Please Note: This report offers technology and resource assessments to enable Washington policy makers to make more informed decisions “for increasing the economic value and sustainability of Washington's agriculture sector through the use of industrial symbiosis principles,” as directed by the 2022 Washington State Legislature.

Washington State University enlisted expert investigators with Pacific Northwest National Laboratory and the Center for Sustainable Infrastructure as partners to develop this report. In addition to the five lines of targeted research that will be highlighted in the Key Findings section of this report and detailed in Appendices I - IV, technology and resources findings that enable policy recommendations were informed by interviews and consultations with several dozen agriculture symbiosis experts, innovators, and stakeholders, led by CSI.

The recommendations were developed by CSI to synthesize insights from the project’s key findings and consultations, and to distill a set of strategic recommendations to achieve the Legislature’s intent, as expressed in the budget proviso directing this study.

CSI solicited review and feedback on a draft of these recommendations from project partners and the experts, innovators and stakeholders consulted by the project. The final recommendations contained in this report, however, are the responsibility of CSI, and do not necessarily reflect the position of partner organizations or any of the leaders and organizations consulted.

Please cite this report as:


Cover photo credit: Perca, Inc.
1. Introduction & Overview

The 2022 Washington State Legislature directed Washington State University (WSU) to partner with organizations with relevant expertise to “develop recommendations for increasing the economic value and sustainability of Washington’s agriculture sector through the use of industrial symbiosis principles.”

In response, this Agriculture Symbiosis report has been produced by WSU in partnership with the Center for Sustainable Infrastructure (CSI) and the Pacific Northwest National Laboratory (PNNL) through research and consultations with stakeholders and experts.

Agriculture Symbiosis happens when food, beverage, or farm businesses partner with each other, or with businesses from other industry sectors, to share their surplus resources – energy, water, and organic ‘wastes’ – for mutual economic benefit. Successful symbiosis projects offer both a compelling business case for each participating company and deliver substantial sustainability performance improvements. For the purposes of this report, the terms “agriculture sector” and “agriculture symbiosis” include the food and beverage sectors to reflect a more holistic food system perspective that includes broader agriculture supply chains.¹

This age-old strategy of generating economic value by sharing and re-using resources such as water, heat, and organic materials is being taken to promising new levels, contributing to business growth, improving energy and water efficiency, building soil health, addressing emissions, and helping maintain the state’s clean water and air.

Agriculture is among Washington’s most successful and important industry sectors, generating over $10.2 billion in production value in 2022, according to USDA and National Academy of Sciences figures. Competition and consumer demands within the farming, food, and beverage sectors means that businesses can benefit from new efficient processes that produce higher value while reducing wastes and costs.

Washington agriculture has achieved remarkable levels of productivity and competitiveness through a history of innovation. And through a rich history of agricultural cooperatives, deep experience in economic cooperation is woven throughout our food systems. As on-farm, in-house and collaborative innovations continue, new value and new products will continue to sustain and grow Washington’s agricultural economy.

Building on this history, this report explores whether there are new, untapped opportunities to enhance agriculture symbiosis by finding new value from waste, or ‘surplus resources,’ with agreements and infrastructure that connects multiple parties. With these opportunities in mind, we seek to identify what kinds of support and solutions are needed to overcome existing barriers and help individual businesses come together in symbiotic relationships that benefit all parties involved and Washington’s citizens.

¹ While we recognize the potential for symbiosis efforts that involve post-consumer food waste, this report focuses on organic waste streams from farm to processor to retailer, but prior to purchase by consumers.
INTRODUCTION

There are many potential benefits of agriculture symbiosis for Washington's agricultural economy and communities. Symbiosis projects can convert waste into new products and revenues. Waste-to-resource products can include renewable energy and fuels, clean fertilizers and soil amendments, recycled water, and feedstocks for a range of bio-based products, such as higher value proteins and polymers. Recycled heat, water, and organic materials can replace a portion of imported, price-volatile feedstocks and resource inputs for agriculture producers. By providing additional strategies for maintaining air and water quality, symbiosis can also reduce waste management and compliance costs and liabilities.

By supporting the development of high-quality agriculture symbiosis projects, Washington will be better positioned to secure funding from an unprecedented wave of anticipated federal investment over the coming decade, as projects with demonstrated economic, environmental, and social benefits gain competitive advantage. Further, Washington companies that develop know-how in agriculture symbiosis and resource efficiencies can leverage their leadership and track record of successful projects to market their services in other areas of the U.S. and globe.

This report is organized as follows:
I. Introduction and Overview
II. Project Genesis
III. Understanding Agriculture Symbiosis
IV. Agriculture Symbiosis Examples in Washington and Beyond
V. Key Findings of Consultations and Targeted Research
VI. Recommendations for the Washington Legislature

Throughout the report, some of Washington's agriculture symbiosis pioneers are profiled. These innovators are certainly not the only symbiosis innovators in Washington. However, together they offer a reasonable illustration of the diversity and range of forward-thinking agriculture symbiosis projects around the state today.
II. Project Genesis

Beginning in 2017, over two dozen Washington state legislators – evenly distributed between Republicans and Democrats -- participated in study tours in Denmark\(^2\) where they observed industrial symbiosis (IS) in action.

These bipartisan legislators found significant common ground in seeing the potential to adapt Denmark’s IS model to benefit industries in a wide range of Washington communities, from very small towns to bigger cities, and at the same time gain substantial economic, environmental, and social benefits for Washingtonians. Legislators were especially inspired by Kalundborg, Denmark – home of the world’s oldest and most advanced industrial symbiosis, where over two dozen resource-sharing agreements are delivering very substantial economic and climate returns (see Appendix D).

\(^2\) These legislators received scholarships covering their participation costs courtesy of the Seattle-based Scan Design Foundation, whose mission is to grow, develop, and encourage the relationship between the US and Denmark: [www.scandesignfoundation.org](http://www.scandesignfoundation.org)
Working collaboratively, these legislators have led successful efforts in consecutive legislative sessions to make strategic investments to seed and grow IS in Washington. In 2018, the state commissioned a guide to industrial symbiosis to support economic development efforts in Raymond, WA. In 2019, the state commissioned a study to inform statewide IS policy development, which in turn led to the unanimous passage in 2020 of the nation’s first statewide IS program – only to have it vetoed in the face of plummeting state revenues in the early days of the pandemic.

But legislators returned in 2021 to pass SB 5345, which was signed by the governor and launched the new IS program at the Department of Commerce. That program is providing grants “to expand existing industrial symbiosis efforts, assist others that are on their way, and support those still on the drawing board.”

In 2022, legislators increased funding for the new IS program, and in addition appropriated funds for WSU and partners to undertake this study of agriculture symbiosis opportunities for Washington.

Thanks to these strategic investments by the Washington State Legislature, agriculture businesses and entrepreneurs are increasingly inspired to expand and develop new symbiosis projects, and Washington is gaining international attention as the leading U.S. state for industrial symbiosis. In October 2022, CSI was invited to share Washington's IS story at the Global Leadership Conference convened by Kalundborg Symbiosis, which drew together some of the world's top IS practitioners.

III. Understanding Agriculture Symbiosis

At their heart, agricultural businesses such as farms and food processors take raw materials and add value to create products they can sell. **Agriculture Symbiosis** can add value for agriculture businesses by enabling them to reduce costs or generate new revenue by sharing surplus resources – energy, water, and organic ‘wastes’:

- Capture and recycle waste heat to displace fossil fuel purchases for process heat.
- Optimize and recycle wastewater to ensure water quality, extract organics for value, and generate clean water for reuse.

Symbiosis projects align well with the goals of increasing economic development and achieving environmental sustainability because they offer both a compelling business case for each participating company and deliver substantial sustainability performance improvements.

Major cost centers for agriculture producers include both the purchase of energy, water and organic resource inputs, and the costs to manage the waste flows resulting from production processes. Symbiosis agreements and infrastructure can enable businesses to profitably share surplus resources and reduce waste management costs. Of particular importance to agriculture can be projects to:

- Recover and recycle organic, carbon-rich wastes to generate clean resource products with market value, including energy, soil amendments, and high-value bio-chemicals, industrial feedstocks and compounds like proteins and polymers.
In this study, we identified two main categories of agriculture symbioses:

- **Business-to-Business Symbiosis**
  Agricultural businesses forge waste-to-value partnership agreements to share surplus resources for mutual economic benefit and environmental gains.

- **Utility-Enabled Symbiosis**
  Clusters of 2 or more industrial facilities are served by symbiosis infrastructure that is financed and operated by one or more utilities, who ideally provide integrated services and support across multiple resources.

Most agriculture symbiosis projects in Washington that we identified in our initial scan are business-to-business (B2B) symbiosis projects, initiated and financed by the participating businesses. This contrasts with Denmark, where most symbiosis projects are financed, operated, and facilitated by the local utility provider, in cooperation with the industries they serve. When utilities take the lead, agriculture businesses are likely more willing to engage because they do not have to become expert in technologies and invest significant time and energy navigating the complexities of financing and developing multi-partner projects. But in the absence of utility leadership, B2B symbiosis projects, which tend to be smaller scale and less complex, can enable a few nimble business innovators to put projects to share surplus resources into operation and to expand incrementally into adjacent opportunities.

