Division of Marketing
Agricultural Development and Diversification (ADD) Program

1996 Grant Final Report

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Wisconsin Department of Agriculture, Trade and Consumer Protection
Agriculture Development and Diversification Program
Eighth Round Grants For
1996 Grant Projects

Solar Cold Climate Greenhouse Technology

Final Report

REA Farm
and
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Roald Gundersen Design

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The following work is dedicated to and in large part inspired by the great American family farmer who is intimately connected to the earth, the sun and the cycles of the seasons. May Solar Greenhouses empower you and become your "new barn". And to the related farming tradition of American Pragmatism which is a wellspring of creativity in developing ways of living better and more sustainably for the generations to follow. I would like to thank the citizens of Wisconsin and the ADD Grant administrators for this grant entrusting me to pursue an effort which will, I hope, be for everyone's benefit.

Introduction:

A broad brush must first be applied to understand the goals of this endeavor: I built my first solar greenhouse or SCCG 1 in 1992. The theme then was single-mindedly energy; how little fuel could you use to grow crops year-round in cold climates? The answer is zero auxiliary fuel to grow even tomatoes. But with that astonishing result came more detailed questions of economic feasibility and an exciting web of possibilities for integrating SCCGs into the family farm. What has become clear is that the single-minded application of this technology will not utilize it to the best of its ability and hence economy. This is especially true with historically low fuel prices. Analogous with automobiles, their are primary uses for them, such as commuting, but they can perform many other functions which contribute substantially to their utility and worth. An example of this is an solar greenhouse I designed and built this summer, near Duluth, MN, which replaces a $10,000 septic system. Its cost was under $10,000 and the owner has a year-round garden to boot! The doubling of SCCGs as septic systems may make their initial cost immanently affordable. This winter I will finally hook my SCCG up to my home to provide heat for in-floor heating and hot water preheating (it already functions as an experimental gray water system).

While these and other uses of SCCG technology are not the primary use here, they should be taken together to receive an accurate accounting of their value. Unfortunately this accounting is beyond the scope of this grant. I had designed the goals of SCCG 2 along the lines of a Volkswagen Beetle; a basic low cost shell with basic growing features for the do-it-yourself farmer. Its not as fuel efficient as SCCG 1, but 70-80% more efficient than conventional greenhouses. I have accomplished these goals with SCCG 2. Over the course of the last couple of years I have designed a range of SCCG models for a range of crops and applications. Thanks in part to the use of this "VW "as a test model and for marketing, I have designed over 16 different variations on a theme of SCCGs all for client's customized applications. The following are the stated goals of this grant:

Grant Goals:

The following six goals were outlined in my grant applications "Statement of Objectives":

1) To design, and construct a low-cost ($10/sq. ft.) 2000 sq. ft. commercial prototype at REA Farm : The final SCCG we built with ADD grant assistance is over 2800 sq. ft. for a total cost of just over $26,721.02. This includes 3% design costs for my architectural services for a total accounting of "turn-key" costs. This comes to $9.54 per sq. ft. This is below my goal of $10 per sq. ft. which my market research indicated was low enough for broad market acceptance. Since this design had never been built before and we used many innovative construction techniques there is room for improvement. If we were to build the same one again we could get costs below $8.00/sq. ft. in labor efficiencies alone. Add in design improvements resulting in additional material and labor reductions and costs could well drop below $7.00/sq.ft. Even lower cost designs, one of which I will build in 1999 at REA Farm, are estimated to cost between $3.00 and $5.00/sq. ft. turn-key costs. These costs are comparable to that of low cost hoop houses, which are not permanent structures and which require substantial heating and plastic replacement every couple years. I have also accomplished SCCGs using conventional materials for costs between $15-20 per sq. ft.

