

Commonwealth Energy Biogas/PV Mini-Grid
Renewable Resources Program

***Making Renewables Part of an Affordable and
Diverse Electric System in California***

Contract No. 500-00-036

**Digester Comparison Study
Technical, Economic, and Environmental Performance
of IEUA RP-5 Digester and
Other Dairy Waste Digesters**

Project No. 3.1 Dairy Waste to Energy Project

Task 3.1.1a (1) Final Report

Prepared For:
California Energy Commission
Public Interest Energy Research Renewable Program

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Section	Page
Preface.....	v
11. Introduction	1-1
1.1 Background	1-1
1.2 Overview of Project 3.1, Dairy Waste to Energy	1-1
1.3 Digester Comparison Report Summary	1-3
1.4 Report Content and Organization.....	1-5
2. Description of Technologies.....	2-1
2.1 Plug-Flow Digesters	2-1
2.2 Complete Mix Digesters	2-2
2.3 Comparison of Plug-Flow and Complete Mix Designs	2-2
3. Design of the RP-5 Digester.....	3-1
4. Comparison of Performance Parameters	4-1
4.1 Gas Yield (Volume of Biogas Produced vs. Volume of Biomass Processed)	4-1
4.2 Volume of Biogas Produced vs. Digester Volume	4-2
4.3 Volume of Biogas Produced vs. Digester Capital Cost	4-2
4.4 Capital Costs Reported and Used for the RP-5 Digester	4-2
5. Data for U.S. Digesters.....	5-1
6. Data for Danish Complete Mix Digesters	6-1
7. Performance of the RP-5 Digester.....	7-1
7.1 Summary of RP-5 Digester Performance Data	7-1
7.2 Comparison of RP-5 performance to Other U.S. Plug-Flow Systems	7-3
7.2.1 Gas Yield	7-3
7.2.2 Biogas Produced vs. Digester Capital Cost.....	7-4
7.3 Comparison of RP-5 performance to U.S. Complete Mix Digesters.....	7-5
7.3.1 Gas Yield	7-5
7.3.2 Biogas Produced vs. Digester Capital Cost.....	7-6
7.4 Comparison of RP-5 performance to Danish Complete Mix Systems	7-6
7.4.1 Gas Yield	7-7
7.4.2 Biogas Produced vs. Digester Capital Cost.....	7-8
8. Case Study of Tinedale Farms	8-1
9. Environmental Considerations for the RP-5 Digester	9-1
9.1 Water Quality	9-1
9.2 Air Quality	9-2
9.3 Greenhouse Gas Reduction	9-2
9.4 Renewable Energy Credits (“Green Tags”)	9-3
9.5 Summary Table of Economic Benefits	9-3
9.6 Life-Cycle Analysis.....	9-4

Section	Page
10. Potential Research Modifications to the RP-5 Digester	10-1
10.1 Research modifications to Existing Plug-Flow Configuration	10-1
10.2 Conversion to a Complete Mix System	10-1
10.3 Conversion to a TPAD system	10-1
10.4 Life Cycle Benefits of Proposed Changes	10-2
11. Conclusions	11-1
12. References	12-1

Appendixes

A	Capital Cost Breakdown for Danish Centralized Digesters
B	Calculations for Potential Greenhouse Gas Credits From the RP-5 Digester
C	Calculations For Avoided Desalting Cost Due To RP-5 Digester
D	Energy Production Calculations for RP-5 Digester
E	Capital Cost Breakdown Report for RP-5 Digester

Tables

4-1	Capital Costs For RP-5 Digester For Comparison.....	4-2
5-1	Data for U.S. Plug Flow and Complete-Mix Digesters.....	5-2
5-2	Status of Farm-Based Digesters in the U.S. as of 1998.....	5-4
6-1	Danish Complete Mix Digester Summary	6-2
7-1	Synagro digester Operating Data from March-April 2003	7-1
9-1	Total Monetized Benefits from Digester At RP-5.....	9-5

Figures

2-1	Flow Diagram for Plug-Flow Digester	2-1
2-2	Flow Diagram for Complete Mix Digester	2-2
3-1	Top View of RP-5 Digester Layout	3-1
7-1	Graph of RP-5 Operating Data: February - August 2003	7-3
7-2	Biogas Production Versus Manure Input (Dry Lb./Day)-U.S. Plug-Flow Digesters..	7-4
7-3	Distribution of Capital Cost Per CFD of Biogas - U.S. Plug-Flow Digesters	7-5
7-4	Biogas Production Versus Manure Input (Dry lbs./Day) - U.S. Complete-Mix Digesters	7-6
7-5	Biogas Production Vs. Manure Slurry Input - RP-5 Digester And Danish Centralized Units	7-7
7-6	Distribution Of Capital Cost Per cf. Of Biogas Production For Danish Units And RP-5 Digester	7-8
8-1	Top View of Tinedale Farms Digester Layout.....	8-1

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to \$62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/ Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

For more information on the PIER Program, please visit the Commission's Web site at: <http://www.energy.ca.gov/research/index.html> or contact the Commission's Publications Unit at 916-654-5200.

For Commonwealth Program-specific information, please visit <http://www.pierminigrid.org>.

What follows is a comparison report for the **California Energy Commission, Public Interest Energy Research Program, Contract Number 500-00-036**, conducted by the **Commonwealth Energy Team**. The report is entitled **Inventory Digester Comparison Study**. This project contributes to the **Renewable Energy** component of the PIER program.

1. Introduction

In June 2001, the Commonwealth Energy Team was awarded a programmatic contract under the California Energy Commission's Public Interest Energy Research (PIER) Program to conduct research on strategies for making renewable energy more affordable in California. The Commonwealth Energy approach involves assessing the combined potential of biogas and photovoltaic (PV) resources in a defined study area and identifying how these resources could be developed in a complementary and cost-effective manner. The Commonwealth Energy Team conducted this research in a real world setting so that the findings could be applied elsewhere in California and thereby benefit more California ratepayers. The local area Commonwealth Energy selected for its renewable energy research activities is the Chino Basin, referred to in this report as the "study area."

1.1 Background

The Chino Basin is rich in PV and biogas resources. Moreover, it is a rapidly growing area with substantial and yet increasing electrical loads. The underlying goal of the Commonwealth Energy Program is to identify potential Chino Basin Building Integrated PV (BIPV) and biogas energy projects, bring innovative technologies and business practices to these projects, assess the benefit to the local electricity distribution system (the "mini-grid"), and then use the findings to develop a business model for siting cost-effective, renewable energy projects. A description of the Commonwealth Energy PIER Program, including the results of some of the work undertaken to date, is presented in the project Web site, <http://www.pierminigrid.org>.

An important element of the Commonwealth PIER Program is a project devoted to research on the use of dairy manure for energy by means of anaerobic digestion. This project is identified as Project 3.1., Dairy Waste to Energy. The work summarized in this report is one of the first activities of Project 3.1.

1.2 Overview of Project 3.1, Dairy Waste to Energy

The primary objectives of the Commonwealth PIER Program Dairy Waste to Energy Project are to:

- Develop technologies that can be used to maximize the energy recovery from animal waste.
- Develop and evaluate different pilot projects that will include facilities at existing treatment plants and at individual and/or clusters of dairies.
- Evaluate and test the effectiveness of low and high technologies developed in North America and Europe for the collection and processing and energy recovery of animal waste.

The Chino Basin is an ideal location for undertaking these projects. It has one of the largest concentrations of dairy cows in the world, with over 300,000 cows located within a 50 square mile area. It is also well suited for PIER research because Inland Empire Utilities Agency (IEUA), the region's entity responsible for treating wastewater, has led the region in its efforts to better manage the waste from the dairies and to explore alternatives to use it to produce energy. IEUA is a partner in the Commonwealth PIER Program. Recognizing the opportunity created by IEUA's program in converting manure to energy, the Energy Commission authorized the Commonwealth Team to evaluate the performance of anaerobic digestion projects to convert dairy manure to energy. The purpose of this evaluation was to provide a baseline against which the performance of digester projects at IEUA facilities could be compared.

The primary objectives of project 3.1 are to:

- Assess and evaluate technologies available for the conversion of animal waste to energy.
- Select sites for animal waste to energy pilot plant(s).
- Design, construct and operate pilot plant(s).
- Summarize and evaluate economic and environmental costs and benefits associated with developing animal waste to energy facilities.

The Commonwealth team, after its work on inventorying dairy waste in the Chino Basin in the Planning and Analysis Project, recommended focusing future efforts in Project 3.1 on researching improvements to existing facilities at IEUA Regional Plants 1 and 4. These plants, which represent the only major dairy cluster project in the United States, offer a unique opportunity to test and develop regional or dairy cluster technology applicable to other dairy regions throughout California. Before such efforts were authorized, however, the Energy Commission asked Commonwealth to review the performance of these facilities in light of what is occurring elsewhere in the United States and Europe on anaerobic digestion projects. As part of this evaluation, the Commonwealth team sought to identify the areas where further research could produce the most public benefits in terms of energy conversion efficiency and production, environmental benefits, and overall economic performance.

The Commonwealth team completed this study by assembling a team of experts led by its biogas team lead, CH2M HILL. CH2M HILL efforts were supported by NIRAS, a Danish firm with internationally recognized expertise in biogas projects using animal waste. In addition, other sources used in preparing this report included the U.S. Environmental Protection Agency (EPA) Ag Star Program, other work funded by the U.S. Department of Energy (DOE) and U.S. Department of Agriculture (USDA), as well as numerous consultations with dairy operators and consultants involved in animal waste anaerobic digestion projects. The efforts in preparing this report were overseen by the Commonwealth PIER Program Manager, Itron. The results will be used in shaping the direction of the remaining activities in Project 3.1.

1.3 Digester Comparison Report Summary

This report compares both the performance and capital costs of the anaerobic digester being used on dairy manure at Inland Empire Utilities Agency (IEUA) Regional Plant #5 (RP-5) treatment facility with other anaerobic digesters in similar applications. The RP-5 digester is the one of the first documented centralized digesters in the United States. The report also provides the basis for an economic analysis of the RP-5 digester, including monetized environmental benefits that accrue from its operation, and a framework for evaluating impact of potential research modifications to the digester.

Anaerobic digestion of animal waste, while not new, has not yet converged to a single design or operating practice. In the United States, individual initiative on the part of farmers has resulted in a wide variety of designs and wide variation in success rates of projects. All of these digesters are single-farm units, and they are different in scale from the RP-5 digester. In Denmark, there has been an evolution to a more consistent base design for centralized digesters; however, all of these digesters are different in design from the RP-5 digester. Thus, there are no digesters exactly comparable to the digester at RP-5; all digesters have some unique circumstances. Where data were available to make a more direct comparison, adjustments have been made to do so. Because these data were not available in many cases, qualifying explanations of comparisons made are documented below.

The RP-5 digester's performance with respect to biogas production is compared to that of U.S. on-farm plug-flow digesters and Danish complete mix digesters. The comparisons show that against the other plug-flow digesters, RP-5's performance is on par with or slightly better than the benchmark set by other plug-flow units. The gas production performance of the Danish complete mix units is on average better than that of the RP-5 digester, which is not surprising for the following reasons:

- The Danish units are configured as complete mix units and some of them are thermophilic (higher operating temperature than the digester at RP-5).
- Operating practices and pretreatment have been optimized for steady, consistent operation of the digester.
- Most importantly, they all practice some amount of co-digestion of other wastes, typically food wastes, which produce higher amounts of methane than manure. The data suggest that co-digestion at the RP-5 plant has a potential for significant increase in performance. A Danish report suggests that on average, adding 24 percent co-digested waste to the manure stream may be increasing gas production at some facilities by up to 50 to 85 percent over manure use alone (Hjort-Gregersen, 1999).

The RP-5 digester's capital cost, per unit of biogas produced, is compared in this report with U.S. on-farm plug-flow digesters, and with Danish centralized complete mix digesters. Both of these comparisons require qualification to be understood, and adjustments have been made to produce comparable capital costs for the RP-5 digester, and the Danish units. Two capital costs are used for the RP-5 digester in this analysis; one for comparison with U.S. on-farm plug-flow digesters, and one for comparison to Danish centralized complete mix digesters. The RP-5 digester cost for comparison to the U.S. on-farm units is a base cost with

items associated with a centralized unit, and some unique items for RP-5, deducted. The RP-5 digester cost for comparison to the Danish units has items considered part of building a centralized unit included, but some unique items for RP-5 situation removed. All of these adjustments are discussed in section 4 of this report, and shown in Appendix E.

