EXECUTIVE SUMMARY

This report summarizes the feasibility of a solar hot water heating system for one greenhouse at the Old Athens Farm in Putney, VT. Michael Collins, the grower, together with Chris Callahan, a consulting engineer, have reviewed an evacuated tube solar hot water system that is comprised of 8 panels (160 tubes) and is capable of producing 132,000 BTU/day on average. This system produces hot water which can be stored in a used, converted and insulated propane tank for use at night or on cloudier days. In this system design, the tank has been integrated into the envelope of the greenhouse so that "tank losses" become "greenhouse heat."

In summary, an investment of $14,675 in an evacuated tube solar collector can provide nearly 83% of the heat needed for a 24'x60'greenhouse in Vermont for at least two of the main growing months (May and June). It will also likely provide between 10% and 20% in the early growing months of March and April. The system will reduce this grower's dependence on imported fuel sources and will reduce the impact of fuel price volatility on his operating costs. Furthermore, the new infrastructure providing "free" recurring energy could enable flexibility in and extension of the growing season which could enable diversification of the Old Athens Farm production model. If used for three months of the year, this system is predicted to avoid 1.3 tons of CO_2 emissions (equivalent to 3,300 miles of typical passenger car travel).

DISCUSSION

Michael Collins at Old Athens Farms has been considering solar hot water heating of one greenhouse to augment his propane and wood heat inputs. Chris Callahan of Callahan Engineering, PLLC has been assisting Michael with the review of a solar hot water heating system that could provide this additional heat. The two have reviewed an evacuated tube solar hot water system similar in nature to the one installed at State Line Farm for oil seed drying and space heating (See Figure 1 from a previous REAP Grant Report[1]).

The target greenhouse for this system is a 24'W x 60'L x 10'H house with double poly roof / side walls and uninsulated plywood ends. The perimeter has been insulated with 1½ - 2" Styrofoam (i.e. "blueboard") to an average depth of 12". The western most 20' of the house includes a concrete slab with depth of 4-6" and 2" of Styrofoam insulation underneath. The current heat inputs include both propane heaters and a cord wood furnace. Michael's annual propane usage for this house has averaged 1,947 gal / yr (179 million BTU/yr, see Table 2) and he estimates he burns approximately 2 cord of firewood in the furnace (40 million BTU/yr). The annual heating requirement for this house beyond direct solar gain is, thus, approximately 219 million BTU under current heated usage from March-June.

Figure 1 - The target greenhouse at Old Athens Farm.

A heat loss analysis and initial solar heating assessment was performed by John Bartok, Agricultural Engineer with the University of Connecticut. This assessment reviewed the requirements of a solar heating

[1] http://www.vsjf.org/biofuels/documents/SolarDryerFeasibility_October2008.pdf

system to cover the entire heat load of the greenhouse for an average day in March. The result was an estimated requirement of 1,450,000 BTU/day, and suggested a 6,000 gallon storage tank to cover 3 days total heat load (since 2 days of cloudy weather is not uncommon).

Michael wondered if instead of handling the total heating requirement whether a supplemental solar heating system could be worthwhile.

Under funding from UVM Extension and the Vermont Agency of Agriculture, Food and Markets, the team assessed a partial load solar hot water system for greenhouse heating. Evacuated tube solar hot water collectors are well suited to the Vermont climate since they have increased cold weather and year round solar collection efficiency when compared to a flat plate solar collector. The use of an insulating vacuum inside the tubes along with special surface coating results in less loss of collected solar radiation. Additionally, they provide water at higher temperature than flat panel collectors. This higher temperature can be more effectively used in a variety of heat transfer appliances. For example, it can be used directly in a forced air hydronic coil unit heater or can be mixed down to be used in a radiant PEX system (see Figure 2).

A system of 8 panels (160 tube) was settled on due to budgetary guidance and cumulative collector performance that represents a measurable contribution to the overall heat load. This solar hot water system also incorporates a 1000 gallon hot water storage tank could take the form of a used, converted and insulated propane tank. A review of heat loss from the tank suggested that the tank be incorporated within the envelope of the heated greenhouse. In so doing, any losses from the tank will serve to heat the greenhouse prior to being lost a second time to the ambient environment (see Figure 9.)

