Biomass Program Perspectives on Anaerobic Digestion and Fuel Cell Integration at Biorefineries

Biogas and Fuel Cell Workshop
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DOE Biomass Program
Outline

• The Importance of Anaerobic Digestion for Fuels, Products, and Power

• Biomass Program Perspective

• The Potential for Biogas/Fuel Cell Integration at Biorefineries
  o Retrofit Applications for 1st-Generation Biofuels Plants
  o Integration Opportunities in Advance Biofuel Production

• Potential for EERE Multi-Program Joint Solicitation
Anaerobic Digestion:

An Underappreciated and Underutilized Conversion Pathway for Biofuels, Bioproducts, and Bioenergy
Anaerobic Digestion

• Microbial bioconversion process generates methane
• Emerging global technology
• Has a “Bad Rep” in the US from numerous failed applications: still needs RD&D for widespread acceptance and commercialization
• Reduces GHG emissions (22:1 vs. CO2)
• Dependent on sales to grid like other distributed energy techs
• Lack of national feed-in tariff retarding deployment
• Lack of process reliability retarding financing and deployment
Anaerobic Digestion

Organic Recycling for Renewable Energy

AD takes waste organic feedstocks…

- Municipal Operations
- Industrial Operations
- Institutions Correctional
- Homes
- Restaurants Supermarkets
- Colleges Schools
- Islands

And Recycles the Organics

Organic Recycling and Renewable Energy Facility

Into Renewable Energy…

- Electricity
- Steam
- Heat
- Pipeline Injection
- CNG for Vehicles
- Biogas

And Value-Added Bioproducts:

- Quality Compost
- Liquid Fertilizer
- Landfill Daily Cover
- Retail Products
- Bio-remediation

Effluent

GOAL: Recycle the waste into energy as close to the point of generation as possible
**Anaerobic Digestion**

**Biomass Feedstock Applications**

- 6.75 billion tons of domestic solid waste
- 240 million tons of MSW per year
- 5+ tons animal waste per person per year
- Growing at 3-5% per year

- Municipal Solid Waste
- Wastewater
- Spent Beverages
- Food Processing Wastes
- Food Residuals
- Agricultural Residues
- Animal Manure
- Industrial Sludges

- Biosolids
- Slaughterhouse Waste
- Animal Mortalities
- Industrial Wastes
  - Pharmaceutical
  - Rendering
  - Textile
  - Tannery
Anaerobic Digestion:

Biomass Program Perspective
"The Anaerobic Digestion Relay Race: Passing the Carbon Baton"

- Complex Biological Polymers $C_{100-10,000}$
- Hydrolytic Bacteria
- Shorter Hydrolysis Products $C_{10-1,000}$
- Fermentative/Acidogenic Bacteria
- Short Chain Fatty Acids $C_{5-20}$
- Acetogenic Bacteria
- Soluble Organic Acids $C_{2-10}$
- Methanogenic Bacteria
- Single Carbon CO2 and CH4
Biomass Program Perspective: AD for Fuels

- Biogas can be used as a Transportation Fuel
- Biogas-derived Methane is equivalent to CNG
- Biogas-derived Methane qualifies for a RIN under RFS2
- Hard to compete for CNG market with Natural Gas at $2-3/mmbtu
- Need other incentives like RINs or carbon-credits to compete as CNG
- Excellent potential to fuel waste collection vehicles and milk tankers with CNG in closed/recycle system
- Also source of carboxylic acids/salts that can be converted to RE Hydrocarbons (Terrabon)
- Possible source of Hydrogen Fuel
Anaerobic Digestion