With respect to the U.S. digesters, the cost per unit of biogas for RP-5 is higher than the average. This is not surprising for the following reasons:

- Labor and overhead costs associated with construction are fully reported for RP-5, whereas the on-farm units would contain unreported costs for time spent by the farm owner or other farm employees on the system.
- The RP-5 digester is constructed to all applicable codes and building practices, using durable materials with operating lives of 20 years or more, whereas many on-farm units are not built to the same code standards, using less durable materials (such as flexible fabric covers), which require replacement in less than 20 years.
- The RP-5 digester was subjected to a full design and permitting process, whereas many on-farm digesters have not been in the past.

With respect to the Danish digesters, the RP-5 unit's comparable capital cost per unit of biogas produced falls close to the average. The Danish units have certain ancillary items such as pretreatment and storage tanks. Some of the Danish units also include cost of trucks for delivery of manure to the centralized facility, and costs for a distribution system for heat generated by the biogas. Where cost breakdown data were available, deductions were made from the costs for the Danish units to arrive at a base cost for them that could be compared to the cost for the RP-5 digester. This is discussed in section 6, and shown in detail in Appendix A.

The same level of detail was not available all of the U.S. on-farm facilities. In many cases, only a cost for the entire system was available, without the benefit of a cost breakdown. In others, a breakdown into top-level items, such as digester versus generator, was available, but nothing further. Therefore, the exact extent of costs that are or are not included in the some of the comparison projects is not fully known.

Based on conclusions in this report, and reviews by NIRAS, a digester design company in Denmark, there are several avenues for making research modifications to RP-5 to increase its performance and biogas production that should be investigated:

- Research modifications to the existing plug-flow design, including better pretreatment to remove stones and grit, and optimization of the manure delivery schedule. These changes would likely result in the RP-5 digester producing consistently at or above the design biogas rate of 210,000 cubic feet per day.
- Research modifications to add mixing to RP-5 to make a complete mix digester. This change would likely increase the efficiency of the RP-5 digester, and likely enable the co-digestion of food waste, which would further increase biogas production.
- Research modifications to add a thermophilic (higher temperature) phase to the digester. This change would likely result in further increases in biogas production, and improved

volatile solids destruction, resulting in cleaner, more usable effluent solids from the digester.

A framework for an economic analysis is presented in this report. The framework accounts for environmental benefits that accrue from the practice of using anaerobic digestion for management of animal waste. This project is not merely an energy producer, and merely accounting for energy revenue would make any economic analysis incomplete. This project is a comprehensive environmental solution, which improves environmental quality along several lines:

- Air quality improvement, owing to reduction of ammonia and odor emissions
- Water quality improvement, owing to capture and diversion of nitrates and salts that would otherwise enter the Santa Ana watershed
- Greenhouse gas reduction, through capture of methane and nitrous oxide emissions
- Solid waste management, through reduction of manure to a usable compost material

Assigning a monetary value to these environmental benefits is an emerging practice. Some of these values have assignable credits that can be traded in a market, though these types of trades are relatively new. Estimates are given in the report for what some of these values could be, subject to further review. Some of these values may have significant positive effect on the economic analysis of the RP-5 and other digesters going forward. Further research along these lines is another recommendation of this report.

1.4 Report Content and Organization

The report presents findings from a study comparing performance and cost of plug-flow digesters to complete-mix digesters for dairy cattle waste, and draws comparative conclusions about the performance of the dairy waste digester at Inland Empire Utilities Agency (IEUA) Regional Plant #5 (RP-5), located in the Chino Valley area of Southern California, versus other digester installations. Included in the study is a discussion of the environmental benefits of anaerobic digestion in the Chino Valley, and a framework for putting monetary values to those environmental benefits. This framework will provide an important path to a comprehensive economic analysis for installing anaerobic digestion technology for regional treatment of animal waste.

Each of the digesters studied for this comparison, including the RP-5 digester, has some unique aspects. However a sizeable body of knowledge on specific digester case studies exists, so that a number of installations could be compared with each other, and with RP-5.

During the study, it became evident that direct comparisons between plug-flow and complete-mix digester designs could not be made without considering several other factors, including:

- Operating temperature (mesophilic or thermophilic range),
- Centralized digesters (taking in waste from several farms) versus on-farm digesters
- Differences in economic and regulatory environments between America and Europe

- Small-scale digesters (under 1,000 cows) versus large-scale digesters (over 1,000 cows)

Anaerobic digestion technology for animal wastes has followed a different evolutionary path in America than in Europe. American installations have been driven primarily by the initiative of individual farmers, responding to location-specific requirements, and taking advantages of various rebate-based and loan-based incentive programs. These on-farm units have been at the scale of several hundred head of dairy cows, and have been designed for simplicity and low capital cost. Most have been plug-flow units. Typically, the individual dairy farmers have had to learn from experience (both good and bad) how best to operate the digesters, and the successful installations have occurred where a commitment was made to learn about, maintain, and operate the system on the part of the farmer.

In Europe, Denmark presents a significant collection of experience in centralized anaerobic digestion for animal waste. In Denmark, a significant effort has been made to plan and support centralized digester facilities that treat waste from several farms, through environmental regulation policy, electric utility structures that aid in selling the power generated, and funding assistance. At the same time, the required infrastructure has been built for the methane gas transport to support distributed generation. This has caused the evolution of a favorable environment for planned, regional digester facilities that are generally economically viable based on these instituted policies. Of the 19 Danish centralized biogas plants surveyed in 2000, all were operational, with four showing unsatisfactory financial results for that year (Hjort-Gregersen, 1999). This compares with American individual on-farm projects, which have experienced a much higher failure rate (Lusk, 1998).

Early testing in Europe starting in 1980 indicated that complete mix design provided better performance than plug-flow. The plug-flow design they tested exhibited poor gas production, possibly due to “channeling”, wherein solids built up creating a narrow passage for the slurry (STUB, 1981). Therefore, all of the twenty centralized digester facilities in Denmark are complete mix units. Their success rate has been more consistent than that of the U.S. on-farm digesters.

The digester at IEUA’s RP-5 facility is one of the largest plug-flow digesters in the world, and to date, is the first centralized dairy waste digester in the U.S. Therefore, RP-5 has some similarities to other plug-flow digesters (i.e. design), and some similarities to complete mix digesters in Denmark (i.e. size, centralized operations), but is not fully comparable to either approach, due primarily to its centralized approach and scale of production.

This report is organized as follows:

- Section 1 introduces the Commonwealth Energy program, provides background information on the Chino Basin, and presents an overview of the Commonwealth Pier Program dairy waste to energy project.
- Section 2 compares the plug-flow digester and the complete mix digester design and characteristics.
- Section 3 summarizes the design of the IEUA RP-5 plug-flow digester.

- Section 4 describes the comparative performance parameters of the RP-5 digester to other plug-flow digesters.
- Section 5 provides data for plug-flow digesters installed on U.S. farms.
- Section 6 provides data for Danish complete mix digesters.
- Section 7 summarizes the performance of the RP-5 plug-flow digester and provides graphs of comparative digester performance.
- Section 8 describes a case study of the complete mix digester located at Tinedale Farms in Wisconsin.
- Section 9 describes the environmental considerations and benefits of the RP-5 digester.
- Section 10 identifies potential research modifications to the existing RP-5 digester, designed by Synagro, LLC
- Section 11 highlights conclusions derived from this study.
- Section 12 provides a bibliography of references consulted in preparing this report.

2. Description of Technologies

This section compares two types of digesters: the plug-flow digester and the complete mix digester. Advantages and disadvantages of both digester approaches are summarized.

2.1 Plug-Flow Digesters

The plug-flow configuration is the simplest, least expensive design for anaerobic digesters (Burke, 2001). The typical design consists of a horizontal trough. Waste slurry enters at one end of the trough and exits from the other end. The trough is covered with either a fixed (concrete) or flexible (hypalon or polypropylene) cover, which collects the biogas. The biogas is then piped off to a flare, or an engine generator. Temperature control (heating to 95°F) is achieved by circulating hot water through pipes that run through the trough. Waste heat from an engine generator can be used to provide the hot water. Figure 1-1 shows a simplified flow diagram for a plug-flow digester.

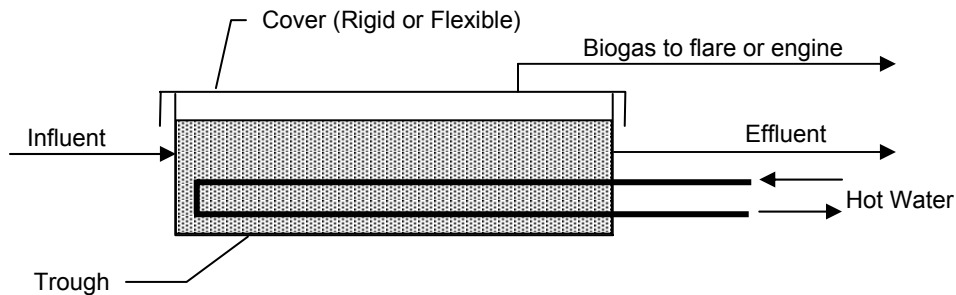


FIGURE 2-1. FLOW DIAGRAM FOR PLUG-FLOW DIGESTER

Plug-flow digesters operate in the mesophilic temperature range of 90–95°F, with a hydraulic retention time (HRT) of 20–30 days (Lusk, 1998). A “plug” of slurry, at about 10 to 13 percent solids concentration, enters the influent end and pushes the contents of the digester through to the other end. A portion of the anaerobic bacteria is wasted with the effluent, and a portion of the influent must be converted into new bacteria. This is called a growth-based system. Early plug-flow units were developed in the late 1970s at Cornell University as a less capital-intensive alternative to the complete mix designs that existed at the time. The first commercial plug-flow unit was installed in 1979 at Mason Dixon Dairy Farms in Gettysburg, Pennsylvania (Lusk, 1998).

Owing to their relative simplicity, plug-flow digesters have been a common choice among individual farmers in the U.S. Almost all of the digesters operating on agricultural waste in the U.S. are “on-farm” units. Most of the digesters at dairies are plug-flow units. Most of

these installations are for herd sizes between 300 and 1,000 cows, with two units studied that served herds of between 2,000 and 3,000 cows.

2.2 Complete Mix Digesters

The complete mix digester consists of a tank that is heated and mixed. A typical design is a round tank that is stirred with a mechanical mixer. Recirculating pumps can also be used for mixing. In most units, temperature control is achieved using a spiral-flow heat exchanger. Complete mix digesters can operate at mesophilic (90-95°F) or thermophilic (140-145°F) temperatures, and operational experience exists for both. Figure 1-2 shows a simplified flow diagram for a complete mix digester.

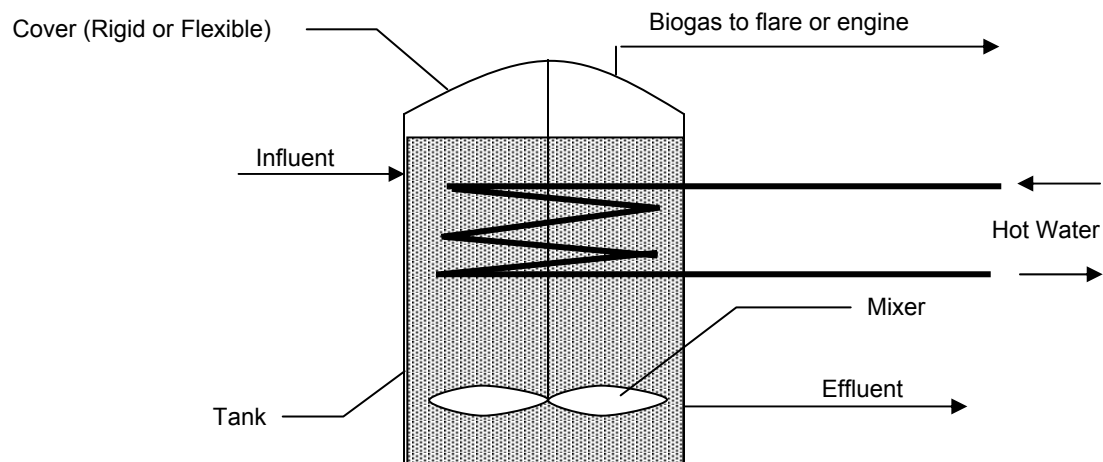


FIGURE 2-2 FLOW DIAGRAM FOR COMPLETE MIX DIGESTER

Complete mix digesters are standard technology at municipal wastewater treatment plants, with extensive operational application. They typically operate at an inlet concentration of 3 to 10 percent solids. They are used on U.S. farms for some dairy applications, but more for swine, and poultry waste applications. In Denmark, the complete mix reactor is the standard design for centralized anaerobic digesters running on animal waste, with 20 units installed to date.

