Agricultural Assessment Report
For

OSU Greenhouse

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Corvallis, Or. 97331

ENERGY / EFFICIENCY CENTER

OREGON STATE UNIVERSITY
ENERGY/EFFICIENCY CENTER

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PREFACE

The work described in this report is a service of the Oregon State University Energy/Efficiency Center.

The primary objective of the E/EC agricultural assessment is to identify and evaluate opportunities for energy conservation, waste minimization, and productivity improvements through visits to agricultural sites. Data is gathered during a one-day site visit and assessment recommendations (ARs) are identified. Some ARs may require additional engineering design and capital investment. When engineering services are not available in-house, we recommend that a consulting engineering firm be engaged to provide design assistance as needed. In addition, since the site visits by E/EC personnel are brief, they are necessarily limited in scope and a consulting engineering firm could be more thorough.

We believe this report to be a reasonably accurate representation of energy use, waste generation, and production practices, and opportunities in your plant. However, because of the limited scope of our visit, the Oregon State University Energy/Efficiency Center cannot guarantee the accuracy, completeness, or usefulness of the information contained in this report, nor assumes any liability for damages resulting from the use of any information, equipment, method or process disclosed in this report.

Pollution prevention recommendations are not intended to deal with the issue of compliance with applicable environmental regulations. Questions regarding compliance should be addressed to either a reputable consulting engineering firm experienced with environmental regulations or to the appropriate regulatory agency. Clients are encouraged to develop positive working relationships with regulators so that compliance issues can be addressed and resolved.

The assumptions and equations used to arrive at energy, waste, productivity, and cost savings for the recommended ARs are given in the report. We believe the assumptions to be conservative. If you do not agree with our assumptions you may follow the calculation methodologies presented using revised assumptions to develop your own estimates of energy, waste, productivity, and cost savings.

Please feel welcome to contact the E/EC if you would like to discuss the content of this report or if you have another question about energy use or pollution prevention. The E/EC staff that visited your site and prepared this report is listed on the preceding page.

TABLE OF CONTENTS

1. INTRODUCTION

This report describes how energy is used in your plant, and includes our recommendations on cost effective steps you can take to reduce your energy and waste costs and increase productivity. The contents are based on our recent visit to your plant. The report is divided into 6 major sections and 2 appendices:

1. **Introduction.** The purpose, contents and organization of the report are described in this section.

2. **Narrative.** This section contains a description of the processes at your site and efficiency measures we discussed.

3. **Assessment Recommendations.** This section contains our Assessment Recommendations (AR), briefly highlights the current and proposed systems and summarizes the cost savings available upon implementation. Some of our recommendations will require a significant investment to implement, while others will cost little or nothing.

4. **Other Measures Considered.** These measures are just estimations made with limited data or analysis because; (1) we were unable to obtain the information necessary to estimate savings or cost accurately; (2) the measure would adversely affect production. Some measures are included in response to specific questions you raised during the plant visit, but which do not appear to be feasible.

5. **Energy Balance.** Energy use and waste generation costs, productivity, energy, and waste savings are summarized here.

6. **Calculation Methodology.** This section includes the detailed calculations for the Assessment Recommendations (AR). It includes any data that was collected during the audit, assumptions we use to estimate savings, our estimate of the implementation cost and the simple payback of implementation.

Appendix A: Utilities. Your utility bills and energy use by process are summarized and plotted in detail. Due to the changes in rate schedules and adjustments our calculations are an approximation and may not be exactly consistent with your bills. When available, we also include water and solid waste bills.

Appendix B: Lighting. The number and type of lighting fixtures are recorded for each area. This appendix also includes the Lighting Worksheet Definitions, which describe the symbols and terminology used in our lighting calculations. The lighting power and annual energy use for each plant area are summarized in the Lighting Inventory worksheet.

2. NARRATIVE

This section includes a summary of processes and equipment used in your plant and our brainstorm ideas discussed on site.

Processes: Following is a summary of processes that occur in the greenhouses.

- **Irrigation:** Plants are watered by hand.
- **Steam Heating:** Steam from the university steam plant is delivered to greenhouses from about September to June to maintain growing conditions for plants.
- **Air Movement & Cooling:** In hot weather, fans and swamp coolers operate to keep plants from getting too hot.
- **Roof Vents:** Roof vents open to allow hot air to escape.
- **Lighting:** Lights operate to maintain growing conditions even in winter.

Equipment: Following is a list of large equipment and its application

- **Air Compressors:** Used to actuate pneumatic controls for temperature regulation (opening and closing steam valves, opening and closing roof vents)
- **Electronic Temperature Control System:** In one green house, a Wadsworth EnviroSTEP controller performed all the tasks of the air actuated devices. This controller can be set up to turn lights off when sunlight intensity is high and deploy a heat/shade curtain to maintain optimal temperatures/light intensity.
- **Steam Heating:** A system of steam piping delivers heat throughout greenhouse complex. Valves are used to close off portions of the greenhouse not in use.
- **Swamp Coolers:** Numerous coolers per house are used to keep the greenhouse interior cool in hot weather. These coolers function by drawing outside air through a curtain of water using a fan.
- **Swamp Fans:** These special fans circulate air to even out the temperature in the greenhouses. Some fans mist water to further cool the air in hot weather.

Brainstorm Ideas: Following is a list of ideas we considered quantifying and recommending in our report.

- **Drip Irrigation:** Drip irrigation systems throughout greenhouses could apply just enough water to plants, provide researchers better control of watering rates and times and reduce the labor demand for hand watering.

- **Swamp Coolers:** A centralized cooling tower could duct cool air throughout the greenhouse complex instead of the dozens of small coolers between greenhouses.

- **Angle Fans Downward:** Angling fans downward would better mix air vertically.

- **Optimize Lighting:** Although most greenhouses simply leave lights on all day, and turn them off with a timer, some greenhouses have the capability to measure sunlight intensity and turn off lights inside the house when sun lighting levels are sufficient for plant growth. Adding a light sensing capability throughout the facility could reduce lighting costs. Additionally, partitioning lighting would allow lights to be turned off in idle areas.

- **Fix Steam Leaks:** We observed visible steam leaks in unheated areas of the facility. These leaks are costing you and offer no useful function.

- **Insulate Steam Lines:** There is a great deal of un-insulated steam piping, particularly in the steam distribution room and the greenhouse corridors. This piping dissipates a large amount of heat into areas that do not require it.

- **Improve Steam Heat Transfer Using Pipes with Fins:** Heating in the greenhouses currently takes place using rusty, straight steel pipes. Replacing these pipes with stainless steel pipes or pipes with fins could allow them to better radiate heat.

- **Improve Steam Heat Transfer Using Steam Air Handling Units:** Heating in the greenhouses takes place using straight pipes. This is an inefficient heat transfer mechanism that results in a good deal of steam heat energy heating up the concrete walls and glass panes of the greenhouse, not the air that is in contact with the plants. We considered installing steam air handling units to more efficiently transfer steam heat to greenhouse air. We further considered directing condensate lines underneath benches to heat the undersides of the pots in order to maximize heat use.

- **Heat Corridors to Target Temperatures:** Corridors connecting greenhouse wings contain un-insulated steam pipes that dissipate a great deal of heat into the corridors at uncontrollable rates. At times, the corridors overheat, causing roof vents to open in winter. Insulating steam pipes, installing steam air handling units in corridors and controlling their operation with a thermostat to maintain the desired corridor temperature could conserve heat energy and be less costly.

- **Optimize Steam use for Pasteurization:** We observed live steam used to sterilize pots. This periodic operation occurred in a wagon covered with a tarp, from which a great deal of steam escaped. Given that a target temperature of 170° F is sufficient, we suggest a tighter vessel to minimize steam usage while still providing thorough sterilization.

- **Optimize Compressed Air Usage:** We observed that air compressors were operating at high discharge pressures but were subsequently valved down to lower pressures. Running air compressors at lower discharge pressures to match demand pressure would reduce compressor operating energy. Replacing a section of compressed air piping with a larger diameter pipe would eliminate the need for remote “booster” compressors.

- **Replace Air Controls with Electronic Controls:** Currently, most temperature controls use compressed air - a costly, and (according to greenhouse personnel) unreliable control method. Transitioning to electronic controls throughout the greenhouses could offer more reliable and less costly operation.

- **Greenhouse Partitioning:** Partitioning greenhouses can reduce energy usage because it allows unused sections to be closed off, not requiring heating, cooling or lighting. In a research facility like this one, partitioning would also allow for different climactic regimes to be maintained.

- **Glass vs. Polycarbonate vs. Plastic:** We considered the longevity, cost and insulation value of various materials used for greenhouse walls.

- **Charge Based on Bench Area:** Greenhouse personnel told us that greenhouse pricing is currently determined using the floor area of greenhouse labs, even though some labs have more bench space than others. We suggested charging users based on bench space.

- **Discontinue White Washing:** Greenhouse personnel told us that roofs and walls of greenhouses are currently whitewashed in spring to keep temperatures down during hot summer months. This whitewash must be removed in fall using an acid. We discussed moving to Heat/Shade Curtains, as described in the next section, instead of whitewashing to save acid and labor costs.

- **Roll-over Insulating Mats:** Some greenhouses are covered with insulating mats to minimize heat loss during winter nights. Need for such mats would be eliminated with the use of the Heat/Shade Curtains described in the next section.

- **Optimize Temperature Management in Basement of Service House:** We observed that the basement of the Service House was very warm. Personnel told us that the offices above this space were air conditioned in hot weather. In addition to the existing insulation, we suggest installing vent fans to remove heat from that area directly in hot weather. This will allow the air conditioning in the offices to operate more efficiently.

