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THE DEPARTMENT OF ENERGY'S
ENERGY INTEGRATED FARM SYSTEM PROGRAM

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ABSTRACT

The Department of Energy (DOE) recently completed a
program investigating the feasibility of integrating diverse
energy production and energy conservation practices to
reduce agriculture's dependence on fossil fuels. The Energy
Integrated Farm System (EIFS) program was established in
1980 in response to the hardship imposed on U.S. farmers by
high fuel costs and unreliable fuel supplies. Seven farms
located in various geographical regions of the U.S. and
Puerto Rico participated in the program. Each of these
farms developed an energy integrated farm system project
that used a unique combination of energy production and
energy conservation methods to supply energy to the farm and
reduce the farm's dependence on energy produced from
nonrenewable sources such as coal and oil. Methods used at
these projects included conservation tillage, solar heating,
waste heat recovery, methane production from the anaerobic
digestion of animal manure, electricity production from
biogas, alcohol fuel production, fluidized-bed combustion of
crop wastes, and computer-aided conservation irrigation.
This paper gives a summarized report of the work done at the
seven projects. It presents highlights and results,
provides an overview of successes and problems, and lists
recommendations.

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THE DEPARTMENT OF ENERGY'S
ENERGY INTEGRATED FARM SYSTEM PROGRAM

INTRODUCTION

The Energy Integrated Farm System (EIFS) program was established by the U.S. Department of Energy (DOE) in 1980 to demonstrate that U.S. farmers can use existing resources and technologies to reduce the purchase of commercial fuels and reduce on-farm energy consumption. Specific questions addressed by the program included: (a) Can existing energy conservation technologies and practices be used to reduce energy requirements? (b) How well can alternative energy sources be integrated into a working farm operation? (c) Can waste products be converted into a reliable energy source that farmers can manage? (d) Are EIFSs economical and reliable options that should be considered on individual farms? Seven different farms from various parts of the U.S. (Puerto Rico, Georgia, New York, Nebraska, North Dakota, Arizona, and Texas) were selected by DOE as sites for EIFS projects. See Figure 1. DOE cost-shared in the design, construction, and demonstration of energy integrated systems on these farms. This paper presents a summarized report of the work done at the seven projects and explains how EIFS concepts can be used to reduce energy consumption on the farm. Throughout this paper, the projects are referred to by the state or commonwealth where they are located (e.g., New York, Puerto Rico).

Background

The EIFS program was initiated in response to spot shortages of fuel to farmers and rapidly escalating prices for those fuels. The dependence of U.S. farms on commercially available fuels caused concern that farm operations could be drastically impacted by fuel shortages or fuel rationing. While conservation technologies and designs for alternative energy production were being tested and used on a variety of individual farms, the concept of combining these developments in an integrated system had not been implemented. The EIFS program specifically addressed the need to investigate, test, and demonstrate how farms can integrate conservation techniques and off-the-shelf technologies to both reduce energy consumption and produce energy from on-farm sources.

In accordance with program guidelines, each of the selected projects first conducted a systems analysis and followed with the design, construction, and testing of the integrated system. Each project was unique in that a system was designed specifically for the individual farm. When commercial equipment and/or technology was available, it was used as part of the system; however, some of the components

were designed and constructed onsite to meet the
requirements of the particular farm operation and climatic
conditions.

Program Objectives

The overall objective of the EIFS program was to
determine if U.S. farmers have the potential for major
reductions in purchased energy on their individual farms.
The program had the following specific objectives:

1. Determine the potential of existing energy
   conservation technologies and practices in
   reducing the total energy requirements.

2. Investigate the possibility that alternative
   energy sources, such as solar heating of water
   and/or space and conversion of field crops to
   ethanol, can supply energy to the farm.

3. Evaluate the practicality of using waste products,
   such as animal manure or by-products from
   processing operations, as farm energy sources.

4. Evaluate the reliability of new technologies for
   use in farm applications.

5. Provide design specifications, construction
   illustrations, and economic analyses of components
   and systems.

6. Conduct a technology transfer program to
   disseminate program results.

The long range purpose of the program was to provide
sufficient information to encourage the acceptance and
application of energy integrated systems on U.S. farms. A
technical manual was prepared at the completion of each
project. These seven manuals provide details on the design,
operations, and technical and economic performance of the
specific projects. They are designed to assist educators,
sales representatives, contractors, and farmers in assessing
systems for development at individual farms. Readers who
would like additional information on a specific project are
encouraged to consult the appropriate technical manual. In
addition, interested parties, after making proper inquiries
and arrangements, may be able to visit the farms and see the
projects for themselves. An eighth report provides an
overview of the EIFS program and summarizes the seven
technical manuals. The manuals and the report, listed in
the bibliography at the end of this paper, are available
from:

National Technical Information Service
U.S. Department of Commerce
5825 Port Royal Road
Springfield, VA 22161.

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METHODS

Each of the seven farms designed and developed a project that used a combination of existing technologies to both conserve energy and produce energy onsite. Generally, experimental technologies were not studied as part of the EIFS program; rather, existing technologies were applied in new, integrated combinations. Various types of subsystems were implemented, including controlled irrigation, minimum tillage, windbreaks, solar systems, and heat exchangers. Manure management systems with anaerobic digesters were employed to convert manure into biogas, which in turn was used to produce electricity and heat. Energy was also produced by converting milo grain and sweet sorghum into alcohol and by using a fluidized-bed gasifier to burn cotton gin trash to produce low-Btu gas. Computers played an important role in tracking and controlling some of these systems.

The systems designed and developed at the various farms differed according to the farms' operations and needs; thus each project was unique. Table 1 presents a summary of the methods used at each of the farms. These methods, when employed in energy-integrated farming, are not intended to function independently; rather, the components of the system are designed to work together in an integrated fashion. For example, the Texas project was designed to use manure from the hog operation to produce methane, electricity from the methane subsystem to support operation of the hog facilities, and heat from the methane subsystem to heat the hog barns and to ferment and distill fuel alcohol. The digested manure from the methane subsystem was carefully managed and applied to replace some of the commercial fertilizer needed for crop production. Processed feedstock from the alcohol facility was used as hog feed. Figure 2 presents a flow diagram representing the Texas EIFS project. Generally, the other projects integrated the components of their systems in similar ways. Figures 3 through 8 show flow diagrams of the other six projects.

DISCUSSION

Conservation Tillage

Five of the projects (Nebraska, New York, North Dakota, Texas, and Georgia) used conservation tillage to reduce energy consumption. Among the methods employed at these projects were chisel plowing (instead of moldboard plowing), strip tillage, and planting with no-till drills. In addition, a modified version of reduced tillage was used to produce tropical forage grasses at the Puerto Rico project. Results from the projects vary. At the New York project,

yields for corn and corn silage were reduced by 10 to 15% with the use of conservation tillage. Fuel and other cost savings associated with conservation tillage were not great enough to compensate for the reduced yields. The Georgia project compared a reduced tillage system (chisel plowing and disking instead of moldboard plowing) to a no-till system. Though no reduction in yields was observed for the no-till system, additional energy needed for the manufacture and application of contact herbicide (paraquat) caused the net energy input for the no-till system to be slightly greater. For the Nebraska project, comparative tests were not possible because of the crop rotation and field layout. Nevertheless, yields obtained during the EIFS project were thought to be equal to those obtained prior to implementation of conservation tillage. The North Dakota project compared minimum tillage with conventional tillage methods on 15 acre test plots and demonstrated significant cost savings with no reduction in yields using reduced tillage. These savings resulted in an 11% increase in net return for barley, a 5% increase for spring wheat, a 27% increase for soybeans, and a 9% increase for sugarbeets during crop years 1982 through 1984.

Conservation Irrigation

A conservation irrigation system was used on the Arizona project's 3400-acre cotton farm complex. The system used soil sensor stations and pump monitors connected to a personal computer through radio transmitters. Several soil-moisture sensors, buried at various depths, were connected to a remote field station (also buried to avoid interference with field work), which transmitted data to the computer through a radio antenna. See Figure 9. The sensors and monitors enabled the farmer to assess moisture conditions from his office without spending time and energy going to the field, and the computer system determined water application rates to meet specific crop needs. The system showed potential; however, the sensors proved to be somewhat unreliable. Since the time this project was completed, the design of sensors for such applications has been improved. The unreliable sensors allowed only intermittent operation of the system, so cost savings resulting from the system can only be estimated. Operating experience at the Arizona project indicated that computer-aided conservation irrigation will reduce water and electricity consumption by 15 to 20%.

