CHAPTER 4. Citrus Waste Ethanol

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4.1 Citrus Background and Overview

4.1.1 Introduction

Citrus is both the common and Latin name for a genus of flowering plants in the rue (Rutaceae) family. The plants are believed to have originated in southeast Asia, but have been grown throughout the world for centuries. Spanish explorers first brought the plants to what is now the United States. Oranges grown for the frozen juice industry currently dominate US citrus production and Florida is the primary location of citrus agriculture.

Citrus trees require consistent sunlight, minimal exposure to freezing temperatures, significant amounts of water combined with periods of drought, and well-drained soil. Consequently, large scale cultivation in the US is limited to just four states, Florida, California, Texas, and Arizona, where the weather is sunny and warm and where irrigation is used to manage both supply and timing of water application. Drainage systems are constructed in places where the water table is less than several meters below the surface, as is often the case in Florida. The trees require significant nutrient and pesticide management. Fruit begins to ripen in late fall or early winter, but growth of specific cultivars allows for nearly year round supply of fruit in the US (Figure 4.1).

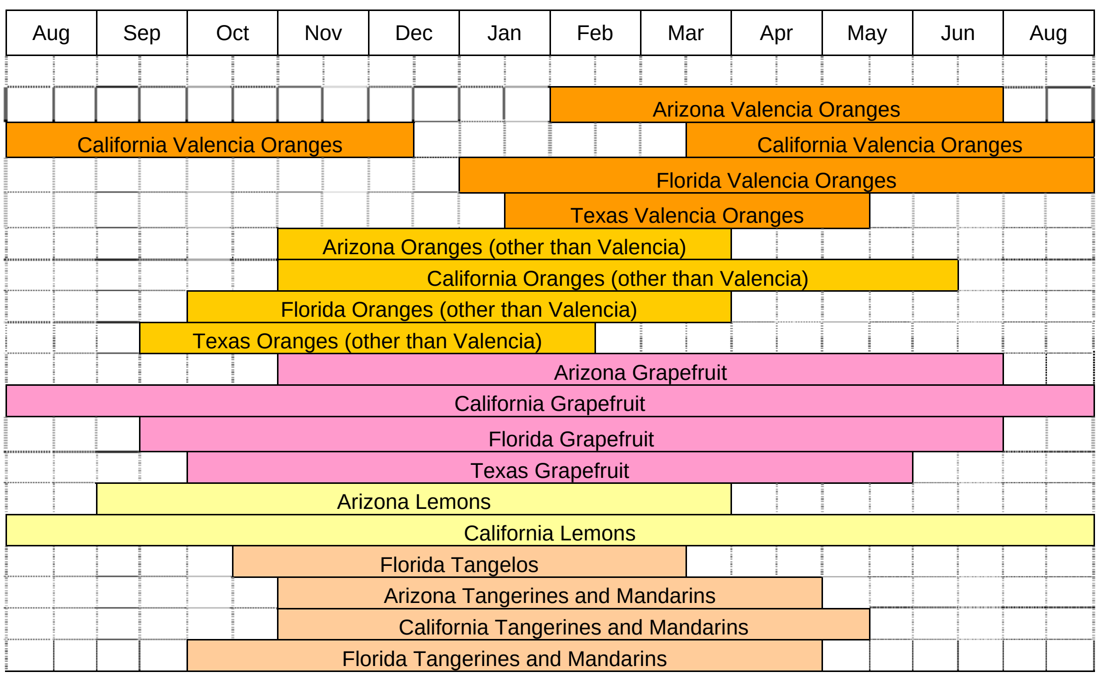

Figure 4.1. Citrus fruit is available year-round in the United States (based on data from ERS, 2009a).

4.1.2 Historical Trends

The United States produced an average of 11.8 million tons (10.7 x 10^9 kg) of citrus fruit per year between 2006/7 and 2008/9. The two largest producing states were Florida (70%) and California (26%), with Texas and Arizona supplying much lower amounts, at 3% and 1%, respectively (ERS, 2009a). The total US acreage used for growing citrus tends to be cyclical. During the past 30 years, a maximum of 1.15 x 10^6 acres (0.47 x 10^6 hectares) planted in citrus occurred during the 1997-98 growing season and a minimum of just over 800,000 acres (324,000 hectares) is observed in 1986-87. A graph of bearing acreage from 1980 to 2008 is shown in Figure 4.2. Note that because citrus does not produce fruit in the first few years, approximately 10% more land is required than is indicated by these numbers. The citrus industry is dominated by oranges, increasing from approximately 70% to nearly 80% of total production during the past three decades. Grapefruit is a distant second, decreasing from approximately 18% of all citrus production in the 1980's to just below 10% in the last few years. Lemons, limes, tangelos, and tangerines make up the remaining approximately 10%.

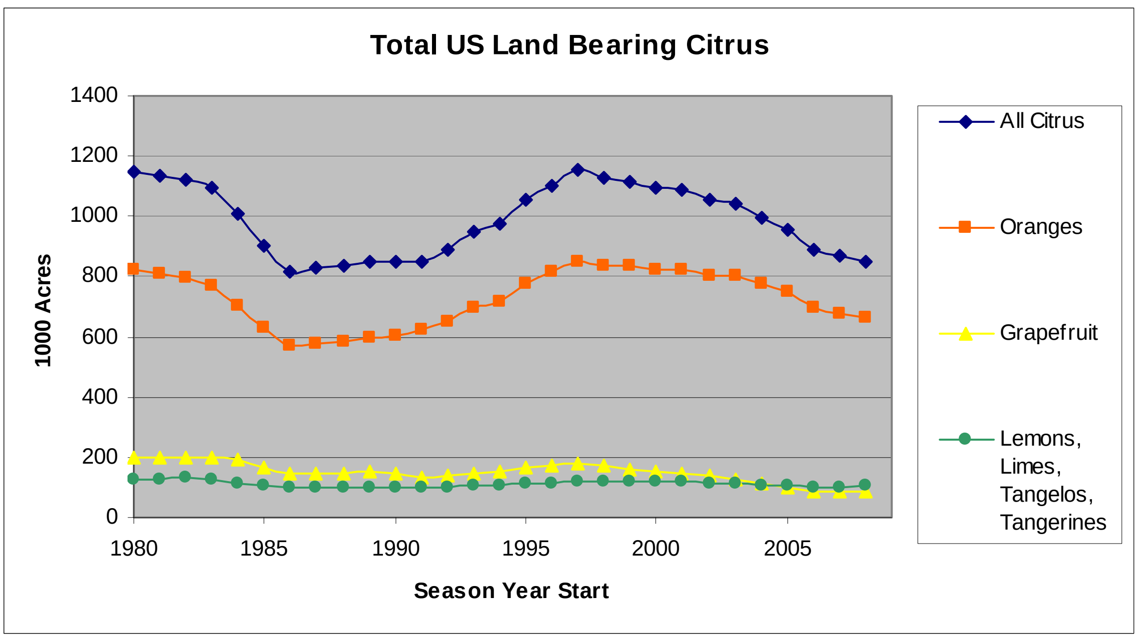

Figure 4.2. The total amount of land used in the United States for citrus production is cyclic and has ranged from 0.8 to 1.2 x 10^6 acres (0.4 to 1.1 x 10^6 hectares) over the past thirty years (based on data from ERS, 2009b).

Production of citrus fruit is commonly tracked and reported by the number of boxes. Boxes are a standard unit of measure, but the amount contained within a box varies by fruit and state (Table 4.1). All data in this analysis are given in units of mass.

Table 4.1. Mass of boxes used as a standard unit of measure to report citrus production in the US (ERS, 2009a)

Fruit	Mass per Box							
	Florida		California		Texas		Arizona	
	lbs	kg	lbs	kg	lbs	kg	lbs	kg
Oranges	90	40.8	75	34.0	85	38.6	75	34.0
Grapefruit	75	34.0	67	30.4	80	36.3	67	30.4
Lemons	--	--	76	34.5	--	--	76	34.5
Tangelos	90	40.8	--	--	--	--	--	--
Tangerines and Mandarins	95	43.1	75	34.0	--	--	75	34.0

Orange yield for the US varied from an average of 9.8 tons per acre to 16.7 tons per acre between the years 1980 and 2008 (ERS, 2009b, Table-C19). This is equivalent to 22 to 37 tonnes (metric tons) or megagrams (Mg) per hectare (ha). There was a relatively steady increase until 2003, after which a continuous decline is observed (Figure 4.3). The mean yield over the past nearly 3 decades is 13.9 tons per acre (31.2 Mg/ha). The median yield during this time period is 14.0 tons per acre (31.4 Mg/ha), and the distribution is bimodal around 13 and 15 tons per acre (29.1 and 33.6 Mg/ha). Yields within a given year can be sharply curtailed by catastrophic events such as a hard freeze or a severe infestation of pests (microbes or insects). Overall, California has approximately 20% lower yields than Florida, while Texas and Arizona produce less than half the amount of fruit per acre (Table 4.2).

Grapefruit yield has varied, since 1980, from 10.0 to 19.2 tons of fruit per acre (22.4 to 43 Mg/ha) (ERS, 2009b, Table-C11) with a sharp increase during the 1980's and a notable dip centered on the 2004-05 season. The mean yield during this time period is 16.1 tons of fruit per acre (36.1 Mg/ha), the median is 16.3 tons per acre (36.5 Mg/ha), and the distribution is bimodal around 16 and 19 tons per acre (35.9 to 42.6 Mg/hectare). California has similar, although slightly lower, yields as compared to Florida. Texas and Arizona have both lower overall yields as well as a greater spread in yield (due to extremely low production in some years) Table 4.2.

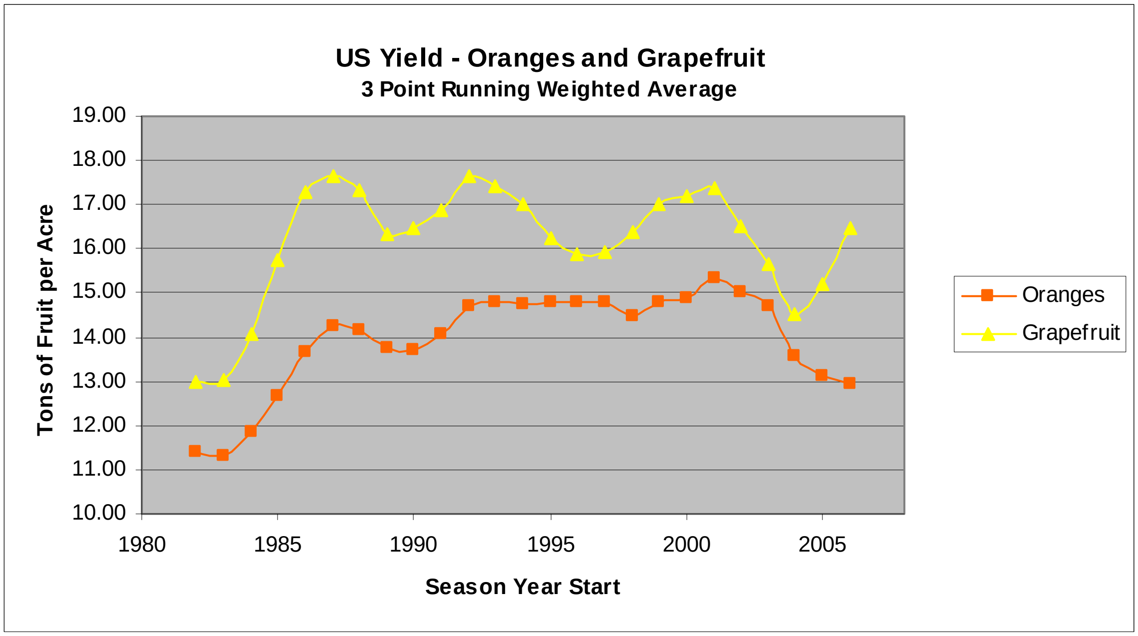

Figure 4.3. Orange and grapefruit yields have averaged 14 tons per acre (31.4 Mg/ha) and 16 tons per acre (35.9 Mg/ha), respectively, over the past 30 years (based on data from USDA, 2009b)

Table 4.2. Orange and grapefruit yields by state (based on data from ERS, 2009b)

	Oranges: Yield, Fruit per Harvested Area 1980-81 through 2008-09									
	FL		CA		TX		AZ		US	
	tons/acre	Mg/ha	tons/acre	Mg/ha	tons/acre	Mg/ha	tons/acre	Mg/ha	tons/acre	Mg/ha
minimum	10.1	22.7	5.4	12.1	0.4	0.9	3.0	6.8	9.8	21.9
maximum	19.3	43.2	16.1	36.1	10.6	23.8	11.3	25.3	16.7	37.4
mean	14.9	33.4	11.5	25.8	6.6	14.8	6.0	13.3	13.9	31.1
median	15.4	34.5	12.0	26.9	7.1	15.8	6.1	13.7	14.0	31.4
	Grapefruit: Yield, Fruit per Harvested Area 1980-81 through 2008-09									
	FL		CA		TX		AZ		US	
	tons/acre	Mg/ha	tons/acre	Mg/ha	tons/acre	Mg/ha	tons/acre	Mg/ha	tons/acre	Mg/ha
minimum	7.7	17.1	9.1	20.5	0.4	0.8	2.1	4.7	10.0	22.5
maximum	21.8	48.8	20.1	45.1	15.4	34.4	15.9	35.7	19.2	43.0
mean	17.6	39.5	15.2	34.1	9.8	22.0	8.8	19.7	16.1	36.1
median	17.8	39.8	14.7	32.9	11.2	25.2	8.7	19.5	16.3	36.5

4.2 Citrus Waste Supply

4.2.1 Current Supply

Most of the citrus grown in the US is processed into juice. This includes approximately 95% of all oranges and 60% of all grapefruit. Based on data reported by the US Department of Agriculture (ERS, 2009a) the mass fraction of juice in Florida Valencia oranges is 0.57 and in navel oranges is 0.51. Juice production from oranges grown in other states may differ; however, as Florida oranges dominate the market, these values are taken as typical for the analysis presented here. Grapefruit is assumed to have a juice yield of 48% (Braddock, 1999, Table 17.2). Data for juice fractions from other fruits were not found in the literature. They are assumed to contain 50% juice, with the remainder waste.

The US produced oranges for processing at the rate of approximately 7 x 10^6 short tons per year between 2004 and 2008, down from an average 10 x 10^6 tons per year in the previous 5 years (Figure 4.4) (ERS, 2009b). This has been attributed in part to weather losses (hurricanes and freezes) as well as disease (citrus canker and citrus greening).

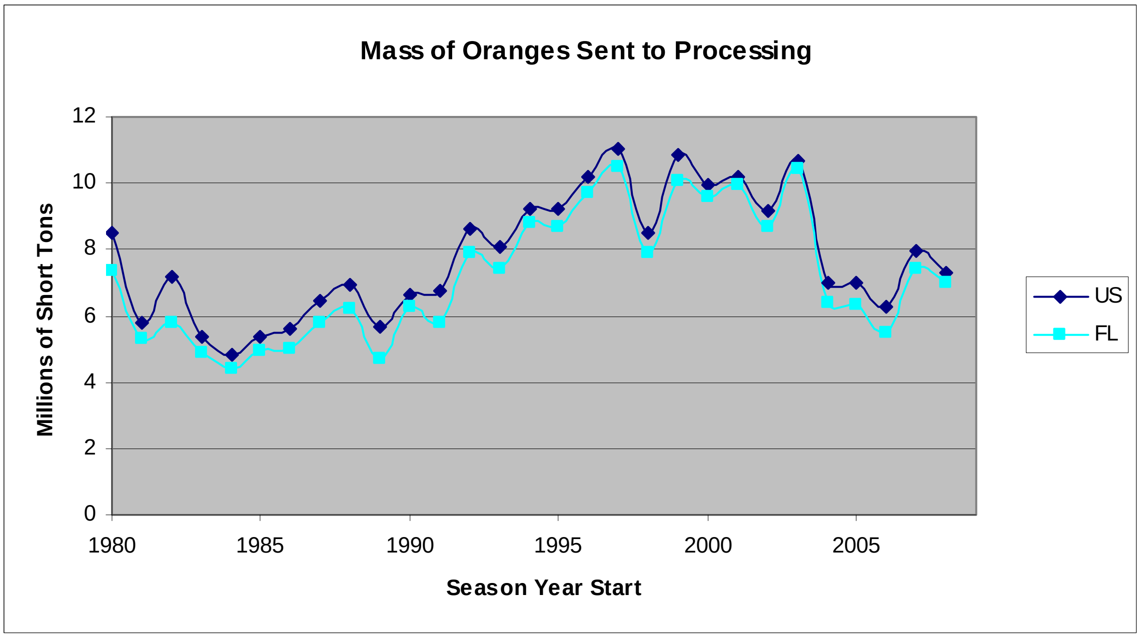

Figure 4.4. Historically, the US has produced as much as 10 x 10^6 short tons of oranges for processing per year (ERS, 2009b).

While most of the value in processed fruit is the juice produced, there are also by-products associated with citrus fruit processing (Braddock, 1999; Goodrich and Braddock, 2006). During the 2003-2004 season, Florida citrus processors produced more than 1.1 x 10^6 tons of citrus pulp and meal, 38 thousand tons of molasses, and nearly 36 x 10^6 pounds of d-limonene (Hodges et al., 2006). Essential oils (which contain about 95% d-limonene) are obtained from the flavedo, the outer, colored portion of the peel, where the oil sacs are located (Figure 4.5). The albedo, a thin white tissue at the interior of the peel, can be a source of pectin, a thickener used in jams and jellies, but is generally not economical to recover. The seeds are typical of oilseeds and contain lipids, proteins, and carbohydrates, but they account for less than 1% of the mass and are not commercially exploited as a separate commodity; instead, they are included in the residue that goes to cattle feed (Braddock, 1999). The juice sacs, or vesicles, form pulp when they are ruptured during the juicing process. The segment membranes and core of the fruit, which remain after the juice extraction process, are collectively referred to as the rag. The dominant, current practice for management of citrus peel waste is to dry and sell it as low-value cattle feed (Zhou et al., 2007). Other options include using it as compost, or treating it with enzymes followed by fermentation. Smaller producers typically do not try to produce any by-products from the juicing operation and send all residues to land-fill (Braddock, 1999).

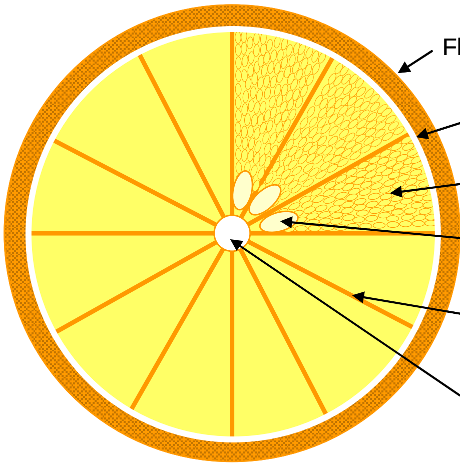

Figure CW 5. Citrus fruit includes oil sacs in the peel and a thin skin (albedo) on the interior (after Matthews, 1994).

