

Feasibility Analysis:

Solar Seed Dryer and Storage Bin at State Line Farm, Bennington, VT



PREPARED FOR:

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Executive Summary

This report summarizes the recent installation of a solar hot water grain drying system at State Line Biofuels (SLB). The work was funded, in part, by the Vermont Agency of Agriculture, Food and Markets under the Renewable Energy for Agriculture Grant Program (REAP). Additional support was provided by the Vermont Sustainable Jobs Fund. SLB has been experimenting with biodiesel production from oilseed crops and has found a significant challenge imposed by the need to dry and store the oilseeds. The use of a solar hot water system to fuel the grain dryer is shown to dry the grain in half the time when compared to an ambient air drying system. Additionally the solar hot water system will be used to heat the biodiesel barn, raise the temperature of pressed oil for conversion to biodiesel and may be used for the recovery of methanol following biodiesel production.

This project has succeeded in establishing SLB as a processor of oilseed crops for other local farmers, which is projected to result in revenues of approximately \$25k annually in the next three years. Operational savings associated with this type of system are estimated at 7 to 9 cents per bushel of grain dried. When considering other applications of this system to displace fuel oil, propane or electrical fuel sources savings approach \$900 per year resulting in a pay-back period on the solar hot water system of 7 to 9 years.

Project Background and Description

State Line Biofuels, LLP (SLB) has been at the forefront of growing and processing oilseed crops in Vermont. They have experimented primarily with sunflower and canola varieties in an effort to fuel their farm with biodiesel. SLB is also becoming a contract processor for other local farms entering the oilseed arena.

The goals of the farm have shifted over the past decade as the operation has shifted from a dairy to producing sugar products and biofuels. The goals most relevant to the current project include:

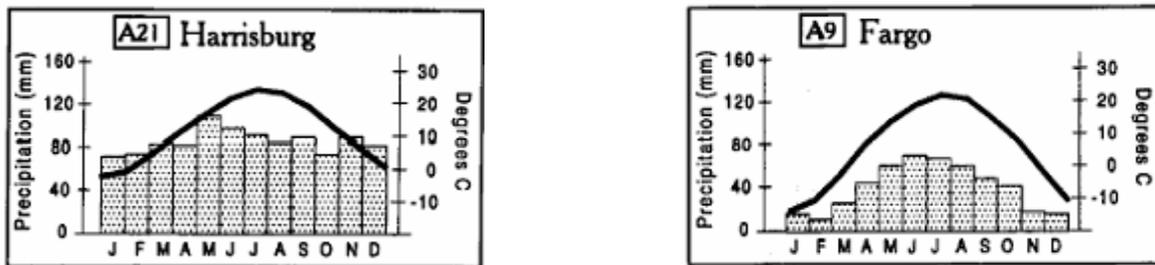
1. Growing the farm's own oilseed crops. Drying, storing and milling the grain into oil and meal and produce biodiesel from the processed oil. The resultant end-products will then be used on-farm or sold locally to agricultural producers and grain dealers.
2. On a "per unit" rate structure, provide drying/milling and biodiesel production services to other area producers. The resultant biodiesel will then be returned to the respective producer for use on their farms.

3. Provide start-up and operational technical assistance to other VT producers who desire to establish similar on-farm BD processing facilities.

Oilseed crop planting, cultivating, harvesting, cleaning, pressing and conversion to biodiesel have all been successfully established at a pilot scale at SLB. One of the primary lessons learned and significant challenges faced related to seed drying and long term storage.

The Northeast, and VT in particular, has relatively high levels of fall precipitation making harvest of oilseeds quite challenging. Other high production regions in the USA and Canada have much less rain during harvest time. Figure 1 shows a comparison of Northeast weather compared with Midwestern weather. There is clearly more precipitation in the Northeast, particularly during the harvest season (August through September).

FIGURE 1: COMPARISON OF NORTHEAST (A21 HARRISBURG, PA) AND MIDWEST (A9 – FARGO, ND) CLIMATES - TEMPERATURE (LINE) & PRECIPITATION (BARS)



USDA. Major World Crop Areas and Climate Profiles. Agricultural Handbook Number 664. September 1994.

This climatological dynamic influences SLB in two ways: (1) the timing of harvest depends on plant maturity and dry-down but also is highly dependant on erratic Fall weather and (2) the seeds are generally coming off the field at the high end of recommended moisture content. On-farm grain drying and bulk storage is essential for oilseed production in this environment.

