Estimating Greenhouse Gas Reductions For a Regional Digester Treating Dairy Manure

Deborah Bartram
Eastern Research Group, Incorporated
14555 Avion Parkway, Suite 200
Chantilly, Virginia 20151
deborah.bartram@erg.com

Wiley Barbour
Environmental Resources Trust, Incorporated
1612 K Street, NW Suite 1400
Washington, DC 20006
wbarbour@ert.net

ABSTRACT

Inland Empire Utilities Agency (IEUA), a municipal water district serving California's Chino Basin region, provides utility-related services to seven communities and 700,000 residents, including a number of local dairy operations. Dairy farms are California's largest agricultural sector and dairy manure is one of the most severe sources of air and water pollution in the Chino Basin as well as the Central Valley. As part of an overall Organics Management Strategy program, IEUA developed and implemented a manure anaerobic digestion demonstration project for the collection and treatment of dairy manure. The state-of-the-art anaerobic digesters operate as a centralized manure management facility, and currently process manure from 14 dairy farms in Chino Basin. Future plans for expansion will increase the service area.

A model was developed to quantify and verify methane and other greenhouse gas emission reductions and the environmental benefits of renewable energy produced by the digesters. Baseline emissions of methane, nitrous oxide, and ammonia associated with dairy manure management, including land application, prior to implementation of the digester project were estimated using farm-specific operational data. Post-digester emissions, including emissions associated with the transportation of manure and combustion emissions from the digesters, were calculated and used to estimate greenhouse gas reductions achieved through the operation of the anaerobic digesters at IEUA facilities. A monitoring plan was also developed to identify the data inputs required by the emissions model in order to monitor emissions and reductions associated with the project. This paper focuses on greenhouse gas reductions associated with the project.

The products and tools developed in this project are expected to assist with the development of verified and tradable emission reductions and renewable energy green tags resulting from digester activity.

INTRODUCTION

Inland Empire Utilities Agency (IEUA) is a municipal water district, serving the region for over 50 years. IEUA's mission is to supply imported drinking water and recycled water, collect, treat and dispose of wastewater, and provide utility-related services to the 7 communities and 700,000 residents in their service territory, including the local dairy operations. Dairy farms are California's largest agricultural sector and dairy manure is one of the most severe sources of air and water pollution in the Chino Basin as well as the Central Valley.

IEUA developed an Organics Management Strategy program to protect the Chino Groundwater Basin from infiltration of salts, nutrients and pathogens generated by dairies and to reduce future costs of removing contaminants from the groundwater. Stakeholders involved in the planning and decision-making process included the surrounding public, regulatory officials, elected representatives, environmental organizations, and the IEUA's member communities. An important first step for the implementation of the Organics Management Strategy was the development of the manure anaerobic digestion demonstration projects, located at the IEUA Regional Plant Numbers 1 (RP-1) and 5 (RP-5), for the collection and treatment of dairy manure. IEUA operates these state-of-the-art anaerobic digester facilities, constructed in a public-private partnership consisting of IEUA, US Department of Agriculture, US Department of Energy, the Milk Producers Council, the California Energy Commission, and Synagro Technologies.

Manure is currently collected from 14 dairies in the Chino Basin area and is processed in either RP-1 or RP-5. Figure 1 present the flow diagrams for both of these digesters.

