Energy Management for Controlled Environment Agriculture (CEA) Tomato Production

FINAL REPORT

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SUMMARY

This report summarizes an 18-month research collaboration between Cornell University's CEA Program and a commercial tomato grower, Underwood Farms, Shushan, NY, under the Project Management of Mr. Edward Kear, NYSERDA.

The objectives of the study were: 1) to demonstrate the use of innovative lighting strategies to improve the productivity of New York tomato winter-production growing at two greenhouse sites; 2) to compare time-of-day supplemental lighting strategies with a lighting algorithm (Albright, US Patent No. 5,818,734, Oct. 6, 1998) that optimizes plant growth and electrical energy consumption; 3) to achieve yearly productivity of at least 14 lbs of tomatoes/ft2 with reduced unit production costs and energy content (Btu/lb) compared to imported tomatoes.

Additional winter-production data is needed, however the work performed in this study suggests a strong potential for increasing winter production of tomato in New York. Further, the study shows that the additional value of winter tomatoes would allow the installation of a supplemental lighting system to pay for itself within 3 years. The data show that if year round production (12 months per year) was conducted in New York State with supplemental lighting, a yearly production of at least 16 lbs of tomatoes/ft^2 is possible.

While night (off-peak) timer control of lights was successful in significantly increasing production at the commercial facility, the amount of light applied to the crop by increasing light intensity and using inter-canopy lighting (to avoid burning leaves with high light intensity) under integral-light control to 30 mols per day has the potential to increase year-round production to summer production rates of 2.2lb/month (or 26 lbs/ft^2 per year).

TABLE OF CONTENTS

BACKGROUND

The changing dynamics of the fresh tomato industry in the United States

Although, historically, a greenhouse tomato industry has existed for many years in the United States, winter production was limited, distribution was local, and quality was marginal. During the 1990s, imported Dutch technologies (and growers) stimulated the Canadian greenhouse tomato industry to the point where Canada ended the decade as the largest North American producer of greenhouse tomatoes (nearly half of the North American production). The relatively weak Canadian dollar during those years assisted that growth, with sales particularly strong in the northwestern and northeastern states of the U.S. (Canadian production is primarily in Ontario and British Columbia.)

Greenhouse tomatoes now account for 37 percent of the fresh tomatoes sold in the U. S. (Cook and Calvin, 2005). Much of this increase has come at the expense of the traditional field product, the mature, field-grown, green tomato. Although greenhouse tomatoes are not harvested “garden-ripe”, their harvest is delayed until past the breaker stage, when the sugar contents and aromatic flavors are higher. However, the lack of winter light in Canada limits their winter supply. As fresh, high quality, greenhouse tomatoes are demanded year-round, and are becoming more of a mainline commodity; opportunities exist to develop production methods that lead to significant mid-winter local production in the northern U.S.

Tomato consumption and sources of imports in New York

The United States imports more tomatoes than any other country in the world. For example, 847 thousand metric tons were imported in 1998 (1). The same year, tomatoes arriving in New York (1,142,000 cwt) came from Florida (39%), California (15%), and outside New York (41% including shipments from Israel, Netherlands, Canada, Dominican Republic, Morocco, Spain, and Puerto Rico) (2) (Figure 1).

Figure 1. Arrivals of New York winter tomato imports, 1998 data.

Is there an opportunity for New York growers to compete effectively in the winter tomato market?

<u>Influence of climate on need for imports to New York</u>

Tomato production is optimized at temperatures near 24 to 27 degrees C (75 to 80 degrees F). Frost kills flower buds and leaf and stem tissue. New York State has cold winters that make outdoor tomato production impossible during the winter months. Average minimum winter temperatures in New York range from –35 to 15 degrees F (Figure 2).