Biomass Program Perspective: AD for Products

- Anaerobic digesters can be a source of Bioproducts
- Carboxylic salts, hydrogen
- Anaerobic Compost:
  - Soil amendments, erosion control, tilth
  - Berms, spill control products
  - Flowerpots, molded products
  - Fuel pellets
- Organic fertilizer, liquid nutrient solutions, “teas”
- Enormous, untapped potential in the mixed microbial consortia
- Potential is only limited by our ability to identify and culture anaerobic strains, need new techniques, expanded methodologies
- Potential exists along the entire continuum from hydrolysis, acidogenesis, acetogenesis, methanogenesis
Anaerobic Digestion

Biomass Program Perspective: AD for Power

- Excellent for smaller scale, distributed power applications
- Opportunity for every community to become a link in a distributed generation “net”
- Highly appropriate for industrial CHP retrofits to reduce operating costs and improve profitability
- Convert organic wastes to heat and power at or as close to source of origin to minimize transport and GHG emissions
- Need to combine with RECs for profitability; feed-in tariffs
- Most efficient use can be thermal
- Need improvements for small scale reactor design
- Need improvements in remote operations and telemetry
- Opportunity for third party O&M/service industry as “hosts” may not want to be involved
Need to maximize all revenue streams for profitability:

1. Tipping Fee/Service Fee/Recycling Fee
2. Sales of Bioenergy: Biogas/Methane/Electricity/Thermal
   • RECs, Carbon Credits
   • Avoided cost of CHP and waste disposal for industrial applications
3. Sales of the solid effluent: “Anaerobic Compost” and products
4. Sales of the pressate/centrate: “Liquid Fertilizer
5. Potential future value of recycled water
6. **Potential value of methane capture: carbon trading at 22:1**
Anaerobic Digestion:

An Integrated Waste and Energy Management Strategy
An Integrated Waste and Energy Strategy: “Closing the Loop”

- Organic Waste Feedstocks
- Biogas Fuels Waste Collection
- Organic Recycling Facility
- Biogas
- Parasitic Load
- Compost
- Fertilizer
- Greenhouse/Aquaculture/Algae Production
- Production Wastes
- CO₂
- Heat
- CNG
- CH4 Splitting
- FC/CHP
- Parasitic Load
- Light Energy
- Biogas Fuels Product Delivery
- Products to Consumers
- Biogas
- CNG
- Heat
Anaerobic Digestion:

Process Technologies:
Feedstock Resource Drives Process Design
AD: Low Solids Applications

- <3% total solids by weight
- little or no suspended solids
- single phase liquid system, readily mixed

- Low Solids Feedstocks
  - Secondary wastewater treatment
  - Spent beverages & out of spec/expired products
  - Hydraulic flush manure systems (swine)

- Low Solids Processes
  - Anaerobic Lagoons - Fixed, Floating, or Submerged Covers
  - Completely Mixed Reactors
  - Anaerobic Filter Reactors
  - Upflow Anaerobic Sludge Blanket Reactors
  - Fixed-film Packed Bed Reactors
Anaerobic Digestion

Low Solids Covered Lagoon
AD: Medium Solids Applications

- 3% to 12% total solids by weight
- contains suspended solids
- slurry system, can still be mixed

- Medium Solids Feedstocks
  - Dairy manure
  - “Scraped” swine manure
  - Industrial DAF sludges

- Medium Solids Processes
  - Plug Flow Reactors
  - Complete Mix Slurry Reactors
  - Slurry-Loop Reactors
Anaerobic Digestion

Medium Solids Applications:
Complete Mix Slurry Digesters

(Photo Courtesy of the Danish Biogas Program)
Medium Solids Applications: Plug Flow Slurry Digesters

Poultry and cattle manure digester at Coleraine, N. Ireland, built by Practically Green

Dairy cow manure digester at Craven Farms (1,000 cows), Oregon, USA
AD: High Solids Applications

- up to 30% total solids by weight
- “solids-processing” system
- requires non-traditional mixing

High Solids Feedstocks
- Organic Fraction of MSW
- Ag-residues
- Food Processing Waste; Food Residuals
- Clarifier sludges (pulp/paper)