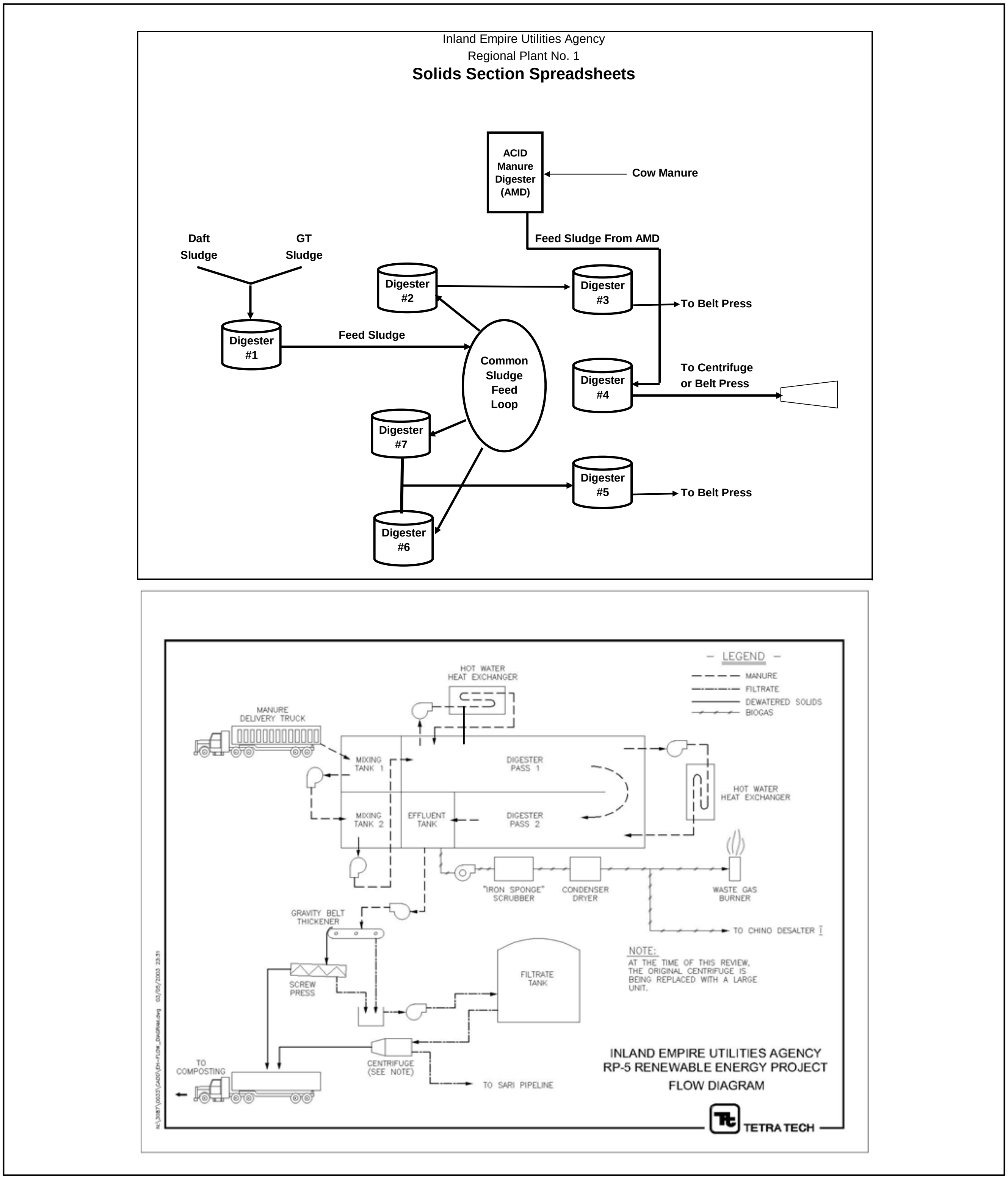
RP-1 consists of six digesters used to treat biosolids, and one digester (#4) used solely to treat dairy cow manure. The manure is delivered to the digester in nurse tanks and pumped through direct connecting hoses to the acid manure digester. Utility water is also pumped to the digester to achieve a solids content of approximately 13 percent, prior to being fed to Digester #4. The RP-1 digestion system is a complete mix digester, with a retention time of approximately 30 days. IEUA has operated this system at both mesophilic and thermophilic temperatures.

Manure is delivered to the RP-5 digester in end dump trucks. The trucks enter the digester building, where the manure is transferred to the digester mix tank and mixed with utility water. RP-5 is a plug flow digester with a retention time of about 21 days. This digester typically operates with a temperature in the range of 90˚F to 95˚F.

IEUA has commissioned the creation of a monitoring and verification protocol as part of an effort to study and document the digester's environmental performance. IEUA is drawing on the strengths of private, public, and academic project partners to comprehensively measure multiple environmental and economic benefits of treating animal manure through anaerobic digestion in California. The protocol details the methodology for assessing and verifying greenhouse gas emissions, criteria emissions, and surface runoff impacts with and without the project. A spreadsheet model has been developed to complete the actual calculation of emissions and reductions.

The model consists of a system to quantify and verify methane and other greenhouse gas emission reductions and the environmental benefits of renewable energy produced by the digester that will be applicable for comparable systems throughout the Western United States and possibly other parts of the country. Full and accurate measurement and assessment of digester performance and related manure management issues will accelerate the development of verified and tradable emission reductions and renewable energy green tags resulting from digester activity, and will contribute to their commercial viability in their respective emerging markets within the agricultural sector.

Figure 1. RP-1 and RP-5 flow diagrams.



OVERVIEW OF MANURE MANAGEMENT PRACTICES IN THE CHINO BASIN

Agricultural operations, such as dairies, emit greenhouse gases and other air emissions associated with the management of manure. Cattle also emit methane as a by-product of the digestion process. These enteric fermentation emissions are related to the diet and performance of the animal.