The use of low-pressure center pivot systems in conjunction with computer-aided irrigation scheduling was evaluated at the Nebraska EIFS. Results from these trials showed that reductions in operating pressure and pump horsepower resulted in a 40% reduction in energy used. The use of irrigation scheduling reduced the energy requirements of the center pivot system by about 20%. A computer program was used to update crop water use, soil moisture status, and the suggested date for next irrigation.

Solar Heating

Solar systems were installed at the North Dakota and Nebraska projects to heat livestock housing areas. At the North Dakota project, a solar collector was built on the south wall of a barn to provide heat for a calf housing area. The Nebraska project used a combination of active and passive solar systems to heat swine barns. In addition, natural air grain drying was used at the Nebraska project to dry corn. This process proved to be very successful.

Heat Recovery

Rock bed heat recovery units were added to the dairy barns at North Dakota to capture heat from exhaust ventilation air. Heat exchangers were used at the North Dakota, Georgia, and New York projects to heat water by capturing reject heat from milk refrigeration units. The Georgia heat recovery system saved 140,000 Btu of heat energy daily for heating water. The New York project replaced an existing heat recovery unit with a combination of a precooler and a new heat recovery unit.

Alcohol

The Nebraska and Texas projects produced fuel alcohol from field crops. The Nebraska project developed an innovative harvesting press to extract juice from sweet sorghum in the field to use as feedstock in their alcohol facility. Sweet sorghum was selected as a feedstock because of the potential to produce more alcohol per acre of crop with sweet sorghum than can be produce with cereal grains. Actual yields at the Nebraska project, in terms of gallons of juice extracted per ton of foliage and gallons of alcohol produced per gallon of juice, were much lower than projected, and the process was not economical.

The Texas project used an acid hydrolysis process to convert the starch in whole grain to sugar and included a low-pressure, low-temperature distillation column. The Texas facility was operated for only a short time with limited success.

Wet alcohol was used as fuel in pump motors at the Nebraska project. The engines experienced excessive wear. An aqueous alcohol injection kit was installed and tested on a turbocharged diesel engine. With the alcohol replacing some of the diesel fuel, the modified engine produced about the same horsepower as it did before modification. However, the modification was unsuccessful because the aqueous alcohol, injected into the airstream ahead of the turbocharger, caused excessive wear to the turbocharger blades.

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Fluidized-bed Gasification

The Arizona project used crop waste to produce heat for drying cotton. See Figure 10. Machinery was designed and constructed to handle the cotton trash and feed it as fuel to a fluidized-bed gasifier. The gasifier partially burned the cotton trash to produce low-Btu gas. The gas produced in the gasifier was burned in a combustion chamber to provide heat for drying cotton during the ginning process. Propane could also be burned in the combustion chamber to provide supplemental heat when gas production from the gasifier was low. An oil loop transferred the heat from a heat exchanger in the combustion chamber to the gin dryers. The system proved capable of producing 5704 M Btu during the 150-day ginning season. This is equivalent to approximately 84% of the 74,000 gallons of propane needed each season for drying. The system also provided a means to dispose of the cotton trash, which constitutes about 30 to 40% of the weight of the cotton before processing. Capital cost of the system was approximately $300,000. Annual operating expenses were calculated at $11,922.

Anaerobic Digestion

The other six farms included anaerobic digestion systems as key components of their EIFS projects. The biogas produced in digesters at these six projects was used to produce electricity, provide space heating, or provide heat for an alcohol process. The Texas and Nebraska farms used hog manure; the New York, Georgia, North Dakota, and Puerto Rico farms used dairy manure. Some of the projects used plug-flow type digesters (see Figure 11) or modified-plug-flow digesters (see Figure 12); the others used the mixed-tank type and used gas recirculation to mix the digester contents. Some of the digesters had flexible covers to provide limited gas storage space. Others had solid covers. All of the digesters worked well once the initial start-up problems were worked out. Information on digester design and performance at the six farms is summarized in Table 2.

All six of these projects included engine-generator systems to use the biogas to produce electricity. The Texas, Nebraska, and North Dakota projects produced electricity intermittently to operate ventilation fans, power grain handling equipment, or meet other specific farm needs; the Georgia, Puerto Rico, and New York projects produced electricity for their farms and sold surplus electricity to the local electric utility companies when farm demand was low. Waste heat from the engines was used to heat the digesters to maintain the temperature at the optimum level for biogas production.

The Georgia project used a liquid/solids separator to collect solids from the digester effluent. The solids were dried and composted and then used for bedding. By replacing sawdust purchased for bedding, the dried solids provided a

savings of approximately $20,000 annually. In contrast to sawdust, dried solids used for bedding did not cause any problems in the digester. Electricity produced annually by the engine-generator was valued at $11,650, and annual maintenance and operational costs were calculated at $12,375.

The anaerobic digestion system provided for much better management of animal wastes on the Georgia farm. Not long before operation of the system began, the farm was assessed a fine of several thousand dollars because effluent from the dairy operation was polluting a stream. Operation of the anaerobic digestion system solved this pollution problem and brought the farm into compliance with environmental regulations. It is evident that though the system did not produce enough energy to offset operating expenses, savings on bedding, together with the economic benefits of compliance with environmental regulations, make the operation of such a system economically attractive.

The Puerto Rico project, like the Georgia project, included a solids separator in the system. Composted, dried solids were either sold as a soil conditioner or used for bedding. Management problems prevented the system from operating consistently, but when the digester and engine-generator were in full operation, the system produced more electricity than the farm consumed.

At the North Dakota project, solids were removed from the undigested influent. This practice did not work well; the resulting low solids content of the influent caused problems in the digester, and the separator experienced frequent mechanical problems.

At the New York project, operation of the digester and engine-generator system was quite successful. A few problems were encountered at startup, but once the problems were corrected, the New York system functioned very well. It provided electricity for farm use and for sale to the utility company, and waste heat produced by the engine was sufficient to not only maintain the temperature of the digester, but also preheat the digester influent and provide heat for the farm house. Capital cost of the digester and engine generator was approximately $120,000. Annual operating expenses (excluding interest) were calculated at $3,917. The system proved capable of yielding a net annual return of $12,500 over operating expenses.

In addition to providing energy from waste products, anaerobic digestion of manure allows for major improvements in manure handling. In cases where manure is not properly managed, environmental regulations may be enforced and fines assessed against violating farms. An anaerobic digestion system, coupled with sound manure management practices, can help to avoid problems with environmental compliance. Anaerobic digestion systems generally provide for regular (daily) collection of manure. The digestion process reduces

odors and stabilizes the manure by removing most of the
volatile solids, but the fertilizer value of the manure, in
terms of nitrogen, phosphorus, and potassium, is preserved.
The discharge from the digester can be stored in a holding
pond and later applied to croplands. Incorporating the
material immediately into the soil, either by injection or
by plowing, prevents nitrogen loss and further reduces odor
problems. At all six of the projects that used anaerobic
digestion systems, the systems greatly improved manure
management and made the farms' operations more acceptable
from an environmental viewpoint.

RESULTS

Performance of the systems varied with the design,
implementation, and management of the systems. The more
successful systems were simple to operate and maintain and
did not require a large amount of time from the
farmer/operator.

Many of the subsystems showed promise for on-farm
implementation. Several other subsystems showed promise
from a technical viewpoint, but because of current fuel
prices they are not economical at this time (1987). The
EIFS program showed that farms can supply most of their
energy with current technology. Whether or not a system is
installed depends on economic considerations, but related
concerns over environmental compliance, soil conservation,
future fuel prices, and proper management of farm waste
products may provide additional justification for installing
systems that cannot currently be justified on an economic
basis alone.

Energy Savings

The following estimates of energy savings are based on
data that were available for the respective projects. The
technical reports can be reviewed for additional details.
Note that some of these estimates represent approximate
actual savings, while others represent approximate potential
or projected savings.

The components of the New York integrated system were
specifically designed for the farm and fully incorporated to
demonstrate the energy savings. The annual purchased energy
reduction was approximately 20% of all liquid fuels and 61%
of the total electricity consumption. The fertilizer
available from the careful management of the cow manure
eliminated the purchase of anhydrous ammonia.

