Emission Benefit From Firing Orchard Residue at Delano Energy Company

Final Report

Prepared For

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1.0 Executive Summary

This report compares the 1996 emissions associated with processing, trucking and controlled combustion of orchard residues at Delano Energy Company (DEC) to the emissions that would have been generated had the fuel been open field burned. It was determined that combusting orchard residues as fuel at DEC resulted in a significant reduction in emissions of all pollutants every month of the year. In 1996, had the orchard residues utilized at DEC been open field burned, 7451 tons of criteria pollutants would have been emitted compared to the 262 tons of emissions associated with controlled combustion of the fuel at DEC, or a 96 percent reduction in emissions. Similarly, 5458 pounds of PAH would have been emitted compared to the 0.67 pounds associated with combustion at DEC. One of the benefits of the proposed California Air Quality Improvement Initiative is that these emission reductions are anticipated to continue. Further, an additional 2000 tons of criteria pollutants and 1500 lbs of PAH would be avoided due to increased diversion of orchard residues to DEC.

2.0 Introduction

One objective of the proposed California Air Quality Improvement Initiative is to reduce emissions from open field burning of agricultural waste by providing an incentive for it to be utilized as a power plant fuel. In Kern County, where Delano Energy Company is located, almond orchards are a significant source of biomass fuel. The fuel consists of orchard removals and prunings. When orchards pass their prime, they are removed and replanted with more productive varieties. The old trees are referred to as "removals". Removals are currently either open field burned, cut for residential firewood, or chipped and transported to biomass power plants. Orchard prunings are most often open field burned because it is too expensive to gather, chip and transport to the power plant.

Economics aside, this study provides an assessment of the emission benefits associated with processing, transporting, and controlled combustion of agricultural waste at a biomass power plant as compared with open field burning. Specifically, the emissions generated by controlled combustion of almond tree waste in Delano Energy Company's (DEC's) fluidized bed boilers in 1996 are compared to the emissions that would have been generated if this waste had been open field burned. The pollutants evaluated include: NO_X, CO, SO_2, PM_{10}, total hydrocarbons (THC), and polyaromatic hydrocarbons (PAHs).

Depending on the reader's perspective, the benefit associated with diverting agricultural fuel to DEC may be evaluated in two different ways. First, if the reader is interested in the bigger picture of how much benefit is derived from allowing agricultural fuel to be diverted from open field burning to DEC, a net benefit would be calculated. One would determine the amount of agricultural fuel burned by the plant, estimate the corresponding open field burning emissions, and subtract out the emissions associated with collecting, transporting, processing and firing the waste in the steam generator. Alternatively, if the reader is more rooted in reality and takes the perspective that the steam generator is permitted and will continue to operate regardless of the fate of the local agricultural fuel, the benefit is simply the avoided open field burning emissions.

Both perspectives are accommodated in this analysis since the reader may choose whether or not to subtract the emissions associated with firing agricultural fuel at DEC.

Section 3 of this report presents the emission factors for open field burning of almond tree waste. Section 4 presents the emissions associated with processing, transporting, and controlled combustion at DEC. The results are compared and discussed in Section 5.

3.0 Open Field Burning Emission Factors

To estimate emissions from open field burning of almond tree waste (removals and prunings), the following sources were considered:

- Recent experiments conducted in a wind tunnel at UC Davis[1] and sponsored by the California Air Resources Board
- Experiments conducted for the California Air Resources Board in the 1970s[2,3]
- AP-42, the US EPA's compilation of emission factors[4]

The recent work at UC Davis consisted of burning piles of various biomass fuels including almond tree prunings within a wind tunnel. The exhaust stream flowed from the wind tunnel through a stack and was analyzed for NO_X, CO, CO_2, SO_2, THC, CH_4, PM, PM_{10}, $PM_{2.5}$, polyaromatic hydrocarbons (PAHs) and VOC. This work is the only source for PM_{10}, $PM_{2.5}$, PAH and VOC emission factors. It was found that 98 percent of the particulate matter has a mean diameter less than 10 microns and 93 percent is less than 2.5 microns. Because of the limited number of tests conducted, the author has stated that a 50 percent error should be applied to these emission factors[5].

The work from the late 1970s was conducted by Ellis Darley and consisted of burning prunings under a hood/stack and sampling the exhaust stream for NO_X, CO, SO_2, and PM. EPA's compilation of emission factors, AP-42, is based on work by Darley from the early 1970s. Although no error bands are recommended by the author, a survey of the data indicates that the scatter is within 12 percent of the reported average values.

Tables 1 and 2 present the open field burning emission factors for almond tree waste provided by the sources mentioned above. Table 1 provides a summary of the reported criteria pollutant emission factors for open field burning of almond tree waste. The wind tunnel emission factors were reported on a dry basis. To convert to an as fired basis, a fuel moisture content of 35 percent was assumed. An average of all the values except those obtained from "roll-on" tests is calculated; the "roll-on" data were obtained by rolling fresh fuel on the top of an older, smoldering fire. These conditions produced higher emissions and were excluded from the average because "rolling-on" is not considered a normal burning practice.

The polyaromatic hydrocarbon (PAH) emission factors for open field burning of almond tree waste are provided in Table 2. The reported emission factor in mg per kg of dry fuel has been converted to a wet basis by assuming a 35 percent moisture content. Emissions of PAH are estimated to be 9.3 mg for every kg of wet fuel burned.

Table 1. Criteria Pollutant Emission Factors for Open Field Burning of Almond Tree Waste

	CARB 1996 35% H_2O[1,2] lb/ton	AP-42[3] lb/ton	Darley[4], lb/ton			Darley[5] Cold Piles 26% H_2O	Average[6] lb/ton
			Cold Piles		Roll-on		
			39% H_2O	26% H_2O	39% H_2O		
CO	41.5	46	37.4	20.1	43.4	29.2	34.8
NO_2	4.7					3.2	4.0
SO_2	0.1					0.3	0.2
CO_2	2,383						2,383
PM_{10}	5.6						5.6
$PM_{2.5}$	5.3						5.3
THC	7.3	8	6.9	3	8.9	4.5	5.9

1. Reference 1. Values reported on dry basis, assumed 35% moisture to arrive at as fired
2. Due to velocity measurement errors authors recommend using factors based on calculated
3. Based on 1974 and 1975 Darley work.
4. Reference 3. Cold piles are emissions from a single pile. Roll-on refers to rolling new fuel onto old
5. Reference 2.
6. Average of all values but Darley's Roll-on.

Table 2. PAH Emission Factors for Open Field Burning of Almond Tree Waste

Pollutant	PAH Emission Factors		
	mg/kg fuel[1]		lb/ton fuel
	dry	35% H_2O	35% H_2O
Naphthalene	7.307	4.750	9.50E-03
2-Methylnaphthalene	0.145	0.094	1.89E-04
Acenaphthylene	2.667	1.734	3.47E-03
Acenaphthene	0.178	0.116	2.31E-04
Fluorene	0.046	0.030	5.98E-05
Phenanthrene	2.039	1.325	2.65E-03
Anthracene	0.319	0.207	4.15E-04
Fluoranthene	0.524	0.341	6.81E-04
Pyrene	0.447	0.291	5.81E-04
Benzaanthracene	0.214	0.139	2.78E-04
Chrysene	0.206	0.134	2.68E-04
Benzo[b]fluoranthene	0.043	0.028	5.59E-05
Benzo[k]fluoranthene	0.05	0.033	6.50E-05
Benzo[a]pyrene	0.028	0.018	3.64E-05
Benzo[e]pyrene	0.017	0.011	2.21E-05
Benzo[ghi]perylene	0.003	0.002	3.90E-06
TOTAL PAH	14.233	9.251	1.85E-02

1. From 1996 CARB Wind Tunnel Experiments, Reference 1.

4.0 Emissions Associated With Power Generation

The boilers at DEC fire a mix of agricultural fuel (almond tree waste) and dry urban waste. In 1996, the fuel mix consisted of 63 percent agricultural fuel and 37 percent dry urban fuel. The total amount of agricultural fuel fired was 295,000 tons. Because DEC is required to obtain emission offsets, all of the agricultural fuel delivered to the plant comes with documentation certifying that it would otherwise have been open field burned. An example of a certification document is provided in the Appendix. The fuel is delivered to the plant at the time that it would otherwise have been open field burned (orchards do not have storage capacity), and the plant typically maintains a 30 day inventory of agricultural fuel. During the peak removal season, the inventory may be as high as 45 days. Therefore, it is correct to state that all the agricultural fuel received at DEC would otherwise have been open field burned and further, the time that this fuel is fired is approximately coincident with the time that it would have been open field burned. This is an important point when considering the seasonality issue of diverting agricultural waste from open field burning to DEC.

