DEMONSTRATION OF CEA LETTUCE PRODUCTION MODULE

FINAL REPORT

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Executive Summary

Background

Agway, Inc., operated the lettuce greenhouse from July 1999, until October 1, 2000. Limited data are available from their operation that can be included in this report, however. One set of data that is available is the summary of lettuce sales. In the table below are the data for dollar values of lettuce sales for the time period of their operation.

Month	Sales, $	Retained by Agway	Paid to Cornell
Jul 99	$9,248.75	$6,000.00	$3,248.75
Aug 99	$6,053.85	$6,000.00	$53.85
Sep 99	$9,743.80	$6,000.00	$3,743.80
Oct 99	$6,326.85	$6,000.00	$326.85
Nov 99	$10,035.10	$6,000.00	$4,035.10
Dec 99	$2,744.50	$2,744.50	$0.00
Jan 00	$1,664.00	$1,664.00	$0.00
Feb 00	$5,724.50	$5,724.50	$0.00
Mar 00	$1,007.00	$1,007.00	$0.00
Apr 00	$851.00	$851.00	$0.00
May 00	$7,438.60	$6,000.00	$1,438.60
Jun 00	$4,542.60	$4,542.60	$0.00
Jul 00	$16,142.00	$16,142.00	$0.00
Aug 00	$4,098.00	$4,098.00	$0.00
Sep 00	$2,779.00	$2,779.00	$0.00
Total	**$88,399.55**	**$75,552.60**	**$12,846.95**

Data are not available to Cornell to quantify the number of heads of lettuce sold each month, nor the sales price of each head.

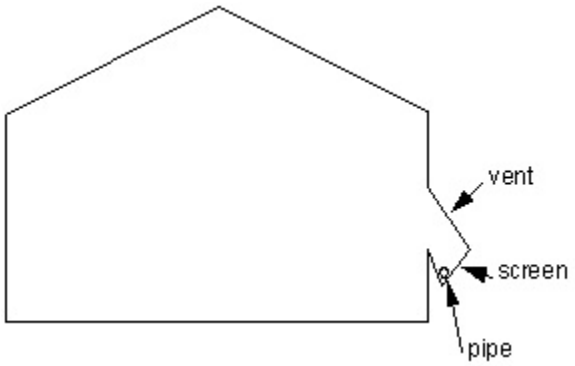
Two major and related episodes caused lost production for extended periods. The first was the outbreak of aphids during the late fall of 1999, an outbreak that caused production to cease for more than a month.

Aphids had been seen occasionally since greenhouse operation began in May 1999. However, in October the population began to explode, and winged aphid forms appeared. The hypothesis is that, when extended supplemental lighting began to be used, the long photoperiods, or perhaps the spectral characteristics of the High Pressure Sodium (HPS) lamps, stressed the aphids and led to formation of winged forms. It is believed that when the mother aphids are stressed, the next generation is born with wings to escape the stress. Winged aphids spread quickly throughout the greenhouse, multiplied rapidly, and made the crop totally unmarketable.

The greenhouse was emptied of lettuce in mid December 1999 and the air temperature was raised to above 90 degrees for six days. Advice from entomologists suggested that high temperature, and lack of food, would rid the facility of aphids in four days. This proved not to be the case because the aphids reappeared almost immediately. Lady bugs were then tried as biological control for several months but proved to be ineffective. Aphids can hide deep within a lettuce head and lady bugs cannot find them in the small spaces. As the aphid population grew, another means of control became necessary. The greenhouse was again emptied of plants (January 2000) and the decision was made to restart production, but use some form of chemical control of the aphids.

Several “natural” chemical controls were applied during February and March of 2000 (e.g., Neem oil extract, cinnamon extract) and each exhibited some efficacy, but none were suitably effective. A decision was made to use nicotine fog, which is approved for use on greenhouse lettuce to control aphids. The greenhouse was fogged in early April 2000. The day after, crawling aphids were seen and two days later winged forms were seen. Advice from the company that supplied the nicotine spray suggested that three repeated applications would work and any residues would evaporate within five days after the last application. Three applications were then made and that sequence did kill all the aphids. Unfortunately, the nicotine also made the lettuce unmarketable by imparting a strong and very objectionable taste to the lettuce; the taste did not disappear in five days. It never disappeared from the lettuce that had been fogged. Lettuce was discarded for three weeks, through the end of April. Agway promised to pursue possible damage reimbursement from the company that made the nicotine, but any possible outcome of that action is not known by Cornell.