All totaled an 8 panel (160 tube) system would cost approximately $8,800 for the panels, $1000 for a used 1000 gallon propane tank, an estimated $2,000 for balance of the system (pumps, plumbing) and $450 for a small unit air heater. Assuming an installation by Michael ($1,200: 40 hours at $30/hr), the total installed cost would be $14,675 (see Table 1).

Item	Cost		Qty	Materials	Labor	Total
Panels	$1,100	/panel	8	$8,800		
Tank	$1	/gallon	1000	$1,000		
Balance of Plumbing				$2,000		
Unit Heater (19kBTU/hr)	$450		1	$450		
Contingency	10	%		$1,225		
Installation	$30	/hr	40		$1,200	
Total				$13,475	$1,200	**$14,675**

Table 1 – Cost summary of system

The system has an estimated annual average output of 48 million BTU (if used all 12 months)[2]. At the cost estimated above, this translates to either $10.19 or $15.29 per million BTU depending on assumed system lives of 30 and 20 years respectively. Compared to propane and heating oil ($40.76 and $28.57 per million BTU respectively) this represents a relatively cheap source of energy[3].

This solar hot water system incorporates a 1000 gallon hot water storage tank could take the form of a used, converted and insulated propane tank. A review of heat loss from the tank suggested that the tank be incorporated within the envelope of the heated greenhouse. In so doing, any losses from the tank will serve to heat the greenhouse prior to being lost a second time to the ambient environment.

[2] Solar hot water systems generally require a circulation pump. Pump electrical usage assumes 1.5 Amps at 110 VAC = 165 Watts. Assuming 5 hours of operation per day, annual energy is approximately 301 kWhr / yr = 1.0 Million BTU / yr by conversion. These circulation pumps can be run by small photovoltaic solar panels to avoid this load, and packaged solar powered circulator systems are commercially available.
[3] Propane and fuel oil pricing is based on review of 2004-2009 retail pricing averages from DOE EIA database (see Figure 2 and Figure 3). Fuel content assumed is 92,000 BTU/gal of propane at an average price of $3.00 per gallon and 140,000 BTU/gal of fuel oil at an average price of $4.00 per gallon. Both oil and propane are assumed to be converted in 80% efficient heaters.

Solar collectors have naturally variable performance depending on day length and the cloud cover in the sky. This analysis incorporates these variations by making use of 30 year average weather data including solar radiation and cloud cover. Table 3 summarizes the variance of performance for an 8 panel system over the course of the year based on the change in day length and solar elevation noted in Figure 5.

From the perspective of cost/benefit and payback period, a solar hot water system for greenhouse heating also fairs well. With an installed cost of $14,675 and an average output of 132,000 BTU/day the system will displace 1.4 gallons propane or 0.9 gallon fuel oil per day. This results in fuel cost savings of approximately $5.25/day in propane or $4.5/day in fuel oil[4]. Payback period depends on the number of days that the solar heat is used in the greenhouse. Michael indicates that if the heat is "free", he would like extend the period over which he heats his house, even if only for moisture control. Table 5 demonstrates the payback period of the solar hot water system assuming two different growing period scenarios.

In summary, an investment of $14,675 in an evacuated tube solar collector can provide nearly 50% of the heat load for a 24'x60'greenhouse in Vermont for at least two of the main growing months (May and June). It will also likely provide between 10% and 20% in the early growing months of March and April. The system will reduced the dependence of this grower on imported fuel sources and reduce the impact of fuel price volatility on his operating costs. Furthermore, the new infrastructure which will provide "free" recurring energy could enable flexibility in and extension of the growing season which could enable diversification of the Old Athens Farm production model.

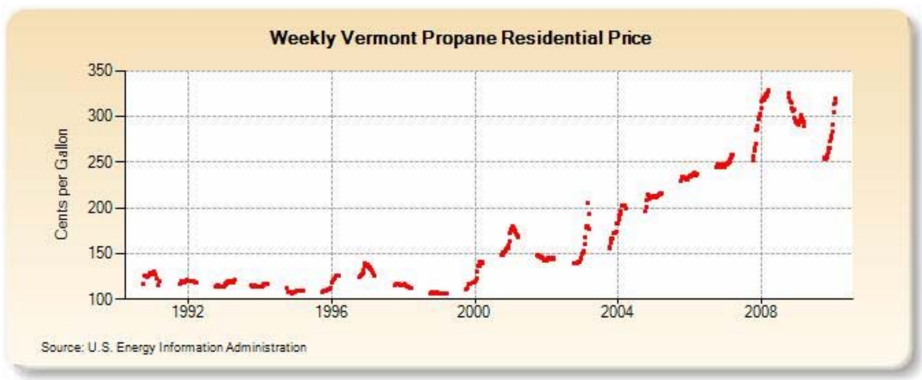

Figure 2 - Historical propane costs (residential) - from US DOE EIA. For purposes of this study a low price is assumed to be $2.00/gal and a high price is $4.00/gal.

