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Category-Level Product Environmental Footprints of Foods

Recommendations for Further Evaluation

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STATEMENT OF WORK:
Review and recommendations of food types for further research: Contractor will prepare a separate document containing its recommendations for which food types (commodities) to study in further detail. For the purpose of this contract, "commodity" is defined not only as a farm-level output but rather as a distinct type of food product. For example, "fluid milk" (for use in making food products or final consumption in fluid form) is a commodity, while "yogurt", "ice cream" and "cheese" are separate commodities. Contractor may propose more food types than budget allows, and contractor may rank or group commodities (for example "high priority", "medium priority", and "not recommended"). At a minimum, ten commodities will be recommended as "high priority" with at least four additional commodities identified as contingencies. Recommendations will be based on the quality of environmental information available (based on the results of literature scan), giving preference to high volume products produced or purchased in the states of Oregon and Washington, while also taking into account the organizational structure of the agricultural and food industry as well as interest by institutional buyers.

1. Introduction

Climate, soils and topography make food production in the states of Oregon and Washington a valuable and diverse economic sector. Tables 1 & 3, below, indicate the top ranking agricultural commodities in Oregon and Washington, respectively. In addition, Oregon and Washington rank as dominant U.S. producers of a number of unique crops, as seen in Tables 2 & 4, making their production practices relevant not only locally but to national and international consumers as well.

Food production contributes significantly to environmental concerns, and by extension, offers potential for significant improvement. Production of the food consumed in the U.S. accounts for on the order of 10% of the country's *total* in-boundary greenhouse gas emissions[1]. Food and beverages contribute close to 15% of Oregon's consumption-based greenhouse gas emissions. Figure 1 demonstrates the contribution by various food sectors to the 7.9 million metric tons of CO_2-eq attributable to food and beverage consumption (excluding restaurants) in Oregon in 2014. These impacts include not only the agricultural production of food, but also contributions from processing, distribution, and storage. It is important to note that these emissions are due to food and beverages *consumed* by Oregonians, and only an estimated 20% of them occur due to in-state activities. Figure 2Figure 3 serve to better describe the specific foods that make up the highly aggregated sectors of "fruits & vegetables" and "meats" in the Oregon Consumption-Based Emission Inventory. These figures are based on per capita national food availability, combined with emission factors for individual food types[1].

Making reductions in the environmental footprint of supplying food requires an understanding of the sources of current impacts, along with guidance as to where

[1]Heller, M. C. and G. A. Keoleian (2014). "Greenhouse Gas Emission Estimates of U.S. Dietary Choices and Food Loss." Journal of Industrial Ecology **19**(3): 391-401.

improvement efforts should focus for maximum effectiveness. These answers aren't always intuitive. For example, a USDA analysis of energy use in the U.S. food system found that transportation represented only about 3.5% the energy used in the U.S. food system in 2002, whereas household activities (refrigeration, cooking) contributed 28%[2]. Similarly, researchers at Carnegie Mellon found that transportation as a whole represents only 11% of life-cycle greenhouse gas emissions associated with the U.S. food system, with final delivery from producer to retail contributing only 4%[3]. Both of these studies arise out of life cycle assessment principles.

The objective of the current project is to highlight those stages of the life cycle of individual food commodities that contribute significantly to overall environmental impacts ("hot spots"), to evaluate opportunities to reduce environmental impacts, and to identify attributes and characteristics of individual food commodities that are meaningful predictors of reduced environmental impact. This will be done through a series of summary reports capturing what is known about the environmental impacts of specific foods or food commodities, based largely on review of the LCA literature, but drawing from other scientific fields as well. The purpose of the current document is to recommend the specific commodities to focus on for further evaluation, as well as to engage stakeholders to offer feedback on these recommendations.

[2] Canning, P.; Charles, A.; Huang, S.; Polenske, K. R.; Waters, A. *Energy use in the US food system*; ERR-94; U.S. Dept. of Agri., Econ. Res. Serv.: 2010. http://www.ers.usda.gov/media/136418/err94_1_.pdf

[3] Weber, C. L. and H. S. Matthews (2008). "Food-miles and the relative climate impacts of food choices in the united states." Environmental Science & Technology **42**(10): 3508-3513.

Table 1. Oregon's top 20 Agricultural Commodities: 2014[4] (gray shaded commodities will not be considered in this phase of the project)

Rank	Commodity	Value - Dollar
1	Cattle & calves	922,031,000
2	Greenhouse &nursery	829,909,000
3	Hay	703,080,000
4	Milk	656,635,000
5	Grass seed	449,018,000
6	Wheat	302,056,000
7	Potatoes	164,703,000
8	Hazelnuts	129,600,000
9	Pears	127,392,000
10	Grapes for wine	118,320,000
11	Onions	106,334,000
12	Christmas Trees	103,777,000
13	Blueberries	102,325,000
14	Cherries	82,709,000
15	Eggs	65,781,000
16	Mint, for oil	51,433,000
17	Blackberries	50,133,000
18	Crab	47,980,000
19	Sweet Corn	45,121,000
20	Apples	42,240,000

