End-Use Technology Study – An Assessment of Alternative Uses for Associated Gas

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Background

- This was a North Dakota Industrial Commission and U.S. Department of Energy-funded project, with commercial support and cost share from Continental Resources.
- The focus of the study was on flared associated gas in the Williston Basin (primarily produced from the Bakken Formation).
- The intent of the study was to assess the technical viability of technologies utilizing associated gas at locations upstream of traditional gas-processing plants and define economic conditions that would enable commercial deployment.
  - Define unutilized gas resource in the Williston Basin
  - Identify natural gas use options that match quality and quantity of gas
  - Identify distributed-scale gas cleanup technologies
  - Find uses tolerant of moisture or natural gas liquids (NGLs)
  - Assess economic conditions that could lead to viable uses

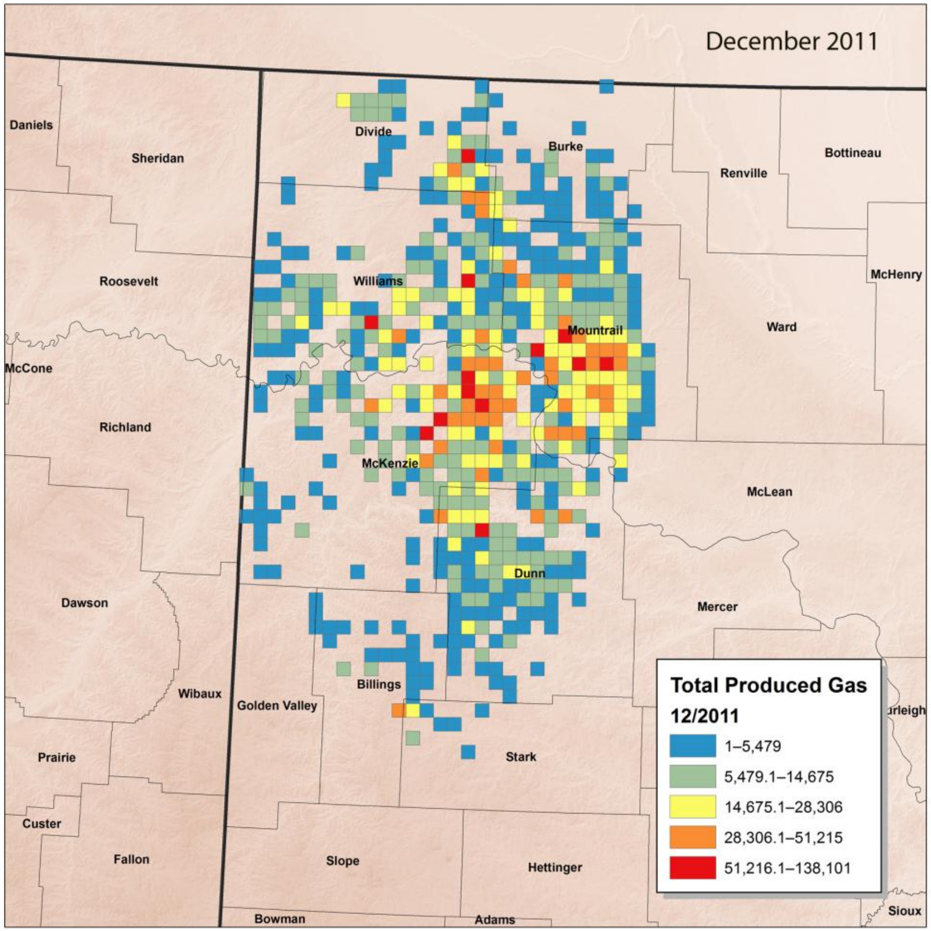
Introduction to ND Oil and Gas Production