The emissions associated with firing agricultural fuel at DEC consist of: off-site fuel preparation and transportation emissions, boiler emissions, and emissions from on-site diesel equipment. The equipment can be summarized as follows:

Off-site and Transportation:	Bobcats to load waste onto chipper Chipper Trucks
Boilers:	Unit 1 fluidized bed boiler Unit 2 fluidized bed boiler
On-site Diesel Equipment:	Unit 1 emergency generator Unit 2 emergency generator Diesel driven fire pump Skip loader 1 Skip loader 2

Emissions from each group of equipment were carefully quantified and are presented in detail in the following sections.

4.1 Off-site and Transportation Emission Estimate

Figures 1 and 2 are photographs of the bobcats, chipper, and a typical truck used to transport the waste to DEC. During 1996, 90 percent of the agricultural fuel was orchard removals and 10 percent was prunings. This split was used to determine how many hours of operation were required from the bobcats and shredder. It was estimated[6] that when prunings are chipped, 2 bobcats and 1 chipper fill 6 trucks in a ten hour day. When removals are chipped, 4 bobcats and 1 chipper fill 15 trucks in a ten hour day. Each truck carries approximately 25 tons

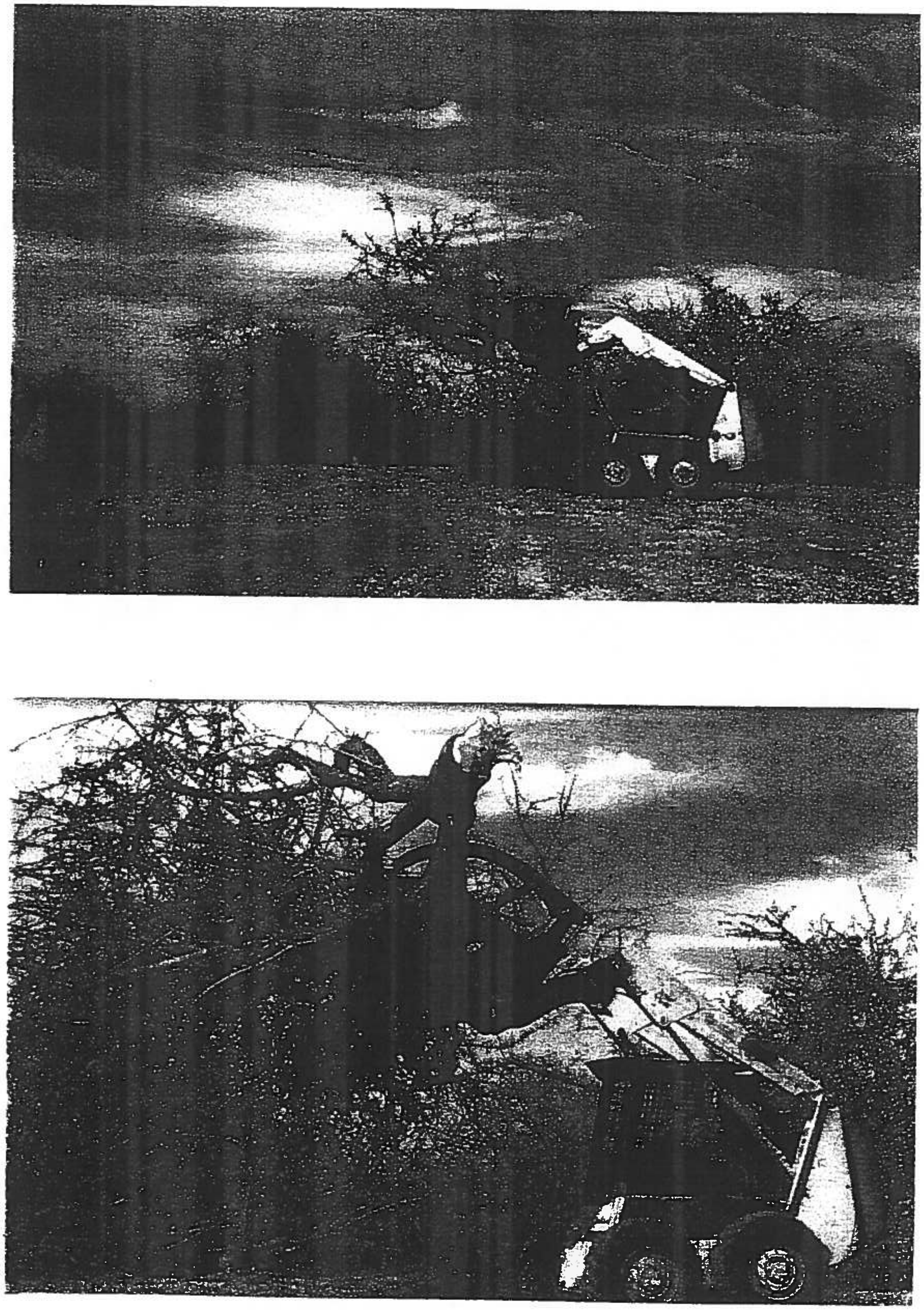


Figure 1. Bobcats loading almond orchard removals onto chipper.

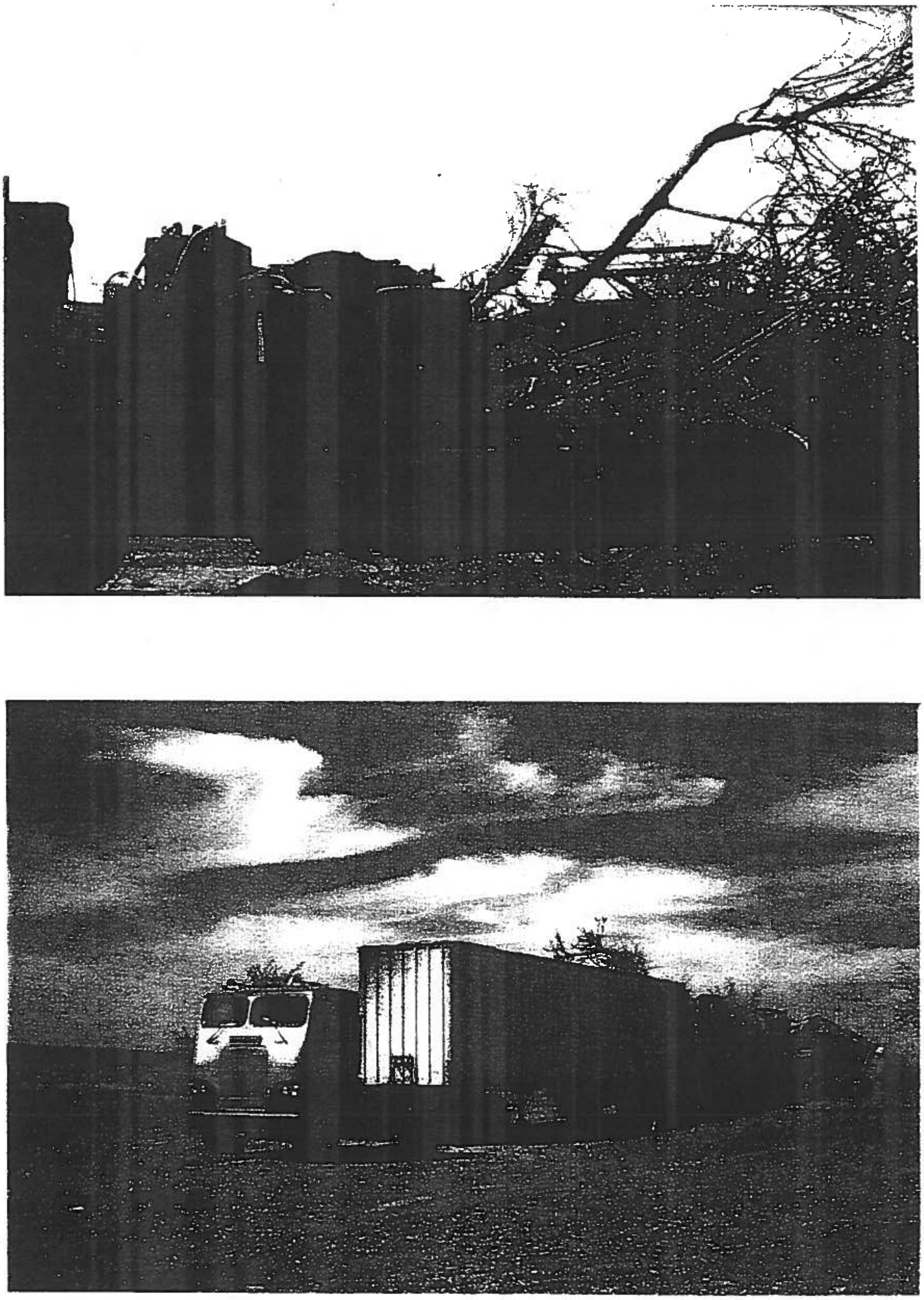


Figure 2. Almond tree fed into chipper which ejects chipped wood into truck.

of 35 percent moisture almond tree waste. The average distance to collect agricultural fuel in 1996 is estimated by the plant to be 29 miles.