Table 2. National Ranking of Oregon Agricultural Production: 2014[4] (gray shaded commodities will not be considered in this phase of the project)

Commodity	Ranking among states	Percent of US production
Blackberries	1	100%
Boysenberries	1	100%
Hazelnuts	1	100%
Raspberries, black	1	100%
Ryegrass seed	1	92%
Orchardgrass seed	1	94%
Crimson clover	1	85%
Fescue seed	1	61%
Sugarbeets for seed	1	47%
Red clover seed	1	75%
Potted florist azeleas	1	59%
Onions, storage	1	22%
Christmas trees	1	17%
Peppermint	2	32%
Sweet cherries	2	16%
Hops	2	12%
Dungeness crab	3	27%
Pears	3	26%
Kentucky bluegrass seed	3	20%
Austrian winter peas	3	16%
Nursery stock	3	11%
Snap beans, processing	3	5%
Raspberries, red	3	2%
Strawberries	3	1%
Garlic	3	<1%
Blueberries	4	15%
Green peas	4	11%
Mink	4	8%
Cranberries	4	6%
Wine grapes	4	1%

[4]Oregon Department of Agriculture, "Oregon Agriculture Facts and Figures", July, 2015. http://www.oregon.gov/ODA/shared/Documents/Publications/Administration/ORAgFactsFigures.pdf.

Table 3. Washington's top 10 Agricultural Commodities: 2013[5] (gray shaded commodities will not be considered in this phase of the project)

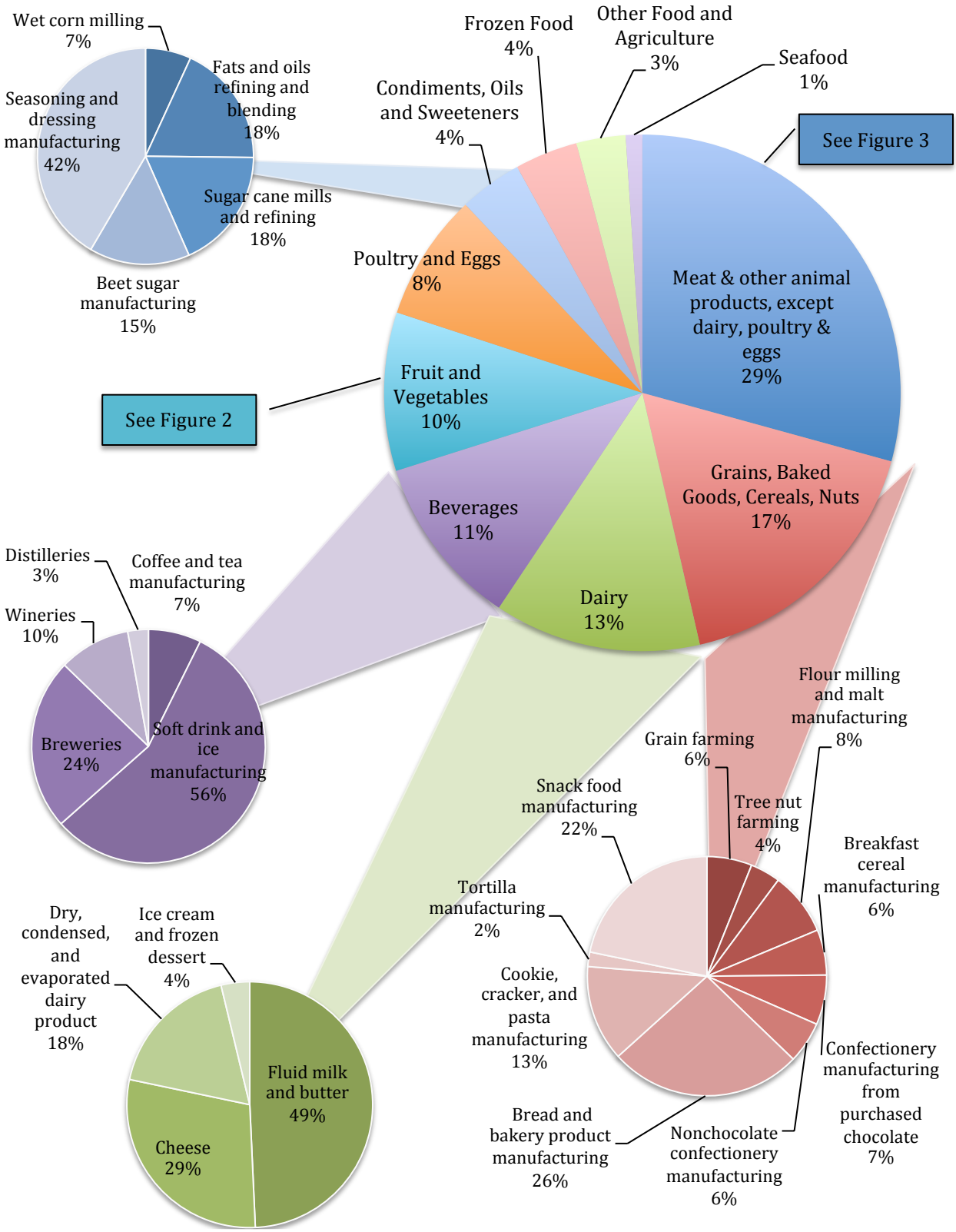
Rank	Commodity	Value - Dollars
1	Apples	2,189,095,000
2	Milk	1,298,880,000
3	Wheat	1,014,032,000
4	Potatoes	792,000,000
5	Cattle and calves	706,447,000
6	Hay	675,050,000
7	Cherries	385,198,000
8	Grapes	278,640,000
9	Pears	225,392,000
10	Hops	202,101,000