Virtually all waste that could be used to produce ethanol is expected to come from processed fruit, as there would be little to no access to waste from fruit sold as fresh. Thus, the maximum available waste is calculated as:

$$m_{waste,\,max} = \sum_{k} (1 - fraction_{juice,\,k}) * m_{fp,\,k} \qquad (4.1)$$

where

$m_{waste,\,max}$ is the maximum potential mass of waste that can be produced as a by-product

$fraction_{juice,\,k}$ is the fraction of juice extracted from each fruit type k and

$m_{fp,\,k}$ is the mass of each type of fruit that is processed rather than sold as fresh.

Based on data from the seasons 2006-07 through 2008-09 (ERS, 2009a), there is the potential (under current practices) to produce an average of 3.9 x 10^6 tons (3.6 x 10^9 kg) of citrus waste per year in the United States, with a range of 3.2 and 4.5 x 10^6 tons (Table 4.3). Zhou and others (2007) state that the citrus juice industry produces 3.5 to 5.0 x 10^6 tons of peel waste per year, but do not cite a source or describe the method used to make this determination. While this range is slightly higher than the one calculated here, the numbers are in good agreement if one assumes production levels similar to those observed between 1999 and 2003.

Florida oranges are currently the most significant source of citrus waste (78%), followed by Florida grapefruit, California oranges and California lemons. Combined, these sources account for 96% of all US citrus waste (Table 4.3).

Table 4.3. Citrus waste by fruit and state (estimated from data in ERS, 2009a)

		Estimated Waste					
		Min		Max		Mean	
Fruit	State	1000 tons	10^6 kg	1000 tons	10^6 kg	1000 tons	10^6 kg
Navel & Other	FL	1,355	1,229	1,770	1,605	1,627	1,476
Valencia	FL	1,184	1,074	1,640	1,487	1,426	1,294
Grapefruit	FL	273	248	359	326	328	298
Navel & Other	CA	96	87	257	233	177	161
Lemons	CA	103	93	169	153	138	125
Valencia	CA	44	39	82	75	68	61
Grapefruit	TX	48	43	76	69	60	54
Tangelos, Tangerines & Mandarins	FL	39	35	77	70	57	51
Lemons	AZ	10	9	36	33	19	17
Tangelos, Tangerines & Mandarins	CA	17	15	21	19	19	18
Navel & Other	TX	4	4	9	8	7	6
Grapefruit	CA	0	0	12	11	4	4
Tangelos, Tangerines & Mandarins	AZ	2	2	2	2	2	2
Valencia	AZ	1	1	1	1	1	1
Navel & Other	AZ	1	0	1	1	1	1
Valencia	TX	2	1	0	0	1	1
Grapefruit	AZ	0	0	0	0	0	0
Total						3,935	3,569

It is estimated that an optimized facility can produce between 12 and 14 gallons of ethanol per ton of wet citrus peel (Zhou et al., 2007). Taking mid-point values of 13 gallons per ton, and 4 x 10^6 tons of waste, an estimated 52 x 10^6 gallons per year of ethanol could be produced from US citrus waste. Assuming that ethanol has an energy content of 76,330 Btu/gal (LHV) and conventional gasoline has an energy content of 116,090 Btu/gal (LHV) (ANL, 2009), this amount of ethanol could displace 34 x 10^6 gallons of conventional gasoline per year, or 0.025% of the 135 x 10^9 gallons consumed in the US in 2008 (EIA, 2009, Table 5.13c). Similarly it has the potential to increase the 9.6 x 10^9 gallons of fuel ethanol consumed in 2008 (EIA, 2009, Table 10.3) by 0.35%.

4.2.2 Potential to Increase Supply

The climate restrictions for growing citrus at a commercial scale mean that the total land area available in the US is limited. Fruit yields have remained relatively flat for decades, so it is unlikely that these will increase by any notable degree without significant changes in technology (including cultivars that might become available) and/or economic incentives.

Waste yield in terms of tons per unit area can be calculated as

$$yield_{waste,\,\mathrm{k}} = (1 - fraction_{juice,\,\mathrm{k}}) * (yield_{f,\,\mathrm{k}}) \tag{4.2}$$

where

$fraction_{juice,\,\mathrm{k}}$ is the fraction of juice extracted from each fruit type k and

$yield_{f,\,\mathrm{k}}$ is tons per unit area of fruit type k produced.

Based on this calculation and using production and yield data from the last three years (ERS 2009a), it appears that the most productive fruits and areas for citrus waste in terms of yield per unit area are grapefruit, particularly from Florida and California (Table 4.4). Texas grapefruit also has relatively high waste yield. Note that while Arizona produces grapefruit, it is all sold as fresh fruit and therefore does not currently have a commercial waste citrus stream. Florida overall has the highest waste per area yield and Arizona has the lowest.

Table 4.4. Waste yield by fruit and state (estimated from data in ERS, 2009a)

		Estimated Waste Yield					
		Min		Max		Mean	
Fruit	State	tons/acre	Mg/ha	tons/acre	Mg/ha	tons/acre	Mg/ha
Grapefruit	FL	9.2	20.7	10.7	24.0	10.1	22.7
Grapefruit	CA	9.4	21.2	10.2	22.8	9.9	22.1
Navel & Other	FL	6.8	15.2	9.1	20.4	8.3	18.5
Lemons	CA	6.0	13.4	8.9	19.9	7.4	16.6
Tangerines & Mandarins	FL	6.2	13.9	8.7	19.5	7.3	16.4
Grapefruit	TX	6.2	13.8	8.0	17.9	7.0	15.6
Valencia	FL	4.7	10.5	6.5	14.6	5.7	12.8
Tangelos	FL	5.0	11.1	6.5	14.5	5.5	12.4
Navel & Other	CA	4.5	10.1	5.9	13.1	5.0	11.1
Valencia	CA	3.8	8.5	5.8	13.1	4.9	10.9
Tangelos, Tangerines & Mandarins	CA	3.5	7.7	5.5	12.2	4.5	10.1
Navel & Other	TX	3.6	8.1	4.4	9.9	4.2	9.3
Lemons	AZ	2.4	5.3	4.8	10.6	3.6	8.2
Valencia	TX	2.2	5.0	5.3	12.0	3.4	7.7
Grapefruit	AZ	1.1	2.5	3.5	7.8	2.5	5.6
Tangelos, Tangerines & Mandarins	AZ	1.9	4.2	3.0	6.7	2.5	5.5
Navel & Other	AZ	1.8	4.1	2.8	6.3	2.3	5.1
Valencia	AZ	1.8	4.0	2.7	6.0	2.1	4.7

Two scenarios for increasing citrus waste production are explored, both of which involve increasing the amount of land that is planted in citrus. In the first scenario, it is assumed that the best areas for growing citrus are in the counties where it is currently produced and all existing cropland in counties that currently have more than 1000 acres planted in citrus is converted to citrus groves. In the second scenario, the area where citrus is grown is expanded to include all areas of the US that lie within USDA Hardiness Zone 9b or higher (USNA, 2003). While this is not a realistic scenario, it provides a theoretical maximum for citrus production and its accompanying waste in the US.

4.2.2.1 Scenario: Conversion of Existing Cropland to Citrus

In this scenario, all existing cropland in counties that currently have more than 1000 acres (405 hectares) planted in citrus is converted to citrus groves. The amount of citrus area and cropland is taken from the 2007 Census of Agriculture, which lists both citrus area and total cropland for each county (USDA, 2009). It is assumed that displaced crops would be grown on land that is not currently cropland and would thus result in land use change for non-cropland. All of the new production would be processed rather than being sold as fresh so that waste is easily recovered. Two alternative cases within this scenario are examined. In the first case, it is assumed that only the most productive fruit (from a waste standpoint) is grown on the additional land. In the second case, navel oranges are grown on all new land. The maximum fruit yield (tons per acre) for each of these fruits for the last three years is assumed. As county-level yield data is not given in the census, state-level data (ERS, 2009a) is assumed for all counties. The current supply, of both waste and juice are given in Table 4.5. These are based on mean production values for 2006 through 2008 (ERS, 2009a) and assumed juice/waste fractions as described above. Existing citrus and cropland from the 2007 census (USDA, 2009) are also presented.

Table 4.5. Current citrus waste potential, juice production, and land use (based on data from ERS, 2009a and USDA, 2009)

	Existing Citrus Waste [1]		Existing Juice Production				Existing Citrus Land (2007)				Existing Cropland (2007) [2]	
	All Fruit Types		Grapefruit		Orange		All Citrus		Bearing Citrus		All Crops, including citrus	
State	1000 tons	Gg	1000 tons	Gg	1000 tons	Gg	1000 acres	1000 hectares	1000 acres	1000 hectares	1000 acres	1000 hectares
AZ	23	21	0	0	2	2	17	7	16	6	460	186
CA	406	368	4	3	274	249	300	121	276	112	4,579	1,853
FL	3,438	3,119	303	275	3,583	3,251	652	264	616	249	1,937	784
TX	68	61	55	50	8	8	27	11	26	11	630	255
TOTAL	3,935	3,569	362	329	3,868	3,509	996	403	935	378	7,607	3,078

[1] Mean potential 2006-08

[2] In counties with >1000 acres planted in citrus

Using the mean maximum potential waste yield (tons of citrus waste per acre) for the years 2006 through 2008, based on data from the USDA (ERS, 2009a) and the calculations given by expressions 4.1 and 4.2, it is predicted that the amount of citrus waste could be increased to 11 times the current level if navel oranges are grown on the new land and to 16 times the currently levels if grapefruit are grown on the new land (Table 4.6). Assuming that citrus waste could supply 13 gallons of ethanol per ton of wet citrus peel in a commercial scale facility (Zhou et al., 2007) this would provide between 544 and 821 x 10^6 additional gallons of ethanol per year, which is equal to 5.7% to 8.6% (for orange and grapefruit respectively) of the current 9.6 x 10^9 gallons of fuel ethanol per year consumed in 2008. Similarly, it could displace 0.40% to 0.61% of the 135 x 10^9 gallons of motor gasoline consumed in 2008. (Fuel consumption data are from the US Department of Energy (EIA, 2009)). Such a change however, would also result in an increased supply of orange juice (11 times the current level) or in grapefruit juice (152 times the current level). Without significant expansion of these markets, it is likely that the juice itself would become waste material. In addition, this scenario would result in land use change affecting a total of 6.6 x 10^6 acres (2.7 x 10^6 hectares) (Table 4.7) as non-citrus crops currently grown in counties with citrus are displaced and grown elsewhere on non-cropland.

Table 4.6. Potential increase in citrus waste with expansion of citrus onto all cropland in counties with greater than 1000 acres (405 hectares) of citrus; assuming either all grapefruit or all navel oranges grown on new land

	Grapefruit							
State	Waste Yield [1]		New Waste		Total Waste		Factor of Existing Waste	10^6 gallons of EtOH
	tons/acre	Mg/ha	1000 tons	Gg	1000 tons	Gg		
AZ	3.5	7.8	1,488	1,350	1,511	1,370	66	20
CA	10.2	22.8	40,031	36,316	40,437	36,684	100	526
FL	10.7	24.0	13,012	11,804	16,450	14,923	5	214
TX	8.0	17.9	4,652	4,220	4,720	4,282	70	61
TOTAL			59,183	53,690	63,117	57,260	16	821
	Navel Oranges							
State	Waste Yield [1]		New Waste		Total Waste		Factor of Existing Waste	10^6 gallons of EtOH
	tons/acre	Mg/ha	1000 tons	Gg	1000 tons	Gg		
AZ	2.81	6.3	1,200	1,089	1,223	1,110	53	16
CA	5.86	13.1	23,104	20,960	23,511	21,329	58	306
FL	9.11	20.4	11,055	10,029	14,493	13,148	4	188
TX	4.44	9.9	2,584	2,344	2,651	2,405	39	34
TOTAL			37,944	34,422	41,878	37,992	11	544

1 Maximum potential 2006-08

Table 4.7. Potential increase in orange or grapefruit juice and amount of land use change with expansion of citrus onto all cropland in counties with >1000 acres (405 hectares) of citrus

	Additional Juice				Total Juice with Expansion				Factor of Existing Juice Supply		New Citrus Land			
	Grapefruit		Navel Orange		Grapefruit		Navel Orange				All Citrus		Bearing Citrus	
State	10^6 tons	10^6 Mg	10^6 tons	10^6 Mg	10^6 tons	10^6 Mg	10^6 tons	10^6 Mg	Grape-fruit	Navel Orange	10^6 ac	10^6 ha	10^6 ac	10^6 ha
AZ	1.4	1.2	1.2	1.1	1.4	1.2	1.3	1.1	na	555	0.44	0.18	0.43	0.17
CA	37.0	33.5	24.0	21.8	37.0	33.5	24.3	22.1	9849	89	4.28	1.73	3.94	1.60
FL	12.0	10.9	11.5	10.4	12.3	11.2	15.1	13.7	41	4	1.29	0.52	1.21	0.49
TX	4.3	3.9	2.7	2.4	4.3	3.9	2.7	2.4	79	324	0.60	0.24	0.58	0.24
TOTAL	54.6	49.6	39.5	35.8	55.0	49.9	43.4	39.3	152	11	6.61	2.68	6.17	2.49

4.2.2.2 Scenario: Conversion to Citrus of All Available Land in USDA Hardiness Zones 9b or Higher

The second scenario, while extremely improbable, is undertaken in an attempt to define a physical maximum for citrus waste production in the US. Most commercial citrus groves are located within USDA Hardiness Zone 9b or higher (USNA, 2003), where minimum daily temperatures rarely go below 25º F and therefore risks of freezing are extremely low. If there were economic incentives and/or other changes (botanical, climatic, etc) it is possible that the amount of land planted in citrus could be increased, but under current conditions this is taken as the upper limit. According to the Hardiness Zone map, approximately 10% of Arizona, 20% of California, 10% of Texas, and 40% of Florida have temperatures warm enough to sustain citrus groves.

Based on data from the Natural Resources Conservation Service (NRCS, 2007) the most land that in the most extreme case could be used to grow citrus in the US is estimated as the sum of all land currently used to grow citrus, Conservation Reserve Program (CRP) land, rangeland, pastureland, other rural land, and forestland in the portions of states with the appropriate climate. Although much of this land actually is not and never would be available to grow citrus it is, at least for this exercise, regarded as land on which citrus conceivably could be grown, given strong enough market forces and/or policy. Land that is considered completely unavailable includes developed land, cropland used for crops other than citrus, water areas, and federal land (Table 4.8).

Table 4.8. Land use and maximum available land for growing citrus in the US, assuming a USDA Hardiness Zone of 9b or higher (based on 2003 data from NRCS, 2007 and USDA, 2009)

	"Available" Land								Unavailable Land		
State	Citrus Land	CRP	Pasture-land	Range-land	Other Rural Land	Forest Land	Maximum New Citrus Land	Maximum New Citrus Bearing Area	Non-Citrus Cropland	Developed, Federal, and Water Areas	Total Surface Area
	-- 1000 Acres --										
AZ [1]	17	0	8	3,226	303	414	3,967	3,818	77	3,252	7,296
CA [2]	303	27	238	3,552	925	2,781	7,825	7,204	1,591	10,887	20,302
FL [3]	28	31	1,448	1,079	1,123	5,093	8,801	8,495	1,122	5,090	15,014
TX [1]	656	399	1,584	9,611	229	1,061	13,540	12,788	1,900	1,665	17,105
Total	1,004	457	3,277	17,467	2,579	9,349	34,133	32,305	4,689	20,895	59,717

[1] All land areas in Arizona and Texas scaled to 10% to represent land in Zones 9b or higher (USNA, 2003).
[2] All land areas in California scaled to 20% to represent land in Zones 9b or higher (USNA, 2003).
[3] All land areas in Florida scaled to 40% represent land in Zones 9b or higher (USNA, 2003).

Were these lands to be converted to citrus, only about 95% of the area would bear fruit at any given time. Assuming the maximum yields observed in 2006 through 2008 and calculating waste production at waste fractions of 0.52 for grapefruit and 0.49 for navel oranges, a total of 182 x 10^6 tons would be generated if the additional land were planted in navel oranges and 272 x 10^6 tons would be available if the additional land were planted in grapefruit (Table 4.9). If 13 gallons of ethanol can be produced per ton of wet citrus waste (Zhou et al., 2007), this would result in a total of 2.4 to 3.5 x 10^9 gallons of ethanol.

Table 4.9. Estimated production of juice and citrus waste ethanol from additional land if all available land in USDA Hardiness Zone of 9b or higher were planted in citrus.

	Maximum New Citrus Bearing Area	Waste Yield [1] (tons/acre)		New Citrus Waste 10^6 tons		New Citrus Juice 10^6 tons		Ethanol Potential 10^9 gallons [2]	
State	1000 Acres	grapefruit	navel oranges	grapefruit	navel oranges	grapefruit	orange	grapefruit	navel oranges
AZ	3,802	3	3	13	11	12	11	0.17	0.14
CA	6,925	10	6	70	41	65	42	0.91	0.53
FL	8,468	11	9	91	77	84	80	1.18	1.00
TX	12,168	8	4	97	54	90	56	1.26	0.70
Total	31,363			272	182	251	190	3.53	2.37

[1] Maximum waste yield 2006-2008 (based on ERS, 2009a)

[2] 13 gallons of ethanol per ton of wet peel (Zhou et al., 2007)

Citrus production at this level would provide a notable amount of fuel that could offset gasoline consumption by 1.8% to 2.6% or increase fuel ethanol production by 25 to 37%, but it would simultaneously result in nearly 50 times the amount of orange juice currently produced or 700 times the amount of grapefruit juice. In addition, it would require that 34 x 10^6 acres (13.8 x 10^6 hectares) be converted to cropland (57% of the total surface area located in Zones 9b and higher) (Table 4.10). Neither of these is likely nor desirable.

Table 4.10. Estimated impacts on current production of juice and fuel if all available land in USDA Hardiness Zone of 9b or higher were planted in citrus.