Other off-site emissions that were not included in the equation are those from: the bobcats that cut the trees down, equipment to prune the trees, the bobcats that move the trees/prunings to the edge of the field, and the stump grinder. These were not included because the emissions would occur whether or not the agricultural waste was used as fuel.

The NO_2, CO, THC, and PM_{10} emission factors used for the bobcats, chipper and trucks are shown in Table 3. The bobcat and chipper emission factors are from the California Air Resources Board (CARB) emission inventory for off-road engines[7]. The truck emission factors are from the current CARB on-road emission factor model (EMFAC7G)[8]. Finally, the emissions associated with processing and transporting the 295,000 tons of agricultural fuel burned at DEC in 1996 are also shown. Emissions of SO_2 are considered to be negligible. A standard emission factor for diesel engine PAH is not available at this time, so these emissions are not estimated.

4.2 Boiler Emissions Estimate

Delano Energy Company operates two fluidized bed boilers built in the late 1980s. Each boiler is equipped with flue gas recirculation and selective non-catalytic reduction for NO_X control, sorbent injection for SO_2 control and a baghouse for particulate control. The boiler generating capacities and efficiencies are as follows:

Unit 1:

Net Generating Capacity	27 MW
Net Heat Rate	13,560 Btu/kWh
Heat Input Rate	366 MMBtu/hr

Unit 2:

Net Generating Capacity	21 MW
Net Heat Rate	12,904 Btu/kWh
Heat Input Rate	271 MMBtu/hr

The boilers operate at full load year round and are only down for scheduled and occasional unscheduled outages. In May of 1996 the boilers were. Not counting this outage, the 1996 capacity factors are 84 and 91 percent for units 1 and 2, respectively.

Table 4 provides the monthly breakdown of criteria pollutant emissions from the boilers. It is important to stress that care was taken to best approximate actual boiler year round emissions. The emissions of NO_X, CO, and SO_2 are based on monthly continuous emission monitor (CEM) average emission rates. DEC maintains CEMs that comply with performance specifications in Appendix B to 40 CFR Part 60 and performs regular RATAs and emission source testing using approved reference methods and quality assurance practices. The CEM data were used in this analysis since it more accurately represents actual monthly emissions than the annual compliance source test results.

Table 3. Off-site Equipment Emissions to Prepare and Transport 1996 DEC Agricultural Fuel

Off-site equipment inputs		
Bobcats[1]	number	3.8
Bobcat size	hp	50
Chipper[1]	number	1.0
Chipper size	hp	700
Hours of operation	hrs/day	10
Truck loads[1]	number	14
Ag fuel per truck	tons/truck	25
Roundtrip distance	miles	58
Engine Load Factors	%	50
Equipment operation to provide 1996 ag fuel to DEC		
Bobcat operation	hrs/ton	0.11
Chipper operation	hrs/ton	0.03
Ag Fuel Consumption	tons/1996	295,000
Truck loads	trips/yr	11,800
Truck mileage	miles/yr	684,400
Bobcat operation	hrs/yr	31,801
Chipper operation	hrs/yr	8,369

		NO_X	CO	PM_{10}	THC[4]
Emission Factors					
Bobcat[2]	g/bhp-hr	11	4	0.8	1.00
Chipper[2]	g/bhp-hr	13	2.2	0.6	0.75
Trucks[3]	gm/mi	12.6	15.6	1.2	2.4
Emissions					
Bobcat	tons/yr	9.6	3.5	0.7	0.9
Chipper	tons/yr	42.0	7.1	1.9	2.4
Trucks	tons/yr	4.8	5.9	0.5	0.9
TOTAL	tons/yr	56.4	16.5	3.1	4.2

1. Approximately 90% of agricultural fuel from orchard removals, 10% from prunings
   Removals: 4 bobcats+1 shredder = 15 truck loads per 10 hr day
   Prunings: 2 bobcats + 1 shredder = 6 truck loads per 10 hr day
2. Bobcat and chipper emission factors from off-road CARB Inventory (reference 7)
3. Truck emission factors from onroad CARB model EMFAC7G (reference 8) assuming 1990 model year and 250,000 miles of degradation.
4. CARB models output TOG rather than THC. TOG emission factors were corrected to THC by dividing by 1.202 (reference 9).

Table 4. DEC Boilers Operation and Emissions in 1996

	Units	Jan-96	Feb-96	Mar-96	Apr-96	Jun-96	Jul-96	Aug-96	Sep-96	Oct-96	Nov-96	Dec-96	Total[2]	Average
Unit 1 Generation (net)	MWh	13,491	15,630	19,274	14,469	18,272	16,996	15,185	19,675	15,771	14,870	17,703	181,336	16,485
Unit 2 Generation (net)	MWh	9,811	13,582	16,790	13,090	14,738	14,217	13,300	18,209	13,680	13,395	14,767	155,579	14,144
Unit 1 Ag Fuel Burned	tons	11,348	15,463	23,302	11,183	12,842	15,954	11,195	14,386	12,049	13,152	17,937	158,811	14,437
Unit 2 Ag Fuel Burned	tons	8,252	13,437	20,298	10,117	10,358	13,346	9,805	13,314	10,451	11,848	14,963	136,189	12,381
Total Ag Fuel Burned	tons	19,600	28,900	43,600	21,300	23,200	29,300	21,000	27,700	22,500	25,000	32,900	295,000	
Total Urban Fuel Burned	tons	13,000	11,700	9,700	16,700	23,100	11,400	13,600	21,300	16,400	16,400	18,900	172,200	15,655
Percent Ag Fuel Burned	% wt	60	71	82	56	50	72	61	57	58	60	64		63
Unit 1 Fuel Burned[1]	tons	18,875	21,723	28,486	19,951	25,629	22,161	18,445	25,448	20,831	21,780	28,241	251,570	22,870
Unit 2 Fuel Burned	tons	13,725	18,877	24,814	18,049	20,671	18,539	16,155	23,552	18,069	19,620	23,559	215,630	19,603
Boiler Emissions (1&2)[3,4]														
CO	lb	16,405	8,886	4,504	7,371	7,133	1,084	4,318	4,095	5,348	7,344	10,312	76,800	6,982
NO_X	lb	28,100	28,177	29,102	28,673	29,874	32,956	31,404	30,993	28,949	27,324	30,793	326,345	29,668
SO_X	lb	1,714	1,607	1,176	1,007	2,383	1,171	1,492	1,588	1,068	1,365	1,097	15,668	1,424
THC	lb	196	237	311	220	273	239	201	283	227	240	304	2,730	248
Total PM	lb	10,079	12,703	16,680	11,922	14,414	12,702	10,832	15,397	12,170	12,985	16,163	146,049	13,277
PM_{10}	lb	5,204	6,707	8,810	6,326	7,541	6,675	5,725	8,193	6,424	6,887	8,491	76,983	6,998
Boiler Emissions (1&2) Attributed to Ag Fuel														
CO	lb	9,863	6,325	3,684	4,132	3,574	780	2,621	2,315	3,093	4,435	6,550	47,372	4,307
NO_X	lb	16,894	20,057	23,806	16,072	14,969	23,725	19,060	17,521	16,744	16,500	19,558	204,906	18,628
SO_X	lb	1,031	1,144	962	564	1,194	843	906	898	618	824	697	9,680	880
THC	lb	118	168	254	123	137	172	122	160	131	145	193	1,724	157
Total PM	lb	6,060	9,043	13,644	6,683	7,223	9,144	6,574	8,704	7,039	7,841	10,266	92,221	8,384
PM_{10}	lb	3,129	4,774	7,206	3,546	3,779	4,805	3,475	4,631	3,716	4,159	5,393	48,613	4,419

1. Total fuel split based on agricultural fuel split. Ratio of ag fuel to urban fuel is the same at each unit.
2. No emissions in May 1996 - Boilers off-line.
3. PM & THC emissions based on compliance test lb/MMBtu and fuel HHV.
4. CO, NO_X, SO_2 emissions based on monthly CEM average emission rates.