Table 4. National Ranking of Washington Agricultural Production: 2013[5] (gray shaded commodities will not be considered in this phase of the project)

Commodity	Ranking among states	percent of US production
Red raspberries	1	93
Hops	1	79
Spearmint oil	1	73
Wrinkled seed peas	1	60
Apples	1	57
Sweet cherries	1	51
Pears	1	50
Grapes, concord	1	37
Carrots, processing	1	37
Green peas, processing	1	34
Peppermint oil	1	31
Sweet corn, Processing	2	25
Potatoes	2	24
Onions	2	21
Apricots	2	11
Nectarines	2	8
Grapes, all	2	5
Asparagus	3	25
Lentils	3	19
Grapes, Niagra	3	19
Prunes and plums	3	18
Blueberries	3	15
Dry edible peas	3	12
Tart cherries	3	6
Barley	4	7
Wheat	4	7
Cranberries	5	2
Strawberries	5	0
Dry edible beans	6	9
Peaches, freestone	7	2
Milk	10	3

[5]USDA NASS, "Value of Washington's 2013 Agricultural Production Surpasses Ten Billion Dollars," January 26, 2015. http://www.nass.usda.gov/Statistics_by_State/Washington/Publications/Current_News_Release/2015/VOP_2014.pdf

Figure 1. Food consumption contributes to greenhouse gas emissions through a combination of the quantity of foods consumed and the emission intensity of producing a given food. This figure shows the percent contributions of different food categories to the "Food and Beverages" portion of the 2014 Oregon Consumption-based Emissions Inventory.



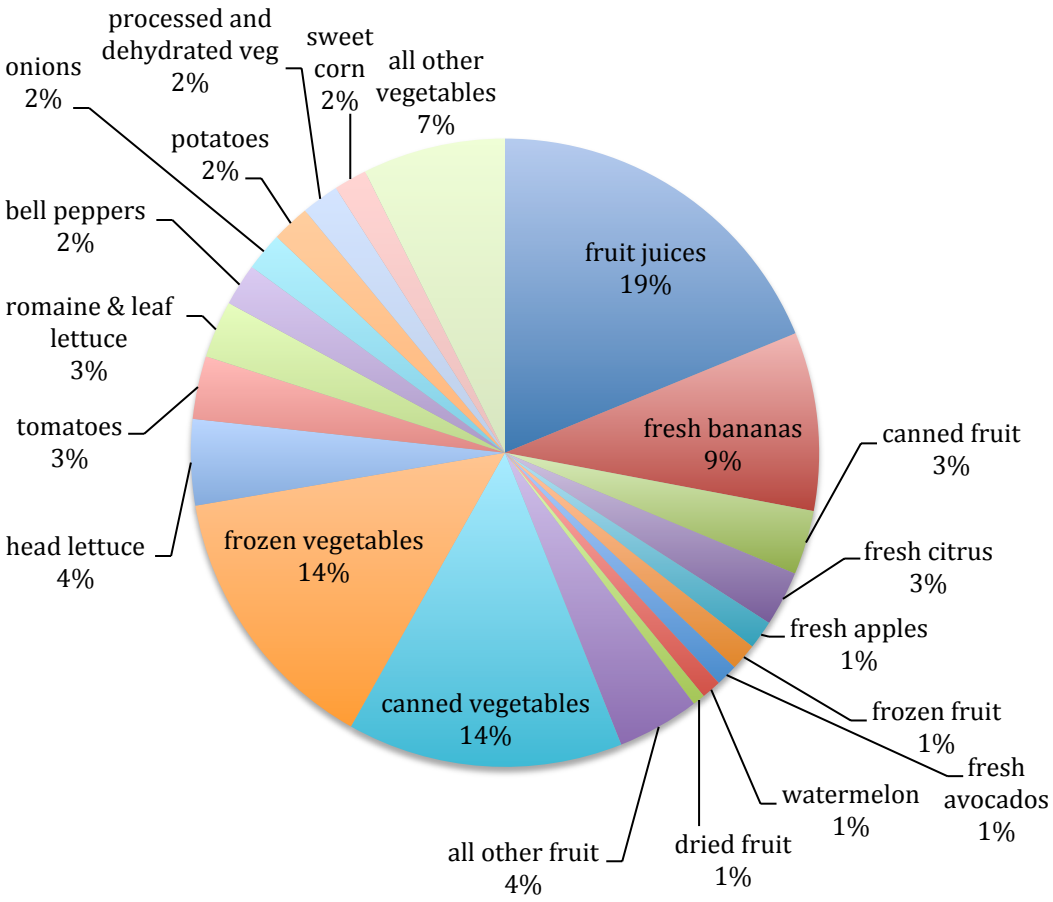


Figure 2. Contributions of various fruits and vegetables to the greenhouse gas emissions associated with total U.S. fruit and vegetable food supply. Based on 2010 retail-level food availability from USDA, and methods presented in Heller and Keoleian, 2014[1].