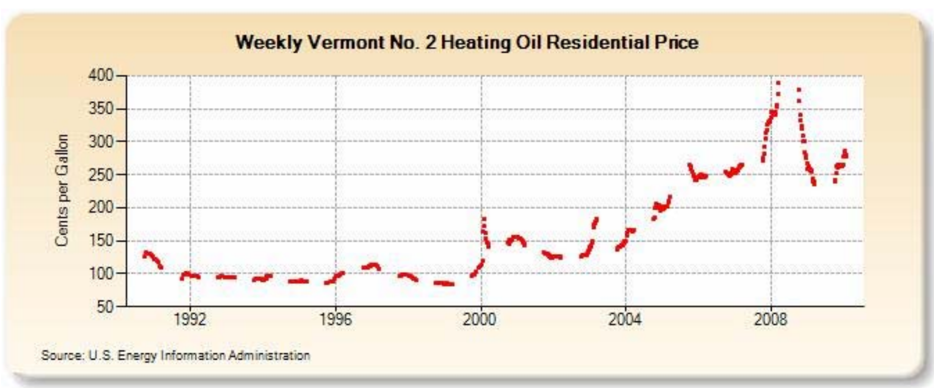

Figure 3 - Histortical fuel oil costs (residential) - from US DOE EIA. For the purposes of this study a low price is assumed to be $2.50/gal and a high price is $5.00/gal.

[4] Accounting for heater efficiency, and using the same prices are previously noted.

Fuel Usage History	
Year	Propane (gal)
2005	2154
2006	1310
2007	2411
2008	1912

Table 2 - Propane used the target greenhouse at Old Athens Farm (2005-2008).

Figure 4 - Grower, Michael Collins, in the target greenhouse.

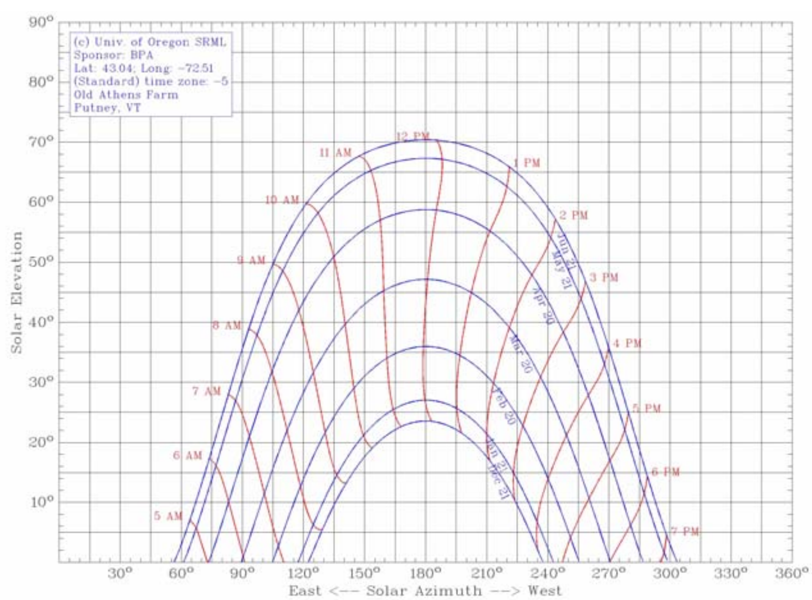

Figure 5 – Sun chart for Putney, VT showing the variation of sun position (and day length) during the course of the year. The cycle reverses every 6 months, and repeats every 12 months. This variation effects the period of time each day during which the solar hot water system can generate hot

water. Combined with historical incident solar radiation and cloud cover data, this can be used to estimate the seasonal solar hot water system output in millions of BTU each month (see Table 3).