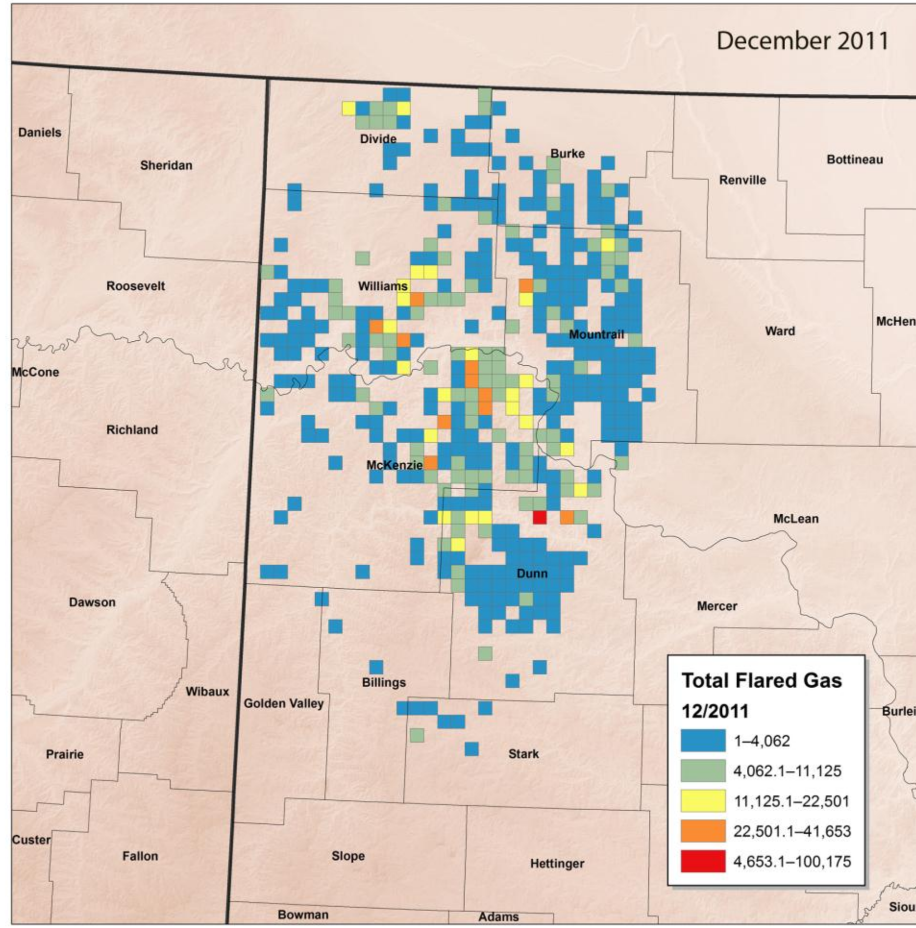
- At the end of 2011:
  - Daily oil production exceeded 500,000 bbl a day
  - Daily gas production exceeded 540,000 Mcf a day
  - Flaring rates exceeded 35%
- As of August 2012:
  - Daily oil production exceeded 700,000 bbl a day
  - Daily gas production exceeded 760,000 Mcf day
  - Flaring rates have been consistently between 30% and 35%

Observations Regarding Flaring

- Current flaring in the Williston Basin is a result of:
  - A rapid increase in oil production
  - Growing but still insufficient intrabasin infrastructure to move rich gas to processing
  - Growing but still limited infrastructure to move dry gas and NGLs to markets outside the state.
- With that said,
  - Forecasts indicate that oil and gas production should stabilize.
  - Industry is investing significant amounts of money to develop infrastructure and processing capabilities.
- The opportunity to capture revenue from flared gas is a moving target.
  - Location-specific (geographic)
  - Time-limited (temporal)

