Dairy CAFO Wastewater, Water Harvesting and Ammonia Fuel Cells

Computerized Conservation Accounting of water quality and air emissions from Animal Feeding Operations while diverting problematic wastewater into useful resources for precision agriculture and energy

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ABSTRACT

Spiralcat describes a Dairy CAFO project located within the Chesapeake Bay Watershed which brings together precision agriculture and targeted air quality strategies while conserving water, and provides new market opportunities for farmer's waste effluents. The CAFO's Anaerobic Digester wastewater is diverted directly into the Spiralcat CPARE processing unit where the salts and biosolids are separated from the water fraction and the appropriate nutrients are retained in the water to grow hydroponic tomatoes. The possibility of integrating recovered ammonia hydrogen from CAFO air emissions into PEM fuel cell system is considered. . Here hydrogen extraction from NH_3 and N_2 released provides a very promising approach for animal farmers to maximize the value of the NH_3 while eliminating the negative environmental impact of the N-content of their manures.

CAFO, Ammonia Emissions, Water Harvesting, Fuel Cells

1. WATER SCARCITY AND AIR QUALITY

Water scarcity is the number one global market factor affecting food and energy production. In their 2006 Annual Report the WHO declared that agriculture accounts for 70% consumption of the world's fresh water resources.[9] The World Health Organization reports that approximately 2.6 billion people are currently living without access to improved sanitation facilities. They also reported that by the year 2008 nearly 900 million people will be living in countries or regions with absolute water scarcity; and, two thirds of the world population, including parts of the western US, will be living under stress conditions.[9] The Western United States is now experiencing a prolonged drought; and, it is impacting both agriculture and communities. The recycling of wastewater is one solution that can effectively reduce source water intake by up to 80%. Ironically, across the US severe weather has spawned deadly tornadoes and produced severe floods threatening agriculture and food production.

In some regions rain patterns have become more intense with greater runoff volumes contributing to the serious contamination of our streams and waterways. In other areas, drought has caused desertification, dust storms and firestorms that have covered several states. The US Drought Monitor in April 2012 indicated that the US has not been this dry in five years. Even the Eastern Coast of the United States is exhibiting early drought warning signs. Due to the mild dry winter, nearly 61% of the lower 48 states are described as "abnormally dry" or experiencing drought conditions.[10]

Table 1. Mid-Atlantic States CAFO Ammonia Inventory:

State	tons/year
Maryland	19,467
Delaware	11,558
New Jersey	2658
New York	41173
Pennsylvania	64735
Virginia	35956
Total Regional	175,547
EPA National Inventory Animal Husbandry Operations 2010	

The anthropogenic production of reactive nitrogen, particularly from agricultural activities in the last few decades, now exceeds the rate of natural fixation of nitrogen (N_2).[6] Ammonia, reactive nitrogen and nitrous oxide emissions are of significant environmental concern. According to a recent ammonia emission assessment of agriculture in the United States, accumulation of atmospheric nitrogen oxides enhances the scope of the global nitrogen cycle, contributing to multiple environmental consequences including photochemical air pollution acidification, eutrophication, reduced visibility, ecosystem fertilization, global warming and stratospheric ozone depletion.[1] In 2010 the Agriculture sector was responsible for emissions of 428.4 teragrams of CO_2 equivalents or 6.3% of total US greenhouse gas emissions. Methane emissions from enteric fermentation and manure management represent about 21% and 8% of total CH_4 emissions from anthropogenic activities, respectively.[10]

Recent studies regarding the Chesapeake Bay Estuary estimate that ammonia emissions represent ***175,547 tons/year*** within the Chesapeake Bay Airshed. The 2010 Ammonia index price is $410/ton. Thus, when monetized, ammonia emissions from Animal Production operations represent a lost income of $72 Million dollars annually. Today that price is closer to $610/ton. [7]