2) Record all construction costs for economic feasibility analysis: The enclosed "SCCG 2 Construction Cost" spread sheet itemizes construction costs for materials and labor both grant supported and in-kind contributions. I have provided totals for materials

SCCG 2 Construction Cost

		Materials & Equip.		Labor Costs			
	Item	Grant	In-Kind	Grant	In-Kind	Totals	% of total
1	Staking Site	21.86			48.00		
2	Excavating: Bulldozer	400.00					
3	Backfill: Bobcat	800.00		260.00	323.00		
4	Gravel	412.50					
5	Survey	40.00	40.00				
6	**Total Site Work:**	1674.36	40.00	260.00	371.00	2345.36	9.04
7	Concrete	223.23		75.00	48.00		
8	Mesh and Tie Wire	32.96		148.00	96.00		
9	Anchor Bolts & Hrdw.	28.72		49.00	12.00		
10	Concrete Block	234.00		36.00	46.00		
11	Treated Wood & Hrdw	139.97		77.00	112.00		
12	Duct Tape	7.10		26.00	48.00		
13	Corrugated Tubing	94.33		26.00	33.00		
14	Rigid Extruded Poly Insul.		572.57	73.00	24.00		
15	**Total Foundation Costs:**	760.31	572.57	510.00	419.00	2261.88	8.72
16	Hardware	207.28	58.99				
17	Framing Wood	324.35	278.23	2080.00	1773.00		
18	**Total Framing Costs:**	531.63	337.22	2080.00	1773.00	4721.85	18.20
19	Straw Bales for Roof Insul.	520.00		366.00	360.00		
20	Hardware: wire staples etc.	28.78	41.33				
21	Wound Wire		98.00	260.00	120.00		
22	**Total Roof Insulation**	548.78	139.33	626.00	480.00	1794.11	6.92
23	Plastic Vapor Barrier	99.65		269.00	112.00		
24	Metal Roofing	1201.84	549.12	504.00	785.00		
25	Metal Ceiling & End Walls	700.56		1013.00	640.00		
26	Polycarbonate Glazing		1050.72	235.00	96.00		
27	Tempered Glazing and Tape		2311.25	372.00	360.00		
28	Window Mullions, Mtl. Trim	310.51	58.05	621.00	480.00		
29	Double Doors	622.36			192.00		
30	Roofing Screws, Staples, Etc.		27.74				
31	**Total Roofing & Glazing**	2934.92	3996.88	3014.00	2665.00	12610.80	48.61
32	Misc. Construction Tools		296.24			296.24	1.14
33	Electrical Equip. & Supplies	712.50	37.50				
34	Mech. Equip. & Supplies	787.50					
35	Plumbing Equip. & Supplies		375.00				
36	**Total Equipment Costs**	1500.00	412.50			1912.50	7.37
37	**Total Costs**	7950.00	5794.74	6490.00	5708.00	25942.74	100.00
38	% of Total Costs	30.65	22.33	25.01	22.01	100.00	

and labor and phases of construction. The total cost came in at $25,942.74. Total material costs were around 53% of total costs. Labor costs were 47% of total costs. Almost half the costs (48.61%) was in windows, doors, roofing, interior ceiling and vapor barrier. Two major cost reductions could come by eliminating the metal ceiling, at a cost of over $2000, in favor of a high grade white reflective vapor barrier (Tu-Tuff). I could also replace the wood cross strap with an aircraft cable and turn buckle for a net estimated cost reduction of over $800. Even without these savings I came in under our goal of $10/sq.ft. shell costs.

The project took roughly 1500 working hours or twelve and a half full time weeks for three people. This considers that I hired two unskilled contract laborers at $6.50/hr. which I thought would be the worst case scenario of available labor. They required significant training and supervision which slowed our efforts substantially. I billed my time as in-kind at $12.00/hr. Although I'm an architect, I have built only several structures and have only basic carpentry tools. I'm not as fast or skilled as most full time carpenters. Hiring skilled carpenters would have been an option as my clients have done on solar greenhouses using conventional material. However, the innovative use of on-site materials for this project, such as black locust pole framing and straw bale insulation, discouraged most carpenters from participating on more than a workshop basis. I have been cultivating a group of carpenters who I've trained in the construction of SCCGs using conventional materials. and who have participated in the construction of other SCCGs. SCCG 2 should be able to be built by two skilled carpenters in twelve weeks for a comparable labor cost..

