CLEAN AIR TASK FORCE

Putting Out the Fire:

Proven Technologies to Improve Utilization of Associated Gas from Tight Oil Formations

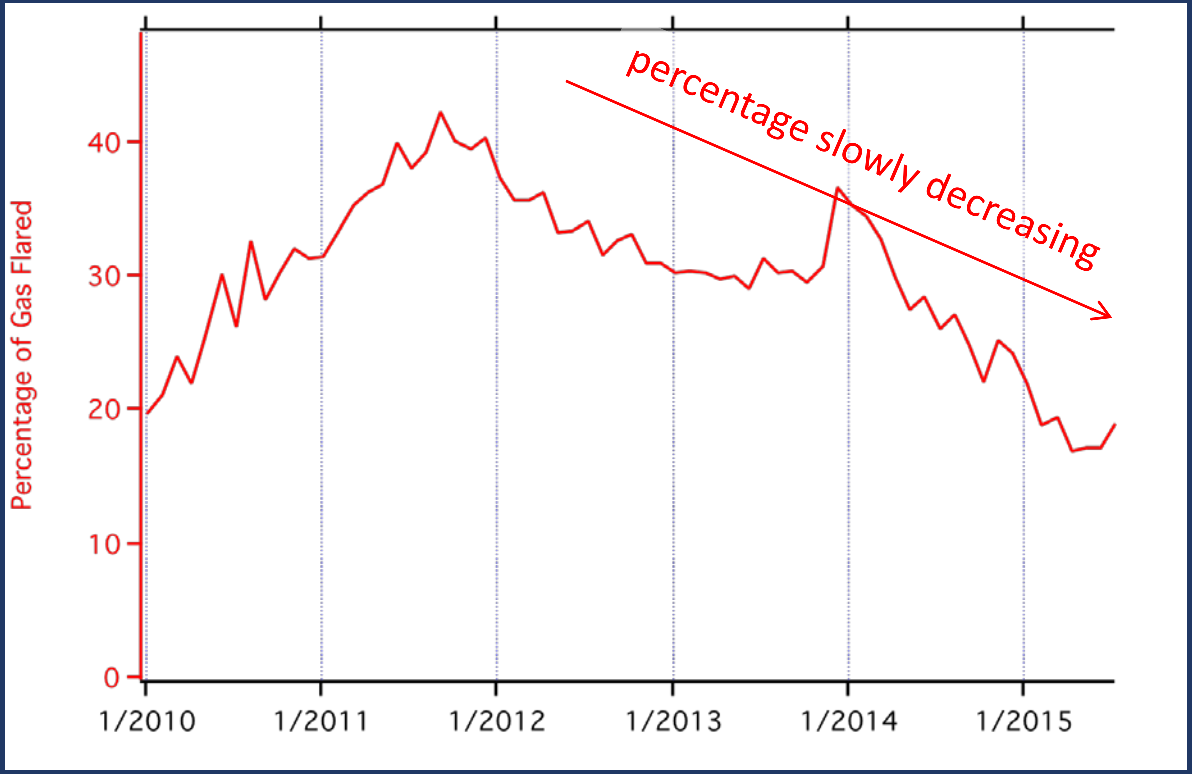
LESLEY FLEISCHMAN

RESEARCH ASSOCIATE

NOVEMBER 17, 2015

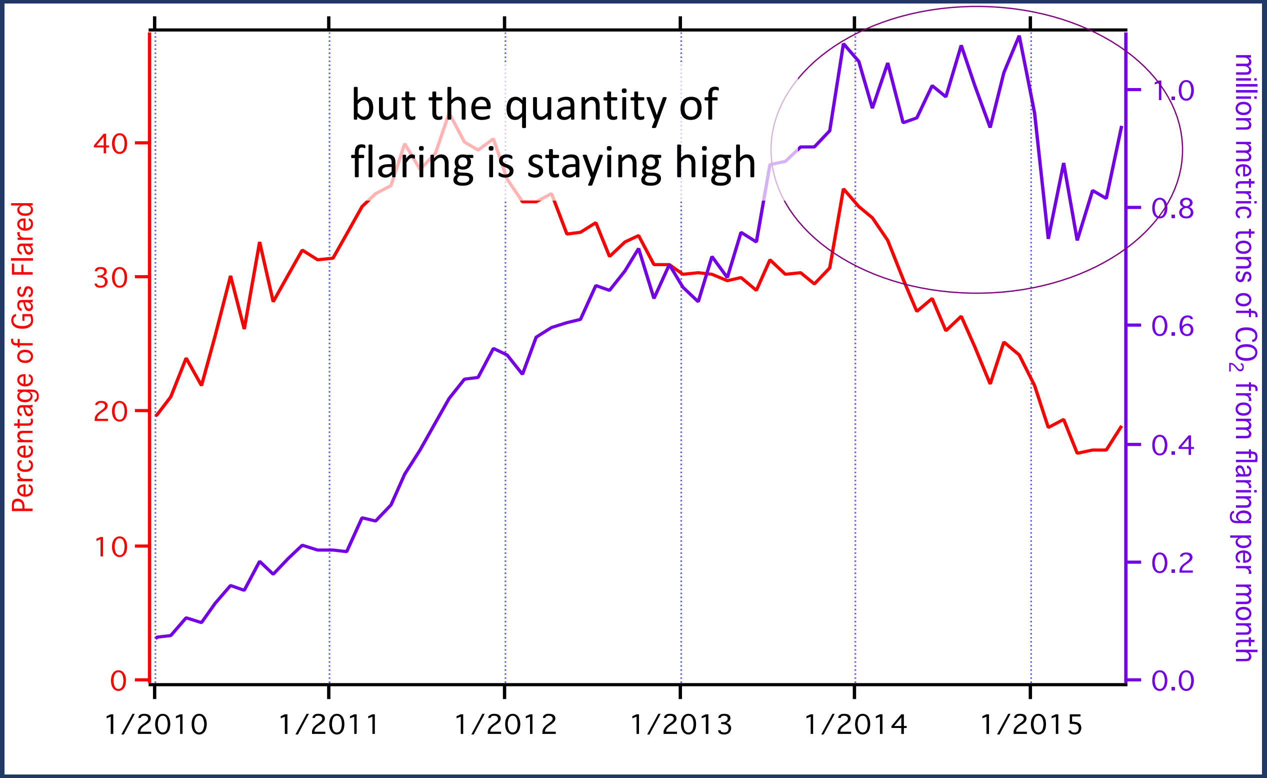
Flaring of associated gas from tight oil formations pollutes and wastes energy resources, delivering no energy benefit to society

Flaring from the Bakken Formation in N Dakota



Flaring of associated gas from tight oil formations pollutes and wastes energy resources, delivering no energy benefit to society

