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Highlights of Two Case Studies Illustrate the Diverse Renewable Energy Opportunities for Colorado Agriculture

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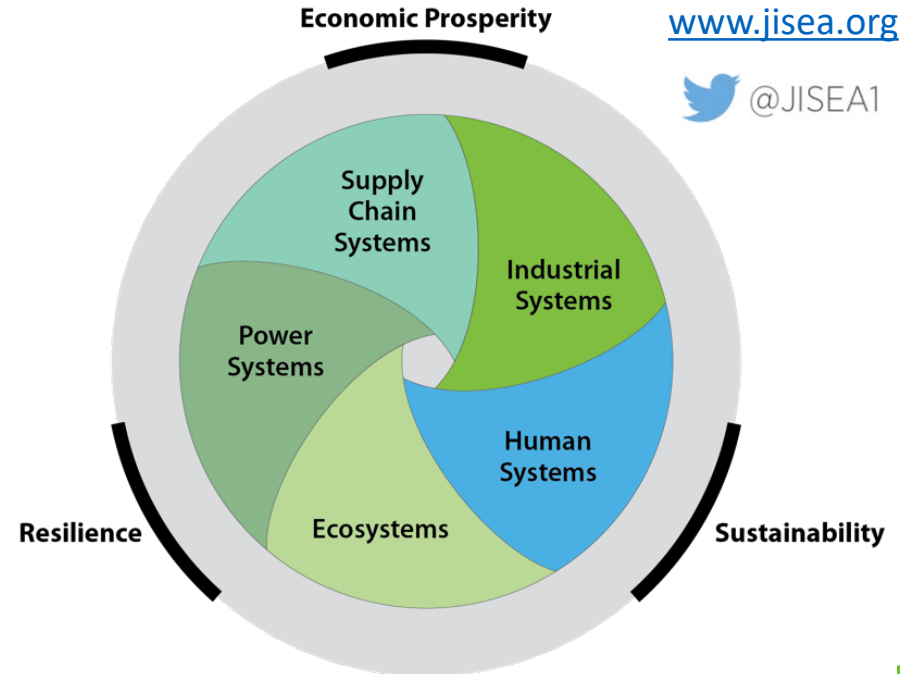
Joint Institute for Strategic Energy Analysis

Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.

“JISEA is researching ways to reduce the cost of energy in food systems, reduce emissions, assess new energy sources for agriculture, and increase food resilience.”

- Jill Engel-Cox, JISEA

From powering farm equipment to heating and cooling, energy is a major cost for most agricultural operations.






Generate renewable biogas while addressing environmental concerns at a Colorado dairy



Save and generate energy by incorporating solar technologies in greenhouse design

Energy and Agriculture Case Studies

Two case studies funded by the Colorado Department of Agriculture and the Colorado Energy Office highlight the diversity of approaches to saving energy, reducing environmental impact, and improving the energy economics for Colorado farms.



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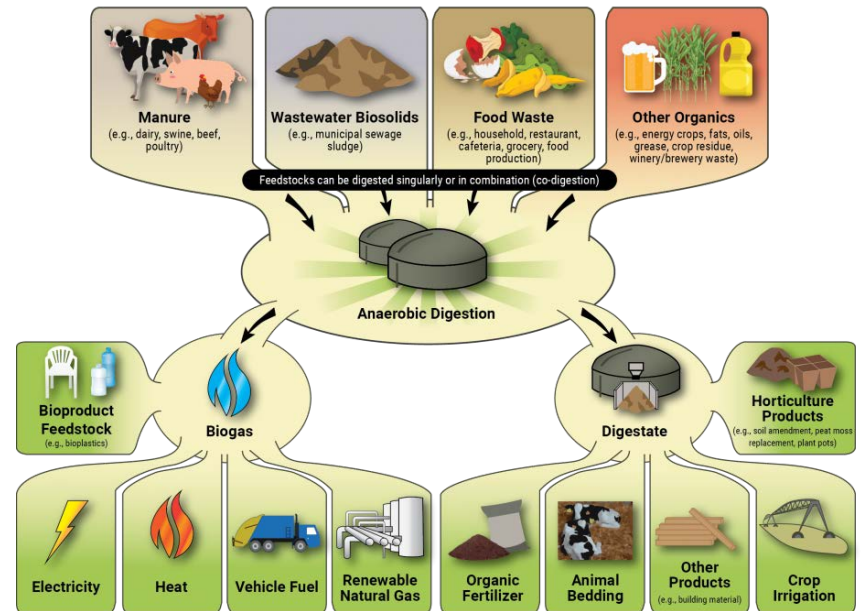
ANAEROBIC DIGESTION IMPLEMENTATION AT DAIRIES IN COLORADO

Photo courtesy of Candice Stacey, Aurora Organic Dairy

Anaerobic Digestion at Dairies in Colorado

Anaerobic digestion naturally occurs when microorganisms break down organic matter, producing biogas.