While bulk capacity for storage has a straightforward solution in the form of grain bins, the need for a sustainable drying process remains to be addressed. Wet oilseeds will tend to mold or sprout weed seeds that end up in the harvest. This can result in lower yields due to wasted grain. Optimal pressing of oil also depends heavily on careful control of moisture content upstream of the press.

A guiding principle at SLB is to use renewable and free resources as much as possible to enhance the sustainability of their farm and the overall operational model of small scale, farm-based biofuels production. In that spirit the concept of a hybrid solar / biomass hot water based dryer has been assessed with funding from the VT Agency of Agriculture REAP program.

While the procurement and installation of a fossil-fueled seed dryer would be relatively easy, it would be opposed to the nature of the enterprise and biofuels production in general. This

would also represent a significant and volatile recurring expense to the fledgling enterprise. Additionally, the barn which houses the SLB biofuels operation is well situated to take advantage of solar gain year round and the waste meal from pressing has been shown elsewhere to be a viable fuel for combustion.

This project sought to construct a grain drying and storage bin with low grade heat input from a solar hot water system. Drying oilseeds does not actually require heat and is generally done with forced air flow only. However, there are two motivations for exploring this option in the present circumstance: (1) with the addition of heat by hot water the same amount of air can remove more moisture from the grain and result in shorter run times of the electrical fan and (2) forced air drying with heat addition by hot water may accommodate seeds with higher moisture content as a result of unfavorable weather patterns making a harvest feasible when it might otherwise be lost.

System Description

The system originally conceived included (1) solar hot water collector panels to be roof mounted facing south, (2) insulated hot water storage tank, (3) heat exchanger to produce hot, dry air from hot water, (4) blower fan to blow hot, dry air over the seeds to be dried, (5) circulation pumps for the hot water system, (6) grain bin with agitator to serve as the drying vessel (7) backup pellet boiler (possibly fueled by seed meal) for making additional heat when needed and (8) plumbing and controls. A brief description of each system component follows.

Schedule and funding limitations required omitting some components from this original design. Specifically there is presently no hot water storage tank and no pellet boiler. The system as presently constricted is shown in Figure 2.

The solar hot water collector purchased is made by SunMaxx Solar (Bainbridge, NY – www.sunmaxxsolar.com). The team settled on four SunMaxx 20 evacuated tube solar collectors. With the excellent southern orientation at the facility, on a clear day this results in about 160,000 BTU/day of collection with a peak of about 80,000 BTU/hr. John and Tanner assembled the system on top of a shed made for the purpose of supporting the panels and housing a biomass boiler inside (see Figure 3 & Figure 4). They also performed all required plumbing of the hot water system and wiring for electronic controls.

Due to funding and schedule constraints, the hot water storage tank has not yet been installed. The cost of this component was higher than expected due to increased demand at the manufacturer. The project installation also quickly ran into the start of grain harvesting. As a result a minimally functional system was installed and employed for the immediate need of grain drying. John intends to construct an insulated hot water storage tank once harvesting is completed.

A used radiator from a Ford truck has served as the heat exchanger used to heat the air blown into the dryer with hot water from the solar collectors (see Figure 5). In all operation to date, the heat exchanger has worked very well. The temperature drop across it on the water side is

significant meaning that the air is picking up most of the heat in the hot water.