The objective of the analysis was to estimate emissions associated with dairy operations before and after the implementation of the IEUA manure digesters. The emission of greenhouse gases and criteria air pollutants associated with the management of manure at the dairy, land application of manure, off-site processing of manure (e.g., composting), and transportation of manure off the farm (on-site transportation emissions were not estimated) were analyzed. Emissions were estimated using farm-specific operational data, where available, coupled with pollutant-specific emission factors.

Dairies in the Chino Basin are unique in that the vast majority house dairy cattle in corrals, rather than barns. Bedding is sometimes added under the shades in the corral. The cattle are fed along a concrete feed lane and about 85 percent of the daily manure excreted is deposited throughout the corral and feed lanes. Bedding may also be tracked into the feed lanes.

Figure 2 presents a typical corral dairy. Manure is scraped from the feed lanes into the corral weekly and either spread out or stacked. Two to three times a year, manure is hauled locally for direct land application on neighboring farms or for composting, or the manure is hauled to neighboring counties, such as Riverside County or beyond.

Figure 2. Corral-style dairy, Chino CA.

Lactating cows are milked two to three times daily, and about 15 percent of the daily manure excreted is deposited in the milk parlor and holding areas. Parlors are cleaned with water, which collects in an on-site storage lagoon. The lagoon also receives runoff from the corrals and feed lanes. Lagoons solids are cleaned out every 2 to 3 years. Effluent from the lagoon is applied to neighboring land for irrigation.

The dairies participating in the digester project have implemented certain changes that affect the management of manure at their operations. The most significant change affects the method and frequency of manure collection. Each participating dairy now uses a “honey vac” vacuum tanker truck to collect fresh manure along the feed lanes daily, as shown in Figure 3. Manure must be collected within 24 hours of being excreted. Manure collected for the digester comes from the corrals and feed lanes used with lactating dairy cows. In some cases, the dairy may also house dry cows in these areas. The honey vac truck is run several times per day for each group of cows fed.

Figure 3. Honey vac manure collection.

The manure is transported to an "end dump" truck, or in some cases a nurse tank truck, which resides at the dairy. Throughout the day, the dairy collects manure from the feed lanes into these holding areas. Once per day, a manure hauler arrives and transports the manure to either RP-1 or RP-5, depending on the dairy's location and the capacity of the digesters. Figure 4 shows an end dump truck unloading manure at RP-5. Manure collected for the digester is transported locally to the digester and the digested solids are transported to the co-composting facility, where the end product is sold.

Figure 4. End dump unloading manure at RP-5.

EMISSION REDUCTIONS CALCULATIONS

Emission reduction estimates were originally calculated in October 2003, using data provided by IEUA and the Milk Producers Council. Since that time, site visits were conducted to the dairies and the digesters to identify improvements that could be made to the calculations. To generate emission calculations, the daily records of actual manure delivered and processed each day at the RP-1 and RP-5 digesters were used, as were measured values of volatile solids in the manure. The reductions in ammonia and greenhouse gas emissions are obtained by subtracting the basecase emissions from the total emissions generated at the IEUA Manure Renewable Energy Projects.

Estimates of methane and nitrous oxide emissions are based on the Intergovernmental Panel on Climate Change (IPCC) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*[1], as well as the methodology used by US EPA to generate the annual Inventory of U.S. Greenhouse Gas Emissions and Sinks[2]. Site-specific data and literature data are used to select emission factors and, in some cases, location-specific data are used to calculate emission factors. For example, location-specific temperature data are used to develop methane conversion factors for dairy lagoons located in San Bernardino, California. Estimates of ammonia emissions are based on methodologies developed by US EPA to generate the 2002 National Emission Inventory for animal husbandry operations[3]. Emission factors for the estimation of criteria air pollutants from transportation are developed using EPA's Mobile 6.2 model[4].

Methane and ammonia emissions from the following operations are included in the analysis: dairy cattle enteric fermentation (methane only), manure management in the corral and anaerobic lagoon, off-site composting, and land spreading. Nitrous oxide emission estimates include: (1) direct emissions from manure management at the dairy and manure nitrogen applied to soil and (2) indirect emissions from volatilization and subsequent deposition of nitrogen and leaching and runoff of applied nitrogen. Indirect emissions of N_2O associated with leaching at the dairy are not included in the estimates.

Sensitivity Analysis

A sensitivity analysis was performed of the initial baseline calculations (dated October 2003) to identify those variables that are most critical to the estimation of the emission reductions, and to determine the validity of the data used. This analysis evaluated 12 variables used in the calculation of CH_4, N_2O, and NH_3 emissions:

- Amount of manure processed;
- Manure total solids;
- Manure volatile solids;
- Maximum methane producing capacity of the manure (B_o);
- Amount of manure transported from corrals in runoff to on-site lagoons;
- Amount of manure land applied;
- Amount of nitrogen that leaches or runs off from land application;
- Amount of manure co-composted;
- Corral methane conversion factor;
- Amount of nitrogen excreted;
- Amount of manure produced per cow; and
- Typical animal mass.