	Avg Temp	HDD 62	Heat Loss	Solar Radiation[+]	Average Solar Contribution*	
	°F	°F-day	million BTU	BTU/hr/ft2	million BTU	%
January	20	1314	62	950	2.5	4%
February	18	1231	58	1108	2.6	5%
March	29	1039	49	1769	4.7	10%
April	42	610	29	1860	4.8	17%
May	59	195	9	2086	5.5	60%
June	64	90	4	2102	5.4	127%
July	70	31	1	2133	5.6	388%
August	68	44	2	2127	5.6	270%
September	58	184	9	1678	4.3	50%
October	50	392	19	1294	3.4	18%
November	36	774	37	598	1.5	4%
December	25	1156	55	583	1.5	3%
Year	**45**	**7059**	**333**	**1524**	**48**	**14%**
	avg	*cum*	*cum*	*avg*	*cum*	*avg*

[+] - Direct normal solar radiation, accounts for both average cloud cover as well as seasonal solar day changes.
* - Assumes 8 panels.

Table 3 - Summary of seasonal heating need to keep the greenhouse at 62 °F including variation of solar panel performance and contribution to the heat load. Note, the surplus heat in the summer months would either need to be "dumped" to a coil in the ground or directed to some other useful purpose on the farm such as potable hot water. The millions of BTU's noted can be converted to equivalent fuel amounts as shown in Table 4.

	Solar Collection		Equivalent Fuel Displaced					
	Incident	Cumulative	Propane			Oil		
	BTU/hr/ft2	mill BTU	gallons	@$2.00/gal	@$4.00/gal	gallons	@$2.50/gal	@$5.00/gal
January	950	2.5	34	$ 68	$ 137	22	$ 56	$ 112
February	1,108	2.9	40	$ 80	$ 159	26	$ 65	$ 131
March	1,769	4.7	64	$ 127	$ 254	42	$ 104	$ 209
April	1,860	4.9	67	$ 134	$ 267	44	$ 110	$ 220
May	2,086	5.5	75	$ 150	$ 300	49	$ 123	$ 246
June	2,102	5.6	76	$ 151	$ 302	50	$ 124	$ 248
July	2,133	5.6	77	$ 153	$ 307	50	$ 126	$ 252
August	2,127	5.6	76	$ 153	$ 306	50	$ 126	$ 251
September	1,678	4.4	60	$ 121	$ 241	40	$ 99	$ 198
October	1,294	3.4	46	$ 93	$ 186	31	$ 76	$ 153
November	598	1.6	21	$ 43	$ 86	14	$ 35	$ 71
December	583	1.5	21	$ 42	$ 84	14	$ 34	$ 69
Totals	**1,524**	**48**	**657**	**$ 1,315**	**$ 2,629**	**432**	**$ 1,080**	**$ 2,160**
	avg	*per year*	*cum*	*cum*	*cum*	*cum*	*cum*	*cum*
CO2 emissions avoided (tons annually)			4.0			4.8		
Equivalent car miles (25 mpg)			10,225			12,356		
CO2 emissions avoided (tons over 30 year life)			120.0			145.0		
Equivalent car miles (25 mpg)			306,742			370,683		

Table 4 - Summary of potential fuel displacement for an 8 panel (160 tubes) evacuated tube solar hot water system used at various times of the year. Fuel displacement assumes 80% heater efficiency. Displacement of fuel in the summer months would require a useful purpose other than greenhouse heating (e.g. potable hot water, moisture control, etc.) The actual savings experienced depends on the growing period when the houses are heated (see Table 5). CO_2 emissions avoided are based solely on use of either propane or fuel oil (i.e. no cord wood) for ease of comparison.

Scenario 1 - growing from March 15 through June 15 with heat addition

			Equivalent Fuel Displaced					
	Growing	**Solar**	**Propane**			**Oil**		
	% of month	million BTU	gallons	@$2.00/gal	@$4.00/gal	gallons	@$2.50/gal	@$5.00/gal
January	0%	0.0	0	$ -	$ -	0	$ -	$ -
February	**0%**	0.0	0	$ -	$ -	0	$ -	$ -
March	**50%**	2.3	32	$ 64	$ 127	21	$ 52	$ 104
April	**100%**	4.9	67	$ 134	$ 267	44	$ 110	$ 220
May	**100%**	5.5	75	$ 150	$ 300	49	$ 123	$ 246
June	**50%**	2.8	38	$ 76	$ 151	25	$ 62	$ 124
July	0%	0.0	0	$ -	$ -	0	$ -	$ -
August	0%	0.0	0	$ -	$ -	0	$ -	$ -
September	0%	0.0	0	$ -	$ -	0	$ -	$ -
October	0%	0.0	0	$ -	$ -	0	$ -	$ -
November	0%	0.0	0	$ -	$ -	0	$ -	$ -
December	0%	0.0	0	$ -	$ -	0	$ -	$ -
Totals	**3**	**16**	**211**	**$ 423**	**$ 846**	**139**	**$ 347**	**$ 695**
	months	*cum*	*cum*	*cum*	*cum*	*cum*	*cum*	*cum*
CO2 emissions avoided (tons annually)			1.3			0.8		
Equivalent car miles (25 mpg)			3,289			2,161		
CO2 emissions avoided (tons over 30 year life)			38.6			25.4		
Equivalent car miles (25 mpg)			98,664			64,837		
System payback, self-funded (years)				**35**	**17**		**42**	**21**
System payback, with $10k grant (years)				**11**	**6**		**13**	**7**