The Georgia farm showed that an EIFS could be applied
to a certified raw milk operation and reduce total energy
consumption by about 41%.

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The system at Nebraska showed that the annual purchased energy requirements for this typical size swine farm could be reduced by approximately 63%.

At Texas, the EIFS reduced total purchased energy on the farm by 65% for operating years 1983-84. Field application of the digester effluent reduced the annual commercial fertilizer requirement by approximately 18,000 pounds of nitrogen and 9,000 pounds of phosphorus.

For the North Dakota operation, the combination of conservation and energy production activities applied throughout the dairy barn and during crop production reduced the annual purchased energy inputs by approximately 500 gallons of fuel oil and 51,000 kWh of electricity.

Because Puerto Rico is an island having very limited energy resources of its own, the cost of energy and related farm operations is high. The energy-saving technologies used in this project have the potential to reduce the total purchased energy at the dairy farm by approximately 88%.

At Arizona, the irrigation management/conservation system was used in conjunction with the biomass combustor to reduce energy inputs. These systems were designed to replace electricity and propane fuel to save approximately 27 billion Btus annually, or about 25% of the energy used for crop irrigation and operation of the cotton gin. Operating experience at the Arizona project showed that the biomass combustor had the potential to replace approximately 84% of the 74,000 gallons of propane used annually for the drying of cotton during the ginning process.

Economic Performance

Simple payback values ranged from .75 years for specific components to as much as 30 years for entire systems. Simple payback is defined as the period of time required to recover the original capital investment. For instance, if a farmer invests $1,800 in equipment that is expected to result in added earnings (after operating expenses) of $1,200 a year, the payback period would be one and one-half years. It is a simple method that is widely used to assess the economic value of an investment. Because interest payments and the useful life of the investment do not enter into the equation, simple payback does not actually measure profitability. It only measures how quickly an investor can recover the initial investment. Specific information on economic considerations is presented in the seven technical manuals. Where applicable, these data are presented in Table 3.

RECOMMENDATIONS

The following recommendations are given based on experience gained from the successes and difficulties experienced during the EIFS program. These recommendations may provide guidance in developing an EIFS and in designing individual subsystems. Recommendations given here do not represent all that was learned from the seven EIFS projects, nor does a particular recommendation necessarily apply in every case. Additional specific information is available in the technical manuals prepared for the seven projects. Included in the following discussion are factors that can contribute to the success of a project, as well as problems that can be avoided.

When planning and designing a system, use quality consultants and seek advice from county and federal agents [e.g., Agriculture Extension Service, Soil Conservation Service (SCS), U.S. Department of Energy, U.S. Department of Agriculture]. The county and federal agents can assist farmers in their efforts to improve farm energy management and reduce overall costs and labor and can provide specific information based on experience with similar projects.

Anyone considering any of the subsystems should conduct a preliminary evaluation to (a) determine whether enough resources (i.e., manure, acres, solar day, etc.) are available to make a system operate efficiently, and (b) assess the actual resource size available or expected to become available on the farm (e.g., herd size) and design the size of the system accordingly. Experience shows that a system that is too small will not have a good payback because it cannot generate enough output; if the system is oversized, the capital cost will be excessive and thus payback will be poor. For example, the Nebraska biogas system was too small, while the Georgia biogas system was designed for a larger herd than was maintained on the farm. In those cases, poor economic performance was observed. Payback and performance were better for those subsystems (e.g., solar, grain drying, and Texas and New York biogas systems) that were properly sized.

An experienced consultant should be contacted who will size the engine-generator set and provide some guarantee of power production for a specific gas production. Sizing an engine-generator set is difficult because of fluctuations in gas production and because anticipated gas production rates are not always realized. Small fluctuations can be accommodated by gas storage space, but large amounts of gas cannot be easily or inexpensively stored. If the engine-generator set is too small, it will be necessary to vent and waste some of the biogas. An engine-generator that is too large can be run only intermittently or at such a low speed that little or no electricity is produced. Intermittent operation is hard on the engine and requires

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extra attention unless automatic controls are installed. In general, a slightly undersized engine-generator serves better than an oversized one. Calculation of the projected gas production rate should be based on realistic estimates of herd size, manure produced per animal, manure recovery rate, and gas production per unit of recovered manure. An oversized system typically results when plans for expanding the herd are not realized or when manure recovery rates calculated during design are too optimistic. If construction and operating schedules and other considerations permit, it might be advisable to operate the digestor until gas production stabilizes and then size the engine-generator based on actual rather than calculated gas production. Doing this would waste biogas for a few months, but it would avoid problems resulting from miscalculating the digester loading rate or the gas production rate.

At several of the projects, the engine-generator sets did not consistently give reliable performance. Some of the problems resulted from the presence of H_2S and other impurities in the biogas. The need for inexpensive, effective gas scrubbing units for farm-scale digesters was observed. Commercially available scrubbers are too large and expensive, and smaller custom-made units were not consistently effective. When a complete engine-generator system, including controls and scrubbers, is purchased, a reputable dealer should should be sought who will provide some level of guarantee on operation, safety, and expected life of the engine-generator set. More research is needed to develop an engine that runs efficiently on biogas and requires only minimum maintenance. Engines have been developed that run on landfill gas, but these engines are currently too large for on-farm use. Smaller landfill-gas engines might become commercially available in the near future.

Where the intention is to interconnect with a local utility and sell electricity, a developer should check with the utility company well in advance to determine what equipment and procedures are necessary to meet the utility's requirements.

Where biogas will be used on dairy farms to produce electricity, a developer might want to make provision in the design for using farm-generated electricity for milking, cooling, etc. independent of the utility such that the dairy's operation need not be interrupted by power outages.

A digester should be designed with the assistance of an experienced consultant. Several types of digesters should be considered, and one selected based on the location, mode of operation, space available, etc. Any design must include adequate provision for heating the influent and keeping it warm during digestion. Information on specific digesters is available in the technical manuals.

When designing a digester, provide generous access for cleaning and maintenance. Use gravity to move material whenever possible. Be aware of harmful material that may enter the digester. Disinfectant, mercury, certain feed additives, and other substances can inhibit or kill anaerobic bacteria. It is a lot easier to clean up a spill of a substance that is toxic to a digester before it enters the digester than it is to drain a sour digester and start over.

Safety is an important concern when working with explosive fuel systems. Precautions must be taken to avoid the hazards of poisoning and suffocation associated with manure tanks, pits, and digesters. Biogas contains H_2S, which is extremely dangerous because it rapidly debilitates the sense of smell and can cause sudden unconsciousness.

The farmer/operator should be involved early in the planning process and throughout the design of any integrated or single system. This will help ensure that the farmer/operator's needs are met and that the final product is a system he likes and one that he can operate and maintain. Once the system is in operation, it is important that the farmer take an active role in management. Proper management is often overlooked when designing a system, but it is usually the key parameter that dictates whether a project will succeed or fail.

During the planning stage, select specific equipment by its performance record and be sure that a reputable dealer is available who provides good service and stocks critical parts.

Maintenance of the system needs to be addressed during the early planning stages. If adequate steps are taken during design, the system will perform better and be easier to service when required. Examples of items that should be added during design include scrubbers, digester access and cleanouts, water traps in gas lines, and fencing to protect equipment and prevent foreign objects from damaging the system.

In general, farm-scale alcohol production facilities may be too expensive to build and too difficult and time-consuming to operate and may offer too low a return (under current economic conditions) for widespread application. The acid hydrolysis system experienced numerous problems in producing a quality product because certain operational procedures had to be so strictly followed. Sweet sorghum can serve as a feedstock for alcohol production, but at the present time special harvesting and handling equipment is required. Actual alcohol yields were much lower than yields predicted by earlier studies. Other types of alcohol production processes may be more feasible than those used in this program.

Solar systems proved feasible and viable for heating livestock areas. Local climate must be considered in the assessment and design of such systems.

Keep a system as simple as possible. The more complicated a system is, the greater the likelihood of failure. A project may not succeed if too much time is required for repairs and maintenance.

CONCLUSIONS

The EIFS program was established during a time of high fuel prices and unreliable fuel supplies. Worldwide oil surpluses and lower fuel prices make projects such as those described in this paper less attractive than they were a few years ago, especially those projects involving high risks and high capital costs. However, concerns over environmental compliance, along with concerns over future fuel prices and supplies, may help to justify development of such energy projects where development cannot be justified on an economic basis alone.

