

BioCycle – Renewable Energy From Organics Recycling

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Upgrading
Renewable
Natural Gas to
Pipeline Quality

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Outline

- Biogas Properties
- Western Wisconsin Natural Gas Dairy Basin Biogas Collection
- Gas Technology Institute Report (9/30/09)
- H₂S and CO₂ Removal Systems
- Water Scrubbing – A&B Process



Biogas Composition Issues

- Hydrogen sulfide and carbon dioxide - corrosive to pipeline infrastructure
- Dairy waste - copper sulfate or residual antibiotics
- Agricultural waste - pesticide residue
- Municipal - heavy organics or heavy metals
- Landfills - wide variety of organics and inorganics

Sources of RNG

- RNG is most economically supplied from large sources of anaerobic digestion:
 - Landfills with ≥ 2.5 million m³ waste-in-place & LFG collection systems
 - Dairy farms with ≥ 500 head; swine farms with ≥ 2000 head
 - Wastewater treatment (WWWT) plants serving $\geq 50,000$ people (≥ 5 MMGPD inflow)
- Vast majority of operational projects produce electricity
- Nearly half of landfill market now recovers biogas, ~2% of livestock, 10% of WWWT

Source United States Department Of Energy 2009



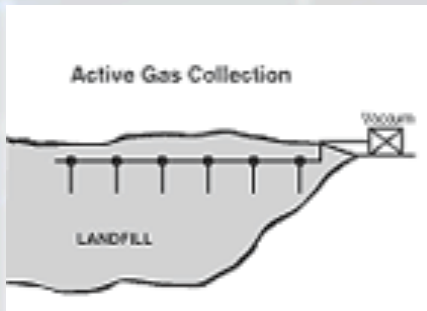
Biogas Basin Concept



**Agricultural
Anaerobic
Digester(s)**

Biogas Gathering Pipeline

**Municipal
&/or
Industrial
Digester(s)**



**Landfill Gas Collection &
Management**

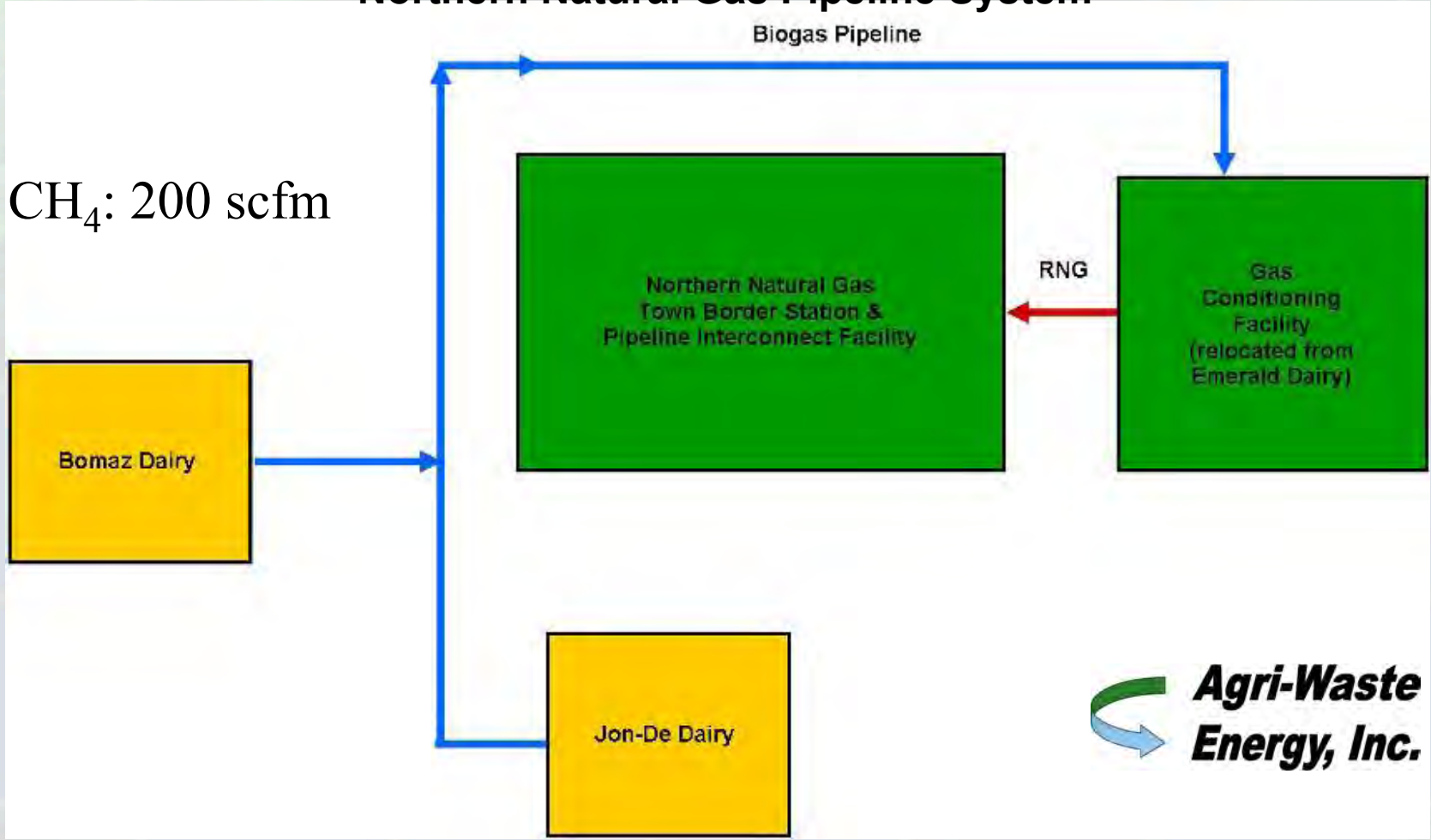
**Gas
Conditioning
Facility (GCF)**

To Natural Gas Pipeline



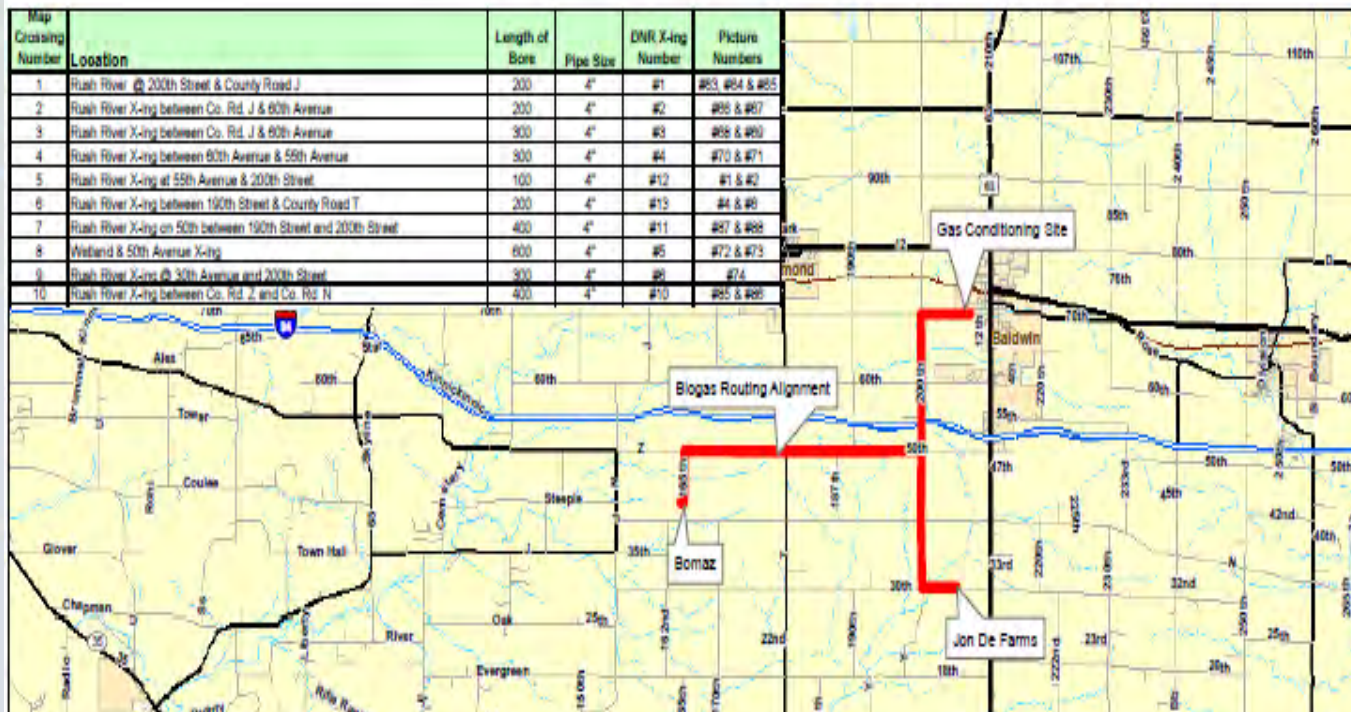
Western Wisconsin Natural Gas Dairy Basin Biogas Collection from Dairy Farms