Industrial symbiosis is one of at least four key links in a ‘Clean Industry’ supply chain by which businesses can improve sustainability performance and profits across their operations. These four key links include:

- **Sustainable Resource Inputs**
  Utilizing renewable and recycled energy, not only for electricity but for process heat; and for farmers, growing soil health with clean soil amendments and bio-fertilizer products produced by recycling organic wastes.

- **Resource Efficient Production Processes**
  Optimizing the use and reuse of energy, water, and organic materials within a business’s facilities and across operations.

- **Industrial Symbiosis**
  Cycling remaining waste streams between businesses for mutual economic benefit.

- **Clean Transport of Feedstock and Products**
  Cultivating local suppliers to shorten haul distances and increasing use of clean fuels for trucking.

This report focuses on the Industrial Symbiosis link in the Clean Industry chain, specifically its potential to benefit the agriculture sector. But projects that demonstrate a positive return-on-investment for agriculture businesses in any of these four Clean Industry categories will also improve sustainability performance across the overall food system’s supply chains. And, of course, some projects will span links on the supply chain, for example, by shortening haul distances and enabling profitable symbioses.
IV. Agriculture Symbiosis: Examples in Washington & Beyond

Our scan of agriculture symbiosis projects in Washington uncovered 18 illustrative projects that appear to meaningfully reflect IS principles and are in active operation or development.

Sprinkled through this report, are profiles of several of Washington's agriculture symbiosis project pioneers to provide a fuller picture of a diverse subset of the innovative projects highlighted in the table on page 10.

Industrial symbiosis is a new term for the agriculture sector in Washington, and several innovators we talked to have integrated symbiosis principles into how they do business without using this term to describe it. For this reason, ongoing systematic investigation would undoubtedly uncover other worthwhile projects.

Other examples of innovative agriculture symbiosis projects that are no longer in active operation were also discovered in Washington, underscoring the fact that these arrangements are business partnerships at their heart, and must generate economic value to remain viable. In some cases, other barriers also contributed. These barriers are more fully described later in this report.

Appendix D offers a compilation of successful industrial symbiosis projects from beyond Washington with significant agriculture sector components, selected to provide additional insight into the scope and scale to which agriculture symbiosis principles could be applied in Washington.
## Agriculture Symbiosis Projects in Washington State – Initial Scan

### Projects in Active Development:

| 
| --- | --- | --- |
| **Divert Longview** | Longview | Divert works with grocers to reduce wasted food, and to divert remaining food waste from landfills to biogas production facilities that efficiently convert methane to a valuable renewable natural gas product. They are pursuing development of a facility in Longview to process food waste from up to 650 grocery stores across the Pacific Northwest. |
| **HeartFoods** | Bellingham | Mark and Jessie Buehrer have launched HeartFoods to pilot a closed loop model for organic greenhouse agriculture that "utilizes food waste to transform how local communities grow healthy food." Their aim is to achieve net zero energy, water, and carbon while creating local food and jobs by cycling and optimizing flows of nutrients, water, and energy. |
| **Lamb Weston Plant** | Richland | Lamb Weston has committed to sell raw renewable natural gas made at its Richland site to Pine Creek RNG who will finish the gas before selling to Cascade Natural Gas along with RNG from Horn Rapids Landfill. Raw natural gas produced at Lamb Weston’s Richland location is generated at their agricultural biogas recovery system and is currently being flared, but will be captured, processed and distributed through Cascade’s system at the end of 2023. |
| **Myno Carbon** | Kettle Falls | Myno Carbon is developing a large-scale biochar carbon removal facility that will utilize forestry and mill waste residuals to produce 40,000 tons of biochar and 18 megawatts of carbon negative electricity per year, integrated with Avista’s Kettle Falls Generating Station. They are also exploring combining waste carbon dioxide with crushed basalt to create a liming soil amendment. |
| **Pacific Ag Renewables** | Sunnyside | Pacific Ag Renewables plans to begin construction soon on a series of digesters to convert agricultural wastes – crop residues and dairy manure – into pipeline-quality renewable natural gas, and potentially other products like molded fiber packaging. |
| **Pasco Process Water Reuse Facility (PWRF)** | Pasco | The City of Pasco, in a public private partnership with Burnham RNG, broke ground in the second quarter of 2023 on a $137 million modernization and expansion of the PWRF to treat 2 billion gallons per year of industrial wastewater from seven major food processors. Anaerobic digestion will be the source for 900 million btu/day of pipeline-quality renewable natural gas, after which the growth of algae will remove nitrogen from the water so it can be beneficially reused for irrigating crops, and provide feedstock for a nitrogen-rich fertilizer product. |

---

### Map of Projects

- **Divert Longview** in Longview
- **HeartFoods** in Bellingham
- **Lamb Weston Plant** in Richland
- **Myno Carbon** in Kettle Falls
- **Pacific Ag Renewables** in Sunnyside
- **Pasco Process Water Reuse Facility (PWRF)** in Pasco
## Operational Projects

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augean Project</td>
<td>Yakima</td>
<td>The Augean Renewable Natural Gas (RNG) project in Yakima County is producing pipeline quality RNG from the digestion of dairy manure from the DeRuyter &amp; Sons and D&amp;D Dairies. Benefits include greenhouse gas reductions, renewable transportation fuel, resource recovery including the production of biofertilizer and digested dairy fiber for use as cow bedding or as a peat moss substitute, and reclaimed irrigation water.</td>
</tr>
<tr>
<td>Beta Hatch</td>
<td>Cashmere</td>
<td>Locally sourced agriculture wastes, plus waste heat from a nearby data center, feed an insect farm that produces high-value proteins for animal food products. Insect wastes known as 'frass' are sold as a high-value fertilizer.</td>
</tr>
<tr>
<td>Edaleen Cow Power, LLC</td>
<td>Lyden</td>
<td>Edaleen Dairy recycles cow manure and pre-consumer food waste using anaerobic digestion to collect methane to produce electricity. As of 2022, they are generating enough clean energy to power 380 local homes. The emission-free electricity is sold into transportation markets to power electric vehicles. The system also produces soil amendment products and liquid fertilizer for Edaleen fields while assisting local food processors in treating their waste materials.</td>
</tr>
<tr>
<td>Inland Empire Paper</td>
<td>Millwood</td>
<td>Inland Empire Paper Company transforms their waste fly ash into a pelletized form that can be delivered to agricultural soils using conventional farm equipment. The fly ash neutralizes acidity and adds minerals to the soil, benefiting soil health and crop yields.</td>
</tr>
<tr>
<td>Qualco Energy</td>
<td>Monroe</td>
<td>Qualco Energy, a partnership between the Tulalip Tribes and Warkhoven Dairy, operates a dairy waste digester to save money and improve water quality. Snohomish Public Utility District uses the resulting biogas to run a generator and digestate from the process is utilized on farm fields, with nutrients that are more accessible to the farm's field crops.</td>
</tr>
<tr>
<td>Qualterra Agriculture Regeneration Stations</td>
<td>Pullman (HQs)</td>
<td>Qualterra designs biomass processing units that their agriculture industry customers can use to create Agricultural Regeneration Stations’, integrated systems to process organic waste into biochar and renewable energy. A single unit can process 450 tons of biomass per year, resulting in 112 tons of biochar, and generating 30x more energy as an output than is required as an input. The company is partnering with Eastern WA farmers to conduct R&amp;D both on-farm and from their research and production facilities in Spokane, Pullman, and Sunnyside.</td>
</tr>
<tr>
<td>Rainier Biogas</td>
<td>Enumclaw</td>
<td>Rainier Biogas collaborated with three family farms— Ritter Dairy, Wallin Dairy, and the DeGroot Brothers Dairy—to build a digester that serves approximately 1,200 cows. The project generates electricity, sold to Puget Sound Energy, and carbon credits that result from the capture of methane, a potent greenhouse gas.</td>
</tr>
<tr>
<td>Royal Dairy</td>
<td>Royal City</td>
<td>Royal Dairy cleans and recycles washwater from milking barns via a 7-acre BioFiltro worm bed made of locally-sourced wood waste. Developed in partnership with Organic, the worms not only filter water clean, but produce rich organic soil amendments that can enhance farm soils or help remediate brownfields.</td>
</tr>
<tr>
<td>Vander Haak Dairy</td>
<td>Lyden</td>
<td>Vander Haak Dairy installed Washington’s first dairy digester in 2004. It converts manure and food waste from nearby food processors to produce renewable energy while capturing and using the methane. Digestate (solids and liquid fertilizer) can be used in animal bedding and crop production. The project was the first demonstration site for several emerging nutrient recovery technologies. The dairy partners with 15-20 food waste suppliers as well as the local municipality.</td>
</tr>
<tr>
<td>Vashon Bioenergy Farm</td>
<td>Vashon Island</td>
<td>Chomp (formerly known as Impact Bioenergy) is producing RNG from organic wastes generated by Island Spring Organics manufacturing plant, which is then used to power production processes at the facility. They also capture waste heat from the facility to heat the digester and manufacture certified organic liquid fertilizer.</td>
</tr>
<tr>
<td>Wind River Project</td>
<td>Carson</td>
<td>Wind River Circular Systems (a collaboration of Wind River Biomass Utility and Gorge Greens) creates value from waste wood by converting it to heat and power for year-round organic greenhouse food production. They also produce firewood, wood chips, and biochar from wood waste.</td>
</tr>
<tr>
<td>Yakama Nation Farms</td>
<td>Yakama Nation Indian Reservation</td>
<td>Yakama Nation Farms grows crops on 1500 acres, one third of which is certified organic. The farm produces compost from wood and fisheries waste. They are partnering with NW Harvest on a new storage facility and free food market that improves nutrition in their community. The Nation is working with EPA on the Columbia River Restoration and are exploring vermiculture for remediation with Perca, Inc. Others involved in these symbiotic remediation efforts include Save Family Farming and Salmon Safe.</td>
</tr>
</tbody>
</table>
City of Pasco Process Water Reuse Facility

The City of Pasco broke ground in 2023 on a $137 million modernization and expansion of its Process Water Reuse Facility to treat 2 billion gallons per year of industrial wastewater from seven major food processors.

