Project Title: Life Cycle Assessment for Apple Production in the Pacific Northwest.

Report Type: Final Project Report

Primary PI: Greg Thoma
Organization: Resilience Services, PLLC
Telephone: 479-445-5277
Email: gjthoma@gmail.com
Address: 7017 Roaring Fork Trail
City/State/Zip: Boulder, CO 80301

Co-PI 2: Janjoris van Diepen
Organization: Silliker, Inc.
Telephone: (240) 330-7542
Email: janjoris@blonksustainability.com
Address: 1250 24th Street NW
City/State/Zip: Washington DC

Co-PI 3: Georgine Yourgey
Organization: Washington State University
Telephone: (206) 235-7154
Email: yorgey @wsu.edu
Address:
City/State/Zip:

Co-PI 4: Suzette Galinato
Organization: Washington State University
Telephone: (509) 335-1408
Email: sgalinato@wsu.edu
Address:
City/State/Zip:

Cooperators: Chad Kruger (WSU), Andrew Bierer (USDA ARS), Brent Milne (McDougall & Sons, Inc.), Derek Tweedy (Domex Superfresh), Greg Pickel (G.S. Long), Suzanne Bishop (Allan Brothers F), Marty Matlock (Nokose, Inc.)

Project Duration: 3 Year

Total Project Request for Year 1 Funding: $ 161,531
Total Project Request for Year 2 Funding: $ 192,195
Total Project Request for Year 3 Funding: $ 174,900

Other Funding Sources: None
WTFRC Collaborative Costs: None

Budget 1
Primary PI: Greg Thoma
Organization Name: Resilience Services, PLLC.
Contract Administrator: Greg Thoma
Telephone: 479-445-5277
Contract administrator email address: gjthoma@gmail.com

	2023	**2024**	**2025**
Salaries (fully burdened) Thoma & Matlock	$32,500	$48,500	$55,000
Benefits			
Wages			
Benefits			
RCA Room Rental			
Shipping			
ISO Review Panel		$15,000	
Travel	$4,800		
Plot Fees			
Miscellaneous			
Total	$37,300	$63,500	$55,000

2025 expenses to be invoiced:
Thoma salary: $55,000
ISO review ($15,000) paid in 2025 following completion of the review.
Travel: $0

Budget 2

Co PI 2: Janjoris van Diepen
Organization Name: Silliker, Inc.
Contract Administrator: Janjoris van Diepen
Telephone: (240) 330-7542
Contract administrator email address: "Janjoris van Diepen" <janjoris@blonksustainability.com>

	2023	2024	2025
Salaries	$65,200	$92,400	$92,400 **+$10,000 = $102,400**
Benefits			
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies			
Travel	$2,500	$2,500	$2,500
Survey Dissemination			
Miscellaneous			
Total	$67,700	$94,900	$94,900 **+ $10,000 = $104,900**

Actual costs 2025

Salaries: $102,400

Perpetual EcoInvent data license $2500

Travel: $0

Budget 3

Co-PI 3: Georgine Yorgey (WSU lead Co-PI), Suzette Galinato (WSU Co-PI)
Organization Name: Washington State University
Contract Administrator: Stacy Mondy
Telephone: 916-897-1960
Contract administrator email address: arcgrants@wsu.edu
Station Manager/Supervisor: Chad Kruger (Tree Fruit Research and Education Center Director, Center for Sustaining Agriculture & Natural Resources Director)
Station manager/supervisor email address: cekruger@wsu.edu

	2023	2024	2025
Salaries (1)	$14,901	$22,962	
Benefits	$4,972	$10,064	
Wages (2)	$28,800	$9,318	
Benefits	$2,938	$951	
RCA Room Rental			
Shipping			
Supplies (3)	$1,920		
Travel (4)	$3,000	$500	
Plot Fees			
Miscellaneous		$5000	
Total	$56,531	$48,795	$ 0

Life Cycle Assessment for Apple Production in the Pacific Northwest.

Objectives

We conducted a lifecycle assessment to evaluate the environmental impacts of apple production from orchard establishment through harvest and cold storage (or alternate supply chain stage where the apples are ready for delivery to the consumption stage). The analyses included upstream (e.g., suppliers) and downstream (e.g., waste management) processes associated with apple orchard and warehouse operations (e.g., production of raw, auxiliary, and operating materials), including all relevant inputs, emissions into the air, water, and soil, and disposal of all elements of production (e.g., pruning wood and end-of-life trees). This enables the apple industry to respond with cost-effective adaptive strategies to sustain production and profitability into the future, address buyer concerns, take advantage of government programs, and prepare for potential federal regulatory oversight (e.g., reduction in GHG emissions) being developed. The results of this LCA offer insights into the entire production system from which the sector could construct a public policy or public relations narrative regarding the impacts of tree fruit production on climate change and other environmental impacts.

