Environmental Issues related to Flaring of Natural Gas

- Each year, 260 billion cubic meters of flare gas is burned in an effort to reduce costs as well as increase efficiency of the well
- Emits pollutants such as marticulate matter, ash, SOx, and NOx
- Produces 4.9 billion tons of CO2 emissions annually
- Heat damage to ecosystems and agriculture
- Numerous effects on human health
- Flare gas represents a wasted energy source that has economic value

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Flare Gas Alternatives:

Animal Feed Through Methane Oxidation

Goal: To create the most efficient and cost effective flare gas mitigation system through the growth and treatment of methanotrophs.

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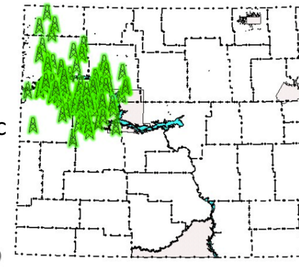
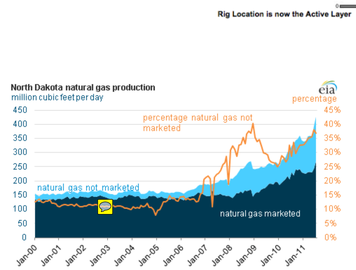
Flare Gas Volumes and Composition

Bakken Oil Fields, ND
Numerous wells within a 100 miles
Calculated 3.650 million cubic feet flared / year / well
Assumed flare gas chemical composition:

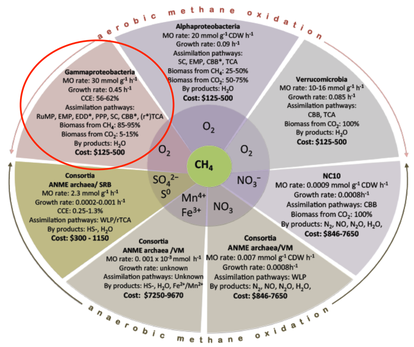


Methane	95.00%
Ethane	2.50%
Propane	0.20%
Butane	0.60%
High Alkanes (C5, C10)	0.02%
Nitrogen	1.60%
Carbon Dioxide	0.70%
Hydrogen Sulfide	Trace
Water	Trace



Types of Methane Oxidation

- Bacteria v. Archaea: anaerobic and aerobic methane oxidation
- Aerobic oxidation is more well known
- Three types of aerobic methanotrophs: I, II, X
- *Methylococcus Capsulatus* (Type X, Gammaproteobacteria)
  - This species has "shown high efficiency in production of bacterial protein from methane" (Bothe)
- *M. capsulatus* cannot survive in pure natural gas
- Mixed culture of 80% MC, 19% DB3, 0.3% DB4, and 0.5% DB5
- Heterotrophic strains of that remove acidic contaminants



Growth and Treatment

GROWTH: one kilogram of dry biomass using 2 cubic meters of methane

Custom loop fermenter (Overland)
Ammonia, oxygen, and a mineral solution additives

TREATMENT: centrifuge, ultra-filtered, heat inactivated, spray dried

Dietary Impacts

POSITIVE OUTCOMES

- Improved digestibility of amino acids and lean-fat ratio in broiler chickens
- Increased weight gain in salmon and broiler chickens
- Improved pig meat storage quality
- The following percentages of bacterial meal replacing dietary protein (soybean meal and fishmeal) showed no impairment in animal growth performance:
- Pigs 41%, Broiler Chickens 15%, *Mink 20%, *Blue Fox 30%, *Atlantic Salmon 52%, *Rainbow Trout 38%, *Atlantic Halibut 13% ('*' Carnivorous)

CONSIDERATIONS and NEEDED RESEARCH

- Production efficiency
- Improved nutritional quality
- Alterations for specific animal preferences

Environmental Benefits from Feed Replacement

Soybean Meal:

- Freshwater and groundwater contamination
- Conversion of natural flora and fauna
- Soil erosion and contamination
- Threat to food security
- Water intensive

Fish Meal:

- Unsustainable harvest levels (overfishing)
- Marine habitat destruction
- Seawater contamination
- Energy intensive
- Scarce raw material
- Spoilage

Why Animal Feed?

- Formaldehyde Production
  - Harvesting formaldehyde as an intermediary of the RuMP/serine cycles
  - Too hard to isolate and produce at appreciable amounts
- Biomass Fuel
  - Using dried bacteria pellets as fuel source
  - Active dehydration too energy intensive to be feasible
- Bioplastics
  - Cultivating methanotrophs for polyhydroxybutyrate (PHB) production
  - Will become feasible once an appropriate biocatalyst is developed

Economic Analysis

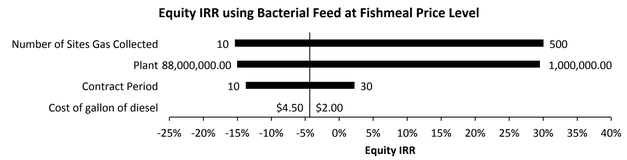
- Transport CNG from local well heads to a centralized biological processing plant
- Sell bacterial meal to farmers for less than the cost of soybean meal and fishmeal

Global Commodity Prices (10/2014)

- Soybean Meal: 459$/mt
- Fishmeal: 1689$/mt

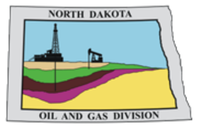
Equity IRR

	Corresponding Input Value			Output Value				Percent	
Input Variable	Low Output	Base Case	High Output	Low	Base	High	Swing	Swing^2	>0% IRR given other bases
Number of Sites Gas	10	30	500	-15%	-4%	30%	45%	47.9%	44
Plant	$88,000,000	$30,000,000	$1,000,000	-15%	-4%	30%	45%	46.1%	$20,452,202
Contract Period	10	15	30	-14%	-4%	2%	16%	5.9%	21.00
Cost of gallon of diesel	$ 4.50	$ 2.68	$2.00	-4%	-4%	-4%	0%	0.0%	N/A



North Dakota Industrial Commission Goals:

- Cut flaring to 5-10% of production volumes by Q4 2020 from current ~22%
- Improve communication between producers and midstream companies
- Require detailed gas capture plans to obtain drilling permits



Conclusions

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We would like to acknowledge the information shared with and help received from the other two Feasible Alternatives for Flare gas sub-teams