The EIFS program was designed to determine the potential energy savings and to assess the economic feasibility of developing integrated systems on working farms. A vast amount of experience was gained from this program. While the program did show that EIFSs have the potential to save money and energy, some of the systems did not perform as well as hoped or expected. During operation of these systems under actual on-farm conditions, design and/or management difficulties were encountered that prevented the systems from performing to their potential. In many cases, it was possible to remedy the difficulties. For example, the New York project reported unfavorable economic performance during its demonstration phase, but after design and equipment changes were made in the digester-cogeneration subsystem, and after the minimum tillage subsystem was discontinued, the New York project turned out to be very successful. In all cases, the lessons learned from the successes and difficulties experienced at these farms can be valuable to anyone interested in the concept of energy-integrated farming. Persons planning to develop any of the specific subsystems (e.g., digesters, engine-generators, solar systems) studied during the EIFS program can also benefit from this information. Such persons are encouraged to consult the appropriate technical manuals (listed in the bibliography). By following the recommendations given in the manuals and in this paper, people who undertake to develop such systems in the future should be able to build and operate systems with substantially better economic performance, in terms of simple payback, than was experienced during the EIFS program.

BIBLIOGRAPHY

Berdoll, D. et al., Del Valle (Texas) Hog Farm Energy Integrated Farm System, DOE/ID/12493, 1985.

Breckenridge, R. P. et al., Energy Integrated Farm System Technical Summary Report, DOE/ID-10167, 1987.

Energy Management Corporation, Energy Integrated Cotton Farm System in Arizona, DOE/CS/40382, 1985.

Pratt, G. et al., Energy Integrated Dairy Farm System in North Dakota, DOE/CS/40377, 1986.

Walker, L. P. et al., Energy Integrated Dairy Farm System in New York, DOE/CS/40380, 1985.

Sasscer, D. S. et al., Energy Integrated Dairy Farm System in Puerto Rico, DOE/CS/40376, 1986.

Splinter, W. E. et al., Energy Integrated Swine Farm System in Nebraska, DOE/CS/40378, 1986.

Walsh, J. et al., Energy Integrated Dairy Farm System in Georgia, DOE/CS/40379, 1986.
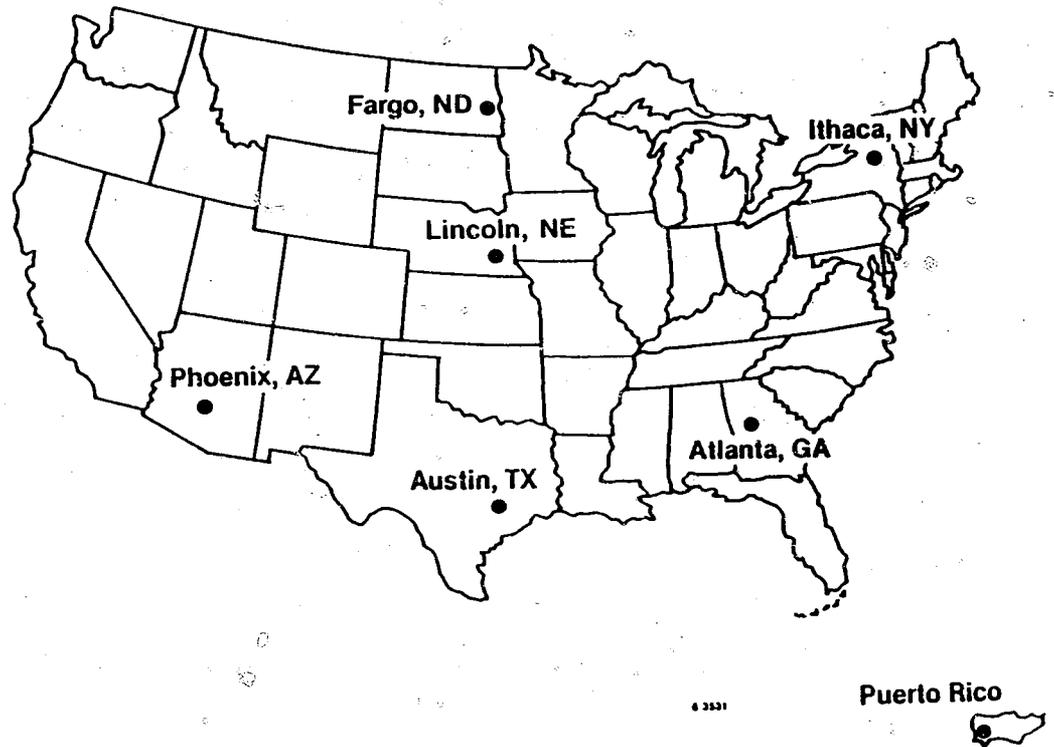
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Figure 1. Geographic locations of the seven EIFS projects.