High Solids Processes
- “Dry” Continuous
- Plug Flow
- Dry Batch with Permeate Recycle
- Sequencing Batch Reactors
High Solids Applications: Demo-Scale Plug Flow Digester

Photo of Plug Flow MSW Digester Courtesy of Pinnacle Biotechnologies
Developed at NREL and Sponsored by DOE 1991-2001
Anaerobic Digestion
Anaerobic Digestion

High Solids Applications: Commercial Scale Plug Flow Digester

(Photograph Courtesy of www.kompogas.ch)
Anaerobic Digestion:

A Success Story:
The Danish Model
Summary of Biogas Program in Denmark: Why it works

• Nationwide program started in 1988
• 21 centralized plants
• Laws prohibit landfilling or land application
• Laws mandate 7 month winter hold
• Government provides 20-40% financing subsidy
• Law mandates electricity purchase
• Law mandates minimum price
• Cities use centralized heat
• Collection trucks powered by biogas
• Effluent delivered back to farms
Anaerobic Digestion

Blaabjerg Plant Equipment:
1. Blending Tank
2. Industrial Sludge Holding Tank
3. Manure Hold Tank
4. Digester
5. Gas holder
6. Effluent Sludge Tank
7. CO-GEN Building
8. Office & Laboratory Bldg.

Blaabjerg Main Operating Data:
Animal manure............................ 222 tons/day
Alternative biomass..................... 87 tons/day
Biogas production....................... 3,1 mill Nm³/year
Digester capacity (2 x 2500 m³).. 5000 m³
Process temperature............... 53,5°C
Utilisation of biogas............... CHP-plant
Average transport distance........ 5,0 km
Contact: Manager
Jens Riddersholm Jensen
Tlf./Fax: 75287948 / 75287348
Contractor: BWSC Ltd
Anaerobic Digestion

Lintrup Main data:
Animal manure............................ 410 tons/day
Alternative biomass..................... 137 tons/day
Biogas production....................... 5,7 mill Nm³/year
Digester capacity (3 x 2400 m³).. 7200 m³
Process temperature................... 53,0° C
Post-digestion temperature......... 42,0° C
Utilisation of biogas.................... CHP-plant/gas boiler
Average transport distance...... 7,5 km
Contact: Manager Tom Buhl
Tlf./Fax: 74855344 / 74855203
Contractor: Kruger Ltd
Year: 1990

Arhus Main data:
Animal manure........................ 346 tons/day
Alternative biomass............... 46 tons/day
Biogas production................. 3,8 mill Nm³/year
Digester capacity................. 8500 m³
Process temperature
- slurry + org. waste............... 38° C
- household waste.................. 52° C
Utilisation of biogas.............. CHP-plant
Average transport distance...... 5,5 km
Contact: Manager John Sønder Jensen
Tlf./Fax: 86989432 / 86989209
Contractor C.G. Jensen Ltd
Year: 1995
Anaerobic Digestion:

R&D Needs for Broad Commercial Deployment:

Reducing the “Art of the Black Box” to Science:
R&D Needs for Broad Commercialization: Cost Reduction and Process Optimization for Reliability

- Development of inoculum methodologies and anaerobic culture techniques
- Understanding the microbial population dynamics of the mixed consortium
  - consortium optimization and “health”
  - Prescriptive and preventative “therapeutic” methods
  - “Mining” the consortium for strains that make other products instead of biogas
- Reactor design optimization
- Process optimization: the 65% “wall”
  - Enhancing biogas productivity: higher yields from volatile solids
  - Enhancing biogas quality: higher methane content
R&D Needs for Broad Commercialization: Cost Reduction and Process Optimization for Reliability

- Process automation through real-time instrumentation and remote operations/telemetry
- Value-added effluent processing and co-product optimization
  - Compost stabilization
  - “Mining the Pressate”
  - Development of new products
  - Cheap and efficient water recycling technologies
- Methane splitting and cleanup
- Material Recovery Facility (MRF) technology development
- Community education for organic recycling
The Potential for Biogas/Fuel Cell Integration at Biorefineries
Benefits of Fuel Cell Integration with Biorefineries (or any industrial facility with organic wastes with potential for biogas production)

