Investigating Straight Vegetable Oil as a Diesel Fuel Substitute

Final Report to Colorado Agricultural Value-Added Development Board

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Camelina sativa

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Investigating Straight Vegetable Oil as a Diesel Fuel Substitute

This report is meant to provide a thorough explanation of the issues surrounding the use of straight vegetable oil as a source of sustainable on-farm fuel. As has been widely reported, American farmers and their family farming operations have struggled to survive in recent decades because the viability of American farming operations is largely dependent upon variables that farmers have very little control over. One of the most important variables is the price of oil. Petroleum-based fuel is a major input cost for farming operations, and in the recent years, the world has witnessed a precipitous climb in oil prices. This results in an increase in production costs for farmers. If farmers were to have control over the supply of their fuel, their farming operations would have more predictable costs and may be much more viable and profitable in the long-term. One of the most logical solutions that allows farmers to take control of their fuel needs is to use straight vegetable oil from seed crops they grow themselves to fuel their farming operations.

The benefits for farmers to grow and produce their own crops are many, and include:

- Energy independence
- Potential savings in fuel expenditures
- Additional savings and subsidies from government programs meant to help the agricultural industry and meant to promote sustainable development
- A decrease in carbon emissions

II. Project Overview

This research project proposes to explore the issues surrounding the growing, processing and use of Straight Vegetable Oil (SVO) as an alternative fuel replacement for petroleum diesel, especially for on-farm use. Production of biodiesel begins with producing SVO, then treating it with chemicals to make biodiesel. SVO can be the ideal bio-fuel replacing diesel and/or biodiesel for farm use. SVO energy ratio (output/input) is higher than diesel and biodiesel improving the carbon foot print and net energy gain. Moreover, it avoids use of chemicals and disposal of by-products. SVO meal is premium quality which is essential to calculating the total value of the biofuel economic feasibility. Finally, spring oilseed crops add value to the cropping system by adding a crop in the rotation.

Research and development steps to use SVO as a diesel fuel substitute:

- Development and testing of appropriate oilseed varieties
- Overcoming political and regulatory issues to certify SVO as a bio-fuel
- Usage (producer concerns on using SVO)

- Technical issues surrounding the use of SVO in farm equipment
- Diesel engine conversion necessary to use SVO in farm equipment
- Need for establishing standards for SVO as a bio-fuel
- Economic considerations including investment, payback and financial viability of SVO production and consumption.

III. Key Finding and Recommendations

Benefits of SVO for Colorado

SVO has many benefits when compared to petro-diesel. Because it requires no refining, it also has advantages over biodiesel and other biofuels. Most importantly, as a renewable resource, it provides an energy autonomy opportunity for countless generations of farming communities.

SVO is a triglyceride that consists of one glycerol and three fatty acids (figure 1). SVO is not harmful to humans, animals, plants, soils or water. The German Federal Water Act on the Classification of Substances Hazardous to Waters denotes SVO as NWG (non hazardous to water)[1.] The same classification ranks biodiesel as slightly hazardous to water while diesel and gasoline as toxic. A North American study on the toxicity of vegetable oil in freshwater also concluded SVO had no harmful effects[2.]

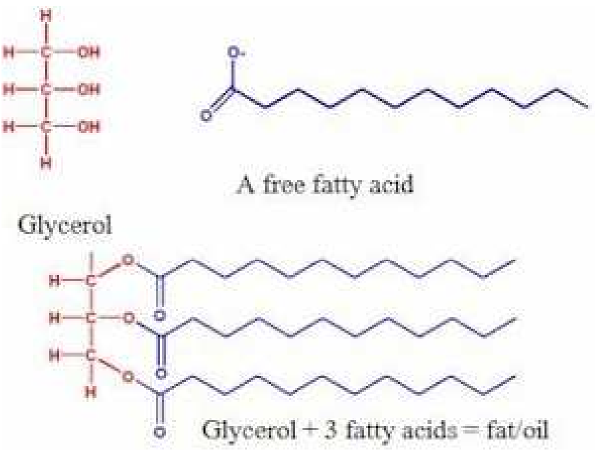

Figure 1: Fatty acid structure (Source: http://www.scienceinafrica.co.za/pics/12_2006/oil1.jpg)

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[1]((*WGK (Wassergefährdungsklassen):The German Water hazard classes.* Available at http://www.folkecenter.dk/plant-oil/WGK_ENG.htm; http://www.folkecenter.dk/plant-oil/publications/vwvws.pdf)

[2] (http://www.epa.gov/oilspill/pdfs/Li-Lee-Cobanli-Wrenn-Venosa-Doe_FSS06.pdf)

As a fuel, it emits 40 to 60% less soot[3,4] compared to petro-diesel. It does not contain sulphur and therefore does not cause acid rain5. In addition, carbon monoxide and particulate emissions are slightly lower. CO_2 emissions are also reduced by 80 to 96%[6,7] compared to petro-diesel when locally produced and used. Finally, Polycyclic Aromatic Hydrocarbons (PAH) emissions are distinctly lower for all vegetable fuels, reducing risks of cancer[8] (Fig 2).

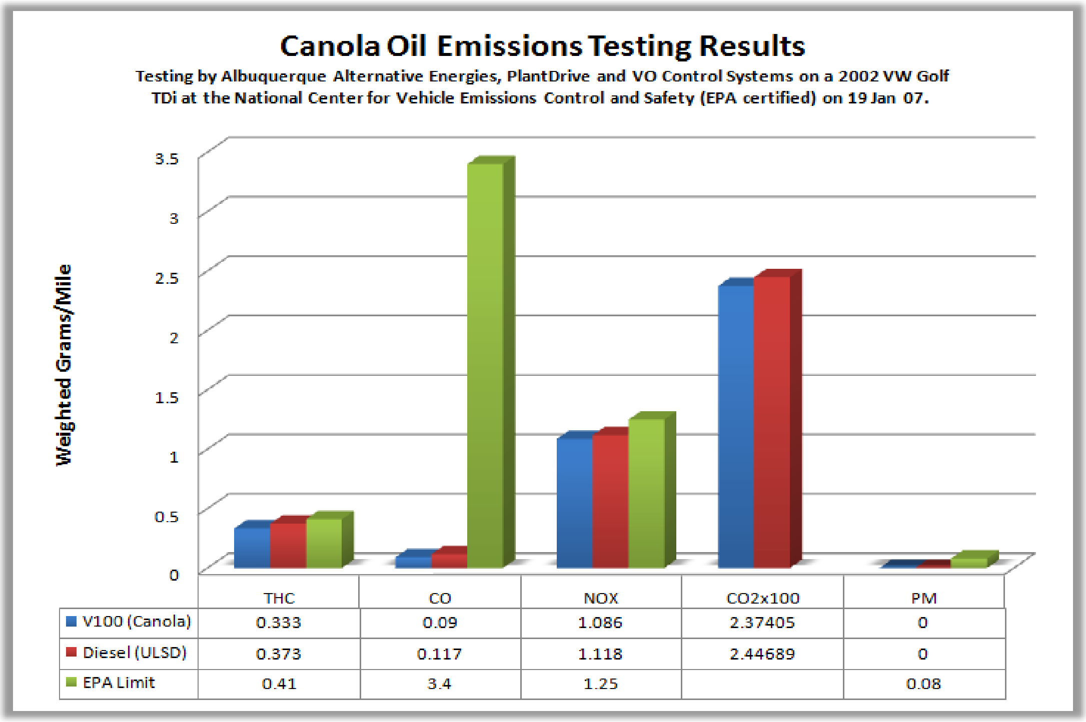

Figure 2: Canola Oil Emissions Testing Results.

SVO can also be a contributor to Colorado rural food, energy and feedstock independence. Gasoline has a 0.8739 energy ratio (energy yield/energy input). If we include distribution and the meal, the number for canola based SVO is 5.4510 while for sunflower based SVO, it is 6.3311 (Table 1). In comparison, corn ethanol has a 1.2412 energy ratio.

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3 (http://home.clara.net/heureka/gaia/veggie-oil.htm).
4 (http://www.biomatnet.org/secure/Fair/F484.htm)
5 www.folkecenter.dk/plant-oil/publications/PPO-emissions.htm
6 (http://www.folkecenter.dk/plant-oil/publications/energy_co2_balance.pdf)
7 Institut Français des Huiles Végétales Pure, ADEME 21/11/06
8 http://www.biomatnet.org/secure/Fair/F484.htm

9 Institut Français des Huiles Végétales Pure, ADEME 21/11/06
10 http://www.valbiom.be/, Biomass certification

Table 1: Energy ratio of different fuel including SVO

	Regular Unleaded	Diesel	Biodiesel Canola	Biodiesel Sunflower	SVO Canola	SVO Sunflower
Ration energy produced/ Non renewable energy used	0.873	0.917	2.99	3.16	**5.45**	**6.33**
Green house gas emissions (q eq. CO2/kg)	3650	3390	888	745	**660**	**498**

IV. Research on Oilseed Crops Adaptable to Colorado Conditions

In 2007 and 2008, five oilseed crops were studied: soybean, safflower, sunflower, canola and camelina. Performance trials were conducted at nine locations within Colorado: Fort Collins, Akron, Walsh, Dailey, Idalia, Julesburg, Brandon, Yuma and Rocky Ford. Oilseed crops were tested under three environmental conditions: dryland, limited irrigation and full irrigation. Crop data collected included seed yield, percent seed moisture, plant height, pod shattering and oil content. The oil profile was evaluated for safflower, canola and camelina in 2007.

The five oilseed crops can be good fits in three Colorado cropping systems (Table 2). Sunflower, soybean and safflower are considered as summer annual broadleaf crops. Late fall harvest of these crops eliminate the possibility of planting winter crops. Soybean is primarily an irrigated crop. Sunflower is both a dryland and an irrigated crop. Safflower is primarily a dryland crop.

Winter canola and winter camelina can be either integrated into the dryland wheat cropping system or in an irrigated cropping system. However, canola should be considered as an irrigated crop whereas camelina is best suited to dryland conditions.

Camelina provides an opportunity crop that could be integrated into the dryland winter wheat rotation predominant in eastern Colorado, planted in early spring, harvested in July and followed by wheat planting in September. Spring canola may be limited by high summer temperatures

[11] ADVA 31

[12] US Department of Agriculture, (July 1995). Available at: http://www.ethanol-gec.org/corn_eth.htm

which reduce pollination and pod filling. Camelina is more drought tolerant and less sensitive to high temperature during pollination and pod filling. Camelina is resistant to flea beetle and false chinch bug which deleteriously affect canola. Roundup Ready (RR) cultivars of canola are available while no chemical weed control package exists for camelina

Table 2: Cropping Systems Adaptable Oilseed crop for Colorado

	Months										
Crops	August	September	October to February	March	April	May	June	July	August	September	October
Soybean						Planting date				Harvesting	
Sunflower							Planting date				Harvesting
Safflower							Planting date				Harvesting
Winter Canola and Winter camelina		Planting date						Harvesting	Planted back to wheat		
Spring Camelina and Canola				Planting date				Harvesting	Planted back to wheat		

Results of 2007 and 2008 Crop Variety Performance Trials

In 2007, six variety performance trials of soybean, nine of sunflower, three of safflower, six of canola and three of camelina where conducted. In 2008, one variety performance trial of soybean, four of sunflower, ten of canola and eight of camelina where conducted. A total of 31 oilseed crop variety trials were conducted in nine eastern Colorado locations (Table 3) in 2007 and 23 in 2008 which is a total of 54 oilseed trials over the two years project. Table results are in appendix.