Hot Water

Electricity

Space Heat
Propane

Feed Supplement

Swine Production System

Pork

EIFS System

Hot Water
Electricity
Space Heat
Manure

Methane System

Cogeneration

Feed

Heat

Feed

Effluent

Feedstock

Fuel Savings

Alcohol System

Fuel

Fertilizer

Petroleum Fuel

Crop Land 2000 Acres

Field Management System
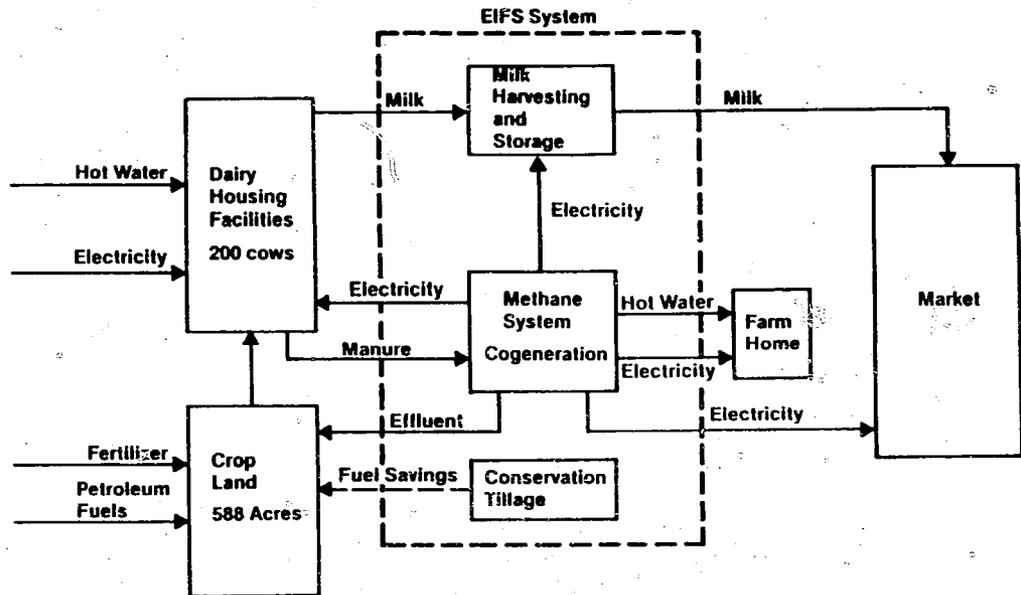
Market

Feed

Cash Crops

Beef System

Beef
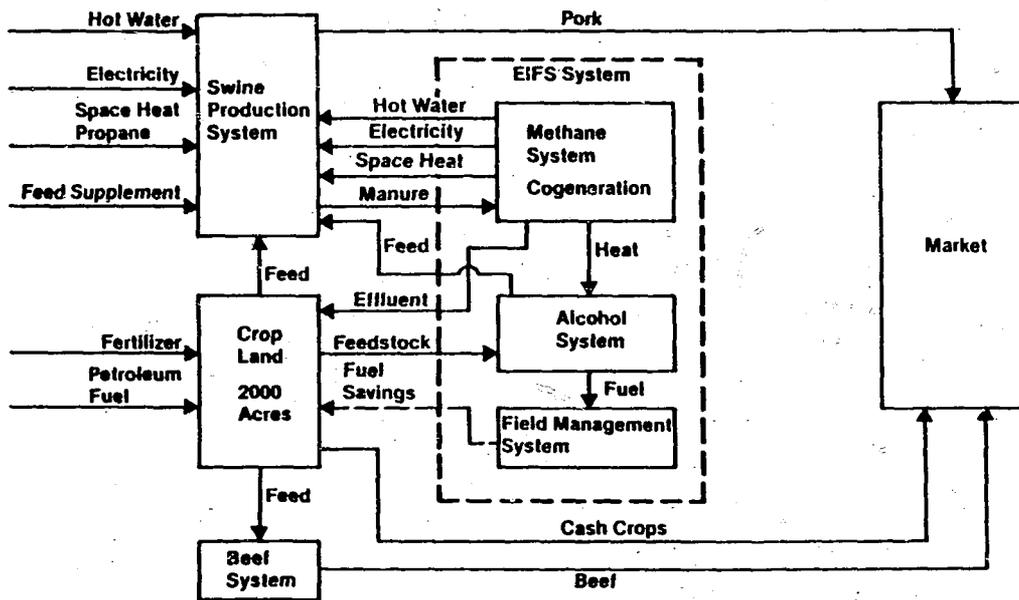
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Figure 2.   The Texas EIFS developed at the Del Valle farm.
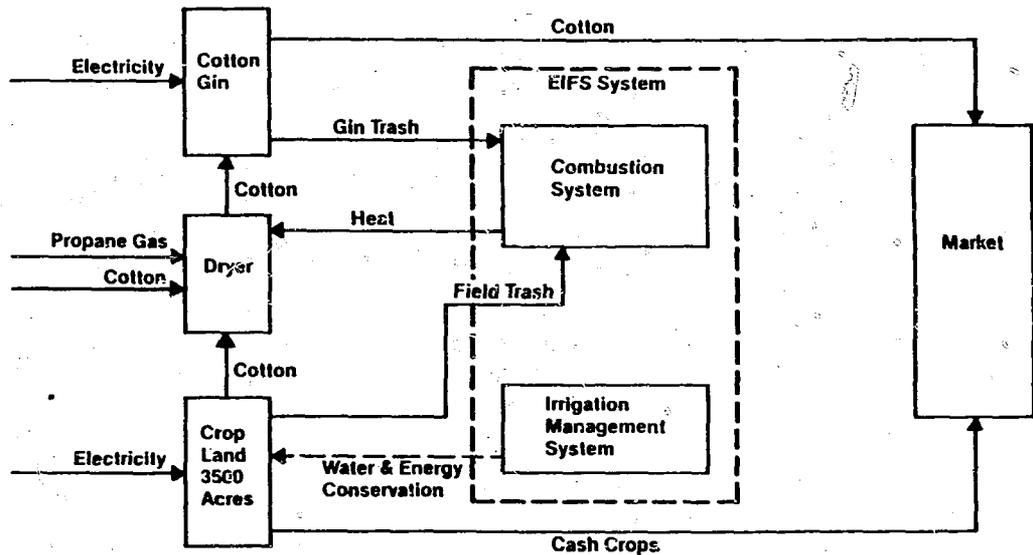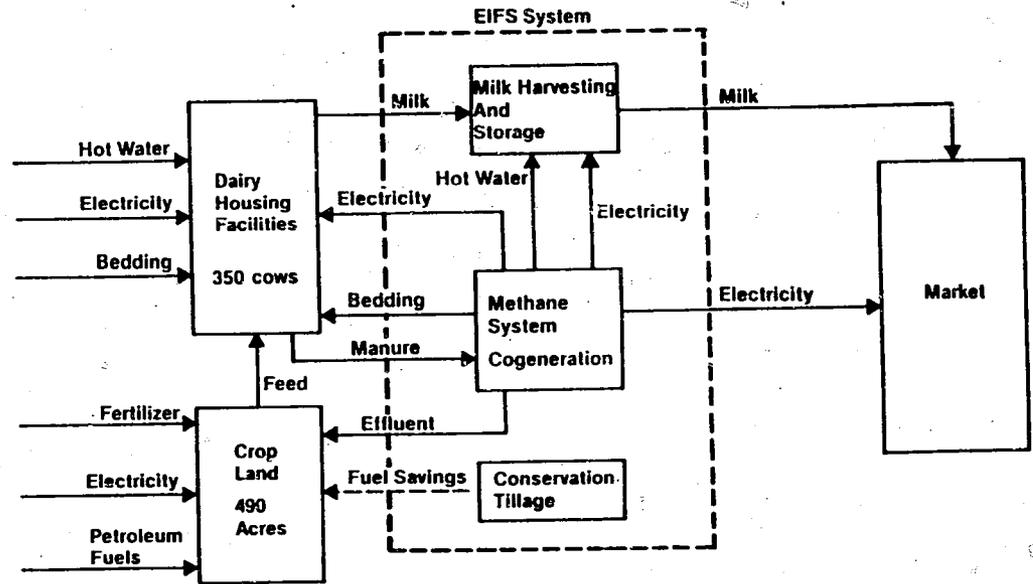
Figure 3. The Arizona EIFS developed by EMC Corporation at the Odom-Golightly farm.

Figure 4.   The New York EIFS developed by Cornell University at the Millbrook farm.

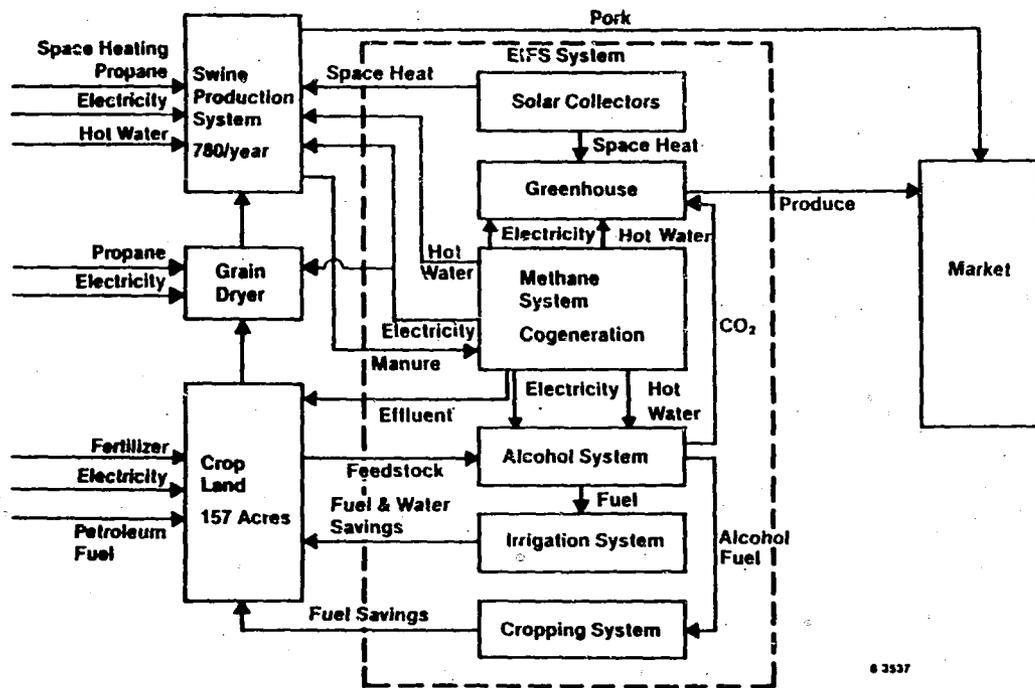Figure 5. The Georgia EIFS developed by Georgia Tech Research Institute (GTRI) at the Mathis farm.