Conditioning of Biogas to create Renewable Natural Gas for delivery to Northern Natural Gas Pipeline System



 **Agri-Waste Energy, Inc.**

AGRI-WASTE ENERGY LOW PRESSURE BIOGAS ROUTING BALDWIN, WISCONSIN



Page Index
 G1 - Cover Sheet
 C1 - Site Plan and Details
 C2 - Biorefinery to 200th St
 C3 - Co Rd J to 60th Ave
 C4 - 60th Ave to 50th Ave
 C5 - 50th Ave to Co Rd N
 C6 - Co Rd N to 30th Ave
 C7 - 200th St to 190th St
 C8 - 190th St to Co Rd T
 C9 - Co Rd T to 165th St
 C10 - Co Rd Z to Co Rd N
 C11 Gas Well Detail

7.5 mile of 4" MDPE



Gas Conditioning Commercialization: Relocate GCF adjacent to NNG Pipeline Interconnect



*Pipeline Quality
Biomethane: North
American Guidance
Document for
Introduction of
Dairy Waste
Derived
Biomethane into
Existing Natural
Gas Networks*



TASK 1 FINAL REPORT

GTI PROJECT NUMBER 20614

**Technology Investigation, Assessment, and
Analysis**

Project Period:
October 2007 through June 2008

Final Report Issued:
September 30, 2009

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Who Defines BioMethane

- Methane is methane – CH₄
- No universal definition of trace impurities allowed
- Europe vs. United States minimum energy injection standards
 - Switzerland 96% methane
 - France 34.2MJ/nm³ HHV – 87%
 - Sweden 11kWh/nm³ LHV*
 - Germany 87% methane
 - British-Columbia 36MJ/nm³ HHV (95.5% methane)
 - Michigan 93.5% methane

*100% methane (CH₄) LHV is 9.97kWh/nm³



Pipeline Quality Gas Tariffs

- The quality of geologically-derived natural gas is specified in gas transportation tariffs, as required by the Federal Energy Regulatory Commission (FERC).
- These specifications can vary by region and by individual tariff.
- Biomethane generated through anaerobic digestion of waste biomass is not sufficiently characterized by these tariff provisions

FERC Tariff Standards

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Gas Property	Value	% Respondents
Water Content (lb./MMscf)	=3	0.64%
	=4	13.03%
	=5	15.38%
	=6	3.21%
	=7	64.10%
Maximum Heating Value (Btu/scf)	≤1018	3.30%
	1051-1150	73.74%
	1151-1250	21.21%
	≥1600	1.01%
Minimum Heating Value (Btu/scf)	≤900	1.18%
	926-950	38.82%
	951-1000	59.41%
	≥1100	0.59%
Maximum Temperature (°F)	≤80	0.68%
	100-119	10.14%
	120-128	87.84%
	≥129	1.35%
Minimum Temperature (°F)	≤20	15.79%
	26-35	10.53%
	36-50	69.74%
	≥65	2.63%
Hydrogen Sulfide-H ₂ S (grains / 100 scf)	0.01-0.09	0.57%
	0.20-0.25	66.67%

FERC Tariff Standards

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September 30, 2009

Hydrogen Sulfide (grains / 100 scf)	0.26-0.50	8.05%
	0.75-1.0	22.99%
	≥1.1	1.68%
Total Sulfur Compounds, as sulfur (grains / 100 scf)	≤1	7.6%
	1.1-5.0	25.73%
	5.1-10	14.04%
	≥20	52.05%
Hydrogen (%)	0.01-0.05	90.91%
	0.051-0.1	9.09%
Oxygen - O ₂ (%)	0.0001-0.001	17.76%
	0.0011-0.005	5.26%
	0.011-0.1	7.24%
	0.11-0.2	40.79%
	0.21-0.5	15.13%
	0.51-1.0	13.82%
Nitrogen - N ₂ (%)	≤1.0	1.85%
	1.0-1.9	3.70%
	2.0-2.9	12.96%
	3.0-3.9	72.22%
	≥4.0	9.26%
Carbon Dioxide - CO ₂ (%)	.001-.0019	0.70%
	1.0-1.9	9.86%
	2.0-2.9	50.70%
	3.0-3.9	38.03%
	≥4.0	0.7%

Composition of Raw Biogas vs. Pipeline Quality Gas.