PRE-SYMBIOSIS

Pasco’s facility for treating and reusing wastewater from major food processing facilities faced multiple challenges:

- The treatment facility required expansion to be able to handle an increase of nitrogen loads that are projected due to the growth of the food processing industry.
- Aged-out infrastructure needed replacement.
- System data gaps limited whole-system efficiency.
- Business-as-usual solutions promised high capital and operating costs, high long-term energy demand, odor issues, and insufficient wastewater storage to support year-round food processing and corresponding job growth.

Instead of dispersing low-quality water over a larger area, innovators at Pasco Public Works re-examined the whole system, and developed a symbiotic network of solutions that capture value from waste, reduce reliance on fossil fuel and enable the creation of hundreds of jobs as new storage will make year-round food processing a reality.

BENEFITS

Expanded, year-round food processing; job creation in the hundreds; Darigold expansion; cost-effective regulatory compliance; value capture from wastewater (biogas and nutrients); better data, collaboration and system protocols; avoidance of costly SBR technology and high ongoing (polluting) power demand, local investment and construction jobs, model for others in the industry.

SYMBIOSIS IN ACTION

The City is moving forward with:

- Addition of Low Rate Anaerobic Digesters to capture methane gas from food processing wastewater to produce renewable natural gas.
- Close to 1.5 billion gallons per year of pre-treated water with some nitrogen will be used to irrigate crops, reducing the need for farmers to purchase fertilizers.
- Biological, low-energy nitrogen removal system uses algae.
- Marketable algae-based fertilizer is a resulting product.
- Creation of 300+ full-time jobs due to year-round capacity for food processing, plus construction jobs.
- Treating (and capturing value from) waste streams from new Darigold facility.
- Possible future inclusion of post-consumer food waste in anaerobic digestion.

Emerging interest to capture nutrients can help decrease the cost of nitrogen removal treatment. Good data and data-sharing are critical. Lowering power need sets up decades of energy savings and pollution avoidance. Innovative approaches take time, good data and good analysis. Strong proposals with multiple benefits can attract significant funding. AD technology allows for more and more ways to extract valuable energy from wastewater, enabling converting cost centers to value centers.
v. Key Findings of Consultations and Targeted Research

The WSU-CSI-PNNL project team combined several different approaches for the work summarized in this report.

Working collaboratively with the team, CSI conducted interviews, consultations, and site visits with experts, innovators and stakeholders from Washington and beyond, while WSU and PNNL researchers conducted several lines of targeted research to strategically expand our understanding of the agriculture sector’s symbiosis opportunities and challenges.

Key findings from this body of work are presented in this section, in three subsections: Stakeholder-Identified Opportunities, Stakeholder-Identified Barriers, and Targeted Research.

---

Stakeholder-Identified Opportunities

Washington State Leads

Washington is already leading in industrial and agriculture symbiosis projects (see Section IV) that point to an opportunity-rich environment for growth and expansion of these pioneering projects.

Waste Presents Opportunities to Create Value

Agriculture producers can generate economic value and reduce costs by sharing and re-using water, heat, and organic materials. Experts recommend businesses take steps to optimize the efficiency and cycling of these resources within and throughout their own operations, and then use symbiosis projects to create value from waste streams that remain.

Symbiosis Infrastructure and Agreements Needed

Converting waste into new value for participating businesses requires infrastructure and symbiosis agreements that benefit all participants by producing new products and revenues or decreasing costs and waste.

Promising Opportunities Abound in Washington State

Waste heat recovery and recycling, harvesting value from organics-rich agricultural wastewater, enhancing soil fertility, and generating other high-value bioproducts from organic wastes are promising symbiosis opportunities for Washington agriculture.

Symbiosis Can Help Solve Thorny Problems

Symbiosis projects can in some cases provide new options to help solve persistent, statewide problems – such as orchard waste or logging slash that is now burned, wastewater overloaded with nutrients, volatile prices for synthetic fertilizer and natural gas, food waste, and climate pollution.

Equity

Clean industry investment by governments can be an effective way to advance equity goals because jobs in industry, manufacturing, and production are accessible to workers without a college degree yet tend to pay well. The jobs are also widely dispersed throughout the state, benefiting the full geographic sweep of Washington communities.

Utilities Can Help

Utility organizations can play a crucial role in facilitating and financing symbiosis projects and infrastructure, if creative, flexible new authorities to organize multi-resource, district-scale utility enterprises are available.
### Stakeholder-Identified Barriers

Our consultations with experts, innovators, and stakeholders for this study surfaced a variety of barriers impacting agriculture producers’ ability to fully realize profitable symbiosis opportunities. Here we have synthesized this input to distill five major barriers to overcome for agriculture symbiosis to thrive and grow in Washington:

**Competing Priorities**
Agriculture businesses are experts in, and focus primary attention on, delivering their primary merchantable products, not on state-of-the-art symbiosis infrastructure and solutions. As a result, they may not be aware of, or knowledgeable about, positive business opportunities for agriculture symbiosis projects.

**Capital Squeeze**
Agricultural businesses continuously must make hard choices over where to target scarce capital investment dollars. Many options have potentially positive return-on-investment, so proposed symbiosis and resource optimizing projects must compete with other proposed projects that may seem production-critical or have shorter ‘payback’ times. For businesses on the margins of profitability, capital dollars may be quite scarce, especially for projects that produce returns on investment over longer time periods.

**Hedging Real and Perceived Risk**
Implementing innovative new systems and processes can be riskier than the tried-and-true approach. Agriculture businesses often operate on narrow profit margins and are naturally reluctant to put their own capital at risk, especially on systems they are not expert in. Symbiosis participation needs to be easy and low-risk for agriculture businesses, but models to deliver easy, low-risk on-ramps to participate are still immature in Washington.

**Utilities Have the Skills, but Not the Authorities**
Utility organizations exist to bring expertise and patient capital to energy, water, and waste management, and so should be in a better position to deploy capital on symbiosis infrastructure that will benefit industry and sustainability. But U.S. utilities are quite siloed, hindering their capacity to deploy and manage multi-resource symbiosis infrastructure.

**Funding Siloes Can be Blind to Integrated Solutions**
State and federal incentive programs to improve the efficiency and sustainability of energy, water, and waste infrastructure are similarly siloed, targeting narrowly defined projects at the expense of integrated solutions that can maximize economic and sustainability benefits.
Targeted Research

To complement the findings from interviews, consultations, and site visits with experts, innovators and stakeholders from Washington and beyond, the team also conducted several lines of targeted research and analysis to strategically expand our understanding of the agriculture sector's symbiosis opportunities and challenges:

1. A Quantitative Assessment of Agriculture Symbiosis Opportunities
2. Technology Development Review and Evaluation of Benefits
3. High Level Review of Policy Context
4. Compilation of Select International Agriculture Symbiosis Projects
5. Overview of California's BEAM Initiative

Key findings from these five lines of targeted research are presented next, while detailed findings are presented in Appendices A through D.
1. Quantitative Assessment of Agriculture Symbiosis Opportunities

Refer to Appendix A for further information.

The Quantitative Assessment Appendix focused on identifying opportunities through sector-wide inventories and geospatial analysis to discern general solutions and symbiosis pathways with the largest overall potential impact. This analysis is useful for delineating opportunities for large corporate development or policy makers. This work consisted of several key steps, including creating a facility database with more than 1,000 entities involved in agriculture and food manufacturing, characterizing the supply chains of several of the state’s most important agriculture products, and analyzing potential uses for waste biomass and heat.

KEY FINDINGS

Opportunities Vary by Location
The highest value agricultural supply chains are mostly concentrated in Eastern Washington. In particular, the Yakima Valley and Mid-Columbia Basin present attractive opportunities for symbiosis because they are home to both producers and processors. Supply chains for several commodities of interest like apples, potatoes, beef, and grapes are almost completely contained within this area while dairy also has a major presence. The Detailed Supply Chain Appendix describes where different feedstocks are produced in addition to other considerations like seasonality and competition from other users.

Technologies Must be Appropriate for Small & Medium Scales
Most agricultural commodities in Washington generate waste biomass that is a challenge to manage. Because this biomass typically has a high moisture content, transportation is expensive, particularly over long distances. Additionally, no single commodity is available at a large enough volume to support a facility that is dependent on a large scale to be profitable, like an advanced biofuels or biochemical manufacturer. Typically, these plants are most profitable at scales that use hundreds of thousands of tons of feedstock per year, which would place the demand for waste near the annual incoming capacity of many primary processing plants, let alone their waste output. The largest fruit processors use between 100,000 – 200,000 tons per year and the largest potato processors use between 200,000 – 450,000 tons per year. Reflecting this, emphasis should be placed on technologies such as anaerobic digestion and others that can accept a diverse range of feedstock throughout the year and be built at a variety of scales.