From this analysis, it was concluded that the baseline emission calculations are highly sensitive to the following variables:

- Amount of manure in the corral that is incorporated into run off and deposited in on-site lagoons;

- Amount of manure processed at the RP-1 and RP-5 digesters;

- Methane conversion factor for corrals; and

- Amount of nitrogen excreted.

ERG re-estimated the amount of manure in runoff from the corrals using precipitation and soil data specific to the Chino dairies. The amount of manure processed at the RP-1 and RP-5 digesters is measured at the time of delivery to digesters. These data should be updated over time to reflect actual operations at the dairies and the digesters.

Other variables, including the methane conversion factor for corrals and the amount of nitrogen excreted, are based on the best available data to estimate emissions from dairy operations. It may be possible to update these variables in the future as new data related to emissions from dairy operations becomes available; however, these variables are not expected to change related to operations.

Methane Emissions

Baseline CH_4 emissions were estimated for the following: 1) Enteric fermentation emissions; 2) Corral emissions; 3) Lagoon emissions; and 4) Co-composting emissions. This section documents the equations used to calculate CH_4 emissions.

Enteric Fermentation Emissions

Enteric fermentation is that which takes place in the digestive systems of ruminant animals such as cattle, sheep, and goats. Specialized bacteria break down coarse plant material that monogastric animals cannot digest into soluble products that can be utilized by the animal. Methane is produced in the rumen by the bacteria as a by-product of the fermentation process. This CH_4 is belched by the animal and released into the atmosphere.

Enteric fermentation emissions are related to the number of cows digesting feed. Therefore, the amounts of manure processed at the RP-1 and RP-5 digesters were added together and then used to calculate the equivalent number of cows that would produce that amount of manure. The number of cows was then multiplied by an emission factor to obtain the total amount of CH_4 emissions per year.

The following equation shows how to estimate the equivalent number of cows that would produce the amount of manure transported daily to the digesters.

Head = Tot Man / Day Cow Man (1)

where:

Head = Equivalent number of cows
Tot Man = Total amount of manure processed at the digesters annually
Day Cow Man = Amount of manure produced per day by each cow

The following equation illustrates the calculation of enteric CH_4 emissions:

Enteric CH_4 = # Head * Enteric EF (2)

where:

Enteric EF = Methane emission factor for enteric fermentation emissions

Since there are no documented changes in feed to the dairy cows following implementation of the digesters, enteric fermentation emissions are not expected to change.

Corral Emissions

Methane emissions from the corrals were calculated by using VS data from the digesters to estimate the amount of VS generated per day. Equation 3 illustrates the calculation of CH_4 emissions for corrals:

Corral CH_4 = VS * B_o * Corral Man * Corral MCF (3)

where:

VS = Volatile solids in digester manure
B_o = Maximum methane producing capacity
Corral Man = Percent of manure managed in the corral
Corral MCF = Methane conversion factor for corrals

Lagoon Emissions

Equation 4 illustrates the calculation of CH_4 emissions for lagoons:

Lagoon CH_4 = VS * B_o * Lagoon Man * Lagoon MCF (4)

where:

VS	=	Volatile solids in digester manure
B_o	=	Maximum methane producing capacity
Lagoon Man	=	Percent of manure managed in the lagoon
Lagoon MCF	=	Methane conversion factor for lagoon

Co-Composting Emissions

Equation 5 illustrates the calculation of CH_4 emissions for co-composting:

$$\text{Co-compost } CH_4 = \text{Tot Man} * \text{Corral Man} * \text{Compost Man} * \text{Compost EF} \quad (5)$$

where:

Tot Man	=	Total amount of manure processed at the digesters annually
Corral Man	=	Percent of manure managed in the corral
Compost Man	=	Percent of manure managed in the co-composting facility
Compost EF	=	Methane emission factor for co-composting

Summary of Methane Emissions

Using the following equation, the CH_4 emissions from the four sections were summed and represent the total amount of CH_4 emitted by the manure management practices of the dairies in Chino before implementation of the digesters.

$$\text{Baseline } CH_4 = \text{Enteric } CH_4 + \text{Corral } CH_4 + \text{Lagoon } CH_4 + \text{Co-compost } CH_4 \quad (6)$$

Nitrous Oxide Emissions

Nitrous oxide emission estimates include: (1) direct emissions from manure management at the dairy and manure nitrogen applied to soil and (2) indirect emissions from volatilization and subsequent deposition of nitrogen and leaching and runoff of applied nitrogen. Indirect emissions of N_2O associated with leaching at the dairy are not included in the estimates. This section documents the equations used to calculate N_2O emissions.