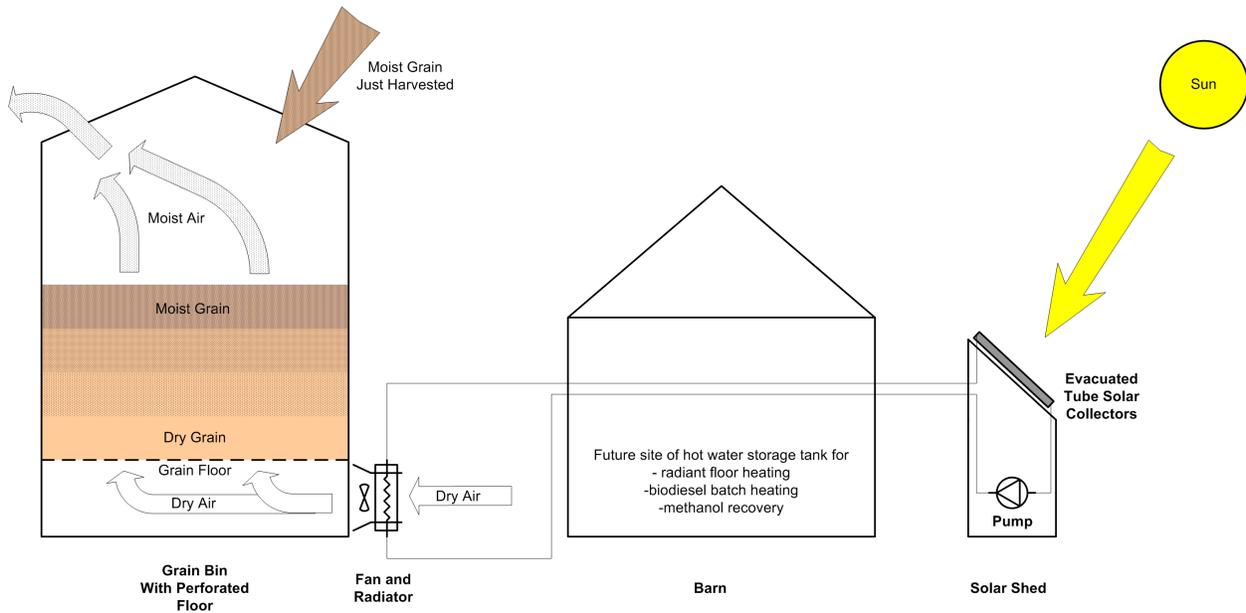
The blower fan selected is a Sukup 18" 3 Hp fan which delivers 5600 CFM at 1.5 inches of water static pressure (see Figure 9). The fan is controlled manually, and has been run primarily during the day only.

The circulation pump and solar controller were purchased along with the solar collectors from SunMaxx Solar. The pump is a Taco 0011 hot water circulator (see Figure 8) and the solar controller is a Goldstar differential controller which is designed to turn the circulator on when the collector temperature is a certain number of degrees above the tank temperature. Without the tank in the present system, the ambient temperature is used for reference. Thus when ever the water in the collectors is above ambient temperature circulation of water is initiated.

A used grain bin with a small seed floor (12 feet diameter x 15 feet high) was discovered on a farm in Stephentown, NY which no longer has use for it. The owner was willing to give it to SLB for no charge if they dismantled it and removed it from the site. John and Tanner did so and also repaired some worn and rusted sections of the grain floor. Obtaining this bin at no charge saved SLB about \$10,000 – \$12,000.

A pellet boiler or other biomass boiler is planned in the future and will be connected to the hot water loop. Schedule and financial constraints prevented the incorporation of it into the system during this stage of the project.

FIGURE 2: SCHEMATIC OF STATE LINE'S SOLAR GRAIN DRIER



System Performance

The performance of this system is based on how well and how quickly it is able to remove moisture from harvested grain, thus allowing it to be stored for prolonged periods of time. Air only grain drying is practiced on many farms around the world with reliability and success. The current system is quite similar, but also adds low-grade heat to supplement the drying rate. The addition of a solar hot water heater to such a system raises the temperature of the ambient air being used for drying and lowers its relative humidity. This allows the same air to remove more water from the grain by evaporation. To understand the significance of using hotter air for drying, one needs to consider the moisture carrying capacity of air at different temperatures (known as psychrometrics). In simple terms, hot air can carry more moisture than cold air.

The use of low grade heat is important when considering oilseeds. High temperature air (such as from an oil or propane burner) can over dry seeds and may be potentially hazardous resulting in a fire. The current system represents a compromise between an air only system and a burner-based system.

Performance was measured on September 18, 2008 on a day when sunflowers were being harvested and the grain bin was about ½ full (about 500 bushels). It was a very clear, sunny day and the solar collectors were absorbing solar radiation well. The circulation pump was running somewhat less than optimally due to air being present in the system. Data recorded on this day indicates that the supplemental heat from the solar hot water system allows for drying in about 50% the time of ambient air drying. This is shown with the following calculation.

