Energy Investments and CO_2 Emissions for Fresh Produce Imported Into New York State Compared to the Same Crops Grown Locally

Final Report 08-10
March 2008

New York State
Energy Research and
Development Authority

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Final Report

Prepared for the

New York State Energy Research and Development Authority

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NOTICE

ABSTRACT

The project reported below is a paper study of energy types and quantities required to grow and ship selected types of fresh produce into New York State from open-field production outside the state, and contrasts the sources and amounts of energy required to grow the same crops in Controlled Environment Agriculture (CEA) facilities in New York State, and with open field, seasonal production in the state.

KEY WORDS

Controlled-Environment Agriculture, agriculture, greenhouse, local food production, food, energy, food miles, carbon dioxide

ACKNOWLEDGMENTS

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SUMMARY

Conclusions resulting from the study include the following:

1. Energy used directly in field agriculture is dominated by petroleum fuel for transportation.
2. The price of diesel fuel already favors local production of all our field crops (and many others) because a good deal more fuel is burned to transport product to NY than is needed for production.
3. New York's disadvantage in perishable field crops is the shortness of the growing season and the difficulty of securing market share for perishable crops on a short-term basis.
4. Climate favors parts of Pennsylvania, New Jersey, Long Island, Maryland, Delaware and Virginia, where less supplemental heat and light is needed than in upstate New York and transportation costs to New York would be less than from Florida, California, Arizona, and Mexico. This may favor greenhouse production in neighboring states and encourage rapid expansion of a CEA industry in those areas.
5. We can reduce heating and lighting costs in various ways. We can use heat retention technologies more effectively, extend the duration of CO_2 enrichment through greenhouse air dehumidification and optimize venting for temperature control, and generate electricity on site, coupled with using the waste heat and CO_2 that comes from doing so. It may also be possible to achieve advantage by securing favorable deals with municipalities for electricity, particularly renewable energy (e.g., hydropower).
6. A final consideration is that, whether or not more total energy is needed to grow crops out of season in cloudy northern latitudes, where market opportunity exists it will happen. It may be that, by direct marketing that avoids middlemen, market share to the grower will be sufficiently large that opportunities will always exist for local outdoor and CEA operations. Moreover, small growers may be able to survive by rapidly adjusting to changing desires of the buying public and continually develop new market product niches.
7. If CEA production is desired in less advantageous climate zones, where it is illogical to do so from the perspective of current energy use intensity, there is all the more need to develop technologies to be more energy efficient per unit of product consumed by the public.

TASK 1: DEVELOP LIST OF CROPS IN STUDY

Determine, in consultation with the NYSERDA Project Manager, the crops to be included in the study. A default list for CEA production systems is: butterhead (bibb or Boston) lettuce, baby-leaf spinach, and tomato. A default list for outdoor production systems is: apple, strawberry, and iceberg lettuce.

GENERAL

For greenhouse crops, we have included three crops which the Cornell Controlled-Environment Agriculture (CEA) program has investigated under New York State Energy Research and Development Authority (NYSERDA) sponsorship, which either are in extensive production already (tomatoes) or have potential for much expanded production in New York (Boston lettuce and baby-leaf spinach). For field production we have included two fruit crops, apple and strawberry, and will also consider head lettuce (i.e. iceberg), baby-leaf spinach and field grown tomato. With the exception of baby-leaf spinach, all of these field crops have been grown in significant quantity in New York at one time or another. In selecting these crops we are following the default list suggested by NYSERDA.

GREENHOUSE CROPS

It appears the increased proportion of the fresh market tomato crop being grown in greenhouses will be maintained. Current greenhouse production in the Northeast is not year-round, and California and Mexico cover the periods when Canada and Florida are out of production. (Cook, 2005) In addition to New York competing directly with remote producers during the normal greenhouse tomato seasons - spring through fall - there is the possibility of competing during the winter also (year-round) by making use of supplementary lighting. In Chapter 5 of this study we examine the energy and financial cost of year-round tomato production in the Northeast. (The tomatoes in CEA/greenhouse production systems are all fresh-use tomatoes, whether beefsteak, cluster or cherry type.)

Boston/Bibb lettuce is an established, commercially-viable greenhouse crop grown in Europe and Canada, and has shown success grown in New York on a small scale (e.g., Finger Lakes Fresh, http://www.fingerlakesfresh.com). In the case of Boston lettuce there is a question: will local New York production be able to compete with intermediate-distance Tennessee production, due to begin production in the near future? More generally, we would like to know how greenhouse production of Boston lettuce can be made more profitable and environmentally sound though improved energy management.

Greenhouse production of spinach in New York, and the U.S. generally, is currently on a tiny scale. Baby-leaf spinach is grown predominantly in California and Arizona as an outdoor crop. Spinach is grown extensively as a greenhouse crop in Japan and Korea, although to a larger size plant than we envisage for

CEA in the U.S.. In Cornell CEA we have performed extensive research on greenhouse spinach production and have reason to believe it is more promising as a greenhouse crop than lettuce from a commercial standpoint, provided market demand recovers after the 2006 *E. coli* scare.

FIELD CROPS

New York is the second largest producer of apples in the United States, behind the state of Washington. New York exports a considerable volume of apples, but also imports from both U.S. and foreign producers. The apple industry is a stable mature industry. Transportation could very well be an important factor in how much local product versus out-of state product is consumed in New York.

Head lettuce, tomatoes, and strawberry, the other field crops we are considering, are viable crops for summertime field production in New York, but little is currently grown of any of these crops. There is potential for much-expanded field production in New York in these crops if profit margins change. Strawberry also has potential as a greenhouse crop out of season. The desire for locally produced goods also favors New York production of these crops.

TASK 2: DATA ON CROP QUANTITIES AND ORIGINS

Develop, from data available through the Economic Research Service of the USDA, a data bank of quantities and geographic sources of the chosen produce types (open-field production) as shipped into New York State, as well as locally produced.

GENERAL

As far as we have been able to determine, up-to-date data do not exist for quantities of foodstuff that enters and leaves New York in interstate trade, or any other state for that matter. The closest data we have found is for arrivals of agricultural commodities in selected conurbations by state of origin, for which limited data up to 1998 are available (e.g. Agricultural Marketing Service, Fruit and Vegetable Programs, Market News Branch, 1998;. Fruit and Vegetable Arrivals in Eastern Cities by Commodities, States, and Months, FVAS-1, United States Department of Agriculture, USA). Nor have we been able to find up-to-date data on how much of each commodity is sold and consumed in New York. On the other hand we do have solid data on how much of each commodity is produced in the country as a whole, and on a state-by-state basis, and how much is imported into and exported from the U.S. This makes it possible to estimate utilization (or disappearance) rates for each commodity for the country as a whole and, if we assume utilization rates are much the same throughout the country, to estimate utilization of each commodity in each state. If we know how much is produced in the state we can deduce how much needs to be brought in to meet the needs of the state's population and, conversely, what excess is available for trading out-of-state. This figure is actually the minimum that needs to be brought in for, if some of what is produced is traded out of state, more needs to be brought in to make up for what is traded out of state. For a variety of reasons, it is often the case that produce is traded out of state even when annual production is less than is utilized by the state population. For farms located near state borders, the most accessible/desirable markets may be across the border. In perishable crops, the state population may be too small to utilize what comes available during harvest season, requiring export of the excess. Consumers have come to expect to be able to buy most produce items year-round. When local supply is exhausted, needs are met by foreign imports and remote U.S. suppliers. Additionally, consumers may prefer out-of-state produce for price and quality reasons, or in order to get a particular variety. (Note. By convention, the terms "import" and "export" are reserved for foreign trade exclusively.)

FRUIT AND VEGETABLE PRODUCTION AND CONSUMPTION IN NEW YORK STATE

Table 2-1 shows the production and consumption patterns of New York as they were in the late 1990's, based on analysis by the Department of Applied Economics and Management at Cornell University (Peters, Bills et al., 2002, 2003) of data from interview surveys of U.S. consumers conducted intermittently by the federal government. (The last survey was approximately 10 year ago, between 1996 and 1998.) Only through such surveys is it possible to estimate actual consumption of foodstuffs in the sense of what is eaten after accounting for losses that occur from the farm gate through kitchen preparation. It is of interest that, for the fruits under consideration here, 35 to 40% was lost between harvest and eating. In tomato and lettuce nearly 50% was lost, and in spinach nearly 60%. For our purposes it is important to note whether differences exist in per capita consumption in the Northeast compared to the country as a whole. Here we see table tomato, lettuce and strawberry were consumed in the Northeast in identical amounts to the national average. Spinach consumption was substantially greater in the Northeast than in the rest of the country. However, sufficiently rapid changes have taken place in spinach consumption throughout the country during the past ten years that we do not attach much significance to the difference between the Northeast and the country as a whole when the survey was completed. Apple consumption was slightly higher in the Northeast, probably because it is a good apple growing area, with a population traditionally accustomed to eating the fruit.

In Table 2-1, estimated consumption in 1999 is presented based on per capita rates and the 1999 population. We have also presented estimates of “Production Required for New York Consumption”, namely “utilization” in New York (as mentioned above); the ratio of utilization figures to consumption figures gives the values for shrinkage. When farm production within New York is deducted from “Production Required for New York Consumption” (i.e. utilization in New York), we get the minimum that must be brought into New York from outside either through interstate commerce or foreign imports, or to meet the needs of New York. We see, for the vegetable crops we are considering, New York production in 1999 was less than 5% of the New York utilization in 1999. For strawberry, New York production was 7% of utilization. Only in the case of apple was New York production sufficient to supply New York utilization – it was actually 37 percent in excess of New York utilization.

The per capita consumption data shown in Table 2-1 are the most recent data on per capita consumption available even though it is 10 years old. We have used these data to check that per capita consumption rates are similar in our region to those nationally, and we will also use them as our best estimate of shrinkage factors. We do not have up-to-date per capita consumption rates, but we do have good historic and up-to-date crop production data for the U.S. and for individual states, from which we can determine accurate per-capita utilization rates for each year. If we assume shrinkage factors have remained much the same over the past 10 years, we can estimate what shifts in consumption have taken place up to the present, and present day consumption rates. They appear to have been substantial for the crops we are considering (see Table 2-2 and following figures).

Table 2-1: Vegetable and Fruit Production and Consumption in New York State in 1999, and Minimum Out-of-State Requirements for Selected Commodities

1999 NY population 18,200,000		Annual Consumption US lbs/capita	NY lbs/capita	NY State Consumptn million lbs	Shrinkage: Prod. to Consump.	Ratio: Prod. to Consump.	Annual NY Farmgate Production Actual Production million lbs	Area acres	Yield lb/acre	Production reqd for NY Consumption	Production deficit million lbs	Max % of NY needs met in-State
Tomato	fresh	19.1	18.1	330	0.53	1.88	34	2.660	12.767	622	588	5
Tomato	dried	0.04	0.0	0.6								
Tomato	juiced	2.1	2.7	50								
Tomato	paste	2.8	3.2	57								
Tomato	pureed	12.0	12.3	224								
Tomato	**Total**	**35.9**	**36.4**	**662**	n/a							
Lettuce	head	11.6	11.6	211	0.54	1.87	16	800	24,000	393	377	4
Lettuce	leaf	0.7	0.9	16	0.50	1.98	14	600	24,000	31	16	47
Lettuce	**Total**	**12.4**	**12.4**	**226**	**0.52**	**1.92**	**31**	1.400	24.000	**434**	**404**	**7**
Spinach	**Total**	**1.6**	**2.3**	**42**	**0.42**	**2.38**	**5**	627	8,000	**99**	**94**	**5**
Apple	Fresh	11.7	12.1	214	0.61	1.65	482.0			353.0	-129.0	137
Apple	Juice	14.2	18.9	335	0.62	1.61	197.4			538.6	341.2	37
Apple	Processed	3.4	3.6	63	0.67	1.49	384.6			94.2	-290.4	408
	canned					1.49	296.2					
	frozen					1.98	63.4					
	other proc.					1.80	25.0					
Apple	**Total**	29.3	34.6	**613**	n/a	n/a	**1.064.0**	**56.400**	**18.865**	**985.7**	**-78.3**	**108**
Strawberry	Fresh	1.7	1.8	32								
Strawberry	Juice	1.3	1.3	24								
Strawberry	Processed	1.0	0.9	15								
Strawberry	**Total**	4.0	4.0	**71**	0.64	**1.56**	**7.5**	**1.980**	**3.788**	**111.6**	**104.1**	**7**

Adapted from: Christian Peters, Nelson Bills, Jennifer Wilkins, and R. David Smith (2003). Fruit consumption, dietary guidelines and agricultural production in New York State - implications for local food economies.
Research Bulletin 2003-02, Department of Applied Economics and Management, Cornell University. Ithaca NY
URL for printable pdf is: /aem.cornell.edu/research/researchpdf/rb0302.pdf or Google on title.
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Table 2-2: Estimates of US Per-Capita Utilization of Selected Fruit and Vegetable Commodities, Past and Future

Year	US Population Millions	Lettuce Head lettuce	Romaine & leaf	All lettuce	Spinach Fresh	Tomato Fresh Tomatoes	Canning Tomatoes	All Tomatoes	Strawberry Fresh market	Processed	Apple Fresh	Processed
	USA annual Per Capita Utilization: lbs (= US Production - exports + imports, divided by US population)											
	(Figures on shaded background are estimated/projected from trends)											
1992	256.894	25.8	4.7	30.5	0.82	15.4	73.3	88.7	3.59	1.19	19.1	27.3
1993	260.255	24.4	5.0	29.4	0.66	16.3	75.8	92.1	3.62	1.16	19.0	29.3
1994	263.436	25.0	5.7	30.7	0.75	16.2	76.3	92.5	4.05	1.12	19.4	29.8
1995	266.557	22.2	5.9	28.1	0.67	16.8	74.6	91.4	4.10	1.27	18.7	26.4
1996	269.667	21.6	5.8	27.4	0.63	17.4	73.4	90.8	4.32	1.27	18.7	27.7
1997	272.912	23.9	6.6	30.5	1.11	17.3	72.6	89.9	4.10	1.09	18.1	27.0
1998	276.115	22.3	6.6	28.9	0.97	18.5	74.0	92.5	3.92	1.25	19.0	28.4
1999	279.295	24.9	7.6	32.5	0.97	19.1	71.2	90.3	4.57	1.20	18.5	28.6
2000	282.430	23.5	8.4	31.8	1.37	19.0	70.1	89.1	4.86	1.39	17.5	27.5
2001	285.454	23.0	8.0	31.0	1.07	19.2	65.5	84.7	4.21	1.63	15.6	27.8
2002	288.427	22.5	9.6	32.1	1.43	20.3	69.3	89.6	4.65	1.43	16.0	27.1
2003	291.289	22.2	11.1	33.3	1.77	19.5	69.7	89.3	5.58	1.71	16.9	29.6
2004	294.056	21.2	9.7	31.0	2.02	20.0	70.4	90.4	5.47	1.54	18.8	31.8
2005	296.940	21.0	10.6	31.6	2.49	20.2	73.5	93.7	5.82	1.93	16.9	28.9
2006	299.801	18.7	11.0	29.7	2.01	19.9	64.4	84.3	5.70	1.70	17.0	28.7
2007	302.690	18.4	11.2	29.5	1.80	20.4	70.5	90.9	5.80	1.70	18.0	28.7
2008	303.598	18.2	11.5	29.7	2.00	20.5	70.5	91.0	5.90	1.80	17.0	28.7
2009	306.272	18.0	12.0	30.0	2.20	20.5	70.5	91.0	5.80	1.80	17.0	28.7
2010	308.936	17.8	12.5	30.3	2.50	21.0	70.0	91.0	5.90	1.80	17.0	28.7
2004-5 Average		**21.1**			**2.26**	**20.1**			**5.65**		**17.9**	

Data were obtained from various USDA ERS and NASS tables, and population estimates from Bureau of Census.

Table 2-3a: Estimation of NY State Out-of-State Requirements for Selected Fruit and Vegetable Commodities

NY State Crop Utilization by Resident Population — 1000 cwt

Year	NY Population	Lettuce: Head lettuce	Romaine & leaf	All lettuce	Spinach: Fresh	Tomato: Fresh Tomatoes	Canning Tomatoes	All Tomatoes	Strawberry: Fresh market	Processed	Apple: Fresh	Processed
1992	18,246,653	4,708	858	5,565	150	2,810	13,375	16,185	655	217	3,492	4,980
1993	18,374,954	4,483	919	5,402	121	2,995	13,928	16,923	665	213	3,491	5,384
1994	18,459,470	4,615	1,052	5,667	138	2,990	14,085	17,075	748	207	3,574	5,503
1995	18,524,104	4,112	1,093	5,205	124	3,112	13,819	16,931	759	235	3,462	4,894
1996	18,588,460	4,015	1,078	5,093	117	3,234	13,644	16,878	803	236	3,470	5,147
1997	18,656,546	4,459	1,231	5,690	207	3,226	13,545	16,770	765	203	3,375	5,028
1998	18,755,906	4,188	1,240	5,428	182	3,470	13,879	17,349	735	234	3,560	5,321
1999	18,882,725	4,704	1,433	6,137	183	3,601	13,445	17,045	863	227	3,493	5,400
2000	18,998,889	4,457	1,592	6,049	260	3,606	13,324	16,930	923	264	3,317	5,228
2001	19,095,604	4,390	1,531	5,922	204	3,664	12,508	16,172	804	311	2,979	5,307
2002	19,167,600	4,317	1,836	6,153	274	3,889	13,275	17,174	891	274	3,065	5,191
2003	19,238,252	4,271	2,126	6,397	341	3,742	13,411	17,180	1,073	329	3,253	5,689
2004	19,291,526	4,094	1,877	5,971	390	3,849	13,589	17,438	1,055	297	3,633	6,137
2005	19,306,183	4,060	2,046	6,107	481	3,892	14,194	18,086	1,124	373	3,267	5,579
2006	19,315,721	3,618	2,123	5,741	388	3,848	12,435	16,283	1,101	328	3,284	5,563
2007	19,346,333	3,556	2,159	5,715	348	3,949	13,643	17,592	1,122	329	3,482	5,572
2008	19,383,109	3,489	2,229	5,718	388	3,974	13,669	17,643	1,144	349	3,295	5,582
2009	19,415,485	3,398	2,330	5,728	427	3,980	13,692	17,672	1,126	349	3,301	5,592
2010	19,443,672	3,305	2,430	5,736	486	4,083	13,611	17,694	1,147	350	3,305	5,600
2004-5 Average		**4,077**			**435**	**3,870**			**1,089**		**3,450**	

(NY population times lbs utilized per capita; assumes NY utilization rates same as US rates)

Table 2-3b: Estimation of NY State Out-of-State Requirements for Selected Fruit and Vegetable Commodities

NY State Production — 1000 cwt

Year	NY Population	Lettuce: Head lettuce	Lettuce: Romaine & leaf	Lettuce: All lettuce	Spinach: Fresh	Tomato: Fresh Tomatoes	Tomato: Canning Tomatoes	Tomato: All Tomatoes	Strawberry: Fresh market	Strawberry: Processed	Apple: Fresh	Apple: Processed
1992	18,246,653	76	228	304	24	176	0	176	78	0	5,200	6,500
1993	18,374,954	63	190	253	24	276	0	276	156	0	4,000	4,700
1994	18,459,470	61	184	245	24	400	0	400	96	0	4,900	6,100
1995	18,524,104	34	101	135	24	300	0	300	77	0	4,800	6,300
1996	18,588,460	20	60	80	24	152	0	152	74	0	5,000	5,300
1997	18,656,546	49	147	196	24	384	0	384	67	0	5,200	6,000
1998	18,755,906	41	124	165	24	462	0	462	61	0	4,200	5,400
1999	18,882,725	38	113	150	24	357	0	357	78	0	5,900	6,400
2000	18,998,889	38	113	150	24	540	0	540	65	0	4,600	4,750
2001	19,095,604	38	113	150	24	480	0	480	60	0	4,200	5,200
2002	19,167,600	38	113	150	40	378	0	378	63	0	3,100	3,200
2003	19,238,252	38	113	150	30	322	0	322	50	0	5,100	5,500
2004	19,291,526	38	113	150	15	360	0	360	65	0	6,600	6,200
2005	19,306,183	38	113	150	9	360	0	360	52	0	4,900	5,400
2006	19,315,721	38	113	150	9	360	0	360	60	0	5,300	5,500
2007	19,346,333	38	113	150	9	360	0	360	60	0	5,300	5,500
2008	19,383,109	38	113	150	9	360	0	360	60	0	5,300	5,500
2009	19,415,485	38	113	150	9	360	0	360	60	0	5,300	5,500
2010	19,443,672	38	113	150	9	360	0	360	60	0	5,300	5,500
2004-5 Average		**38**			**12**	**360**			**59**		**5,750**	

One disadvantage of remote production of perishable food crops is the added delay before consumption and the concomitant additional physical handling and vibration to which the produce is subjected before use. It is a reasonable to assume that shrinkage factors for local New York produce are smaller than for West Coast and Mexican produce because New York produce does not have to undergo approximately three days of shipping and endure the associated extra handling and potential inadequate environmental control, primarily temperature control. In determining energy use that goes into the produce eaten in New York, we will first determine the energy use in farm production and transportation of the food utilized in New York and then, as a final step, we will apply factors to take into account shrinkage to determine energy use on a food-consumed basis. Shrinkage factors for local produce will be less than for remote produce.

For all the preliminary calculations in determining energy use, the produce quantity we will be considering is not the amount eaten/consumed, but the amount that must be produced and transported to supply what eventually is consumed. Instead of per capita consumption we will be thinking in terms of per capita utilization of crop harvest. What is consumed may be as little as half of that harvested and directed to the consumer, as shown in Table 2-1.

Per capita utilization of our crops of interest on a nationwide basis is given in Table 2-2, and charted in Figures 2-1 through 2-6. Over the fifteen year period from 1992 to 2007, use of head/iceberg lettuce has trended down slightly (Fig.2-1), but Romaine + leaf lettuce up sharply (Fig.2-2).

Spinach also has undergone an extraordinary expansion in use (see Fig. 2-3), a roughly fourfold increase over this period, reaching 2.5lbs per capita in 2005. However, the *E. coli* scare of September, 2006 depressed annual use by approximately 20% in 2006 compared to 2005. Production and use for 2007 are not yet available but, during January of 2007, sales values were off by 25%. In Fig. 2-3 we have shown spinach use rebounding to the 2005 level by 2010, but this depends on how well the industry is able to deal with future instances of contamination and recovering from shaken public confidence.

The great expansion in spinach and lettuce types such as romaine is largely because of their use in pre-cut and baby-leaf packaged salad mixes (Ryder, 2002.) Butterhead/bibb/Boston lettuce is more commonly used in tossed salads, sandwiches, and as a wrapper for other food, and has not undergone similar expansion. Data are not kept for Boston lettuce separately in USDA surveys but its total use is less than romaine and leaf lettuce and its trend appears to have been flat (Fig. 2-4, from Ryder, 2002) (and see shipments data following). In one-year of data for lettuce sales in a major New York supermarket chain (2000), Boston lettuce sales were roughly 1% of all lettuce sales, iceberg claiming, 62%, romaine 13%, leaf lettuce 13%, and spring mix 6% (Figure 2-5, from Salamanca, 2002).

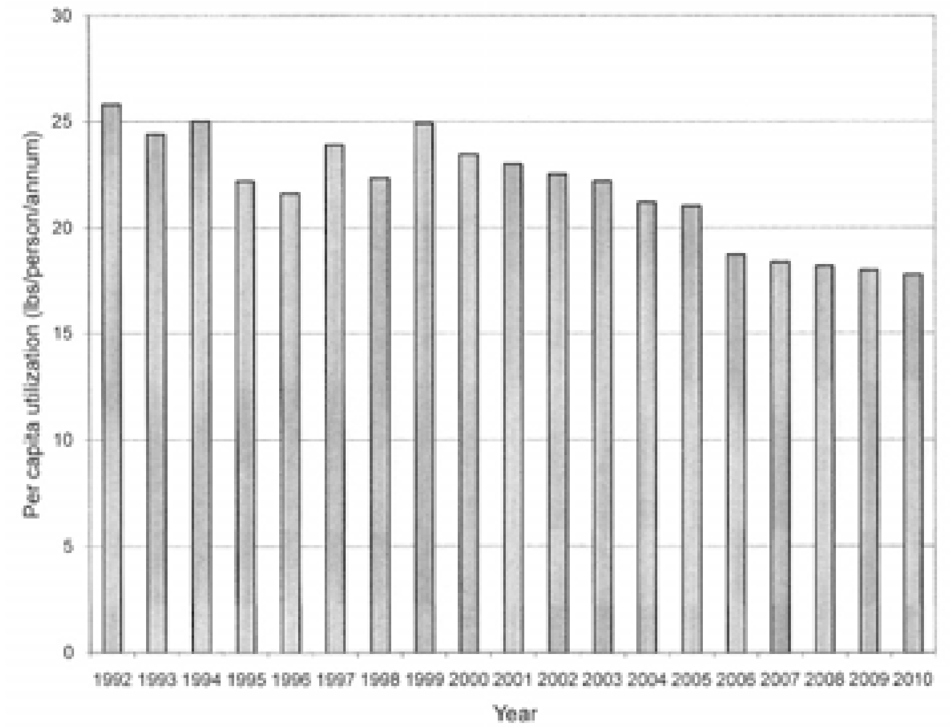

Figure 2-1. Historic and Projected Head Lettuce Utilization in the US

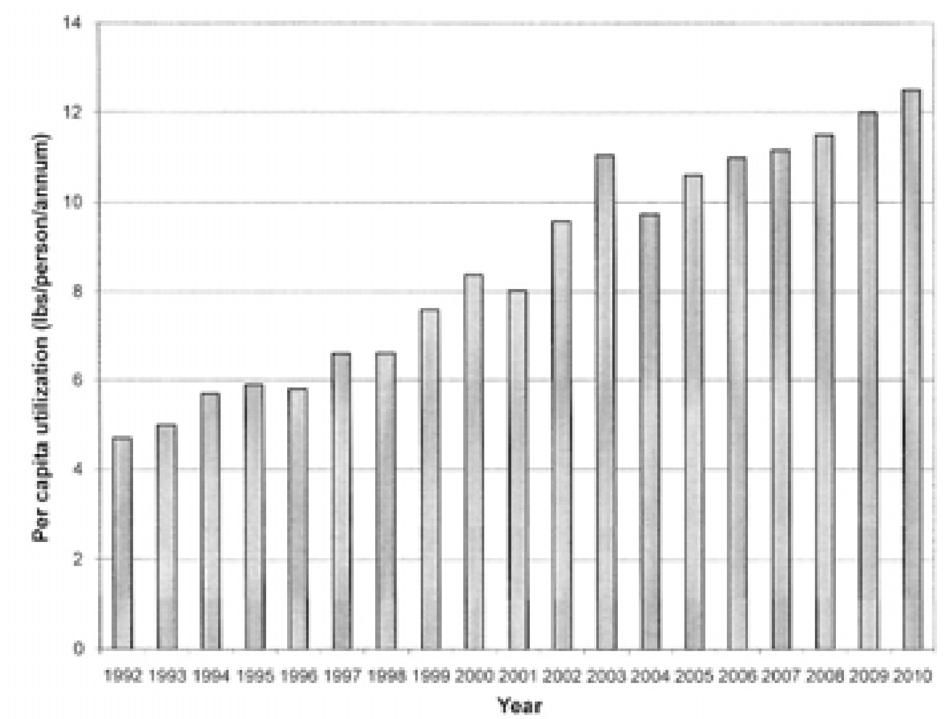

Figure 2-2. Historic and Projected Romaine and Leaf Lettuce Utilization in the US

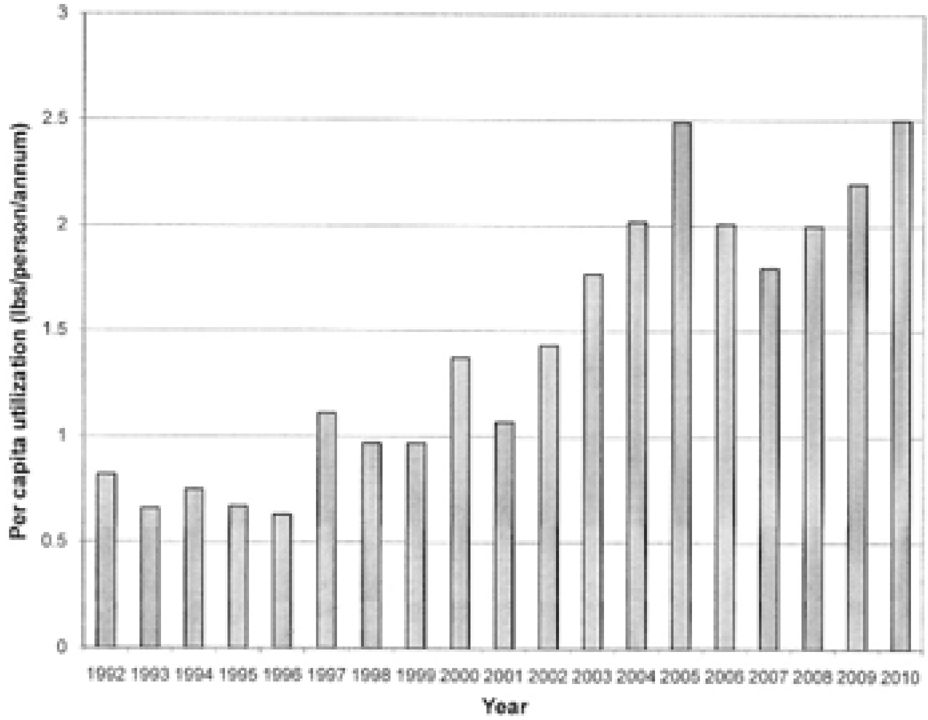

Figure 2-3. Historic and Projected Fresh Spinach Utilization in the US

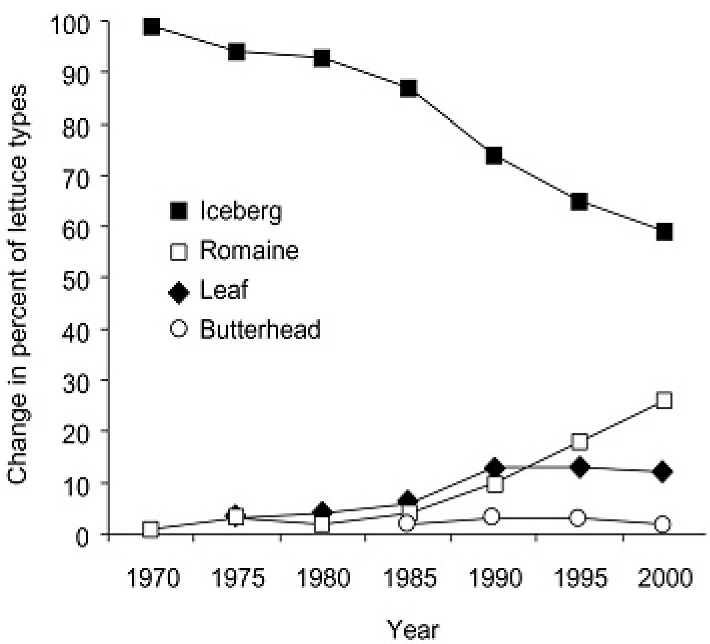

Figure 2-4. Comparison of Historic Use of Iceberg and Other Lettuce Types in the United States

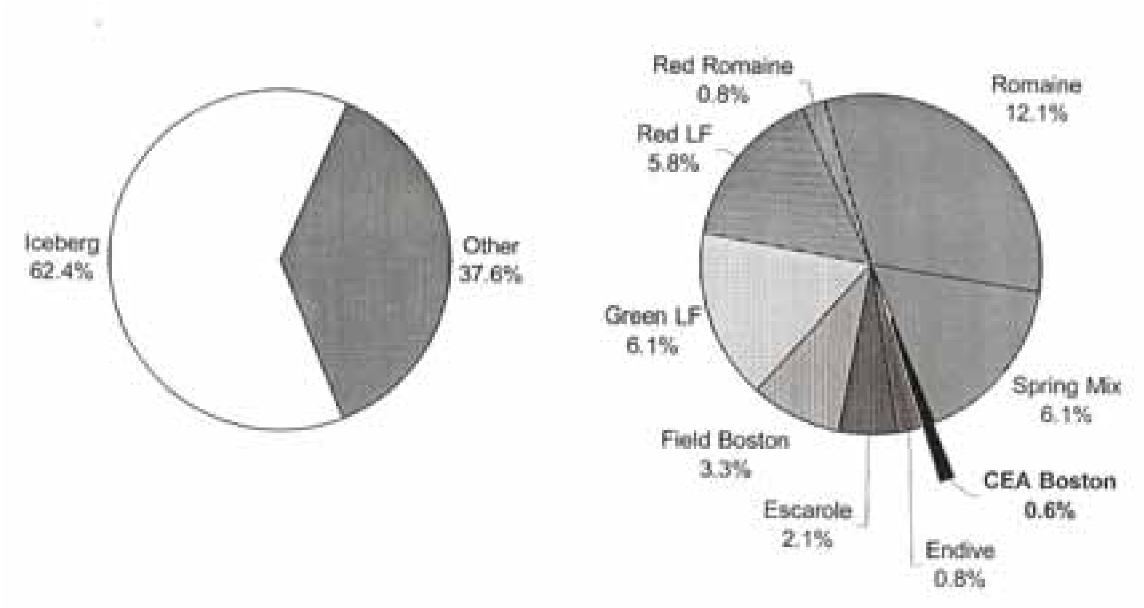

Figure 2-5. Percent Sales of All Lettuce Types Sold in Local Supermarket Chain Stores During 2000 (taken from Salamanca, 2002 doctoral thesis)

Fresh tomato use has shown a steady increase over the 15-year period starting in 1992 (Fig. 2-6). There may have been a slight decline in processed tomato use. Not shown in Fig. 2-6 is a dramatic increase in the proportion of table tomatoes grown in greenhouses in recent years. This important development is discussed in detail by Cook and Calvin (2005).

Data on greenhouse production is beginning to be kept separately for the U.S. as a whole in shipments data, but geographic origins are not published, done to protect grower identities and, furthermore, the industry is in a state of flux with operations starting in many places but not always succeeding. Expansion in tomato consumption appears to have come in large part through introduction of new products – vine/cluster tomatoes and grape tomatoes. The green-picked field staking tomato has, so far, held its place.
In fruits, strawberry use has dramatically increased as production costs in California have fallen (Fig. 2-7), and apple use has remained steady in both fresh and processed categories (Figs. 2-8).

Table 2-3 shows the estimated annual crop amounts needed to satisfy the New York population if New York consumers behave like the country as a whole. It also shows how much is produced in New York. Table 2-4 shows minimum amounts that must be brought into New York by deduction of the two sets of values in Table 2-3. In the case of the four commodities other than apple, the amounts produced in New York are so small, currently and historically, that there is little danger any significant amount is/was sold out of state, even if the harvest is/was concentrated in a short time period.

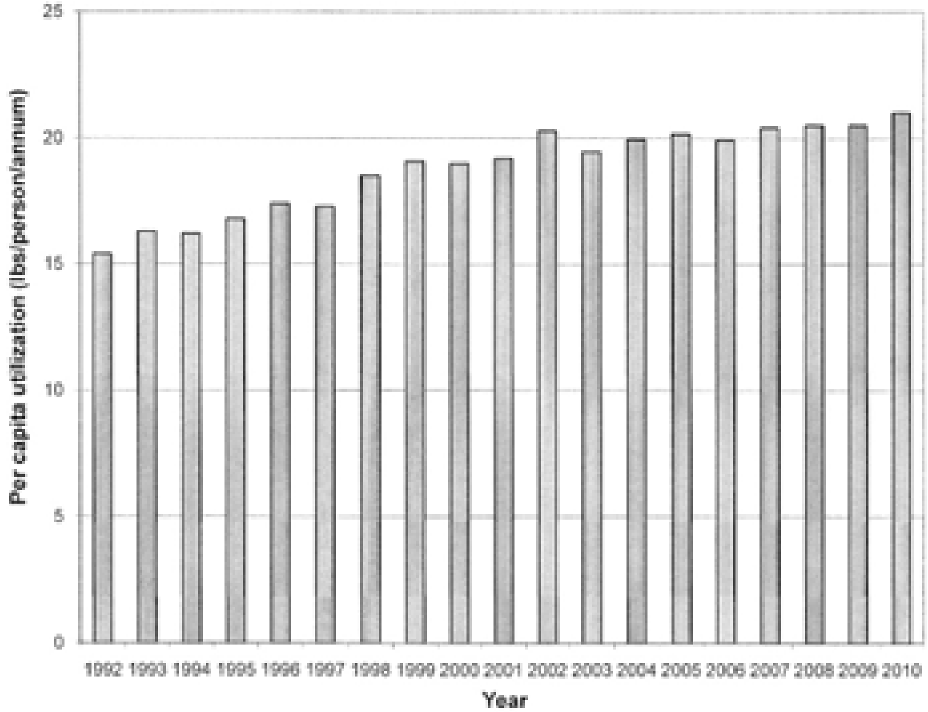

Figure 2-6. Historic and Projected Fresh Tomato Utilization in the US

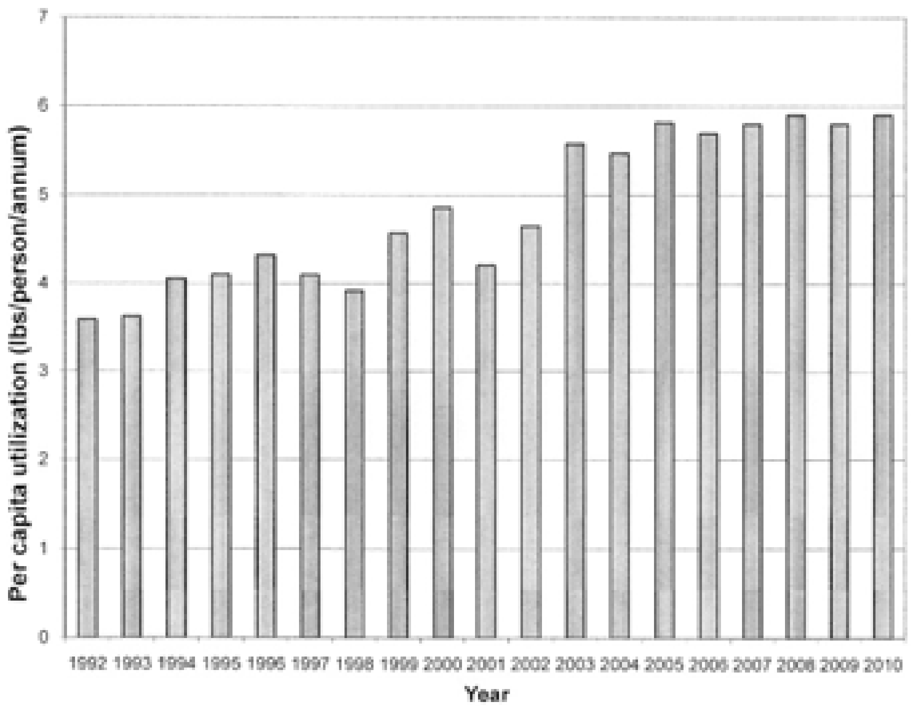

Figure 2-7. Historic and Projected Fresh Strawberry Utilization in the US

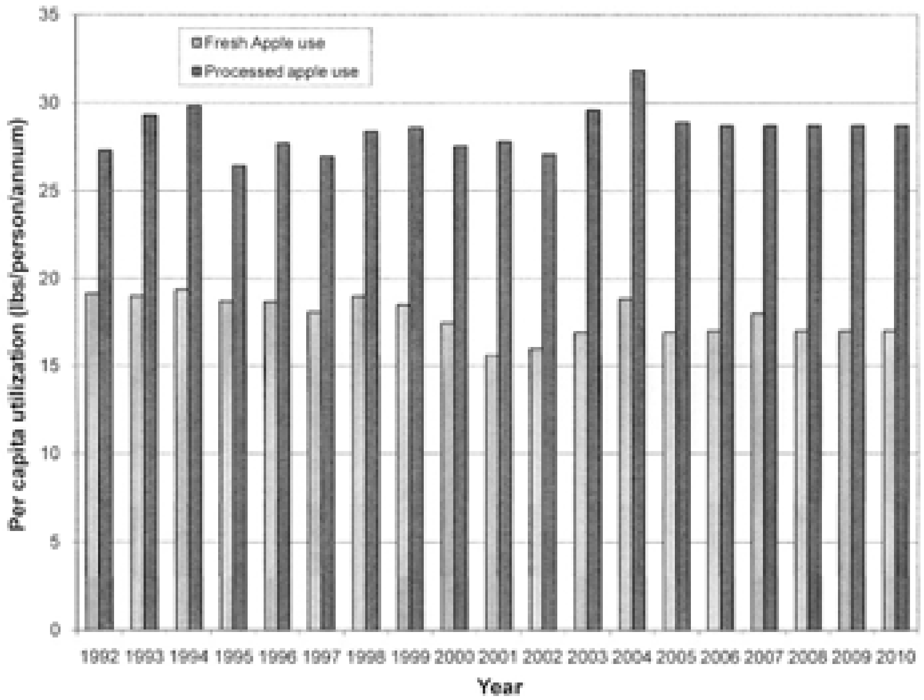

Figure 2-8. Historic and Projected Apple Utilization in the US

Table 2-4a. NY State Out-of-State Requirements for Selected Fruit and Vegetable Commodities.

Out-of-State Requirements (1000 cwts).

Year	NY Populatior	Lettuce: Head lettuce	Lettuce: Romaine & leaf	Lettuce: All lettuce	Spinach: Fresh	Tomato: Fresh Tomatoes	Tomato: Canning Tomatoes	Tomato: All Tomatoes	Strawberry: Fresh market	Strawberry: Processec	Apple: Fresh	Apple: Processed
1992		4,632	630	5,261	126	2,634	13,375	16,009	577	217	792	-1,520
1993		4,420	729	5,149	97	2,719	13,928	16,647	509	213	1,991	684
1994		4,554	868	5,422	114	2,590	14,085	16,675	652	207	1,174	-597
1995		4,079	992	5,070	100	2,812	13,819	16,631	682	235	1,162	-1,406
1996		3,995	1,018	5,013	93	3,082	13,644	16,726	729	236	970	-153
1997		4,410	1,084	5,494	183	2,842	13,545	16,386	698	203	675	-972
1998		4,147	1,116	5,263	158	3,008	13,879	16,887	674	234	1,860	-79
1999		4,666	1,321	5,987	159	3,244	13,445	16,688	785	227	93	-1,000
2000		4,420	1,480	5,899	236	3,066	13,324	16,390	858	264	1,217	478
2001		4,353	1,419	5,772	180	3,184	12,508	15,692	744	311	1,279	107
2002		4,279	1,724	6,003	234	3,511	13,275	16,796	828	274	2,465	1,991
2003		4,233	2,013	6,247	311	3,420	13,411	16,858	1,023	329	653	189
2004		4,056	1,765	5,821	375	3,489	13,589	17,078	990	297	0	-63
2005		4,023	1,934	5,957	472	3,532	14,194	17,726	1,072	373	867	179
2006		3,580	2,010	5,591	379	3,488	12,435	15,923	1,041	328	484	63
2007		3,518	2,047	5,565	339	3,589	13,643	17,232	1,062	329	682	72
2008		3,451	2,117	5,568	379	3,614	13,669	17,283	1,084	349	495	82
2009		3,360	2,217	5,578	418	3,620	13,692	17,312	1,066	349	501	92
2010		3,268	2,318	5,586	477	3,723	13,611	17,334	1,087	350	505	100
2004-5 Average		**4,039**			**423**	**3,510**			**1,031**		**433**	

Table 2-4b. NY State Out-of-State Requirements for Selected Fruit and Vegetable Commodities.

NY Production as Proportion of Total NY Requirement

1992	0.02	0.27	0.05	0.16	0.06	0.00	0.01	0.12	0.00	1.49	1.31
1993	0.01	0.21	0.05	0.20	0.09	0.00	0.02	0.23	0.00	1.15	0.87
1994	0.01	0.17	0.04	0.17	0.13	0.00	0.02	0.13	0.00	1.37	1.11
1995	0.01	0.09	0.03	0.19	0.10	0.00	0.02	0.10	0.00	1.39	1.29
1996	0.00	0.06	0.02	0.20	0.05	0.00	0.01	0.09	0.00	1.44	1.03
1997	0.01	0.12	0.03	0.12	0.12	0.00	0.02	0.09	0.00	1.54	1.19
1998	0.01	0.10	0.03	0.13	0.13	0.00	0.03	0.08	0.00	1.18	1.01
1999	0.01	0.08	0.02	0.13	0.10	0.00	0.02	0.09	0.00	1.69	1.19
2000	0.01	0.07	0.02	0.09	0.15	0.00	0.03	0.07	0.00	1.39	0.91
2001	0.01	0.07	0.03	0.12	0.13	0.00	0.03	0.07	0.00	1.41	0.98
2002	0.01	0.06	0.02	0.15	0.10	0.00	0.02	0.07	0.00	1.01	0.62
2003	0.01	0.05	0.02	0.09	0.09	0.00	0.02	0.05	0.00	1.57	0.97
2004	0.01	0.06	0.03	0.04	0.09	0.00	0.02	0.06	0.00	1.82	1.01
2005	0.01	0.05	0.02	0.02	0.09	0.00	0.02	0.05	0.00	1.50	0.97
2006	0.01	0.05	0.03	0.08	0.09	0.00	0.02	0.05	0.00	1.61	0.99
2007	0.01	0.05	0.03	0.09	0.09	0.00	0.02	0.05	0.00	1.52	0.99
2008	0.01	0.05	0.03	0.08	0.09	0.00	0.02	0.05	0.00	1.61	0.99
2009	0.01	0.05	0.03	0.07	0.09	0.00	0.02	0.05	0.00	1.61	0.98
2010	0.01	0.05	0.03	0.07	0.09	0.00	0.02	0.05	0.00	1.60	0.98
2004-5 Average	0.01			0.03	0.09			0.05		1.66	

In the case of fresh apples, where New York grows considerably more than the state population eats, we have estimated half the fresh apples produced in New York are sent out of state and approximately twenty percent of the consumption by New Yorkers is of apples grown outside New York. Enough apples are produced in New York to meet (theoretically) consumer demand, but storage lives of varieties such as Macintosh and Empire are not long and that, along with consumer preferences, lead to a considerable amount of out-of-state trade. The negative figures under the processing apple commodity indicate the maximum amount that might be exported after satisfying New York requirements for processed apple products; we will not pursue apple processing further but it would make economic sense for processing to be conducted in New York and the lightened product to be shipped rather than exporting the apples themselves for processing out of state.

We have very good figures for what needs to be brought into New York for four of our crops, and a reasonable estimate for the fifth crop (apples) (See Table 2-4). It now becomes a matter of determining the quantities from each origin. Here we are helped by the situation that, in each commodity of interest (lettuce, spinach, tomato, strawberry and apple), there are only a few major suppliers. California and Mexico figure largely in most of the crops, followed by Arizona, Florida, and Washington.

We have two main independent ways to assign geographic origins for food shipped into New York: farm production data and shipping data. Both need to be supplemented by foreign import-export data.

SHIPPING DATA

Data are available on line for the amount of each fresh produce commodity shipped by state of origin, by mode of transport, by month for 1999 through 2006, and on-going. (e.g. Agricultural Marketing Service, Fruit and Vegetable Programs, Market News Branch, 2002: Fresh fruit and vegetable shipments by commodities, states, and months. FVAS-4, Calendar year 2002. United States Department of Agriculture, http://www.ams.usda.gov/fv/mncs/shipsumm02.PDF). Lettuce and tomato are divided into several sub-categories. Exports to foreign lands from each state, by commodity, and imports from foreign lands into the U.S. as a whole, by commodity, are also listed.

These data do not claim to catch every possible load shipped; nor is it guaranteed all the shipments leave the state of origin – in a stretched-out populous state such as California, there is considerable intrastate trade and shipment. Nevertheless, the data show a reasonable correspondence with independently developed farm production data and appear to be a representative sample of what is shipped in interstate commerce if one makes allowance for intrastate shipment. At the very least, they indicate which states are shipping large amounts of produce.

Annual shipments data are tabulated in Appendices 1 thru 10 of this report, for the years 1999 to 2006, organized by commodity, state of origin, and mode of transport. Monthly breakdowns are available in the original sources, on-line. It can be seen for a commodity like fresh apple, which is grown in most regions of the country, shipments originated in 13 different states, exports went out of the country from 5 states, and imports arrived from 10 countries. In the case of iceberg lettuce, a specialized crop, shipments originated from 5 states and imports arrived in the U.S. from 3 countries. However, two U.S. states, California and Arizona, and one foreign country, Mexico, accounted for over 98% of all shipments in the U.S.. The other five sources contributed less than 1%.

Tables 2-5 through 2-9 summarize the data from the Appendix tables on shipments by/from major geographic sources, defined as those contributing over 1% of the total shipments. The percentage attributable to each source, and how much of total shipments is accounted for in this way, is also given. Fresh strawberry and apple shipments are tabulated in Table 2-5, spinach and iceberg lettuce shipments in 2-6 and other lettuce types in 2-7. Tomato data are given in Tables 2-8 and 2-9. Fresh tomato totals often represent a combination of plum, staking and greenhouse tomatoes. We have presented each category separately (Table 2-8) and combined (Table 2-9). It can be seen the USDA did not start to keep separate tallies for plum tomatoes and greenhouse tomatoes until 2002 and 2004, respectively. In the case of greenhouse tomatoes, unfortunately, only U.S. totals are given, not even state of origin, in order to protect the production information of individual growers.

Table 2-5. Fresh Strawberries and Apples Shipped by Major Producers for US Use by Year.

Origin	1999	2000	2001	2002	2003	2004	2005	2006	2004-2005
Strawberries - all transport modes Units of 1000 cwt, annual.									Average
CALIFORNIA	10,908	12,007	11,291	13,122	12,614	11,706	12,851	13,523	12,279
FLORIDA	1,150	1,394	1,199	990	774	832	895	1,446	864
MEXICO-IMPORT	1,005	737	676	871	857	995	1,199	1,124	1,097
TOTAL	**13,063**	**14,138**	**13,166**	**14,983**	**14,245**	**13,533**	**14,945**	**16,093**	**14,239**
Percentage of strawberries shipped and used in US									Ratio
CALIFORNIA	81.7	83.0	84.1	86.5	87.7	85.4	84.9	82.3	0.86
FLORIDA	9.6	10.9	10.0	7.1	5.7	6.5	6.4	9.8	0.06
MEXICO	8.4	5.8	5.6	6.2	6.3	7.8	8.5	7.7	0.08
TOTAL	**99.7**	**99.6**	**99.7**	**99.8**	**99.7**	**99.8**	**99.8**	**99.8**	**99.8**
Fresh Apples - all transport modes Units of 1000 cwt, annual.									Average
APPALACHIA	645	795	571	664	508	624	779	989	702
CALIFORNIA	1,778	2,301	1,359	1,679	1,693	1,235	1,319	1,226	1,277
MICHIGAN	2,858	2,806	2,579	1,977	1,880	2,406	2,426	2,434	2,416
NEW YORK	1,805	2,129	2,869	2,640	2,573	2,779	3,012	2,799	2,896
NORTH CAROLINA	213	293	157	186	117	480	306	516	393
OREGON	773	782	691	708	652	691	660	695	676
WASHINGTON	25,816	24,756	25,027	24,492	25,688	26,282	29,609	29,004	27,946
CANADA	939	844	852	953	819	668	744	769	706
CHILE	944	959	1,268	1,375	1,986	2,492	1,198	1,818	1,845
NEW ZEALAND	1,349	1,576	1,066	1,292	1,125	1,270	711	824	991
TOTAL	**37,120**	**37,241**	**36,439**	**35,966**	**37,041**	**38,927**	**40,764**	**41,074**	**39,846**
Percentage of fresh apples shipped in US									Ratio
APPALACHIA	1.7	2.1	1.5	1.8	1.3	1.6	1.9	2.4	
CALIFORNIA	4.6	6.0	3.6	4.6	4.5	3.1	3.2	3.0	0.03
MICHIGAN	7.4	7.3	6.9	5.4	5.0	6.1	5.9	5.9	0.06
NEW YORK	4.7	5.5	7.6	7.2	6.8	7.0	7.3	6.7	
NORTH CAROLINA	0.6	0.8	0.4	0.5	0.3	1.2	0.7	1.2	
OREGON	2.0	2.0	1.8	1.9	1.7	1.7	1.6	1.7	
WASHINGTON	66.9	64.4	66.6	66.6	67.9	66.2	71.4	69.8	0.70
CANADA	2.4	2.2	2.3	2.6	2.2	1.7	1.8	1.9	0.02
CHILE	2.4	2.5	3.4	3.7	5.2	6.3	2.9	4.4	0.05
NEW ZEALAND	3.5	4.1	2.8	3.5	3.0	3.2	1.7	2.0	0.02
TOTAL	**96.2**	**96.8**	**96.9**	**97.8**	**97.9**	**98.1**	**98.4**	**98.9**	**1.00**

Table 2-6. Iceberg Lettuce and Fresh Spinach Shipped by Major Producers for US Use

Origin	1999	2000	2001	2002	2003	2004	2005	2006	2004-2005
Fresh spinach - all transport modes Units of 1000 cwt, annual.									**Average**
ARIZONA	113	143	84	87	83	92	163	342	128
CALIFORNIA	144	436	551	509	528	536	534	478	535
TEXAS	143	137	103	113	79	13	13	12	13
CANADA	0	0	0	0	52	26	51	27	39
MEXICO	92	122	197	207	179	238	281	233	260
TOTAL	**492**	**838**	**935**	**916**	**921**	**905**	**1,042**	**1,092**	**974**
Percentage of total shipped and used in US									**Ratio**
ARIZONA	22.6	16.8	8.8	9.1	9.0	10.0	15.5	31.0	0.13
CALIFORNIA	28.7	51.4	57.5	53.4	57.3	58.5	50.7	43.3	0.55
TEXAS	28.5	16.1	10.7	11.9	8.6	1.4	1.2	1.1	0.01
CANADA	0.0	0.0	0.0	0.0	5.6	2.8	4.8	2.4	0.04
MEXICO	18.4	14.4	20.5	21.7	19.4	26.0	26.7	21.1	0.27
TOTAL	**98.2**	**98.7**	**97.5**	**96.1**	**99.9**	**98.8**	**98.9**	**98.8**	**1.00**
Iceberg lettuce - all transport modes Units of 1000 cwt, annual.									**Average**
ARIZONA	11,463	10,637	11,272	10,116	9,916	10,121	9,488	9,613	9,805
CALIFORNIA	28,472	28,906	27,799	27,608	27,775	26,404	26,761	25,243	26,583
MEXICO	223	224	438	1,119	898	824	1,239	1,333	1,032
TOTAL	**40,158**	**39,767**	**39,509**	**38,843**	**38,589**	**37,349**	**37,488**	**36,189**	**37,419**
Percentage of total shipped and used in US									**Ratio**
ARIZONA	27.9	26.1	27.8	25.5	25.2	26.5	24.8	26.1	0.26
CALIFORNIA	69.3	71.0	68.5	69.6	70.6	69.2	70.0	68.4	0.71
MEXICO	0.5	0.6	1.1	2.8	2.3	2.2	3.2	3.6	0.03
TOTAL	**97.7**	**97.7**	**97.4**	**98.0**	**98.1**	**97.9**	**98.0**	**98.1**	**1.00**

Table 2-7. Lettuce Types Other Than Iceberg Shipped by Major Producers for US Use

Origin	1999	2000	2001	2002	2003	2004	2005	2006
Romaine lettuce - all transport modes Units of 1000 cwt, annual.								
ARIZONA	2,606	2,547	3,116	3,286	3,458	3,823	3,897	4,059
CALIFORNIA	6,262	6,957	6,748	6,753	8,591	9,570	10,433	10,329
TOTAL	**8,868**	**9,504**	**9,864**	**10,039**	**12,049**	**13,393**	**14,330**	**14,388**
Percentage of total shipped and used in US								
ARIZONA	29.1	26.5	31.5	32.6	28.3	28.3	26.9	28.0
CALIFORNIA	69.8	72.4	68.1	66.9	70.4	71.0	71.9	71.1
TOTAL	**98.9**	**98.9**	**99.6**	**99.4**	**98.7**	**99.3**	**98.8**	**99.1**
"Other" lettuce - all transport modes Units of 1000 cwt, annual.								
ARIZONA	1,055	1,016	1,083	933	924	919	1,024	1,103
CALIFORNIA	2,751	2,974	3,042	2,846	2,934	2,918	2,949	2,708
CANADA	181	252	243	206	140	214	266	298
TOTAL	**3,987**	**4,242**	**4,368**	**3,985**	**3,998**	**4,051**	**4,239**	**4,109**
Percentage of total shipped and used in US								
ARIZONA	25.7	23.4	24.5	23.2	23.1	22.6	24.0	26.6
CALIFORNIA	67.1	68.6	68.7	70.9	73.2	71.6	69.0	65.4
CANADA	4.4	5.8	5.5	5.1	3.5	5.3	6.2	7.2
TOTAL	**97.3**	**97.9**	**98.7**	**99.3**	**99.8**	**99.5**	**99.2**	**99.2**
Processed lettuce - all transport modes Units of 1000 cwt, annual.								
ARIZONA	4,317	5,909	5,634	5,233	5,249	5,359	4,587	3,137
CALIFORNIA	497	1,138	2,583	1,707	4,501	4,483	3,419	3,229
COLORADO	161	116	230	158	212	215	341	341
TOTAL	**4,975**	**7,163**	**8,447**	**7,098**	**9,962**	**10,057**	**8,347**	**6,707**
Percentage of total shipped and used in US								
ARIZONA	86.3	82.1	66.5	73.6	52.6	53.2	55.0	46.8
CALIFORNIA	9.9	15.8	30.5	24.0	45.1	44.5	41.0	48.1
COLORADO	3.2	1.6	2.7	2.2	2.1	2.1	4.1	5.1
TOTAL	**99.4**	**99.6**	**99.8**	**99.8**	**99.9**	**99.8**	**100.0**	**100.0**

Table 2-8. Fresh Table Tomatoes Shipped by Major Producers for US Use by Type.

Origin	1999	2000	2001	2002	2003	2004	2005	2006
Field-produced Table Tomatoes - all transport modes Units of 1000 cwt, annual.								
CALIFORNIA	9,315	7,472	6,184	7,184	6,691	6,497	6,868	6,170
FLORIDA	15,208	14,943	14,292	13,610	14,501	14,900	13,221	14,886
NORTH CAROLINA	167	175	268	327	446	407	528	421
SOUTH CAROLINA	612	752	486	332	486	407	414	526
TENNESSEE	279	220	199	317	387	236	396	316
VIRGINIA	0	0	0	895	841	923	678	1,027
CANADA	1,473	1,157	1,027	1,675	1,917	17	4	0
MEXICO	12,910	7,250	8,266	8,337	8,677	7,054	5,583	4,464
TOTAL	**39,964**	**31,969**	**30,722**	**32,677**	**33,946**	**30,441**	**27,692**	**27,810**
Percentage of total shipped and used in US								
CALIFORNIA	22.5	22.9	19.7	21.4	19.3	21.1	24.3	21.7
FLORIDA	36.7	45.6	45.3	40.5	41.8	48.2	46.7	52.4
NORTH CAROLINA	0.4	0.5	0.9	1.0	1.3	1.3	1.9	1.5
SOUTH CAROLINA	1.5	2.3	1.5	1.0	1.4	1.3	1.5	1.8
TENNESSEE	0.7	0.7	0.6	0.9	1.1	0.8	1.4	1.1
VIRGINIA	0.0	0.0	0.0	2.7	2.4	3.0	2.4	3.6
CANADA	3.6	3.5	3.3	5.0	5.5	0.1	0.0	0.0
MEXICO	31.2	22.2	26.3	24.9	25.1	22.9	19.7	15.7
TOTAL	**96.5**	**97.7**	**97.6**	**97.4**	**97.9**	**98.7**	**97.9**	**97.8**
Greenhouse Tomatoes - all transport modes Units of 1000 cwt, annual.								
UNITED STATES PRODUCED						511	3,523	3,224
CANADA						2,869	2,497	2,965
MEXICO						1,160	2,316	3,396
NETHERLANDS						251	105	130
TOTAL	n/a	n/a	n/a	n/a	n/a	**4,791**	**8,441**	**9,715**
Percentage of total shipped and used in US								
UNITED STATES PRODUCED						10.4	41.6	32.8
CANADA						58.2	29.5	30.2
MEXICO						23.5	27.4	34.6
NETHERLANDS						5.1	1.2	1.3
TOTAL						**97.1**	**99.7**	**98.9**
Plum tomatoes - all transport modes								
CALIFORNIA			926	1,040	972	753	1,129	1,056
FLORIDA			1,695	1,397	1,626	2,089	1,984	2,415
SOUTH CAROLINA			19	40	66	25	33	60
VIRGINIA			0	0	147	203	303	172
MEXICO			5,035	5,792	6,566	6,850	7,506	6,949
TOTAL	n/a	n/a	**7,675**	**8,269**	**9,377**	**9,920**	**10,955**	**10,652**
Percentage of total shipped and used in US								
CALIFORNIA			12.1	12.6	10.4	7.5	10.2	9.8
FLORIDA			22.1	16.9	17.3	20.8	17.9	22.4
SOUTH CAROLINA			0.2	0.5	0.7	0.2	0.3	0.6
VIRGINIA			0.0	0.0	1.6	2.0	2.7	1.6
MEXICO			65.6	70.0	69.9	68.4	67.9	64.4
TOTAL			**100.0**	**99.9**	**99.9**	**99.0**	**99.1**	**98.7**

Table 2-9. All Fresh Table Tomatoes (Field and Greenhouse)

Origin	1999	2000	2001	2002	2003	2004	2005	2006	2004-2005
All Table Tomatoes (field and greenhouse) - all transport modes Units of 1000 cwt, annual									**Average**
CALIFORNIA	9,315	7,472	7,110	8,224	7,663	7,250	7,997	7,226	7,624
FLORIDA	15,208	14,943	15,987	15,007	16,127	16,989	15,205	17,301	16,097
NORTH CAROLINA	167	175	268	327	446	407	528	421	468
SOUTH CAROLINA	612	752	505	372	552	432	447	586	440
TENNESSEE	279	220	199	317	387	236	396	316	316
VIRGINIA	0	0	0	895	988	1,126	981	1,199	1,054
UNITED STATES GH	0	0	0	0	0	511	3,523	3,224	2,017
CANADA	1,473	1,157	1,027	1,675	1,917	2,886	2,501	2,965	2,694
MEXICO	12,910	7,250	13,301	14,129	15,243	15,064	15,405	14,809	15,235
NETHERLANDS	0	0	0	0	0	251	105	130	178
TOTAL	**39,964**	**31,969**	**38,397**	**40,946**	**43,323**	**45,152**	**47,088**	**48,177**	**46,120**
GRAND TOTAL US-UTILIZED	**41,357**	**32,696**	**39,117**	**41,792**	**44,027**	**45,769**	**47,812**	**49,050**	**46,791**
Percentage of total shipped and used in US									**Ratio**
CALIFORNIA	22.5	22.9	18.2	19.7	17.4	15.8	16.7	14.7	16.3
FLORIDA	36.8	45.7	40.9	35.9	36.6	37.1	31.8	35.3	34.4
NORTH CAROLINA	0.4	0.5	0.7	0.8	1.0	0.9	1.1	0.9	1.0
SOUTH CAROLINA	1.5	2.3	1.3	0.9	1.3	0.9	0.9	1.2	0.9
TENNESSEE	0.7	0.7	0.5	0.8	0.9	0.5	0.8	0.6	0.7
VIRGINIA	0.0	0.0	0.0	2.1	2.2	2.5	2.1	2.4	2.3
UNITED STATES GH	0.0	0.0	0.0	0.0	0.0	1.1	7.4	6.6	4.3
CANADA	3.6	3.5	2.6	4.0	4.4	6.3	5.2	6.0	5.8
MEXICO	31.2	22.2	34.0	33.8	34.6	32.9	32.2	30.2	32.6
NETHERLANDS	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.3	0.4
TOTAL	**96.6**	**97.8**	**98.2**	**98.0**	**98.4**	**98.7**	**98.5**	**98.2**	**98.6**
GRAND TOTAL US-UTILIZED	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

FARM PRODUCTION DATA

Agricultural activity and trade are closely monitored and statistics are developed by the USDA and the Department of Commerce for all major fruit and vegetable crops. A Census of Agriculture is conducted every five years (the most recent for which data are published being 2002) in which farming acreage use at the county level is determined. Supplementary data are developed annually through more limited continuing surveys of representative farms throughout the country. Harvest data and forecasts are published annually by NASS (National Agricultural Statistics Service) and ERS (USDA's Economic Research Service) along with analyses of trends. What we find is that historical data are copious for some states such as California but quite scanty in other, smaller, states. However, we can usually find data on production for at least the past five years.