	Percent of 2008 gasoline consumption		Percent of 2008 fuel ethanol consumption		Factor of 2008 juice production		Land Use Change (conversion to citrus cropland)	
State	grapefruit	navel oranges	grapefruit	navel oranges	grapefruit	orange	10^6 acres	10^6 hectares
AZ	0.1%	0.1%	1.8%	1.4%	na	5,563	4.0	1.6
CA	0.7%	0.4%	9.5%	5.5%	16,230	154	7.5	3.0
FL	0.9%	0.7%	12.3%	10.4%	277	22	8.8	3.6
TX	0.9%	0.5%	13.2%	7.3%	1,631	7,022	12.9	5.2
New Potential	2.6%	1.8%	36.8%	24.7%	692	49	33.1	13.4
Current Potential	0.025%		0.35%				1.0	0.4
TOTAL	2.6%	1.8%	37.1%	25.0%			34.1	13.8

4.2.3 Potential Decreases in Supply

Citrus production in the United States is currently threatened by a bacterial disease known as citrus greening or HLB (huanglongbing, Chinese for "yellow dragon disease"). It is one of the most serious citrus diseases in the world, and while caused by a bacterium, it is spread by an insect, the citrus psyllid. Once infected, there is no cure and it will eventually kill the tree. The treatment is to spray with insecticide to kill the psyllids and then to remove infected trees to eliminate the presence of the bacterium in the orchard. The disease is currently a problem in Florida and citrus psyllids recently have been spotted in California.

4.3 Citrus Waste Ethanol, Life Cycle Assessment

The life cycle assessment approach taken is that of an attributional rather than consequential LCA and evaluates the typical practices in the United States in the year 2007 (approximately). A description of life cycle assessment, and in particular, its application to transportation fuels is addressed in Chapter 1 of this report. A simplified process flow, illustrating the overall life cycle of anhydrous ethanol produced from a citrus waste feedstock is presented in Figure 4.6.

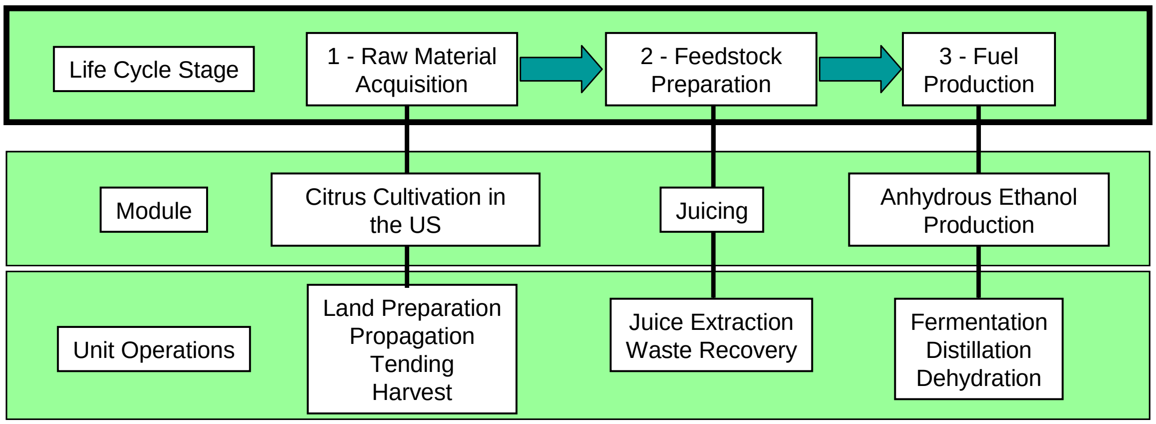

Figure 4.6. Ethanol produced from citrus waste can be characterized by three life cycle stages each possibly separated by a transportation event

4.3.1 Citrus Waste Ethanol, LC Stage 1, Raw Material Acquisition: Land Preparation, Propagation, Nurturing, and Harvest

4.3.1.1 General

4.3.1.1.1 System Boundaries

The first life cycle stage in the production of ethanol from citrus is the acquisition of citrus fruit through conventional agricultural systems in the US. This entails preparation of the land for planting, planting of seedlings, tending of the citrus trees, and harvest of the fruit. Because the greatest amount of data is available for 2007, to the extent possible, that is the reference year for this analysis. The system includes consumption of raw materials, energy, land, and water, as well as emissions to air. Emissions to land and water are addressed only as contributors to greenhouse gas emissions. Upstream energies associated with production of agricultural chemicals and fertilizers are included, but development of infrastructure and manufacture of farm equipment are not (Figure 4.7). The downstream system boundaries are terminated at harvest; thus transport and storage activities from and off the cropland are included in life cycle stage 2. This decision is driven primarily by the change in reference flow from a unit area of land in life cycle stage one to a unit mass of fruit in life cycle stage two and the recognition that activities for transportation and storage are better modeled in units of mass.

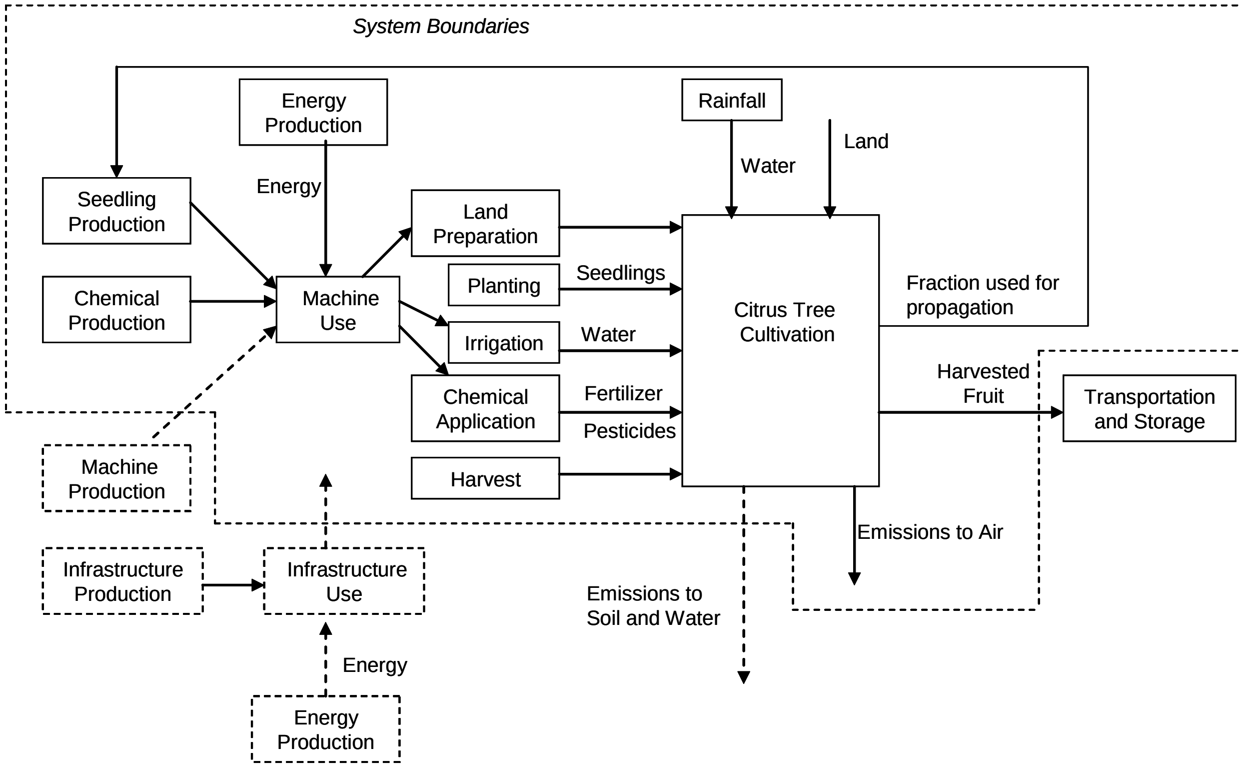

Figure 4.7. The above diagram shows a simplified process flow and the system boundaries for citrus waste ethanol life cycle stage 1 (raw material acquisition), which includes land preparation, seedling propagation, tending, and harvest.

4.3.1.1.2 Units

The basis for this portion of the life cycle is one hectare of harvested land in one year (1 ha-yr). Most US agricultural data are reported in English units; therefore, both metric and English units will be used in the tracking of flows. Although it is more common to use the harvested product as the reference flow, this value can vary significantly because of the range in crop yields. In addition, the material and energy flows associated with this life cycle stage are much more tightly coupled to the amount of land acted upon than they are to the mass of plant matter removed. A final transformation to mass of fresh citrus fruit produced per area of land per year (kg/hectare-yr) is performed at the end of this stage, along with the embodied inventories, for input into the second stage of the life cycle where the basis is one kilogram (1 kg) of fresh fruit with variances noted as a function of harvest yield.

4.3.1.1.3 Resources

Growing citrus tress requires, as do all agricultural products, sunlight, land (soil), water, and nutrients. Sunlight is limited by climate and location of the field (degrees latitude). The amount of land that must be committed (actively managed) in order to produce a hectare of citrus fruit is greater than the final harvested area. The first few years after planting, seedlings do not produce fruit. In addition, a certain amount of land (or equivalent) is required to raise seedlings. There are also crop failures and diseases that require tree removal. The amount of land suitable for growing citrus is limited by climate, terrain, and competing demands from both within and external to the agricultural sector. While rain is an important source of water, all citrus grown in the US is irrigated in order to manage the timing of water received by the trees, even in areas that receive adequate precipitation. Nutrients naturally available in the soil are insufficient for commercially viable yields, thus these must also be supplied. Equipment, buildings, and energy in the form of electricity and liquid fuel are required to manage these resources.

4.3.1.2 Unit Operations and Activities

The unit operations involved in the growing of citrus trees include: land preparation and management, planting of seedlings, tending (including application of fertilizer and pesticides, irrigation, and trimming), harvesting, and storage and transportation on the farm.

The specific list of activities that are performed within these unit operations and their descriptions are taken from cost and return documents that are supplied by state agricultural extension services as planning aids for citrus farmers. Citrus trees are grown in orchard groves at typical densities of 100 to 150 trees per acre (250 to 370 trees per hectare) depending upon the variety of tree and specific location. Trees can live for more than 30 years, but they are typically removed and replaced when production falls below 50% of the expected yield (Muraro *et a*l., 2004). The proportion of land affected by different activities and unit operations is derived from Muraro and others (2004) and is taken to be representative of US citrus including very young trees (Table 4.11).

Table 4.11. Percent of US citrus cropland area affected by different activities and unit operations (based on Muraro *et a*l., 2004)

Percentage of Land Area	Activity	Unit Operation (s)
3%	Pull and reset trees	Land preparation. Planting
6%	Grow 1 to 2-year old trees (non-producing)	Tending
91%	Grow producing trees	Tending. Harvesting

Citrus growers prefer to delay planting trees until they are near fruit-bearing age (3 to 4 years). Young grafted trees are typically grown in nurseries until that time; however, documentation of the resources required to grow trees in nurseries was not available. The 2007 agricultural census (USDA, 2009) indicates that 94% of citrus cropland is bearing, rather than 91% as indicted by Muraro and others (2004). This 3% delta is taken to be a surrogate for propagation and nurturing of young trees. Based on this, all of the inventories under the tending unit operation are burdened by an additional 3% to account for trees grown in nurseries rather than on cropland.

4.3.1.2.1 Land preparation and management

4.3.1.2.1.1 General Description:

The initial activity in establishing an orchard is to prepare the land for planting trees. Soil must be loosened to facilitate root growth and beds are formed to facilitate tending and harvesting operations. Irrigation and drainage systems are also created at this time. The activities include defining the layout and rows, using tractor implements to improve the soil texture, and contouring beds (Hinson *et al*., 2006). All citrus cropland is initially subjected to this unit operation. If a 50-year life-span for the orchard is assumed, the initial activity rate can be amortized at one-fiftieth (0.02) per hectare-year. Once the orchard is established, approximately 3 to 4 percent of old, non-productive, or diseased trees are removed per year and the land is reworked in preparation for the planting of new trees. Steps include removal of existing trees, plowing and grading the site, and laying and/or replacing drainage and irrigation systems. In Florida, where citrus greening is a problem, up to 5% of the trees may require replacement in any given year (Muraro, 2008a; 2008b); grapefruit also requires replacement at a rate of 5% per year (Muraro and Hebb, 2005). It is assumed in this analysis that 4% of the land is subjected to tree-removal and site preparation/repair on an annual basis; thus, including the amortized initial preparation of the site, the burdened total for land preparation is taken to be 6% of the citrus cropland.

Most of the budgets provided by the state agricultural extensions do not include detailed information regarding equipment used in the operation of citrus orchards. This is because it is generally assumed that these activities are outsourced and because chemical management is a much more significant expense than machinery. Louisiana is not currently known for commercial citrus production, but evidently there is interest. The extension service had developed an information series document (Hinson *et al*., 2006), with very detailed information regarding equipment required in the first five years of establishing a citrus orchard, including land preparation. The list of equipment supplied by the Louisiana document is used in this analysis to model the initial land preparation as well as annual land related activities. California also provides information about start-up costs for an orange grove (O'Connell, *et al*, 2009). While there is less information with regards to specific cultivation implements (such as fuel use and performance rates), the general description of the operation, as well as the type of equipment and activities employed, appear to be similar to that expected for Louisiana.

4.3.1.2.1.2 Activities

The first step in preparing land for planting is deep ripping of the soil to a depth of 4 to 6 feet, which is done to break up compacted and stratified layers that could affect root and water penetration. The ground is disced two to six times (typically at right angles) in order to break up large clods. Finally the ground is leveled (O'Connell, *et al*, 2009).

For subsequent maintenance of the land, (i.e., during tree replacement), it is assumed that the activities would be similar to those used during establishment of the orchard, except that it would not require the use of implements needed for primary tillage. The 2008 Texas budget reports a cost of $150 per acre per year for annual tree removal and land management; the Florida 2008 budget for central Florida gives a range of roughly $120 to $240 per acre, depending upon the percentage of trees removed (2.5 to 5%) (Muraro, 2008a; 2008b). The sum fixed and variable cost of land preparation in Louisiana, excluding the plow and blade, is $123, which is consistent with the prices assumed for custom work in Texas and Florida. The California budget (O'Connell, *et al*, 2009) assumes that the new orchard is established on the site of an old one and includes tree removal. Tree removal is not included in this analysis, as it is not clear how representative it is of US practice. Tree removal is, however, part of annual maintenance in a mature citrus grove. This is commonly achieved using a tree shear mounted to a front-end loader, in a process that is referred to as “clipping” or “clip-shear.” Stumps are treated with an herbicide and removed trees are subsequently burned (Muraro, 2008a; Futch, *et al*, 2008). Alternatively a spade may be mounted to the front-end loader for complete tree removal.

A list of the equipment, reflecting the activities performed during land preparation in Louisiana, is presented in Table 4.12. This is taken to be representative of US citrus groves. The first three pieces of equipment are used to condition and form the soil both initially and on an annual basis. The front loader is used in the tree removal process only.

Table 4.12. Equipment used in the land preparation unit operation for citrus (based on Hinson *et al*., 2006)

Equipment	Size/ Unit	Unit Power (HP)	Fuel Use Rate		Performance Rate		Times Over	Fuel Consumption	
			gal/hr	liters/hr	hr/ac	hr/ha		gal/acre	liters/ha
1 Row Disk	6 ft	50	2.57	9.73	0.57	1.41	4	5.9	54.8
1 Row Disk Bed (Hipper)	3 ft	50	2.57	9.73	0.75	1.85	2	3.9	36.1
Subsoiler	1 shank	50	2.57	9.73	0.5	1.24	1	1.3	12.0
Initial Land Prep Only									
Plow	6 ft	50	2.57	9.73	1.52	3.74	1	3.9	36.4
Blade	6 ft	50	2.57	9.73	2.50	6.18	1	6.4	60.1
Maintenance Only									
Front-end Loader *		50	2.57	9.73	1.00	2.47	1	2.6	24.0
TOTAL								12.9	120.6

*Assume similar to 50 hp tractor with a performance rate of 1.0 hr/ac, Muraro et al., 2004

4.3.1.2.2.3 Direct Material and Energy Flows

The direct material and energy flows associated with the land preparation and management unit operation include land, diesel fuel to power the equipment, as shown in Table 4.12, and emissions to air.

Emissions to air include criteria air pollutants (or precursors thereof) as well as greenhouse gas emissions. Criteria air pollutants that result from the burning of diesel fuel in the equipment listed in Table 4.12 are calculated from the formulas and emission factors used in the US Environmental Protection Agency's NONROAD model (EPA, 2004; EPA, 2005). The equipment population is based on lifetime expectancies for the equipment (Hinson *et al*., 2006), with most of the equipment at or near the median age. With estimated lifetimes of 10 years or more, most of the equipment in 2007 is assumed to be model years 2001 to 2004 and because it is all low power equipment (50 horsepower) it is primarily Tier 1 technology. The sulfur content of the diesel fuel is assumed to be 0.05 wt%, as would be expected for agricultural equipment in 2007. Additional details are provided in section 4.3.1.3.4 of this report. Emissions in grams per liter and grams per hectare for the initial land preparation are given in Table 4.13. Emissions in grams per liter and grams per hectare for land maintenance are given in Table 4.14.

Table 4.13. . Emissions in grams per liter (g/liter) of diesel fuel burned and grams per hectare (g/ha) for initial land preparation (based on emission factors from the NONROAD model (EPA, 2004; 2005) and equipment data from (Hinson *et al*., 2006))

Equipment	Unit Power (HP)	Fuel Use liters/ha	Emissions g/liter					Emissions g/ha				
			VOC	CO	NOX	PM	SO_2	VOC	CO	NO_X	PM	SO_2
1 Row Disk	50	54.8	0.85	4.68	6.37	0.74	0.23	46	256	349	40	13
1 Row Disk Bed (Hipper)	50	36.1	1.69	9.36	12.75	1.48	0.46	61	337	460	53	17
Subsoiler	50	12.0	3.38	18.72	25.49	2.95	0.93	41	225	306	35	11
Plow	50	36.4	3.38	18.72	25.49	2.95	0.93	123	682	928	107	34
Blade	50	60.1	3.38	18.72	25.49	2.95	0.93	203	1125	1532	177	56
TOTAL		199.4						475	2626	3576	414	130

Table 4.14. Emissions in grams per liter (g/liter) of diesel fuel burned and grams per hectare (g/ha) for land maintenance (based on emission factors from the NONROAD model (EPA, 2004; 2005) and equipment data from (Hinson *et al*., 2006))

Equipment	Unit Power (HP)	Fuel Use liters/ha	Emissions g/liter					Emissions g/ha				
			VOC	CO	NO_X	PM	SO_2	VOC	CO	NO_X	PM	SO_2
1 Row Disk	50	54.8	0.85	4.68	6.37	0.74	0.23	46	256	349	40	13
1 Row Disk Bed (Hipper)	50	36.1	1.69	9.36	12.75	1.48	0.46	61	337	460	53	17
Subsoiler	50	12.0	3.38	18.72	25.49	2.95	0.93	41	225	306	35	11
Front Loader	50	24.0	3.38	18.72	25.49	2.95	0.93	81	450	613	71	185
TOTAL		126.9						229	1269	1728	200	225

Greenhouse gas emissions from burning of diesel fuel are estimated using IPCC emission factors (IPCC, 2006a). The default carbon dioxide (CO_2) emission rate for agricultural diesel operations is 74.1 kilograms (kg) of CO_2 per gigajoule (GJ) of fuel burned. If diesel is assumed to have a lower heating value (LHV) energy content of 0.0358 GJ/liter (ANL, 2009), this is equivalent to 2.65 kg CO_2 per liter of diesel burned. Similarly, the IPCC default value for methane (CH_4) is 4.15 kilograms per terajoule (TJ) and the default value for N_2O is 28.6 kg/TJ. These equate to emissions of 0.149 and 1.02 grams of CH_4 and N_2O, respectively, per liter of diesel combusted. Applying these values to the total fuel consumed during land preparation (199.4 liters per hectare), the operation of diesel powered equipment results in per hectare emissions of 529 kg of CO_2, 0.0296 kg of CH_4, and 0.204 kg of N_2O. Similarly land maintenance, with 126.9 l/ha diesel consumed results in per hectare emissions of 337 kg of CO_2, 0.0189 kg of CH_4, and 0.130 kg of N_2O.