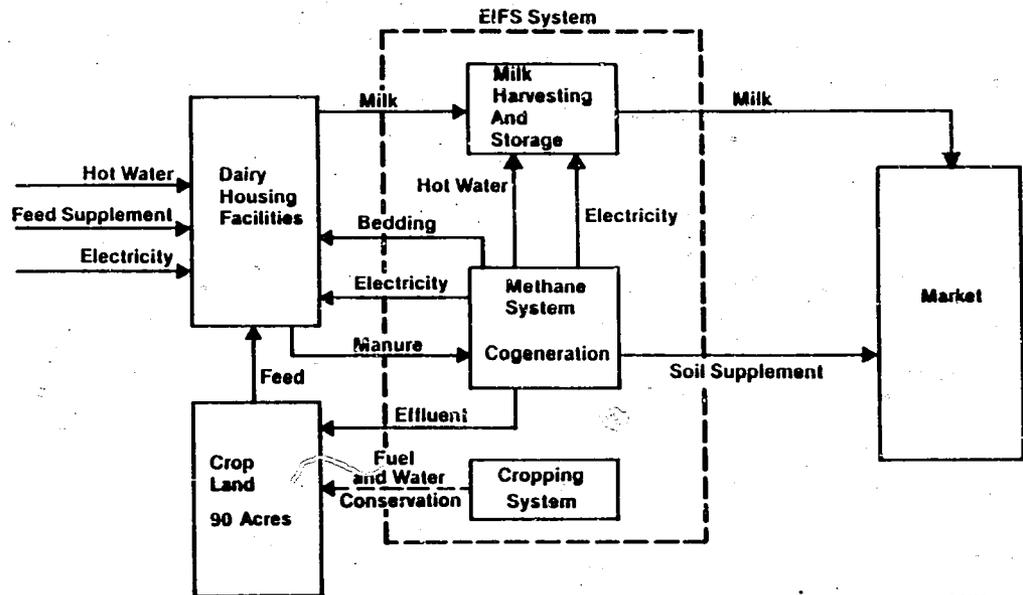Figure 6.   The Nebraska EIFS developed by the University of
            Nebraska.

Figure 7. The Puerto Rico EIFS developed by the University of Puerto Rico at the Ubarri-Blanes dairy farm.
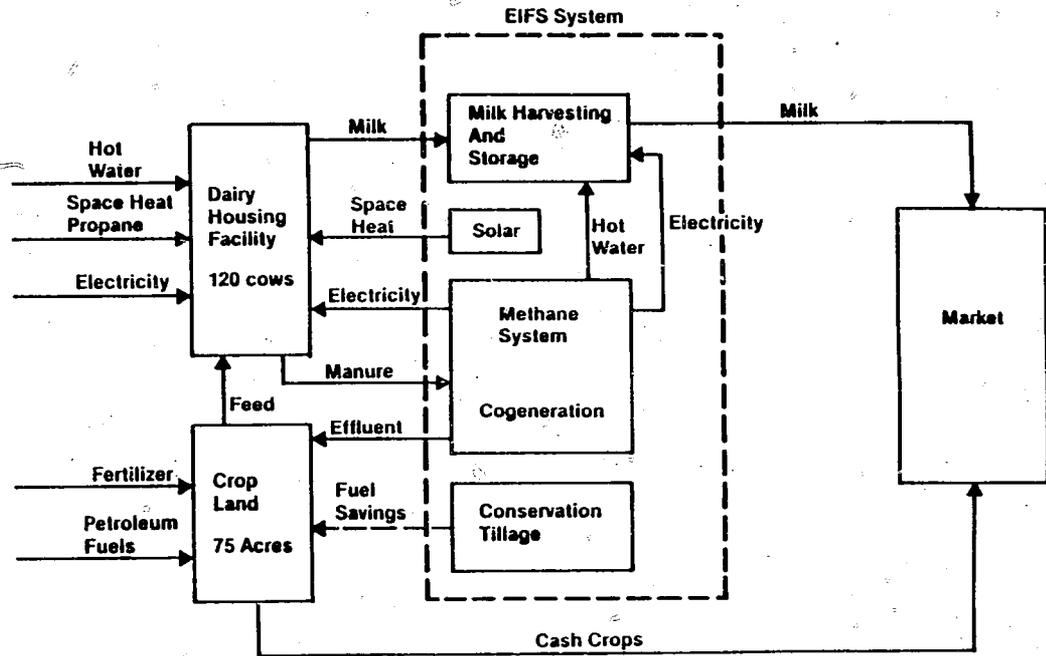
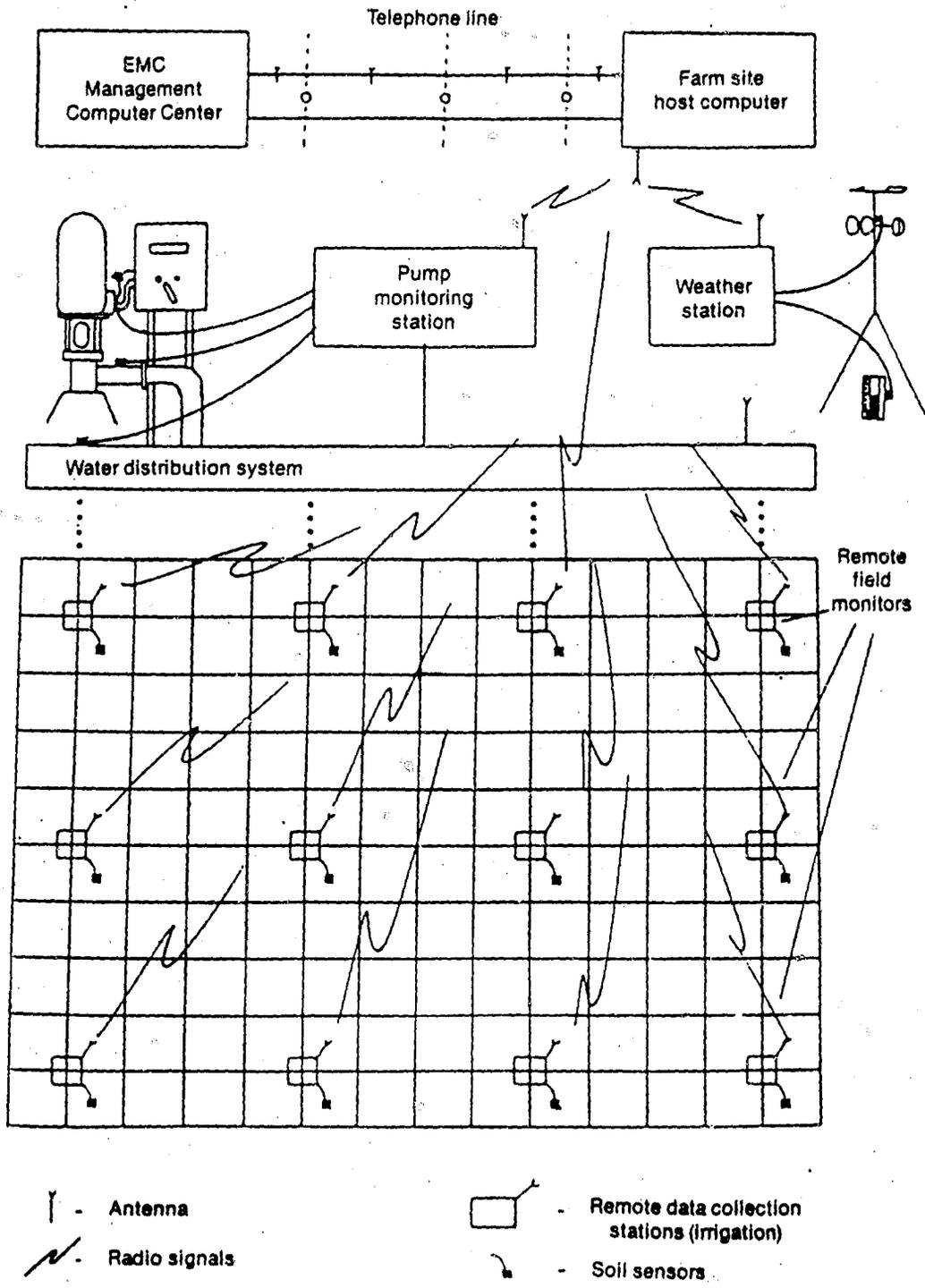Figure 8.   The North Dakota EIFS developed by North Dakota
State University.