The Total Kjeldahl nitrogen excreted per year was calculated using the following equation:

$$\text{TKNex} = \text{TAM} * \text{Nex} * 365 * \text{\# Head} \quad (7)$$

where:

TAM	=	Typical animal mass
Nex	=	Nitrogen excretion rate per 1,000 pounds cow
365	=	Days per year
# Head	=	Equivalent number of cows

Direct Corral Emissions

Equation 8 illustrates the calculation of direct N_2O emissions for corrals:

$$\text{Corral } N_2O = \text{TKNex} * \text{Corral Man} * \text{Corral } N_2O \text{ EF} * 44/28 \quad (8)$$

where:

TKNex	= Total Kjeldahl Nitrogen excreted per year
Corral Man	= Percent of manure managed in the corral
Corral N_2O EF	= N_2O conversion factor for corrals
44/28	= Conversion factor for N_2O to nitrogen gas

Lagoon Emissions

Equation 9 illustrates the calculation of direct N_2O emissions for lagoons:

$$\text{Lagoon } N_2O = \text{TKNex} * \text{Lagoon Man} * \text{Lagoon } N_2O \text{ EF} * 44/28 \quad (9)$$

where:

TKNex	= Total Kjeldahl nitrogen excreted
Lagoon Man	= Percent of manure managed in the lagoon
Lagoon N_2O EF	= N_2O conversion factor for lagoons
44/28	= Conversion factor for N_2O to nitrogen gas

Indirect Corral Emissions

Equation 10 illustrates the calculation of indirect N_2O emissions for corrals:

$$\text{Ind Corral } N_2O = \text{\# Head} * \text{Corral } NH_3 \text{ EF} * \text{Vol } N_2O \text{ EF} * 44/28 \quad (10)$$

where:

# Head	= Equivalent number of cows
Corral NH_3 EF	= Emission factor for amount of nitrogen excreted at corral that volatilizes to NH_3 per head
Vol N_2O EF	= Nitrous oxide emission factor resulting from NH3 and oxides of nitrogen volatilization
44/28	= Conversion factor for N_2O to nitrogen gas

Land Application Emissions

Equation 11 illustrates the calculation of direct N_2O emissions for land application:

$$\text{Land App } N_2O = \text{Corral N-Air loss} * \text{Bulk Man} * \text{Land App } N_2O \text{ EF} * 44/28 \quad (11)$$

where:

Land App N_2O	= N_2O emissions from land application of manure
Corral N-Air loss	= Nitrogen remaining in corrals after air losses
Bulk Man	= Manure from corral used as bulking agent or land spread
Land App N_2O EF	= Nitrous oxide emission factor for land spreading
44/28	= Conversion factor for N_2O to nitrogen gas

Emissions from Leaching and Runoff

Equation 12 illustrates the calculation of N_2O emissions from leaching and runoff:

$$\text{Ind L\&R } N_2O = \text{N Bulk Man} * \text{N runoff} * \text{L\&R } N_2O \text{ EF} * 44/28 \quad (12)$$

where:

Ind L&R N_2O	= Indirect N_2O emissions from leaching and runoff
N Bulk Man	= Nitrogen content in the manure used as bulking agent
N runoff	= Percentage of total nitrogen that leaches or runs off
L&R N_2O EF	= Nitrous oxide emission factor for leaching and runoff
44/28	= Conversion factor for N_2O to nitrogen gas

<u>Emissions from Volatilization</u>

Equation 13 illustrates the calculation of N_2O emissions associated with volatilization of nitrogen:

Ind Vol N_2O = N Bulk Man* N App vol * Vol N_2O EF * 44/28 (13)

where:

Ind Vol N_2O	= Indirect N_2O emissions from volatilization
N Bulk Man	= Nitrogen content in the manure used as bulking agent
N App vol	= Percentage of total nitrogen applied to land that volatilizes to NH_3 and oxides of nitrogen
Vol N_2O EF	= Nitrous oxide emission factor resulting from NH_3 and oxides of nitrogen volatilization
44/28	= Conversion factor for N_2O to nitrogen gas

<u>Co-Composting Emissions</u>

Equation 14 illustrates the calculation of direct N_2O emissions for co-composting:

Co-compost N_2O = Man to Co-compost * Co-compost NH_3 EF / 2,000 lbs/ton * 28/17 * Vol N_2O EF * 44/28 (14)

where:

Co-compost N_2O	= N_2O emissions from co-composting facility
Man to Co-compost	= Manure shipped from corrals to the co-composting facility
Co-compost NH_3 EF	= NH_3 emission factor for co-composting facility
Vol N_2O EF	= Nitrous oxide emission factor resulting from NH_3 and oxides of nitrogen volatilization
44/28	= Conversion factor for N_2O to nitrogen gas
28/17	= Conversion factor for NH_3 to nitrogen gas

<u>Summary of Nitrous Oxide Emissions</u>

Using Equation 15, the N_2O emissions from the above sections were summed and represent the total amount of N_2O emitted by the manure management practices of the dairies in Chino before implementation of the digesters.