Table 3: Number of Trials by Location and by Crop in 2007 and 2008

Water regime	**Dryland**		**Limited Irrigation**		**Full irrigation**	
Year	**2007**	**2008**	**2007**	**2008**	**2007**	**2008**
Soybean	1	0	4	0	1	1
Sunflower	4	2	2		2	2
Safflower	1	0	2	0	0	0
Canola (spring)	1	2	3	2	1	1
Canola (Winter)	1	1	2	2	3	2
Camelina (spring)	1	2	2	4	0	2
Total	9	7	15	8	7	8
Total Trials						54

Soybean

Soybean is a well-established oilseed crop currently grown on limited acreage in Eastern Colorado. It has an established market and federal crop insurance. Soybeans are a relatively good fit for irrigated cropping systems but are not suited for dryland production. Soybean variety trial maximum yields in eastern Colorado were 99 bu/ac in 2006 and 2007 (Table 3). Soybeans require 24 inches of water to produce maximum yields.

We feel like soybean is an underexploited crop in Colorado due to low input costs and lower water requirements than corn. Major seed companies are investing millions of dollars in soybean research, some of which benefits Colorado producers. Pest management and agronomics are well understood under Colorado conditions. Soybeans have excellent emergence and stand establishment is not problematic. Soybeans fit into an irrigated winter wheat rotation with wheat benefitting from symbiotically-fixed nitrogen from soybeans. Soybean processing into biofuel is straight-forward and simply requires pressing the oil from the seed. Soybeans are the major oil source for current biodiesel production in the U.S. The soybean oil profile is in accordance with the U.S. biodiesel standard (ASTM PS 121-99). It has a high level of oleic fatty acid, low level of saturated fatty acid, and medium polyunsaturated fatty acid content (24%), which also makes soybean oil a good source for SVO. Soybean meal has high protein content and is the preferred and most consumed livestock protein feed additive, something of considerable interest to Colorado confined feeding operations. No specialized equipment is needed for soybean planting, cultivation, and harvest.

Limitations to soybean production in Colorado also exist. All soybean production, like most of our sunflower crop, must be transported out of state, usually to Goodland KS, for crushing and processing. It is felt that the lack of a Colorado soybean crushing capacity in northeast Colorado is a major constraint to more widespread cultivation of soybeans in our state. Other constraints include above average sensitivity to high pH, salty and sodic soil conditions. Soybean crop residue after harvest is insignificant. Soybeans have low oil content by comparison to other oilseed crops (15-20%). Planting, irrigation and harvest may overlap other summer crops creating a time constraint for some farmers. There is no state 'check-off' program in Colorado to support state crop improvement research. All soybean production in the US, including Colorado, is potentially threatened by soybean rust.

Table 4: Soybean Trial performance Summary

Location	Maturity	Water regime	Average	Max	Min	Oil
			bu/ac	bu/ac	bu/ac	gal/ac
Akron	Early	Dryland	11.4	18.2	5.9	14
Fort Collins	Early	Limited Irrigation	20.7	30.3	10.9	25
Fort Collins	Medium	Limited Irrigation	25.4	33.3	15.4	30
Rocky Ford	Early	Limited Irrigation	34.5	48.9	20.6	41
Rocky Ford	Medium	Limited Irrigation	40.4	44.9	36.5	48
Yuma 2007	Late	Irrigated	78	99.4	66.9	94
Yuma 2008	Late	Irrigated	59	72	52	71

*Soybean oil content is estimated to be 18%.

Sunflower

Sunflower is a crop that has a long history in Colorado but large acreages have been grown in Colorado since the early-1990s due to local development and extension efforts by Golden Plains agronomist, Ron Meyer. Sunflower is adapted to both dryland and irrigated production. Crop variety trials conducted since early-1990s show dryland oil sunflower yields from 1000-2000 lb/ac and irrigated yields in excess of 3000 lb/ac with oil content in seed as high as 47% (Table 4). High yields have been obtained under limited irrigation in northeast Colorado where available water for irrigation is a serious production constraint for all crops. There is a well established market for the crop and an established federal crop insurance program. There is a premium for high oil content paid to sunflower producers. There is a good understanding of pest problems and management in Colorado conditions and sunflowers are better able to recover from hail damage than many crops. Sunflowers fit well into both a conventional and no-till cropping systems. Colorado producers are adopting rotations including a summer crop like sunflower, corn, or proso millet while moving away from the traditional wheat-fallow rotation. Many high-yielding and high oil content sunflower hybrid varieties are available for producers who benefit from sunflower improvement conducted by many major crop seed companies and crop variety testing under Colorado conditions. Sunflowers are well suited for direct harvest with planting, tillage, and harvest equipment already owned by Colorado producers. Even prior to the recent release of herbicide resistant sunflower hybrids, conventional chemical weed control packages existed those, albeit not perfect, were suitable for Colorado production. High protein sunflower meal is valuable to sunflower processing companies. In addition to the National Sunflower Association who support research and promotes sunflower products, the Colorado Sunflower Administrative Committee, our state ‘check-off’ organization created and funded by Colorado producers, supports applied research and promotion of Colorado produced sunflower products. Sunflower oil is the second most produced oilseed for biofuel in Europe.

Figure 3: Sunflower Field, Yellow Jacket CO

There are some constraints to sunflower production that should be mentioned. When rotating to other crops after sunflower there have been some instances of yield reduction in the subsequent crop due to extensive water and nutrient extraction by a good sunflower crop. Sunflowers have a history of poor emergence under dry planting conditions resulting in poor stand establishment. Weed management in sunflower can be troublesome when dealing with late emerging weeds. Sunflower residue after harvest is not significant and does not stand up to high winds. Rodent, voles, ground squirrels, and birds can unearth newly planted sunflower seed causing poor stand establishment in parts of fields. Bird damage can be severe before harvest, especially in areas where sunflowers are widely grown and become targets of local blackbird populations. When processing sunflower for biofuel, wax content from the oils needs to removed to avoid damage to engines. Although sunflower has good potential as a biofuel crop in Colorado, vegetable oil market prices have historically exceeded the value of the oil for biofuel. The Colorado company crushing sunflowers for oil is in Lamar and the whole oil is exported out of Colorado for refining and retail sales. The majority of the Colorado sunflower crop produced in northeast Colorado must be transported to Goodland, KS for crushing. A new facility will begin operations in 2009 in Dove Creek Colorado.

Table 5: 2007 and 2008 Sunflower Trial Performance Summary

Location	Type	Water regime	Average		Max		Min		Oil		Gallon
			2007	2008	2007	2008	2007	2008	2007	2008	Average
			lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	%		gal/ac
Brandon	Oil	Dryland	2005	1366	2445	1936	1611	953	38.7	40	89.9
Julesburg	Oil	Irrigated	2768		3474		2278		41.15	40	147.6
Idalia		Irrigated		2407		3620		1269		40	128.4

Safflower

Safflower is a potential oilseed crop for Colorado production that is more suited for dryland production. There is a limited market established for safflower in the state meaning that producers interested in growing safflower should identify a market before planting the crop. There is no crop insurance available for safflower in Colorado and there is no 'check-off' or grower organization that would support research and marketing of safflower. Being a relatively short season crop it fits well into crop rotations. It is also an aggressive scavenger for water and residual fertility. Safflower has relatively high oil content and is easily processed; it requires no special equipment for planting and is directly harvested. Emergence and stand establishment typically are not a problem in production.

Safflower production and use constraints outnumber the constraints for more widely produced crops like sunflower and soybean. There is not a varietal improvement program in the High Plains and seed for planting can be hard to find. Weed management in safflower can be problematic due to the lack of herbicides labeled for broadleaf weed control. Hauling the harvested crop is an issue since the market is limited. The research knowledge base for safflower production in Colorado is scarce since there is no producer organization to promote this crop. Safflower's response to irrigation is not established but is being researched. Safflower can be a fire hazard during harvest and leaves little residue. Safflower is another potential biofuel crop but competes directly with human consumption the same as sunflower.

Safflower has an acceptable oil profile for SVO. 2007 trial results show yields up to 467 lbs/ac (Table 6). However, much higher yields have been achieved in different years with better crop management practices. Safflower oil content can approach 50% in some cultivars.

Table 6: Safflower Trial Variety Performance Summary

Location	Water regime	Average	Max	Min	Oil	gal/ac
		lb/ac	lb/ac	lb/ac	%	
Akron	Dryland	430	467	395	40	22.9
Fort Collins*	Limited irrigatior	221	301	182	40	11.8
Walsh	Dryland	208	250	148	40	11.1

*Grown under specific limited irrigation conditions in high pH and highly sodic soils.

Winter and Spring Canola

Canola is another potential irrigated biofuel crop in Colorado that could find a niche in limited irrigation rotations. There are both winter and spring canola varieties that can be planted in Colorado. Winter canola needs to be planted before the end of August to obtain plants that are developed enough to be able to withstand low winter. Late planted winter canola, especially north of I-70, has not been able to withstand winter freeze. Weed control is generally not a problem because winter canola starts regrowth in early spring and competes well with weeds. Varieties from public and private sources have been screened in five different Colorado agro-climatic conditions through a collaborative research program with Kansas State University. Planting and harvest equipment are readily available although canola is commonly swathed prior to threshing to allow uniform maturity of pods from the top to the bottom of the canopy and to avoid excessive shattering. Fall planted varieties have a grazing opportunity for livestock and can still yield well. Spring canola might be an attractive alternative crop under limited irrigation due existence of high yielding roundup-ready cultivars from private seed companies. Peak water use for canola is at the end of May and early June, well before peak water demands of summer crops (corn, alfalfa, and sunflower). Canola leaves relatively sturdy residue after harvest. Oil content in Canola is relatively high (40-45%) and the seed is easily processed. The meal byproduct is high in protein and is a valuable livestock feed like soybean. Canola produces a high quality fuel and has good potential for biofuel and meal production for use on the farm.

There are several downsides to canola production. Flea beetles that attack young canola seedlings must be controlled with chemical treatments. There is not a well established market and there is no Colorado grower organization to promote production and research. Canola is not a good candidate for direct harvest and should be swathed and then picked up much the same as millet. Canola is sensitive to many of the herbicides that we use in other crops and in fallow periods such as atrazine, Ally, and others. Since there is not a well established market for canola in Colorado, hauling of the harvested product can be an issue. Canola is small-seeded and needs to be shallow planted to obtain good stands. Deep seeding, or soil crusting, or planting into dry soil conditions can significantly reduce stands. Canola is sensitive to high temperatures during flowering and yields can be reduced. Lack of adequate soil moisture will reduce yields more than camelina. Canola has a taproot system giving the crop access to deep water and nutrients (Downey et al., 1974). However, when grown in semiarid regions such as the High Plains, the canola roots require adequate subsoil moisture to sustain the crop during flowering and seed filling. Under managed irrigation winter canola is capable of yielding more than 3,000 lbs/ac. Low crop prices and lack of an established market infrastructure for canola are significant obstacles to more widespread production in Colorado. With limited grower experience and the lack of insurance programs, production of canola has been limited.