The final solution to the aphid problem involved two approaches. One approach was the installation of insect screening over the inlet vents during the summer of 2000.The screen is a long strip (as long as the vents) that is 6' wide. One side is fastened to the greenhouse just below the vent. The other side is fastened to the bottom edge of the vent. A length of plastic pipe runs the length of the screen and weights the screen material so it hangs down from the vent. As the vent opens, the screen remains taught and in the shape of an inverted triangle to maintain maximum area for air flow. Dust accumulation has not been a severe problem; occasional washing with a water hose suffices.



The second approach was use of the predatory wasp. *A. colemani* which lay eggs in the bodies of aphid-pests and mummify the aphids. In order to maintain a continuous supply of *colemani* to seek out invading aphids, cereal aphids (which do not grow on lettuce) were raised (and are still being raised) on barley plants in the greenhouse. New cereal aphids are introduced to the "*colemani* nursery" on a regular basis. *A. colemani* leave the nursery to seek out and eliminate invading aphid pests on the lettuce.The *colemani* have provided excellent control. The alternative is to purchase the *colemani* but the cost is prohibitive – roughly $0.25 per wasp. Regular scouting for insect pests is performed as part of this biological control program.

The living lettuce concept of marketing was tested during June of 2000 and was highly successful as can be seen from the July, 2000, sales data. The greenhouse operation was able to sell all of its product for that month-long sales trial. This added value approach to lettuce sales was under the direction of a Cornell graduate student, Mauricio Salamanca, as part of his doctoral thesis experimentation and demonstrates the critically important notion that added value products play a central role in making a marginally profitable CEA operation into one that is profitable.

Corresponding to the lettuce production data, in the table below are summarized the electricity data resulting from operating the lettuce greenhouse during the same time period. It should be noted, however, that during this period the environmental control program supplied by QCom was unable to operate the greenhouse under the Cornell light control algorithm that optimizes greenhouse lighting timing. The QCom computer programmer was not able to modify their DOS-based control program in a way that permitted the light control feature to operate for more than a day or two at a time. Thus, the percentages of on-peak electric use are somewhat higher than current operation shows, where currently light control is based on a locally-produced light and shade control computer program, named LASSI (Light And Shade Supplementation Implementation).

After Cornell assumed responsibility for operating the facility, a locally written computer program (LASSI.C) was completed and has controlled the supplemental lights and shades for the past year. A hard copy of the program, and its two accompanying utility files, are included as an appendix to this report. All coding is in the C computer language and was compiled using the Borland C/C++ version 4.5 integrated development environment (IDE).

Read Date	No. days	On kWh	Off kWh	Total kWh	On kW	Off kW	Total $	$/kWh	$/day
7/27/99	29	18,800	18,720	37,520	150.4	147.2	$5,283.3	$0.14	$182.18
8/25/99	29	19,840	21,290	41,130	148.0	146.4	$5,481.7	$0.13	$189.03
9/24/99	30	23,600	23,520	47,120	148.0	148.0	$5,283.3	$0.11	$176.11
10/22/99	28	22,240	28,400	50,640	151.2	151.2	$5,481.7	$0.11	$195.78
11/29/99	38	38,000	65,840	103,840	142.8	148.8	$9,455.1	$0.09	$248.82
12/29/99	30	30,560	34,000	64,560	148.8	148.0	$6,488.0	$0.10	$216.27
1/26/00	29	32,400	46,960	79,360	148.8	148.8	$7,404.5	$0.09	$255.33

Read Date	No. days	On kWh	Off kWh	Total kWh	On kW	Off kW	Total $	$/kWh	$/day
2/27/00	32	27,920	41,440	69,360	149.6	150.4	$6,689.1	$0.10	$209.04
3/24/00	25	19,440	27,920	47,360	152.0	147.2	$5,171.7	$0.11	$206.87
4/25/00	32	34,640	39,520	74,160	149.6	149.6	$6,286.2	$0.08	$196.44
5/24/00	29	17,520	28,960	46,480	155.2	150.4	$5,096.5	$0.11	$175.74
6/23/00	30	18,320	27,600	45,920	151.2	148.8	$5,043.2	$0.11	$168.11
7/25/00	32	15,840	27,920	43,760	148.8	146.4	$4,809.2	$0.11	$150.29
8/23/00	29	14,560	23,920	38,480	143.2	146.4	$4,396.2	$0.11	$151.59
9/22/00	30	15,200	24,240	39,440	144.8	145.6	$4,491.4	$0.11	$149.71
Total/Ave	**452**	**348,880**	**480,250**	**829,130**	**148.8**	**148.2**	**$86,861.63**	**$0.11**	**$191.42**

Natural gas use during the same time period is shown by data in the following table. As with the electricity use data, there is not a differentiation between use for the greenhouse and use for the head house. The facility is not metered to provide such data.