Figure 9. Irrigation management system schematic (Arizona project).
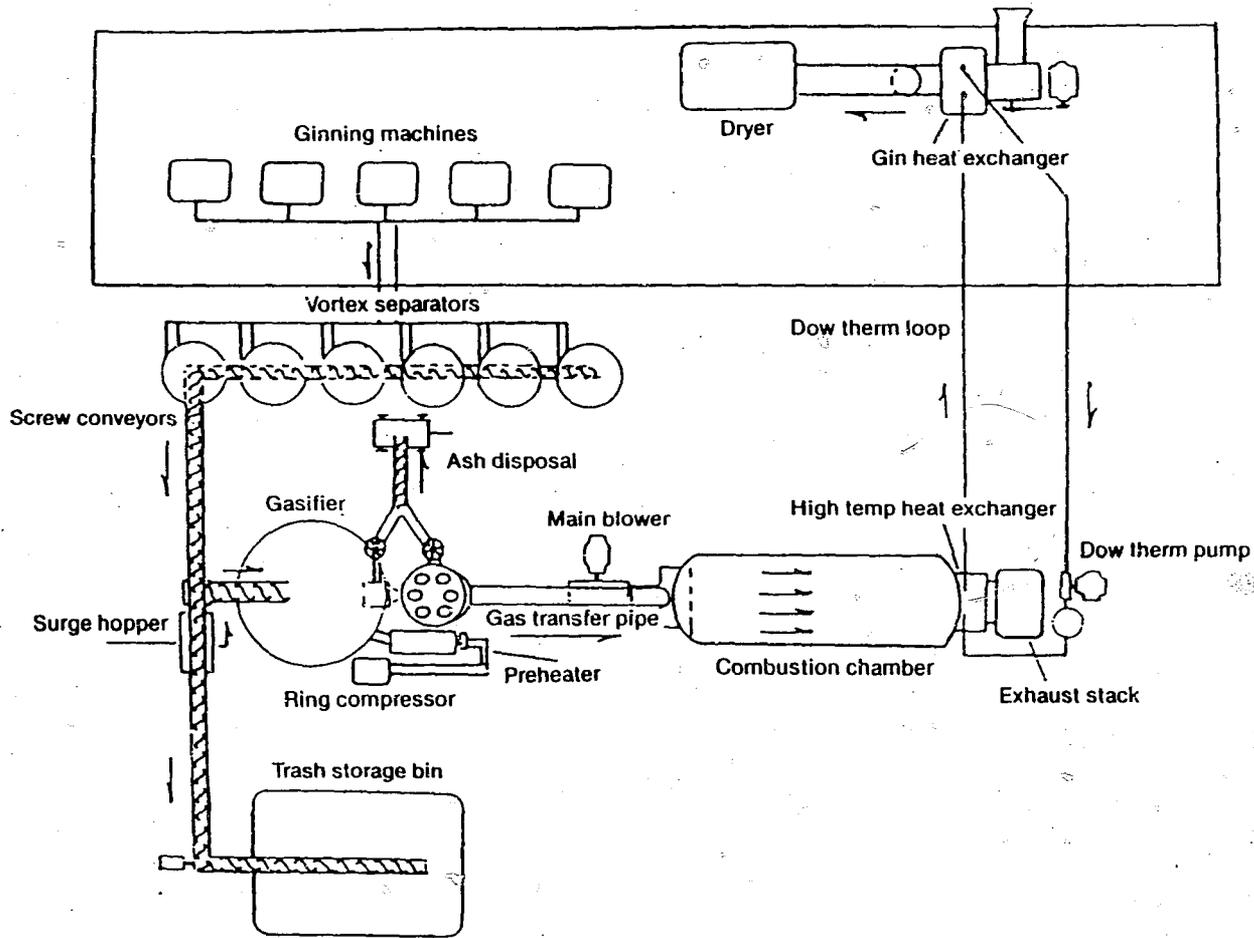
Figure 10. Schematic diagram of the fluidized-bed gasifier developed at the Arizona project.

FLEXIBLE COVER
(shown inflated)

8 cm RIGID INSULATION
(3") (with wood frame)

MANURE FROM
MAIN BARN

INFLUENT
MANHOLE

SHORT HEATING
GRID
(see detail)

6.10m
(20')

INFLUENT
MANHOLE

EFFLUENT MANHOLE

TO EARTHEN
STORAGE

.25 m
(10')

2.44 m
(8')

10 cm FOOTER
(4") DRAIN

5 cm RIGID INSULATION
(2")

MANURE FROM
YOUNGSTOCK BARN

22.56 m
(74')

.30 m
(11')

1.68 m
(5'6")

LONG HEATING GRID

5 cm RIGID INSULATION
(2")

Figure 11. Cutaway view of .g-flow type anaerobic
digester (New York project).

Figure 12. Cross-sectional view of a modified-plug-flow type
anaerobic digester (Puerto Rico project).