2.3 Comparison of Plug-Flow and Complete Mix Designs

The main advantage of the plug-flow design is that it is simple and economical to install and operate. However, it is not as efficient or as consistent as the complete mix design. Plug-flow units are limited to applications with low amounts of sand, dirt, or grit, because these substances will tend to stratify and settle out inside the digester, requiring significant effort to clean out. Plug-flow units are also subject to "crusting," the result of lighter solids floating to the top of the slurry in the digester and drying to form a "skin." The hot water pipes running through the trough can be cumbersome to work around when cleaning the unit out. They are suitable for dairy manure, but, poultry waste is not a good application for them, as the fine solids content of this waste is generally higher than that of dairy waste, and

can fall out of suspension in a plug-flow unit (Lusk, 1998). For similar reasons, plug-flow units are probably not well-suited to co-digestion with other waste materials, such as food processing waste, though specific data on such operation for a plug-flow unit have not been found.

Complete mix units are more expensive to install and operate than plug-flow units, because they require both the capital equipment and the energy for mixing. However, they are more consistent in their performance, and not as susceptible to accumulation of sand, grit, and other foreign materials, given that these materials are kept in suspension by the mixing action. Furthermore, they may be operated in mesophilic or thermophilic mode. In thermophilic mode, the HRT is reduced, reducing the size of the vessel needed, gas production is increased, and the volatile solids destruction rate is increased. The cost for this increased performance is that more heat is needed to control digester temperatures in the range of 140°F. Complete mix is a proven design for anaerobic digesters, with extensive application in municipal waste treatment. Combined with extensive on-farm application in treating dairy, swine, and poultry waste, complete mix is a more appropriate design for a centralized unit where co-digestion of mixed wastes is being considered.

SECTION 3

3. Design of the RP-5 Digester

The RP-5 digester is a “plug-flow loop” design, which is a variation on the standard plug-flow design in which the material flows down one side of a divided trough and back up the other side. There is no mixing provided. The target solids content going into the digester is 11 to 12 percent. The design HRT is approximately 20 to 25 days. The temperature is controlled in the mesophilic range, with a target range of 95 to 100°F. The digester volume is about 1 million gallons, or 133,680 cubic feet. The digester design feed rate is 225 wet tons per day of manure. On average, about 40,000 to 50,000 gallons of slurry is fed to the digester each day. Figure 3-1 shows a top view of the layout:



FIGURE 3-1. TOP VIEW OF RP-5 DIGESTER LAYOUT

4. Comparison of Performance Parameters

This study compares the performance of the RP-5 digester to other plug-flow digesters in the U.S., and to Danish complete mix centralized digesters. Parameters compared are:

- Gas yield for RP-5 and U.S. digesters: Volume of biogas produced (ft³/day) versus dry pounds of manure input per day.
- Gas yield for RP-5 and Danish digesters: Volume of biogas produced (ft³/day) versus volume of biomass processed (ft³/day).
- (Both U.S. and Danish units) : Average volume of biogas produced per day versus digester capital cost

4.1 Gas Yield (Volume of Biogas Produced vs. Volume of Biomass Processed)

For the Danish digesters, this parameter divides cubic feet (or cubic meters) per day of biogas produced by cubic feet (or cubic meters) per day of biomass slurry input. The Danish literature cites this parameter for each of the Danish digesters, and it is consistently measured at the Danish facilities. The parameter is dimensionless; as both the numerator and denominator are volumetric.

It should be noted that variations in slurry concentration will affect this gas yield calculation. The reported solids concentrations of the input slurry to the RP-5 digester have varied from 8 to 12 percent, with a typical average being about 10.4 percent (Synagro, 2003). Danish digesters report input slurry concentrations in the 8 to 10 percent range. Where data were available on U.S. plug-flow digesters, the solids concentration of the input slurry ranged from 9 to 12 percent.

A better calculation of this parameter would be to reduce the input slurry to dry tons, using the concentration (by weight) of the solids in the slurry. The parameter would be cubic feet per day (cfd) of biogas over dry tons per day of input. For the U.S. digesters, dry tons per day of input data was only available for the RP-5 digester for this report, however all other U.S. digesters studies are single-farm units, and herd size served was consistently available. Herd size served was translated to dry pounds per day of manure input using 14 dry lbs./day per milking cow (Burke, 2001). Herd sizes were reviewed where possible to translate herds that may include non-milking cows into an equivalent number of milking cows. So, for the U.S. digesters, the comparison is cubic feet per day of biogas out versus dry tons/day of manure in. This was not done for the Danish digesters because they are centralized facilities, and a specific "herd size" served was not available.

4.2 Volume of Biogas Produced vs. Digester Capital Cost

This parameter compares gas production, in cubic feet per day, to the installed cost of a system, and suggests the relative amount of product obtained per dollar of investment.

Most of the case literature cited reports capital costs inclusive of the generator. It would be preferable to back out the cost of the generator so that only digester costs are being compared. However, generator costs alone are not broken out for most comparable units, suggesting the need for further investigation. As presented, the cases compared include the generator cost. For RP-5, a reasonable portion of the total cost of the 1,000 kW generator that powers the desalter unit was used for generator costs. The RP-5 digester alone provides approximately 500 kW running at design capacity.

The comparison for this parameter involves calculating the total capital cost per cubic foot/day of biogas produced for all installations, and making a “histogram” showing the distribution of those costs from lowest to highest. As expected, the distributions for both U.S. plug flow and Danish digesters show a peak at the average calculated, with tail on both the low-cost and high-cost ends. The RP-5 digester’s comparable cost is noted on both distributions.

4.3 Capital Costs Reported and Used for the RP-5 Digester

The Synagro-designed digester at RP-5 has a number of unique circumstances that affect its capital costs. This includes provisions for stormwater, odor, and dust abatement required due to the facilities urban location in the Chino Valley, brine handling equipment needed to address groundwater issues specific to the area, and long pipelines to run water and biogas between existing IEUA facilities. In order to provide an accurate cost comparison between the RP-5 digester and the other facilities in this study, a cost breakdown was generated by IEUA staff from internal data. Line items in this cost breakdown were compiled to provide cost numbers for comparable equipment which do not include some of the items that were needed due to IEUA’s specific location and circumstances. The complete cost breakdown is included as appendix E. Table 4-1 below summarizes capital costs used to compare to U.S. on-farm and Danish centralized digesters.

TABLE 4-1: CAPITAL COSTS FOR RP-5 DIGESTER FOR COMPARISON

Situation	Cost
On-site Dairy Digester with 500 kW Capacity (Compare to U.S. on-farm digesters)	
Total Capital Cost	\$ 3,054,262
Cost for a Centralized Dairy Digester w/ 500 kW Capacity (Compare to Danish centralized Digesters)	
Total Capital Cost	\$ 4,035,260

Source: IEUA internal data

For other U.S. digesters, it was necessary to adjust costs for past years to 2002 dollars, given the inflation rate of 3.3 percent. Cost adjustments were made for the Danish units as well, to remove certain costs specific to some locations where entire district-wide heating system was built. It was also necessary to convert from Danish kroners to U.S. dollars. An exchange rate of 6.93 Danish kroners per dollar was used. The IEUA cost data is for 2002, so no inflation adjustment was needed for it.

5. Data for U.S. Digesters

The digesters compared to RP-5 for this study are all installed on U.S. farms. Typically, the owner has had a high level of involvement with the design, installation, and operation of the unit. In early installations (pre-1982), many of the digesters were designed and built by the farmers themselves, who learned and invented as they went along. The success of these units is spotty, and a number of them have been shut down and abandoned. More recent installations (1982 and later) have been more successful, primarily owing to improvements in design (Ag Star, 1997). Table 5-1 shows selected cost and performance information for American plug-flow and complete-mix dairy digesters.

As Table 5-1 shows, the typical size for the farm units is 350 to 1,000 cows. The RP-5 digester was designed to serve several larger dairies and is a much larger unit.

Only units that are in operational mode with stable data for at least six-months are included in this study. As stated previously, all of the animal waste digesters in the U.S. for which study data were found are on-farm units, with the exception of the RP-5 digester. Also, only dairy units were used to compare with the RP-5 digester. Hog waste and poultry waste units are not included in this study. A number of units in the U.S. have been shut down and consequently are not included in Table 5-1. The status of farm-based digesters in the U.S. as of 1998 is summarized in Table 5-2.

Table 5-1

Data for U.S. Plug-Flow and Complete-Mix Dairy Digesters

State	Start Date	Herd Size	Manure Input (dry lbs./day) ³	Biogas Production (ft3/day)	Biogas Production (ft3/day)/dry lb. input	Capital Cost	Inflation Adj. Cap Cost ¹	Adj. Cap cost/ cfd Biogas Production
<i>Plug-Flow</i>								
VT	1982	340	4,760	37,500	7.88	\$ 185,000	\$ 354,143	\$ 9.44
CA	1982	400	5,600	22,000	3.93	\$ 200,000	\$ 382,857	\$ 17.40
NY	1997	550	7,700	42,000	5.45	\$ 311,500	\$ 366,404	\$ 8.72
MI	1981	500	7,000	43,200	6.17	\$ 200,000	\$ 395,491	\$ 9.15
WI	2002	710	9,940	55,000	5.53	\$ 532,000	\$ 532,000	\$ 9.67
MN	1999	750	10,500	70,000	6.67	\$ 355,000	\$ 391,318	\$ 5.59
WI	2002	730	10,220	58,000	5.68	\$ 500,000	\$ 500,000	\$ 8.62
IA	2002	633	8,867	59,040	6.66	\$ 500,000	\$ 500,000	\$ 8.47
WI	2001	2,850	39,900	190,000	4.76	\$ 1,300,000	\$ 1,342,900	\$ 7.07
WI	2001	1,200	16,800	54,000	3.21	\$ 450,000	\$ 464,850	\$ 8.61
CA	2002	1,200	16,800	75,000	4.46	\$ 235,000	\$ 235,000	\$ 3.13
IL	2002	1,200	16,800	83,000	4.94	\$ 875,000	\$ 875,000	\$ 10.54
CA (RP-5 at start-up)	2002	3,300 ²	40,692	155,373 ⁴	3.82	\$ 3,054,262 ⁵	\$ 3,054,262	\$ 19.66
CA (RP-5 at design)	2002	3,300 ²	40,692	210,000	5.16	\$ 3,054,262 ⁵	\$ 3,054,262	\$ 14.54
				Average⁶	5.31	Average⁶		\$ 10.05

State	Start Date	Herd Size	Manure Input (dry lbs./day)	Biogas Production (ft ³ /day)	Biogas Production (ft ³ /day)/dry lb. input	Capital Cost	Inflation Adj. Cap Cost	Adj. Cap cost/ cfd Biogas Production
<i>Complete-Mix</i>								
NY	1987	330	4620	21,500	4.65	\$ 230,000	\$ 374,311	\$ 17.41
CT	1997	600	8400	38,000	4.52	\$ 450,000	\$ 529,315	\$ 13.93
NY	2001	900	12600	250,000 ⁴	19.84	\$ 625,000	\$ 645,625	\$ 2.58

Source: Compiled from data presented by Kramer (2002) and Lusk (1998), and conversations with individual dairies and/or system designers.

NOTES:

1. An inflation rate of 3.30% per year was used to adjust for inflation.
2. About six dairies are served by the RP-5 digester. Based on gallons of manure slurry received (about 44,500 per day on average), this equates to manure from about 3,300 cows using 13.5 gallons per day per cow (Burke, 2001).
3. Dry solids are calculated using heard size and multiplying by 14 lbs. dry solids per cow per day (Burke, 2001). Exception is the RP-5 digester, where operational data includes dry weight of solids received each day – average over the study period was 40,692 lb./day.
4. These operational biogas production numbers include some co-digestion with food waste.
5. Comparable capital costs for the RP-5 digester as shown in table 4-1
6. Averages shown for plug-flow digesters, but not for complete-mix due to variability and small sample size of complete-mix data.

TABLE 5-2
Status of Farm-Based Digesters in the U.S. as of 1998

	Plug-Flow	Complete Mix
Operating	8	6
Not Operating	18	10
Farm Closed	11	5
Under Construction/Planning Phase	2	4
Planned but Never Built	8	1
TOTAL	47	26

Source: Lusk, 1998.