The primary project goals were to provide a baseline assessment of the environmental sustainability of Northwest apple production and to ***develop a scenario analysis tool*** that will support the evaluation of management decisions over the orchard life cycle and provide the standard against which future improvements can be documented. These objectives were achieved through stakeholder-engaged efforts to define the sector's most relevant data and sustainability metrics.
At scale, we envision a continuum of orchard stages. As new practices and technologies emerge, the scenario tool can inform decisions regarding the next establishment phase's management. Since environmental sustainability metrics are vital components of the scenario analysis tool, baseline life cycle impact assessment results are a key deliverable from this project and implemented in the tool.
Specific objectives of this project are:

- Design and test a comprehensive life cycle data collection survey to provide data for a baseline sustainability assessment [complete] (e.g., Carbon and water footprint, energy consumption, eutrophication, etc.) and the development of a scenario tool for the evaluation of alternate management scenarios (e.g., biomass to energy versus composting of end-of-life trees).
- Provide an evaluation of current sustainability metrics of a range of management alternatives of NW apple production – that is, ***a baseline suite of metrics against which future progress can be evaluated***.
- Develop an LCA model for environmental impact assessment and scenario testing.
- Engage stakeholders in the development of a scenario analysis tool with which producers can simulate alternate management practice effects on environmental sustainability metrics that can be used to identify strengths and weaknesses of alternate management systems to identify environmental hotspots as opportunities for improvement.

Significant Findings

Workflow 1: Survey implementation

- An extensive list of over 100 questions for apple orchard growers was created based on a literature review, expert judgment and previous LCA experience. This list formed the basis for focused, in-depth interviews. Subsequently a shortened survey was deployed via Qualtrics and available for most of 2024. A total of 62 surveys (including focus group interviews) were used to generate the inventory model in the Simapro LCA software platform.

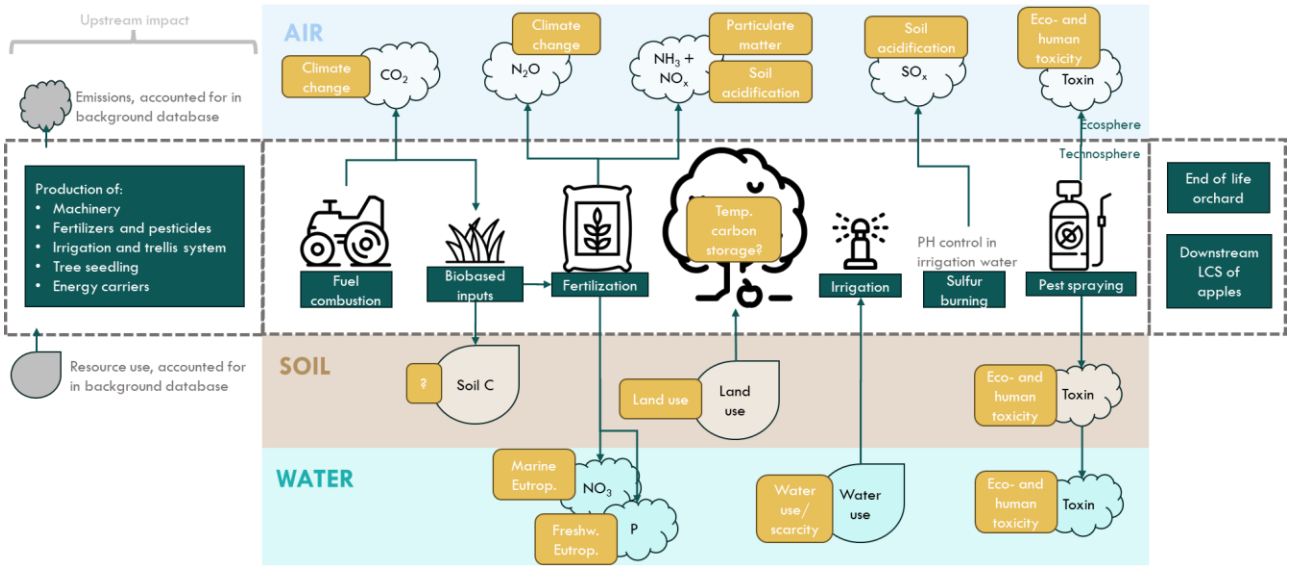

Figure 1. Schematic overview of processes considered in the LCI and associated environmental impacts.