Re-use is an Important Component within Agricultural Waste Management
The default use for much of the waste from the Washington agriculture sector is focused on relatively low value uses that mitigate disposal costs. For instance, biomass is frequently sold for cattle feed, and much of the wastewater from fruit and vegetable processors is used to irrigate local fields during the growing season. Neither of these applications generate significant revenue and both are also subject to significant limitations. High moisture and low energy content in biomass like fruit pomace and potato trimmings cap feed rates in cattle rations. Use of wastewater for irrigation requires that the generating facilities be near irrigated fields. Irrigation can only be done during the growing season, and there are maximum levels of organic and inorganic materials that can be present in the water.

Low-level heat
As discussed in the Heat Sharing section of Appendix A, waste heat generated by most agriculture processors is low-grade, meaning it is difficult to capture and use compared to heat generated by other heavy industries. Despite this, waste heat from processors may be useful for several purposes like preheating water for steam, heating water for sanitation, supplying heat for biological processes like fermentation, and space heating. Some of the most likely customers of this low-grade waste heat within the agriculture sector include wineries, which maintain consistent cellar temperatures throughout the year and fish hatcheries, which use heat to encourage biological processes. Campus-style non-industrial facilities that use natural gas to heat their facilities, like college campuses and hospitals, may also be able to use waste for space heating.
2. Technology Review and Evaluation of Benefits

Refer to Appendix B for further information.

Based on the evaluation of potential biomass types and flows within our agricultural system, a literature review was conducted to explore anaerobic digestion and developments that might be applicable to agriculture symbiosis projects in Washington State and to evaluate the potential environmental and economic benefits of adopting those technologies in the near term and in the future.

Among existing, well-established technologies applicable to agricultural waste streams, anaerobic digestion (AD) offers great opportunities for agriculture symbiosis projects in Washington State. Through AD, wet organic wastes from food processors and manure can be converted to biogas which may be used to produce renewable natural gas (RNG). The subsequent use of the RNG not only provides a renewable energy source for combined heat and power (CHP) or as a feedstock for sustainable liquid fuels, but it also eliminates the emission of greenhouse gases (carbon dioxide or methane) from the decomposition of this waste.

The composition of the feedstock used in AD directly influences the biogas yield and quality, and combinations of different wastes may be most productive. Carbon/Nitrogen (C/N) ratios between 25-30 are considered optimal for digester functioning. Fruit waste as a single substrate can lead to a rapid decrease in pH due to the high sugar content, thus inhibiting biogas and methane production.

Agriculture symbiosis projects utilizing mixed waste streams have the greatest potential to maximize biogas production. For example, adding manure as a source of nitrogen to the fruit waste substrate may considerably increase biogas and methane yields. Alongside manure, supplementing lignocellulosic biomass (such as crop residues) to the fruit waste-manure substrate may result in yet higher biogas and methane yields. Biomass pretreatment prior to anaerobic digestion may be used to improve digestion yields.

Transportation is a key consideration for biomass, particularly wet wastes, because they are heavy due to the high moisture content, and are therefore costly to transport. Solutions to optimize logistics include analysis to find areas where wastes are produced in proximity across sectors, co-location of waste-generating entities, piping when wastes will be generated over the long-term at short distances from each other, and - when trucking is needed - utilizing clean fuels for transportation to reduce the carbon footprint.

An analysis of existing RNG facilities suggests that AD is underutilized in Washington. The RNG production potential is vastly underutilized in the United States, with existing facilities representing less than 20% of the total potential nationwide. Washington State currently ranks 22nd of 50 states.

Agriculture symbiosis projects that use AD technology have the potential to generate capital investments, permanent jobs, and additional revenue within the agriculture sector in Washington while benefiting the climate. The energy generated by a digester comes from biomass and therefore climate benefits are generated by displacing fossil-based natural gas, heat, and electricity. In some cases, climate benefits also result from reducing methane and carbon dioxide emissions from current waste management practices.

Among emerging technologies, hydrothermal liquefaction (HTL) presents potential future opportunities for agriculture symbiosis applications in Washington State. HTL, which is not yet commonly used at commercial scale, converts agricultural wet waste streams into biocrude and subsequently biofuels. HTL can be used to treat a diverse range of waste streams, including food waste, sludge, manure, oil, fats and grease, and others.

Other technologies for wet wastes, e.g., bioconversion, fungi-based treatments, vermicomposting, microbial fuel cells and others, may be suitable for small scale opportunities.
Royal Dairy
A large, family-owned dairy worked with BioFiltro to establish a 7-acre worm-bed processing system for dairy wastewater.

PRE-SYMBIOSIS
- Greenhouse gases and ammonia are produced when wash water sits in dairy lagoons, the typical process for settling out solids when vermiculture isn’t used.
- Additional water usage was required prior to recycling of dairy wash water.

SYMBIOSIS IN ACTION
- Wash water from milking barns is treated in the worm bed and reused on-farm
  - Liquids flows through large beds made up of gravel, wood chips, and worms — this cleans the water and reduces nutrients to the point where it can be land-applied or reused as wash water.
  - Once the wood chips are largely broken down, they are rich in worm castings and every couple of years the top layer can be harvested and used as a fertilizer that is full of beneficial microbes.
  - Wood chips are sourced from local “retired apple trees” which are traditionally burned.
- Cows are fed a diet of 12 locally grown ingredients.
  - Crops are rotated so that the cow’s manure adds nutrients to the soil; a variety of cover crops keeps the soil in place. Crops are beneficial to carbon sequestration when combined with minimal tillage and effective manure management practices.
  - Cows are fed farm wastes that don’t meet standards for human consumption: potato skins, apples, carrots and peas that are the wrong size.
  - Symbiotic relationship with Allred family apple and cherry farms — “the soils and the ruminants and their byproducts, and the cover crops are all working together…”

BENEFITS
- Removes odor and ammonia, and inhibits the production of greenhouse gases from dairy waste.
- Produces an amendment that can be applied to regenerate soil health and help sequester carbon.
- Removes 80% of nitrogen from wastewater and reduces phosphorous and other problem nutrients. Remainder can be applied to fields.

KEY TAKEAWAYS
Verniculture can effectively reduce nutrients in dairy wastewater, prior to the formation of potent greenhouse gases that are normally produced in lagoons.

This technology is scalable and can work for large operations like Royal Dairy, as well as smaller ones.
3. Overview of Policy Context

Refer to Appendix C for further information.

To provide a better high-level understanding of where and how existing policies are shaping the development and implementation of agriculture symbiosis, the team summarized and contextualized some key elements of the policy landscape. The goal of this work was not to dig into the details of particular regulations, grant programs, or other support. Instead, the goal was to identify major areas in which existing policies are relevant to industrial symbiosis in the agriculture sector.

To identify the most important policy-related opportunities and barriers relating to agriculture symbiosis in Washington, the team summarized key policy lessons from the stakeholder interviews carried out by CSI. To place these insights into a broader context, the WSU team then reviewed recent Washington- and Northwest-focused road-mapping efforts related to specific industrial symbiosis technologies with agricultural applications for policy-related insights; key elements of the state policy landscape; and the academic literature relating to industrial symbiosis policy.

**KEY FINDINGS**

**Agreement that Incentive-Based Programs are Key to Create Opportunity.** Many current regulatory policies such as waste diversion laws and clean fuels programs have been praised by the stakeholders that were interviewed, including those in the agriculture industry, for helping catalyze agriculture symbiosis opportunities. However, there is broad stakeholder agreement that incentive-based policies would be most helpful in creating opportunity moving forward. Incentives play an important role in reducing risk that accompanies the implementation of new technologies and processes, and in reducing the need for high capital investments. Some stakeholders suggested that the state could continue and expand support for agriculture symbiosis projects through existing or new grant programs, while others had a variety of other ideas, including support for market development, for research and development activities more generally, or for feasibility studies. Incentives could be tailored to address existing issues in the agricultural industry while providing support for engaging in new forms of symbiosis. Stakeholders were clear that regardless of the type of incentive, it is essential that any programs are easy to navigate so that the opportunities are obvious to those in the industry.

**Rapid development of state and federal policy in the areas of energy, climate, and solid organics is supporting opportunities for agriculture symbiosis.** Ensuring that these opportunities are realized may require better access; for example, some federal opportunities may be unclear or difficult to navigate. It will also require understanding where alignment (or realignment) of policy at multiple levels can ensure greater returns and greater impacts for symbiosis innovation. For example, the recently passed HB 1799 requires the diversion of organic material from the landfill. As local jurisdictions and businesses begin recovering this post-consumer waste, an opportunity may exist to create low-carbon energy such as renewable natural gas or liquid fuels. Local jurisdictions could consider collaborating with nearby industrial facilities to promote symbiosis opportunities. These collaborations can ensure these renewable energy facilities can obtain the feedstock necessary to create low-carbon fuels. Likewise, local jurisdictions could review their organic waste disposal requirements for business and residences, to ensure that they encourage, rather than discourage or prevent symbiosis opportunities.