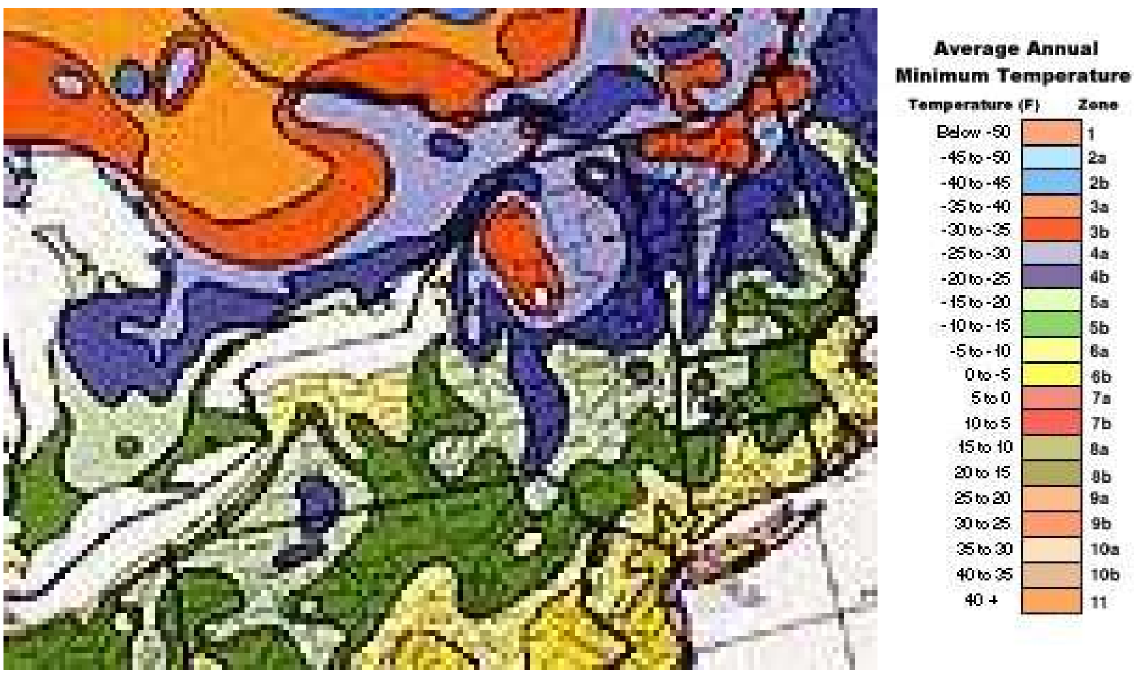

Figure 2. New York State average annual minimum temperatures

Source: (USDA Publication No. 1475, 1990) (3)

Influence of season on retail price of tomato in New York

The winter months also historically bring the highest market prices for fresh tomatoes as home-gardeners' are no longer able to grow their own backyard tomatoes (Figure 3) and nearby Northeastern field-grown tomatoes are also unavailable.

Figure 3. Average monthly retail price for fresh tomato over a ten year period (1991 – 2001 Northeast data) shows increased winter retail prices. *Source: Bureau of Labor Statistics, U.S. Dept. of Labor, 2001.*

Historically, the retail price of tomato increases as the cooler temperatures and decreased sunlight occur in the Northeast (Fig. 3). Growing winter tomatoes in a New York greenhouse would require the input of energy for heating and supplemental lighting. The months of November through April represent the time of year that a New York greenhouse tomato grower may best compete with the imported fresh tomato market.

Influence of shipping on the price of New York winter tomatoes

Tomatoes are shipped to New York State by truck within the Continental US and Mexico, and by plane from Europe and the Middle East.

Trucking charges influence the market price of fresh winter tomatoes in the Northeast. Additionally, the price of diesel fuel influences the price of product shipment and therefore the price of imported tomato. The following chart shows typical winter-month trucking charges for tomato from Florida to the New York over a seven year period from 1983 to 1991 (Table 1).

Table 1. Truck charges for shipment of tomato from Florida to New York City.
Source: Agricultural Marketing Service, Economic Research Service and Agricultural Marketing Service, U.S. Dept. of Agric.

Dollars per 25 lb carton

	JAN	FEB	MAR	APR	MAY
1985	1.15	1.15	1.15	1.15	1.41
1986	1.09	1.25	1.25	1.34	1.36
1987	1.31	1.31	1.31	1.31	1.33
1988	1.36	1.36	1.36	1.25	1.28
1989	1.23	1.23	1.12	1.17	1.28
1990				1.17	1.39
1991	1.25	1.12	1.12	1.20	1.28
AVERAGE	1.23	1.24	1.23	1.22	1.27

Previous studies on energy requirements for tomato production

DESCRIPTION OF THE PROBLEM BEING ADDRESSED

APPROACH and EXPERIMENT DESIGN

Preliminary site work and greenhouse installation (TASKS 1 and 4)

Prior to initiation of the experiment, a weather station and data recording system were installed at the commercial test site.

Design and installation of luminaires and electrical service were completed at the commercial test site. The commercial test site luminaires provided approximately 100 µmol $m^{-2}s^{-1}$ at the top of the crop canopy, which was approximately seven feet above the floor.