- Livestock manure management accounted for 62.4 MMT of CO₂ equivalent (CO₂eq) emissions in 2019.
- Anaerobic digestion facilities control digestion and capture the biogas.
- The digestate has many beneficial uses.

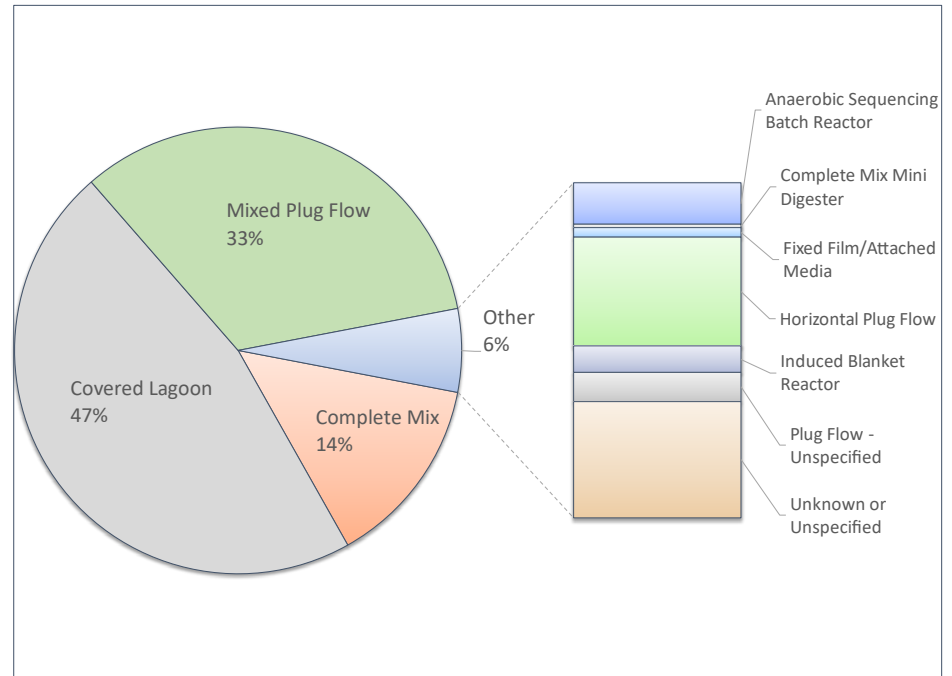


Anaerobic digestion/biogas system flow diagram (EPA 2020)

Anaerobic Digestion Facilities at U.S. Dairies

Digester types used for biogas production at U.S. dairies

- Unheated covered lagoon digesters are impractical for Colorado's climate.
- Heated and mixed digesters speed up digestion, producing more biogas in less volume.



Data Source: US EPA, OAR. 2014

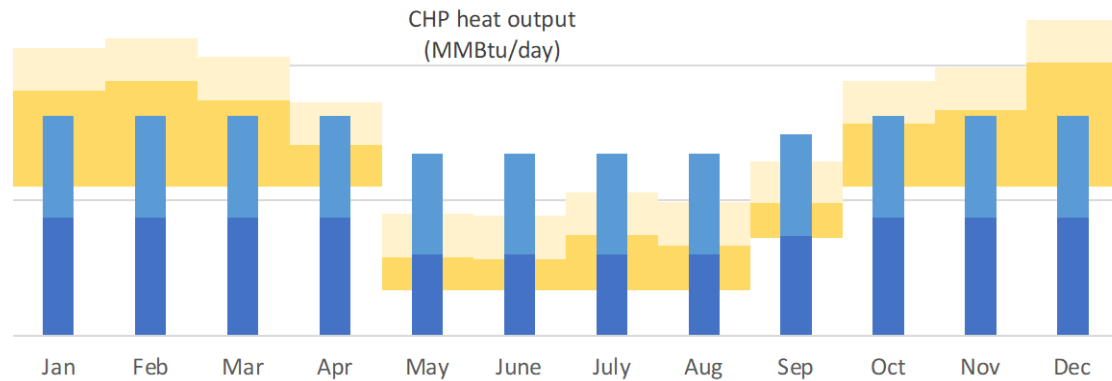


Photo courtesy of Candice Stacey, Aurora Organic Dairy

Aurora Organic Dairy

- 13,000 cows in four dairies.
- Seasonal variation in output because cows are pastured during the summer.
- 39 32,000 gallon induced blanket reactors (IBR) modeled in the case study.
Modeled yield: ~16 MMBtu of CH₄ (pure methane) /cow/year
Heated and stirred reactors mean short retention time (5 days or less) and smaller tanks.