Because monthly average values for PM_{10} and THC are not available, these estimates were based on the emission factors from the 1996 compliance source test. These emission factors were previously submitted and accepted by the San Joaquin Valley Unified Air Pollution Control District. It is important to stress that the firing rate and the fuel used during the compliance test are consistent with normal year round operation. As mentioned previously, the boilers typically operate at full load, and the compliance test fuel moisture content is within the range of that fired throughout the year as may be seen in the Appendix. The emission factors for THC and PM_{10} measured during the 1996 compliance source test are listed below in lb/MMBtu:

	Unit 1	Unit 2
THC	0.0006	0.0003
PM_{10}	0.0084	0.0184

The emission factors were multiplied by the average compliance test heating value to arrive at an emission factor for each unit in terms of lb/ton of fuel fired. This emission factor was then multiplied by the tons of fuel fired each month in each unit to determine the pounds of pollutant emitted per month. The tons of fuel fired in each unit were estimated from the known agricultural fuel split between the two units and the total amount of fuel fired per month. The pounds of each pollutant emitted which are attributed to firing almond tree waste were estimated by multiplying the total pounds emitted by the fraction of fuel which was almond tree waste. It is important to note that the fuel split between urban waste and agricultural fuel is fairly uniform year round.

The annual boiler emissions of criteria pollutants are summarized in Table 5. The permit levels for the criteria pollutants are also shown. In all cases, the actual emissions are well below the permit levels. The PAH levels measured during the 1996 AB2588 air toxics testing are also shown. The testing was performed only on unit 1. It was assumed that the unit 1 emission rates would be similar to the unit 2 emission rates, so they were applied to unit 2 as well to estimate total PAH emissions. The plant emits less than one pound of PAH per year.

4.3 Emissions From Other On-Site Equipment

The emissions from all of the other on-site equipment were determined through the use of the CARB off-road emission factors referenced above. A load factor of 50 percent was assumed in all cases. The emissions from the diesel on-site equipment are presented in Table 6.

Table 5. DEC Boiler Permit Levels and 1996 Emissions

Pollutant		Permit Level Unit 1	Unit 2	Total	1996 Emissions Total	Ag Fuel
NO_X	tons/yr	140	110	250	163	102
CO	tons/yr	245	193	438	38.4	23.7
SO_2	tons/yr	58	46	103	7.8	4.8
PM	tons/yr				73	46
PM_{10}	tons/yr	39	31	70	38	24
NMHC	tons/yr	140	33	173		
THC	tons/yr				1.4	0.86
Naphthalene	lb/yr				0.567	0.354
2-Methylnaphthalene	lb/yr				0.081	0.051
Acenaphthylene	lb/yr				0.015	0.010
Acenaphthene	lb/yr				0.016	0.010
Fluorene	lb/yr				0.057	0.035
Phenanthrene	lb/yr				0.171	0.107
Anthracene	lb/yr				0.055	0.034
Fluoranthene	lb/yr				0.043	0.027
Pyrene	lb/yr				0.039	0.024
Benz-a-anthracene	lb/yr				0.004	0.002
Chrysene	lb/yr				0.004	0.002
Benzo[b]fluoranthene	lb/yr				0.004	0.002
Benzo[k]fluoranthene	lb/yr				0.004	0.002
Indeno-123-cd-pyrene	lb/yr				0.004	0.002
Dibenzo[ah]anthracene	lb/yr				0.004	0.002
Benzo[ghi]perylene	lb/yr				0.004	0.002
TOTAL PAH	lb/yr				1.070	0.669

Notes:
1. Emissions of NO_X, CO, and SO_2 based on monthly average CEM data.
2. Emissions of THC and PM based on June 1996 Compliance Source Test Report.
3. PAH emissions based on emission factors (lb/MMBtu) from Unit 1 1996 AB2588 testing. PAH Unit 1 emission factors were also applied to Unit 2 to arrive at total PAH emissions.
4. Emissions due to agricultural waste fuel were determined by multiplying total emissions by the fraction of agricultural fuel fired.
5. Compliance Source Test value reported for NMHC is actually THC.

Table 6. Other On-Site Emissions at DEC in 1996

	Engine Size hp	Hours in 1996 hr/yr	Load Factor[3] %	Emission Factors[2] gm/bhp-hr				1996 Emissions tons/yr			
				NO_X	CO	PM_{10}	THC[4]	NO_X	CO	PM_{10}	THC
Unit 1 Emergency Generator	1106	26	0.5	13	2.2	0.6	0.75	0.2	0.03	0.01	0.01
Unit 2 Emergency Generator	830	6	0.5	13	2.2	0.6	0.75	0.04	0.01	0.00	0.00
Diesel Driven Fire Pump	244	992	0.5	12	2.8	0.6	0.83	1.6	0.37	0.08	0.11
Skip Loader 1 (Caterpillar 966)	170	5,256	0.5	11	3.4	0.7	0.92	5.4	1.67	0.34	0.45
Skip Loader 2 (Caterpillar 980)	275	5,256	0.5	12	2.8	0.6	0.83	9.6	2.23	0.48	0.66
Water Spray Truck[1]	150	1,460	0.5	11	3.4	0.7	0.92	1.3	0.41	0.08	0.11
Total								18.1	4.7	1.00	1.3

1. Assume water spray truck is 150 hp
2. Emission factors from CARB Off-Road Mobile Equipment Emission Inventory (reference
3. Load factor of 50% assumed
4. CARB HC emission factor is TOG. This has been converted to THC by dividing by 1.202 (reference 9)

5.0 Summary and Discussion

The previous sections have provided estimates of the emissions associated with preparing, transporting, and controlled combustion of DEC's 1996 agricultural fuel as well as estimates of the emissions that would have been incurred had the same waste been open field burned. Table 7 provides a comparison of the two estimates for criteria pollutants. The total criteria pollutant emissions attributable to agricultural fuel in 1996 from DEC is 262 tons. Had the same fuel been open field burned, 7451 tons of criteria pollutants would have been emitted. As may be seen in Table 8, the total PAH emissions attributable to agricultural fuel in 1996 from DEC is 0.67 pounds. Had the same fuel been open field burned, 5,458 pounds of PAH would have been emitted.

If the reader perspective is one of justifying whether the biomass facilities should exist, the benefit of interest is equivalent to avoided open field burning less the DEC emissions. Hence the net benefit of DEC is 7200 tons of criteria pollutants and 5457 pounds of PAH. If the reader realizes that DEC is permitted and will continue to fire biomass fuels whether it is local almond tree waste or not, the overall benefit is simply equivalent to the avoided open field burning emissions.

In 1996, 63 percent of the DEC fuel was local almond tree waste. It is anticipated that passage of the California Air Quality Improvement Initiative would increase the local almond tree waste portion to 80 percent. As shown in Table 9, this would result in an additional 1989 tons of avoided open field burning criteria pollutants and 1457 pounds of avoided open field burning PAH emissions. Conversion to 100 percent agricultural fuel is also indicated in the table.

One argument that occasionally surfaces during discussions regarding diverting agricultural waste from open field burning to biomass facilities is seasonality. While it is true that open field burning of almond tree waste predominantly occurs during the fall and winter months, there is a steady stream of local waste throughout the year which has been sufficient to supply DEC with fuel on a year round basis. As shown in Figure 3, DEC is able to keep its agricultural fuel consumption fairly constant throughout the year. Because DEC maintains a 30 to 60 day inventory, it is reasonable to assume that the time of agricultural fuel consumption at DEC approximates the time that it would have been open field burned, providing an emission benefit year round. Furthermore, recent changes to burn permit regulations and variables in orchard management activities tend to levelize the amount of open field burning over a year. The 1996 monthly emissions from DEC attributable to agricultural fuel are compared graphically to the avoided open field burning emissions in Figures 4 and 5. These figures indicate that there is a substantial reduction in emissions of each criteria pollutant every month of the year.