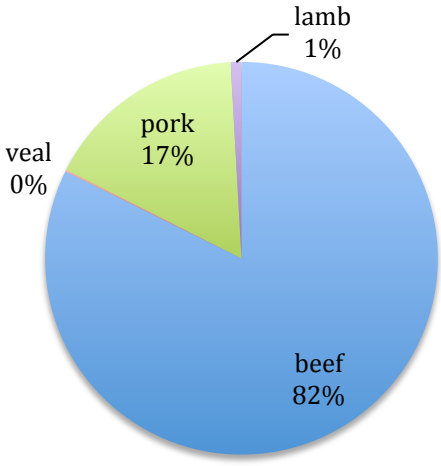


Figure 3. Contributions of different meat types to the greenhouse gas emissions associated with total U.S. red meat (i.e., excluding poultry) supply. Based on 2010 retail-level food availability from USDA, and methods presented in Heller and Keoleian, 2014[1].

2. Selection criteria

We have attempted to combine our review of existing LCA literature with an appreciation of food production as well as consumption in Oregon and Washington to recommend a collection of commodities for further research and summary report development. Criteria accounted for in the recommendations include:

- Production considerations:
  - Food commodities produced in large volume in OR and/or WA.
  - Commodities for which production in OR and/or WA represent a large fraction of total U.S. production.
  - Commodities for which the environmental impact of their production in OR and WA is significant, based on estimated greenhouse gas emissions associated with on-farm production.
- Consumption considerations: Foods that play an important role in the consumption-based emissions of OR, and, by extension, WA.
- Data availability considerations: Food commodities and/or products for which the available LCA literature is of sufficient quantity and quality to offer sound guidance.
- Diversity considerations: Foods that represent a diversity of food types, in order to denote a range of product life cycles in the final summary documents. For example, including both apples (a hard fruit) and raspberries (a soft fruit) may be warranted as they represent very different handling, storage and distribution product chains and may therefore provide lessons transferrable to other foods of their type.

As the scope of this project is limited to *foods*, agricultural crops that are not typically food for humans, such as grass and clover seed (shaded gray in Tables 1-4), were not considered. Beef is not recommended for further evaluation in the current phase of this project based in part on high variability in production methods and associated environmental impacts. In addition, for cattle that graze on rangelands (a common production practice in Oregon), the impacts of grazing on soil carbon can vary significantly and soil carbon impacts lack clear standards for accounting.

Table 5 summarizes the scoring rubric used to arrive at recommended foods. Foods identified as a potential interest for this project were given a 0-5 score in each of four categories, and arranged based on the sum of the four categorical scores. Subjective rearrangements were then made to accommodate the diversity criteria and to account for LCA quality scores deemed too low to warrant further research. Table 6 provides more detailed information on the foods *produced* in large quantities in OR and WA, including production quantity and value and a cursory estimate of the greenhouse gas emissions attributable to that production. This information led to the first two columns in the scoring rubric in Table 5. Table 7 summarizes information on the quantity and quality of the LCA literature for considered foods as gathered from the literature review, and forms the basis of the scores in the third column of Table 5. Scores in the fourth column, consumption impact, are derived from the distributions in Figures 1-3.

Brief justifications for recommended foods follow in Section 3.

Table 5. Summary of scoring rubric and foods recommended for further research. Higher scores are better. The first 15 foods are recommended as viable options for product footprint summaries.

		Production value	Production impact*	LCA data quality	Consumption impact*	Diversity (food type)
1	Dairy and dairy products	5	5	5	5	dairy
2	Wheat and bread†	5	5	5	4	Grain
3	Apples	5	4	5	2	Pome fruit
4	Potatoes and products	4	5	4	2	Vegetable
5	Eggs	3	4	4	3	Egg
6	Wine	4	3	3	3	Beverage
7	Pork	1	2	5	4	Meat
8	Citrus fruits & juices	0	0	5	3	Citrus fruit
9	Freshwater Aquaculture	2	N/A	3	1	Fish
10	Raspberries	2	1	2	1	Soft fruit
11	Pears	4	3	3	1	Pome fruit
12	Chicken	N/A	N/A	3	5	Meat
13	Hazelnuts	2	2	2	1	Nut
14	Bananas	0	0	4	3	Tropical fruit
15	Tomatoes	N/A	N/A	5	2	Vegetable
16	Onions	3	4	1	2	Vegetable
17	Cherries, sweet	4	3	2	1	Stone fruit
18	Blueberries	3	2	2	1	Soft fruit
19	Green peas (for processing)	1	2	2	1	Processing vegetable
20	Snap beans, processing	1	2	2	1	Processing vegetable
21	Strawberries	1	1	3	1	Soft fruit
22	Garlic	1	1	1	1	Vegetable
23	Carrots (for processing)	N/A	N/A	2	1	Processing vegetable

* "impact" is estimated here in terms of the relative contribution to state-level greenhouse gas emissions.