Two Primary Options for Using the Biogas Product



Electricity

Supply the dairies' electricity (including digesters) + 1.1 – 1.9 MW excess to the grid

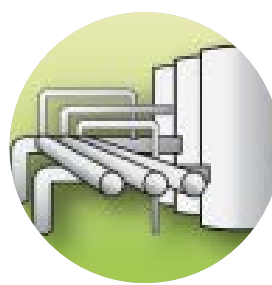
+



CHP Heat

Supply the dairies' heat and hot water needs and heat the digesters

or



RNG

After upgrading, over 170,000 MMBtu renewable natural gas produced per year



Milk Trucks

Less than 7% of the upgraded RNG would supply the milk truck fleet.



Digestate

Over 90% of pathogens are destroyed, resulting in many beneficial uses

Generate Electricity or Upgrade to Renewable Natural Gas (RNG)?

Electricity generation should be considered if:

- Electricity is large fraction of farm expenses or is unreliable, and/or
- The farm can take advantage of an incentive for using or producing renewable electricity, and/or
- The waste heat from electricity generation can be used onsite to replace fossil fuel heating.

Upgrading to RNG should be considered if:

- There is a nearby connecting point to a natural gas pipeline.
- Or there is a nearby CNG station or there is demand for a CNG station.
- The farm is unable to take advantage of incentives for renewable electricity generation.

Digestate from the Aurora Organic Dairy farms would contain:

Over 180,000 gal. liquids / day

- 3,600 lb nitrogen
- Small amounts of phosphorus & potassium

Over 149,000 lb solids / day

- 3,200 lb phosphorus
- 4,700 lb potassium

Digestate & Liquids

Anaerobic digestion (especially if heated) destroys over 90% of pathogens and concentrates nutrients in solids and liquids left after digestion:

1. No longer produce harmful greenhouse gases or cause other negative environmental impacts (e.g., odors)
2. Digestate can be used on the farm or sold as fertilizer or other products.



Key Considerations

Anaerobic digestion can supply the dairies' energy needs and provide environmental benefits and the potential for additional income.

- Digesters are expensive and complex to operate. Third-party owners or operators can provide an income stream for the farm without the up-front investment and learning curve.
- Numerous incentives, tax advantages, and assistance programs are available. Careful consideration is needed for each farm's unique situation.



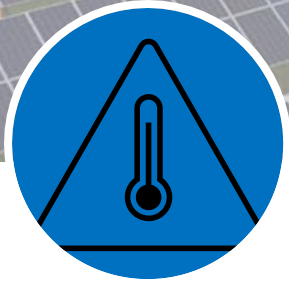
Photo courtesy of Candice Stacey, Aurora Organic Dairy



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RENEWABLE ENERGY FOR HEAT AND POWER IN GREENHOUSES

Energy is used in greenhouses to maintain optimal growing conditions.



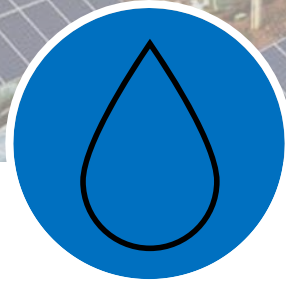
Temperature

Maintaining the temperature accounts for most of the energy demand in typical greenhouse construction.



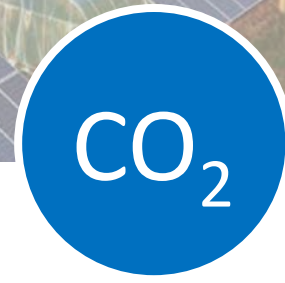
Light

Different crops require different amounts of photosynthetically active radiation (PAR, 400-700 nm).



Humidity

Maintaining proper humidity is a critical function of heating, ventilation, and air conditioning equipment.



CO₂ concentration

CO₂ concentration directly influences plants' photosynthetic rates.