Figure 4: 2008 Oilseed Harvest at Fort Collins

Winter and spring canola varieties are being screened to identify promising cultivars for Colorado's limited irrigation and dryland conditions. Trials conducted in 2007 and 2008 demonstrate yields of 800 lbs/ac under dryland, of 2,400 lbs/ac under limited irrigation and up to 3724 lbs/ac under full irrigation (Table 6).

Table 7: Canola Trial Performance Summary

Location	Source	Year	Water regime	Average	Max	Min	Oil*	gal/ac
				Lbs/ac	Lbs/ac	Lbs/ac	%	
Akron	Commercial	2007	Limited Irrigation	1891	2397	1458	40	101
	Commercial	2007	Full Irrigation	1837	2424	1205	40	98
	Cargill	2007	Limited Irrigation	1645	2900	831	40	88
	Cargill	2007	Dryland	401	807	343	40	21
	Blue Sun	2007	Limited Irrigation	1259	1777	1406	40	67
Fort Collins	Commercial	2007	Limited Irrigation	259	761	79	40	14
Fruita	National trial	2006-2007	Irrigated	2339	3621	872	40	125
Yello Jacket	National trial	2006-2007	Irrigated	651	1236	428	40	35
Rocky Ford	Commercial	2006-2007	irrigated	1750	3171	752	40	93
Rocky Ford	National trial	2007-2008	Irrigated	1816	2703	815	40	97
Fruita	National trial	2007-2008	Irrigated	2760	3724	2124	40	147
Walsh	National trial	2007-2008	dryland	602	1175	102	40	32
Akron winter canola	Blue Sun	2007-2008	Limited Irrigation	1172	1784	731	40	63
Akron winter canola	National trial	2007-2008	Limited Irrigation	1370	2236	828	40	73

Camelina

Camelina is an oilseed crop native to Southeast Europe and Southwest Asia. The plant has been known for about 4000 years as a cultivated crop but there has been relatively little research conducted on it worldwide. Camelina is a promising new oilseed crop that has become the subject of widespread research in the last few years because Camelina is not attacked by flea beetles, is more resistant to drought than other spring oilseed crops, and can be direct harvested. Camelina is a low input crop. It can be grown in dryland and limited irrigation cropping systems.

Water requirements for irrigated Camelina are being investigated but like canola its peak water demand is early in the season when full summer crop water demands are low. Camelina is an early maturing crop, planted in early April and harvested in mid-July. Although some production issues must be solved, Camelina could become an excellent crop for our wheat-based no-till cropping systems that dominate eastern Colorado. If there is sufficient spring precipitation, Camelina can be planted in the spring following fall harvest of corn or sunflowers or proso millet and can be harvested in time to allow for accumulation of late July to mid-September precipitation before planting wheat. Instead of harvesting two crops in three years, the current improved cropping system, by producing Camelina in the spring it would be possible to harvest three crops in three years. The seed is extremely small, seeding rates are low, and seed costs are low. Fertilizer requirements are low and response to nitrogen fertilizer application has been low. Several private seed companies and universities have Camelina improvement projects that are providing varieties for testing in Colorado. Winter Camelina is more winter hardy than winter canola and can be planted later in the fall and still survive low winter temperatures. Camelina does not require any special planting equipment and can be direct harvested which means that equipment is readily available for production. Insect pressure on Camelina is almost non-existent. Camelina oil is high in Omega 3 fatty acids and studies are currently underway to determine if real health benefits result from consumption of Camelina oil. Camelina meal has been fed under experimental condition to livestock in Montana and Wyoming and it appears that it is wholly satisfactory.

Currently, there are significant production and marketing constraints for Camelina. Understandably, the agronomics of Camelina production are less well known than for other crops. Due to small seed size, Camelina must be planted shallow and pressed into the soil to have good seed to soil contact. Camelina can be planted in early spring; some claim that it can be seeded anytime during the winter or spring. Emergence is slow under cool spring soil temperatures, especially in variable soil moisture conditions. Unlike canola, Camelina is not attacked by flea beetles but stand establishment and weed control, although difficult currently, are being investigated actively in the Great Plains and the Pacific Northwest. There is currently very little acreage of Camelina being planted in Colorado and there is no grower 'check-off' program to support research and production. Federal and state agencies are providing research funds that have helped address some basic water and fertilizer requirement issues and to conduct variety trials. For several years Camelina producers were able to sell seed to Blue Sun Biodiesel but seed prices were low and hauling to crushing facilities was an additional cost. Marketing needs to be fully investigated by producers before planting. Camelina is a small seeded crop that may require adjustments to equipment to prevent loss during harvest and hauling. The meal currently is not legal for sale as livestock feed although high Omega 3 content in the oil and meal indicates that it might be more beneficial than other oilseed for human and livestock health.

Figure 5: Charlie Rife, Breeder from Blue Sun, Inspects Camelina Trials

Camelina oil content ranges from 30% to 45%. Over 50% of its fatty acid, when cold pressed, is polyunsaturated. Alpha linolenic acid (omega 3) represents 30% to 45% of the total oil. Omega 3 fatty acid content has been shown to have beneficial effects on human health.

Trials conducted in 2007 and 2008 show dryland yields up to 1,138 lbs/ac under dryland conditions, up to 1,725 lbs/ac under limited irrigation, and up to 2386 lbs/ac under full irrigation (Table 7).

Table 8: Camelina Trial performance Summary

Location	Source	Water regime	Average		Max		Min		
			2007 lb/ac	2008 lb/ac	2007 lb/ac	2008 lb/ac	2007 lb/ac	2008 lb/ac	gal/ac
Akron	Sun/GPO/ MSU	Limited Irrigation	1243	1053	1725	1332	973	555	53.6
Akron	Sun/GPO/ MSU	Dryland	789	-	1138	-	529	-	36.8
Fort Collins	Sun/GPO/ MSU	Limited Irrigation	547	1159	839	1500	283	794	39.8
Yellow Jacket	Sun/GPO/ MSU	Fully Irrigated	.	2002	.	2386	.	1739	93.4

a) *Oil Meal Quality*

Camelina meal contains 40% to 45% crude protein and 10% fiber which is similar to soybean. The glucosinolate content is close to zero (Korsrud et al., 1978; Lange et al, 1995) and camelina meal has 12% oil remaining after cold pressing with 5% of omega 3. Study shows that omega 3 content in eggs increases with increases of camelina meal content in feed. Up to 15% can be integrated into a balanced feed ration (Pilgeram et al., 2007). Budin et al. (1995) found that Camelina oil has 30% more antioxidant than other commercial edible oil that could explain superior storage quality of raw camelina oil. Feed for beef containing camelina meal does not show significant difference for average daily gain nor feed efficiency (Pilgeram et al., 2007).

b) Fuel properties

The cloud point of camelina biodiesel is 4°C, and pour point is -8°C (Fröhlich et al., 2005) which is similar to other biodiesel feedstocks such as canola.

Table 9: Low temperature properties of blends of camelina ester and mineral diesel oil

Camelina ester %	Mineral diesel %	Cloud point °C	CFPP °C	Pour point °C
100	0	+3	-3	-4
80	20	+3	-7	-6
60	40	+3	-9	-9
40	60	+3	-11	-12
20	80	+3	-13	<-18
0	100	+3	-15	<-21

(Source: Fröhlich et al., 1998).

CFPP: Cold filter plug point

Camelina oil has a high iodine value, 155 mg I2/g Oil. The limit of the European standard is 120 mg I2/g Oil. This can be an issue for cold climates. A concern with a high iodine value is that unsaturated acids might polymerize in the engine and cause deterioration.

Oil Profile Analysis of the Targeted Crops

Different vegetable oils for fuel can be differentiated by their oxidative and cold flow properties. These two criteria are linked. Some vegetable oils have to be heated to ensure flow but warm temperatures increase the rate of fatty acid oxidation which adversely affects power.

Fatty acids which reduce the cold flow quality of SVO are palmitic (C16:0) and stearic acids (C18:0). The cloud point is correlated to the level of saturated fatty acid. The cloud point of vegetable oil goes from 8C to -18C with changes in saturated fat from 23% to 3%. Table 10 underlines the percentage of these fatty acids in three main crops of the study.

Table 10: Saturated fatty acid profile summary

Species Unit	Camelina %	Canola %	Safflower %
Palmitic (C16:0)	6	5	6
Stearic (C18:0)	2.5	2	2.5
Total saturated	11.5	8.5	10

There are no significance differences among these crops for saturated fatty acid content. These levels of saturated fatty acid are acceptable for SVO.

Polyunsaturated fatty acids improve cold flow properties but are more susceptible to oxidation. Bringe (2004) recommends no more than 24% polyunsaturated fatty acids in vegetable oil for dual use in the food and fuel industry. The level of polyunsaturated fatty acid (PUFA) has another major impact. High levels of PUFA increase the amount of nitrogen oxides released into the atmosphere upon combustion (McCormicke et al., 2001). Another important property of oil for fuel is ignition quality which is measured by the cetane number (CN). High CN is desired to have the best ignition and combustion. The more oleic acid in the oil profile, the higher the CN.

Table 11: Oleic and polyunsaturated fatty acid profile

Species	Camelina %	Canola %	Safflower %
Oleic (C18:1)	19	62	37
Linolenic (C18:3)	30	6	0.1
Total polyunsaturated	51	25	52

There are significant differences among crops. Camelina has a very high level of linolenic acid and polyunsaturated fatty acid (Table 11). Crop improvement is needed to increase the oleic acid content of camelina. The ideal fuel oil profile is approximately 65% oleic acid, 22% linoleic fatty acid, 3% linolenic acid and the lowest possible level of palmitic and stearic fatty acid (2%). The high level of polyunsaturated acid makes camelina one of the best crops known for human vegetable oil consumption.

Canola has an acceptable oil profile for fuel with a high level of oleic acid and medium level of polyunsaturated acids. This oil profile is the result of strong breeding programs.

Safflower’s oil profile is similar to camelina. However, high variation is noticed between safflower cultivars. Selection has been done to reduce the level of polyunsaturated acid and increase the level of oleic acid. Oleic acid level varies from 14% to 70 % and polyunsaturated fatty acids levels range from 18 to 75 %.