Table 5-2 shows status of on-farm plug-flow and complete mix digesters in the U.S. as of 1998. This suggests a high failure or abandon rate for both plug-flow and complete mix digesters on U.S farms. Since 1998, newer units with improved designs have started up and are operational. Many of the early units did not have the benefit of design experience gained later. Even more notable is the number of farm closures. In these situations, the digester was operational, possibly even successful, but the farm closed for other reasons, such as competitive or economic difficulties. One such example is Craven Farms in Oregon, which installed a successful digester in 1995-1996. The farm was subsequently sold and the new owners shut down the digester (Thompson, 2001). This example suggests that the practice of using on-farm digesters, while admirable for those farmers who commit to the project, cannot be sustained with consistency across all farms. Factors such as poor farming economics due to variability in milk pricing/ government support and passage of farm ownership generally make the operating environment on dairy farms too unstable for the long-term investments required to successfully sustain anaerobic digestion at this scale.

6. Data for Danish Complete Mix Digesters

Denmark is home to a number of centralized, complete mix digester facilities. Table 6-1 provides data for 18 centralized Danish digesters. All are complete mix design configuration, with stirred tanks. All practice co-digestion. Most have higher biogas production performance than the RP-5 plug-flow digester. One reason suggested in the case literature is the amount of co-digested waste. The RP-5 digester falls in the mid-range of sizes of the Danish digesters.

Capital cost data shown for the Danish digesters is for the base units, including generation capacity, where applicable. Data available for the Danish units listed breaks down capital costs into:

- The biogas production unit, including on-site pre-and post storage tanks, in-plant pipelines, and combined heat/power generation. (This amount is used in table 6-1, and for comparison to the RP-5 base data).
- Slurry Transport Vehicles (these costs are excluded from the Danish units, as they are from the RP-5 base cost).
- Off-site storage tanks, at farms or in other rural areas, which are used as intermediate storage for some facilities (these costs are excluded from the Danish units, and do not apply to the RP-5 digester).
- Other Investments. These include extra separation and composting equipment, costs for straw and chip-burning plants, and distribution piping to local heating systems, which are provided by some of the plants. These costs have been excluded from the Danish units, as they do not apply to the base costs for the RP-5 digester.

Appendix A shows a breakdown of reported costs for the Danish Centralized Biogas Plants. Special conditions for certain plants are noted.

TABLE 6-1. DANISH CENTRALIZED COMPLETE MIX DIGESTER SUMMARY

Plant	Start-up Yr.	TOTAL BIOMASS (m3/day)	TOTAL BIOMASS (cfd)	% co-digested (not animal waste)	Biogas Production (m3/day)	Biogas Production (cfd)	Digester Volume (m3)	Digester Volume (ft3)	Biogas prod m3/day per m3 Digester Volume	Gas Yield (m3/m3 Biomass)	Investment Cost for the Base Plant(DKK)	USD (Inflation Adjusted)	Cost (adj. USD)/ biogas (cfd)
Vester Hjermitselev	1984	45	1589	24%	4,088	144,366	1,500	52,972	2.73	91	kr 11,287,000	\$ 2,920,792	\$ 20.23
Davinde	1988	33	1165	11%	773	27,298	750	26,486	1.03	23	kr 12,474,000	\$ 3,025,013	\$ 15.53
Fangel	1989	158	5579	13%	6,233	220,117	3,750	132,430	1.66	39	kr 3,870,000	\$ 879,492	\$ 32.22
Hashoj	1994	126	4449	28%	6,860	242,259	3,000	105,944	2.29	54	kr 20,750,000	\$ 4,715,622	\$ 20.76
Hodsage	1993	51	1801	13%	1,797	63,461	880	31,077	2.04	35	kr 15,850,000	\$ 3,486,983	\$ 15.84
Nysted	1998	160	5650	15%	3,973	140,305	5,000	176,574	0.79	25	kr 28,950,000	\$ 6,165,507	\$ 13.38
Vegger	1986	56	1977	29%	5,515	194,761	920	32,490	5.99	98	kr 32,310,000	\$ 6,881,089	\$ 19.13
Sinding-Orre	1988	135	4767	13%	6,433	227,179	2,250	79,458	2.86	48	kr 43,330,000	\$ 8,647,853	\$ 16.86
Ribe	1990	444	15678	16%	13,047	460,751	5,235	184,872	2.49	29	kr 6,700,000	\$ 1,294,476	\$ 20.40
Lintrup	1990	354	12500	25%	10,186	359,716	7,200	254,266	1.41	29	kr 18,300,000	\$ 3,422,710	\$ 14.13
Lemvig	1992	428	15113	17%	14,526	512,981	7,600	268,392	1.91	34	kr 25,600,000	\$ 4,788,053	\$ 15.08
Thorso	1994	315	11123	12%	8,989	317,444	4,650	164,213	1.93	29	kr 9,500,000	\$ 1,720,055	\$ 14.53
Filskov	1995	82	2895	23%	3,353	118,410	880	31,077	3.81	41	kr 54,200,000	\$ 9,813,364	\$ 26.28
Studsgaard	1996	305	10770	14%	16,003	565,141	6,000	211,888	2.67	52	kr 46,550,000	\$ 8,159,020	\$ 14.44
Biabjerg	1996	315	11123	28%	9,041	319,280	5,000	176,574	1.81	29	kr 35,400,000	\$ 6,204,711	\$ 19.43
Snertinge	1996	120	4237	39%	4,641	163,896	3,000	105,944	1.55	39	kr 18,600,000	\$ 3,260,103	\$ 19.89
Blahoj	1997	83	2931	20%	3,707	130,912	1,320	46,615	2.81	45	kr 16,500,000	\$ 2,799,638	\$ 21.39
Arhus Nord	1995	382	13489	12%	10,575	373,453	8,500	300,175	1.24	28	kr 31,700,000	\$ 5,206,872	\$ 37.11
RP-5 (start-up)	2002	164	5781	0%	4,361	153,998	3,786	133,695	1.15	27		\$ 4,035,260 ¹	\$ 22.79
RP-5 (design)	2002	189	6684	0%	5,947	210,000	3,786	133,695	1.57	31		\$ 4,035,260 ¹	\$ 16.71

Source: Hjort-Gregersen, 2000. (and IEUA internal data for RP-5)

NOTES:

1. RP-5 comparable capital cost as shown in Table 4-1.

SECTION 7

7. Performance of the RP-5 Digester

This section evaluates the performance of the RP-5 digester, designed and operated by Synagro, LLC. As discussed in Section 3, the RP-5 digester is a “plug-flow loop” design, which is a variation on the standard plug-flow design in which the material flows down one side of a divided trough and back up the other side.

7.1 Summary of RP-5 Digester Performance Data

The Synagro-designed digester at RP-5 was designed to produce 210,000 cfd of biogas when fed at its maximum rate of 225 wet tons per day of manure. Table 7-1 presents recent operating data from February 24 through August 24 2003.

TABLE 7-1. SYNAGRO DIGESTER OPERATING DATA FROM FEBRUARY-AUGUST 2003
Weekly Averages

Week Beginning	Avg. Gallons slurry in per day	Avg. scfd biogas production
02/24/2003	25,914	98,734
03/03/2003	39,214	110,612
03/10/2003	58,200	114,759
03/17/2003	49,900	154,629
03/24/2003	9,429	130,853
03/31/2003	36,229	122,286
04/07/2003	57,757	165,156
04/14/2003	49,243	168,164
04/21/2003	44,771	155,532
04/28/2003	49,043	150,103
05/05/2003	50,457	148,684
05/12/2003	51,386	137,139
05/19/2003	53,429	146,064
05/26/2003	40,800	167,343
06/02/2003	41,900	143,247
06/09/2003	47,700	182,421
06/16/2003	50,371	180,672
06/23/2003	49,000	177,271
06/30/2003	43,171	178,539
07/07/2003	41,886	159,008
07/14/2003	49,514	174,135
07/21/2003	46,486	174,171

07/28/2003	33,857	161,764
08/04/2003	46,086	190,040
08/11/2003	40,100	151,624
08/18/2003	49,843	196,738
Averages	44,449	155,373

Source: Synagro Weekly Operational Reports, February - August, 2003

These data show an average biogas production of 155,373 cfd of biogas in March-April 2003.

This set of operational data is shown graphically in Figure 7-1. The data show that system production will decrease when operational problems arise, such as the dewatering system interruption in late March. This is consistent with reports from other case studies that consistent feeding of the digester is a key to successful and consistent performance (Kramer, 2002). Overall, however, there is an increasing trend in biogas production, due in part to increasing consistency of operation over the summer, and the beginnings of co-digestion starting June 16th, with lactose whey from a local dairy operation.

To compare RP-5 performance to other digesters, the average of 155,373 cfd from the February-August 2003 data in table 7-1, and the design amount of 210,000 cfd, were used.

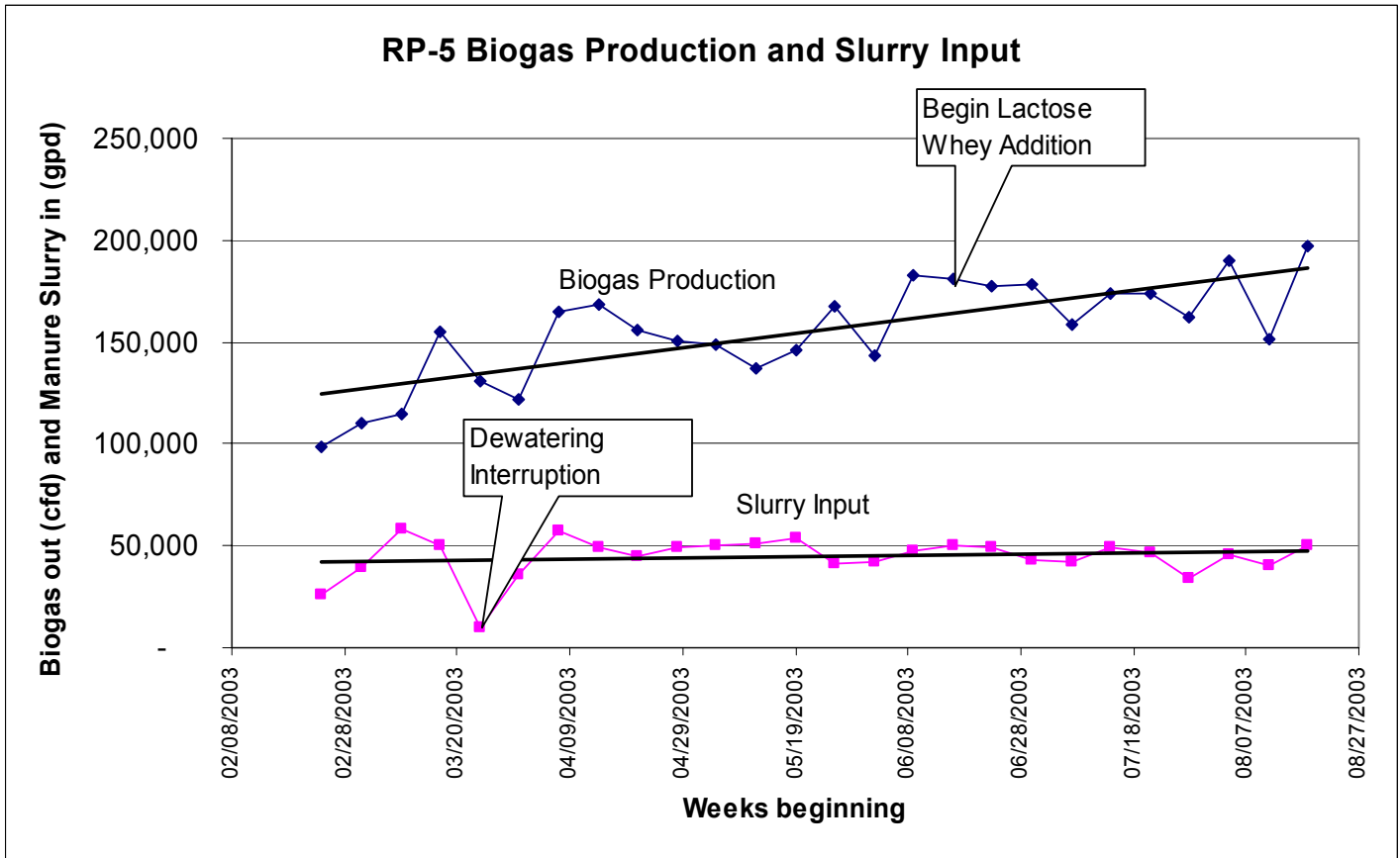


FIGURE 7-1: RP-5 OPERATIONAL DATA, FEBRUARY-AUGUST, 2003

7.2 Comparison of RP-5 performance to Other U.S. Plug-Flow Systems

The RP-5 digester is larger than all other U.S. plug-flow installations. It is one of the only centralized animal waste digesters in the U.S., taking in manure via vacuum truck from six local dairies in the Chino Basin.