	Compound	Biogas ^[57]	Representative Pipeline Quality Natural Gas ^[59]
CH ₄	Methane	54 - 70%	75% +
CO ₂	Carbon Dioxide	27 - 45%	3 - 4%
N ₂	Nitrogen	0.5 - 3%	3 - 4%
H ₂	Hydrogen	1 - 10%	0
CO	Carbon Monoxide	0 - 0.1%	Not specified
O ₂	Oxygen	0 - 0.1% 0 - 1000 ppm	0.2 - 1.0 ppmv
H ₂ S	Hydrogen Sulfide	600 - 7000+ ppm ^[56] 37.5 - 437.5 gr/100scf	0.25 - 1.0 gr/100scf
	Total Sulfur	Not specified	5 - 20 gr/100scf
	Trace elements, amines, non-methane volatile organic carbons (NMVOC)[56], Halocarbons[56]	Trace amounts	Not Specified

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Three Major Levels of Upgrades for RNG

- On site Boiler
 - Moisture
- Onsite Genset
 - Moisture and H₂S
- Pipeline Quality
 - Moisture and H₂S
 - O₂, N₂, NH₃, CO₂
 - BTU to High BTU Fuel



Making the Technology Choice

All technologies Work – Separated by:

- Capital investment
- Percent of methane recovery
 - Tail gas composition
 - Maintenance costs
- Parasitic load – Operating costs



H₂S & CO₂
Removal
Processes

Absorption

Membrane
Permeation

Biological

Adsorption

*Water
Removal
Process*

Dry

Liquid

Physical
Solvent

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Absorption

Dry

Liquid

Physical
Solvent

Iron Oxides
*(Iron Sponge,
Sulfa Treat,
Sulfur-Rite)*

Zinc Oxides
(Puraspec)

Alkaline
Solids
(Sofnolime)

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Iron Oxides

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	Iron Sponge	SulfaTreat®	Sulfur-Rite®	SULFA-BIND®
Substrate containing iron oxide material	Wood chips	Proprietary granules	Ceramic base	Calcinated, inorganic, natural material
Coated or Impregnated	Impregnated	Coated	Impregnated	Coated
Primary Constituent	Fe ₂ O ₃ , Fe ₃ O ₄	Fe ₂ O ₃ , Fe ₃ O ₄	Not known	Fe(OH) ₃
Regenerable?	Y, up to 3x	N	N	Y, up to 15x
Pyrophoric?	Y	N	N	N
H ₂ S Removed per Kilogram of Product	2.5 kg H ₂ S / kg Fe ₂ O ₃	0.55 – 0.72 kg H ₂ S / kg Fe ₂ O ₃	Not known	0.5 kg H ₂ S / kg media
Spent Media Hazardous?	Y	N	N	N
Reduction of H ₂ S	3600 ppm to < 1 ppm	Not known	Down to < 1 ppm	60 - 100 ppm to < 0.2 ppm
Cost per removed kg of H ₂ S	\$0.35 – 1.55	\$4.85 – 5.00	\$7.95 – 8.50	\$2.90 – 3.00
Annual Product Cost? (100 ppm – 400 ppm loading) [53]	\$250 – 4,300	\$3,400 – 13,500	\$5,560 – 23,840	\$2,050 – \$8,290

Technical Options for Cleaning Biogas

- Pressure Swing Absorption (PSA or mole sieve)
- Amine Scrubbing
- Membrane Separation
- Cryogenic Separation
- ***Water Scrubbing***

Water Scrubbing

Henrys Constants for Various Gases in Water at 70 deg F

Gas	Henrys Constant (x107)	Solubility ratio (to methane)
Nitrogen	150	0.4
Hydrogen	175	0.5
Oxygen	250	0.7
Methane	350	1
Carbon dioxide	8000	23
Hydrogen sulfide	20000	57