Table 12: Oil Profiles of the Targeted Crops

	Palmitic (C16:0)	Stearic (C18:0)	Total saturated	Oleic (C18:1)	Linoleic (18:2)	Linolenic (C18:3)	Total polyunsaturated
unit	%	%	%	%	%	%	%
Ideal SVO Profile	**<6**	**<5**	**<13**	**>50**	**±20**	**<5**	**<25**
Soybean	5	2	10	65	18	2	22
Sunflower	5	2	8	75	8	2	12
Safflower	6	2.5	10	37	40	0.1	52
Canola	5	2	8.5	62	18	6	25
Camelina	6	2.5	11.5	19	20	30	51

V. Economic feasibility

The following economic feasibility study is designed to address three practical economic questions frequently asked about oilseed production for use as SVO on the farm. Oilseed crops in the Brassicacea family, like canola and Camelina, are good rotation crops because high levels of glucosinolates can effectively break some harmful pest cycles.

1. What is the break-even price per pound and yield that would make it economically feasible to produce oilseed under limited irrigation conditions, dryland and full irrigation?
2. What price per gallon of petroleum diesel vs.oilseed yield, does it become feasible to grow your own fuel?
3. What is the break-even price per pound and diesel that would make it economically feasible to buy and crush oilseed for fuel without growing any crop?

There are cropping systems options that can be considered that includes oilseed production for biofuel, but in the interest of answering these three questions as succinctly and clearly as possible our economic example is based on:

1. A limited irrigation system: three crops in three years and including winter wheat: Corn/Spring canola /Winter Wheat
2. A dryland system: three crops in three years and including winter wheat: Corn/Spring Camelina/Winter Wheat

The rotation with spring canola allows the producer to harvest the oilseed in late July and plant back to winter wheat the same year. Our limited irrigation cropping system production costs differ from the costs of full irrigation by lower costs of nitrogen fertilizer and slightly lower irrigation costs. Moreover, the fixed cost per crop is lower in the spring oilseed/winter wheat rotation because there are three crops in three years as opposed to three crops in four years. The operating costs and direct costs assumed for this example are provided in Table 17. The nitrogen cost is very volatile. The price used is $0.6/lb. Note that oilseed meal (approximately 2/3 of harvest weight) from crushed oilseed is currently worth approximately $0.15/lb and has been included in the net return calculations on the assumption that it could be sold locally or used on the farm.

Limited Irrigation Rotation

Price $/lb	Alternative Yield (lbs/acre)					
	1800	2000	2200	2400	2600	2800
0.1	-167	-147	-127	-107	-87	-67
0.12	-131	-107	-83	-59	-35	-11
0.14	-95	-67	-39	-11	17	45
0.16	-59	-27	5	37	69	101
0.18	-23	13	49	85	121	157
0.2	13	53	93	133	173	213
0.22	49	93	137	181	225	269
0.24	85	133	181	229	277	325
0.26	121	173	225	277	329	381
0.28	157	213	269	325	381	437

1. Limited Irrigated Spring Canola Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) in Eastern Colorado.

Price $/lb	Alternative Diesel price($/gal)					
	2.5	2.8	3.1	3.4	3.7	4
0.1	246	276	306	336	366	396
0.12	202	232	262	292	322	352
0.14	158	188	218	248	278	308
0.16	114	144	174	204	234	264
0.18	70	100	130	160	190	220
0.2	26	56	86	116	146	176
0.22	-18	12	42	72	102	132
0.24	-62	-32	-2	28	58	88
0.26	-106	-76	-46	-16	14	44
0.28	-150	-120	-90	-60	-30	0

3. Limited Irrigated Spring Canola Break-Even Analysis – Per 2200 lbs Returns Over Total Cost Oilseed ($/lb) and Diesel Price ($/gal) in Eastern Colorado.

1. Producing canola under limited irrigation is profitable producing a positive net return of 49 $/ac
2. Producing seed and crushing is the most interesting option at current diesel price: 127 $/ac
3. Buying seed and crushing give a net return of $100 for every 2200 lbs crushed

Price $/gal	Alternative Yield (lbs/acre)					
	1800	2000	2200	2400	2600	2800
1.9	-33	2	37	71	106	141
2.2	-8	29	67	104	142	180
2.5	16	57	97	137	178	218
2.8	41	84	127	170	213	256
3.1	65	111	157	203	249	295
3.4	90	139	187	236	284	333
3.7	115	166	217	269	320	371
4	139	193	248	302	356	410

2. Limited Irrigated Spring Canola Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) as a function of diesel price, in Eastern Colorado

Figure 6: Canola Economic study under Limited Irrigation

At average yield of 2,200 lbs/ac under limited irrigation (2007 average trial yield), the net return at the current market price ($0.18/lb) would be $127/ac, when crushing on farm. The break even-point would be at $0.15/lb at yields of 2200 lb/ac or at $0.14/lb at yields of 2400 lb/ac. After several years of experimentation and experience in farmer's fields, we believe that average and sustainable limited irrigation canola yields of 2000-2400 lb/ac are realistically attainable. Even when the price of petroleum diesel is at $2.50/gallon and hypothetical yields of 1800 lb/ac, positive returns per acre would be expected for Straight Vegetable Oil (SVO) production on the farm with canola but not with camelina. At average yields of 2200 lb/ac and petroleum diesel at $2.50/gallon, net returns would be expected to be $96/ac

Dryland Rotation

Price $/lb	Alternative Yield (lbs/acre)					
	400	600	800	1000	1200	1400
0.1	-75	-55	-35	-15	5	25
0.12	-67	-43	-19	5	29	53
0.14	-59	-31	-3	25	53	81
0.16	-51	-19	13	45	77	109
0.18	-43	-7	29	65	101	137
0.2	-35	5	45	85	125	165
0.22	-27	17	61	105	149	193
0.24	-19	29	77	125	173	221
0.26	-11	41	93	145	197	249
0.28	-3	53	109	165	221	277

1. Dryland Spring Camelina Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) in Eastern Colorado.

Price $/lb	Alternative Diesel price($/gal)					
	2.5	2.8	3.1	3.4	3.7	4
0.1	112.0	125.6	139.1	152.7	166.3	179.8
0.12	92.0	105.6	119.1	132.7	146.3	159.8
0.14	72.0	85.6	99.1	112.7	126.3	139.8
0.16	52.0	65.6	79.1	92.7	106.3	119.8
0.18	32.0	45.6	59.1	72.7	86.3	99.8
0.2	12.0	25.6	39.1	52.7	66.3	79.8
0.22	-8.0	5.6	19.1	32.7	46.3	59.8
0.24	-28.0	-14.4	-0.9	12.7	26.3	39.8
0.26	-48.0	-34.4	-20.9	-7.3	6.3	19.8
0.28	-68.0	-54.4	-40.9	-27.3	-13.7	-0.2

3. Dryland Spring Camelina Break-Even Analysis – Per 1000 lbs Returns Over Total Cost Oilseed ($/lb) and Diesel Price ($/gal) in Eastern Colorado.

1. Producing camelina under dryland is profitable. At 0.18 $/lbs and 1000 lbs/ac, the net return is 46 $/ac.
2. Producing seed and on farm crushing bring the biggest net return: 81.5 $/ac
3. Buying seed and crushing has an equivalent net return that to only producing seed, but safer.

Price $/gal	Alternative Yield (lbs/acre)					
	400	600	800	1000	1200	1400
1.9	-45	-10	24	59	94	129
2.2	-40	-2	35	73	111	148
2.5	-34	6	46	87	127	167
2.8	-29	14	57	100	144	187
3.1	-23	22	68	114	160	206
3.4	-18	31	79	128	176	225
3.7	-12	39	90	142	193	244
4	-7	47	101	155	209	263

2. Dryland Spring Camelina Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) as a function of diesel price, in Eastern Colorado

Figure 7: Camelina Economic study under Dryland production

At average yield of 1,000 lbs/ac under dryland (2007 average trial yield), the net return at the current market price ($0.18/lb) would be $81.5/ac when crushing on farm. After several years of experimentation and experience in farmers fields, we believe that average and sustainable dryland camelina yields of 800-1000 lb/ac are realistically attainable. Perhaps equally important is that on-farm production of biofuel (independence from foreign energy) would make Colorado's food and feed supply more secure and less likely to be affected by world affairs beyond local control. In addition, the carbon footprint of Colorado agriculture would be smaller.

Table 13: 2006 Estimated Production Costs and Returns – Limited Irrigated Spring Canola, Colorado.

2008 Estimated Production Costs and Returns - Irrigated Spring Canola, Colorado

	Unit	Cost/unit	Quantity	**Cost/value per ac**	Cost per unit of production
Production	lbs.	0.11	3000	330	
Total Receipts				330	0.11
Direct Cost:					
Operating Preharvest					
Disc	Acre			2.66	0.006
Nitrogen	lbs.	0.60	120	72.00	0.164
Phosphate	lbs.	0.33	20	6.60	0.015
Potassium	lbs.	0.14	24	3.36	0.008
Sulfur	lbs.	0.21	10	2.10	0.005
Custom Fertilizer Appl	Acre			1.16	0.003
Seed	lbs.	7.00	5	35.00	0.080
Herbicide (Sonalan/treflan)	oz	0.40	24	9.60	0.022
Custom Herbicide Appl	Acre			1.55	0.004
Irrigation Energy	Acre			40.00	0.091
Irrigation Labor	hr.	10.00	1	10.00	0.023
Interest on Op.Cap	DOLS.				0.000
Total Preharvest:	DOLS.			184.03	0.419
Operating Harvest:					
Machinery Operating Cost/haul	bu.	0.24	50	12.00	0.004
Total Harvest				12.00	0.064
Total Operating Cost:				196.03	0.483
Property and Ownership Costs:					
Machinery replacement & Machinery Taxes & Insura	DOLS.			9.7	
General Farm Overhead	DOLS.			15	
Real Estate taxes	DOLS.			16	
Total Property and ownership costs:	DOLS.			40.7	
Total Direct Costs:				236.73	
Factor payment:				111.05	
Net Receipts - Factor Payments:				347.78	0.12
Net Return				-17.78	
Break-even to cover:	lbs			3,162	0.12

Table 14: 2008 Estimated Production Costs and Returns – Dryland Spring Camelina, Colorado.

2008 Dryland Spring Camelina in Northeastern Colorado						
		Unit	Cost/unit	Quantity	**Cost/value per ac**	Cost per unit of production
Production		lbs.	0.15	1000	150	
Total Receipts					150	0.15
Direct Cost:						
Operating Preharvest						
	Nitrogen	lbs.	0.6	40	24	0.0547
	Phosphate	lbs.	0.33	0	0	0.0000
	Potassium	lbs.	0.14	0	0	0.0000
	Sulfur	lbs.	0.21	0	0	0.0000
	Custom Fertilizer Appl	Acre			1.16	0.0026
	Seed	lbs.	2	2.5	5	0.0114
	Herbicide (Sonalan/treflan)	oz	0.4	24	9.6	0.0219
	Custom Herbicide Appl	Acre			1.55	0.0035
	Machinery Op. Costs	DOLS.			19.85	0.0452
Total Preharvest:		DOLS.			61.16	0.0942
Operating Harvest:						
	Machinery Operating Cost	DOLS.			15.2	0.0152
	Hauling	DOLS.			4	0.0040
Total Harvest					19.2	0.0641
Total Operating Cost:					80.36	0.1583
Net return					69.64	
Property and Ownership Costs*:						
	Machinery replacement & Machinery Taxes & Insurance	DOLS.			18.0	
	General Farm Overhead	DOLS.			6.6	
	Real Estate taxes	DOLS.			1.2	
Total Property and ownership costs*:		DOLS.			35.0	
Total Direct Costs:					115.4	
Factor payment*: land at 4.00%					19.0	
Net Receipts - Factor Payments:					134.4	0.13
Net Return with fixe cost					15.6	
Break-even to cover:		lbs			1,222	0.13
*Fix costs established in a three years rotation with three crops.						