7.2.1 Gas Yield

Figure 7-2 shows gas production in cfd versus manure input in dry pounds per day.

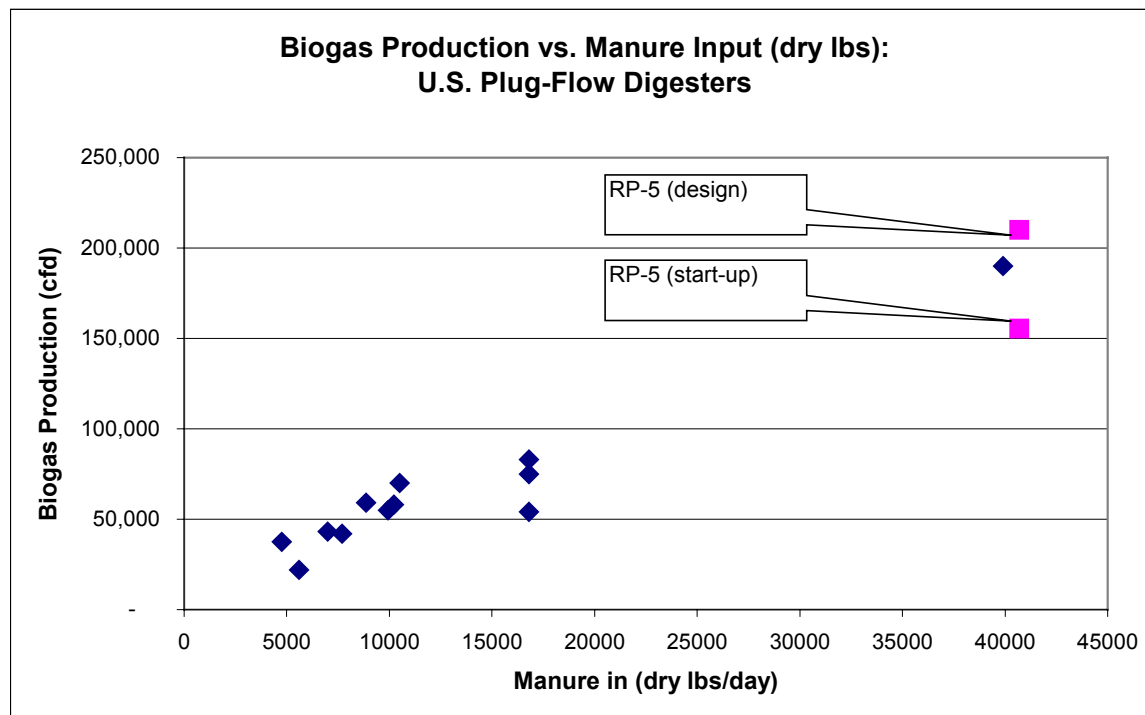


FIGURE 7-2. BIOGAS PRODUCTION VERSUS MANURE INPUT (DRY LBS/DAY) – U.S. PLUG-FLOW DIGESTERS

For RP-5, data on dry pounds per day of manure input were taken from RP-5 weekly operational reports. For the other (on-farm) digesters, dry pounds of manure per day was calculated using herd size and assuming 14 dry pounds per day per milking cow (Burke, 2001). The average for the on-farm units is about 5.3 cfd of biogas per dry pound of manure in. As shown, the start-up performance at RP-5 is below the average performance. However, when running at design production of 210,000 cfd of biogas, the gas yield would be 5.16 cfd/dry lb. input – within 3percent of the average. Over the past six months, gas yield at RP-5 has increased as operation has stabilized and some lactose whey has been added. Operations reports in late August and early September 2003 indicate gas production in the 190,000 – 210,000 cfd range.

Because the Tinedale Farms digester has not successfully reached stable operation, its parameters are not included in this data.

7.2.2 Biogas Produced vs. Digester Capital Cost

Figure 7-3 shows a distribution of digesters arrayed according to capital cost (\$) per cfd of biogas production. As shown, the majority of U.S. plug-flow units range from \$6 to \$11 per cfd of biogas production. The RP-5 digester start-up and design parameters, using the comparable capital cost for RP-5 versus on-farm digesters, as described and broken out in table 4-1, are \$19.66 and \$14.54 per cfd of biogas respectively. This reflects the fact that the other U.S. plug-flow digesters have been designed for minimal capital outlay. RP-5 is designed and constructed for longer expected service life, which would tend to make it more capital-intensive than the on-farm projects.

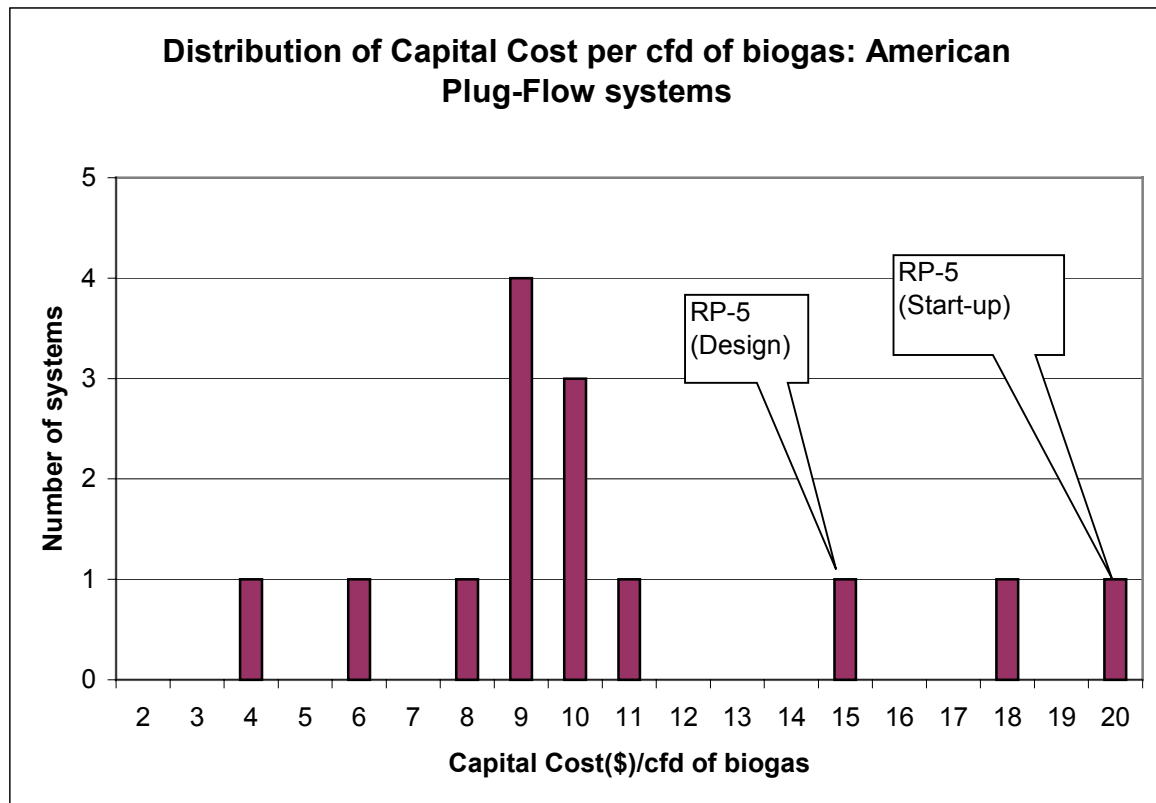


FIGURE 7-3. DISTRIBUTION OF CAPITAL COST PER CFD OF BIOGAS – U.S. PLUG-FLOW DIGESTERS

7.3 Comparison of RP-5 performance to U.S. Complete Mix Digesters

Three complete-mix dairy digesters were found in the U.S. for this study to compare with RP-5. All were on-farm units. More complete-mix on-farm units exist in the U.S., however they are running on hog or poultry waste, and were not considered for this study.

7.3.1 Gas Yield

Figure 7-4 shows gas production in cfd versus manure input in dry pounds per day for the U.S. complete-mix systems, with the RP-5 digester data super-imposed for comparison.

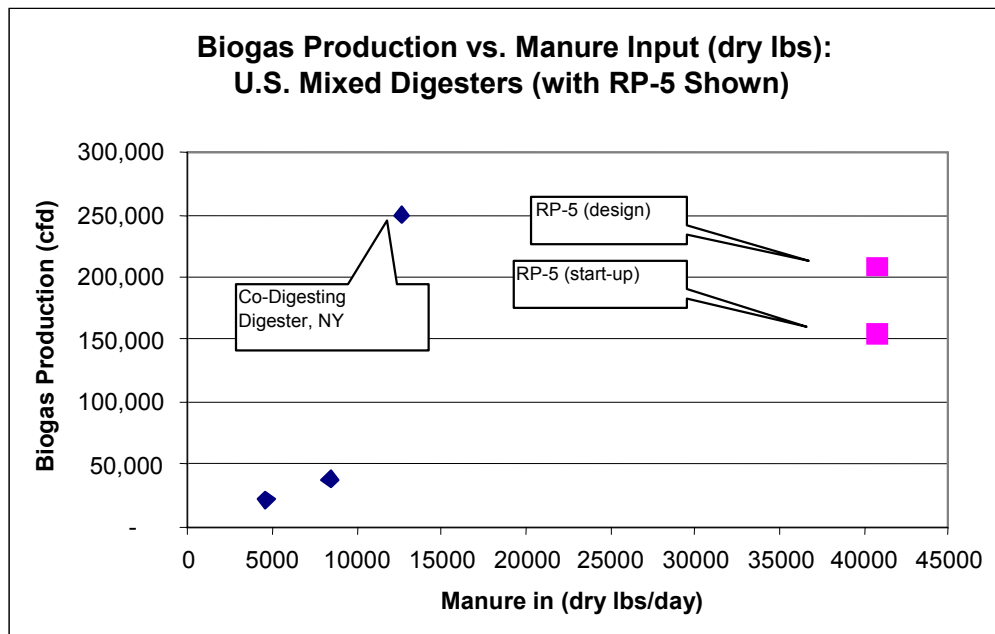


FIGURE 7.4. BIOGAS PRODUCTION VERSUS MANURE INPUT (DRY LBS/DAY) – U.S. COMPLETE-MIX DIGESTERS

The data point for the co-digest dairy in New York is noted because that facility co-digests industrial waste, up to 12,000 gallons per day, with the manure from a 900 cow dairy. This co-digestion practice is said to create 400 percent more biogas for this digester than the manure alone would produce (Mattocks and Moser, 2002). This extra performance is reflected in the graph.

7.3.2 Biogas Produced vs. Digester Capital Cost

Due to the small number of complete-mix digesters compared, a histogram was not produced. The two smaller units shown have a cost/cfd of biogas of \$17.41 and \$13.93, close to the RP-5 costs, and higher than most of the plug-flow unit costs, due to the addition of mixing equipment. The co-digest facility, due to its increased production, showed a cost/cfd of biogas of only \$2.58.

7.4 Comparison of RP-5 performance to Danish Complete Mix Systems

The RP-5 unit can be compared to Danish centralized units, however different parameters must be used, with qualifiers. First, the Danish units do not record dry weight of manure input as does RP-5, nor are there accurate “herd sizes” to work with, because these are centralized digesters. The Danish do record volume of manure slurry in, and calculate gas yield based on cubic meter of gas production per cubic meter of slurry fed (this parameter is dimensionless). They claim to typically get a gas yield of 20 m³/m³ on manure alone; more with co-digestion as described below. This parameter will vary with solids concentration of the input slurry; it should be noted that these are all complete-mix digesters, with solids concentrations in the range of 8-10 percent. Second, while the RP-5 digester contained unique items in its capital cost that were accounted for, some of the Danish units also

contain unique items in their capital cost. Among these are extra collection trucks, and in some cases, a localized heat distribution system in addition to electrical generation. As was done with the RP-5 digester, these costs have been broken out and deducted from the Danish units to the extent that data were available, to provide a base cost that could be reasonably compared with the RP-5 digester. This break-out is shown in Appendix A. Finally, all of the Danish units include co-digestion of other biomass, including food waste. This increases the biogas yield, as will be discussed.