Best Practices: Following is a list of activities we observed that we considered to be efficient or appropriate technologies.

- **Rolling Beds:** In an effort to maximize floor space within individual greenhouses, beds are designed to roll so aisle locations can be changed as needed.

- **Heat/Shade Curtain:** In some cases, instead of whitewashing the exterior of greenhouses each spring and removing that same whitewashing in the fall, you use an automated heat/shade curtain inside the greenhouse to reflect sunshine in hot weather and hold in warm temperatures during cold periods.

- **Steam Metering:** We observed that you were metering steam usage in order to verify steam charges.

Quantified Recommendations Summary: Our recommendations are summarized in the following table.

Assessment Recommendation Summary					
AR#	Description	Energy (MMBtu)	Cost Savings	Implementation Cost*	Payback (years)
1	Insulate Steam Pipes	2,079	$44,914	$6,449	0.1
2	Drip Irrigation	0	$75,440	$40,500	0.5
3	Lighting	66.9	$1,345	$1,131 [1,2]	1.2
4	Air Compressor	2.1	$329	$40	0.1
Totals		**2,148**	**$120,112**	**$48,120**	**0.4**

* *Implementation Cost in this column represents your final cost after any applicable incentives as noted.*
1 *This final cost is reduced by an Oregon Department of Energy Business Energy Tax Credit.*
2 *This final cost is reduced by Energy Trust of Oregon Incentives.*

Total savings are the sum of the savings for each recommendation. Some of the recommendations may interact. Therefore, actual savings may be less than the total indicated above. In our calculations we indicate where we have assumed that other recommendations will be implemented in order to provide a realistic estimate of actual savings. When either one or another recommendation can be implemented, but not both, we have included the recommendation we recommend in this table and the alternate recommendation in a later section, Other Measures Considered. Total savings, including interactions among recommendations, can be better estimated after you select a package of recommendations.

3. ASSESMENT RECCOMENDATIONS

Insulate Steam Pipes

Currently you have 1,074 ft of un-insulated steam pipes of varying diameters. These pipes lead to rooms that require steam heating from October to June. Un-insulated lines are a common contributor to energy losses in heated delivery systems. Heat lost from these lines must be made up by additional steam. Insulate currently un-insulated steam lines with 1.5 inch thick insulation to reduce further energy losses. Insulation of these lines will save energy and improve steam system efficiency. We recommend you install fiberglass or mineral fiber insulation with an all service jacket.

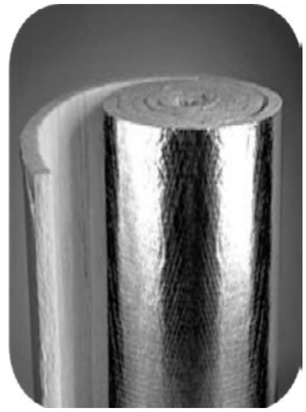


Image courtesy of The Boiler Burner

As detailed in the Insulate Steam Pipes Calculation Methodology, there is a 0.14 year payback with $6,449 implementation cost.

Drip Irrigation

Currently all watering is performed by hand with a hose and wand. Excess water filters though the pots, evaporates off the leaves or misses the plants altogether. Greenhouse personnel estimated that with hand watering only 25% of the total water is used by the plants, but with drip irrigation 75% of the water is used by the plants. More delivered water would be utilized by the plants. Install drip irrigation to replace current hand watering. This will save 67% of the current water use and reduce your monthly water bill.

Image courtesy of Nova Scotia Agriculture and Fisheries

As detailed in the Drip Irrigation Calculation Methodology, there is a 0.5 year payback with a $40,500 implementation cost.

Lighting

Replace 1000 Watt Metal Halide fixtures with 400 Watt Metal Halide fixtures and install Photocells to reduce operating hours. We are modeling this report on Metal Halide fixtures, because of their ability to re-strike quickly allowing Photocell installation. However, High Pressure Sodium fixtures replacements are also included in the tables at the end to show the savings and payback, were you to replace those also. Replacing the current Metal Halide fixtures and installing Photocells will reduce lighting energy use by 49%.

Image courtesy www.hydroempire.com

As detailed in the Lighting Calculation Methodology, there is a 1.2 year payback with a $1,131 implementation cost.

Air Compressor

Reduce pressure: Reduce the pressure in your air system to 27 psi for the highest use load. Currently the air compressor produces 75 Psi air, and it is then reduced down to 17 Psi in several steps for the individual greenhouse temperature control modules. Significant energy is being used to compress the air to 75 Psi is subsequently wasted when the air pressure is reduced. There are several circumstances that can contribute to this pressure drop.


Image courtesy of www.rogers-machinery.com

Replace components: Replace air operated thermostats and valves with electronic thermostats and operators. Use an electronic thermostat (with electronic outputs) that can be sent to a Control Valve (Analog Current or Voltage Input to Pneumatic Output) for Pneumatic steam valve operation. This will eliminate the lowest pressure air load.

Standardize air piping to the greenhouse corridors: This removes piping constrictions to the individual wings, and allows booster compressors removal. Sizing air pipes correctly will allow for the desired air pressure at all the valve operators.

Reduce Air Leaks: Air leaks reductions remove a non-working load on the air system, and reduce the air that has to be compressed to operating pressures.

As detailed in the Air Compressor Calculation Methodology, there is a 0.1 year payback with a $40 implementation cost.

OTHER MEASURES CONSIDERED

Angle Fans

1. It is important to have a fan to circulate air through the foliage of plants, 24 hours a day, every day that you have plants inside your greenhouse. This brings a fresh supply of needed carbon dioxide to the leaves. Air circulation also prevents diseases that like to start in areas of cold and stagnant air. This will also help with condensation inside your greenhouse (better air circulation will result in less condensation) as well as reduce or eliminate hot and cold areas in your greenhouse. Because warm air rises it is best to angle the fans slightly up or down to help pull warm air off the ceiling and push it down to the plants. This is especially important in the winter months, and helps reduce heating costs. This does not appear as a full recommendation because of lack of quantifiable data. Although we know that angling the fans can help reduce heating cost, no case studies could be found quantifying how much savings is available. Angling the fans has a minimal labor cost, so whatever savings are available will payback immediately.

Steam Heating Units

Image courtesy of grainger.com

2. Use a steam heating unit to provide winter heat for the corridors of the west greenhouses. This will be used once the steam pipes are insulated and no longer provide indirect heating to the corridor. Greenhouse facility personnel told us that occasionally, corridors get so hot from heat dissipating from steam lines that automatic roof vents open to keep the heat from becoming excessive, wasting a great deal of steam energy in the process. We were also told that steam lines were not insulated in order to prevent excessive snow accumulation by melting any snow which settled on corridor roofs. Using this type of steam heater allows you to control the temperature inside corridors according to your needs. These heading units are designed to work with low pressure steam and they have an electric fan for air movement. These heating units can be used for individual greenhouse room heat also, if the heat is wanted in the center of the room instead of the outer circumference as it is currently located.

5. ENERGY BALANCE

Energy use, productivity, energy, and waste savings, are summarized here.

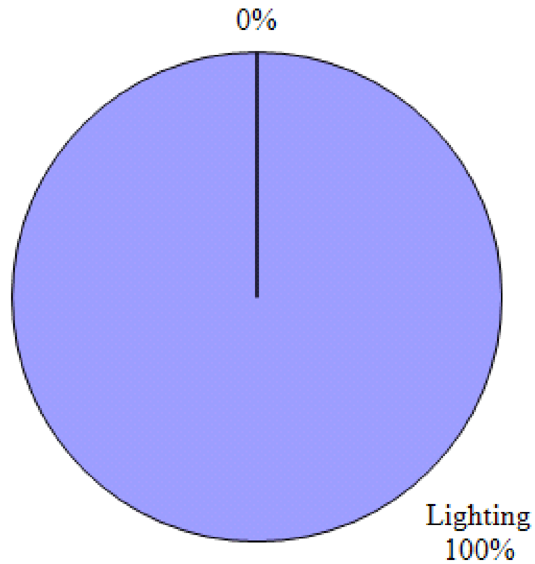
END USE SUMMARY

Average Electricity Cost:	$0.04700	/kWh
Average Natural Gas Cost:	$1.19170	/therm
	$11.92	/MMBtu

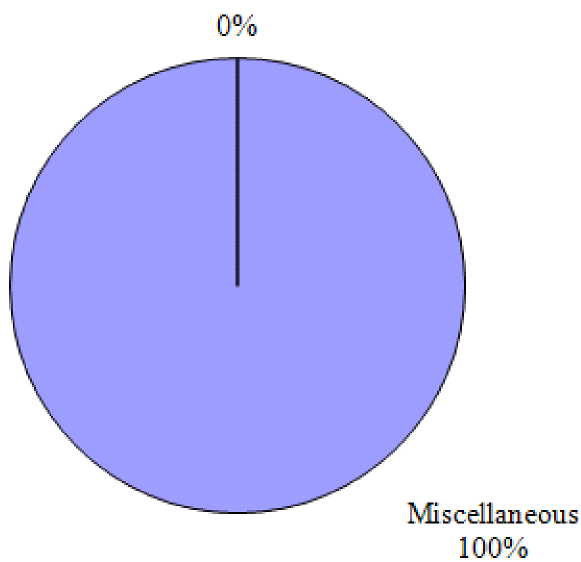
	USE	UNIT	MMBtu	ENERGY %	COST	COST%
ELECTRICITY						
Lighting	516,100	kWh	1,761	100.0%	$24,257	100.0%
NATURAL GAS						
Office Heat	3,577	therm	358	100.0%	$4,263	100.0%
OTHER						
Steam	7,059,000	Lbs	9,471	100.0%	$120,000	100.0%