**A Role for the State to Facilitate Convening Opportunities in Support of Agriculture Symbiosis.** Stakeholders suggested that a high priority need is a forum for those in the industry to convene with each other and with other stakeholders (government/agency, academic, non-profit) to exchange information, ideas, and best practices; identify common challenges and opportunities; and develop next steps where consensus exists. Incentives and collaborative opportunities can work hand-in-hand to reduce risk related to implementing new symbiosis approaches.
**KEY FINDINGS**

Business-as-usual regulatory language and processes can limit innovation and can be a particular barrier for newer agriculture symbiosis technologies. Because almost all symbiosis projects include industrial facilities, some of them quite complex, developing projects need to navigate existing regulatory requirements. This often includes (but is not limited to) air and water quality permitting, and sometimes solid waste permitting or water rights/water supply. Permitting needs and pathways can be unclear for newer technologies (i.e., those that are not business-as-usual), and this can create delays, added costs and added uncertainty. Regulators – as well as those implementing agriculture symbiosis projects – have an important interest in ensuring the protection of both public and environmental health. And yet facilitating efficient pathways for appropriate oversight and permitting is a key need.

Ensuring policy coordination and alignment is helpful. The web of policies that encourage or discourage agriculture symbiosis projects is highly complex. Agriculture operates within multiple policy areas, including renewable energy, air, water, climate, organic solid waste management, and soil health. These policy areas have historically developed separately, with little attention paid to the connections between them. At the state level, there are few explicit mentions of symbiosis in policy, and most current policies have a more singular focus (e.g., promoting biofuel production). Many symbiosis relationships are maximally beneficial when resources are transformed (e.g., organic waste to energy, wastewater to fertilizer, etc.) and transferred across sectors, but navigating across siloed policy areas can be difficult since policies may be misaligned, explicitly or implicitly prohibitive, or unclear.

Sustained symbiosis thrives when there are both private economic and public policy incentives designed to perpetuate transactions. A range of existing policy analyses, and Washington’s experiences with various technologies, suggest that economic benefits must be sustained in order for industrial symbioses to persist over time. As markets and incentives change, symbiosis projects may need to pivot or generate different products to remain viable. Within this context, policy does have a role to play in encouraging industrial symbiosis, especially for new areas and new technologies that are likely to be economically viable long-term but may have significant up-front costs. In this case, incentives play a role in reducing and rewarding the risk assumed by the early adopters.
4. Compilation of Select International Agriculture Symbiosis Projects

Refer to Appendix D for further information and additional examples.

Our global scan of relevant agriculture symbiosis examples resulted in profiles describing what we think are the most interesting case studies that may hold lessons for Washington practitioners.

**KEY FINDINGS**

Denmark's decades-long history and the nation's ongoing focus on improving symbiosis cooperative agreements and technical expertise has resulted in a variety of projects where agriculture-relevant waste byproducts are re-purposed by the agriculture sector and other industries:

- Solrød Biogas utilizes more than 190,000 tons of biomass feedstocks annually from local industry waste streams. They process pulp, pectin, and carrageenan from biotech processors as well as manure from local farms to produce heat and electricity to replace fossil fuels. Their processes also result in non-fossil fertilizers.

- GreenLab Skive, a 'green energy park of the future' is producing clean heat, animal proteins, electro-fuels, and other products from agriculture and other waste streams at, as of this writing, five private industrial facilities. Investment to date totals over $400 million. A noteworthy organic input, invasive starfish, is featured in Danish Marine Protein's process to produce supplemental protein for animal feed.

- Kalundborg Symbiosis, one of the oldest examples of symbiosis in the world, is located in the City of Kalundborg in Denmark. It is estimated to save the city $28 million annually by recycling water, energy, and materials between the 16 participating public and private entities. Together these partners offset 600,000 tons of carbon dioxide emissions annually. They are supported by a local multi-utility that directs the flow of water, wastewater, district heating and other resources.

Other nations across Europe feature advanced agriculture symbiosis operations:

- United Kingdom's British Sugar factory in Wissington is one of the largest beet sugar operations in Europe. They strive to utilize all waste byproducts, and methane generated from anaerobic digestion provides fuel to a combined heat and power plant, which provides carbon dioxide to a horticultural complex.

- Sweden’s Sotenäs Municipality in Gothenburg converts organics, including aquaculture waste from fish farms, into fertilizer and biogas. Other aquaculture byproducts serve as inputs for production of algae onsite.

- Germany’s Biowert Biorefinery, near Frankfurt, converts grass to biobased plastics while producing renewable energy and biofertilizers as coproducts.

South Asian and East Asian nations are making significant progress developing agriculture symbiosis partnerships, but English-language resources describing their operations are limited.

- In India's Nanjangud Industrial Area, located in a region that is rich with sugar and coffee producers as well as other farms, 45 companies have partnered to collectively process 900,000 tons of organic waste residues. It is estimated that 99.5% of residuals are recycled at least once.

- China’s Guitang Group in the Guangxi Zhuang Autonomous Region leverages sugar cane residue to produce paper, alcohol, calcium carbonate, cement, and power.
Vashon Bioenergy Farm

Chomp, formerly Impact Bioenergy, has invented a small-scale, modular anaerobic digester and deployed a pilot system at a tofu factory on Vashon Island.

PRE-SYMBIOSIS

- Disposal costs were higher because organic waste was transported off-island; more fossil fuels were needed for heat and powering trucks.

SYMBIOSIS IN ACTION

- The pilot system at Vashon Bioenergy Farm transforms the waste from Island Spring Organics tofu production process into an organic liquid fertilizer and ‘organic’ renewable natural gas (ORNG) that replaces natural gas on-site or in vehicles.

SYMBIOSIS IN PROGRESS

- In coordination with Zero Waste Vashon, Chomp is considering a bigger aerobic/anaerobic system for collecting additional organic waste from the community (commercial, residential and farm waste) to process on-island and reduce the need to transport waste off-island.

BENEFITS

- Reduces fossil fuel inputs and costs in heat and transportation; increases organic waste recycling; creates a marketable product, organic liquid fertilizer, that can offset the use of fossil-based fertilizers; generates ORNG for on-island use.
- Reduces greenhouse gas emissions by diverting organic waste from landfills: avoids trucking and transportation emissions and results in ORNG production on-site rather than methane escaping from landfills.
- Decentralized systems offer resilience and energy independence.
- These circular, closed-loop systems turn food waste into renewable energy and organic biofertilizer to grow more food.

KEY TAKEAWAYS

- Anaerobic digestion (AD) is feasible on a community scale.
- Anaerobic Digester systems can offset the cost of waste management for smaller food processing businesses by converting moderate waste streams to value.
- Liquid digestate from AD can be used as an effective fertilizer.
- Marketing innovative new products (like microbial fertilizers) is challenging.
- Sales of RNG for vehicle fuel can be more economical than displacing on-site natural gas usage.
- Creating close-looped systems in hard-to-reach locations, such as islands, can greatly alleviate costly transportation and associated emissions.
5. Overview of California’s BEAM Initiative

The North San Joaquin Valley’s BioEconomy, Agriculture & Manufacturing (BEAM) Initiative in California provides an agriculture-centered innovation cluster model that can inform thinking for a Washington agriculture symbiosis initiative. This overview provides an introduction to the genesis and structure of BEAM, but further investigation and knowledge exchange can more fully reveal lessons learned and their applicability to supporting agriculture symbiosis in Washington, as suggested in Recommendation #3 in the following section of the report.

The BEAM initiative grew out of an effort to build “a regional economy that is more diverse, inclusive, connected, vibrant and resilient,” and that identified bioindustrial manufacturing as its key strategy to achieve those goals.

Bioindustrial manufacturing has strong overlap with agriculture symbiosis, in that both are about repurposing wasted or underutilized organic resources, often amongst multiple companies, to generate higher economic value with corresponding environmental and social benefits. A literature review and interview with their executive director highlighted several relevant challenges they face and the strategies they are using to address them.

A backbone organization that provides a clear locus of effort and direct assistance is critical to overcoming barriers to biomanufacturing. The initiative is driven by such an organization, called BEAM Circular, that serves as the ongoing “innovation engine” to advance and sustain bioindustry in California’s agricultural hub.

Siloed, targeted regulatory and funding programs can create barriers to projects that involve multiple parties, span siloes and offer multiple benefits. BEAM provides sustained support for identifying and addressing regulatory barriers to bioindustrial manufacturing, which relies on sharing waste streams and converting them to value.

Emerging carbon markets and ESG (environmental, social and governance) investments offer access to new capital, but only with certification and validation services that can prove project performance across specific criteria, including decarbonization. BEAM provides access to certification and validation services that help companies prove triple-bottom-line project performance to investors and public agencies, facilitating private and public investment and bringing the initiative to scale.

Addressing skills development and lowering non-skill barriers to jobs and training (e.g., childcare, transportation) among the workforce, particularly in rural communities, will increase the skills and economic mobility of workers and drive inclusive economic development. As these services flow to some of the state’s most disadvantaged communities, they can help expand access to opportunity and address geographic and racial disparities for workers, their families and communities.

"Startup accelerator services" are offered by BEAM to help individual businesses grow, as is common to many economic development strategies. BEAM will offer the following accelerator services to ramp up bioindustrial manufacturing:

- Technical advice and mentorship
- Access to testing and research facilities
- Curated connections to potential customers and investors
- Shared services like marketing support
- Post-accelerator services for alumni firms designed to encourage companies to stay and grow in the region, such as assistance identifying space and recruiting employees
- A Center of Excellence to provide ongoing locus of effort
VII. Recommendations for the Washington Legislature

This section provides recommendations for increasing the economic value and sustainability of Washington's agriculture sector through the use of industrial symbiosis principles. Because the scale and economic value of the agriculture sector in Washington is so large, the potential for economic benefit and value creation from sustainable resource recovery from the sector’s energy, water and organic waste streams is also large in scale. The recommendations offered here, therefore, are designed to give lawmakers options to stimulate large-scale economic and sustainability benefits in the agriculture sector.