ESTIMATES OF OUT-OF-STATE TRADE WITH NEW YORK

Our preliminary goal is to estimate how much of each commodity of interest is available for interstate commerce for each major producing state and foreign source exporting to the U.S. Once we have those figures we can allocate New York requirements to these sources in proportion to amounts available at the sources and/or in accordance with other relevant criteria.

We must first determine per capita utilization of the crop at the U.S. level. This was based on fifteen years of U.S. data where possible, to develop confidence in the figure we are to use. Per capita utilization calculations require knowing total imports and exports in addition to U.S. domestic production. Table 2-10 illustrates this calculation for lettuce. Next we need to determine the level of production of the crop over the past few years in the major producing states. Table 2-11 is an example. In this table, we also make our best estimate of current production, by state, for subsequent use. For this purpose, we have been averaging the years 2004 and 2005, the most recent for which settled data are available. If something peculiar is evident in the data for one of these two years, a more typical year is substituted (e.g., Table 2-11 contains additional data on lettuce types other than iceberg; these are of interest but are not used in further calculations.) The third and fourth tables are in a standardized form. The third table involves a multi-step calculation to determine the quantity of commodity each of the major producing states is likely to have available for out-of-state sales. In Table 2-12, it can be seen production figures for the major lettuce producing states have been carried over from Table 2-11. We have estimated how much of each state's production is consumed within the state based on the duration over which the product is available and the size of the state's population. This is deducted from each state's production total and gives the amount available for out-of-state trade (including export). We now have a list of domestic suppliers and the amounts of supply they have. Foreign imports are added to this list and the relative magnitude of the potential sources of supply to New York State is calculated as a set of ratios.

Table 2-10. Historic US Lettuce Production, Imports, Exports and Utilization

	Head/ Iceberg lettuce					US Leaf and Romaine lettuce					Leaf only
Year	Produc-tion	Imports	Exports	US Utilized	Per cap. use	Produc-tion	Imports	Exports	US Utilized	Per cap. use	Produc-tion
			1000 cwt					1000 cwt			1000 cwt
1992	70,810	212	4,768	66,254	25.8	13,887	59	1,950	11,996	4.7	8,235
1993	67,811	327	4,636	63,503	24.4	15,355	68	2,302	13,121	5.0	8,773
1994	70,058	206	4,388	65,877	25.0	17,100	89	2,231	14,958	5.7	8,946
1995	62,349	518	3,779	59,088	22.2	17,874	117	2,279	15,712	5.9	9,344
1996	62,072	283	4,175	58,180	21.6	17,756	166	2,234	15,688	5.8	9,188
1997	68,794	393	3,957	65,230	23.9	20,245	286	2,533	17,998	6.6	10,387
1998	65,461	229	4,047	61,643	22.3	20,767	320	2,823	18,264	6.6	10,382
1999	73,181	289	3,900	69,570	24.9	23,931	284	3,012	21,203	7.6	11,112
2000	69,673	319	3,742	66,249	23.5	27,024	328	3,674	23,678	8.4	11,979
2001	68,917	458	3,788	65,587	23.0	26,461	346	3,904	22,902	8.0	11,394
2002	68,140	1,066	4,259	64,946	22.5	31,974	336	4,670	27,640	9.6	13,410
2003	68,248	941	4,536	64,654	22.2	36,193	331	4,336	32,188	11.1	13,490
2004	66,228	921	4,746	62,403	21.2	33,145	352	4,898	28,599	9.7	14,790
2005	65,749	1,190	4,487	62,452	21.0	35,817	519	4,863	31,473	10.6	15,885
2006	58,692	1,105	3,642	56,155	18.7	36,959	612	4,616	32,955	11.0	17,154

Table 2-11. Historic US Lettuce Production by Major State Producers

Year	2000	2001	2002	2003	2004	2005	2006	2004-2005 Average	Ratios
Iceberg Lettuce									
				1000 cwt				1000 cwt	
Arizona	18,100	19,327	17,780	18,064	16,890	16,220	15,708	16,555	0.25
California	50,700	48,640	49,400	49,500	48,470	48,750	42,500	48,610	0.74
Colorado	680	700	810	522	704	684	448	694	0.011
New Jersey	193	250	150	158	164	95	36	130	0.002
United States	69,628	70,350	68,140	68,244	66,228	65,749	58,692	65,989	1.00
Imports	319	458	1,066	941	921	1,190	1,105	1,056	
Exports	3,742	3,788	4,259	4,536	4,746	4,487	3,642	4,617	
Total Utilized in U S	**66,204**	**67,020**	**64,946**	**64,650**	**62,403**	**62,452**	**56,155**	**62,428**	
Romaine and Leaf Lettuce				1000 cwt					
Arizona	5,408	5,640	6,759	6,923	7,855	8,607	8,714	8,231	0.24
California	21,915	21,230	25,215	29,270	25,290	27,210	28,245	26,250	0.76
Other States	486	441							
United States	**27,809**	**27,311**	**31,974**	**36,193**	**33,145**	**35,817**	**36,959**	**34,481**	1.00
Romaine and Leaf Imports	328	346	336	331	352	519	612	435	
Romaine and Leaf Exports	3,674	3,904	4,670	4,336	4,898	4,863	4,616	4,880	
Total Romaine and Leaf Utilized in U S	**24,463**	**23,752**	**27,640**	**32,188**	**28,599**	**31,473**	**32,955**	**30,036**	
Romaine Lettuce				1000 cwt					
Arizona	3,660	3,813	4,389	4,703	5,755	6,402	6,365	6,079	0.32
California	11,340	11,340	14,175	18,000	12,600	13,530	13,440	13,065	0.68
Florida, NJ	360	334							
United States	**15,830**	**15,487**	**18,564**	**22,703**	**18,355**	**19,932**	**19,805**	**19,144**	1.00
Leaf Lettuce				1000 cwt					
Arizona	1,748	1,827	2,370	2,220	2,100	2,205	2,349	2,153	0.14
California	10,575	9,890	11,040	11,270	12,690	13,680	14,805	13,185	0.86
Other States	126	107							
United States	**11,765**	**11,824**	**13,410**	**13,490**	**14,790**	**15,885**	**17,154**	**15,338**	1.00

Table 2-12. Head/Iceberg Lettuce Estimated Annual Interstate Trade by Major Producers

Producing State or Exporter	Population	Per capita Utilization	Annual State Utilization	Est. Months Local Supply	Est. Possible Local Supply	State Production	Out-state Est. Trade	Est. Export allocation	Interstate Trade Est.	Ratios between All suppliers
	millions	lbs/annum	1000 cwt	months	1000 cwt	1000 cwt	1000 cwt	1000 cwt	1000 cwt	
Arizona	5.80	21.13	1224	5	510	16,555	16,045	1292	14,753	0.27
California	35.99	21.13	7602	12	7602	48,610	41,008	3302	37,706	0.70
Colorado	4.63	21.13	978	5	408	694	286	23	263	0.005
US Major Producers: ST.						65,859	57,339	4,617	**52,722**	**0.98**
Mexico									813	0.015
Canada									232	0.004
Imports, Major: ST.									**1,056**	**0.02**
US Utilization, Major: Total									**53,778**	**1.00**

In the final table, exemplified in lettuce Table 2-13, the New York out-of-state requirement for lettuce to meet consumer demand, which was calculated in Table 2-4, is divided among producing states according to the ratio of amounts available. Before committing to this particular set of ratios, however, the amounts available for interstate trade determined in shipping totals (Tables 2-5 through 2-9) are compared to those determined from crop production data and any discrepancies are investigated. The final column of Table 2-13 gives our best estimate of how much lettuce is shipped into New York from each of the outside sources, foreign and domestic.

Tables 2-14 to 2-17 provide this sequence of calculations for spinach; Tables 2-18 to 2-21 are for tomato, Tables 2-22 to 2-25 for strawberry, and Tables 2-26 to 2-29 for apple.

The estimated amounts of produce shipped to New York for consumption from various external sources derived from the above calculations, as well as that produced and consumed inside New York, are summarized by mode of transport in Table 2-30. The “data bank of quantities and geographic sources of the chosen produce types as shipped into New York State” constituted in these tables will be used in Chapter 4 to calculate energy required for shipping.

Table 2-13. Head/Iceberg Lettuce Estimated Interstate Trade by Production Area: Comparison of Production-based and Shipment-based Estimates

Origin of Production	State Production	Interstate Trade est.	Shipments in US	State Production	Interstate Trade est	Shipments in US	NY Require-ment
	1000 cwt	1000 cwt	1000 cwt	1000 cwt	Ratios	Ratios	1000 cwt
Domestic							
Arizona	**16,555**	14,753	9,805	0.25	0.28	0.27	1108
California	**48,610**	37,706	26,583	0.74	0.72	0.73	2832
Colorado	**694**	263	205	0.01	0.005	0.006	20
US Major Producers: ST.	**65,859**	**52,722**	**36592**	**1.00**	**1.00**	**1.00**	**3960**
Imports							
Mexico		813	1,032		0.77	0.82	61
?Canada		232	233		0.22	0.18	17
Imports, Major: ST.		**1,056**	**1265**		1.00	1.00	79
US Utilization, Major: Total		**53,778**	**37,857**				**4039**

Note. In this commodity, 30% of interstate trade in domestically produced head lettuce is missed in the shipment figures, though shipments are in almost the same proportion for Arizona and California as production-based trade estimates. Possibly packaged salad uses are omitted

Table 2-14. Historic US Spinach Production, Imports, Exports and Utilization

	Fresh spinach					Processing spinach						
Year	Produc-tion	Imports	Exports	US Utilized	Per cap. use	Produc-tion	Imports	Beginning Stocks	Exports	Ending Stocks	US Utilized	Per cap. use
			1000 cwt					1000 cwt, fresh weight basis				
1992	2,351	21	274	2,098	0.82	1,316		533	92	562	1,195	0.47
1993	1,976	27	272	1,731	0.66	1,428		562	102	674	1,214	0.47
1994	2,230	16	263	1,983	0.75	1,671		674	104	1,001	1,240	0.47
1995	2,036	33	280	1,789	0.67	1,500		1,001	84	986	1,431	0.54
1996	1,934	41	282	1,693	0.63	1,691		986	103	685	1,889	0.70
1997	3,265	57	300	3,022	1.11	1,730	87	685	134	959	1,409	0.52
1998	2,960	56	339	2,677	0.97	1,363	86	959	113	990	1,305	0.47
1999	3,057	36	379	2,714	0.97	1,643	99	990	120	1,049	1,563	0.56
2000	4,239	72	429	3,882	1.37	2,099	104	1,049	129	726	2,397	0.85
2001	3,458	154	551	3,061	1.07	2,141	175	726	119	910	2,013	0.70
2002	4,625	132	633	4,124	1.43	1,924	135	910	134	804	2,031	0.70
2003	5,569	203	619	5,153	1.77	2,159	179	804	126	665	2,351	0.81
2004	6,266	216	555	5,927	2.02	2,388	312	665	122	497	2,746	0.93
2005	7,581	276	474	7,383	2.49	1,788	419	497	136	607	1,961	0.66
2006	6,207	200	378	6,029	2.01	1,307	286	607	146	754	1,300	0.43
2007	6,800	210	360	6,650	2.20	1,350	314	750	150	416	1,848	0.61

Table 2-15. Historic Fresh Spinach Production by Major State Producers

Year	2000	2001	2002	2003	2004	2005	2006	2004-2005 Average	Ratios
State				1000 cwt				1000 cwt	
California	3,060	2,325	3,255	4,160	4,590	5,850	4,620	5,220	0.75
Arizona	782	360	714	780	1,050	1,090	900	1,070	0.15
New Jersey			157	252	171	200	298	186	0.03
Texas		225	242	204	250	210	176	230	0.03
Colorado, Maryland			257	173	205	231	213	218	0.03
US- Total of above	**3,842**	**2,910**	**4,625**	**5,569**	**6,266**	**7,581**	**6,207**	**6,924**	**1.00**
US Imports	72	154	132	203	216	276	200	246	
US Exports	429	551	633	619	555	474	378	514	
Utilized in US	**4,343**	**3,615**	**4,124**	**5,153**	**5,927**	**7,383**	**6,029**	**6,655**	

Table 2-16. Fresh Spinach Estimation of Annual Interstate Trade by Major Producers

Based on average annual production, 2004- 2005.

Producing State or Exporter	Population (Est.) millions	Per capita Utilization (Est.) lbs/annum	Annual State Utilization (Est.) 1000 cwt	Months of Local Supply (Est.) months	Local Need Met (Est.) 1000 cwt	**State Production** 1000 cwt	Out-of-state Trade (Est.) 1000 cwt	Export Allocation (Est.) 1000 cwt	**Interstate Trade Estimate** 1000 cwt	Ratios between Suppliers
<u>Domestic</u>										
California	35.99	2.26	812	12	812	**5,220**	4,408	409	**3,999**	0.76
Arizona	5.80	2.26	131	5	54	**1,070**	1,016	94	**921**	0.17
New Jersey	8.69	2.26	196	5	82	**186**	104	10	**94**	0.02
Texas	22.72	2.26	512	5	214	**230**	16	2	**15**	0.00
Major State Producers: ST.						**6,706**	5,544	514	**5,030**	**0.95**
<u>Imports</u>										
Mexico									n/a	
Canada									n/a	
Major Exporters to US: ST.									**246**	**0.05**
U S Utilization Total: All Major Sources									**5,276**	**1.00**

Table 2-17. Fresh Spinach Estimated Annual Interstate Trade by Production Source: Comparison of Production-based and Shipment-based Estimates

Origin of Production	Produc-tion	Interstate Trade est.	Shipments in US	Produc-tion	Interstate Trade est	Shipments in US	NY Require-ment
		1000 cwt	1000 cwt	Ratios	Ratios	Ratios	1000 cwt
<u>Domestic</u>							
California	5,220	3,999	535	0.78	0.80	0.79	320.8
Arizona	1,070	921	128	0.16	0.18	0.19	73.9
New Jersey	186	94		0.03	0.02	0.00	7.6
Texas	230	15	13	0.03	0.00	0.02	1.2
US Major Producers: ST.	**6,706**	**5,030**	**676**	**1.00**	**1.00**	**1.00**	403.5
<u>Imports</u>							
Mexico		214	260			0.87	17.2
Canada		32	39			0.13	2.5
Imports, Major: ST.		**246**	**298**			**1.00**	19.7
US Utilization Total: Major Sources		**5,276**	**974**				**423**

Note. In this commodity, the vast majority of interstate trade in domestically produced spinach is missed in the shipment figures (over 85%), though shipments are in roughly the same proportion for Arizona and California as production-based trade estimates. Possibly only bunching spinach is included.
A breakdown of imports independent of shipping data was not located

Table 2-18. Historic US Fresh and Processed Tomato Production, Imports, Exports and Utilization

Year	Fresh Tomato					Processing Tomato						
	Produc-tion	Imports	Exports	US Utilized	Per cap. use	Produc-tion	Imports	Beginning Stocks	Exports	Ending Stocks	US Utilized	Per cap. use
			1000 cwt					1000 cwt, fresh weight basis				
1992	39,033	4,322	3,675	39,680	15.5	175,549	4,500	154,891	15,715	130,882	188,343	73.3
1993	36,663	9,224	3,458	42,429	16.3	193,533	5,557	130,882	17,005	115,758	197,209	75.8
1994	37,387	8,730	3,407	42,709	16.2	230,794	8,585	115,758	18,565	135,622	200,950	76.3
1995	34,098	13,689	2,892	44,895	16.8	225,700	7,036	135,622	20,159	149,447	198,752	74.6
1996	33,634	16,251	2,954	46,931	17.4	228,146	4,828	149,447	22,029	163,384	197,008	73.1
1997	34,248	16,368	3,417	47,199	17.3	199,465	7,060	163,384	26,715	145,136	198,058	72.6
1998	35,256	18,680	2,863	51,073	18.5	188,040	9,311	145,136	24,762	113,318	204,407	74.0
1999	40,269	16,331	3,343	53,256	19.1	256,720	13,396	113,318	22,028	162,616	198,790	71.2
2000	41,620	16,094	4,104	53,610	19.0	217,165	5,914	162,616	22,313	165,319	198,063	70.1
2001	40,611	18,156	3,979	54,788	19.2	184,974	11,069	165,319	24,104	150,297	186,961	65.5
2002	42,893	18,949	3,323	58,518	20.3	233,416	15,167	150,297	24,583	174,536	199,761	69.3
2003	39,098	20,711	3,142	56,667	19.5	196,394	11,528	174,536	29,356	150,031	203,071	69.7
2004	41,814	20,542	3,693	58,663	20.0	245,328	12,827	150,031	29,898	171,144	207,144	70.4
2005	42,204	20,981	3,265	59,920	20.2	203,862	13,076	171,144	29,710	140,062	218,310	73.5
2006	40,981	21,877	3,179	59,679	19.9	212,236	16,978	140,062	30,422	145,854	193,000	64.4

Notes for fresh tomato

Source: National Agricultural Statistics Service (NASS), USDA Economic Research Service (ERS), USDA

Includes ERS estimates of domestically-grown hothouse tomatoes after 1996. Imports include hothouse tomatoes.

Notes for Processing Tomato

Source: National Agricultural Statistics Service, USDA, and Bureau of the Census, U.S. Dept. of Commerce.

All product weight were converted to a fresh-weight basis using--Whole=1.553; Paste=5.432; Sauce=3.247; Juice=1.527; Catsup=2.457.

Stocks estimated based on a weighted average Jan. 1 stocks to pack. Source: California League of Food Processors.

Table 2-19. Historic Fresh and Processing Tomato Production by Major State Producers

These fresh tomato production data exclude Cherry, Grape and Greenhouse tomato production.

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2004-2005**	
Fresh Tomato,								**Average**	**Percent**
State				1000 cwt				1000 cwt	
FL	15,760	14,908	13,975	14,190	15,120	15,540	13,475	15,330	40.2
CA	11,600	10,260	12,600	10,200	13,020	11,200	11,480	12,110	31.7
VA	1,287	1,443	2,120	1,824	2,090	2,072	2,233	2,081	5.5
OH	1,125	1,947	2,479	1,155	1,106	2,145	1,980	1,626	4.3
GA	1,365	949	1,650	1,530	986	2,142	2,160	1,564	4.1
TN	1,131	495	1,462	1,610	900	936	1,190	918	2.4
SC	884	1,088	837	1,023	1,050	390	480	720	1.9
NC	696	832	891	896	620	800	918	710	1.9
NJ	720	714	759	682	690	600	522	645	1.7
PA	840	537	731	441	555	513	630	534	1.4
MI	408	378	420	484	546	440	460	493	1.3
NY	540	480	378	322	360	360	400	360	0.9
?AL	242	212	351	330	342	341	335	342	0.9
AR	150	299	336	384	137	414	306	276	0.7
IN	248	281	248	248	272	225	165	249	0.7
MD	247	266	111	90	156			156	0.4
TX	182	180	240	169	116	150	110	133	0.3
Other states	240	258							
US-Total of above	**37,665**	**35,527**	**39,588**	**35,578**	**38,066**	**38,268**	**36,844**	**38,167**	**100.0**
Processing Tomato				1000 cwt					
CA	205,730	172,803	221,120	185,040	233,440	192,000	202,080	212,720	94.7
IN	4,580	5,022	5,129	4,046	5,496	5,329	4,510	5,413	2.4
MI	1,680	2,108	2,520	2,508	2,170	2,250	2,310	2,210	1.0
OH	3,174	3,292	2,993	3,466	3,546	3,506	3,336	3,526	1.6
PA	851	0	0	0	0	0	0	0	0.0
Other states	1,149	1,749	1,655	1,335	676	777	n/a	726	0.3
US-Total of above	**217,165**	**184,974**	**233,416**	**196,394**	**245,328**	**203,862**	**212,236**	**224,595**	**100.0**

Source: NASS Annual Statisical Yearbooks

Table 2-20. Fresh Table Tomato Estimation of Annual Interstate Trade by Major Producers

Based on average annual production, 2004- 2005. Cherry and grape tomato crops excluded.

Producing State or Exporter	Population (Est.) millions	Per capita Utilization (Est.) lbs/annum	Annual State Utilization (Est.) 1000 cwt	Months of Local Supply (Est.) months	Local Need Met (Est.) 1000 cwt	**State Production** 1000 cwt	Out-of-state Trade (Est.) 1000 cwt	Export Allocation (Est.) 1000 cwt	**Interstate Trade Estimate** 1000 cwt	Ratios between Suppliers
Domestic Field Crop										
Florida	17.567	20.07	3525	6	1762	**15,330**	13,568	1640	**11,927**	0.26
California	35.998	20.07	7223	8	4815	**12,110**	7,295	882	**6,413**	0.14
Virginia	7.518	20.07	1509	5	629	**2,081**	1,452	176	**1,277**	0.03
Ohio	11.466	20.07	2301	4	767	**1,626**	859	104	**755**	0.02
Georgia	9.034	20.07	1813	5	755	**1,564**	809	98	**711**	0.02
Tennessee	5.921	20.07	1188	5	495	**918**	423	51	**372**	0.01
South Carolina	4.221	20.07	847	5	353	**720**	367	44	**323**	0.01
North Carolina	8.602	20.07	1726	3	431	**710**	279	34	**245**	0.01
New Jersey	8.690	20.07	1744	4	581	**645**	64	8	**56**	0.00
Pennsylvania	12.391	20.07	2486	4	829	**534**	0	0	**0**	
Minnesota	5.111	20.07	1025	4	342	**493**	151	18	**133**	0.00
New York	19.304	20.07	3873	4	1291	**360**	0	0	**0**	
Major Field Producers: ST.			**29,259**			**37,091**	**24,772**	**2,995**	**22,211**	**0.48**
US Greenhouse Production						4,919	4,000	484	3,516	0.08
All Major U S Production: ST						**42,009**	**28,772**	**3479**	**25,727**	**0.55**
Imports										
Mexico									**17,397**	0.37
Canada									**2,986**	0.06
Netherlands									**258**	0.01
Israel									**65**	0.00
Spain									**55**	0.00
Major Exporters to US: ST.									**20,762**	**0.447**
U S Utilization Total: All Major Sources									**46,489**	**1.00**

Table 2-21. Fresh Table Tomato Estimated Annual Interstate Trade by Production Source: Comparison of Production-based and Shipment-based Estimates

Cherry and Grape Tomato Production is not included, Greenhouse, Field and Plum is included.

Origin	Production	Interstate Trade est.	Shipments in US	Production	Interstate Trade est	Shipments in US	NY Requirement
Domestic field crop	1000 cwt	1000 cwt	1000 cwt	Ratios	Ratios	Ratios	1000 cwt
Florida	15,330	11,927	15,205	0.36	0.46	0.52	898
California	12,110	6,413	7,997	0.29	0.25	0.28	483
Virginia	2,081	1,277	981	0.05	0.05	0.03	96
Ohio	1,626	755		0.04	0.03	0.00	57
Georgia	1,564	711		0.04	0.03	0.00	54
Tennessee	918	372	396	0.02	0.01	0.01	28
South Carolina	720	323	447	0.02	0.01	0.02	24
North Carolina	710	245	528	0.02	0.01	0.02	18
New Jersey	645	56		0.02	0.00	0.00	4
Pennsylvania	534	0		0.01	0.00	0.00	
Minnesota	493	133		0.01	0.01	0.00	10
New York	360	0		0.01	0.00	0.00	
Major Field Producers: ST.	**37,091**	**22,211**	**25,554**	**0.88**	**0.86**	**0.88**	**1672**
US Greenhouse Production	4,919	3,516	3,523	0.12	0.14	0.12	265
All Major US Production: ST	**42009**	**25,727**	**29,077**	**1.00**	**1.00**	**1.00**	**1937**
Imports							
Mexico		17,397	15,405		0.84	0.86	1310
Canada		2,986	2,501		0.14	0.14	225
Netherlands		258	105		0.01	0.01	19
Israel		65			0.00	0.00	5
Spain		55			0.00	0.00	4
Imports, Major: ST.		**20,762**	**18,011**		**1.00**	**1.00**	**1563**
US Utilization Total: Major Sources		**46,489**	**47812**				**3500**

Note. The interstate trade estimate for each producer state is calculated as state production minus intra-state consumption of the state crop and also minus the state's share of exports.
Interstate trade estimates are based on average annual production in 2004 and 2005. In view of anomalies in the 2004 greenhouse data, Shipments are based on 2005 data only.

Table 2-22. Strawberry Production and Utilization in the US: Fresh and Processing

Year	2000 Total	2001 Total	2002 Total	2003 Total	2004 Total	2005 Total	2006 Total
			1,000,000 lbs				
California	1,573.2	1,372.8	1,609.7	1,909.2	1,958.8	2,058.0	2,116.3
Florida	220.5	169.0	176.0	156.2	163.3	178.9	204.4
North Carolina	23.1	19.6	22.5	17.0	17.6	19.5	21.6
Oregon	35.3	40.2	33.8	29.5	32.4	25.0	23
Washington	12.9	16.0	16.2	16.2	15.3	15.0	12.8
Pennsylvania	6.5	8.6	7.3	8.3	7.9	7.0	7.4
Michigan	8.3	5.0	5.6	6.3	4.1	5.2	5.5
New York	6.5	6.0	6.3	5.0	6.5	5.2	4.4
Ohio	3.1	3.2	2.8	3.8	3.8	4.2	4.3
Wisconsin	4.4	4.6	4.3	4.5	4.1	4.1	4.3
Virginia	5.4	4.1	--	--	--	--	--
New Jersey	1.6	1.8	--	--	--	--	--
U.S. Production	**1,901**	**1,651**	**1,885**	**2,156**	**2,214**	**2,322**	**2,404**
Total Imports	153	147	202	210	220	284	**n/a**
Total Exports	179	171	202	218	205	230	**n/a**
Total Utilized in US	**2,038**	**1,774**	**2,040**	**2,333**	**2,390**	**2,532**	**n/a**

Note. Oregon and Washington produce processing strawberries primarily

Table 2-23a. Fresh and Total Strawberry Production in the US: Major Producing States

These states are all those that contribute more than c. 1% to US Strawberry Production

Year	2000	2001	2002	2003	2004	2005	2006	2004-2005	
Fresh Strawberry Utilized Production				million lbs				**Average**	**Percent**
California					1,483	1,583	1,654	1,533	87.5
Florida					163	179	204	171	9.8
North Carolina					17.6	19.5	21.6	19	1.1
Oregon					2.9	2.4	3.6	3	0.2
Washington					1.7	2.0	1.7	2	0.1
Pennsylvania					7.9	7.0	7.4	7	0.4
Other States					18.0	18.2	18.2	18	1.0
US Fresh Production	1,435	1,261	1,406	1,642	**1,694**	**1,811**	**1,911**	**1,752**	100.0
Fresh Imports	75	71	90	90	94	123	n/a	108.6	
Fresh Exports	137	128	157	195	183	208	n/a	195.1	
Total Utilized in US	**1,373**	**1,204**	**1,339**	**1,538**	**1,606**	**1,726**	n/a	**1,666**	
Total Production: Fresh plus Processing (Frozen) Strawberry						million lbs		**Average**	**Percent**
California	1,573	1,373	1,610	1,909	1,959	2,058	2,116	2,008	88.6
Florida	221	169	176	156	163	179	204	171	7.5
North Carolina	23	20	23	17	18	20	22	19	0.8
Oregon	35	40	34	30	32	25	23	29	1.3
Washington	13	16	16	16	15	15	13	15	0.7
Pennsylvania	7	9	7	8	8	7	7	7	0.3
Other States	22	19	19	20	19	19	19	19	0.8
US Total Production	**1,901**	**1,651**	**1,885**	**2,156**	**2,214**	**2,322**	**2,404**	**2,268**	100.0
Mexican imports	137	124	155	177	176	209		193	
Total Imports	153	147	202	210	220	284	n/a	252	
Total Exports	179	171	202	218	205	230	n/a	217	
Total Utilized in US	**1,874**	**1,627**	**1,884**	**2,148**	**2,229**	**2,377**	n/a	**2,303**	

Table 2-23b. Fresh and Total Strawberry Production in the US: Major Production States

Fresh Strawberry as Percent of Total Utilized Production					percent			2004-2005
California					76	77	78	76
Florida					100	100	100	100
North Carolina					100	100	100	100
Oregon					9	10	16	9
Washington					11	13	13	12
Pennsylvania					100	100	100	100
Other States					97	97	98	97
US	75	76	75	76	77	78	79	77.3
Total Imports	49	48	44	43	43	43	n/a	43.1
Total Exports	76	75	78	89	89	90	n/a	89.8
Total Utilized in US	**73**	**74**	**71**	**72**	**72**	**73**	n/a	**72.3**

Table 2-24. Strawberry. Estimated Relative Amounts of Interstate Trade by Major Producers, US and Foreign

Producing State or Exporter	Population	Per capita Utilization	Annual State Utilization	Est. Months Local Supply	Est. Possible Local Supply	State Production	Out-state Est. Trade	Est. Export allocation	Interstate Trade Est.	Ratios between All supplier
	millions	lbs/annum	1000 cwt	months	1000 cwt	1000 cwt	1000 cwt	1000 cwt	1000 cwt	
Fresh										
California	35.99	5.65	2033	12	2033	15,328	13,294	1764	**11,530**	**0.83**
Florida	17.35	5.65	980	4	327	1,711	1,384	184	**1,201**	**0.09**
North Carolina	8.60	5.65	486	4	162	186	24	3	**20**	**0.001**
Oregon	3.61	5.65	204	4	68	27	0	0	**0**	
Washington	6.21	5.65	351	4	117	19	0	0	**0**	
Pennsylvania	12.39	5.65	700	4	175	75	0	0	**0**	
US Major Producer Totals						**17,344**	14,702	**1951**	**12,751**	**0.92**
Imports (almost all Mexico)									**1,086**	**0.08**
US Utilization, Major, Total									**13,837**	**1.00**
Processing (frozen)										
California	35.99	1.74	626	12	626	4,757	4,130	206	**3,925**	**0.69**
Florida	17.35	1.74	302	6	151	0	0	0	**0**	
North Carolina	8.60	1.74	150	6	75	0	0	0	**0**	
Oregon	3.61	1.74	63	6	31	261	229	11	**218**	**0.04**
Washington	6.21	1.74	108	6	54	133	79	4	**75**	**0.01**
Pennsylvania	12.39	1.74	216	6	108	0	0	0	**0**	
US Major Producer Totals						**5,150**	4,438	**221**	**4,217**	**0.75**
Imports (treat as Mexico)									**1,436**	**0.25**
US Utilization, Major, Total									**5,654**	**1.00**
Total (Fresh plus processing)										
California	35.99	7.39	2659			20,084			**15,455**	**0.79**
Florida	17.35	7.39	1282			1,711			**1,201**	**0.06**
North Carolina	8.60	7.39	636			186			**20**	**0.00**
Oregon	3.61	7.39	267			287			**218**	**0.01**
Washington	6.21	7.39	459			152			**75**	**0.00**
Pennsylvania	12.39	7.39	916			75			**0**	**0.00**
US Major Producer Totals						**22,494**		**2172**	**16,969**	**0.87**
Imports (treat as Mexico)									**2,522**	**0.13**
US Utilization, Major, Total									**19,491**	**1.00**

Table 2-25. Fresh Strawberry. Estimation of Annual Interstate Trade by Major Producers

Comparison of Production-based and Shipment-based Estimates

Origin of Production	State Production	Interstate Trade est	Shipments in US	State Production	Interstate Trade est	Shipments in US	NY Require-ment
	1000 cwt	1000 cwt	1000 cwt	Ratios	Ratios	Ratios	1000 cwt
Domestic Crop							
California	15,328	11,530	10,908		0.83	0.84	861
Florida	1,711	1,201	1,150		0.09	0.09	91
North Carolina	186	20	0		0.001	0.00	0
Oregon	27	0	0				
Washington	19	0	0				
Pennsylvania	75	0	0				
Major US Producers	**17,344**	**12,751**	**12,058**		**0.92**	**0.92**	**952**
Imports (Mexico)		**1,086**	**1,005**		**0.08**	**0.08**	**79**
US Utilization Total		**13,837**	**13,063**		**1.00**	**1.00**	**1031**

Table 2-26. Apple: Historic Fresh and Total Production by Major Producing States

These states are all those that contribute more than 1% US Fresh Apple Production

Year	2000	2001	2002	2003	2004	2005	2004-2005	
Fresh Apple Production		million lbs, utilized production					Average	Percent
WA	4,300	3,700	3,900	3,600	4,600	4,400	4,500	70.4
NY	460	420	310	490	660	490	575	9.0
MI	260	270	150	310	240	265	253	3.9
CA	250	220	230	220	165	160	163	2.5
PA	127	120	74	95	110	127	119	1.9
VA	99	88	70	52	132	81	107	1.7
OR	122	94	115	90	110	95	103	1.6
Other States	639	558	517	585	626	529	578	9.0
US	**6,257**	**5,470**	**5,366**	**5,442**	**6,643**	**6,147**	**6,395**	100.0
Total Production: Fresh plus Processing Apples				million lbs, utilized prod.			Average	Percent
WA	6,000	5,050	5,100	4,550	6,150	5,700	5,925	59.3
NY	935	940	630	980	1,280	1,020	1,150	11.5
MI	795	900	515	890	730	755	743	7.4
?CA	590	490	460	440	355	355	355	3.6
PA	475	480	369	442	400	495	448	4.5
VA	314	306	247	262	297	277	287	2.9
OR	162	141	187	132	160	135	148	1.5
Other States	1,131	907	867	927	999	881	940	9.4
US	**10,402**	**9,214**	**8,375**	**8,623**	**10,371**	**9,618**	**9,994**	**100.0**
Fresh Apple as Percent of Total Utilized Production					percent		2004-2005	
WA	72	73	76	79	75	77	76	
NY	49	45	49	50	52	48	50	
MI	33	30	29	35	33	35	34	
CA	42	45	50	50	46	45	46	
PA	27	25	20	21	28	26	26	
VA	32	29	28	20	44	29	37	
OR	75	67	61	68	69	70	69	
Other States	56	61	60	63	63	60	61	
US	**60**	**59**	**64**	**63**	**64**	**64**	**64**	

Table 2-27. Fresh Apple Imports Into the US by Origin

Source Country	2000–1	2001-2	Year 2002-3	2003-4	2004-5	2005-6	2004-2005 Average	Percent
			millions of pounds					
Chile	116	136	175	236	135	177	156	50
New Zealand	135	127	101	150	68	88	78	25
?Canada	83	86	101	68	67	82	75	24
South Africa	17.9	13.6	4.2	6.6	2.5	0.1	1	0
Mexico	0.00	0.00	0.00	0.04	0.00	0.04	0	0
Other countries	7	4	11	10	4	3	4	1
Total	**361**	**367**	**392**	**471**	**278**	**352**	**315**	**100**

Table 2-28. Fresh Apple. Estimation of Annual Interstate Trade by Major Producers

Based on average annual production, 2004- 2005.

Producing State or Exporter	Population (Est.) millions	Per capita Utilization (Est.) lbs/annum	Annual State Utilization (Est.) 1000 cwt	Months of Local Supply (Est.) months	Local Need Met (Est.) 1000 cwt	State Production 1000 cwt	Out-of-state Trade (Est.) 1000 cwt	Export Allocation (Est.) 1000 cwt	Interstate Trade Estimate 1000 cwt	Ratios between Suppliers
Domestic Crop										
Washington	6.21	17.9	1,109	12	1,109	45,000	43,891	12,308	**31,582**	0.796
New York	19.24	17.9	3,440	12	3,440	5,750	2,310	648	**1,662**	0.042
Michigan	10.18	17.9	1,820	4	607	2,525	1,918	538	**1,380**	0.035
California	35.99	17.9	6,433	0.2	107	1,625	1,518	426	**1,092**	0.028
Pennsylvania	12.39	17.9	2,215	6	1,107	1,185	78	22	**56**	0.001
Virginia	7.51	17.9	1,342	6	671	1,065	394	111	**284**	0.007
Oregon	3.61	17.9	646	6	323	1,025	702	197	**505**	0.013
All Major US Production: ST			**17,005**			**58,175**	**50,811**	**14,249**	36,562	**0.922**
Imports										
Canada									747	0.019
Chile									1,564	0.039
New Zealand									785	0.020
Major Exporters to US: ST.									**3,095**	0.078
US Utilization Total: All Major Sources									39,657	**1.000**

Note: California grows a specialty apple, assumed to be 1/20th of annual consumption, and over 4 months provision period

Table 2-29. Fresh Apple. Estimated Interstate Trade by Production Area

Comparison of Production-based and Shipment-based Estimates

Origin of Production	State Produc-tion	Interstate Trade est.	Shipments in U S	State Produc-tion	Interstate Trade est	Shipments in U S	Shipments without NY	NY Require-ment
	1000 cwt	1000 cwt	1000 cwt	Ratios	Ratios	Ratios	Ratios	1000 cwt
<u>Domestic</u>								
Washington	45,000	31,582	27,946	0.77	0.86	0.79	0.78	390
New York	5,750	1,662	2,896	0.10	0.05	0.08		
Michigan	2,525	1,380	2,416	0.04	0.04	0.07	0.07	34
California	1,625	1,092	1,277	0.03	0.03	0.04	0.04	18
Pennsylvania	1,185	56		0.02	0.00	0.00	0.00	
Virginia	1,065	284		0.02	0.01	0.00	0.00	
Oregon	1,025	505	676	0.02	0.01	0.02	0.02	9
US Major Producers: ST.	**58,175**	**36,562**	**35,210**	**1.00**	**1.00**	**1.00**	**0.90**	**451**
Exports	**14,249**							
<u>Imports</u>								
Canada		747	706		0.24	0.20	0.02	10
Chile		1,564	1,845		0.51	0.52	0.05	26
New Zealand		785	991		0.25	0.28	0.03	14
Imports, Major: ST.		**3,095**	**3,542**		**1.00**	**1.00**	**0.10**	**49**
US Utilization, Major: Total		**39,657**	**38,751**				**1.00**	500

Table 2-30. Estimated Annual Produce Amounts Shipped to NY by Origin, and Mode of Transport

Origin	Fresh Spinach 1000 cwt	Fresh Strawberry	Fresh Tomato	Head Lettuce 1000 cwt	Fresh Apple
US Out-of-State Sources					
California-Total	321	861	**483**	**2832**	**18**
CA-Trucked			475	2706	17
CA-Piggyback			4.5	126	0.74
CA-Railcar			3.1	0.00	0.02
Arizona-Total	74			**1108**	
Arizona-Trucked				1060	
Arizona-Piggyback				48	
Florida-total		91	**898**		
Florida-Trucked			895		
Florida Piggyback			2.5		
Colorado				20	
New Jersey	7.6		4.2		
Texas	1.2				
Virginia			96		
Ohio			57		
Georgia			54		
Tennessee			28		
South Carolina			24		
North Carolina			18		
Minnesota			10		
Michigan					34
Washington-Total					**390**
Washington-Trucked					375
Washington-Piggyback					4.9
Washington-Railcar					9.8
Oregon-Total					**9**
Oregon-Trucked					7.14
Oregon-Piggyback					2.13
Oregon-Railcar					0.15
Domestic Greenhouse Production (place unspecified)			265		
All US Production: ST	**403**	**952**	**1937**	**3960**	**451**
Imports					
Mexico (truck)	17.2	79	1310	61	
Canada (truck)	2.5		225	17	10
Netherlands			19		
Israel (air)			4.9		
Spain (air)			4.1		
Chile (boat)					26
New Zealand (boat)					14
Imports, Major: ST.	**20**	**79**	**1563**	**79**	**49**
All Out-of-State Sources	**423**	**1031**	**3500**	**4039**	**500**
New York	**9**	**59**	**360**	**38**	**2950**
Total NY Utilization	**432**	**1090**	**3860**	**4077**	**3450**

TASK 3: DATA ON CROP OPERATIONS AND ENERGY REQUIREMENTS

Develop, from the available literature, a data bank of operations required for each crop for open-field production, and the associated energy requirements (energy types and amounts).

GENERAL

The objective for this chapter is to determine energy use and CO_2 emissions in field production of head lettuce, fresh spinach, and fresh tomatoes amongst vegetables, and fresh strawberries and fresh apples in the fruit category. In Chapter 4 we will determine energy use and CO_2 emissions in transportation of these commodities to New York. Combination of the data from the two chapters will give us the total energy and CO_2 emissions in growing and delivering the produce to New York consumers, and permit comparison of local versus remotely produced field crops from the point of view of energy expended, food miles, and carbon footprints. Further on, in Chapter 5, we will determine energy use in greenhouse production of Boston lettuce, baby-leaf spinach, and tomatoes in the upstate New York and compare local, year-round production of these crops in protected culture in New York to remote field production.

The most obvious energy use in field agriculture is petroleum fuel used for operating tractors and machinery and for transporting to the point of sale. In some locations, electricity is used extensively to pump water and, in most locations, it is required to refrigerate the crop following harvest. Natural gas and propane have very limited direct applications in field agriculture but are used extensively in greenhouse operations. We are particularly interested in how much liquid petroleum fuel is needed for mobile equipment because dependence on this energy source has critical implications for future costs and CO_2 emissions different from those for electricity and natural gas. Human energy is always used to some degree in agriculture, but even in intense operations such as hand-picking of fruit, it is negligible compared to other energy uses.

The amount of direct use of petroleum, electricity and other fossil fuels is of great interest in itself, but it represents just part of the energy use in crop production we need to consider. The majority of energy used in crop production is embodied in structures, equipment, and supplies used in crop production – buildings, tractors, fertilizers, and materials in general. Embodied energy is energy that previously went into manufacture, construction, transportation and installation of equipment, buildings, and materials. In these cases there is often discretion as to what energy source to use and the location of manufacture.

Fuels and electricity also have energy embodied in them, from when they were extracted and refined or, in the case of electricity, generated.

When fuels are used to perform agricultural operations, the amount of fuel used can be measured by weight or volume, and the energy expended obtained by applying an average figure for the energy content of that particular type of fuel. It requires energy to extract and refine petroleum fuels and to generate electricity, apart from the nominal value of the fuel and electricity consumed, and there is the production energy to consider. Table 3-1 gives the energy content and production energy for several common fuels and electricity.

Table 3-1. Energy Content of Fuels, Energy Use in Production, and Adjustment Factors for Total Fuel-Associated Energy Expenditure

Fuel	Unit	Enthalpy MJ/unit	Enthalpy kBTU/unit	Enthalpy kcal/unit	Production Input kcal/unit	Total Expended kcal/unit	Inverse Efficiency Factor	Efficiency (Energy out/in)
Gasoline	L	34.2	32.5	8,179	1930	10109	1.236	4.2
Diesel	L	38.7	36.6	9,235	2179	11414	1.236	4.2
Propane (liquid)	L	26.1	24.7	6,234	1471	7705	1.236	4.2
Natural Gas	m3	41.4	39.2	9,885	1928	11813	1.195	5.1
Coal	kg	30.2	28.7	7,222	563	7785	1.078	12.8
Hardwood	kg	19.3	18.3	4,600	345	4945	1.075	13.3
Electricity	kWh	3.6	3.41	859	2004	2004	2.333	0.43

Adapted from Pimentel 1980
Note. Figures for electricity depend on mix of generation methods.

In the US, energy contents of liquid fuels are generally given as BTU/gallon. In terms of the scientifically preferred SI metric system, the appropriate energy units for liquid fuels are joules (J) and liters (l). There is a frequent need to convert different forms of work and energy to common units. Electricity used for such things as running pumps or refrigeration is measured in terms of kilowatt hours. When mechanical work is done, for instance water is pumped from a depth, we encounter the work unit ft-lb or newton-meter. Much of our source data for agricultural operations was developed in terms of the kilocalorie (also called kilogram calorie) which relates to energy content of food. Table 3-2 gives standard conversion factors between energy types. We will, in general, reduce all energy forms to joules (J) and British thermal units (Btu), and more specifically to megajoules (MJ) and kilo-British thermal units (kBtu). We will present results, for the most part, in both British and SI units.

Table 3-2. Energy Conversion factors

	Joules (newton-meters)	Mega-Joules	Giga-Joules	British Thermal Units	kilo-BTUs	Mega-BTUs	kilowatt-hours	kilogram calories	foot-pounds
	J	MJ	GJ	BTU	kBTU	MBTU	kWh	kcal	ftlb
1 Joule equals:	1	1.0E-06	1.0E-09	9.478E-04	9.478E-07	9.478E-10	2.78E-07	2.389E-04	0.7376
1 Megajoule equals:	1.0E+06	1	0.001	947.817	0.94782	9.478E-04	0.27778	238.85	7.376E+05
1 Gigajoule equals:	1.0E+09	1000	1	9.478E+05	947.817	0.94782	277.778	238,850	7.376E+08
1 BTU equals:	1055.056	1.055E-03	1.055E-06	1	0.001	1.00E-06	2.93E-04	0.252	777.90
1 kiloBTU equals:	1.055E+06	1.055056	1.055E-03	1,000	1	0.001	0.29308	252	7.779E+05
1 MegaBTU equals:	1.055E+09	1055.056	1.055056	1.E+06	1,000	1	2.93E+02	252,000	7.779E+08
1 Kilowatt hour equals:	3,600,000	3.6	0.0036	3,412	3.412	3.412E-03	1	860	2,655,000
1 Kilocalorie equals:	4,186.73	4.187E-03	4.187E-06	3.96825	3.968E-03	3.968E-06	1.163E-03	1	3,088.326
1 Foot-pound equals:	1.356	1.356E-06	1.356E-09	1.285E-03	1.285E-06	1.285E-09	3.766E-07	3.238E-04	1

http://www.uwsp.edu/CNR/woee/keep/Mod1/Whatis/energyresourcetables.htm. Accessed 2008

Note: There are just over 1000 joules in a BTU. A joule is a newton-meter or watt-second; there are exactly 3.6 MJ per kWh

The output of this chapter is <u>itemized energy use in field production of each commodity by the respective method of production for each production location</u>, so that energy use may be calculated appropriately according to source. We also provide a breakdown by type of energy resource used so that corresponding CO_2 emissions factors may be applied. We separate total energy use into embodied energy versus direct fuel use and the latter into fossil fuel use (all petroleum in the case of field crops) versus electricity.

GENERAL DISCUSSION OF ENERGY USE IN CROP PRODUCTION AND DELIVERY

In an attempt to account for all energy used in producing and delivering produce, we first categorize and discuss where energy use potentially occurs. Following crop production chronologically, the five divisions in this discussion are the following: Infrastructure; Structures and Equipment – Farm, Greenhouse, and Off-farm; Crop Production and Harvest; Post-harvest Processing and Transport; and Environmental Impact.

<u>Infrastructure</u>

Agriculture is supported by the developmental level of the society in which it is practiced, particularly with respect to the state of rural electrification and fuel supply, manufacturing capability (for fertilizer and farm machinery particularly), transportation networks, and knowledge level in agronomic practices. Two hundred years ago in the US, most energy input into crop production was physical labor of humans and animals, and fertilizer came from manure/cover crops. The energy embodied in farm tools and implements also largely came from human and animal energy inputs (the smithy, for instance) and burning of solid fuels such as wood. Wind and water power were tapped to a small extent.

Everything has changed as a result of the industrial revolution, the exploitation of fossil fuels, the development of steam and combustion engines, the discovery of electricity, and the cumulative human effort to increase productivity by all means possible. We have become adept at obtaining, producing and distributing energy cheaply, and are willing to use very large amounts of energy in agriculture to increase yields. The input–output ratio of energy has changed accordingly.

We take the level of support agriculture receives from US infrastructure as given. However, in some regions of the US, agriculture is supported by far more elaborate infrastructure than other regions. California, which plays a prominent if not dominant role in the crops of interest to us, is a case in point. California agriculture is supported by an elaborate system of water supply and irrigation on a scale unmatched in other US production areas, (certainly not in New York) that typically have either sufficient rainfall or some other inexpensive means to obtain water. Every California river of any significance is dammed; water is imported from surrounding states, pumped over mountain ranges where necessary, extracted from deep aquifers; billions of dollars have gone into water management. The question arises: should the energy historically expended in constructing and operating water supply for agriculture in California, both the failed and successful projects, be included in energy-use calculations" If so, how accurately can it be determined and assigned to particular crops?

For the crops we are considering, (all are very perishable, except for apples) the Interstate highway system is used for long-distance trucking to transport produce to New York. New York-produced goods, on the other hand, have much less need for or use of this system. The trucking industry involves an elaborate infrastructure of weigh stations, truck stops and service centers, police enforcement, and road maintenance and federal management. Should the energy expended in constructing and operating the Interstate highway system and other infrastructure supporting the trucking industry be included in calculations, and how accurately can it be determined?

It is beyond the scope of this study to answer these questions, and perhaps there are no good answers to them. In general, we have accepted other scientists' published estimates of energy required for irrigation and transportation without determining to what extent the infrastructure mentioned has been accounted for. This area might merit additional consideration at a future time.

Structures and Equipment – Greenhouse, Farm, and Off-farm

The energy cost of providing farm/greenhouse structures and equipment consists of: 1) the energy required to produce the raw material of which the structure/equipment is composed (steel, plastic, aluminum, etc.), 2) the energy required to manufacture the finished item (tractors, trusses, girders, pipes, etc.), and 3) the energy required to deliver and/or install the structure or equipment and maintain it. One could go further back and consider the energy that went into making the equipment through which ores are refined and engine parts are milled, the blast furnaces, machine tools, etc, and the scientific work that led to development of the manufacturing processes but, by convention, the energy embodied in those structures and pieces of equipment is ignored, and so too the research efforts. Only the energy required to prepare the raw materials and supply them to the factories to make the items used on the farm is considered. The most convincing rationale for ignoring precursor infrastructure of the kind mentioned is that it has so much use over so long a time, and perhaps also so much future use anticipated, that the amount of energy attributable to any particular use of the infrastructure is negligible.

The land on which today's farms and greenhouses are situated was cleared of trees and rocks and had access roads and other infrastructure installed. We will consider these energy expenditures to be amortizable over such a long period that they will end up too small to be significant when amortized against each unit of today's production (given the amount of use that has followed or else will follow.)

Greenhouse. For the greenhouse, we may assume a cleared level site. We need to determine quantities of material to construct typical greenhouses on a per hectare (or acre) basis (with head house and passageway allowances), and calculate manufacturing energy for the construction materials (gravel, concrete, steel, glass or plastic film, aluminum, copper, wood and insulation, in particular). We also need to quantify the energy expended in construction activity.

We also must identify the contents of the greenhouse: the pipework, the wiring, and the equipment – for example, furnaces, circulation pumps, compressors, ventilation fans, luminaires, moveable shades, motors for vents and shades, fuse boxes, conduit, cooling pads, insect screen, dollies and lift jacks, trolleys to move materials, and work benches. Depending on the growing system and crop considered, additional specialized equipment is required. For deep trough hydroponic production, pond walls, a plastic liner, and a nutrient solution circulation system are required; for the tomato crop, a trellis system and specialized harvest equipment is needed to allow pickers to operate high above the floor.

Any permanent transportation associated with the greenhouse should also be included (e.g., a refrigerated delivery truck.)

The greenhouse and all other items must be assigned a life expectancy, which will not be the same in every instance. The energy costs for these items will be prorated/amortized over their lives, and expressed in energy units per year.

Farm. The farm has built-structures of various sorts in which fertilizer and other supplies are stored and equipment sheltered and serviced. Processing and cold storage facilities are needed on site for most of the crops. Specialized equipment to pack, sort and wash the harvested crop may be required, along with a means to palletize the crop and load trucks from a loading dock. Temporary housing for the field workers, and portable latrines, may also be needed. All these structures should be analyzed in the same way as the greenhouse structure.

A farm requires ditches and roads and fences, culverts, drainage tile, and irrigation lines. Pumps may be needed for irrigation. Tractors and various specialized implements for working the soil, fumigation, seeding, transplanting, and pesticide applications are needed. In most of the crops, precision leveling of the fields, accomplished by graders, is required to form uniform raised beds and furrows for irrigation. After grading, specialized equipment is required to form the beds and furrows themselves and lay down plastic mulch. Trucks, wagons, fork-lifts and bins of various kinds are needed for harvest operations, and, in some cases, complex harvesters.

Off-farm. For post-harvest processing and transportation, dedicated structures exist off the farm for two of the crops – facilities to wash and package salad-mix spinach and lettuce, and sort and store apples long-term.

Crop Production

Structures and equipment described above are used over many crop cycles. Their energy role in crop production is as an embodied energy cost that happened beforehand and is prorated over the years/amounts of crop production they subsequently support. In crop production itself, fuels and energy are consumed directly, as also are materials that are used up within the course of the crop cycle. In addition, there are ongoing energy expenditures in general support of production, such as maintenance.

Greenhouse. In greenhouse crop production, energy is continually spent to vent and heat for temperature control, and for lighting on an as-needed basis. There is usually a cold storage facility that consumes electricity continuously, as does lighting the head house where processing takes place. Pumps are in continuous use to move nutrient solution and motors are activated as needed to open and close vents and operate shade curtains. Fans run continuously to mix de-stratify air. These operations consume fuel and electricity directly.

Fertilizers and pesticides are consumed during crop production, as well as seeds and media for germinating seeds. Media such as rock wool, peat moss, vermiculite and perlite are used in substantial quantities in most greenhouse crop-production systems. Liquid O_2 is used to oxygenate water in pond systems, and CO_2 may be used to speed growth. A good deal of water is used and it may be pre-filtered using disposable filters or a Reverse Osmosis (RO) unit in which membranes are expended. Whether it is well water or municipal water, energy goes into its delivery to the greenhouse under pressure and is pressurized further if RO water is used. Detergents/disinfectants (e.g., Clorox©) are needed to clean floats and other equipment. Floats are consumed over a short life cycle. Plastic film has many applications. Crates, cartons and smaller plastic containers are used in packaging and harvest. The energy used in the manufacture of all these items should be determined. It falls in the category of embodied energy, but it consists of things that are consumed rapidly.

Farm. On the farm, diesel fuel is typically used by tractors performing various tillage operations, seeding, and in harvest operations. Some vehicles may use propane or gasoline. Soil may require fumigation. Herbicides and pesticides may be applied several times by tractor, or by aerial crop dusters. If available, grid electricity is used to pump water. Irrigation typically is needed several times during a crop cycle, usually requiring pumps. When frost threatens during critical times, either plants are sprayed with water or air is blown over the crops. These operations consume fuel/gas/electric energy directly.

Some of the major consumable items in field production are chemical fertilizers, lime, manure, fumigants, pesticides, fungicides and herbicides. Plastic sheeting is commonly used during fumigation and as mulch to cover raised beds in strawberry and tomato production, and spun-bonded polyester row covers are frequently employed to protect young plants. Water delivered from off-farm requires energy for pumping and treatment, apart from the energy used on farm to deliver it to the crop. In apple and tomato crops, stakes or trellis systems are typically used for part or all of the crop cycle. Packaging materials such as clamshells, plastic bags, and boxes/crates are needed as much in farm production as for greenhouse production

For all consumables (including the fuels and electricity), the energy required to produce and deliver them to the farm should be calculated and included.

Maintenance. Both in farms and greenhouses there is an annual expense to maintain structures and equipment, and in making repairs as needed. Outdoor activities include mowing and weed control in non-cropped areas, cleaning out ditches, and road maintenance. In greenhouses in temperate climates, even when crops are not currently in progress, some heating must be used to protect the structure against freezing and snow overload during winter. The same may be true of farm out-buildings. There are also ongoing services such as deliveries, garbage pick-up, snow plowing, and maintenance

Processing and transport.

An attempt is made in field production to do as much crop processing as possible at harvest time, either in the field and/or on the farm in the interest of economy and quality control. Of the crops we are considering, only baby-leaf spinach is consistently machine-harvested. If it is to end up in bagged salad packs for the New York market, baby-leaf spinach and lettuce is bulked, chilled, and sent directly to washing and packing plants in the East. Bunching spinach typically is not washed, but is formed into bundles ready for shipping and eventual sale. Most head lettuce is packed in the field, without washing, after removal of some outer leaves, whereupon it is chilled and sent directly to its final distribution point ready for retail sale. Strawberries are handpicked and immediately chilled in a nearby facility, ready for sale and shipping in final packaging, and without washing. Most field tomatoes are washed; greenhouse tomatoes typically are not. Both tomatoes and apples are graded as to size and color, which in very large operations could take place on the farm, but otherwise is done at a nearby center shared by many growers. A considerable part of the apple crop (c. 50%) goes into long-term controlled-atmosphere storage. (Losses occur in storage, which affect unit costs.)

As mentioned above, baby leaf spinach is bulked at harvest and sent directly to washing and packaging centers near final sales points. Only a few such centers exist in the country because the equipment is very specialized and expensive (D. Schwartz, personal communication). A substantial portion of the other harvested crops is shipped to terminal markets around the country for wholesale and further distribution. The remainder, grown under contract to large supermarket chains, is shipped directly to private corporate terminals. In all cases, during transit the produce is kept in controlled-temperature environments to preserve freshness, and also while held at intermediate destinations. In the estimates we find in the literature for energy used in crop production, the post harvest processing equipment described above is not accounted for, neither are the off-farm processing centers and terminal markets.

Over 95% of the crops we are considering is shipped in refrigerated trucks on the highways, with just a small amount of apple and head lettuce going by piggyback rail or railcar. Imports, other than those from Canada and Mexico arrive by ship or air. Most material trucked from Mexico is unloaded and reloaded at the border. (See Chapter 4.)

Ton-mile energy estimates exist that take into account the embodied energy of refrigerated trucks, in addition to fuel consumption. An allowance is included for highway maintenance costs. In view of the fact overloading (by a substantial amount) is widely tolerated in some areas of the country, the allowance for highway maintenance should perhaps be revised upwards (and assuming the rate of damage increases more rapidly than the magnitude of wheel loading). A difficulty in assigning trucking expenses lies in determining what percentage of the trucks/trailers must be returned empty when there is an imbalanced traffic in goods between source of produce and destination.

Environmental impacts

In estimating energy use in production it is easy to forget what happens after the crop is harvested. Plastic mulch must be taken up and disposed of, crop residues are removed and most likely burned to prevent spread of disease, and trellises are dismantled and sterilized before reuse. Something must be done with outmoded machines, discarded tires, left-over pesticides, apples trees past their prime, abandoned greenhouses and farm buildings, etc. Waste handling uses energy.

It may be necessary to use a crop rotation, in which case energy is expended in planting and managing that crop. Unless cash crops are used in the rotation, the energy uses in crop rotations should be prorated over the years when the fields are in production.

Depending on soil composition and geology, dryland farming by irrigation tends to have severe consequences by moving salts from the area farmed into adjacent wetlands and waterways, or alternatively if there is a hardpan, by degrading the upper strata by wicking salts from lower down to the surface. For example, the US is obligated by treaty to desalinate Colorado River water as it enters Mexico because farming operations in the US beside the river upstream have made it too saline to use for crops (water trickling back into the river after use for irrigation is highly saline.) A more common situation is where fertilizer run-off pollutes wetlands or ground water (e.g., the Everglades.)

Aquifers in the valleys of California have become heavily depleted, increasing the cost of obtaining water for everyone in the future because water must be pumped from deeper aquifers.

These examples underscore how there are often hidden demands for energy either in the immediate aftermath of crop production or for remediation of the long-term effects of crop production. The latter may only become apparent over time. Nevertheless they are legitimate additions to the energy cost of crop production in a sustainable system.

