimated attendees: 50
 - **Stacey, N.** Biochar and Co-composted Biochar in Strawberries and Potatoes. Pacific and Mountain West Nutrient Cycling, Soil Health and Food Safety Virtual Conference. October 29, 2020. Estimated attendees: 42
 - **Garcia-Perez, M., A. Tanzil, M. Wolcott, X. Zhang, and J. Hollday.** Production of Cheap Sustainable Aviation Fuels (SAFs): A Carbon Balance Problem. Washington Academies of Science Symposium, September 17, 2020 (Estimated attendees: 150), Graduate seminar Biological Systems Engineering, September 24, 2020 (Estimated attendees: 70), National Biochar Week, December 7, 2020 (Estimated attendees: 50)
 - **Fuchs, M.** Changing the Biomass to Biochar Paradigm. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 27, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 35
 - Han, H.S., J. Dooley, **B. Pecha, K. Wilson, T. Miles, and D. Drinkard.** Fundamentals of Biomass Handling and Biochar Production. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 27, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 35
 - Vallet, J. Climate Change and Biochar Use in Broad-Area Agriculture: The USDA-ARS Perspective. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 28, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 35
 - Baltar, R. California State Biochar Activity Update: Strategies for Scaling Production and Use. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 28, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 35

- **Amonette, J.E., D. Page-Dumrose, D. Laird, M. Garcia-Perez, and K. Trippe.** Biomass Availability and Biochar Properties. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 28, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 35
- Rodriguez-Franco, C. Climate Change and Carbon Drawdown in Forestry. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 29, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 39
- Graw, R. B. Springsteen, J. Inihara, C. Christoforou, and G. Glass. Environmental Permitting Issues for Biochar. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 29, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 39
- Laird, D. Modeling Biochar Systems: Soil-Crop Responses, Technoeconomics, and Economic Viability. Biomass to Biochar: Maximizing the Carbon Value Virtual Workshop. April 30, 2020. Organized by **Amonette, J.E., K. Hills, M. Fuchs, G.G. Yorgey,** and J. Dooley. Estimated attendees: 35
- **Collins, D.P., A. Bary, A. Nichols.** On-Farm Composting Workshop, WSU Puyallup Research and Extension Center, Co-sponsored by Pierce Conservation District. 2 days Feb-March 2020. Coordinator, presenter. Attendees: 29
- **Collins, D.P., N. Stacey, T. Tea, S. Seefeldt, W. Hoashi-Erhardt, D. Gang, T. Jobson, M. Garcia Perez, J. Cleary, and M. Fuchs.** 2019. Biochar and Co-composted Biochar in Strawberries and Potatoes. Great Lakes Expo, Grand Rapids, MI. Invited Speaker. Attendees: 30
- **Brady, M., K. Hills, and G. Yorgey.** Compost Research Findings of the 2017-2019 Waste to Fuels Technology Partnership: Lessons for Compost Policy from Recycling Policy, and Differentiating the Value and Cost of Compost Across Likely Farm Use Scenarios in Western Washington. Washington Organic Recycling Council Board Meeting, August 15, 2019. Estimated attendees: 12
- **Yorgey, G.** Biosolids Quality: Emerging Contaminants of Potential Concern. Island County Biosolids Community Forum. Coupeville, WA. October 3, 2019. Estimated attendees: 40
- **Hills, K.** Value and Cost of Compost Across Likely Farm Use Scenarios in Western Washington. Washington Organic Recycling Council Conference. Vancouver, WA. November 8, 2019. Estimated attendees: 50
- Additional talks that were given to share the results of the roadmap developed as part of the *Biomass to Biochar: Maximizing the Carbon value* process are described and listed later in this chapter.