SVO Production

As for the production of SVO, the following table shows the cost of a facility that would produce different amounts each year assuming a 24 hours per day operation, seven days out of the week for 40 weeks. These numbers should be used as a guide since every facility will be different. The large discrepancies between the numbers come from the range in equipment. The main manufacturers are found in Europe, India and China. European equipment is more expensive and of higher quality. Some distributers recommend only running the cheaper equipment when supervised. This will obviously change the numbers shown bellow. Since a lot of the equipment is modular, increasing capacity is not as complicated as a biodiesel or ethanol facility. However it is important that the equipment be used as continuously as possible in order to shorten the return on investment. For this reason, producers interested in starting a project should contemplate a cooperative ownership structure or sizing the equipment carefully.

Table 15: Facilities Cost according to their size

[redacted]

VI. Technical Issues with SVO

a. Oil Extraction

Once harvested, dried and cleaned, oil seeds must be pressed. Oil can be separated from the solid biomass of the seed by chemical or mechanical extraction.

i. Chemical Extraction

Chemical extraction uses a solvent, usually hexane, and is traditionally the method of choice in operations producing in the millions of gallons per year. Estimates from the soybean processing industry in the United States and the oil seed industry in Canada provide a fairly accurate operating expense of $.62/bushel or $0.0124/lb. This estimate includes utilities, maintenance, labor, administration and interest on capital expenses. Since hexane extraction uses 470 kWh per metric ton of seed (Ferchau, 2000), energy is a critical factor in determining the cost of production. Chemical extraction also uses a lot of water and requires operating permits from the Department of Health and Environment since the main component, n-hexane, is regulated as a

Hazardous Air Pollutant[13]. This strategy extracts almost all the oil with the resulting cake containing less than 1% oil.

ii. Mechanical Extraction

Mechanical extraction produces meal with a higher commercial value because it leaves 3% - 15% residual oil in the meal and does not contain residual chemicals. There are two broad categories of continuous mechanical expellers. Both use a screw however the pressure point in one is horizontally at the tip of the screw while the other screw applies pressure laterally at choke points in the screw.

Presses with lateral pressure are equipped with a screw that is in a series of barrel shims. Temperatures can reach 280 degrees F[14]. A die at the end of the screw can be adjusted depending on the size of the seed. These systems may require a ‘cooker’ to preheat softer seeds such as soy and may be equipped with a cooling system to keep the temperature constant. iCAST’s experience with one model that had multiple choke points along the length of the screw demonstrated that cleaning can be very time intensive. The high temperature and pressure can easily turn the seeds into a dense material that can clog the screw and make it very difficult and time consuming to disassemble. Other designs have only one choke point at the end of the screw, which may make cleaning easier.

Presses with a horizontal pressure use a screw to press the oil seeds on a die. The die can be changed to optimize the size of the whole depending on the size of the seed to be crushed. The pressure point in this system is much smaller resulting in a colder operating temperature. Softer seeds will not produce enough friction heat in this case so a heating element may be needed on the nozzle. iCAST’s experience with these presses conclude that cleaning can be done very quickly by unscrewing the encasing that holds the die in place. Since the pressure is horizontal unscrewing the die means relieving pressure from the point of oil expelling. This means even in the case of clogging and solidifying of the seeds, opening the screw chamber for maintenance can be easily done. These presses are generally smaller. Many are used in parallel in order to increase capacity.

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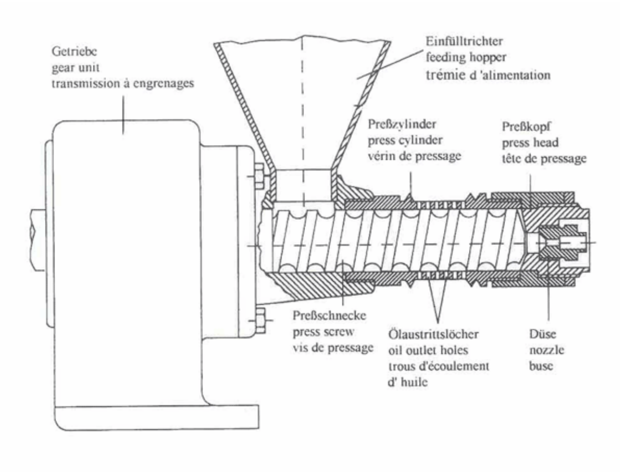
[13] Wakelyn, P., Wan, P., (2004). Edible oil extraction solvents: FDA regulatory considerations. Commodity Utilization Research, Agricultural Research Service.

[14] Interview with Robert Byrnes of Nebraska Renewable Energy Systems and Goyum distributor; Interview with Kingstar Manufacturer

Table 16: Komet Cold Press



iii. Operating an Oil Press

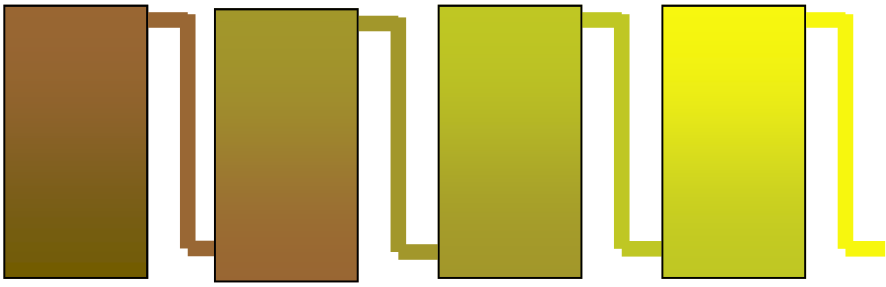
Oil presses are designed to operate for long periods of time. Some however require continuous monitoring while others can operate continuously if equipped with a sensor to ensure no clogging and a continuous supply of seeds. There is a startup time to all presses that includes pre-heating the press, running it at very slow speeds with a small supply of seeds and slowly accelerating the crushing speed to the desired rotations per minute. Faster operation will not extract all the oil. Each application must therefore evaluate the optimal production rotations per minute in order to get the greatest value from both the oil and the meal.

The meal will be the main product. It is therefore essential to identify nearby or on-site markets for it as it will significantly impact the economic viability of operating an oil press.

b. Oil Filtering & Refining

i. Sedimentation

Sedimentation is the least expensive and slowest method for cleaning oil. The higher density of the solid contaminants in the oil brings them to settle to the bottom of a bin. Four or five bins can be stringed together, connecting the top of the first the bottom of the second and so on allowing overflowing of clean oil.

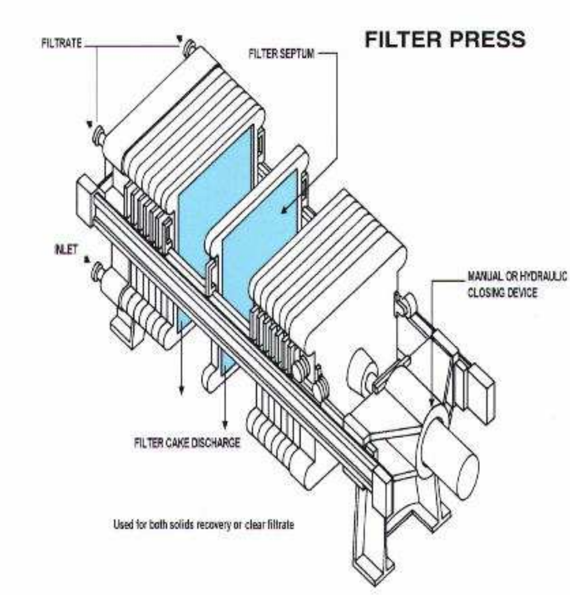


With ambient temperatures of 68 F, the Nordic Folkecenter for Renewable Energy removed all particles >8 µm. They recommend adding a bag filter to filter out the finer contaminants and do not recommend this system for systems much larger than 80 gallons per day.

Sedimentation takes time, 2 to 4 days to complete. It also leads to high losses of oil in the sediment. The sediment however can be re-pressed. Additionally, there is a risk of oxidization if the oil if left in the sedimentation bins for too long a period of time.

ii. Filter Press

Filter presses are the most commonly used technique for filtering oil. They consist of a series of filter plates that are held together with a hydraulic ram or screw. A pump fills the plates with oil. Once saturated, the oil will be forced out of the plates passing through the filtering membrane. Filter presses come in multiple sizes. Unfiltered oil is homogenized with the help of an agitator in order to ensure that the oil flows smoothly throughout the press. Cleaning involves separating the plates and easily removing the solid buildup.



iii. Centrifuge

Another technique that is gaining popularity is the centrifuge. A centrifuge uses the difference in specific mass of the vegetable oil and different contaminants, including water, to create a clean SVO stream. This strategy works very well however the SVO may need multiple passes through the centrifuge in order to remove all particles beyond 5 µm. From iCAST experience, it is important to size the centrifuge appropriately in order to minimize the cleaning needs.

iv. Phosphorous

Some oil seeds or beans have high levels of phosphorus, also known as phospholipids or 'gums'. According to experiments using rape (canola), keeping oil temperature below 100 degrees F during the extraction process will limit the amount of phosphorus in the final oil to 0.55% of total phosphorus[15]. The friction caused by hard seeds should be enough to keep this temperature constant however at startup and when crushing softer seeds, a heating element no hotter than 180 degrees F may be needed to avoid blockage caused by the extruded cake[16]. If this is impossible for a specific oil press, because of high operating temperature for example, removal of phosphorus, also known as 'degumming' will need to be done.