The Cost Benefit Analysis (see SCCG 2 Spread Sheet) has a total SCCG 2 cost of $26,721 which includes 3% for design costs. For annual production costs I logged an average of ten hour a week which I billed for $10 per hour totaling $5200. I had very low additional production costs of $830 for a total of $6030. I subtracted this from the averaged production cost of $14,129.53 for a net annual profit of $8,099.53. If this profit is maintained SCCG 2 would be paid for in 3.3 years. When interest payments are included on a loan the payback will be in the range of four to five years.

3) Select and grow a representative sampling of high-end crops through four seasons: The enclosed "Crop Production SCCG 2" spread sheet shows thirteen crops. The first column shows the production in pounds per square foot per year. The second figure is a wholesale prices per pound of produce. The third column extrapolates a crop's test plot's production for the whole 1700 sq. ft. of growing space in SCCG 2. The fourth column is the crop production per square foot of growing space, and the fifth column is the crop production for the gross area of the SCCG 2 greenhouse. I've then averaged all crops for each column. The gross production per square foot of $7.06 is in line with the $7.00/ sq. ft. of commercial greenhouse operations. This is remarkable considering the small size of this operation (less than 10% of the average greenhouse size) and the economies of scale. Greens, like Mustards, Arugula, Spinach, and Lettuce, performed best with hot weather crops such as tomatoes, and basil performing least well. Its also remarkable because of my relative inexperience at greenhouse management and the very low expenditures on fuels and growing supplies, less than a tenth that of conventional operations. I have run the greenhouse for organic ready to eat crops. I have used integrated pest management techniques and organic fertilizers.

Still I've have had a mixed bag of results over the last two years on the growing end mostly due to human factors. The surprisingly encouraging results can only improve from here. My former wife, who was to play a key role as grower, left the project early on. I solicited additional grower help with only two seasons with the assistance of a part time grower's attention. The hours spent gardening averaged ten hours per week. Having started my own office at 40-60 hrs. a week and constructing other projects out of town, I have had my share of fried crops and disappointments. However most crops have done surprisingly well - considering their gardener's negligence. I attribute this to

	Solar Cold Climate Greenhouse 2			
	Cost Benefit Analysis			
Construction Costs:				
Item:	Description:			
1	Site Work	$2,345.36		
2	Foundation Costs	$2,261.88		
3	Framing Costs	$4,721.85		
4	Roof Insulation	$1,794.11		
	Roofing & Glazing	$12,610.80		
5	Construction Tools	$296.24		
6	Equipment Costs	$1,912.50		
7	Design Cost (~3% of const. costs)	$778.28		
8	Total of all Construction Costs	$26,721.02		
Annual Production Costs				
9	Growing Equip.	$100.00		
10	Irrigation Equip.	$100.00		
11	Seeds	$350.00		
12	Integrated Pest Management	$80.00		
13	Potting Soil, Misc. Other	$200.00		
14	Labor: 10 hr./week x $10/hr.	$5,200.00		
15	Total Production Costs	$6,030.00		
Annual Crop Production				
16	SCCG 2 Averaged Gross Production	$14,129.53		
17	Production Costs	(-)$6,030.00		
18	Net Annual Profit	$8,099.53		
Pay Back:				
17	Without Loan	3.3 yrs.		
18	With Loan (estimate)	4 to 5 yrs.		
Annual Other Benefits:				
19	Home Space Heating	$500.00		
20	Home Domestic Hot Water Preheat	$200.00		
21	Domestic Gray Water	?		
22	Domestic Septic System	?		
23	Deferred Day Care	?		
24	Deferred Transportation	?		
25	Other	?		
26	Total Intangible Benefits	?		
27	Payback w/Intangibles	?		