FUEL SUMMARY	USE	UNIT	MMBtu	ENERGY %	COST	COST%
ELECTRICITY	516,100	kWh	1,761	15.2%	$24,257	16.3%
STEAM	7,059,000	Lbs	9,471	81.7%	$120,000	80.8%
NATURAL GAS	3,577	therm	358	3.1%	$4,263	2.9%
TOTALS			11,590	100.0%	$148,519	100.0%

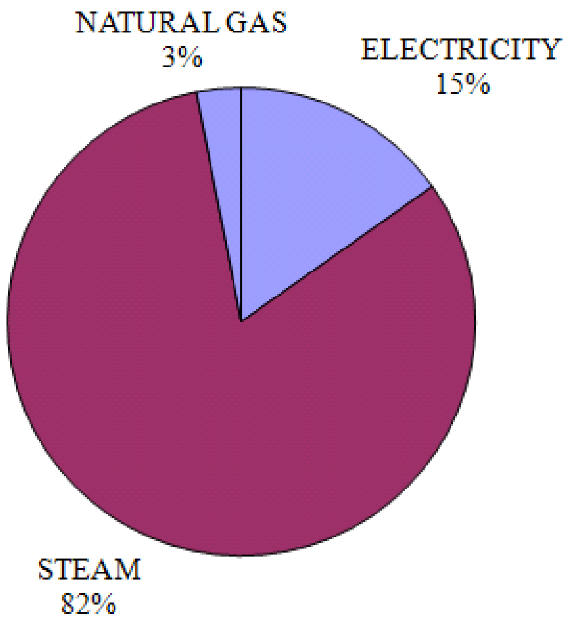
Electricity Use



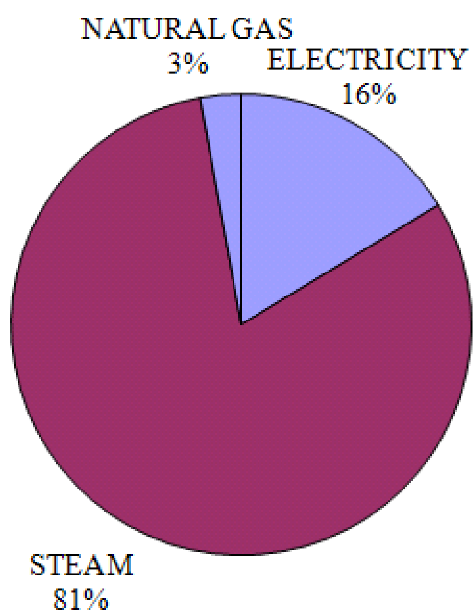
Natural Gas Use



Energy Use



Energy Cost



6. CALCULATION METHODOLOGY

AR No. 1
Insulate Steam Pipes
Calculation Methodology

Recommendation

Insulate all exposed steam pipes to reduce convection and radiation heat losses. Adding the specified insulation will reduce overall heat loss of un-insulated lines by 91%.

Assessment Recommendation Summary				
Energy (MMBtu)	Energy (Therms)*	Cost Savings	Implementation Cost	Payback (years)
2079	20,790	$44,914	$6,449	0.1

** 1 MMBTU = 10 Therms*

Data Collected Summary

The following information was obtained during our visit:

- Process temperature of steam: 213°F
- Operation hours: 6,480 hours (9 months – October to June)
- Geometry Description: Steel Pipe

We estimate the average ambient temperature to be 60°F; this is a conservative number because you are running steam from October to June. Average ambient temperatures would be much lower. Our energy savings and cost savings should be lower than the minimum you can actually save.

The following information was obtained from the current Oregon State Steam Plant:

- $19.50 /1000 lb of steam
- 903 Btu/lb
- Fuel Cost of steam: $21.6/MMBtu (This was calculated with data from OSU's Steam Plant)

An inventory of exposed lengths of pipe was taken during our visit:

Exposed Pipe Characterization	
Pipe Diameter (in)	Exposed Length (ft)
0.5	4
0.75	9
1.0	51
1.25	5
1.5	51
2.0	144
2.5	125
3.0	160
3.5	265
4.0	205
5.0	40
6.0	15

Savings Analysis

Un-insulated lines are a common contributor to energy losses in heated delivery systems. More steam must be used to compensate for the energy loss. Reducing the heat transfer coefficient by adding insulation will yield significant energy and cost savings. Note that the following calculations assume that fluid in the pipes is constantly flowing and thus staying at the same temperature that we observed.

We used 3E plus software, a free insulation calculation tool developed by NAIMA and provided by the U.S.DOE, to compare current and proposed energy uses and energy cost savings for several insulation thicknesses. Cost savings are based on a steam cost of $21.6/MMBtu. We used fiberglass insulation with an all service jacket for our energy savings calculations in 3E plus. The 3.5 inch un-insulated pipe with 1.5 inch insulation calculation is taken as an example:

CS = Cost Saved
= ES × FC × L
= 2.2228 MMBtu/ft/yr × $21.6 /MMBtu × 265 ft
= $12,723

Where,

L = Un-insulated 3.5 inch pipe length
= 265 ft

FC = Fuel Cost of steam
= [1/ (H_S × UC)] × (P_S)
= [1/ (903 Btu/lb × 1 MMBtu/1,000,000 Btu)] × $19.5/1000 lb
= $21.6 /MMBtu

$$ES = EC - EP$$
$$= 2.430 \text{ MMBtu/ft/yr} - 0.2072 \text{ MMBtu/ft/yr}$$
$$= 2.2228 \text{ MMBtu/ft/yr}$$

Where,

EC = Current Energy Loss
= 2.430 MMBtu/ft/yr

EP = Proposed Energy Loss with 1.5 inch insulation
= 0.2072 MMBtu/ft/yr

H_S = Quality of Steam
= 903 Btu /lb

UC = Unit Conversion
= 1 MMBtu/ 1,000,000 Btu

P_S = Price of Steam
= $19.5/ 1000 lb

Total annual cost savings are summarized in the following Savings Summary table:

Savings Summary				
Pipe Diameter	Heat Saved (MMBtu/ft/yr)	Un-insulated Length (ft)	Annual Heat Saved (MMBtu/yr)	Total Cost Saved
0.5	0.280	4	2.014	$44
0.75	0.343	9	5.551	$120
1.0	0.426	51	39.092	$844
1.25	0.532	5	4.792	$103
1.5	0.601	51	55.192	$1,192
2.0	0.744	144	193.349	$4,176
2.5	0.902	125	203.575	$4,397
3.0	1.075	160	309.120	$6,677
3.5	1.235	265	589.042	$12,723
4.0	1.371	205	504.157	$10,890
5.0	1.670	40	120.192	$2,596
6.0	1.972	15	53.300	$1,151
Total			**2,079**	**$44,914**

Cost Analysis

Implementation costs include material costs for the following insulation:

- Insulation Layer 1: Fiberglass
- Outer Jacket Material: All Service Jacket
- Outer Surface Emittance: 0.9

We selected an optimum insulation thickness of 1.5 inches. Implementation costs were obtained from the RSMeans Mechanical Cost Data (2006).

Total implementation costs are summarized in the following Implementation Summary table:

Implementation Summary				
Pipe Diameter	Quantity	Units	$/Unit	Cost
0.5	4	L.F.	$4.12	$16
0.75	9	L.F.	$4.24	$38
1.0	51	L.F.	$4.48	$228
1.25	5	L.F.	$4.77	$24
1.5	51	L.F.	$4.86	$248
2.0	144	L.F.	$5.22	$752
2.5	125	L.F.	$5.54	$693
3.0	160	L.F.	$5.85	$936
3.5	265	L.F.	$6.30	$1,670
4.0	205	L.F.	$6.90	$1,415
5.0	40	L.F.	$7.56	$302
6.0	15	L.F.	$8.51	$128
Total				**$6,449**

Savings will pay for implementation in 0.1 years.

Heat Loss/yr (Btu/ft/yr)												
Insulation Thickness	Pipe Diameter (in)											
	0.5	0.75	1	1.25	1.5	2	2.5	3	3.5	4	5	6
Bare	590,100	717,200	875,500	1,080,000	1,220,000	1,500,000	1,790,000	2,140,000	2,430,000	2,710,000	3,310,000	3,910,000
0.5	152,100	172,600	202,200	251,400	282,600	311,800	363,900	464,300	376,800	553,200	696,900	847,100
1	106,800	128,600	133,500	172,000	174,000	203,500	234,000	277,000	259,200	331,400	413,500	490,800
1.5	86,600	100,400	109,000	121,700	137,800	157,300	161,400	208,000	207,200	250,700	305,200	356,700
2	76,630	87,210	94,290	111,900	109,100	132,400	139,600	173,100	176,100	206,600	247,500	279,500
2.5	66,870	74,780	84,810	98,760	98,720	117,400	124,800	150,900	155,400	178,600	207,800	238,200
3	62,830	69,760	78,420	90,190	91,110	106,800	114,000	135,400	138,800	157,000	184,100	209,800