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[15] Ferchau, E., (2000, November). Equipment for decentralized cold pressing of oil seeds. Folkecenter for Renewable Energy. Retrieved Nov 4th, 2008 from http://www.folkecenter.net/mediafiles/folkecenter/pdf/dk/efdcpos_ef.pdf

[16] Ferchau, E., (2000, November). Equipment for decentralized cold pressing of oil seeds. Folkecenter for Renewable Energy. Retrieved Nov 4th, 2008 from http://www.folkecenter.net/mediafiles/folkecenter/pdf/dk/efdcpos_ef.pdf

Phosphorus must be removed because once in the exhaust stream, it will harm the catalytic converter resulting in higher NOx, CO and hydrocarbon emissions.[17]

Degumming oil requires adding an acid such as citric acid to react with the phospholipids and then filtering or centrifuging the sediment out. Do not use nitric acid as it will react with the glycerin in the svo chain.

c. Oil Storage

Oil will oxidize, reducing its fuel quality. It is therefore imperative to store SVO in a cool, dark environment with minimal airflow. The presence of oxygen will accelerate the polymerization into a solid varnish. Different oils have different shelf lives. For example, vegetable oil in an airtight container will have roughly a year long life.

d. Types of Oils

As outlined in the crops section, each oil crop has a specific oil profile. Nettles-Anderson[18] from Colorado State University points out that oils rich in monounsaturated fatty acids such as Oleic and Erucic acid will be in a liquid state at a lower temperature, making it a fuel that will flow more easily in the injection system. Anderson also describes that every additional unsaturated bond will lower the melting point. However, oils high in polyunsaturated acids are also called drying oils and are used as varnish, needless to say that this is not a good characteristic for fuel.

e. Engine Coking

Engine coking is a buildup of carbon deposits from unburned fuel that prevents the engine from running smoothly. Since SVO is more viscous, fuel injectors will have a harder time atomizing the fuel, which will hinder a complete burn. The larger particles that are not burned will coke and eventually build up. SVO's higher flash point and higher viscosity can cause larger droplets to be formed during the atomization of the fuel in a diesel engine. These droplets will not burn completely and may cause coking from carbon deposits on the pistons and head of the engine. This problem can be solved by heating SVO prior to combustion. An oil droplet combustion study shows that at temperatures between 210 and 266^{o}F (100-130 ^{o}C), coking problems are avoided. These temperatures are possible because SVO is stable up to temperatures of 392 ^{o}F (200 ^{o}C) in an oxidative atmosphere[19]. This study found that adding a small quantity of alcohol to SVO dropped the ideal combustion temperature to 176^{o}F (80^{o}C) meaning that certain SVOs can effectively be used as a fuel in properly converted engines. In older engines, specifically old tractor engines, no modification is required in the summer time.

[17] Ludwig, L., (2007, May). Heavy-duty diesel engine oil developments and trends. *Machinery Lubrication Magazine.* Retrieved Nov 4th, 2008 from http://www.machinerylubrication.com/article_detail.asp?articleid=1036)

[18] Nettles-Anderson, S., Olsen, D., (Submitted for publication) 2009 SAE World Congress.

[19] *http://www.biomatnet.org/secure/Fair/F484.htm*

f. Viscocity

SVO is different from diesel and as such can only function with limited success in modern diesel engines. Most technical issues arise from the greater viscosity of SVO. Table 17 underlines such difference between diesel, biodiesel and SVO. As soon as the temperatures increase, the differences among the fuels decrease. Hence, this issue can be resolved through simple engine conversion pre-heating the SVO before the combustion chamber.

Table 17: Fuel Viscosity

	Diesel	**Canola SVO**	**Biodiesel**
Density kgL^{-1} @ 60^oF ($15.5^o C$)	0.84	0.92	0.88
Calorific value MJL^{-1}	38.3	36.9	33 – 40
Viscosity mm^2s^{-1} @ 68^oF (20^oC)	4 - 5	70	4 – 6
Viscosity mm^2s^{-1} @ 104^oF (40^oC)	4 - 5	37	4 – 6
Viscosity mm^2s^{-1} @ 158^oF (70^oC)	4	10	4
Cetane number	45	~ 40 - 50	45 – 65

VII. Diesel Engine Conversion

Most successful SVO engines are equipped with indirect injection (IDI). These injectors are equipped with a pre-chamber that improves the atomization of the SVO. Although some individuals simply add a thinner to the SVO and use it in IDI engines, especially more rugged Cummins and Deutz engines, long term wear on the cylinders will shorten engine life. As for direct injection (DI) diesel engines, there are again some individuals that have reported success however the difference in viscosity between SVO and petro-diesel will hinder engine performance. To address this problem, there are two practical conversion strategies that allow an engine to run on SVO. The first consists of converting the engine so it may function with a single tank of SVO. The second is called the two tank system because it involves adding another fuel tank for the SVO.

a. Single Tank

A single tank conversion kit includes new injector components, glow plugs, an electrical fuel heater and filter, a temperature switch, a coolant-water heat exchanger to pre-warm fuel as well as additional pipes and cabling. The heated oil and new injectors will allow the engine to handle the more viscous fuel, enabling complete atomization and eliminating the risk of carbon buildups.

Many engine conversion patents are held by Elsbett, a German company, with four partners servicing the US.[20] Elsbett also has an engine specifically designed to run on SVO. However, the company only has the two-tank systems for agriculture equipment, which represents an opportunity for American companies to take a leadership role.

Figure 8: Elsbett Kit System

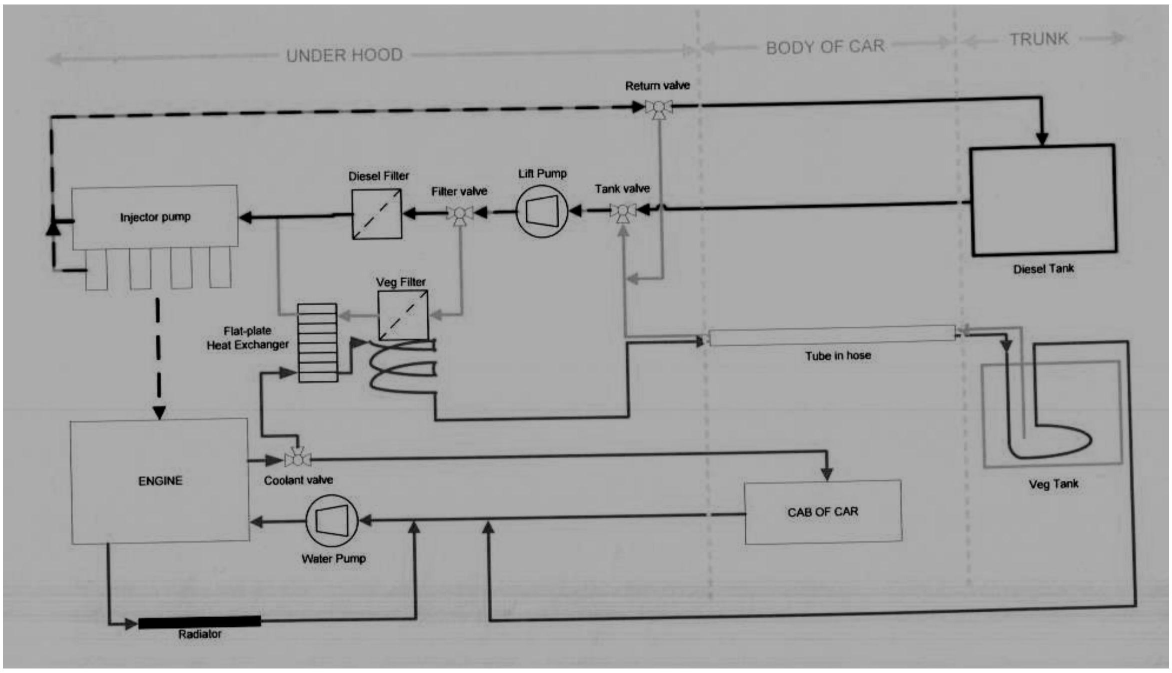
b. Two-Tank System

This system is more popular due to its accessibility to enthusiasts with mechanical skills. The process involves starting the engine on diesel or biodiesel in order to heat up the engine and the SVO. The fuel supply line is then switched to the second tank, which contains SVO. Before turning the engine off, the engine runs on diesel or biodiesel in order to flush SVO out of the engine.

The two-tank conversion system includes an additional tank for SVO and a switching mechanism. Ideally, the SVO tank will be near the engine to recover heat however some prefer to use the existing tank for SVO because it is usually larger than the additional tank. The supply line of the engine is then connected to both tanks. A switch allows the operator to choose which fuel to use. There is usually a heater on the SVO supply line that recovers heat from the coolant system. Most systems also have an additional filter and pump. The SVO line must be heated in order to combust efficiently. This is usually done by recovering the engine coolant heat. Filters will also need to be heated with the help of an electric ring heater.

[20] http://www.elsbett.com/us/local-partners.html

Figure 9: 2-Tank Schematic by Curt Busby of Surcharge Electric



VIII. On-Farm Use of SVO: Policy and Legal Issues

One of the most complicated challenges surrounding a sustained movement for the use of straight vegetable oil (SVO) to fuel Colorado's and America's farms, are those dealing with regulatory and legal issues. These considerations include, but are not limited to, the following:

- Steps for developing a recognized SVO standard in the United States and for it to be recognized as an approved fuel by the Environmental Protection Agency (EPA).
- Political climate in the United States
- Economic climate in the United States
- Taxation (Federal, state, local)
- Permitting (mostly local)
- Diesel Engine Manufacturer's Warranties

- Diesel Engine Conversion Kit Warranties
- Certifying Conversion Kit Installers
- Overcoming the Hurdles

a. SVO Standard

Colorado government agencies (Governor's Office of Management and Conservation, Colorado Department of Agriculture, Colorado Governor's Energy Office and the Denver Regional Office of the US Department of Energy), should develop an interim standard for SVO that can serve as a model for a national standard. These agencies should work with the American Society for Testing and Materials and relevant stakeholders to create a vegetable oil standard and work with the EPA to recognize SVO as a legitimate fuel. Additionally, we need to learn from new research about the use of SVO as a fuel and improve upon the German standard.

As was the case for bio-diesel and ethanol, establishing a recognized fuel standard for straight vegetable oil is necessary if straight vegetable oil is to be a viable fuel. The viability of any fuel, be it fossil fuels, bio-diesel or SVO, depends on the successful establishment and implantation of a recognized standard.

One of the main problems with using straight vegetable oil as a fuel source is that countless variables can affect the quality of the final fuel product. The type of input seed, the location from whence that seed came from, the harvesting time/method/climate, and the seed cleaning/pressing methods are some of the main variables that affect that final fuel product. However a fuel quality that is dependent upon many variables is not exclusive to straight vegetable oil; in fact, countless variables also impact the final fuel products of bio-diesel, ethanol, and even fossil fuels. The reason for establishing a recognized standard for anything is to force producers to make their products meet certain requirements; and users can use those products with a certain amount of confidence and with reasonable expectations.

In the United States, The American Society for Testing and Materials (ASTM) serves as the industry organization that establishes the consensus standard for fuels. As such, the American Society for Testing and Materials (ASTM) should put straight vegetable oil through its rigorous evaluation and testing process, and establish a standard for SVO. ASTM Committee D02 on Petroleum Products and Lubricants is responsible for fuel standards, and the committee is comprised of fuel producers, engine manufacturers and third-party interests (users, government agencies, consultants). The committee makes use of a ballot process to determine whether a standard is achieved, and one negative vote could effectively prevent a standard, making the ASTM a true consensus organization. As such, an ASTM standard is hard to achieve and can take years to establish. Although the ASTM process represents a road-block for establishing an SVO standard, that same process ensures that if and when an SVO standard is established, the complications surrounding the use of SVO will be well mitigated. Most importantly, the United States Environmental Protection Agency relies heavily on ASTM-established standards when dealing with the official recognition of fuels. An ASTM-established SVO standard would certainly support the cause for SVO to be recognized as a fuel by the EPA.