Another issue concerning diversion of agricultural waste from open field burning to biomass plants is spatial variations in emissions. Specifically, there is a concern that despite overall reductions in emissions, the air quality at the biomass plant will deteriorate. This is a complicated issue requiring site specific modeling which is beyond the scope of this study. However, several mitigating factors for the DEC plant include:

Table 7. DEC and Avoided Open Field Burning Criteria Pollutant Emissions for 1996

	Open Burn Emissions[1] Tons in 1996	Burning of Agricultural Fuel at DEC Tons in 1996			
		Off-site	Boiler	On-site	Total
NO_X	583	56	102	18	177
CO	5,139	16	23.7	4.7	45
SO_2	28		4.8		5
PM_{10}	825	3	24	1.0	28
THC	876	4	0.9	1.3	6
Total	7,451				262

1 Determined by multiplying emission factor by tons of ag fuel fired at DEC in 1996.

Table 8. Comparison of DEC and Avoided Open field burning PAH Emissions for 1996

Pollutant	Open Burn Emissions lb in 1996	DEC Boiler Emissions lb in 1996
Naphthalene	2,802	0.354
2-Methylnaphthalene	56	0.051
Acenaphthylene	1,023	0.010
Acenaphthene	68	0.010
Fluorene	18	0.035
Phenanthrene	782	0.107
Anthracene	122	0.034
Fluoranthene	201	0.027
Pyrene	171	0.024
Benz[a]anthracene	82	0.002
Chrysene	79	0.002
Benzo[b]fluoranthene	16	0.002
Benzo[k]fluoranthene	19	0.002
Indeno-123-cd-pyrene		0.002
Dibenzo[ah]anthracene		0.002
Benzo[a]pyrene	11	
Benzo[e]pyrene	6.5	
Benzo[ghi]perylene	1.2	0.002
TOTAL PAH	5,458	0.669

Table 9. Estimated Impact of California Air Quality Improvement Initiative on Avoided Open field burning Emissions Due to DEC Operation

		DEC Firing 100% Ag Fuel	DEC Firing 80% Ag Fuel
Total Fuel Consumed in 1996	tons	467,200	467,200
Ag Fuel Consumed in 1996	tons	295,000	295,000
Additional Ag Fuel Consumption	tons	172,200	78,760
Additional Avoided Criteria Pollutants			
CO	tons/yr	3,000	1,372
NO_2	tons/yr	340	156
SO_2	tons/yr	16	7
PM_{10}	tons/yr	481	220
THC	tons/yr	512	234
Total Criteria	tons/yr	4,349	1,989
Additional Avoided PAH Emissions			
Naphthalene	lb/yr	1,636	748
2-Methylnaphthalene	lb/yr	32	15
Acenaphthylene	lb/yr	597	273
Acenaphthene	lb/yr	40	18
Fluorene	lb/yr	10	5
Phenanthrene	lb/yr	456	209
Anthracene	lb/yr	71	33
Fluoranthene	lb/yr	117	54
Pyrene	lb/yr	100	46
Benzaanthracene	lb/yr	48	22
Chrysene	lb/yr	46	21
Benzo[b]fluoranthene	lb/yr	10	4
Benzo[k]fluoranthene	lb/yr	11	5
Benzo[a]pyrene	lb/yr	6	3
Benzo[e]pyrene	lb/yr	4	2
Benzo[ghi]perylene	lb/yr	1	0
TOTAL PAH	lb/yr	3,186	1,457

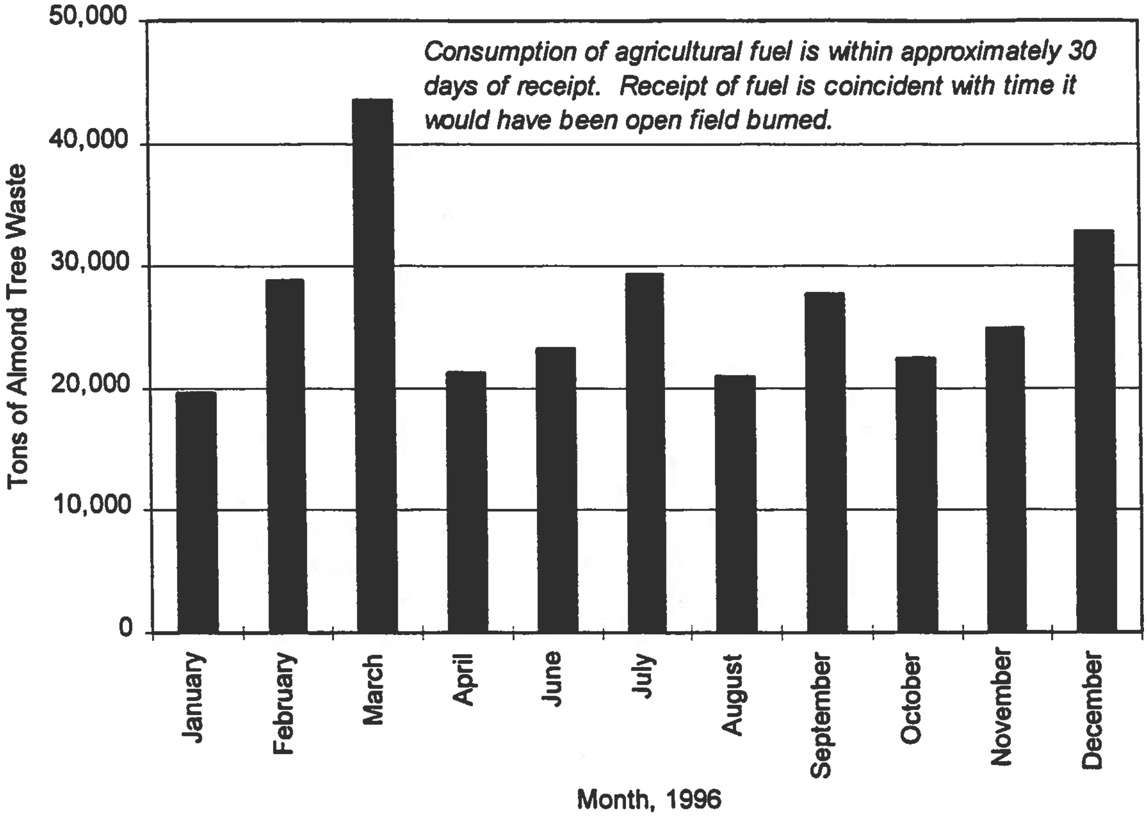
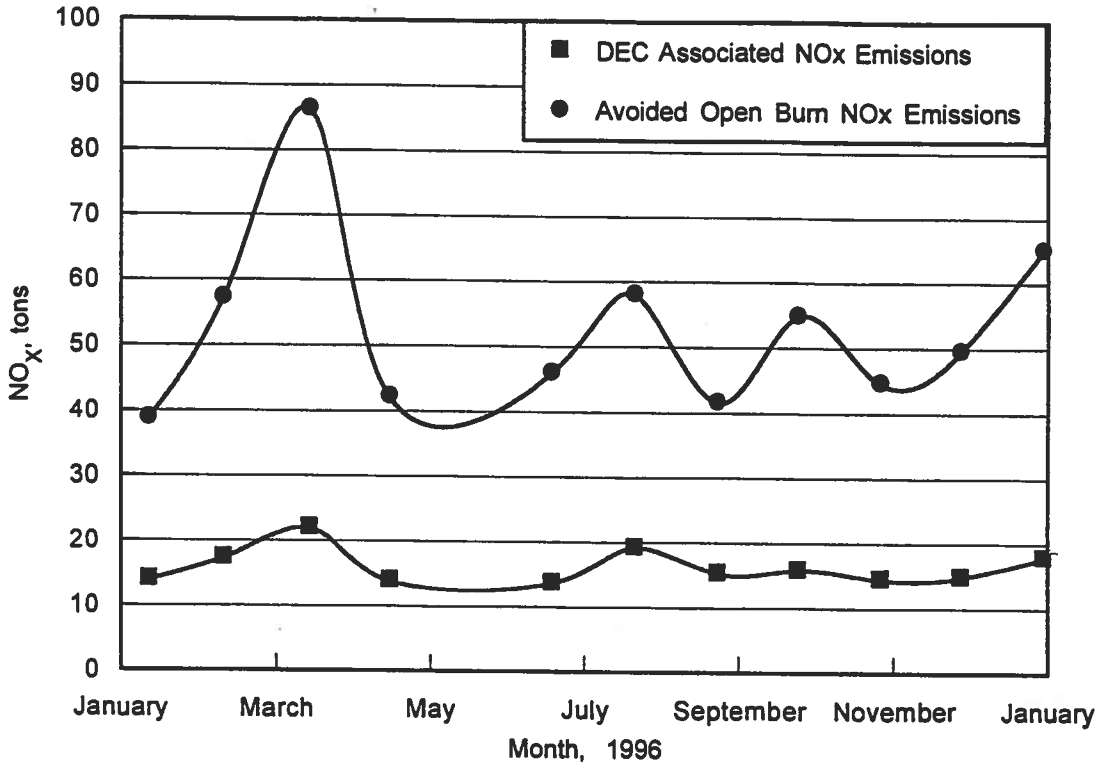


Figure 3. Agricultural fuel consumption at DEC in 1996.