Heat Saved/yr (MMBtu/ft/yr)												
Insulation Thickness	Pipe Diameter (in)											
	0.5	0.75	1	1.25	1.5	2	2.5	3	3.5	4	5	6
Bare	-	-	-	-	-	-	-	-	-	-	-	-
0.5	0.438	0.545	0.673	0.829	0.937	1.188	1.426	1.676	2.053	2.157	2.613	3.063
1	0.483	0.589	0.742	0.908	1.046	1.297	1.556	1.863	2.171	2.379	2.897	3.419
1.5	0.504	0.617	0.767	0.958	1.082	1.343	1.629	1.932	2.223	2.459	3.005	3.553
2	0.513	0.630	0.781	0.968	1.111	1.368	1.650	1.967	2.254	2.503	3.063	3.631
2.5	0.523	0.642	0.791	0.981	1.121	1.383	1.665	1.989	2.275	2.531	3.102	3.672
3	0.527	0.647	0.797	0.990	1.129	1.393	1.676	2.005	2.291	2.553	3.126	3.700

Cost Saved ($/ft/yr)												
Insulation Thickness	Pipe Diameter (in)											
	0.5	0.75	1	1.25	1.5	2	2.5	3	3.5	4	5	6
Bare	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
0.5	$9.46	$11.76	$14.54	$17.90	$20.25	$25.67	$30.80	$36.20	$44.35	$46.59	$56.44	$66.16
1	$10.44	$12.71	$16.03	$19.61	$22.59	$28.00	$33.61	$40.24	$46.89	$51.38	$62.56	$73.85
1.5	$10.88	$13.32	$16.56	$20.70	$23.38	$29.00	$35.18	$41.73	$48.01	$53.12	$64.90	$76.75
2	$11.09	$13.61	$16.87	$20.91	$24.00	$29.54	$35.65	$42.49	$48.68	$54.07	$66.15	$78.42
2.5	$11.30	$13.88	$17.08	$21.19	$24.22	$29.86	$35.97	$42.96	$49.13	$54.68	$67.01	$79.31
3	$11.39	$13.98	$17.22	$21.38	$24.38	$30.09	$36.20	$43.30	$49.49	$55.14	$67.52	$79.92

Total Cost Saved ($)												
Insulation Thickness	Pipe Diameter (in)											
	0.5	0.75	1	1.25	1.5	2	2.5	3	3.5	4	5	6
Bare	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0.5	$38	$106	$742	$89	$1,033	$3,696	$3,850	$5,791	$11,753	$9,550	$2,258	$992
1	$42	$114	$817	$98	$1,152	$4,033	$4,201	$6,439	$12,426	$10,532	$2,503	$1,108
1.5	**$44**	**$120**	**$844**	**$103**	**$1,192**	**$4,176**	**$4,397**	**$6,677**	**$12,723**	**$10,890**	**$2,596**	**$1,151**
2	$44	$122	$861	$105	$1,224	$4,254	$4,456	$6,798	$12,901	$11,085	$2,646	$1,176
2.5	$45	$125	$871	$106	$1,235	$4,300	$4,496	$6,874	$13,020	$11,209	$2,680	$1,190
3	$46	$126	$878	$107	$1,244	$4,333	$4,525	$6,928	$13,115	$11,305	$2,701	$1,199

AR No. 2
Drip Irrigation
Calculation Methodology

Recommendation

Install a drip irrigation system in the greenhouse labs. This will reduce water usage by 67%.

Assessment Recommendation Summary			
Waste (gal)	Cost Savings	Implementation Cost	Payback (years)
1,408,235	$75,440	$40,500	0.5

Data Collected Summary

Greenhouse personnel provided us with the following data:

- Currently all watering is done by hand using a hose and wand
- Hand watering delivers excess water that filters through pots, evaporates from leaves and misses pots altogether
- Portion of water applied by hand that is useful to the plant: 25%
- Portion of water applied by drip irrigation that is useful to the plant: 75%
- Irrigation water consumption: 2,112,352 gallons/yr

Assumptions:

- Cost of drip irrigations systems per pot: $1.00
- One gallon pots per bench: 162
- Benches per lab: 5
- Labs: 50
- Current time for watering one lab: 30 min/lab/day
- Time to water a lab with drip irrigation: 2 min/lab/day
- Estimated labor cost: $8.50/hr

Savings Analysis

Drip irrigation will place water directly into the container for the plant, where hand watering will spray water all over the plant stem, leaves, the pot surface area and the ground. Drip irrigation will use less water than hand watering, with a higher percentage of the irrigation water being useable by the plants. The volume of water that the plants use does not change, but the amount of excess water is significantly decreased. Annual cost savings are calculated by finding the cost of water saved by installing a drip irrigation system.

CS	=	Cost Savings
	=	WS × WC / UC + LC
	=	1,408,235 gal × \$1.55/CCF ÷ 748 gal/CCF + \$72,520
	=	\$75,440

Where,

UC	=	Unit Conversion
	=	748 gal/CCF
WC	=	Average Incremental Cost of Water
	=	\$1.55/CCF
WS	=	Gallons of Water Saved
	=	T – [(T × 0.25) ÷ (1- 0.25)]
	=	2,112,352 gal – [(2,112,352 gal × 0.25) ÷ (1- 0.25)]
	=	1,408,235 gal
LC	=	Labor Value Saved
	=	CL – PL
	=	\$77,560– \$5,044
	=	\$72,520

Where,

T	=	Current Water Consumption
	=	2,112,352 gal
CL	=	Current Labor Cost for Watering
	=	CT × L × 356 days/yr × (1 hr/60 min) × LC
	=	30 min/lab/day × 50 labs × 365 days/yr × (1 hr/60 min) × \$8.50/hr
	=	\$77,560
PL	=	Proposed Labor Cost for Watering
	=	PT × L × 356 days/yr × (1 hr/60 min) × LC
	=	2 min × 50 labs × 356 days/yr × (1 hr/60 min) × \$8.50/hr
	=	\$5,044

Where,

CT	=	Current Watering Time per Lab
	=	30 min/day
L	=	Number of Labs
	=	50 labs
LC	=	Cost per Hour for Labor
	=	\$8.50/hr

Savings Summary				
Source	Quantity	Units	$/Unit	Total
Water Savings	1,883	CCF	$1.55	$2,918
Labor Savings	8,306.6	Hours	$8.50	$70,606
Total				$73,524

Cost Analysis

The cost of installing drip irrigation is based on the assumption that there are 162 pots per bench, 5 benches per lab, and 50 labs total. We also estimated the cost of drip irrigation equipment to be about $1.00 per pot based on preliminary internet research.

Total implementation costs are summarized in the following Implementation Summary table:

Implementation Summary				
Source	Quantity	Units	$/Unit	Total
Material Costs	40,500	pots	$1.00	$40,500

Savings will pay for implementation in 0.6 years.

Note

The implementation cost and savings assume that every pot is fitted with drip irrigation. Of course, the project can be split into smaller manageable stages of implementation. We assume labor savings on watering the plants will be invested in more productive activity elsewhere in the greenhouse.

AR No. 3
Lighting
Calculation Methodology

Recommendation

Change the 1000 Watt Metal Halide fixtures to 400 Watt Metal Halide fixtures and install Photocells to reduce the operating hours. We are modeling this report on Metal Halide fixtures, because of their ability to re-strike quickly allowing Photocell installation. However, High Pressure Sodium fixtures replacements are also included in the tables at the end to show the savings and payback, were you to replace those also. Replacing the current Metal Halide fixtures and installing Photocells will reduce lighting energy use by 49%.

Assessment Recommendation Summary				
Energy (MMBtu)	Energy (kWh)*	Cost Savings	Implementation Cost**	Payback (years)
66.9	19,628	$1,345	$2,171	2.3

**1 kWh = 3,410 Btu*
***No incentives included*

Estimated Incentive Summary			
ETO[1] Incentive	BETC[2] Tax Credit	Net Cost	Net Payback (years)
$543	$497	$1,131	1.2

[1] *Energy Trust of Oregon Incentive*
[2] *Oregon Department of Energy Business Energy Tax Credit*

Data Collected Summary

We identified potential savings based on a small selection of the many lights in the Greenhouses. The ultimate decision to change light fixtures and bulbs rests on the type and amount of light needed by specific plants to grow effectively in a greenhouse situation. We focused on the commonly used 1000 watt and 400 watt lights throughout the Greenhouse. Some rooms would benefit from having smaller wattage lights and still more would benefit from having fewer fixtures in operation at any one time. The proposed setup would have 6 fixtures and 1 photocell per room.

Savings Analysis

Fixture Replacement

Energy and maintenance cost savings are calculated using the lighting worksheets that follow this calculation summary. Terminology for the lighting worksheet is described in Appendix B.

Energy savings associated with replacing light fixtures and reducing run time are estimated using current power, proposed power and operating hours per year. Energy cost savings are estimated with an incremental energy cost of $0.0470/kWh. All of the calculations are preformed using an excel document.

Savings Summary

Installing lamps with lower power usage and reducing light operating hours will decrease maintenance costs, as calculated in the lighting tables at the end of this calculation methodology. The table below summarizes energy savings from replacing fixtures and installing photocells in one room:

Saving Summary				
Source	Quantity	Units	Energy MMBtu	Cost $
Demand	0.7	kW		$26.00
Energy Use	20,457	kWh	69.8	$961.00
Maintenance Material				$160.68
Maintenance Labor				($9.56)
Total			69.8	$1,138.12

Cost Analysis

The cost to replace metal halide lighting fixtures with integrated photo cells consists of material and installation costs. We estimate labor installation costs at $50 per hour, one hour per sensor installation. The scenario is 5 fixtures and one photocell per room. Implementation costs for fixture replacement are summarized in the following table.

Implementation Cost				
Source	Quantity	Units	$/Unit	Cost
Metal Halide	12	Fixtures	$202	$2,424
Photo Cell	1	Fixtures	$129	$129
Metal Halide	12	Lamps	$80	$960
Electrician Labor	13	hours	$50	$650
Total				**$4,163**

Before incentives, cost savings will pay for implementation costs in 3.7 years.