The four key recommendations:

1. Coordinate and invest in agriculture symbiosis programs in concert with others supporting clean industry

2. Support market accelerator research targeting key opportunities for agriculture symbiosis

3. Help key state programs and industry to strategically align services to support agriculture symbiosis innovators

4. Forge collaboration agreements with countries and states who are symbiosis innovation leaders
RECOMMENDATION #1

Coordinate and invest in agriculture symbiosis programs, in concert with others supporting clean industry

Why this recommendation?

• Agriculture is very important to the state’s economy. The opportunities to optimize resource use and reuse to benefit both the bottom line for producers and their sustainability performance appear to be very significant, but still largely untapped.

• Several key barriers constrain the ability of Washington innovators to develop agriculture symbiosis, including competing demands for scarce capital for upgrades and lack of experience with symbiosis technology and processes.

• Washington state boasts a wide range of programs and investments to advance the clean industry supply chain, many of which have direct relevance to agriculture symbiosis. To the extent these wide-ranging programs are dispersed in state government, they can be more difficult than necessary to access for proponents of integrated, multi-resource projects.

• State grant investment targeting innovative projects can be a powerful catalyst for private investment, tipping the balance to enable value-generating projects to leapfrog barriers and pencil out for all parties involved.

This recommendation suggests lawmakers consider ways to:

• Coordinate symbiosis programs with others designed to support clean industry, and

• Invest targeted slices of the state’s clean energy and climate funds for symbiosis projects.
COORDINATE

Washington state policymakers, recognizing the benefits of supporting the clean industry supply chain (see Section III), have adopted a wide range of programs and investments in recent years, across various segments of clean industry. Many of these programs have direct relevance to agriculture symbiosis. These segments range from organics recycling to renewable natural gas, sustainable aviation fuel, renewable hydrogen, bioproducts, industrial energy efficiency, sustainable farms, and more. In some but not all segments, policymakers have adopted framework legislation to strategically coordinate and focus state policy and investment in a particular segment. (see Summary of Policy Context in Appendix C).

With so many state programs to support different clean industry segments, agricultural and food processing companies may not realize that such opportunities are relevant to them, and proponents of agriculture symbiosis and related projects may find widely dispersed state programs and functions difficult to navigate. Legislators could help by investing in a one-stop shop for clean industry projects to access state financial and technical assistance, and to help leaders of key state programs coordinate delivery to better support great projects to overcome hurdles and advance toward fruition.

Symbiosis projects face unique barriers because they connect separate companies for mutual benefit, but forging these links is not in anyone’s job description. Symbiosis enables companies to look across market segments at the whole supply chain to identify synergies that can optimize economic benefits and sustainability performance. But for many companies, the pressures of achieving profitability within their niche consume most of their attention.

A single point of state government contact to access assistance and support can make it much easier for symbiosis project proponents to benefit from state support. Valuable services could include:

- Helping project proponents to navigate the complex landscape of regulations, incentives, and permitting, and access the full range of funding sources for which projects are eligible.
- Providing a ‘case bank’ of successful symbiosis projects, and benefit-cost analyses to help participants make go/no-go decisions on specific technology investments.
- Offering skilled symbiosis facilitation services to help separate companies forge resource-sharing partnerships for mutual economic benefit.
- Helping projects commission highly-credible third-party performance evaluation to show public and private investors the economic and environmental returns on investment in such projects.

INVEST

Additional public investments in agriculture symbiosis could help to address stakeholders’ wishes for a more incentive-based approach to symbiosis. These can act to de-risk projects through guaranteed payouts over multiple years, and/or reduce initial start-up costs for innovative symbiosis projects. State investments could also position Washington’s symbiosis innovators to attract private investment and better compete for federal funding, which often requires matching funds.

Other regions and countries have had success in stimulating innovation in agriculture symbiosis projects through targeted investments. In addition to the BEAM Initiative in Central California, several international examples are described in Appendix D.
Washington has a history of incentivizing technology innovation in targeted areas to stimulate strategic sectors and opportunities, and the state is already a national industrial symbiosis leader. The 2021 Legislature adopted the nation’s first statewide IS program, and appropriated a $2 million funding pool for the 2023-2025 biennial budget. The Department of Commerce is distributing these funds through competitive grants, with demand (reflected in applications to the IS program) already outstripping available funds.

To scale up state support for symbiosis and the clean industry sector broadly in Washington, policymakers could consider carving out symbiosis and clean industry programs within the state’s two biggest, most directly relevant funding programs. The Clean Energy Fund (CEF) and the Climate Commitment Account (CCA) are both designed to speed Washington’s transition to zero climate pollution by scaling 21st century clean technologies, while growing Washington jobs and businesses in the clean economy. Examples of existing targeted carve-outs programs include the Rural Clean Energy Innovation Fund ($4.9 million in early 2023) and the Research, Development, and Demonstration Program ($8.5 million in 2022). Program carve-outs like this can advance innovation and help Washington organizations to attract federal and other matching funds.

Although agriculture symbiosis projects are eligible for some CEF and CCA funding, a more targeted approach to invest in the agriculture sector could help bring visibility and coordination to this emerging approach. This approach would also benefit a fuller geographic sweep of Washington communities, many of whom face persistent barriers to success. Because agricultural waste resources are dispersed through many parts of the state, the jobs and economic benefits from investing in agriculture symbiosis will be distributed statewide as well.
Lamb Weston Richland

Lamb Weston’s Richland plant processes organic waste to produce renewable natural gas (RNG) that will be captured, processed, and distributed. The company also internally reuses water, heat and RNG at other facilities.

**PRE-CIRCULARITY**

- Raw natural gas produced at Lamb Weston’s Richland plant is generated at their agricultural biogas recovery system and is currently being flared.
- Water and heat demands are substantial and required significant resources prior to implementation of circular practices in Oregon, Louisiana, and Minnesota facilities.

**CIRCULARITY IN PROGRESS**

- Lamb Weston has committed to sell raw renewable natural gas (RNG) made at its Richland site to Pine Creek RNG who will finish the gas before selling it to Cascade Natural Gas along with RNG from the nearby Horn Rapids Landfill.

**CIRCULARITY IN ACTION**

- At some of LW’s other facilities outside of Washington (including those in Delhi, Louisiana and Park Rapids, Minnesota) RNG is captured and reused internally. Process water treatment at these plants includes anaerobic digestion, using potato waste to create renewable natural gas, which is used as fuel for each site’s boilers, thus offsetting fossil fuel use and lowering carbon emissions.
- Another example of internal reuse of resources that is closer to home can be seen in the Hermiston, Oregon plant’s state-of-the-art water reuse system. Process water is treated through anaerobic and aerobic processes and then treated for reuse using ultrafiltration, reverse osmosis, and disinfection processes before being returned to the production process.

**BENEFITS**

- In Richland, Lamb Weston’s agricultural biogas recovery system and the landfill are expected to produce more than 2.5 million therms of RNG annually, displacing the need for fossil fuel based natural gas. This volume is enough gas to serve approximately 4,173 Washington homes each year with renewable fuel.
- In Hermiston, their water reuse system supported the expansion of the Hermiston operation, allowing them to add an additional production line without using any additional water. Clean water leaving this site is used to irrigate neighboring farms, delivering value for growers while reducing demands on local water supply.
RECOMMENDATION #2
Support market accelerator research targeting key opportunities for agriculture symbiosis

Why this recommendation?
Targeted research can play a role in accelerating the deployment of new technologies and growth of industrial symbiosis, contributing to Washington's leadership in this space.

Examples of the types of targeted research that could accelerate agriculture symbiosis markets and that were identified through research and consultations include:

- Forest products symbiosis
- Capture and recycling of industrial waste heat
- Multi-resource, utility-enabled Symbiosis Innovation Districts
- Development of new markets and products derived from organic wastes
- Documenting the benefits provided by agriculture symbiosis strategies

This recommendation could leverage current efforts at some of Washington's top research institutions. For example, Richland sits at the intersection of the state's agricultural and energy sectors. It is also home to the newly established WSU Tri-Cities Institute for Northwest Energy Futures (INEF). INEF emphasizes a system-level approach to decarbonization of energy and recognizes that adapting industry and agriculture is a critical component of this goal. Pacific Northwest National Laboratory’s (PNNL) Process Development Units have long been used to research HTL (hydrothermal liquefaction), a process that converts wet wastes, like manure, biosolids, or food waste, into crude-like oil that can be used as a petroleum replacement. Additional efforts from these institutions and others can provide interdisciplinary expertise in areas spanned by agricultural symbiosis like water, organics and carbon cycling.

Five specific opportunities to accelerate symbiosis markets through strategically targeted, interdisciplinary research emerged from this project's consultations and research, including:

1. Forest products symbiosis

Like the agriculture sector, forest products facilities use significant volumes of heat, water, and organic material resources, and in the process often generate significant heat, water and organic waste streams. As with agriculture, they also face daunting logistical challenges in moving heavy waste products over significant distances, posing added challenges to capturing value from waste.