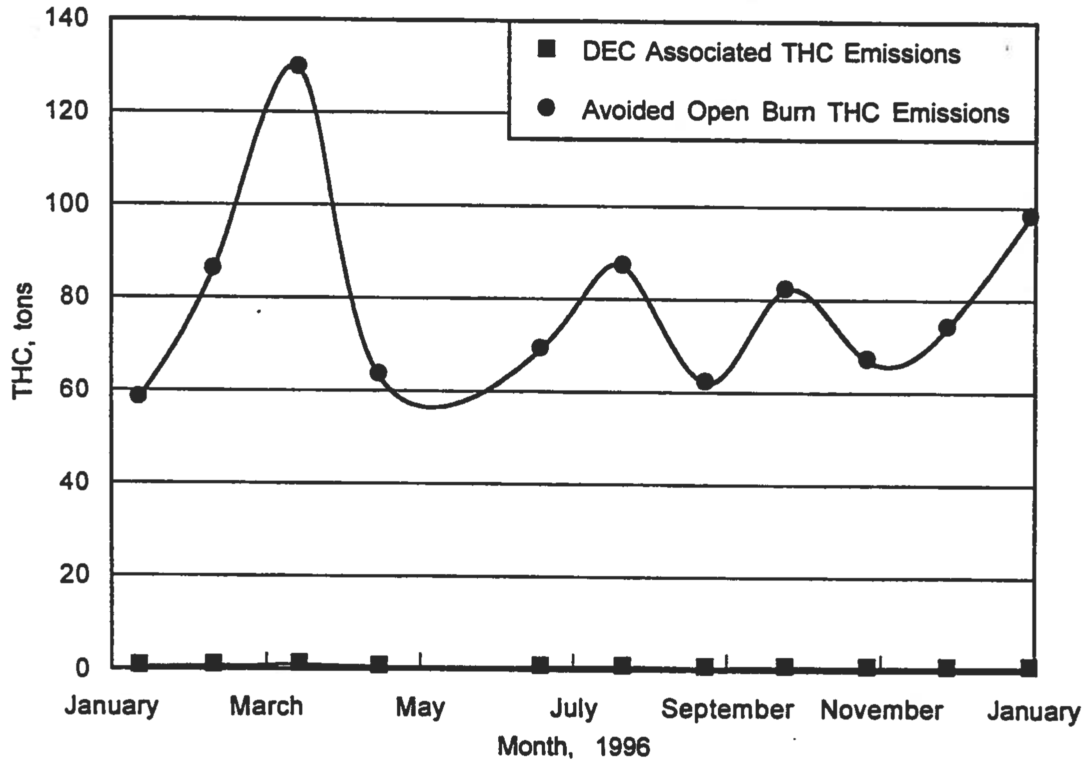


Figure 4. Comparison of DEC agricultural fuel emissions and avoided open field burning emissions for 1996.

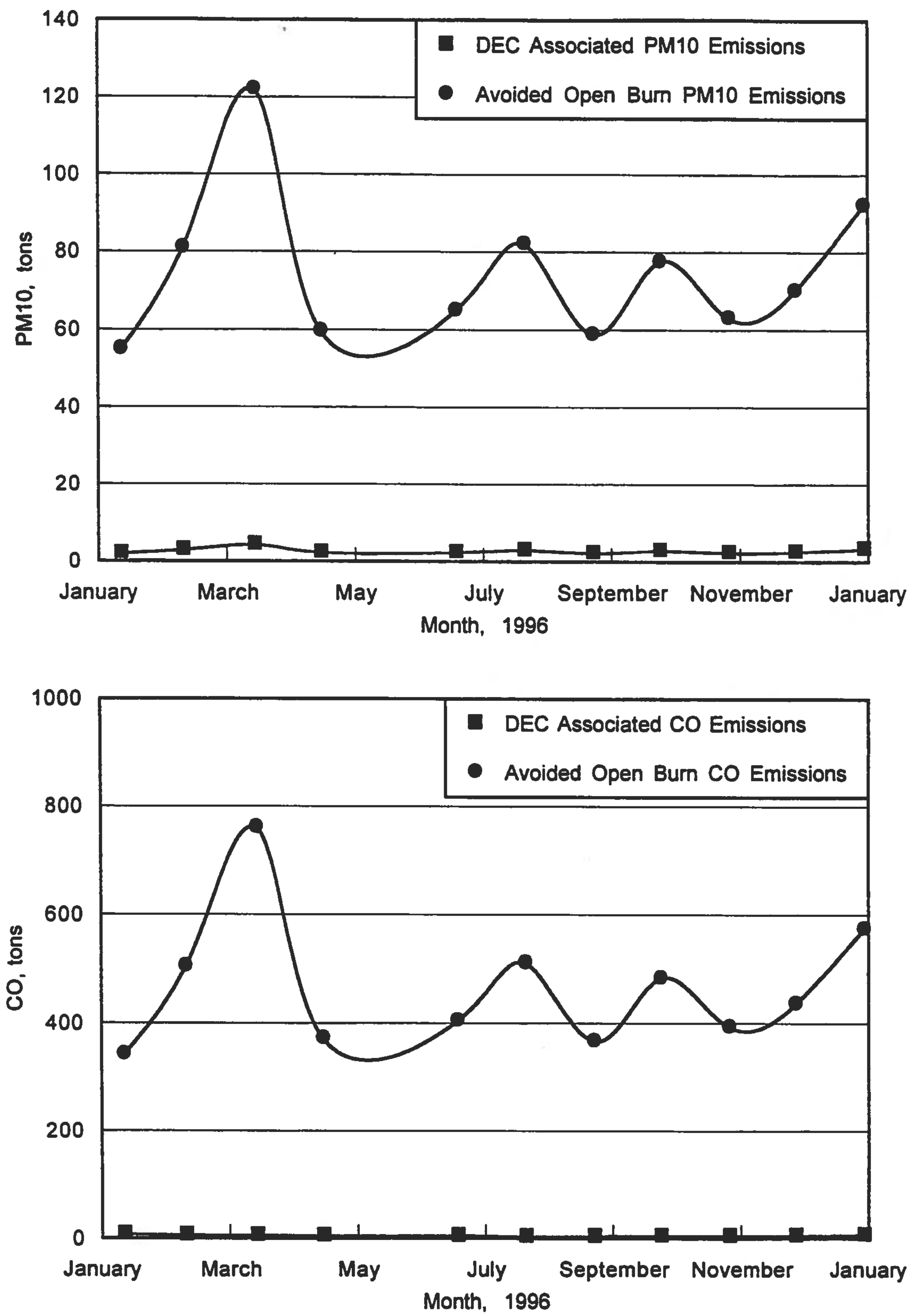


Figure 5. Comparison of DEC agricultural fuel emissions and avoided open field burning emissions for 1996.

- Open field burning occurs at ground level as opposed to the 150 foot DEC stacks
- Open field burning emission rates are several orders of magnitude higher than those from DEC for all pollutants evaluated, particularly PAH.
- Agricultural fuel fired at DEC is local; it is collected from within a 29 mile radius
- Open field burning can affect visibility over large areas; very possibly more than 29 miles

5.0 References

1. B. Jenkins et. al., "Atmospheric Pollutant Emission Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulation", Final Report, April 1996. CARB Project Number A932-126.