†may include other wheat products beyond bread

N/A = data necessary for evaluation unavailable through USDA QuickStats

Table 6. Summary of production quantity and value in Oregon and Washington, as well as estimated farm-level greenhouse gas emissions, for foods under consideration.

	Oregon Production				Washington Production			
food	2014 production (lbs)[a]	$ value (2014)[a]	ranking in $ value	estimated annual GHGE (at farm gate)[b] kg CO_2eq	2014 production (lbs)[c]	$ value (2014)[c]	ranking in $ value	estimated annual GHGE (at farm gate)[b] kg CO_2eq
dairy (farm milk)	2,555,000,000	656,635,000	4	1,263,232,000	6,584,000,000	1,626,248,000	2	3,255,233,000
wheat	2,666,640,000	302,056,000	6	374,966,000	6,507,600,000	719,270,000	3	915,057,000
apples	155,000,000	43,269,000	20	17,577,000	7,300,000,000	1,895,887,000	1	827,806,000
potatoes	2,256,200,000	178,240,000	7	368,422,000	10,147,500,000	771,210,000	4	1,657,018,000
eggs	94,914,000	65,781,000	15	146,808,000	254,583,000	176,805,000	15	393,777,000
wine grapes	116,000,000	118,320,000	10	24,204,000	454,000,000	251,970,000	8	94,728,000
pears	432,000,000	127,392,000	9	48,204,000	832,000,000	233,824,000	9	92,838,000
hazelnuts	72,000,000	129,600,000	8	16,982,000	N/A	N/A		-
raspberries	8,650,000	17,159,000	37	800,000	72,990,000	57,921,000	24	6,754,000
aquaculture (food fish)	N/A	1,536,587		-	N/A	83,570,349	17	-
strawberries	15,500,000	13,125,000	40	3,797,000	9,900,000	11,093,000	33	2,425,000
onions	1,423,800,000	106,334,000	11	251,872,000	1,300,000,000	106,444,000	11	147,418,000
blueberries	87,300,000	102,325,000	13	18,611,000	94,600,000	112,638,000	19	20,168,000
cherries, sweet	115,800,000	82,709,000	14	28,364,000	474,000,000	502,370,000	7	116,102,000
green peas (for processing)	82,860,000	10,466,000	39	20,296,000	236,880,000	29,433,000	25	58,021,000
Carrots (for processing)	N/A	N/A		-	(D)	(D)		-
snap beans(for processing)	69700000	13,940,000		47,423,000	N/A	N/A		-
garlic	1,200,000	1,080,000		354,000	N/A	N/A		-
Pork (hogs)	2,420,000	2,017,000		15,125,000	(D)	(D)		-

[a] http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=OREGON and NASS QuickStats database: http://quickstats.nass.usda.gov/

[b] Annual farm gate GHG emissions estimated based on average emission factors from Food LCA Literature Review database and 2014 state production values.

[c] http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=WASHINGTON and NASS QuickStats database: http://quickstats.nass.usda.gov/

N/A = data not available through USDA QuickStats

(D) = withheld by USDA to avoid disclosing data for individual operators

Table 7. Summary of information gleaned from the Food LCA literature review for foods under consideration.

	LCA data quality and quantity				
food	rating of LCA data	# entries in DB	# studies	U.S. Studies?	NOTES
dairy (milk and dairy products)	high	87	16	Yes	some comparisons of conventional & organic. Numerous alternative production methods represented; includes entries on: butter (5), cheese (18), yogurt (11),
wheat	high	19	7	Yes	Organic vs. conventional comparisons, crop rotation comparisons; 9 additional entries for bread
apples	high	25	12	Yes	numerous comparisons between conventional & organic. One study explores local cold storage vs. imports from southern hemisphere (in UK context)
Potatoes and potato products	high	16	7	No	conventional & organic comparisons; includes peeled, mashed, potato flour, & potato chips
eggs	high	30	9	Yes	comparisons of production styles
wine grapes	medium	11	4	yes	comparisons between conventional & organic.; all focused on grape production (do not include impacts of wine making)
pears	low	8	5	no	comparisons of conventional & organic production in China; studies consider impacts up to point of retail
hazelnuts	low	9	2	no	
raspberries	low	5	3	no	UK study explores seasonality& local vs. import
aquaculture (food fish)	medium	27	8	no	comparisons of production systems (recirculation, flow-through, etc)
strawberries	medium	11	7	Yes	comparisons of conventional & organic, greenhouse & open field, local & import
onions	very low	1	1	no	no detailed info on production impacts
blueberries	low	4	2	Yes	compares conventional & organic
cherries, sweet	low	3	1	no	considers local vs. imported
green peas (for processing)	low	3	1	no	considers local vs. imported
Carrots (for processing)	low	5	2	no	
snap beans(for processing)	low	4	1	no	considers local vs. imported
garlic	low	3	1	no	considers local vs. imported
Citrus fruits and juices	high	17	12	yes	Conventional vs. organic. Concentrated and not-from-concentrate juices.
Bananas	high	9	7	no	Study looking at US importer and retail chain
Tomatoes	high	47	11	yes	Field vs. greenhouse, conventional vs. organic, local vs. national; includes processed forms: paste, chopped, puree, juice.
chicken	medium	18	7	yes	Various production methods
pork	high	39	15	yes	Various production methods

3. Recommended foods for further evaluation and development of Categorical Footprint Summaries

The following paragraphs provide a brief justification for the top recommended commodities. Note that budget restrictions will permit further evaluation of only *ten* foods. Additional foods are included here to allow some flexibility in the final selection process.