Assume 1200 bushels of sunflower seed harvested at 15% moisture which needs to be dried to 5% moisture in order to be stored without sprouting and mold. The ambient conditions are 71 deg F and 62% relative humidity and a clear sky. The fan provides 5600 CFM of air flow through the bin. The solar hot water system is capable of raising the 71 deg F ambient air to 85 deg F using a radiator.

TABLE 1: CALCULATION COMPARING AMBIENT AIR DRYING TO SOLAR HOT WATER AUGMENTED DRYING.

	Case 1 Ambient Air Drying	Case 2 Solar Heated Air Drying
Amount of Grain	1200 bushels	
Mass of Grain	36,000 lb	
Moisture Content	15%	
Moisture Content Target	5%	
Mass of Water to be Removed	3,600 lbs	
Ambient Air Temperature	71 deg F	
Relative Humidity (ambient air)	62%	
Humidity Ratio (ambient air)	0.01002 lb water/ lb air	
Air Temperature into Bin	71 deg F	85 deg F
Relative Humidity of Air to Bin	62%	39%
Humidity Ratio of Air to Bin (when saturated)	0.01633 lb water / lb air	0.02631 lb water / lb air
Air Flow to Bin	5,600 ft ³ /min (25,110 lb air / hr)	5600 ft ³ /min (24,465 lb air /hr)
Water Removal Rate (by evaporation)	50 lb water / hr	102 lb water / hr
Hours to Target Moisture	72 hours	35 hours

Performance similar to that in the above calculation was measured in late September when the system had just started to be operated. Several factors indicate that this performance is below what will ultimately be possible. There was some air still in the circulation loop and insulation had not yet been fully installed on all the hot water lines. For example, the temperature of the water coming off the solar collector was measured as 120°F in the barn, but was losing at least 20°F before reaching the radiator. John plans to address these issues as soon as this year’s harvest is concluded.

Operational Impact – Energy, Finance and Risk

Inclusion of a grain bin with drying capacity at SLB makes contract processing a reality for the enterprise. Previously, harvest carts and portable exhaust fans have been used for storage and drying. These methods are quite inefficient and prone to grain loss. The constant cross section area of the grain bin also allows for more accurate measurement of grain added to the bin from various sources (although tare mass measurement is likely the ultimate method.) The new grain bin also provides a greater quantity of storage enabling handling of other producer’s grains.

In this sense, the project has succeeded in establishing SLB as a processor of oilseed crops for other local farmers. This service is projected to provide revenues of \$15,230 in 2008, \$24,265 in 2009 and equal or greater in 2010. It also enables revenue associated with biodiesel production (from the pressed oil) which is estimated at \$12,774 in 2008 and \$23,100 in 2009 and equal or greater in 2010. In short, the total revenue enabled by this system is roughly \$28,000 in the first year and close to \$50,000 in the following two years.

Aside from helping to generate revenue, the system can also be used to reduce costs. The total energy embodied in the solar hot water used for drying this 1200 bushels is roughly 2.95 million BTU (or 2,462 BTU/bushel of grain). This is equivalent to about 21 gallons of heating oil (at 140,000 BTU/gal), 32 gallons of propane (at 92,000 BTU/gal) or 864 kWhr of electric heating (at 3413 BTU/kWhr). This avoids a financial expense of between \$87 and \$112 (using \$0.13 / kWhr for electric, \$4.13 / gal for fuel oil and \$3.27 / gal for propane¹) for each complete fill of the drying bin. This assumes, of course, that a comparable low-grade heat supply can be derived from a fossil fuel source which has not been well demonstrated.

SLB could ultimately process nearly 187,500 bushels of grain to 300,000 gallons of fuel annually using the existing biodiesel processor on site. While grain storage and handling capacity and fuel storage capacity is far short of that presently, the figure provides visibility into a possible future state of operation. At that capacity, the savings are between \$13,600 and \$17,500 annually.

Operationally, this savings is between 7 and 9 cents per bushel of grain processed at SLB. One estimate of market price for processing oilseed crops from seed to oil is about \$2 per bushel. So the savings associated with solar drying could provide 3% to 5% more net profit for an operation such as SLB.

The solar hot water system is also not dedicated solely to drying grain. The system at SLB will also be used to heat the biodiesel processing facility during the winter months and can also be used to heat up oil for batches of fuel. These two uses increase the operational savings significantly perhaps doubling or tripling them.