	Crop	lds./sq. ft./yr.	Price/ lb.	$/1700 sq. ft./yr.	$/1700 sq. ft./yr.	$/2000 sq.ft./yr.
1	Arugula	2.90	$3.00	$14,790.00	$8.70	$7.39
2	Basil	1.20	$6.00	$12,240.00	$7.20	$6.12
3	Bell Pepper	3.05	$2.50	$12,962.50	$7.62	$6.48
4	Greek Oregano	1.24	$6.00	$12,648.00	$7.44	$6.32
5	Green Leaf Lett	3.85	$2.00	$13,090.00	$7.70	$6.54
6	Mizuna	2.75	$3.50	$16,362.50	$9.62	$8.18
7	Mustard	3.65	$3.00	$18,615.00	$10.95	$9.30
8	Sage	1.11	$6.00	$11,322.00	$6.66	$5.66
9	Spinach	3.00	$3.00	$15,300.00	$9.00	$7.65
10	Sugar Peas	2.50	$3.00	$12,750.00	$7.50	$6.37
11	Swiss Chard	3.25	$3.00	$16,575.00	$9.75	$8.28
12	Thyme	1.45	$6.00	$14,790.00	$8.70	$7.39
13	Tomato	4.80	$1.50	$12,240.00	$7.20	$6.12
	Averaged	2.67	$3.73	$14,129.53	$8.30	$7.06

growing in beds with lots of thermal and moisture reservoir and SCCG 2's low maintenance design. I'm still learning a lot about what crops to plant when and how to grow them in a solar greenhouse which differs substantially from a conventional greenhouse. I still have primitive production equipment and plan labor and production enhancing up-grades such as an automated drip irrigation system and in-ground heat transfer system which will secure crops even in my absence. Having chosen an ambitious number of crops for such a small garden, most of my harvests were too small for store consumption. I have planted crops both in-bed and in trays on tables for starts.

Other production factors to consider:
1) I have not used any auxiliary heat or light, a modicum of which could substantially boost production of off season hot weather crops.
2) SCCG bed soils are still developing and will require at least another year or two to mature into full fertility.
3) SCCG's site grades a "C-" being a valley site receiving as little as six to seven hours of light in the winter. This site provides a baseline on the potential of SCCG's.

SCCG growing seasons seem to be defined by three seasons:
1) Late Winter/Spring: (Feb.-May): Early starts of seedlings for transplant or sale for growing along south side tables (south beds rest). Greens and other cool weather crops growing in north beds.
2) Summer: (June - August): Delicate hot weather crops such as tomatoes, peppers, basil for early harvest in south beds. North beds rest
3) Autumn/Winter: (Sept.-Jan.) Late start hot weather crops for late harvest in Oct.-Nov. along south beds. Greens and other cool weather crops planted in north beds.

The most promising crops for my SCCG at this stage of its evolution are off-season specialty greens which are most resilient to low winter light levels and temperatures. Next are the Mediterranean herbs with the exception of Basil. While this is a small market it looks promising for development. Herbs are more labor intensive and require more controls. To a greater extent than the herbs, hot weather crops such as basil and tomatoes will require more investment in equipment, controls and heating fuels to optimize these crops in the winter season especially with this SCCG on this site. Specialty greens are a promising entry market now dominated by California. They are relatively easy to grow and have short shelf-lives favoring the local grower. The specialty greens market is growing rapidly due in part to publicity of medical findings of their collective health benefits. Once this market is saturated other crops will need to be developed.

Other crops which I've grown successfully are Tomatoes in the spring summer and fall. The advantages of controlled growing in a greenhouse in the summer became evident when compared with a control crop of tomatoes grown outside. I've done this the last two summers of '97 and '98. Both summers had periods of severe storms mixed with drought and heavy rains. The tomatoes outside became diseased with fungus during wet periods. Most fruit was diseased or damaged by hail. The fruit which was salvageable had tough skin and mushy meat which was not sweat. By contrast the SCCG tomatoes were relatively disease free with tender skins and firm sweet meat. The size and productivity of the plants were greater than outside. I now grow tomato crops for fruiting in early summer and fall on the south side of SCCG.

Philip Rutter, the owner of the first SCCG at Badgersett Research Farm in Southeastern Minnesota, has gotten his hybrid hazelnut seedling production up to near capacity. This last season he produced over 60,000 trees at an average retail price of $3.50/ea. Next year he expects to be at peak production at 80,000 trees for over a quarter of a million

dollars retail value. While most people don't have a hybrid crop with such a well developed market, the potential is there. I will be experimenting with growing Ginkgo Trees which are good urban landscaping trees and have become a popular medicinal herb. Five year old male trees can sell for $300.00