Providing technical support

The team also answered numerous individual inquiries relating to anaerobic digestion, biochar, nutrient recovery, and carbon sequestration from recycled organic matter. Technical support included both formal participation in advisory panels and stakeholder groups, as well as many ad hoc responses to individuals who reached out to Washington State University (WSU) and the Center for Sustaining Agriculture and Natural Resources (CSANR):

Advisory Panel and Stakeholder Groups:

In the first half of 2021, Yorgey and Bronstad were invited by the Center for Sustainable Infrastructure (CSI) to participate on a technical team advisory panel that sought to evaluate wastewater treatment options for a cluster of industrial food processors in the City of Pasco. They spent approximately four months interacting with food processor staff, engineers, and CSI to research and contribute to sustainable waste solutions using the knowledge garnered from WTFT research and investigations. With complementary funding from CSI, Bronstad and Yorgey participated in CSI's value planning process with the City and diverse stakeholders of the City's Process Water Reuse Facility (PWRF). Bronstad also led the development of a final report, *Feeding the Future: City of Pasco, WA* in collaboration with the technical team and CSI. The report summarizes recommended immediate technical and non-technical solutions. It also laid out some longer-term strategies that the City could take to reduce water use and generate more value from the nutrient-enriched water generated. Future collaboration between WSU and CSI in furtherance of the industrial symbiosis/biorefinery concept has been discussed for Pasco as well as other communities around the state.

Bronstad also has ongoing participation in the [King County Organics Stakeholder Meetings](#) to stay apprised of solid waste issues in the Puget Sound region and on-going policy and technical efforts to address them.

Technical Support, Guidance and Resource Sharing:

Insights and expertise were provided to a number of individuals relating to composting (throughout Washington), biosolids (Island County), and black soldier fly efforts (Chelan County). Several on our team also provided interviews and insights to a research effort led by Zero Waste Washington, [Improving Organic Materials Management in Washington State](#).

Yorgey and Bronstad have also been collaborating with Biomethane LLC and The Lands Council (Spokane County) and have provided them support in the form of numerous WTFT reports and documents on a variety of topics.

We provided insight and expertise on the topic of biochar to individuals involved in several nascent biochar-related efforts across the state, including Okanogan, Whatcom, Spokane, and Lewis Counties. There has also been quite a lot of interest, including from Natural Resources Conservation Service personnel in Washington, in understanding the potential air quality impacts of biochar. A chapter co-authored by Yorgey and other participants of the Biomass to Biochar workshop (described below) on *Air Pollutant Emissions and Air Emissions Permitting for Biochar Production Systems* has been distributed to these individuals in draft form.

Many stakeholders across the state have also reached out with questions which are explored in-depth in the extension document [Carbon Sequestration Potential in Cropland Soils in the Pacific](#)

[*Northwest: Knowledge and Gaps*](#), completed as part of the Waste to Fuels Technology Partnership during the 2017-2019 biennium (currently in revision within the WSU peer review system). A range of environmental groups from across the state are seeking a better understanding of the potential for agricultural croplands to store carbon through amendment and other strategies, as well as agricultural groups, who are interested in the potential to build more resilient soils and/or address climate issues.

Extension resources

Written extension resources are available online and provide on-demand information to a wide variety of stakeholders interested in improved organics management. These resources are an important complement to in-person presentations and individual conversations. This biennium's efforts included a number of blog posts highlighting the insights learned from last biennium's projects. Posts were cross posted on AgClimate.net (a website with a regional audience, featuring topics related to climate change and agriculture/forestry) and CSANR's "Perspectives on Sustainability" blog. Blog posts were shared via AgClimate and CSANR's social media and there was a continued effort to reach the broader organics community by directly sending posts to representatives of this community.

- **Hills, K.** 2020. [Check It Out: Can Biochar be Used for Carbon Dioxide Drawdown in Washington State?](#) (March 13, 2020)
- **Hills, K.** 2020. [A New Method for Measuring Plant Available Water Capacity Helps Document Benefits of Biochar-Soil Mixtures](#) (May 18, 2020)
- **Hills, K.** 2020. [Boutique Biochars: Exploring Engineering Strategies to Increase Phosphate Adsorption](#) (August 10, 2020)
- **Hills, K.** 2020. [Municipal Compost Use in Agriculture: A Question of Cost and Value](#) (September 23, 2020)
- **Hills, K.** 2020. [Compost Emissions – More than Just a Matter of Smell.](#) (October 20, 2020)
- **Bronstad, E.** 2021. [Developing Biochar Markets in the Pacific Northwest.](#) (January 29, 2021)
- **Brady, M.** 2021. [Lessons from Recycling Policy can Inform Compost Policy.](#) (April 8, 2021)