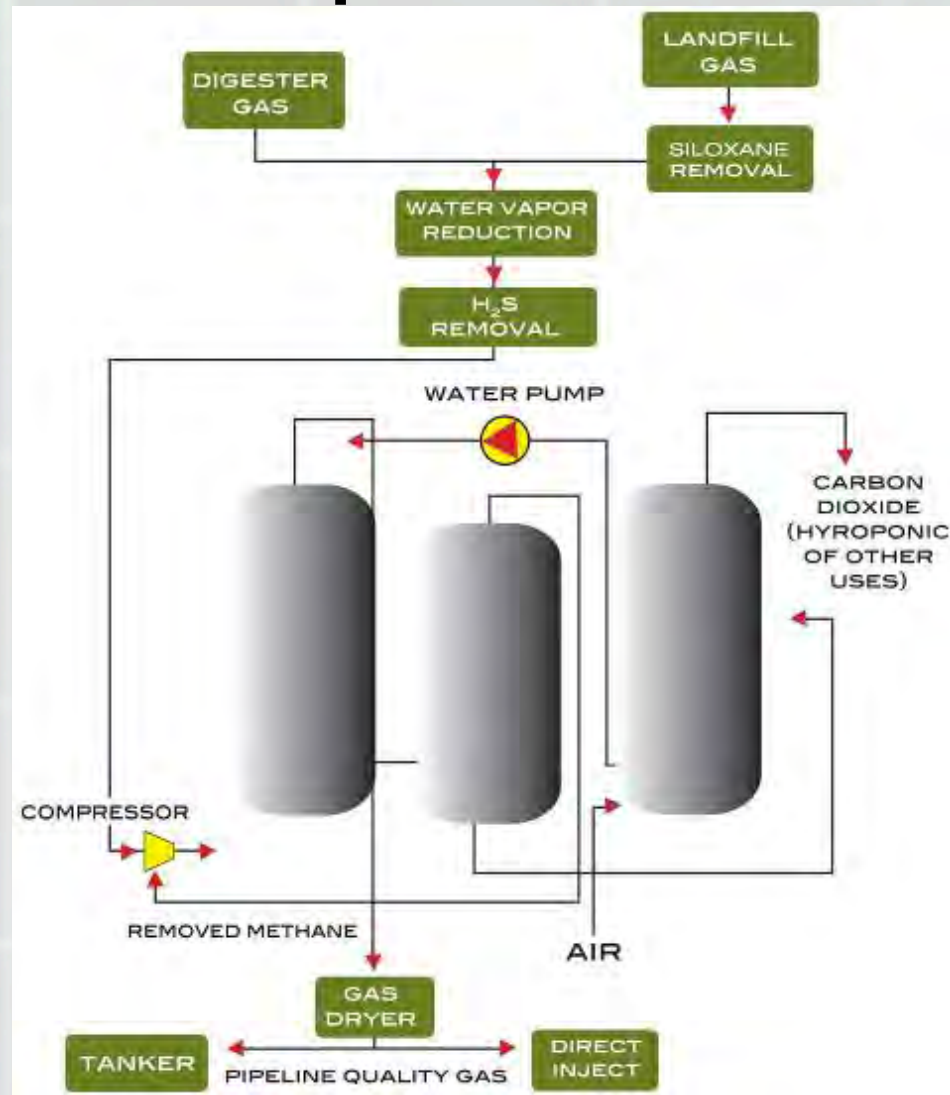
- CO₂ is approximately 23 times more soluble in water compared to CH₄
- N₂, H₂ and O₂ are less soluble than CH₄ therefore will not be separated from CH₄ by water scrubbing

Why Water Scrubbing

- Old well understood approach
- Greater per cent age capture of methane than single pass PSA or membrane
- Tail gas is industrial quality CO₂
- Much lower operating pressures than Amine or cryogenic systems
- No flammable tail gas



Basic System Operation



A&B's Improvements on Prior Art

- Remove H_2S prior to water scrubbing the CO_2 – eliminate sulfur buildup/corrosion
- Close loop all but eliminates water consumption
- Ability to impact O_2 levels required in the majority of North American Tariffs



Second Value Stream

Tail gas stream of Carbon Dioxide

- Green House
- Irrigation
- Algae



Why Upgrade RNG?

\$ Site Situational Economics \$

- Barriers to electricity generation
- Unable to Use Heat from Combined Heat and Power
- Unable to Consume all of the Gas on Site
 - Availability Niche Market
- Premium on Green Attributes of Biomethane

Review your site ROI



Positives for Biomethane

- Storable Green Energy Source
- Vehicle Fuel or Pipeline Portable
- Infrastructure Exists
- Can Help Electrical Utilities Meet Mandates Using Existing Equipment

Challenges of BioMethane

- Currently Lacks Same Federal Economic Incentives as Does Solar and Wind
- Bills Pending in Congress Could Radically Change Production Landscape
- Misunderstandings of Product and its Quality

Questions



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