A new lighting system was installed at the university test site that allowed testing of two light intensities (10 mol and 20 mol per day). A third area of the university test site was left without lamps to provide a natural daylight control. The university test site luminaires provide approximately 100 µmol $m^{-2}s^{-1}$ at the canopy in the 10 mol treatment section and 200 µmol $m^{-2}s^{-1}$ in the 20 mol treatment section. Specific data are in the following table. Data above seven feet from the floor were not taken because the plants were not allowed to grow above this height due to the mounting height of the luminaires.

Height Above Floor	4'	5'	6'	7'
<u>10 mol/m^2 daily PPFD integral treatment area</u>				
Average $\mu m^{-2}s^{-1}$	92.5	103	116	130
Minimum $\mu m^{-2}s^{-1}$	64.5	74.6	94.5	84.9
Maximum $\mu m^{-2}s^{-1}$	108	119	149	205
Average deviation, $\mu m^{-2}s^{-1}$	6.84	6.43	6.97	20.1
Hourly integral, mol/m^2	0.333	0.371	.0417	0.468
20 hour integral, mol/m^2	6.66	7.42	8.35	9.36
<u>20 mol/m^2 daily PPFD integral treatment area</u>				
Average $\mu m^{-2}s^{-1}$	180	199	216	235
Minimum $\mu m^{-2}s^{-1}$	157	179	193	165
Maximum $\mu m^{-2}s^{-1}$	199	219	246	300
Average deviation, $\mu m^{-2}s^{-1}$	5.98	5.57	9.87	27.8
Hourly integral, mol/m^2	0.648	0.716	0.778	0.846

20 hour integral, mol/m^2	12.96	14.33	15.55	16.92

Daily PPFD integrals were in addition to naturally provided light. The average expected daily outdoor solar PPFD integral values for Ithaca are listed in the following table. The PPFD received indoors is, of course, modified by the transmissivity of the greenhouse.

Month	Mol/m^2
Jan	10.38
Feb	15.57
Mar	24.31
Apr	29.26
May	36.24
Jun	42.56
Jul	41.81
Aug	36.13
Sep	27.05
Oct	17.96
Nov	9.96
Dec	7.84
Average	24.9

Control Algorithm for supplementary lighting of tomato (TASK 3)

The control algorithm for supplemental lighting of tomato was based upon an existing control algorithm for supplemental lighting (US Patent No. 5,818,734) and also incorporated consideration of the physiological requirements for a minimum 4 hour dark period in tomato production. The duration of the 4 hour dark period was not optimized in this study but was based on values proposed in the research literature as being the minimum dark period required for adequate fruit productivity and vine health. A feature in which the control algorithm was implemented was to place as much as possible of this dark period during the on-peak electric rate time of day. Time of day electricity rates are important for greenhouse lighting. The light control program calculates the times of sunrise and sunset each day. The dark period was assumed to begin an hour after sunset, which placed all the dark period into the on-peak electric rate time during the peak lighting times of mid fall to early spring. This is the part of the year when the greatest amount of supplemental lighting is required.

Project Advisory Board (TASK 8)

February 2001 Advisory Panel Meeting Feedback on the Tomato Project:

The February 2001 Advisory Panel Meeting began with presentations of program overviews and research status including the tomato project. Tours of the research facilities and commercial demonstration facility were followed by a feedback session from the Advisory Panel members.

Summary of feedback & questions relating to the tomato research project from Advisory Panel Members:

TOMATO PROJECT FEEDBACK

- How was tomato variety selected? *Response: The variety, Trust, was selected because it is the variety being used by our commercial partners (The Underwoods) in the project.*
- Development of stronger ties with other university and research groups would be beneficial (e.g., Research Station in Naaldwjk, Laval Univ., Rutgers Univ.). *Response: This is important and is one of the reasons for including a representative from Rutger's University on the Advisory Panel.*
- There may be challenges with tomato photoperiod tolerance with supplemental lighting systems. This might be a good project for a horticulture graduate student. *Response: The CEA Program is pursuing ways of continuing and helping fund a strong graduate program for Horticulture*

students. The photoperiod question will be an important part of the light-control parameters for tomato.