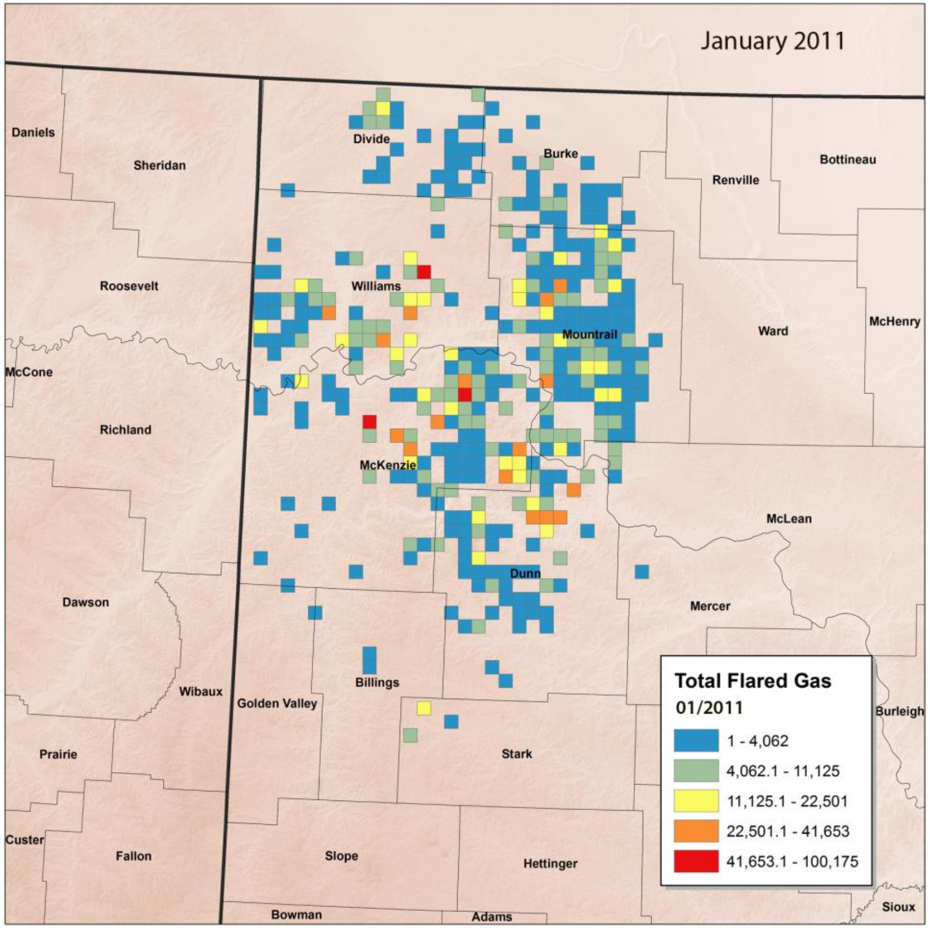
Flaring Occurrences Are Geographic

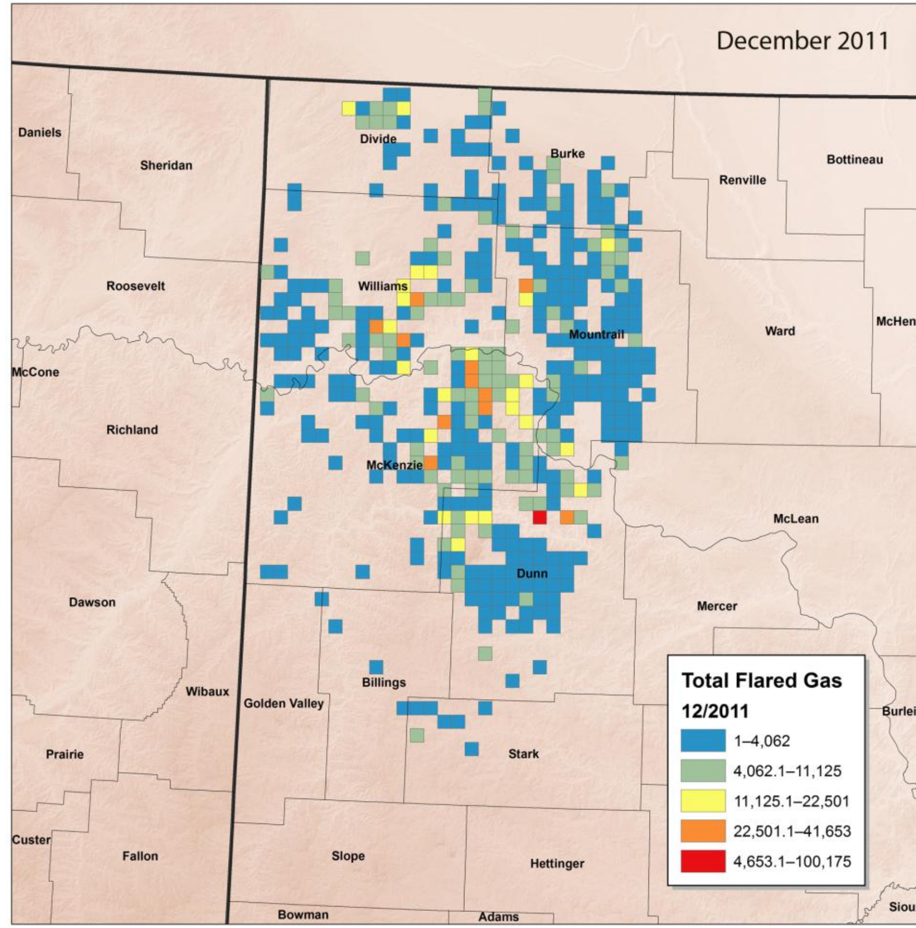




December 2011 Total Produced Gas Versus Total Flared Gas