Workflow 2: Life cycle inventory and report

- A parameterized lifecycle inventory (LCI) model has been created in the SimaPro software platform. The model includes an accounting of inputs (including upstream processes), outputs, and emissions of the establishment and production phases of apple cultivation. The model formed the basis for the full lifecycle impact assessment and sensitivity which was delivered in early 2025. A schematic overview of the production activities within the scope of the model, and the associated environmental impacts, are depicted in Figure 1.
- The full LCA report has undergone an ISO conformance review and the panel report has been submitted along with the full report which describes the LCA process and methodologies employed in detail.

Workflow 3: LCA tool development

- The learnings regarding management practices and LCA calculations form the basis for the scenario analysis tool. It was developed with stakeholder engagement and delivered separately from this report with a user's manual.

Quantifying the impacts of current Pacific Northwest apple production practices on the environment is important to understand the environmental impacts associated with apple production and supply chains in the region, to position the apple industry to be in compliance with buyer demands, and to engage with the USDA Climate-Smart Commodities Program. The LCA from this project has provided a baseline environmental profile and can assist in identifying opportunities for greenhouse gas mitigation and other sustainability efforts, in turn allowing the apple industry to make impactful, data-driven decisions. Further, the effort can support communication to educate the Pacific Northwest apple industry, retail partners, and consumers about the sustainability characteristics of apple production. Finally, the research provides the industry with a credible, science-based narrative showcasing its efforts as good caretakers of the land and resources.

Broadly, this project has relied on stakeholder-engaged life cycle inventory data collection, which was used in standard LCA software to calculate carbon and water footprints and other sustainability

indicators. A lifecycle inventory model is constructed as a set of linked unit processes. Each unit process accounts for a specific activity in the supply chain (e.g., drip or other irrigation systems, or application of crop protection chemicals) and captures the full production chain of the system under study.

The overarching structure of this project was highly integrated from the outset. Close coordination between the three workflow activities has been achieved through weekly or biweekly team meetings. Our efforts in year 3 were focused on completing the scenario tool and finalizing the ISO review of the full LCA report.

Scenario assessment tool

The spreadsheet tool and user's guide have been separately submitted to the WTFRC and not reproduced in this report.

The tool was constructed to include baseline life cycle impact assessment results and to support simulation of management practices on environmental sustainability metrics. It will allow users to identify strengths and weaknesses of alternate management systems to identify environmental hotspots as opportunities for improvement.

We met with stakeholders in 2025 to discuss the tool requirements and development process (Figure 1). The goal is to provide utility for a range of operators. While the vertically integrated operations (i.e., through to the retail receiving gate) are likely to have someone who can be assigned to use the tool, we know from many other situations that small, independent farms and ranches generally struggle to use complicated tools / models – both from a technical skillset perspective and from a "too many competing priorities" perspective. To lower the barrier to adoption, we have included several ready-to-run templates for users to modify to match their operations.

Figures 2 and 3 present examples of the output generated from the scenario tool, here comparing the benchmark from the ISO reviewed report against an alternative high density/high yield scenario.

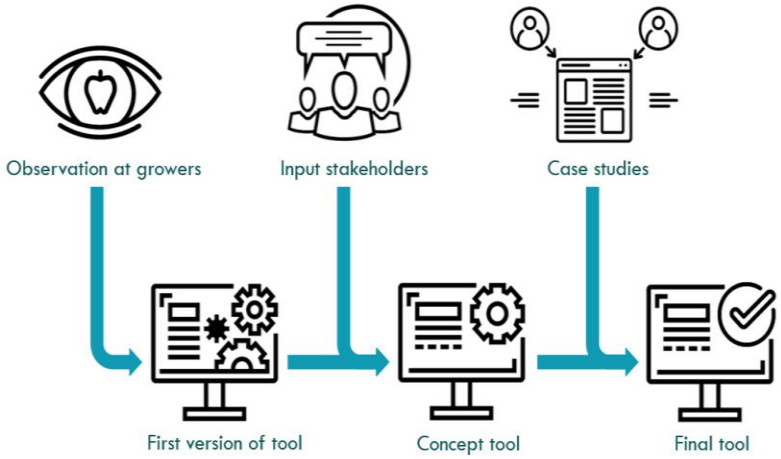

Figure 1. Schematic of the stakeholder-engaged process for creating the scenario analysis tool.