Incentive Summary

Energy Trust cash incentives are available to help pay for implementation of energy saving measures if they save at least 10% of the energy used in a system. Incentives can be anticipated to equal the minimum of 25% of total project cost, $0.12 per kWh saved, or $1 per therm saved. This is modeled using one room of Metal Halide fixtures.

ETO	=	ETO Cash Incentive			
	=	Minimum of	TES x $0.12	or	0.25 x TC
	=	Minimum of	20,457 kWh x $0.12	or	0.25 x $4,163
	=	Minimum of	$2,455	or	$1,041
	=	$1,041			

Where,

TES	=	Total Energy Savings
	=	20,457 kWh
TC	=	Total Implementation Cost
	=	$4,163

You may also be eligible for the Oregon Business Energy Tax Credit. If a project reduces system energy use by at least 10%, the incentive can be expected to equal 35% of project costs after applying other incentives. However, the tax credit accrues over a 5 year period (10%, 10%, 5%, 5%, and 5%), or over one year for projects with implementation costs of less than $20,000. The Oregon Department of Energy also allows the “pass through” of a onetime lump sum, which is 25.5% of project costs over $20,000 and 30.5% of project costs under $20,000. As this is a reasonable estimate of the net present value of the 35% tax credit, we will use 30.5% as the value of the tax credit in our analysis and estimate of the payback period.

BETC	=	Business Energy Tax Credit
	=	(TC – ETO) x 0.305
	=	($4,163– $1,041) x 0.305
	=	$952

The following table summarizes implementation costs before and after incentives.

Incentive Summary	
Description	Cost
Pre-incentive Cost	**$4,163**
Energy Trust Incentives	($1,041)
Business Energy Tax Credit	($952)
Total after Incentives	**$2,170**

Savings will pay for implementation costs in 1.9 years after incentives.

Note:

The light quality differences between fixtures (florescent, metal halide and high pressure sodium) for plant growing purposes are significant. Both metal halide and high pressure sodium are better for total plant growth. However, T-5 fluorescent lights will provide enough light for the plants to grow, but not the best growth results. Thusly we did not include changing metal halide and high pressure sodium to florescent fixtures. The lighting savings described here for metal halide and high pressure sodium lights will be even greater if those fixtures are changed over to fluorescent T-5 fixtures.

Metal Halide: Replace Fixtures					
PLANT DATA			Report Number:	1000-D	
Building:	1000-D		Incremental Demand Cost:	$3.12	/kW-mo.
Area:	Greenhouse		Incremental Energy Cost:	0.047	/kWh
Lamp Replacement Time:	1/6 hours		Recommended Foot-candles:		
Ballast Replacement Time:	1/2 hours		Maintenance Labor Rate:	$15.00	/hour
Fixture Replacement Time:	1 hours		Electrician Labor Rate:	$50.00	/hour
FIXTURES		Existing	Proposed	Savings	Units
FIXTURE CODE	LB-MH1000		LB-MH400		
Description:		Metal Halide	Metal Halide		
Quantity:		6	12	0	
Operating Hours:		4,160	4,160	0	hours
Output Factor:		100%	100%	0%	
Lamps per Fixture:		1	1	0	
Ballasts per Fixture:		1	1	0	
Fixture Cost:		$0.00	$202.25	($202.25)	
LAMPS					
LAMP CODE		M1000	M400		
Description:		1000 Watt Clear Met. Hal.	400 Watt Clear Met. Hal.		
Quantity:		6	12	(6)	
Life:		12,000	20,000	(8,000)	hours
Lamp Cost:		$145.37	$80.35	$65.02	
Watts per Lamp:		1,000	400	600	watts
Lumens:		72,300	30,000	42,300	
Replacement Fraction:		35%	21%	0	
Annual Lamp Replacement Cost:		$302.37	$200.55	$101.82	
Annual Maintenance Labor Cost:		$5.18	$6.22	($1.04)	
BALLASTS					
BALLAST CODE		M1000	M400		
Description:		1000 watt Metal Halide	400 watt Metal Halide		
Quantity:		6	12	(6)	
Life:		60,000	60,000	0	hours
Ballast Cost:		$168.25	$119.20	$49.05	
Ballast Factor:		100%	100%	0	
Input Watts:		1,080	458	622	watts
Replacement Fraction:		7%	7%	0	
Annual Ballast Replacement Cost:		$69.99	$99.17	($29.18)	
Annual Maintenance Labor Cost:		$10.40	$20.80	($10.40)	
POWER AND ENERGY					
Power:		6.5	5.5	1.0	kW
Energy Use:		27,040	22,880	4,160	kWh
LIGHT LEVEL CHECK					
Total Lumens:		433,800	360,000	73,800	
Foot-candles:		65	54	11	
Lighting Efficiency:		66.9	65.5	1	Lum./W
ANNUAL OPERATING COST					
Demand Cost:		$243	$206	$37.00	
Energy Cost:		$1,271	$1,075	$196.00	
Maintenance Material Cost:		$372	$300	$72.63	
Maintenance Labor Cost:		$16	$27	($11.44)	
Total Operating Cost:		$1,902	$1,608	$294.20	
IMPLEMENTATION COST					
Materials:				$6,300	
Labor:				$1,400	
Total Implementation Cost:				$7,700	
SIMPLE PAYBACK				26.2	years

Metal Halide: Reduce Runtime

PLANT DATA			Report Number:		1000-D	
Building:		1000-D	Incremental Demand Cost:		$3.12	/kW-mo.
Area:		Greenhouse	Incremental Energy Cost:		0.047	/kWh
Lamp Replacement Time:	1/6	hours	Recommended Foot-candles:			
Ballast Replacement Time:	1/2	hours	Maintenance Labor Rate:		$15.00	/hour
Fixture Replacement Time:	1	hours	Electrician Labor Rate:		$50.00	/hour

FIXTURES	Existing	Proposed	Savings	Units
FIXTURE CODE	LB-MH400	LB-MH400		
Description:	Metal Halide	Metal Halide		
Quantity:	12	12	0	
Operating Hours:	4,160	2,745	1,415	hours
Output Factor:	100%	100%	0%	
Lamps per Fixture:	1	1	0	
Ballasts per Fixture:	1	1	0	
Fixture Cost:	$202.25	$202.25	$0.00	
LAMPS				
LAMP CODE	M400	M400		
Description:	400 Watt Clear Met. Hal.	400 Watt Clear Met. Hal.		
Quantity:	12	12	0	
Life:	20,000	20,000	0	hours
Lamp Cost:	$80.35	$80.35	$0.00	
Watts per Lamp:	400	400	0	watts
Lumens:	30,000	30,000	0	
Replacement Fraction:	21%	14%	0	
Annual Lamp Replacement Cost:	$200.55	$132.34	$68.22	
Annual Maintenance Labor Cost:	$6.22	$4.10	$2.11	
BALLASTS				
BALLAST CODE	M400	M400		
Description:	400 watt Metal Halide	400 watt Metal Halide		
Quantity:	12	12	0	
Life:	60,000	60,000	0	hours
Ballast Cost:	$119.20	$119.20	$0.00	
Ballast Factor:	100%	100%	0	
Input Watts:	458	458	0	watts
Replacement Fraction:	7%	5%	0	
Annual Ballast Replacement Cost:	$99.17	$65.44	$33.73	
Annual Maintenance Labor Cost:	$20.80	$13.73	$7.08	
POWER AND ENERGY				
Power:	5.5	5.5	0.0	kW
Energy Use:	22,880	15,098	7,782	kWh
LIGHT LEVEL CHECK				
Total Lumens:	360,000	360,000	0	
Foot-candles:	140	140	0	
Lighting Efficiency:	65.5	65.5	0	Lum./W
ANNUAL OPERATING COST				
Demand Cost:	$206	$206	$0.00	
Energy Cost:	$1,075	$710	$365.00	
Maintenance Material Cost:	$300	$198	$101.95	
Maintenance Labor Cost:	$27	$18	$9.19	
Total Operating Cost:	$1,608	$1,132	$476.14	
IMPLEMENTATION COST				
Materials:			$1,800	
Labor:			$400	
Total Implementation Cost:			$2,200	
SIMPLE PAYBACK			4.6	years

High Press. Sodium: Replace Fixtures						
PLANT DATA			Report Number:	1000-D		
Building:		1000-D	Incremental Demand Cost:		$3.12	/kW-mo.
Area:		Greenhouse	Incremental Energy Cost:		0.047	/kWh
Lamp Replacement Time:	1/6	hours	Recommended Foot-candles:			
Ballast Replacement Time:	1/2	hours	Maintenance Labor Rate:		$15.00	/hour
Fixture Replacement Time:	1	hours	Electrician Labor Rate:		$50.00	/hour

