WTFRC Technology Roadmap

Short-list Priority: Harvest Labor

Short-list Priority: Harvesting Labor

Current Harvest Labor Technology Landscape

Harvesting labor is the single largest cost and single highest priority among the over 100 apple industry stakeholders in Washington State consulted for this project. At present, adoption of fully autonomous apple harvesting robots is minimal (trials and pilots only) and there are no commercially available apple harvesting robots. Instead, harvest is conducted manually. Yet, growers are facing annual labor shortages for some of the most labor-intensive seasonal tasks (picking/thinning/pruning), and the temporary foreign guest worker program (H-2A) is the only alternative.

For the purpose of this roadmap, harvest labor technology includes **Assistive Technologies**, **Labor Management Systems**, and **Harvesting Robots**.

Voices of the Industry
"I see that automated/mechanical harvesting is beyond years out... Yes, we need more focus on harvesting - but let's be realistic in what we need to focus on topics that have more potential for impact in the short term." - Industry vendor & service provider "I think everybody thought we'd be further along. I'm sure the people on that original committee who are, if they're still alive today, they're like, wow, we thought we would be leap years ahead of where we're at right now to try to replace people, and that's really what we have to do if we're gonna survive." – Washington Apple Grower "When the Washington State Tree Fruit Research Commission was formed, the primary rationale for the formation of it was to investigate the automation of harvesting because labor was short and people were not getting their crops harvested on a timely basis. And here we are 55 years later. And we're still trying to jump across that bridge." – Washington Apple Grower "Labor is the issue, and harvest is at the core of the labor issue." – Washington Apple Grower

Harvest Labor Technology Categories

Assistive Technologies include software enabled harvest-assist platforms and other worker-assistive technologies, such as crop transport systems or virtual reality (VR) assistive headsets. Harvest platforms have been around since the 1990s, and have been used to increase hand-harvest efficiency and to eliminate ladder usage for pickers. They have been exhibited to show at least a 30% savings in labor hours required for harvest, and, when coupled with electric shears, a similar savings in pruning (Verbiest et al. 2020.) There are a wide range of platforms available on the market today (examples provided below.)

Looking forward, there is an opportunity to leverage digital technologies to increase the already proven value of harvest platforms through simple upgrades like variable rate cruise control. There are also opportunities to bridge the gap between today's harvesting robotics technologies (vision in particular) and the harvesting robotics technology of the future via increased data capture.

There are also opportunities beyond platforms to leverage technologies that increase worker efficiency, whether that is through VR training programs to decrease onboarding times and costs, human-operated hardware systems, or bin transportation systems.

Example offerings include:

Harvest Platforms:

- Automated Ag Systems'Bandit harvesters (multiple products)
- Huron Fruit Systems' Work Platform (simple harvesting and pruning platform)
- Provide Agro's Chariot (simple harvesting and pruning platform)
- N. Blosi's Zip 30 (simple harvesting and pruning platform - basically a scissor lift)
- Orsi Groups' Lifitng Platforms (simple harvesting and pruning platforms)
- Blueline Manufacturing's Orchard Harvesting Platform (mid-complexity harvesting and pruning platform)
- Argiles AF-10 EVOLUTION (relatively complex harvesting and pruning platform)
- Munckof's Pluk-O-Trak (relatively complex harvesting and pruning platform)
- Oesco's Revo Piuma 4WD (relatively complex harvesting and pruning platform)

Harvest Assistant Technologies:

- Daxo Robotics
- Precise Manufacturing's Bin Haulers
- Huron Fruit System's Self-propelled Bin Shuttle

Relevant Research:

- *Bin-Dog* - Transports full apple bins autonomously, reducing need for forklift drivers.
- Stavros Vougioukas's work with "next-generation, robotic harvest-aid orchard platforms" (results are pre peer-review) - Opportunities to outfit platforms with low-tech technologies (eg/ variable rate cruise control) to increase worker efficiency incrementally.
- Manoj Karkee's work with harvesting robots and image libraries
- Ming Luo's work with soft-growing robots and "Design, Modeling, and Control of a Low-Cost and Rapid Response Soft-Growing Manipulator for Orchard Operation"