7.4.1 Gas Yield

Figure 7-5 shows Gas yield for the Danish digesters, with RP-5 start-up and design performance superimposed on the graph. The average performance line equates to about 43 cfd biogas produced per cfd biomass slurry in. Note that this is also cubic meters per cubic meter. Compared with the Danish units, the gas yield of RP-5 is lower. Several factors are responsible. First, the Danish units are all complete mix, stirred-tank design. Second, some of them are thermophilic operation. Third, and possibly most important, all of the Danish installations add other biomass, such as food waste, to the manure slurry. The biogas yield from these wastes is higher than from manure, and this increases overall gas production. In fact, the case literature reports that typical animal manure slurry in these digesters has a gas yield of about 20, with the rest of the yield (up to 45 percent) coming from the other co-digested waste. On average, this co-digested waste represents about 24 percent of the volume input to the digesters (Hjort-Gregersen, 2000). The majority of the Danish co-digested waste is food processing waste, including intestinal contents (paunch), fat or flotation sludge, fish processing waste, and dairy waste. Other industry waste, such as sewage sludge and household waste are also included, to a lesser extent. IEUA is exploring food processing waste for introduction to the RP-5 digester.

In comparing the typical gas yield of 20 cfd biogas per cfd of pure animal slurry reported above with the average of 29 reported for U.S. units in section 7.2.1, it should be noted that the target solids concentration of the slurry for the Danish units is slightly lower (8% - 10%) than that for the typical U.S. units (9% - 12%).

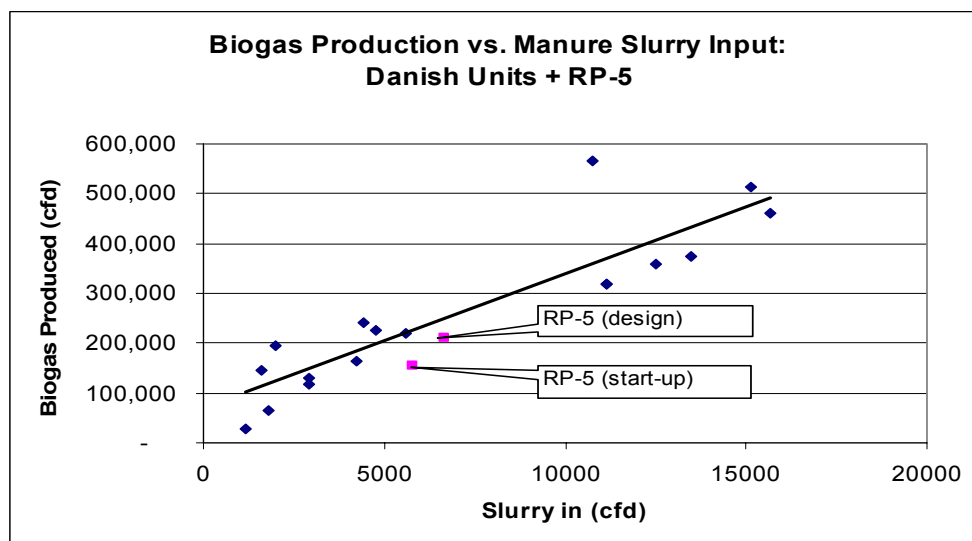


FIGURE 7-5. BIOGAS PRODUCTION VS. MANURE SLURRY INPUT – RP-5 DIGESTER AND DANISH CENTRALIZED UNITS

Biogas Produced vs. Digester Capital Cost

Figure 7-7 applies a distribution to the Danish units' capital cost per cfd of biogas produced. The average for the Danish units is \$19.81 per cfd of biogas produced. The base costs, as described in section 6 and broken out in Appendix A, are used to compute this data. Compared to these units, RP-5 at the start-up production is higher than the average. However, if running at design production levels (210,000 cfd), the RP-5 digester is very close to the average. The comparable capital cost used for the RP-5 digester to compare with the Danish units is summarized in table 4-1 and broken down in Appendix E.

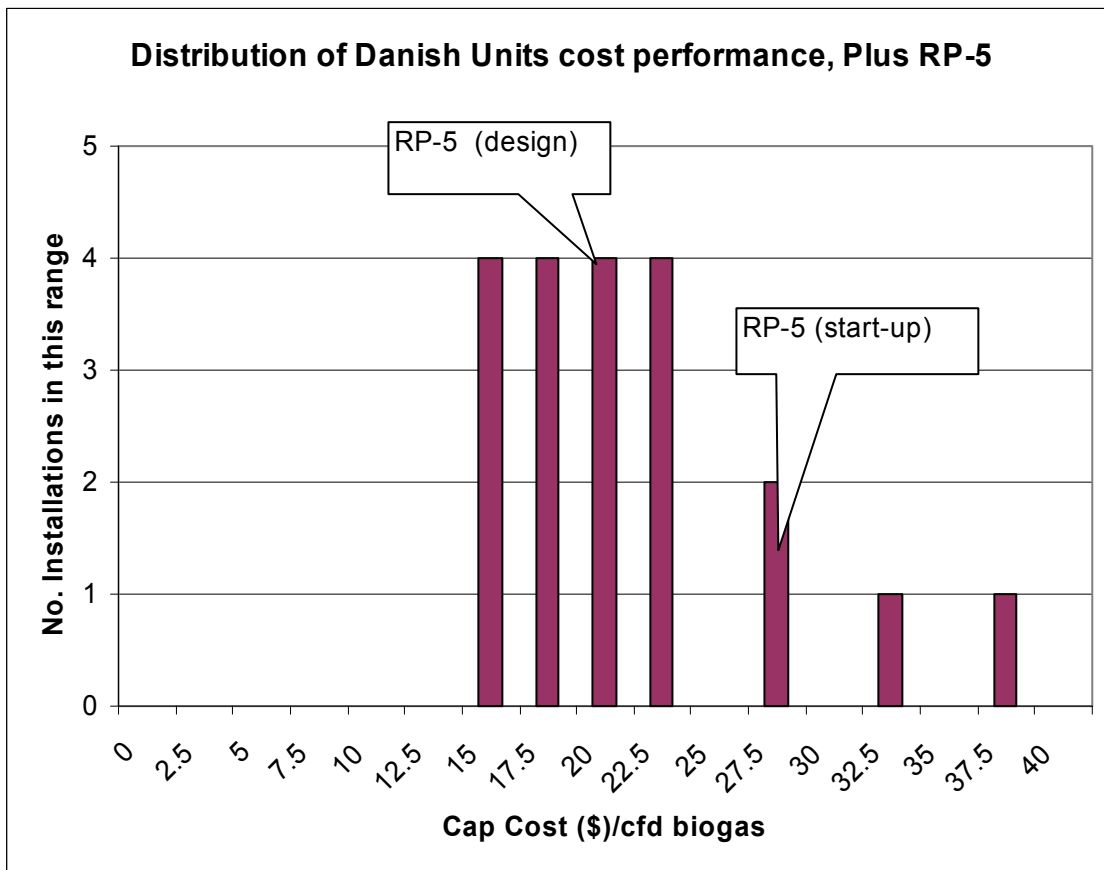


FIGURE 7-6. DISTRIBUTION (HISTOGRAM) OF CAPITAL COST PER CFD OF BIOGAS PRODUCTION FOR DANISH UNITS AND RP-5 DIGESTER

8. Case Study of Tinedale Farms

At the beginning of this project, it was desired to study the digester at Tinedale Farms in Wisconsin, with a view to learning lessons from its experience. This unit was originally designed as a plug-flow trough, but has been modified as a complete mix digester. Further changes have split the unit into a thermophilic section followed by a mesophilic section. This process is called Temperature-Phased Anaerobic Digestion (TPAD). Figure 8-1 shows a simplified diagram of the design (top view).

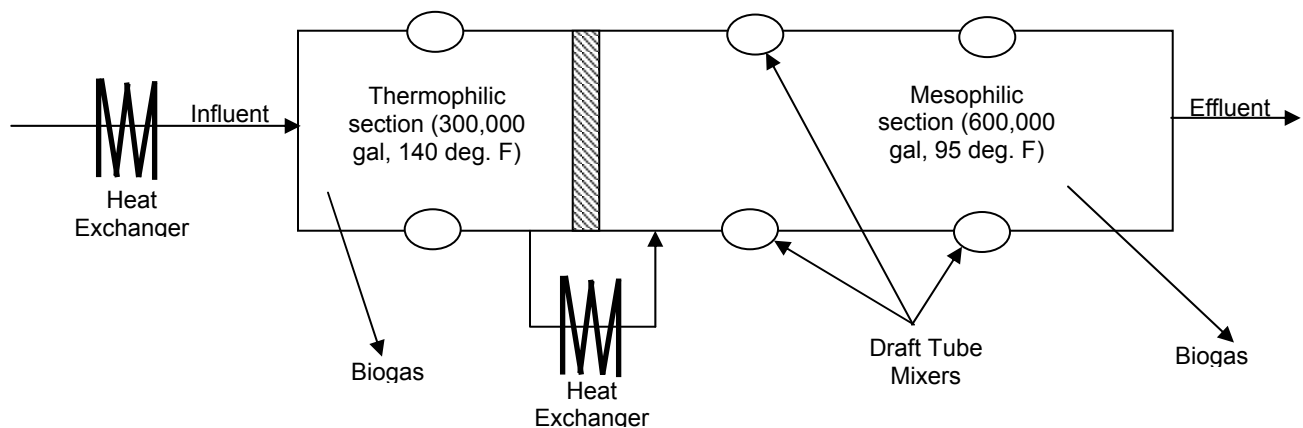


FIGURE 8-1. TOP VIEW OF TINEDALE FARMS DIGESTER

This design was patented by Iowa State University. The facility at Tinedale serves a single farm with a herd size of about 2,400 cows. The basis of the design is a thermophilic phase with a hydraulic retention time of about 10 days, followed by a mesophilic phase with a hydraulic retention time of about 20 days (Energy Center of Wisconsin, 2002). Thermophilic digestion is gained, followed by an additional mesophilic phase.

The Tinedale unit started up in 2001, but the heat exchanger that would cool the effluent from the thermophilic phase entering the mesophilic chamber was not performing properly (Energy Center of Wisconsin, 2002). The unit then needed to run for several months as mesophilic only. As of this report, full TPAD operating data were not yet public. Final capital investment needed for full TPAD operation also were not yet available. Therefore, it was deemed that the Tinedale unit has not had sufficient stable running conditions for comparison to other digesters, and further study to see if Tinedale's experience can be successful is recommended before implementation of any similar measures at RP-5.

The Tinedale unit is comparable to the RP-5 digester for two reasons. First, even though it is on a single farm, it serves a large herd and is roughly comparable in size to RP-5. Second, most of the complete mix, and all of the Danish units, are stirred round tanks. If modifications were to be made to the RP-5 unit to make it a complete mix, existing design

constraints must be considered. For example, RP-5 is a concrete trough, not a round tank. Therefore, to add mixing, the changes to RP-5 would be similar to those made at Tinedale to make it a mixed unit – specifically, the addition of mixers along the length of the trough. Tinedale added four in the mesophilic section, and two in the thermophilic section. These are the types of changes that might be instituted at RP-5 to improve biogas production.

Experience at Tinedale has shown that, for a future project, it would be better to start with round tanks. If conversion to TPAD were of interest at RP-5, a better way to accomplish this may be to install a mixed round tank as a thermophilic phase in front of the existing concrete trough. This would allow for better separation between the two temperature regimes (Tinedale operation, 2003)

9. Environmental Considerations for the RP-5 Digester

Anaerobic digestion in the Chino Valley is not just an energy producer. In order to be properly valued, it must be understood to be a holistic waste and energy solution that has simultaneous positive impacts on a number of environmental problems in the area.

In the area of water quality, it is well established that agricultural waste has, over the years, added significant salts and nitrates to the groundwater. Implementation of rules for concentrated animal feeding operations (CAFOs) to meet National Pollutant Discharge Elimination System (NPDES) regulations, promulgated by EPA under 40 CFR 122.23, is currently being coordinated in the Chino Basin by the Santa Ana Regional Water Quality Control Board (SARWQCB). Requirements include removal of stockpiles of manure from dairies (AQMD, 2002). Anaerobic digestion at centralized facilities such as RP-5 directly aid SARWQCB in meeting these goals, and directly reduces migration of salts and nitrates into the ground water, and the Santa Ana river.