Conceptually, we have accounted for all the energy uses in crop production. Following a natural-seeming division, we have distinguished between energy use embodied in more or less permanent structures and equipment, and energy use attributable to specific crop cycles. The latter encompasses direct energy use (electricity), fuel use (diesel, gasoline, and propane or natural gas), and consumption of materials in which energy use is embodied in their manufacture (fertilizers, pesticides etc.).

THE ICEBERG LETTUCE CROP: PROFILE AND ENERGY USE

Iceberg lettuce information sources

A good account of California production is given in “Iceberg Lettuce Production in California” (1996), by faculty of UC Davis, including details of harvest and packing procedures. (http://vric.ucdavis.edu/selectnewcrop.lettuce.htm) Accessed 03-2008.

A second source for information on cultural practices is "Crop Profile for iceberg lettuce in California" (2001) by the California Lettuce Research Board, which gives schedule of harvest by area. (http://www.ipmcenters.org/cropprofiles/docs/calettuce-iceberg.html) Accessed 03-2008.

"Wrapped iceberg lettuce projected production costs 2002-2003" by faculty of UC Davis, lists the field operations during head lettuce production in detail. Accessed 03-2008. (http://vric.ucdavis.edu/veginfo/commodity/lettuce/lettuce-head-costs03.pdf)

A brief account of head lettuce production in Arizona, the second leading center of US production is given in "Crop Profile for Lettuce in Arizona" (2000) in which harvesting technique is also described. (http://cipm.ncsu.edu/cropprofiles/docs/azlettuce.html) Accessed 03-2008.

"Guidelines for Head Lettuce Production in Arizona", IPM series # 12 (1999) is comprehensive and good, and has photographs
(http://ag.arizona.edu/pubs/crops/az1099/) Accessed 03-2008.

Iceberg lettuce production overview

In 2004 and 2005, more than 98% of head lettuce shipped in the US originated in California, Arizona and Mexico, in proportions of 70%, 25%, 3%, with the remaining 2% split between several states such as Colorado and New Mexico in amounts less than 1% each. Among US producing states, farm production data gave similar proportions, namely 74% for California, 25% for Arizona, with the remaining 1% in Colorado. If we search back 50 years, there was significant head lettuce production in the Eastern part of the US – in New York, New Jersey, and Florida. However, the drier climates of the west offer protection against disease in this, as in several other crops, and production has become concentrated there. (Note: "head lettuce" and "iceberg lettuce" are often used interchangeably in the literature and in the following.)

We have energy use estimates for production of single crops of head lettuce for Salinas Valley and Imperial Valley, representing the main summer and winter production areas in California. (Ryder; in Pimentel, 1980). Imperial Valley acreage in lettuce is less than in the more northerly coastal valleys of California and far less is grown there (6% of annual CA shipments in 2004-5). Arizona now provides the bulk of winter national supply when Imperial Valley is in production (Arizona shipped 6 times the shipments of Imperial Valley over the winter period). Additionally, Arizona is closer for supply purposes to New York. Overall, supply to the US is constant throughout the year.

Per capita use of head lettuce has declined slightly during the last 25 years (from c. 25lbs/capita/annum to below 20 lbs/capita/annum during the last 15 years), especially in terms of home consumption, where romaine and leaf lettuces have increased (Ryder, et al.). Productivity and yield have made steady gains over the intervening 25 years since the lettuce energy use estimates were made, but techniques appear to have changed little, for the industry was already mature at that time. In 1977, California yield averaged c. 26,500 lbs/acre; in 2004-5 it was c. 36,500 lbs/acre. Yield for Arizona head lettuce in 2004-5 was c. 35,000 lbs/acre. The apparent gains in yield may well be an artifact because more than one crop cycle per year is possible in some growing areas, and double-cropping the same acreage would inflate yield figures, which generally refer to single crop cycles.

Energy Use in Iceberg Lettuce Production

In developing energy-use estimates for iceberg lettuce production, the figures Ryder et al used for productivity were 28,200 lbs/acre for Salinas Valley, California, and 23,400 lbs/acre for Imperial Valley, CA (Pimentel, 1980). We will assume yield increases since the time these estimates were made have been accompanied by increases in intensity of pesticide and fertilizer use and corresponding increased fuel use, so that energy inputs per lb of lettuce have changed little. We will use the figures shown in Tables 3-3 and 3-4 for energy use in head lettuce production in the various producing areas. The Arizona season of production and geographic situation is similar to that of Imperial Valley (winter, interior desert) so we will use Imperial Valley figures for energy use in production in Arizona. Colorado production is tiny; we will assign it to Arizona conditions. We will assume production in Mexico requires the same pattern of energy use as in California. Because Imperial Valley shipments are such a small part of total CA shipments, we will use just one energy figure for CA (and Mexican) production, that of the dominant northern growing areas.

In Table 3-5 we have estimated energy use in field production of Boston lettuce for purposes of comparison with CEA and field crops of this lettuce type when grown in New York.

Table 3-3. Estimate of Energy Use and CO2 Emissions in Iceberg Lettuce Production for California and Mexico (from Salinas, CA, summer estimate, Pimentel, 1980)

Item	Unit	need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	171				
machinery	kg	30	75.4	2,259	867	3
gasoline	l	37.1	42.3	1,569	602	2
diesel	l	617	47.8	29,466	11,302	36
electricity	kWh	989.3	12.0	11,851	4,546	14
All fuels and Electricity				**42,885**	**16,450**	**52**
nitrogen	kg	280.1	50.2	14,063	5,394	17
phosporus	kg	78.4	12.6	984	377	1
potassium	kg	78.4	6.7	525	201	1
lime	kg					
All soil amendments				**15,572**	**5,973**	**19**
seeds/seedlings	kg	0.3	16.7	5	2	0
seed coating	kg	1.5	147.0	220	85	0
irrigation water	cm	150.7	63.4	9,539	3,659	12
pvc pipe						
pe trickler						
insecticides	kg	29	363.9	10,545	4,045	13
fungicides	kg					
herbicides	kg	1.7	418.3	711	273	1
soil fumigant						
All pesticides				**11,256**	**4,318**	**14**
transportation	kg	582.6	1.1	626	240	1
Total Energy Use/ha or acre				**82,364**	**31,593**	**100**
Energy Use per Unit of Product at Farmgate						
Yield	kg/ha			31,595	31,595	
(see footnote)	lb/acre			28,189	28,189	
Energy use units				MJ	kBTU	
Energy use/ kg product				**2.61**	**2.47**	
Energy use/ lb product				**1.18**	**1.12**	

Energy Use and Emissions by Fuel Type

	CO2 E. rate	Energy Use	Emissions	Emissions
	kg/GJ	MJ/ha	kg CO2/ha	lb CO2/acre
Liquid fuel	70	31,661	2,216	1977
Electricity	100	21,390	2,139	1908
Embodied (all other)	60	29,313	1,759	1569
Total		**82,364**	**6,114**	**5,455**
Emissions as proportion of product weight			**0.19**	
Liquid fuel proportion of total energy		**0.38**		
Liquid fuel per unit of product - MJ/kg		**1.00**		

Note. California yield value is from the late 70's.Yields have since increased.
We have assumed energy use increases match yield increases; per-lb values are the same.

Table 3-4. Estimate of Energy Use and CO2 Emissions in Iceberg Lettuce Production for Arizona and Colorado (from Imperial Valley, CA Estimate, Pimentel, 1980)

Item	**Unit**	need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	243.8				
machinery	kg	30	75.4	2,259	867	2
gasoline	l	283.9	42.3	12,008	4,606	12
diesel	l	576.5	47.8	27,531	10,560	28
electricity	kWh	0	12.0	0	0	0
All fuels and Electricity				**39,539**	**15,166**	**40**
nitrogen	kg	224.1	50.2	11,252	4,316	11
phosporus	kg	201.7	12.6	2,532	971	3
potassium	kg	0	6.7	0	0	0
lime	kg					
All soil amendments				**13,783**	**5,287**	**14**
seeds/seedlings	kg	0.3	16.7	5	2	0
seed coating	kg	1.5	147.0	220	85	0
irrigation water	cm	357.6	63.4	22,714	8,713	23
pvc pipe						
pe trickler						
insecticides	kg	53.8	363.9	19,563	7,504	20
fungicides	kg					
herbicides	kg	1.7	418.3	711	273	1
soil fumigant						
All pesticides				**20,274**	**7,777**	**20**
transportation	kg	733.3	1.1	789	302	1
Total Energy Use/ha or acre				**99,584**	**38,198**	**100**
Energy Use per Unit of Product at Farmgate						
Yield	kg/ha			30,300	30,300	
(see footnote)	lb/acre			27,033	27,033	
Energy use units				MJ	kBTU	
Energy use/ kg product				**3.29**	**3.12**	
Energy use/ lb product				**1.49**	**1.41**	
Energy Use and Emissions by Fuel Type						
		CO2 E. rate kg/GJ		**Energy Use** MJ/ha	**Emissions** kg CO2/ha	**Emissions** lb CO2/acre
Liquid fuel		70		40,328	2,823	2519
Electricity		100		22,714	2,271	2026
Embodied (all other)		60		36,542	2,193	1956
Total				**99,584**	**7,287**	**6,501**
Emissions as proportion of product weight					**0.24**	
Liquid fuel proportion of total energy				**0.40**		
Liquid fuel per unit of product - MJ/kg				**1.33**		

Note. Arizona yield values are based on relative yields today, extrapolated to late 70S.
We have assumed energy use increases match yield increases, and per-lb values are the same.

Table 3-5. Estimate of Energy Use and CO_2 Emissions for Boston Lettuce Production in Remote Locations, and Iceberg Lettuce in New York

California, Mexico		
Energy use units	MJ	kBTU
Energy use/ kg product	5.21	4.94
Energy use/ lb product	2.36	2.24
Emissions as proportion of product weight		0.39
Liquid fuel per unit of product - MJ/kg	2.00	
Arizona. Colorado		
Energy use units	MJ	kBTU
Energy use/ kg product	6.57	6.23
Energy use/ lb product	2.98	2.83
Emissions as proportion of product weight		0.48
Liquid fuel per unit of product - MJ/kg	2.66	

Note. Boston lettuce estimates assume yields are halved for the same imputs
New York yield of iceberg assumed halved for same inputs

Looking at these energy use estimates, it can be seen the main difference in energy use per hectare comes from greater water use in Imperial Valley. Insecticide use is also somewhat higher. The difference in energy use per lb of produce is exaggerated because of differences in yield. For our purposes, we will accept the differences in energy use per hectare, but consider the yield differences between California and Arizona production areas to be in the same ratio as they are today (36,500:35,000 lb/acre).

The omissions for this crop are the same as those for several of the crops we are addressing. A value is not set on “producing” water, only on putting it on the crop. Energy embodied in irrigation equipment also seems to be left out.

Lettuce, like strawberry and spinach, must be chilled quickly after harvest to maintain quality. No allowance is made for this energy use or for energy embodied in the requisite facilities to do so. (Understandably: this is not part or production, but is part of post harvest). Most lettuce (c. 70%), like strawberry, is packed in the field for delivery to final destination, for the most part using individual cello-wrap, and cartons/cases with a fixed number of heads. Part of the crop is put into cartons “naked”. The remainder is bulked and sent to remote processing facilities where it is shredded, washed, and treated with preservative for use in salad mixes and institutional purposes.

THE FRESH SPINACH CROP: PROFILE AND ENERGY USE

Fresh spinach Information Sources

Spinach production in California before the advent of baby-leaf spinach as a product is described in “Spinach Production in California” (M/ Le Strange et al, UC Extension, 1999) (http://anrcatalog.ucdavis.edu/pdf/7212.pdf) and in “Crop Profile for Spinach in California” by the USDA (http://pestdata.ncsu.edu/cropprofiles/docs/caspinach.html) Accessed 03-2008

The “Crop profile for spinach in Arizona” 2001, gives useful descriptions of cultural and harvest practices for both bunching and baby leaf spinach in Arizona, (http://pestdata.ncsu.edu/cropprofiles/docs/AZspinach.html). Accessed 03-2008.

Fresh Spinach Production Overview

Spinach has seen most dramatic changes in use over the last 70 years, as shown in Figure 3-1 (G. Lucier, et al., 2006). Before World War II, spinach consumption was even higher than it is today. The choices were fresh or canned spinach (freezers were not yet in general use) and fresh spinach dominated; 2.75 lbs out of the 3.75 lbs used were fresh. Per capita use of fresh spinach fell to an all time low in the early 1970s, a mere 0.25 lbs out of 1.75 lbs total use. Over the next 20 years to 1990, fresh use rose slowly back to 0.6 lbs/person at the expense of canned and frozen spinach while overall spinach use continued to decline slowly (to a low of 1.4 lbs/person). Since 1990, through 2005, fresh-use spinach has seen a steadily accelerating increase from 0.6 to 2.5 lbs/person/annum, at which time the 2006 *E.coli* outbreak and temporary ban on spinach sales put a damper on the increase. (See Gary Lucier, 2006 and other articles). Accompanying the changes in total amounts of spinach consumed, there have also been changes in the form

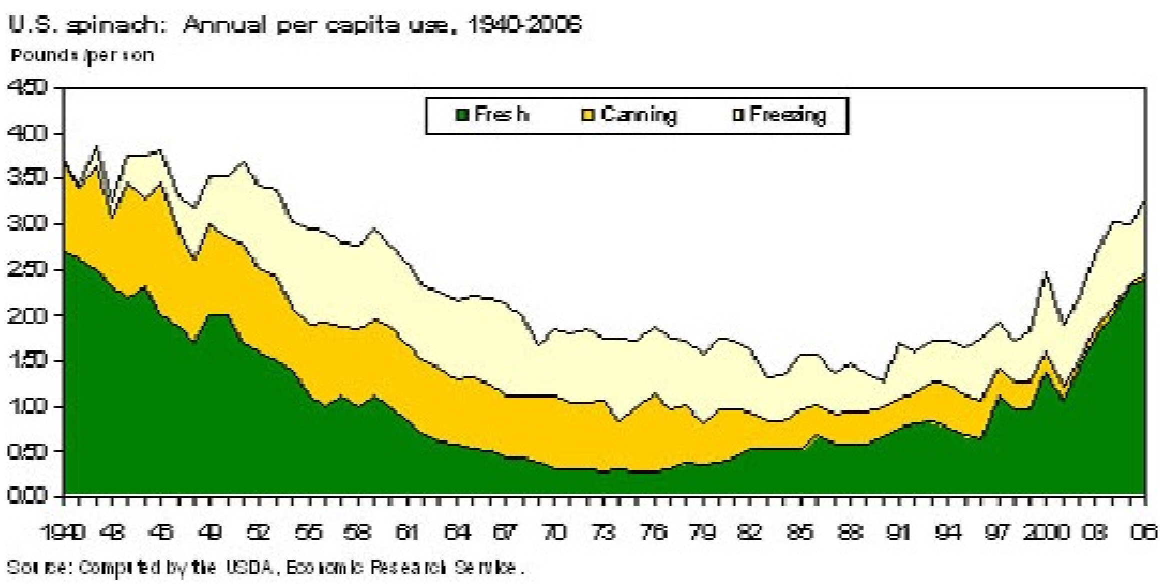

Figure 3-1. US Annual Spinach Consumption, lbs/person, from 1940 to 2006 (from Lucier, et al., 2006)

in which spinach is consumed. Canned spinach has disappeared almost entirely and traditional bunched spinach has largely been replaced with loose-leaf, washed, bagged spinach, most often of young leaves. Spinach today is most often eaten fresh, uncooked, in salads, whereas in the past it was cooked.

Whereas US spinach production was once widely distributed, it is now concentrated primarily in two states. California and Arizona, in 2004-2005, controlled 90% of US fresh spinach production. California has always been a leading grower, but Arizona is a newcomer. Traditional spinach growing states, New Jersey and Texas, were each responsible for 3% of US production, and Colorado and Maryland between them were responsible for the remaining 3%. Mexico has become a large supplier of fresh spinach to the US and Canada also exports a significant amount to the US.

In terms of shipments in the US, including imports, California was responsible in 2004-2005 for 54%, Arizona 13%, Mexico 26%, Canada 3.9 % and Texas 1.3%. Mexico was the second largest source of fresh spinach in the US (Arizona's share increased in 2006).

Unlike the other crops we are considering, all of which have a clear stage of development that must be reached before harvesting, spinach can be harvested at any stage and find a market. At present, baby-leaf spinach is the dominant form of fresh spinach and we will focus on it for comparison with CEA production. However, since the conversion of public preferences to buying spinach in bags rather than bunches, we have begun to see loose-leaf spinach sold in a range of sizes larger than baby-leaf, with corresponding price adjustment. (The preferred crop stage could rapidly change even more if the public concludes spinach must be cooked for safety, in which case large leaves and plants would be better value.)

Baby spinach can be grown as a "cut-and-come-again" crop, the first cut going to fresh, loose-leaf spinach and the second to processing. A third cut is sometimes possible. Alternatively, because the baby-leaf crop cycle is much shorter than the bunching spinach cycle, more than one crop can be grown in one season on the same land, perhaps in rotation with similar baby leaf salad greens such as lettuce, endive, beet greens etc.

Energy use in fresh spinach production

Data on what is happening in today's spinach production are not readily available. The crop profiles referenced are detailed and comprehensive, but they were written before the cut-salad greens trend had really taken hold and at a time when production methods for salad greens were unsettled. The techniques described are primarily for bunching and processing spinach, which are harvested at a later stage than baby-leaf spinach. The same is true for our energy estimates, which date from even earlier. In Tables 3-6 and 3-7 we have tabulated estimates from Pimentel,1980, for spinach production in California and Texas before the advent of the cut green salad trend. We will modify these estimates to cover the cut leaf situation.

Table 3-6. Estimate of Energy Use and CO_2 emissions for Spinach Production in California and Mexico. Salinas, Ca, Winter Estimate (Pimentel, 1980)

Item	Unit	Bunching Spinach 1 crop					Baby spinach 2 crops			
		need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total	need/ha	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis										
labor	hr	45								
machinery	kg	40	75	3,014	1,156	11	54	4,070	1,561	9
gasoline	l	55	42	2,328	893	8	96	4,074	1,563	9
diesel	l	100	48	4,779	1,833	17	175	8,363	3,208	18
electricity	kWh									
All fuels and Electricity				**7,107**	**2,726**	**25**		**12,436**	**4,770**	**27**
nitrogen	kg	202	50	10,149	3,893	36	202	10,149	3,893	22
phosporus	kg	60	13	754	289	3	60	754	289	2
potassium	kg									
lime	kg									
All soil amendments				**10,902**	**4,182**	**39**		**10,902**	**4,182**	**24**
seeds	kg	17	15	256	98	1	170	2,562	983	6
seed coating										
irrigation water	cm	15	206	3,091	1,186	11	60	12,364	4,743	27
pvc pipe										
pe trickler										
insecticides	kg	5.6	364	2,038	782	7	5.6	2,038	782	4
fungicides	kg	3.6	99	355	136	1	3.6	355	136	1
herbicides	kg	2.2	418	920	353	3	2.2	920	353	2
soil fumigant										
All pesticides				**3,313**	**1,271**	**12**		**3,313**	**1,271**	**7**
transportation	kg	183	1	197	76	1	367	394	151	1
Total Energy Use/ha or acre				**27,881**	**10,694**	**100**		**46,042**	**17,660**	**100**
Energy Use per Unit of Product at Farmgate										
Yield	kg/ha			22,400	22,400			7,467	7,467	
	lb/acre			19,985	19,985			6,662	6,662	
Energy use units				MJ	kBtu			MJ	kBtu	
Energy use/ kg product				**1.24**	**1.18**			**6.17**	**5.84**	
Energy use/ lb product				**0.56**	**0.54**			**2.80**	**2.65**	

Energy Use and Emissions by Fuel Type

	Bunching Spinach				Baby spinach		
	CO2 E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	7,304	511	456	12,831	898	801
Electricity	100	3,091	309	276	12,364	1,236	1,103
Embodied (all other)	60	17,486	1,049	936	20,847	1,251	1,116
Total		**27,881**	**1,870**	**1,668**		**3,385**	**3,020**
Emissions as proportion of product weight			**0.08**			**0.45**	
Liquid fuel proportion of total energy		**0.26**			**0.28**		
Liquid fuel per unit of product - MJ/kg		**0.33**			**1.72**		

Adjustments for baby spinach: Harvester assumed to weigh 5 metric tons, and 10 year life
Gasoline and diesel up by 1.75, and transportation doubled and irrigation water quadrupled
Seeds increased tenfold. No change in fertilizer and pesticides

Table 3-7. Estimate of Energy Use and CO_2 Emissions for Spinach Production in Texas, New Jersey and New York. Texas, Winter Estimate (Pimentel 1980)

Item	Unit	Bunching Spinach 1 crop need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total	Baby spinach 2 crops need/ha	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis										
labor	hr	270								
machinery	kg	40	76	3,023	1,159	14	54	4,081	1,565	10
gasoline	l	50	42	2,116	812	10	88	3,703	1,420	9
diesel	l	90	48	4,301	1,650	20	158	7,527	2,887	18
electricity	kWh									
All fuels and Electricity				**6,417**	**2,461**	**29**		**11,230**	**4,307**	**26**
nitrogen	kg	67	50	3,376	1,295	15	67	3,376	1,295	8
phosporus	kg	90	13	1,130	434	5	90	1,130	434	3
potassium	kg									
lime	kg									
All soil amendments				**4,507**	**1,729**	**21**		**4,507**	**1,729**	**10**
seeds	kg	20	15	301	116	1	200	3,014	1,156	7
seed coating										
irrigation water	cm	11.4	360	4,099	1,572	19	46	16,395	6,289	38
pvc pipe										
pe trickler										
insecticides	kg	4.5	364	1,637	628	7	4.5	1,637	628	4
fungicides	kg	7.8	99	770	295	4	7.8	770	295	2
herbicides	kg	2.2	418	920	353	4	2.2	920	353	2
soil fumigant										
All pesticides				**3,327**	**1,276**	**15**		**3,327**	**1,276**	**8**
transportation	kg	174	1	187	72	1	348	374	144	1
Total Energy Use/ha or acre				**21,861**	**8,385**	**100**		**42,929**	**16,466**	**100**

Energy Use per Unit of Product at Farmgate		Bunching MJ/ha basis	Bunching kBTU/acre basis	Baby MJ/ha basis	Baby kBTU/acre basis
Yield	kg/ha	20,160	20,160	6,720	6,720
	lb/acre	17,987	17,987	5,996	5,996
Energy use units		MJ	kBtu	MJ	kBtu
Energy use/ kg product		**1.08**	**1.03**	**6.39**	**6.05**
Energy use/ lb product		**0.49**	**0.47**	**2.90**	**2.75**

Energy Use and Emissions by Fuel Type

	Bunching Spinach CO2 E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre	Baby spinach Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	6,604	462	412	11,604	812	725
Electricity	100	4,099	410	366	16,395	1,640	1,463
Embodied (all other)	60	11,158	669	597	14,929	896	799
Total			**1,542**	**1,375**		**3,348**	**2,987**
Emissions as proportion of product weight			**0.08**			**0.50**	
Liquid fuel proportion of total energy		**0.30**			**0.27**		
Liquid fuel per unit of product - MJ/kg		**0.33**			**1.73**		

Adjustments for baby spinach: Harvester assumed to weigh 5 metric tons, and 10 year life
Gasoline and diesel up by 1.75, and transportation doubled and irrigation water quadrupled
Seeds increased tenfold. No change in fertilizer and pesticides

Some differences between the crops can be identified. The baby leaf crop has a crop cycle about half as long as that of the normal bunching spinach crop. This is weather dependent, but one can estimate 25 days on the average when temperatures are optimum. The crop thus, ostensibly, requires less water and fertilizer, and also fewer fungicide applications in each crop cycle. Conversely, because it is planted at a higher density, it requires more seed, fertilizer, and water. It must be planted at a much higher plant density or yield will suffer greatly. With a sufficient increase in plant density, and multiple succession croppings on the same land, whole plant productivity (average daily yield) can, in theory, be maintained if crops are grown in quick succession with no down time – say two crops of baby leaf spinach in the same time as one of bunching spinach. However, the stipulation of no down time (the field must be fitted for the next crop and seeds must germinate) is not possible in field production and some loss of productivity is inevitable on this account.

In addition to some loss in plant productivity from growing two crops successively, there is also a large loss in amount of saleable material harvested, when just leaf blades rather than the whole plant is sold, as our research at Cornell (sponsored by NYSERDA) has shown. Specialized band-saw type harvesters have been designed specifically for baby-leaf salad crops, and mechanical harvesting is the practice. In mechanical harvesting, the cut is in a plane and needs to be high enough leave behind most of the leaf petioles (and to clear the growing tips). As a consequence, half the plant shoot weight is lost (we have experimentally determined this) compared to bunching spinach, which is cut through the hypocotyl, in which case virtually none of the plant shoot is lost. In keeping petioles suitably short on those leaves harvested, the base of the plant, the growing tip, and half or more of the petioles are left behind (either to grow again or discarded as trash), and these items represent half of the shoot weight.

As far as we know, data are not available in the public domain on yield in baby-leaf spinach production in contrast to bunching spinach production. In reality, no good yield data are available for cut salad crops in general. Annual yield figures for fresh spinach are available but, within those figures, mixed types of product are combined and, because of multiple cropping of the same land in some cases and not in others, they are questionable and will remain so until the industry becomes more highly structured and growers are willing to share their data.

Under the best of circumstances, in continuous non-stop production throughout the season, cut baby leaf spinach yield would be 50% that of bunching spinach simply because only the leaf portion of the shoot is harvested. Due to additional losses resulting from down time between successive crops, and some losses in compensating for early harvest by increased plant density, it would be an achievement to reach 33% of the bunching spinach yield over the same time duration. This is the figure we will use. We will assume inputs are the same as for bunching spinach, except for increased seed use (which we will assume is in 10 times the amount for bunching spinach), increased water use for many more plants and two seed germination phases, increased fuel for a specialized harvest machine, and increased embodied energy for the harvest machine. On this basis, energy use for baby spinach leaf production is as shown in Tables 3-6 and 3-7, representing spinach production in the dry west and humid east, respectively.

In the adjusted estimate for energy use in baby spinach production, we have allowed for harvesting by machine. Spinach for the east coast is bulked in bins, chilled using forced air or vacuum cooling means as soon as possible after harvest, and sent to east coast washing and packing facilities, after which it goes on to wholesale distribution centers.

THE FRESH STRAWBERRY CROP: PROFILE AND ENERGY USE

Fresh Strawberry: Information sources

Nine tables on energy use in strawberry production in different parts of the country and under different scenarios are provided in Pimentel's Handbook of Energy Utilization in Agriculture (Pimentel, 1980). The introduction to these tables by Galletta and Funt is valuable as an overview of the widely differing strawberry production situations in the US.

USDA supplies an overview of the industry from the mid 90s, "The US strawberry industry" (Bertelson, 1995) (http://www.nal.usda.gov/pgdic/Strawberry/ers/ers.htm), accessed 03-2008.

An excellent crop profile for Californian strawberry production was prepared in 1999 by the USDA, UC Davis, and others. It is available online under the title "Crop Profile for Strawberries in California" (http://fruitsandnuts.ucdavis.edu/crops/strawberry.shtml). Accessed 03-2008.

Practices in Florida, the second leading producer of strawberries in the US, may be found in the document "Florida crop/pest management profiles: Strawberries" prepared through University of Florida in 2004 (http://edis.ifas.ufl.edu/PI037), accessed 03-2008, and in the bulletin by Legard, D.E., Hochmuth, G.J., Stall, W.M., Duval, J.R., Price, J.F., Taylor, T.G., and Smith, S.A. September 2001. Strawberry Production in Florida. Horticultural Sciences Department Document HS736, University of Florida, Institute for Food and Agricultural Sciences and Florida Cooperative Extension Service. This unfortunately is no longer web accessible.

Strawberries are grown rather differently in Oregon, the 3rd leading producer, as attested in "Crop Profile for Strawberries in Oregon", 2002, Oregon State University (http://pestdata.ncsu.edu/cropprofiles/docs/ORstrawberries.html). Accessed 03-2008.

The worldwide situation for strawberry production is reflected in the USDA FAS article "Strawberry situation and Outlook", 2001 (http://www.fas.usda.gov/htp/Hort_Circular/2001/01-01/strawbry.htm), accessed 03-2008. (It is of interest that Japan has a very large production of strawberry in hothouses, serving most of its fresh strawberry needs. To quote the report – "Almost all of Japan's strawberries are produced in hot houses, with production from December through June. Peak harvesting occurs from January through April…" ... " "Strawberry production for 2000/01 (October - September) is forecast at 180,000 tons, down 3 percent from the 185,000 tons produced in 1999/2000".)

China is entering the world stage in strawberry production. A recent article "China's strawberry industry: an emerging competitor for California?" 1995, details their production. (http://www.agecon.ucdavis.edu/extension/update/articles/v9n1_3.pdf). Accessed 03-2008.

California Strawberry Production Overview

California strawberry crop. In the 1999 USDA article "Crop Profile for Strawberries in California" cited above, items of relevance to this study follows. Rather than rewording the pertinent data, information is presented as a series of quotations from relevant references listed above.

Yield: California yield was 49,000 lbs/ acre, this being twice that for Florida, and ten times that for New York State. Looking at historic UDSA figures, the claim seems to have been correct.

Location: "California strawberry production occurs primarily along the central and southern coast, with a small but significant production occurring in the Central Valley." ... "Nursery stock are produced in two areas of the state, the Central Valley and in high elevation nurseries in Northeastern California. Central Valley nurseries are primarily located in the Northern San Joaquin Valley and Northern Sacramento Valley." ... "Strawberries are harvested in one or more of the growing areas every month of the year, with peak production occurring in late spring."

Productivity: "The high production of strawberries in California can be attributed to the yield potential of the cultivars grown, the mild coastal climates that are ideal for strawberries, the use of annual production systems that use pathogen- and pest-free planting stock each year, and the intensive management of the crop with a third of the state's acreage being replanted after a one year rotation to an alternate crop." ... "The high level of crop rotation (about 1/3 of the production acreage) and the high level of new plantings each year results in discrepancies in the statistical estimates of strawberry production per year"

Overview of Production: "All of California's strawberry acreage is irrigated and most of the crop is grown on an annual basis. Strawberry plants for planting stock are initially grown in the state's nurseries followed by transplantation during the summer or fall. Strawberries are harvested during the following winter, spring, summer and fall. The plants are destroyed after the first harvest season and new plantings are established for subsequent crops. Strawberry plants produce fruit for six months or longer in California."

Nursery Stocks: "In California, commercial strawberry plant propagation is a multi-year process. Runner plants produced in one nursery propagation cycle are used as planting stock in the next cycle. The first runner generation is produced in a screen-house, with at least three additional runner generations produced in field nurseries. Two or more field propagation cycles occur in low-elevation (less than 500 ft elevation) nurseries in the state's interior valleys (primarily the Sacramento Valley) where climatic conditions result in prolific runner production during a long growing season. A final field propagation cycle occurs in high-elevation nurseries in northeastern California (at greater than 3,200 ft elevation), where temperature and photoperiodic conditions limit nursery runner production but result in increased transplant vigor, productivity, and fruit quality." ... "Nursery stock for summer-planted fields comes from low-elevation nurseries located in the Central Valley. These nursery fields are planted in the mid-Spring and harvested at the end of the calendar year. The resulting nursery stock are trimmed, packaged, and kept in cold storage until transplanting into fields the next summer. High-elevation nurseries are used for fall plantings. In these cases, harvested nursery stock are used immediately for transplanting into production fields."

Fumigation: "Several weeks before planting, in essentially all but the organically-grown acreage of the state, the soil is fumigated with a combination of methyl bromide and chloropicrin applied under a sealed plastic tarp, which is removed after about of 5 days (120 hours). Plants are set by hand into deep, narrow holes on pre-moistened beds. If bed fumigation is used, plants are set through holes in the plastic at least two weeks after fumigation, and the plastic mulch stays in place until the plants are removed."

Mulch: "Mulch can be used to ensure that the strawberries and plant foliage are separated from the ground. This reduces pathogen transfer, enhances soil warming and improves water management. If mulch is used, it is put on immediately after planting. Typically, clear polyethylene mulch is applied to warm the soil, increase early plant growth, and keep the berries off the damp ground. The color of the tarp is important for efficacy and productivity. In Southern California, use of black or colored tarps can reduce weed populations but result in a 10% yield reduction due to less effective soil warming."

Harvesting: "The grower/shipper or shipper assumes control of all operations related to harvest. Once harvesting commences, hand-harvesting continues for several months on a 3 to 5 day cycle. This continual harvesting ceases when the productivity of the field diminishes significantly. ….Strawberries are harvested carefully by hand and are not subject to washing at the time of harvest. Harvested strawberries are placed in trucks, within an hour or two of picking, which transport the strawberries to a cooling facility. All strawberries are cooled, usually within 1 to 4 hours after harvest. Strawberries are typically forced-air cooled at temperatures of 34F. Cooling reduces decay and prolongs the fruits shelf-life."

Post harvest: "Nearly all strawberries are shipped to the market in refrigerated trucks, and temperatures in the range of 34-36F are maintained during shipment." ... "The following examples are provided to indicate typical times associated with the harvesting, cooling, and shipping operations:

Day 1 Harvest: Delivery to yard and cooling (1-4 hours).

Day 2-6 Shipping within the United States:

To Seattle - 1 day

To Denver - 2 days

To Chicago - 3 days

To New York/Boston - 4 days

Receiving dock to supermarket: 1 day"

Post harvest deterioration appears to be primarily "…caused by the fungus *Rhizopus stolonifer*. Spores of this fungus are usually present in the air and are easily spread. This fungus will not grow at temperatures below 5°C (41°F), therefore temperature management is the simplest method of control.

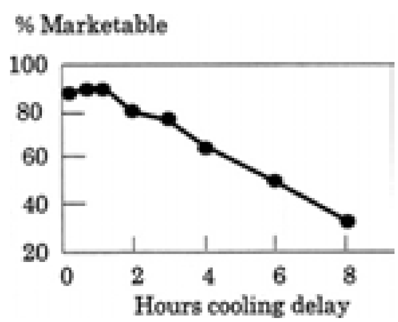

Figure 3-2. Cooling and Deterioration. Strawberries should be cooled as soon as possible after harvest; delays beyond 1 hour reduce the percentage of marketable fruit."

Crop Rotation: "Strawberry fields are sometimes rotated with cover crops such as rye or barley, or another cash crop such as beans, broccoli, lettuce, and cauliflower to reduce pest populations and improve soil structure. Time is allowed from one crop to another to allow crowns from the previous crop to decompose completely. In the south and central coast areas, where land and water costs are high, cover crops are not economically feasible."

Cost per Acre: "The cost to produce an acre of strawberries/year amounts to $9,500 to $12,000 per acre, pre-harvest. The value per acre for harvested strawberries varies based on yield (trays/acre) and quality. Total costs per acre, including harvest costs which typically are $3.25 per tray of berries, range between $25,000 and $30,000."

In summary, for California strawberry production, we see two stages/crops here; runner production and fruit production, and they are separated geographically. Some fruit production areas may also use a cover crop in rotation every 3 years, but not if the land is expensive. Note that only one long season of fruiting (6 months) is permitted before putting in new plants.

For fruit production, main energy use is in leveling, forming raised beds and furrows, fumigating, laying down plastic, and planting, and in irrigation and pesticide applications, and eventually in turning residues under. The number of irrigations and pesticide applications no doubt vary annually. Harvest itself is by hand, with copious truck support to bring fruit to chilling facilities.

There appears to be no washing process or elaborate storage. However, packaging must prevent crushing. Post harvest life is best just above freezing in 15% CO_2 modified atmosphere. Typically it takes 6 days for strawberries to reach retail outlets on the East Coast. Productivity is evidently much greater in CA than elsewhere because of cultivars, climate, and technique. See Table 3-8 for data.

Table 3-8. Estimate of Energy Use and CO_2 Emissions in Strawberry Production for California and Mexico (From CA Estimate, Pimentel, 1980)

Item	Unit	need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	6,214				
machinery	kg	87	75	6,519	2,500	4
gasoline	l	539	42	22,813	8,750	13
diesel	l					
electricity	kWh	1,419	12	17,009	6,524	10
All fuels and Electricity				**39,822**	**15,274**	**23**
nitrogen	kg	45	62	2,770	1,062	2
phosporus	kg	22	13	276	106	0
potassium	kg	22	7	147	57	0
lime	kg					
All soil amendments				**3,193**	**1,225**	**2**
seedlings	no.	114,812	0.21	24,131	9,256	14
seed coating						
irrigation water	ha.cm	64	See footnote			
pvc pipe						
pe trickler						
insecticides	kg	17	257	4,375	1,678	3
fungicides	kg	17	116	1,977	758	1
herbicides	kg					
soil fumigant	kg	281	99	27,733	10,637	16
All Pesticides				**34,085**	**13,074**	**20**
transportation	kg	2,427	1	2,611	1,001	2
covercrop seed	kg					
plastic mulch	kg	450	141	63,586	24,389	37
Total Energy Use/ha or acre				**173,946**	**66,720**	**100**

Energy Use per Unit of Product at Farmgate

Yield	kg/ha	53,891	53,891
	lb/acre	48,082	48,082
Energy use units		MJ	kBtu
Energy use/ kg product		**3.2**	**3.1**
Energy use/ lb product		**1.5**	**1.4**

Energy Use and Emissions by Fuel Type

	CO2 E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	25,423	1,780	1588
Electricity	100	17,009	1,701	1517
Embodied (all other)	60	131,513	7,891	7040
Total		**173,946**	**11,371**	**10,145**

Emissions as proportion of product weight		**0.21**
Liquid fuel proportion of total energy	**0.15**	
Liquid fuel per unit of product - MJ/kg	**0.47**	

Note. Energy spent in irrigation is part/all of electricity.
No allowance is made for pipe and trickler system.

Florida Strawberry Production Overview

General Information: "Florida produces 15 percent of the total U.S. crop, and 100 percent of the domestically produced winter crop." "220,500,000 pounds of fresh berries valued in excess of $167 million were produced during the 1999-00 crop year on 6,300 acres." (Gives yield of 35,000 lbs/acre). "Production costs (1998-99) averaged $17,100 per acre, which makes strawberry one of the most expensive crops to produce." "Approximately 95 percent of Florida's commercial strawberry production acreage is located in Hillsborough and Manatee counties with the remainder in several other counties."

Cultural methods: "Transplants are set in late September through early November. Drip and overhead irrigation is used to help establish plants, irrigate plants, and protect the plants from frost. Following early vegetative growth, the cool nights and short days of winter stimulate the plant to produce flowers which, after pollination, develop into fruits ready for harvest in four to six weeks. This results in three or four crops of fruit from each plant (based on a 30-day cycle). Flowers are present on plants in production areas continuously from shortly after planting until the end of harvest, but there are typically two peak flowering periods each season, one in November or December, and the other in mid to late January. The average harvest period runs from late November through early April. Fruit are harvested by hand every three days throughout the harvest season. Due to the frequency of harvest, preharvest intervals (PHIs) and restricted entry intervals (REIs) are important factors when growers select pesticides for use on strawberries. Pesticides are applied exclusively by ground application equipment. Florida's warm, humid climate is ideal for the development of many insect and mite, nematode, disease, and weed pests."

"…it is strongly recommended that strawberries be grown only on full-bed plastic mulch, and that a multi-purpose fumigant be applied to the bed as the plastic is laid over it. Therefore, strawberries are grown as an annual crop in Florida using the hill (raised bed) system, with two to four rows of plants per raised bed. Methyl bromide, in combination with chloropicrin, is currently applied approximately two weeks prior to planting transplants for the management of soilborne diseases, nematodes, insects, and weeds. A single application at an average rate of approximately 140 to 180 pounds of product per acre (approximately 300 pounds per treated acre) is injected into the soil during construction of the raised-beds. Row middles are not treated. The bed is then immediately covered with plastic mulch."

"Worker activities during fumigation include mostly tractor-driven related operations, such as cultivation, fertilization, operating the fumigation rig, and laying drip tape. The only field task is shoveling dirt on the mulch to bury it, which generally requires three people per end. The two-row fumigation rig will cover about eight acres a day. With average size farm of 40 acres, shovel crews would be needed 40 hours a year. Workers then set transplants, cut runners, and harvest strawberries as the season progresses." See Table 3-9 for associated data.

Table 3-9. Estimate of Energy Use and CO_2 Emissions in Strawberry Production for Florida (From Pimentel Estimate, 1980)

Item	Unit	need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	6,446				
machinery	kg	38	75	2,864	1,098	1
gasoline	l	786	42	33,267	12,760	16
diesel	l					
electricity	kWh	3,089	12	37,024	14,201	18
All fuels and Electricity				**70,291**	**26,961**	**34**
nitrogen	kg	224	62	13,786	5,288	7
phosporus	kg	56	13	703	270	0
potassium	kg	185	8	1,450	556	1
lime	kg	140	9	1,239	475	1
All soil amendments				**17,179**	**6,589**	**8**
seedlings	no.	59,304	0.33	19,615	7,524	10
seed coating						
irrigation water	ha.cm	57 to 97	See footnote			
pvc pipe						
pe trickler						
insecticides	kg	34	257	8,750	3,356	4
fungicides	kg	259	116	30,113	11,550	15
herbicides	kg	4	263	1,051	403	1
soil fumigant	kg	224	99	22,107	8,480	11
All Pesticides				**62,022**	**23,789**	**30**
transportation	kg	2,621	1	2,820	1,082	1
covercrop seed	kg	56	59	3,282	1,259	2
plastic mulch	kg	215	126	27,005	10,358	13
Total Energy Use/ha or acre				**205,077**	**78,661**	**100**

Energy Use per Unit of Product at Farmgate

Yield	kg/ha	23,538	23,538
	lb/acre	21,001	21,001
Energy use units		MJ	kBtu
Energy use/ kg product		**8.7**	**8.3**
Energy use/ lb product		**4.0**	**3.7**

Energy Use and Emissions by Fuel Type

	CO2 E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	36,087	2,526	2254
Electricity	100	37,024	3,702	3303
Embodied (all other)	60	131,966	7,918	7064
Total		**205,077**	**14,146**	**12,621**

Emissions as proportion of product weight		**0.60**
Liquid fuel proportion of total energy	**0.18**	
Liquid fuel per unit of product - MJ/kg	**1.53**	

Note. Energy spent in irrigation is part/all of electricity. No allowance is made for pipe and trickler sys
High Florida rate of electricity use in irrigation may relate to pressure required for application

Oregon Strawberry Production Overview

General Information: “Oregon ranks third nationally in strawberry production. Two percent of the nation's strawberries are grown in Oregon.” ... “Yield per acre varies from year to year, depending on weather and incidence and severity of disease and insect pests. Average yield is about 10,000 pounds per acre although in 2001, the state average was 13,000 pounds per acre.”... “Production costs for established strawberries are approximately $3,500 per acre.” ... “ Almost all of Oregon's strawberries are grown west of the Cascade Mountains in the Willamette Valley. Fertile soils, mild winters and cool summers allow growers to produce high quality berries with good flavor, color and texture. Marion County has the most strawberry acreage in the state (47%)”

Cultural Methods. “Oregon strawberries are grown as a perennial, with fields remaining productive for two to four years. Many fields are productive for only two seasons due to declining plant vigor, which is commonly a result of root rot disease or root weevil larvae feeding. Plants do not produce a marketable crop in the planting year, but will bear fruit in subsequent years. Harvest generally begins in early June and lasts for about three weeks. The fruit is harvested by hand, with the cap (calyx and stem) being removed from the berry if the berries are destined for processing.”

“Perennial weeds are controlled prior to planting with a non-selective herbicide, such as glyphosate, in the fall or early spring. Soil fumigation for weed and disease control is sometimes used but is not common due to the high costs associated with this practice. In preparation for planting, the soil is disked and cultivated to produce a smooth surface. Some growers create and plant on raised beds, which can help reduce incidence of root rot and fruit rot diseases; however, raised beds are more difficult to maintain and are not common.” ... “Strawberry crowns are planted in the spring. A preemergence herbicide is applied either pre-plant or post-transplant. Irrigation is necessary after planting and weekly, thereafter until rainfall begins in early fall. During the establishment year, plants are fertilized at planting and then again in mid-summer. A preemergence herbicide is again applied in the fall.”

“In established strawberry fields, it takes approximately 30 to 40 days for the plant to progress from bloom to harvest. Fruit rot caused by *Botrytis cinerea* is common and fungicides are applied during bloom period. Two to four weeks after the last fruits are harvested, the strawberry field is renovated. Renovation involves mowing the plants to just above the crown, disking between the rows, fertilizing and irrigating; a preemergence herbicide is often applied after renovation”

Energy Use in Fresh Strawberry Production

The most current estimates we have of energy needed to produce fresh strawberries date from the late 1970s, with estimates of yield appropriate to that time. Then, as today, California yield was twice that of Florida, and ten times that of NY, largely because of climatic factors and the length of the growing season. The Florida crop nicely complements the California crop in terms of when production peaks, however. From the itemized energy expenditures and footnotes, it appears that in Florida and the southern growing area of California, the production techniques used today were already in place in these estimates – namely cropping systems using transplants, termination of plants after one year of production, annual soil fumigation, and use of plastic-mulch covered raised beds with irrigation.

Current yield for the California crop is 59,500 lbs/acre (2004, 2005 average) as opposed to 24,000 lbs/acre in Florida. (Historically Florida managed a yield around 29,000 lbs/ acre in the 1990s; the current dip in productivity may be temporary.)

In the yield estimates we have from Pimentel's handbook (1980), the California south growing region yielded 54,000 lb/acre, and the Florida yield was 21,000 lbs/acre. These values are sufficiently close to today's yield figures (59,500 and 24,000 lbs/acre) to be of little cause for concern, although we can not be certain whether the yield increase is accompanied by an increase in inputs or some other factor. (e.g., increased plant density, fertilizer, etc.) We will assume so, and apply the per lb energy values to today's crops. (Yield is in terms of 12-pint flats/trays, weighing 10lb each.)

A very substantial amount of strawberry production capacity, comparable to that in Florida, has arisen in Mexico. Mexico has a wide range of climatic options as to where best to locate strawberry production. The three areas in which strawberry production takes place are all west of the Cordilleran mountain chain, so we will assume they are similar in climate to California, and assume energy use in production is the same as that in California. More than 90 percent of Mexico's strawberries are produced in Michoacan, Guanajuato, and Baja California. Michoacan is the most important growing region for the winter crop and is the first to reach market. The Guanajuato crop, which is more important for the summer crop, typically reaches market two months later. Michoacan is located to the southwest of Mexico City, Guanajuato to the northwest. Baja is the long north-south peninsula immediately south of San Diego. (http://www.fas.usda.gov/htp/horticulture/berries/Strawberry%20Situation%20Report%202-10-04.pdf)

The New York strawberry crop is small and production techniques are quite different from the major producers' production systems. Galletta and Funt have produced an estimate for small-scale, U-pick, operations typical of upstate New York and we shall use that, with some minor modifications. Energy use in strawberry production, based on data from Pimentel (1980), is shown in Tables 3-8, 3-9 and 3-10 for California (and Mexico), Florida, and a small New York farm, respectively.

There appear to be several omissions from the energy use calculations presented in these data. One is that the energy used to get water to the farm in either Florida or California is not assessed, only energy use in “putting on” the water. In both cases “manufacturing and installing energy of irrigation pipe” is also not included, as footnoted.

It is essential to chill strawberries within two hours of picking or, as shown in Figure 3-2, berries deteriorate quickly. Infrastructure and operating cost of chilling facilities are not included in production costs. Containers (clamshell pint packs for instance, as are currently in use) are not included, nor is energy embodied in trays needed in the field by harvesters.

The category “transportation” appears to refer to getting materials to the farm, not moving the weight of harvested strawberries from field to chilling plant. The machinery to do this (flat-bed trucks of some sort) does not appear to be covered. This same machinery would also move flats and workers to and from picking areas, a never-ending activity throughout the harvesting time of the crop. Possibly gasoline for the trucks so employed was included in the gasoline total, but that is not clear from the data presented.

Finally, the chilling facility would likely be in one of several farm buildings, including a loading bay and equipment to load pallets onto delivery trucks. These buildings and pieces of equipment, and the energy to operate the equipment, have not been included but, ideally, should be.

California used twice as much plastic film as Florida, but half the pesticides (specifically fungicides). These offset. In the modern era, CA probably is now using just one plastic sheet for the dual purpose of retaining soil fumigant and mulch; however, it is likely fertilizer and energy use are closer together today than in these estimates which have California using far less fertilizer than Florida despite twice the yield and a longer crop cycle, and also less water, notwithstanding the longer cropping period. We will take these factors to be offsetting, assume improvements in yield are matched by increases in inputs, and use the energy estimates as they stand.

Table 3-10. Estimate of Energy Use and CO_2 Emissions in Strawberry Production, Small NY Farm, from Pimentel, 1980

Item	Unit	need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	1369				
machinery	kg	40	75	3,014	1,156	9
gasoline	l	112	42	4,740	1,818	14
diesel	l					
electricity	kWh	355	12	4,252	1,631	13
All fuels and Electricity				**8,993**	**3,449**	**27**
nitrogen	kg	190	62	11,694	4,485	36
phosporus	kg	45	13	565	217	2
potassium	kg	45	7	301	116	1
lime	kg					
All soil amendments				**12,560**	**4,818**	**38**
seedlings	no.	13454	0.33	4,450	1,707	14
seed coating						
irrigation water	ha.cm	16	See footnote			
pvc pipe						
pe trickler						
insecticides	kg	9	257	2,316	888	7
fungicides	kg	9	116	1,046	401	3
herbicides	kg					
soil fumigant	kg					
All Pesticides				**3,363**	**1,290**	**10**
transportation	kg	512	1	551	211	2
covercrop seed	kg					
plastic mulch	kg					
Total Energy Use/ha or acre				**32,931**	**12,631**	**100**

Energy Use per Unit of Product at Farmgate

Yield	kg/ha	15,163	15,163
	lb/acre	13,528	13,528
Energy use units		MJ	kBtu
Energy use/ kg product		**2.2**	**2.1**
Energy use/ lb product		**1.0**	**0.9**

Energy Use and Emissions by Fuel Type

	CO2 E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	5,291	370	330
Electricity	100	4,252	425	379
Embodied (all other)	60	23,387	1,403	1252
Total		**32,931**	**2,199**	**1,962**
Emissions as proportion of product weight			**0.15**	
Liquid fuel proportion of total energy		**0.16**		
Liquid fuel per unit of product - MJ/kg		**0.35**		

Irrigation at the level of 1/4 that in California is added to Pimentel Handbook figures for small farm production for NY production

THE FRESH TOMATO CROP: PROFILE AND ENERGY USE

Sources of Information on Fresh Tomato Production Practices

Fresh Tomato Production. Tomato production practices in Florida are described in "Florida crop/pest management profiles: tomato", U of Florida Extension, 2004 &2007, (http://edis.ifas.ufl.edu/PI039). Florida harvest and processing techniques are described in detail in, with pictures in: "Handling Florida vegetables series: Round and Roma tomato types" S. Sargent et al, 2005, (http://edis.ifas.ufl.edu/VH079), both accessed 03-2008.

One third of US fresh market tomatoes were grown in California at the time the USDA crop profile was prepared in 2000, "Crop Profile for Tomatoes (fresh market) in California" (http://pestdata.ncsu.edu/cropprofiles/docs/catomatoes-freshmarket.html)

An extensive account or the various methods of producing fresh market tomatoes in California is given in the UC Division of Agriculture and Natural Resources publication 8017, entitled "Fresh market tomato production in California" le Strange et al, 2000 (http://anrcatalog.ucdavis.edu/pdf/8017.pdf).

The same authors have produced an accompanying document, "Sample costs to produce fresh market tomatoes"2007, listing operations and materials needed for production in detail. (http://www.agecon.ucdavis.edu/outreach/crop/cost-studies/2000FreshToms.pdf). All accessed 03-2008.

An overview of production options and relative merits of production practices is provided by M. Peet of NCSU, "Tomato: Production practices" (http://www.cals.ncsu.edu/sustainable/peet/profiles/pp_toma.html). Accessed 03-2008.

In 2001, the 3rd largest US tomato grower was Virginia; "Crop profile for tomatoes in Virginia", 2001, is available at (http://cipm.ncsu.edu/cropprofiles/docs/VAtomato.html). Accessed 03-2008.

Greenhouse Production. The best overview of the greenhouse tomato industry as it involves the three NAFTA members, Canada, the US and Mexico, is by Roberta Cook and Linda Calvin, 2005. The title of this paper is "Greenhouse tomatoes change the dynamics of the north American fresh tomato industry" (http://www.ers.usda.gov/Publications/ERR2/). Accessed 03-2008. It is available as a pdf file.

Greenhouse tomato culture is described in some detail under the title "Greenhouse tomato culture", (http://aggie-horticulture.tamu.edu/greenhouse/hydroponics/tomato.html), Texas Agricultural Extension Service, accessed 03-2008.

Village Farms in 2002 presented a paper "US greenhouse/hothouse hydroponic tomato time line", P. Selina and M.Bledsoe, including a useful overview of the industry at that time as well as tabulation of operations. (http://cipm.ncsu.edu/cropTimelines/pdf/USgreenhousetomato.PDF), accessed 03-2008.

For Florida, G.J. Hochmuth "Production of greenhouse tomatoes – Florida greenhouse vegetable production handbook, Vol 3", revised 2001, (http://edis.ifas.ufl.edu/CV266) is available.

Fresh Tomato Production Overview

Tomato is a complicated crop from the viewpoint of data analysis because, in addition to the division between fresh and processing categories, fresh tomatoes are divided between field grown and greenhouse tomatoes, and specialty tomatoes such as cherry, grape, and plum types. In the last ten years there has been a dramatic increase in greenhouse tomatoes in the marketplace but, unfortunately, as the government does not release information about how much is grown by location within the country, only overall US figures are available for the greenhouse tomato industry and their accuracy is an open issue. Even more recently, grape tomatoes have become important.

Over the past 15 years, per capita use of fresh tomato has increased from 15 lbs/capita in 1992 to 20 lbs/capita at present (See Table 3-11). Total US production has not changed a great deal over this period despite the increase in population and in per capita use. The increase in demand has been met by a large increase in imports, mostly from Mexico. The increase in fresh tomato use has primarily been through expansion of use in greenhouse, cherry and grape tomatoes types, while use of field-grown slicing tomatoes has stayed more or less the same.

Tomatoes are grown in significant quantities as a summer crop in many states, as shown in Table 3-12. However, Florida and California account for 72% of all US fresh tomato production. (Note: California completely dominates in processing tomato production.) In estimating energy use in fresh tomato production, we will concentrate on production methods in these two states, and focus on field-grown slicing tomatoes in particular.

Florida Tomato Production. Florida tomato production dominates US supplies for 8 months of the year, including all the winter months, from November through June (Figure 3-3 below). Early production is primarily in the southern part to the state, with production later on in the Florida panhandle for the early summer. (19% of production takes place in the panhandle, 29% in the Tampa Bay area, and the remaining 52% farther south.)

Table 3-11. Historic US Fresh and Processing Tomato Production, Imports, Exports and Utilization

Year	Fresh Tomato					Processing Tomato						
	Production	Imports	Exports	US Utilized	Per cap. use	Production	Imports	Beginning Stocks	Exports	Ending Stocks	US Utilized	Per cap. use
			1000 cwt					1000 cwt, fresh weight basis				
1992	39,033	4,322	3,675	39,680	15.5	175,549	4,500	154,891	15,715	130,882	188,343	73.3
1993	36,663	9,224	3,458	42,429	16.3	193,533	5,557	130,882	17,005	115,758	197,209	75.8
1994	37,387	8,730	3,407	42,709	16.2	230,794	8,585	115,758	18,565	135,622	200,950	76.3
1995	34,098	13,689	2,892	44,895	16.8	225,700	7,036	135,622	20,159	149,447	198,752	74.6
1996	33,634	16,251	2,954	46,931	17.4	228,146	4,828	149,447	22,029	163,384	197,008	73.1
1997	34,248	16,368	3,417	47,199	17.3	199,465	7,060	163,384	26,715	145,136	198,058	72.6
1998	35,256	18,680	2,863	51,073	18.5	188,040	9,311	145,136	24,762	113,318	204,407	74.0
1999	40,269	16,331	3,343	53,256	19.1	256,720	13,396	113,318	22,028	162,616	198,790	71.2
2000	41,620	16,094	4,104	53,610	19.0	217,165	5,914	162,616	22,313	165,319	198,063	70.1
2001	40,611	18,156	3,979	54,788	19.2	184,974	11,069	165,319	24,104	150,297	186,961	65.5
2002	42,893	18,949	3,323	58,518	20.3	233,416	15,167	150,297	24,583	174,536	199,761	69.3
2003	39,098	20,711	3,142	56,667	19.5	196,394	11,528	174,536	29,356	150,031	203,071	69.7
2004	41,814	20,542	3,693	58,663	20.0	245,328	12,827	150,031	29,898	171,144	207,144	70.4
2005	42,204	20,981	3,265	59,920	20.2	203,862	13,076	171,144	29,710	140,062	218,310	73.5
2006	40,981	21,877	3,179	59,679	19.9	212,236	16,978	140,062	30,422	145,854	193,000	64.4

Notes for fresh tomato

Source: National Agricultural Statistics Service (NASS), USDA Economic Research Service (ERS), USDA

Includes ERS estimates of domestically-grown hothouse tomatoes after 1996. Imports include hothouse tomatoes.

Notes for Processing Tomato

Source: National Agricultural Statistics Service, USDA, and Bureau of the Census, U.S. Dept. of Commerce.

All product weight were converted to a fresh-weight basis using--Whole=1.553; Paste=5.432; Sauce=3.247; Juice=1.527; Catsup=2.457.

Stocks estimated based on a weighted average Jan. 1 stocks to pack. Source: California League of Food Processors.

Table 3-12. Historic Fresh and Processing Tomato Production by Major State Producers

These fresh tomato production data exclude Cherry, Grape and Greenhouse tomato production.

Year	2000	2001	2002	2003	2004	2005	2006	2004-2005	
Fresh Tomato.								Average	Percent
State				1000 cwt				1000 cwt	
FL	15,760	14,908	13,975	14,190	15,120	15,540	13,475	15,330	40.2
CA	11,600	10,260	12,600	10,200	13,020	11,200	11,480	12,110	31.7
VA	1,287	1,443	2,120	1,824	2,090	2,072	2,233	2,081	5.5
OH	1,125	1,947	2,479	1,155	1,106	2,145	1,980	1,626	4.3
GA	1,365	949	1,650	1,530	986	2,142	2,160	1,564	4.1
TN	1,131	495	1,462	1,610	900	936	1,190	918	2.4
SC	884	1,088	837	1,023	1,050	390	480	720	1.9
NC	696	832	891	896	620	800	918	710	1.9
NJ	720	714	759	682	690	600	522	645	1.7
PA	840	537	731	441	555	513	630	534	1.4
MI	408	378	420	484	546	440	460	493	1.3
NY	540	480	378	322	360	360	400	360	0.9
?AL	242	212	351	330	342	341	335	342	0.9
AR	150	299	336	384	137	414	306	276	0.7
IN	248	281	248	248	272	225	165	249	0.7
MD	247	266	111	90	156			156	0.4
TX	182	180	240	169	116	150	110	133	0.3
Other states	240	258							
US-Total of above	**37,665**	**35,527**	**39,588**	**35,578**	**38,066**	**38,268**	**36,844**	**38,167**	**100.0**
Processing Tomato				1000 cwt					
CA	205,730	172,803	221,120	185,040	233,440	192,000	202,080	212,720	94.7
IN	4,580	5,022	5,129	4,046	5,496	5,329	4,510	5,413	2.4
MI	1,680	2,108	2,520	2,508	2,170	2,250	2,310	2,210	1.0
OH	3,174	3,292	2,993	3,466	3,546	3,506	3,336	3,526	1.6
PA	851	0	0	0	0	0	0	0	0.0
Other states	1,149	1,749	1,655	1,335	676	777	n/a	726	0.3
US-Total of above	**217.165**	**184.974**	**233.416**	**196.394**	**245.328**	**203.862**	**212.236**	**224.595**	**100.0**

Source: NASS Annual Statisical Yearbooks

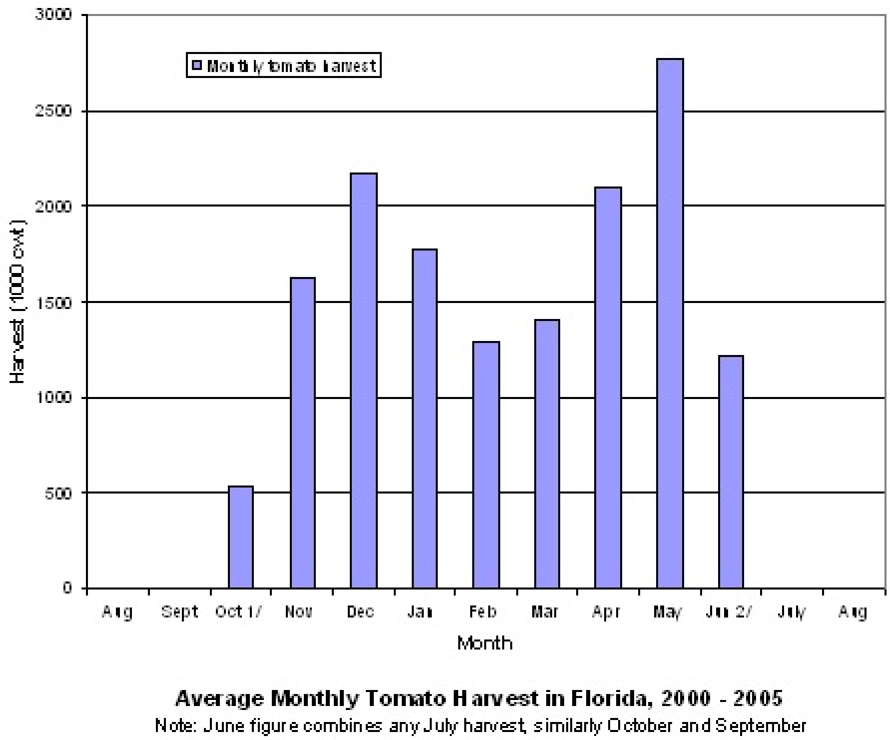

Figure 3-3. Monthly Tomato Harvest, Florida, 2000 to 2005

In Florida, a given planting of tomatoes is usually harvested for a period of only 4 to 6 weeks before plants are terminated. The market is served for 8 or 9 months by successive plantings, not by maintenance of the same plants as is typically the case in greenhouse production.