FIXTURES	Existing	Proposed	Savings	Units
FIXTURE CODE	LB-HPS1000	LB-HPS400		
Description:	H.P. Sodium	H.P. Sodium		
Quantity:	6	15	0	
Operating Hours:	4,160	4,160	0	hours
Output Factor:	100%	100%	0%	
Lamps per Fixture:	1	1	0	
Ballasts per Fixture:	1	1	0	
Fixture Cost:	$0.00	$199.00	($199.00)	
LAMPS				
LAMP CODE	S1000	S400		
Description:	1000 Watt H.P. Sodium	400 Watt H.P. Sodium		
Quantity:	6	15	(9)	
Life:	24,000	24,000	0	hours
Lamp Cost:	$87.66	$51.45	$36.21	
Watts per Lamp:	1,000	400	600	watts
Lumens:	126,000	48,600	77,400	
Replacement Fraction:	17%	17%	0	
Annual Lamp Replacement Cost:	$91.17	$133.77	($42.60)	
Annual Maintenance Labor Cost:	$2.59	$6.47	($3.88)	
BALLASTS				
BALLAST CODE	S1000	S400		
Description:	1000 Watt H.P. Sodium	400 Watt H.P. Sodium		
Quantity:	6	15	(9)	
Life:	72,000	72,000	0	hours
Ballast Cost:	$276.50	$197.00	$79.50	
Ballast Factor:	100%	100%	0	
Input Watts:	1,100	457	643	watts
Replacement Fraction:	6%	6%	0	
Annual Ballast Replacement Cost:	$95.85	$170.73	($74.88)	
Annual Maintenance Labor Cost:	$8.67	$21.67	($13.00)	
POWER AND ENERGY				
Power:	6.6	6.9	(0.3)	kW
Energy Use:	27,456	28,704	(1,248)	kWh
LIGHT LEVEL CHECK				
Total Lumens:	756,000	729,000	27,000	
Foot-candles:	65	63	2	
Lighting Efficiency:	114.5	106.3	8	Lum./W
ANNUAL OPERATING COST				
Demand Cost:	$247	$258	($11.00)	
Energy Cost:	$1,290	$1,349	($59.00)	
Maintenance Material Cost:	$187	$305	($117.48)	
Maintenance Labor Cost:	$11	$28	($16.88)	
Total Operating Cost:	$1,735	$1,940	($204.37)	
IMPLEMENTATION COST				
Materials:			$486	
Labor:			$400	
Total Implementation Cost:			$886	
SIMPLE PAYBACK			Negative Savings	years

High Press. Sodium: Reduce Runtime

PLANT DATA			Report Number:	1000-D		
Building:		1000-D	Incremental Demand Cost:		$3.12	/kW-mo.
Area:		Greenhouse	Incremental Energy Cost:		0.047	/kWh
Lamp Replacement Time:	1/6	hours	Recommended Foot-candles:			
Ballast Replacement Time:	1/2	hours	Maintenance Labor Rate:		$15.00	/hour
Fixture Replacement Time:	1	hours	Electrician Labor Rate:		$50.00	/hour

	Existing	Proposed	Savings	Units
FIXTURES	Existing	Proposed	Savings	Units
FIXTURE CODE	LB-HPS400	LB-HPS400		
Description:	H.P. Sodium	H.P. Sodium		
Quantity:	15	15	0	
Operating Hours:	4,160	2,745	1,415	hours
Output Factor:	100%	100%	0%	
Lamps per Fixture:	1	1	0	
Ballasts per Fixture:	1	1	0	
Fixture Cost:	$199.00	$199.00	$0.00	
LAMPS				
LAMP CODE	S400	S400		
Description:	400 Watt H.P. Sodium	400 Watt H.P. Sodium		
Quantity:	15	15	0	
Life:	24,000	24,000	0	hours
Lamp Cost:	$51.45	$51.45	$0.00	
Watts per Lamp:	400	400	0	watts
Lumens:	48,600	48,600	0	
Replacement Fraction:	17%	11%	0	
Annual Lamp Replacement Cost:	$133.77	$88.27	$45.50	
Annual Maintenance Labor Cost:	$6.47	$4.27	$2.20	
BALLASTS				
BALLAST CODE	S400	S400		
Description:	400 Watt H.P. Sodium	400 Watt H.P. Sodium		
Quantity:	15	15	0	
Life:	72,000	72,000	0	hours
Ballast Cost:	$197.00	$197.00	$0.00	
Ballast Factor:	100%	100%	0	
Input Watts:	457	457	0	watts
Replacement Fraction:	6%	4%	0	
Annual Ballast Replacement Cost:	$170.73	$112.66	$58.07	
Annual Maintenance Labor Cost:	$21.67	$14.30	$7.37	
POWER AND ENERGY				
Power:	6.9	6.9	0.0	kW
Energy Use:	28,704	18,941	9,763	kWh
LIGHT LEVEL CHECK				
Total Lumens:	729,000	729,000	0	
Foot-candles:	33	33	0	
Lighting Efficiency:	106.3	106.3	0	Lum./W
ANNUAL OPERATING COST				
Demand Cost:	$258	$258	$0.00	
Energy Cost:	$1,349	$890	$459.00	
Maintenance Material Cost:	$305	$201	$103.58	
Maintenance Labor Cost:	$28	$19	$9.57	
Total Operating Cost:	$1,940	$1,367	$572.15	
IMPLEMENTATION COST				
Materials:			$3,605	
Labor:			$1,750	
Total Implementation Cost:			$5,355	
SIMPLE PAYBACK			9.4	years

AR No. 4
Air Compressor
Calculation Methodology

Recommendation

Reduce the Air Compressor outlet to 35 psi from the current setting of 75 psi. Along with reducing the pressure, you can remove the pressure reducers that are unneeded. Whenever working on the air system, reducing air leaks and unnecessary air uses is also important. Reducing the air compressor outlet will reduce energy use by 20%.

Assessment Recommendation Summary				
Energy (MMBtu)	Energy (kWh)*	Cost Savings	Implementation Cost**	Payback (years)
2.1	7,008	$329	$40.10	0.1

**1 kWh = 3,410 Btu*
***No incentives included*

Data Collected Summary:

Compressor Horsepower: 5 Hp
Recommended Pressure Drop: 40 psi
Conversion Hp to kW: 0.8
Run Time: 2,920 hrs/year

Assumptions:

Energy drop per psi: 1% Hp /2 psi
Load Factor: 75%
Time to Adjust Air Pressure: 0.1 hr
Time to Remove Equipment: 2 hr
Pressure Reducers to Remove: 2
Labor Pay: $10/hr

Savings Analysis:

Savings are due to reducing the compressor output pressure from 75 psi to 35 psi. This allows the compressor to run using less power.

CS	=	Annual Cost Savings
	=	ES x EC
	=	7,008 kWh/year x $0.0470 /kWh
	=	$329
ES	=	Energy Savings
	=	CE – PE
	=	8,760 kWh - 1,752 kWh
	=	7,008 kWh
EC	=	Energy Cost
	=	$0.0470 /kWh

Where,

CE	=	Current Energy Use
	=	LF x HP x EC x AP x CV x RT
	=	75% x 5 Hp x 0.8 kW/Hp x 2,920 hrs/year
	=	8,760 kWh
PE	=	Proposed Energy Use
	=	75% x 1 Hp x 0.8 kW/Hp x 2,920 hrs/year
	=	1,752 kWh

Where,

PH	=	Proposed Hp
	=	5 Hp x 1%/ 2 psi x 40 psi
	=	1 Hp
LF	=	Load Factor
	=	75%
HP	=	Compressor Horsepower
	=	5 Hp
AP	=	Recommended Pressure Drop
	=	40 psi
EC	=	Energy drop per psi
	=	1% Hp /2 psi
CV	=	Conversion Hp to kW
	=	0.8
RT	=	Run Time
	=	2,920 hrs/year

Cost Analysis:

Labor costs include setting the compressor output to 35 psi and removing the superfluous air reducers.

LC	=	Labor Costs
	=	TA + TR x PR x LP
	=	0.1 hr + 2 hr x 2 x $10/hr
	=	$40.10

Where,

TA	=	Time to Adjust Air Pressure
	=	0.1 hr
TR	=	Time to Remove Equipment
	=	2 hr
PR	=	Pressure Reducers to Remove
	=	2
LP	=	Labor Pay
	=	$10/hr

Savings Summary:

The table below summarizes energy savings from reducing the compressor outlet air pressure:

Assessment Recommendation Summary				
Energy (MMBtu)	Energy (kWh)*	Cost Savings	Implementation Cost**	Payback (years)
2.1	7,008	$329	$40.10	0.1

**1 kWh = 3,410 Btu*

***No incentives included*

APPENDIX A

UTILITIES

A.1. Energy Definitions

An essential component of any energy management program is tracking energy. When utility bills are received, we record energy use and cost in a spreadsheet and get the appropriate graphs. A separate spreadsheet may be required for each type of energy used, such as oil, gas, or electricity. A combination might be merited when both gas and oils are used interchangeably in a boiler. In such a case we suggest using a common energy unit for a cost-benefit analysis that can represent most fuel options: the Btu.

We have prepared a utility spreadsheet analysis based on the information provided by you or your utility companies. The worksheets are in section A.3, Energy, Waste, and Production Accounting. They show how energy is used and help identify potential energy savings.

We use specific terminology and calculations in analyzing and discussing your energy, water, and waste expenses. Energy related terms and calculations are detailed below followed by those for waste and water.

Electricity Definitions:

Average Energy Cost. The total amount billed for 12 months of energy, divided by the total number of energy units. Each energy type (oil, gas, electricity, propane, etc.) has its own average energy cost. The average cost per energy unit includes the fees, taxes and unit cost.

$$\text{Average Energy Cost} = (\text{Total Billed \$}) \div (\text{Total Energy Units})$$

Average Load Factor. The ratio of annual electrical energy use divided by the average kilowatts (kW) and the hours in a year.

$$\text{Average Load Factor} = (\text{Total kWh/yr}) \div (\text{Average kW x 8,760 hrs/yr})$$

Average Load Factor expresses how well a given electrical system uses power. A higher load factor yields lower average energy cost.