In the area of air emissions, accumulated manure on the ground emits several air contaminants, including ammonia (NH_3), methane (CH_4), and nitrous oxide (N_2O). The ammonia is understood to be a precursor to PM_{10} (fine particulate matter less than 10 microns in diameter). The area around the Chino Valley is part of the South Coast Air Quality Management District (AQMD), and it currently exceeds State and federal ambient air quality standards for PM_{10} emissions, making it a “non-attainment zone”. The AQMD has set goals for reduction of these emissions, including removal of manure from dairies, through its proposed rule 1127. Anaerobic digestion is described in this rule is a practice that will reduce these emissions, so that the RP-5 digester directly contributes to the goals of the AQMD (AQMD, 2002).

The greenhouse gases methane and nitrous oxide contribute to global warming. Relative values for reduction credits of these gases have been established with the guidance of the Kyoto Protocol, which has not been ratified by the United States. Nevertheless, there is a nascent market for trading of greenhouse gas reduction credits, which is expected to expand worldwide as more countries ratify the agreement.

Any economic evaluation of possible research modifications to the current RP-5 digester should, as much as possible, take into account these wider environmental benefits that accrue from its operation, including water quality, air quality, greenhouse gas reduction, and renewable energy credits. Some of these benefits and ways to quantify them are discussed below.

9.1 Water Quality

Anaerobic digestion of manure removes that manure from the ground, which keeps the nitrates and salts from that manure from entering the groundwater. In the Chino basin,

years of agricultural activity, including dairy farming, have increased the salt levels in the ground water to the point that water must be desalinated before it can be drawn for human use. In the Chino basin, this is done using reverse osmosis. This process requires both capital cost and constant energy input to perform. All manure removed from the ground and managed through anaerobic digestion removes corresponding amounts of salt and nitrates from the groundwater, eventually reducing the need for desalination, and its operating costs, and possibly reducing future needs for desalting plants. Therefore, these offset desalination costs should be included as part of the benefit in an economic study of digesters. A preliminary estimation suggests that the RP-5 digester project diverts up to 527 tons of TDS salt per year from the groundwater, and that the offset cost of removing this salt with the desalting plant could be close to \$200,000 annually.

Removal of manure from farms also has a positive impact on the farms' compliance with NPDES regulations. EPA has issued a policy regarding trading of water quality credits for reductions of pollutants beyond regulatory requirements. Establishing values for these credits is currently in progress.

9.2 Air Quality

Untreated manure emits both PM₁₀ (particles 10 microns and smaller) and ammonia, which creates PM₁₀ emissions in the atmosphere. Removing this manure while it is fresh will reduce these emissions. Because the Chino Valley is in a federal non-attainment area, emissions are highly restricted, and emissions credits resulting from reduction have the potential to be valuable in a trading market. For the Chino Valley, these values could be in the range of \$50,000 per ton/year of reduction. This value could possibly accrue to IEUA or to individual farmers, however specific rules applying to the situation are under study, and IEUA may or may not be eligible to receive credits. EPA has established emissions factors for dairies based on number of cows. However, these emissions factors are subject to more recent review.

9.3 Greenhouse Gas Reduction

Untreated manure emits methane (CH₄) and nitrous oxide (N₂O), both of which are significant greenhouse gas contributors. Preliminary estimations by IEUA indicate that as much as 248 tons per year of methane and 14.2 tons per year of nitrous oxide may be captured by operation of the RP-5 digester, which serves the equivalent of about 3,750 cows between several dairy farms currently participating the centralized digester program (IEUA, 2003). These greenhouse gas reductions may soon be able to be marketed as credits by IEUA and traded in an open market. They are governed by the Kyoto Protocol, which establishes limits for greenhouse gas emissions worldwide. Values in the U.S. are likely to be lower than in Europe, however international trading markets for the credits are in their early stages. The 248 tons per year of methane would translate to almost 5,200 tons per year of equivalent carbon credits, and the nitrous oxide would translate into about 4,400 tons per year of equivalent carbon credits. An initial estimate values these credits at \$1 - 3 per ton, resulting in \$9,600 - \$28,800 per year of annual benefit from the RP-5 digester. This amount may increase as more countries ratify the Kyoto protocol.

9.4 Renewable Energy Credits (“Green Tags”)

Every kilowatt-hour (kWh) of energy produced at digester plants has the potential to be worth 0.5 - 1 cent more as requirements develop state-wide for renewable energy portfolios. Under these requirements, power producers must generate or buy a certain amount of energy from “green” sources. If a producer chooses to buy, a source such as IEUA may be able to sell credits from generation of biogas power. At 0.5 cents per kWh generated, these would add another \$23,760 to the monetized benefits from the RP-5 digester.

9.5 Summary Table of Economic Benefits

Table 9-1 identifies environmental considerations and includes a start at quantifying some of these benefits. All of these numbers are preliminary, for illustration purposes, and subject to finalization of rules. Other benefits may be found, and entered into this table. The total annual monetized benefits would then capture the comprehensive value from both product sales (electricity, biogas, and or compost), and environmental benefits generated by the project. This number would be used, along with up-front investment cost and annual operating costs, to perform a life-cycle financial analysis for the project.

Details and assumptions for specific entries in Table 9-1 are as follows:

- For electricity calculations, it is assumed that all electricity produced by the RP-5 digester is used on-site for running the desalter, and therefore offsets TOU-8 retail rates at an average of \$0.12 per kWh. If excess electricity were produced, it could be sold back at wholesale rates, however this would require power purchase agreements with customers for the power, and wholesale rates are lower. However, a provision under AB 2228 would allow net-metering, wherein excess electricity generated could be sold back to the grid at the time it is generated through a meter at retail rates, subject to a cap. If this is done during peak hours, the average value for electricity sold through net-metering could be higher than average retail paid by the plant, however it is not clear that this would be the case for energy produced from biogas. A rate equal to the average retail rate of \$0.12/kWh for net-metered electricity has been entered, however the scenario considered for RP-5 alone does not include any net-metered electricity, because all of it is being used in the desalter. This matches current operating conditions at the IEUA plant. As generation capacity increases, opportunities for net-metering may emerge.
- Greenhouse Gas Benefits include reductions of methane (CH₄) and nitrous oxide (N₂O) from the manure diverted to the digester. These emissions are translated to Carbon Dioxide Equivalents (CO₂E) as shown in the calculations in Appendix B. Actual Carbon Dioxide (CO₂) emissions are not included, because they would likely be offset by CO₂ emissions from the engine generator used.
- The numbers for benefit of water quality improvements due to salt loading reductions are based on the avoided cost of removing those salts using the desalting plant. Operating costs for the desalter, provided by IEUA, were used to estimate this monetary benefit, as shown in Appendix C.

9.6 Life-Cycle Analysis

A life-cycle analysis of benefits, costs, and investment, can be done using discounted cash-flow calculations. This will produce a net-present-value (NPV) and rate-of-return estimate. Requirements for setting up this analysis are:

- The investment amount, estimated in this report in table 4-1.
- Monetized benefits as summarized in table 9-1, and
- Operating costs. IEUA has information for first-year operating costs only for the RP-5 digester. Some of these costs may be expected to decline in the future due to learning curve effects on costs associated with labor, and due to more economical use and purchase of materials such as polymer chemicals fed to the centrifuge. The operating costs could be in the range of $\frac{1}{2}$ to $\frac{2}{3}$ of the first year's costs in future years, however more rigorous analysis is warranted.

Because not all of the information is yet assembled with regard to future benefits and operating costs, a full life-cycle analysis of the RP-5 digester as currently configured is not presented.

Table 9-1.
Potential Monetized Benefits From Digester At RP-5

	Units Measured	Units/ Year			\$/Unit			\$/year
Energy								
Electricity used on premises (retail offset)	kWh	4,752,027 ¹	kWh/year	X	\$0.12	\$/kWh	=	\$ 570,243
Electricity Sold to grid or customers (wholesale)	kWh	0	kWh/year	X	\$ 0.01 - \$0.02	\$/kWh	=	-
Net Metered Electricity (AB 2228)	kWh	0	kWh/year	X	\$ 0.12	\$/kWh	=	-
Biogas used or sold	MMBTU	0	MMBTU/year	X		\$/MMBTU	=	-
Green Tags (Renewable Energy Credits)	kWh	4,752,027	kWh/year	X	\$ 0.005 - \$0.01	\$/kWh	=	\$ 23,760 - \$47,520
Environmental Benefits								
Greenhouse Gas Credits								
From CO2 Reductions								
From CH4 Reductions	5,198 ²	tons of CO2 Equiv.						
From N2O Reductions	4,401 ²	tons of CO2 Equiv.						
Total GHG credits	9,599 ²	tons of CO2 Equiv.	9,599	tons of CO2 Equiv./yr.	X	\$1.00 - \$3.00	\$/ton	= \$ 9,599 - \$28,797
Water Quality Improvements								
Avoided desalting operating cost	Tons of TDS salt	526 ³	tons/year	X	\$380 ³	\$/ton	=	\$ 200,059
Avoided Desalting Plant Capacity (Annualized) – Awaiting Information								
TOTAL POTENTIAL MONETIZED BENEFITS								\$803,661 - \$846,619
EMERGING BENEFITS THAT MAY BECOME MONETIZED (SUBJECT TO RULES)								
Air Quality Emission Reductions								
PM10 (Based on Ammonia Reductions)	tons		tons/year	X		\$/ton	=	
Water Quality (NPDES) Emissions Credits								
TDS Emission Reductions	tons		tons/year	X		\$/ton	=	
NO3 Emission Reductions	tons		tons/year	X		\$/ton	=	
NH3 Emission Reductions	tons		tons/year	X		\$/ton	=	
Compost/Bedding Material	tons		tons/year produced	X		\$/ton	=	

1. See Appendix D for determination of this number.

2. See Appendix B for determination of these numbers.

3. See Appendix C for determination of these numbers.

10. Potential Research Modifications to the RP-5 Digester

Potential research modifications to the existing RP-5 system to increase performance should be considered as new investment opportunities, and analyzed as incremental research projects, with new capital costs, versus incremental benefits from the changes. These modifications could be used to apply lessons to incorporate into design of future digesters. Possible changes fall along three lines, as described in this section.

10.1 Research modifications to Existing Plug-Flow Configuration

Changes would include increased grit and stone removal in front of the digester, possibly including a new settling and pre-digestion storage tank to reduce grit in the digester. On Danish units, stone traps, macerators (to reduce the size of straw and similar materials) , and pre-storage tanks are common pre-screening measures (NIRAS, 2003).

An operational modification would be to study the schedule for deliveries of manure to the RP-5 digester. The goal would be to optimize manure delivery to provide consistent production from the digester. Because the digester uses a community of living organisms, a consistent feeding schedule is important to maximize performance. As was stated in one case study for Fairgrove Farms, one of the most successful plug-flow digesters in the U.S., "You have to think of the digester as a big stomach that needs to be fed twice a day." (Kramer, 2002).

10.2 Conversion to a Complete Mix System

This would involve installing mixers along the side of the concrete trough. Several mixers (four to five) would be needed. This would likely reduce settling and stratification in the digester, and could aid in implementing co-digestion of other wastes. One item that must be studied is whether mixers can be sourced that would be able to run at the 11-12% solids concentrations found in the RP-5 digester. Mixers have extensive experience in municipal digesters, however most of these run at solids concentrations in the 7-8% range.

10.3 Conversion to a TPAD system

This would involve adding new walls in the concrete trough of the RP-5 digester to separate it into thermophilic and mesophilic sections, or adding a mixed thermophilic tank in front of the existing RP-5 digester. Pumps, interconnecting piping, and a new heat exchanger would be required. Part of the existing mesophilic volume would be changed over to a thermophilic chamber. The cost to include these items is not yet established, and is

recommended for further study. Also, a license may be needed for the patented technology. Further lessons from the Tinedale experience should be considered before moving ahead with any such changes.

The benefit of these changes could be an increase in gas production by 25 percent or more, and better volatile solids reduction. Also, due to the higher temperature operation, the resulting compost may be able to be rated as class A biosolids, which are pathogen-free, making it a more salable product.

10.4 Life Cycle Benefits of Proposed Changes

These proposed changes should be analyzed as incremental research projects for purposes of life-cycle costs and benefits. Each project will have its own investment cost, and additive effects on benefits and operating costs. For instance, if a \$1.0 million project to add mixing and introduce co-digestion to RP-5 were to increase gas production from the same manure amount by 50%, and the project added another \$100,000 to the operating costs of the facility (due to power needed for mixing and running a co-digestion program), then benefits could increase by almost \$250,000 per year. Such an incremental project would have a positive net-present-value of about \$1 million, (at a discount rate of 3.5% and a life of 20 years), and a simple payback in the range of 6-7 years.