These blogposts, and older WTFT blogposts from previous biennia, were viewed 5,775 times between July 1, 2019 and June 30, 2021. Beyond the initial readership, posts on biochar markets had also garnered the attention of Pacific NW Ag Network. In February 2021, a reporter from the organization reached out with an interview request to develop a story on the biochar markets work. This resulted in a short story that ran in PNW Ag Network in March 2021, [Biochar Holds Great Potential For Rural Northwest Communities](#).

In addition to these blog efforts, other resources including extension documents and talk recordings completed via the Waste to Fuels Technology partnership and a wealth of other

information related to organic resource recovery is being maintained on the [waste management topic pages](#) of the Center for Sustaining Agriculture and Natural Resources website, which includes subtopic pages for compost, pyrolysis (biochar), anaerobic digestion, biofuels, and nutrient recovery. In total, on-demand products (other than blogs) that were directly relevant to Waste to Fuels Technology (those produced this biennium, and those produced in previous biennia) were viewed a total of 11,112 times during the 2019-2021 biennium.

Biomass to Biochar Regional Workshop

Biochar technology has potential to mitigate climate change, improve forest and soil health, decrease wildfire risk, and revitalize rural economies in the Pacific Northwest and beyond. There are now more than 20 companies making and providing biochar in Washington State and the Pacific Northwest (T. Miles, personal communication; see <http://www.pnwbiochar.org/producers/>). Within this context, a workshop called *Biomass to Biochar: Maximizing the Carbon Value* was held to work with current industry, research, and other stakeholders to identify current barriers and chart a roadmap for future development of biochar technology in the Pacific Northwest and beyond. Though originally envisioned as an in-person event, due to COVID-19, this virtual workshop took place from April 27-30, 2020. Workshop participants represented a wide breadth of regional expertise in biochar including participants from industry, NGOs, government, and researchers.

The main objectives of the workshop were to:

1. Explore five of the most promising contexts for biochar production and use in the Pacific Northwest, identifying current barriers and the most impactful strategies for moving each sector forward, and
2. Define the key elements of an overall strategy for investors, philanthropists, policy makers and others looking to help transform biochar technology into a widespread, effective method for addressing climate change while maximizing its beneficial impacts on managed ecosystems and rural communities.

During the course of the four-day workshop, keynote talks were given on big picture topics related to biochar and climate change, biochar use in agriculture, carbon drawdown in forestry, and California's strategy for biochar and fire reduction. In addition, participants presented on topics related to biomass availability, biomass handling, biochar production, and biochar properties, and environmental permitting issues.

Ecology funding via the partnership supported two of the five workgroups exploring different contexts, specifically the production of biochar from municipal resources co-located with commercial composting facilities, and a second scenario focused on distributed smaller-scale systems. This investment was complemented by funding from U.S. Forest Service (USFS) region 6, which supported the other workgroups. Workgroups met initially during the workshop, and continued to meet over several months to consider the opportunities that conversion of biomass to biochar offers as a way to mitigate climate change, improve forest and soil health, decrease wildfire risk, bolster ecosystem services, and revitalize rural economies. They explored how biomass is harvested, converted to biochar and applied, and where operational changes and

funding could significantly magnify biochar's contributions. The five workgroups (and the source of financial support) were:

- Place-Based Biochar Production (Ecology support)
- Moderate Scale Biochar Production Across Forested Landscapes (USFS support)
- Centralized Biochar Production Facilities (USFS support)
- Biochar Produced and Utilized at Municipal Compost Facilities (Ecology support)
- Agricultural Use (USFS support)

In a post-event evaluation, 79% and 74% of participants reported that the workshop achieved its objectives well or very well for objectives 1 and 2, respectively. In addition, 84% of participants anticipated that new knowledge or new connections that they made as a result of the workshop would impact their work relating to biochar over the next year.