Scenario 2 - growing from February 15 through June 15 with heat addition

			Equivalent Fuel Displaced					
	Growing	**Solar**	**Propane**			**Oil**		
	% of month	million BTU	gallons	@$2.00/gal	@$4.00/gal	gallons	@$2.50/gal	@$5.00/gal
January	0%	0.0	0	$ -	$ -	0	$ -	$ -
February	**50%**	1.5	20	$ 40	$ 80	13	$ 33	$ 65
March	**100%**	4.7	64	$ 127	$ 254	42	$ 104	$ 209
April	**100%**	4.9	67	$ 134	$ 267	44	$ 110	$ 220
May	**100%**	5.5	75	$ 150	$ 300	49	$ 123	$ 246
June	**50%**	2.8	38	$ 76	$ 151	25	$ 62	$ 124
July	0%	0.0	0	$ -	$ -	0	$ -	$ -
August	0%	0.0	0	$ -	$ -	0	$ -	$ -
September	0%	0.0	0	$ -	$ -	0	$ -	$ -
October	0%	0.0	0	$ -	$ -	0	$ -	$ -
November	0%	0.0	0	$ -	$ -	0	$ -	$ -
December	0%	0.0	0	$ -	$ -	0	$ -	$ -
Totals	**4**	**19**	**263**	**$ 526**	**$ 1,053**	**173**	**$ 432**	**$ 865**
	months	*cum*	*cum*	*cum*	*cum*	*cum*	*cum*	*cum*
CO2 emissions avoided (tons annually)			1.6			1.1		
Equivalent car miles (25 mpg)			4,093			2,690		
CO2 emissions avoided (tons over 30 year life)			48.0			31.6		
Equivalent car miles (25 mpg)			122,790			80,691		
System payback, self-funded (years)				**28**	**14**		**34**	**17**
System payback, with $10k grant (years)				**9**	**4**		**11**	**5**

Table 5 – Comparison of two scenarios for greenhouse heating using solar hot water contribution. Both scenarios assume a 2460 ft2 house kept at 62 °F and compare against propane and fuel oil being used in 80% efficient heaters. The difference between the scenarios is the *heated* growing period assumed; 3/15-6/15 in the first and 2/15-6/15 in the second. CO_2 emissions avoided are based solely on use of either propane or fuel oil (i.e. no cord wood) for ease of comparison.