Similarly, if another \$2 million were invested to introduce a thermophilic phase and make a TPAD system at RP-5, and it resulted in another 50% increase in biogas production and added another \$100,000 to the operating costs of the facility (due to heating plus more complexity), then benefits might increase by another \$370,000 per year. Such an incremental project would have net-present-value of about \$1.8 million (at a discount rate of 3.5% and a life of 20 years), and a simple payback period in the range of 7-8 years.

These numbers are rough estimates, to understand the potential impact of research modification projects for the RP-5 digester. Further engineering analysis is needed to gain a better understanding of costs and expected performance increases from these projects. These projects would also benefit the overall financial performance of the entire RP-5 digester project. However, when analyzing these incremental projects, the incremental benefits and costs should be broken out for the analysis, as described above, and sunk costs (money already invested) should be omitted from analysis of the incremental research modification projects.

11. Conclusions

The relative consistency of performance of the Danish units suggests that the centralized model, using complete mix design, with provisions for co-digestion of food processing and other waste and thermophilic operation is a good model to follow when applying anaerobic digestion to an area of highly concentrated dairy farms, such as the Chino basin. The practice in the U.S. to date, while innovative for individual farms, does not show consistent success over large numbers of farms. This may be attributed to:

- Lack of consistent commitment on the part of dairy farmers to the practice—some “stars” exist in the field, but not a majority of farmers willing to install the technology.
- Farmers are challenged in the U.S. by low dairy market prices, thus they do not produce a consistent enough income on their existing investment to justify investing new capital.
- The difficulty of contracting with local utilities to sell power back to the grid in the United States means that a potential source of income is denied to the farmers (Langerwerf, 2003).
- Dairy farmers tend to want to stick to running a dairy farm, not a digester (Langerwerf, 2003).
- Individual farms, especially family farms at the scale of under 1,000 head, are becoming less and less economically viable, and many are shutting down rather than being passed on in the family.

This makes a case for centralized digesters, which have been successful in Denmark. This would be especially true in the high-concentration dairy cluster of the Chino basin. The close proximity of farms has resulted in air and water quality issues, but also minimizes transportation distances from various farms to the centralized unit, making this area a good candidate for the centralized concept.

The RP-5 digester has shown capability to deliver comparatively good performance as a plug-flow digester. Several options exist to increase its performance and value, including better pretreatment, adding complete mixing, and conversion to a multiphase TPAD unit. Furthermore, the Danish experience indicates that complete mix with co-digestion of other wastes increases gas production further. These changes have the potential of increasing biogas and energy production above existing performance, while improving the quality of the effluent solids from the digester. They should be investigated further in specific feasibility studies.

While the Danish experience provides some insight on possible performance improvements, especially with regard to co-digestion, design changes to the RP-5 digester cannot mimic the Danish designs exactly, because the RP-5 digester’s structure is already established as a rectangular trough, not round tanks like the Danish designs. Possible design changes to RP-5 should be considered with further information from the Tinedale Farms digester in

Wisconsin which, similar to RP-5, started out as a plug-flow trough, and has been altered to complete mix, and to the combination thermophilic-mesophilic design.

Efforts should continue to further quantify and give monetary value to the environmental benefits for anaerobic digestion in the Chino Basin. This process should be valued not only as a renewable energy producer, but also as a comprehensive environmental solution. Air and water quality will be positively impacted by proactive management of dairy waste, and not only in the Chino Basin, but also downstream in Orange County, meeting goals of the South Coast Air Quality Management District, and the Santa Ana Region Basin Plan for water quality. As new rules are generated by EPA and local agencies, the possibilities for capturing monetary value from these environmental benefits should be studied further, using a framework for valuation such as the one shown in Table 9-1.

SECTION 12

12. References

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APPENDIX A

Cost Breakdown for Danish Centralized Digesters

Appendix A: Cost Breakdown for Danish Centralized Digesters

COST ELEMENTS (Danish Kroners, not inflation-adjusted)

PLANT	Base Biogas Plant ¹	Vehicles	Storage Tanks ²	Separation Facilities	Other Investments	TOTAL
Vester Hjermitselev	kr 11,287,000	kr 600,000			kr 529,000 ³	kr 12,416,000
Vegger	kr 12,474,000	kr 350,000			kr 552,000 ³	kr 13,376,000
Davinde	kr 3,870,000	kr 600,000			kr 1,310,000 ⁴	kr 5,780,000
Sinding-Orre	kr 20,750,000	kr 2,500,000	kr 2,900,000			kr 26,150,000
Fangel	kr 15,850,000	kr 1,300,000	kr 5,150,000	kr 2,950,000		kr 25,250,000
Ribe	kr 28,950,000	kr 3,700,000	kr 12,600,000			kr 45,250,000
Lintrup	kr 32,310,000	kr 3,060,000	kr 2,380,000	kr 5,800,000		kr 43,550,000
Lemvig	kr 43,330,000	kr 3,570,000	kr 8,300,000			kr 55,200,000
Hodsage	kr 6,700,000	kr 500,000			kr 12,000,000 ⁴	kr 19,200,000
Hashoj	kr 18,300,000	kr 1,200,000	kr 2,300,000			kr 21,800,000
Thorso	kr 25,600,000	kr 3,500,000				kr 29,100,000
Filskov	kr 9,500,000	kr 700,000	kr 1,000,000		kr 12,000,000 ⁴	kr 23,200,000
Arhus Nord	kr 54,200,000					kr 54,200,000
Studsgaard	kr 46,550,000	kr 3,700,000	kr 2,850,000		kr 2,600,000 ⁵	kr 55,700,000
Biabjerg	kr 35,400,000	kr 3,500,000	kr 3,000,000			kr 41,900,000
Snertinge	kr 18,600,000	kr 1,200,000	kr 1,200,000		kr 26,800,000 ⁴	kr 47,800,000
Blahoj	kr 16,500,000	kr 400,000	kr 400,000		kr 16,100,000 ⁴	kr 33,400,000
Nysted	kr 31,700,000	kr 1,200,000	kr 1,800,000		kr 8,980,000 ⁴	kr 43,680,000

Source: Hjort-Gregersen, 1999

NOTES:

1. The Base number has been used to compare to the RP-5 base costs. Includes Biogas Production Units, on-site storage tanks and pipes, and Generator
2. Slurry storage tanks at farms or in rural areas, except for Sinding and in part Studsgard, where extra tanks are at the plant.
3. These are Wind Turbines (not included in comparison to RP-5 digester)
4. Straw and wood-chip burning facility, and district heating system.
5. Extra pipeline for slurry pumping off-site.

APPENDIX B

Calculations for Potential Greenhouse Gas Credits From the RP-5 Digester

APPENDIX B: CALCULATIONS TO DETERMINE POTENTIAL GREENHOUSE GAS CREDITS FROM THE RP-5 DIGESTER

Methane (CH4) Redcution

CH4 Reduction at RP-5 Digester from IEUA Study:

110 US tons/yr/100 US tons/day manure

Source: IEUA Internal Study "Estimated Annual Greenhouse Gas Emission Reductions Resulting From Manure Management That Include Manure to Energy Facilities"

Manure supplied to Digester:

225 US tons/day

Source: IUEA Design Data for RP-5 Digester

CH4 reduction for digester

110 X (225/100) = 248 US tons/yr as CH4

Convert to CO2E (equivalent)

21 Global Warming Potential (GWP) for CH4 as CO2E

Source: NatSource; <http://209.25.242.106/markets/index.asp?s=20>

248 X 21 = 5,198 tons/year CO2E

Nitrous Oxide (N2O) Reduction:

N2O Reduction at RP-5 Digester from IEUA Study:

6.31 US tons/yr/100 US tons/day manure

Source: IEUA Internal Study "Estimated Annual Greenhouse Gas Emission Reductions Resulting From Manure Management That Include Manure to Energy Facilities" (Modified)

Manure supplied to Digester:

225 US tons/day

Source: IUEA Design Data for RP-5 Digester

CH4 reduction for digester

6.31 X (225/100) = 14.20 US tons/yr as N2O

Convert to CO2E (equivalent)

310 Global Warming Potential (GWP) for N2O as CO2E

Source: NatSource; <http://209.25.242.106/markets/index.asp?s=20>

14.2 X 310 = 4,401 tons/year CO2E

APPENDIX C

Calculations For Avoided Desalting Cost Due To RP-5 Digester

**APPENDIX C: CALCULATIONS FOR DETERMINING
AVOIDED DESALTING COST DUE TO RP-5 DIGESTER**

Annual operating cost for desalting plant	\$	4,300,000	\$/year	
<i>Source: IEUA Internal Plant Data</i>				
Desalting Plant Inlet TDS		950	mg/l	
Desalting Plant Permeate TDS		20	mg/l	
<i>Source: IEUA Internal Plant Data</i>				
Desalting Plant TDS Removal		930	mg/l	
The desalting plant removes		930	mg from each liter of product water	
Desalting Plant Production		8,000,000	gal/day	
<i>Source: IEUA Internal Plant Data</i>				
		30,280,000	l/day	
Total TDS salt removed by desalter		28,160,400,000	mg/day	
...amount removed from each liter X liters produced/day				
		28,160,400	grams/day	
		62,027	lb./day	
		31.01	tons/day	
		11,320	tons/yr.	assumes 365 day/yr. operation
Operating cost per ton of TDS salt removed	\$	380	\$/ton	
Amount of TDS salt diverted per year by RP-5 digester		526		
<i>Source: IEUA Presentation. 790 tons diverted for RP-1 and RP-5 combined, assume 2/3 is from RP-5.</i>				
Avoided cost due to diverting salt with RP-5 digester	\$	<u>200,059</u>		(526 tons/year)

Desalting Plant Inlet Nitrate		200	mg/l	
Desalting Plant Permeate Nitrate		24	mg/l	
Desalting Plant Nitrate Removal		176	mg/l	
The desalting plant removes		176	mg from each liter of product water	
Desalting Plant Production		8,000,000	gal/day	
		30,280,000	l/day	
Total TDS salt removed by desalter		5,329,280,000	mg/day	
amount removed from each liter X liters produced/day				
		5,329,280	grams/day	
		11,739	lb./day	
		5.87	tons/day	
		2,142	tons/yr.	
assumes 365 day/yr. operation				
Operating cost per ton of TDS salt removed	\$	2,007	\$/ton	assumes 365 day/yr. operation
Amount of Nitrate diverted per year by RP-5 digester		22		
<i>Source: IEUA Presentation. 33 tons diverted for RP-1 and RP-5 combined, assume 2/3 is from RP-5.</i>				
Avoided cost due to diverting Nitrates with RP-5 digester		<u>44,159</u>		

This avoided cost is lower, and it is assumed that they are not additive, therefore it is not included in the total benefit.

APPENDIX D

Energy Production Calculations for RP-5 Digester

Appendix D: Electrical Energy Calculations for RP-5 Digester

Biogas Generated/Day at RP-5	210,000 cfd	Design for RP-5
Biogas per hour	8,750 cfh	
Methane Content	60%	Typical
BTU content	600 BTU/cf	Typical
Engine Efficiency	36%	Typical
Kilowatts Generated	548.10	Calculated
Engine Availability	100%	(8,760 hours/year)
kWh generated per year	4,752,027	Calculated
Portion used on premises	100%	Current Operation
Portion sold outside	0%	Current Operation
Portion Subject to Net Metering	0%	Current Operation

APPENDIX E

Capital Cost Breakdown for RP-5 Digester

Capital Cost Break-out for IEUA RP-5 Digester

A.	Total Cost for Core Digester & 500 kW Generation Facility	\$3,054,262
B.	Total Cost for Support Facilities for Centralized Digester	\$980,998
C.	Total Cost for Urban Infrastructure Requirements	\$1,678,085
D.	Total Cost for Regional Board Requirements Specific to Chino Basin	\$515,696
E.	Total Cost for Tech. License & Management Fee	\$643,910
F.	Total Additional Cost for Desalter Generation Facility Over 500 kW	\$3,044,200
G.	Total Cost for Infrastructure Needed to Deliver Gas to Generators at Desalter Facility	\$1,662,433
H.	Total Operation Cost for Facility Startup	\$50,063
	Total Cost of The Project	\$11,629,648