Flaring Occurrences Are Temporal

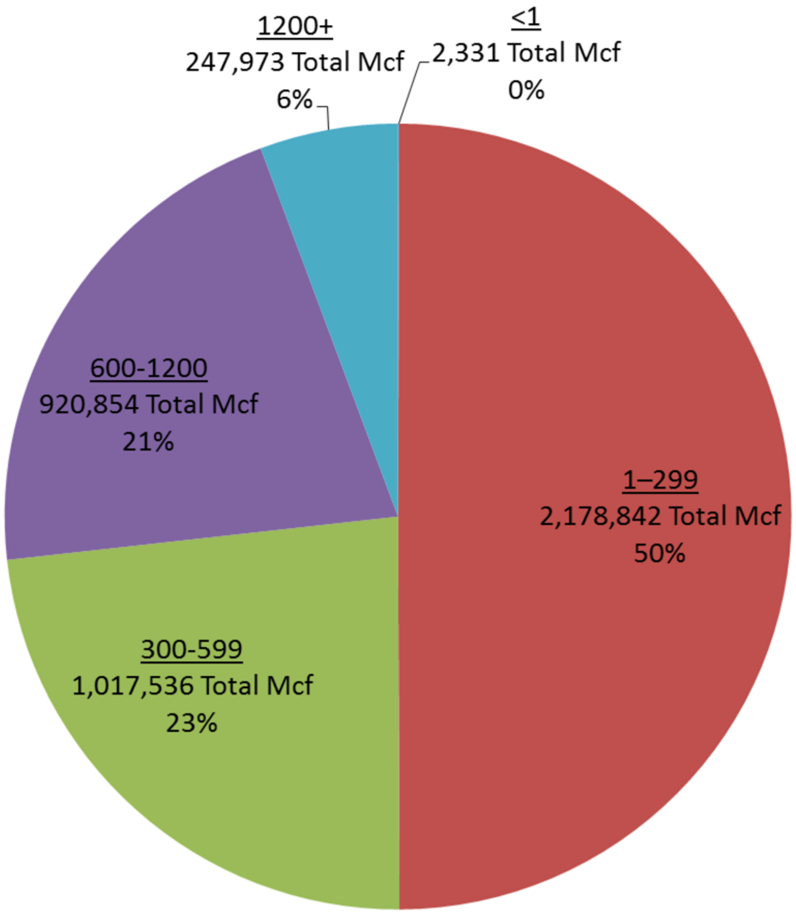




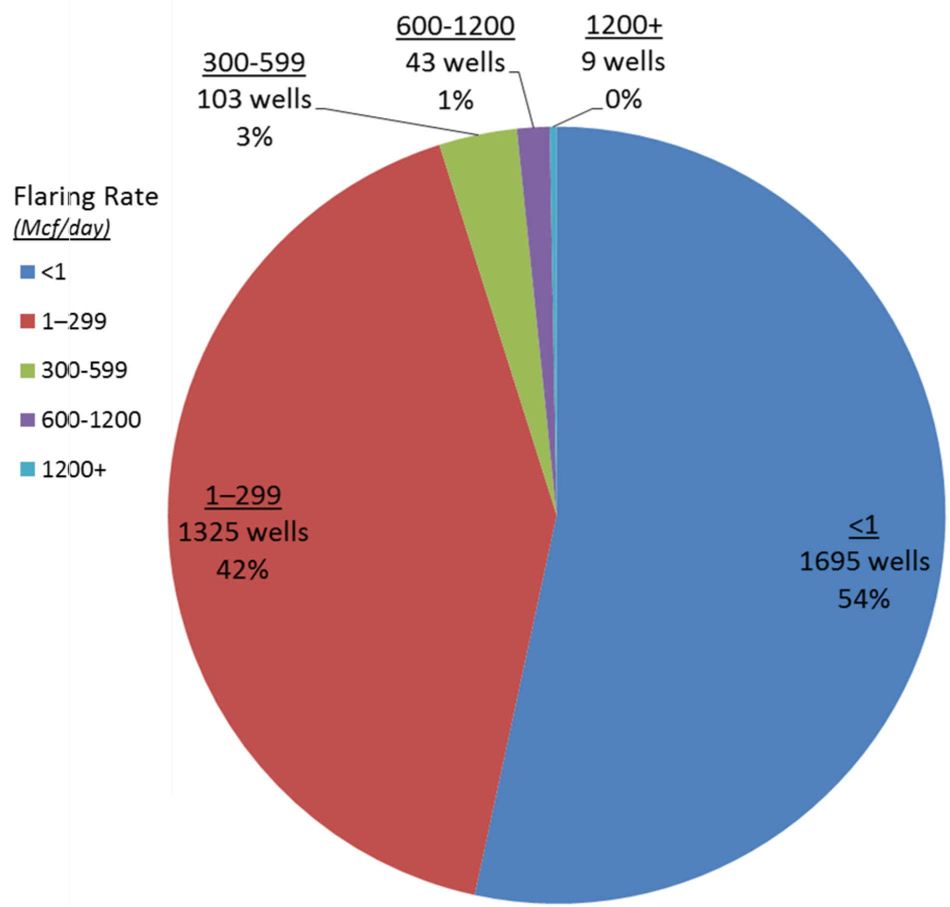
January 2011 Total Flared Gas Versus December 2011 Total Flared Gas