1. Dairy and dairy products

Dairy is an important economic commodity in both Oregon and Washington, and because of the relatively large carbon footprint of dairy production, it also represents a significant fraction of the total greenhouse gas emissions in these states (2% in OR[6], 3.5% in WA[7]). Dairy also contributes significantly to consumption based greenhouse gas emissions, contributing 13% of the food and beverage sector, or 1.7% of the total consumption-based emissions. Dairy production has been extensively studied with LCA, including a comprehensive, geo-spatially explicit U.S. study sponsored by Dairy Management Inc. The Center for Sustainable Systems (CSS) was part of the research team for this national study and they have intimate familiarity with the study and its results. Combined with other milk LCA literature, this will offer a robust summary statement about the environmental impact of dairy production in OR and WA. In addition, CSS has previously studied the environmental trade-off between energy and water use in sourcing feed crops[8] and can apply insights from that work to dairy in the Pacific Northwest. Note that we are currently recommending that the focus be on farm-gate milk, as the bulk of the environmental impacts for processed dairy products (cheese, yogurt, etc.) originate on-farm (an insight that would be communicated through LCA evidence in the final product footprint summary). However, if the interest arises, specific consumer-level dairy products could be considered independently. According to USDA QuickStats, there are 20 dairy processing plants in OR, and 10 in WA, providing some indication of the structure of dairy processing in the region.

2. Wheat and wheat products (bread)

Wheat is also a very important crop economically in both Oregon and Washington. The region produces primarily soft white wheat, used in pastries, cakes, pretzels, cookies and Asian noodles, but also includes hard red winter and spring wheats. With more than 85% of Oregon-grown wheat being exported, wheat is the #1 product exported through the Port of Portland. A large number of LCA studies on wheat exist in the literature. In addition, wheat is one of seven commodities currently represented in the USDA's LCA Digital Commons[9], with inventories derived from USDA Ag census and other data available specifically for OR and WA production over multiple years. Bread production has also been extensively studied via LCA, offering insight into the relative contributions of on-farm

[6] Based on Oregon 2014 total in-boundary emissions of 60.1 million MT CO2 eq. (http://www.oregon.gov/deq/AQ/Pages/Greenhouse-Gas-Inventory-Report.aspx#inventory)

[7] Based on Washington 2012 Total Gross Emissions of 92.0 million MT CO_2 eq. (http://www.ecy.wa.gov/climatechange/docs/2012GHGtable.pdf)

[8] Heller, M. C. and G. A. Keoleian (2011). "Exploring a Water/Energy Trade-off in Regional Sourcing of Livestock Feed Crops." Environmental Science & Technology **45**(24): 10619-10626.

[9] https://www.lcacommons.gov/discovery/search

activities to the remainder of the product chain. While studies that explicitly examine the consumer products typically made from soft white wheat were not uncovered in the literature scan, further research will focus in this direction.

3. Apples

Washington is the leading producer of apples in the U.S., with apples being the state's highest value agricultural commodity. Apple production is also important in Oregon. Long-term storage in controlled temperature and atmosphere facilities is common with apples, and often in market competition with fruit imported out-of-season from southern hemisphere growing regions. This is a particularly interesting trade-off to examine with LCA, and two identified studies examine the seasonality of local vs. imported apples in a European context. Apple processing (into juices, sauce, etc.) is also important to the apple industry in the Pacific Northwest, and while LCA studies on these final products specifically were not identified, we are investigating other means of estimating processing impacts in order to offer perspective on their relative importance.

4. Potatoes and potato products

Potatoes are Oregon's 7thhighest value crop; potatoes rank #4 in Washington. Because of the large volume of production, the potato industry also represents a noticeable portion of each state's greenhouse gas emissions: an estimated 0.6% of total state emissions in OR, and 1.8% in WA. Potatoes are annual vegetables, so their production typology differs from the perennial fruits included among recommended commodities. Some of the LCAs of potatoes consider processed end forms and find significant increases (above farm-gate impacts) in carbon footprint: peeled potatoes 50-60% greater, mashed potatoes 2-2.8 times greater, potato chips 3-4 times greater. Refinement of this type of information may provide insights to hotspots in potato processing, in addition to considerations of the production phase.