Baseline N_2O = Corral N_2O + Lagoon N_2O + Ind Corral N_2O + Land App N_2O + Ind L&R N_2O + Ind Vol N_2O + Co-compost N_2O (15)

Emissions Related to Transportation

This section presents an estimation of air emissions related to the transport of manure from the dairies. Both baseline and post-digester emissions are estimated.

Pre-Digester Emissions

Before the RP-1 and RP-5 digesters existed, manure was stockpiled at the dairies and transported for land application in Riverside County using an end dump truck with a gross vehicle weight (GVW) of 32,000 lbs, a 1995 diesel engine, and a loading capacity of 20 tons. Manure was transported 2 to 4 times a year per dairy, and the average trip length was about 85 miles. Pre-digester emissions are calculated for the amount of manure currently hauled to the digesters. The number of truckloads needed to transport the manure 85 miles was calculated by dividing the truckload capacity by the annual amount of manure transported. Emission factors for manure transportation were calculated using US EPA's MOBILE6.2 model for the following pollutants:

- VOC: 1.0475 g/mile
- CO: 3.9368 g/mile
- NOx: 13.3069 g/mile
- CO_2: 1346.5 g/mile
- CH_4: 0.0489 g/mile

Equation 16 was used to calculate truck emissions related to manure transportation before the digesters existed and to convert into lbs/day:

$$\text{Emissions} = Tm * EF / 1{,}000 * 2.2 * Tr\ loads \quad (16)$$

where:

Emissions	=	Pollutant
Tm	=	Truck daily mileage, (miles/trip)
EF	=	Pollutant emission factor (g/mile)
1,000	=	Conversion factor – g/kg
2.2	=	Conversion factor – lbs/kg
Tr loads	=	Number of truck loads per year needed (trips/yr)

Post-Digester Emissions

Based on information provided by the primary manure hauler, a truck and nurse tanker with a gross vehicle weight (GVW) of 45,000 lbs and a 1995 diesel engine is used to transport the manure from dairies to the RP-1 digester. The truck travels an average of 60 miles per day to pick up manure from selected dairies in Chino, California. US EPA's MOBILE6.2 model was used to calculate emission factors for VOC, CO, NOx, CO_2, and CH_4 as follows:

- VOC: 1.0095 g/mile
- CO: 5.3631 g/mile
- NOx: 16.1566 g/mile
- CO_2: 1552.7 g/mile
- CH_4: 0.0471 g/mile

An end dump truck with a GVW of 32,000 lbs and a 1995 diesel engine is used to transport manure from dairies to the RP-5 digester. The truck travels an average of 55 miles per day. Emission factors for manure transportation to the RP-5 digester were calculated using US EPA's MOBILE6.2 model for the following pollutants:

- VOC: 1.0475 g/mile
- CO: 3.9368 g/mile
- NOx: 13.3069 g/mile
- CO_2: 1346.5 g/mile
- CH_2: 0.0489 g/mile

Equation 17 was used to calculate truck emissions related to manure transportation to RP-1 and RP-5 and to convert into lbs/yr:

$$\text{Emissions} = Tm * EF / 1{,}000 * 2.2 * 365 \qquad (17)$$

where:

Emissions	=	Pollutant
Tm	=	Truck daily mileage, (miles/trip)
EF	=	Pollutant emission factor (g/mile)
1,000	=	Conversion factor – g/kg
2.2	=	Conversion factor – lbs/kg
365	=	Trips the truck makes per year (one trip per day)

MONITORING METHODOLOGY

The monitoring plan addresses how the data inputs required by the baseline model will be monitored. For example, IEUA staff actively monitor all aspects of digester operations and summarize pertinent data in weekly and monthly operating reports for each plant. Daily measurements of manure loading, biogas generation, and gas characterization are taken and recorded. The monitoring plan could call for IEUA to maintain records of all process operations for at least five years. Using this methodology, emission trajectories can be developed with a daily, weekly, or monthly resolution and are capable of capturing seasonal variations in manure loading and methane generation. The spreadsheet model contains details of all required data inputs. The monitoring plan for this project is based on the current practice of:

- Daily monitoring of all wastes received at the digester facilities;
- Regular random samples for manure characteristics such as moisture content, volatile solids, and nitrogen content;
- Periodic monitoring of dairy conditions and management practices;
- Continuous metering of biogas flow to flares, engines, and boilers; and
- Regular random analysis of biogas composition.