Read Date	No. days	Therms	Therms/ day	Cost	$/day
7/27/99	29	192	6.6	$187.81	$6.48
8/25/99	29	89	3.1	$97.75	$3.37
9/24/99	30	301	10.0	$300.41	$10.01
10/22/99	28	633	22.6	$587.82	$20.99
11/29/99	38	1,358	35.7	$1,192.07	$31.37
12/29/99	30	3,278	109.3	$2,489.45	$82.98
1/26/00	29	4,989	172.0	$3,685.61	$127.09
2/27/00	32	5,954	186.1	$4,510.56	$140.96
3/24/00	25	3,740	149.6	$2,903.81	$116.15
4/25/00	32	3,804	118.9	$3,014.71	$94.21
5/24/00	29	2,934	101.2	$2,424.71	$83.61
6/23/00	30	2,050	68.3	$1,872.96	$62.43
7/25/00	32	1,789	55.9	$1,753.58	$54.80
8/23/00	29	1,957	67.5	$1,855.21	$63.97
9/22/00	30	2,007	66.9	$1,921.59	$64.05
Total/Ave	**452**	**35,073**	**78.2**	**$28,798.05**	**$64.17**

During the months preceding Agway's departure, D. Ciolkosz of the Cornell CEA team completed an analysis of the physical systems of the lettuce module. A copy of his report is included as an appendix to this report, and was the basis of the list of tasks developed for the

extension of the project, which began upon Agway's departure and Cornell's assumption of responsibility for operating the greenhouse. The work completed for those tasks follows as the remainder of this report.

Individual Tasks

Task 1 - Project Management/Reporting

A CEA Advisory Board was established for the project, comprising the following members:

E. B. Kear, NYSERDA Project Manager
R.A. Peterson, NYSEG Project Manager
J. Brenner, Cornell Research Foundation
A.J. Both, Rutgers University
L. Dam
J. Sager, Kennedy Space Center, NASA
D. Schwartz
P. Underwood, Underwood Greenhouses
W. Underwood, Underwood Greenhouses
R. Wheeler, Kennedy Space Center, NASA
M.F. Walter, Cornell University
H.C. Wien, Cornell University

Project meetings of Cornell project participants were held every week. Advisory Board meetings were held on February 22/23, 2001, and August 23/24, 2001, in Ithaca. Written comments from the Board at the August meeting were obtained, replied to, and the list of questions and replies is included as an appendix to this report.

The annual agricultural conference sponsored by NYSERDA was attended and presentations made. The presenter for the 2000 conference was R.W. Langhans and the presenter for the 2001 meeting was L.D. Albright. Printed copies of the PowerPoint slides used for the 2001 presentation are included as an appendix to this report.

Task 2 - Lettuce Module Upgrade

Lamp chiller: The lamp chiller was relocated to the outside of the head house, along the north wall. A small shelter was constructed to surround the chiller and reduce solar loading during the summer. The shelter is amply ventilated for summer operation and, as a result of the move, the chiller provides adequate capacity - heat rejection is to the cooler outdoor air instead of the warmer head house air. For this reason, a new chiller was not purchased to replace the original.

Paddle fans: A pair of paddle fans were installed and continue to operate. The benefit of the fans is to produce a wider zone of air movement within the canopy of the crop, with the same or

greater average air velocity but lower localized air velocity directly under the fans. However, although real, the benefit was sufficiently small that the entire greenhouse was not retrofitted with the fans. However, paddle fans will be specified for the next generation of greenhouse, and will be the type of fan used should any of the original fans fail to operate properly.

Oxygen injection system: The situation addressed was that oxygen being added to keep the nutrient solution in the greenhouse lettuce production ponds near the oxygen saturation point (relative to air ... approximately 8 ppm.)

Careful evaluation of the oxygen addition process disclosed the main cause of excessive oxygen use. Under the original protocol, two oxygen tanks were always kept in the greenhouse. One was for use and the second was the replacement when the first ran out, at which time a new backup oxygen tank was ordered. However, the tanks have a continuous bleed off system to release oxygen that has evaporated within the tank as heat from the surroundings diffuses in and causes evaporation. The rate of use within the lettuce ponds was sufficiently slow that the bleed-off tank was losing perhaps three-quarters of its oxygen before the tank was actually needed. Thus, most of the oxygen being purchased was being simply vented and lost.