Flaring from the Bakken Formation in N Dakota

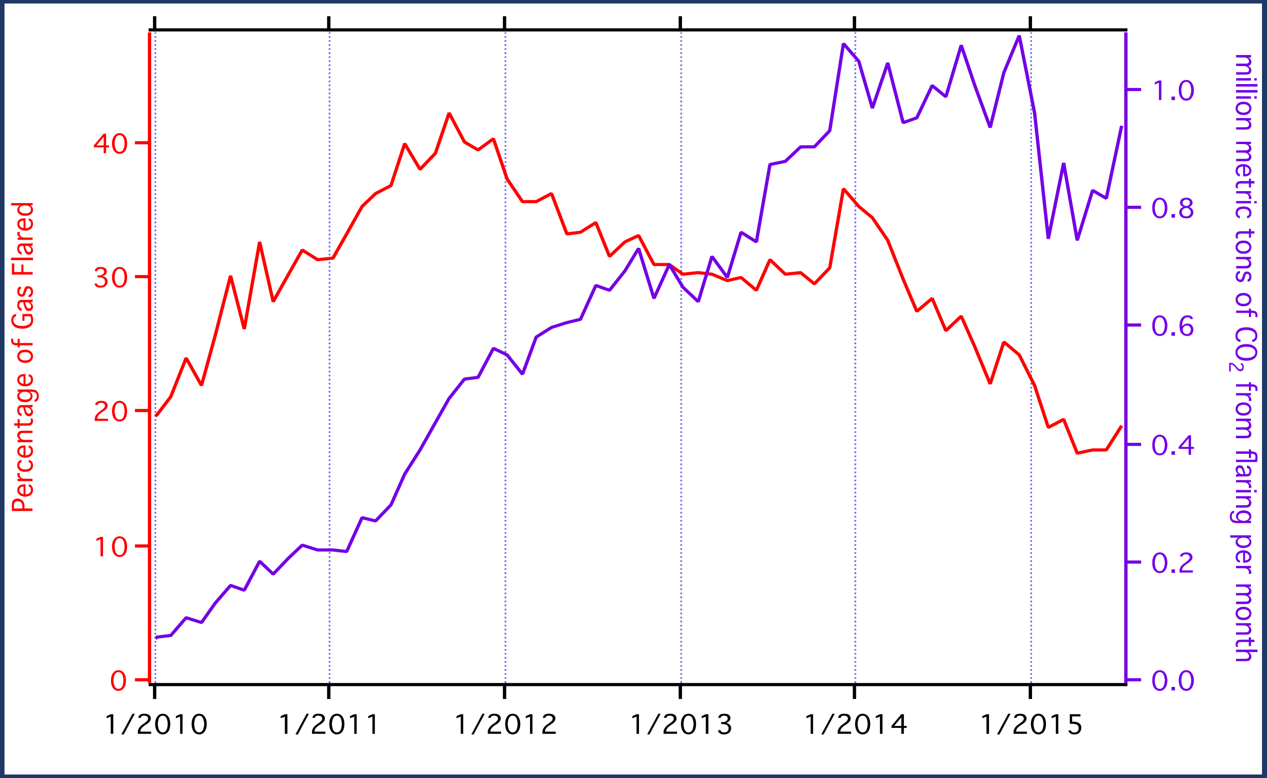


Flaring from the Bakken:

- Produces as much CO_2 as three coal-fired power plants
- Consumes enough natural gas to heat ~1.7 million homes

Flaring of associated gas from tight oil formations pollutes and wastes energy resources, delivering no energy benefit to society