Digester RP-5 is equipped with a tipping scale enabling accurate weight measurements of all manure loads delivered to the RP-5 digester. Although RP-1 does not have a scale at this time, IEUA and their contractors have used the scales at RP-5 to develop density profiles for all participating dairies. This allows accurate estimation of weight based on volume even at RP-1. The plant personnel maintain daily logs of waste loads received and monthly summary totals of all emissions and reductions will be developed following the methodology detailed in this protocol. The data will be archived for at least five years in order to facilitate verification.

Data input requirements are summarized in the spreadsheet model. The following table summarizes data input requirements for RP-1:

RP-1 Data Entry Worksheet

Date	Est. Tons In at AMD	%TS	%VS	BioGas Production Dig #4 (1000 ft3/day)	Biogas Flow Rate: Flare (scfd)	Biogas Flow Rate: ERB (scfd)	Biogas Flow Rate: SMB (scfd)	Methane Flow rate: Flare (scfd)	Methane Flow rate: ERB (scfd)	Methane Flow rate: SMB (scfd)	H2S Conc. (ppmv): Inlet	H2S Conc. (ppmv): Outlet
01/01/03	0			73.7	1,745	55,178	16,776	1,047	33,107	10,066	185	41
01/02/03	108			106.6	2,524	79,810	24,265	1,515	47,886	14,559	116	35
01/03/03	72	13	79	99.1	2,347	74,196	22,558	1,408	44,517	13,535	89	15
01/04/03	108			128.8	3,050	96,431	29,319	1,830	57,859	17,591	122	32
01/05/03	90			126.0	2,984	94,335	28,681	1,790	56,601	17,209	137	16

The following table summarizes data input requirements for RP-5:

RP5 Data Entry Worksheet

Date	Manure Processed (Wet Tons)	% TS	Biogas Production (scfd)	% CH4 (mol %)	Total Gas to Desalter (scfd)	Biogas Used On-Site (scfd)	Hours of Flare Operation (hrs/day)	Gas To Flare (scfd)
1/7/2003	154	14%	87950		60466	0	8	27484
1/8/2003	122	10%	97747		46837	0	13	50910
1/9/2003	152	14%	98256		14329	0	21	83927
1/10/2003	186	14%	107582		62756	0	10	44826
1/11/2003	150	18%	93712		42951	0	13	50761

Fugitive emissions of methane from loading operations are not included as these are expected to be negligible. The loading area is kept under negative pressure and all gases from the digester building are vented to a biofilter.

Additional boiler emissions might be caused as a result of this project if heating of the digesters at RP-1 or RP-5 is required during the winter months. This is currently under investigation and if additional energy needs are identified then emissions resulting from natural gas combustion will be quantified and added to the "with project" case.

CONCLUSIONS

This baseline analysis estimated air emissions associated with dairy manure management both before and after implementation of the IEUA digester project. ERG estimated greenhouse gas and ammonia air emissions related to dairy housing, manure management, and land application, as well as manure composting off site. ERG also estimated criteria air pollutants associated with the transport of manure to off site land application areas. A summary of the emissions calculations are shown in Tables 1 through 3.

Table 1. Emissions related to dairy manure management (including composting and land application).

Pollutant	Methane		Nitrous Oxide		Ammonia	
Baseline Emissions	335.4	tons CH_4 /yr	23.2	tons N_2O /yr	227.2	tons NH_3/yr
Post-Digester Emissions	266.3	tons CH_4 /yr	1.1	tons N_2O /yr	56.1	tons NH_3/yr
Reductions	69.1	tons CH_4 /yr	22.1	tons N_2O /yr	171.1	tons NH_3/yr

Table 2. Emissions related to the transportation of manure.