- Industrial retrofits with Fuel Cell applications reduce operating costs:
  - Onsite distributed power generation: CHP
  - Avoided cost of electricity
  - Avoided cost of waste treatment, collection and disposal
  - Fossil fuel displacement
  - Reduces production GHG footprint/LCA of products
  - Distributed generation for energy security, environmental stewardship, economic development
  - Industrial and municipal biogas facilities can become the backbone of a hydrogen Infrastructure: production and fueling
FC Integration for CHP in Biofuel Production

GHG Contributions

CO2 Exhaust or Recovery

Biogas to Flare

Process Wastewater

Water Recycle

Anaerobic Digester (small)

Dryer Exhaust (VOCs)

Steam

Thermal Oxidizer

HRSG

Natural Gas

Water

Electricity

Exhaust (NOx)

Dry Mill Ethanol Plant (Current)

DDGS

Ethanol

Sludge to Landfill or Field Applied

Steam

DDGS

Ethanol
Dry Mill Ethanol Plant (Fuel Cell Integration)
FC Integration for CHP in Biofuel Production

**GHG Contributions**
- CO2 Exhaust or Recovery
- Ethanol
- Distillers Grains
- Biogas Feed to Boiler
- Makeup Water
- Process Wastewater
- Sludge to Landfill or Field Applied
- Manure
- Recycle Water to Operations
- Surplus Electricity to Grid
- Steam
- Electricity
- Exhaust (NOx)
- Startup Natural Gas Electricity
- FUEL CELL
- HRSG

**Integrated Feed Lot/Dry Mill Ethanol Plant (Fuel Cell Integration)**
- Ethanol
- Beef
- Biogas
- Manure
- Sludge
- Surplus Electricity
- Startup Natural Gas Electricity
- Electric Power
- Fuel Cell Integration for CHP in Biofuel Production
FC Integration for CHP in Biofuel Production

GHG Contributions

- Startup
- Natural Gas
- Electricity

Exhaust (NOx)

CO2 Exhaust or Recovery

Ethanol

Dry Mill Ethanol Plant with DWG Digestion (Current)

Ethanol Plant

- Distillers Grains

- Process Wastewater

Boiler

COGEN

- Steam
- Electricity

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

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Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

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Steam

Electricity

Boiler

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Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

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Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

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Boiler

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Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

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Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid

FC Integration for CHP in Biofuel Production

Gas

Electricity

COGEN

Steam

Electricity

Boiler

COGEN

Surplus Electricity to Grid

Biogas Feed to Boiler

Makeup Water

Anaerobic Digester (large)

Sludge to Landfill or Field Applied

Surplus Electricity to Grid
FC Integration for CHP in Biofuel Production

Dry Mill Ethanol Plant with DWG Digestion (Fuel Cell Integration)

GHG Contributions

- Startup Natural Gas Electricity
- Exhaust (NOx)
- CO2 Exhaust or Recovery

Fuel Cell

- Steam
- Electricity
- Surplus Electricity to Grid

Distillers Grains
- Biogas Feed to Boiler

Anaerobic Digester (large)
- Sludge to Landfill or Field Applied
- Makeup Water

Ethanol
- Process Wastewater

Not shown:
- Full heat integration of fuel cell waste heat throughout the biorefinery
Integrated Biorefinery – Biochemical
(Current Envisioned)
FC Integration for CHP in Biofuel Production

Integrated Biorefinery – Biochemical Ethanol (Fuel Cell Integration)

GHG Contributions

- CO2 Exhaust or Recovery
- Biomass Feedstock

Exhaust (NOx)

Fuel Cell

HRSG

Electricity to Grid

Natural Gas Supplement

Water

Dryer Exhaust (VOCs)