Other Observations

Breakdown By Total Gas Flared, December 2011 Data



Breakdown by Number of Wells, December 2011 Data



Gas Composition Example

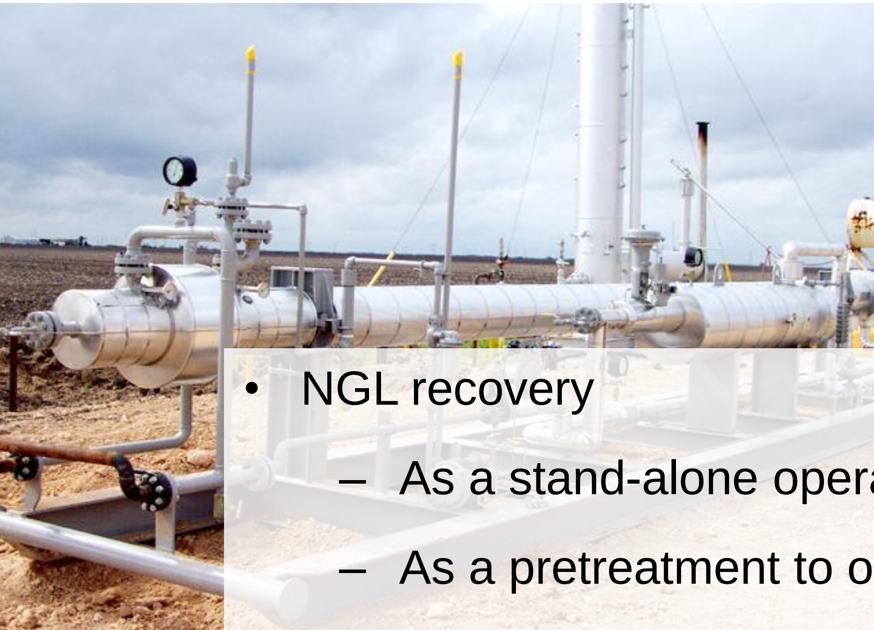
Bakken associated gas is typically low in sulfur and high in NGLs

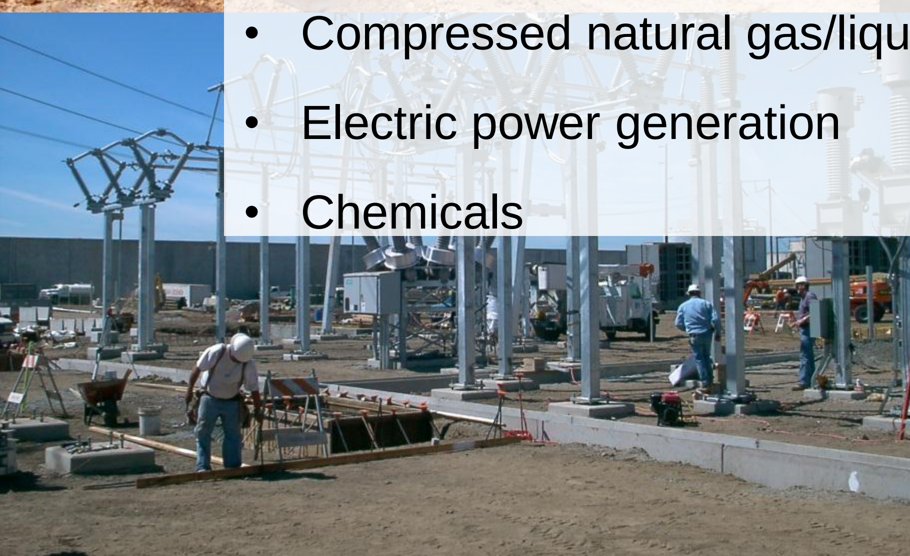
Bakken-Rich Gas Composition

Component	mol%
H_2O (water)	0.02
N_2 (nitrogen)	5.21
CO_2 (carbon dioxide)	0.57
H_2S (hydrogen sulfide)	0.01
C1 (methane)	57.67
C2 (ethane)	19.94
C3 (propane)	11.33
I-C4 (isobutane)	0.97
N-C4 (n-butane)	2.83
I-C5 (isopentane)	0.38
N-C5 (n-pentane)	0.55
C6 (hexane)	0.22
C7	0.09
C8	0.04
C9	0.01
C10–C11	0.00
C12–C15	0.00