Labor management software systems will play a critical role in the short, mid, and long term in integrating all of the aforementioned technologies throughout this roadmap. Labor management software systems enable growers to get a handle on their costs on a per field/orchard basis, thus enabling individual growers to calculate the ROIs of various technology improvements and make the appropriate decisions for their operations. In the short term, labor management software provides a means to more efficiently deploy scarce labor resources and to assess the efficacy of readily available commercial technologies on individual operations. In the mid term, labor management software products will create a layer of data that is essential to better understand the true value that growers can capture from harvest labor assistive technologies. In the long term, these labor management technologies will provide a means to

integrate humans and robotics in order to most efficiently deploy a blended workforce of the future.

Example offerings include:

Labor Management Systems - Timekeeping

- Pago - Ag labor platform designed to help Farms and Farm Labor Contractors with wages and labor law compliance; integrates with Ganaz
- FieldClock - Simple timekeeping software
- PickTrace -
- CropTracker -
- HeavyConnect - Food safety, worker timecard, and QA/QC-program compliance software

Labor Management Systems - HR/Compliance

- Ganaz - Workforce management platform to help ag and food processing employers recruit, retain, communicate, onboard, train and pay their workforce (H2A.) Integrates with multiple Timekeeping systems.
- Harvust - Farm worker onboarding and HR software
- Croft - Earlier stage H2A recruiter, incubated by Purdue & Dial Labs
- Seso* - H2A recruiter and compliance software

Labor Management Systems - Integrated Crop Management

- Dataphyll - RFID & software based orchard management and timekeeping platform
- Hectre - Orchard management and fruit sizing/quality assessment software

Harvesting Robots are the end goal. If it were possible to wave a magic wand and create a single technical solution to the harvest labor problem, most apple industry experts would build an affordable robot that can operate fully autonomously to harvest, thin, and prune apples with <4-5% fruit damage rates (current standard for hand harvest.) However, this has proven to be quite challenging, and it will likely take a long time to get there (see barriers, below) There are some quasi-commercial solutions that exist, but none are widely available or truly hardened. Most of the focus in the next 2-3 years for harvesting robots is therefore likely to be R&D focused.

Example offerings include:

- Advanced Farm* - Custom-built robotic harvesters for apples and strawberries
- Fresh Fruit Robotics* -
- Ripe Robotics
- Tevel
- Nanovel (not active in apples but claims that it translates easily)
- Aigritec (also does chem thinning)
- Milano Technical Group
- RIP: Abundant Robotics

Barriers to Adoption of Harvesting Technologies in Washington Orchards

Overall Opportunity for Growers: The key opportunities of adopting harvest labor technologies are:

1) Cutting back on demand for increasingly hard-to-come-by seasonable labor during peak times
2) Increasing the efficiency of the existing workforce via augmentations.
3) Inserting collaborative robots into the existing workforce to do manual labor in a cost-effective, safe manner, freeing human workers up for higher value tasks.

However, for most growers to seize these opportunities, several barriers will have to be overcome.

Technical Complexity. Apple harvesting is a complex task with many technically complex subtasks. Integration of components of the system (vision, end-effectors, fruit transport, bin transport) is non-trivial, and individual components of the system are co-dependent. Because startup companies in the space are facing strong incentives to deliver commercial solutions, solution providers are often starting from scratch, meaning that (a) there are many inefficiencies in use of resources and (b) it's easy to run out of money before delivering a market-ready solution. Splitting the problem into components can help to some extent with this, but if the system is broken up too much, stitching the puzzle back together will be impossible.

Expensive. The cost of purchasing and servicing apple harvesting technology is going to be a barrier for most growers.