After the workshop, the five working groups continued to meet to write and finalize report chapters, and the core team (Amonette, Yorgey, Hills, and Jim Archuleta from USFS) drafted additional chapters to provide background. Workshop findings were presented through a number of different presentations at the [Scaling Biochar Forum](#) which took place October 13 and 14, 2020, and hosted a range of West Coast individuals and entities interested in learning more about strategies for encouraging broader development of the biochar sector. [Presentations](#) that were made based on the Biomass to Biochar workshop included:

- **J.E. Amonette**, Major Funding Priorities Identified by the Biomass to Biochar: Maximizing the Carbon Value Workshop. (Estimated 55 attendees; 114 views of recording.)
- K. Wilson, A Carbon Conservation Corps to Restore Forests with Biochar. (Estimated 35 attendees; 189 views of recording.)
- J. Archuleta, Toward Sustainable Forest, Farm, and Urban Management: Biochar's Place within Landscape Reallocation of Organic Matter. (Estimated 35 attendees; 69 views of recording.)
- D. Dumroese and C. Rodriguez-Franco, Using Biochar for Abandoned Minelands and Forest Restoration. (Estimated 35 attendees; 69 views of recording.)
- G. Flora, Building a Sustainable Biochar Industry. (Estimated 35 attendees; 88 views of recording.)
- J. Dooley, Maximizing the Net Carbon Content of Biochar at Distributed and Community-Scale Production Sites. (Estimated 35 attendees; 71 views of recording.)
- M. Fuchs, Integrating the Biochar and Compost Industries: Carbon Drawdown for Profit. (Estimated 35 attendees; 108 views of recording.)
- T. Miles, Building a Large-Scale Biochar Industry. (Estimated 35 attendees; 3539 views of recording.)

- K. Trippe, Developing a Nationwide Framework for Evaluating and Predicting Agronomic Responses to Biochar-Based Amendments. (Estimated 35 attendees; 71 views of recording.)

The workshop also helped catalyze Jim Amonette and two other workshop participants (David Laird and Deborah Page-Dumroese, with other co-authors) to collaborate on an article, [“Integrated Biochar Research—A Road Map”](#) that was published in the Journal of Soil and Water Conservation.

Leveraging Waste to Fuels Technology funds to increase impact

The Waste to Fuels Technology partnership plays an important role in engaging researchers at WSU and beyond in next-generation waste processing issues. Many partners use their work within the partnership to leverage additional funding that enhances their work and impact in the region. Partnership researchers and extension professionals were able to leverage the Waste to Fuels Technology work to successfully obtain \$2,689,778 in additional funds during the 2019-2021 biennium. Since 2017, the partnership has obtained a cumulative total of \$3 million. Tables 1 and 2 provide details.

Table 1. External funds obtained during the 2019-2021 biennium by partnership members to work on issues relating to the issues explored under the Waste to Fuels Technology Partnership.

Award Details	Dollars Awarded
Current Biennium (2019-2021)	
O’Neil, T. and T. Jobson (2020), Research to Improve Compost Facility Air Emissions Permitting, Environmental Education & Research Foundation, 2021-2022	\$225,000
Yorgey, G.G. and E. Bronstad . (2021). Smaller Cohorts for Bigger Advancements: Honest Admissions About Anaerobic Digestion Project Risks and Rewards. United States Environmental Protection Agency. 2020-2022.	\$129,727
Yorgey, G.G. and J.E. Amonette . (2020). Biomass to Biochar: Maximizing the Carbon Value. United States Forest Service, Region 6. 2020.	\$46,000
J.E. Amonette, D.P. Collins, N. Stacey, and A. Dhingra. (2021). Quantifying Synergy Among Soil-Based Carbon-Drawdown Approaches. WSU CSANR BIOAg. 2021-2022	\$40,000
J.E. Amonette and G. G. Yorgey . (2021). A Plus Tree Biochar and Milling Project. Sonoma Ecology Center (funds from the California Climate Investment Grant Program through Cal Fire). 2021-2023	\$15,000

Chen, S. (2020). Develop an Efficient and Cost-Effective Novel Anaerobic Digestion System Producing High Purity of Methane from Diverse Waste Biomass. US Department of Energy.	\$2,234,051
Current Biennium (2019-2021) Total	\$2,689,778

Table 2. External funds obtained during the 2017-2019 biennium by partnership members to work on issues relating to the issues explored under the Waste to Fuels Technology Partnership.