The real impact of solar augmented grain drying, however, has to do with the ability of the enterprise to weather the weather. Having the capability to either dry relatively high moisture content harvest or to dry larger quantities of moist grain in a shorter period of time is a risk management tool in the Vermont climate. The benefit could be saving a portion of the harvest that might otherwise be lost to sprouting, mold growth or that might otherwise be left in the field unharvested. Having enhanced drying capability allows the farmer greater flexibility in choosing a harvest date and protects the harvested crop from moisture related damage when stored. Both of these features support the viability of the farm.

¹ From Vermont Public Service Commission Monthly Fuel Report, September 2008. Downloaded from <http://publicservice.vermont.gov/pub/vt-fuel-price-report.html> on 9/24/08.

Applicability to Other Farms

The performance and financial savings demonstrated above relate directly to any farmer with a seasonal demand for grain drying closely following a grain harvest. However, the solar hot water collectors utilized in this system function year round and can produce hot water for other uses. This system concept and individual parts of it can be readily adapted to various types of farms. Some farms that might have interest include:

1. Any farm seeking faster grain drying to accommodate higher than desired harvest moisture of oilseed crops.
2. Farms presently using fossil fueled heaters for grain drying that desire to move away from those fuels to a sustainable fuel.
3. Any farm that has relatively high demand for hot water (such as flushing of dairy lines).

When considering other potential farm applications of energy embodied in hot water the following financial payback information may be helpful (Table 2).

TABLE 2: FINANCIAL PAYBACK INFORMATION		
		Notes
Cost of SLB Solar Installation	\$6500 (approximate)	1
Anticipated Life	30 years or more	2
Average Annual Energy Collected	26.5 Million BTU/yr	3
Average Electrical Consumption of Circulation Pump	3.0 Million BTU/yr	4
Amortized Cost of Solar Installation	\$217 / yr	
Annual Net Energy Gain	23.5 Million BTU/yr	
Fuel Oil Equivalent	168 gallons / yr	5
Fuel Oil \$ Equivalent	\$693 / yr	5
Propane Equivalent	255 gallons / yr	5
Propane \$ Equivalent	\$835 / yr	5
Electricity Equivalent	6885 kWhr / yr	5
Electricity \$ Equivalent	\$895 / yr	5
Payback Period Range	7.3 to 9.4 years	6

Notes:

1. Cost is for the 4 evacuated tube collectors, solar plumbing and controller.
2. Warranty is 10 years, expected life is 20-30 years
3. Annual energy collected is based on historical weather data (cloudiness) and SRCC certification report for the SunMaxx solar tubes which indicates performance of the tubes at different cloud cover conditions.
4. Pump electrical usage is based on 1.76 Amps at 110 VAC = 187 Watts. Annual energy is approximately 879 kWhr / yr = 3.0 Million BTU / yr by conversion. Usage estimate assumes pump is only on when solar gain is present (i.e. sun is up). These circulation pumps can be run by small photovoltaic solar panels to avoid this load.
5. Comparison fuel heating values and costs are noted in the text above.
6. Payback is determined by dividing the initial cost of the solar system (\$6500) by the estimated avoided cost of the various competing fuels per year (\$693 - \$895 / yr).

As demonstrated, the application of a solar hot water system based on evacuated tube collectors results in fairly short payback. This is due largely to the significant increase in the cost of competing fuels (oil, propane, and electricity). The example above is based on the SLB installation. An installation for a farm with smaller or larger energy demand will differ as will the specific avoided costs. However, the payback period range is generally unaffected by the scale of the solar system installed.

Cost Breakdown

The following is a summary of the costs incurred as part of the installation of the solar grain dryer at SLB (Table 3).

TABLE 3: COST BREAKDOWN FOR SOLAR GRAIN DRYER		
System Component	Cost	Notes
Site Work (grading)	\$861.18	Grading of site for grain slab
Grain Bin		
Bin (1200 bushel)	Free	Typically \$10-12k
Slab for Bin	\$767.97	Slab on grade
Repairs	\$201.60	Repair holes in floor
Drying Fan		
	\$1,190.00	Sukup 3 HP 18" Grain Fan
Solar Shed		
	\$1,631.57	Wood frame on slab / block foundation
Solar Collectors		
	\$3,606.99	4 Sunmaxx Solar Evacuated Tube Collectors
Plumbing & Controller		
	\$1,287.05	Mainly copper pipe
TOTAL MATERIALS	\$9,546.36	
Construction Labor		
	\$5,760.00	320 hours of construction @ \$12/hr
Design Support		
	\$2,840.00	35.5 hours of engineer support @ \$80/hr
TOTAL LABOR	\$8,600.00	
TOTAL COST	\$18,146.36	Probably \$30,000 if buying a new bin

FIGURE 3: STATE LINE'S BIO BARN, SOLAR SHED AND GRAIN BIN (LOOKING NORTHWEST).