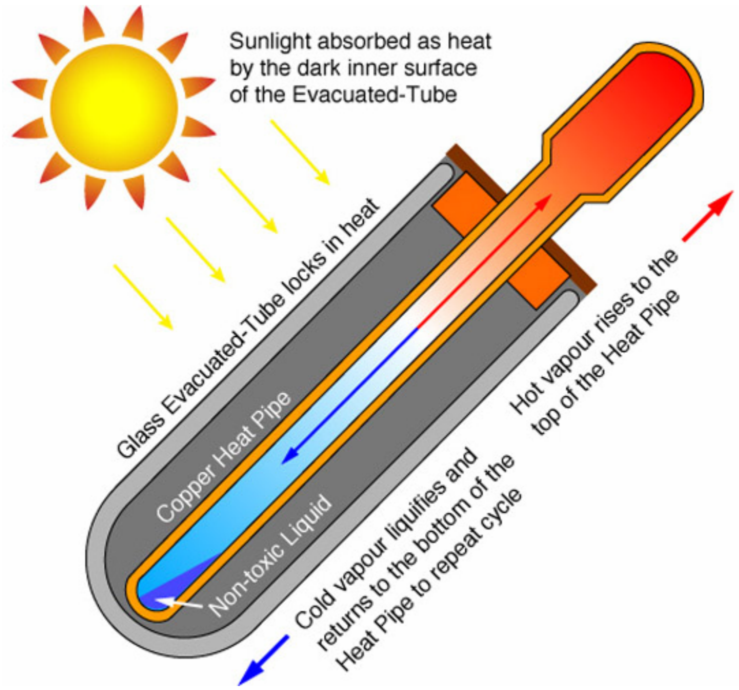

Figure 6 - Schematic of how an evacuated tube collector works.
(Downloaded from SunMaxx Solar's website.)

Figure 7 - Image of assembly of evacuated tube collector. The collector tubes do not directly interface with the circulated heating fluid. That fluid is carried in the manifold, and extracts heat from the bulb of the collector tubes by conduction.
(Downloaded from Silicon Solar's website.)

Figure 8 - Example of evacuated tube solar collector installed at State Line Farm in Shaftsbury,VT. This was a 4 panel (80 tube) system purchased from SunMaxx Solar in Bainbridge, NY.

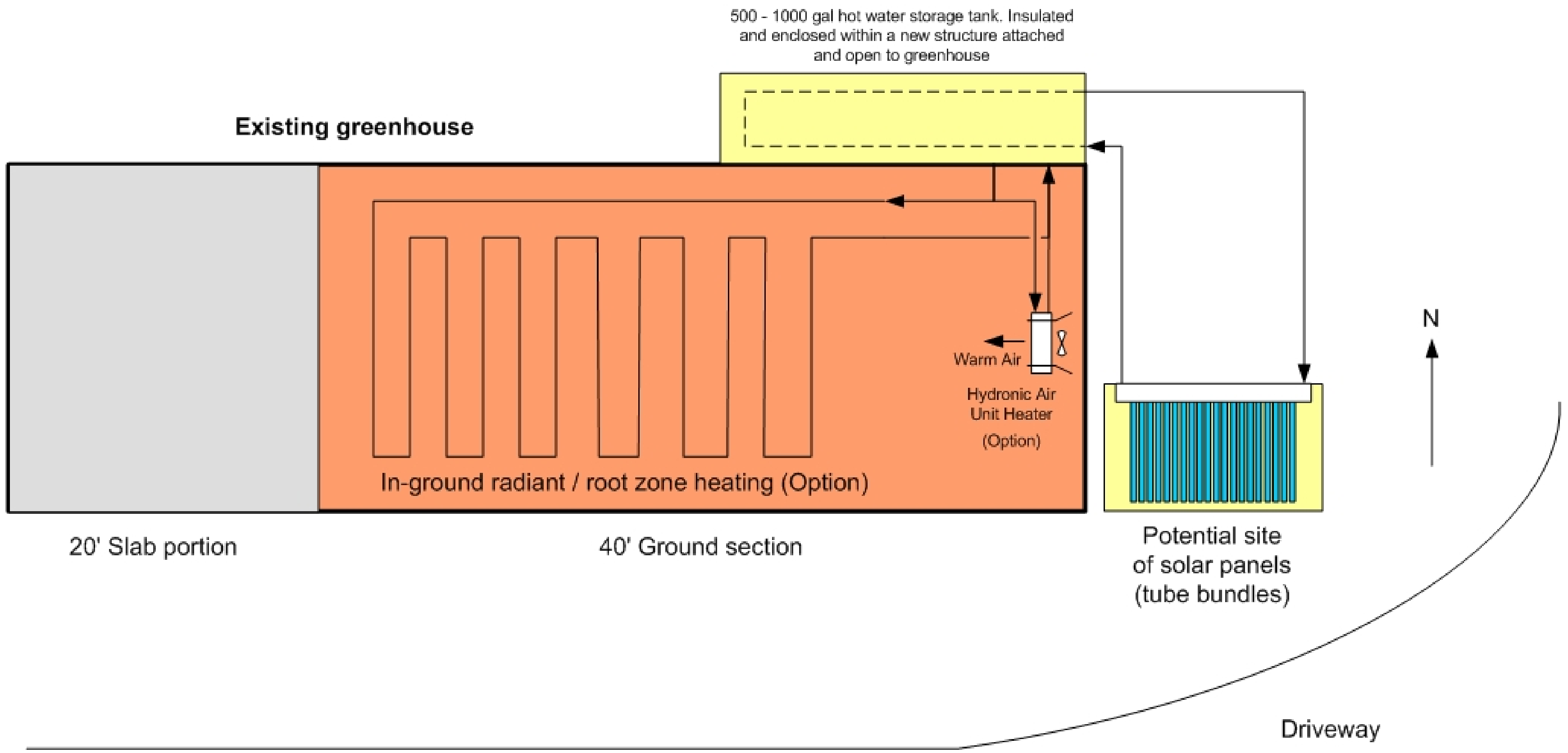

Figure 9 - Schematic layout of the solar hot water system at Old Athens Farm.