5. Eggs

While perhaps not considered an iconic Pacific Northwest food, egg production is nonetheless a strong agricultural commodity, ranking 15th in dollar value in both OR and WA. It is estimated that eggs contribute about 1.5% of the greenhouse gas emissions associated with Oregon food and beverage consumption. Egg production practices vary widely, with a number of choices available in the marketplace (organic, conventional, cage free, free range, etc). Many of these options have been compared in LCA studies (albeit in a European context), offering insights into differences in environmental impact. In general, feed production accounts for the largest share of impacts in egg production, so feed conversion efficiencies lead to reduced overall emissions. But these efficiencies need to be considered in light of the environmental costs of feed sourcing as impacts of feed production can vary significantly. Likewise, feed sourcing in the arid west is of particular interest due to irrigation needs for feed crop production; energy/water trade-offs in feed sourcing, mentioned previously, also apply here.

6. Wine

Wine grapes are a distinctive product of the Pacific Northwest that contributes significantly to the agricultural economy of the region. Viticulture presents a unique set of perennial

cultivation practices with distinct differences from orchard crops. Grape production in California's wine growing regions has been analyzed with LCA, and insights gained in those studies may be translatable to OR and WA wine grape regions. Still other LCA studies consider the full wine production method, shedding light on stages where mitigation strategies should be focused.

7. Pork

While not necessarily an emblematic food of Pacific Northwest agriculture, pork represents an estimated 4.5% of the food and beverage component of the Oregon consumption-based greenhouse gas emissions inventory. It also offers a telling example of the impacts of meat production. A thorough 'cradle-to-grave' LCA of U.S. pork found that 62% of the carbon footprint occurs on farm, yet 23.5% occurs at the consumer level (refrigeration, cooking, food waste disposal). A number of pork production strategies are compared in the LCA literature.

8. Citrus fruits and juices

Clearly, citrus fruits are not produced in the Pacific Northwest. Yet, citrus fruit and juices are a common part of the diets of most Americans. Citrus juices are 62% (by mass) of the juice consumed in the U.S. The quality of LCA research on citrus production is quite high, and includes at least one U.S. based study. A product footprint summary of citrus fruits and juices will demonstrate the impact, relative to on-farm production, of citrus transport from Florida (for example) to the Pacific Northwest. It may also demonstrate the impacts of concentrated vs. not-from-concentrate juice.

9. Freshwater Aquaculture

Both Oregon and Washington have aquaculture industries with significant growth potential. The Oregon Department of Agriculture has acknowledged this growth potential and has pledged to continue to support development and expansion of an aquaculture industry in Oregon[10]. While demand for seafood products continues to grow, aquaculture faces numerous hurdles, including misinformation and public misperceptions regarding the aquaculture industry[11]. LCA studies of aquaculture practices have been conducted in regions across the globe, with many studies making direct comparisons between alternative production practices[12]. A categorical footprint summary of aquaculture may be valuable to the developing industry in the Pacific Northwest in overcoming popular misconceptions. Note that while commercial wildcatch fisheries have also been analyzed via LCA, they are regionally dependent (e.g., how far ships must travel from port) and we have been unable to identify LCA studies of Pacific Northwest fisheries. Wildcatch fisheries

[10]Industry Report from the State Board of Agriculture, January, 2015. http://www.oregon.gov/ODA/shared/Documents/Publications/Administration/BoardReport.pdf.

[11]Developing Additional Investment in Aqua Farming in Oregon: a roadmap for sustainable development. Oregon Department of Agriculture RFP #2014-05. March, 2015.http://www.oregon.gov/ODA/shared/Documents/Publications/MarketAccess/AquacultureInvestment.pdf

[12]Cao, L., J. S. Diana, G. A. Keoleian (2013). "Role of life cycle assessment in sustainable aquaculture." Reviews in Aquaculture **5**(2): 61-71.

also vary greatly year-to-year depending on ocean and fish stock conditions, making it more challenging to generalize conclusions from LCA studies. It is our impression that the environmental performance of aquaculture practices is less location dependent and therefore lessons gleaned from LCA studies can be applied to current or future production in the Pacific Northwest.

10. Raspberries (cane berries)

Cane berry production, including red and black raspberries, blackberries, and boysenberries, is very important in the Pacific Northwest. Oregon is the lead U.S. producer of blackberries, boysenberries and black raspberries, growing nearly all of the country's commercial crop. Washington is the top producer of red raspberries, with OR ranking 3rd among states. These small, soft fruits have short shelf lives as fresh berries, thus requiring expeditious distribution channels that make their life cycles considerably different than pome fruits such as apples and pears. Because of their high perishability, processing methods (freezing, canning, preserves) are important to the overall product chain. We have found only a few LCA studies focused on raspberries; however, we anticipate (and will confirm) that production methods among cane berries may be similar enough that combining cane berries into a single environmental footprint summary will be appropriate. If we discover this not to be true, we would limit this analysis to raspberries only. Information from raspberry LCAs will be combined with data on energy use of freezing and processing soft fruits and studies that examine the relative environmental impact of transport to offer environmental impact information of value to the berry industry.

11. Pears

Pear production ranks 9th in terms of value of agricultural commodities in both OR and WA, with WA being the top U.S. producer at 50% of the U.S. pear crop, and OR with 26% of U.S. production. In 2005, the Oregon legislature named the pear the state fruit. LCA studies of pear production in Switzerland Portugal, Italy, and China have been identified. From an environmental impact perspective, pear cultivation, storage, processing, and distribution is likely similar to apples; this should be considered in making the final commodity selection.