The solution was to make arrangements with the oxygen supply business to assure that a replacement tank could be brought to the greenhouse within a day of being ordered. Operation is now satisfactory with a single tank, and oxygen is being used at least three times as efficiently. There is still some bleed off of vapor from the tanks, especially during warmer weather, but much less is lost than before.

Winter air inlet system: Two perforated polyethylene tubes were installed near the peaks of two of the four greenhouse bays, oriented parallel to the peaks of the roof. During winter, and the colder days of fall and spring, the intake vent for the greenhouse is kept closed and ventilation is limited to the lower stages of air flow.

When ventilation is needed, whether for temperature or humidity control, the exhaust fans pull air through the vent tubes. and the uniformly spaced small holes in the tube distribute fresh air along the length of the greenhouse. The tubes are oriented so their intakes are above the exhaust fans. Perforated polyethylene tubes usually provide more air flow (approximately double) at the end farthest from the entry, thus the greatest air flow rate is at the end of the greenhouse farthest from the exhaust fans. This provides greater air flow along the entire length of the greenhouse and enhances temperature uniformity. This has provided winter ventilation without the excessive chilling that occurred when fresh air all entered at the inlet end of the greenhouse, the end farthest from the exhaust fans.

A further refinement will be to add motorized louvers to the intakes of the ventilation tubes. Fixed louvers are currently in use. This can lead to a problem on days when there is need for occasional ventilation - such as a sunny but cool day. Between fan cycles, heat builds in the air near the peak (and the vent tubes.) When ventilation is activated and air enters through the tubes, it drags the hot air down into the plant growing space, leading to a decision by the control

computer that even more ventilation is needed. Additional ventilation stages are, thereby, activated.

When hot air that had been near the greenhouse roof is finally removed, only cool air is available to bring down into the plant growing area, adding to the cool air coming through the sidewall vents (which are opened by pressure difference control when the additional ventilation stages are activated.) Ventilation from two directions, and delay times built into the environmental control program, lead to excessive chilling in the plant growing zone and turn off all ventilation. This cycle repeats and, during certain weather conditions, leads to unacceptable temperature oscillations near the plants. A solution is to use motorized louvers for the vent tubes, and this improvement will be part of the design of the next greenhouse module, and will be added to the Cornell module as funds permit.

Screen doors: The two screen doors to the head house were repaired by the facility manager without replacement.

Growth room lamps:

Boiler room exhaust: A 14" diameter propellor fan was obtained from within the Department of Biological and Environmental Engineering. It awaits installation in the wall of the boiler room.

Fertilization valves:

Styrofoam floaters: Final plant spacing for the research and development work at the Kenneth Post greenhouses was approximately 30% closer on a unit areas basis than final plant spacing originally designed for the lettuce module[1]. As designed, plant spacing at the module is 21 plants per 2'x4' floater in a 3 by 7 grid.

The exact spacing used at the Post greenhouses can not be achieved, but it can be approximated by changing to a 4 by 8 grid, or 28 plants per floater. This increases the production capacity of each grow-out pond from 315 heads per day (150 floaters, 21 heads per floater, 10 days in the pond) to 420 heads per day (150 floaters, 28 heads per floater, 10 days in the pond.) The current greenhouse design is for three ponds, thus the analysis in this report is for a daily production of 1260 heads per day. The labor and other production costs below are based on this assumed daily production rate.

Replacement floaters for the facility were cut to size and holes were bored to reduce plant-to-plant spacing to match the spacing that had, historically, been used in the research phase of this work on the Cornell campus. Floaters measure 24" x 48". Plant population per board was increased from 21 (3 rows of 7 each) to 28 (4 rows of 7 each) as shown in the sketch below. Floaters were made from the 1" thick Styrofoam ("blue board") commonly used as sheathing in the construction industry. The previous floaters had been made from the same material and showed adequate strength and robustness.

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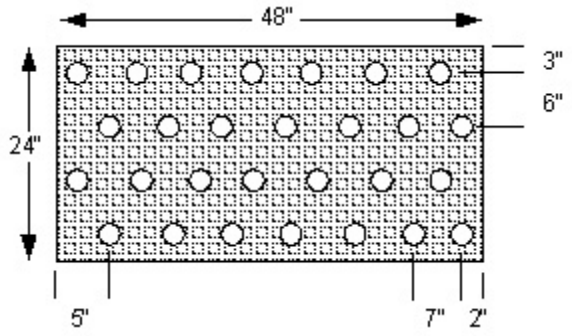
[1] The commercial lettuce demonstration greenhouse located off campus will be termed the lettuce "module".