In addition to emissions that are released through the use of diesel fuel, a number of gaseous species are emitted to the atmosphere during tree burning. Many of these may contribute to net greenhouse emissions and/or criteria air pollutant levels. The total emissions released depends upon the amount of matter that is available to be burned (fuel), the fraction that is actually burned (the combustion factor), and the emission factor for each species (the amount of a given compound that is release when a unit amount of biomass combusts.

Calculation of both criteria and greenhouse gas emissions due to burning is based on 2006 Intergovernmental Panel on Climate Change Guidelines, Volume 4, Equation 2.27 Estimation of Greenhouse Gas Emissions from Fire (IPCC, 2006).

$$E_{burn,k} = M_{BM} * C_f * EF_{BM,\mathrm{k}} \tag{4.3}$$

where:

$E_{burn,k}$ is the mass of emissions for species k emitted per hectare

M_{BM} is the mass of biomass per unit area that combusts; it replaces $A * M_B * C_f$ in IPCC Eq 2.27.

$EF_{BM,\mathrm{k}}$ is the emissions factor for species k as given for agricultural residues per unit mass of dry matter. It is equivalent to factor G_{ef} in IPCC Eq 2.27.

Table 2.4 in the IPCC guidelines estimates that trees in a temperate forest, when felled and burned, provide 48.4 tonnes of combustible material (dry matter) per hectare. Using a combustion factor of 51% (IPCC, 2006b, Table 2.6), the original density of plant matter would be 95 tonnes of dry matter per hectare. Trees grown in a citrus orchard are estimated to have half the mass per unit area as compared to a natural setting, but the combustion would likely be close to 100%. This analysis assumes that 45,000 kg of dry matter per hectare of trees removed is burned.

Table 4.15 presents the emission factors for gaseous species that contribute to greenhouse gases and criteria pollutants and the estimated mass of emissions emitted per hectare of trees removed. Emission factors are from Andre and Merlet, 2001, which are also used in the IPCC guidelines (IPCC, 2006b, Table 2.5). The carbon monoxide and VOCs emitted are expected to be quickly converted to CO_2, and its equivalent carbon will be reabsorbed in the replacement tree. Therefore the net contribution to greenhouse gases for these three species is assumed to be zero.

Table 4.15. Emission factors (grams emitted per kilograms of dry matter burned), and total emissions by species (kilograms per hectare) per hectare of trees removed and burned. Emission factors from Andre and Merlet, 2001 and IPCC, 2006b).

	Emission factor (g emitted / kg dry matter burned)	Mass (kg) emitted per hectare of trees removed
CO_2	1569	70,605
CH_4	4.7	212
N_2O	0.26	12
CO	107	4,815
NO_X (as NO)	3	135
SO_2	1	45
PM	17.6	792
VOC (as NMHC)	5.7	257

The overall material and energy flows for this unit operation are summarized in Table 4.16.

Table 4.16. Direct material and energy flows for land preparation and maintenance of US citrus cropland.

Resource	Preparation	Maintenance			Calculation	Value	Units
Land	0.02 / yr	0.04 / yr			(0.02 + 0.04) ha / 1 ha-yr	0.06	1/yr
Diesel							
Volume	199	127			(0.02 / yr * 199 + 0.04 / yr * 127) l / ha	9.1	l/ha-yr
Mass [1]	167	106			9.1 liters / ha-yr * 0.837 kg / liter	7.6	kg/ha-yr
Energy [1]	7,139	4,544			9.1 liters / ha-yr * 35.8 MJ / liter	325	MJ/ha-yr
Criteria Air Pollutants and Precursors							
	Preparation	Maintenance					
Species	Diesel	Diesel	Burn	Total	Calculation	Value	Units
VOC	475	229	257	486	(0.02 / yr * 475 + 0.04 / yr * 486) l / ha	29	kg/ha-yr
CO	2,626	1,269	4,815	6084	(0.02 / yr * 2,626 + 0.04 / yr * 6084) l / ha	296	kg/ha-yr
NO_X	3,576	1,728	135	1863	(0.02 / yr * 3,576 + 0.04 / yr * 1863) l / ha	146	kg/ha-yr
PM	414	212	792	1004	(0.02 / yr * 414 + 0.04 / yr * 1004) l / ha	48	kg/ha-yr
SO_2	130	12	45	57	(0.02 / yr * 130 + 0.04 / yr * 57) l / ha	5	kg/ha-yr
Greenhouse Gases							
CO_2	528	336	0	336	(0.02 / yr * 528 + 0.04 / yr * 336) l / ha	24	kg/ha-yr
CH_4	0.030	0.019	212	212	(0.02 / yr * 0.030 + 0.04 / yr * 212) l / ha	8.46	kg/ha-yr
N_2O	0.203	0.129	12	11.83	(0.02 / yr * 0.203 + 0.04 / yr * 11.83) l / ha	0.48	kg/ha-yr

[1] US conventional diesel (default inputs to GREET (ANL, 2009)

Density is 3167 grams per gallon, equivalent to 0.837 kg/liter.

Lower heating value (LHV) energy content is 128,450 Btu per gallon, equivalent to 35.8 MJ/liter

4.3.1.2.2 Propagation

Trees are not planted from seed, but rather obtained from nurseries. Citrus trees are generally propagated by grafting a twig or bud from a "parent" tree with desired traits to rootstocks grown from seeds. This preserves the desired genetic characteristics in the tree. Seedlings are grown in a nursery for 1 to 2 years before being planted in a commercial grove at densities of up to 150 trees per acre (370 trees per hectare) (Braddock, 1999). Trees are planted and their trunks subsequently wrapped by hand. Therefore, the primary resource is labor, which is not accounted for in this analysis. The upstream inputs required to grow the seedlings is estimated by burdening the tending unit operation by 3%. (See the discussion under section CS.3.1.2 of this report). While this is not the most the most precise accounting method, the resources used in the nursery operation are expected to scale relatively well and the overall contribution to the life cycle is believed to be relatively small.

4.3.1.2.3 Tending

4.3.1.2.3.1 General Description

The primary objectives of tending are to maintain a weed-free environment, to protect the trees and fruit from damaging insects, microbes and frost, and to provide the plants with adequate water and nutrients. Trees are also trimmed to keep limbs away from the ground, and to reduce the amount of vegetative growth. There are slight differences in the treatment of young trees (within the first five years of planting) than with mature ones.

While weeds historically have been managed through mechanical cultivation, herbicides are currently extremely important tools for the citrus farmer in managing unwanted growth. The weed population needs to be minimized in order to eliminate plants that could compete with the shallow-rooted citrus trees for both water and nutrients. In addition, weeds tend to reflect solar energy, which prevents the underlying soil from heating up during the day. Without nighttime radiant heat from the underlying ground, trees are at increased risk of frost damage in cold weather (O'Connell, *et al*., 2009).

The use of insecticides on citrus has increased recently, especially in Florida, due to the introduction of huanglongbing (HLB) disease, or "citrus greening," within the last 10 years. The bacteria that cause HLB are carried and spread by Asian citrus psyllids, insects. While HLB has not yet been found in Arizona and Californa, citrus psyllids have been observed in both states during 2009 and there is concern that the disease could begin affecting citrus crops outside of Florida. This is a serious threat to the US citrus industry, as the disease is fatal to the trees and cannot be cured; infected trees are destroyed to prevent its spread.

At any given time, it is assumed that 97% of citrus cropland has trees that are being tended (Table 4.11). A total of 85% of the land contains trees that are at or near maturity. The remaining 12% consists of trees that have been planted within the last 4 years. There are variations in the management of trees within this population of mature and maturing trees (e.g., specific spray and cultivation programs). While the Florida budgets, which account for 90% of the US citrus production slated for processing rather than the fresh market, note that young trees need different spray and fertilizer programs, they do not describe the specifics of these activities. California, Texas, and Louisiana do provide a significant amount of detail regarding the cultivation of young trees. However, these data are not used for the following reasons: 1) the fruit from these states represent a small portion of the total population, 2) the young trees occupy a small portion of the land 3) while the specific activities and material flows (e.g., types of formulations used) may vary, the total mass does not change significantly and 4) merging data between different management systems is not necessarily straightforward.

Florida oranges and grapefruit, combined with California oranges and lemons, account for 96% of all US citrus waste (Table 4.3) and are taken to represent all citrus feedstock of interest in this study. Florida oranges constitute roughly 80% of this total. Data regarding oranges grown for processing in both central and southwestern Florida are provided by the University of Florida, Citrus Research and Education Center (Muraro, 2008a; 2008b). According to the 2007 Census (USDA, 2009), approximately 60% of Florida oranges are grown in the center of the state (primarily Polk and Highlands Counties) and roughly 40% are grown in the southwest region (primarily Hendry County). Activity data for these two populations of oranges are weighted accordingly. Thus, central and southwestern Florida oranges are taken to represent 48% (80% of the US * 60% of Florida) and 32% (80% of the US * 40% of Florida) of US citrus waste, respectively. Florida grapefruit is assumed to represent all US production of grapefruit for processing. The available data for Florida grapefruit (Muraro, 2008b; 2008c) describe fruit grown for the fresh market rather than for processing. Because appearance is important when selling fresh citrus, management systems for fresh fruit may be slightly more intense than for grapefruit grown for the purpose of processing it into juice. However, differences in cultivation practices are relatively minor and not likely to be significant to the overall analysis, especially given that grapefruit represents only 10% of the total citrus waste produced. Practices used on California oranges and lemons are from the University of California Cooperative Extension (O'Connell, *et al*, 2009, O'Connell, *et al*, 2005) and are taken to equal 6% and 4% of US citrus waste, respectively. California lemons are assumed to be characteristic of all US lemons.

4.3.1.2.3.2 Activities

The general approach to tending citrus is relatively similar between states and fruit types. Most of the variation occurs in the specific nutrients and pesticides that are applied. However, there are enough differences between the data sources, that a weighted average approach is used in applying activity data from specific states and fruit types to a general model for the US. Where there are clear and documented differences between the practices of a state and/or fruit, the activity data are weighted based on the estimated US citrus waste fraction (Table 4.17); otherwise, the best available information is applied equally to all fruits and regions.

Table 4.17. Amount of citrus waste by state and fruit type and corresponding weight applied to activity data as applicable; data sources as indicated

State/Fruit	Weight given to activity data	Primary Source of Activity Data
Florida Oranges, Central Region	48%	Muraro, 2008a
Florida Oranges, SW Region	32%	Muraro, 2008b
Florida Grapefruit, SW region	5%	Muraro, 2008b
Florida Grapefruit, Indian River	5%	Muraro, 2008c
California Oranges	6%	O'Connell, et al, 2009
California Lemons	4%	O'Connell, et al, 2005
	100%	

Because of the level of detail provided, activity data specific to equipment operation (fuel use and performance rates (time per unit area)) are taken from the Louisiana extension service (Hinson *et al*., 2006). With the exception of mowing, all equipment use is related to distribution of pesticides and nutrients. General descriptions of the equipment used in Florida and California allow reasonable matches to be made with specific equipment described in the Louisiana budget.

A list of tending activities that use equipment powered by a 50 horsepower tractor is presented in Table 4.18. The number of times the piece of equipment is used, according to state and fruit type, is also indicated. Table 4.19 indicates fuel consumption, with the number of uses per hectare-year weighted per the values in Table 4.18. Fertilization in California is accomplished by including nutrients either in the irrigation system or in combination with pesticide sprays (as a foliar application) and thus is not reflected in a separate piece of equipment. Mowing is not mentioned for California, although this activity occurs 3 to 4 times per year in Florida.

Table 4.18. Tending activities powered by a diesel tractor, corresponding implements, use rates (times over area per year) by state and fruit type, and weighted use rate for US citrus.

		Oranges			Grapefruit		Lemons	Citrus
		Central FL	Southwest FL	CA	Southwest FL	Indian River FL	CA	US
Activity	Equipment	48%	32%	6%	5%	5%	4%	Weighted Mean
Mow middles	Rotary Mower	4	3	0	3	3	0	3.18
Mow brush after hedging	Rotary Mower [1]	0.5	0.5	0.5	0.5	0.5	1	0.52
Chemical mow	Sprayer Boom	3	3	0	3	3	0	2.7
Herbicide application	Sprayer, Air blast	3	3	0	3	3	0	2.7
	Sprayer Boom	0	0	5	0	0	5	0.5
Fertilizer application	Fertilizer Spreader	4	4	0	4	4	0	3.6
Insecticide and other applications *	Sprayer Boom	2 or 6 [2]	2 or 6 [2]	5 or 7 [3]	6 or 9 [2]	6 or 10 [2]	4	
	mean	4	4	6	7.5	8	4	4.495

[1] Surrogate for a shredder or chopper

[2] Higher value applies when HLB is present

[3] Higher value applies for navel (as opposed to Valencia) oranges

Table 4.19. Equipment (tractor implements) used in the tending unit operation for citrus

Equipment	Size/ Unit	Unit Power (HP)	Fuel Use Rate		Performance Rate		Times Over	Fuel Consumption	
			gal/hr	liters/hr	hr/ac	hr/ha		gal/acre	liters/ha
Rotary Mower	6.7 ft	50	2.57	9.73	0.40	0.99	3.7	3.8	35.6
Sprayer Boom	1 row	50	2.57	9.73	1.00	2.47	3.2	8.2	76.9
Sprayer, Air blast	16 ft	50	2.57	9.73	0.33	0.82	2.7	2.3	21.6
Fertilizer Spreader	6 ft	50	2.57	9.73	0.39	0.97	3.6	3.6	33.9
TOTAL								18.0	168.0

Activities not reflected in the above list of equipment include irrigation, frost protection, and pruning. Pruning is typically performed in biennial cycles, depending on which part of the tree is being trimmed (bottom branches, sides, or tops). As this is usually done by hand, there is no use of resources other than labor. The trimmings are chopped or shredded upon completion of the pruning. A rotary mower is use as a surrogate for a shredder in Table 4.18.

All commercial US citrus is irrigated; in Florida and California it is assumed that irrigation systems are low volume. Florida uses microsprinklers for irrigation; most of which are fueled by diesel powered pumps. California uses drip irrigation and supplies fertilizer and soil amendments, such as gypsum, through the irrigation system. No information was provided in the California costs and returns study regarding the means by which the irrigation system is powered, but at an average of $10.75 per acre-inch it is presumed to be propane rather than electric or diesel powered pumps, both of which would be notably more expensive. (The California study estimates the cost of diesel to be $3.70/gallon, while propane is priced at $1.97/gallon). Gypsum is incorporated into the irrigation system using a pump, designed specifically for this purpose and is referred to as a gypsum machine. Gypsum ($CaSO_4 \cdot OH$) provides a ready source of calcium, increases the pH, and acts as a soil conditioner such that water infiltration is improved. No mention is made of either fuel or power requirements to operate the gypsum machine; a 10% burden is added to the irrigation system requirements to account for it.

Citrus is very intolerant of freezing temperatures. Both California and Florida use supplemental irrigation as a means of frost protection. In addition, California uses propane-powered wind machines to mix low level cold air with upper-level warm and thus increase the temperature near the ground in the vicinity of the trees. Effective use of wind machines requires strong temperature inversions (gradients of more than 5º F), which tend to occur when there is no cloud cover (Venner and Blank, 1995). Florida tends to have a lower incidence of effective inversions and the water supply is less critical than in California; therefore, cold protection programs rely on supplemental watering to raise the temperature.

4.3.1.2.3.3 Direct Material and Energy Flows

The direct material and energy flows associated with the tending unit operation include diesel fuel to power the equipment (168 liter per hectare-year), as shown in Table 4.19, as well as additional energy to power irrigation pumps, addressed below in section CS.3.1.2.3.3.2. The California budget includes gasoline to power a half-ton pickup truck and estimates fuel usage at 9.26 gallons per acre-year. Although this is not mentioned in the Florida budget, it seems a likely activity for any citrus grove and is modeled as representative for all of the US. Nutrients and pesticides are applied in both dry and liquid form. Water is added through irrigation and removed through drainage and through the plants (evapotranspiration). Emissions to air include both criteria air pollutants and their precursors and greenhouse gases. They are associated primarily with the operation of diesel equipment and the application of fertilizer.

4.3.1.2.3.3.1 Water

The US Geological Survey reports that in 2005, a total of 996 x 10^6 gallons per day (1.38 x 10^{12} liters per year) were withdrawn for Florida citrus agriculture (Marella, 2008). During the 2004/2005 and 2005/2006 seasons, Florida had an average of 608,900 acres of bearing citrus (ERS, 2007). Multiplying this by 1.06 to account for land with non-bearing trees gives 645,400 acres (261,200 ha) planted in citrus. From this data, water withdrawals for irrigation of Florida citrus are determined to be 5.27 x 10^6 liters per hectare-year (0.563 x 10^6 gallons per acre-year). This water is used primarily for irrigation, but a small portion (less than 10%) is used for freeze protection. These water use rates are slightly higher, but not inconsistent with a study completed by Romero and others (2009), which examined irrigation water used in Highlands, Polk, and Hillsborough Counties, but which did not include water used for cold protection.

Crop evapotranspiration (ET_C) for Florida citrus is estimated to be 1200 mm per year (Consoli *et al*., 2006; Romero, *et al*., 2009)). This is equivalent to the amount lost to the atmosphere. Thus, the total volume of water consumed for Florida citrus is equal to 1.20 meter * 10,000 m2 or 10,000 m3 per hectare-year, which is equal to 12.0 x 10^6 liters per hectare-year (1.28 x 10^6 gallons per acre-year). The average rainfall in the citrus growing regions of Florida (Polk, Highland, Hendry, and Indian River Counties) is 1300 mm per year (WorldClimate, 2008), which is equivalent to 13 x 10^6 liters per hectare-year. The total amount of water supplied by rainfall plus irrigation is 18.27 x 10^6 liters of water per hectare-year ([5.27 + 13] x 10^6 liters/ha-yr), or 6.27 x 10^6 liters/ha-yr more than the trees actually require. This discrepancy is partly due to irrigation inefficiency and freeze protection, but primarily it is the result of less than perfect correlation between when rain falls and when the trees need water. All of the excess water, which is drained to surface waters, would be degraded by the presence of suspended soils as well as chemical run-off (pesticides and fertilizers) from the surrounding cropland.