Flaring from the Bakken Formation in N Dakota



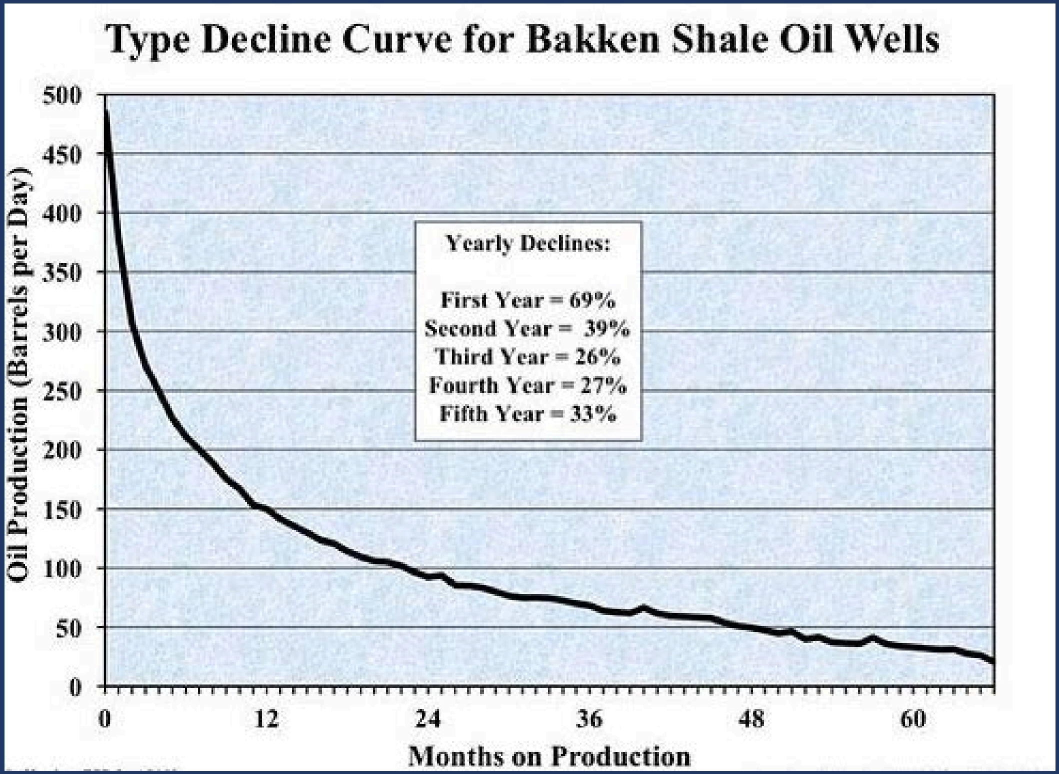
"Traditional" gas gathering systems bring the vast majority of non-flared gas to market.

When pipelines are not available at tight oil wells, or the pipelines can't take all the gas, what other technologies can utilize the associated gas?

Question:

Are there mature technologies, beyond gas gathering systems, that are proven ways to utilize associated gas in tight oil plays?

- Tight oil presents specific challenges to gas utilization:
  - High gas-to-oil ratios
  - Well production rates rapidly change over hours / days / months; wells produce half of their lifetime gas in their first two years



- Combined with classic rush dynamics & permissive regulation, utilization of the gas from tight oil formations (Bakken, Eagle Ford) has been poor.