Diversity within operations. Orchard architecture is highly variable in terms of controllable elements like trellising and genetics, and in terms of less controllable factors, like, climate, weather, slope, and soil type. Not all orchards are designed with the intent to be "robot ready." Furthermore, apple harvesting must integrate with Crop Load Management systems, which are constantly evolving/imperfect.

Assessing businesses as well as technologies requires expertise. It is presumed that the "solutions" to apple harvest automation will be commercial, yet there are countless reasons that commercial products fail. A technologist with a perfect technical solution may run his company into the ground because he's not a skillful businessperson, for example. Similarly, a well intended businessperson might convince funders to invest in his product, for which he knows there is a market opportunity, but he may never be able to actually build the product. Therefore, it's essential to vet commercial products from a variety of perspectives to understand the risks and opportunities of any one particular project.

Harvest Labor Technology Strategies

While limited access to, and high costs of, harvesting labor is a high priority for Washington growers, it is unlikely to be resolved overnight by a comprehensive robotic solution. Instead, a phased approach to automation and labor-assistance technologies can help fill the existing gap.

The following strategies have been identified to put Washington Tree Fruit Growers on a realistic pathway towards alleviating harvest labor pressures in the short term while enabling a more holistic robotic solution in the long term.

Lower the costs of developing commercially viable mechanical/autonomous apple harvesting solutions.

End Goal: Increase the amount of collaborations between technology developers, academic researchers, and commercial R&D providers to reduce duplication of efforts in the development of harvest labor solutions.

Priority: 1

Example Activities:

- Support the development of common technical infrastructure and/or trial infrastructure, including apple transfer systems and bin fillers.
- Catalyze collaboration and co-opetition (i.e., when competitors work together for mutual benefit) by requiring WTFRC grantees to attend in-person, facilitated meetings
- Develop and publish an index/library of 'what did/didn't work' in prior harvest labor efforts to enable future technology companies/vendors to accelerate their progress, and to optimize for shared learnings regardless of commercial outcome. Consider collaboration, for example, with efforts like the Agtech Toolkit.
- Ensure RFPs target specific gaps in the existing landscape and/or focus on integration challenges

Educate vendors and developers to ensure harvest labor solutions are designed to work within the operational and financial constraints of existing systems.

End Goal: Vendors come to market not just with technology that works, but that is also affordable and easily integrated into apple orchards

Priority: 2

Example Activities:

- Continue to publish and share data on apple orchard crop budgets and management systems (e.g., Agtech Toolkit, Apples.Extension.Org, etc.)
- Create and publish an industry "primer," or overview of the characteristics of the industry, to support developers to get up to speed (e.g., # acres, costs, pain points, etc.)
- Consider novel service models that enable the cost of harvesting equipment to be dispersed in a way that is profitable to farm operations of various types, and economically viable for technology providers.

Help WA apple growers get "robot ready"

End Goal: WA apple growers are able to take advantage of emerging harvest labor solutions with minimal negative commercial impacts/trade offs.

Priority: 3

Example Activities:

- Support research that investigates the genetics behind traits that are optimal for robot ready canopies (e.g., weeping, smaller leaves, easier chem thinning, control of fruit abscission, bruising sensitivity, maturation, etc.)
- Continue to support and publish standards for "robot ready canopies."
- Support cost-studies comparing robot ready canopies to other trellising systems for both manual, partially mechanical, and fully autonomous systems.

Update WTFRC's RFP processes to efficiently engage the appropriate experts in vetting new research and commercialization proposals.

End Goal: Ensure that limited resources for harvest labor solutions are appropriately and efficiently distributed, based on a range of required lenses for evaluating technologies (e.g., technical, industry, commercial, etc.) and development teams.

Priority: 2

Example Activities:

- Ensure proposals are evaluated by the list of expert consultants created for this project (or similar) and use their guidance to ensure validity of projects.
- Create streamlined application and feedback processes to enable multiple parties to easily view and comment on/rate RFP submissions.
- Outline specific criteria for applicants to meet, considering the broad range of required assessment factors, including technical need and readiness level, team capacity & capabilities, and relevance to the priorities outlined in this roadmap.