The recommended amount of water needed to irrigate California oranges using a low volume drip system is 30 acre-inches (2.5 acre-feet) per year (O'Connell, *et al*, 2009); lemons require 33 acre-inches (2.75 acre-feet per year) (O'Connell, *et al*, 2005). Both fruit use an additional 2.2 acre-inches per year for frost protection for a total of 2.7 to 2.9 acre-feet per year. An acre-foot is the volume of water that would cover an acre to the depth of one foot and is equal to 325,851 gallons (1,233,480 liters) of water. Thus, orange groves in California require 0.874 x 10^6 gallons per acre-year (8.18 x 10^6 liters/ha-yr) for low volume irrigation. Lemon groves need 0.956 x 10^6 gallons per acre-year (8.94 x 10^6 liters/ha-yr). The irrigation rates are weighted according to factors assigned California orange waste and lemon waste, 6% and 4% respectively (Table 4.17).

Annual rainfall of approximately 250 mm is received in the major orange growing regions of California (Tulare, Fresno, and Kern Counties) (WorldClimate, 2008). This is equal to 2.5 x 10^6 liters per hectare-year. Drip irrigation systems are very efficient, in that water is applied only where needed (near the roots of the tree). Assuming this is only 60% of the total land area, the irrigation depth achieved with 2.8 acre-feet would be equivalent to an irrigation depth of 4.7 feet (1400 mm). Summing precipitation and effective irrigation depth yields 1650 mm per hectare-year available to the citrus trees. Annual crop evapotranspiration (ET_C) for California citrus were not found. Hourly values for July and August are given by Consoli and others (2006). Using a very rough interpretation of the graphical data presented, it appears that annual rates for California are perhaps 30% higher than those for Florida, or 1600 mm per year. If this is correct, 1.60 meter * 10,000 m2 or 10,000 m3 per hectare-year, or 16.0 x 10^6 liters per hectare-year is consumed. This would be consistent with highly efficient use of irrigation and precipitation as described above and is taken to be the consumption for California citrus.

A summary of water used in the tending unit operation is given in Table 4.20.

Table 4.20. Water used in the tending unit operation for citrus

State / Activity	Withdrawals		Consumption		Weighted Value
	10^6 liters/ha-yr	10^6 gal/ac-yr	10^6 liters/ha-yr	10^6 gal/ac-yr	
Florida / Irrigation & Freeze Protection	5.27	0.56	12	1.28	90%
California Orange / Irrigation & Freeze Protection	8.18	0.87	16	1.71	6%
California Lemon / Irrigation & Freeze Protection	8.94	0.96	16	1.71	4%
US weighted average	5.59	0.60	12.40	1.32	100%

4.3.1.2.3.3.2 Energy for Irrigation and Freeze Protection

The California costs and returns document estimates that water for irrigation costs an average of \$10.75 per acre-foot (O'Connell, *et al*, 2009), but does not indicate the energy source used for pumping. As the budget does allow for gas storage tanks, it is assumed that the pumps are fueled by propane, at \$1.97 per gallon. This would place fuel usage at 5.5 gallons per acre-foot, or 14.8

gallons per acre (138 liters/ha) for oranges and 15.9 gallons per acre (149 liters/ha) for lemons. Propane has an energy value of 84,950 Btu/gallons LHV (ANL, 2009), which is equal to 23.68 MJ/liter. Thus total energy used to irrigate and provide water as part of a freeze protection program, requires 3,289 MJ/ha-yr and 3,533 MJ/ha-yr for California oranges and lemons respectively. A 10% burden is added to each to account for operation of the gypsum machine to give final estimates of 3,618 MJ/ha-yr for oranges and 3,886 for lemons. Weighting these by the proportion of US citrus for processing that each of these represents gives:

$$0.06 * 3{,}618 \text{ MJ/ha-yr} + 0.04 * 3{,}886 \text{ MJ/ha-yr} =$$

$$372.5 \text{ megajoules / hectare-year} \qquad (4.4)$$

Frost protection in California includes the use of wind machines, which pulls warm air from above the trees and mixes it with the colder air near the ground. Each of these propane powered machines protects 10 acres and uses 15 gallons of propane per hour (O'Connell, *et al*, 2009). Annual use is estimated to be 100 hours per machine (Venner and Blank, 1995). Dividing this by the 10 acres per machine gives a performance rate of 10 hours per acre. Fuel use is thus 150 gallons/ac-yr or 1400 liters/ha-yr. Given 23.68 MJ per liter of propane (LHV), the total energy demand for wind machines is 33,225 MJ/ha-yr. Weighting this by 10% to account for the proportion of US citrus for processing that California represents gives 3,323 MJ/ha-yr.

In Florida, diesel to power microsprinker irrigation systems was estimated to cost $93.16 per acre in 2008 (Muraro, 2008a; 2008b; 2008c). At $2.50 per gallon, this equates to 37.3 gallons of diesel per acre-year (349 liters/ha-yr). Diesel has an energy value of 128,450 Btu/gallons LHV (ANL, 2009), which is equivalent to 35.8 MJ/liter. Consequently the energy requirement for irrigation of Florida citrus is estimated to be 12,479 MJ/ha-yr. Weighting this by 90% to account for the proportion of US citrus for processing that Florida represents gives 11,231 MJ/ha-yr.

A summary of fuel used in the tending unit operation, including gasoline and diesel used to operate machinery is given in Table 4.21.

Table 4.21. Summary of direct fuel and energy use in the tending unit operation

State / Activity	Weight	Fuel Consumption			Fuel Type	Energy Value [4] (LHV) MJ/liter	Energy Use
		gal/ac-yr	liters/ha-yr	wtd l/ha-yr			MJ/ha-yr
US, 1/2 ton pickup truck [1]	100%	9.3	87	87	Gasoline	32.36	2,803
US, tractor implements [2]	100%	18.0	168	168	Diesel	35.80	6,016
FL Citrus, water pumps	90%	37.3	349	314	Diesel	35.80	11,231
CA Citrus, wind machines	10%	150.0	1403	140	Propane	23.68	3,323
CA Orange, water pumps	6%	14.8	138	8	Propane	23.68	197
CA Lemon, water pumps	4%	15.9	149	6	Propane	23.68	141
CA Orange, gypsum machine [3]	6%	1.5	14	1	Propane	23.68	20
CA Lemon, gypsum machine [3]	4%	1.6	15	1	Propane	23.68	14
US weighted TOTAL							19,278

[1] Listed for California; assumed applicable to all US

[2] Table 4.19, this report

[3] Assumed as 10% of water delivery

[4] ANL, 2009, converted from Btu/gallon

4.3.1.2.3.3.3 Major Nutrients

A weighted average of 218 kilograms of nitrogen per hectare is added to US citrus crops per year. In Florida, nitrogen is applied in mixed dry form, combined with a nearly equal amount (204 kg /ha-yr) of potassium as K_2O. Magnesium (MgO) is also included in the mixture and is applied at rates of 34 to 56 kg/ha-yr. Phosphorous is added to Florida grapefruit and to oranges in the southwestern region of the state. Only nitrogen fertilizer is used in California (O'Connell *et al*., 2009, Table 4), at rates that are about half that used in Florida. It is applied either through the irrigation system as a urea ammonium nitrate solution (UN-32 (32-0-0)) or as a foliar spray (urea low biuret (46-0-0). Biuret is a phytotoxic impurity found in all urea, but which can be particularly problematic when sprayed on leaves, as it can cause burning. The values for each state and fruit along with the weighted average for the US are given in Table 4.22.

Table 4.22. Major nutrients applied to US citrus during the tending unit operation

State / Fruit	Form	Percent of US	Nitrogen (N)		Phosphorous (P_2O_5)		Potassium (K_2O)		Magnesium (MgO)	
			lb/ acre-yr	kg/ ha-yr	lb/ acre-yr	kg/ ha-yr	lb/ acre-yr	kg/ ha-yr	lb/ acre-yr	kg/ ha-yr
FL Oranges, central	16-0-16-4 MgO	48%	200	224	0.00	0	200	224	50	56
FL Oranges, SW	17-4-17-2.4MgO	32%	220	247	51.8	58	220.0	247	31.1	35
FL Grapefruit	16-2-16-3MgO	10%	160	179	20	22	160	179	30	34
CA Oranges	UN-32 (32-0-0)	6%	80	90	0	0	0	0	0	0
CA Lemons	UN-32 (32-0-0)	4%	100	112	0	0	0	0	0	0
CA Citrus	Urea Low Biuret (46-0-0)	10%	30	34	0	0	0	0	0	0
Weighted US TOTAL				217.7		20.8		204.4		41.4

4.3.1.2.3.3.4 Herbicides

The herbicide diuron, sold under the trade name Karmex DF is used in cultivation of all citrus crops in Florida and California and is taken to be representative of the US. It is applied at a rate of 4 lbs of active ingredient per acre per year (4.48 kg/ha-yr). Glyphosate (Roundup) is also used ubiquitously, although the noted rate of use in Florida is higher than in California. This may be related to the higher humidity in Florida or under-estimating in California. The (weighted) mean application rate of the active ingredient (a.i.) for the US is 2.82 kg a.i./ha-yr. The herbicide norflurazon is used at the rate of 3 lb a.i./acre-year in Florida. California uses 4 lbs a.i./acre-year of simazine. The values for each state along with the weighted average for the US are given in Table 4.23.

Table 4.23. Herbicides applied to US citrus during the tending unit operation

		Active Ingredient (a.i.)			Active Ingredient Use Rate		US Weighted Mean	
Trade Name	Common Name	lb/gal [1]	State / Fruit	Percent of US	gal/ acre-year	lb/ acre-year	lb/acre-year	kg/ha-year
Solicam 80 DF	norflurazon		FL Citrus	90%		3.00	2.70	3.03
Karmex WP	diuron		US Citrus	100%		4.00	4.00	4.48
Roundup Weather Max	glyphosate	5.5	FL Citrus	90%	0.5	2.75	2.52	2.82
Roundup Original Max		5.5	CA Citrus	10%	0.075	0.41		
Princep 90S	simazine		CA Citrus	10%		4.00	0.40	0.45

[1] MWSC, 2009

4.3.1.2.3.3.5 Pesticides, Minor Nutrients, and Soil Amendments

Dolomite ($CaMg(CO_3)_2$) is added to the soil of Florida citrus groves at the rate of 667 pounds per acre-year; weighted at 90% of US production, this is equivalent to 600 lb/ac-yr (673 kg/ha-yr). Irrigation water in California is supplemented with gypsum ($CaSO_4 \cdot 2H_2O$) at the rate of 2000 pounds per acre-year, which is equal to 200 lb/ac-yr (224 kg/ha-yr) for the US.

The spray programs used on citrus vary depending upon location and fruit type. In addition, the presence of huanglongbing (HLB), or citrus greening disease, may require changes to the amounts and types of substances that are applied to the trees. The cost and returns budgets for Florida (Muraro, 2008a; 2008b; 2008c) give many different spray programs that were merged and weighted by the percent of US citrus waste that each fruit and region is expected to account for. It is assumed that 30% of Florida orchards are treated for HLB. The final weighted value for each substance is presented in Table 4.24.

Table 4.24. Pesticides, micronutrients, and soil amendments used in Florida, weighted by the percent of US citrus waste each fruit type and region could supply and whether or not HLB is present (based on Muraro, 2008a; 2008b; 2008c).

Region/ Fruit/ HLB Status	Substance	Amt	Unit	% of US Citrus Waste	HLB Factor	Percent of US	US Weighted Value per acre-year	
All FL Orange no HLB	Agri-Mek	5	ozs	80%	0.7	56%	3.30	ozs
All Grapefruit		5	ozs	10%	1	10%		
All FL citrus	B (Borates)	0.25	lbs	90%	1	90%	0.23	lbs
IR Grapefruit no HLB	Copper (Kocide 3000)	14	lbs	5%	0.7	4%	7.22	lbs
SW Orange no HLB		8	lbs	32%	0.7	22%		
All Grapefruit w/HLB		20	lbs	10%	0.3	3%		
All FL Orange w/HLB		7.5	lbs	80%	0.3	24%		
CF Orange no HLB		6.5	lbs	48%	0.7	34%		
SW Grapefruit no HLB		10	lbs	5%	0.7	4%		
All FL citrus w/HLB	Danitol	2	pt	90%	0.3	27%	0.58	pt
SW Grapefruit no HLB		1	pt	5%	0.7	4%		
All FL citrus	Dolomite	667	lbs	90%	1	90%	600	lbs
All IR Grapefruit	Lorsban 4EC	10	pts	5%	1	5%	4.19	pts
SW Grapefruit w/HLB		10	pts	5%	0.3	2%		
SW Orange w/HLB		10	pts	32%	0.3	10%		
All CF Orange		5	pts	48%	1	48%		
SW Grapefruit no HLB		5	pts	5%	0.7	4%		
All FL citrus	Mn (Manganese)	3	lbs	90%	1	90%	2.70	lbs
IR Grapefruit w/HLB	Mustang	4.3	ozs	5%	0.3	2%	0.83	ozs
CF Orange w/HLB		4.3	ozs	48%	0.3	14%		
All SW Grapefruit no HLB		4.3	ozs	5%	0.7	4%		
All FL citrus w/HLB	Provado	16	ozs	90%	0.3	27%	4.32	ozs
All FL Orange	Spray Oil (97+%)	10	gals	80%	1	80%	8.75	gals
IR Grapefruit w/HLB		11	gals	5%	0.3	2%		
SW Grapefruit w/HLB		13	gals	5%	0.3	2%		
SW Grapefruit no HLB		3	gals	5%	0.7	4%		
IR Grapefruit no HLB		8	gals	5%	0.7	4%		
SW Orange w/HLB	Temik 15G	33	lbs	32%	0.3	10%	3.17	lbs
All FL Grapefruit	Vendex 50W	2	lbs	10%	1	10%	0.20	lbs
All FL citrus	Zn (Zinc)	3	lbs	90%	1	90%	2.70	lbs

The California cost and return study assumes fewer substances and lower application rates than does Florida. However, since the former is a study with recommendations, rather than based on actual practices, it is unknown how closely the California study reflects typical use patterns. A small amount of growth regulator that may be used on lemons and navel oranges is not included.

Table 4.25. Pesticides and micronutrients used in California, weighted by the percent of US citrus waste each fruit (based on Table 4 in O'Connell *et al*., 2005; 2009).

Fruit	Substance	Amt	Unit	% of US Citrus Waste	US Weighted Value US per acre-year	
CA oranges	Dipel ES	2	pint	6%	0.12	pint
CA oranges and lemons	Esteem	17	floz	10%	1.70	floz
CA oranges and lemons	Gypsum ($CaSO_4 \cdot 2H_2O$)	2000	lb	10%	200	lb
CA oranges and lemons	Hydrated Lime ($Ca(OH)_2$)	10	lb	10%	1.00	lb
CA oranges and lemons	Kocide 20/20	10	lb	10%	1.00	lb
CA oranges	Spray Oil 415	1	gal	6%	0.08	gal
CA lemons		0.5	gal	4%		
CA oranges	Success	12	oz	6%	0.96	oz
CA lemons		6	oz	4%		
CA oranges and lemons	Tecmangam (31% Mn)	2	lb	10%	0.20	lb
CA oranges and lemons	Zinc Sulfate 36%	2	lb	10%	0.20	lb

The data in Tables 4.24 and 4.25 are merged and combined with information regarding amount of active ingredient in each of the substances in order to obtain a weighted US average for pesticides and micronutrients (Table 4.26).

Table 4.26. Representative amounts of pesticides and micronutrients used on US citrus fruit grown for processing

		application rate (a.i.)	
Trade Name	Active Ingredient	lb/ac-yr	kg/ha-yr
Pesticides			
Agri-Mek	abamectin	0.21	0.23
Temik 15G	aldicarb	0.48	0.53
Lorsban 4EC	chlorpyrifos	2.09	2.35
Copper (Kocide 3000)	copper hydroxide	3.33	4.08
Kocide 20/20		0.31	
Vendex 50W	fenbutatin oxide	0.10	0.11
Danitol	fenpropathrin	0.17	0.19
Provado	imidacloprid	0.05	0.06
Mustang	zeta-cypermethrin	0.05	0.06
Dipel ES	Bacillus thuringiensis	0.11	0.12
Esteem	pyriproxyfen	0.01	0.01
Success	spinosad	0.01	0.01
US Weighted TOTAL			7.75
Micronutrients and Other			
Borates	B	0.23	0.25
Hydrated Lime	$Ca(OH)_2$	0.10	0.11
Manganese compound	Mn	2.90	3.25
Zinc Sulfate	Zn	2.90	3.25
Spray Oil	C15-C40 paraffin	63	71
Dolomite	$CaMg(CO_3)_2$	600	673
Gypsum	$CaSO_4{\cdot}2H_2O$	200	224

4.3.1.2.3.3.6 Emissions to Air

Criteria Air Pollutants

Criteria air pollutants that result from the burning of gasoline and diesel fuel in the operation of field equipment during the tending unit operation, as listed in Table 4.19, are calculated from the formulas and emission factors used in the US Environmental Protection Agency (EPA) NONROAD model (EPA, 2004; EPA, EPA, 2005). The equipment population is based on lifetime expectancies for the equipment (Hinson *et al*., 2006) with most of the equipment at or near the median age. With estimated lifetimes of 10 years or more, most of the equipment in 2007 is assumed to be model years 2001 to 2004 and because it is all low power equipment (20 to 75 horsepower) it is primarily Tier 1 technology. The sulfur content of the diesel fuel is assumed to be 0.05 wt%, as would be expected for agricultural equipment in 2007. Additional details are provided in section 4.3.1.3.4 of this report.

Diesel and propane powered pumps used for water management systems and freeze protection (Table 4.21) also release emissions. Criteria air pollutants and their precursors are determined using EPA AP-42 guidelines for stationary gasoline and diesel engines (EPA, 1996, Table 3.3-1) and for liquefied petroleum combustion (EPA, 2008, Table 1.5-1). The light-duty truck is assumed to be a model year 2000 vehicle with a fuel economy of 12 miles per gallon (slightly lower than when used on paved roads). Emissions factors are from the GREET model, for the vehicle referred to as “light-duty truck 2” (ANL, 2009).

Emissions of criteria pollutants and their precursors in grams per liter and grams per hectare for the tending unit operation are given in Table 4.27.