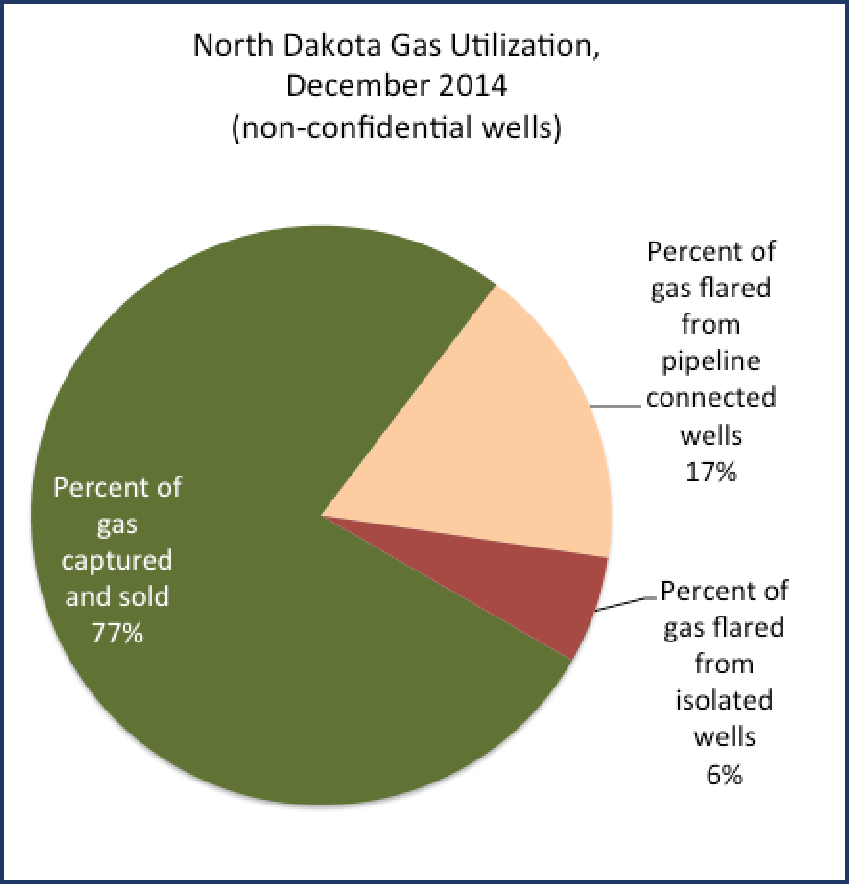
Carbon Limits Flaring Study

- Previous reports describing technologies and approaches to utilize stranded gas have focused on conventional oil fields.

- *Clean Air Task Force worked with Carbon Limits, a consultancy (based in Norway) with extensive experience in greenhouse gas emissions quantification and reduction strategies for the oil and gas industries, to assess technologies for utilizing associated gas specifically from tight oil formations.*

Flaring occurs for three main reasons

1. Emergencies / Upset conditions / Mishaps
2. Lack of gas utilization capacity – isolated well flaring
3. Lack of gas utilization capacity – pipeline-connected flaring



Both isolated well flaring and pipeline connected flaring are significant in tight oil basins in the U.S.

The technologies highlighted in this report address both isolated well and pipeline-connected well flaring.

Approach

Potential technologies were carefully screened for maturity, appropriate scalability, and portability

Initial Technology Screening

- Mature
  - Deployed commercially in more than one tight oil developments
  - Delivery to site within weeks or months
- Right Sized and Scalable
  - Able to up or down in a modular manner
- Portable
  - Moved to new site within a day or week
  - Dismantled or scaled down once pipeline is in place

Technologies Examined

- Ammonia production
- Compressed natural gas (CNG) trucking
- Gas injection into nearby underground reservoirs
- Gas-to-power – grid
- Gas-to-power – local
- Mini Gas-to-Liquids – Methanol
- Mini Gas-to-Liquids – Fischer Tropsch (synthetic diesel)
- Mini-Liquefied natural gas
- Recovery of natural gas liquids (NGLs)

Commercially Available Technologies

- 3 technologies in-use in tight oil fields & meet screening criteria

  1) Trucking CNG short distances (**CNG Trucking**)
  2) Extracting Natural Gas Liquids from the gas (**NGL Recovery**)
  3) Using the gas for electric power generation (**Gas-to-Power**)

- NGL Recovery and Gas-to-Power technologies are partial solutions, which typically can use some but not all gas at a site.
- These technologies can be paired with one another so that most or all of the gas at a site can be used.
- These technologies can be profitable for well owners and provide a low cost means of pollution abatement for CO_2 and other pollutants, particularly NO_x.

Cost Model Methodology

- Assess the economic and environmental impact of the technologies using a simple cost model.
- The model uses a typical associated gas production profile as an input:
  - A typical well in the Bakken
- Key factors:
  - Gas composition: lean or rich based on data from the Bakken)
  - Number of wells per pad
    - Single well (1 well) and Multiple wells (4 wells) per pad
  - Build size of the gas utilization technology.

Cost Model Results

- The model shows that all three technologies can be deployed profitably, or at low net cost (details in following slides)
- Does not model some important factors that may improve the overall economics of the systems
  - Renting equipment instead of purchasing a single size installation
  - Using technologies in tandem.
- Since these technologies reduce pollution by large amounts, the abatement cost of deploying them (net cost per ton of avoided pollution) is negative or quite low.

Natural Gas Liquids (NGL) Recovery

- NGLs removed from associated gas with equipment on wellpads and trucked away for sale.
- NGL systems work best with rich associated gas and are suitable for both single and multi-well pads.

- The residue dry gas remaining after NGL recovery can be gathered with pipelines, captured with CNG trucking, or used for power generation.
- In general, gathering and other gas capture & utilization approaches work better with drier gas, though contractual arrangements may hinder use of NGL recovery at wells hooked to pipelines.