Award Details	Dollars Awarded
Previous Biennium (2017-2019)	
Garcia-Perez M., G. Moller, and M. Strawn (2019) Engineered Biochars to Enhance the Profitability of Distributed Energy Systems to Reduce the Environmental Impact of Anaerobic Digesters.	\$246,000
Yorgey, G.G., D. Gang, D.P. Collins, and S. Seefeldt (2019) Integrating Municipal Compost and Biochar for Production of High-Value Crops. United States Department of Agriculture, McIntire Stennis Capacity Funding (Internal competitive allocation of funds).	\$50,000
Collins, D.P., A. Siegner, and N. Stacey (2019) Investigating the Elasticity of Biochar: Manure Handling, Compost Feedstock, Soil Amendment and Carbon Storage. United States Department of Agriculture, Western SARE, Professional + Producer Grant.	\$49,988
Amonette, J.E. (2019) Impact of Process Emissions on Climate Offsets by Different Biochar Production Methods, Washington State University BIOAg.	\$11,670
Past Biennium (2017-2019) Total	\$357,658

National and International Reach

Though not the primary goal of the Waste to Fuels Technology partnership, sharing the results of partnership research with researchers across the U.S. and the world, via presentations and journal publications, is an important avenue for generating interest and momentum relating to next-generation organics processing.

Relevant peer-reviewed journal publications from this biennium that resulted from work carried out either in part or in whole as the results of the partnership include:

- **Stacey, N., T. Tea, S. Seefeldt, A. Bary, and D.P. Collins.** In review. Biochar-poultry manure compost alters temperature and nitrogen dynamics during composting

- and improves crop growth following field application. *Compost Science and Utilization*. Under Review; submitted 25 May, 2021.
- Lehmann, J., A. Cowie, C.A. Masiello, C. Kammann, D. Woolf, **J.E. Amonette**, M.L. Cayuela, M. Camps-Arbestain, and T. Whitman. (Revised and resubmitted) Biochar in climate change mitigation. Review article submitted to *Nature Geoscience*.
 - **Haghighi-Mood, S., M. Ayiania**, H. Cao, O. Marin-Flores, **Y. Jefferson Milan, M. Garcia-Perez**. Nitrogen and Magnesium Co-doped Biochar for Phosphate Adsorption. Paper Accepted in *Biomass Conversion and Biorefinery*, 2021
 - **Amonette, J.E.**, H. Blanco-Canqui, C. Hasebrook, D.A. Laird, R. Lal, J. Lehmann, and D. Page-Dumroese. *Journal of Soil and Water Conservation* January 2021, 76 (1) 24A-29A; DOI: <https://doi.org/10.2489/jswc.2021.1115A>
 - Zhang, J., **J.E. Amonette**, and **M. Flury**. 2021. Effect of biochar and biochar particle size on plant-available water of sand, silt loam, and clay soil. *Soil & Tillage Research* 212:104992. <https://dx.doi.org/10.1016/j.still.2021.104992>
 - Cao, H., X. Wu, S.S.A. Syed-Hassan, S. Zhang, S.S. Mood, **Y. Jefferson-Milan**, and **M. Garcia-Perez**. Characteristics and mechanisms of phosphorous adsorption by rape straw-derived biochar functionalized with calcium from eggshell. *Bioresources Technology*, 2020, 318, 124063.
 - **Ayiania, M.**, E. Weiss-Hortala, **M. Smith**, J.S. McEwen, and **M. Garcia-Perez**. Microstructural Analysis of Nitrogen Doped Char by Raman Spectroscopy: Raman Analysis from First Principles. *Carbon*, 2020, 167, 15, 559-574.
 - **Haghighi-Mood, S., M. Ayiania, Y. Jefferson-Milan**, and **M. Garcia-Perez**. 2020. Nitrogen doped char from anaerobically digested fiber for phosphate removal in aqueous solutions, *Chemosphere*. 2020 Feb; 240:124889. doi: 10.1016/j.chemosphere.2019.124889. Epub 2019 Sep 17. PMID: 31563102.
 - **Ayiania, M, M. Smith**, A.J.R. Hensley, L. Scudero, J.-S. McEwen, and **M. Garcia-Perez**. 2020. Deconvoluting the XPS spectra for nitrogen-doped chars: An analysis from first Principles. *Carbon*, 162:528-544.
 - **Ayiania, M.**, A.J.R. Hensley, K. Groden, **M. Garcia-Perez**, and J.-S. McEwen. 2019. Thermodynamic stability of nitrogen functionalities and defects in graphene and graphene nanoribbons from first principles. *Carbon*, 152: 715-726, doi.org/10.1016/j.carbon.2019.06.019.