2. E. Darley et. al., "Hydrocarbon Characterization of Agricultural Waste Burning", Final Report, April 1979. CARB Project Number A7-068-30.

3. E. Darley et. al., "Emission Factors From Burning Agricultural Wastes Collected in California", January 1977. CARB Project Number 4-011.

4. "AP-42 Compilation of Air Pollutant Emission Factors", U.S. EPA.

5. Conversation with Professor Brian Jenkins, September 1997.

6. Conversation with San Joaquin Helicopter Company representative, September, 1997.

7. "Off-Road Mobile Equipment Emission Inventory Estimate", prepared for the California Air Resources Board by Booz-Allen & Hamilton, 1992.

8. "Derivation of Emission and Correction Factors for EMFAC7G", State of California Air Resources Board.

9. "Methodology for Estimating Emissions from On-Road Vehicles - Volume II: EMFAC7G", State of California Air Resources Board, November, 1996.

Appendix

Examples of Offset Fuel Certification
Examples of Fuel Analyses

DELANO ENERGY COMPANY

31800 [illegible]
P.O. Box 1481
Delano, CA 93215
(805) 792-[illegible]
(805) 792-3072 [illegible]

NEW JOB #: 0465
DATE: 5-30-96
BY: Ron St. Clair

[illegible]

Offset Fuel Supplier

San Joaquin Biomass Company	Address: Route #1, Box 422
Mr. Lee Brown	Delano, CA 93215
Hauler: San Joaquin Biomass Co.	Phone: (805) 725-1898
	Fax: (805) 725-5401

Offset Fuel Information

Crop Type: Almond	Start Date: 5-31-96
Fuel Type:	
Pruning: ☐ Removal: ☑	Finish Date:
Location:	Job Size (acres): 192.25
Township: 28S Range: 22E	Estimated Tons: 10,000
Section: 16 Subsection: SW	Phone:
Nearest Crossroads: Lerdo Hwy & Lost Hills Road	Fax:

San Joaquin Valley Unified Air Pollution Control District Information

1.	Is crop residue (fuel) listed in State of California Air Resources Board's "A Procedure to Implement the Provisions of Health and Safety Code Section 41605.5 (AB 1223, 1983) Relating to the Determination of Agricultural/Forestry Emission Offset Credits (June 21, 1984, modified November 1984)" Table 1, "Crops Open Field Burned in California"?	YES
2.	Is origin of crop residue (fuel) in the San Joaquin Valley Air Basin?	YES
3.	Is origin of crop residue (fuel) within fifteen (15) mile radius of plant?	NO
4.	Was the crop residue (fuel) from this job previously open burned?	YES

Certification

I certify that to the best of my knowledge, the above information is correct.

[illegible signature]
Supplier Signature

5-30-96
Date

Notes:

DELANO ENERGY COMPANY

21800 [illegible]
P.O. Box 1481
Delano, CA 93216
(805) 792-3067
(805) 792-3072 (fax)

NEW JOB #: 0540
DATE: 7-17-96
BY: RON ST. CLAIR

[illegible] OFFSET FUEL NOTICE AND CERTIFICATION

OFFSET FUEL SUPPLIER

SAN JOAQUIN BIOMASS COMPANY	ADDRESS: 1407 So. Lexington
Mr. LEE E. BROWN	DELANO, CA 93215
HAULER: SAN JOAQUIN BIOMASS CO.	PHONE: (805) 725-1898
	FAX: (805) 725-5401

OFFSET FUEL INFORMATION

CROP TYPE: ALMOND	START DATE: OCTOBER 1996
FUEL TYPE:	
PRUNING: ☐ REMOVAL: ☑	FINISH DATE:
LOCATION:	JOB SIZE (ACRES): 241.99
TOWNSHIP: 27S RANGE: 25E	ESTIMATED TONS: 9075
SECTION: 19 SUBSECTION: SW	PHONE:
NEAREST CROSSROADS: KIMBERLINA & DRIVER	FAX:

SAN JOAQUIN VALLEY UNIFIED AIR POLLUTION CONTROL DISTRICT INFORMATION

1.	IS CROP RESIDUE (FUEL) LISTED IN STATE OF CALIFORNIA AIR RESOURCES BOARD'S "A PROCEDURE TO IMPLEMENT THE PROVISIONS OF HEALTH AND SAFETY CODE SECTION 41605.5 (AB 1223, 1983) RELATING TO THE DESIGNATION OF AGRICULTURAL/FORESTRY EMISSION OFFSET CREDITS (JUNE 21, 1984, MODIFIED NOVEMBER 1984)" TABLE 1, "CROPS OPEN FIELD BURNED IN CALIFORNIA"?	YES
2.	IS ORIGIN OF CROP RESIDUE (FUEL) IN THE SAN JOAQUIN VALLEY AIR BASIN?	YES
3.	IS ORIGIN OF CROP RESIDUE (FUEL) WITHIN FIFTEEN (15) MILE RADIUS OF PLANT?	YES
4.	WAS THE CROP RESIDUE (FUEL) FROM THIS JOB PREVIOUSLY OPEN BURNED?	YES

NOTES:

CERTIFICATION

I CERTIFY THAT TO THE BEST OF MY KNOWLEDGE, THE ABOVE INFORMATION IS CORRECT.

[signature] 7-17-96

SUPPLIER SIGNATURE DATE

BC
RATORIES

CHEMICAL ANALYSIS

LANO ENERGY
). BOX 1461
500 POND ROAD
LANO, CA 93215
:n: GEORGE HALL 805-792-3067

Date Reported: 07/11/96
Date Received: 06/24/96
Laboratory No.: 96-07294-11

"Compliance Test"
ple Description: EFFECIENCY TEST (FUEL) UNIT I COMPOSITE AG 100% SAMPLED ON 6-17-96 THRU 6-24-96

stituents	Sample Results As Received	Sample Results Dry Basis	Units	Method P.Q.L.	Method
sture	18.00		%	0.05	BC
atiles	64.51	78.67	%	0.05	-
bon	39.75	48.48	%	0.05	AOAC-972.43
rogen	5.14	6.27	%	0.05	AOAC-972.43
gen	34.01	41.48	%	0.05	Calculated
ed Carbon	14.88	18.15	%	0.05	-
	2.61	3.18	%	0.05	ASTM-D1102
ss Heating Value	6560.	8000.	BTU/lb.	20.	ASTM-E711
al Nitrogen	0.48	0.59	%	0.05	AOAC-972.43
al Sulfur	None Detected	None Detected	%	0.05	AOAC-972.43

.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

ERENCES:
OAC = "Official Methods of the Association of Official Analytical Chemists"
STM = "American Society for Testing and Materials"
BC = BC Laboratory In-House Method

Schultz
oratory Director

THERMO ENERGY SYSTEMS - BRUCE GERMINARO
THERMO ECOTEK CORPORATION - PAUL DESROCHERS

BC LABORATORIES

CHEMICAL ANALYSIS

DELANO ENERGY
P.O. BOX 1461
31500 POND ROAD
DELANO, CA 93215
Attn: ROY ASHBROOK 805-792-3067

Date Reported: 03/01/96
Date Received: 02/19/96
Laboratory No.: 96-02001-7

Sample Description: SJH III COMPOSITE DAILY AG SAMPLED ON 1-25-96 THRU 2-9-96

Constituents	Sample Results As Received	Sample Results Dry Basis	Units	Method P.Q.L.	Method
Moisture	19.33		%	0.05	BC
Ash	1.3	1.6	%	0.05	ASTM-D1102
Gross Heating Value	6570.	8140.	BTU/lb.	20.	ASTM-E711
Total Potassium	1450.	1800.	mg/kg	50.	SW-7610
Total Sulfur	None Detected	None Detected	%	0.05	AOAC-972.43
Chlorine	33.	41.	mg/kg	20.	ASTM-808
Total Sodium	112.	139.	mg/kg	50.	SW-7770

P.Q.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

REFERENCES:
AOAC = "Official Methods of the Association of Official Analytical Chemists"
ASTM = "American Society for Testing and Materials"
BC = BC Laboratory In-House Method
SW = "Test Methods for Evaluating Solid Wastes Physical/Chemical Methods", EPA-SW-846, September, 1986.