An example of how load factor applies: A large air compressor has high electric demand for small periods of time and is not a large energy user. It will usually have low load factor and relatively high demand charges. A smaller air compressor that runs for longer periods of time at higher part load efficiency will have higher load factor and lower demand charges.

Basic Charge. The fee a utility company can charge each month to cover their administrative, facility, or other fixed costs. Some companies have higher energy or power rates that compensate for no or low basic charge.

Energy. The time-rate of work expressed in kWh for electric energy. The common unit is million Btu. For a more complete description, see Power.

Energy = Work ÷ Time = (Force x Distance) ÷ Time

Incremental Demand Cost. It is the price charged by your utility company for the capacity to meet your power needs at any given time. Peak demand is the highest demand level required over a set period of time and is calculated by continuously monitoring demand levels. Demand is usually billed based on peak power, but charges such as facility charges and other fees billed per kW are also included in the incremental demand cost. If your utility company has stepped demand cost rates, the step with the greatest demand is considered in the incremental demand cost. If your utility company bills one set rate for all power needs, this value is used as the incremental demand cost.

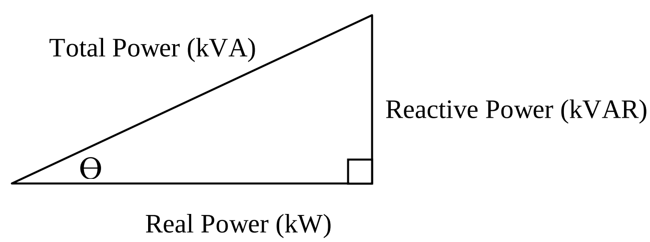
Incremental Energy Cost (Electricity). It is cost of one more unit of energy, from current use. This cost is usually taken from your utility rate schedule. When all large meters are on the same rate schedule, the incremental energy cost is the cost from the highest energy tier, or tail block. To further clarify this method: if a company is charged $0.05/kWh up to 100,000 kWh, and $0.03/kWh over 100,000 kWh and they are consistently buying over 100,000 kWh each month, any energy savings will be calculated using the $0.03/kWh cost.

If your company has multiple meters on different rate schedules or tariffs, the incremental cost is calculated by adding electrical energy costs and dividing by the total electrical energy use.

Incremental Energy Cost = (Total kWh $) ÷ (Total kWh)

Minimum Charge. The least amount billed by a utility at the end of the billing period.

Power (and Energy). The rate at which energy is used, expressed as the amount of energy use per unit time, and commonly measured in units of watts and horsepower. Power is the term used to describe the capacity the utility company must provide to serve its customers. Power is specified three ways: real, reactive and total power. The following triangle gives the relationship between the three.



Real power is the time average of the instantaneous product of voltage and current (watts). Apparent power is the product of rms (root mean square) volts and rms amps (volt-amps).

Demand
The highest electrical power required by the customer, generally averaged over 15 minute cycling intervals for each month. Demand is usually billed by kW unit.

Kilovolt Amperes (kVA)

Kilovolt amperes are a measure of the current available after accounting for power factor. See the triangle on the previous page. Power is sometimes billed by kVA.

Reactive Power

Reactive power is measured in units of kVAR. Reactive power produces magnetic fields in devices such as motors, transformers, and lighting ballasts that allow work to be done and electrical energy to be used. Kilo Volt Amperes Reactive (kVAR) could occur in an electrical circuit where voltage and current flow are not perfectly synchronized. Electric motors and other devices that use coils of wire to produce magnetic fields usually cause this misalignment of three-phase power. Out-of-phase current flow causes more electrical current to flow in the circuit than is required to supply real power. kVAR is a measure of this additional reactive power.

High kVAR can reduce the capacity of lines and transformers to supply kilowatts of real power and therefore cause additional expenses for the electrical service provider. Electric rates may include charges for kVAR that exceed a normal level. These charges allow the supplying utility to recover some of the additional expenses caused by high KVAR conditions, and also encourages customers to correct this problem.

Power Factor

The ratio of real power to total power. Power factor is the cosine of angle θ between total power and real power on the power triangle.

$$PF = \cos\theta = kW \div kVA$$

Disadvantages of Low Power Factor

- Increases costs for suppliers because more current has to be transmitted requiring greater distribution capacity. This higher cost is directly billed to customers who are metered for reactive power.
- Overloads generators, transformers and distribution lines within the plant, resulting in increased voltage drops and power losses. All of which represents waste, inefficiency and wear on electrical equipment.
- Reduces available capacity of transformers, circuit breakers and cables, whose capacity depends on the total current. Available capacity falls linearly as the power factor decreases.

Low Power Factor Charges

Most utilities penalize customers whose power factor is below a set level, typically in the range of 95% - 97%, or kVAR greater than 40% of kW. Improving power factor may reduce both energy and power costs, however these are generally much less than savings from real power penalties enforced by electrical utilities. Energy savings are also difficult to quantify. Therefore in our recommendations, only power factor penalty avoidance savings are included.

Improving Power Factor

The most practical and economical power factor improvement device is the capacitor. All inductive loads produce inductive reactive power current (lags voltage by a phase angle of 90°). Capacitors, on the other hand, produce capacitive reactive power, which is the opposite of inductive reactive power (current leads…). Current peak occurs before voltage by a phase angle of 90°. By careful selection of capacitance required, it is possible to totally cancel out the inductive reactive power, but in practice it is seldom feasible to correct beyond your utilities' penalty level (~95% for kVA meters).

Improving power factor results in:

- Reduced utility penalty charges.
- Improved plant efficiency.
- Additional equipment on the same line.
- Reduced overloading of cables, transformers, and switchgear.
- Improved voltage regulation due to reduced line voltage drops and improved starting torque of motors.

Power Factor Penalty

Utility companies generally calculate monthly power factor two ways. One way is based on meters of reactive energy and real energy.

$$\text{Monthly PF} = \cos\left[\tan^{-1}(\text{kVARh} \div \text{kWh})\right]$$

The second method is based on reactive power and real power.

$$\text{Monthly PF} = \cos\left[\tan^{-1}(\text{kVAR} \div \text{kW})\right]$$

Power Factor is often abbreviated as "PF". Also see the Power Factor definition below.

Cost Calculations

Annual operating expenses include both demand and energy costs. Demand cost (DC) is calculated as the highest peak demand (D) multiplied by your incremental demand charge and the number of operating months per year:

$$DC = D \times \text{demand rate } (\$/\text{kW}\cdot\text{mo}) \times 12 \text{ mo/yr}$$

Energy cost (EC) is energy multiplied by your incremental electric rate:

$$EC = E \times \text{energy rate } (\$/\text{kWh})$$

Natural Gas Definitions:

Rate Schedules. (Or tariffs) specify billing procedures and set forth costs for each service offered. The state public utility commission approves public utility tariffs. For example: an electric utility company will set a price or schedule of prices for power and energy and specify basic and PF charges. A natural gas utility will specify cost to supply or transport gas and include costs such as price per therm, basic charge, minimum charges and other costs. Current rate schedules can often be found online at the utility company's website. If you think your company belongs in a different rate schedule, your utility representative can help you best.

Tariff. Another term for *rate schedule*.

Therm. The unit generally used for natural gas (1 therm = 100,000 Btu), but sometimes it is measured in 10^6 Btu.

Commodity Rate. The component of the billing rate that represents the company's annual weighted average commodity cost of natural gas.

Transportation. The movement of customer-owned natural gas from the pipeline receipt point(s)

Waste and Water Definitions:

Average Disposal Cost. The average cost per pickup or ton of waste or other scrap material. This cost is calculated using all of the annual expenses to get a representative cost per unit of disposal.

Average Disposal Cost / Ton = (Total Disposal $) ÷ (Total tons removed)

Average Disposal Cost / Pickup = (Total Disposal $) ÷ (Total number of pickups)

BOD Charge. Charge levied by the sewer/water treatment utility to cover extra costs for high strength wastewater. High strength wastewater requires more intensive treatment by the utility and extra processing due to very low oxygen levels. BOD, biochemical oxygen demand, is a measure of how much oxygen will be used to microbiologically degrade the organic matter in the wastewater stream. State agencies such as a Department of Environmental Quality set BOD and other regulations that wastewater treatment facilities must meet to discharge treated water into nearby waterways. Your treatment facility may have ideas that could help lower the strength of your wastewater.

Box Rental Charge. The fee imposed by the waste or recycling utility to cover costs of their receiving containers.

Disposal Cost. Incurred by the waste utility for disposing of your waste in a landfill or other facility. These charges increase when hazardous materials are present in the waste.

Pickup Costs. The cost charged by the waste utility for each pickup of waste or recycling. This charge is usually applied when the utility is working on an "on call" basis. Pickup costs can also be a flat rate for a certain number of pickups per month.