Lignin/Sludge Dryer

Solids to Biomass Power Market

Process Wastewater

Water Recycle

Ethanol/RE HCs

Sludge to Dryer

Biogas to Fuel Cell
Integrated Biorefinery – Thermochemical (Current Envisioned)

**Biomass Feedstock**

- Exhaust (NOx)
- Natural Gas (startup)
- Electricity
- Hydrogen* (NG/SMR)

**Gasification or Pyrolysis Plant**

- Tail Gas
- Steam

**HSRG**

- Water

**Biomass Dryer**

- Dryer Exhaust (VOCs)

**Anaerobic Digester**

- Process Wastewater
- Water Recycle
- Sludge to Landfill or Field Applied

**Biofuel/Products**

- Ash

**GHG Contributions**

- Biogas to Flare

*A 60 mmgy pyrolysis to diesel plant will utilize ~20,000 tons of H2/year ~7.5e9 scf/yr

**FC Integration for CHP in Biofuel Production**
Integrated Biorefinery – Thermochemical (Fuel Cell integration)

* A 60 mmgy pyrolysis to diesel plant will utilize ~20,000 tons of H2/year
  ~7.5e9 scf/yr

**Fuel Cell**

**Gasification or Pyrolysis Plant**

- Biomass Feedstock
- Exhaust (NOx)
- Dryer Exhaust (VOCs)
- Tail Gas
  - Steam
  - Hydrogen
  - Electricity

**GHG Contributions**

**Biomass Dryer**

- Biogas to Fuel Cell
- Process Wastewater
- Water Recycle

**Anaerobic Digester**

- Sludge to Landfill or Field Applied
- Biofuel/Products
- Ash

**HRSG**
Concept for an EERE Multi-Program Joint Solicitation:

“Integration and Demonstration of a Biogas/Fuel Cell CHP/Tri-gen System at a Biorefinery”
Concept Basis

An innovative approach to meeting the Administration’s goals in a cost-effective and sustainable manner:

• Integration of stationary combined heat and power (CHP) and Tri-gen fuel cell systems at biorefineries and biofuel production facilities

• Use the biogas generated from anaerobic digestion of biorefinery wastes as a feedstock in stationary combined heat and power (CHP) fuel cell utility systems to further reduce production costs and GHG footprint and LCA

• Potential to utilize hydrogen for catalytic applications

• Capitalize on stranded renewable energy resources for distributed generation, economic development, and environmental stewardship
Potential EERE Program Collaboration

• **FCTP** – sponsorship of Molten Carbonate Fuel Cells with Industrial Partners

• **OBP** - sponsorship of Advanced Biofuel Integrated Biorefinery with Industrial Partners

• **AMO** – sponsorship of biogas/FC retrofit packages for 1st-generation biorefineries and other industrial applications with Industrial Partners

• **VTP** – sponsorship of hydrogen fueling infrastructure with Industrial/Municipal Partner(s)
Goals/Benefits/Outcomes

• Develop optimized biogas production technologies
• Improve anaerobic digestion reactor design and control
• Develop cheaper biogas cleanup, splitting and methane separation technologies
• Fuel cell integration
• Hydrogen production for on-site use or vehicles
• Improvements in waste heat recovery and integration/interface with plant utility systems
• Development of retrofit packages for biorefineries and other industrial applications involving biogas
• Validation of business model and operating cost reductions
Goals/Benefits/Outcomes

- Develop optimized biogas production technologies
- Improve anaerobic digestion reactor design and control
- Develop cheaper biogas cleanup, splitting and methane separation technologies
- Develop markets for fuel cell integration
- Produce hydrogen for on-site use or vehicles
- Improve waste heat recovery systems and integration/interfacing with plant utility systems
- Develop retrofit packages for biorefineries and other industrial applications involving biogas
- Validate the business models and operating cost reductions
Thank you!

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