Table 4.27. Emissions of criteria pollutants and their precursors in grams per liter and grams per hectare for the tending unit operation

Equipment	US Fuel Use liters/ha	Emissions g/liter					Emissions g/ha				
		VOC	CO	NO_X	PM	SO_2	VOC	CO	NO_X	PM	SO_2
Diesel											
Rotary Mower	54.8	0.91	5.06	6.89	0.80	0.25	50	277	378	44	14
Sprayer Boom	36.1	1.06	5.85	7.97	0.92	0.29	38	211	287	33	10
Sprayer, Air blast	12.0	1.25	6.93	9.44	1.09	0.34	15	83	113	13	4
Fertilizer Spreader	36.4	0.94	5.20	7.08	0.82	0.26	34	189	258	30	9
Water pumps	313.7	5.45	14.61	67.83	4.77	4.46	1,710	4,583	21,279	1,496	1,399
TOTAL diesel	453.0						1,847	5,344	22,315	1,616	1,437
Gasoline											
Pickup truck	86.6	2.61	27.91	3.27	0.12		226	2417	283	10	0
Propane											
Water pumps	14.3	1.72	12.88	22.32	1.20	0.03	24	184	318	17	0
Gypsum pumps	1.4	1.72	12.88	22.32	1.20	0.03	2	18	32	2	0
Wind machines	140.3	1.72	12.88	22.32	1.20	0.03	241	1,807	3,132	169	4
TOTAL propane	156.0						268	2,009	3,482	187	5
US Citrus for processing TOTAL							2,341	9,770	26,080	1,814	1,442

Greenhouse Gas Emissions

Greenhouse gas emissions from burning of diesel, gasoline, and propane fuel are estimated using IPCC emission factors (IPCC, 2006a). A summary of the factors used and the estimated emissions are presented in Table 4.28.

Table 4.28. Direct greenhouse gas emissions due to fuel combustion during the tending unit operation

		Emission Factor g/GJ [1]			Emission Factor g/liter			US Fuel Consumption	Emissions (kg/ha-year)		
Fuel	Energy Content (GJ/liter) [2]	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	liters/ ha-yr	CO_2	CH_4	N_2O
Diesel	0.0358	74,100	4.15	28.6	2,653	0.149	1.024	453	1,202	0.067	0.464
Gasoline, 4-stroke	0.0324	69,300	80	2	2,242	2.588	0.065	87	194	0.224	0.006
Propane	0.0237	63,100	5	0.1	1,494	0.118	0.002	156	233	0.018	0.000
US TOTAL									1,629	0.310	0.470

[1] IPCC, 2006a, Table 2.5 and Table 3.3.1, for agricultural use; default values expressed as kg/TJ

[2] ANL, 2009, converted from Btu/gallon

Direct greenhouse gas emissions are also released as a consequence of using fertilizers. The application of nitrogen fertilizer contributes to emissions of nitrous oxide (N_2O). The rate at which this occurs is based on IPCC guidelines (IPCC, 2006b, Equation 11.1). Additional sources of nitrous oxide emissions that occur as the result of citrus farming are presented in section 4.3.1.2.7 of this report. In considering only nitrogen fertilizer application, the rate of direct N_2O emissions can be expressed as

$$N_2O_{fert} = N_{fert,N} * EF_{N\,fert} * N_2O_{mw} /(2 * N_{aw}) \qquad (4.5)$$

where

N_2O_{fert} is the mass of annual nitrous oxide emissions per unit area due to fertilization

$N_{fert,N}$ is the mass of nitrogen fertilizer, as nitrogen, applied annually per unit area

$EF_{N\,fert}$ is the emission factor for added nitrogen, taken to be 0.01 per IPCC guidelines, (IPCC, 2006b, Table 11.1)

$N_2O_{mw} /(2 * N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, equal to 44/28

Representative nitrogen fertilization rates for US citrus are taken to be 217.7 kg/ha-yr (Table 4.22). Thus direct N_2O emissions for nitrogen fertilization of citrus crops are calculated as

$$217.7 \text{ kg/ha-yr} * 0.01 * 44/28 =$$

$$3.42\ N_2O \text{ kilogram / hectare-year} \qquad (4.6)$$

Pruning of citrus trees is performed on the bottoms to prevent branches from touching the ground, at the sides to prevent trees from touching each other and to allow for clearance between rows, and at the top to enhance fruit production. Pruning schedules call for different parts of the tree to be trimmed at different times, but the entire circumference of the tree is pruned once every two years. The limbs that are trimmed are primarily new growth with a high leaf to branch ratio and with relatively high nitrogen content in the leaves. After pruning, the trimmings are chopped and left as mulch on the ground. As the chopped trimmings decompose, nitrous oxide is released as an intermediate in the reaction that takes fixed nitrogen back to dinitrogen in the atmosphere.

No information was found regarding the mass of material that is removed during the pruning operation. The following calculations are based on what are thought to be reasonable estimates. It is first assumed that a negligible amount of material is trimmed from trees on 10% of the cropland. These include the youngest trees as well as older trees that are removed due to low productivity; (the latter are subsequently burned as described in section 3.1.2.1). An average of 50 kilograms (20 to 80 kilograms per pruning) is removed from maturing trees (40% of the orchard area) and 60 to 100 kilograms (an average of 80 kg) per pruning is removed from the largest trees (50% of the orchard area). Thus an average of 60 kilograms (0.4 * 50 + 0.5 * 80) is removed per tree per pruning. Dividing this in half to account for the fact that this is a biennial operation gives 30 kilograms per year per tree. If the tree density is 300 per hectare, this is equivalent to 9,000 kilograms of tree trimmings treated per hectare year. Because the trimmings are chopped and left as mulch on the ground, they are treated as crop residues.

The rate of direct N_2O emissions due to crop residues can be expressed as

$$N_2O_{CR} = m_{CR} * fraction_{N,CR} * EF_{N,CR} * N_2O_{mw} /(2 * N_{aw}) \qquad (4.7)$$

where

N_2O_{CR} is the mass of annual nitrous oxide emissions per unit area due to crop residues

$m_{CR,N}$ is the mass of crop residues, supplied annually per unit area

$fraction_{N,CR}$ is the fraction of nitrogen in the crop residues, estimated to be 0.005 for a mixture of leaves and twigs.

$EF_{N,CR}$ is the emission factor for crop residue nitrogen, taken to be 0.01 per IPCC guidelines, Table 11.1.

$N_2O_{mw} /(2 * N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, equal to 44/28

Applying equation 4.7 gives N_2O emissions due to pruning as

$$9000 \text{ kg/ha-yr} * 0.005 * 0.01 * 44/28 =$$

$$0.707 \ N_2O \text{ kilograms / hectare-year} \qquad (4.8)$$

The specific use of urea as a nitrogen fertilizer produces emissions of CO_2 as well as N_2O. In the presence of water, urea $CO(NH_2)_2$ reacts to form ammonium (NH_4^+), hydroxyl ion (OH^-), and bicarbonate (HCO_3^-). The bicarbonate ion then reacts further to form CO_2 and water. In the development of inventories, in which flows in and out of the atmosphere are categorized by sector, the manufacturing of urea is credited with the removal of CO_2 from the atmosphere. This same CO_2 is released from the urea upon use. For the purposes of this study, which includes upstream inputs to fertilizers and other chemicals applied to the citrus crops, a CO_2 emission credit is given to urea production and thus emissions of CO_2 upon use of the fertilizer must be taken into account. Another approach (not taken here) would be to assume that net CO_2 emissions are zero. IPCC guidelines call for assuming that all of the carbon in the urea is oxidized to CO_2 and released as emissions to air. There are two nitrogen atoms for every carbon atom in urea, thus the mass fraction of carbon relative to nitrogen applied as urea is ratio of the atomic masses (12/2*14), which is equal to 0.429. The amount of CO_2 formed per atom of carbon is expressed as (12+2*16)/12, which is equal to 3.67. The mean US application of urea on citrus crops grown for processing is 13.23 kg/ha-yr (Table 4.22). The resulting CO_2 emissions are calculated as

$$13.23 \text{ kg / ha-yr} \;*\; 12 / (2 * 14) \;*\; (12 + 2*16) / 12 \;=$$

$$20.79 \text{ kilograms / hectare-year} \qquad (4.9)$$

The application of dolomite ($CaMg(CO_3)_2$) as a soil amendment in Florida citrus groves also contributes to CO_2 emissions. Dolomite is similar to limestone, but the calcium is partially substituted with magnesium. IPCC guidelines (IPCC, 2006b) give an emission factor of 0.13 for dolomite. This is multiplied by the mass of dolomite used (US weighted average) and by 44/12 to convert carbon to CO_2 for a total emission rate of

$$0.13 \;*\; 673 \text{ kg/ha-yr} \;*\; 44/12 \;=$$

$$320.8 \text{ kilograms } CO_2 \text{ / hectare-year} \qquad (4.10)$$

The use of spray oils on the citrus trees likely results in emissions of CO and VOCs. The total use is 71 kg/ha-yr and the total carbon content is estimated to be 85 wt%. If 10% of these oils are volatilized, this would produce emissions of 6 kg/ha-yr, which would oxidize to form 22 kg CO_2 /ha-yr. As this number is small and highly uncertain, it is not included in the analysis.

4.3.1.2.3.3.6 Summary of Direct Material and Energy Flows for Tending

The tending unit operation is assumed to apply to all citrus cropland. Material and energy flows are burdened by 3% to account for seedlings grown in nurseries. The final overall material and energy flows for this unit operation are summarized in Table 4.29.

Table 4.29. Direct material and energy flows for tending of US citrus for processing

Resource	Calculation	Value	Units
Land [1]	1.03 hectares / 1 hectare-year	1.03	1/yr
Diesel			
Volume	1.03 / year * 453 liters / hectare	467	l/ha-yr
Mass [1]	467 liters / hectare-year * 0.837 kilograms / liter	390	kg/ha-yr
Energy [1]	467 liters / hectare-year * 35.8 megajoules / liter	16,704	MJ/ha-yr
Gasoline			
Volume	1.03 / year * 86.6 liters / hectare	89	l/ha-yr
Mass [1]	89.2 liters / hectare-year * 0.744 kilograms / liter	66	kg/ha-yr
Energy [1]	89.2 liters / hectare-year * 32.4 megajoules / liter	2,886	MJ/ha-yr
Propane (LPG)			
Volume	1.03 / year * 156 liters / hectare	161	l/ha-yr
Mass [1]	161 liters / hectare-year * 0.508 kilograms / liter	82	kg/ha-yr
Energy [1]	161 liters / hectare-year * 23.7 megajoules / liter	3,804	MJ/ha-yr
Major Nutrients			
Nitrogen (N)	1.03 / year * 217.7 kilograms / hectare	224	kg/ha-yr
Phosphorous (P_2O_5)	1.03 / year * 20.8 kilograms / hectare	21	kg/ha-yr
Potassium (K_2O)	1.03 / year * 204.4 kilograms / hectare	211	kg/ha-yr
Magnesium (MgO)	1.03 / year * 41.4 kilograms / hectare	43	kg/ha-yr
Micronutrients and Other			
B	1.03 / year * 0.252 kilograms / hectare	0.26	kg/ha-yr
Ca(OH)2	1.03 / year * 0.112 kilograms / hectare	0.12	kg/ha-yr
Mn	1.03 / year * 3.25 kilograms / hectare	3.35	kg/ha-yr
Zn	1.03 / year * 3.25 kilograms / hectare	3.35	kg/ha-yr
Spray Oil	1.03 / year * 70,961 kilograms / hectare	73	kg/ha-yr
Dolomite	1.03 / year * 673 kilograms / hectare	693	kg/ha-yr
Gypsum	1.03 / year * 224 kilograms / hectare	231	kg/ha-yr

[1] Energy content and density of liquid fuels, default inputs to GREET (ANL, 2009)

Table 4.29, continued

Resource	Calculation	Value	Units
Herbicides			
norflurazon	1.03 / year * 3.03 kilograms / hectare	3.12	kg/ha-yr
diuron	1.03 / year * 4.48 kilograms / hectare	4.62	kg/ha-yr
glyphosate	1.03 / year * 2.82 kilograms / hectare	2.91	kg/ha-yr
simazine	1.03 / year * 0.448 kilograms / hectare	0.46	kg/ha-yr
Pesticides			
abamectin	1.03 / year * 0.231 kilograms / hectare	0.24	kg/ha-yr
aldicarb	1.03 / year * 0.533 kilograms / hectare	0.55	kg/ha-yr
chlorpyrifos	1.03 / year * 2.35 kilograms / hectare	2.42	kg/ha-yr
copper hydroxide	1.03 / year * 4.08 kilograms / hectare	4.20	kg/ha-yr
fenbutatin oxide	1.03 / year * 0.112 kilograms / hectare	0.12	kg/ha-yr
fenpropathrin	1.03 / year * 0.193 kilograms / hectare	0.20	kg/ha-yr
imidacloprid	1.03 / year * 0.0605 kilograms / hectare	0.06	kg/ha-yr
zeta-cypermethrin	1.03 / year * 0.0584 kilograms / hectare	0.06	kg/ha-yr
Bacillus thuringiensis	1.03 / year * 0.121 kilograms / hectare	0.12	kg/ha-yr
pyriproxyfen	1.03 / year * 0.0128 kilograms / hectare	0.01	kg/ha-yr
spinosad	1.03 / year * 0.00656 kilograms / hectare	0.01	kg/ha-yr
Water			
Withdrawn	1.03 / year * 5.59 x 10^6 liters/ hectare	5.76	10^6 liters/ha-yr
Consumed	1.03 / year * 12.40 x 10^6 liters/ hectare	12.77	10^6 liters/ha-yr
Criteria Air Pollutants and Precursors			
VOC	1.03 / year * 2.341 kilograms / hectare	2.41	kg/ha-yr
CO	1.03 / year * 9.77 kilograms / hectare	10.06	kg/ha-yr
NO_X	1.03 / year * 26.08 kilograms / hectare	26.86	kg/ha-yr
PM	1.03 / year * 1.814 kilograms / hectare	1.87	kg/ha-yr
SO_2	1.03 / year * 1.442 kilograms / hectare	1.49	kg/ha-yr
Greenhouse Gases			
CO_2	1.03 / year * (1629 + 321) kilograms / hectare	2,008	kg/ha-yr
CH_4	1.03 / year * 0.31 kilograms / hectare	0.319	kg/ha-yr
N_2O	1.03 / year * (0.47 + 3.42+0.707) kilograms / hectare	4.735	kg/ha-yr

4.3.1.2.4 Harvesting (separation of target material from growing medium):

4.3.1.2.4.1 General Description

Citrus fruit is currently harvested by hand. Although there is equipment that is designed to pick fruit from the tree, it is not in general use. It is also assumed that fruit is accessed primarily by ladders rather than by mechanized lifts. Once picked, the fruit is transferred to trailers for transport to the juicing facility by means of electrically powered conveyors.

4.3.1.2.4.2 Activities

The only activity that is included in the model is operation of the conveyor belts, as labor is not included in this analysis. Electrical energy required for operation of the belts is taken from Louisiana cost and returns document (Hinson *et al*., 2006) as it is not specified in either the Florida or California budgets.

4.3.1.2.4.3 Direct Material and Energy Flows

The amount of energy in the form of electricity required to operate the conveyor is taken to be 175 kWh per acre-year (Hinson *et al*., 2006), which is equal to 432 kWh/ha-yr or 1557 MJ/ha-yr.

4.3.1.2.5 Waste management

There are no known waste management activities for this life cycle stage.

4.3.1.2.6 Summary of Direct Material and Energy Flows for Life Cycle Stage One

Tables SC.30, SC.31, and SC.32 sum all of the direct flows accounted for in sections 4.3.1.2.1 through SC.3.1.2.5 of this report.

Table 4.30. Direct flows of energy and water for life cycle stage one, raw material acquisition, in production of ethanol from citrus waste

	Electricity		Diesel		Gasoline		Propane (LPG)		Water	
			Volume	Energy	Volume	Energy	Volume	Energy	Withdrawn	Consumed
Unit Operation	kWh/ ha-yr	MJ/ ha-yr	liter/ ha-yr	MJ/ ha-yr	liter/ ha-yr	MJ/ ha-yr	liter/ ha-yr	MJ/ ha-yr	10^3 liter/ ha-yr	10^3 liter/ ha-yr
Land Preparation	0	0	9	325	0	0	0	0	0	0
Planting	0	0	0	0	0	0	0	0	0	0
Tending	0	0	467	16,704	89	2,886	161	3,804	5,758	12,772
Harvesting	432	1,557	0	0	0	0	0	0	0	0
TOTAL	432	1,557	476	17,029	89	2,886	161	3,804	5,758	12,772

Table 4.31. Direct emissions to air for life cycle stage one, raw material acquisition, in production of ethanol from citrus waste

	Criteria Air Pollutants and Precursors					Net Greenhouse Gases		
	kg/ha-yr					kg/ha-yr		
Unit Operation	VOC	CO	NO_X	PM	SO_2	CO_2	CH_4	N_2O
Land Preparation	28.9	296	146	48.4	4.87	24	8.46	0.48
Seeding and Planting	0	0	0	0	0	0	0	0
Tending	2.4	10	27	1.9	1.49	2,008	0.32	4.73
Harvesting	0	0	0	0	0	0	0	0
TOTAL	31.3	306	173	50.3	6.35	2,032	8.78	5.21

Table 4.32. Application of chemicals to land in life cycle stage one, raw material acquisition, in production of ethanol from citrus waste; all are attributed to the tending unit operation

Pesticides		Nutrients and Amendments		Herbicides	
Type	kg/ha-yr	Type	kg/ha-yr	Type	kg/ha-yr
abamectin	0.24	Nitrogen (N)	224	norflurazon	3.12
aldicarb	0.55	Phosphorous (P_2O_5)	21	diuron	4.62
chlorpyrifos	2.42	Potassium (K_2O)	211	glyphosate	2.91
copper hydroxide	4.20	Magnesium (MgO)	43	simazine	0.46
fenbutatin oxide	0.12	Boron (B)	0		
fenpropathrin	0.20	Hydrated Lime $Ca(OH)_2$	0.12		
imidacloprid	0.06	Manganese (Mn)	3		
zeta-cypermethrin	0.06	Zinc (Zn)	3		
Bacillus thuringiensis	0.12	Dolomite	693		
pyriproxyfen	0.01	Gypsum	231		
spinosad	0.01				
spray oil	73				

4.3.1.3 Environmental Metrics

Four categories of environmental metrics are considered in the study: land use, net energy, water use, and emissions to air. Land use includes a quantitative assessment of the total amount of land required to support production of the crop. Net energy is the difference between quantity of energy required to produce the product less energy generated. Water use includes both consumption and withdrawals (i.e., that lost to evaporation and that returned to the source in an altered state). Emissions to air that are considered in the analyses include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), particulate matter (PM), volatile organic compounds (VOCs), oxides of nitrogen (NO_X), and oxides of sulfur (SO_X). This section is also used to account for indirect flows and embodied inventories that occur due to activities upstream from the reference flow of citrus agriculture. In the case of the latter, only energy and emissions to air are considered.