Emissions of ammonia and hydrogen sulfide aerosols also play an important role in the formation of fine particles in the atmosphere. Ammonia is often described as a precursor of $PM_{2.5}$ and PM_{10} particulates which are a regulated criteria air pollutants. Under typical atmospheric conditions, ammonia reacts with gaseous emissions of sulfur dioxide and oxides of nitrogen to form sulfate and nitrate fractions of fine particles (defined as particles less than 2.5 microns in aerodynamic diameter). [5]

Beginning in 1989, the South Coast Air Quality Management District in California (SCAQMD) included in its Air Quality Management Plan a control measure to reduce ammonia emissions. SCAQMD showed in its computer modeling of air pollution in the South Coast Air Basin (greater Los Angeles area) that as air polluted masses from coastal counties passed over inland dairy areas, the reaction products of the oxides of nitrogen and sulfur produced by vehicles and industries combined with the ammonia from dairies and created secondary aerosol particulates that contributed to peak PM_{10} levels. . Both wet and dry ammonia spatial deposition contributes to the acidification and eutrophication of ecosystems. Ammonia is regarded as a significant agent participating in the gradual extinction and damage of ecosystems and forests. The need for improved manure management by intensive Confined Animal Feed Operations (CAFOs) becomes increasingly apparent as fertilizer costs continue to rise and environmental degradation continues to occur.

It can therefore be assumed, based upon the US GHG emission inventory and Chesapeake Bay Foundation reports, that a similar spatial distribution mechanism is also found along the Eastern United States. However, it is difficult to contain ammonia emissions without establishing a collection, delivery and monitoring system that integrates into the CAFO Production operations where the manure and wastewater are stored. The Anaerobic Digester is the logical source of containment and the best available facility to capture and mitigate emissions. Many systems have been discussed in the literature and bench scale models constructed. Our approach goes beyond control and seeks to recover market value and derive renewable energy from these emissions using Fuel Cells.

2.1 NEW MARKETS: INCOME

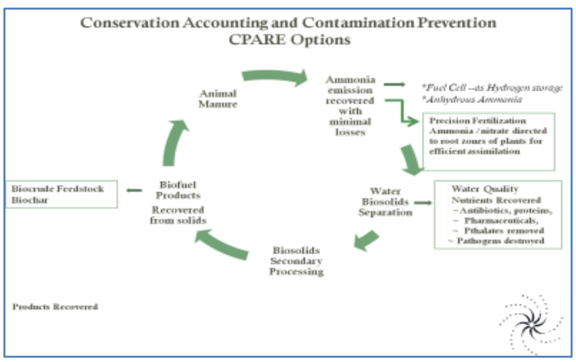
To address this need of ammonia capture, Spiralcat of Maryland adapted its waste processing technology developed under a Department of Defense Contract, to animal production operations. The Spiralcat CPARE [Conservation, Prevention, Accounting, and Renewable Energy] equipment was found to improve the capture of nitrogen, ammonia, nitrogen oxide and hydrogen sulfide emissions in septic and manure systems, recovering the organics as gaseous and liquid fuels and utilizing an ammonia stripping technology that captures ammonia as both a liquid byproduct, and as an anhydrous ammonia.[6] This technology has been demonstrated at various types of animal farms and represents a technology that helps the grower deal with excess manure by recovering raw materials and decreasing nitrogen and phosphorus losses from the field while generating income in new markets. Current efforts to recover the ammonia for selling on the anhydrous NH_3 market have been motivated by recent prices of over $600/ton for this product. However, NH_3 also has significant value as a potential energy source.

2.2 WATER HARVESTING

Water Harvesting has become a necessary component in water quality resource management. Throughout the world many such projects are under construction and it is rapidly gaining favor as a water management tool with agriculture, animal feedlots and food production operations in the United States. Precision agriculture is one way to affect this change while harvesting recoverable and purified water resources from manure. It is known that 90% of swine manure is composed of water. Thus, out of 3 million gallons of manure nearly 2.7 million gallons of water is recoverable. Surprisingly, dairy manure contains nearly 70% to 80% water and with the addition of wash water more recoverable water is possible. The objective is to focus upon the potential water resources that can contribute to the sustainability of agriculture within dry regions of the country.