- To obtain an "organic" label, there might be some options for collecting fertilizers from bio-reactor processes from composted materials. *At this time, the CEA program is not pursuing an "Organic" label. Hydroponic systems using chemical fertilizer salts rather than organic waste are more biologically safe from a HACCP standpoint.*
- Light sensors, light quantity data logger, and natural light historical data for the Shushun area are needed. *Response: This will be included in the research equipment for the Shushun site. The closest weather station with historical data for the region might be from Albany.*
- If the project is successful, who does CEA plan to market the technology to and what will prevent growers from ignoring Cornell CEA patent rights? *Response: The commercial technology will be marketed to family-owner/operators. Use of the patented light control algorithm would be easy to detect by observing energy use, and light and shade use in any facility.*

August 2001 Advisory Panel Meeting Feedback on the Tomato Project:

Suggestions regarding HPS light layout design challenges

As this project begins, a major concern came up during the pre-trials. The overhead HPS lamps caused some leaf burn on leaves within about 2 ft of the overhead lights at the Cornell site. The Cornell group expressed concern for the light design at the commercial site because ceilings are lower at the Shushan site.

Suggestions/remarks regarding Cornell site leaf burn and light design:

1. With the heavy foliage, how is the light going to be uniformly distributed?
2. Try topping the tomatoes to avoid light damage.
3. There will be some light diffusion on Cornell's tomato site due to the lighting set up. Could you have a light meter to record mols for high and medium test areas.

4. Is it possible to angle lights to maximize distance from the plants to reduce leaf burn?

RESPONSE: We will use a light meter to create a light map for the test site at Cornell. The light will not be uniformly distributed throughout the crop, but there will be a fairly uniform plane of light at a distance of approximately 5 feet from the lamps. Angling the lamps would not work because this would change the light distribution pattern in the canopy.

<u>Suggestions/remarks regarding the Shushan site light design with low ceilings</u>
In the Netherlands, low greenhouses use a gutter-system for growing tomatoes.

<u>Suggestions regarding culture methods and data collection for the tomato project</u>

1. Have a taste testing under the different light treatments.
2. Use another growth media. The Cornell plants look too vegetative. This is due to using peat.
3. Try lighting between the rows or root zone heating (75 ^{o}F).
4. Maximize the use of similar growing practices between both sites for consistence in measuring results.
5. The quality of the fruit may not be related to vegetative quality.
6. Try to grow as already done in practice.

<u>Other suggestions outside the scope of the current tomato project</u>

1. Have you preformed an economic optimization analysis regarding the number of clusters to grow prior to removing the plants?
2. Try growing ‘specialty’ tomatoes: cluster, cherry, grape, heirlooms.
3. The crop characteristics need to be defined, i.e., height, light input, number of clusters, culture for nutrient delivery, and pathogen control should be gathered from previous research and commercial production systems.

ESTIMATING VALUE TO NEW YORK

Electricity requirements for supplemental lighting (TASK 6)

The amount of electricity needed to operate the lights at the Shushan facility was determined through comparison of previous electrical bill KWh usage reported prior to and after installation of the lamps. The lamps increased KWh usage by 7000 to 8000 KWh per month.

The amount of electricity needed to operate the lights at the Cornell test site was calculated by multiplying the energy use of a single lamp by the number of lights utilized per unit area per unit time. It is assumed a single 400 W lamp, with ballast, generates 1620 BTU per hour of operation.

Cost/Benefit Analysis (TASK 7)

DEVELOPMENT OF A SOLAR TRANSMISSIVITY FUNCTION (TASK 2)

Solar insolation data were logged outside the commercial and university test sites and inside the greenhouses over the center of the crop areas. The data were utilized to develop a solar transmissivity math function for both greenhouses based on time of day and time of year.

FIELD DEMONSTRATION EXPERIMENT RESULTS (TASK 5)

The commercial test greenhouse was utilized to grow tomatoes under time-of-day lighting only. This method provided lighting to the crop with varying daily light integral, depending on the solar lighting history. The university test greenhouse was controlled to two specific targets (10 mols and 20 mols $m^{-2}d^{-1}$) and also included a natural daylight control treatment plot. Production at each test site was evaluated by measurement and recording of total harvested fruit weight under continuous production. Tomato crop production values (per unit area, per number of plants, and per unit energy input) were determined.

TREATMENT	WINTER PRODUCTION Nov – Mar Avg (lbs)		
	per plant	per ft2	per lighting BTU
Natural daylight, Shushan [A]		0.25 (0.1)	
Lights on night timer, Shushan[B]		1.26 (n=1)	
Natural daylight, Ithaca[C]		0.49 (0.1)	
10 mols per day, Ithaca[C]		0.43 (0.1)	
20 mols per day, Ithaca[C]		1.06 (0.4)	

A - Data from 1999 and 2001 pre-light installation, average Nov – Mar (n = 5 months)
B – Data from March 2003 (only winter month with full production at Shushan) (n = 1 month)
C – Data from 2002/2003 winter season, average Nov – Mar (n = 5 months)

TECHNOLOGY TRANSFER (TASK 9)

Companies that may make use of lighting technology for tomato production

BARBER'S FARM

HCR-1 – Box 29
Middleburgh, New York 12122
518-827-5454

BLACK HORSE FARMS, INC.