Dan Schultz
Laboratory Director

cc: THERMO FUELS - GREG KAYLOR
cc: THERMO FUELS - PAUL DESROCHERS

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DELANO ENERGY
P.O. BOX 1461
31500 POND ROAD
DELANO, CA 93215
Attn: ROY ASHBROOK 805-792-3067

Date Reported: 07/19/96
Date Received: 07/05/96
Laboratory No.: 96-07820-6

Sample Description: JACK RABBIT COMPOSITE DAILY AG SAMPLED ON 3-11-96 THRU 6-8-96

Constituents	Sample Results As Received	Sample Results Dry Basis	Units	Method P.Q.L.	Method
Moisture	25.94		%	0.05	ASTM-E871
Ash	2.8	3.8	%	0.05	ASTM-D1102
Gross Heating Value	5890.	7950.	BTU/lb.	20.	ASTM-E711
Total Potassium	2400.	3240.	mg/kg	50.	SW-7610
Total Sulfur	None Detected	None Detected	%	0.05	AOAC-972.43
Chlorine	66.	89.	mg/kg	20.	ASTM-808
Total Sodium	None Detected	None Detected	mg/kg	50.	SW-7770

P.Q.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

REFERENCES:
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ASTM = "American Society for Testing and Materials"
SW = "Test Methods for Evaluating Solid Wastes Physical/Chemical Methods", EPA-SW-846, September, 1986.

Dan Schultz
Laboratory Director

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cc: THERMO ECOTEK CORPORATION - PAUL DESROCHERS

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CHEMICAL ANALYSIS

DELANO ENERGY
P.O. BOX 1461
31500 POND ROAD
DELANO, CA 93215
Attn: ROY ASHBROOK 805-792-3067

Date Reported: 08/02/96
Date Received: 07/19/96
Laboratory No.: 96-08424-1

Sample Description: WILSON AG COMPOSITE WEEKLY AG SAMPLED ON 5-31-96 THRU 7-4-96

Constituents	Sample Results As Received	Dry Basis	Units	Method P.Q.L.	Method
Moisture	25.87		%	0.05	ASTM-E871
Ash	1.5	2.0	%	0.05	ASTM-D1102
Gross Heating Value	6050.	8160.	BTU/lb.	20.	ASTM-E711
Total Potassium	1170.	1580.	mg/kg	50.	SW-7610
Total Sulfur	None Detected	None Detected	%	0.05	AOAC-972.43
Chlorine	None Detected	None Detected	mg/kg	20.	ASTM-808
Total Sodium	38.	52.	mg/kg	50.	SW-7770

P.Q.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

REFERENCES:
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SW = "Test Methods for Evaluating Solid Wastes Physical/Chemical Methods", EPA-SW-846, September, 1986.

Dan Schultz
Laboratory Director

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DELANO ENERGY
P.O. BOX 1461
31500 POND ROAD
DELANO, CA 93215
Attn: ROY ASHBROOK 805-792-3067

Date Reported: 07/19/96
Date Received: 07/05/96
Laboratory No.: 96-07820-5

Sample Description: SJH I COMPOSITE DAILY AG SAMPLED ON 6-19-96 THRU 7-3-96

Constituents	Sample Results As Received	Sample Results Dry Basis	Units	Method P.Q.L.	Method
Moisture	14.71		%	0.05	ASTM-E871
Ash	1.3	1.5	%	0.05	ASTM-D1102
Gross Heating Value	6780.	7950.	BTU/lb.	20.	ASTM-E711
Total Potassium	1300.	1520.	mg/kg	50.	SW-7610
Total Sulfur	None Detected	None Detected	%	0.05	AOAC-972.43
Chlorine	55.	65.	mg/kg	20.	ASTM-808
Total Sodium	196.	230.	mg/kg	50.	SW-7770

P.Q.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

REFERENCES:
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ASTM = "American Society for Testing and Materials"
SW = "Test Methods for Evaluating Solid Wastes Physical/Chemical Methods", EPA-SW-846, September, 1986.

Dan Schultz
Laboratory Director

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DELANO ENERGY
P.O. BOX 1461
31500 POND ROAD
DELANO, CA 93215
Attn: ROY ASHBROOK 805-792-3067

Date Reported: 03/01/96
Date Received: 02/19/96
Laboratory No.: 96-02001-4

Sample Description: SJH II COMPOSITE DAILY AG SAMPLED ON 1-19-96 THRU 1-30-96

Constituents	Sample Results As Received	Sample Results Dry Basis	Units	Method P.Q.L.	Method
Moisture	33.32		%	0.05	BC
Ash	1.9	2.9	%	0.05	ASTM-D1102
Gross Heating Value	5500.	8250.	BTU/lb.	20.	ASTM-E711
Total Potassium	1890.	2830.	mg/kg	50.	SW-7610
Total Sulfur	None Detected	None Detected	%	0.05	AOAC-972.43
Chlorine	39.	59.	mg/kg	20.	ASTM-808
Total Sodium	72.	108.	mg/kg	50.	SW-7770

P.Q.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

REFERENCES:
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ASTM = "American Society for Testing and Materials"
BC = BC Laboratory In-House Method
SW = "Test Methods for Evaluating Solid Wastes Physical/Chemical Methods", EPA-SW-846, September, 1986.

Dan Schultz
Laboratory Director

cc: THERMO FUELS - GREG KAYLOR
cc: THERMO FUELS - PAUL DESROCHERS

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CHEMICAL ANALYSIS

DELANO ENERGY
P.O. BOX 1461
31500 POND ROAD
DELANO, CA 93215
Attn: ROY ASHBROOK 805-792-3067

Date Reported: 08/02/96
Date Received: 07/19/96
Laboratory No.: 96-08424-1

Sample Description: WILSON AG COMPOSITE WEEKLY AG SAMPLED ON 5-31-96 THRU 7-4-96

Constituents	Sample Results: As Received	Sample Results: Dry Basis	Units	Method P.Q.L.	Method
Moisture	25.87		%	0.05	ASTM-E871
Ash	1.5	2.0	%	0.05	ASTM-D1102
Gross Heating Value	6050.	8160.	BTU/lb.	20.	ASTM-E711
Total Potassium	1170.	1580.	mg/kg	50.	SW-7610
Total Sulfur	None Detected	None Detected	%	0.05	AOAC-972.43
Chlorine	None Detected	None Detected	mg/kg	20.	ASTM-808
Total Sodium	38.	52.	mg/kg	50.	SW-7770

P.Q.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

REFERENCES:
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ASTM = "American Society for Testing and Materials"
SW = "Test Methods for Evaluating Solid Wastes Physical/Chemical Methods", EPA-SW-846, September, 1986.

Dan Schultz
Laboratory Director

cc: THERMO ENERGY SYSTEMS - BRUCE GERMINARO
cc: THERMO ECOTEK CORPORATION - PAUL DESROCHERS

ABORATORIES

CHEMICAL ANALYSIS

DELANO ENERGY
P.O. BOX 1461
31500 POND ROAD
DELANO, CA 93215
Attn: ROY ASHBROOK 805-792-3067

Date Reported: 12/06/96
Date Received: 11/18/96
Laboratory No.: 96-13407-6

Sample Description: JACK RABBIT COMPOSITE DAILY AG FUEL SAMPLED ON 9-30-96 THRU 11-11-96

Constituents		Sample Results As Received	Sample Results Dry Basis	Units	Method P.Q.L.	Method
Moisture		33.15		%	0.05	ASTM-E871
Ash		1.5	2.3	%	0.05	ASTM-D1102
Gross Heating Value		5390.	8060.	BTU/lb.	20.	ASTM-E711
Total Potassium		2190.	3280.	mg/kg	50.	SW-7610
Total Sulfur	*	0.05	0.07	%	0.05	AOAC-972.43
Chlorine		38.	57.	mg/kg	20.	ASTM-808
Total Sodium		39.	58.	mg/kg	50.	SW-7770

P.Q.L. = Practical Quantitation Limit (refers to the least amount of analyte quantifiable based on sample size used and analytical technique employed).

REFERENCES:
AOAC = "Official Methods of the Association of Official Analytical Chemists"
ASTM = "American Society for Testing and Materials"
SW = "Test Methods for Evaluating Solid Wastes Physical/Chemical Methods", EPA-SW-846, September, 1986.

Flag Explanations:
* = Sample analyzed by Desert Analytics

Dan Schultz
Laboratory Director

cc: THERMO ENERGY SYSTEMS - BRUCE GERMINARO
cc: THERMO ECOTEK CORPORATION - PAUL DESROCHERS