FIGURE 4: FOUR SUNMAXX SOLAR "SUNMAXX 20" EVACUATED TUBE SOLAR COLLECTORS ARE SOURCE OF HOT WATER FOR THE SYSTEM.



FIGURE 5: A FORD F250 RADIATOR WAS ADAPTED FOR USE AS AN AIR HEATER AHEAD OF THE SUKUP 18" 3 HP DRYING FAN. THE FAN PROVIDES ABOUT 5600 CFM AT 1.5 INCHES OF WATER STATIC PRESSURE.



FIGURE 6: HOT WATER FROM THE SOLAR COLLECTORS ENTERS THE BUILDING ON THE SOUTHEAST CORNER. THE PLATFORM IS THE FUTURE HOME OF A HOT WATER STORAGE TANK.



FIGURE 7: PROOF IS IN THE PUDDING. A THERMOMETER READING 120 DEG F SHOWS THAT THE SOLAR COLLECTOR IS WORKING AND SUPPLYING HOT WATER TO THE RADIATOR FOR GRAIN DRYING.



FIGURE 8: PUMP PERFORMANCE CURVE FOR TACO-0011 AND OTHER PUMPS

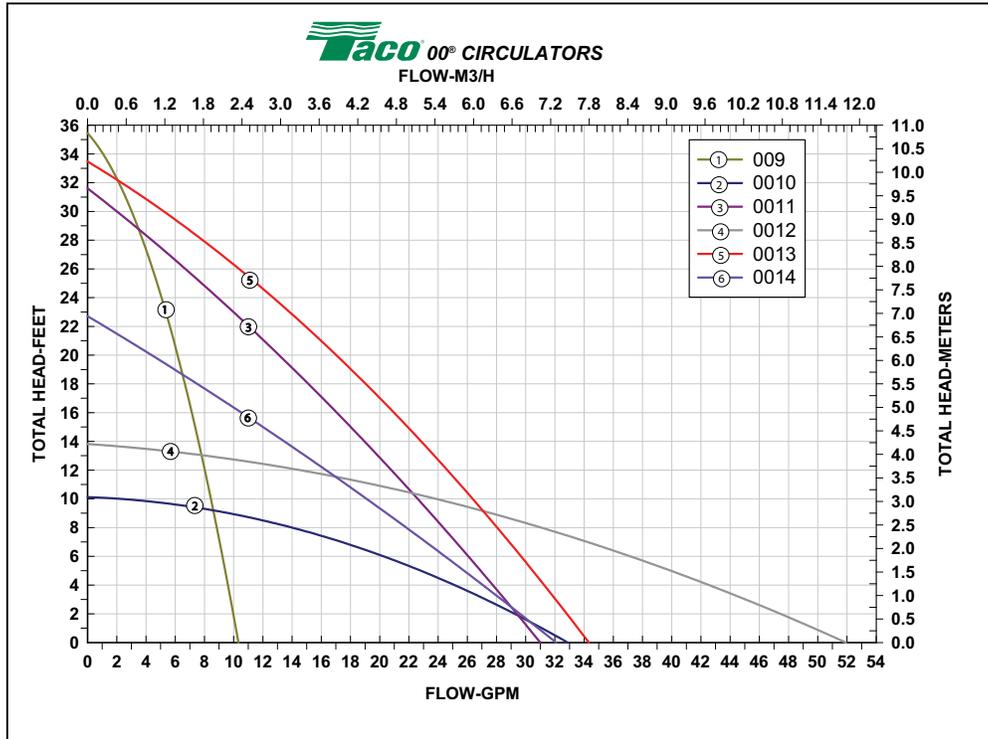


FIGURE 9: FAN PERFORMANCE CURVE FOR SUKUP 18" 3 HP FAN.

Flow vs. Pressure for 18" Sukup 3 Hp Fan