TABLE 1. Summary of Energy Production and Conservation Methods Used at Energy Integrated Farm System Projects
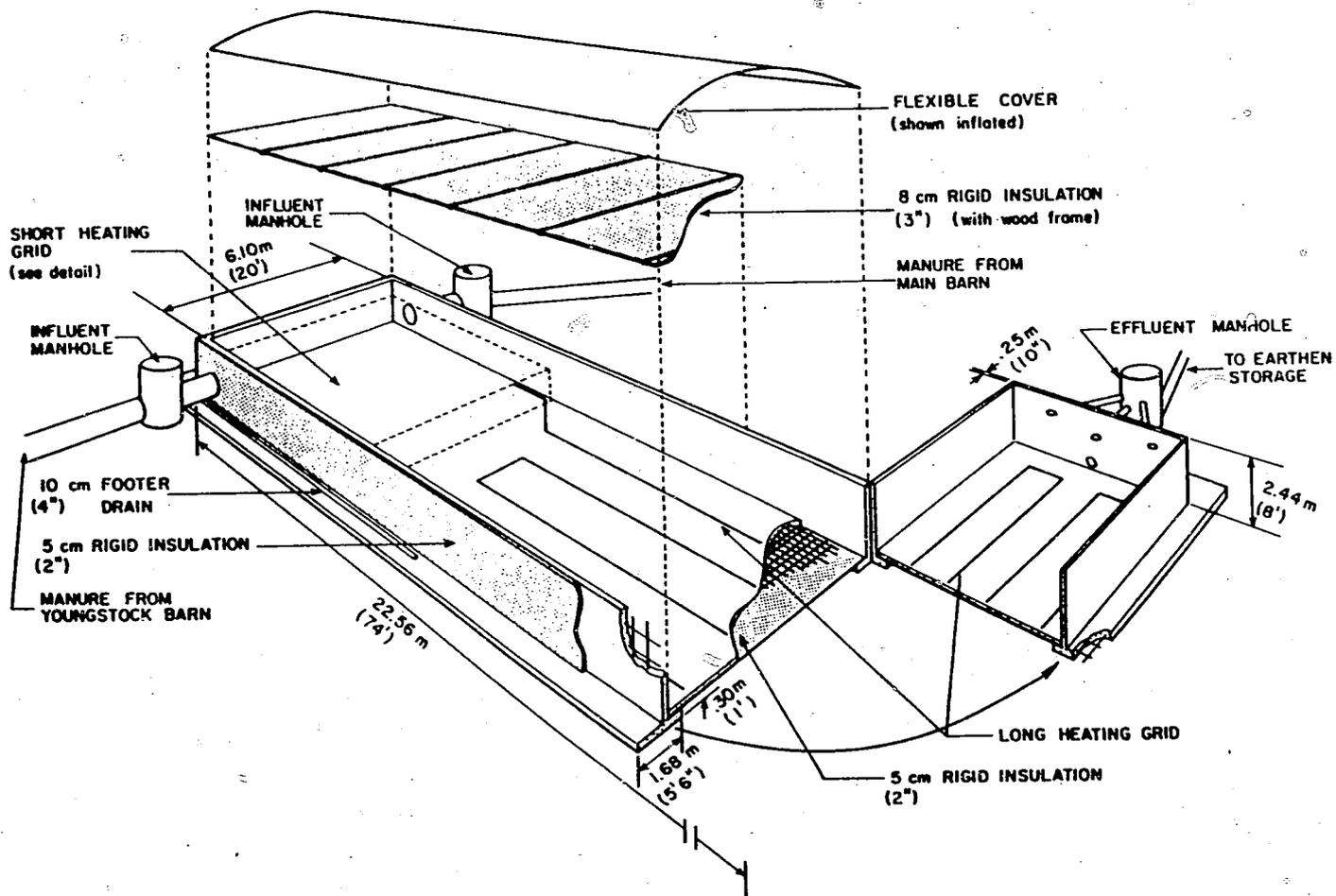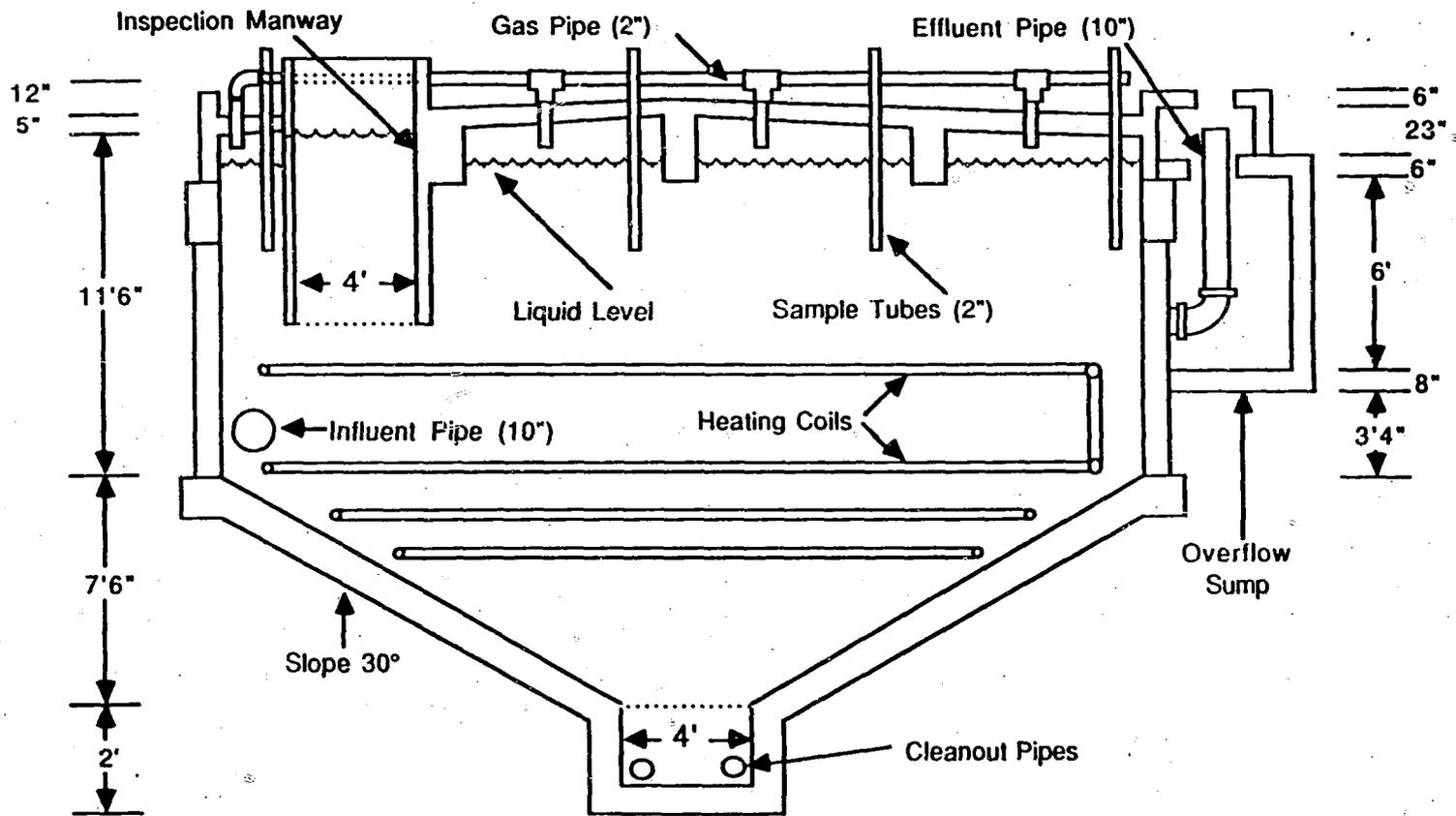
Project	Crop Waste Combustion	Biogas Production	Electricity Generation	Alcohol Production	Waste Heat Recovery	Solar Heating	Conservation Tillage	Irrigation Management
Arizona	Heat for drying cotton	--	--	--	--	--	--	Used computer system and remote data collection stations
Georgia	--	Dairy manure, plug flow	55 kW generator	--	Heat exchanger on milk cooler	--	Corn, silage sorghum	--
Nebraska	--	Hog manure, mixed tank	13 kW generator	Sweet sorghum feedstock	--	Active and passive heating of swine barns	Soybeans, corn, oats, sweet sorghum	Used gated pipe irrigation, reduced pressure sprinkler system, and computer-aided irrigation scheduling
New York	--	Dairy manure, plug flow	27-kW generator	--	Heat exchanger on milk cooler	--	Corn	--
North Dakota	--	Dairy manure, mixed tank	10-kW generator	--	Heat exchanger on milk cooler, rock beds in ventilation system	Active heating of calf housing area	Barley, wheat, sugarbeets, corn, soybeans	--
Puerto Rico	--	Dairy manure, modified plug flow	40-kW generator	--	--	--	Forage grasses	--
Texas	--	Hog manure, mixed tank	4-kW generator	Acid hydrolysis process	--	--	--	--

TABLE 2. EVALUATION OF BIOGAS SYSTEMS

					Design Parameters		
Project	Type System	Feedstock	Size (ft³)	HRT (days)	Mixing System	Temperature (°F)	Daily Feed Rate (lbs VS/ft³ digester)
New York	Plug flow	Dairy manure	11,840	25 to 35	NA	95 to 100	--[a]
Puerto Rico	Modified plug flow	Dairy manure	2 @ 11,760	28	Gas lines, if needed	95 to 104	0.5 to 2.0
Texas	Complete mix	Hog manure	4,200	15 to 20	Gas recirculation	95	0.22
North Dakota	Complete mix	Separated dairy manure	2,962	15 to 20	Propeller[b]	95	0.38
Georgia[c]	Plug flow	Dairy manure	23,216	37	20 hp chopper pump[b]	95 to 100	0.18
Nebraska	Complete mix	Hog manure	770	17.9	Gas recirculation 10 min/hr	95	0.23

TABLE 2. (continued)

	Operational Parameters				**Gas Production**			
			Solid Reduction		Content			
Project	pH	BOD$_5$[d] Reduction (%)	VS[e] (%)	TS[f] (%)	CH$_4$ (%)	CO$_2$ (%)	ft³ Biogas/ ft³ Digester/day	ft³ Biogas/lbs VS Destroyed
New York	7.5 to 8.1	--[a]	10 to 30	--[a]	55 to 60	40 to 45	1.19	--[a]
Puerto Rico	7.3 to 7.6	75	30	25	54 to 58	42 to 45	1.04	6 to 7
Texas	8.1 to 8.7	--[a]	45	42	70	25	1.8	7.4 to 8.9
North Dakota	7.1 to 7.4	--[a]	35	--[a]	60	39	1.8	10.5
Georgia[c]	6.8 to 7.8	65.4	56.7	61.9	58	41	0.68	6.7
Nebraska	7.6 to 8.0	--[a]	--[a]	--[a]	60 to 65	40 to 35	1.75	7.5

a. Specific data not available.

b. These mechanical mixers were used in the mixing pit, not in the digester itself.

c. Designed for 550 cows, but operated with 350 cows. This accounts for the long HRT, the low ft³ biogas/ft³ digester/day, etc.

d. Five day biochemical oxygen demand.

e. Volatile solids.

f. Total solids.

TABLE 3. ECONOMIC ASSESSMENT OF EIFS PROJECTS AND SUBSYSTEMS
         (PAYBACK IN YEARS)

Project	Passive Energy Systems	Biogas System (Biomass Gasifier)[a]	Computer Management System	Cogeneration (Alcohol)[b]	Conservation Tillage	Entire System w/o Tillage	Entire EIFS System
Arizona	NA	(8.7)[a]	3.2	NA	NA	NA	6.8
New York	2.5	6 to 8	--[c]	8.6	35[d]	18	30
Puerto Rico	NA	13.1	NA	13.1	1.7[e]	--[c]	5.5
Texas	NA	6.7	--[c]	(8.5)[b,e]	NA	NA	14.4[e,f]
North Dakota	7.5 to 10	11.56	--[c]	6.5[e]	--[c]	--[c]	7.5[e]
Georgia	6.7	12.9	NA	12.9	None[g]	12.7	13.7
Nebraska	6.6 to 14.8	27.6	--[c]	(13.2)[b]	--[c]	--[c]	--[c]

a. Item in parentheses refers to a biomass gasifier and combustor, not a biogas system.

b. Items in parentheses refer to alcohol production facilities, not cogeneration systems.

c. Specific data not available.

d. Payback for combined manure management and conservation tillage. Conservation tillage alone showed a loss.

e. Estimated value--not included in technical report.

f. Worst case scenario.

g. No positive payback; system showed a loss.

END

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