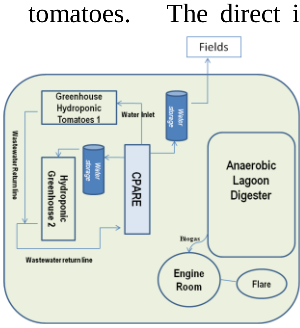
Spiralcat's CPARE [Conservation, Prevention, Accounting and Renewable Energy] is a process that aggregates manure, mitigates NH3 and H2S and their associative emissions and recovers commodities. CPARE is a controlled automated process using Allen Bradley programmable automation controllers (PACs) and programmable logic controllers (PLC). Safety PLCs allow standard and safety-related programs to reside in a single controller chassis, providing flexibility in programming as well as a familiar and easy to use environment for programmers. Data Acquisition is a large part of the manure handling and processing which enables conservation accounting via computer integrated analysis. This enables in situ modeling capabilities.

The CPARE Conservation method provides: (1) Harvesting recoverable water; (2) purifying water and removing pathogens; (3) recovering nutrients in separation columns; (4) removing antibiotics, hormones, Pthalates, metals, and other contaminants from the recovered water; (5) storing the water for reuse using precision agriculture or simply for field irrigation; (6) removing ammonia and reactive nitrogen, VOC's, H_2S, bioaerosols and other targeted air emissions from the manure storage facility; and (7) providing new sources of raw materials for new markets. This is the logical market driven approach to conservation accounting and new market creation. Additionally, each installed project combines the Conservation efficiencies of an automated and computer driven CPARE to recover Ammonia based Hydrogen that can be used to provide Combined Heat and Power using typical Fuel Cell systems, and perhaps an internal combustion engine.



2.3 PRECISION AGRICULTURE

The Chesapeake Bay Watershed is the location where our Dairy CAFO Project brings together ***precision agriculture*** and targeted ***air quality conservation strategies*** to assist the Dairy CAFO in meeting their goal of conserving water, adding a new valued crop to their farm and removing unwanted salts and excess nutrients from their wastewater streams. The proposed project diverts the CAFO's Anaerobic Digester wastewater directly into the ***Spiralcat CPARE*** processing unit where the salts and biosolids will be separated from the water fraction and the appropriate nutrients will be retained in the water to grow hydroponic tomatoes. The direct interconnection from the digester into the CPARE is unbroken and neither ammonia nor VOC, nor CO_2 emissions are lost to the environment. The reuse water is pumped to a storage vessel for composition analyses and to calculate flow rates and nutrient metrics prior to greenhouse use. Each CPARE system is equipped



with automated ControlLogix modules and network configuration (Rockwell Automation Integration Architecture) to provide information for production and performance management along with a Rockwell Automation Logix control platform to oversee monitoring and data acquisition on board systems.

The Aquaculture Research and Education Laboratory at Cheyney University (AREL) is actively involved in aquaponics/hydroponics research and extension. The primary role of AREL for this project will be to evaluate the conversion of aqueous nutrients to plant biomass by various strains of tomatoes and other crops to be used in the described system. This will be done using analysis of both influent and effluent water streams in addition to chemical analyses of plant tissues. Through this methodology the study will be able to quantify the rates at which individual plants uptake and retain critical nutrients while also assessing the effectiveness of different strains to both grow and revitalize effluents passed through this system design. The critical nature of this data assessment relates specifically to the matching of the nutrient content of the inflow with the physiology of the plants being tested. Very diffuse and incomplete data exists which demonstrates that only certain strains of a particular plant will thrive under the conditions of high moisture and high nutrient availability which are a significant part of aquaponic/hydroponic systems. Therefore the assessment and selection of the correct plants at the beginning of the system design process is critical to eventual success.