Natural Gas Liquids (NGL) Recovery (cont.)

- Systems that can capture C5 and heavier hydrocarbons are simple and inexpensive, but reduce flaring a limited amount.
- Technologies that also capture C3 and C4 capture a larger portion of the input gas and result in less flaring. They require a larger initial investment, but smaller systems are profitable or low costs.

	Gas Composition	Pad Size	Flare Reduction	CO_2e Reduction (flare only)	Abatement Cost ($/ton CO_2e)
NGL Recovery (C5+)	Rich	Single Well	4%	5%	***$250***
		Multi Well	4% to 5%	5% to 6%	-$21 to $0
NGL Recovery (C3+)		Single Well	14% to 18%	15% to 19%	-$23 to $0
		Multi Well	18% to 21%	19% to 22%	-$89 to $0

*Reflects cost in ND, where heavy natural gas liquids must be stored and trucked to plant.

- Higher rates of flare reduction can be achieved by coupling NGL recovery with other technologies.

Power Generation (Local)

- A variety of technologies are available for power generation, for local loads, here we look at reciprocating engines and gas turbines.
- Local load systems work best when using lean associated gas, including the residual gas after NGL recovery.
  - Added benefit: reduce expense (and emissions) associated with trucking in diesel fuel for on-site generators.
- The cost estimates for local loads shown below are for equipment sized to match the power demand on the well-site (we did not model costs for grid level solutions).

	Gas Composition	Pad Size	Flare Reduction	CO_2 Reduction (including flare and diesel substitution)	Abatement Cost ($/ton CO_2)
Reciprocating Engine	Lean	Single Well	18%	33%	-$165
		Multi Well	19%	36%	-$194
Gas Turbine		Single Well	21%	31%	-$33
		Multi Well	22%	33%	-$54

Power Generation (Grid)

- Grid level gas-to-power works best at sites with lean associated gas and is suitable for large multi-well pad developments in areas with small well spacing.

- This option should be considered if a number of wells are distant from gas gathering systems.