With regard to timing, for a first harvest (in October) transplants need to be set 2.5 to 3 months earlier, in late July. After general tillage operations, raised beds are formed (listed), mulched with plastic, and fumigated at least two weeks in advance of transplant. Beds typically are 5 to 6 feet on center, and plants are set 18 inches to 30 inches apart in the row giving a plant density as high as 4840 plants per acre. After transplanting is complete, 4ft stakes are placed midway between plants (every other pair), plants are pruned to one or two stems, and twine is strung around stakes and plants down the row. Additional twine is strung every two weeks through the life of the plant giving several horizontal tiers about a foot apart. Some cultivars may be topped. Tomatoes are picked when sufficiently mature to ripen off the vine. First harvest is generally 10 to 11 weeks after transplant. When harvest is complete, herbicide is used to kill plants and dismantling operations follow, including sterilizing stakes for re-use. Because they are under mulch, tomato plants need to be irrigated the entire time they are in the field, which is approximately 4 months, and this is generally done by buried drip tube.

Much of the technique used in tomato production in Florida is the same as that for strawberry. Raised beds are prepared, covered with plastic (mulched) and fumigated in preparation to receive hardened transplants; irrigation is by drip tube. Herbicides, pesticides and fungicides are all used. Two to three pickings are typical; production is thus very labor intensive, as with strawberry.

Florida tomatoes are typically picked when some tomatoes on the plant have reached breaker stage, when some small sign of pink shows on the tomato, and other tomatoes are judged mature enough to ripen off the plant under the right conditions – the latter are called “green-harvested” (a pre-breaker stage). After picking, tomatoes are washed and graded as to size and maturity (green or breaker) and field heat is removed. Tomatoes are then placed in 25 pound cartons, which are “unitized” on pallets of 80 cartons, thus weighing c. 2000 lbs or 1 ton. The standard pallet dimensions are 40 x 48 inches. 20 pallets constitute a trailer load.

Green harvested tomatoes are brought to breaker stage by application of ethylene in special facilities of the packing houses. Optimum ripening conditions are 68 to 72°F, 85 to 95% relative humidity, and 150 ppm ethylene, and 1 to 3 days are needed (ref). Carbon dioxide accumulation from respiration must be prevented. Once at breaker stage, all tomatoes will ripen more or less quickly depending on storage temperature. They can be held at 55F to delay ripening to suit market conditions, or brought to 68 to 72°F, the optimal ripening temperature for good flavor and color development, to speed ripening.

California Tomato Production. Californian production methods differ substantially from those of Florida for reasons largely dictated by climatic factors. Raised beds and transplants are used in common but, beyond that, little else is in common until after harvest. Even the raised beds are used without plastic mulch or fumigation. Californian production uses two distinctly different methods, staked and un-staked, using different cultivars for each case.

The largest part of California’s fresh tomato crop (75%) comes from the San Joaquin Valley and employs bush-type plants that do not require staking. These crops usually are harvested in one picking. Furrow irrigation is used for two-thirds of the Valley crops, for cheap water is available from the irrigation district with minimal pumping cost, but approximately one-third of Valley production uses sub-surface drip irrigation, which is less demanding of water. High precision land leveling is required for furrow irrigation, for it is critical not to let the surface of the soil become wet once plants have attained size – to avoid weed germination and disease problems. Approximately three acre-feet of water or 3,700 m^3/acre are required per crop (1234 m^3/acre-ft) when using furrow irrigation on bush plants, or two acre-feet i.e., 2,467 m^3/acre when using subsurface drip irrigation. Crops require, typically, three treatments of insecticides, one and one-half to two of fungicides, and fallow herbicide is sometimes used. Plant density is about 5,600 plants/acre or 13,700/ha. Nitrogen requirement for the bush crop is 140 lb/acre or 156 kg/ha. Phosphorus needs may be c. 90 lb/acre, but 120 lb/acre is more typically applied. Average potassium application might be 60 lb/acre because Californian soils are usually rich in potassium.

The southern part of the San Joaquin Valley supplies fresh tomatoes from mid-June to September, slightly earlier than the Northern region that supplies from July through October. Thus, the main period for Californian production for out-of-state sales is 4 to 5 months, June to October, which nicely coincides with the months Florida is out of production. The one-time harvest is by hand, and yields 12 to 24 tons/acre gross weight. The pack-out rate is 60 to 70%, netting 8 to 18 tons per acre. It appears the energy cost refers to a net average yield of approximately 26,000 lbs/acre or a gross yield of 36,000 lbs/acre. Most of the crop is put into 25 lb cartons, but some of the select, more mature, fruit is packed in trays (like vine-ripened pole tomatoes – see below).

Pole-tomato production systems predominate in the coastal and southern growing areas and are responsible for 25% of the annual Californian crop. Irrigation is effected by drip lines buried in the raised beds, and the plants are trellised and picked multiple times, often two to three times per week. Unlike in Florida, tomatoes are typically picked at the pink stage (a stage beyond breaker stage and riper) and sold as "vine-ripened." Harvest may continue for as long as 4 months, cultivars and weather permitting, leading to very high yields. Yields of 2500 to 3000 cartons (30-35 tons) per acre (68-79 t/ha) are average, and yields of 4000 cartons (45-50 tons) per acre (101-113 t/ha) have been achieved. Irrigation for the extended season of staked tomatoes is three acre-ft. Nitrogen requirement is the same in this crop as for bush until the first harvest, and thereafter is c. 10lb/acre or 11 kg/ha for each succeeding week. If harvest is extended to ten weeks, growers might add 100 lb/acre or 110 kg/ha.

The southern growing areas (including the Imperial Valley) extend the season at both ends, harvesting as early as May from January plantings and into December from July plantings, but the acreage is much less than in the San Joaquin Valley, and probably most of the extended-season crop goes for in-state needs. It is commonplace to protect young plants before they are staked with row covers or plastic tunnels if the time of planting is early enough in the season for cold temperatures to be a threat.

Vine-ripened pole-tomato production is packed in two or three layer trays, each layer containing 16, 36, or 56 fruits, depending on size. Two layer packs weigh c. 18 lbs. Otherwise, post harvest practices are much the same in California as in Florida, where mature green tomatoes are concerned, with the crop being packed in 25lb cartons, and stored at 55F to delay ripening if so desired, and treated with ethylene to hasten ripening. Evidently ripening with ethylene can be done before or after storage, to suit logistics.

In California, the green tomato crop is mainly marketed west of the Mississippi, only 25% reaching the East. Vine-ripened tomatoes are more widely distributed through the country.

Virginia Tomato Production. Production in Virginia, the third largest US producer, although minor by comparison to Florida and California, appears to be primarily of vine-ripened staked tomatoes, harvested over as long a period as can be managed, and grown on sub-irrigated mulched beds. Thus it is a hybrid of Californian and Floridian practices.

Mexican Tomato Production. We have found no data on Mexico production methods, yields etc. We know that most imports to the US are ESL (extended shelf life) vine-ripened tomatoes, and we have overall amounts imported by month, year, and type of tomato. For our purposes we will assume production is like that of California pole tomato. The position of imports is discussed in Roberta Cook's overview of greenhouse trends in the Americas.

Energy Use in Tomato Production

As was shown in Chapter 2, most tomatoes shipped into New York come from four sources; Florida, California, Mexico, and Canada; these sources cover roughly 85% of outside supply to New York. In addition, several mid-Atlantic and mid-country states produce well in excess of what is needed for home consumption during summer months, and are candidates to ship into New York during that time, namely, Virginia, Ohio, Georgia, Tennessee, the Carolinas, and New Jersey. The Netherlands, Israel, and Spain also historically have shipped small quantities to the US.

Pimentel's handbook of energy use in agriculture does not include estimates for tomato. In the literature we have found estimates for energy use in tomato production for the California Central Valley field crop (without stakes) (Stanhill, 1980), for trellised tomato production in Israel (Stanhill, 1980), and for stake-tomato production in Turkey (Esegun et al, 2006). We also have energy analyses for strawberry production in both California and Florida, which in some respects has the same energy requirements and employ the same techniques as are used in tomato production, and thus may be used to check the reasonableness of the tomato estimates. We will estimate energy use in greenhouse production of tomatoes in the next chapter.

Following the procedure we used for apple production, we will determine basic energy use/acre for tomato production, and then make adjustments for the different production areas. We have yield statistics for the various producing states, and will calculate energy use per pound from energy use per acre and yield per acre in each producing region.

Table 3-13 presents our best estimate for field production of bush tomato in the San Joaquin valley, accounting for the main items on which energy is expended. Labor is lower than in other production systems because it is primarily required for planting seedlings and during the single, final harvest, there being no staking or tying up, or multiple harvests. This estimate deviates from that of Stanhill (1980) in a number of ways. Fertilizer quantities were overly generous, and the unit values were suspect. Elsewhere we have been using 12.6 MJ/kg for phosphate and 6.7 MJ/kg for potash (from the Pimentel Handbook) rather than 2MJ/kg used by Stanhill. In Stanhill the quantity of irrigation water required was less than is typically used currently (6,835 m^3/ha amounts to 2.25 ft/acre, or 75% of the current estimate for water usage in furrow irrigation, which is 3 ft/acre. See above.). Granted, water quantity was under-estimated by a small amount. Additionally, energy allocated to handling water was relatively low at 1.12 MJ/m^3 or 1.06 kBTU/m^3. In furrow irrigation, energy is minimal for distributing water if the water supplied by the irrigation district is at the same height/elevation as the fields, which appears to be the assumed situation, but what of energy spent by the irrigation district to bring water to the farm? In our estimate we have included an allowance for producing: the water. For the Washington apple growing area, we assigned a figure of 5.5 kBtu/m^3 to pump water to supply orchard irrigation needs, this being the energy needed to raise water 100 m vertically using diesel-operated pumps. We assumed the orchards were located well above the river source. The above estimate of 1.06 kBtu/m^3 may be realistic for on-farm energy use handling water, but it is not so for obtaining water from deep aquifers or low lakes, or lifting it over obstacles to get it to the farm.

The problem of energy spent in getting water to the farm (not under pressure) keeps recurring. In comparisons of crops fed by rainfall alone versus irrigated crops, it is a large difference and cannot be ignored. On the other hand, every farm situation is different and the true energy cost of getting water to farms located in diverse growing areas, such as are found in California, is problematic to determine. Where it seems appropriate, we will apply a set energy requirement of 2.75 kBtu/m^3 to supply water to farm elevation, this being the energy needed to lift water 50 m using a diesel operated pump. (From Batty, in Pimentel’s Handbook) In our estimate for San Joaquin irrigation energy, we added this figure to the figure already included for distribution of water on the farm in un-staked field production of tomato.

The other questionable item in Stanhill’s estimate was the yield, which was 44,600 lbs/acre, which is optimistic. As discussed above, the best gross yield might be as high as 48,000 lbs/acre but on average it is 36,000 lb/acre. Average net useable yield is more like 26,000 lbs /acre, which is what we are interested in, and the figure we used in calculating energy use per lb of production of this type of tomato. Our energy estimate for California San Joaquin Valley bush plant production of fresh tomatoes is shown in Table 3-13, revised from Stanhill (1980) as discussed. Apart from differences because of the yield being lowered, the main difference is that irrigation water now is responsible for 35% of total energy use/area instead of 11%. Additionally, values for enthalpy and production energy of fuels are corrected and brought up to date.

Table 3-13. Energy Use in Field Production of Table Tomato in San Joaquin Valley, CA Using Furrow Irrigation

Item	Unit	Bush Tomato San Joaquin Valley (Revised from Stanhill, 1980). need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	1070	0.70			
machinery	kg/hr			4,050	1,553	4
gasoline	l	400	42.3	16,929	6,494	17
diesel	l	305	47.8	14,575	5,591	15
electricity	kWh					
All fuels and Electricity		705		**31,505**	**12,084**	**32**
nitrogen	kg	156	64	9,984	3,830	10
phosporus	kg	135	12.6	1,689	648	2
potassium	kg	67	6.7	451	173	0
lime	kg					
All soil amendments				**12,124**	**4,650**	**12**
seedlings	No.	13,700	0.58	7,890	3,026	8
irrigation water on farm	m3	8381	1.12	9,387	3,600	10
irrigation water to farm	m3	8381	2.75	23,048	8,840	23
pvc pipe						
pe trickler						
insecticides	kg	42	100	4,200	1,611	4
fungicides	kg	60	100	6,000	2,301	6
herbicides	kg					
soil fumigant	kg					
All Pesticides				**10,200**	**3,912**	**10**
plastic mulch	kg					
Total Energy Use/ha				**98,203**	**37,667**	**100**
Energy Use per Unit of Product at Farmgate						
Yield	kg/ha			29,142	29,142	
	lb/acre			26,000	26,000	
Energy use units				MJ	kBtu	
Energy use/ kg product				**3.37**	**3.19**	
Energy use/ lb product				**1.53**	**1.45**	

Energy Use and Emissions by Fuel Type

	CO2 E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	31,505	2,205	1968
Electricity	100	32,434	3,243	2894
Embodied (all other)	60	34,264	2,056	1834
Total		**98,203**	**7,505**	**6695**

Emissions as proportion of product weight		**0.26**
Liquid fuel proportion of total energy	**0.32**	
Liquid fuel per unit of product - MJ/kg	**1.08**	

1 ft of water over the land = 1233.48 m3/acre or 3048.0 m3/ha

Note. Allocation of energy for water production may not be comparable to treatment for other crops

Californian pole-tomato production differs from bush production in that plants are harvested for many weeks, and they are trellised. This means considerably more labor is required and, also, yield is considerably increased. Because the crop cycle is longer, there is a higher water requirement (offset by irrigation being by subterranean drip) and nitrogen requirement. Additional materials are needed to set up the trellis – stakes, an apical wire, and string – and for the drip irrigation system.

Net average yield of California pole tomato was estimated at 65,000 lbs/acre net, or 73,500 kg/ha above, recognizing it could be over 100, 000 kg/ha on occasion. (Yields of 2500 to 3000 cartons (30-35 tons) per acre (68-79 t/ha) are average, and yields of 4000 cartons (45-50 tons) per acre (101-113 t/ha) have been achieved.)

To approximate energy use in California pole tomato production we modified Table 3-13 to reflect these differences, after considering the staking tomato estimates by Stanhill (1980) for Israel, and Esegun et al (2007) for Turkey. The results for Californian pole/staking tomato are presented in Table 3-14.

Florida Stake Tomato Crop

Florida stake tomato production is different from California pole tomato production in that the raised beds are fumigated and covered in plastic mulch. Furthermore, only two harvests are usually made, although sometimes three, so that yield is lower than for pole tomato production. However, it is significantly higher than bush production in California where only one terminal harvest is made. The Florida crop is grown during the dry season and, thus, one can expect as much water to be needed as in California, but it is more humid in Florida, which favors disease and requires more use of fungicides. Our estimate for Florida staking tomato production is found in Table 3-15. We will treat Florida energy needs as prototypical of New York and other humid eastern US production areas.

Table 3-14. Energy Use in Production of Pole Tomato in Coastal and South CA and Similar Mexican Locations

Item	Unit	Pole Tomato Coast and South CA need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	6,250	1			
machinery	hr	108	63	6,797	2,607	3
gasoline	l					
diesel	l	724	48	34,588	13,267	15
natural gas/propane	m3					
All fuels and Electricity				**34,588**	**13,267**	**15**
trellis posts	kg	4,000	18	72,000	27,617	31
trellis wire	kg	1,000	24	24,000	9,206	10
string						
nitrogen	kg	290	62	17,830	6,839	8
phosporus	kg	296	13	3,713	1,424	2
potassium	kg	108	7	722	277	0
lime	kg					
All soil amendments				**22.264**	**8.540**	**10**
seeds/seedlings	kg	13,700	1	7,890	3,026	3
seed coating	kg					
irrigation water on fa	m3	9,144	1	10,241	3,928	4
irrigation water to far	m3	9,144	3	25,146	9,645	11
pvc pipe	kg					
pe trickler	kg	415	122	10,126	3,884	4
tanks	kg			7,200	2,762	3
insecticides	kg	42	100	4,200	1,611	2
fungicides	kg	60	100	6,000	2,301	3
herbicides	kg					
soil fumigant	kg					
All Pesticides				**10.200**	**3.912**	**4**
plastic mulch	kg					
Total Energy Use/ha				**230,453**	**88,394**	**100**
Energy Use per Unit of Product at Farmgate						
Yield	kg/ha			73.500	73.500	
	lb/acre			65,577	65,577	
Energy use units				MJ	kBtu	
Energy use/ kg product				**3.14**	**2.97**	
Energy use/ lb product				**1.42**	**1.35**	

Energy Use and Emissions by Fuel Type

	CO2 E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	34,588	2,421	2160
Electricity	100	35.387	3.539	3157
Embodied (all other)	60	160,477	9,629	8590
Total		**230,453**	**15,589**	**13908**
Emissions as proportion of product weight			**0.212**	
Liquid fuel proportion of total energy		**0.15**		
Liquid fuel per unit of product - MJ/kg		**0.47**		

Note: assumes annual post replacement

Table 3-15. Energy Use in Staked Tomato Production in Florida and Similar Eastern and Central Producing Areas of the US

Item	Unit	Staking Tomato Florida need/ha	MJ/unit	MJ/ha	kBTU/acre	Percent of total
Itemized Energy Use on Area Basis						
labor	hr	6,250	0.7			
machinery	hr	108	62.7	6,797	2,607	2
gasoline	l					
diesel	l	724	47.8	34,588	13,267	12
electricity	m3					
All fuels and Electricity				**34,588**	**13,267**	**12**
trellis posts	kg	4,000	18.0	72,000	27,617	26
trellis wire	kg	1,000	24.0	24,000	9,206	9
string						
nitrogen	kg	200	61.5	12,309	4,721	4
phosporus	kg	150	12.6	1,884	723	1
potassium	kg	100	6.7	670	257	0
lime	kg					
All soil amendments				**14,863**	**5,701**	**5**
seeds/seedlings	kg	11960	0.6	6,888	2,642	2
seed coating	kg					
irrigation water on fa	m3	7620	1.1	8,534	3,273	3
irrigation water to far	m3	7620	2.8	20,955	8,038	8
pvc pipe	kg					
pe trickler	kg	415	122.0	10,126	3,884	4
tanks	kg			7,200		0
insecticides	kg	42.0	257.4	10,809	4,146	4
fungicides	kg	160.0	116.3	18,602	7,135	7
herbicides	kg	4.0	262.8	1,051	403	0
soil fumigant	kg	224.0	98.7	22,107	8,480	8
All Pesticides				**52,570**	**20,164**	**19**
plastic mulch	kg	215.0	125.6	27,004	10,358	10
Total Energy Use/ha				**285,526**	**106,756**	**100**

Energy Use per Unit of Product at Farmgate

Yield	kg/ha	40,351	40,351
	lb/acre	36,000	36,000
Energy use units		MJ	kBtu
Energy use/ kg product		**7.08**	**6.54**
Energy use/ lb product		**3.21**	**2.97**

Energy Use and Emissions by Fuel Type

	CO2E. rate kg/GJ	Energy Use MJ/ha	Emissions kg CO2/ha	Emissions lb CO2/acre
Liquid fuel	70	34,588	2,421	2160
Electricity	100	29,489	2,949	2631
Embodied (all other)	60	221,448	13,287	11854
Total		**285,526**	**18,657**	**16645**
Emissions as proportion of product weight			**0.46**	
Liquid fuel proportion of total energy		**0.12**		
Liquid fuel per unit of product - MJ/kg		**0.86**		

Note: assumes annual post replacement

THE FRESH APPLE CROP: PROFILE AND ENERGY USE

Fresh Apple: Information Sources

A good description of apple production in Washington, far and away the leading producer of apples in the US, is found on-line under the title "Crop Profile for Apples in Washington", 2001. (http://www.tricity.wsu.edu/~cdaniels/profiles/apple.pdf), accessed, 03-2008.

A synopsis of crop practices in New York state equivalent to the Washington crop profile does not exist to our knowledge. Trends in apple cultural practice in New York are described in the article "Evolution towards more competitive apple orchard systems in New York" (Terence Robinson et. Al, New York Fruit Quarterly, Spring 2007). Other articles on the issue a of tree density are to be found in the New York Fruit Quarterly; particularly see Spring 2003 issue on density and training systems and Spring 2005 on high density planting. (http://www.nyshs.org/fq/07spring/07SpringFQ.pdf). Accessed 03-2008

An excellent profile for Michigan apples under"Crop profile for Apple in Michigan", 2004 by Michigan State University, (http://www.ipmcenters.org/cropprofiles/docs/MIapples.pdf). Accessed 03-2008.

Funt's introduction to energy use tables in apple production in Handbook of Energy Utilization in Agriculture (Pimentel, 1980) is a useful overview of the industry, with particular application to PA.

Fresh Apple Production Overview

Apple, like corn and potato, is a crop grown in almost every state. However, most apple varieties need a winter chilling period, which limits production in some southern states. A short growing season limits yields in some northern states.

The state of Washington dominates apple production in the US to a high degree, followed by New York and Michigan as distant second and third producers, after which there are several smaller producers such as Pennsylvania, Virginia, California, Oregon and North Carolina contributing less than 5% of production (see Table 3-16). Collectively, the states named above account for 90% of US domestic production.

Apples store well, and approximately half of the fresh crop is put into controlled atmosphere storage and distributed over the rest of the year. Overall, 64% of production is used as fresh apples, and the remainder is processed, as shown in Table 3-17. Washington and Oregon produce fresh apples primarily (70%). In contrast, 70% of Michigan's production is for processing. New York production is half for fresh and half for processing.

Table 3-16. Apple Production in the US by State - Combined Fresh and Processing

State	2000	2001	2002	2003	2004	2005	2006	2004-2005 Average	Percent
				Year					
				million lbs, utilized production					
WA	6,000	5,050	5,100	4,550	6,150	5,700	5,700	5,925	59.3
NY	995	1,000	630	980	1,280	1,020	1,260	1,150	11.5
MI	800	930	515	890	730	755	890	743	7.4
PA	475	480	369	442	400	495	457	448	4.5
CA	570	520	460	440	355	355	325	355	3.6
VA	320	310	247	262	297	277	265	287	2.9
OR	167	142	187	132	160	135	155	148	1.5
NC	190	112	155	130	132	118	169	125	1.3
OH	103	86	70	88	90	98	101	94	0.9
WV	85	105	92	85	80	83	88	82	0.8
ID	140	80	79	70	80	70	60	75	0.8
WI	71	62	52	58	55	50	60	52	0.5
MO	38	41	36	40	47	47	51	47	0.5
NJ	50	55	32	40	38	44	45	41	0.4
MD	34	41	32	38	33	41	34	37	0.4
IN	45	53	36	48	58	40	49	49	0.5
IL	42	44	35	46	51	39	41	45	0.4
UT	49	30	7	28	31	36	9	34	0.3
VT	42	41	28	38	38	30	31	34	0.3
ME	39	47	44	40	43	29	26	36	0.4
CO	30	23	20	21	27	27	14	27	0.3
MA	50	39	28	37	37	26	28	32	0.3
?AZ	95	5	26	7	37	22	30	30	0.3
NH	34	30	25	25	28	20	28	24	0.2
MN	22	24	18	20	20	16	17	18	0.2
CT	21	21	12	20	19	15	17	17	0.2
GA	14	9	10	13	12	14	12	13	0.13
TN	10	9	6	12	11	8	9	9	0.09
KY	7	8	4	7	7	5	6	6	0.06
SC	20	6	7	5	3	3	2	3	0.03
IA	8	9	5	5	5	2	6	3	0.03
RI	2	2	2	2	2	1	2	2	0.02
AR	7	6	3	2	1	0	0	1	0.01
KS	3	4	2	3	2	0	0	1	0.01
NM	8	6	2	2	3	0	0	1	0.01
US	10,584	9,429	8,374	8,623	10,361	9,618	9,985	9,989	100.0

Note. 2006 values are provisional
Less than 1/3 N C production is in fresh category.

Table 3-17. Apple: Historic Fresh and Total Production by Major Producing States that Contribute More than 1% of US Fresh Apple Production

Year	2000	2001	2002	2003	2004	2005	2004-2005	
Fresh Apple Production			million lbs, utilized production				Average	Percent
WA	4,300	3,700	3,900	3,600	4,600	4,400	4,500	70.4
NY	460	420	310	490	660	490	575	9.0
MI	260	270	150	310	240	265	253	3.9
CA	250	220	230	220	165	160	163	2.5
PA	127	120	74	95	110	127	119	1.9
VA	99	88	70	52	132	81	107	1.7
OR	122	94	115	90	110	95	103	1.6
Other States	639	558	517	585	626	529	578	9.0
US	**6,257**	**5,470**	**5,366**	**5,442**	**6,643**	**6,147**	**6,395**	100.0
							2004-2005	
Total Production: Fresh plus Processing Apples				million lbs, utilized prod.			Average	Percent
WA	6,000	5,050	5,100	4,550	6,150	5,700	5,925	59.3
NY	935	940	630	980	1,280	1,020	1,150	11.5
MI	795	900	515	890	730	755	743	7.4
?CA	590	490	460	440	355	355	355	3.6
PA	475	480	369	442	400	495	448	4.5
VA	314	306	247	262	297	277	287	2.9
OR	162	141	187	132	160	135	148	1.5
Other States	1,131	907	867	927	999	881	940	9.4
US	**10,402**	**9,214**	**8,375**	**8,623**	**10,371**	**9,618**	**9,994**	**100.0**
Fresh Apple as Percent of Total Utilized Production				percent			**2004-2005**	
WA	72	73	76	79	75	77	76	
NY	49	45	49	50	52	48	50	
MI	33	30	29	35	33	35	34	
CA	42	45	50	50	46	45	46	
PA	27	25	20	21	28	26	26	
VA	32	29	28	20	44	29	37	
OR	75	67	61	68	69	70	69	
Other States	56	61	60	63	63	60	61	
US	**60**	**59**	**64**	**63**	**64**	**64**	**64**	

Ninety-nine percent of imports to the US originate in just three countries: Chile, Canada and New Zealand, as shown in Table 3-18. Six years ago, New Zealand was the leading exporter of apples to the US; New Zealand's exports have decreased since while Chile's have increased. If and when the US permits China to export fresh apples here, China will likely become the largest source of fresh apple imports to the US. At present, China already has a very large share in processed apple imports to the US, and is responsible for half the juice consumed in the US.

Table 3-18. Fresh Apple Imports into the US by Origin

Source Country	2000–1	2001-2	Year 2002-3	2003-4	2004-5	2005-6	2004-2005 Average	Percent
			millions of pounds					
Chile	116	136	175	236	135	177	156	50
New Zealand	135	127	101	150	68	88	78	25
Canada	83	86	101	68	67	82	75	24
South Africa	17.9	13.6	4.2	6.6	2.5	0.1	1	0
Mexico	0.00	0.00	0.00	0.04	0.00	0.04	0	0
Other countries	7	4	11	10	4	3	4	1
Total	**361**	**367**	**392**	**471**	**278**	**352**	**315**	**100**

Energy Use in Apple Production

Apple orchards can have a very long life, over 50 years. As a consequence, determining energy use in apple production is somewhat different than for the other commodities. Trees bear very little during the first two years after seedling-tree transplant, and after that production increases year by year and energy use per pound of fruit harvested decreases over time. Furthermore, there has been a rapid evolution in planting systems over the past 40 years, resulting in a concurrent variety of orchards, from traditional, low-density, free standing trees to very high-density, trellised trees, as the literature cited shows. Additionally, apples brought into New York derive from several sources and needs and practices differ geographically. In Washington, irrigation is a necessity because apples are planted in a semi-desert inland from the coastal range. Water is plentiful but must be pumped and distributed. In New York and Michigan, irrigation is typically only used for high-density plantings and little is required. Yet another difference with this crop is that the fruit can be stored using controlled atmosphere (CA) storage with little loss of quality and then distributed for sale all year. The energy used to maintain the storage environment needs to be included if we consider apple energy costs on a year-long basis.

We have based our energy analysis for apples on the PhD dissertation of R.C Funt, in which energy use is determined for Pennsylvania orchards in the first, tenth, and 20th year for low, medium and high density orchards (Pimentel, 1980). We take the life of the orchard to be 30, 35, and 45, years, respectively, for the different orchard densities. We computed total energy use and apple production during the life of each type of orchard and then calculated average energy use per unit weight of apple produced over that life, thereby producing a weighted average production. We will assume farm orchards across all states now comprise equal areas of low medium and high density trees. Thus, average energy use per unit weight of apple produced is the average of energy use in each of the three types of orchard, over the lives of the orchards.

We consider nine different possible outside sources of apples to New York, seven from inside the US (see Table 3-17) and three from outside (Table 3-18). From yield data, we know yield varies considerably by state and year-to-year (Tables 3-19 and 3-20). We assume this is primarily due to climatic factors which make one area more suitable than another for apple growing rather than a matter of cultural technique.

Energy use during the 1st, 10th and 20th year of orchard ages, as developed by Funt for each of three orchard densities, is shown in Tables 3-21, 3-22, and 3-23. In these estimates, irrigation water pumping and distribution equipment is used only for high density orchards, and at its highest level of use is minor. Irrigation accounts for less than one percent of energy use per acre in the high density planting.

Overall energy use, CO_2 emissions and fuel sources used for the different types of orchard calculated over the whole life of the orchards is shown in Table 3-24. Results for the three orchard types are combined in Table 3-25. Averaged across orchard types, total energy use was 49,303 kBtu/acre /annum, which for the yields assumed gives a figure of 1.08 kBtu/lb or 2.51MJ/kg of apples at the farm gate.

The yield figures suggested by Funt for idealized Pennsylvania orchard systems are attainable, although they exceed average Washington State yield figures, which are the highest in the country. We will assume the energy use per unit area per growing season exclusive of energy required for irrigation developed by Funt is reasonable, and is the same for all nine potential suppliers of apples to New York, regardless of yield. Traditionally, some areas manage with little or no irrigation while others are entirely dependent on it. It is beyond the scope of this report to determine the height to which water must be pumped in each farm situation throughout orchard districts in different parts of the country and world. The estimates used are based on existing practice so far as we know it, and naturally occurring rainfall (or lack of it) during the time orchards are actively growing, and an estimated length of the growing season. We assume in all cases water must be pumped from a depth of 100m using diesel motor pumps. (It is not uncommon for orchards to locate on elevated land where Spring frost is avoided.) We have assumed all areas now use some irrigation, with the introduction of high density orchards. We have estimated how much irrigation is used in each of the supply areas, and energy expended and CO_2 emissions associated in Table 3-26.

Table 3-19. Apple Yield in Washington and NewYork Historically

Year	Washington State Bearing acreage	Washington State Production Utilized	Washington State Yield	New York State Bearing acreage	New York State Production Utilized	New York State Yield
	acres	million lbs	lbs/acre	acres	million lbs	lbs/acre
1977	78,800	2,083	26,400	60,000	900	15,000
1978	81,000	2,148	26,500	63,000	1,080	17,143
1979	83,000	2,619	31,600	62,000	1,035	16,694
1980	86,000	3,005	34,900	64,400	1,100	17,081
1981	90,000	2,760	30,700	64,000	800	12,500
1982	95,000	2,615	27,500	63,500	1,130	17,795
1983	102,000	3,055	30,000	63,000	1,100	17,460
1984	105,000	2,950	28,100	62,800	1,020	16,242
1985	112,000	2,050	18,300	63,800	1,090	17,085
1986	126,000	3,160	25,100	63,000	900	14,286
1987	135,000	4,800	37,000	62,000	880	14,194
1988	128,000	3,900	30,500	61,000	910	14,918
1989	130,000	5,000	38,500	58,000	960	16,552
1990	136,000	4,800	35,300	56,000	990	17,679
1991	139,000	4,300	30,900	55,000	1,050	19,091
1992	142,000	4,650	32,700	56,000	1,170	20,893
1993	147,000	5,000	34,000	56,000	870	15,536
1994	152,000	5,750	38,500	57,000	1,100	19,298
1995	158,000	4,750	30,700	57,500	1,110	19,304
1996	164,000	5,500	33,500	57,500	1,030	17,913
1997	170,000	5,000	29,400	55,000	1,120	20,364
1998	172,000	6,100	38,400	55,000	1,070	19,455
1999	172,000	5,000	29,100	55,000	1,260	22,909
2000	168,000	6,000	35,700	40,000	995	24,875
2001	160,000	5,050	31,600	45,000	1,000	22,222
2002	155,000	5,100	32,900	45,000	680	15,111
2003	155,000	4,550	29,400	45,000	1,070	23,778
2004	156,000	6,150	39,400	45,000	1,280	28,444
2005	157,000	5,700	36,300	45,000	1,040	23,111
2006	158,000	5,650	35,800	45,000	1,250	27,778
Av. 2004-2005			**37,850**			**25,778**
Av 2000-2005			**34,217**			**22,924**

Table 3-20. Historical Apple Yield in Major Producing States

Year	WA Yield	NY Yield	MI Yield	PA Yield	CA Yield
			lbs/acre		
2000	35,700	24,875	16,500	20,700	17,300
2001	31,600	22,222	20,900	20,900	17,300
2002	32,900	15,111	12,000	16,800	16,800
2003	29,400	23,778	21,400	20,100	16,080
2004	39,400	28,444	18,000	18,300	13,660
2005	36,300	23,111	19,000	22,900	14,200
2006	35,800	27,778	21,800	22,400	15,440
Av. 2004-2005	37,850	25,778	18,500	20,600	13,930
Av 2000-2005	34,217	22,924	17,967	19,950	15,890

Note. Some 2006 figures are provisional still

Table 3-21. Energy Use in Apple Production: Pennsylvania Low-density Orchard, 165 Trees per ha; Not Irrigated, Mechanical Harvesting.

Item	Unit	Pennsylvania, 1st year, low density				Pa, 10th year, low density				Pa, 20th year, low density			
		need/ha	MJ/unit	MJ/ha	kBTU/acre	need/ha	MJ/unit	MJ/ha	kBTU/acre	need/ha	MJ/unit	MJ/ha	kBTU/acre
labor	hr	70				91				138			
machinery	kg	88	22.9	2,016	773	151	31.0	4,674	1,793	151	48.0	7,241	2,777
gasoline	l	325	42.3	13,755	5,273	715	42.3	30,242	11,600	1531	43.1	65,977	25,307
diesel	l	202	47.8	9,653	3,700	298	47.8	14,231	5,459	483	47.8	23,066	8,848
electricity	kWh	20	12.0	240	92	20	12.0	240	92	20	12.0	240	92
All fuels and Electricity				**23,648**	**9,065**			**44,713**	**17,151**			**89,283**	**34,247**
trellis posts													
trellis wire													
nitrogen	kg	3	61.5	185	71	30	61.5	1,845	708	45	61.5	2,768	1,062
phosporus	kg	114	23.0	2,625	1,006	114	23.0	2,623	1,006	114	23.0	2,623	1,006
potassium	kg	114	8.5	969	371	114	8.5	968	371	114	8.5	968	371
lime	kg	682	8.8	6,019	2,307	682	8.8	6,015	2,307	682	8.8	6,015	2,307
All soil amendments				**9,798**	**3,756**			**11,452**	**4,393**			**12,374**	**4,747**
irrigation water	cm												
pvc pipe													
pe trickler													
insecticides	kg	4	184.2	737	282	47	257.4	12,088	4,637	47	257.4	12,088	4,637
fungicides	kg	27	92.1	2,487	953	49	116.3	5,693	2,184	49	116.3	5,693	2,184
herbicides	kg	2	238.6	477	183	6	418.3	2,508	962	6	418.3	2,508	962
All pesticides				**3,701**	**1,419**			**20,289**	**7,783**			**20,289**	**7,783**
transportation	kg	1561	1.1	1,680	644	2206	1.1	2,437	935	3222	1.1	3,561	1,366
service buildings				60	23	2206		60	23			60	23
Total Energy Use/ha				**40,876**	**15,679**			**83,624**	**32,076**			**132,808**	**50,942**
Yield	kg/ha			0	0			22,861	22,861			54,743	54,743
	lb/acre			0	0			20,397	20,397			48,842	48,842
Energy use units				MJ	kBTU			MJ	kBTU			MJ	kBTU
Energy use/ kg product				n/a	n/a			**3.66**	**3.47**			**2.43**	**2.30**
Energy use/ lb product				n/a	n/a			**1.66**	**1.57**			**1.10**	**1.04**

Energy Use and Emissions by Fuel Type

	CO2 E-rate kg/GJ	Energy Use MJ/ha	Emiss-ions kg CO2/ha	Emiss-ions lb CO2/acre	CO2 E-rate kg/GJ	Energy Use MJ/ha	Emiss-ions kg CO2/ha	Emiss-ions lb CO2/acre	CO2 E-rate kg/GJ	Energy Use MJ/ha	Emiss-ions kg CO2/ha	Emiss-ions lb CO2/acre
Liquid fuel	70	25.088	1.756	1567	70	46.910	3.284	2930	70	92.605	6.482	5783
Electricity	100	240	24	21	100	240	24	21	100	240	24	21
Embodied (all other)	60	15,548	933	832	60	36,475	2,188	1953	60	39,964	2,398	2139
Total		40,876	**2,713**	**2,420**		83,624	**5,496**	**4,903**		132,808	**8,904**	**7,944**
Emissions % of product weight			n/a				**0.24**				**0.16**	
Liquid fuel % of total energy			**0.61**				**0.56**				**0.70**	
Liquid fuel per unit weight - MJ/kg			n/a				**2.05**				**1.69**	

Note. Conversions: 1 kcal = 0.004187MJ = 0.0039683kBTU. One hectare = 2.471acres. One kg = 2.2046lb One MJ = 0.94782 kBTU

Table 3-22. Energy Use in Apple Production: Pennsylvania Medium-density Orchard, 453 Trees per ha; Not Irrigated, Mechanical Harvesting.

Item	Unit	Pennsylvania, 1st year, medium de				Pa, 10th year, medium density				Pa, 20th year, medium density			
		need/ha	MJ/unit	MJ/ha	kBTU/acre	need/ha	MJ/unit	MJ/ha	kBTU/acre	need/ha	MJ/unit	MJ/ha	kBTU/acre
labor	hr	95				126				144			
machinery	kg	82	22.9	1,882	722	139	45.2	6,288	2,412	139	53.3	7,413	2,843
gasoline	l	325	42.3	13,746	5,273	1303	42.3	55,112	21,140	1887	42.3	79,813	30,614
diesel	l	202	47.8	9,647	3,700	439	47.8	20,965	8,042	563	47.8	26,887	10,313
electricity	kWh	20	12.0	240	92	20	12.0	240	92	20	12.0	240	92
All fuels and Electricity				**23,633**	**9,065**			**76,316**	**29,273**			**106,939**	**41,019**
trellis posts													
trellis wire													
nitrogen	kg	8	61.5	492	189	82	61.5	5,043	1,935	82	61.5	5,043	1,935
phosporus	kg	114	23.0	2,623	1,006	114	23.0	2,623	1,006	114	23.0	2,623	1,006
potassium	kg	114	8.5	968	371	114	8.5	968	371	114	8.5	968	371
lime	kg	682	8.8	6,015	2,307	682	8.8	6,015	2,307	682	8.8	6,015	2,307
All soil amendments				**10,099**	**3,874**			**14,650**	**5,619**			**14,650**	**5,619**
irrigation water	cm												
pvc pipe													
pe trickler													
insecticides	kg	4	184.1	736	282	47	257.2	12,088	4,637	47	257.2	12,088	4,637
fungicides	kg	27	92.0	2,485	953	49	116.2	5,693	2,184	49	116.2	5,693	2,184
herbicides	kg	2	238.5	477	183	6	418.0	2,508	962	6	418.0	2,508	962
All pesticides				**3,699**	**1,419**			**20,289**	**7,783**			**20,289**	**7,783**
transportation	kg	1560	1.1	1,677	643	2975	1.1	3,199	1,227	3683	1.1	3,960	1,519
service buildings				60	23			60	23			60	23
Total Energy Use/ha				**41,049**	**15,745**			**120,802**	**46,337**			**153,311**	**58,807**
Yield	kg/ha			0	0			41.546	41.546			70.961	70.961
	lb/acre			0	0			37,067	37,067			63,311	63,311
Energy use units				MJ	kBTU			MJ	kBTU			MJ	kBTU
Energy use/ kg product				n/a	n/a			2.91	2.76			2.16	2.05
Energy use/ lb product				n/a	n/a			1.32	1.25			0.98	0.93

Energy Use and Emissions by Fuel Type

	CO2 E-rate	Energy Use	Emiss-ions	Emiss-ions	CO2 E-rate	Energy Use	Emiss-ions	Emiss-ions	CO2 E-rate	Energy Use	Emiss-ions	Emiss-ions
	kg/GJ	MJ/ha	kg CO2/ha	lb CO2/acre	kg/GJ	MJ/ha	kg CO2/ha	lb CO2/acre	kg/GJ	MJ/ha	kg CO2/ha	lb CO2/acre
Liquid fuel	70	25.070	1.755	1566	70	79.276	5.549	4951	70	######	7.746	6911
Electricity	100	240	24	21	100	240	24	21	100	240	24	21
Embodied (all other)	60	15,739	944	842	60	41,287	2,477	2210	60	42,412	2,545	2270
Total		41.049	2,723	2,430		#######	8,050	7,182		######	10,315	9,203
Emissions % of product weight			n/a				0.19				0.15	
Liquid fuel % of total energy			0.61				0.66				0.72	
Liquid fuel per unit weight - MJ/kg			n/a				1.91				1.56	

Note. Conversions : 1 kcal = 0.004187MJ = 0.0039683kBTU. One hectare = 2.471acres. One kg = 2.2046lb One MJ = 0.94782 kBTU

Table 3-23. Energy Use in Apple Production: Pennsylvania High-density Orchard, 1512 Trees per ha; Irrigated, Mechanical Harvesting.

Item	Unit	Pennsylvania, irrigated, 1st year, high density				Pa, irrigated 10th year, high density				Pa, irrigated 20th year, high density			
		need/ha	MJ/unit	MJ/ha	kBTU/acre	need/ha	MJ/unit	MJ/ha	kBTU/acre	need/ha	MJ/unit	MJ/ha	kBTU/acre
labor	hr	206				158				158			
machinery, hand	kg	72	29.7	2,137	820								
machinery, mech						118	42.9	5,061	1,941	118	50.2	5,926	2,273
gasoline	l	345	42.3	14,602	5,601	1821	42.3	77,071	29,563	2292	42.3	97,006	37,209
diesel	l	95	47.8	4,540	1,741	127	47.8	6,069	2,328	127	47.8	6,069	2,328
electricity, gen.	kWh	20	12.0	240	92	20	12.0	240	92	20	12.0	240	92
electricity, irrig.	kWh	75	12.0	899	345	130	12.0	1,558	598	130	12.0	1,558	598
electricity total	kWh	**95**	12.0	**1,139**	**437**	**150**	12.0	**1,798**	**690**	**150**	12.0	**1,798**	**690**
All fuels and Electricity				**20,280**	**7,779**			**84,938**	**32,580**			**104,873**	**40,227**
trellis posts		62	8.6	535	205	62	8.6	535	205	62	8.6	535	205
trellis wire		252	71.4	18,000	6,904	252	71.4	18,000	6,904	252	71.4	18,000	6,904
nitrogen	kg	27	61.5	1,662	637	137	61.5	8,432	3,234	137	61.5	8,432	3,234
phosporus	kg	114	23.0	2,625	1,007	114	23.0	2,625	1,007	114	23.0	2,625	1,007
potassium	kg	114	8.5	969	372	114	8.5	969	372	114	8.5	969	372
lime	kg	682	8.8	6,019	2,309	682	8.8	6,019	2,309	682	8.8	6,019	2,309
All soil amendments				**11,275**	**4,325**			**18,045**	**6,922**			**18,045**	**6,922**
irrigation water	cm	See electricity, kWh above for pump use											
pvc pipe		10	0.0	0.3	0.1	10	0.0	0.3	0.1	10	0.0	0.3	0.1
pe trickler		26	0.0	0.7	0.3	26	0.0	0.7	0.3	26	0.0	0.7	0.3
insecticides	kg	4	184.2	737	283	47	257.4	12,096	4,640	47	257.4	12,096	4,640
fungicides	kg	27	92.1	2,487	954	49	116.3	5,697	2,185	49	116.3	5,697	2,185
herbicides	kg	2	238.6	477	183	6	418.3	2,510	963	6	418.3	2,510	963
All pesticides				**3,701**	**1,420**			**20,303**	**7,788**			**20,303**	**7,788**
transportation	kg	1832	1.1	1,971	756	3565	1.1	3,836	1,471	4036	1.1	4,343	1,666
service buildings				60	23			60	23			60	23
Total Energy Use/ha or acre				**57,960**	**22,232**			**150,778**	**57,835**			**172,073**	**66,003**
Yield	kg/ha			0	0			59.124	59.124			79.784	79.784
	lb/acre			0	0			52,750	52,750			71,183	71,183
Energy use units				MJ	kBTU			MJ	kBTU			MJ	kBTU
Energy use/ kg product				n/a	n/a			**2.55**	**2.42**			**2.16**	**2.04**
Energy use/ lb product				n/a	n/a			**1.16**	**1.10**			**0.98**	**0.93**

Energy Use and Emissions by Fuel Type

	CO2 E-rate kg/GJ	Energy Use MJ/ha	Emiss-ions kg CO2/ha	Emiss-ions lb CO2/acre	CO2 E-rate kg/GJ	Energy Use MJ/ha	Emiss-ions kg CO2/ha	Emiss-ions lb CO2/acre	CO2 E-rate kg/GJ	Energy Use MJ/ha	Emiss-ions kg CO2/ha	Emiss-ions lb CO2/acre
Liquid fuel	70	21,113	1,478	1319	70	86,976	6,088	5432	70	107,417	7,519	6708
Electricity	100	1,139	114	102	100	1,798	180	160	100	1,798	180	160
Embodied (all other)	60	35,709	2,143	1912	60	62,004	3,720	3319	60	62,857	3,771	3365
Total		57,960	**3,734**	**3,332**		150,778	**9,988**	**8,911**		172,073	**11,470**	**10,234**
Emissions % of product weight			n/a				**0.17**				**0.14**	
Liquid fuel % of total energy			**0.36**				**0.58**				**0.62**	
Liquid fuel per unit weight - MJ/kg			n/a				**1.47**				**1.35**	

Note. Conversions: 1 kcal = 0.004187MJ = 0.0039683kBTU. One hectare = 2.471054acres. One kg = 2.2046lb One MJ = 0.94782 kBTU 1 in = 2.54

Table 3-24. Energy Use and CO2 Emissions over the Life of Low, Medium, and High Density Apple Orchards in Pennsylvania

	Yield lb/acre	Total Energy kBTU/acr.	Total Energy kBTU/lb	CO2 Emissions lb/acre	CO2 Emissions lb/lb	Yield kg/ha	Liq. Fuel Energy MJ/ha	Electricity Energy MJ/ha	Embod. Energy MJ/ha	Total Energy MJ/ha	Liq. Fuel Energy MJ/kg	Electricity Energy MJ/kg	Embod. Energy MJ/kg
Low density orchards													
Year 1	0	15,679		2,420		0	25,088	240	15,548	40,876			
Year 10	20,397	32,076		4,903		22,861	46,910	240	36,475	83,624			
Av 1-10	10,199	23,878		3,662		11,431	35,999	240	26,011	62,250			
Cumul.Tot 1-10	101,985	238,775	2.34	36,620	0.36	114,305	359,987	2,397	260,115	622,499	3.1	0.02	2.3
Year 20	48,842	50,942		7,944		54,743	92,605	240	39,964	132,808			
Av. 11-20	34,620	41,509		6,424		38,802	69,757	240	38,219	108,216			
Cumul. Tot 11-20	346,195	415,090	1.20	64,237	0.19	388,020	697,571	2,396	382,193	1,082,160	1.8	0.01	1.0
Av. Years 21-45	48,842	50,942		7,944		54,743	92,605	240	39,964	132,808			
Cumul. Tot 21-45	1.221.050	1.273.550	1.04	198.599	0.16	1.368.575	2.315.114	5.989	999.093	3.320.197	1.7	0.00	0.7
Grand Total: Yrs 1-45	1,669,230	1,927,415	1.15	299,456	0.18	1,870,900	3,372,673	10,782	1,641,401	5,024,856	1.8	0.01	0.9
Av. Over 45 yrs	37,094	42,831	1.15	6,655	0.18	41,576	74,948	240	36,476	111,663	1.8	0.01	0.9
Medium density orchards													
Year 1	0	15,745		2,430		0	25,070	240	15,739	41,049			
Year 10	37,067	46,337		7182		41546	79276	240	41287	120802			
Av 1-10	18,534	31,041		4,806		20,773	52,173	240	28,513	80,925			
Cumul.Tot 1-10	185,335	310,410	1.67	48,060	0.26	207,730	521,731	2,396	285,127	809,254	2.5	0.01	1.4
Year 20	63,311	58,807		9203		70961	110660	240	42412	153311			
Av. 11-20	50,189	52,572		8,192		56,254	94,968	240	41,849	137,057			
Cumul. Tot 11-20	501,890	525,720	1.05	81,925	0.16	562,535	949,677	2,396	418,494	1,370,567	1.7	0.00	0.7
Av. Years 21-35	63,311	58,807		9,203		70,961	110,660	240	42,412	153,311			
Cumul. Tot 21-35	949,665	882,105	0.93	138,039	0.15	1,064,415	1,659,895	3,594	636,182	2,299,671	1.6	0.00	0.6
Grand Total: Yrs 1-35	1,636,890	1,718,235	1.05	268,023	0.16	1,834,680	3,131,303	8,385	1,339,804	4,479,492	1.7	0.00	0.7
Av. Over 35 yrs	46,768	49,092	1.05	7,658	0.16	52,419	89,466	240	38,280	127,985	1.7	0.00	0.7
High density orchards													
Year 1	0	22,232		3,332		0	21,113	1,139	35,709	57,960			
Year 10	52,750	57,835		8,911		59,124	86,976	1,798	62,004	150,778			
Av 1-10	26,375	40,034		6,121		29,562	54,044	1,468	48,856	104,369			
Cumul.Tot 1-10	263,750	400,335	1.52	61,215	0.23	295,620	540,444	14,684	488,565	1,043,693	1.8	0.05	1.7
Year 20	71,183	66,003		10,234		79,784	107,417	1,798	62,857	172,073			
Av. 11-20	61,967	61,919		9,572		69,454	97,197	1,798	62,431	161,425			
Cumul. Tot 11-20	619,665	619,190	1.00	95,724	0.15	694,540	971,968	17,980	624,306	1,614,254	1.4	0.03	0.9
Av. Years 21-30	71,183	66,003		10,234		79,784	107,417	1,798	62,857	172,073			
Cumul. Tot 21-30	711,830	660,030	0.93	102,336	0.14	797,840	1,074,175	17,980	628,572	1,720,726	1.3	0.02	0.8
Grand Total: Yrs 1-30	1,595,245	1,679,555	1.05	259,275	0.16	1,788,000	2,586,587	50,643	1,741,443	4,378,673	1.4	0.03	1.0
HD Av. Over 30yrs	53,175	55,985	1.05	8,642	0.16	59,600	86,220	1,688	58,048	145,956	1.4	0.03	1.0

Table 3-25. Energy Use and CO_2 Emissions Over the Life of Low, Medium, and High Density Apple Orchards in Pennsylvania

	Yield lb/acre	Total Energy kBTU/acr.	Total Energy kBTU/lb	CO2 Emi-ssions lb/acre	CO2 Emi-ssions lb/lb	Yield kg/ha	Liq. Fuel Energy MJ/ha	Electricity Energy MJ/ha	Embod. Energy MJ/ha	Total Energy MJ/ha	Liq. Fuel Energy MJ/kg	Electric Energy MJ/kg	Embod. Energy MJ/kg
Low density orchards													
Av 1-10	10,199	23,878		3,662		11,431	35,999	240	26,011	62,250			
Av. 11-20	34,620	41,509		6,424		38,802	69,757	240	38,219	108,216			
Av. Years 21-45	48,842	50,942		7,944		54,743	92,605	240	39,964	132,808			
Weighted Av. Over 45 yrs	**37,094**	**42,831**	**1.15**	**6,655**	**0.18**	**41,576**	**74,948**	**240**	**36,476**	**111,663**	**1.8**	**0.01**	**0.9**
Medium density orchards													
Av 1-10	18,534	31,041		4,806		20,773	52,173	240	28,513	80,925			
Av. 11-20	50,189	52,572		8,192		56,254	94,968	240	41,849	137,057			
Av. Years 21-35	63,311	58,807		9,203		70,961	110,660	240	42,412	153,311			
Weighted Av. Over 35 yrs	**46,768**	**49,092**	**1.05**	**7,658**	**0.16**	**52,419**	**89,466**	**240**	**38,280**	**127,985**	**1.7**	**0.00**	**0.7**
High density orchards													
Av 1-10	26,375	40,034		6,121		29,562	54,044	1,468	48,856	104,369			
Av. 11-20	61,967	61,919		9,572		69,454	97,197	1,798	62,431	161,425			
Av. Years 21-30	71,183	66,003		10,234		79,784	107,417	1,798	62,857	172,073			
Weighted Av. Over 30yrs	**53,175**	**55,985**	**1.05**	**8,642**	**0.16**	**59,600**	**86,220**	**1,688**	**58,048**	**145,956**	**1.4**	**0.03**	**1.0**
Average annual yield, all orchard types, if in equal numbers													
	45,679	**49,303**	**1.08**	**7,652**	**0.17**	**51,198**	**83,545**	**722**	**44,268**	**128,535**	**1.63**	**0.01**	**0.86**

Table 3-26. Estimated Energy Use and Emissions in Irrigation for Apple Production

Production Area	Natural Rainfall est. in./month	Water use est. for Irrigation ft/acre	Water use est. for Irrigation m3	Diesel use for Irrigation liters	Irrigation Pumping Energy kBTU/acre	Irrigation Pumping Energy MJ/ha	Irrigation Emiss-ions kg CO2/ha	Irrigation Emiss-ions lbCO2/acre
Washington	1.0	3.5	4,317	524	23,739	61,890	4,332	3,865
New York	3.0	0.5	617	75	3,391	8,841	619	552
Michigan	3.0	0.5	617	75	3,393	8,845	619	552
Pennsylvania	3.5	0.5	617	75	3,393	8,845	619	552
California	0.5	3	3,700	449	20,347	53,048	3,713	3,313
Virginia	3.5	0.5	617	75	3,393	8,845	619	552
Oregon	1.5	3	3,700	449	20,347	53,048	3,713	3,313
Chile	1.0	3.5	4,317	524	23,739	61,890	4,332	3,865
NewZealand	3.5	0.5	617	75	3,393	8,845	619	552
Canada	3.0	0.5	617	75	3,393	8,845	619	552

Note: fuel used to pump100 m3 water (1 ha.cm) 100 m vertically is taken as 12.14 l diesel fuel (Handbook)
Note: CO2 emissions are calculated at the rate of 70kg CO2 per GJ of liquid petroleum fuel

In Table 3-27, energy used for irrigation is combined with production energy determined in Table 3-25 to give energy use in field production of apples.

Production Energies by Source

The estimated energy used in field production in all of the source areas for produce shipped to New York, as estimated and discussed in this chapter, is summarized in Tables 3-28 and 3-29 for the two leafy green crops and the three fruit crops we have considered. Energy for transportation as developed in Chapter 4, following is included. The implications of these findings are discussed in Chapter 6, the concluding chapter.

Table 3-27. Total Energy Use for Apple Production by Production Area

Production Area	Basic Production Energy	Irrigation Pumping Energy	Total Production Energy	CO_2 Emissions in Production	Irrigation Emissions	Total CO_2 Emissions	Liq. Fuel Energy	Yield Av. For 2000-2005	Energy per Unit Wght Apples	CO_2 Emissions per unit	Liq. Fuel Energy per unit
	kBTU/acre	kBTU/acre	kBTU/acre	lbCO2/acre	lbCO2/acre	lbCO2/acre	BTU/acre	lbs/acre	kBTU/lb	lbCO2/lb	BTU/lb
Washington	49,303	23,739	73,042	7,652	3,865	11,517	55,784	34,217	2.13	0.34	1.63
New York	49,303	3,391	52,694	7,652	552	8,204	35,436	22,924	2.30	0.36	1.55
Michigan	49,303	3,393	52,696	7,652	552	8,204	35,438	17,967	2.93	0.46	1.97
Pennsylvania	49,303	3,393	52,696	7,652	552	8,204	35,438	19,950	2.64	0.41	1.78
California	49,303	20,347	69,650	7,652	3,313	10,965	52,392	15,890	4.38	0.69	3.30
Virginia	49,303	3,393	52,696	7,652	552	8,204	35,438	19,950	2.64	0.41	1.78
Oregon	49,303	20,347	69,650	7,652	3,313	10,965	52,392	34,217	2.04	0.32	1.53
Chile	49,303	23,739	73,042	7,652	3,865	11,517	55,784	34,217	2.13	0.34	1.63
NewZealand	49,303	3,393	52,696	7,652	552	8,204	35,438	34,217	1.54	0.24	1.04
Canada	49,303	3,393	52,696	7,652	552	8,204	35,438	22,924	2.30	0.36	1.55
	MJ/ha	MJ/ha	MJ/ha	kg CO2/ha	kg CO2/ha	kg CO2/ha	MJ/ha	kg/ha	MJ/kg	kgCO2/kg	MJ/kg
Washington	128,539	61,890	190,428	8576	4,332	12,909	145,435	38,352	4.97	0.34	3.79
New York	128,539	8,841	137,380	8576	619	9,195	92,386	25,694	5.35	0.36	3.60
Michigan	128,539	8,845	137,384	8576	619	9,196	92,390	20,138	6.82	0.46	4.59
Pennsylvania	128,539	8,845	137,384	8576	619	9,196	92,390	22,361	6.14	0.41	4.13
California	128,539	53,048	181,587	8576	3,713	12,290	136,593	17,811	10.20	0.69	7.67
Virginia	128,539	8,845	137,384	8576	619	9,196	92,390	22,361	6.14	0.41	4.13
Oregon	128,539	53,048	181,587	8576	3,713	12,290	136,593	38,352	4.73	0.32	3.56
Chile	128,539	61,890	190,428	8576	4,332	12,909	145,435	38,352	4.97	0.34	3.79
NewZealand	128,539	8,845	137,384	8576	619	9,196	92,390	38,352	3.58	0.24	2.41
Canada	128,539	8,845	137,384	8576	619	9,196	92,390	25,694	5.35	0.36	3.60

Table 3-28. Estimated Energy Use Growing and Shipping Head Lettuce and Spinach for New York Consumption -- per Kilogram Farm Produce Shipped

Head lettuce

Source	Iceberg-field			Boston-field			Boston- greenhouse		
	Prod. MJ/kg	Transp. MJ/kg	Total MJ/kg	Prod. MJ/kg	Transp. MJ/kg	Total MJ/kg	Prod. MJ/kg	Transp. MJ/kg	Total MJ/kg
CA	2.6	10.6	**13.2**	5.2	10.6	**15.8**			
AZ	3.8	9.4	**13.2**	7.6	9.4	**17.0**			
CO	3.8	6.2	**10.0**	7.6	6.2	**13.8**			
Mex	2.6	9.3	**11.9**	5.2	9.3	**14.5**			
Can	5.2	1.6	**6.8**	10.4	1.6	**12.0**	77	1.6	**78.6**
Out of State (Weighted)		10.2			10.2				
NY	5.2	0.4	**5.6**	10.4	0.4	**10.8**	97	0.4	**97.4**

Fresh spinach

Source	Bunching-field			Baby leaf - field			Baby leaf - greenhouse		
	Prod. MJ/kg	Transp. MJ/kg	Total MJ/kg	Prod. MJ/kg	Transp. MJ/kg	Total MJ/kg	Prod. MJ/kg	Transp. MJ/kg	Total MJ/kg
CA	2.2	11.8	14.0	9.7	11.8	**21.5**			
AZ	2.2	10.5	**12.7**	9.7	10.5	**20.2**			
NJ	1.79	0.9	**2.7**	9.2	0.9	**10.1**			
TX	1.79	7.0	**8.8**	9.2	7.0	**16.2**			
Mex	2.2	10.3	**12.5**	9.7	10.3	**20.0**			
Can	1.79	1.8	**3.6**	9.2	1.8	**11.0**			
Out of State (Weighted)		11.4			11.4				
NY	1.79	0.4	**2.2**	9.2	0.4	**9.6**	89	0.4	**89.4**

Note. For shaded producers and crops, detailed estimates were taken from the literature, or made *de novo*, but with unknown accuracy. Other estimates are based on similarity of production circumstances
Greenhouse growing scenario (light, CO2, duration) is noted in Excel cell comments

Table 3-29. Estimated Energy Use in Growing and Shipping Tomato, Apple, and Strawberry for New York Consumption per Kilogram Farm Produce Shipped

Fresh Tomato Source	Field Prod MJ/kg	Transp MJ/kg	Total MJ/kg	GrnHse Prod MJ/kg	Transp MJ/kg	GrnHse Total MJ/kg	Fresh Apple (field) Source	Prod MJ/kg	Transp MJ/kg	Total MJ/kg	Fresh Strawberry (field) Source	Prod MJ/kg	Transp MJ/kg	Total MJ/kg
CA field	3.4	10.7	**14.1**											
CA pole	3.1	10.7	**13.8**				CA	10.2	10.6	**20.8**	CA	3.2	11.8	**15.0**
FL	7.1	3.8	**10.9**				MICH	6.8	2.1	**8.9**	FL	8.7	4.2	**12.9**
NJ	7.1	0.8	**7.9**				WA	5.0	9.4	**14.4**				
VA	7.1	1.7	**8.8**				OR	4.7	9.3	**14.0**				
OH	7.1	2.0	**9.1**				NY	5.4	0.4	**5.8**				
GA	7.1	3.6	**10.7**											
TN	7.1	3.5	**10.6**											
SC	7.1	2.8	**9.9**											
NC	7.1	2.1	**9.2**											
MN	7.1	4.1	**11.2**											
Mex	3.4	9.3	**12.7**								Mex	3.2	10.3	**13.5**
US				13.2	6.7	**19.9**	Can	5.4	1.6	**7.0**				
Can				66	1.6	**67.6**	Chile	5.0	4.8	**9.8**				
Neth				66	128.0	**194.0**	NZ	3.6	8.0	**11.6**				
Israel				13.2	199.0	**212.2**								
Spain				13.2	126.0	**139.2**								
All out of State		5.7 to 7.9					All out of State		8.9	**8.9**	All out of State		11.1	
NY	7.1	0.4	**7.5**	66	0.4	**66.4**	NY	5.4	0.4	**5.8**	NY	2.2	0.4	**2.6**

Note. For shaded producers and crops, detailed estimates were taken from the literature, or made *de novo*, but with unknown accuracy. Other estimates are based on similarity of production circumstances
Greenhouse growing scenario (light, CO_2, duration) is noted in Excel cell comments

TASK 4: ENERGY IN LONG-DISTANCE TRANSPORT

Develop, based on the data above, a weighted Btu index (Btu/lb) and weighted CO_2 index (lb CO_2/lb) for each of the crops, shipped to the center of New York State.