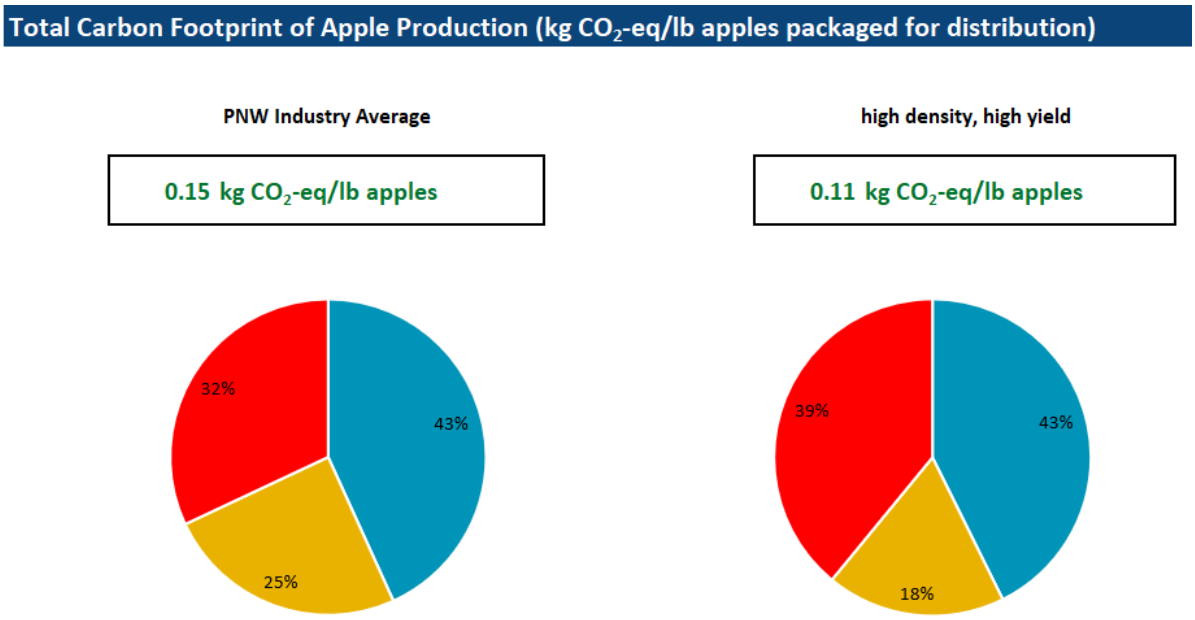

Figure 2. Example of graphical output from the scenario tool, providing a comparison of the benchmark LCA from the ISO report to one of the pre-populated scenarios.