Academic/national and international presentations that occurred during the current biennium included:

- **Khosravi, N.**, and **B.T. Jobson**. Estimation of VOC emission factors for manure composting by PTR-MS. American Geophysical Fall Meeting, Dec 2020.
- **Haghighi Mood, S., M. Ayiania**, and **M. Garcia-Perez**. Phosphate Removal from Aqueous Solution Using Nitrogen-Metal Co-Doped Biochar. Presentation at the Thermal & Catalytic Sciences Virtual Symposium, October 2020.
- **Ayiania, M., S. Haghighi Mood**, J.-S. McEwen, and **M. Garcia-Perez**. Novel Amorphous Carbons for the Adsorption of Phosphates. TCS 2020.

- **Garcia-Perez, M.**, and J. Almodovar. Acid Carbonization Process to Maximize Carbon Efficiency: Novel path for Carbon Storage and Biofuel Production. Presentation to the University of Tennessee, March 29, 2021.
- **Garcia-Perez, M.** Progress in Biomass Fast Pyrolysis and Bio-oil Refining. China Agriculture University virtual presentation, May 24, 2020.
- **Garcia-Perez, M., A. Tanzil, M. Wolcott, X. Zhang, and J. Hollday.** Production of Cheap Sustainable Aviation Fuels (SAFs): A Carbon Balance Problem. Cape Breton University Canada, February 9, 2021 (Estimated attendees: 50), National University of Colombia, March 15, 2021 (Estimated attendees: 150), DAABON Midterm Summit, Colombia, May 2021 (Estimated attendees: 20).

Impacts of technology transfer, outreach and extension activities

In total, extension efforts resulted in an estimated 1,448 in-person and virtual opportunities for live interactions with key stakeholders who work either primarily on organics management in the region, or whose work touches on sustainable organics management in various ways. Our efforts also resulted in 16,887 views of Waste to Fuels Technology reports, publications, blog posts, recordings, and other extension resources that were funded (either fully or in part) via the partnership. Work carried out in the previous and current biennium was used to leverage an additional \$2,689,778 awarded during this biennium to support work in areas related to Waste to Fuels Technology priorities.

While the ultimate outcome of these interactions and activities is likely to be realized in the long term, there are short-term indications that stakeholders have found them useful. We heard numerous times from both municipal and industry stakeholders in Washington that they were very excited to hear that Ecology was involved in this type of work, support WSU's engagement in this type of research, and appreciate the extension support provided relating to these topics. A few representative comments include:

- "These are really good resources, I look forward to reading all of them in detail!"
- "I was very pleasantly surprised at how well the workshop was executed, people stayed engaged, and progress was made on time. Kudos to the WSU team!"
- "Considering the situation with COVID-19 I truly believe the overall workshop was well planned and executed. Thank you very much."

While we are not always able to capture the direct impacts of our interactions with individuals across the state, our existing survey data suggest that we are having an influence. As one example, 84% of participants in the *Biomass to Biochar* workshop said that they anticipated that new knowledge or connections that they made as a result of the workshop would impact their work relating to biochar over the next year, suggesting that our extension effort was effective.