Many key barriers and solutions for agriculture identified in this report can be adapted to benefit the forest products industry. But important differences between agriculture and forest products resource inputs and waste streams can inform follow-on market accelerating research. For example, the volumes of woody wastes managed by the forestry sector tend to be much larger than organic wastes in the agriculture sector. Processing forest products may be more heat-intensive than many food processing operations. Woody wastes are mostly drier than the primarily wet wastes from agriculture. The crisis of forest fuel overloading across large swaths of Washington's forestlands, and planned forest health treatments, may dramatically increase the supply of forest waste requiring processing for years to come.
2. Capture and recycle of industrial waste heat
A primary use of energy for industry is for heating and cooling, but inadequate attention has been paid to understanding and developing cost-effective strategies to decarbonize industrial heat globally, nationally, and in Washington. New research in the European Union, led by Denmark’s Aalborg University, found that waste heat is “the world’s largest untapped energy source,” and that available waste heat in the EU is nearly equal to total EU-wide energy demand for heat and hot water.

The Heat Sharing section of Appendix A provides a high-level assessment of heat sharing opportunities and technologies applicable for the Washington agriculture industry. A market accelerator research initiative could expand on this work by focusing initially on the agriculture and forest products sectors by mapping industrial heat demand and recoverable waste heat flows at a more detailed level, and identifying locations with concentrations of resource-intensive facilities where greatest near-term economic and sustainability gains can be achieved through sharing of waste heat. The Northwest Combined Heat-and-Power Program, a US Dept of Energy initiative, housed in WSU’s energy program in Olympia, possesses invaluable expertise that can be tapped to support this research initiative.

3. Investigation of multi-resource, utility-enabled Symbiosis Innovation Districts
Industrial facilities in close proximity all require resource inputs and waste management systems. Utilities exist to bring expertise and patient, low-interest capital to energy, water, and waste management, and, in theory should be positioned to develop and operate symbiosis infrastructure and services that serve clusters of industrial facilities. But most U.S. utilities are quite siloed, required to focus on just one or two of the several resource inputs and waste services needed by industry. Utilities that are strictly siloed are poorly equipped, and often constrained by regulation, in deploying and managing multi-resource symbiosis infrastructure. Dealing with multiple, siloed utilities across an integrated industrial network presents yet another barrier to industries seeking to strengthen their bottom line through symbiosis.

Market accelerating research can inform lawmakers on options to update existing laws that authorize providers of energy, water, and waste services, including cities and counties (Title 35), port districts (Title 53), public utility districts (Title 54), and other utilities (Title 80). Researchers can analyze how these laws might be adjusted to expand allowed services to include all those needed by industry and key to symbiosis, from district heat and cooling, to recycling of waste and wastewater, to carbon management. They could also look at options to explicitly authorize Symbiosis Innovation Districts that leverage the strengths that utilities bring, while enabling more flexible, nimble, efficient, multi-resource utility enterprises that can develop richer, integrated symbiosis opportunities and infrastructure.

4. Development of new markets and products derived from organic wastes
Beyond energy, industrial symbiosis technologies can potentially generate a range of other products from organic wastes, while addressing both resource and energy flows. These can include clean soil amendments, along with other products, ranging from biochars, to specialty chemicals and functional fillers for polymers, lubricants, proteins for livestock, fish, pets or humans, and building materials.
Myno Carbon Kettle Falls

Myno Carbon is building a large-scale biochar production facility integrated with Avista’s Kettle Falls Generating Station.

A Washington startup that aims to build large-scale carbon removal facilities that profitably remove and sequester carbon to mitigate the climate crisis and meet the needs of industry partners. The facility will intake wood waste from several sources and convert it into biochar, and also convert waste heat into renewable electricity.

SYMBIOSIS IN ACTION

- **Biochar production** converts wood wastes from timber slash and mill residuals into biochar, which is in turn used as a soil amendment to be applied to agricultural lands and forestlands.
- **Waste heat** from biochar production is used to pre-heat water for steam generation of renewable electricity at the Avista generating station.
- Myno is exploring utilizing the biogenic **gas emissions** to weatherize basalt as a secondary soil amendment.

SYMBIOSIS IN PROGRESS

- **Renewable electricity** generated from steam using waste heat can be used to electrify heavy duty trucks, reducing transportation emissions.
- **Biochar** can be sold as direct-to-consumer products and generate carbon reduction credits as well as support the decarbonization of other industries.
- Efforts to work with WA DNR, USFS, and tribal partners, including the Colville Tribes to procure additional feedstock from forest health treatments (forest thinning waste) will come online in the next few years.
- No agriculture feedstock is planned for the facility, but they will explore opportunities as they arise.

BENEFITS

When applied to soil, biochar sequesters carbon dioxide and reduces nitrous oxide emissions. It also helps retain more water and nutrients in the soil, requiring less fertilizer be purchased and reducing emissions from fertilizer production.

Biochar production can sequester carbon from forest waste rather than slash pile burning, reducing greenhouse gas, toxic emissions, and wildfire risks.

KEY TAKEAWAYS

Co-locating biochar production at a power-generating station unlocks many efficiencies, including the ability to capture waste heat generated during biochar production for power generation.

Washington’s farm and forest lands produce huge quantities of biomass that can be put to higher value use, with the primary bottlenecks being logistics and transportation.
Higher value products (on a pound-for-pound basis) can provide profitable – though often smaller – markets, that can enhance profitability for some symbiosis projects. Applied research can support market development for such products by helping demonstrate performance, addressing user questions, and providing guidelines for use for new bioproducts. State investment in bioproducts innovation can attract federal investment, which has recently ramped up in this area, particularly at USDA and DOE.

5. Document the benefits provided by agriculture symbiosis strategies
Agriculture symbiosis relationships offer both economic and environmental benefits, and in many cases corresponding social benefits. Delineating the various benefits of these projects helps these entities showcase their contributions to stakeholders, funding agencies and the public, and enables comparison to other models that can inform wise policy decisions on programs and funding. It can also encourage others to adopt these newer approaches, based on sound, common sense science.

Over time, credibly measuring costs and benefits of agriculture symbiosis will inform and help projects excel at optimizing economic, environmental and social performance. State investment in these efforts can also spur additional technology development aimed at maximizing benefits alongside improving economics.
Edaleen Cow Power
A key example of in-house circularity using anaerobic digestion (AD)

PRE-CIRCULARITY

• Manure and its nutrients are valuable byproducts from the dairy farm that were not being fully utilized.
• Costs and environmental concerns resulting from chemical fertilizer use
• Wood shavings used for cow bedding grew more expensive and harder to find when housing construction slowed in the region.

CIRCULARITY IN ACTION

• Dairy farmers are the original recyclers; producing a product, milk, and using byproducts, manure, to fertilize crops to feed back to cows to produce more milk, and more manure, to continue the cycle.
• Anaerobic digestion efficiently produces and captures biogas from the manure, then a system of solids separation extracts fibrous materials for re-use as cow bedding. Any remaining solids are land-applied to crops. The digester allows the farm to capture the biogas from manure to be used for renewable energy, advancing the farm's historical practice of recycling.
• Remaining liquid is treated to produce a stackable, truckable, phosphorous-rich solid to be used as fertilizer and a liquid that has a significantly reduced and well-balanced nutrient concentration.
• In 2022 the AD system required new investment to keep it maintained and operational. 3Degrees, a renewables and decarbonization firm, agreed to finance the project, and is now selling the digester electricity into transportation markets and capturing clean fuel standards credits.

BENEFITS

• Reliance on chemical fertilizers is reduced when AD nutrients are land-applied.
• There is no more need to purchase and transport cow bedding.
• Results in carbon-free electricity production.
• The system allows for a fine-tuned nutrient management process.
• After ten years the digester has supplied enough emission-free electricity to power 380 local homes while improving climate, air, and water quality, according to Bryan Van Loo of Regenis, who operates the AD for Edaleen.

KEY TAKEAWAYS

Large AD systems incur maintenance costs as they age, but there are innovative new financing options to extend renewable energy production with existing infrastructure.

Dairies can make good use of AD byproducts on-site, including fibrous materials and phosphorous-rich solids for fertilizer.
RECOMMENDATION #3

Help key state programs and industry to strategically align services to support agriculture symbiosis innovators

Why this recommendation?

• While symbiosis offers economic advantages, its implementation presents barriers that individual businesses are often ill-equipped to overcome. Symbiosis is about finding higher value through new networks, partners, technologies and shared infrastructure, and establishing symbioses may often take businesses beyond their capacity or areas of expertise and control.

• Securing capital investment to support less established, multi-party approaches like industrial symbiosis can be a constraint. An effective backbone organization can bring a variety of tools to overcome barriers and facilitate public and private investment.

This study has revealed multiple opportunities across Washington to use symbiosis to create new earnings and multiple benefits in the ag sector. But it has also identified challenges. The nature of symbiosis is such that individual companies are often ill-equipped to unlock the potential of innovative, value-adding resource exchanges between multiple companies or sectors. Successful symbiosis relies on new networks, partners, technologies and often shared infrastructure and utility services.

An example can be found in Pasco, where food processors initially received recommendations to use algae for denitrification of their wastewater with some skepticism. They had no knowledge of this technology and perceived it to be unproven, and so were concerned about exposing their companies to excessive risk. The City, who processes these companies’ wastewater, likewise had no algae expertise. A modest $50,000 grant from Commerce’s Industrial Symbiosis grant allowed the City to dig into and ultimately decide on algae as an effective, proven treatment option. Algae will require significantly less energy over the multi-decade life of the infrastructure, produce a fertilizer as a marketable product, and save money for processors and ratepayers. Without this external support, this symbiotic opportunity would have remained hidden from view.