Box 48A
Coxsackie, New York 12051
518-943-9324
contact: Lloyd Zimmerman

BOWMAN FARMS, INC.

11259 Rt. 62
North Collins, New York 14111
716-337-3325
Contact: Lynn Bowman, Jr.

Buhrmaster Fruit and Produce, Inc.
180 Saratoga Road
Scotia, New York 12302
518-399-5931
Contact: Keith Buhrmaster

CRS GROWERS/FLO (CERTIFIED ORGANIC PRODUCE)

2622 North Triphammer Road
Ithaca, New York 14850
607-257-2195
Contact: Carol Stull

Cropsey, James W.
230 Little Tor Road South
New City, New York 10956
914-634-4719
Contact: James Cropsey

EDEN VALLEY GROWERS, INC.

7502 Gowanda State Road
Eden, New York 14057
716-992-9721
Contact: Gary Balone

MORRIS ELLIS FARMS

195 U.S. 11
Gouverneur, New York 13642
315-287-3896
Contact: Vicki Ellis

EMMI AND SONS, INC.

275 Elwood Davis Road
Liverpool, New York 13088
315-451-3800
Contact: Carmen Emmi Jr. or Tony Emmi

FISH FARM MARKET

4494 Mt. Payne Road
Shortsville, New York 14548
716-289-4215
Contact: Lynn Fish

FREATMAN FARM

3699 N. Ridge Road
Lockport, New York 14094
716-434-1373
Contact: Paul Freatman

Paul Hafner Farms
1481 Genesee Road
Baldwinsville, New York 13027
315-635-6126
Contact: Paul Hafner, Jr.

HAND MELON FARM

533 Wilbur Avenue
Greenwich, New York 12834
518-692-2376
Contact: John Hand

HAYES PRODUCE MARKET

Route 22 – Box 181A
Cambridge, New York 12816
518-677-2372
Contact: C.J. Hayes

EDMUND HODUN AND SONS

1688 Middle Road
Calverton, New York 11933
516-727-2618
Contact: Ed Hodun

ISLAND END FARMS, INC.

P.O. Box 166
Peconic, New York 11958-0166
516-734-7271
Contact: Gene Wesnofske

LAZZAR GROWERS

908 Klem Road
Webster, New York 14580
716-671-4471
Contact: Ted. B. Lazzar

DEWEY LEWIN AND SONS

Sound Avenue
Calverton, New York 11933
516-929-6439
Contact: Howard

MKZ FARMS

P.O. Box 442
Jamesport, New York 11947-0442
516-722-3061
Contact: Mark or Ken Zaweski

MASON/OLD RIDGE FARMS

3135 Ridge Road
Williamson, New York 14589-9387
315-589-2857
Contact: Douglas P. Mason

MIGLIORELLI FARM

46 Freeborn Lane
Tivoli, New York 12583
914-757-3276
Contact: Kenneth A. Migliorelli

Morrow Creek Farm

199 Algerine Road
Lansing, New York 14882
607-533-4295
Contact: Daniel Konowalow
Or Marcy Rosenkranz

Moses Farm

43 Grandma Moses Road
Eagle Bridge, New York 12057
518-686-7729
Contact: Richard A. Moses

Mosher Farms

RD 1 - Box 69
Bouckville, New York 13310
315-893-7173
Contact: Terry Mosher, Joan Mosher

Norwich Meadows Farm

105 Old Stone Rd
Norwich, NY 13815
607-336-1238

Paffenroth Gardens

95 Little York Road
Warwick, New York 10990
914-258-4746
Contact: Alex Paffenroth

Porter Farms (certified organic produce)
5020 Edgerton Road
P.O. Box 416
Elba, New York 14058-0416
716-757-6823
Contact: Steve Porter