A.2. Energy Conversions

An essential component of any energy management program is a continuing account of energy use and its cost. This can be done best by keeping up-to-date graphs of energy consumption and costs on a monthly basis. When utility bills are received, we recommend that energy use be immediately plotted on a graph. A separate graph will be required for each type of energy used, such as oil, gas, or electricity. A combination will be necessary, for example, when both gas and oil are used interchangeably in a boiler. A single energy unit should be used to express the heating values of the various fuel sources so that a meaningful comparison of fuel types and fuel combinations can be made. The energy unit used in this report is the Btu, British Thermal Unit, or million Btu's (10^6 Btu). The Btu conversion factors and other common nomenclature are:

Energy Unit	Energy Equivalent	
1 kWh	3,413	Btu
1 MWh	3,413,000	Btu
1 cubic foot of natural gas	1,030	Btu
1 gallon of No. 2 oil (diesel)	140,000	Btu
1 gallon of No. 6 oil	152,000	Btu
1 gallon of gasoline	128,000	Btu
1 gallon of propane	91,600	Btu
1 pound of dry wood	8,600	Btu
1 bone dry ton of wood (BDT)	17,200,000	Btu
1 unit of wood sawdust (2,244 dry pounds)	19,300,000	Btu
1 unit of wood shavings (1,395 dry pounds)	12,000,000	Btu
1 unit of hogged wood fuel (2,047 dry pounds)	17,600,000	Btu
1 ton of coal	28,000,000	Btu
1 MWh	1,000	kWh
1 therm	100,000	Btu
1 MMBtu	1,000,000	Btu
1 10^6Btu	1,000,000	Btu
1 kilowatt	3,413	Btu/hr
1 horsepower (electric)	2,546	Btu/hr
1 horsepower (boiler)	33,478	Btu/hr
1 ton of refrigeration	12,000	Btu/hr

Unit Equivalent		
1 gallon of water	8.33	pounds
1 cubic foot of water	7.48	gallons
1 kgal	1,000	gallons
1 unit wood fuel	200	ft^3

The value of graphs can best be understood by examining those plotted for your company in the Energy Summary. Energy use and costs are presented in the following tables and graphs. From these figures, trends and irregularities in energy usage and costs can be detected and the relative merits of energy conservation can be assessed.

APPENDIX B

LIGHTING

B.1 Lighting Worksheet Definitions

The following lighting inventory and any lighting worksheets contained in the report use information obtained during the on-site visit to determine any potential energy savings related to lighting improvements. In all cases the value in the Savings column is the existing value less the proposed value. The terminology and calculations are described as follows:

PLANT

Building. A description of the building if the plant includes several buildings.

Area: The lighting calculations may refer to a specific location within the building.

Recommended Footcandles. The recommended footcandle levels come from the Illuminating Engineering Society (IES) Lighting Handbook.

Average Demand Cost (D$). The demand cost ($/kW-month) is taken from the appropriate rate schedule of your utility. Winter and summer rates are averaged, if necessary.

Average Energy Cost (E$). The energy cost ($/kWh) is taken from the appropriate rate schedule of your utility for the least expensive energy block. Winter and summer rates are averaged, if necessary.

Labor Cost ($/H). The cost of labor is estimated for operating and installation cost calculations.

FIXTURES

Description (FID). Fixture type, size, manufacturer, or catalog number may be included here.

Quantity (F#). The number of fixtures in the area are recorded during the site visit.

Operating Hours (H). The number of hours which the lighting fixtures operate each year.

Use Factor (UF). The fraction of fixtures that are used multiplied by the fraction of operating hours (H) that the lights are on.

Lamps/Fixture (L/F). The number of lamps in each fixture.

Ballasts/Fixture (B/F). The number of ballasts in each discharge fixture.

Cost (FC). The cost of the existing and proposed fixtures can be compared when modifying or replacing fixtures.

LAMPS

Description (LID). Lamp type, size, manufacturer, or catalog number may be included here.

Quantity (L#). The number of lamps can be calculated from the number of fixtures and the number of lamps per fixture:

$$L\# = F\# \times L/F$$

Life (LL). Lamp life is defined as the number of operating hours after which half the original lamps will fail. The life recorded here is based on 3 operating hours per start. This provides a more conservative estimate of lamp life than using longer hours per start.

Replacement Fraction (Lf). The fraction of lamps that normally can be expected to burn out during a year can be calculated from the operating hours, the use factor, and the lamp life:

$$Lf = H \times UF / LL$$

Watts / Lamp (W/L). The rated lamp power does not include any ballast power, which is included in the Ballasts section.

Lumens (LM). Lamp output is measured in lumens. Lumens are averaged over lamp life because lamp output decreases with time.

Cost (C/L). The retail cost per lamp is entered here.

BALLASTS

This section applies only to discharge lamps with ballasts. This section will be blank for incandescent lamps.

Description (BID). Additional information such as type, size, manufacturer, or catalog number may be included here.

Quantity (B#). The number of ballasts can be calculated from the number of fixtures and the number of ballasts per fixture:

$$B\# = F\# \times B/F$$

Life (BL). Ballast life is determined from manufacturer's data. A life of 87,600 hours for a standard ballast and 131,400 hours for an efficient ballast is used in the calculations.

Replacement Fraction (Bf). The fraction of ballasts normally expected to burn out during a year can be calculated from the operating hours, the use factor, and the ballast life:

$$Bf = H \times UF / BL$$

Input Watts (IW). Ballast catalogs specify ballast input watts that include lamp power. The input wattage varies for different combinations of lamps and ballasts.

Cost (BC). The retail ballast cost is entered here.

POWER AND ENERGY

Total Power (P). For incandescent lamps total power is the product of the number of lamps and the watts per lamp.

$$P = L\# \times W/L \qquad \text{(Incandescent Lamps)}$$

For discharge lamps total power is the product of the ballast input watts and the number of ballasts:

$$P = B\# \times IW \qquad \text{(Discharge Lamps)}$$

Energy Use (E). The annual energy use is the product of the total power, the use factor, and the annual operating hours:

$$E = P \times UF \times H / (1{,}000 \text{ watts/kilowatt})$$

LIGHT LEVEL CHECK

Total Lumens (TLM). The existing and proposed lumen levels are summed for all lamps.

$$TLM = L\# \times LM$$

Footcandles (FC). Light is measured in units of footcandles. The existing footcandle level (FC0) is measured, while the proposed level (FC1) is determined from the ratio of the proposed total lumens (TLM1) to existing total lumens (TLM0) times the existing footcandle level.

$$FC1 = FC0 \times (TLM1 / TLM0)$$

The proposed footcandle level can then be compared to both the existing and the recommended levels to determine if there will be adequate light for the work space.

Lumens / Watt (LM/W). The total lamp output in lumens divided by the total power is a measure of lighting efficiency.

$$LM/W = TLM / P$$

ANNUAL OPERATING COST

Power Cost (PC). The annual demand cost is the total power times the average monthly demand cost from the worksheet times 12 months per year:

$$PC = P \times D\$ \times 12 \text{ months/year}$$

Energy Cost (EC). The annual energy cost is the energy use times the electricity cost from your utility rate schedule:

$$EC = E \times E\$$$

Lamp O&M Cost (LOM). Operation and maintenance costs are the sum of lamp and labor costs for replacing the fraction of lamps (L# x Lf) that burn out each year.

$$LOM = L\# \times Lf \times [LC + (0.166 \text{ hours} \times \$/H)]$$

We assume that two people can replace a lamp and clean the fixture and lens in about five minutes (0.166 man-hours/lamp), replacing lamps as they burn out.

Ballast O&M Cost (BOM). Operation and maintenance costs are the sum of ballast (BC) and labor costs ($/H) for replacing the fraction of ballasts (B# x Bf) that burn out each year.

$$BOM = B\# \times Bf \times [BC + (0.5 \text{ hours} \times \$/H)]$$

We assume that one person can replace a ballast in about thirty minutes (0.5 man-hours/ballast), replacing ballasts as they burn out.

Total Operating Cost (OC). The sum of the annual power and energy costs and lamp and ballast O&M costs.

$$OC = PC + EC + LOM + BOM$$

IMPLEMENTATION COST

The implementation costs depend on whether refixturing, group relamping, or spot replacing of lamps and ballasts is recommended.

Refixturing

Materials: The cost is the cost per fixture (C/F) times the number of fixtures (F#) plus the lamp cost (LC) times the number of lamps (L#).

$$M\$ = F\# \times (C/F) + L\# \times C/L$$

Labor: The labor cost includes the removal of the existing fixtures and the installation of the recommended fixtures.

Group Relamping

Materials: When replacing all lamps at one time (group relamping), the cost of materials can be found from

M$ = L# x C/L

Labor: We estimate the labor cost for group relamping to be one half the cost of replacing each lamp as it burns out. We assume that two people can replace two lamps and clean the fixture and lens in about 5 minutes (0.083 man-hours/lamp, H/L). Because relamping does not require a licensed electrician, the labor rate for relamping is often lower than the labor rate for fixture replacement. To calculate the total labor cost for group lamp replacement we calculate the labor cost of group replacing all of the lamps.

L$GROUP = L# x H/L x $/H

Spot Replacement of Lamps & Ballasts

Materials: When replacing lamps only as they burn out (spot relamping), we use the cost difference (LC1 - LC0) between standard and energy-efficient lamps for all lamps.

M$ = L# x (LC1 - LC0)

When replacing ballasts only as they burn out (spot reballasting), we use the cost difference (BC1 - BC0) between standard and energy-efficient ballasts for all ballasts.

M$ = B# x (BC1 - BC0)

Labor: There is no additional labor cost.

Total Cost (IC). Total implementation cost is the sum of materials and labor cost

IC = M$ + L$

SIMPLE PAYBACK.

The simple payback (SP) is calculated on each lighting worksheet.

SP = IC / OC

Appendix C

Greenhouse Water Savings per Room

This Appendix outlines savings that can be realized by implementing watering changes in each room. The implementation cost to install drip irrigation in every room is significant. Given that the rooms are run by different groups, implementing drip irrigation room by room may be a better option.

Savings Summary Per Lab				
Source	Quantity	Units	$/Unit	Total
Water Savings	37.7	CCF	$1.55	$58
Labor Savings	166	Hours	$8.50	$1,411
Total Savings				$1,469

Drip Irrigation Summary Per Lab			
Waste (gal)	Cost Savings	Implementation Cost	Payback (years)
28,164.7	$1,469	$810	0.6