Study Focus

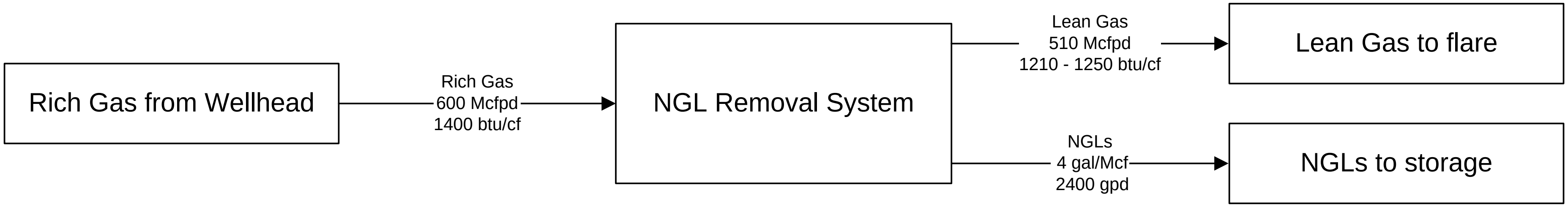
- NGL recovery
  - As a stand-alone operation
  - As a pretreatment to other operations (i.e., power generation)
- Compressed natural gas/liquefied natural gas for vehicles
- Electric power generation
- Chemicals





Small-Scale NGL Recovery

- Rich-gas flow rate from wellhead; average = 300 Mcf/day
- Rich-gas flow rate from wellhead; economic cutoff = 600 Mcf/day
- Rich-gas flow rate from wellhead; design flow = 1000 Mcf/day
- Rich-gas heat content = 1400 btu/cf (10–12 gallons of NGLs)
- Lean-gas flow rate = 85% of rich-gas flow rate
- Lean-gas heat content = 1210–1250 Btu/cf
- NGL recovery rate = 4 gallons/Mcf



Small-Scale NGL Economics

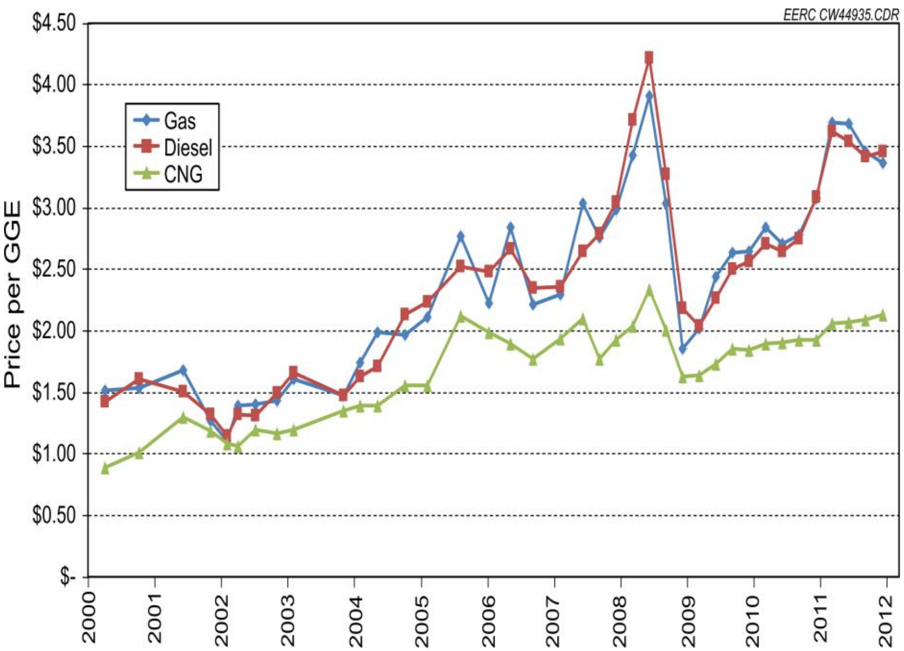
- Assumptions
  - Value (cost) of rich gas at the wellhead = $0.00/Mcf
  - Value of lean gas = flared
  - Value of NGLs = $1.00/gallon
  - Annual O&M = 10% of CAPEX
- Results
  - CAPEX = $2,500,000
  - Annual O&M = $250,000
  - Annual revenue (NGL only)

    $700,800 (600 Mcf/day rich-gas flow rate)