Colorado farms have and continue to exist as experimental testing grounds for on-farm SVO use. Researchers and scientists from Colorado State University Extension and the Great Plains Agricultural Research Station in Akron, CO, have worked with and will continue to work with Colorado farmers to explore the feasibility of on-farm SVO use. Colorado government agencies should collaborate and expand its support for an on-farm SVO program. Such an initiative should lead to an interim SVO-standard, which could serve as a model and expedite the nationwide standard. These agencies would lend credibility to an alternative fuel that would demand attention and consideration from the ASTM, and the EPA.

Creating an SVO standard would force SVO producers to strive for consistency in their end product. While producers may struggle initially to meet those standards, the establishment of such a standard will help the long-term viability of SVO as a sustainable fuel for on-farm use. As producers, scientists and engineers work together, best practices for the selection/planting/harvesting of seed crops and for SVO production methods will be developed, and that knowledge can be disseminated to a broader community. Similarly an established SVO standard will give engine manufacturers an improved understanding of what will fuel their existing diesel engines, and may even encourage manufacturers to develop stock engines that can run on straight vegetable oil. For example, engine manufacturers strongly encouraged the biodiesel industry to develop an ASTM standard for biodiesel so these manufacturers could provide their customers with a more definitive judgment on how the fuel could affect engine and fuel systems operations relative to the fuel the engine was originally designed for. Thus, an established SVO standard will help ease the discomfort that currently exists amongst farmers who find the potential for economic and environmental benefits to be attractive but are reluctant to rely on SVO because of the many uncertainties surrounding its production and use.

b. Political Climate

Given the shifting political climate, this project team recommends differentiating SVO from other biofuels and educating the public and policy makers regarding the opportunities of SVO. This team also recommends completing lifecycle assessments of SVO produced and used in Colorado and compare it to other lifecycle and carbon assessments completed on various biofuels.

The recent election of Barack Obama as President of the United States and his specific support for sustainable farm fuels such as biodiesel, combined with major conflicts and instability in oil-producing nations and strained relations between the United States and these oil-producing nations has bolstered the national support for alternative energy initiatives.

To begin, President-elect Obama has made it abundantly clear that a center-piece of his economic, domestic and foreign policy plan will be centered on creating jobs and stimulating innovation by supporting alternative energy projects.

The Obama-Biden comprehensive New Energy for America Plan promises to:

- Implement an economy-wide cap-and-trade program to reduce greenhouse gas emissions 80 percent by 2050.
- Help create five million new jobs by strategically investing $150 billion over the next ten years to catalyze private efforts to build a clean energy future.
- Eliminate current oil imports from Middle East and Venezuela within 10 years.
    - Increase fuel economy standards.
    - Create $7000 Tax Credit for Purchasing Advanced Vehicles
    - Establish a National Low Carbon Fuel Standard
- Create millions of new green jobs
    - Ensure 10 percent of Our Electricity Comes from Renewable Sources by 2012, and 25 percent by 2025.
    - Deploy the Cheapest, Cleanest, Fastest Energy Source – Energy Efficiency

If a standard vegetable oil becomes a cost-effective alternative fuel source for America's farms, then an SVO for farm fuel autonomy initiative could successfully support many of the goals of the New Energy for America Plan:

- If small family farms can become self-sustaining, they will certainly help reduce greenhouse gas emissions. In fact in a report comparing the energy balance of rape seed oil (canola oil) to convention fossil fuels, the Danish Folk Center for Renewable Energy states that, "Rape [seed] has a strongly positive energy and CO_2 balance, and rape seed oil can be termed genuinely CO_2 neutral because the CO_2 reductions from the rape straw by far surpasses the CO_2 emission by cultivation and processing." That positive balance would also be positively augmented in this proposed on-farm SVO program because the diesel equipment used for cultivation and processing would also run on SVO.
- Moreover, the success of small family farms in reducing their emissions by using SVO could encourage larger farming operations to adapt SVO. Any serious consideration of an expanded on-farm SVO program, will require a "lifecycle assessment" of on-farm SVO to determine if locally produced and used SVO is sustainable, and if so, to quantify the sustainability. If family farming operations can become self-sustaining, with the help of state and federal agencies, this may provide greater profit margin. It is vital to keep farmers farming to reduce imports and improve the United States' trade balance. It is also vital to keep farmers farming to prevent the labor markets from being flooded with additional workers, which would increase unemployment rates and put additional strains on government resources.
- If small family farms can produce their own fuel, then there will be less demand for oil, thereby making it easier to eliminate dependence on Middle-Eastern and Venezuelan oil.
- Farming operations, large and small, would have a natural place in a nation-wide cap-and-trade program, and many small farms can be encouraged to switch to SVO by carbon cap limits and by economic incentives given to those who effectively emit less than the cap limits.

- The part of the Obama-Biden Energy Plan that seeks to increase fuel economy standards and offer tax credits for the purchase of advanced vehicles may provide additional economic incentives for farm equipment manufacturers to develop SVO-compatible products and for farmers to use those products.

Even though the Obama-Biden Energy Plan has set definitive goals, the means through which those goals will be achieved remains a question. President-elect Obama has made it clear that his administration will be very open to experimentation. They will look at various solutions and try different ones to see which will work. In the past, there has been a general reluctance to look at SVO as a legitimate part of the solution for our nation's energy and environmental problems. The National Renewable Energy Laboratory released a brief fact sheet regarding the use of SVO as a fuel. In that report, the NREL suggested that SVO caused too much long-term engine damage to warrant serious consideration as a fuel. However, the NREL report contains inherent shortcomings. First, it overlooks the fact that not all SVO have a desirable oil profile. A high-quality SVO can run relatively safely in diesel engines with the appropriate modifications. In a report by Syndi Nettles-Anderson from Colorado State Extension, she recommends using SVO that are "higher in saturated and monosaturated fats, and use a retrofit kit/heating system with a new injector for direct inject engines. This will provide a lower emissions profile and increased engine longevity." The optimal fuel quality recommended in the Nettles-Anderson report is exactly what a SVO standard would demand of SVO producers.

Despite past reservations about an expanded SVO program, the incoming administration may be much more open to trying SVO as one solution to our nation's problems. SVO for on-farm use is attractive because it seeks to alleviate not just one, but many of our nation's problems. It can be part of the solution to the United States energy, economic and environmental woes. The problem is that few policy-makers have given SVO an opportunity, but this administration can change that.

c. Economic Climate

It is prudent and necessary to explore SVO for on-farm use because the economic outlook for agriculture is uncertain, and the long-term outlook for fuel prices indicate that prices will return to unfavorably high levels.

The United States domestic economy and the global economy as a whole have experienced significant downturns in the last two fiscal quarters, and will probably continue to decline in the next two quarters. Financial institutions worldwide have been belabored by weak investments, and many traditionally stalwart institutions have failed or would have failed had governments not intervened. Tight credit markets have hurt businesses and consumers. Unemployment is rising in the United States, while housing prices and manufacturing continues to decline. In fact, on December 1, 2008, the National Bureau of Economic Research proclaimed that the economy is in the eleventh month of a recession.

While the agricultural sector appeared to have weathered the economic storm, recent market events indicate that the agricultural sector may be lagging in terms of when it feels the effects of the larger recession. Crop prices have recently fallen, and it appears that the commodities boom may become a bust. Problematically for farmers, input costs continue to rise. The United States Department of Agriculture reports the following:

> The rising cost of fuel and other products helped drive U.S. farm production expenditures to a record $260 billion in 2007. […] Increasing petroleum costs meant farmers not only paid more for fuel, but also for fertilizer products, chemicals and transportation services. Indirectly, fuel prices and the growth in ethanol production also led to higher crop prices, resulting in increased cost for livestock feed.[21]

Other market fundamentals suggest that the challenge of high-input costs, largely resulting from fuel costs, will continue to exist. Although demand has temporarily slowed, and oil prices have fallen from record-highs, the long-term outlook for the price of fuel remains bleak. It does not appear as if the constant instability in the oil-producing regions of the Middle East will cease in the foreseeable future. Furthermore, many analysts predict that emerging economies will continue to place a major strain on the oil supply in the long-run. In short, it is almost a certainty that oil prices continue on an up-trend in the mid-to-long-term. Additionally, the input costs for farmers have historically outpaced the price level for crops, as the chart below demonstrates. Even if commodity prices recover, there remains a reasonable expectation for input prices to outpace commodity prices, which would further diminish profit margins for farmers.

[21] http://library.osu.edu/sites/guides/csegd.php#otherfour

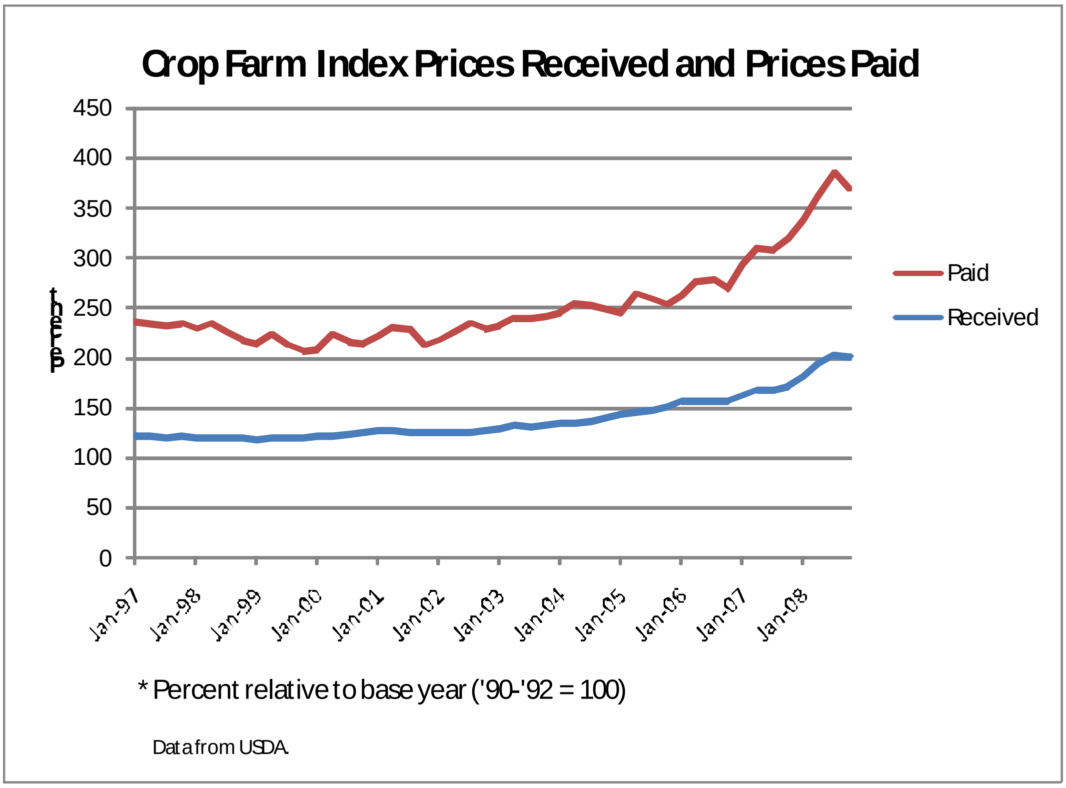


Figure 10: Crop Farm Index Prices Received and Prices paid (Source: USDA)

There also exists a short-term economic justification for turning to SVO for farmers. Farmers receive loans to fund their farming operations in the beginning of each year. As such, farmers successfully secured their loans for this year's farming operations before the credit crisis hit. However, when these same farmers return to the banks for their funding needs next year, they will find that loans will be much more difficult to secure. They would need much more collateral to get loan approval. Some farmers will experience a funding crunch. Additionally with rising input costs, the credit restriction crunch that will hit farmers offers an even greater incentive to explore the possibility of growing and producing their own fuel, allowing use of their cash resources on something other than fossil fuels.

d. Taxation

Federal and state fiscal policy remains favorable for farmers, and for those using alternative fuel. As such, farmers who use SVO should find added financial benefits, such as additional subsidies, tax credits and/or exemptions for their investment in SVO and SVO-related products. It is important that SVO be standardized and recognized so that tax credits that relate to alternative energy solutions will be given to those who use SVO.