4) Record the interior/exterior daily high/low temperature, humidity and light levels and the harvest totals: SCCG 2 has not performed as well as SCCG 1 at Badgersett. This is to be expected since SCCG 2 cost less than a third as much. SCCG 2 is not as tightly constructed and lacks a vestibule on one end. Other reasons for this are that SCCG 2 sits in a cool valley where it gets only 6.5 hours of light at the winter solstice as compared with over 8 hours of light for SCCG 1. The polycarbonate plastic glazing, used on the top third of the south glazing wall, has performed poorly and needs to be replaced. The vains between the double-walled plastic glazing have become filled with moisture substantially reducing its light transmitance. I have run SCCG 2 without any added heat or light over the last two years. I will be running it with a wood furnace for the late winter/spring season. The inside of SCCG 1 had 140% of outside ambient light levels when the shutters were positioned for optimal reflection. SCCG 1 has an excellent reflective snow field with few obstructions. SCCG 2 has only 85% of outside ambient light levels. To help increase light levels I still plan on adding exterior operable insulation shutters along the top 4' of glazing similar to what was installed on SCCG 1. SCCG 2 has an okay snow field with a number of shadows from trees, house, and hills. I will also experiment with artificial lighting and some of the photo-period sensitive crops to increase yields. I will also be selecting six to eight of my most promising crops to focus on developing more seriously.

SCCG 2 sees winter interior temperatures track 20-40 F above outside ambient temperatures on cloudy days and at night. I'm working to bump this up to 30-50 F above outside ambient temperatures. Winter interior temperatures on sunny days track at between 50-70 F above outside ambient. The winter of '97-'98 was one of the cloudiest on record as well as one of the mildest. This was not good for growing in a solar greenhouse. Colder weather has more days of sun due to the atmosphere's reduced ability to carry moisture. More normal winter temperatures should improve growing conditions and productivity. Daytime humidity levels generally ranged between 50-70%. Nighttime would increase to 80-90%. Humidity is a problem most in the fall when soil temperatures are highest creating mold and mildew problems for crops. I plan to aggressively reduce humidity and store heat with a hydronic heat exchanger. This will reduce day/night temperature variations as well.

Crop production figures (see Crop Production spread sheet) for SCCG 2 . I measured the production of thirteen crops in pounds per square foot per season and interpolated the results for each crop grown over the course of a year. I selected the best seasonal production which would be difficult to reproduce year round for any given crop. I think I've compensated for any seasonal overproduction by under-estimating wholesale prices. I then gave the wholesale market price per pound and the estimated production value for the 1700 square feet of growing area per year. The wholesale market price is for organic produce since I used organic growing techniques and no chemical fertilizers, pesticides or herbicides. I used a low wholesale organic price for each crop. An actual grower would likely specialize in fewer crops and be able to perfect production techniques and markets. A more experienced grower should be able to perform substantially better. I have averaged the thirteen crops for an annual production value of $14,129.54 or $7.06 per square for the 2000 square foot SCCG 2. This compares favorably with national commercial greenhouse gross sales figures of $7.00 per square foot for operations

averaging 10 times as large as SCCG 2, presumably with economies of scale. SCCG 2 also had no fuel or utility costs.

5) Publish detailed construction and production costs, and crop harvest yields:
As I mentioned in goal #6, I will proceed with publishing SCCG 2 Cost Benefit Analysis in concert with other publicity this late winter and early spring.

6) Give ongoing monthly tours of SCCG 2 to prospective clients and media.
The goals of SCCG 2 has always been to prove the technologies cost effectiveness as well as use the solar greenhouse for marketing. Since, I have had thirteen open houses, four workshops, and three university classes at REA Farm . I have also spoken at two conferences including the Upper Midwest Organic Farming Conference which I will again speak at. It was my contention that people and farmers in particular would do well to see, touch, taste, and smell the "real thing". This "real marketing" approach has been successful in attracting SCCG clients. I have resisted more media attention until I'm able to serve more clients. I also wanted more measurable results and more SCCG projects under my belt. The few articles which have appeared in newspapers have generated more business than I can handle. I have since been working hard at growing my architectural business. I'm looking forward to more media attention this late winter and early spring when I will be introducing three SCCG "plan kits", five workshops, and speaking at three conferences.