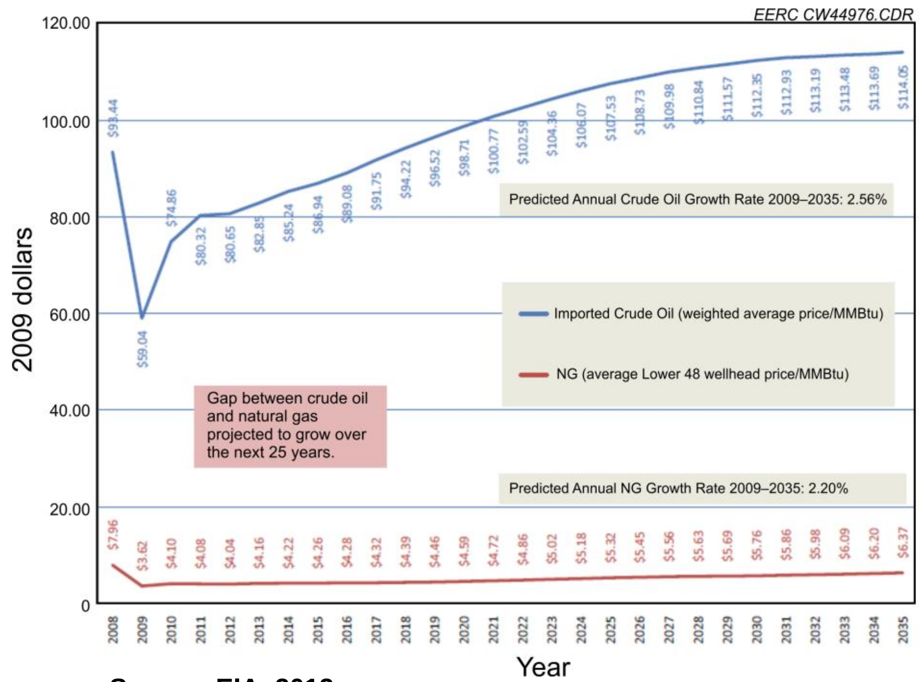
    $1,168,000 (1000 Mcf/day rich-gas flow rate)

CNG/LNG for Vehicles

- A disconnect exists between pipeline gas quality and required CNG fuel quality standards.
- The opportunity for CNG exists as a diesel displacement fuel because of the price differential between natural gas and diesel fuel.



Source: Alternative Fuels and Advanced Vehicles Data Center, 2012



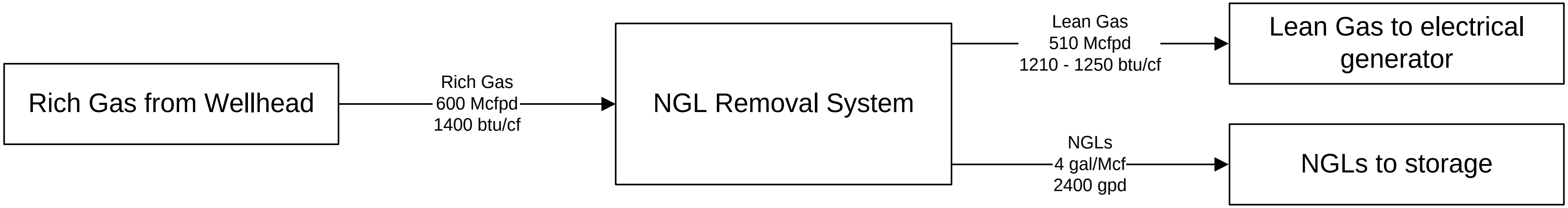
Source: EIA, 2012

CNG Economics Heavy-Duty Scenario

- Assumptions
  - Value (cost) of rich gas at the wellhead = $0.00/Mcf
  - Value of lean gas (CNG quality) = $1.89 GGE
  - Price of diesel = $3.65 GGE
  - Value of NGLs = $1.00/gallon
  - Annual O&M = 10% of CAPEX
- Results
  - CAPEX = $3,900,000
  - Annual O&M = $390,000
  - Annual NGL revenue $700,800 (600 Mcf/day rich-gas flow rate)
  - Annual fuel savings versus diesel $306,000