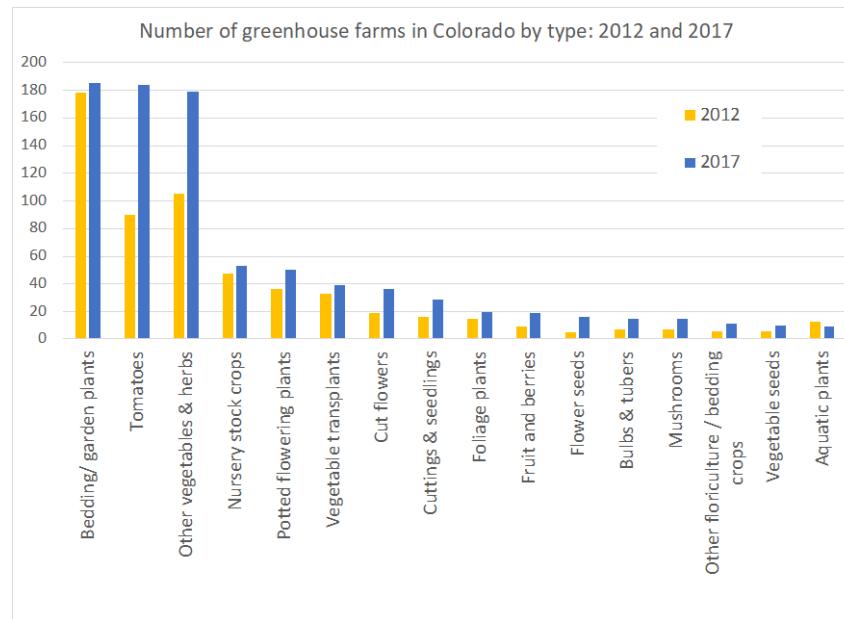


Mechanical

Energy is used for pumps, sprayers, mechanical harvesters, vents, curtains and other control equipment.

Crops Grown Under Protection in Colorado

- The number of Colorado agricultural greenhouse farms increased 47% between 2012 and 2017
 - The number of greenhouse tomato farms more than doubled.
 - The number of other vegetable and fresh herb farms grew by 70%.
- Greenhouses producing cuttings and seedlings increased in area by 17.5 acres from 2012 to 2017.



Active Versus Passive Greenhouse Systems

Passive

Passive solar greenhouses use siting and design strategies to maximize efficient capture, storage, and utilization of incoming solar energy.

- High thermal mass materials that minimize diurnal temperature variations
- Mechanical shades to reduce overheating

Active

In active solar greenhouses, solar technology systems, such as photovoltaic (PV) panels or solar thermal collectors, are used to produce electricity and/or improve thermal performance beyond what can be achieved through passive design.

Solar Technologies and Greenhouse Lighting Needs

The type and configuration of solar panels can be selected to provide the right amount of shading

- Semitransparent bifacial panels reduce shading from panels.
- Organic PV cells can be designed to use non-PAR wavelengths for electricity generation, allowing PAR wavelengths through (new technology).
- Dynamic PV shading controls move PV panels to increase or decrease shading.
- Checkerboard configuration provides more even lighting for crops.



Photovoltaic solar panels installed on a greenhouse. Photo from iStock 1207270991

Solar Thermal and Hybrid Technologies

Combinations of electricity generation and heat storage can improve system efficiency

- Hybrid photovoltaic-thermal (PVT) system uses a cooling medium to extract excess heat from PV panels improving electrical efficiency
- Latent thermal energy storage (LTES) uses phase-change materials to store heat
- Sensible thermal energy storage (STES) stores excess heat in high thermal capacity materials (e.g., rocks)
- Concentrating solar collectors; curved or focusing collectors reduce crop shading



Non-concentrating solar hot water collector system. *Photo by Dennis Schroeder, NREL 48515*

Key Considerations

The specific requirements of crops, cultivation, and climate should be the starting point for evaluating solar technologies and strategies.

- Thermal regulation typically accounts for the majority of energy demand. Hybrid systems can improve thermal and electrical efficiency.
- Passive technologies are most easily implemented in the design phase.
- Newer technologies such as organic PV cells require further development to be economically competitive.



Greenhouse interior. Photo from iStock 950588546

Key Considerations

Optimal technologies and strategies to meet energy demands will depend site-specific greenhouse characteristics, including structural design, crop systems, climate control technologies, and cultivation practices.

- Optimal combinations of active and passive solar power and solar thermal technologies could deliver multiple energy and non-energy benefits (e.g., shade protection for sensitive crops, improved humidity control, or water conservation)
- An energy audit is the best way to evaluate current energy use and identify cost-efficient combinations of technical and nontechnical energy solutions



Solar PV panels on a greenhouse. Photo from iStock 1129147050

NREL/PR-6A50-81737

For more information on this work, see our reports:

- Anaerobic Digestion Implementation at Dairies in Colorado, <https://www.nrel.gov/docs/fy21osti/80381.pdf>
- Renewable Energy for Heat and Power Generation and Energy Storage in Greenhouses, <https://www.nrel.gov/docs/fy21osti/80382.pdf>

Thank You

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