Reeves Farm Market

1362 Lamson Road
Phoenix, New York 13135
315-678-2018
Contact: Tim Reeves

Reeves Farms

1100 Reeves Road
Baldwinsville, New York 13027
315-635-3357
Contact: Mark or Brian Reeves

Robinson Farms

3677 North Ridge Road
Lockport, New York 14094
716-434-1805
Contact: Jackie or Don Robinson

The W. Rogowski Farm, LLC
421 Pulaski Highway
Goshen, New York 10924
914-258-4456
A. Sam Farms, Inc.
P.O. Box 591
West Lake Road
Dunkirk, New York 14048-0591
716-366-6666
Contact: Charles E. Sam

Samascott Orchards

5 Sunset Ave
Kinderhook, NY, 12106
(518)758-7224

V.R.Saulpaugh and Sons

1960 Route 9
Germantown, New York 12526
518-537-6494
Contact: Larry Saulpaugh

Saunderskill Farms

Box 183B – Garden Lane
Accord, New York 12404
914-626-7103
Contact: Dan Schoonmaker

F and W Schmitt Brothers Farm

26 Pinelawn Road
Melville, New York 11747
516-423-5693

Contact: Teresa Schmitt

Sodoma Farms, Inc.
4490 Sweden Walker Road
Brockport, New York 14420
716-637-4470
Contact: Robert Sodoma

STORY FARMS

4640 Route 32
Catskill, New York 12414
518-678-9716
Contact: Matt Story

TASSONE FARM/WILLIAM FARM

7993 North Vernon Road
Cicero, New York 13039
315-699-3442
Contact: Sam Tassone

TRI-WAY VIEW FARMS

2185 Manitou Road
Rochester, New York 14606
716-352-3019
Contact: Robert Brongo

CHARLES B.TROLLEY FARMS

14945 Holley Road
Albion, New York 14411
716-589-4007
Contact: Chuck Trolley

VOLLMER FARMS

6576 Collamer Road
East Syracuse, New York 13057
315-463-4902
Contact: Harold or David Vollmer

WELLS HOMESTEAD ACRES

4945 Sound Avenue
Riverhead, New York 11901
516-722-8097
Contact: Lyle or Susan Wells

Werner Farms and Greenhouses

8427 W. Henrietta Road
Rush, New York 14543
716-533-1627
Contact: Alan Werner

Wickham's Fruit Farm

Route 25
Cutchogue, L.I., New York 11935
516-734-5454
Thomas Wickham or Prudence Heston

Wilcox Farms

581 Fyler Road
Kirkville, New York 13082
315-656-3168
Contact: Lawrence T. Wilcox III

Zehr Farms, Inc.

6178 Jacques Road
Lockport, New York 14094
716-778-9872
Contact: Ernest Zehr

Berkshire Berries®

RD #1, Chester, MA 01011
Tel. 800 - 5BERRYS
800-523-7797
Fax: 413-623-5023

Sylvan Botanicals

New York Ginseng
P.O. Box 91
Cooperstown, New York 13326
607-264-8455

Charlie's Garlic Farm

Charlie Bishop
16094 CR 23
Unadilla, NY 13849
Phone: (607) 563-3531

Seven Pines Rose Farm

Michael Barry
Long Island, New York

Stokes Farm, Inc.
23 De Wolf Road
Old Tappan, NJ 07675
201-768-3931
201-768-2239

Red Jacket Orchards

957 Canandaigua Road
Geneva, New York 14456
800-828-9410
fax:315-781-2875

CONCLUSIONS AND RECOMMENDATIONS

PRODUCTION LOCATION (Distance miles)	Btu's/lb tomatoes Production**	Transport to NY*
Winter production in New York State	39247	
Florida (1000 miles)	480	15,444
California (2400 miles)	480	37,067
Israel (5500 miles)	480	84,944
Transport from Netherlands GH		61,788
Transport from Canada winter production		7,722
Transport from Dominican Republic	480	30,889
Transport from Morocco	480	57,144
Transport from Spain	480	54,056
Transport from Puerto Rico	480	23,167

**Assumes 50 miles per passenger (180lb) per gallon and assumes 139,000 BTU/gallon diesel*

***Field production values calculated from pre-processing energy usage data for California tomato production database, UC Davis and California Dept of Food and Agriculture, Sacramento, "Summary of Energy Requirements for Agriculture in California", 1978.*

The energy utilized to produce NY winter tomatoes (estimated Btu's per pound) was significantly less than the energy utilized to transport winter tomatoes to New York from winter production areas.

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Cook, R. and L. Calvin. 2005. Greenhouse tomatoes change the dynamics of the North American fresh tomato industry. Economic Research Report, United States Economic Research Service, No. 2. 81 pp. (http://www.era.usda.gov)

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