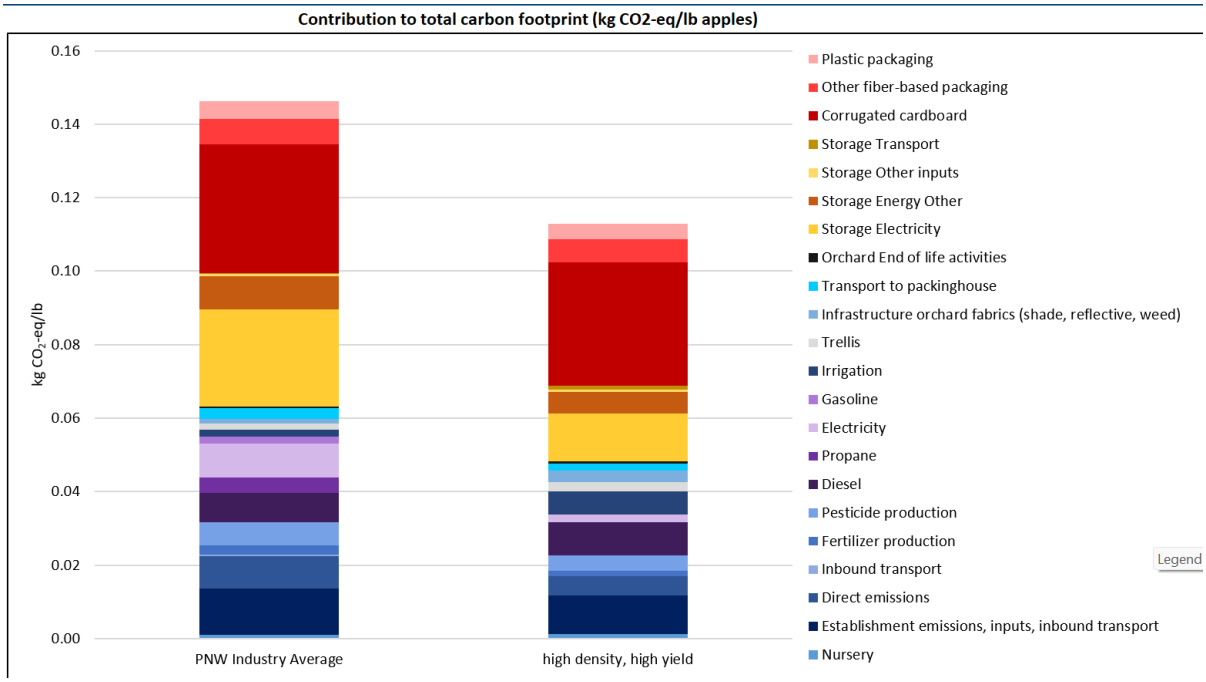

Figure 3. Example contribution analysis output from the scenario tool

Executive Summary: The Environmental Footprint of PNW Apples

The Life Cycle Assessment (LCA) establishes a clear environmental benchmark for Pacific Northwest (PNW) apples, which constitute **over 76% of the U.S. fresh apple crop**. The study confirms that PNW production methods are **highly efficient** but critically reveals that over half of the environmental burden occurs **after the apple leaves the orchard**. This analysis provides the necessary data to accurately quantify our regional advantages, defend our production standards, and focus investment for the highest possible return.

Baseline Findings: Pinpointing the Footprint (The "Whys and Hows")

The baseline footprint for **one pound** of packaged PNW fresh apples is **0.15 kg CO_2-equivalents** (climate change impact) – about the same as 0.4 kWh of electricity. The system boundary spans nursery → establishment → full production/harvest → transport to storage → climate-controlled storage → packaging for distribution. Indicators: climate change, fossil resource scarcity, water consumption, land occupation. A key finding is the split in the footprint contribution across the supply chain, demonstrating significant post-orchard contributions to consumer-ready apples:

Footprint Breakdown

The LCA shows that the **post-harvest system dominates** the overall carbon and fossil energy footprints, contributing **57%** and 62% of the total impact, respectively and contributes 47% to land occupation. For climate change, the breakdown is: **Packaging Materials: 32%; Storage-Processing: 25%**, and **Orchard Production: 43%.** Of the 43% attributable to the orchard: **Energy use** (diesel, electricity for pumping, etc.) is the single largest factor at **37%** of the production footprint.

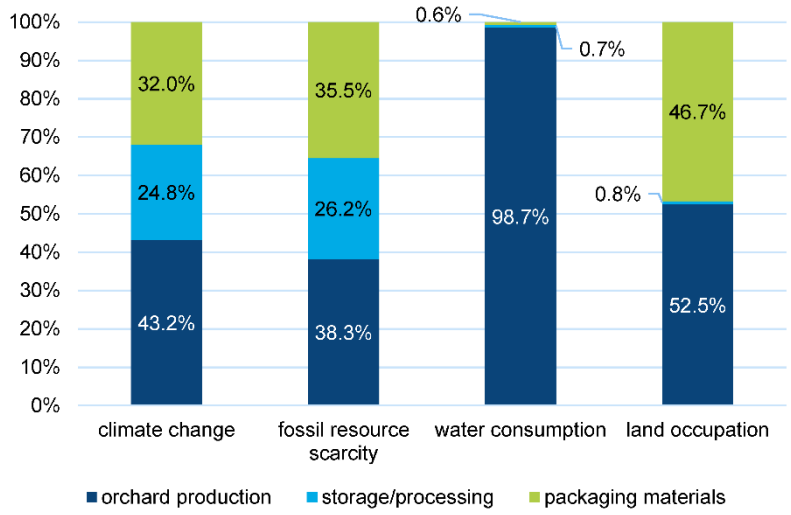

Figure 4. Contribution analysis for primary impact categories.