ENERGY USE IN TRANSPORT

The best source we have found for energy use in transport by different transportation modes dates from 1982. It is a thorough and detailed analysis, prepared by R. R. Mudge for the Congressional Budget Office of the US Congress and appears not to have been superceded (Mudge, 1982). In this study, energy needs for freight transportation are analyzed in terms of:

- Vehicle propulsion energy
- Vehicle manufacturing energy
- Guideway construction energy
- Terminal and maintenance energy
- Circuity, and
- Energy used in access

The first item listed is also called "Operating Energy." Typically, operating energy includes an allowance for fuel used in refining crude oil (an inverse efficiency factor), and allowance is also made for empty/less-than-fully-loaded movements of railcars, tractors and trailers (empty back-haul, also empty through-haul).

Empty cars are a particularly important factor in rail transport efficiency. The Interstate Commerce Commission (ICC) has calculated that cars go 79 miles empty for every 100 miles filled. Because the average empty rail car weighs 60,000 to 65,000 lbs and the payload perhaps half as much, this is a great deal of dead weight. (See Mudge, p. 22 and reference.) Operating energy is given in terms (or Btu) per ton-mile of cargo. Energy use can also be calculated in terms of gross loaded weight, which tends to be two or more times cargo/payload weight and, thus, reduces energy per ton-mile substantially.

Collectively, the first four items (through "Terminal and maintenance energy") are called "Line-haul Energy". All items included together are called "Modal Energy." Circuity is a factor to account for indirectness of routes as compared to straight-line/great circle distances.

Transportation to and from loading and unloading points composes Energy-used-in-access. Because Circuity and Energy-used in-access vary considerably across modes, comparisons between modes of transport are more meaningful with these added. Mudge does not attempt to estimate access energy, but we will take it into account by estimating distance from farm to loading point for long-distance transportation of farm produce.

Most of the produce considered in this report is hauled long-distance on the highway system in insulated refrigerated trailers pulled by diesel truck-tractors, but a small portion of head lettuce and apples is moved by train. Produce moved by train is split between that packed into refrigerated railcars and that carried on flatcars in "piggyback" mode - refrigerated trailers on flat cars (TOFCs), - which means it can easily be transferred between railway and highway transport modes at suitable terminals possessing cranes to lift the trailers on and off the flat cars. Railcar trains, on the other hand, make sense when they can be loaded close to the farm/farms and unloaded where additional long-distance trucking is not needed. Railcar assemblies are more aerodynamic than TOFC trains and, therefore, require less operating energy than TOFCs.

The volumes currently moved by rail are small relative to truck volume, and are unlikely to have a large effect on weighted energy-use indices. However, railcar transportation is particularly suited to long distance deliveries to terminal markets in large urban centers such as Chicago, Boston and New York City, and regional centers such as Albany, NY, and a disproportionate part of produce leaving the west coast may come to New York State via this mode. A dedicated train began in September, 2006, to make a weekly trip from Wallula, WA to Rotterdam, NY (near Albany) carrying apples and other produce. This project, in which $40 million was invested, has apparently been successful, and plans are in place operate the service twice weekly on the existing line and add routes between Wallula and California, and California and Rotterdam, NY, as reported in the following recent Union Bulletin news article (http://www.union-bulletin.com/articles/2008/02/08/local_news/local01.txt Accessed March 2008).
We have also begun to hear and see advertising of the advantages of railcar transportation for reducing fuel use and CO_2 emissions in national mass media. However, it should be noted the dedicated rail service still requires 5 days to complete the journey, a significant addition to post-harvest storage time for remote producers compared to local producers.

Most produce imported to the U.S. is from Mexico and Canada, and is transported by truck. Until 2007, Mexican trucking was not permitted to penetrate farther than 25 miles into the US, which led and still leads to considerable delays at the border. A pilot program allowing 500 Mexican trucks full access in the US was begun in 2007 and continues, although the attempt to expand the program was recently voted down in Congress. (http://www.brownsvilleherald.com/news/mexican_83444___article.html/border_program.html, accessed March 2008) Some imported apples come from Chile and New Zealand by ship through the Panama Canal, and small amount of tomatoes are flown to the US from European origins (most likely as subsidized "belly" cargo). In each of these cases, additional hauling by local delivery truck is required to complete the journey.

Treating Albany as the destination for all the produce coming to New York is artificial, since the actual population center of the state is much closer to New York City. The effect is to add a small distance to travel and, in the case of boat and airfreight, an additional leg to the journey by a different mode. Also, in absolute terms, obviously Albany does not consume all this produce. In terms of weighted energy use per lb, however, the figures are our best estimate for Albany.

Mudge describes his method of estimation of overall, modal energy efficiency in freight transportation as follows:

> *"In this paper the estimation of energy efficiency is carried out in three steps. First, operating energy is calculated—the energy required for vehicle propulsion divided by the average load. Estimates of average load must be adjusted for the amount of travel with no load (called empty back-hauls). Energy losses during the refining process are incorporated as well.*
> *The second step is to estimate line-haul energy. This adds to operating energy the energy used to maintain vehicles and guide ways, the energy required to construct the guide ways, and the energy used in vehicle manufacture. Estimates must also be made of the length of life of vehicles and guide ways in order to allocate construction and manufacturing energy over their effective lives.*
> *Third, the estimate of line-haul energy is modified to take account of the additional energy used in circuity or roundaboutness, and the energy used in access. Circuity is the amount of excess or unproductive travel used to move goods from one point to another, as compared with the theoretical minimum distance or great-circle route. Access energy is the amount of energy required to move the cargo to and from the system. The resulting measure (line-haul energy adjusted for circuity and access) is termed "modal energy."*

Table 4-1, modified from Mudge (1982), contains estimates of the relative energy efficiencies of different modes of transport for the country as a whole. These figures do not include access energy, but do include circuity factors. One gallon of diesel fuel is taken to contain, on average, 138,700 Btu of energy, and a gallon of gasoline 125,000 Btu. We can see that energy required per unit of cargo moved by train is roughly half that of truck cargo, and air cargo requires roughly ten times as much energy as truck and train cargo. Deep-sea shipped freight is not shown but it is energetically more efficient than train cargo.

Table 4-1. Average Distances and Amounts Shipped for Selected Produce Consumed in New York

Geographic source	Quantities shipped – 1000 cwt					Average distance shipped – miles				
	Fresh Spinach	Fresh Straw-berry	Fresh Tomato	Head Lettuce	Fresh Apple	Fresh Spinach	Fresh Straw-berry	Fresh Tomato	Head Lettuce	Fresh Apple
	1000 cwt	1000 cwt	1000 cwt	1000 cwt	1000 cwt	miles	miles	miles	miles	miles
Outside NY State, US	403	952	1,937	3,960	451	2,962	2,897	1,695	2,983	2,615
Outside NY State, Foreign	20	79	1,563	79	49	2,850	2,850	2,879	2,822	6,458
Outside NY State, All	423	1,031	3,500	4,039	500	2,956	2,894	2,224	2,980	2,995
Inside NY State	9	59	360	38	2,950	100	100	100	100	100
All Utilized in NY State	432	1,090	3,860	4,077	3,450	2,897	2,742	2,026	2,953	520

To arrive at the figures for propulsion energy, Mudge (1982) evaluated a large collection of historical estimates and measurements of road and rail performances (that are shown in his appendices and discussed in detail), and judged what was typical and appropriate.

For our part, we do not require circuity factors for rail and road transport (or combinations thereof) because we have determined road mileage by road atlas (American Map, 2005) to get distances from produce sources to Albany, and are using the same distances for rail traffic. Air cargo transportation requires a circuity factor (1.05) to be applied to great circle distance between airports. For ocean freight from New Zealand and Chile we have taken great circle routes in two steps, first to Panama, then to New York, and also applied a circuity factor of 1.05 to cover negotiation of the Panama Canal and the Caribbean.

Accepting Mudge’s figures as well chosen, there are a number of special issues concerning propulsion energy to consider and adjustments to make in our particular instance. We will consider each mode in turn.

TRAIN TRANSPORTATION

The only significant train traffic to New York shown in the Agricultural Market Service fresh produce shipments data for the commodities we are considering is from beyond the continental divide. For trains to cross the divide surely requires more energy than for train traffic in the country as a whole, as attested in the data presented by Mudge in appendices (See footnote to Table 4-1 above.) In crossing the Rockies, large inter-conversions in potential energy occur in raising and lowering the train mass, no doubt with some inefficiency with respect to horizontal progress. Additional engines are required in some cases. On up-slopes wheels may slip, and on down-slopes energy may be lost due to the need for braking. (To give some idea of the potential energy involved, a change from no grade to a 1% grade in Iowa DOT data for a 10-car TOFC train raised Btu per ton-mile requirement from 1,500 to 4,100.) We have increased the propulsion energy requirement for TOFCs originating on the west side of the continental divide by 20% to account for the need to cross the divide, leaving other factors the same.

Mudge does not specifically address railcars as a mode different from TOFC. Trains made up of railcars or other standard rolling stock are more aerodynamic than TOFC trains but is it is unclear by how much. Both refrigerated railcar trains and TOFC trains operate faster than common goods trains, so aerodynamic factors are significant. We will assume a 20% savings for railcar trains, offsetting the 20% increase for crossing the Rockies, thus leaving the total unchanged. The refrigerated rail cars and trailer-flat bed combinations clearly require more manufacturing energy than common rolling stock. For this reason, for both modes we will use the values given for "Rail-Overall".

Refrigeration is not mentioned in Mudge's study, and may or may not have been factored into energy use for any of the modes. The differences in time in transit are not large between fast-service rail and truck, and refrigeration is needed in all cases, so relatively speaking, the omission, if there is such, has little effect.

TRUCK TRANSPORTATION

As far as truck transportation goes, Mudge notes: *"One of the more significant variables is cargo density—a ton of television sets requires five to six times as much space as a ton of coal, for example. Many manufactured goods fill the space available before reaching the weight limit for the vehicle. This is particularly common with trucks, which often fill up before reaching their maximum allowable weight."*

For the produce items we are considering, some items -- head lettuce, apples and tomatoes -- are inherently dense, and can be packed closely, thereby permitting heavy payloads. On the other hand, strawberries and baby-leaf spinach suffer damage and loss of quality if more than lightly pressed together, with the result cargoes are less dense and trailer payloads are smaller for these crops; energy efficiency is reduced as a consequence. Fresh strawberries are picked and handled carefully and are placed in their final containers specially designed to avoid crushing between containers either at or shortly after harvest, and thereafter shipped to market as soon as possible. Spinach, which is primarily grown in CA and AZ, is loosely bulked for transport East before being triple-washed, dried, and packaged in the East. If spinach were to be packaged in the West, it would make for even less dense cargos and greater energy use and expense in shipping. (If baby-leaf spinach were shipped in 12 oz packages or Boston lettuce in clamshells, the packing density might well be a mere 20% of head-lettuce loads.)

In practice most produce is delivered in fully-loaded refrigerated semi-trailer trucks in which the average payload is around 18 tons. In this case the gross weight would likely be 54,000 lbs, 18,000 lb for the tractor and empty trailer, and 36,000 lb for the load. Estimates and measurements of fuel economy presented by Mudge show that fully loaded trucks achieve around 4.5 to 5 miles per gallon of diesel, and unloaded get around 6 miles per gallon. Pending precise figures for each of the individual crops we are considering, let us assume that the more dense commodities make up average loads of 18 tons and that leaf spinach and strawberry pack at 75% the density of the other crops, and thus give loads of c. 13.5 tons. (In practice loads are often made up of mixtures of commodities, but that does not affect the calculation of energy use for each commodity.)

The energy efficiency in delivering the payloads depends not only on how large the payloads are (which translates to density) but also how much of the time the truck is operated empty (e.g. empty back-haul). Ability to find loads for return trips is something which is constantly changing with the season and differs from year to year. In summer of 2007, for instance, some trucks delivering to the East coast had to travel empty half way across the country before finding another load, or else accept trivial prices for partial loads. Mudge gives estimates of average annual empty capacity of 31% in 1974 and 27% in 1976.

Calculations of the effect of different speeds on fuel consumption indicate large penalties in going faster than 55 mph in trucks – about 1 mile per gallon of diesel for a 10 mph increase over 55 mph. Trucks routinely travel as fast as the speed limit permits. Regardless of this reality, over most of the country the speed limit is now back to 70 mph. We have some concern the estimates of fuel-use presented by Mudge posited a lower road speed (55 mph) than actually is used in practice on cross-country interstate highway routes. For our purposes, estimates of efficiency perhaps should be based on 4.5 miles per gallon rather than on 5.5 mpg. However the modern day loss of efficiency due to higher speeds may be offset by gains in engine efficiency and increased aerodynamic efficiency during the intervening years since the Mudge study was done; we have assumed these two factors cancel.

In addition to the foregoing, Iowa DOT data show an increase in Btu per ton-mile of roughly 50% as a result of a 1% grade change in a truck with a 10-ton cargo. Since much of the trucked produce in New York comes from across the continental divide, there is again the issue whether this reduces efficiency of transport in the particular case of New York. In highway design and construction the contours of the land are followed more or less as found. This means, in mountainous areas, ascents and descents are steep and trucks are forced to brake when travelling down hills, and thus are unable to convert all the potential energy they gained going up hills to forward progress on the down hill sections. We have applied a factor for trucked produce originating beyond the continental divide to take into account extra energy required in crossing the divide.

Energy efficiency is affected by gross weight. National Highway Safety Administration data in a 53-mile road test, showed Btu/ton-mile rose from 1,207 to 2,514 when the gross weight was reduced from 72,000 to 48,000 lbs. (If we assume curb weight was 18,000 lbs, payloads went from 54,000 lb to 30,000 lbs, or a near-maximum 27 tons to 15 tons.). Paxon demonstrated a progressive increase in Btu/ton-mile for payloads decreasing from 25, to 20, to 15 tons, from 1425 to 1690, to 2170 Btu/ton-mile (figures may not be adjusted for empty rate, however). Rose gave a range between 1,860 and 4,120 Btu/ton-mile for different payloads, with 2,470 Btu/ton-mile for a payload of 18 tons, and assuming an empty rate of 31%. We are positing average payloads of 36,000 lbs or 18 tons for apples, lettuce, and tomatoes, and 27,000 lbs or 13.5 tons for spinach and strawberries, in standard-sized fully-loaded tractor semi-trailer combinations. If we assume curb weights of 18,000 lbs, gross laden weights would be 54,000 and 45,000 lbs.

Mudge's average operating energy of 2,100 Btu/ton-mile for the US as a whole is not unreasonable for the data presented, but in view of the considerations above, at least for long-distance western sources, a figure of 2,300 Btu/ton-mile would seem appropriate for the heavier produce, apples, tomatoes and head lettuce, rising to 2,600 Btu/ton-mile for spinach and strawberry. Figures of 2,100 Btu/ton-mile and 2,400 Btu/ton-mile will be applied to corresponding produce types originating from sources east of the continental divide and from Mexico and Canada.

Local delivery is recognized to be more expensive than full-load long-distance trailer trucking. An operating energy figure of 3,000 Btu/ton-mile will be applied in this category. Airfreight and ocean shipping cargoes are assumed to require local delivery legs by delivery truck to point of origin and from port of entry in to the US, 100 miles at point of origin and 170 miles for the trip from New York to Albany. For both kinds of railroad transport, 100 miles of local delivery by truck is assumed to make up access energy – to get material to the railhead or, in some cases, from rail drop off point to wholesale distribution center.

DEEP DRAFT BOAT SHIPPING

Operating energy for deep-draft Great Lakes shipping is given in the vicinity of 450 Btu/ton mile, although estimates are quite variable. Pending better figures we will use this value for apples shipped from Chile and New Zealand by boat.

AIR FREIGHT

The energy cost for passenger airlines per ton of payload (considering human passengers and their luggage as payload) is higher than that for freight planes. We reject the rationale that the energy use in "belly cargo" can calculated at a different rate than other "cargo" on the plane. Airfreight energy use is quite consistent at around 26,000 Btu/ton mile, and we will accept Mudge's figure.

Taking into account the considerations raised above, Table 4-2 below presents the line-haul and modal energy use values we are using to calculate energy expended in getting produce to Albany, N.Y.

Table 4-2. Modal Energy Use in Freight Transportation for the NY Situation

Adapted from Mudge et al.

Transportation Mode	Propul-sion energy	Vehicle Manufact-ing energy	Constr-uction energy	Main-tenance energy	Subtotal Line-Haul	Circuity	Total Modal	Liquid Fuel Use: Propul-sion plus Maint.	Liquid Fuel Use: % of Total
	BTU/ton-mile							BTU/ton-mile	
Rail						Not applicable			
Railcar	1,000	90	200	180	1,470			1,180	0.80
TOFC	1,200	90	200	180	1,670			1,380	0.83
Truck: Fully -Loaded, Refrigerated Intercity									
Beyond the Divide						Not applicable			
Denser commodities	2,300	100	300	300	3,000			2,600	0.87
Less-dense	2,600	100	300	300	3,300			2,900	0.88
East, North and South									
Denser commodities	2,100	100	300	300	2,800			2,400	0.86
Less-dense	2,400	100	300	300	3,100			2,700	0.87
Local Refrigerated Truck Delivery	3,000	100	300	300	3,700			3,300	0.89
Deep Draft Ocean Freight, Refrigerated									
Barge - Overall	450	40	50	30	570	1.05	599	480	0.84
Air Freight									
All-cargo plane	26,250	150	100	750	27,250	1.05	28,613	27,000	0.99

The results of this chapter's computations are presented in summary Table 4-7, which lists total energy use, weighted unit energy use, total CO_2 emissions, and weighted unit CO_2 emissions for bringing each of the field crops of interest into New York to meet consumer needs, as compared to figures for the same crops produced in New York. Table 4-8 gives average food miles for each of the commodities we are considering. Tables 4-3 through 4-6 show the means by which the energy use and emissions were calculated, and the assumptions made as to distance, quantities, and ton-mile energy rates.

Strawberry, lettuce, and spinach require about 11 MJ/kg in transportation and tomato and apple about 8 MJ/kg; these compare to about 0.4MJ/kg for all New York produced goods. Tomatoes require less energy for transportation than lettuce and spinach because there are a number of close suppliers, such as Canada and the mid Atlantic states. In the case of apples, Washington, the main supplier, is closer than California, and uses some rail shipment, which is more efficient. There is also some supply from Michigan, which is relatively close. Deep-sea freight makes Chilean and New Zealand apples the least energetic to bring to New York of any outside apples, despite the great distance involved (10,000 miles in the case of New Zealand, 5000 for Chile).

Table 4-3A Estimated Annual Amounts Shipped to NY by Origin and Mode of Transport, and Estimated Miles Traveled

Origin	Fresh Spinach 1000 cwt	Fresh Straw-berry 1000 cwt	Fresh Tomato 1000 cwt	Head Lettuce 1000 cwt	Fresh Apple 1000 cwt
US Out-of-State Sources					
California-Total	321	861	**483**	**2832**	**18**
CA-Trucked			475	2706	17
CA-Piggyback			4.5	126	0.74
CA-Railcar			3.1	0.00	0.02
Arizona-Total	74			**1108**	
Arizona-Trucked				1060	
Arizona-Piggyback				48	
Florida-total		91	**898**		
Florida-Trucked			895		
Florida Piggyback			2.5		
Colorado				20	
New Jersey	7.6		4.2		
Texas	1.2				
Virginia			96		
Ohio			57		
Georgia			54		
Tennessee			28		
South Carolina			24		
North Carolina			18		
Minnesota			10		
Michigan					34
Washington-Total					**390**
Washington-Trucked					375
Washington-Piggyback					4.9
Washington-Railcar					9.8
Oregon-Total					**9**
Oregon-Trucked					7.14
Oregon-Piggyback					2.13
Oregon-Railcar					0.15
Domestic Greenhouse Production (place unspecified)			265		
All US Production: ST	**403**	**952**	**1937**	**3960**	**451**
Imports					
Mexico (truck)	17.2	79	1310	61	
Canada (truck)	2.5		225	17	10
Netherlands (air: Amsterdam)			19		
Israel (air: Tel aviv)			4.9		
Spain (air: Madrid)			4.1		
Chile (boat: Santiago, via Panama)					26
New Zealand (boat: Wellington, via Panama)					14
Imports, Major: ST.	**20**	**79**	**1563**	**79**	**49**
All Out-of-State Sources	**423**	**1031**	**3500**	**4039**	**500**
New York as Source	**9**	**59**	**360**	**38**	**2950**
Total NY Utilization	**432**	**1090**	**3860**	**4077**	**3450**

Table 4-3B. Estimated Miles Travelled to NY by Origin and Mode of Transport

Origin	Albany to:	Road mileage assumed (miles)	Local Adjustment to:	Add (miles)	Sub-tract (miles)	Truck Total in Nrth Am. (miles)	Train (miles)	Air /boat Grt Circ to NYNY (miles)	Circuitry x1.05 air and boat (miles)	Foreign allow-ance (miles)
US Out-of-State Sources										
California-Total										
CA-Trucked	Los angele	2860	Fresno	220		**3080**				
CA-Piggyback						100	3080			
CA-Railcar						100	3080			
Arizona-Total										
Arizona-Trucked	Phoenix	2560	Yuma	180		**2740**				
Arizona-Piggyback						100	2740			
Florida-total										
Florida-Trucked	Jacksonvil	1095	Gainesville	70		**1165**				
Florida Piggyback						100	1165			
Colorado	Denver	1830	Colo. Sprg	70		**1900**				
New Jersey	Philadelphi	220	Vineland	40		**260**				
Texas	San Antoni	1950				**1950**				
Virginia	Richmond	480	Farmsville	40		**520**				
Ohio	Columbus	620				**620**				
Georgia	Atlanta	1010	Macon	85		**1095**				
Tennessee	Nashville	1000	Mancheste	65		**1065**				
South Carolina	Charlotte	770	Columbia	90		**860**				
North Carolina	Raleigh	640		20		**660**				
Minnesota	Minneapoli	1245				**1245**				
Michigan	Detroit	570	Lansing	90		**660**				
Washington-Total										
Washington-Trucked	Seattle	2900	Wenatchee		150	**2750**				
Washington-Piggyback						100	2750			
Washington-Railcar						100	2750			
Oregon-Total										
Oregon-Trucked	Portland	2955				**2955**				
Oregon-Piggyback						100	2955			
Oregon-Railcar						100	2955			
Domestic Greenhouse Production	Texas/ Ari	2000				**2000**				
All US Production: ST										
Imports										
Mexico (truck)	Laredo Tx	2100	S. Luis Pot	750		**2850**				
Canada (truck)	Leamingto	500				**500**				
Netherlands (air: Amsterdam)	NY, NY	170				**170**		**3648**	**3830**	100
Israel (air: Tel aviv)	NY, NY	170				**170**		**5671**	**5955**	100
Spain (air: Madrid)	NY, NY	170				**170**		**3588**	**3767**	100
Chile (boat Santiago, via Panama	NY, NY	170				**170**		**5187**	**5446**	100
New Zealand (boat: Wellington, vi	NY, NY	170				**170**		**9657**	**10140**	100

Sources for mileage, 2007:
http://www.timeanddate.com/worldclock/distance.html
http://www.mapcrow.info/
http://www.geobytes.com/CityDistanceTool.htm?loadpage

Table 4-4. Proportion of Produce Shipped by Each Mode of Transportation in States Using Multiple Modes

Origin	Fresh Tomato	Head Lettuce	Fresh Apple	Fresh Tomato	Head Lettuce	Fresh Apple
		Proportion			1000 cwt	
US Out-of-State Sources						
California-Total	**1.000**	**1.000**	**1.000**	**483**	**2832**	**18**
CA-Trucked	0.984	0.956	0.957	475	2706	17.0
CA-Piggyback	0.009	0.044	0.041	4.5	126	0.74
CA-Railcar	0.006	0.000	0.001	3.1	0.00	0.02
Arizona-Total		**1.000**			**1108**	
Arizona-Trucked		0.956			1060	
Arizona-Piggyback		0.044			48	
Florida-total	**1.000**			**898**		
Florida-Trucked	0.997			895		
Florida Piggyback	0.003			3		
Washington			**1.000**			**390**
Washington-Trucked			0.962			375
Washington-Piggyback			0.013			5
Washington-Railcar			0.025			10
Oregon-Total			**1.000**			**9**
Oregon-Trucked			0.758			7.14
Oregon-Piggyback			0.226			2.13
Oregon-Railcar			0.016			0.15

Table 4-5. Produce Shipped, and BTU Rates for Shipping to NY by Origin, Mode of Transport, and Produce Type

Origin	Light Cargo Items		Heavy cargo items			Long distance truck			Air/boat/train		Local truck Foreign or domestic	
	Fresh Spinach 1000 cwt	Fresh Strawbry 1000 cwt	Fresh Tomato 1000 cwt	Head Lettuce 1000 cwt	Fresh Apple 1000 cwt	Total in Nrth Am. (miles)	Light Cargo BTU/ton-mile	Heavy Cargo BTU/ton-mile	(miles)	BTU/ton-mile	(miles)	BTU/ton-mile
US Out-of-State Sources												
California-Total	321	861	483	2832	18	3080	3300	3000				
CA-Trucked			475	2706	17	3080		3000				
CA-Piggyback			4.5	126	0.74	100		3,700	3080	1,670		
CA-Railcar			3.1	0.00	0.02	100		3,700	3080	1,470		
Arizona-Total	74			1108		2740	3300					
Arizona-Trucked				1060		2740		3000				
Arizona-Piggyback				48		100		3,700	2740	1,670		
Florida-total		91	898			1165	3100					
Florida-Trucked			895			1165		2800				
Florida Piggyback			2.5			100		3,700	1165	1,670		
Colorado				20		1900		2800				
New Jersey	7.6		4.2			260	3100	2800				
Texas	1.2					1950	3100					
Virginia			96			520		2800				
Ohio			57			620		2800				
Georgia			54			1095		2800				
Tennessee			28			1065		2800				
South Carolina			24			860		2800				
North Carolina			18			660		2800				
Minnesota			10			1245		2800				
Michigan					34	660		2800				
Washington-Total					390			2800				
Washington-Trucked					375	2750		3000				
Washington-Piggyback					4.9	100		3,700	2750	1,670		
Washington-Railcar					9.8	100		3,700	2750	1,470		
Oregon-Total					9							
Oregon-Trucked					7.14	2955		3000				
Oregon-Piggyback					2.13	100		3,700	2955	1,670		
Oregon-Railcar					0.15	100		3,700	2955	1,470		
Domestic Greenhouse Production (place unspec)			265			2000		2900				
All US Production: ST	403	952	1937	3960	451							
Imports												
Mexico (truck)	17.2	79	1310	61		2850	3100	2800				
Canada (truck)	2.5		225	17	10	500	3100	2800				
Netherlands (air: Amsterdam)			19			170			3830	28613	100	3,700
Israel (air: Tel aviv)			4.9			170			5955	28613	100	3,700
Spain (air: Madrid)			4.1			170			3767	28613	100	3,700
Chile (boat: Santiago, via Panama)					26	170			5446	599	100	3,700
New Zealand (boat: Wellington, via Panama)					14	170			10140	599	100	3,700
Imports, Major: ST.	20	79	1563	79	49							
All Out-of-State Sources	423	1031	3500	4039	500							
New York	9	59	360	38	2950						100	3,700
Total NY Utilization	432	1090	3860	4077	3450							

Table 4-6A Estimated Energy Consumed Annually in Shipping Produce to NY by Origin, and Mode of Transport

Origin	Quantity shipped					Total energy spent				
	Fresh Spinach	Fresh Strawberry	Fresh Tomato	Head Lettuce	Fresh Apple	Fresh Spinach	Fresh Strawberry	Fresh Tomato	Head Lettuce	Fresh Apple
	1000 cwt	1000 cwt	1000 cwt	1000 cwt	1000 cwt	MBTU	MBTU	MBTU	MBTU	MBTU
US Out-of-State Sources										
California-Total	321	861	483	2,832	18	163,037	437,518			
CA-Trucked			475	2,706	17			219,556	1,250,233	7,876
CA-Piggyback			4	126	1			1,234	34,670	203
CA-Railcar			3		0.02			756		5
Arizona-Total	74			1,108		33,411				
Arizona-Trucked				1,060					435,563	
Arizona-Piggyback				48					11,933	
Florida-total		91	898				16,390			
Florida-Trucked			895					146,044		
Florida Piggyback			3					293		
Colorado				20					5,261	
New Jersey	8		4			305		154		
Texas	1					363				
Virginia			96					6,998		
Ohio			57					4,933		
Georgia			54					8,205		
Tennessee			28					4,174		
South Carolina			24					2,925		
North Carolina			18					1,703		
Minnesota			10					1,744		
Michigan					34					3,113
Washington-Total					390					
Washington-Trucked					375					154,686
Washington-Piggyback					5					1,223
Washington-Railcar					10					2,157
Oregon-Total					9					
Oregon-Trucked					7					3,165
Oregon-Piggyback					2					564
Oregon-Railcar					0					36
Domestic Greenhouse Production (place unspec)			265					76,773		
All US Production: ST	403	952	1,937	3,960	451	197,116	453,907	475,493	1,737,660	173,029
Imports										
Mexico (truck)	17	79	1,310	61		7,591	35,040	522,606	24,366	
Canada (truck)	3		225	17	10	198		15,738	1,221	689
Netherlands (air)			19					107,433		
Israel (air)			5					41,802		
Spain (air)			4					22,379		
Chile (boat)					26					5,285
New Zealand (boat)					14					4,779
Imports, Major: ST.	20	79	1,563	79	49	7,788	35,040	709,958	25,588	10,753
All Out-of-State Sources	423	1,031	3,500	4,039	500	204,904	488,947	1,185,451	1,763,248	183,782
New York	9	59	360	38	2,950	167	1,092	6,660	703	54,575
Total NY Utilization	432	1,090	3,860	4,077	3,450	205,071	490,038	1,192,111	1,763,951	238,357

Table 4-6B Estimated Energy Consumed Annually in Shipping Produce to NY by Origin, and Mode of Transport

Origin	Energy per Unit weight BTU/lb					Energy per Unit weight MJ/kg				
	Fresh Spinach BTU/lb	Fresh Strawberry BTU/lb	Fresh Tomato BTU/lb	Head Lettuce BTU/lb	Fresh Apple BTU/lb	Fresh Spinach MJ/kg	Fresh Strawberry MJ/kg	Fresh Tomato MJ/kg	Head Lettuce MJ/kg	Fresh Apple MJ/kg
US Out-of-State Sources										
California-Total	5,082	5,082				11.8	11.8			
CA-Trucked			4,620	4,620	4,620			10.7	10.7	10.7
CA-Piggyback			2,757	2,757	2,757			6.4	6.4	6.4
CA-Railcar			2,449		2,449			5.7		5.7
Arizona-Total	4,521					10.5				
Arizona-Trucked				4,110					9.6	
Arizona-Piggyback				2,473					5.8	
Florida-total		1,806					4.2			
Florida-Trucked			1,631					3.8		
Florida Piggyback			1,158					2.7		
Colorado				2,660					6.2	
New Jersey	403		364			0.9		0.8		
Texas	3,023					7.0				
Virginia			728					1.7		
Ohio			868					2.0		
Georgia			1,533					3.6		
Tennessee			1,491					3.5		
South Carolina			1,204					2.8		
North Carolina			924					2.1		
Minnesota			1,743					4.1		
Michigan					924					2.1
Washington-Total										
Washington-Trucked					4,125					9.6
Washington-Piggyback					2,481					5.8
Washington-Railcar					2,206					5.1
Oregon-Total										
Oregon-Trucked					4,433					10.3
Oregon-Piggyback					2,652					6.2
Oregon-Railcar					2,357					5.5
Domestic Greenhouse Production (place unspecified)			2,900					6.7		
All US Production: $T	4,885	4,770	2,455	4,388	3,840	11.4	11.1	5.7	10.2	8.9
Imports										
Mexico (truck)	4,418	4,418	3,990	3,990		10.3	10.3	9.3	9.3	
Canada (truck)	775		700	700	700	1.8		1.6	1.6	1.6
Netherlands (air)			55,223					128.4		
Israel (air)			85,612					199.1		
Spain (air)			54,321					126.4		
Chile (boat)					2,054					4.8
New Zealand (boat)					3,460					8.0
Imports, Major: $T.	3,947	4,418	4,542	3,226	2,177	9.2	10.3	10.6	7.5	5.1
All Out-of-State Sources	4,842	4,742	3,387	4,366	3,676	11.3	11.0	7.9	10.2	8.5
New York	185	185	185	185	185	0.4	0.4	0.4	0.4	0.4
Total NY Utilization	4,745	4,496	3,088	4,327	691	11.0	10.5	7.2	10.1	1.6

Table 4-7. Summary: Annual Energy Consumption and CO_2 Emissions in Shipping Produce to NY, Totals and Unit Rates

Origin	Quantity shipped					Total energy spent					Energy per Unit weight BT			
	Fresh Spinach	Fresh Strawberry	Fresh Tomato	Head Lettuce	Fresh Apple	Fresh Spinach	Fresh Strawberry	Fresh Tomato	Head Lettuce	Fresh Apple	Fresh Spinach	Fresh Strawberry	Fresh Tomato	Head Lettuce
British Units	1000 cwt	1000 cwt	1000 cwt	1000 cwt	1000 cwt	MBTU	MBTU	MBTU	MBTU	MBTU	BTU/lb	BTU/lb	BTU/lb	BTU/lb
U S Production, not NY	403	952	1,937	3,960	451	197,116	453,907	475,493	1,737,660	173,029	4,885	4,770	2,455	4,388
Imports, Major. ST.	20	79	1,563	79	49	7,788	35,040	709,958	25,588	10,753	3,947	4,418	4,542	3,226
All Out-of-State Sources	423	1,031	3,500	4,039	500	204,904	488,947	1,185,451	1,763,248	183,782	4,842	4,742	3,387	4,366
New York Produced	9	59	360	38	2,950	167	1,092	6,660	703	54,575	185	185	185	185
Total NY Utilization	432	1,090	3,860	4,077	3,450	205,071	490,038	1,192,111	1,763,951	238,357	4,745	4,496	3,088	4,327
Metric Units	tonnes	tonnes	tonnes	tonnes	tonnes	GJ	GJ	GJ	GJ	GJ	MJ/kg	MJ/kg	MJ/kg	MJ/kg
U S Production, not NY	18,301	43,168	87,858	179,610	20,440	207,969	478,899	501,673	1,833,335	182,556	11.4	11.1	5.7	10.2
Foreign Production	895	3,598	70,901	3,597	2,240	8,217	36,969	749,048	26,997	11,345	9.2	10.3	10.6	7.5
All Out-of-State Prod.	19,197	46,766	158,759	183,208	22,680	216,186	515,868	1,250,722	1,860,332	193,901	11.3	11.0	7.9	10.2
New York Produced	408	2,676	16,329	1,724	133,811	176	1,152	7,027	742	57,580	0.4	0.4	0.4	0.4
Total NY Utilization	19,605	49,442	175,088	184,932	156,491	216,362	517,020	1,257,749	1,861,074	251,481	11.0	10.5	7.2	10.1
						Annual CO2 Emissions for diesel fuel @69kgCO2/GJ								
						tonnes CO2	tonnes CO2	tonnes CO2	tonnes CO2	tonnes CO2	kg CO2 per kg	kg CO2 per kg	kg CO3 per kg	kg CO4 per kg
U S Production, not NY						14,350	33,044	34,615	126,500	12,596	0.78	0.77	0.39	0.70
Foreign Production						567	2,551	51,684	1,863	783	0.63	0.71	0.73	0.52
All Out-of-State Prod.						14,917	35,595	86,300	128,363	13,379	0.78	0.76	0.54	0.70
New York Produced						12	79	485	51	3,973	0.03	0.03	0.03	0.03
Total NY Utilization						14,929	35,674	86,785	128,414	17,352	0.76	0.72	0.50	0.69

Note. NY Produced means produced and consumed in NY. Total NY apple production exceeds NY consumption.
Note. All energy in transportation has been treated as diesel fuel derived for simplicity. Direct liquid fuel use is from 80 to 90 % of total energy. See Table 4-2

Table 4-8. Average Distances and Amounts Shipped for Selected Produce Consumed in New York

Geographic source	Quantities shipped -- 1000 cwt					Average distance shipped -- miles				
	Fresh Spinach	Fresh Straw-berry	Fresh Tomato	Head Lettuce	Fresh Apple	Fresh Spinach	Fresh Straw-berry	Fresh Tomato	Head Lettuce	Fresh Apple
	1000 cwt	1000 cwt	1000 cwt	1000 cwt	1000 cwt	miles	miles	miles	miles	miles
Outside NY State, US	403	952	1,937	3,960	451	2,962	2,897	1,695	2,983	2,615
Outside NY State, Foreign	20	79	1,563	79	49	2,850	2,850	2,879	2,822	6,458
Outside NY State, All	423	1,031	3,500	4,039	500	2,956	2,894	2,224	2,980	2,995
Inside NY State	9	59	360	38	2,950	100	100	100	100	100
All Utilized in NY State	432	1,090	3,860	4,077	3,450	2,897	2,742	2,026	2,953	520

TASK 5: DATA ON CEA CROP OPERATIONS AND ENERGY REQUIREMENTS

Develop, based on computer simulation and operating experience at Cornell, a data bank of CEA crop operations and the associated energy requirements for the chosen produce types if grown in New York State CEA facilities.

HISTORY AND APPROACH

Lettuce has been grown for several years in pond culture by Cornell CEA and Challenge Industries in Ithaca, NY, and by Luc Desrochers and his associates of Hydroserre Mirabel Inc., Montreal, Canada, who have franchised their system to other places in the world under Hydronov Inc. Lettuce is also grown in NFT/channel culture in many parts of the world, particularly Europe and Japan. We have considerable knowledge of environmental effects on lettuce productivity, and several years of data on energy use in commercial production using light integral control to draw on for energy analysis of this crop in the northeastern region of the US.

Spinach is grown extensively in protected culture using NFT in Japan and Korea. In the US, excellent outdoor conditions for spinach production exist in California and Arizona, requiring greenhouse production to be highly efficient to compete economically with the outdoor crop. Susceptibility of the crop to *Pythium* root-rot disease when grown in hydroponic culture has made it necessary to thoroughly sterilize equipment between crop cycles, which has made this manner of production too risky and/or labor intensive to be economically viable in the US. The outdoor crop does not suffer from this problem. However, the CEA program at Cornell, supported by NYSERDA, has determined the growing requirements for successful disease-free spinach production in pond culture which is less capital intensive and labor-demanding than NFT culture, and we believe this crop has a bright future in pond culture in the US (Albright, et al., 2005). A scale-up project to commercial level of production is underway.

The yield characteristics for spinach are very similar to those for lettuce, so that, with minor changes (for example seed quantities, medium used, harvest equipment, pond cooling requirements,) the analysis for lettuce will apply to spinach.

Greenhouse tomato is grown extensively all over the US and throughout the world, the Dutch and British having developed the initial expertise. US neighbors Mexico and Canada have recently greatly expanded their greenhouse tomato industries (Cook and Calvin, 2005). Greenhouse tomatoes are being produced successfully at the latitude of the US- Canada border, from Maine to British Columbia. In the South, large-scale production is found in Texas, Colorado, Arizona and several parts of Mexico, Eurofresh Farms and Village Farms being large players in the US.

In principle, we can determine the energy embodied in the greenhouse structure and the equipment it contains, and in the seed, water, fertilizer, and growing medium that are always consumed during the life of a crop. When it comes to the amount of energy required to maintain environmental set points, the situation is more complex. The energy required to run a greenhouse varies greatly with the time of year. As the temperature decreases as winter approaches, heating is required in ever increasing amounts in temperate latitudes. (In the current era it is usually supplied by natural-gas-fired boilers, but greenhouse growers may revert back to coal as natural gas resources become scarcer.) As the temperature increases in the summer, more ventilation is required and evaporative cooling of intake air may be employed. Large electric fans are used to exchange air. (Farther south, water in the form of fog is injected into the greenhouse for additional cooling.) As the summer season turns into winter, less natural light is available for the crop and growth slows unless supplementary lighting is used. Serious deterioration in crop quality occurs under low light – nitrate content may increase to dangerous levels in leafy greens, lettuce heads do not form properly, and tomatoes lose flavor and sweetness and the tomato plants become spindly and may cease production during mid winter.

In practice, most greenhouse growers of lettuce and tomato in northern temperate climates historically have not used supplementary lighting in winter months to any significant extent but, instead, have either closed their greenhouses for a period of time, using this opportunity to terminate old plants and make a fresh start (tomato growers), or allowed productivity to fall to a fraction of summertime values (lettuce growers in Europe and Canada). Lettuce growers also typically have used lower growing temperatures in the winter. There is a growing trend to install some lighting capability, but in almost all cases so far it is in a token amount, insufficient to support normal growth in mid winter.

The Northeast and Midwest of the United States and Canada are densely populated and provide an excellent market opportunity for greenhouse-grown produce. However, in these regions the winter climate is sufficiently harsh and the light conditions sufficiently poor that it may not be economically feasible to maintain year-long production, even though it is possible to do so. Leamington Ontario tomato growers have been highly successful in supplying tomatoes for 7 to 10 months in the year (Papadopoulos and Gosselin, 2007) but have not taken the step of moving to year-long production under supplemental lighting because of the energy costs involved, even though they risk losing market position by not maintaining a year-long supply.

With increasing transportation costs for remote producers such as California, Mexico and Florida, it is becoming economically more advantageous to grow crops closer to markets in the Northeast. However, greenhouse energy costs are also rising. In order to properly evaluate this issue, we need to model greenhouse energy use year-long, and also for the shorter seasons often used in practice, as well as with and without supplemental lighting and CO_2 enrichment, to determine how the competitiveness of the greenhouse crop with the field crop (that must be transported) varies under different production scenarios.

In performing an energy analysis of greenhouse production of lettuce and tomato, it becomes clear, then, that the analysis depends on the particular climatic conditions where the greenhouse is located. The analysis also depends on what one assumes will be the production practice. We have a range of lighting and heating options to consider, as well as different cropping durations. We need to model year-long production in which environmental set points and productivity are maintained the same throughout the year, and also existing practice in the tomato industry, in which operations are terminated for the coldest and darkest months after a period of diminishing daily natural light integrals.

Our plan in this report is to consider the Ithaca, New York, location as an exemplar of greenhouse crop production in the northern tier of the US for lettuce, spinach, and tomato, and determine fuel and electricity use (and, by implication, cost) to maintain steady production throughout the year in a feasible, near-optimum environment, achieved through use of supplemental lighting and CO_2 enrichment. In this analysis we will assume use of the advanced algorithms developed in the Cornell CEA program for control of supplemental light and CO_2 enrichment to optimize the energy and operating costs in controlling the greenhouse environment (LASSI-1 for light, LASSI-2 for light plus CO_2). We will compare energy use (i.e. supplied energy) in production with and without daily light integral control and with and without CO_2 enrichment. We will make this analysis on 8, 10, and 12-month bases to show how energy use for production changes with the season, and under what circumstances local greenhouse production is energetically more efficient than remote, transported production. Using Ithaca as an exemplar, we can claim "If you can make it here you can make it anywhere" because upstate New York is, in most respects, as challenging or more challenging for year-round greenhouse production than anywhere else in the US.

OPERATIONS IN TOMATO PRODUCTION

Tomato greenhouse production practices are constantly evolving and several kinds of systems are in use today. Scheduling the annual crop cycle is quite different in different parts of the country, with down-time scheduled for midsummer in the south and midwinter in the north. However, in the northern temperate regions, there is economic pressure to extend the harvest period as much into the winter as possible, as noted above. As the following account will show, tomato production is a highly specialized practice requiring constant attention to the plants and is labor intensive.

In large, state of the art greenhouses in the northern tier, such as those at Leamington, Ontario (the largest complex in North America,) it is typical to start seedlings in small rock wool blocks (often in December) in a dedicated part of the facility approximately eight weeks in advance of when they will be transplanted to the greenhouse onto large rock wool slabs. The slabs on which the seedlings are placed rest in gutters/troughs that are raised some 2 ft (0.6m) above the floor. Each plant is supplied with a drip-irrigation loop, through which it is irrigated many times a day. Excess nutrient solution (c. 20%) is drained via the trough to a collection tank, where it is periodically treated, amended, and recycled.

In greenhouse tomato production, the same plants are kept producing as long as 12 months before being replaced, and the vines become very long. Plant spacing is important for transmitting light down to lower leaves. Plants are arranged in long double rows. The double rows are just over 5 ft (1.6m) apart, center to center. The distance between paired plants in the double rows is approximately 2 ft 3 in (0.7 m) apart, leaving 3 ft (0.9 m) clear between outer rows for harvest and plant tending operations. Motorized vehicles run on tracks in this 3 ft alley. Plants typically are 18 in (0.5 m) apart within the row. These relations can be seen in Figures 5-1 and 5-2.

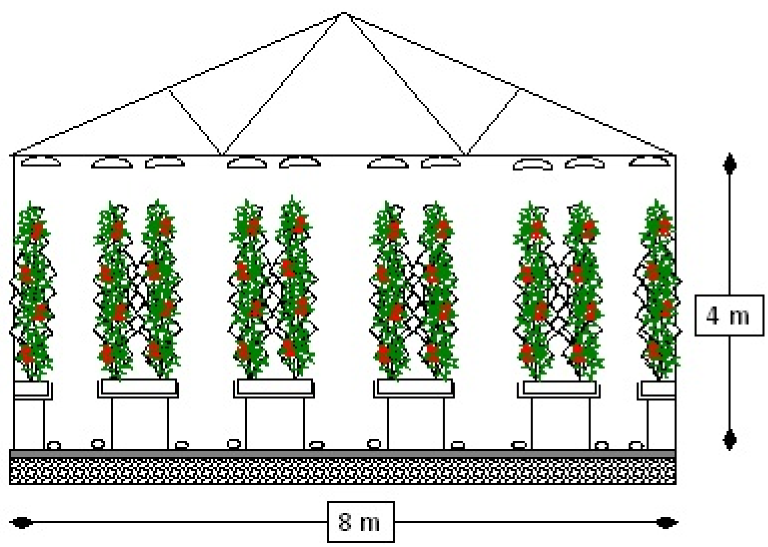

Figure 5-1. Profile View of Example Tomato Greenhouse

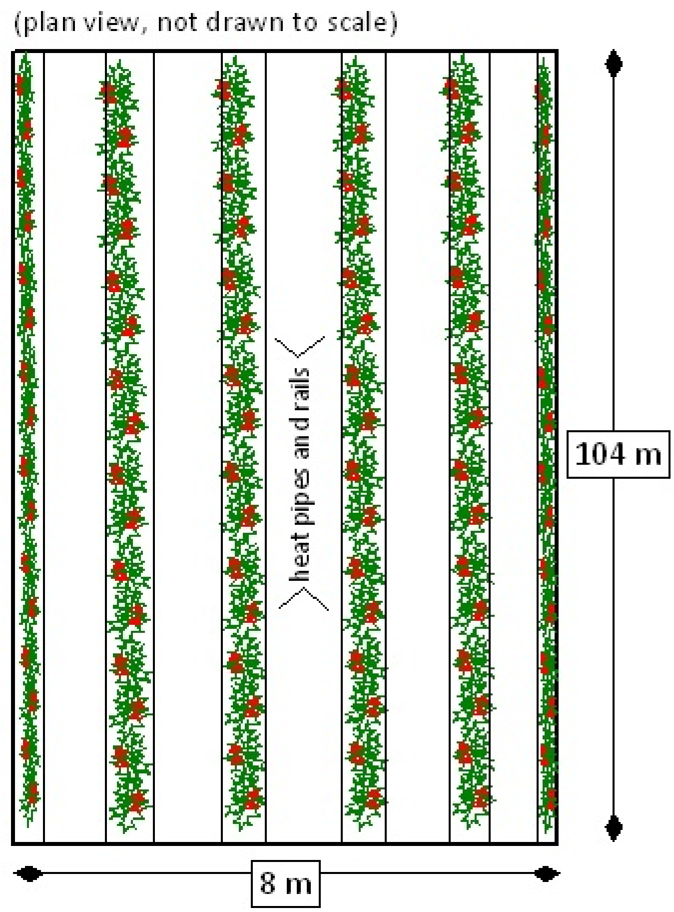

Figure 5-2. Plan View of Example Tomato Greenhouse

Before new plants are so tall they fall over, they are tied to strings attached to an overhead wire/cable about 10 ft (3m) above the floor. Additional turns are taken about the stem of each plant to support new growth every week. Plants are pruned to just one stem by pinching out shoots other than the apical meristem. The number of fruits allowed to develop in each flower truss is limited, typically to four for large tomatoes. Bumble bees are used to pollinate plants or, alternatively, flowers trusses are vibrated to ensure self pollination. As fruits become heavy, each fruit truss may be individually supported to prevent breakage, depending on cultivar and type of tomato. When plants have reached the desired final height (c. 8 ft or 2.5 m from the base), they are "let down" approximately 16 inches (40cm) as frequently as they grow back to the final height (which depends on weather conditions and fruit load, but might be every week to ten days.) In this process, lower leaves (below fruit-bearing trusses) are stripped and the bottom part of the stem is made to lie horizontally at the level of the rock wool substrate, in the same direction for all plants. In time, a thick horizontal cable of tomato stems is formed, and the vertical productive part of the plant may reach 25 feet or more away from its starting point and root system. Fruit is harvested about twice a week at breaker stage, or a more mature stage. Harvest frequency and maturity stage depend on growing conditions and market requirements.

In the primary scheme we are positing, the crop is grown in this fashion for 10 months, during 8 of which fruit is harvested (April to November), after which the crop is terminated and the greenhouse is cleaned and sterilized. The greenhouse is unoccupied for two of the coldest and darkest months (December and January). However, during this time seedlings are under production elsewhere in growth chambers or a small lighted greenhouse to be ready for transplant in February. Seedlings are often bought in from greenhouse operations specializing in seedling production.

If light is supplied as needed during winter months, the crop may be grown continuously by gradually replacing older plants with inter-plants. In modeling greenhouse tomato production using light integral control, we envisage this procedure being adopted. However, it is desirable to disinfect the greenhouse every two years at a minimum and preferably every year, so continuous harvest is not possible in a single facility (though could easily be managed by staggering operations in separate adjacent facilities) without risking catastrophic failure due to disease. If two months are needed to return to production, starting from seedlings, and disinfection is scheduled every two years, under so-called continuous production systems only 11 months of harvest is possible, as a maximum. However, the greenhouse would be in continuous production in the sense of having plants growing in it continuously, apart from the few days required for disinfection and clean up and, thus, would require light and heat continuously.

For the purposes of this analysis, we would like to consider production scenarios for each of the crops, in which cropping is conducted for 8, 10, and 12 months of the year, with and without supplemental lighting and with and without CO_2 enrichment. In the case of tomato, it is not possible to maintain the plants in healthy condition in northern latitudes all the way through the winter without use of supplemental lighting, so 12-month cropping scenarios without supplemental lighting are not feasible and will not be considered. They will be considered with supplemental lighting, however.

In the 8-month cropping scenario for tomatoes, plants occupy the greenhouse from March to October but only yield for 6 months, from May through October. The greenhouse is empty and on maintenance-level heating for 4 winter months, from November through February. In the 10-month cropping scenario, tomato plants occupy the greenhouse from February to November but only yield for 8 months, from April through November. The greenhouse is empty and on maintenance-level heating for 2 months, December and January. In the 8 and 10 month scenarios for lettuce and spinach crops, we assume one month is needed to return to operation, during which there is no yield but heat and light are required; annual yield is based on 7 and 9 months harvest respectively.

In the 12 month cropping scenario for tomato, with supplemental lighting, we must take into account that harvest can only be conducted 11 months of the year (on average) but heat and light are required continuously. In the continuous cropping scenarios for lettuce and spinach, we have built in the assumption the greenhouse must be closed for one month every 3 years for renovation and disinfection operations.

OPERATIONS IN BOSTON LETTUCE PRODUCTION

Spinach and lettuce crops can each be grown in pond culture or NFT culture; pond culture is arguably the more efficient and certainly it is the method that safeguards best against catastrophic failure; it is the one we will consider here.

In typical pond culture, separate sections are used to accommodate plants at different densities and growth stages for logistical reasons, which is why we refer to ponds plural. (See below.) Ponds are simple to construct but in all cases they need to incorporate a means of stirring the solution to distribute nutrients uniformly to plants, a means of adding stock solutions and adjusting pond pH as needed, a means of dissolving oxygen in the water, and a means of heating or cooling the pond water to maintain desired root zone temperature. These functions are combined in a circulation system that operates continuously and incurs a significant energy cost. In deep ponds (c. 12 inches, or 30 cm), plumbing for circulation and aeration can be placed within the ponds. In shallow ponds (c. 3 inches, or 8 cm) there may not be room for plumbing in the pond and an external reservoir may be needed.

Flotation devices are needed to support plants in ponds and also to act as rafts to move the crop about. High-density polystyrene sheet material is typically used for this purpose. It is readily available and easily cut and machined. Floats are commonly composed of 1 inch thick HD polystyrene, with holes drilled to receive plants in their containers/cubes at the desired plant density. For ease of handling, floats are typically no larger than 8 sq ft (2 ft by 4 ft). In large-scale commercial production, more durable and environmentally friendly floats can be custom made.

If large heads of lettuce are to be grown, the usual procedure is to produce seedlings outside the pond growing area, and transplant them into the ponds when they are c. 12 days old. The exact time it takes to reach transplant size depends on light conditions. If a growth chamber is used, the daily light integral can be raised above the 17 mol m^{-2} d^{-1}, typical of greenhouse space, to shorten the time to 11 days. Under greenhouse conditions, the more economic option for seedling production, the time might be as long as 15 days. To be able to handle and transplant seedlings easily, each seedling needs to be started in an individual small pot or block such as a rock wool cube. Seedlings can be produced using ebb and flood benches, floating in ponds, or with overhead irrigation. They are produced on site at high density (c. 2 in^2 or 13 cm^2 per plant) to conserve space.

Twelve-day-old seedlings require 24 days additional growing time to reach saleable size at a Photosynthetically Active Radiation (PAR) intensity of 17 mol m^{-2} d^{-1}. At time of transplant into ponds, plants are allocated c. 21 in^2 (135 cm^2). Plants are grown at this spacing for 10 days, by which time they have become crowded and are re-spaced to 42 in^2 per plant (270 cm^2) for the final 14 days. Separate ponds are used at each of these plant densities, sized so that the plants reach the end of the pond at the appropriate time for re-spacing or harvest.

In continuous production, crops are harvested daily and new crops are seeded daily to sustain production. Every day four main operations need to be completed: seeding, transplant, re-spacing and harvest. Each of the operations needs to be performed in proper order because the greenhouse is kept as full as possible, and only by harvesting mature plants is more space made available for new crop cohorts; this requirement imposes the order of daily tasks in the greenhouse.

Lettuce is harvested by removing floats at one end of the final grow-out pond. The raft of remaining plants is pushed along the pond to make space at the other end. This makes room for new floats to be moved into the final grow-out pond from the first pond which permits the plant to be re-spaced. Removing plants at the exit end of the initial pond in turn makes room to add new floats containing new seedlings at the entry end of this pond. Enough seedling flats must be sown each day to replenish seedlings as they are used.

The scheme described was developed for cultivars such as Ostinata, Vivaldi, and Flandria. The densities and durations mentioned apply if 16 to17 mol m^{-2} d^{-1} daily light integral are used and a 5 to 6 oz head is required, but the optimal plant density and crop duration at each plant density differs from cultivar to cultivar, and according to greenhouse growing conditions and target plant size. When growing 5 oz Boston lettuce plants it is most cost effective to use just one re-spacing after transplant, although more are certainly possible, and would be desirable for larger plants.

Of the daily operations required in lettuce production, the harvest phase is typically the most time-consuming and also most variable because it involves individually inspecting, trimming and packaging each head and must be performed with care not to damage the plant.

OPERATIONS IN BABY LEAF SPINACH PRODUCTION

If spinach is grown for baby-leaf salad greens, the crop is grown from seed to harvest in about the time it takes to produce lettuce seedlings, c. 14 days, 12 of which are spent in ponds. Very high plant densities are used (c. 1500 plants per m^2). Seeding is to final density and there is no transplant operation and no re-spacing operation. Germination is accomplished before flotation. It requires 48 hours in warm, dark, humid conditions. Floats may be stacked vertically to save space during this time. After germination, flats are floated and remain in the same pond until harvest. Supplemental lighting is necessary during wintertime, to ensure the crop is removed speedily enough to avoid a complete Pythium reproductive cycle before harvest, with reinfection of new plants placed into the pond. It is desirable, year-round, to regulate rate of growth and in-pond crop duration, and to offer some flexibility in meeting market needs. There is an alternative option to avoid disease, that of splitting the growth between two or more ponds, which incurs added labor cost and slows growth. Harvest requires special machinery – a cutter something like a horizontal band saw to cut and cleanly recover the small leaves and conveyor belts to move the cut product to the packing station.

In baby leaf production, the crop cycle is so short and the plant density so high that the number of seeds used per pound of product is orders of magnitude greater than for head lettuce or tomato – 390,000,000 seeds per ha per annum versus 7,300,000 for lettuce and 2,400 for tomato (see Tables 5-3, 4, and 5). More growing medium is used annually to germinate this large number of seeds than in the case of lettuce, although less is needed per individual plant. In terms of energy use, heat and light requirements are very similar to those for lettuce and tomato but the ponds need to be cooled to a greater degree in summer, at an expenditure in energy.

Spinach production is potentially less labor intensive than lettuce or tomato production for there is no transplanting and re-spacing, or plant care or repeated harvest as in the case of tomato, and seeding and harvesting necessarily are mechanized. Packaging too would be mechanized in larger operations. The biggest challenge in baby leaf production is material handling. A very large area of floats needs to be moved through the greenhouse every day and then cleaned for re-use.

The production system described supposes that each crop is harvested once only. In baby leaf production it is possible to harvest the same crop more than once, and the CEA program at Cornell has invested research time into this possibility (Albright, et al., 2005). With care how the first harvest is made, a second harvest can be made after re-growth that looks almost as good as the initial harvest. The appearance of subsequent harvests (3^{rd} on) is not as good because any cut leaves left behind become unsightly as they grow out; but the option is available of selling follow-on harvests for cooking/processing purposes, as is done in the field crop. Multiple harvesting of the same crop stand saves on seed and seeding expenses, and on float cleaning operations, but requires transfer of floats to a different pond after each harvest to eliminate potential disease problems. Supplemental lighting is necessary to ensure in-pond durations are no longer than the allowed limit in the repeated cropping scenario than in the single harvest scenario.

ENERGY ANALYSIS: ELECTRICITY AND FOSSIL FUEL IN GREENHOUSE PRODUCTION

Introduction

Production of crops in greenhouses involves direct use of energy provided by fuels, electricity and human labor, use of physical objects such as the greenhouse itself, and equipment and supplies, all of which required energy in their manufacture. We will evaluate all of the objects used in crop production as to how much energy went into their manufacture. Some items are consumed completely in one crop cycle whereas others are reused for many years. Examples of things consumed in one crop cycle are: fertilizer, seeds, packaging and water. Examples of things used over more than one crop cycle are: polystyrene floats, pumps and motors, and the greenhouse structure itself. The expected average life of these items ranges from 1 to 30 years. In calculating annual energy use, the conventional energy invested in material things or "embodied", is amortized over the estimated lives of the items.

Our analysis shows that manufacturing energy invested in physical objects, including the greenhouse structure, accounts for just 5% of total energy use, while direct use of electricity and fossil fuel accounts for 95% of the total supplied-energy expended in greenhouse production in the Northeast. The two main sources for direct energy are natural gas and electricity. The relative amounts of these energy sources required depends on whether supplementary lighting and CO_2 enrichment are used. Our main interest is how much of each kind of fuel or electricity is used in production, and how muchCO_2 is released into the atmosphere as a result of using these energy sources. We do not account how much free energy is supplied by the sun in the form of heat and light.

For the purposes of this energy analysis, we are omitting the energy of physical labor for two reasons. First, it is negligible compared to other energy uses. A person working an 8 hour shift of moderate physical activity expends about 0.7 megajoules (Stanhill, 1980). This is less than one-quarter of a kilowatt-hour per person per day, a trivial energy use compared with others, even if a large work-force is employed. Second, we argue it should not be included in principle. The reason for not including it in principle is that there is no marginal increase in human energy expended in the geographic domain in which greenhouse activities take place (which we take to be North America) by virtue of greenhouse crop production so long as the work involved in greenhouse activities is no harder than that in general living and working. (However, one could argue that the work opportunity afforded by industry in general is what sustains any given size of population, and greenhouse activity thus ultimately causes an increase in population and energy use. The current level of greenhouse production activity in the Northeast is unlikely to make such a difference today.)

The amount of use of direct energy resources depends on the production scenario (with or without supplementary lighting, with or without CO_2 enrichment, and length of the cropping season) and each production scenario corresponds to particular yield/productivity figures. Our ultimate goal is to calculate energy use intensity in greenhouse crop production, i.e., energy use per unit weight of commodity: how much electricity and natural gas is used directly per pound produced, and how much embodied energy.