The asymmetry of the new board requires greater attention when placing in the pond so all are aligned in the same way and plant spacing around the edges is consistent with the centers of the boards. However, this has not been an operational problem. The boards are stacked and aligned prior to having plants placed in them, making alignment automatic at plant respacing time.

Task 3 - Lettuce Module Operation

Management of the lettuce greenhouse was transferred from Agway, Inc. to Cornell on October 1, 2000. Mr. Robert LaDue was hired as greenhouse manager with a starting date of November 1, 2000. Mr. LaDue is a Cornell graduate in agricultural engineering and brought a great deal of experience related to agriculture and closed environment systems to the position. He remains the manager and has been a critical key to bringing the operation of the greenhouse back to the high level of standards that had been expected when the project began.

Increasing production to 1260 heads per day, and using clamshells for packaging, increases labor needs above the two person operation initially assumed (with packaging in plastic bags.) The two person scenario was realistic for that production rate, based on operation of the module for one year by Agway. Experience since, with packaging in clamshell containers, indicates three full-time workers will be required for full production.

If a manager and two full-time workers are assumed, labor costs for this analysis are assumed to be $125,000 per year, including fringe benefits and other associated costs. Note that one or perhaps both full-time workers could be replaced by several part-time workers, but the manager must be full time and the manager must be compensated at a level commensurate with the skills required.

The expenses listed in the table below are based on operation of the module for the past year. Production has not been at 1260 heads per day with clamshell packaging. Thus, some of the costs are extrapolated from current operation. However, many of the costs are not production dependent, or are based on a unit cost independent of how many lettuce heads are produced.

Relatively Fixed Production Expenses	$/day	$/head
Nutrients	$8.22	$0.0065

Oxygen	$2.15	$0.0017
Nutrient Analysis	$3.29	$0.0026
Integrated Pest Management	$3.29	$0.0026
Water	$6.58	$0.0052
Trash removal	$9.86	$0.0078
Snow plowing	$2.74	$0.0022
Misc. supplies	$6.58	$0.0052
Phone/office supplies	$6.58	$0.0052
Property taxes	$35.62	$0.0283
System maintenance	$16.44	$0.0130
Total	$101.35	$0.0805
Variable Production Expenses	$/day	$/head
Rock wool cubes	$75.00	$0.0595
Seed	$22.05	$0.0175
Electricity[2]	$200.00	$0.1587
Natural gas	$116.00	$0.0921
Labor	$340.00	$0.2698
Total	$753.05	$0.5977
Total Cost	$854.40	$0.6781

Marketing the lettuce has been the major problem of the facility, aphids and mildew included. Ithaca is near no major markets and transport to those markets is problematic because of the cost of long distance transport, and the relatively poor road system in the region surrounding Ithaca.

The initial efforts to market the lettuce were through a local produce company, Eddydale Farms. All lettuce was sold as cut heads in bags, the same form as Agway had been selling. The first shipment was December 9, 2000. Most of the lettuce was apparently simply sold through the Philadelphia wholesale market.

A total of 94,656 heads of lettuce were sold through August 8, 2001, to Eddydale Farms. However, the marketing arrangement with them failed when they ceased to reimburse us for the lettuce, and suffered other financial setbacks. Payments actually ceased after March 13, 2001, and were incomplete even for the three months covered by the payments. The accounts receivable for Eddydale was written off as a loss for the CEA program and was a major contributor to the inability to achieve our income target for the life of the project.

[2] Electricity rate based on current full-rate schedule, NYSEG, and includes both use and demand. If operated as a commercial facility, roughly a 20% reduction of the electricity rate would be possible in the NYSEG service territory. Comparable savings can be expected in other service areas.

On July 2, 2001, an arrangement began with another local produce company, Ithaca Produce, to market the lettuce locally and also to the Wegman's supermarket chain through their distribution point in Rochester. Ithaca Produce became the marketing agent and remained our primary outlet through the end of this project. The product was marketed in clamshells with the roots attached rather than as cut heads on the request of Wegman's. This necessitated using different shipping boxes (with 12 heads per box rather than 24) and added considerably to the cost of packaging.

However, due in large part to Ithaca's location (removed from centers of population) the sales have not been near full production capacity.

Task 4 - Commercialization of the CEA Lettuce Production System