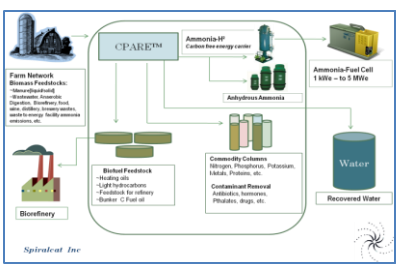
The data collected by AREL staff from this project will be further compartmentalized to provide information on how much of the absorbed nutrients are being incorporated into root, stem/leaf, and fruit production as this division will be critical to the overall profitability of this portion of the project. The most important mineral components of the influent stream relating to eventual effluent concerns and regulations (nitrogen, potassium and phosphorus) will be of primary concern, but data on other nutrients will also be summarized as their data will allow. In addition, this data will be used to develop models of nutrient removal efficiency that can be incorporated into the overall system engineering model. This data will also begin to fill in the information voids relating to all aquaponics/hydroponics systems.

3. AUTOMATION: DATA CAPTURE

To assist in the collection of data we have included in situ Monitoring and Data Acquisition system (DAS) equipment. Suggested applications for this unit will include data archiving (using one or more schemes). Such client applications would include system/process specific displays suitable to the farm facility/operations configuration. Wherever possible or practical, measurement and analysis uncertainties will be calculated by the software as an aide in determining reliability of measured process data and the results calculated from them. A wireless connection by relaying on a Windows-NT Remote Access Service (RAS) provides a secure means of field access by the team and operators. The suggested client archive application could be based on either Microsoft Access native (file /server), database or SQL Server (client/server) databases. The issues of future up-sizing and remote client access are addressed by the nature of the database and the RAS, respectively. The proposed DAS is intended to function as a foundation for continued development and monitoring of the CPARE processor and confirm quality of anhydrous ammonia production. Pre-analysis of the quality of ammonia is required as sulfates and salts will damage the fuel cell components. The DAS sampling rates are suitable for DC measurement of all process parameters. Sample rates on all channels of the order 1 per minute will be supported.

4. AMMONIA FUEL CELLS

Alternatively, the possibility of integrating ammonia in a PEM fuel cell system involving hydrogen extraction from NH_3 and N_2 release provides a very promising approach for animal farmers to maximize the value of the NH_3 while eliminating the negative environmental impact of the N-content of their manures. Spiralcat has adapted its CPARE technology to provide a relatively high purity NH_3 stream for integration with the fuel cell or internal combustion engine. This system will be integrated with Spiralcat's Dairy farm in Maryland and a second will be installed on a swine CAFO in Pennsylvania. Both farms operate using conservation techniques which include storm water management from building roofs, fencing, constructed wetlands and energy crop plantations as riparian barriers. Each CAFO has a Conservation Reserve Enhancement Program Agreement in place. For these two installations Spiralcat will use an ammonia cracker to decompose NH_3 into N_2 and H_2 and to provide ~ 5+ kW of clean electric power from the NH_3 waste.



5. PROBLEM TO PROFIT

The CPARE automation, process controls and data acquisition software programming affords precision agriculture and mitigates air emissions from CAFOS while producing power. This project demonstrates an in situ modeling procedure that downloads quantifiable data within a computerized integrated architecture for Conservation Accounting that determines and reports in real time ecosystem services, improvements, mitigations; and, effects as related to each food production operation. Each project broadens the assessment capabilities to address future conservation effects assessments and return added value through the quantification of nutrient credits, water quality credits, renewable energy credits and power production credits. Quantification by "measurable computerized accounting of valuable ***new*** recoverable commodities" enables each farm to: (1) commoditize raw materials from waste effluents; (2) expand laterally into new markets; (3) reduce vulnerability from climate changes; and, (4) reduce uncertainty in the model estimates of conservation benefits for each animal CAFO operation.

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