Fuels, such as natural gas, and electricity should be assigned manufacturing energy in addition to their heat value (or enthalpy). For fossil fuels, the energy required to extract, process and transport the fuels is in the range of 10 to 20% of their heating value (See Table 3-1). In effect, the energy we get out of petroleum is very nearly free; it is after all, stored solar energy. The situation with electricity is more complicated. Electricity from the grid has typically been generated at a number of different locations using a variety of methods, some requiring consumption of fossil fuels, others not. If the method of generation is transduction of solar energy in the form of wind, water or sunlight, we are only interested in accounting for the "manufacturing energy" that went into the photovoltaic panels, the wind turbines or hydroelectric facility, not the efficiency of transduction of the solar energy resource. (To be consistent we should not count the electricity itself when it comes from solar sources, because it is renewable and free except for the manufacturing energy. But we will be inconsistent on this point.) If, on the other hand, electricity is produced using fossil fuels, we wish to know and account for all the fossil fuel required; the efficiency of conversion is about 30 to 40%, depending on the fuel and the method; roughly 2.5 to 3 times as much heat energy goes into producing electricity as can be recovered when it is converted back to heat in a power generation station.

Thus, to calculate CO_2 emissions and fossil fuel use when electricity is used in crop production, we need to know what proportion of the electricity is produced using fossil fuels and what proportion comes from renewable resources such as wind, solar, or hydro. For that part produced using fossil fuel (or fissionable material in the case of nuclear power), we need to take into account the efficiency of energy conversion in generation of electricity, and also include an allowance for extraction, refinement and delivery of the fuel. But, for that part produced using renewable resources (wind, hydroelectric, photovoltaic), we are not concerned with energy conversion efficiency. In these "alternative" sources of electricity, the energy not converted is of minor interest because it is renewable and free, but we still need to account for the energy embodied in the equipment for generating electricity.

In the analysis of greenhouse energy use that follows, we have presented direct energy use at face value. The figures for electricity are the actual kilowatt hours used on site, without regard for method of generation or energy use in generation. Similarly, the natural gas figures are for the quantity of natural gas required on site. Subsequently, we have also calculated direct energy use when manufacturing/generating energy is included. We know what mix of methods typically goes into electricity generation in NY, which enables the calculation, and have also needed this information to calculate carbon dioxide emissions corresponding to the electricity used in greenhouse production.

In the case of energy embodied in materials and supplies, energy intensities for different materials and products are taken from many sources, and inverse efficiency factors for electricity and fuel production may have been included in some cases but not in others. When estimating CO_2 emissions in connection with manufacturing energy, uncertainty as to the mixture of energy sources used in manufacturing makes these estimates less certain.

Although it is possible to compute a figure for total energy use in production (i.e., supplied energy), and we have done so, this figure can be quite misleading unless it is clear what it represents – because it requires combining different types of energy together, some from renewable and some from non-renewable energy resources, and a large part of the energy that goes into production is excluded entirely. In this analysis we are not enumerating solar light and heat energy that enters the greenhouse directly through the glass. However, solar energy acquired directly, both heat and light, is computed and used in the algorithms that determine how much supplementary lighting, heating, and CO_2 are needed.

A critical difference between greenhouse and field production in the Northeast, and any kind of remote production, is that energy needed for transportation to final consumers is much less. This means there is considerably less reliance on liquid fossil fuels in road and rail transportation, a fact that can be expected to take on increased significance as petroleum reserves are exhausted. Greenhouse energy use divides between electricity and natural gas at present, and no liquid fossil fuel is used directly. The electricity required in greenhouse production potentially can be generated entirely without use of fossil fuels or CO_2 emissions, (as is done with hydropower in Quebec, Canada) or, if fossil fuels are used, with coal for which reserves are much greater than other fossil fuels. In regard to natural gas use, although greenhouses have a high heat requirement in the winter, only a low-grade form of energy is required and by-product waste heat produced in the generation of electricity and other manufacturing processes is perfectly suitable if the heat sources are near enough to markets. (In Poland, for instance, a conscious effort has been made to provide cheap heat energy from power plants to the greenhouse industry.) It is also possible to exploit geothermal heat, or store summertime heat in the ground and in aquifers for use in winter; these technologies are being actively developed. In conclusion, total energy use may not be as useful or meaningful to us as how much of each kind of energy resource is used when it comes to evaluating future possibilities.

Embodied Energy

We are modeling greenhouse production in a hypothetical modern glasshouse with a growing area of one hectare (ha) (2.47 acres), and head house and walkways comprising an additional 0.2 ha (0.5 acres). In the tables that follow, supplied-energy use is presented on a per-hectare basis but this should be taken to mean per 1-ha-growing-area-greenhouse.

The energies embodied in the greenhouse structure and selected basic functional systems are found in Table 5-1 below. Whatever the crop, the greenhouse needs a heating and ventilation system, but a crop lighting system is optional. A lighting system that would enable year-round production is itemized separately in this table. It can be seen that the embodied energy without a lighting system is 1250GJ/ha/yr, and it is 1500 GJ/ha/yr with a lighting system. The greenhouse structure and concrete pad requires over 1000 GJ. Much of the embodied energy is used in production of items made of steel, and fuels used are a mixture of coal, natural gas, and electricity.

Stanhill (1980) estimated materials and energy use in tomato production in a 1-ha Venlo-style glasshouse facility in southern England, with heating capability. This estimate is shown in Table 5-2. In our estimate, structural materials have all increased greatly. This is in part because greenhouses are now built with much higher side walls. Our materials quantities are from J. Hoogeboom of Rough Bros. (personal communication) using design figures for greenhouses in the northern US. Wind and snow design loads may be greater for the northeastern US than were used in England. We have also included an edge-thickened concrete pad, absent in the Stanhill estimate, and have added 20% more area to allow for head house and walkways while still maintaining 1 hectare of actual growing space.

Each crop requires a different equipment set-up in the greenhouse, and consumes different amounts of supplies. Tables 5-3, 5-4, and 5-5 show the embodied energy for these items specific to lettuce, spinach, and tomato production under 8, 10 and 12-month cropping periods. Crop-specific embodied energy adds about 800 GJ/ha/yr to the common greenhouse embodied energy total. Fortuitously it is similar in all three crops, although each crop has different items for which large amounts of embodied energy are assigned. Tomato is a heavier user of fertilizer than lettuce and spinach, and requires substantial specialized structural components (gutters and rails). Spinach and lettuce require a large investment in flotation devices and pond liner. All three crops need large amounts of substrate for seedlings, although the form differs for each crop.

We have distinguished between supplies that are consumed in each crop cycle – such as water, fertilizer, and growing medium – and more durable items that are used over more than one crop cycle, usually over many years. We have estimated amounts of consumables saved through use of a shorter cropping season but, as can be seen, the savings are very small, effectively negligible compared with other energy uses.

Table 5-1. Energy Embodied in Greenhouse Equipment and Structures common to all crops and CO_2 Emissions in manufacture

Item	Number of items / Quantity	Energy source	Weight of material	Energy rate	Years amort-ized	Embodied Energy	CO_2 Emissions factor	CO_2 Emissions
			kg/ha	MJ/kg	Years	GJ/ha/yr	kg/GJ	kg/ha/yr
Greenhouse Structure: all scenarios, all crops								
steel		coal+ng	196,151	35	30	229	78	17,850
aluminium		mxd	50,439	170	30	286	67	19,064
glass		NG	190,546	26	30	165	38	6,275
concrete pad, @2.4tonne/m3 -m3	1,016	coal	2,438,400	2	30	163	179	29,098
concrete piers, @2.4tonne/m3 -m3	80	coal	192,000	2	30	13	179	2,291
steel re-inforcing for pad		coal+ng	9,484	35	30	11	78	863
steel re-inforcing for edges		coal+ng	1,588	35	30	1.9	78	145
						868		**75,586**
Headhouse and Walkways: all scenarios, all crops								
greenhouse walkways @ 10% GH structure		coal+ng			30	87	78	6,770
headhouse space @ 10% GH structure		coal+ng			30	87	78	6,770
						174		**13,541**
Greenhouse Contents: all scenarios, all crops								
boilers for heating, @5tonne/boiler- No.	4	coal+ng	20,000	46	15	61	78	4,784
heating pipework, steel		coal+ng	89,779	35	30	105	78	8,170
modines, @ 20kg/exchanger - No.	160	coal+ng	3,200	46	30	4.9	78	383
venting fans, @ 50kg/fan -No.	12	coal+ng	600	46	20	1.4	78	108
shade and insulation curtains, 10000m2, PVC		NG	4,320	70	15	20	38	766
motors for inlet vents, @ 50kg/motor -No.	2	coal+ng	100	46	15	0.3	78	24
pumps for pad water circulation, @25kg/pum	2	coal+ng	50	46	15	0.2	78	12
reservoirs for pad water (steel) -No.	2	coal+ng	200	46	30	0.3	78	24
headhouse heating pipework @10% of GH		coal+ng	8,978	46	30	11	78	819
headhouse insulation curtains, PVC, @10% of GH		NG	432	35	15	2.0	38	76
headhouse luminaires, @40kg/luminaire-No.	24	coal+ng	960	46	20	2.2	78	172
						208		**15,337**
Sub-total: embodied energy, all crops, without a lighting system						**1,250**		**104,464**
Crop Lighting system: all crops, but not used in all production scenarios								
GH luminaires, @ 40kg/luminaire-No.	2,497	coal+ng	99,880	46	20	230	78	17,918
copper wiring		mxd	4,642	71	30	11	78	857
wiring sheathing-PVC		NG	500	70	30	1.2	38	44
conduit (steel)		coal+ng	5,400	35	30	6.3	78	491
						248		**19,311**
Total: embodied energy, all crops, with lighting system						**1,498**		**123,776**

Table 5-2. Comparison of Greenhouse Tomato Energy Use Estimates

Item		Tomato (Stanhill, 1980) England, greenhouse, south coast; Spring and Summer, heated, with CO2				Factor 0.947817	CEA Tomato Est. Ithaca, NY. 8 month, with CO2
		need/ha	MJ/l or kg	life, yr	GJ/ha	MBtu/ha	GJ/ha
Greenhouse Structure							
GH glass		120000	23.2	25	111	106	
GH glass replacement (1% per year)					28	26	
GH aluminum		20000	254	25	203	193	
GH steel		7000	90	25	25	24	
GH construction (inc conc)					1	1	
Sub total					**369**	**350**	**1,042**
Greenhouse equipment and consumables							
GH heating system		100000	90 MJ kg-1		600	569	
machinery	kg	(deprectn, repairs)			2	2	
trellis wire		230	24	10	1	1	
string		100	149	1	1	1	
pe trickler		724	106	7	11	10	
tanks		400	90	7	5	5	
other		372	253	10	9	9	
nitrogen	kg	1214					
phosporus	kg	150					
potassium	kg	3255					
All fertilizer					127	121	
lime	kg	10000	2		20	19	
peatmoss	kg	95 m3(peat	8.37 GJ m-3		80	75	
seeds/seedlinç	kg	(seedling and overhead)_			100	95	
irrigation water	cm	11045 m3	9.1MJ m-3		101	95	
All pesticides	kg	180	100		18	17	
Sub total					**1,075**	**1,019**	**1,002**
Direct Energy Use							
labor	hr	19725	.7MJ h-1		13	13	
diesel	l	(mechanical ops.)			6	6	
heating oil	l	505800	46.6		23,570	22,340	
electricity	kWh	74.13	14.4 kWh-1		1,067	1,012	
natural gas/propane		9670kg	56.7		548	519	
Sub total					**25,205**	**23,890**	**25,050**
Total Energy Use/ha					**26,649**	**25,259**	**27,094**
soil fumigant		56200	46.6		2,619	2,482	
Grand Total Energy Use/ha					29,268	27,741	
Yield	kg/ha				213,000	213,000	546,800
	lb/acre				190,039	190,039	487,849
Energy use -units				**kWh**	**MJ**	**kBtu**	**kWh**
Energy use/ kg product				35	125	119	13.8
Energy use/ lb product				16	57	54	6.2

Table 5-3. Lettuce-specific Embodied Energy and CO2 Emissions in Greenhouse Lettuce Production

Item	Number of items/ Quantity	Energy source	Weight of material	Energy rate	Years amort-ized	Embodied Energy	CO2 Emissions factor	CO2 Emissions
			kg/ha	MJ/kg	Years	GJ/ha/yr	kg/GJ	kg/ha/yr
Long-term Equipment: Not dependent on crop duration								
fertilizer mixers, PVC, @25kg.unit- No.	12	coal+ng	300	70	15	2	78	117
pumps for irrigation, @100kg/pump -No.	12	coal+ng	1,200	46	15	4	78	287
plumbing for pond circulation, PVC		ng	3,370	70	30	8	38	299
in-line pond cooling/heating @50kg/unit -No.	12	coal+ng	600	71	15	3	78	222
pond liner HDPE		ng	5,128	103	10	53	38	2,007
pond floats-polystyrene @ xkg/m2		ng	6,510	117	2	381	38	14,472
seeder, trayfiller, @ 200 kg/unit -No.	2	coal+ng	400	46	10	2	78	144
Subtotal						**451**		**17,547**
Consumables: Not dependent on crop duration								
water for cooling pads, @1000kg/m3 - No. m	2,300	elect.	2,300	0.576	1	1	97	129
Subtotal						**1**		**129**
Total: Not dependent on crop duration						**453**		**17,675**
Consumables: Dependent on crop duration								
1. Natural gas based								
fertilizer, N		ng	2,306	62	1	142	38	5,390
P		ng	477	13	1	6	38	228
K		ng	3,306	7	1	22	38	842
fungicides/pesticides		ng	250	100	1	25	38	950
12-day old seedlings, germinated -No.	7,300,000	mxd	__	__	1		__	__
seeds		mxd	8	17	1	0	38	5
seed treatment		ng	41	147	1	6	38	226
seedling rockwool		ng	15,809	14	1	221	38	8,410
Subtotal- 12-month						**422**		**16051**
Subtotal- 10-month						**352**		**13376**
Subtotal- 8-month						**282**		**10701**
2. Electricity based			tonne/ha	MJ/tonne				
water for plants, @1 tonne/m3 -No.m3	15,400	elect.	15,375	0.576	1	9	97	861
water for toiletry, cleaning	4,800	elect.	4,800	0.576	1	3	97	269
Subtotal- 12-month						**12**		**1,129**
Subtotal- 10-month						**10**		**941**
Subtotal- 8-month						**8**		**753**
Total Consumables: Dependent on crop duration								
Total -12 month cropping						**434**		**17181**
Total -10 month cropping						**362**		**14317**
Total -8 month cropping						**289**		**11454**
Lettuce specific embodied energy and CO2 emissions: 12 month cropping						**887**		**34,856**
Lettuce specific embodied energy and CO2 emissions: 10 month cropping						**814**		**31,992**
Lettuce specific embodied energy and CO2 emissions: 8 month cropping						**742**		**29,129**
Embodied energy, common to all crops, without a lighting system						**1,250**		**104,464**
Embodied energy, common to all crops, with lighting system						**1,498**		**123,776**

Table 5-4. Spinach-specific Embodied Energy and CO_2 Emissions in Greenhouse Spinach Production

Item	Number of items/ Quantity	Energy source	Weight of material	Energy rate	Years amort-ized	Embodied Energy	CO_2 Emissions factor	CO_2 Emissions
			kg/ha	MJ/kg	Years	GJ/ha/yr	kg/GJ	kg/ha/yr
Long-term Equipment: Not dependent on crop duration								
fertilizer mixers, PVC, @25kg.unit- No.	12	coal+ng	300	70	15	1.5	78	117
pumps for irrigation, @100kg/pump -No.	12	coal+ng	1,200	46	15	3.7	78	287
plumbing for pond circulation, PVC		ng	3,370	70	30	7.9	38	299
in-line pond cooling/heating @50kg/unit -No.	12	coal+ng	600	71	15	2.8	78	222
pond liner HDPE		ng	5,128	103	10	53	38	2,007
pond floats-polystyrene @ xkg/m2		ng	6,510	117	2	381	38	14,472
seeders, trayfillers, @ 200 kg/unit-No.	4	coal+ng	800	46	10	3.7	78	287
machine harvesters, @100kg/unit -No.	4	coal+ng	400	71	5	2.8	78	222
Subtotal						**456**		**17,912**
Consumables: Not dependent on crop duration								
water for cooling pads, @1000kg/m3 - No. m3	2,300	elect.	2,300	0.576	1	1.3	97	129
Subtotal						**1.3**		**129**
Total: Not dependent on crop duration						**457**		**18,040**
Consumables: Dependent on crop duration								
1. Natural gas/fossil based								
fertilizer, N		ng	2,306	62	1	142	38	5,390
P		ng	477	13	1	6	38	228
K		ng	3,306	7	1	22	38	842
fungicides/pesticides		ng	250	100	1	25	38	950
2-day old seedlings, germinated -No.	390,000,000	mxd						
seeds		mxd	6,250	15	1	94	38	3,563
seed treatment- untreated								
peatmoss @5.7kg/cu.ft -No. cuft	27,545	diesel	156,000	1	1	156	70	10,920
Subtotal - 12-month						**445**		**21892**
Subtotal - 10-month						**371**		**18243**
Subtotal - 8-month						**296**		**14595**
2. Electricity based			tonne/ha	MJ/tonne				
water for plants, @1 tonne/m3 -No.m3	15,400	elect.	15,375	0.576	1	8.9	97	861
water for toiletry, cleaning	10,000	elect.	10,000	0.576	1	5.8	97	559
Subtotal - 12-month						**15**		**1419**
Subtotal - 10-month						**12**		**1183**
Subtotal - 8-month						**10**		**946**
Total Consumables: Dependent on crop duration								
Total -12 month cropping						**459**		**23311**
Total -10 month cropping						**383**		**19426**
Total -8 month cropping						**306**		**15541**
Spinach specific embodied energy and CO2 emissions: 12 month cropping						**917**		**41,352**
Spinach specific embodied energy and CO2 emissions: 10 month cropping						**840**		**37,466**
Spinach specific embodied energy and CO2 emissions: 8 month cropping						**764**		**33,581**
Embodied energy, common to all crops, without a lighting system						**1,250**		**104,464**
Embodied energy, common to all crops, with lighting system						**1,498**		**123,776**

Table 5-5. Tomato-specific Embodied Energy and CO 2 Emissions in Greenhouse Tomato Production

Item	Number of items/ Quantity	Energy source	Weight of material	Energy rate	Years amort-ized	Embodied Energy	CO2 Emissions factor	CO2 Emissions
			kg/ha	MJ/kg	Years	GJ/ha/yr	kg/GJ	kg/ha/yr
Long-term Equipment: Not dependent on crop duration								
fertilizer mixers, PVC, @25kg.unit- No.	12	ng	300	70	15	1	38	53
pumps for irrigation, @50kg/pump -No.	12	coal+ng	600	46	15	2	78	144
plumbing for irrigation, PVC		ng	3,900	70	30	9	38	346
rails for carts		coal+ng	74,069	35	30	86	78	6,740
motorized carts for harvest, @1tonne/cart -No	6	coal+ng	6,000	46	15	18	78	1,435
rockwool troughs (steel)		coal+ng	31,277	46	15	96	78	7,481
trellis wire, and hangers		coal+ng	1,000	35	15	2	78	182
seeder, trayfiller		coal+ng	100	46	10	0.5	78	36
Subtotal						**216**		**16,417**
Consumables: Not dependent on crop duration								
			kg/ha	MJ/kg				
6-week-old seedlings, @2MJ/plnt -No.	24,000	mxd	__	__	1	48	38	1,824
seedling rockwool		ng	207	14	1	3	38	110
rockwool slabs (large)		ng	11,189	14	1	157	38	5,953
string to tie up plants		ng	100	165	1	17	38	627
			tonne/ha	MJ/tonne				
water for cooling pads, @1000kg/m3 - No. m3	2,300	elect.	2,300	0.576	1	1	78	103
Subtotal						**225**		**8,617**
Total: Not dependent on crop duration						**441**		**25,034**
Consumables: Dependent on crop duration								
1. Natural gas based								
fertilizer, N		ng	6,357	62	1	391	38	14,857
P		ng	1,784	13	1	22	38	854
K		ng	11,302	7	1	76	38	2,877
fungicides/pesticides		ng	250	100	1	25	38	950
Subtotal - 12-month						**514**		**19538**
Subtotal - 10-month						**428**		**16282**
Subtotal - 8-month						**343**		**13026**
2. Electricity based			tonne/ha	MJ/tonne				
water for plants, @1 tonne/m3 -No.m3	22,000	elect	22,000	0.576	1	12.7	97	1,229
water for toiletry, cleaning	1,500	elect	1,500	0.576	1	0.9	97	84
Subtotal - 12-month						**13.5**		**1313**
Subtotal - 10-month						**11**		**1094**
Subtotal - 8-month						**9**		**875**
Total Consumables: Dependent on crop duration								
Total -12 month cropping						**528**		**20851**
Total -10 month cropping						**440**		**17376**
Total -8 month cropping						**352**		**13901**
Tomato specific embodied energy and CO2 emissions: 12 month cropping						**969**		**45,886**
Tomato specific embodied energy and CO2 emissions: 10 month cropping						**881**		**42,411**
Tomato specific embodied energy and CO2 emissions: 8 month cropping						**793**		**38,935**
Common structure and equipment without a lighting system						**1,250**		**104,464**
Common structure and equipment with a lighting system						**1,498**		**123,776**

Direct Use of Fuels and Electricity - Miscellaneous

Heating and lighting requirements dominate direct energy use for controlling the aerial environment during winter; these energy uses merit separate treatment. Energy is also used to a significant degree in venting for temperature control during summer, for cooling of ponds and nutrient solution during summer, and heating of nutrient solution and water during winter, and year-long for circulation of nutrient solution, mixing air within the greenhouse, and post-harvest chilling of harvested crops. (Numerous other pumps and motors are used; they are noted although they have a minor effect on total energy use.) Direct energy use in these miscellaneous categories is shown in Tables 5-6, 5-7, and 5-8 for each of the crops. The most startling finding in Tables 5-6 and 5-7 is that the pumps used for circulating the pond nutrient solution (Finger Lakes Fresh lettuce greenhouse) require 2500 GJ/ha/yr, which is 1000 GJ more than the entire embodied energy for the greenhouse structure shown in Table 5-1, and exceeds the grand total for embodied energy. It pinpoints an area where significant savings in use of electricity may be possible in the future.

Direct Energy Use – Heat and Light

Tables 5-9, 5-10, and 5-11 show heat and light energy used to control the aerial environment in detail for each of the crops. Sensible heat loads, supplemental light and CO_2 requirements were produced using historic weather data and the program LITEDUTY© developed by Albright. Close examination of these tables shows that the amount of energy to be supplied for space (sensible) heating, with supplemental lighting (but without CO_2 enrichment), is half that required without supplemental lighting – see the first supplemental heat column, “Supplementary sensible heat reqd.” In fact the sensible heat load of the greenhouse is no different with or without supplementary lighting; lighting is a source of heat and halves the amount of heat that would otherwise be needed for space heating. This has the effect of discounting the cost of using supplemental lighting. Conversely, when CO_2 enrichment reduces the supplemental lighting needed, the space heating requirement increases, which diminishes the cost benefit of CO_2 enrichment. However, need for supplemental lighting/electricity is halved for the 12-month cropping scenario by the use of CO_2, and there is a cost benefit, in addition to the benefit of substituting a low grade, potentially cheap energy source for an expensive high grade source. (The major part of CO_2 requirements of the crop may be met by using the exhaust gas from combustion of natural gas needed for heating. An allowance for natural gas combustion to generate CO_2 during those times CO_2 enrichment is desired but heating is not required, is included under the heading “Summertime CO_2 reqd.”)

Table 5-6. Miscellaneous Direct Energy Use by the Lettuce Crop

Item	Number of items/ quantity	Energy source	Energy rate	Energy rate	Energy rate Units	Energy Used	CO2 Emissions factor	CO2 Emissions
			kWh/m2/yr			GJ/ha/yr	kg/GJ	kg/ha/yr
Direct Energy Use for Lettuce: Miscellaneous items								
Venting and cooling: all scenarios								
operating venting fans		elect.	8.48	3.6	MJ/kWh	305	97	29612
opening/closing intake vents		elect.	0.1	3.6	MJ/kWh	4	97	349
recyling cooling pad water		elect.	0.2	3.6	MJ/kWh	7	97	698
cooling ponds, 3 mnth, 0.5C/day - vol in m3	2,800	elect.		4.186	MJ/deg/m3	176	97	17054
						492		**47,714**
Direct energy use - proportional to cropping duration: here 12-month								
mixing air - HAF		elect.	0.5	3.6	MJ/kWh	18	97	1746
pumping heating water		elect.	0.5	3.6	MJ/kWh	18	97	1746
chilling harvested crop		elect.	2.3	3.6	MJ/kWh	83	97	8032
mixing and circulating pond solutn (HP calc.)		elect.	67.5	3.6	MJ/kWh	2429	97	235605
Total						**2,548**		**247,128**
Direct energy use - special cases: 12-month. Halve for 10-month, halve again for 8 month								
lighting for headhouse work		elect.		24,000	kWh/ha	90	97	8730
heating ponds, 6 mnths, 10C.-vol., m3	7,500	ng		4.186	MJ/deg/m3	349	38	13262
Total						**439**		**21,992**
Grand Total						**3,479**		**316,834**
Lettuce Totals: Direct Energy Use- Misc. at face value						**All**	**Elect.**	**Gas**
	12 month - GJ/ha/yr					**3,479**	**3,130**	**349**
	10 month - GJ/ha/yr					**2,834**	**2,660**	**175**
	8 month - GJ/ha/yr					**2,300**	**2,213**	**87**
Lettuce Totals: Direct Energy Use- Misc. including production energy						**All**	**Elect.**	**Gas**
	12 month - GJ/ha/yr					**7,718**	**7,301**	**417**
	10 month - GJ/ha/yr					**6,414**	**6,206**	**209**
	8 month - GJ/ha/yr					**5,267**	**5,163**	**104**
Lettuce Totals: CO2 Emissions from Direct Energy Use- Misc.						**All**	**Elect.**	**Gas**
	12 month - kg/ha/yr					**316,834**	**303,572**	**13,262**
	10 month - kg/ha/yr					**264,650**	**258,019**	**6,631**
	8 month - kg/ha/yr					**217,964**	**214,648**	**3,316**

Table 5-7. Miscellaneous Direct Energy Use by the Spinach Crop

Item	Number of items/ quantity	Energy source	Energy rate	Energy rate	Energy rate Units	Energy Used	CO2 Emissions factor	CO2 Emissions
			kWh/m2/yr			GJ/ha/y	kg/GJ	kg/ha/yr
Direct Energy Use for Spinach: Miscellaneous items								
Venting and cooling: all scenarios								
operating venting fans		elect.	8.48	3.6	MJ/kWh	305	97	29612
opening/closing intake vents		elect.	0.1	3.6	MJ/kWh	4	97	349
recyling cooling pad water		elect.	0.2	3.6	MJ/kWh	7	97	698
cooling ponds, 4 months, 1C/day- vol., m3	2,800	elect.		4.186	MJ/deg/m3	469	97	45477
Total						**785**		**76,136**
Direct energy use - proportional to cropping duration: here 12-month								
mixing air - HAF		elect.	0.5	3.6	MJ/kWh	18	97	1746
pumping heating water		elect.	0.5	3.6	MJ/kWh	18	97	1746
chilling harvested crop, and cold storage		elect.	2.3	3.6	MJ/kWh	83	97	8032
mixing and circulating pond solutn (HP calc.)		elect.	67.5	3.6	MJ/kWh	2429	97	235605
Total						**2,548**		**247,128**
Direct energy use - special cases: here 12-month. Halve for 10-month, halve again for 8 month cropping								
lighting for headhouse work		elect.		24,000	kWh/ha	90	97	8730
heating ponds, 3 mnths, 5C -vol., m3	4,000	ng		4.186	MJ/deg/m3	92	38	3496
Total						**182**		**12,226**
Grand Total						**3,515**		**335,491**
Spinach Totals: Direct Energy Use- Misc. at face value						**All**	**Elect.**	**Gas**
	12 month - GJ/ha/yr					**3,515**	**3,423**	**92**
	10 month - GJ/ha/yr					**2999**	**2953**	**46**
	8 month - GJ/ha/yr					**2529**	**2506**	**23**
Spinach Totals: Direct Energy Use- Misc. including production energy						**All**	**Elect.**	**Gas**
	12 month - GJ/ha/yr					**8,095**	**7,985**	**110**
	10 month - GJ/ha/yr					**6,944**	**6,889**	**55**
	8 month - GJ/ha/yr					**5,874**	**5,846**	**27**
Spinach Totals: CO2 Emissions from Direct Energy Use- Misc.						**All**	**Elect.**	**Gas**
	12 month - kg/ha/yr					**335,491**	**331,995**	**3,496**
	10 month - kg/ha/yr					**288,190**	**286,442**	**1,748**
	8 month - kg/ha/yr					**243,945**	**243,071**	**874**

Table 5-8. Miscellaneous Direct Energy Use by the Tomato Crop

Item	Number of items/ quantity	Energy source	Energy rate	Energy rate	Energy rate Units	Energy Used	CO2 Emissions factor	CO2 Emissions
			kWh/m2/yr			GJ/ha/yr	kg/GJ	kg/ha/yr
Direct Energy Use for Tomato: Miscellaneous items								
Venting and cooling: all scenarios								
operating venting fans		elect.	8.48	3.6	MJ/kWh	305	97	29,612
opening/closing intake vents		elect.	0.10	3.6	MJ/kWh	3.6	97	349
recyling cooling pad water		elect.	0.20	3.6	MJ/kWh	7.2	97	698
cooling nutrient solutn 10C, 3 month vol., m3	5,500	elect.		4.186	MJ/deg/m3	77	97	7,444
Total						**393**		**38,104**
Direct energy use - proportional to cropping duration: here 12-month								
mixing air - HAF		elect.	0.5	3.6	MJ/kWh	18	97	1,746
pumping heating water		elect.	0.5	3.6	MJ/kWh	18	97	1,746
chilling harvested crop, and cold storage		elect.	1.0	3.6	MJ/kWh	36	97	3,492
recyling irrigation solutn -vol., m3	5,400	elect.		0.04	kWh/m3	0.8	97	75
Total						**73**		**7,059**
Direct energy use - special cases: 12-month. Halve for 10-month, halve again for 8 month								
lighting for headhouse work		elect.		24,000	kWh/ha	90	97	8,730
heating nutrient solutn, 10C, 4 mnths-vol., m3	7,333	ng		4.186	MJ/deg/m3	341	38	12,958
Total						**431**		**21,688**
Grand Total						**897**		**66,851**
Tomato Totals: Direct Energy Use- Misc. at face value						**All**	**Elect.**	**Gas**
	12 month - GJ/ha/yr					**897**	**556**	**341**
	10 month - GJ/ha/yr					**669**	**498**	**171**
	8 month - GJ/ha/yr					**549**	**464**	**85**
Tomato Totals: Direct Energy Use- Misc. including production energy						**All**	**Elect.**	**Gas**
	12 month - GJ/ha/yr					**1,704**	**1,296**	**407**
	10 month - GJ/ha/yr					**1,367**	**1,163**	**204**
	8 month - GJ/ha/yr					**1,184**	**1,082**	**102**
Tomato Totals: CO2 Emissions from Direct Energy Use- Misc.						**All**	**Elect.**	**Gas**
	12 month - kg/ha/yr					**66,851**	**53,893**	**12,958**
	10 month - kg/ha/yr					**54,831**	**48,352**	**6,479**
	8 month - kg/ha/yr					**48,232**	**44,993**	**3,240**

Table 5-9. Lettuce: Light, Heat, and CO_2 Requirements for the Aerial Environment Under Several Production Scenarios

Production Scenario	Supplementary Light: Light or L. Equivlnt available/ supplied mol/m2/day	Supplem-entry light reqd MWh/ha/yr	Supplem-entry light reqd- face value GJ/ha/yr	Supplem-entry light reqd- plus prod. enrgy	Supplementary Heat: Supplmntry sensible heat reqd GJ/ha/yr	Supplmntry latent heat reqd GJ/ha/yr	Walkways sensible heat reqd GJ/ha/yr	Headhouse sensible heat reqd GJ/ha/yr	Summer-time CO2 reqd GJ/ha/yr	Total Heat from NG reqd GJ/ha/yr	Total NG Reqd. for heat (Effic=0.9) GJ/ha/yr	Total NG Reqd plus prod. energy GJ/ha/yr	Total: Total Heat and Light Face value GJ/ha/yr
	Lettuce crop												
No supp. light, no CO2													
12 mnth	12	0	0	0	28,680	9,586	2,866	745	0	41,856	46,507	55,576	46,507
10 mnth	13	0	0	0	19,453	8,322	1,945	596	0	30,316	33,684	40,253	33,684
8 mnth	14	0	0	0	12,829	6,923	1,283	470	0	21,505	23,894	28,553	23,894
No supp. light, with CO2													
12 mnth	14	0	0	0	28,680	11,136	2,866	745	3	43,409	48,232	57,637	48,232
10 mnth	15	0	0	0	19,453	9,451	1,945	596	3	31,447	34,942	41,755	34,942
8 mnth	16	0	0	0	12,829	7,720	1,283	470	3	22,305	24,783	29,616	24,783
Supplementary light, no CO2													
12 mnth	17	8,540	30,744	71,726	14,890	14,000	1,489	745	0	31,124	34,582	41,325	65,326
10 mnth	17	5,400	19,440	45,354	11,913	10,855	1,191	596	0	24,555	27,284	32,604	46,724
8 mnth	17	2,960	10,656	24,860	9,399	8,447	940	470	0	19,256	21,396	25,568	32,052
Supplementary light, with CO2													
12 mnth	17	4,227	15,217	35,501	26,083	14,000	2,608	745	3	43,438	48,265	57,676	63,482
10 mnth	17	2,281	8,211	19,155	18,390	10,855	1,839	596	3	31,683	35,203	42,068	43,414
8 mnth	17	955	3,438	8,021	12,422	8,447	1,242	470	3	22,584	25,094	29,987	28,532

Table 5-10. Spinach: Light, Heat, and CO_2 Requirements for the Aerial Environment Under Several Production Scenarios

Production Scenario	Supplementary Light: Light or L. Equivlnt available/ supplied mol/m2/day	Supplementary Light: Supplem-entry light reqd MWh/ha/yr	Supplementary Light: Supplem-entry light reqd- face value GJ/ha/yr	Supplementary Light: Supplem-entry light reqd- plus prod. enrgy	Supplmntry sensible heat reqd GJ/ha/yr	Supplmntry latent heat reqd GJ/ha/yr	Supplementary Heat: Walkways sensible heat reqd GJ/ha/yr	Supplementary Heat: Headhouse sensible heat reqd GJ/ha/yr	Summer-time CO2 reqd GJ/ha/yr	Total Heat from NG reqd GJ/ha/yr	Total NG Reqd. for heat (Effic=0.9) GJ/ha/yr	Total NG Reqd plus prod. energy GJ/ha/yr	Total Total Heat and Light Face value GJ/ha/yr
Spinach Crop													
No supp. light, no CO2													
12 mnth	14	0	0	0	28,660	11,457	2,866	745	0	43,727	48,586	58,060	48,586
10 mnth	16	0	0	0	19,463	9,787	1,945	596	0	31,781	35,312	42,198	35,312
8 mnth	19	0	0	0	12,829	8,794	1,283	470	0	23,376	25,973	31,038	25,973
No supp. light, with CO2													
12 mnth	16	0	0	0	28,660	12,865	2,866	745	3	45,138	50,153	59,933	50,153
10 mnth	18	0	0	0	19,463	10,926	1,945	596	3	32,922	36,580	43,713	36,580
8 mnth	19	0	0	0	12,829	8,925	1,283	470	3	23,510	26,122	31,215	26,122
Supplementary light, no CO2													
12 mnth	19	8,540	30,744	71,726	14,890	15,537	1,489	745	0	32,660	36,289	43,365	67,033
10 mnth	19	5,400	19,440	45,354	11,913	12,401	1,191	596	0	26,101	29,001	34,656	48,441
8 mnth	20	2,960	10,656	24,860	9,399	10,000	940	470	0	20,809	23,121	27,629	33,777
Supplementary light, with CO2													
12 mnth	19	4,227	15,217	35,501	26,083	15,537	2,608	745	3	44,975	49,972	59,716	65,189
10 mnth	19	2,281	8,211	19,155	18,390	12,401	1,839	596	3	33,228	36,920	44,120	45,131
8 mnth	20	955	3,438	8,021	12,422	10,000	1,242	470	3	24,137	26,819	32,048	30,257

Table 5-11. Tomato: Light, Heat, and CO_2 Requirements for the Aerial Environment Under Several Production Scenarios

Production Scenario	Supplementary Light: Light or L. Equivlnt available/ supplied mol/m2/day	Supplementary Light: Supplem-entry light reqd MWh/ha/yr	Supplementary Light: Supplem-entry light reqd-face value GJ/ha/yr	Supplem-entry light reqd- plus prod. enrgy	Supplementary Heat: Supplmntry sensible heat reqd GJ/ha/yr	Supplementary Heat: Supplmntry latent heat reqd GJ/ha/yr	Supplementary Heat: Walkways sensible heat reqd GJ/ha/yr	Supplementary Heat: Headhouse sensible heat reqd GJ/ha/yr	Summer-time CO2 reqd GJ/ha/yr	Total Heat from NG reqd GJ/ha/yr	Total NG Reqd. for heat (Effic=0.9) GJ/ha/yr	Total NG Reqd plus prod. energy GJ/ha/yr	Total: Total Heat and Light Face value GJ/ha/yr
Tomato Crop													
No supp. light, no CO2													
12 mnth	—		—	—	—	—	—	—	—	—	—	—	—
10 mnth	16	0	0	0	19,453	8,510	1,945	596	0	30,504	33,893	40,502	33,893
8 mnth	19	0	0	0	12,829	6,808	1,283	470	0	21,390	23,766	28,401	23,766
No supp. light, with CO2													
12 mnth	—		—	—	—	—	—	—	—	—	—	—	—
10 mnth	18	0	0	0	19,453	9,333	1,945	596	3	31,329	34,810	41,599	34,810
8 mnth	19	0	0	0	12,829	7,466	1,283	470	3	22,051	24,501	29,278	24,501
Supplementary light, no CO2													
12 mnth	19	8,540	30,744	71,726	14,890	14,000	1,489	745	0	31,124	34,582	41,325	65,326
10 mnth	19	5,400	19,440	45,354	11,913	10,589	1,191	596	0	24,289	26,987	32,250	46,427
8 mnth	20	2,960	10,656	24,860	9,399	8,074	940	470	0	18,882	20,980	25,072	31,636
Supplementary light, with CO2													
12 mnth	19	4,227	15,217	35,501	26,083	14,000	2,608	745	3	43,438	48,265	57,676	63,482
10 mnth	19	2,281	8,211	19,155	18,390	10,589	1,839	596	3	31,416	34,907	41,714	43,117
8 mnth	20	955	3,438	8,021	12,422	8,074	1,242	470	3	22,210	24,678	29,491	28,116

Note: 12 month production in the NE is not possible without supplementray lighting, withour derious plant and fruit deterioration and therefore is not modeled

Greenhouse heating comprises sensible heat loads, reflecting heat losses due to temperature differences between outside and inside environments, and latent heat load, reflecting heat to vaporize water during transpiration and from wet surfaces. Sensible heat loads are little affected by plant growth, which is not true for latent heat loads. If CO_2 is used in conjunction with natural light to increase productivity, the latent heat load increases in proportion to the increase in transpiring biomass. When CO_2 is used with supplemental light (as we are considering it here) to reduce the amount of supplemental lighting required, the same effective light integral or amount of growth is maintained and latent heat load is unaffected. These relations can be seen under the Table 5-9 heading “Supplementary latent heat reqd”. (Loss of heat also occurs when venting is employed in the winter to control humidity, but we do not consider that here.)

Note in these tables that, after the heat need is determined, the volume of natural gas required to achieve that end is computed using an annual fuel use efficiency of 0.9 to take into account furnace heat losses. In the case of supplemental lighting, luminaire efficiency is built into the kWh requirements. Additional columns are provided in which total energy use is computed accounting for production (or manufacturing) energy for gas and electricity. The factors applied are 1.195 for natural gas and 2.333 for electricity.

Crop Light Requirements

The first column in Table 5-9 gives the daily light integral (DLI) received by the crop (natural and supplied light) averaged over the year. The DLI is restricted to 17 mol m^{-2} for lettuce throughout the year to avoid tip burn. Shade curtains are used, when necessary, to ensure this happens. Tip burn is a lesser problem for spinach and tomato and, within reason, more use can be made of natural light entering the greenhouse than is the case for lettuce. The first cropping scenario for each crop, “No supp. light, no CO_2” indicates the contribution of natural solar light energy in the greenhouse. The average annual solar contribution for lettuce is 12 mol m^{-2} d^{-1}, which is 70% of the DLI the crop receives under daily light integral control to 17 mol m^{-2} d^{-1}. Natural light contributes somewhat more for spinach and tomato at 14 mol m^{-2} d^{-1}. In estimating annual yield for spinach and tomato, we assumed the same amount of supplementary lighting was used as for lettuce – enough for a minimum daily light integral of 17 mol m^{-2} d^{-1} – but allowed natural daily light integral for the midsummer months to rise as high as, but no higher than, 22 mol m^{-2} d^{-1}.

Tables 5-12, 5-13, and 5-14 provide an overview of energy use, where the effect of different cropping durations can be clearly seen and the relative proportions of energy use between embodied energy and direct energy use are compared. Embodied energy changes little as a result of different cropping periods (12, 10 or 8 month), but direct energy use changes greatly, more than doubling for some 8 month to12 month comparisons. As a consequence embodied energy use as a proportion of total energy use varies between 3 and 8%.

Table 5-12. Lettuce Annual Energy Use Summary: Embodied vs. Direct Energy Use Under Different Production Scenarios

Production Scenario	Embodied Energy: Common Embodied Energy	Crop-specific emb. Energy	Total Embodied Energy	Proportion of Total Energy	Direct energy use - at face value: Miscell. direct energy	Supplementary light reqd.	Heat reqd. NG equiv.	Total Direct Energy	Proportion of Total	Total: Total All Energy Use	Direct energy use - plus pr: Miscell. direct energy	Supplementary light reqd.	Heat reqd. NG equiv.
	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr		GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr		GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr
	Lettuce crop												
No supp. light, no CO2													
12 mnth	1,250	887	2,137	0.04	3,479	0	46,507	49,985	0.96	52,122	7718	0	55,576
10 mnth	1,250	814	2,064	0.05	2,834	0	33,684	36,519	0.95	38,583	6414	0	40,253
8 mnth	1,250	742	1,992	0.07	2,300	0	23,894	26,194	0.93	28,186	5267	0	28,553
No supp. light, with CO2													
12 mnth	1,250	887	2,137	0.04	3,479	0	48,232	51,711	0.96	53,848	7718	0	57,637
10 mnth	1,250	814	2,064	0.05	2,834	0	34,942	37,776	0.95	39,840	6414	0	41,755
8 mnth	1,250	742	1,992	0.07	2,300	0	24,783	27,083	0.93	29,075	5267	0	29,616
Supplementary light, no CO2													
12 mnth	1,498	887	2,385	0.03	3,479	30,744	34,582	68,804	0.97	71,189	7718	71,726	41,325
10 mnth	1,498	814	2,312	0.04	2,834	19,440	27,284	49,558	0.96	51,870	6414	45,354	32,604
8 mnth	1,498	742	2,240	0.06	2,300	10,656	21,396	34,352	0.94	36,592	5267	24,860	25,568
Supplementary light, with CO2													
12 mnth	1,498	887	2,385	0.03	3,479	15,217	48,265	66,960	0.97	69,345	7718	35,501	57,676
10 mnth	1,498	814	2,312	0.05	2,834	8,211	35,203	46,248	0.95	48,561	6414	19,155	42,068
8 mnth	1,498	742	2,240	0.07	2,300	3,438	25,094	30,832	0.93	33,072	5267	8,021	29,987

Table 5-13. Spinach Annual Energy Use Summary: Embodied versus Direct Energy Use Under Different Production Scenarios

Production Scenario	Embodied Energy: Common Embodied Energy GJ/ha/yr	Crop-specific emb. Energy GJ/ha/yr	Total Embodied Energy GJ/ha/yr	Proportion of Total Energy	Direct energy use - at face value: Miscel. direct energy GJ/ha/yr	Supplementary light reqd. GJ/ha/yr	Heat reqd. NG equiv. GJ/ha/yr	Total Direct Energy GJ/ha/yr	Proportion of Total	Total: Total All Energy Use GJ/ha/yr	Direct energy use - plus pı: Miscell. direct energy GJ/ha/yr	Supplementry light reqd. GJ/ha/yr	Heat reqd. NG equiv. GJ/ha/yr
Spinach Crop													
No supp. light, no CO2													
12 mnth	1,250	917	2,167	0.04	3,515	0	48,586	52,100	0.96	54,267	8,095	0	58,060
10 mnth	1,250	840	2,090	0.05	2,999	0	35,312	38,311	0.95	40,401	6,944	0	42,198
8 mnth	1,250	764	2,014	0.07	2,529	0	25,973	28,502	0.93	30,515	5,874	0	31,038
No supp. light, with CO2													
12 mnth	1,250	917	2,167	0.04	3,515	0	50,153	53,668	0.96	55,835	8,095	0	59,933
10 mnth	1,250	840	2,090	0.05	2,999	0	36,580	39,579	0.95	41,669	6,944	0	43,713
8 mnth	1,250	764	2,014	0.07	2,529	0	26,122	28,651	0.93	30,664	5,874	0	31,215
Supplementary light, no CO2													
12 mnth	1,498	917	2,415	0.03	3,515	30,744	36,289	70,548	0.97	72,962	8,095	71,726	43,365
10 mnth	1,498	840	2,338	0.04	2,999	19,440	29,001	51,440	0.96	53,778	6,944	45,354	34,656
8 mnth	1,498	764	2,262	0.06	2,529	10,656	23,121	36,306	0.94	38,567	5,874	24,860	27,629
Supplementary light, with CO2													
12 mnth	1,498	917	2,415	0.03	3,515	15,217	49,972	68,704	0.97	71,118	8,095	35,501	59,716
10 mnth	1,498	840	2,338	0.05	2,999	8,211	36,920	48,130	0.95	50,468	6,944	19,155	44,120
8 mnth	1,498	764	2,262	0.06	2,529	3,438	26,819	32,786	0.94	35,047	5,874	8,021	32,048

Table 5-14. Tomato Annual Energy Use Summary: Embodied vs. Direct Energy Use Under Different Production Scenarios

Production Scenario	Embodied Energy				Direct energy use - at face value					Total	Direct energy use - plus pı		
	Common Embodied Energy	Crop-specific emb. Energy	Total Embodied Energy	Proport-ion of Total Energy	Miscel. direct energy	Supplem-entry light reqd.	Heat reqd. NG equiv.	Total Direct Energy	Proport-ion of Total	Total All Energy Use	Miscell. direct energy	Supplem-entry light reqd.	Heat reqd. NG equiv.
	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr		GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr		GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr
	Tomato Crop												
No supp. light, no CO2													
12 mnth	—		—		—			—				—	—
10 mnth	1,250	881	2,131	0.06	669	0	33,893	34,562	0.94	36,693	1,367	0	40,502
8 mnth	1,250	793	2,043	0.08	549	0	23,766	24,315	0.92	26,358	1,184	0	28,401
No supp. light, with CO2													
12 mnth	—		—		—			—				—	—
10 mnth	1,250	881	2,131	0.06	669	0	34,810	35,479	0.94	37,610	1,367	0	41,599
8 mnth	1,250	793	2,043	0.08	549	0	24,501	25,050	0.92	27,093	1,184	0	29,278
Supplementary light, no CO2													
12 mnth	1,498	969	2,467	0.04	897	30,744	34,582	66,222	0.96	68,689	1,704	71,726	41,325
10 mnth	1,498	881	2,379	0.05	669	19,440	26,987	47,096	0.95	49,475	1,367	45,354	32,250
8 mnth	1,498	793	2,291	0.07	549	10,656	20,980	32,186	0.93	34,477	1,184	24,860	25,072
Supplementary light, with CO2													
12 mnth	1,498	969	2,467	0.04	897	15,217	48,265	64,378	0.96	66,845	1,704	35,501	57,676
10 mnth	1,498	881	2,379	0.05	669	8,211	34,907	43,786	0.95	46,165	1,367	19,155	41,714
8 mnth	1,498	793	2,291	0.07	549	3,438	24,678	28,666	0.93	30,957	1,184	8,021	29,491

Table 5-15. Yield and Face-value Energy Use per Unit of Product Under Different Production Scenarios

Production Scenario	Total embodied energy	Total Direct Energy	Total Energy Use	Energy Use -- MJ per kilogram: Yield Metric system	Embodied Energy per kg	Direct Energy per kg	Total Energy per kg	Energy use -- kWh per lb: Yield US system	Embodied Energy per lb	Direct Energy per lb	Total Energy per lb
	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	kg/ha/yr	MJ/kg	MJ/kg	MJ/kg	lb/acre/yr	kWh/lb	kWh/lb	kWh/lb
	Lettuce crop										
No supp. light, no CO2											
12 mnth	2,137	49,985	52,122	749,700	2.9	67	70	668,861	0.4	8.4	8.8
10 mnth	2,064	36,519	38,583	650,900	3.2	56	59	580,714	0.4	7.1	7.5
8 mnth	1,992	26,194	28,186	541,500	3.7	48	52	483,111	0.5	6.1	6.6
No supp. light, with CO2											
12 mnth	2,137	51,711	53,848	871,000	2.5	59	62	777,081	0.3	7.5	7.8
10 mnth	2,064	37,776	39,840	739,200	2.8	51	54	659,493	0.4	6.4	6.8
8 mnth	1,992	27,083	29,075	603,800	3.3	45	48	538,693	0.4	5.7	6.1
Supplementary light, no CO2											
12 mnth	2,385	68,804	71,189	1,064,000	2.2	65	67	949,270	0.3	8.1	8.4
10 mnth	2,312	49,558	51,870	825,000	2.8	60	63	736,041	0.4	7.6	7.9
8 mnth	2,240	34,352	36,592	642,000	3.5	54	57	572,774	0.4	6.7	7.2
Supplementary light, with CO2											
12 mnth	2,385	66,960	69,345	1,064,000	2.2	63	65	949,270	0.3	7.9	8.2
10 mnth	2,312	46,248	48,561	825,000	2.8	56	59	736,041	0.4	7.1	7.4
8 mnth	2,240	30,832	33,072	642,000	3.5	48	52	572,774	0.4	6.1	6.5
	Spinach Crop										
No supp. light, no CO2											
12 mnth	2,167	52,100	54,267	448,041	4.8	116	121	399,729	0.6	14.7	15.3
10 mnth	2,090	38,311	40,401	382,738	5.5	100	106	341,468	0.7	12.6	13.3
8 mnth	2,014	28,502	30,515	343,897	5.9	83	89	306,815	0.7	10.4	11.2
No supp. light, with CO2											
12 mnth	2,167	53,668	55,835	503,104	4.3	107	111	448,855	0.5	13.4	14.0
10 mnth	2,090	39,579	41,669	427,273	4.9	93	98	381,201	0.6	11.7	12.3
8 mnth	2,014	28,651	30,664	349,036	5.8	82	88	311,400	0.7	10.3	11.1
Supplementary light, no CO2											
12 mnth	2,415	70,548	72,962	592,088	4.1	119	123	528,244	0.5	15.0	15.5
10 mnth	2,338	51,440	53,778	472,588	4.9	109	114	421,630	0.6	13.7	14.3
8 mnth	2,262	36,306	38,567	381,088	5.9	95	101	339,996	0.7	12.0	12.8
Supplementary light, with CO2											
12 mnth	2,415	68,704	71,118	592,088	4.1	116	120	528,244	0.5	14.6	15.1
10 mnth	2,338	48,130	50,468	472,588	4.9	102	107	421,630	0.6	12.8	13.5
8 mnth	2,262	32,786	35,047	381,088	5.9	86	92	339,996	0.7	10.8	11.6
	Tomato Crop										
No supp. light, no CO2											
12 mnth	—						—				—
10 mnth	2,131	34,562	36,693	620,000	3.4	56	59	553,146	0.4	7.0	7.5
8 mnth	2,043	24,315	26,358	496,000	4.1	49	53	442,517	0.5	6.2	6.7
No supp. light, with CO2											
12 mnth	—						—				—
10 mnth	2,131	35,479	37,610	683,500	3.1	52	55	609,799	0.4	6.5	6.9
8 mnth	2,043	25,050	27,093	546,800	3.7	46	50	487,839	0.5	5.8	6.2
Supplementary light, no CO2											
12 mnth	2,467	66,222	68,689	1,025,329	2.4	65	67	914,769	0.3	8.1	8.4
10 mnth	2,379	47,096	49,475	775,488	3.1	61	64	691,868	0.4	7.7	8.0
8 mnth	2,291	32,186	34,477	591,291	3.9	54	58	527,533	0.5	6.9	7.3
Supplementary light, with CO2											
12 mnth	2,467	64,378	66,845	1,025,329	2.4	63	65	914,769	0.3	7.9	8.2
10 mnth	2,379	43,786	46,165	775,488	3.1	56	60	691,868	0.4	7.1	7.5
8 mnth	2,291	28,666	30,957	591,291	3.9	48	52	527,533	0.5	6.1	6.6

Table 5-16. Yield and Energy Use per Unit of Product, Including Fuel Production Energy, Under Different Production Scenarios

Production Scenario	Total embodied energy	Total Direct Energy	Total Total All Energy Use	Energy Use -- MJ per kilogram: Yield Metric system	Embodied Energy per kg	Direct Energy per kg	Total Energy per kg	Energy use -- kWh per lb: Yield US system	Embodied Energy per lb	Direct Energy per lb	Total Energy per lb
	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	kg/ha/yr	MJ/kg	MJ/kg	MJ/kg	lb/acre/yr	kWh/lb	kWh/lb	kWh/lb
	Lettuce crop										
No supp. light, no CO2											
12 mnth	2,137	63,294	65,431	749,700	2.9	84	87	668,861	0.4	10.6	11.0
10 mnth	2,064	46,667	48,732	650,900	3.2	72	75	580,714	0.4	9.0	9.4
8 mnth	1,992	33,820	35,812	541,500	3.7	62	66	483,111	0.5	7.9	8.3
No supp. light, with CO2											
12 mnth	2,137	65,356	67,493	871,000	2.5	75	77	777,081	0.3	9.5	9.8
10 mnth	2,064	48,169	50,234	739,200	2.8	65	68	659,493	0.4	8.2	8.6
8 mnth	1,992	34,883	36,875	603,800	3.3	58	61	538,693	0.4	7.3	7.7
Supplementary light, no CO2											
12 mnth	2,385	120,769	123,154	1,064,000	2.2	114	116	949,270	0.3	14.3	14.6
10 mnth	2,312	84,372	86,684	825,000	2.8	102	105	736,041	0.4	12.9	13.2
8 mnth	2,240	55,695	57,935	642,000	3.5	87	90	572,774	0.4	10.9	11.4
Supplementary light, with CO2											
12 mnth	2,385	100,896	103,281	1,064,000	2.2	95	97	949,270	0.3	11.9	12.2
10 mnth	2,312	67,637	69,950	825,000	2.8	82	85	736,041	0.4	10.3	10.7
8 mnth	2,240	43,275	45,515	642,000	3.5	67	71	572,774	0.4	8.5	8.9
	Spinach Crop										
No supp. light, no CO2											
12 mnth	2,167	66,155	68,322	448,041	4.8	148	152	399,729	0.6	18.6	19.2
10 mnth	2,090	49,142	51,232	382,738	5.5	128	134	341,468	0.7	16.2	16.9
8 mnth	2,014	36,911	38,925	343,897	5.9	107	113	306,815	0.7	13.5	14.3
No supp. light, with CO2											
12 mnth	2,167	68,028	70,195	503,104	4.3	135	140	448,855	0.5	17.0	17.6
10 mnth	2,090	50,658	52,748	427,273	4.9	119	123	381,201	0.6	14.9	15.6
8 mnth	2,014	37,089	39,103	349,036	5.8	106	112	311,400	0.7	13.4	14.1
Supplementary light, no CO2											
12 mnth	2,415	123,186	125,601	592,088	4.1	208	212	528,244	0.5	26.2	26.7
10 mnth	2,338	86,954	89,292	472,588	4.9	184	189	421,630	0.6	23.2	23.8
8 mnth	2,262	58,363	60,625	381,088	5.9	153	159	339,996	0.7	19.3	20.0
Supplementary light, with CO2											
12 mnth	2,415	103,313	105,727	592,088	4.1	174	179	528,244	0.5	22.0	22.5
10 mnth	2,338	70,219	72,558	472,588	4.9	149	154	421,630	0.6	18.7	19.3
8 mnth	2,262	45,943	48,205	381,088	5.9	121	126	339,996	0.7	15.2	15.9
	Tomato Crop										
No supp. light, no CO2											
12 mnth	—	—					—				—
10 mnth	2,131	41,869	44,000	620,000	3.4	68	71	553,146	0.4	8.5	8.9
8 mnth	2,043	29,585	31,628	496,000	4.1	60	64	442,517	0.5	7.5	8.0
No supp. light, with CO2											
12 mnth	—	—					—				—
10 mnth	2,131	42,965	45,096	683,500	3.1	63	66	609,799	0.4	7.9	8.3
8 mnth	2,043	30,463	32,506	546,800	3.7	56	59	487,839	0.5	7.0	7.5
Supplementary light, no CO2											
12 mnth	2,467	114,755	117,221	1,025,329	2.4	112	114	914,769	0.3	14.1	14.4
10 mnth	2,379	78,970	81,349	775,488	3.1	102	105	691,868	0.4	12.8	13.2
8 mnth	2,291	51,116	53,407	591,291	3.9	86	90	527,533	0.5	10.9	11.4
Supplementary light, with CO2											
12 mnth	2,467	94,881	97,348	1,025,329	2.4	93	95	914,769	0.3	11.7	12.0
10 mnth	2,379	62,236	64,615	775,488	3.1	80	83	691,868	0.4	10.1	10.5
8 mnth	2,291	38,696	40,987	591,291	3.9	65	69	527,533	0.5	8.2	8.7

To this point, we have estimated energy use to supply a variety of environments for crop production without specifying effects on yields. Annual yields under each production scenario are listed in Tables 5-15 and 5-16, along with energy use per unit weight of product. In Table 5-15 fuel and electricity use is given at face value; in Table 5-16 energy used in production of fuel/electricity is included. Daily yield (not shown) is in proportion to average DLI, and increases for spinach and tomato in shorter cropping scenarios (8 and 10 month) as the worst months for natural light are avoided; but annual yield declines because of shorter harvest periods. As expected, there is a substantial decrease in unit energy costs for heat and light by shortening the cropping season despite the inefficiency of having to restart each year. In Tables 5-15 and 5-16, yield and energy use per unit of product are given. For energy use per lb of product, all energy has been converted to kWh equivalents using the factor 3.6 MJ/kWh. In Table 5-15 the values are very close to the actual kilowatt hours that would be required if both heating and lighting were by electricity.

COST AND PROFIT ANALYSIS

In Tables 5-17, 5-18, and 5-19, the actual costs of supplying the direct energy needed are computed using figures for natural gas and electricity charged to commercial customers in 2007. Cost of direct energy per pound of product is lowest in the shortest cropping period under each condition of lighting and CO_2 supplementation. CO_2 has a small positive effect when no light is not supplemented, but a very large beneficial effect when light is supplemented. Supplementing light without CO_2 enrichment is very costly, virtually doubling the energy cost per unit of product over production without CO_2 or light supplementation.

Yields are substantially higher in the longer cropping periods and/or when light supplementation is used, which means sales volumes are higher and could possibly compensate for the increased unit energy costs that also occur when these options are adopted. In Table 5-20 we show the conditions under which it might be profitable to supplement light with year-round cropping, found using a trial and error method. Note the data considers only direct energy use costs, namely cost of fuel and electricity needed for crop production. However, these energy uses cover about 95% of total supplied-energy use.

Consider the situation where all of the product can be sold for a fixed unit price of X dollars per pound. Consider that cost of production, C is computed as dollars per pound for everything except energy use, and deduct this value from the price. This figure, (X-C), is the amount available to cover energy costs (E) and determines profit per pound (profit margin - PM) after energy costs are subtracted. If profit per pound is small, a suitably large volume of sales may generate as much profit as a smaller volume with a higher profit margin. We will consider three figures for the amount available to cover energy use (X-C) and provide the profit margin, namely $1.50/lb, 1.00/lb, and 0.80/lb. (X-C) = E + PM.