12. Chicken

Chicken meat represents an estimated 6% of the food and beverage portion of Oregon consumption-based greenhouse gas emissions. Perhaps because of low volume, broiler production in Oregon and Washington does not appear in the USDA QuickStats database. Chicken therefore represents another food that is likely consumed in larger quantities in the Pacific Northwest that it is produced. Similar to egg production, broiler production practices vary widely, and much of the impact is connected with feed production.

13. Bananas

Aside from feed grains, bananas are the largest food import by mass into the U.S. Based on the estimates shown in Figure 2, bananas constitute 9% of the carbon footprint of fruit and vegetable consumption. Is this due to long transport distances from tropical regions, or simply because bananas are consumed in large quantities? If we're going to eat bananas, what can be done to reduce the impact of that consumption? A product footprint summary would shed light on these types of questions.

14. Hazelnuts

Oregon produces virtually the entire U.S. hazelnut crop, and the U.S. ranks third in global production. The largest hazelnut processor in North America is located in OR. To date, we have identified only two LCA studies that consider hazelnuts: one in an Italian context and the other in Iran. The Italian study considers different final forms (hazelnut paste, spreadable cream, chocolate covered) and includes estimates of energy demand for various processing steps. In addition, we have identified a hazelnut enterprise budget for the Willamette Valley developed by Oregon State University[13] which should allow a scan-level estimate of the environmental impacts of OR hazelnut production.

15. Tomatoes

Tomatoes are an iconic vegetable that is enjoyed both fresh and processed. Because of this, tomatoes have been studied extensively via LCA. Tomatoes also are a good example of the common misconceptions associated with environmental impact of food life cycles. In temperate climates, out-of-season local tomatoes are often produced in heated greenhouses, which drastically increases the energy use and carbon footprint associated with their production. A number of LCA studies compare local out-of-season production with imported tomatoes. A U.S. based LCA of processed tomatoes explores the trade-offs between regional production differences (in this case, CA vs. MI) and long-distance transport, with results being somewhat counter-intuitive to popular beliefs.

Other foods in Table 5

Table 5 lists an additional eight foods that are relevant and important to agriculture in OR and WA, but in most cases the available LCA literature is quite limited. Onions are an interesting example: Oregon is the nation's top onion producer, while Washington ranks number 2. While the value of these onion crops falls farther down the "top commodities" list in each state, because of the high production volume, we estimate that the greenhouse gas emissions associated with this production is rather significant. However, there is very little public domain LCA research that analyzes onion production. Similarly, there is a notable vegetable processing industry in OR and WA: green peas, carrots, snap beans and sweet corn all rank as high volume processed crops. When taken individually, there is limited LCA data on production of these crops. While differences in cultivation and harvesting practices between these crops make farm-gate impacts vary, processing steps – freezing or canning – will be similar. A combined categorical footprint summary with generalized information on the relative importance of processing and distribution to the overall life cycle may be a valuable addition.

4. Conclusions and Next Steps

Recommendations of food commodities for further evaluation and development of categorical footprint summaries were made based on five criteria. The first five of the recommended foods score high in regional production value, estimated environmental

[13] Julian, James W., Clark F. Seavert, and Jeff L. Olsen. *Orchard economics: The costs and returns of establishing and producing hazelnuts in the Willamette Valley*. Corvallis, Or.: Extension Service, Oregon State University, 2008. http://hdl.handle.net/1957/17438.

impact of regional production, quantity and quality of LCA data, and they score reasonably high in consumption-based impacts as well. The remaining recommended foods demonstrate trade-offs in criteria. They were selected based on their scoring in Table 5, as well as to represent a diversity of food types in the final collection of footprint summaries. These recommendations serve as a basis for stakeholder input and determination of a final list for next steps.

The success of this project is dependent on providing information to businesses and organizations that may find it useful in directing change. Often the ease by which change can be made is dependent on the organizational structure of an industry. Therefore, **we welcome input from stakeholders on the organizational structure within the Pacific Northwest of the recommended food industries, as well as suggestions of commodities not included here that may be of particular interest to institutional buyers and/or food processors**.

While the exact form and content of the product footprint summaries resulting from this project will continue to evolve through further research and discussion with stakeholders, it will be important to maintain reasonable expectations of what existing literature can tell us. The product footprint summaries will *not* be able to provide definitive benchmarking of the environmental impact of producing (or consuming) specific foods in the Pacific Northwest, nor will they be able to provide comparative information on specific growing practices or growing regions within Pacific Northwest (since region-specific LCA data is currently unavailable). What they *will* be able to do is demonstrate the relative impacts of on-farm production compared to processing, distribution and transport for typical product chains, or the aspects of on-farm production that are particular "hot spots" in terms of environmental impact (such as, for example, fertilizer use.) In cases where the literature demonstrates a significant difference in the environmental impact categories being investigated, we may be able to make statements on differences in generic production practices (e.g., caged vs. free range eggs). To the extent possible, LCA results from the literature will be modified to better represent the Pacific Northwest by, for example, adjusting for yield or irrigation rates, or typical transport distances.

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