While motivated entrepreneurs are finding ways to overcome the barriers to profitable symbiosis in some instances, addressing them in more systematic ways will make broader adoption faster and easier.

Washington has been pursuing an “innovation cluster” approach in recent years through the Department of Commerce’s Innovation Cluster Accelerator Program (ICAP) to “help promising industry sectors assemble the ingredients they need to grow, such as access to capital, the latest research and support for entrepreneurs.” While ICAP offers a viable approach, additional funding for the program would be needed to add any clusters beyond the nine existing designated clusters.

In considering options for providing the kind of “backbone” support offered by cluster organizations, an informative example can be found in California’s BEAM Initiative (BioEconomy, Agriculture & Manufacturing) in the agriculture powerhouse region of the North San Joaquin Valley. The BEAM Initiative arose from an American Rescue Plan Act (ARPA)-funded process committed to building “a regional
economy that is more diverse, inclusive, connected, vibrant and resilient” that identified bioindustrial manufacturing as its focus. A cross-sector working group of industry, government, academic, and community leaders (including former USDA Director Ann Veneman) developed a multi-faceted ecosystem strategy to provide the structure, capacity, and momentum to build an effective innovation engine for bioindustrial manufacturing. The benefits of the proposed innovation engine are intended to flow to some of the most severely disadvantaged communities in California.

As with the BEAM Initiative, agriculture symbiosis also sits at the intersection of agriculture, manufacturing and the bioeconomy, so this nascent initiative can likely provide helpful lessons as Washington explores how it can best support symbiosis as a means of increasing the economic competitiveness and sustainability of the ag sector.

Whatever pathways are chosen to align state programs to better support agriculture symbiosis innovators, industry support, involvement and leadership are essential. In fact, such leadership is a prerequisite for clusters in the ICAP Program. Efforts to foster alignment should closely coordinate with Commerce’s Industrial Symbiosis Program, where they are gaining valuable experience and insight into the kind of support agriculture innovators need, and how best to provide it. These efforts should also engage other programs that could support agriculture symbiosis projects, such as the Industrial Site Readiness Program and the Evergreen Manufacturing Growth Grants.

One helpful service a backbone organization can provide is high-level perspective on new uses of resources, both to maximize valorization of available feedstocks and prevent negative unintended consequences that may not be visible at the project level. For example, repurposing a waste stream might generate new revenues but disrupt existing, important “virtuous cycles” such as returning certain biomass to croplands for soil health. As new uses and exchanges of wastes and by products expand, guarding against such scenarios could prevent new problems and minimize risk, both real and perceived.
Forge collaboration agreements with countries and states who are symbiosis innovation leaders

Why this recommendation?

- Washington industry and policy leaders benefit from knowledge exchange and partnerships with other states and nations, as our state’s collaborations with Denmark on industrial symbiosis are demonstrating.

- Such partnerships can result in the transfer of research, best practices, technologies, and policies that can improve economic and sustainability performance of Washington businesses.

- Washington innovators can also derive inspiration from seeing the ingenious technologies and solutions that others are implementing which they may not have otherwise imagined.

Two examples of collaboration agreements in other areas that could be used as a template for agriculture symbiosis are Washington’s agreement with Norway for maritime sustainability innovation, and an agreement with the Netherlands for tree fruit innovation. Key lessons can be gleaned from these collaborations to inform the design of Washington’s symbiosis partnerships to achieve better return on investment for the state.

This recommendation supports in the near-term a formalized Washington-Denmark agreement to collaborate on industrial symbiosis. Denmark is the world leader in symbiosis, and public and private agencies in Washington are already collaborating with symbiosis leaders in Denmark.

The tangible outcomes and benefits that collaboration agreements like this can offer to agriculture symbiosis efforts in Washington include:

- Knowledge exchange can enable Washington’s industry innovators to develop better, smarter, more cost-effective symbiosis projects.

- Joint partnerships with companies elsewhere who have deep experience developing and operating symbiosis projects can result in more successful projects that achieve greater scale and benefits in Washington.
Divert Longview
Divert is bringing online an Integrated Diversion and Energy Facility at the Mint Farm Industrial Development Park in Longview.

PRE-SYMBIOSIS

- A large share of the region’s food waste ends up at the landfill where it produces methane. Organic landfill waste is responsible for 15% of US methane emissions¹ and 10% of overall greenhouse gas emissions².
- Wasted food represents a waste of the various resources expended to grow, process, package and distribute that food, and includes associated greenhouse gas emissions throughout the process.

SYMBOISIS IN ACTION

- Once Divert’s Longview facility is brought online (estimated sometime in 2024), it will receive food waste from up to 650 grocery stores around the PNW, resulting in reduced organic waste from participating grocers and reduced greenhouse gas emissions from food waste.
- The company will use proprietary processing solutions to de-package and anaerobically digest incoming food waste. Anaerobic digestion generates biogas that can be used to produce carbon-negative renewable natural gas.

BENEFITS

Resulting renewable natural gas will be pumped directly into the Cascade Gas distribution pipeline, offsetting the use of fossil gas.

The facility’s analytics system will leverage Divert’s IoT (Internet of Things) platform using hardware, sensors, and algorithms to deliver data on the food waste stream to retailers so they can identify trends and further reduce waste at the source. “Source reduction is always the best solution and Divert is incentivized by its retail customer contracts to prevent food from ever leaving the supply chain.”

A solid digestate product is also produced through AD that can be used as a soil amendment that supports and enhances composting.

Because the facility will process significant amounts of wasted food into carbon negative energy, it is projected to offset up to 23,000 metric tons of carbon dioxide per year, equivalent to taking roughly 5,000 gas-powered cars off the road every year.

Divert’s retail partners will be supported to meet their waste diversion goals to comply with Washington’s HB 1799 and Oregon Metro’s food diversion laws. Production of RNG supports low carbon fuel standards in both states.

KEY TAKEAWAYS

Divert’s rapid expansion nationwide over the past 16 years, shows demand from food retailers for this service, and that their model of processing organic waste to produce RNG makes good economic sense.

Food diversion laws and carbon credit markets are expected to further shift the landscape in favor of this model.

¹ US EPA (2022), Basic Information about Landfill Gas
² World Wildlife Fund (2021): “10% of all greenhouse gas emissions come from food we throw in the bin”
Acknowledgements

The project partners would like to extend their sincere thanks to the many individuals who contributed their insights, experiences, and opinions to this report, particularly those active in agriculture symbiosis projects, who were interviewed or consulted by the team, hosted the team for on-site tours, and/or reviewed a report draft. These individuals include:

Virginia Emery, Beta Hatch
Karen Warner, BEAM Circular
Embrey Bronstad, Brown & Caldwell
Alan Johnston, City of Gresham
Steve Worley, City of Pasco
Michael Henao, City of Pasco
Dena Ybarra, Columbia Basin Nursery
Fabian Bühler, Danish Energy Agency
Chris Thomas, Divert Longview
Derek Allred, Double Diamond
Megan Couture, Errant Cellars Winery
Craig Smith, Food Northwest
Paul Simpson, Gross-Wen
Martin Gross, Gross-Wen
Mark Buehrer, Heart Foods
Michael Smith, Chomp (FKA Impact Bioenergy)
Doug Krapas, Inland Empire Paper Co.
Per Moller, Kalundborg Symbiosis
Trudy Slagle, Lamb Weston
Rich Burres, Lamb Weston
Roy Nott, LD Nott Company
Dale Silha, McKinstry
Mike Porter, McKinstry
Lauren Breynaert, Myno Carbon
Lauren McCloy, NW Energy Coalition
Russ Davis, Organix
Harrison Pettit, Pacific Ag
Melanie Roberts, PNNL

Peter Valdez, PNNL
Mike Werner, Qualterra
Austin Allred, Royal Dairy
Kevin Scribner, Salmon Safe
Lynn Mueller, SHARC Energy
Alicia Krueger, Sustainable Energy Ventures
Walker Dimmig, Sustainable Energy Ventures
Julia Terlinchamp, WA Dept. of Agriculture
Derek Sandison, WA Dept. of Agriculture
Megan Finkenbinder, WA Dept. of Agriculture
Dani Gelardi, WA Dept. of Agriculture
Laura Raymond, WA Dept. of Agriculture
Madi Roy, WA Dept. of Agriculture
Rob Duff, WA Dept. of Commerce
Aaron Peterson, WA Dept. of Commerce
Kirk Esmond, WA Dept. of Commerce
Evan Sheffels, WA Dept. of Agriculture
Jason Spadaro, WA Forest Protection Association
Darin Cramer, WA Forest Protection Association
Jim Jensen, WSU
David Gang, WSU
Tim Waters, WSU
Douglas Collins, WSU
David Van Holde, WSU Energy
Lon Inaba, Yakama Nation Farms
Alfonso Contreras, Yakama Nation Farms
Marian Chertow, Yale University, Industrial Ecology
Koichi Kanaoka, Yale University, Industrial Ecology
The team that contributed research, technical expertise, and/or writing to the development of this report includes:

**Washington State University**
- Georgine G. Yorgey
- Michael P. Wolcott
- Chad E. Kruger
- Dane A. Camenzind
- Julie Padowski
- Aaron M. Whittemore

**Center for Sustainable Infrastructure**
- Rhys Roth
- Ted Sturdevant
- Terry Carroll
- Steve Moddemeyer
- Alex Ybarra
- Keira Jensen

**Pacific Northwest National Laboratory**
- Jonathan Male
- Francesca Pierobon