Table 5-17. Lettuce Crop: Direct Energy Use and Cost in 2007 Dollars and Prices

Production Scenario	Yield and total Energy: Yield	Total: All Energy Use	Total Energy per kg	Direct energyy Use: Direct Energy Total	Direct Energy as Electri-City	Direct Energy as Natural Gas	Direct Energy as Electri-City	Direct Energy as Natural Gas	Cost of Direct Energy Use: Cost of Electri-city at $.14/kwh	Cost of Natural Gas at $1.2/therm	Unit cost Electri-city	Unit cost Natural Gas	Unit cost Total Dir. Energy
	kg/ha/yr	GJ/ha/yr	MJ/kg	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	MWh/ha/yr	Therms	1000s $/ha/yr	1000s $/ha/yr	$/lb	$/lb	$/lb
	Lettuce crop												
No supp. light, no CO2													
12 mnth	749,700	52,124	69.5	49,985	3,130	46,856	869	444,100	122	533	0.07	0.32	**0.40**
10 mnth	650,900	38,585	59.3	36,519	2,660	33,859	739	320,915	103	385	0.07	0.27	**0.34**
8 mnth	541,500	28,188	52.1	26,194	2,213	23,981	615	227,296	86	273	0.07	0.23	**0.30**
No supp. light, with CO2													
12 mnth	871,000	53,849	61.8	51,711	3,130	48,581	869	460,452	122	553	0.06	0.29	**0.35**
10 mnth	739,200	39,842	53.9	37,776	2,660	35,116	739	332,830	103	399	0.06	0.25	**0.31**
8 mnth	603,800	29,077	48.2	27,083	2,213	24,870	615	235,721	86	283	0.06	0.21	**0.28**
Supplementary light, no CO2													
12 mnth	1,064,000	71,191	66.9	68,804	33,874	34,931	9,409	331,073	1,317	397	0.56	0.17	**0.73**
10 mnth	825,000	51,872	62.9	49,558	22,100	27,458	6,139	260,248	859	312	0.47	0.17	**0.64**
8 mnth	642,000	36,594	57.0	34,352	12,869	21,483	3,575	203,616	500	244	0.35	0.17	**0.53**
Supplementary light, with CO2													
12 mnth	1,064,000	69,347	65.2	66,960	18,347	48,614	5,096	460,760	713	553	0.30	0.24	**0.54**
10 mnth	825,000	48,562	58.9	46,248	10,871	35,378	3,020	335,309	423	402	0.23	0.22	**0.45**
8 mnth	642,000	33,074	51.5	30,832	5,651	25,181	1,570	238,664	220	286	0.16	0.20	**0.36**

Table 5-18. Spinach Crop: Direct Energy Use and Cost in 2007 Dollars and Prices

Production Scenario	Yield and total Energy Yield	Total: All Energy Use	Total Energy per kg	Direct energyy Use Direct Energy Total	Direct Energy as Electri-City	Direct Energy as Natural Gas	Direct Energy as Electri-City	Direct Energy as Natural Gas	Cost of Direct Energy Use Cost of Electri-city at $.14/kwh	Cost of Natural Gas at $1.2/therm	Unit cost Electri-city	Unit cost Natural Gas	Unit cost Total Dir. Energy
	kg/ha/yr	GJ/ha/yr	MJ/kg	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	MWh/ha/yr	Therms	000s $/ha/y	000s $/ha/y	$/lb	$/lb	**$/lb**
	Spinach Crop												
No supp. light, no CO2													
12 mnth	448,041	54,269	60.6	52,100	3,423	48,678	951	461,369	133	554	0.13	0.56	**0.70**
10 mnth	382,738	40,403	52.8	38,311	2,953	35,358	820	335,124	115	402	0.14	0.48	**0.61**
8 mnth	343,897	30,517	44.4	28,502	2,506	25,996	696	246,389	97	296	0.13	0.39	**0.52**
No supp. light, with CO2													
12 mnth	503,104	55,836	55.5	53,668	3,423	50,245	951	476,224	133	571	0.12	0.52	**0.64**
10 mnth	427,273	41,671	48.8	39,579	2,953	36,626	820	347,144	115	417	0.12	0.44	**0.56**
8 mnth	349,036	30,666	43.9	28,651	2,506	26,145	696	247,800	97	297	0.13	0.39	**0.51**
Supplementary light, no CO2													
12 mnth	592,088	72,964	61.6	70,548	34,167	36,381	9,491	344,818	1,329	414	1.02	0.32	**1.33**
10 mnth	472,588	53,780	56.9	51,440	22,393	29,047	6,220	275,306	871	330	0.84	0.32	**1.15**
8 mnth	381,088	38,569	50.6	36,306	13,162	23,144	3,656	219,356	512	263	0.61	0.31	**0.92**
Supplementary light, with CO2													
12 mnth	592,088	71,120	60.1	68,704	18,640	50,064	5,178	474,505	725	569	0.56	0.44	**0.99**
10 mnth	472,588	50,470	53.4	48,130	11,164	36,966	3,101	350,367	434	420	0.42	0.40	**0.82**
8 mnth	381,088	35,049	46.0	32,786	5,944	26,842	1,651	254,404	231	305	0.28	0.36	**0.64**

Table 5-19. Tomato Crop: Direct Energy Use and Cost in 2007 Dollars and Prices

Production Scenario	Yield and total Energy: Yield	Total: All Energy Use	Total Energy per kg	Direct energy Use: Direct Energy Total	Direct Energy as Electri-City	Direct Energy as Natural Gas	Direct Energy as Electri-City	Direct Energy as Natural Gas	Cost of Direct Energy Use: Cost of Electri-city at $.14/kwh	Cost of Natural Gas at $1.2/therm	Unit cost Electri-city	Unit cost Natural Gas	Unit cost Total Dir. Energy
	kg/ha/yr	GJ/ha/yr	MJ/kg	GJ/ha/yr	GJ/ha/yr	GJ/ha/yr	MWh/ha/yr	Therms	1000s $/ha/	1000s $/ha/	$/lb	$/lb	**$/lb**
Tomato Crop													
No supp. light, no CO2													
12 mth	—	—	—	—	—	—	—	—	—	—	—	—	—
10 mth	620,000	36,694	59.2	34,562	498	34,064	138	322,854	19	387	0.01	0.28	**0.30**
8 mth	496,000	26,359	53.1	24,315	464	23,852	129	226,065	18	271	0.02	0.25	**0.26**
No supp. light, with CO2													
12 mth	—	—	—	—	—	—	—	—	—	—	—	—	—
10 mth	683,500	37,611	55.0	35,479	498	34,981	138	331,550	19	398	0.01	0.26	**0.28**
8 mth	546,800	27,094	49.5	25,050	464	24,586	129	233,027	18	280	0.01	0.23	**0.25**
Supplementary light, no CO2													
12 mth	1,025,329	68,690	67.0	66,222	31,300	34,923	8,694	330,997	1,217	397	0.54	0.18	**0.71**
10 mth	775,488	49,476	63.8	47,096	19,938	27,158	5,538	257,402	775	309	0.45	0.18	**0.63**
8 mth	591,291	34,477	58.3	32,186	11,120	21,066	3,089	199,661	432	240	0.33	0.18	**0.52**
Supplementary light, with CO2													
12 mth	1,025,329	66,846	65.2	64,378	15,773	48,606	4,381	460,684	613	553	0.27	0.24	**0.52**
10 mth	775,488	46,166	59.5	43,786	8,709	35,077	2,419	332,463	339	399	0.20	0.23	**0.43**
8 mth	591,291	30,957	52.4	28,666	3,902	24,764	1,084	234,709	152	282	0.12	0.22	**0.33**

Table 5-20. Profit Under Different Production Scenarios Assuming Different Cost of Production Values

Production Scenario	Yield	Unit Cost for all Direct Energy	Direct Energy Cost Total	$1.50 lb Available for Energy Costs	Profit after Energy Deductn.	$1.00 lb Available for Energy Costs	Profit after Energy Deductn.	$0.80 lb Available for Energy Costs
	lb/ha/yr	$/lb	$/ha/yr	$/ha/yr	$/ha/yr	$/ha/yr	$/ha/yr	$/ha/yr
No supp. light, no CO2	Lettuce crop							
12 mnth	1,652,789	0.40	654,627	2,479,183	1,824,556	1,652,789	998,162	1,322,231
10 mnth	1,434,974	0.34	488,542	2,152,461	1,663,919	1,434,974	946,432	1,147,979
8 mnth	1,193,791	0.30	358,811	1,790,686	1,431,876	1,193,791	834,980	955,033
No supp. light, with CO2								
12 mnth	1,920,207	0.35	674,250	2,880,310	2,206,060	1,920,207	1,245,957	1,536,165
10 mnth	1,629,640	0.31	502,840	2,444,460	1,941,620	1,629,640	1,126,800	1,303,712
8 mnth	1,331,137	0.28	368,921	1,996,706	1,627,785	1,331,137	962,216	1,064,910
Supplementary light, no CO2								
12 mnth	2,345,694	0.73	1,714,594	3,518,542	1,803,947	2,345,694	631,100	1,876,556
10 mnth	1,818,795	0.64	1,171,741	2,728,193	1,556,451	1,818,795	647,054	1,455,036
8 mnth	1,415,353	0.53	744,796	2,123,030	1,378,234	1,415,353	670,558	1,132,283
Supplementary light, with CO2								
12 mnth	2,345,694	0.54	1,266,393	3,518,542	2,252,148	2,345,694	1,079,301	1,876,556
10 mnth	1,818,795	0.45	825,114	2,728,193	1,903,078	1,818,795	993,681	1,455,036
8 mnth	1,415,353	0.36	506,161	2,123,030	1,616,869	1,415,353	909,192	1,132,283
No supp. light, no CO2	Tomato Crop							
12 mnth								
10 mnth	1,366,852	0.34	406,810	2,050,278	1,643,468	1,366,852	960,042	1,093,482
8 mnth	1,093,482	0.30	289,317	1,640,222	1,350,906	1,093,482	804,165	874,785
No supp. light, with CO2								
12 mnth								
10 mnth	1,506,844	0.31	417,245	2,260,266	1,843,022	1,506,844	1,089,599	1,205,475
8 mnth	1,205,475	0.28	297,671	1,808,213	1,510,542	1,205,475	907,805	964,380
Supplementary light, no CO2								
12 mnth	2,260,440	0.73	1,614,403	3,390,660	1,776,257	2,260,440	646,037	1,808,352
10 mnth	1,709,640	0.64	1,084,267	2,564,460	1,480,193	1,709,640	625,373	1,367,712
8 mnth	1,303,560	0.53	672,031	1,955,340	1,283,309	1,303,560	631,529	1,042,848
Supplementary light, with CO2								
12 mnth	2,260,440	0.54	1,166,202	3,390,660	2,224,458	2,260,440	1,094,238	1,808,352
10 mnth	1,709,640	0.45	737,640	2,564,460	1,826,820	1,709,640	972,000	1,367,712
8 mnth	1,303,560	0.36	433,397	1,955,340	1,521,943	1,303,560	870,163	1,042,848
	Yield	Unit Cost for all Direct Energy	Direct Energy Cost Total	$3.00 lb Available for Energy Costs	Profit after Energy Deductn.	$2.00 lb Available for Energy Costs	Profit after Energy Deductn.	$1.60 lb Available for Energy Costs
	lb/ha/yr	$/lb	$/ha/yr	$/ha/yr	$/ha/yr	$/ha/yr	$/ha/yr	$/ha/yr
No supp. light, no CO2	Spinach Crop							
12 mnth	987,752	0.70	686,745	2,963,255	2,276,510	1,975,503	1,288,759	1,580,403
10 mnth	843,785	0.61	516,988	2,531,354	2,014,366	1,687,569	1,170,582	1,350,056
8 mnth	758,155	0.52	393,118	2,274,466	1,881,349	1,516,311	1,123,193	1,213,049
No supp. light, with CO2								
12 mnth	1,109,142	0.64	704,571	3,327,427	2,622,856	2,218,284	1,513,714	1,774,627
10 mnth	941,967	0.56	531,412	2,825,901	2,294,489	1,883,934	1,352,522	1,507,147
8 mnth	769,485	0.51	394,811	2,308,454	1,913,642	1,538,969	1,144,158	1,231,175
Supplementary light, no CO2								
12 mnth	1,305,318	1.33	1,742,484	3,915,953	2,173,469	2,610,635	868,152	2,088,508
10 mnth	1,041,868	1.15	1,201,206	3,125,604	1,924,398	2,083,736	882,530	1,666,989
8 mnth	840,147	0.92	775,079	2,520,441	1,745,362	1,680,294	905,215	1,344,235
Supplementary light, with CO2								
12 mnth	1,305,318	0.99	1,294,283	3,915,953	2,621,670	2,610,635	1,316,352	2,088,508
10 mnth	1,041,868	0.82	854,579	3,125,604	2,271,025	2,083,736	1,229,157	1,666,989
8 mnth	840,147	0.64	536,444	2,520,441	1,983,997	1,680,294	1,143,850	1,344,235

Note: spinach retails at two or more times lettuce and tomato; accordingly, two time the amount is made available for covering energy cost a

The results in Table 5-20 show that when $1.50/lb is available to cover energy expenses and PM, the greatest overall profits come in the two DLI-CO_2 (DLI is Daily Light Integral) scenarios where CO_2 enrichment is used in a 12-month cropping period, and the profits are equally good with and without light supplementation. In the two scenarios without CO_2 enrichment, 12-month profits are somewhat lower (c.20%) than with CO_2 enrichment, and again, the profits are equally good with and without light supplementation. In all four DLI-CO_2 scenarios, it is highly advantageous to use to use twelve-month cropping rather than the shorter cropping durations when $1.50/lb is available after other expenses.

When $1.00/lb and $0.80 are available to cover energy expenses and PM, the No-supplementary-light-with-CO_2 option gradually overtakes the Supplementary-light-with CO_2 option, and Supplementary-light-without-CO_2 becomes untenable. No-supplementary-light-no-CO_2 and Supplementary-light-with-CO_2 give approximately the same profit and both remain viable options. In all three viable DLI-CO_2 scenarios, it is advantageous to use 12-month cropping rather than 8 or 10 month cropping, when $1.00/lb is available, but at $0.80 available the advantage is beginning to tilt toward shorter cropping intervals.

In this cursory analysis we have omitted labor costs, but they should have little effect if we assume labor costs per pound of product are same under all cropping durations. This is a reasonable assumption so long as laying off workers for some months of the year does not have negative repercussions. We have also left out some fixed annual costs that would have effects on the calculations, namely the energy embodied in the greenhouse structure and equipment and annual expenses such as taxes and mortgage payments. Including fixed expenses in the calculations would enhance the advantage of the longer cropping durations, since the fixed costs would be spread over more crop yield, reducing unit costs.

We have based these calculations on commercial pricing of gas and electricity. Larger facilities may benefit from industrial pricing, which would lead to an immediate increase in profit margin. In locating production facilities, there are several ways in which energy costs can be reduced. Certain municipalities and industrial parks attract businesses by offering substantially reduced energy pricing. Waste heat may be available at reduced cost in certain locations, such as being near power stations and solid waste facilities that are generating electricity. In these cases, it helps if the greenhouse facility is integrated in the original design of the complex.

CARBON DIOXIDE ANALYSIS

Introduction

Except for the case of cement manufacture, in which limestone is forced to release the CO_2 it contains chemically as carbonate, carbon dioxide emissions we are considering all result from combustion of fossil fuel hydrocarbons. The higher the carbon content/molecular fraction, the greater the carbon dioxide production. Maximum possible emissions come from high carbon substances such as graphite, anthracite coal, and coke; the lowest emissions are from refined natural gas, which is almost pure methane and has the highest hydrogen to carbon ratio of all fossil fuels. As a result, carbon dioxide emissions of fossil fuels fall within a somewhat narrow range- roughly 45 to 100 kg/GJ. Emissions in generating electricity vary more widely. The efficiency of conversion of heat to electricity in coal and natural gas-fired power stations is approximately 33%, so emissions can theoretically be as high as 300 kg of CO_2 per GJ of electricity (the New York average is close to 100 kg/GJ due to our limited use of coal and high fraction of hydropower and nuclear generation). Nuclear, hydroelectric and solar power stations emit no CO_2 during electricity generation; CO_2 emissions are only those from the fossil fuel use embodied in building and servicing the facilities, or in the case of nuclear power stations, extracting and refining uranium ore.

In the literature on greenhouse gas emissions, new terminology has been developed and some clarification may be of value here. We encounter three terms: carbon dioxide emissions, carbon dioxide equivalents, and carbon equivalents. Carbon dioxide emissions are generally given as weight of CO_2 released as gas per unit of heat energy of each fuel type (for example, per 1000 Btu), but they may also be given in terms of volume or weight of the fuel (e.g., per ton of coal, per CF of natural gas, etc.) Determining emissions is relatively easy for fossil fuels because emissions are highly correlated with the carbon content of the fuel. In the case of electricity, the situation is more complex. Emissions are given per kWh, but they must be determined for each region in which electricity is generated because there are usually several power stations in each region and there can be large differences in CO_2 emissions among power stations depending on type – whether fossil fuel is used in contrast to nuclear or hydroelectric power generation, the emission controls are in place, etc. Emissions for electricity may be converted to SI units of kg/GJ, in common with other energy sources, which is what we will do. Unless otherwise noted, joule equivalents to kWh are calculated using the factor 3.6 MJ/kWh. This conversion does not address the efficiency with which the electricity was generated; however, CO_2 emission rates do reflect the manner of generation.

The only difficulty with using heat content in specifying emissions from fossil fuels is that heat content sometimes counts the latent heat in water vapor formed during combustion and sometimes not (Higher and Lower Heating Values, HHV and LHV). For natural gas, this makes a 10% difference. Giving emissions in terms of volume of gas also causes uncertainty if it is not specified whether the value is for gas under

Normal Temperature and Pressure (NTP), or under Standard Temperature and Pressure (STP). For natural gas this makes a 7% difference in heating value.

Greenhouse gas emissions are also given in CO_2 equivalents; greenhouse gases other than CO_2 emitted are included in this index, weighted as to their greenhouse warming effect relative to the CO_2 warming effect. For example, methane, NO_X, carbon monoxide, and sulfur dioxide are all greenhouse gases. Carbon dioxide emissions are usually the most dominant component of CO_2 equivalent emissions, but CO_2 emissions cannot be safely inferred from CO_2 equivalent emissions because the factors for other greenhouse gases are very large in some cases.

Carbon dioxide emissions are also given in terms of carbon equivalents. In this case, CO_2 emissions are determined (which are slightly less than the oxidized carbon contents of the fuel if combustion is incomplete), and also CO_2 equivalents of other greenhouse gases emitted, and then a factor of 12/44, representing the molecular weight of carbon over the molecular weight of CO_2, is applied to the total. Thus, carbon equivalents can NOT be obtained directly from the carbon component in the molecular formula, or from carbon content of the fuel, as one might assume, but instead depend on the chemical reactions that took place during combustion.

Carbon Dioxide Emission Factors for Direct Use of Fuels and Electricity

Direct energy use in greenhouse production comprises about 95% of total energy use, varying from 92% to 97% depending on length of the cropping season. (In shorter cropping durations, the embodied energy is a larger proportion of total energy.) The bulk of direct energy use in greenhouse production today is either from electricity or natural gas. Coal and fuel oil have been used in the past for heating. The energy embodied in manufactured structural materials, equipment, and consumables, on the other hand, involves mixed energy sources, including some electricity. Among fossil fuels, CO_2 emissions are lowest for natural gas at c. 38 kg/GJ, next is liquid petroleum at c. 70 kg/GJ, and bituminous coal is c. 90 kg/GJ. Electricity in New York is approximately 97 kg/GJ.

When natural gas is used, we assume processed, commercial natural gas which has been refined to the point of being almost pure methane and has a carbon content of 75% by weight. When methane is completely combusted with no residual carbon monoxide, 2.75 lbs of CO_2 are emitted for every lb of methane combusted, based on molecular weights of the elements. However, statistics concerning methane and natural gas are more often given in terms of volume than weight, either at normal temperature and pressure (NTP, 20C and 1 atmosphere) or at standard temperature and pressure (STP, 0C and 1 atmosphere). (The density of methane under NTP is 0.0417 lb/ft3 or 0.668 kg/m^3. Under STP it is 0.0447 lb/ft^3, or 0.717 kg/m^3. Temperature has a large effect on density.)

Carbon dioxide emissions from natural gas are often given in terms of Btu, kWh, or MJ, rather than weight or volume. Because methane has a high ratio of hydrogen to carbon molecules, whether the latent heat of vaporization of the water molecules formed during combustion is recovered and used in heating applications is important. The technologies exist to recover the latent heat; we will assume state of the art furnaces in which latent heat is recovered and use the commonplace HHV figure of 1,027 Btu/ft^3 at NTP. Converted to metric units, the value we will use for carbon dioxide emissions from natural gas is 38 kg/GJ. In calculating emissions from natural gas from the actual volume/weight of gas consumed by the final user, it is legitimate and necessary to take into account emissions during processing and refinement, i.e., include a factor for the manufacturing energy of refinement. We will use the factor 1.195. It may be applied either to the quantity of natural gas required or to the CO_2 emissions factor of 38 kg/GJ, raising that value to c. 45.

Average annual CO_2 emissions in New York State in production of electricity have shown considerable fluctuation over the past ten years – between 353 and 399 tons/GWh (NYSERDA, 2007). In 2005, the most recent year for which data are computed, we were at an intermediate value of 383 tons/GWh. This translates to 0.767lbs/kWh or 97 kg/GJ. It is worth noting that if New York State were more dependent on coal for electricity generation, as some centrally located states and Canadian provinces are, carbon emissions could be 3 times as high, and also include larger quantities of other potent greenhouse gases and air pollutants. At the other extreme, the neighboring Quebec Province of Canada has extremely low CO_2 emissions of about 3 kg/GJ because of hydropower. In 2005, 46% of New York electricity was supplied from fossil fuels, 14% coal, 17% m natural gas and 14% petroleum, and 41% was from renewable/non-emitting sources. The remaining 13% was imported. The value we will use for calculating CO_2 emissions attributable to electricity use in our hypothetical greenhouse production system is the most recent New York estimate of 97kg CO_2/GJ of electricity.

Carbon Dioxide Emissions Embodied in Materials

Determining carbon emissions embodied in the manufacture of structural materials and equipment used in the greenhouse is difficult because multiple types of energy resource are used for the same item and manufacture encompasses multiple steps. However, embodied energy amortized over the life of structures and equipment is a relatively minor part of energy use (c. 5%), as noted above, so uncertainty/imprecision in this area does not affect outcomes a great deal.

Steel is one of the primary materials used for the structure and equipment in the greenhouse. Techniques of steel manufacture have been evolving continuously for the last 100 years with continual changes in how energy is required and used, and also reductions in energy use. The EIA analysis we will follow (Battles et al., 1999,) divides energy inputs into primary inputs, 72% of total, (particularly heavy on coal and coke), and end-use inputs, 28%, (particularly heavy on natural gas). The net result is a distribution of energy use as follows: 46% natural gas, 40% coal/coke, 12% electricity, and 2% fuel oil. Applying individual CO_2 emission rates to each fuel source, we get an overall rate of carbon emissions in steel production of 78 kg CO_2/GJ. Total energy inputs into production of steel were 9.1 kBtu/lb or 21 MJ/kg, so carbon dioxide emissions per pound of steel are 1.64 kg/lb.

We have made an effort to obtain similar representative CO_2 emissions factors for the other main materials used in the greenhouse – aluminum, glass, concrete, polyethylene, and PVC – with varying success and, so, are not confident of their accuracy in all cases. Nevertheless, we know emissions factors must fall within a fairly narrow range of 50 to 100 kg CO_2/GJ, except in the case of concrete (for which we have the estimate of 179 kg/GJ). If our estimates of embodied energy are reasonable, emissions estimates would also be reasonable, even were we simply to apply a universal emissions factor to the figures for embodied energy.

We have calculated CO_2 emissions associated with embodied energy using the emission factors described above and they can be found in Tables 5-1 thru 5-5 alongside energy use calculations.

Carbon dioxide emissions associated with direct use of natural gas and electricity in New York State are computed in Tables 5-21, 5-22, and 5-23, summary tables that also include calculation of emissions per kg of product under all of the production scenarios. Energy use per kg of product is placed alongside to compare patterns. It can be seen that by and large CO_2 emissions follow the same pattern as energy use. However, in the comparison of scenarios in which supplementary light is used, with or without CO_2 enrichment, where energy use per kg of product is virtually identical (see final column of Table 5-15), CO_2 emissions are reduced 20% by virtue of CO_2 enrichment. The reason for this is CO_2 use reduces electricity use for supplemental lighting, for which the emissions rate is 97 kg/GJ, and the added requirement of heat energy due to reduction of supplementary lighting is met by the relatively clean fuel natural gas, with an effective emissions rate 45 kg/GJ.

Reducing CO_2 emissions through use of CO_2 enrichment is particularly effective when a substantial part of electricity generation is from fossil fuels. Nevertheless, it is one more reason to concentrate research efforts in making CO_2 enrichment more feasible in greenhouse crop production.

Table 5-21. Lettuce: Summary of CO_2 Emissions under different Production Scenarios

Production Scenario	CO2 Emissions - Embodied E			CO2 Emissions - Direct energy use				Total	Emissions per kg		Energy
	Common Embodied Energy Emissions	Crop-specific emb. Energy Emissions	Total Embodied Energy Emissions	Miscell. direct energy Emissions	Supplementry light energy Emissions	Heat reqd. NG equiv. Emissions	Total Direct Energy Emissions	Total All Emissions of CO2	Yield Metric system	Emissions per kg Product	Total Energy per kg
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/kg	MJ/kg
	Lettuce crop										
No supp. light, no CO2											
12 mnth	104,464	34,856	139,320	316,834	0	2,111,878	2,428,712	2,568,032	749,700	3.4	70
10 mnth	104,464	31,992	136,457	264,650	0	1,529,611	1,794,261	1,930,718	650,900	3.0	59
8 mnth	104,464	29,129	133,593	217,964	0	1,085,033	1,302,996	1,436,590	541,500	2.7	52
No supp. light, with CO2											
12 mnth	104,464	34,856	139,320	316,834	0	2,190,223	2,507,057	2,646,377	871,000	3.0	62
10 mnth	104,464	31,992	136,457	264,650	0	1,586,698	1,851,348	1,987,804	739,200	2.7	54
8 mnth	104,464	29,129	133,593	217,964	0	1,125,401	1,343,365	1,476,958	603,800	2.4	48
Supplementary light, no CO2											
12 mnth	123,776	34,856	158,631	316,834	2,982,168	1,570,353	4,869,355	5,027,987	1,064,000	4.7	67
10 mnth	123,776	31,992	155,768	264,650	1,885,680	1,238,947	3,389,277	3,545,045	825,000	4.3	63
8 mnth	123,776	29,129	152,904	217,964	1,033,632	971,583	2,223,179	2,376,083	642,000	3.7	57
Supplementary light, with CO2											
12 mnth	123,776	34,856	158,631	316,834	1,476,056	2,191,695	3,984,585	4,143,216	1,064,000	3.9	65
10 mnth	123,776	31,992	155,768	264,650	796,425	1,598,571	2,659,646	2,815,414	825,000	3.4	59
8 mnth	123,776	29,129	152,904	217,964	333,507	1,139,500	1,690,970	1,843,875	642,000	2.9	52

Table 5-22. Spinach: Summary of CO_2 Emissions under different Production Scenarios

Note: Emissions and energy per kg harvest are here given for the whole plant not just leaf. Leaf alone halves yield

	CO2 Emissions - Embodied E			CO2 Emissions - Direct energy use				Total	Emissions per kg		Energy
Production Scenario	Common Embodied Energy Emissions	Crop-specific emb. Energy Emissions	Total Embodied Energy Emissions	Miscell. direct energy Emissions	Supplem-entry light energy Emissions	Heat reqd. NG equiv. Emissions	Total Direct Energy Emissions	Total All Emissions of CO2	Yield Metric system (whle plnt)	Emissions per kg Product (whle plnt)	Total Energy per kg (whle plnt)
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/kg	MJ/kg
	Spinach Crop										
No supp. light, no CO2											
12 mnth	104,464	41,352	145,816	335,491	0	2,206,283	2,541,774	2,687,590	896,082	3.0	61
10 mnth	104,464	37,466	141,931	288,190	0	1,603,521	1,891,711	2,033,642	765,476	2.7	53
8 mnth	104,464	33,581	138,045	243,945	0	1,179,427	1,423,372	1,561,418	687,794	2.3	44
No supp. light, with CO2											
12 mnth	104,464	41,352	145,816	335,491	0	2,277,455	2,612,946	2,758,762	1,006,207	2.7	55
10 mnth	104,464	37,466	141,931	288,190	0	1,661,111	1,949,301	2,091,232	854,547	2.4	49
8 mnth	104,464	33,581	138,045	243,945	0	1,186,188	1,430,134	1,568,179	698,072	2.2	44
Supplementary light, no CO2											
12 mnth	123,776	41,352	165,127	335,491	2,982,168	1,647,879	4,965,537	5,130,665	1,184,176	4.3	62
10 mnth	123,776	37,466	161,242	288,190	1,885,680	1,316,928	3,490,798	3,652,040	945,176	3.9	57
8 mnth	123,776	33,581	157,357	243,945	1,033,632	1,049,913	2,327,490	2,484,847	762,176	3.3	51
Supplementary light, with CO2											
12 mnth	123,776	41,352	165,127	335,491	1,476,056	2,269,220	4,080,767	4,245,894	1,184,176	3.6	60
10 mnth	123,776	37,466	161,242	288,190	796,425	1,676,552	2,761,167	2,922,409	945,176	3.1	53
8 mnth	123,776	33,581	157,357	243,945	333,507	1,217,830	1,795,282	1,952,638	762,176	2.6	46

Table 5-23. Tomato: Summary of CO2 Emissions under different Production Scenarios

Production Scenario	CO2 Emissions - Embodied E			CO2 Emissions - Direct energy use				Total	Emissions per kg		Energy
	Common Embodied Energy Emissions	Crop-specific emb. Energy Emissions	Total Embodied Energy Emissions	Miscell. direct energy Emissions	Supplementry light energy Emissions	Heat reqd. NG equiv. Emissions	Total Direct Energy Emissions	Total All Emissions of CO2	Yield Metric system	Emissions per kg Product	Total Energy per kg
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/kg	MJ/kg
Tomato Crop											
No supp. light, no CO2											
12 mnth											
10 mnth	104,464	42,411	146,875	54,831	0	1539084	1,593,915	1,740,789	620,000	2.8	59
8 mnth	104,464	38,935	143,400	48,232	0	1079229	1,127,461	1,270,861	496,000	2.6	53
No supp. light, with CO2											
12 mnth											
10 mnth	104,464	42,411	146,875	54,831	0	1580744	1,635,574	1,782,449	683,500	2.6	55
8 mnth	104,464	38,935	143,400	48,232	0	1112583	1,160,815	1,304,215	546,800	2.4	50
Supplementary light, no CO2											
12 mnth	123,776	45,886	169,661	66,851	2,982,168	1570353	4,619,373	4,789,034	1,025,329	4.7	67
10 mnth	123,776	42,411	166,186	54,831	1,885,680	1225494	3,166,004	3,332,190	775,488	4.3	64
8 mnth	123,776	38,935	162,711	48,232	1,033,632	952723	2,034,588	2,197,298	591,291	3.7	58
Supplementary light, with CO2											
12 mnth	123,776	45,886	169,661	66,851	1,476,056	2191695	3,734,602	3,904,263	1,025,329	3.8	65
10 mnth	123,776	42,411	166,186	54,831	796,425	1585118	2,436,374	2,602,560	775,488	3.4	60
8 mnth	123,776	38,935	162,711	48,232	333,507	1120640	1,502,379	1,665,089	591,291	2.8	52

TASK 6: CONCLUSIONS REGARDING IN-STATE COMPETITIVE ADVANTAGE

INTRODUCTION

One of the great challenges and problems facing humanity is that, while demand for petroleum fuel increases, the resource is finite. Much has been already used and what remains becomes more difficult and expensive to obtain. For this and other reasons the diesel fuel upon which agriculture and food distribution depends has rapidly increased in price, a trend likely to continue. Much of the motivation for this report was to assess the effects of rising fuel prices on agriculture in New York and particularly on Controlled Environment Agriculture (or CEA) as an alternative means of food production.

Tables 6-1 and 6-2 provide a detailed summary of energy use in producing and transporting five crops to New York from remote areas, and also give an estimate of energy use in producing and transporting these crops when produced inside New York State. It is more accurate to refer to "fossil fuel and electric power use" because the totals do not include solar energy contributed to the crop production process directly, whether outdoors or in the greenhouse, and only include the output energy, not the input, in electric power generation when the input energy source is renewable (such sources as hydroelectric, photovoltaic and wind power). It can be argued we should not count electric energy use if it derives from a renewable source of energy such as wind, high water or sunlight, for the same reason we do not count the sunlight falling on the crop. However, we have taken a pragmatic approach and have counted all electricity use regardless of how produced.

Despite omitting direct solar energy, it should be kept in mind it has a dominating influence on how crops perform outdoors, and how much energy must be supplied for supplementary heating, lighting, and ventilating in the greenhouse.

The energy use figures given include energy used in the manufacture of materials and equipment used in farming and transportation, the so called "embodied" energy, in addition to direct fuel and electricity use. It should also be noted that in the case of fuel and electricity use, factors have been applied to take into account fuel/electricity expended in the production of the fuel/electricity by whatever means it is produced. The factors are about 1.2 for gasoline, diesel and natural gas, and 3.3 for electricity in the case of field crop production out of state. For greenhouse production a factor of 2.3 was applied to electric energy quantities, for the New York case where renewable sources provide a substantial part of the mix.

The energy totals provided have accounted for energy going into field production, harvest, and transportation from a farm to a hypothetical wholesale distribution center in the Albany area, but they are not all inclusive. We have not estimated energy to transport the food from a wholesale warehouse to the homes of consumers, also known as the "last mile" consideration. We have also not estimated energy embodied in packaging and, in general, any post harvest processing other than transportation. Within a given crop we believe the same amount of packaging and post harvest processing takes place regardless of the source of the produce, so this omission is that of a small constant amount and should have little effect on comparisons of energy use among sources.

This project is an analysis of energy use in crop production and, up to this point, we have not tackled economic questions except in a cursory way. The questions posed at the beginning of this chapter are essentially economic in nature and we will answer them as best we can. We believe the simplest and most comprehensible way to do this without undertaking a comprehensive economic analysis is to put a price on actual direct fuel and electricity use in crop production, such as might be found in fuel bills of farmers and greenhouse operators. In Chapter 5 the quantities of natural gas and electricity used in greenhouse CEA production were obtained in the course of estimating total energy use. For field crops we will deduce diesel and electric use from energy totals that already include an energy-production allowance. We will not attempt to put a price on energy embodied in structures and materials, although we have determined what fraction of overall energy use falls in the category "embodied energy". (For greenhouse production it is roughly 5%. In field production it is a much higher percentage, but energy use in field production is minor compared to long-distance transportation energy.)

There is a substantial difference between what is cooked/prepared for eating and what must be grown, which is to say between what enters into the marketing process (utilization) and what is consumed. On a national basis, the "shrinkage" for our crops falls between 40% and 60% (as presented in Table 2-1). One could claim that, if shrinkage occurs after shipment begins, the "food miles" of the product actually consumed should be scaled up to account for this loss (converted to virtual food miles.)

The crops we are analyzing travel an average of 2900 to 3000 miles, except tomato, which travels an average of more than 2200 miles. This travel represents 4 to 6 days in transit for strawberry and lettuce, and longer for spinach, tomato, and apples, which are likely to undergo additional storage and processing. One of the advantages of local production is the product can be delivered to the consumer sooner and so should last longer before spoiling, with less waste (shrinkage) as a result. We have reason to believe this is even truer of greenhouse-produced crops that, in addition to being locally grown, have been protected from the weather and handled gently.

The quantities of crops shipped to New York and grown in New York have been computed on the basis of crop utilization rather than crop consumption because we have reliable recent data for crop utilization but only occasionally-collected survey data for crop consumption. If shrinkage is higher for remotely produced goods than locally produced, it means larger quantities are required to meet consumer demands and their production and transport represent a real additional energy use and cost over locally produced goods. In this chapter we have tried to capture this phenomenon by computing energy use and energy cost per weight consumed as well as per weight utilized. Overall shrinkage rates are well established but hard data are not available for how shrinkage is affected by duration or means of transport or means of crop production. The assumptions we have made as to shrinkage are in Table 6-6 and the factors used to convert energy and cost from a per-utilized to a per-consumed weight basis are given.

FIELD CROP PRODUCTION: LOCAL AND REMOTE COMPARED

We have assembled the findings of the prior chapters in this chapter. Table 6-1 gives the weighted average energy use to produce crops brought to New York (including grown in NY) from data developed in Chapters 2 and 3. Table 6-2 gives the weighted average energy use for transportation of the crops to New York, based on data in Chapters 2 and 4. Tables 6-3 and 6-4 combine these data to give total energy use in production and transportation by source. In summary Table 6-5, we directly compare average energy use to grow and transport all the in-state and out-of-state produce consumed in NY, per unit weight of produce utilized.

Examining Table 6-5 it can be seen there are not large differences in absolute terms for production energy between New York and out-of state producers. It should be noted we do not have confirmed estimates of production energy in New York because the farming of these crops is minor, except for apples, and there is a good deal of uncertainty as to yield. With regard to iceberg lettuce, for which no production statistics are kept in the state, we doubled the California figure, assuming poorer yield. For spinach and tomato we assumed our climate situation during the summer season was similar to Texas and Florida respectively during their production seasons and used those estimates. For strawberry we assumed small-farm U-pick operations to be typical, with low energy inputs and low yields, which is why the New York energy estimate is low.

The transportation energy for remote producers shown in Table 6-5 generally matches or exceeds production energy. For lettuce and strawberry it is triple production energy. It is about the same as production energy for tomato because much of our supply comes from Florida, or nearer, including nearby greenhouse production in Canada. For spinach, transportation energy is high, but so is production energy, because yield is low for cut-salad products. Apple transportation energy is not much higher than production energy because foreign imports use very efficient ocean shipping and the Washington trade uses rail to some extent.

Table 6-1a. Estimated Energy Use in Field Production of Produce Shipped to NY

Iceberg Lettuce

	Weight Shipped	Prodtn. Energy	Total Prodtn. Energy				
	tonnes	MJ/kg	GJ	LP	Elec	Other	Total
		2.61		0.38	0.26	0.36	1.00
Origin		3.8		0.40	0.23	0.37	1.00
US Out-of-State Sources							
California-Total	128,454	2.61	335,265	128,878	87,068	119,319	335,265
Arizona-Total	50,259	3.8	190,986	77,342	43,562	70,082	190,986
Florida-total							
Colorado	897	3.8	3,409	1,380	778	1,251	3,409
New Jersey							
Texas							
Virginia							
Ohio							
Georgia							
Tennessee							
South Carolina							
North Carolina							
Minnesota							
Michigan							
Washington-Total							
Oregon-Total							
Domestic Greenhouse Production (place unspecified)							
All US Production: ST	**179,610**	**2.9**	**529,659**	**207,600**	**131,407**	**190,652**	**529,659**
Imports							
Mexico (truck)	2,770	2.6	7,230	2,779	1,878	2,573	7,230
Canada (truck)	791	5.2	4,123	1,585	1,071	1,468	4,123
Netherlands							
Israel (air)							
Spain (air)							
Chile (boat)							
New Zealand (boat)							
Imports, Major. ST.	**3,597**	**3.2**	**11,353**	**4,364**	**2,948**	**4,041**	**11,353**
All Out-of-State Sources	**183,208**	**3.0**	**541,013**	**211,965**	**134,356**	**194,692**	**541,013**
New York	1,724	5.2	8,980	3,452	2,332	3,196	8,980
Total NY Utilization	**184,932**	**3.0**	**549,993**	**215,417**	**136,688**	**197,888**	**549,993**

Table 6-1b. Estimated Energy Use in Field Production of Produce Shipped to NY

	Fresh spinach			Fresh Strawberry		
	Weight Shipped	Unit Prodtn. Energy	Total Prodtn. Energy	Weight Shipped	Unit Prodtn. Energy	Total Prodtn. Energy
	tonnes	MJ/kg	GJ	tonnes	MJ/kg	GJ
Origin						
US Out-of-State Sources						
California-Total	14,552	9.0	130,764	39,051	3.2	124,963
Arizona-Total	3,352	9.0	30,123			
Florida-total				4,117	8.7	35,818
Colorado						
New Jersey	343	8.5	2,909			
Texas	54	8.5	462			
Virginia						
Ohio						
Georgia						
Tennessee						
South Carolina						
North Carolina						
Minnesota						
Michigan						
Washington-Total						
Oregon-Total						
Domestic Greenhouse Production (place unspecified)						
All US Production: ST	**18,301**	**9.0**	**164,258**	**43,168**	**3.7**	**160,781**
Imports						
Mexico (truck)	779	9.0	7,004	3,598	3.2	11,513
Canada (truck)	116	8.5	981			
Netherlands						
Israel (air)						
Spain (air)						
Chile (boat)						
New Zealand (boat)						
Imports, Major: ST.	**895**	**8.9**	**7,985**	**3,598**	**3.2**	**11,513**
All Out-of-State Sources	**19,197**	**9.0**	**172,243**	**46,766**	**3.7**	**172,294**
New York	408	8.5	3,464	2,676	2.2	5,888
Total NY Utilization	**19,605**	**9.0**	**175,708**	**49,442**	**3.6**	**178,182**

Note: spinach is assumed to be 90% cut, 10% bunching

Table 6-1c. Estimated Energy Use in Field Production of Produce Shipped to NY

	Fresh Tomato			Fresh Apple		
	Weight Shipped	Prodtn. Energy	Total Prodtn. Energy	Weight Shipped	Prodtn. Energy	Total Prodtn. Energy
	tonnes	MJ/kg	GJ	tonnes	MJ/kg	GJ
Origin						
US Out-of-State Sources						
California-Total	21,899	3.4	74,458	808	11	8,643
Arizona-Total						
Florida-total	40,731	7.1	289,190			
Colorado						
New Jersey	192	7.1	1,360			
Texas						
Virginia	4,360	7.1	30,958			
Ohio	2,578	7.1	18,301			
Georgia	2,428	7.1	17,238			
Tennessee	1,270	7.1	9,016			
South Carolina	1,102	7.1	7,825			
North Carolina	836	7.1	5,936			
Minnesota	454	7.1	3,223			
Michigan				1,528	6.8	10,392
Washington-Total				17,677	5.0	88,384
Oregon-Total				427	4.7	2,008
Domestic Greenhouse Product	12,008	13.2	158,510			
All US Production: ST	**87,858**	**7.0**	**616,016**	**20,440**	**5.4**	**109,427**
Imports						
Mexico (truck)	59,412	6.0	356,470			
Canada (truck)	10,198	66.0	673,094	447	5.4	2,412
Netherlands	882	66.0	58,242			
Israel (air)	221	13.2	2,924			
Spain (air)	187	13.2	2,467			
Chile (boat)				1,167	5.0	5,835
New Zealand (boat)				627	3.8	2,381
Imports, Major: ST.	**70,901**	**15.4**	**1,093,196**	**2,240**	**4.7**	**10,628**
All Out-of-State Sources	**158,759**	**10.8**	**1,709,212**	**22,680**	**5.3**	**120,054**
New York	16,329	7.1	115,939	133,811	5.4	722,580
Total NY Utilization	**175,088**	**10.4**	**1,825,151**	**156,491**	**5.4**	**842,635**

Table 6-2a. Estimated Energy Use in Transportation of Produce Shipped to NY from different Areas

Origin	Iceberg Lettuce Weight Shipped tonnes	Prodtn. Energy MJ/kg	Total Prodtn. Energy GJ	Fresh spinach Weight Shipped tonnes	Unit Prodtn. Energy MJ/kg	Total Prodtn. Energy GJ	Fresh Strawberry Weight Shipped tonnes	Unit Prodtn. Energy MJ/kg	Total Prodtn. Energy GJ
California-Total	**128,454**	**10.6**	**1,355,650**	**14,552**	**11.8**	**172,014**	**39,051**	**11.8**	**461,607**
CA-Trucked	122,749	10.7	1,319,071						
CA-Piggyback	5,704	6.4	36,579						
CA-Railcar									
Arizona-Total	**50,259**	**9.4**	**472,135**	**3,352**	**10.5**	**35,251**			
Arizona-Trucked	48,071	9.6	459,545						
Arizona-Piggyback	2,189	5.8	12,590						
Florida-total							**4,117**	**4.2**	**17,292**
Florida-Trucked									
Florida Piggyback									
Colorado	897	6.2	5,550						
New Jersey				343	0.9	321			
Texas				54	7.0	383			
Virginia									
Ohio									
Georgia									
Tennessee									
South Carolina									
North Carolina									
Minnesota									
Michigan									
Washington-Total									
Washington-Trucked									
Washington-Piggyback									
Washington-Railcar									
Oregon-Total									
Oregon-Trucked									
Oregon-Piggyback									
Oregon-Railcar									
Domestic Greenhouse Production (place unspecified)									
All US Production: ST	**179,610**	**10.2**	**1,833,335**	**18,301**	**11.4**	**207,969**	**43,168**	**11.1**	**478,899**
<u>Imports</u>									
Mexico (truck)	2,770	9.3	25,708	779	10.3	8,009	3,598	10.3	36,969
Canada (truck)	791	1.6	1,289	116	1.8	208			
Netherlands (air)									
Israel (air)									
Spain (air)									
Chile (boat)									
New Zealand (boat)									
Imports, Major: ST.	**3,597**	**7.5**	**26,997**	**895**	**9.2**	**8,217**	**3,598**	**10.3**	**36,969**
All Out-of-State Sources	**183,208**	**10.2**	**1,860,332**	**19,197**	**11.3**	**216,186**	**46,766**	**11.0**	**515,868**
New York	**1,724**	**0.4**	**742**	**408**	**0.4**	**176**	**2,676**	**0.4**	**1,152**
Total NY Utilization	**184,932**	**10.1**	**1,861,074**	**19,605**	**11.0**	**216,362**	**49,442**	**10.5**	**517,020**

Table 6-2b. Estimated Energy Use in Transportation of Produce Shipped to NY from different Areas

Origin	Fresh Tomato Weight Shipped	Prodtn. Energy	Total Prodtn. Energy	Fresh Apple Weight Shipped	Prodtn. Energy	Total Prodtn. Energy
	tonnes	MJ/kg	GJ	tonnes	MJ/kg	GJ
California-Total	**21,899**	**10.7**	**233,744**	**808**	**10.6**	**8,530**
CA-Trucked	21,556	10.7	231,644	773	10.7	8,310
CA-Piggyback	203	6.4	1,302	33	6.4	215
CA-Railcar	140	5.7	798	1	5.7	6
Arizona-Total						
Arizona-Trucked						
Arizona-Piggyback						
Florida-total	**40,731**	**3.8**	**154,394**			
Florida-Trucked	40,616	3.8	154,085			
Florida Piggyback	115	2.7	309			
Colorado						
New Jersey	192	0.8	162			
Texas						
Virginia	4,360	1.7	7,383			
Ohio	2,578	2.0	5,204			
Georgia	2,428	3.6	8,657			
Tennessee	1,270	3.5	4,404			
South Carolina	1,102	2.8	3,087			
North Carolina	836	2.1	1,797			
Minnesota	454	4.1	1,840			
Michigan				1,528	2.1	3,284
Washington-Total				**17,677**	**9.4**	**166,769**
Washington-Trucked				17,010	9.6	163,203
Washington-Piggyback				224	5.8	1,290
Washington-Railcar				443	5.1	2,275
Oregon-Total				**427**	**9.3**	**3,972**
Oregon-Trucked				324	10.3	3,339
Oregon-Piggyback				96	6.2	595
Oregon-Railcar				7	5.5	38
Domestic Greenhou	12,008	6.7	81,001			
All US Production:	**87,858**	**5.7**	**501,673**	**20,440**	**8.9**	**182,556**
<u>Imports</u>						
Mexico (truck)	59,412	9.3	551,380			
Canada (truck)	10,198	1.6	16,605	447	1.6	**727**
Netherlands (air)	882	128.4	**113,348**			
Israel (air)	221	199.1	**44,103**			
Spain (air)	187	126.4	**23,611**			
Chile (boat)				1,167	4.8	**5,576**
New Zealand (boat)				627	8.0	**5,042**
Imports, Major: ST	**70,901**	**10.6**	**749,048**	**2,240**	**5.1**	**11,345**
All Out-of-State So	**158,759**	**7.9**	**1,250,722**	**22,680**	**8.5**	**193,901**
New York	**16,329**	**0.4**	**7,027**	**133,811**	**0.4**	**57,580**
Total NY Utilizatio	**175,088**	**7.2**	**1,257,749**	**156,491**	**1.6**	**251,481**

Table 6-3. Estimated Energy Use Growing and Shipping Head Lettuce and Spinach for New York Consumption -- per Kilogram Farm Produce Shipped

Head lettuce

Source	Iceberg-field Prod. MJ/kg	Iceberg-field Transp. MJ/kg	Iceberg-field Total MJ/kg	Boston-field Prod. MJ/kg	Boston-field Transp. MJ/kg	Boston-field Total MJ/kg	Boston- greenhouse Prod. MJ/kg	Boston- greenhouse Transp. MJ/kg	Boston- greenhouse Total MJ/kg
CA	2.6	10.6	**13.2**	5.2	10.6	**15.8**			
AZ	3.8	9.4	**13.2**	7.6	9.4	**17.0**			
CO	3.8	6.2	**10.0**	7.6	6.2	**13.8**			
Mex	2.6	9.3	**11.9**	5.2	9.3	**14.5**			
Can	5.2	1.6	**6.8**	10.4	1.6	**12.0**	77	1.6	**78.6**
All Out of State	**3.0**	**10.2**	**13.2**	**6.0**	**10.2**	**16.2**			
NY	5.2	0.4	**5.6**	10.4	0.4	**10.8**	97	0.4	**97.4**

Fresh spinach

Source	Bunching-field Prod. MJ/kg	Bunching-field Transp. MJ/kg	Bunching-field Total MJ/kg	Baby leaf - field Prod. MJ/kg	Baby leaf - field Transp. MJ/kg	Baby leaf - field Total MJ/kg	Baby leaf - greenhouse Prod. MJ/kg	Baby leaf - greenhouse Transp. MJ/kg	Baby leaf - greenhouse Total MJ/kg
CA	2.2	11.8	14.0	9.7	11.8	**21.5**			
AZ	2.2	10.5	**12.7**	9.7	10.5	**20.2**			
NJ	1.79	0.9	**2.7**	9.2	0.9	**10.1**			
TX	1.79	7.0	**8.8**	9.2	7.0	**16.2**			
Mex	2.2	10.3	**12.5**	9.7	10.3	**20.0**			
Can	1.79	1.8	**3.6**	9.2	1.8	**11.0**			
All Out of State	**c. 2.2**	**11.4**	**13.6**	**c. 9.7**	**11.4**	**21.1**			
NY	1.79	0.4	**2.2**	9.2	0.4	**9.6**	179	0.4	**179.0**

Note. For shaded producers and crops, detailed estimates were taken from the literature, or made *de novo*, but with unknown accuracy. Other estimates are based on similarity of production circumstances
Greenhouse growing scenario (light, CO2, duration) is noted in Excel cell comments

Table 6-4. Estimated Energy Use in Growing and Shipping Tomato, Apple, and Strawberry for New York Consumption per Kilogram Farm Produce Shipped

Fresh Tomato							Fresh Apple (field)				Fresh Strawberry (field)			
Source	Field Prod MJ/kg	Transp MJ/kg	Total MJ/kg	GrnHse Prod MJ/kg	Transp MJ/kg	GrnHse Total MJ/kg	Source	Prod MJ/kg	Transp MJ/kg	Total MJ/kg	Source	Prod MJ/kg	Transp MJ/kg	Total MJ/kg
CA field	3.4	10.7	14.1											
CA pole	3.1	10.7	13.8				CA	10.7	10.6	21.3	CA	3.2	11.8	15.0
FL	7.1	3.8	10.9				MICH	6.8	2.1	8.9	FL	8.7	4.2	12.9
NJ	7.1	0.8	7.9				WA	5.0	9.4	14.4				
VA	7.1	1.7	8.8				OR	4.7	9.3	14.0				
OH	7.1	2.0	9.1				NY	5.4	0.4	5.8				
GA	7.1	3.6	10.7											
TN	7.1	3.5	10.6											
SC	7.1	2.8	9.9											
NC	7.1	2.1	9.2											
MINN	7.1	4.1	11.2											
Mex	6.0	9.3	15.3								Mex	3.2	10.3	13.5
US	13.2	6.7	19.9	13.2	6.7	19.9	Can	5.4	1.6	7.0				
Can	66	1.6	67.6	66	1.6	67.6	Chile	5.0	4.8	9.8				
Neth	66	128.0	194.0	66	128.0	194.0	NZ	3.8	8.0	11.8				
Israel	13.2	199.0	212.2	13.2	199.0	212.2								
Spn	13.2	126.0	139.2	13.2	126.0	139.2								
All out of State	10.8	7.9	18.7				All out of State	5.3	8.9	14.4	All out of State	3.7	11.1	14.6
NY	7.1	0.4	7.5	66	0.4	66.4	NY	5.4	0.4	5.8	NY	2.2	0.4	2.6

Note. For shaded producers and crops, detailed estimates were taken from the literature, or made *de novo*, but with unknown accuracy. Other estimates are based on similarity of production circumstances
Greenhouse growing scenario (light, CO_2, duration) is noted in Excel cell comments

Table 6-5. Estimated Energy Use in Field Production and Transportation of Produce Shipped to NY from different Areas.

	Iceberg Lettuce Weight Shipped	Energy per unit weight	Total Energy	Fresh spinach Weight Shipped	Energy per unit weight	Total Energy	Fresh Strawberry Weight Shipped	Energy per unit weight	Total Energy	Fresh Tomato Weight Shipped	Energy per unit weight	Total Energy	Fresh Apple Weight Shipped	Energy per unit weight	Total Energy
	tonnes	MJ/kg	GJ	tonnes	MJ/kg	GJ	tonnes	MJ/kg	GJ	tonnes	MJ/kg	GJ	tonnes	MJ/kg	GJ
Origin	**Field Production**														
US Production, not NY	179,610	2.9	529,659	18,301	9.0	164,258	43,168	3.7	160,781	87,858	7.0	616,016	20,440	5.4	109,427
Foreign Production	3,597	3.2	11,353	895	8.9	7,985	3,598	3.2	11,513	70,901	15.4	1,093,196	2,240	4.7	10,628
All Out-of-State Prod.	**183,208**	**3.0**	**541,013**	**19,197**	**9.0**	**172,243**	**46,766**	**3.7**	**172,294**	**158,759**	**10.8**	**1,709,212**	**22,680**	**5.3**	**120,054**
New York Produced	**1,724**	**5.2**	**8,980**	**408**	**8.5**	**3,464**	**2,676**	**2.2**	**5,888**	**16,329**	**7.1**	**115,939**	**133,811**	**5.4**	**722,580**
Total NY Utilization	**184,932**	**3.0**	**549,993**	**19,605**	**9.0**	**175,708**	**49,442**	**3.6**	**178,182**	**175,088**	**10.4**	**1,825,151**	**156,491**	**5.4**	**842,635**
	Shipping														
US Production, not NY	179,610	10.2	1,833,335	18,301	11.4	207,969	43,168	11.1	478,899	87,858	5.7	501,673	20,440	8.9	182,556
Foreign Production	3,597	7.5	26,997	895	9.2	8,217	3,598	10.3	36,969	70,901	10.6	749,048	2,240	5.1	11,345
All Out-of-State Prod.	**183,208**	**10.2**	**1,860,332**	**19,197**	**11.3**	**216,186**	**46,766**	**11.0**	**515,868**	**158,759**	**7.9**	**1,250,722**	**22,680**	**8.5**	**193,901**
New York Produced	**1,724**	**0.4**	**742**	**408**	**0.4**	**176**	**2,676**	**0.4**	**1,152**	**16,329**	**0.4**	**7,027**	**133,811**	**0.4**	**57,580**
Total NY Utilization	184,932	10.1	1,861,074	19,605	11.0	216,362	49,442	10.5	517,020	175,088	7.2	1,257,749	156,491	1.6	251,481
	Production and Shipping - Total per kg Utilized														
US Production, not NY	179,610	13.2	529,659	18,301	20.3	164,258	43,168	14.8	160,781	87,858	12.7	616,016	20,440	14.3	109,427
Foreign Production	3,597	10.7	11,353	895	18.1	7,985	3,598	13.5	11,513	70,901	26.0	1,093,196	2,240	9.8	10,628
All Out-of-State Prod.	**183,208**	**13.1**	**541,013**	**19,197**	**20.2**	**172,243**	**46,766**	**14.7**	**172,294**	**158,759**	**18.6**	**1,709,212**	**22,680**	**13.8**	**120,054**
New York Produced	**1,724**	**5.6**	**8,980**	**408**	**8.9**	**3,464**	**2,676**	**2.6**	**5,888**	**16,329**	**7.5**	**115,939**	**133,811**	**5.8**	**722,580**
Ratio. Out-State:In-State		2.3			2.3			5.6			2.5			2.4	
Total NY Utilization	**184,932**	**13.0**	**549,993**	**19,605**	**20.0**	**175,708**	**49,442**	**14.1**	**178,182**	**175,088**	**17.6**	**1,825,151**	**156,491**	**7.0**	**842,635**
	Total Energy per kg consumed														
Factor for shrinkage		1.85			2.38			1.56			1.89			1.64	
All Out-of-State Prod (MJ/kg)		**24.3**			**48.2**			**23.0**			**35.2**			**22.7**	
Factor for shrinkage		1.30			1.41			1.22			1.31			1.24	
New York Produced (MJ/kg)		**7.3**			**12.6**			**3.2**			**9.8**			**7.2**	
Ratio. Out-State:In-State		3.3			3.8			7.2			3.6			3.1	

Note: spinach is assumed to be 90% cut, 10% bunching

New York transportation energy is negligible compared to transportation energy for crops imported to New York and, as a consequence, when total energy in crop production and transportation is considered, in all five crops under consideration, outside suppliers use two and a half times as much energy as local producers (See Table 6-5; five times as much in the case of strawberry, but this is moot as the enterprise is not strictly comparable). When differential shrinkage is factored into the calculation of energy per weight consumed, the outside producers' energy need becomes three to four times that of the New York producer.

New York field production in all the crops except apples, which can be stored well, suffers the disadvantage of the short duration of the growing season and the difficulty of gaining access to markets for the few months produce is available. This in itself is perhaps the greatest restraint on expansion for these crops. However, as has been shown in Table 6-5, the largest component of energy in production by remote suppliers is transportation, and that is specifically reliant on diesel fuel, which has been increasing dramatically in price. For field production in New York, fuel costs can be expected to increase at the same rate as other farm regions, but transportation is so minor a part of fuel energy use in crop marketing in New York that a very substantial relative advantage can be expected for the New York farmer from the recent increase and probable future increases in the price of diesel fuel.

In Tables 6-8, 6-9, we have calculated the energy use (6-8) and transportation cost (6-9) per kilogram of food consumed of delivering our crops when they are imported to New York versus delivery from local New York producers, taking the price of diesel fuel to be $4.00/gallon, a price already exceeded by late March of 2008. To clarify exactly what these figures represent, note that the transportation energy covers propulsion energy and road maintenance energy but not energy embodied in highway infrastructure. It includes an allowance for empty back haul, circuity, and fuel production energy. Because of high shrinkage rates, roughly twice as much produce must be hauled as is consumed, which roughly doubles the energy use and cost of transportation per weight consumed over weight produced/utilized. In calculating cost, we have used the enthalpy value for diesel fuel of 38.7 MJ/l, which works out to $2.73 cents/MJ when diesel costs $4.00/gallon. The bottom line in Table 6-10 is that, whereas New York field production transportation energy cost is about $0.01 per kilogram consumed, it ranges from $0.34 to $0.66 per kilogram for the crops under consideration when they are imported to New York. If diesel doubles, the New York cost will increase to 2 cents/kg whereas the outside sources will begin to approach $1.00/kg consumed. The crops we are considering have retail prices between $2.00 and $7.00/lb, or $4 to $14/kg. Currently, transportation appears to be costing 5 to10% of the retail price for remote producers. If diesel prices double, this penalty will double.