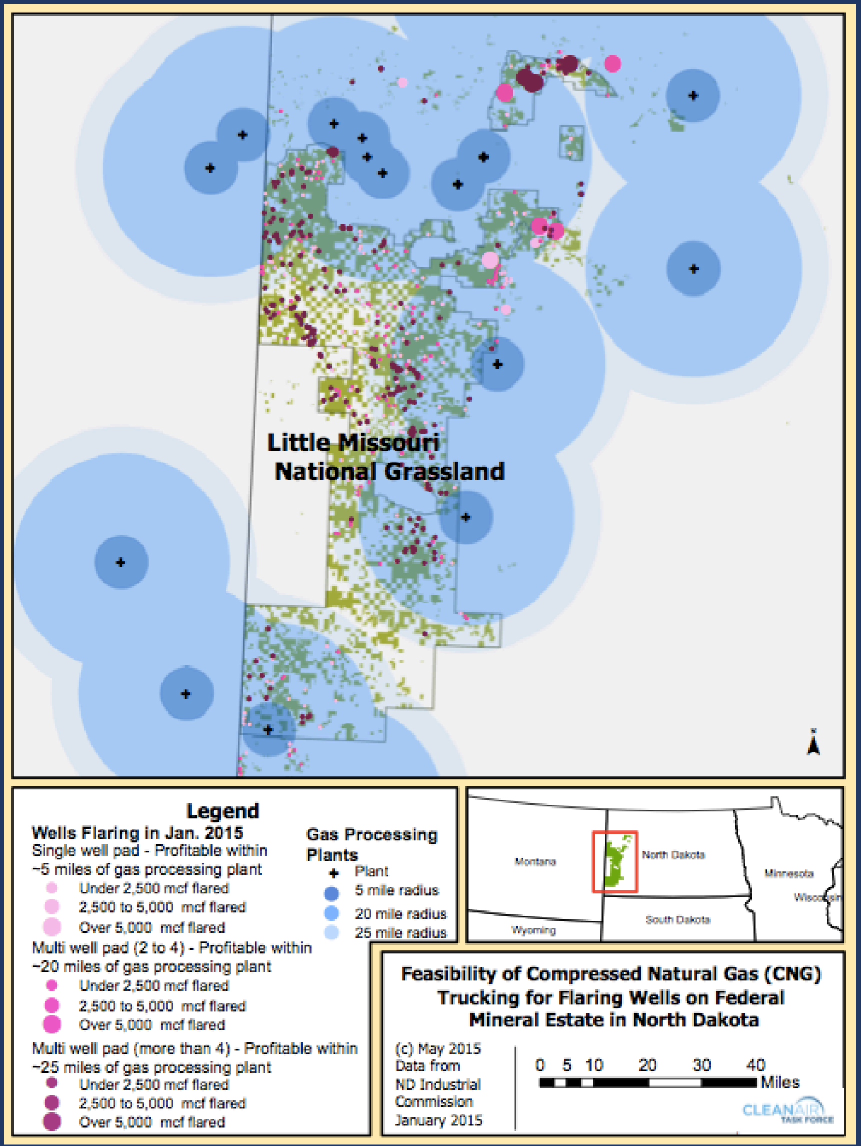
CNG for transport to midstream systems

- Gas can be compressed at the well pad and trucked to a gas processing plant.
- Can be scaled up to utilize nearly all of the natural gas produced, and the CO_2 abatement cost is negative in all scenarios we modeled.
- Feasible at wells relatively close to a processing plant or other point where gas can be put into the pipeline system (20-25 miles or less).
- Cost estimates range between a smaller design size that maximizes profitability of the deployment, and a somewhat larger size that maximizes flare reduction (while remaining profitable).

	Gas Composition	Pad Size	Flare Reduction	CO_2e Reduction (including compressor emissions)	Abatement Cost ($/ton CO_2e)
CNG Trucking	Lean	Single Well	91% to 97%	65% to 85%	-$26 to $0
		Multi Well	95% to 97%	70% to 85%	-$53 to -$40
	Rich	Single Well	93% to 98%	65% to 85%	-$126 to -$107
		Multi Well	96% to 98%	70% to 85%	-$159 to -$151

*Reflects cost in ND, where natural gas liquids that drop out during compression must be stored and trucked separately.

CNG trucking widely feasible



Jan 2015

- Feasibility of CNG trucking in the Little Missouri National Grassland in western North Dakota
- What portion of flaring is from wells close enough to processing plants for CNG Trucking.
  - Single wells: within 5 miles
  - Small multi-well pads (2-4 wells): within 20 miles
  - Large multi-well pads (5+ wells): within 25 miles
- Within the boundaries of the grassland, at least 89% of gas flared could be trucked to plants.

On the Horizon:
Miniature Gas-To-Methanol for Well Sites

- Methanol is an industrial feedstock manufactured at vast scale from natural gas. Historically, only very large methanol plants have been economic, but new technologies offer promise for miniature methanol plants

- Pilot running in tight oil fields with promising results. Waiting for first commercial deployment.

Flaring as currently occurs in tight oil plays is *not* a failure of technology

- In many oil basins, drilling occurs with ~zero routine flaring (aside from flaring due to emergencies, unexpected conditions, etc.).
- With proper regulation, oil development is planned properly so it does not outpace pipeline capacity.
- Concerns are raised that long-term contracts for land and rigs and the complex process of building pipelines make it impossible to develop wells without some routine flaring.
- This report shows that even in situations where operators cannot get pipelines due to unexpected issues, flexible options exist to ensure that associated gas can be utilized.

Clean Air Task Force

www.catf.us

lfleischman@catf.us

CLEAN AIR TASK FORCE