Pollutant	VOC		CO		NOx	
Baseline Emissions	213.7	lbs VOC/yr	803	lbs CO/yr	2,715	lbs NOx/yr
Post-Digester Emissions	94.9	lbs VOC/yr	432.3	lbs CO/yr	1,366	lbs NOx/yr
Reductions	118.8	lbs VOC/yr	371	lbs CO/yr	1,348	lbs NOx/yr
Pollutant	**CO2**		**Methane**			
Baseline Emissions	274,683	lbs CO2/yr	10.0	lbs CH_4/yr		
Post-Digester Emissions	134,277	lbs CO2/yr	4.4	lbs CH_4/yr		
Reductions	140,405	lbs CO2/yr	5.55	lbs CH_4/yr		

Table 3. Summary of Baseline and Post-Digester Greenhouse Gas Emissions

Pollutant	GHG Emissions (CH_4+N20)	
Baseline Emissions	14,221	tons CO_2-eq /yr
Post-Digester Emissions	5,929	tons CO_2-eq /yr
Reductions	8,291	tons CO_2-eq /yr

* Numbers do not include digester emissions.

Limitations of the Baseline Analysis

It is important to consider the limitations and uncertainty associated with the estimation of baseline emissions to help prioritize future efforts to improve the accuracy of such emissions. Ideally, emission estimates would be derived from source-specific measured data. Since it is not practical to measure every emission source in this way, estimates are often based on available data, coupled with known characteristics of typical sources taken to be representative of the population.

In this analysis, certain site-specific data were available, such as total and volatile solids content of the manure and the amount of manure collected for digestion. However, other data, including nitrogen content of the manure, emission factors, amount of manure managed in runoff ponds, and distance manure is transported on and off site, were estimated from the body of available data.

In addition, changes in certain types of emissions were unable to be fully quantified, due to a lack of data. These emissions include:

- Enteric fermentation emissions: Methane emissions associated with enteric fermentation were calculated for the baseline analysis; however, there were insufficient data available to estimate whether there were any changes to these emissions following implementation of the digester project. Dairies participating in the IEUA program are encouraged to follow a standardized feeding regimen to ensure consistency of manure characteristics entering the digester. Specific feed data for both before and after program implementation were unavailable for this analysis.

- Milk parlor emissions: The analysis does not include emissions associated with the milk parlor, as no changes are expected due to implementation of the project.

- Effect of changing nutrient application rates: The analysis does not consider the effects of nutrient application rates on emissions from land application activities. For example, digested manure solids that are composted and sold have a more consistent and documented nutrient content and may result in decreasing the potential to over apply manure nitrogen to land. However, changes in emissions associated with the distance manure (or digested solids) are transported for application are included.

Conversely, there are a number of benefits that have been observed at dairies participating in the program, although these benefits are unable to be quantified at this time. They are:

- Improved dairy conditions: Dairies participating in the program have observed improvements in corral cleanliness due to daily removal of manure from the feed lanes. These conditions have resulted in noticeable reductions in odor and significant reductions of flies and other vectors. Data were not available to quantify potential reductions in pesticide use, or in neighbor complaints.

- Improved herd health: Overall herd health has improved, which is believed due to the more frequent removal of manure from the corrals. Cows are noticeably cleaner and in better health and incidences of mastitis and other diseases have decreased considerably. Although it is possible to quantify the reductions in cases of mastitis, it is not possible at this time to attribute the reduction solely to participation in the digester program.

- Improved milk production: The improved herd health has translated into increased milk production and milk quality at participating dairies. These changes may also be due to changes in feed regimens. Although it is possible to quantify these improvements, it is not possible at this time to attribute the reduction solely to participation in the digester program.

Transference of Results to Other Systems

It is important to note that the baseline methodology described in this report is one that can be transferred to other types of dairies and animal feeding operations. In fact, other types of animal systems may experience much greater benefits associated with the reduction of greenhouse gas emissions than that shown for the Chino dairies. For example, dairies that house their cows in freestall barns equipped with flush systems and manage their manure in open air lagoons generate much greater amounts of methane than corral-style dairies. Conversion of these open air lagoons to covered lagoon digesters or changes to the collection of manure to handle the manure aerobically will result in significant reductions to methane emissions. In addition, these types of systems are more likely to also see improvements to water quality, due to reducing or eliminating lagoon manure storage, which has the potential to contaminate groundwater through the leaching of pollutants and the potential to contaminate nearby receiving streams through overflows or catastrophic failures of the storage system.

REFERENCES

[1] IPCC. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, NGGIP, 2000. Chapter 4, Agriculture.
[2] U.S. EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, U.S. Environmental Protection Agency, Office of Atmospheric Programs, 2004; EPA 430-R-04-003, Chapter 6, Agriculture.
[3] U.S. EPA. *Draft Report of the National Emission Inventory—Ammonia Emissions from Animal Husbandry Operations*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, January 30, 2003.
[4] U.S. EPA. *Mobile 6 Vehicle Emission Modeling Software*. http://www.epa.gov/otaq/m6.htm#m60. 2002.

KEYWORD

Manure Management
Anaerobic Digester
Dairy
Emission Reductions
Ammonia
Methane
Nitrous Oxide