Table 6-6. Shrinkage Nationwide

Crop	Shrinkage (loss, %)	Consum-able (%)	National Factor
Hd lettuce	46	0.54	1.85
Spinach	58	0.42	2.38
Strawberry	36	0.64	1.56
Tomato	47	0.53	1.89
Apple	39	0.61	1.64
Assumed for local NY production			NY factor
Hd lettuce	23	0.77	1.30
Spinach	29	0.71	1.41
Strawberry	18	0.82	1.22
Tomato	23.5	0.77	1.31
Apple	19.5	0.81	1.24

See Table 2-1 for source references

Table 6-7. Average Distances and Amounts Shipped for Selected Produce Consumed in New York

	Quantities shipped -- 1000 cwt					Average distance shipped -- miles				
Geographic source	Fresh Spinach	Fresh Straw-berry	Fresh Tomato	Head Lettuce-Iceberg	Fresh Apple	Fresh Spinach	Fresh Straw-berry	Fresh Tomato	Head Lettuce-Iceberg	Fresh Apple
	1000 cwt	1000 cwt	1000 cwt	1000 cwt	1000 cwt	miles	miles	miles	miles	miles
Outside NY State, US	403	952	1,937	3,960	451	2,962	2,897	1,695	2,983	2,615
Outside NY State, Foreign	20	79	1,563	79	49	2,850	2,850	2,879	2,822	6,458
Outside NY State, All	423	1,031	3,500	4,039	500	2,956	2,894	2,224	2,980	2,995
Inside NY State	9	59	360	38	2,950	100	100	100	100	100
% Produced in NY	2	5	9	1	86					
All Utilized in NY State	432	1,090	3,860	4,077	3,450	2,897	2,742	2,026	2,953	520

Table 6-8. Energy per Unit Weight Consumed Spent in Shipping Produce to NY by Origin and Mode of Transport

Origin	Head Lettuce MJ/kg	Fresh Spinach MJ/kg	Fresh Strawberry MJ/kg	Fresh Tomato MJ/kg	Fresh Apple MJ/kg
US Out-of-State Sources	f=1.85	f=2.38	f=1.56	f=1.89	f=1.64
California-Total	19.5	28.1	18.5	20.1	17.3
CA-Trucked	19.9			20.3	17.6
CA-Piggyback	11.9			12.1	10.5
CA-Railcar				10.7	9.3
Arizona-Total	17.4	25.0			
Arizona-Trucked	17.7				
Arizona-Piggyback	10.7				
Florida-total			6.6	7.2	
Florida-Trucked				7.2	
Florida Piggyback				5.1	
Colorado	11.5				
New Jersey		2.2		1.6	
Texas		16.7			
Virginia				3.2	
Ohio				3.8	
Georgia				6.7	
Tennessee				6.5	
South Carolina				5.3	
North Carolina				4.1	
Minnesota				7.6	
Michigan					3.5
Washington-Total					15.5
Washington-Trucked					15.7
Washington-Piggyback					9.5
Washington-Railcar					8.4
Oregon-Total					15.2
Oregon-Trucked					16.9
Oregon-Piggyback					10.1
Oregon-Railcar					9.0
Domestic Greenhouse Production (place unspecified)				12.7	
All US Production: ST	**18.9**	**27.1**	**17.3**	**10.8**	**14.6**
Imports					
Mexico (truck)	17.2	24.5	16.1	17.5	
Canada (truck)	3.0	4.3		3.1	2.7
Netherlands (air)				167.9	
Israel (air)				260.3	
Spain (air)				165.2	
Chile (boat)					7.8
New Zealand (boat)					13.2
Imports, Major: ST.	**13.9**	**21.9**	**16.1**	**19.9**	**8.3**
All Out-of-State Sources	**18.8**	**26.8**	**17.2**	**14.9**	**14.0**
New York	**0.6**	**0.6**	**0.5**	**0.6**	**0.7**
Total NY Utilization	**18.6**	**26.3**	**16.3**	**13.6**	**2.6**

Table 6-9. Cost of Diesel Fuel per Unit Weight of Produce Consumed, Spent in Shipping Produce to NY, at $4.00 per Gallon Fuel

Origin	Head Lettuce $/kg	Fresh Spinach $/kg	Fresh Strawberry $/kg	Fresh Tomato $/kg	Fresh Apple $/kg
US Out-of-State Sources					
California-Total	0.48	0.69	0.45	0.49	0.43
CA-Trucked	0.49			0.50	0.43
CA-Piggyback	0.29			0.30	0.26
CA-Railcar				0.26	0.23
Arizona-Total	0.43	0.62			
Arizona-Trucked	0.43				
Arizona-Piggyback	0.26				
Florida-total			0.16	0.18	
Florida-Trucked					
Florida Piggyback					
Colorado	0.28				
New Jersey		0.05		0.04	
Texas		0.41			
Virginia				0.08	
Ohio				0.09	
Georgia				0.17	
Tennessee				0.16	
South Carolina				0.13	
North Carolina				0.10	
Minnesota				0.19	
Michigan					0.09
Washington-Total					0.38
Washington-Trucked					0.39
Washington-Piggyback					0.23
Washington-Railcar					0.21
Oregon-Total					0.37
Oregon-Trucked					0.42
Oregon-Piggyback					0.25
Oregon-Railcar					0.22
Domestic Greenhouse Production (place unspecified)				0.31	
All US Production: ST	**0.46**	**0.66**	**0.43**	**0.26**	**0.36**
Imports					
Mexico (truck)	0.42	0.60	0.39	0.43	
Canada (truck)	0.07	0.11	0.00	0.08	0.07
Netherlands (air)				4.13	
Israel (air)				6.40	
Spain (air)				4.06	
Chile (boat)					0.19
New Zealand (boat)					0.32
Imports, Major: ST.	**0.34**	**0.54**	**0.39**	**0.49**	**0.20**
All Out-of-State Sources	**0.46**	**0.66**	**0.42**	**0.37**	**0.34**
New York	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**
Total NY Utilization	**0.46**	**0.65**	**0.40**	**0.33**	**0.06**

The field crops that have received and will receive the most advantage are, in rank order: spinach, iceberg (and Boston) lettuce, strawberry, apple and tomato. Spinach is a clear leader because all current sources are very distant, and shrinkage is the highest of all the crops. Boston lettuce benefits next most since it, too, is highly perishable. Remote producers may be able partially to mitigate the rise in transportation costs by reviving rail transportation, as has already started for apple. However, rail transportation saves only half the fuel cost, and is as totally dependent on diesel fuel as truck transportation, plus generally takes an extra day to cross the country.

NEW YORK CEA PRODUCTION COMPARED WITH REMOTE FIELD PRODUCTION

We have prepared estimates of energy use in greenhouse production of three crops that are more or less similar to the field crops: Boston lettuce (instead of iceberg), baby leaf spinach (instead of a mixture of bunching and cut spinach in the field crop), and greenhouse tomato. Whereas, in the field crop estimates our sources already included production energy in the fuel and electricity totals given, in estimating greenhouse production energy *de novo*, we estimated actual fuel and electricity use (at face value) before adding energy spent to produce the fuel and electricity. In the case of electricity, the required amount of production energy varies greatly by region and has the potential to be reduced substantially in the future. The difference in the energy use totals due to adding in fuel production energy can be seen in Table 6-10.

Greenhouse production of tomato is well established throughout the US and Canada, although usually in more favorable climatic locations than upstate New York. Boston lettuce greenhouse production is very limited and spinach production virtually non-existent in the US. We have modeled greenhouse production under twelve different scenarios, examining yield and energy use under three different cropping durations, 8, 10 and 12 months of the year, and four combinations of light and CO_2 supplementation.

In upstate New York latitudes, tomato is most commonly grown with CO_2 supplementation but without light supplementation, and on a 10-month cropping schedule to avoid the coldest and darkest months of the year. In Table 6-4 we saw that energy use in the Ithaca area of upstate New York under this scenario is 66.4 MJ/kg of greenhouse tomato produced versus 18.7 MJ/kg for outside-New York producers after delivery to New York (some small part of whom are also greenhouse growers). These figures do not take into account any differential shrink. Thus in the case of tomato on a 10-month cropping schedule, the greenhouse crop requires 3 to 4 times as much supplied energy per unit weight as the field crop. (Applying differential shrinkage factors in the case of greenhouse tomato is questionable because the crop typically is picked riper and may, on that account, have a shortened shelf life.)

For Boston lettuce we feel the best advantage commercially is to adopt year-round cropping, with light supplementation and CO_2 enrichment. Energy use under this scenario is 97.4 MJ/kg versus 16.2 MJ/kg estimated for Boston lettuce grown in the field and shipped to New York, as indicated in Table 6-3. Thus there is a six-fold greater energy use by the greenhouse crop grown year round at an upstate New York latitude than by the remote transported field crop. It is possible to shorten the duration of cropping and forgo light and CO_2 and reduce unit energy costs (e.g. as Hydroserre Mirabel has done in Quebec – see the value 79 MJ/kg in Table 6-3), but our analysis in Chapter 5 indicated this may be less profitable than 12 month cropping, due to reduced volume of sales, and also it results in loss of control over market, which could be a critical disadvantage. Energy use under the various options are in Table 6-10. Note that in Tables 6-3 and 6-4, the figures are for total energy use, inclusive of fuel and electricity production allowances.

In the case of spinach, which is as yet not in greenhouse production anywhere in the US, we feel the best advantage commercially is to adopt year-round cropping, with light supplementation as needed to reach a consistent daily light integral, and CO_2 enrichment, for the same reasons as for lettuce. In Table 6-3 we indicate energy use under this option is 179 MJ/kg versus 21 MJ/kg for the field crop brought in from out of state, a 9-fold greater energy use. Spinach grows as well in hydroponic systems as lettuce; the high figure for energy use is because half the plant is wasted when it is used as a cut salad crop, especially a baby-leaf crop; as baby bunching spinach, the energy use would be halved. Of the three crops, spinach sells for the highest rate per pound and likely can support the higher energy use when used for cut leaves. The spinach market has been in a constant state of change over the last few years and is still unsettled after the 2006 scare. It is quite likely it will be possible to market greenhouse baby spinach whole, as is done in Japan, in which case unit energy use will be halved. It also appears there is a trend to larger leaves in bagged spinach, which sell at a correspondingly lower price, and this development could also be advantageous for the greenhouse crop, since it is not efficient in labor and materials to terminate plants at the crop stage just where the fastest growth rate is reached.

As can be seen in Table 6-10 there is a large difference between energy use when it includes fuel production energy and when it is as seen in a utility bill. At face value, energy in cut salad baby spinach production is 120 MJ/kg versus 179MJ/kg and for Boston lettuce 65 MJ/kg versus 97MJ/kg. In the case of tomato production without light supplementation, electricity use, which requires a large production energy factor of 2.333, is small, and the effect is not so large; the drop is from 66 to 55 MJ/kg. At the high energy use figures given it is difficult to imagine competing commercially with remote growers who have much lower energy costs. In Tables 6-11, 6-12 and 6-13 we have computed the cost per lb of product for the three crops based of the nominal gas and electricity used. The values for the scenarios we have selected as most appropriate commercially in New York are: \$0.54/lb for lettuce, \$0.99/lb for spinach, and \$ 0.28/lb for tomato. Note that if one were to opt for 10-month production with CO_2 supplementation but no light for all the crops (instead of just tomato) the bill would become \$0.31/lb for lettuce and \$0.56/lb for baby leaf spinach. In view of current retail prices these energy costs are not excessive.

To directly answer the question "How far must transportation fuel prices rise to tip the advantage to New York State seasonal outdoor production and in CEA facilities?" we have determined the weighted average cost of the actual quantities of diesel fuel and electricity used in production of lettuce and spinach by remote field suppliers to New York. These calculations a can be found in Tables 6-14 and 6-15 and are directly comparable to those for CEA production in Tables 6-11 and 6-12. (Similar calculations are possible for tomato, but complicated by the fact the remote producers are a mixture of greenhouse and field growers. Suffice it to say, the remote field tomato cost of energy and transportation would be almost exactly the same as that for iceberg lettuce.) As a further step we have applied shrinkage factors to put the fuel energy cost on a per-consumed weight basis.

Table 6-14 shows that, for Boston lettuce, before applying shrinkage factors, that cost of diesel and electric at $4.00/gallon and $0.14/ kWh respectively, was $0.27/kg (utilized lettuce) in total, $0.25 of which is in diesel, compared to $0.13 for New York field production, $0.10 of which is in diesel. After shrinkage factors are applied the figures are $0.49/kg (consumed lettuce) for remote producers, $0.46 in diesel, versus $ 0.17 for New York production, $0.13 in diesel. Thus the New York field production has one third the bill, overall, and uses about one-quarter the diesel per kg of Boston lettuce. With reference to comparable figures in Table 3-11 for energy use in CEA Boston lettuce production in New York, with shrinkage factor applied, the lowest figure is for 8 month cropping without light, with CO_2, and it is $0.69/kg consumed. The option we prefer for a variety of reasons is 12 month cropping with light and CO_2. In this case the cost of energy is $1.34/kg lettuce consumed. Natural gas makes up three-quarters of the cost under the 8-month CEA option, and electricity predominates slightly under the 12-month option with lighting. From these data we can conclude there are some options for lettuce production where merely doubling current diesel cost would make CEA production energy cost less than that for remote production with transportation. For our preferred production scenario, diesel would need to triple to equalize cost. Moreover, improving the efficacies of technologies such as LED lighting for greenhouse applications (currently being tested on large scale in The Netherlands) will noticeably reduce CEA energy needs.

For spinach, Table 6-15 shows a fuel and electricity cost of $0.72 /kg spinach consumed for remote producers, $0.65 in diesel, versus $0.14 /kg for New York production. With reference to Table 6-12, the least expensive scenario for CEA spinach is 8-month cropping with CO_2 but without supplementary light, at $1.32/kg consumed. Our preferred 12-month scenario, for reasons of market retention, with light and CO_2, is $2.56/kg consumed.

The reason for the high energy use in spinach production is that only half the plant can be sold as baby leaves. If the whole plant were to be sold, energy cost for 8 month cropping would be less than for remote producers at \$0.66/kg consumed, and simply doubling diesel price would bring the 12-month option equal in cost.

If the energy costs for everything but petroleum were to remain stationary or equivalent, we have shown closure of costs could happen rapidly with rising diesel fuel costs, with doubling or tripling of diesel price in lettuce, depending on production scenario. CEA production in northern latitudes has no direct dependence on petroleum fuel except for local delivery, but has a comparatively high (and unavoidable) level of energy use for heating and electricity in winter time. Reserves of natural gas, which is currently used for heating, are much greater than petroleum reserves and prices presumably will rise more slowly for natural gas, but they will rise. Production and transportation costs for remote field crops can be expected to close on local greenhouse production as diesel cost increases; how rapidly is not clear. One advantage greenhouse growers already have is flexibility as to energy source. If necessary, the fuel source for heating can be switched to coal or biofuel for greenhouse production. It appears that remote field agriculture will have great difficulty getting around dependence on petroleum fuel for transport whereas greenhouse production already does not require petroleum fuel and has several options to control rise in heating costs, such as switching to coal, using natural gas to generate both heat and electricity, and locating near sources of waste heat.

Finally, improved technologies can improve the competitive position of New York CEA growers. Recommendations include the following:

1. Develop methods to enhance the insulation value of movable night curtains to reduce heating needs.
2. Create systems of environmental control wherein there is less need to ventilate the greenhouse for temperature and humidity control, permitting greater use of CO_2 supplementation.
3. Encourage rapid adoption of LED greenhouse lighting as it becomes economically more attractive.
4. Continue to develop handling and storage technologies that reduce shrinkage of locally-produced products.
5. Develop methods and technologies to increase availability of renewable energy designed and scaped specifically for CEA operations.

Table 6-10. Face-value Energy Use per Unit of Product, and Energy Use Including Fuel Production Energy Under Different Production Scenarios

Production Scenario	Energy Use – at face value				With fuel production energy			
	Yield Metric system	Embodied Energy per kg	Direct Energy per kg	Total Energy per kg	Yield Metric system	Embodied Energy per kg	Direct Energy per kg	Total Energy per kg
	kg/ha/yr	MJ/kg	MJ/kg	MJ/kg	kg/ha/yr	MJ/kg	MJ/kg	MJ/kg
No supp. light, no CO2	Lettuce crop							
12 mnth	749,700	2.9	67	70	749,700	2.9	84	87
10 mnth	650,900	3.2	56	59	650,900	3.2	72	75
8 mnth	541,500	3.7	48	52	541,500	3.7	62	66
No supp. light, with CO2								
12 mnth	871,000	2.5	59	62	871,000	2.5	75	77
10 mnth	739,200	2.8	51	54	739,200	2.8	65	68
8 mnth	603,800	3.3	45	48	603,800	3.3	58	61
Supplementary light, no CO2								
12 mnth	1,064,000	2.2	65	67	1,064,000	2.2	114	116
10 mnth	825,000	2.8	60	63	825,000	2.8	102	105
8 mnth	642,000	3.5	54	57	642,000	3.5	87	90
Supplementary light, with CO2								
12 mnth	1,064,000	2.2	63	65	1,064,000	2.2	95	97
10 mnth	825,000	2.8	56	59	825,000	2.8	82	85
8 mnth	642,000	3.5	48	52	642,000	3.5	67	71
No supp. light, no CO2	Spinach Crop							
12 mnth	448,041	4.8	116	121	448,041	4.8	148	152
10 mnth	382,738	5.5	100	106	382,738	5.5	128	134
8 mnth	343,897	5.9	83	89	343,897	5.9	107	113
No supp. light, with CO2								
12 mnth	503,104	4.3	107	111	503,104	4.3	135	140
10 mnth	427,273	4.9	93	98	427,273	4.9	119	123
8 mnth	349,036	5.8	82	88	349,036	5.8	106	112
Supplementary light, no CO2								
12 mnth	592,088	4.1	119	123	592,088	4.1	208	212
10 mnth	472,588	4.9	109	114	472,588	4.9	184	189
8 mnth	381,088	5.9	95	101	381,088	5.9	153	159
Supplementary light, with CO2								
12 mnth	592,088	4.1	116	120	592,088	4.1	174	179
10 mnth	472,588	4.9	102	107	472,588	4.9	149	154
8 mnth	381,088	5.9	86	92	381,088	5.9	121	126
No supp. light, no CO2	Tomato Crop							
12 mnth								
10 mnth	620,000	3.4	56	59	620,000	3.4	68	71
8 mnth	496,000	4.1	49	53	496,000	4.1	60	64
No supp. light, with CO2								
12 mnth								
10 mnth	683,500	3.1	52	55	683,500	3.1	63	66
8 mnth	546,800	3.7	46	50	546,800	3.7	56	59
Supplementary light, no CO2								
12 mnth	1,025,329	2.4	65	67	1,025,329	2.4	112	114
10 mnth	775,488	3.1	61	64	775,488	3.1	102	105
8 mnth	591,291	3.9	54	58	591,291	3.9	86	90
Supplementary light, with CO2								
12 mnth	1,025,329	2.4	63	65	1,025,329	2.4	93	95
10 mnth	775,488	3.1	56	60	775,488	3.1	80	83
8 mnth	591,291	3.9	48	52	591,291	3.9	65	69

Table 6-11. Lettuce crop: Direct Energy Use and Cost in 2007 Dollars and Prices

Production Scenario	Yield and total Energy: Yield	Total: All Energy Use	Direct Energy Total	Proportion of Total	Cost of Electri-city at $.14/kwh	Cost of Natural Gas at $1.2/therm	Cost of Direct Energy Use: Electri-city	Natural Gas	Total Dir. Energy	Electri-city	Natural Gas	Total Dir. Energy	Cost per unit consumed: Electri-city	Natural Gas	Total Dir. Energy
							Cost per unit weight utilized								
	kg/ha/yr	GJ/ha/yr	GJ/ha/yr		1000s $/ha/y	000s $/ha/y	$/lb	$/lb	$/lb	$/kg	$/kg	$/kg	$/kg	$/kg	$/kg
	Lettuce crop												Factor for shrinkage		
No supp. light, no CO2														1.13	
12 mnth	749,700	52,124	49,985	0.96	122	533	0.07	0.32	0.40	0.16	0.71	0.87	0.18	0.80	0.99
10 mnth	650,900	38,585	36,519	0.95	103	385	0.07	0.27	0.34	0.16	0.59	0.75	0.18	0.67	0.85
8 mnth	541,500	28,188	26,194	0.93	86	273	0.07	0.23	0.30	0.16	0.50	0.66	0.18	0.57	0.75
No supp. light, with CO2															
12 mnth	871,000	53,849	51,711	0.96	122	553	0.06	0.29	0.35	0.14	0.63	0.77	0.16	0.72	0.87
10 mnth	739,200	39,842	37,776	0.95	103	399	0.06	0.25	0.31	0.14	0.54	0.68	0.16	0.61	0.77
8 mnth	603,800	29,077	27,083	0.93	86	283	0.06	0.21	0.28	0.14	0.47	0.61	0.16	0.53	0.69
Supplementary light, no CO2															
12 mnth	1,064,000	71,191	68,804	0.97	1,317	397	0.56	0.17	0.73	1.24	0.37	1.61	1.40	0.42	1.82
10 mnth	825,000	51,872	49,558	0.96	859	312	0.47	0.17	0.64	1.04	0.38	1.42	1.18	0.43	1.60
8 mnth	642,000	36,594	34,352	0.94	500	244	0.35	0.17	0.53	0.78	0.38	1.16	0.88	0.43	1.31
Supplementary light, with CO2															
12 mnth	1,064,000	69,347	66,960	0.97	713	553	0.30	0.24	0.54	0.67	0.52	1.19	0.76	0.59	1.34
10 mnth	825,000	48,562	46,248	0.95	423	402	0.23	0.22	0.45	0.51	0.49	1.00	0.58	0.55	1.13
8 mnth	642,000	33,074	30,832	0.93	220	286	0.16	0.20	0.36	0.34	0.45	0.79	0.39	0.50	0.89

Table 6-12. Spinach Crop: Direct Energy Use and Cost in 2007 Dollars and Prices

Production Scenario	Yield and total Energy: Yield	Total: All Energy Use	Direct Energy Total	Proportion of Total	Cost of Electricity at $.14/kwh	Cost of Natural Gas at $1.2/therm	Cost of Direct Energy Use — Cost per unit weight utilized: Electricity	Natural Gas	Total Dir. Energy	Electricity	Natural Gas	Total Dir. Energy	Cost per unit consumed: Electricity	Natural Gas	Total Dir. Energy
	kg/ha/yr	GJ/ha/yr	GJ/ha/yr		1000s $/ha/y	000s $/ha/y	$/lb	$/lb	$/lb	$/kg	$/kg	$/kg	$/kg	$/kg	$/kg
	Spinach Crop													Factor for shrinkage	
No supp. light, no CO2														1.17	
12 mnth	448,041	54,269	52,100	0.96	133	554	0.13	0.56	0.70	0.30	1.24	1.53	0.35	1.45	1.79
10 mnth	382,738	40,403	38,311	0.95	115	402	0.14	0.48	0.61	0.30	1.05	1.35	0.35	1.23	1.58
8 mnth	343,897	30,517	28,502	0.93	97	296	0.13	0.39	0.52	0.28	0.86	1.14	0.33	1.01	1.34
No supp. light, with CO2															
12 mnth	251,552	55,836	53,668	0.96	133	571	0.12	0.52	0.64	0.26	1.14	1.40	0.31	1.33	1.64
10 mnth	213,637	41,671	39,579	0.95	115	417	0.12	0.44	0.56	0.27	0.97	1.24	0.31	1.14	1.45
8 mnth	174,518	30,666	28,651	0.93	97	297	0.13	0.39	0.51	0.28	0.85	1.13	0.33	1.00	1.32
Supplementary light, no CO2															
12 mnth	296,044	72,964	70,548	0.97	1,329	414	1.02	0.32	1.33	2.24	0.70	2.94	2.62	0.82	3.44
10 mnth	236,294	53,780	51,440	0.96	871	330	0.84	0.32	1.15	1.84	0.70	2.54	2.16	0.82	2.97
8 mnth	190,544	38,569	36,306	0.94	512	263	0.61	0.31	0.92	1.34	0.69	2.03	1.57	0.81	2.38
Supplementary light, with CO2															
12 mnth	296,044	71,120	68,704	0.97	725	569	0.56	0.44	0.99	1.22	0.96	2.19	1.43	1.12	2.56
10 mnth	236,294	50,470	48,130	0.95	434	420	0.42	0.40	0.82	0.92	0.89	1.81	1.07	1.04	2.11
8 mnth	190,544	35,049	32,786	0.94	231	305	0.28	0.36	0.64	0.61	0.80	1.41	0.71	0.94	1.65

Table 6-13. Tomato Crop: Direct Energy Use and Cost in 2007 Dollars and Prices

Production Scenario	Yield and total Energy: Yield	Total: All Energy Use	Direct Energy Total	Proportion of Total	Cost of Electri-city at $.14/kwh	Cost of Natural Gas at $1.2/therm	Cost of Direct Energy Use — Cost per unit weight utilized: Electri-city	Natural Gas	Total Dir. Energy	Electri-city	Natural Gas	Total Dir. Energy	Cost per unit consumed: Electri-city	Natural Gas	Total Dir. Energy
	kg/ha/yr	GJ/ha/yr	GJ/ha/yr		1000s $/ha/y	000s $/ha/y	$/lb	$/lb	$/lb	$/kg	$/kg	$/kg	$/kg	$/kg	$/kg
	Tomato Crop												Factor for shrinkage		
No supp. light, no CO2														1.13	
12 mth	—	—	—		—	—	—	—	—	—	—	—	—	—	—
10 mth	620,000	36,694	34,562	0.94	19	387	0.01	0.28	0.30	0.03	0.62	0.66	0.04	0.71	0.74
8 mth	496,000	26,359	24,315	0.92	18	271	0.02	0.25	0.26	0.04	0.55	0.58	0.04	0.62	0.66
No supp. light, with CO2															
12 mth	—	—	—		—	—	—	—	—	—	—	—	—	—	—
10 mth	683,500	37,611	35,479	0.94	19	398	0.01	0.26	0.28	0.03	0.58	0.61	0.03	0.66	0.69
8 mth	546,800	27,094	25,050	0.92	18	280	0.01	0.23	0.25	0.03	0.51	0.54	0.04	0.58	0.62
Supplementary light, no CO2															
12 mth	1,025,329	68,690	66,222	0.96	1,217	397	0.54	0.18	0.71	1.19	0.39	1.57	1.35	0.44	1.78
10 mth	775,488	49,476	47,096	0.95	775	309	0.45	0.18	0.63	1.00	0.40	1.40	1.13	0.45	1.58
8 mth	591,291	34,477	32,186	0.93	432	240	0.33	0.18	0.52	0.73	0.41	1.14	0.83	0.46	1.29
Supplementary light, with CO2															
12 mth	1,025,329	66,846	64,378	0.96	613	553	0.27	0.24	0.52	0.60	0.54	1.14	0.68	0.61	1.29
10 mth	775,488	46,166	43,786	0.95	339	399	0.20	0.23	0.43	0.44	0.51	0.95	0.49	0.58	1.08
8 mth	591,291	30,957	28,666	0.93	152	282	0.12	0.22	0.33	0.26	0.48	0.73	0.29	0.54	0.83

Table 6-14. Lettuce: Estimated Cost of Direct Energy Use in Production and Transportation of Field Lettuce Produced in and out of NY State.

Origin	Weight Shipped	Energy per unit weight	Total Energy	petroleum fuel	natural gas	electri-city	Other: embodied	Total Energy
	Iceberg and Boston Lettuce							
	tonnes	MJ/kg	GJ	GJ	GJ	GJ	GJ	GJ
Field Production								
All Out-of-State Prod.	183,208	3.0	541,013	211,899	0	134,456	194,657	541,013
Ratio of energy use by fuel type				0.39	0.00	0.25	0.36	1.00
Inverse efficiency factor				1.236		3.333	n/a	
GJ direct energy use				171,440		40,341		
1000's of $ (2.73cents/MJ, .14$/kWh)				4,680		1569		
$/kg Iceberg				0.026		0.009		
$/kg Boston				0.051		0.017		
New York Produced	1,724	5.2	8,980	3452	0	2332	3196	8980
Ratio of energy use by fuel type				0.38	0.00	0.26	0.36	1.00
Inverse efficiency factor				1.236		3.333		
GJ direct energy use				2,793		700		
1000's of $ (2.73cents/MJ, .14$/kWh)				76		27		
$/kg Iceberg				0.044		0.016		
$/kg Boston				0.088		0.032		
Shipping								
All Out-of-State Prod.	183,208	10.2	1,860,332	1,637,092	0	0.00	223,240	1,860,332
Ratio of energy use by fuel type				0.88	0.00	0.00	0.12	1.00
Inverse efficiency factor				1.236				
GJ				1,324,508				
1000s $				36,159				
$/kg transport				0.20				
New York Produced	1,724	0.4	742	653	0	0	89	742
Ratio of energy use by fuel type				0.88	0.00	0.00	0.12	1.00
Inverse efficiency factor				1.236				
GJ				528				
1000s $				14				
$/kg transport				0.0084				
Total Direct Energy Cost per kg Utilized								
All Out-of-State Prod.	183,208	13.1	541,013					
$/kg Iceberg				0.22	0.00	0.01		0.23
$/kg, Boston				0.25	0.00	0.02		0.27
New York Produced	1,724	5.6	8,980					
$/kg Iceberg				0.05	0.00	0.02		0.07
$/kg Boston				0.10	0.00	0.03		0.13
Total Direct Energy Cost per kg Consumed				Boston			Iceberg	Boston
Factor for shrinkage				1.85			1.85	1.85
All Out-of-State Prod - $/kg				0.46			0.43	0.49
Factor for shrinkage				1.30			1.30	1.30
New York Produced -$/kg				0.13			0.09	0.17
Ratio. Out-State:In-State				3.7			4.8	2.9

Note : Production energy for Boston lettuce is assumed to be double iceberg, transportation the same.

Table 6-15. Spinach: Estimated Cost of Direct Energy Use in Production and Transportation of Cut Salad Spinach Produced in and out of NY Sate.

Origin	Fresh spinach Weight Shipped	Energy per unit weight	Total Energy	petroleum /liquid fuel	natural gas	Electri-city	Other embodied	Total
	tonnes	MJ/kg	GJ	GJ	GJ	GJ	GJ	GJ
Field Production								
All Out-of-State Prod.	**19,197**	**9.0**	**172,243**	**47,936**	**0**	**47,123**	**77,184**	**172,243**
Ratio of energy use by fuel type				**0.28**	**0.00**	**0.27**	**0.45**	**1.00**
Inverse efficiency factor				1.236		3.333	n/a	
GJ direct energy use				38,783		14,138		
1000's of $ (2.73cents/MJ, .14S/kWh)				1,059		550		
$/kg				**0.055**		**0.029**		
New York Produced	**408**	**8.5**	**3,464**	**936**	**0**	**1323**	**1205**	**3464**
Ratio of energy use by fuel type				**0.27**		**0.38**	**0.35**	**1.00**
Inverse efficiency factor				1.236		3.333		
GJ direct energy use				758		397		
1000's of $ (2.73cents/MJ, .14S/kWh)				21		15		
$/kg				**0.051**		**0.038**		
Shipping								
All Out-of-State Prod.	**19,197**	**11.3**	**216,186**	**190243.89**	**0**	**0**	**25942**	**216186**
Ratio of energy use by fuel type				**0.88**	**0.00**	**0.00**	**0.12**	**1.00**
Inverse efficiency factor				1.236				
GJ				153,919				
1000s $				4,202				
$/kg transport				**0.22**				
New York Produced	**408**	**0.4**	**176**	**155**		**0**	**21**	**176**
Ratio of energy use by fuel type				**0.88**	**0.00**	**0.00**	**0.12**	**1.00**
Inverse efficiency factor				1.236				
GJ				125				
1000s $				3				
$/kg transport				**0.0084**				
Total Direct Energy Cost per kg Utilized								
All Out-of-State Prod.								
$/kg				**0.27**	**0.00**	**0.03**	n/a	**0.30**
New York Produced								
$/kg Boston				**0.06**	**0.00**	**0.04**	n/a	**0.10**
Total Direct Energy Cost per kg Consumed								
Factor for shrinkage				2.38				2.38
All Out-of-State Prod - $/kg				**0.65**				**0.72**
Factor for shrinkage				1.41				1.41
New York Produced -$/kg				**0.08**				**0.14**
Ratio. Out-State:In-State				7.8				5.3

SUMMARY

SPECIFIC CONCLUSIONS

- Miles traveled by the crops in this study are as follows:

Crop	Imported	Overall
Head lettuce	2980	2953
Fresh tomato	2224	2026
Fresh spinach	2956	2897
Fresh strawberry	2894	2742
Fresh apple	2995	520

- Of the crops studied, only apple is grown in significant quantity in New York.

- On a national basis, shrinkage after harvest removes 40% to 60% of the product.

- Energy data, in MJ/kg for production and transport of crops imported to New York (of quantity eaten) are as follows:

Crop	Imported	Local Production	Ratio, Imported to Local
Head lettuce	24	7.3	3.3
Fresh tomato	35	9.8	3.6
Fresh spinach	48	12.6	3.8
Fresh strawberry	23	3.2	7.2
Fresh apple	23	7.2	3.2

- Transportation energy alone, for imported crops, in MJ/kg eaten, ranges from 14 for apples to 27 for fresh spinach. Transportation energy exceeds production energy for imports.

- Production energy needed for imported crops is comparable to that needed to produce crops locally in New York.

- At $4 per gallon, diesel fuel costs roughly 2.7 cents per MJ of transportation energy.

- A third of the energy needed for imported crops that are field grown is liquid fuel based.

- Nearly all the energy needed to transport imported crops comes from liquid fuel.

- Energy data, in MJ/kg for production of crops grown in New York CEA facilities (of quantity eaten) as listed in Table 5-16, show total energy for CEA production is greater than for imports, but various lighting and environmental control options are feasible to improve the ratio.

- Greenhouse tomatoes grown in upstate New York on a 10 month cycle require 3 to 4 times the energy per unit weight eaten, compared to imported tomatoes.

- Head lettuce grown year-round in upstate New York and using current practice requires 6 times the energy per unit weight eaten, compared to imported lettuce.

- Fresh spinach grown year-round in upstate New York and using current practice requires 9 times the energy per unit weight eaten, compared to imported fresh spinach.

- Energy for CEA production in New York is largely for electricity and heating. Electricity in New York from liquid fuels is 8% of the total electricity mix. Electricity can be produced from renewable resources, which greatly reduces the ratio of energy used for CEA production compared to imported. As liquid fuels become less abundant and more expensive, these characteristics will favor local CEA production.

- Better control of supplemental lights and carbon dioxide has been estimated to reduce electricity for supplemental lighting in CEA by half in upstate New York.

- Adopting options related to dehumidification of greenhouse air, temperature modulation during the day, and limited air conditioning to keep vents closed are expected to improve energy efficiency further.

BROADER CONCLUSIONS, WHAT HAS BEEN LEARNED?

- Energy used directly in field agriculture is dominated by petroleum fuel for transportation. Petroleum use in the field may comparatively minor but is unavoidable in field operations as currently practiced.

- A great deal of energy is needed to grow crops out of season in New York and, today, the bulk of supplied energy is from non-renewable resources and involves large emissions of new CO_2. There is, however, little direct use of petroleum and much flexibility exists as to which energy sources can be used, making it possible to anticipate transitions to better future options.

- The price of diesel fuel already favors local production of all our field crops in New York because a good deal more fuel burned to transport product to New York than is needed for production.

- New York's disadvantage in perishable field crops is the shortness of the growing season, and the difficulty of securing market share for perishable crops on a short-term basis.

- Climate favors parts of Pennsylvania, New Jersey, Long Island, Maryland, Delaware and Virginia, where less supplemental heat and light will be needed than in upstate New York and transportation costs to New York would be less than from Florida, California, Arizona, and Mexico. This may favor greenhouse production in neighboring states and encourage rapid expansion of a CEA industry in those areas.

- If CEA production is desired in less advantageous climate zones, where it is illogical to do so from the perspective of current energy use intensity, there is all the more need to develop technologies to be more energy efficient per unit of product consumed by the public.

- We can reduce heating and lighting costs in various ways. We can use heat retention technologies more effectively, extend the duration of CO_2 enrichment through greenhouse air dehumidification and optimize venting for temperature control, and generate electricity on site, coupled with using the waste heat and CO_2 that comes from doing so. Recent advances in LED lighting systems for greenhouse applications suggest this potentially more efficient lighting technology will become economically competitive within the next several years. It may also be possible to achieve advantage by securing favorable deals with municipalities for electricity, particularly renewable energy (e.g., hydropower.)

- A final consideration is that, whether or not more total energy is needed to grow crops out of season in cloudy northern latitudes, where market opportunity exists it will happen. It may be that, by direct marketing that avoids middlemen, market share to the grower will be sufficiently large that opportunities will always exist for local outdoor and CEA operations. Moreover, small growers may be able to survive by rapidly adjusting to changing desires of the buying public and continually develop new market product niches.

APPENDICES

Appendix 2-1. Strawberries, Annual Quantities Shipped, Units of 1000 cwt.

	1999	2000	2001	2002	2003	2004	2005	2006
US INTERNAL TRADE								
TRUCK								
CALIFORNIA-CENTRAL	6,352	7,276	6,616	7,851	7,489	7,101	7,828	7,569
CALIFORNIA-SOUTH	3,406	3,337	3,476	4,281	4,347	3,773	4,128	4,508
FLORIDA	1,150	1,394	1,199	990	774	832	895	1,446
NORTH CAROLINA	15	17	17	14	16	14	19	18
TOTAL	10,923	12,024	11,308	13,136	12,626	11,720	12,870	13,541
PIGGYBACK								
CALIF-CENTRAL					4			
US TOTAL - INTERNAL TRADE	10,923	12,024	11,308	13,136	12,630	11,720	12,870	13,541
US EXPORT TRADE								
AIR								
FLORIDA EXPORT	3	2	1					
US TOTAL - EXPORT TRADE	3	2	1					
U.S. PRODUCED GRAND TOTAl	10,926	12,026	11,309	13,136	12,630	11,720	12,870	13,541
IMPORT								
ARGENTINA		1				1	8	4
AUSTRALIA	1	5	2	3				
CANADA	3	10	5	7	5	4	4	3
CHILE					2	1		
CHINA						2		7
MEXICO	1,005	737	676	871	857	995	1,199	1,124
NEW ZEALAND	11	15	8	11	8	3	2	1
POLAND							1	1
IMPORT TOTAL	1,020	768	691	892	872	1,006	1,214	1,140
GRAND TOTAL US UTILIZED	11,943	12,792	11,999	14,028	13,502	12,726	14,084	14,681

Appendix 2-2. Strawberries, Percentage of Total Shipped and Used in the US

	1999	2000	2001	2002	2003	2004	2005	2006
US INTERNAL TRADE								
TRUCK								
CALIFORNIA-CENTRAL	53.2	56.9	55.1	56.0	55.5	55.8	55.6	51.6
CALIFORNIA-SOUTH	28.5	26.1	29.0	30.5	32.2	29.6	29.3	30.7
FLORIDA	9.6	10.9	10.0	7.1	5.7	6.5	6.4	9.8
NORTH CAROLINA	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
TOTAL-TRUCK	91.5	94.0	94.2	93.6	93.51	92.1	91.4	92.2
PIGGYBACK								
CALIF-CENTRAL	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
US TOTAL - INTERNAL TRADE	91.5	94.0	94.2	93.6	93.54	92.1	91.4	92.2
IMPORT								
ARGENTINA	0.00	0.01	0.00	0.00	0.00	0.01	0.06	0.03
AUSTRALIA	0.01	0.04	0.02	0.02	0.00	0.00	0.00	0.00
CANADA	0.03	0.08	0.04	0.05	0.04	0.03	0.03	0.02
CHILE	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
CHINA	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.05
MEXICO	8.4	5.8	5.6	6.2	6.3	7.8	8.5	7.7
NEW ZEALAND	0.09	0.12	0.07	0.08	0.06	0.02	0.01	0.01
POLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
IMPORT TOTAL	8.5	6.0	5.8	6.4	6.5	7.9	8.6	7.8
GRAND TOTAL US UTILIZED	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 2-3. Summary for Major Shippers of Strawberries, All Transport Modes

	1999	2000	2001	2002	2003	2004	2005	2006
Annual quantities shipped. Units of 1000 cwt								
CALIFORNIA	10,908	12,007	11,291	13,122	12,614	11,706	12,851	13,523
FLORIDA	1,150	1,394	1,199	990	774	832	895	1,446
MEXICO	1,005	737	676	871	857	995	1,199	1,124
TOTAL	13,063	14,138	13,166	14,983	14,245	13,533	14,945	16,093
Percentage of strawberries shipped and used in US								
CALIFORNIA	81.7	83.0	84.1	86.5	87.7	85.4	84.9	82.3
FLORIDA	9.6	10.9	10.0	7.1	5.7	6.5	6.4	9.8
MEXICO	8.4	5.8	5.6	6.2	6.3	7.8	8.5	7.7
TOTAL	99.7	99.6	99.7	99.8	99.7	99.8	99.8	99.8

Appendix 2-4. Fresh Apples, Annual Quantities Shipped, Units of 1000 cwt

	1999	2000	2001	2002	2003	2004	2005	2006
US INTERNAL TRADE								
TRUCK								
APPALACHIA	645	795	571	664	508	624	779	989
CALIFORNIA-CENTRAL	1,718	2,232	1,309	1,607	1,659	1,210	1,308	1,146
CONNECTICUT					1	4	10	8
IDAHO	467	432	390	309	335	232	218	155
MAINE	147	150	136	90	92	118	124	62
MASSACHUSETTS	263	284	254	243	130	99	96	69
MICHIGAN	2,858	2,806	2,579	1,977	1,880	2,406	2,426	2,434
NEW HAMPSHIRE	26	50	54	37	34	55	75	46
NEW YORK	1,805	2,129	2,869	2,640	2,573	2,779	3,012	2,799
NORTH CAROLINA	213	293	157	186	117	480	306	516
OREGON	614	681	643	653	576	581	443	520
VERMONT	53	77	57	50	42	115	107	98
WASHINGTON	25,190	23,824	24,165	23,405	24,651	25,375	28,407	28,135
TOTAL	33,999	33,753	33,184	31,861	32,598	34,078	37,311	36,977
PIGGYBACK								
CALIFORNIA-CENTRAL	60	62	50	71	34	23	11	79
OREGON	156	101	46	46	75	102	203	161
WASHINGTON	471	647	481	444	380	335	372	269
TOTAL	807	818	578	561	489	460	586	509
RAIL								
CALIFORNIA-CENTRAL		7		1		2	0	1
IDAHO	1		1			3	2	
OREGON	3		2	9	1	8	14	14
WASHINGTON	155	285	381	643	657	572	830	600
TOTAL	159	292	384	653	658	585	846	615
US TOTAL - INTERNAL TRADE	34,965	34,863	34,146	33,075	33,745	35,123	38,743	38,101
US EXPORT TRADE								
TRUCK								
APPALACHIA EXPORT	112	63	92	47	39	44	46	51
CALIFORNIA-CENTRAL EXPORT	417	389	18	72	130	39	40	1
IDAHO EXPORT	173	189	188	103	110	88	115	84
OREGON EXPORT	114							
WASHINGTON EXPORT	10,071	11,112	12,169	9,707	9,713	8,416	12,593	12,152
TOTAL	10,887	11,753	12,467	9,929	9,992	8,587	12,794	12,288
PIGGYBACK								
WASHINGTON EXPORT	120	8	1					
AIR								
CALIFORNIA-CENTRAL EXPORT		38	123		1	6	3	4
BOAT								
CALIFORNIA-CENTRAL EXPORT						144		40
US TOTAL - EXPORT TRADE	11,007	11,799	12,591	9,929	9,993	8,737	12,797	12,332
U.S. PRODUCED GRAND TOTAL	45,852	46,654	46,736	43,004	43,738	43,860	51,540	50,433
IMPORTS FROM OVERSEAS								
ARGENTINA	58	46	72	37	103	50	33	33
AUSTRALIA			4	2				
BRAZIL	8	4			6	51		
CANADA	939	844	852	953	819	668	744	769
CHILE	944	959	1,268	1,375	1,986	2,492	1,198	1,818
CHINA					3		3	5
JAPAN					1	1	9	1
NEW ZEALAND	1,349	1,576	1,066	1,292	1,125	1,270	711	824
SOUTH AFRICA	307	148	193	49	63	31	3	
URUGUAY	5	18						
IMPORT TOTAL	3,610	3,595	3,455	3,708	4,106	4,563	2,701	3,450
GRAND TOTAL US UTILIZED	38,575	38,458	37,601	36,783	37,851	39,686	41,444	41,551

Appendix 2-5. Summary for Major Shippers of Fresh Appled, All Transport Modes, Annual Quantities Shipped, Units of 1000 cwt.

	1999	2000	2001	2002	2003	2004	2005	2006
Annual quantities shipped. Units of 1000 cwt								
APPALACHIA	645	795	571	664	508	624	779	989
CALIFORNIA	1,778	2,301	1,359	1,679	1,693	1,235	1,319	1,226
MICHIGAN	2,858	2,806	2,579	1,977	1,880	2,406	2,426	2,434
NEW YORK	1,805	2,129	2,869	2,640	2,573	2,779	3,012	2,799
NORTH CAROLINA	213	293	157	186	117	480	306	516
OREGON	773	782	691	708	652	691	660	695
WASHINGTON	25,816	24,756	25,027	24,492	25,688	26,282	29,609	29,004
US INTERNAL TRADE	33,888	33,862	33,253	32,346	33,111	34,497	38,111	37,663
WASHINGTON	10,071	11,112	12,169	9,707	9,713	8,416	12,593	12,152
US EXPORT TRADE	10,071	11,112	12,169	9,707	9,713	8,416	12,593	12,152
US PRODUCED	43,959	44,974	45,422	42,053	42,824	42,913	50,704	49,815
CANADA	939	844	852	953	819	668	744	769
CHILE	944	959	1,268	1,375	1,986	2,492	1,198	1,818
NEW ZEALAND	1,349	1,576	1,066	1,292	1,125	1,270	711	824
IMPORT TOTAL	3,232	3,379	3,186	3,620	3,930	4,430	2,653	3,411
US UTILIZED, Major producers	37,120	37,241	36,439	35,966	37,041	38,927	40,764	41,074
US UTILIZED, All producers	38,575	38,458	37,601	36,783	37,851	39,686	41,444	41,551

Appendix 2-6. Fresh Apples, Percentage of Total Shipped and Used in US

	1999	2000	2001	2002	2003	2004	2005	2006
US INTERNAL TRADE								
TRUCK								
APPALACHIA	1.7	2.1	1.5	1.8	1.3	1.6	1.9	2.4
CALIFORNIA-CENTRAL	4.5	5.8	3.5	4.4	4.4	3.0	3.2	2.8
CONNECTICUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IDAHO	1.2	1.1	1.0	0.8	0.9	0.6	0.5	0.4
MAINE	0.4	0.4	0.4	0.2	0.2	0.3	0.3	0.1
MASSACHUSETTS	0.7	0.7	0.7	0.7	0.3	0.2	0.2	0.2
MICHIGAN	7.4	7.3	6.9	5.4	5.0	6.1	5.9	5.9
NEW HAMPSHIRE	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
NEW YORK	4.7	5.5	7.6	7.2	6.8	7.0	7.3	6.7
NORTH CAROLINA	0.6	0.8	0.4	0.5	0.3	1.2	0.7	1.2
OREGON	1.6	1.8	1.7	1.8	1.5	1.5	1.1	1.3
VERMONT	0.1	0.2	0.2	0.1	0.1	0.3	0.3	0.2
WASHINGTON	65.3	61.9	64.3	63.6	65.1	63.9	68.5	67.7
TOTAL	88.1	87.8	88.3	86.6	86.1	85.9	90.0	89.0
PIGGYBACK								
CALIFORNIA-CENTRAL	0.2	0.2	0.1	0.2	0.1	0.1	0.0	0.2
OREGON	0.4	0.3	0.1	0.1	0.2	0.3	0.5	0.4
WASHINGTON	1.2	1.7	1.3	1.2	1.0	0.8	0.9	0.6
TOTAL	2.1	2.1	1.5	1.5	1.3	1.2	1.4	1.2
RAIL								
CALIFORNIA-CENTRAL	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00
IDAHO	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
OREGON	0.01	0.00	0.01	0.02	0.00	0.02	0.03	0.03
WASHINGTON	0.4	0.7	1.0	1.7	1.7	1.4	2.0	1.4
TOTAL	0.4	0.8	1.0	1.8	1.7	1.5	2.0	1.5
US TOTAL - INTERNAL TRADE	90.6	90.7	90.8	89.9	89.2	88.5	93.5	91.7
IMPORTS FROM OVERSEAS								
ARGENTINA	0.2	0.1	0.2	0.1	0.3	0.1	0.1	0.1
AUSTRALIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BRAZIL	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
CANADA	2.4	2.2	2.3	2.6	2.2	1.7	1.8	1.9
CHILE	2.4	2.5	3.4	3.7	5.2	6.3	2.9	4.4
CHINA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JAPAN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NEW ZEALAND	3.5	4.1	2.8	3.5	3.0	3.2	1.7	2.0
SOUTH AFRICA	0.8	0.4	0.5	0.1	0.2	0.1	0.0	0.0
URUGUAY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IMPORT TOTAL	9.4	9.3	9.2	10.1	10.8	11.5	6.5	8.3
GRAND TOTAL US UTILIZED	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 2-7. Summary for Major Shippers of Fresh Apples, All Transport Modes

	1999	2000	2001	2002	2003	2004	2005	2006
Percentage of fresh apples shipped in US								
APPALACHIA	1.7	2.1	1.5	1.8	1.3	1.6	1.9	2.4
CALIFORNIA	4.6	6.0	3.6	4.6	4.5	3.1	3.2	3.0
MICHIGAN	7.4	7.3	6.9	5.4	5.0	6.1	5.9	5.9
NEW YORK	4.7	5.5	7.6	7.2	6.8	7.0	7.3	6.7
NORTH CAROLINA	0.6	0.8	0.4	0.5	0.3	1.2	0.7	1.2
OREGON	2.0	2.0	1.8	1.9	1.7	1.7	1.6	1.7
WASHINGTON	66.9	64.4	66.6	66.6	67.9	66.2	71.4	69.8
US INTERNAL TRADE	87.8	88.0	88.4	87.9	87.5	86.9	92.0	90.6
CANADA	2.4	2.2	2.3	2.6	2.2	1.7	1.8	1.9
CHILE	2.4	2.5	3.4	3.7	5.2	6.3	2.9	4.4
NEW ZEALAND	3.5	4.1	2.8	3.5	3.0	3.2	1.7	2.0
IMPORT TOTAL	8.4	8.8	8.5	9.8	10.4	11.2	6.4	8.2
US UTILIZED, Major producers	96.2	96.8	96.9	97.8	97.9	98.1	98.4	98.9
US UTILIZED, All producers	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Appendix 2-8. Iceberg Lettuce, Annual Quantities Shipped, Units of 1000 cwt.

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	10,996	10,009	10,669	9,732	9,581	9,719	9,036	9,116
CALIFORNIA-CENTRAL	24,450	25,132	23,932	24,284	24,630	23,880	23,546	21,970
CALIFORNIA-IMPERIAL VAL	2,437	2,240	2,003	1,980	1,717	1,136	1,897	2,044
CALIFORNIA-SOUTH	285	347	319	121	182	164	181	246
COLORADO	344	323	345	288	191	217	193	180
FLORIDA	59	68	87	74	48	94	107	105
NEW MEXICO	420	379	383	253	310	239	243	186
TOTAL	38,991	38,498	37,738	36,732	36,659	35,449	35,203	33,847
PIGGYBACK								
ARIZONA	467	628	603	384	335	402	452	497
CALIFORNIA-CENTRAL	1,174	983	1,372	1,080	1,063	1,150	1,132	940
CALIFORNIA-IMPERIAL VAL	124	194	154	137	181	74	5	41
CALIFORNIA-SOUTH	2	10	19	2				2
TOTAL	1,767	1,815	2,148	1,603	1,579	1,626	1,589	1,480
RAIL								
CALIF-CENTRAL				4	2			
US TOTAL - INTERNAL TRADE	40,758	40,313	39,886	38,339	38,240	37,075	36,792	35,327
IMPORT								
CANADA	114	156	253	191	197	246	219	220
MEXICO	223	224	438	1,119	898	824	1,239	1,333
PERU				3	5	5	5	
IMPORT TOTAL	337	380	691	1,313	1,100	1,075	1,463	1,553
GRAND TOTAL US UTILIZED	41,095	40,693	40,577	39,652	39,340	38,150	38,255	36,880

Appendix 2-9. Iceberg Lettuce, Percentage of Total Shipped

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	26.8	24.6	26.3	24.5	24.4	25.5	23.6	24.7
CALIFORNIA-CENTRAL	59.5	61.8	59.0	61.2	62.6	62.6	61.6	59.6
CALIFORNIA-IMPERIAL VAL	5.9	5.5	4.9	5.0	4.4	3.0	5.0	5.5
CALIFORNIA-SOUTH	0.7	0.9	0.8	0.3	0.5	0.4	0.5	0.7
COLORADO	0.8	0.8	0.9	0.7	0.5	0.6	0.5	0.5
FLORIDA	0.1	0.2	0.2	0.2	0.1	0.2	0.3	0.3
NEW MEXICO	1.0	0.9	0.9	0.6	0.8	0.6	0.6	0.5
TOTAL	94.9	94.6	93.0	92.6	93.2	92.9	92.0	91.8
PIGGYBACK								
ARIZONA	1.1	1.5	1.5	1.0	0.9	1.1	1.2	1.3
CALIFORNIA-CENTRAL	2.9	2.4	3.4	2.7	2.7	3.0	3.0	2.5
CALIFORNIA-IMPERIAL VAL	0.3	0.5	0.4	0.3	0.5	0.2	0.0	0.1
CALIFORNIA-SOUTH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	4.3	4.5	5.3	4.0	4.0	4.3	4.2	4.0
RAIL								
CALIF-CENTRAL	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
US TOTAL - INTERNAL TRADE	99.2	99.1	98.3	96.7	97.2	97.2	96.2	95.8
IMPORT								
CANADA	0.3	0.4	0.6	0.5	0.5	0.6	0.6	0.6
MEXICO	0.5	0.6	1.1	2.8	2.3	2.2	3.2	3.6
PERU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IMPORT TOTAL	0.8	0.9	1.7	3.3	2.8	2.8	3.8	4.2
GRAND TOTAL US UTILIZED	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 2-10. Summary for Major Shippers of Iceberg Lettuce, All Transport Modes

	1999	2000	2001	2002	2003	2004	2005	2006
Annual quantities shipped. Units of 1000 cwt								
ARIZONA	11,463	10,637	11,272	10,116	9,916	10,121	9,488	9,613
CALIFORNIA	28,472	28,906	27,799	27,608	27,775	26,404	26,761	25,243
MEXICO	223	224	438	1,119	898	824	1,239	1,333
TOTAL	40,158	39,767	39,509	38,843	38,589	37,349	37,488	36,189
Percentage of iceberg shipped in US								
ARIZONA	27.9	26.1	27.8	25.5	25.2	26.5	24.8	26.1
CALIFORNIA	69.3	71.0	68.5	69.6	70.6	69.2	70.0	68.4
MEXICO	0.5	0.6	1.1	2.8	2.3	2.2	3.2	3.6
TOTAL	97.7	97.7	97.4	98.0	98.1	97.9	98.0	98.1

Appendix 2-11. Romaine Lettuce, Annual Quantities Shipped, Units of 1000 cwt

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	2,506	2,457	3,041	3,214	3,391	3,695	3,744	3,839
CALIFORNIA-CENTRAL	5,189	5,930	5,446	5,532	7,129	7,953	8,584	8,175
CALIFORNIA-IMPERIAL VAL	387	415	400	256	227	218	556	678
CALIFORNIA-SOUTH	407	465	697	722	921	990	870	1,046
COLORADO				26	22	47	129	97
FLORIDA	50	87	40	30	42	38	49	36
TOTAL	8,539	9,354	9,624	9,780	11,732	12,941	13,932	13,871
PIGGYBACK								
ARIZONA	100	90	75	72	67	128	153	220
CALIFORNIA-CENTRAL	242	114	182	205	261	376	423	393
CALIFORNIA-IMPERIAL VAL	36	33	22	37	44	17		22
CALIFORNIA-SOUTH	1		1	1	9	16		15
TOTAL	379	237	280	315	381	537	576	650
U.S. TOTAL	8,918	9,591	9,904	10,095	12,113	13,478	14,508	14,521
IMPORT								
CANADA					81	1		
CHILE					4			
ISRAEL					1			
MEXICO	47	16			5	8	2	
PERU					7	1		
IMPORT TOTAL	47	16			98	10	2	
GRAND TOTAL SHIPPED	8,965	9,607	9,904	10,095	12,211	13,488	14,510	14,521

Appendix 2-12. Romaine Lettuce, Percentage of Total Shipped

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	28.0	25.6	30.7	31.8	27.8	27.4	25.8	26.4
CALIFORNIA-CENTRAL	57.9	61.7	55.0	54.8	58.4	59.0	59.2	56.3
CALIFORNIA-IMPERIAL VAL	4.3	4.3	4.0	2.5	1.9	1.6	3.8	4.7
CALIFORNIA-SOUTH	4.5	4.8	7.0	7.2	7.5	7.3	6.0	7.2
COLORADO	0.0	0.0	0.0	0.3	0.2	0.3	0.9	0.7
FLORIDA	0.6	0.9	0.4	0.3	0.3	0.3	0.3	0.2
TOTAL	95.2	97.4	97.2	96.9	96.1	95.9	96.0	95.5
PIGGYBACK								
ARIZONA	1.1	0.9	0.8	0.7	0.5	0.9	1.1	1.5
CALIFORNIA-CENTRAL	2.7	1.2	1.8	2.0	2.1	2.8	2.9	2.7
CALIFORNIA-IMPERIAL VAL	0.4	0.3	0.2	0.4	0.4	0.1	0.0	0.2
CALIFORNIA-SOUTH	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1
TOTAL	4.2	2.5	2.8	3.1	3.1	4.0	4.0	4.5
U.S. TOTAL	99.5	99.8	100.0	100.0	99.2	99.9	100.0	100.0
IMPORT								
CANADA	0.00	0.00	0.00	0.00	0.66	0.01	0.00	0.00
CHILE	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
ISRAEL	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MEXICO	0.52	0.17	0.00	0.00	0.04	0.06	0.01	0.00
PERU	0.00	0.00	0.00	0.00	0.06	0.01	0.00	0.00
IMPORT TOTAL	0.52	0.17	0.00	0.00	0.80	0.07	0.01	0.00
GRAND TOTAL SHIPPED	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 2-13. Summary for Major Shippers of Romaine Lettuce, All Transport Modes

	1999	2000	2001	2002	2003	2004	2005	2006
Annual quantities shipped. Units of 1000 cwt								
ARIZONA	2,606	2,547	3,116	3,286	3,458	3,823	3,897	4,059
CALIFORNIA	6,262	6,957	6,748	6,753	8,591	9,570	10,433	10,329
TOTAL	8,868	9,504	9,864	10,039	12,049	13,393	14,330	14,388
Percentage of romaine shipped in US								
ARIZONA	29.1	26.5	31.5	32.6	28.3	28.3	26.9	28.0
CALIFORNIA	69.8	72.4	68.1	66.9	70.4	71.0	71.9	71.1
TOTAL	98.9	98.9	99.6	99.4	98.7	99.3	98.8	99.1

Appendix 2-14. "Other" Lettuce, Annual Quantities Shipped, Units of 1000 cwt

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	1,055	1,016	1,083	933	924	919	1,024	1,103
CALIFORNIA-CENTRAL	2,387	2,454	2,418	2,321	2,449	2,424	2,406	2,133
CALIFORNIA-IMPERIAL VAL	174	240	265	216	102	82	190	175
CALIFORNIA-SOUTH	190	280	359	309	383	412	353	400
FLORIDA	40	59	47	22	6	9	17	17
U.S. TOTAL	3,846	4,049	4,172	3,801	3,864	3,846	3,990	3,828
IMPORT								
CANADA	181	252	243	206	140	214	266	298
CHILE	3	3	1	2		1		
ECUADOR							1	
ISRAEL	1	1	1			1	1	3
MEXICO	60	18				6	5	
PERU	7	12	9	4	2	5	11	12
IMPORT TOTAL	252	286	254	212	142	227	284	313
GRAND TOTAL SHIPPED	4,098	4,335	4,426	4,013	4,006	4,073	4,274	4,141

Appendix 2-15. “Other” Lettuce, Percentages of Total Shipped

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	25.7	23.4	24.5	23.2	23.1	22.6	24.0	26.6
CALIFORNIA-CENTRAL	58.2	56.6	54.6	57.8	61.1	59.5	56.3	51.5
CALIFORNIA-IMPERIAL VAL	4.2	5.5	6.0	5.4	2.5	2.0	4.4	4.2
CALIFORNIA-SOUTH	4.6	6.5	8.1	7.7	9.6	10.1	8.3	9.7
FLORIDA	1.0	1.4	1.1	0.5	0.1	0.2	0.4	0.4
U.S. TOTAL	93.9	93.4	94.3	94.7	96.5	94.4	93.4	92.4
IMPORT								
CANADA	4.4	5.8	5.5	5.1	3.5	5.3	6.2	7.2
CHILE	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
ECUADOR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ISRAEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
MEXICO	1.5	0.4	0.0	0.0	0.0	0.1	0.1	0.0
PERU	0.2	0.3	0.2	0.1	0.0	0.1	0.3	0.3
IMPORT TOTAL	6.1	6.6	5.7	5.3	3.5	5.6	6.6	7.6
GRAND TOTAL SHIPPED	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 2-16. Summary for Major Shippers of “Other” Lettuce, All Transport Modes

Annual quantities shipped. Units of 1000 cwt								
	1999	2000	2001	2002	2003	2004	2005	2006
ARIZONA	1,055	1,016	1,083	933	924	919	1,024	1,103
CALIFORNIA	2,751	2,974	3,042	2,846	2,934	2,918	2,949	2,708
CANADA	181	252	243	206	140	214	266	298
TOTAL	3,987	4,242	4,368	3,985	3,998	4,051	4,239	4,109
Percentage of "other" lettuce shipped in US								
ARIZONA	25.7	23.4	24.5	23.2	23.1	22.6	24.0	26.6
CALIFORNIA	67.1	68.6	68.7	70.9	73.2	71.6	69.0	65.4
CANADA	4.4	5.8	5.5	5.1	3.5	5.3	6.2	7.2
TOTAL	97.3	97.9	98.7	99.3	99.8	99.5	99.2	99.2

Appendix 2-17. Processed Lettuce, Annual Quantities Shipped, Units of 1000 cwt

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	4,317	5,909	5,634	5,233	5,249	5,359	4,587	3,137
CALIFORNIA-CENTRAL		107	1,594	298	3,334	4,478	3,415	3,229
CALIF-IMPERIAL VALLEY	497	1,031	989	1,409	1,167	5	4	
COLORADO	161	116	230	158	212	215	341	341
NEW MEXICO	29	31	21	16	12	23		
U.S. TOTAL	5,004	7,194	8,468	7,114	9,974	10,080	8,347	6,707
IMPORT								
MEXICO	1							
GRAND TOTAL SHIPPED	5,005	7,194	8,468	7,114	9,974	10,080	8,347	6,707

Appendix 2-18. Processed Lettuce, Percentages of Total Shipped

	1999	2000	2001	2002	2003	2004	2005	2006
TRUCK								
ARIZONA	86.3	82.1	66.5	73.6	52.6	53.2	55.0	46.8
CALIFORNIA-CENTRAL	0.0	1.5	18.8	4.2	33.4	44.4	40.9	48.1
CALIF-IMPERIAL VALLEY	9.9	14.3	11.7	19.8	11.7	0.0	0.0	0.0
COLORADO	3.2	1.6	2.7	2.2	2.1	2.1	4.1	5.1
NEW MEXICO	0.6	0.4	0.2	0.2	0.1	0.2	0.0	0.0
U.S. TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
IMPORT								
MEXICO	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRAND TOTAL SHIPPED	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 2-19. Summary for Major Shippers of Processed Lettuce, All Transport Modes

	1999	2000	2001	2002	2003	2004	2005	2006
Annual quantities shipped. Units of 1000 cwt								
ARIZONA	4,317	5,909	5,634	5,233	5,249	5,359	4,587	3,137
CALIFORNIA	497	1,138	2,583	1,707	4,501	4,483	3,419	3,229
COLORADO	161	116	230	158	212	215	341	341
TOTAL	4,975	7,163	8,447	7,098	9,962	10,057	8,347	6,707
Percentage of processed lettuce shipped in US								
ARIZONA	86.3	82.1	66.5	73.6	52.6	53.2	55.0	46.8
CALIFORNIA	9.9	15.8	30.5	24.0	45.1	44.5	41.0	48.1
COLORADO	3.2	1.6	2.7	2.2	2.1	2.1	4.1	5.1
TOTAL	99.4	99.6	99.8	99.8	99.9	99.8	100.0	100.0

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