Electric Power Generation

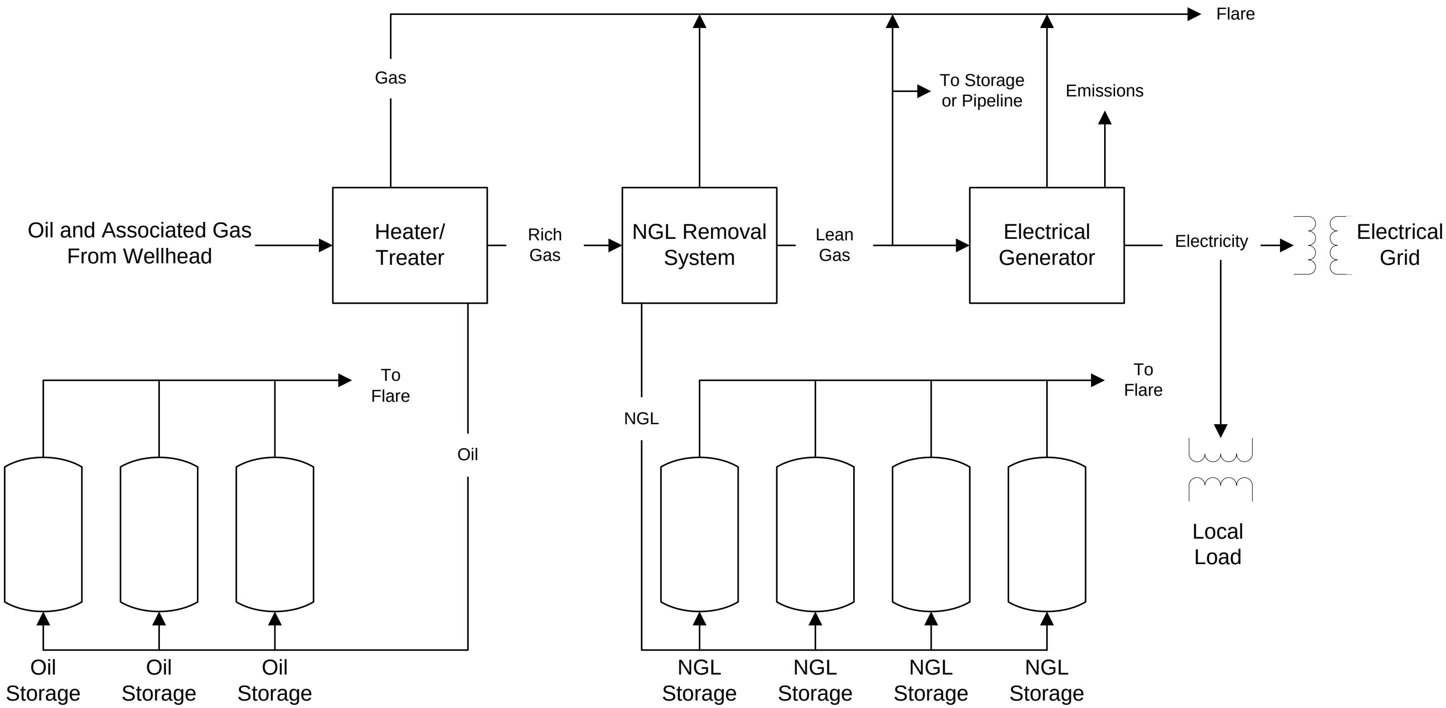
Scenario	Rich-Gas Flow, Mcf/day	NGLs Produced, gallons/day	Lean-Gas Produced, Mcf/day
Grid Support – Reciprocating Engine	1000	4000	850
Grid Support – Gas Turbine	1800	7200	1530
Local Power – Reciprocating Engine	600	2400	510
Local Power – Microturbine	600	2400	510



Electric Power Generation Economics

Scenario	Capital Cost	Annual O&M Cost	NGL Revenue[1]	Electricity Revenue[1]	Lean-Gas Revenue[1]	Annual Revenue[1]
Grid Support – Reciprocating Engine	$7,500,000	$650,000	$1,168,000	$1,664,400	$0	$2,832,400
Grid Support – Gas Turbine	$9,900,000	$890,000	$2,102,400	$2,049,840	$0	$4,152,240
Local Power – Reciprocating Engine	$3,200,000	$270,000	$700,800	$157,680	$291,416	$1,149,896
Local Power – Microturbine	$3,383,200	$283,640	$700,800	$122,932	$269,224	$1,092,956

[1] Assumes 80% annual system availability.



Chemicals

- North American petrochemical industry is located in areas with:
  - Large gas reserves
  - Geologic storage
  - Manufacturing facilities to produce chemical intermediates and finished products
  - Export terminals
- Chemical processes to make nitrogen-based fertilizer may have promise
  - Large agricultural base
  - Stranded gas

Small-Scale Fertilizer Economics

Ammonia Production Cost Estimate at Different Scales and Rates

	Large Unit	Small Unit
NG Feed Rate, Mcfd	2000	320
Capacity, ton/day	90.1	14.4
Production, ton/year	31,227	4,996
Utilization Rate, %	95	95
Fixed Capital Investment, $	52,389,617	17,385,099
Product Cost ($0 rich gas), $/ton	305.71	517.56
Product Cost ($4 rich gas), $/ton	395.71	607.56
Product Cost ($8 rich gas), $/ton	485.71	697.56

Qualitative Summary of Evaluated Technologies

Technology	Gas Use Range, Mcfd	NGL Removal Requirement	Scalability to Resource	Ease of Mobility	Likelihood of Deployment at Small Scale
Power – Grid Support	1000–1800	Minimal	Very scalable	Very easy	Very likely
Power – Local Load	300–600	Minimal	Very scalable	Very easy	Very likely
CNG	50+	Yes	Scalable	Very easy	Possible
Chemicals	1,000,000*	No	Not scalable	Not mobile	Very unlikely
Fertilizer	300–2000	No	Scalable	Not easy	Possible

* Typical commercial-scale plant.

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