If SVO is manufactured to be bought or sold, then taxation issues certainly become complicated. However, since this report only deals with SVO that farmers produce for their own use, federal and local taxation issues may not even apply.

However, farmers will likely be able to get tax deductions for their investment in SVO production equipment. This is a likelihood because the United States tax code and fiscal policy already heavily favors farmers and farming operations, and it is a reasonable expectation to say that this will not change within the foreseeable future. Additionally, as mentioned in the section about the political climate, farmers may even be able to claim an additional $7000 in tax credits for purchasing a vehicle that can be converted to run on SVO.

Most importantly, drought years often see producers without any tax liability in Colorado. With this in mind, policy should foster grant and low interest loan programs rather than tax incentives. This will create a larger incentive and play a larger part in encouraging early adopters in Colorado.

e. Permitting

Permitting is a fairly localized issue, and should not represent a major challenge for farmers looking to produce SVO for on-farm use.

Most permitting issues will arise at the local level, and government officials such as the town clerk, the zoning administrator, the planning commission and the public works department would be good resources to contact when beginning SVO production. These permitting issues will most likely revolve around the production process and facilities involved with the production of SVO. Unless the facilities in question are large-scale productions, permitting issues ought to be minimal. In fact, SVO has a completely benign environmental impact, and is not considered a toxic chemical by any means, which should simplify, if not eliminate, environmental permitting issues.

f. Diesel Engine Manufacturer's Warranties

Government agencies at state and local levels need to continue to work with engine manufacturers to facilitate research and development of SVO-compatible engines.

Typically, diesel engine companies warranty the products they make – engines. These companies warranty their engines for “materials and workmanship.” If there is a problem with an engine part or with engine operation due to an error in manufacturing or assembly within the prescribed warranty period, the problem will be covered by the engine company. Usually, engine companies will define what fuel the engine was designed for and will give recommendations as to what fuel users should put into their engines in the operations manual.

Diesel engine companies do not deal with fuel so these companies will not warranty fuel. Diesel engine companies do not warranty petroleum-based fuels, bio-diesel, and will not warranty SVO as fuel. Any engine problems caused by fuels do not receive warranty coverage from diesel manufacturers. Fuel quality is the responsibility of fuel manufacturers.

The issue with warranties from diesel engine companies is whether they will void the engine warranty itself if SVO is used with a conversion kit. Will diesel engine companies void their "material and workmanship" warranties for users who run the engines on SVO? In the case of biodiesel, many diesel engine manufacturers will still consider the warranty to be effective when biodiesel blends are at or below a certain level. Currently, most diesel engine manufacturers will still cover a warranty if the blend is 20% biodiesel or less, but an engine running on anything higher can effectively void a warranty. Thus, it is probable engine manufacturers will void warranties on engines running straight vegetable oil.

While diesel engine manufacturers will void warranties due to SVO-use in their engines, they are not opposed to participating in the research and development aspect of SVO-use in their engines. Engine manufacturers have provided engines and vehicles for SVO research teams in hopes of facilitating the growth for SVO-use in their engines. There is a high likelihood that diesel engine manufacturers will continue to do their part to contribute to the research and development efforts surrounding SVO-use in their engines.

This is another important reason for why a SVO standard must be achieved by the ASTM and recognized by the EPA. Such a standard would encourage engine manufacturers to develop engines that can work more efficiently with conversion kits and to develop engines that allow for SVO to run in their engines. Having manufacturer's warranty coverage would be critical.

Automakers and engine manufacturers have recently faced Congressional scrutiny because of their woeful financial situations and the poor performance of their companies. It appears as if the government is willing to support the auto industry, but they will be subjected to strict governmental oversight. This presents a new opportunity for the government to strongly encourage automakers and engine manufacturers to dedicate resources to engines that can run on alternative fuel sources.

g. Diesel Engine Conversion Kit Warranties

A SVO standard should be established providing conversion kit companies with specification to manufacture their kits to meet specific standards which could lead to conversion kit warranties.

As the SVO fuel movement continues to grow, there is a reasonable expectation that all related industries could develop accordingly. Manufacturers of engine conversion kits will be one of the key players in the long-term success of the SVO movement. It is highly unlikely that conversion kit manufacturers will take on liability related to any diesel engine problems caused by the use of SVO. The handful of conversion kit manufacturers surveyed for this report said that their companies will warranty the conversion kits, but that they have no control over the fuel pumped through their kits and the engines, and thus they will not warranty anything beyond their kits.

The goal is that as SVO research and development progresses, engine technology and conversion kit technology will improve, thereby limiting the problems associated with SVO-use in diesel engines. An established ASTM SVO standard and EPA-recognition would ensure that conversion kit providers know what fuel specifications their conversion kits would have to deal with.

Initially, it will be important for conversion kit manufacturers to work with diesel engine manufacturers to provide end-users a positive experience using SVO as a fuel. As stated before, engine manufacturers are opposed to providing warranty coverage to engines that run on SVO, but they are not opposed to the use of SVO itself. Because conversion kit manufacturers represent a vital part for the use of SVO in diesel engines, it will be necessary for engine manufacturers to work with conversion kit manufacturers. This may also be step towards providing a quality assurance/control mechanism in which conversion kits can be evaluated. Additionally, conversion kit companies working with engine manufacturers may provide the first step to improve conversion kits and eliminating conversion kits that damage diesel engines. It will become important for conversion kits to be rigorously evaluated by all who are involved in the industry.

As the SVO industry matures, it is probable that engine manufacturers will begin dedicating research and development resources to capture the SVO market. This likelihood increases as the big three American auto manufacturers rely on government financial support for survival. As a condition for government support, American auto manufacturers must focus on energy efficient vehicles and vehicles that are compatible with alternative fuels. If SVO does become a viable fuel with adequate demand, engine manufacturers may roll-out SVO-flex-fuel engines that eliminate the need for conversion kits. While potentially having a negative impact for conversion kit manufacturers, it would be a positive development for the SVO industry.

h. Overcoming the Hurdles:

Establish an SVO trade group to spearhead the effort to make SVO a recognized fuel.

Readers may be asking who should spearhead the efforts above or how those stated goals ought to be achieved and that remains a very good question. SVO for on-farm use as a fuel can only succeed if everyone in the industry – from farmers, to engine manufacturers, to mechanics, to conversion kit manufacturers, to government officials, to agricultural activists and to environmental activists – comes together to define and tackle the issues. The most important call-to-action in this report is for those with a stake in the success of SVO for on-farm use to establish an industry trade group, akin to the National Biodiesel Board. This SVO trade group would be responsible for driving the process that is necessary in order for ASTM to establish a standard and for the EPA to recognize it. This trade group could begin the process of creating an interim SVO standard for Colorado. Part of that process is for the trade group to provide quality assurance and control measures to ensure that the fuel, the conversion kits and the diesel engines running on SVO are optimal. Also, this trade group could help establish a certification process for conversion kit installers. This group will facilitate networking necessary for this project to be a success. Finally, this group will serve as an information generator, working to disseminate best practices as it relates to the various aspects of SVO-use in diesel engines.

IX. Survey of producers

The purpose of this project was to build SID (Seeds Into Diesel) and use it to raise awareness of the production of biodiesel with oilseeds. SID is a mobile biodiesel demonstration unit that covers the process from crushing oil seeds, by transesterification, to washing. Mounted on a trailer, it can easily be moved from one place to another. 1229 producers attended SID workshops in the past 16 months.

Table 18: The SID demonstrations during the summer.

Date	Location	Number of people
June 6th	Akron	20
June 6th	Holyoke	30
June 10th to 14th	9 locations within CO	300
July 26th	Lingle WY	50
August 1st to 4th	WY	140
August 21st	Akron	107
September 8th	Fort Collins, Ag Day	100

Figure 11: iCAST Engineering Project Manager Micah Allen presenting to farmer group.

Throughout this projects life, iCAST worked with 82 university students. See the table bellow for a list of partnering organizations, including Universities. iCAST also worked with a high school student on his science fair project. SID has become a beacon for Colorado producers. Even after the extensive presentations done, conference organizers continue to request its presence. Having a working unit that producers can see and work with has proven to be indispensible to convincing them of the feasibility of this technology and helping them become part of its widespread adoption. Most importantly, this project has laid the foundation for multiple farm scale projects that will soon become the seeds of a transformation that will strengthen Colorado's agricultural sector.

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Appendix A

Company		Contact	phone	e-mail	locations	Service	Cost
Elsbett	http://www.elsbett.com/us/about-us/introduction.html		++49 (0) 9173 79 445 0	info@elsbett.com	Germany	Conversion Kit	$2500-$3000
Grease Car	http://www.greasecar.com/index.cfm		(413) 534-0013	ethan@greasecar.com	Springfield, MA	Conversion Kit	$1500-$2000
Plant Drive	http://www.plantdrive.com/		510-841-3606	craigreece@plantdrive.com	Northern California	Conversion Kit	$450 (does not include tank +$400)
Golden Fuel Systems	http://www.goldenfuelsystems.com/index.php		1-866-473-2735.		Springfield, MO	Conversion Kit	$4000-$6000
RapsTruck	http://www.rapstruck.de/		05103 - 70 441 -0	info@rapstruck.de	Germany	Conversion Kit	
FryBrid	http://www.frybrid.com/		206-322-6242	info@frybrid.com	Seattle, WA	Conversion Kit	$1600-$2800
Grease Kings	http://www.greasekings.com/	Rich Porras	(916)470-8827	Rporras@greasekings.com	Sacramento, CA	Conversion Kit	$235-$425
Goat Industries	http://www.vegetableoildiesel.co.uk/conversionkits.html	Patrick Whetman	44 (0) 7818 691255	sales@vegetableoildiesel.co.uk	UK	Conversion Kit	
Colorado Biodiesel	www.coloradobiodiesel.com	Tom Judd	303.800.4650	coloradobiodiesel@comcast.net	Boulder, CO	conversion, engine research, development	
Suncharge Solar Electric		Curt Busby	(970) 493-2695	curt@xyzworks.com	Masonville, CO	Consultant	