4.3.1.3.1 Land Use, Area Requirements

The reference flow for the first life cycle stage in the production of ethanol from citrus waste is one hectare of land. The amount of citrus that is produced on one hectare of land (yield) is dependent on several factors. The most important are the type of fruit that is grown and the location. Yields in Florida are slightly higher than in California. Both are much higher than that in Texas and Arizona, but as these states produce primarily for the fresh fruit market, yields in those states are not addressed here. Most of the fruit grown for processing includes grapefruit from Florida, oranges from Florida and California, and lemons from California (see discussion in section 4.2.1 and Table 4.3). Yields for each of these four state/fruit combinations are taken for the past 10 years (seasons 1999/2000 through 2008/2009) (ERS, 2000 – 2009). The yield data reported by ERS does not differentiate between yields of fruit for the fresh market and that destined for processing. It is assumed for this analysis that there is no significant difference. The approximate 5th and 95th percentiles, in terms of amount of harvested land producing at a given yield, are determined to be at 20.4 tonnes (Mg) of fruit per hectare and 45.1 tonnes (Mg) of fruit per hectare, respectively. The median (50^{th} percentile) is equal to 32.0 tonnes (Mg) of fruit per hectare. The yield distribution is shown graphically in Figure 4.8.

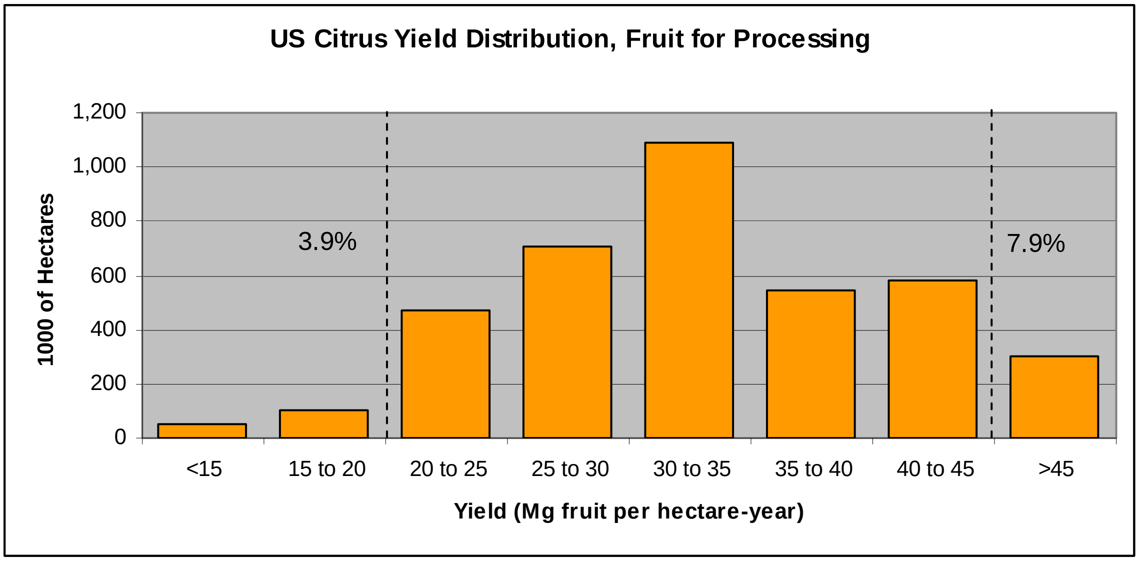

Figure 4.8. The median yield of citrus fruit taken to represent that grown in the US for processing (oranges from Florida and California, grapefruit from Florida, and lemons from California) is equal to 32.0 Mg of fruit per hectare-year.

The yield values are based on bearing acreage, which is estimated to represent 91% of the total land requirement (Table 4.11). Thus the median amount of citrus for processing that is produced per hectare year (for all land required to support cultivation) is calculated as

0.91 * 32.0 Mg citrus fruit for processing / hectare- year) =

29.1 Mg citrus / hectare-year (4.11)

The range, at a 90% confidence interval, is similarly calculated to be 18.6 to 41.0 Mg citrus / hectare-year. This relationship stated in terms of the amount of citrus harvested is a mean land use of 3.43×10^{-5} hectares per kilogram of citrus harvested, with a range of 2.44×10^{-5} to 5.39×10^{-5} hectares of land per kilogram of citrus.

4.3.1.3.2 Water Use

A total of 5.758×10^{6} liters per hectare is withdrawn annually in the US to grow citrus fruit for processing. The amount consumed by the trees is estimated to average 12.772×10^{6} liters per hectare in Florida and California. Note that both of these numbers are higher for Arizona and Texas, but most of the fruit grown in those states is for fresh market. The water lost through drainage to surface waters contains fertilizer, pesticides, and suspended solids.

Given an effective mean yield of 29.1 Mg citrus fruit / hectare-year and a range of 18.6 to 41.0 Mg citrus / hectare-year, this translates to a mean embodied water use of 197.7 liters of water withdrawn and 438.6 liters consumed per kilogram of citrus fruit. The corresponding ranges are

140.3 to 310.2 liters withdrawn /kg fruit and 311.2 to 688.0 liters consumed /kg fruit. To put this in perspective, the amount of water to grow a single fruit is 400 times its mass (200 liters for a one-pound (0.45 kg) grapefruit or 100 liters for an 8 oz orange). Roughly half is provided by rainfall, with the remainder supplied by irrigation.

4.3.1.3.3 Net Energy

There are no energy products produced during this stage of the life cycle, therefore, net energy is equivalent to all the direct energy inputs to citrus agriculture, plus the upstream energy required to generate the direct energy, as well as the embodied energy in the chemicals that are applied to the plants and soil. The upstream energy inputs for energy production are taken from the GREET model (ANL, 2009). The multipliers, based on the sum of the energy used to produce the feedstock plus the fuel, are applied to the energy used to grow citrus in the form of electricity and liquid fuels (Table 4.30). The inputs and calculated upstream energy requirements are shown in Table 4.33. Gasoline is taken to be 90% conventional and 10% California reformulated gasoline in order to reflect the fraction of land used to grow citrus for processing in California.

Table 4.33. Upstream energy required to produce electricity and liquid fuels (based on ANL, 2009)

	MJ/ha-yr	Upstream Energy Factor	Upstream Energy MJ/ha-yr
Electricity	1,557	2.565	3,993
Diesel	17,029	0.180	3,062
Gasoline *	2,886	0.223	643
Propane (LPG)	3,804	0.130	494
TOTAL	25,276		8,192

* Gasoline is 90% conventional and 10% CARFG

The amount of energy consumed in the production of agricultural chemicals (fertilizers and pesticides) is significant. The GREET model (ANL, 2009) is used to determine the values associated with the manufacture and transportation of fertilizers. Upstream energies of pesticides are taken from Bhat and others (1994); transportation energy requirements are from GREET.

The mixed fertilizer used in Florida is assumed to contain nitrogen in the form of ammonium nitrate. Dolomite is essentially the same as limestone (calcium carbonate) in terms of mode of occurrence and density, thus the energies associated with mining and transporting of dolomite should be indistinguishable from that for calcium carbonate ($CaCO_3$). Calcium carbonate is also used as a surrogate for gypsum. Upstream energy inputs for magnesium are estimated assuming that they are similar to potassium Citrus spray oil is essentially mineral oil with a density of 0.860 kg per liter. Its upstream energy requirement is taken to be equivalent to diesel. There are no data for micronutrients. As the mass fraction is small and the specific composition is unknown, the upstream energies associated with micronutrients are not included in the analysis. Total estimated upstream energies for each of the fertilizers are presented in Table 4.34.

Table 4.34. Upstream energies associated with the manufacture and transportation of fertilizer and soil amendments (based on data from ANL, 2009)

Nutrient	Use Rate	MJ/kg nutrient		Total Upstream Energy
	kg/ha-yr	Feedstock + Production	Transportation	MJ/ha-yr
Nitrogen (N) as nitrate	211	62.52	2.57	13,706
Nitrogen (N) as urea	14	51.16	2.15	726
Phosphate (P_2O_5)	21	13.05	0.93	300
Potash (K_2O)	211	7.86	0.91	1,846
Magnesium (Mg) [1]	43	7.86	0.91	374
Dolomite [2]	673	7.86	0.16	5,390
Gypsum [2]	224	7.86	0.16	1,797
TOTAL				24,139

[1] Assume same as K_2O

[2] Assume same as limestone

Energy requirements for production of pesticides are taken from a report produced by the US Department of Energy (Bhat *et al*., 1994). While the information is dated, it is the most complete available and is a key source of data in many life cycle inventory databases for the energy associated with pesticide manufacturing. Citrus spray oil, which is essentially mineral oil (paraffin containing C15 to C40 hydrocarbons), is used as a dispersion aid. It is modeled as diesel. A summary is presented in Table 4.35.

The annual net energy balance per hectare for citrus grown for processing in the US is estimated to be the sum of the following: 1,557 MJ/ha-yr from direct use of electricity plus an additional 3,993 MJ/ha-yr to produce and distribute it; 23,719 MJ/ha-yr from diesel, gasoline, and propane, plus an additional 4,199 MJ/ha-yr to produce and these fuels; 24,139 MJ/ha-yr to manufacture and distribute fertilizers; and 5,358 MJ/ha-yr to manufacture and distribute pesticides and spray oil. This yields a total energy requirement of 63.0 GJ/ha-yr. (Figure 4.9).

The effective mean yield for US citrus grown for processing is 29.1 Mg / hectare-year, with a range of 18.6 to 41.0 Mg (see section 4.3.1.3.1). This translates to a mean embodied energy of 2.164 MJ/kg of harvested citrus fruit, with a range of 1.536 to 3.385 MJ per kilogram of harvested fruit.

Table 4.35. Upstream energies associated with the manufacture and transportation of pesticides (based on data from Bhat *et al*., 1994)

Pesticide	Pesticide Use	Production Energy		Production plus Transportation [1]
	kg/ha-yr	MJ/kg	MJ/ha-yr	MJ/ha-yr
abamectin [2]	0.24	245.06	58	59
aldicarb [2]	0.55	245.06	134	135
Bacillus thuringiensis [2]	0.12	245.06	31	31
chlorpyrifos	2.42	250	604	606
copper hydroxide [2]	4.20	245.06	1,029	1,033
diuron	4.62	200	924	928
fenbutatin oxide [2]	0.12	245.06	28	28
fenpropathrin [2]	0.20	245.06	49	49
glyphosate	2.91	454	1,319	1,322
imidacloprid [2]	0.06	245.06	15	15
norflurazon	3.12	150	468	470
pyriproxyfen [2]	0.01	245.06	3	3
simazine [3]	0.46	214.93	99	100
spinosad [2]	0.01	245.06	2	2
zeta-cypermethrin [2]	0.06	245.06	15	15
spray oil [4]	73.09	7.43	543	562
TOTAL			5,320	5,358

[1] Assume transportation energy is 0.919 MJ/kg except spray oil, modeled as diesel
[2] Modeled as average insecticide
[3] Modeled as average herbicide
[4] Modeled as diesel

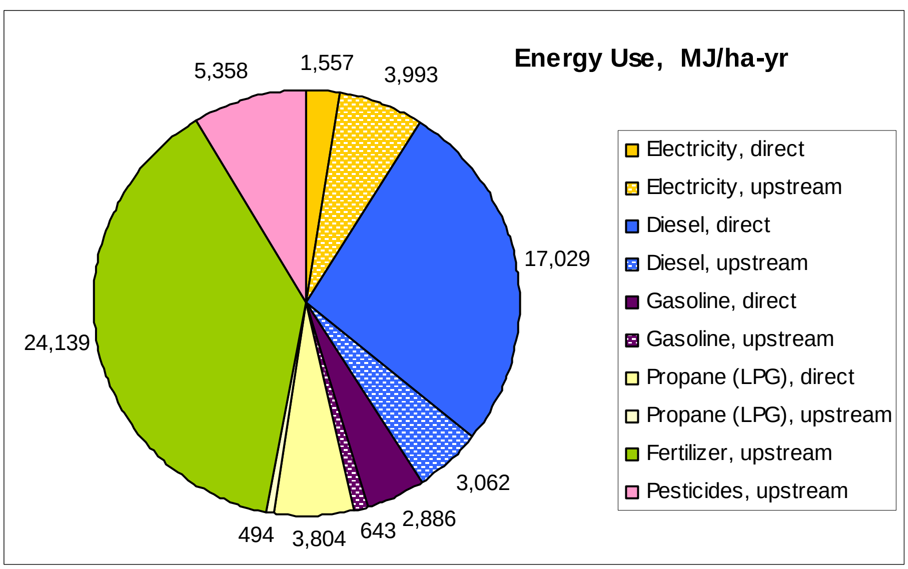

Figure 4.9. US citrus has a total energy requirement of 63.0 GJ/ha-yr, with roughly half due to upstream energy used in the production of fertilizers and pesticides. Two thirds of the diesel is used for irrigation.

4.3.1.3.4 Emissions to Air

Emissions to air include all of the direct emissions that can be attributed to specific unit operations as well as indirect emissions of greenhouse gases due to use of nitrogen fertilizers. Production and distribution of energy, fertilizers, and pesticides also result in emissions to air (Figure 4.7).

4.3.1.3.4.1 Criteria Air Pollutants

Direct Emissions

Criteria pollutants and their precursors are released during the operation of agricultural equipment as a result of fuel combustion, including diesel, gasoline, and propane. Additional emissions occur when trees that have been replaced are burned. Total direct emissions are the sum of those given in Tables 4.16 and 4.29, which are equal to 31.34 kg of VOCs per hectare-year, 306 kg CO/ha-yr, 173 kg NO_X/ha-yr, 50.3 kg PM/ha-yr, and 6.35 kg SO_2/ha-yr.

Emissions to air from diesel powered field equipment are calculated from the formulas and emission factors used in the US Environmental Protection Agency's NONROAD model (EPA, 2004). For HC, CO, and NO_X, the exhaust emission factors for a given diesel equipment type in a given model year and of a specified age are calculated as:

$$EF_{adj\,(HC,CO,NOx)} = EF_{SS} * TAF * DF$$

where:

EF_{adj} is final emission factor adjusted to account for transient operation and deterioration in grams per horsepower-hour (g/hp-hr)

EF_{SS} is the zero-hour, steady-state emission factor (g/hp-hr)

TAF is the transient adjustment factor

DF is the deterioration factor

Determination of EF_{SS} and DF requires that age and the technology of the equipment be known or assumed along with the horsepower of the diesel engine. In the model developed for citrus farming, almost all of the equipment consists of implements pulled by a 50 HP tractor which Hinson and others (2006) estimate to have a life expectancy of 10 years, giving a median model year of 2002/3 in 2007 and a median age of 5 years. The oldest model year would be 1998 and the newest 2007. The technology distribution profile for this tractor is assumed using Table A1 from the EPA (2004) documentation. The equipment population profile is generated assuming that approximately 10% of the equipment is close to the maximum age, another 10% is close to the minimum age, and the remaining 80% is close to the median age. The resulting profile consists of 20% Tier 0, 70% Tier 1, and 10% Tier 2 equipment.

Upstream Emissions

Emissions of criteria air pollutants and their precursors that are released during the production and delivery of electricity, diesel, fertilizers, and pesticides used in citrus agriculture are estimated only as functions of the energy required to produce and deliver these resources. The GREET model (ANL, 2009) is used to calculate these values. . None of the pesticides used on citrus are listed in GREET. Therefore, the assumption is made that emissions resulting from the production of these substances are proportional to the energy used to manufacture them (Table 4.35). The set of emission factors used for the production of the herbicide atrazine is used as the reference. GREET assumes the same emissions per unit mass of pesticide transported, which is applied to all of the pesticides used here.

The upstream emissions for energy are listed in Table 4.36, those for nutrients and amendments are given in Table 4.37, and emissions for pesticides are presented in Table 4.38.

Table 4.36. Upstream criteria air pollutants and precursors from production of energy

Energy Source	Energy Use	Total Upstream Emissions				
		VOC	CO	NO_X	PM	SO_X
	MJ/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr
Electricity	1557	0.028	0.081	0.331	0.424	0.729
Diesel	17029	0.124	0.197	0.670	0.130	0.320
Gasoline *	2886	0.073	0.037	0.123	0.027	0.061
Propane	3804	0.028	0.041	0.147	0.021	0.064
TOTAL		0.253	0.355	1.271	0.601	1.174

* For 10% CARFG; 90% conventional gasoline

Table 4.37. Upstream criteria air pollutants and precursors from production of nutrients and amendments

Nutrient / Amendment	Nutrient / Amendment Use	Total Upstream Emissions				
		VOC	CO	NO_X	PM	SO_X
	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr
Nitrogen (N) as nitrate	204	1.561	1.584	2.077	0.889	0.855
Nitrogen (N) as urea	13	0.079	0.078	0.066	0.012	0.033
Phosphate (P_2O_5)	21	0.008	0.027	0.151	0.036	1.340
Potash (K_2O)	211	0.025	0.090	0.385	0.132	0.281
Magnesium (Mg) [1]	43	0.005	0.018	0.079	0.027	0.057
Dolomite [2]	673	0.050	0.176	0.560	0.400	0.637
Gypsum [2]	224	0.016	0.059	0.187	0.133	0.212
TOTAL		1.744	2.031	3.505	1.630	3.415

[1] Assume same as K_2O

[2] Assume same as limestone

Table 4.38. Upstream criteria air pollutants and precursors from production of pesticides

Pesticide [1]	Pesticide Use	Total Upstream Emissions				
		VOC	CO	NO_X	PM	SO_X
	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr	kg/ha-yr
abamectin	0.24	0.0005	0.0020	0.0073	0.0034	0.0067
aldicarb	0.55	0.0013	0.0047	0.0168	0.0079	0.0154
Bacillus thuringiensis	0.12	0.0003	0.0011	0.0038	0.0018	0.0035
chlorpyrifos	2.42	0.0057	0.0211	0.0754	0.0356	0.0693
copper hydroxide	4.20	0.0097	0.0360	0.1286	0.0607	0.1181
diuron	4.62	0.0087	0.0325	0.1163	0.0545	0.1064
fenbutatin oxide	0.12	0.0003	0.0010	0.0035	0.0017	0.0032
fenpropathrin	0.20	0.0005	0.0017	0.0061	0.0029	0.0056
glyphosate	2.91	0.0122	0.0457	0.1621	0.0777	0.1504
imidacloprid	0.06	0.0001	0.0005	0.0019	0.0009	0.0018
norflurazon	3.12	0.0044	0.0166	0.0597	0.0276	0.0542
pyriproxyfen	0.01	0.0000	0.0001	0.0004	0.0002	0.0004
simazine *	0.46	0.0009	0.0035	0.0125	0.0059	0.0114
spinosad	0.01	0.0000	0.0001	0.0002	0.0001	0.0002
zeta-cypermethrin	0.06	0.0001	0.0005	0.0018	0.0009	0.0017
spray oil [2]	73.09	0.0228	0.0362	0.1231	0.0238	0.0589
TOTAL		0.0448	0.1671	0.5964	0.2817	0.5484

[1] Modeled relative to atrazine

[2] Modeled as diesel

4.3.1.3.4.2 Greenhouse Gases

Direct Emissions

The direct net emissions of greenhouse gases released due to citrus farming are calculated as the sums of the totals in Tables 4.16 and 4.29, which are equal to 2,032 kilograms of CO_2 per hectare-year, 8.78 kg CH_4/ha-yr, and 5.21 kg N_2O/ha-yr. Three-fourths of the CO_2 emissions are from burning of fossil fuels (primarily for irrigation and freeze protection); the remainder is due to the use of dolomite as a soil amendment. Most of the N_2O emissions are the result of using nitrogen fertilizer. Virtually all of the CH_4 emissions are due to burning of removed trees.