Critical Context: Why PNW Apples are Climate-Friendly

- **Hydroelectricity Advantage:** The regional reliance on hydroelectric power is a major competitive advantage. A sensitivity analysis demonstrated that utilizing hydro-generation (the predominant central Washington source) in place of the average Western U.S. grid mix results in a **27% reduction in the total carbon footprint**. This highlights how the region's clean energy infrastructure significantly cuts the post-harvest footprint from cold storage.
- **Water Consumption:** Water consumption impact is **dominated by the apple production phase**. This confirms that continuous focus on irrigation efficiency is paramount for regional water stewardship.
    - Water conservation practices are common in **high density orchards**. Growers already use sprinkler and drip irrigation systems, and they're working towards implementing sensor technology that only irrigates when and where water is most needed.
- **Perennial Crop:** Pacific Northwest tree fruit production can be climate friendly by its nature as a perennial cropping system. In addition to carbon stocks in the trees and soil, growers use **reduced**

or no tillage practices in the orchard and plant vegetation in between tree rows that helps to improve **soil organic matter** and **prevent soil erosion and pesticide runoff**.

Actionable Recommendations: Maximizing Investment

The LCA demonstrates that the highest-impact areas for improvement are in energy use and materials. The sector's strategy should focus on implementation of the following strategic actions:

Track	Strategic Focus	Recommendation	Easiest/Hardest
I. Post-Harvest Efficiency	Cold Storage (25% impact)	Focus on optimizing refrigeration and warehouse energy use and purchasing **Renewable Energy Certificates (RECs)** to formally claim the 27% hydroelectric benefit across the supply chain.	**Easiest Win:** Clear ROI on energy upgrades and a quantifiable environmental claim.
II. Supply Chain Innovation	Packaging Materials (32% impact)	Prioritize collaboration with suppliers to innovate packaging (e.g., lower-carbon substrates, increased recycled content) to drive the largest absolute reduction in the total footprint.	**Strategic Challenge:** Requires significant, collective industry R&D investment.
III a. Orchard Optimization	Energy Use (37% of production impact)	Invest in precision agriculture and electrification of on-farm equipment to reduce diesel consumption and maximize the benefit of PNW's low-carbon grid for powering irrigation and field work.	**Continuous Effort:** Direct control by growers with mid-level investment needed.
III b. Orchard Optimization	Improve data quality and granularity	Implement training and adoption incentives for the scenario analysis tool under development.	**Continuous Effort:** Direct action at sector level with moderate time investment needed.

The Value Proposition

This LCA proves that the investment was essential. It arms industry leaders with the specific data needed to **market the PNW apple as a verifiable, low carbon commodity** and provides the roadmap to focus resources on the efforts with the greatest future sustainability gains.

Over half of the 0.15 kg CO_2e per lb footprint occurs after harvest: packaging (32%) and storage & processing (25%). Thus, interventions like **lower-impact packaging**, **storage energy efficiency**, and **refrigerant management** can move the needle materially, alongside orchard energy efficiency.

- A 10% reduction in packaging impacts lowers total footprint by ~3.2%.
- A 10% reduction in storage/processing impacts lowers total by ~2.5%.
- A 10% reduction in orchard energy lowers total by ~1.6%.
- A 10% increase in yield could lower the total by ~4.6% (e.g., yield increase through genetic improvement enabling fixed inputs).

Life Cycle Assessment for Apple Production in the Pacific Northwest.

Keywords: Sustainability, Lifecycle Assessment, Carbon Footprint, Scenario Analysis

Abstract:
The Life Cycle Assessment (LCA) establishes a clear environmental benchmark for Pacific Northwest (PNW) apples, which constitute over 76% of the U.S. fresh apple crop. The study confirms that PNW production methods are highly efficient but critically reveals that over half of the environmental burden occurs after the apple leaves the orchard. The baseline footprint for one pound of packaged PNW fresh apples is 0.15 kg CO_2-equivalents (climate change impact) – about the same as 0.4 kWh of electricity. The system boundary spans nursery → establishment → full production/harvest → transport to storage → climate-controlled storage → packaging for distribution. A key finding is the split in the footprint contribution across the supply chain, demonstrating significant post-orchard contributions to consumer-ready apples.
This analysis provides the necessary data to accurately quantify regional advantages, defend production standards, and focus investment for the highest possible return. This enables the apple industry to respond with cost-effective adaptive strategies to sustain production and profitability into the future, address buyer concerns, take advantage of government programs, and prepare for potential federal regulatory oversight (e.g., reduction in GHG emissions) being developed.