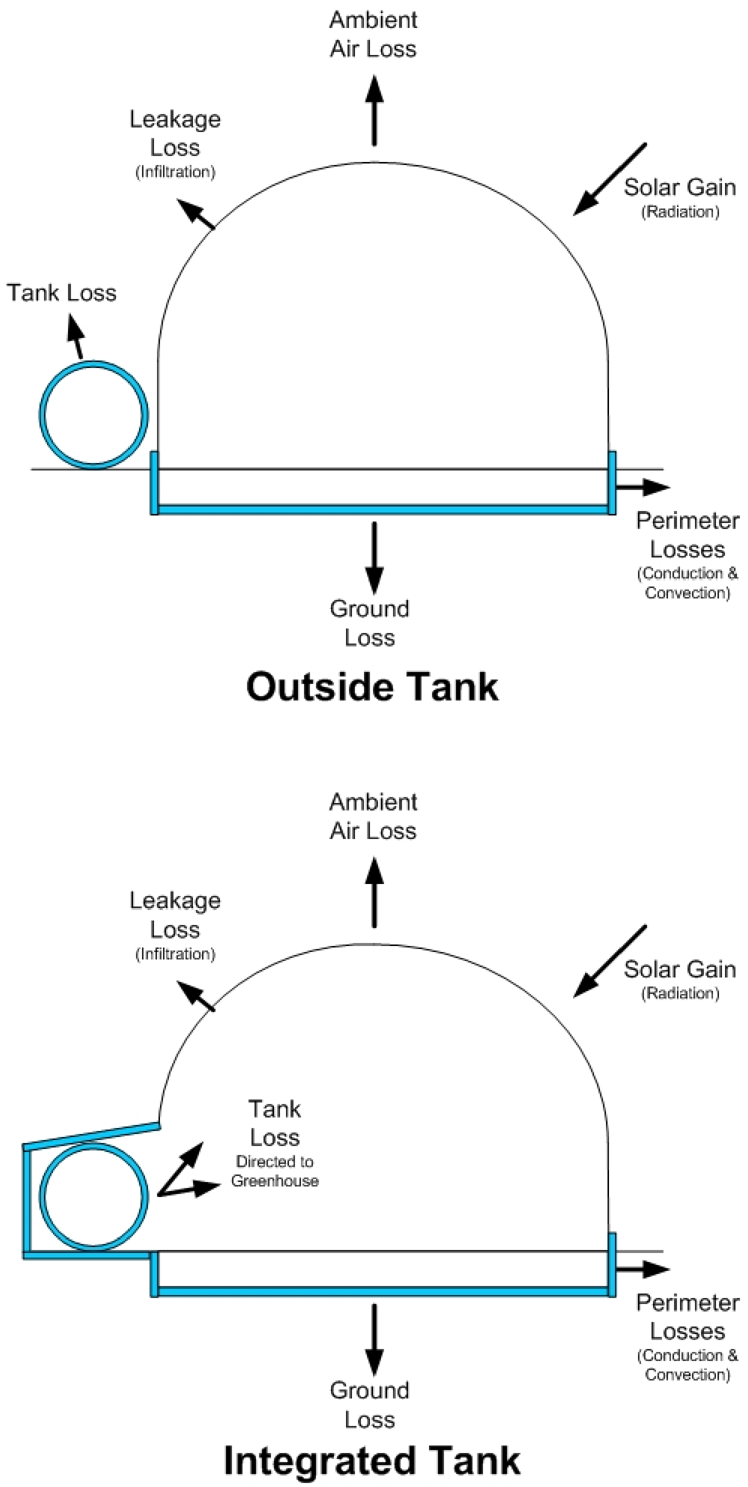

Figure 10 - Diagram showing a solar hot water tank integrated into an existing greenhouse.