Indirect Emissions

In addition to N_2O emissions that are released directly from fertilized cropland, indirect emissions occur in one of two ways. In the first, N is volatilized as NH_3 or oxides of nitrogen (NO_X) and subsequently deposited either in its gaseous form or as NH_4^+ and NO_3^- onto soil, water, or plant surfaces. The second pathway occurs when N is removed from soils by leaching or runoff before being taken up into biological systems. Nitrification and denitrification are the mechanisms by which N_2O is formed, just as in direct emissions, but the reactions occur in water and soils that are peripheral to the agricultural land that was originally enriched in nitrogen (the target area).

The indirect emissions of nitrous oxide are accounted for using IPCC guidelines (IPCC, 2006b). Sources of nitrogen that contribute to indirect emissions of N_2O from citrus farming include synthetic fertilizer application and crop residues (tree trimmings left on the ground after pruning). IPCC Equation 11.9 accounts for N_2O emissions that result from atmospheric deposition of volatilized N; IPCC Equation 11.10 accounts for N_2O emissions that result from leaching and runoff (IPCC, 2006b).

After eliminating factors that are equal to zero for US citrus and converting nitrogen to N_2O, IPCC Equation 11.9 can be written as

$$N_2O_{atm\ dep} = N_{fert,\ N} * fraction_{GASF} * EF_{atm\ dep} * N_2O_{mw} /(2 * N_{aw}) \quad (4.12)$$

where

$N_2O_{atm\ dep}$ is the mass of annual nitrous oxide emissions per unit area produced from atmospheric deposition of nitrogen volatilized from cropland

$N_{fert,\ N}$ is the mass of nitrogen fertilizer, as nitrogen, applied annually per unit area

$fraction_{GASF}$ is the fraction of synthetic fertilizer that volatilizes, assumed to be 0.10 per IPCC guidelines (IPCC, 2006b, Table 11.3).

$EF_{atm\ dep}$ is the mass of annual direct nitrous oxide emission per unit area due to the application of nitrogen fertilizer; assumed to be 0.01 per IPCC guidelines (IPCC, 2006b, Table 11.3, EF_4).

$N_2O_{mw} /(2 * N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, equal to 44/28

Substituting in the rate of nitrogen fertilizer application, as nitrogen, from Table 4.32, the expression becomes

224 kg / ha-yr * 0.10 * 0.01 * 44/28 =

0.352 kilograms N_2O / hectare-year (4.13)

Similarly, after eliminating factors that are equal to zero for US citrus and converting nitrogen to N_2O, IPCC Equation 11.10 (IPCC, 2006b) can be written as

$$N_2O_{leach} = (N_{fert,\ N} + N_{BM,\ N}) * fraction_{LEACH} * EF_{leach} * N_2O_{mw} /(2 * N_{aw}) \quad (4.14)$$

where

N_2O_{leach} is the mass of annual nitrous oxide emissions per unit area produced from leaching and runoff of nitrogen from cropland

$N_{fert,\ N}$ is the mass of nitrogen fertilizer, as nitrogen, applied annually per unit area

$N_{BM,N}$ is the mass of nitrogen in biomass remaining on the ground per unit area

$fraction_{LEACH}$ is the fraction of added nitrogen that volatilizes, assumed to be 0.30 per IPCC guidelines (IPCC, 2006b, Table 11.3).

EF_{leach} is the mass of annual direct nitrous oxide emission per unit area due to the leaching of nitrogen; assumed to be 0.0075 per IPCC guidelines (IPCC, 2006b, Table 11.3, EF_5).

$N_2O_{mw} /(2 * N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, equal to 44/28

The mass of nitrogen fertilizer, as nitrogen, is 224 kg / ha-yr (Table 4.32). The estimated mass of nitrogen present in above-ground biomass due to pruning is estimated to be 9000 kg/ha-yr, consisting of 0.5% nitrogen, to give a total of 45 kg/ha-yr and the expression becomes.

$$(224 \text{ kg / ha-yr} + 45 \text{ kg / ha-yr}) * 0.30 * 0.0075 * 44/28 =$$

$$0.951 \text{ kilograms } N_2O \text{ / hectare-year} \qquad (4.15)$$

The total indirect emissions of N_2O are the sum of equations 4.13 and 4.15 or 1.303 kilograms N_2O / hectare-year.

Upstream Emissions

Upstream greenhouse gas emissions related to the energy, fertilizers, and pesticides used directly in citrus agriculture are estimated only as functions of the energy required to produce and deliver these resources. The GREET model (ANL, 2009) is used to determine these values. None of the pesticides used on citrus are listed in GREET. Therefore, the assumption is made that emissions resulting from the production of these substances are proportional to the energy used to manufacture them (Table 4.35). The set of emission factors used for the production of the herbicide atrazine is used as the reference. GREET assumes the same emissions per unit mass of pesticide transported, which is applied to all of the pesticides used here.

Upstream emissions related to energy production are given in Table 4.39. Those for fertilizer production are presented in Table 4.40; those due to pesticide production are given in Table 4.41.

Table 4.39. Upstream greenhouse gas emissions from production of energy

Energy Source	Energy Use	Total Upstream Emissions		
		CO_2	CH_4	N_2O
	MJ/ha-yr	g/ha-yr	g/ha-yr	g/ha-yr
Electricity	1557	314,220	424	4.14
Diesel	17029	232,671	1,669	3.76
Gasoline *	2886	47,311	292	1.16
Propane	3804	38,633	358	0.64
TOTAL		632,836	2,743	9.70

* For 10% CARFG; 90% conventional gasoline

Table 4.40. Upstream greenhouse gas emissions from production of nutrients and soil amendments

Nutrient / Amendment	Nutrient / Amendment Use	Total Upstream Emissions		
		CO_2	CH_4	N_2O
	kg/ha-yr	g/ha-yr	g/ha-yr	g/ha-yr
Nitrogen (N) as nitrate	204	800,916	880	4,144
Nitrogen (N) as urea	13	20,445	51	0.38
Phosphate (P_2O_5)	21	20,565	37	0.38
Potash (K_2O)	211	137,662	204	2.00
Magnesium (Mg) [1]	43	28,054	42	0.41
Dolomite [2]	673	399,963	606	5.38
Gypsum [2]	224	133,123	202	1.79
TOTAL		1,540,728	2,021	4,155

[1] Assume same as K_2O

[2] Assume same as limestone

Table 4.41. Upstream greenhouse gas emissions from production of pesticides

Pesticide [1]	Pesticide Use	Total Upstream Emissions		
		CO_2	CH_4	N_2O
	kg/ha-yr	g/ha-yr	g/ha-yr	g/ha-yr
abamectin	2.91	4,359	6.31	0.049
aldicarb	4.20	10,043	14.53	0.113
Bacillus thuringiensis	4.62	2,283	3.30	0.026
chlorpyrifos	2.42	45,112	65.28	0.506
copper hydroxide	3.12	76,866	111.22	0.862
diuron	0.55	69,053	99.90	0.776
fenbutatin oxide	0.46	2,113	3.06	0.024
fenpropathrin	0.24	3,646	5.28	0.041
glyphosate	0.20	98,346	142.36	1.101
imidacloprid	0.12	1,141	1.65	0.013
norflurazon	0.12	35,013	50.64	0.394
pyriproxyfen	0.06	241	0.35	0.003
simazine *	0.06	7,418	10.73	0.083
spinosad	0.01	124	0.18	0.001
zeta-cypermethrin	0.01	1,102	1.59	0.012
spray oil [2]	73.09	42,734	306.50	0.690
TOTAL		399,595	822.89	4.693

[1] Modeled relative to atrazine

[2] Modeled as diesel

Calculation of greenhouse gas emissions for the purpose of estimating total global warming potential requires that the each gas be scaled according to its global warming potential relative to carbon dioxide as given in the Fourth Assessment Report of the IPCC (IPCC, 2007). These factored emissions are then summed to give total greenhouse gas emissions in terms of carbon dioxide equivalents (CO_2e). In addition, CO and VOCs are assumed to oxidize readily to CO2. VOCs are taken to have a relatively low molecular weight and consist of 83 wt% C (e.g., pentane). The sum of the mass of greenhouse gas emissions expressed as CO_2 equivalents is thus calculated as:

$$GHG = \sum_k E_k * GWP_k + [E_{CO} * CO_{2\,mw} / CO_{mw}] + [0.83 * E_{VOC} * CO_{2\,mw} / C_{aw}] \quad (4.15)$$

where:

GHG is the sum of the mass of greenhouse gas emissions expressed as CO_2 equivalents

E_k is the mass of emissions of GHG species k

GWP_k is the global warming potential for GHG species k (IPCC, 2007)

E_{CO} is the mass of CO emissions

$CO_{2\,mw} / CO_{mw}$ is the conversion factor for CO to CO_2, equal to 44/28

E_{VOC} * is the mass of VOC emissions

$CO_{2\,mw} / C_{aw}$ is the conversion factor for C to CO_2, equal to 44/12

Total emissions of species contributing to the greenhouse gas inventory are given in Table 4.42 as net emissions, as well as in terms of CO_2 equivalents.

Table 4.42. Greenhouse gas emissions (net and as carbon dioxide equivalents (CO_2e)) in kilograms per hectare-year (kg-ha-yr) released during life cycle stage one, raw material acquisition, in the production of ethanol from citrus waste

	Net Emissions of GHG kg/ha-yr					Emissions of GHG in CO_2e kg/ha-yr					
Source	CO_2	CH_4	N_2O	CO	VOC	CO_2	CH_4	N_2O	CO	VOC	TOTAL CO_2e
GWP (CO_2e factor)	1	25	298	1.57	3.04						
Direct emissions, excluding burning	2,032	0.30	4.73	113	21.1	2,032	8	1,410	178	64	3,692
Burning	0	8.48	0.48	193	10.3	0	212	143	0	0	355
Indirect emissions	0	0	1.30	0	0	0	0	342	0	0	342
Upstream emissions	2,573	5.59	4.17	3	2.25	2,573	140	1,242	5	7	3,967
TOTAL	4,605	14	11	309	34	4,605	359	3,137	183	71	8,355

As can be seen in Table 4.42, nearly half (47%) of all the greenhouse gas emissions can be attributed to upstream flows related to the production and delivery of energy, nutrients, and pesticides used in citrus farming. This is shown graphically in Figure 4.12.

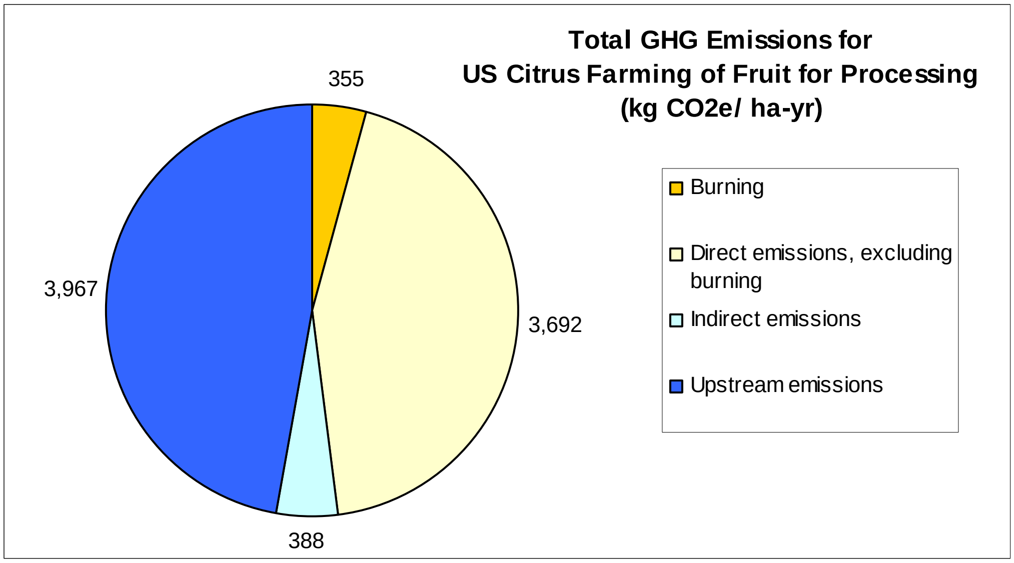

Figure 4.12. Nearly half (47%) of the greenhouse gas emissions associated with US citrus farming for processing, as measured in carbon dioxide equivalents (CO2e) per hectare-year, is due to upstream emissions due to production and delivery of energy, nutrients, and pesticides.

Within the general categories of direct emissions and upstream, which together account for more than 90% of the greenhouse gas emissions associated with citrus farming, several subcategories can be defined. Direct emissions are divided into the following subcategories: 1) emissions from the burning of replaced trees; 2) emissions from diesel powered tractors and gasoline powered pickup trucks used to perform field work in the groves such as tillage, mowing, spraying of pesticides, spreading of fertilizer; and general management; and 3) emissions from diesel and propane powered irrigation pumps, gypsum pumps, and wind machines. Upstream emissions are divided into those due to 1) the provision of energy, 2) the manufacture and transport of pesticides, and 3) the mining and/or manufacture of nutrients and soil amendments and their transport. Both direct and indirect field emissions due to the use of fertilizer and soil amendments are combined into a single category.

The results of this analysis are given in Table 4.43 and are shown graphically in Figure 4.13. As can be seen, the most significant contributions to greenhouse gas emissions are both the upstream burdens and the field emissions associated with the use of fertilizer and soil amendments. The former subcategory accounts for 34% of the total emissions and the latter accounts for 23%. Specifically, these are the result of using nitrogen fertilizer, and dolomite. Also notable, is that 15% of the total emissions are due to the fuel burned to power water pumps and wind machines used for irrigation and freeze protection.

Table 4.43. Greenhouse gas emissions (net and as carbon dioxide equivalents (CO_2e)) in kilograms per hectare-year (kg-ha-yr) for different sources by subcategory

	Net Emissions of GHG kg/ha-yr					Emissions of GHG in CO2e kg/ha-yr					
Source	CO_2	CH_4	N_2O	CO	VOC	CO_2	CH_4	N_2O	CO	VOC	TOTAL CO_2e
GWP (CO_2e factor)	1	25	298	1.57	3.04						
Field work, total	605	0.25	0.16	107	19.05	605	6	48	167	58	885
Burn	0	8.46	0.47	193	10.26	0	212	139	0	0	351
Water & wind	1,097	0.07	0.33	6.8	2.04	1,097	2	99	11	6	1,214
Nutrients, direct and indirect	331	0	5.55	0	0.00	331	0	1,655	0	0	1,986
Upstream Energy	633	2.74	0	0.4	0.25	633	69	3	1	1	706
Upstream Nutrients	1,541	2.02	4.15	2.4	1.95	1,541	51	1,238	4	6	2,839
Upstream Pesticides	400	0.82	0	0	0.04	400	21	1	0	0	422
TOTAL	4,606	14	11	309	34	4,606	359	3,184	183	71	8,402

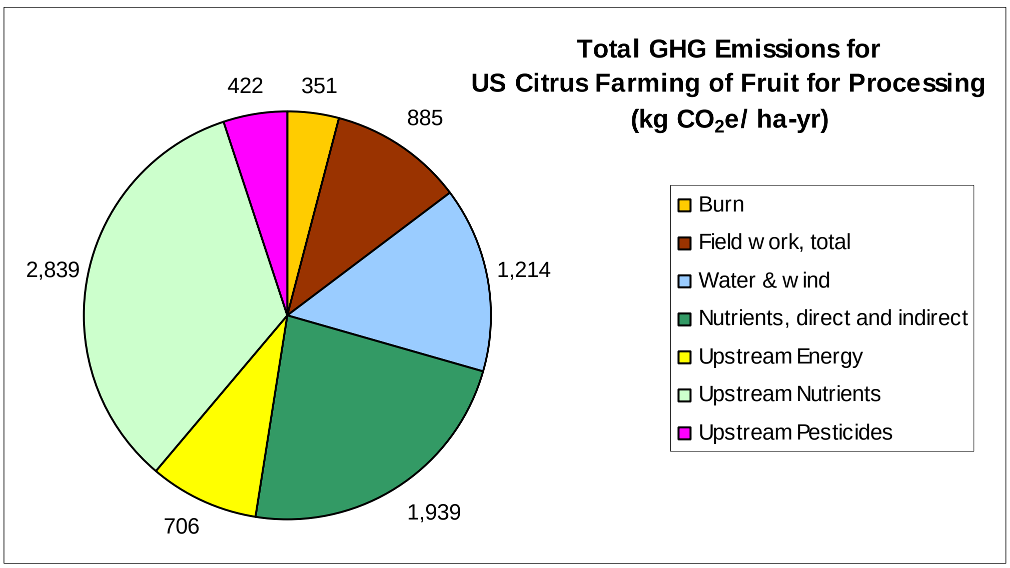

Table 4.13. More than one-third (34%) of the greenhouse gas emissions (as CO_2e/ha-yr) associated with US citrus farming for processing, are due to upstream emissions from production and delivery of fertilizer and soil amendments. Another 23% of total emissions are the result of combined direct and indirect emissions that result from fertilizer application.

4.3.1.4 By-Products

There are no by-products associated with the growing of citrus trees for fruit

4.4 Citrus Waste Ethanol Glossary

Albedo: A thin white tissue at the interior of the citrus peel that is a source of pectin

Brix: A measure of solids content that relates to the sugar content of a liquid

Flavedo: The outer colored portion of citrus peel, where the oil sacs or glands are located

Pulp: Ruptured juice vesicles (sacs) that remain after juice has been extracted

Rag: Membrane and core of citrus fruit that remains after juice has been extracted.

4.5 Citrus Waste Ethanol References

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