

Stranded Gas in North Dakota's Bakken Field: Can It Be Used?

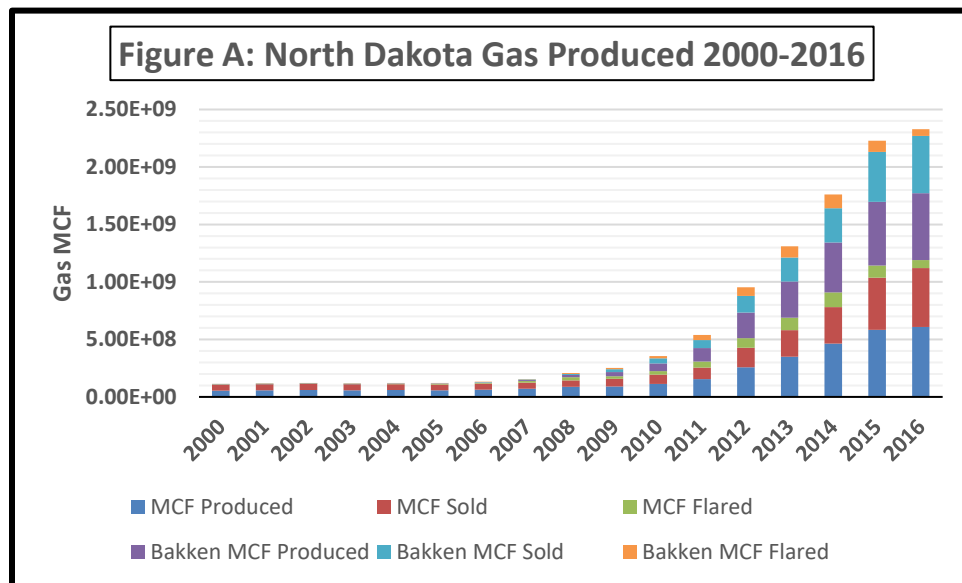
Summary

The Gas Resource

This report considers the stranded gas resources being developed in North Dakota's booming Bakken and Spanish-Three Forks shale oil fields. For simplicity these developing fields will be referred to, collectively, as the Bakken field in this report. The fields are concentrated in northwestern North Dakota with major overlap into eastern Montana, southern Saskatchewan and southwestern Manitoba. These fields are being rapidly developed such that North Dakota has climbed into 3rd place among the oil producing states in the US.

The expansion of the oil recovery operations in the Bakken area has been advancing at rates that have caused the oil and accompanying gas flows to outpace the development of the needed infrastructure required to bring these products to the market. The lack of insufficient transport capacity is particularly acute for the gas products. The oil can and is being shipped out by rail car; the gas, without pipelines, is a stranded gas resource and is flared.

This report looks at several technologies which have been proposed to exploit this stranded gas resource for beneficial use. The proposed applications for use of this stranded gas are promoted by consideration of the quantity of natural gas which is in play. Figure A, below, was derived using data from North Dakota¹ State Statistics. It indicates that considerable quantities of stranded gas are still available although the quantities of gas flared are diminishing per increased regulation.



Several uses for this stranded gas have been proposed. These beneficial uses include conversion to ammonia for fertilizer; conversion to liquids via Fischer-Tropsch or similar processes; and, conversion to electricity using gas turbines or internal combustion engines. Each of these

¹ <https://www.dmr.nd.gov/oilgas/stats/statisticsvw.asp>

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technologies has their own merits and difficulties. This report, part 1 of the series looking at each approach, is focused on the conversion of the gas to ammonia for farm use in North Dakota.

The Need for Ammonia

Corn is one of the major food grain crops of the world. It is a dominant crop in the US Corn Belt of which North Dakota is on the upper (northern edge) end. Corn is a very productive crop especially when provided with enough nitrogen fertilizer. It is the most nitrogen hungry of the major grain crops.

In order to set the stage for the discussion for conversion of the stranded natural gas to beneficial uses, a primer on corn agriculture is included in this report. The section on corn focuses on the crop's need for nitrogen fertilizer in quantities and timing, and costs for the grower. The predominant forms of applied nitrogen fertilizer are all ammonia based so a discussion of ammonia synthesis technology is included. These background discussions are also applicable to the other technologies proposed for the Bakken stranded gas.

Conversion to Ammonia: The Large-Scale Approach

One approach to exploit the stranded gas as a source for ammonia production is to build an industry standard large-scale ammonia plant. The size of the stranded gas resource is large enough to easily support a 500,000 ton/year or larger plant. North Dakota already has a 400,000 ton/year plant operating in Beulah. This plant uses coal gasification to provide the hydrogen.

A feasibility study regarding the suitability of the stranded gas resource for conversion to ammonia in a large-scale plant was performed by personnel at North Dakota State University. This study did confirm that an ammonia plant could be built in North Dakota and would be able to produce ammonia at a competitive price for the state's agricultural market IF the plant would use conventional, pipeline natural gas. The cost of rounding up the stranded gas from the geographically scattered sources would result in a feedstock with an uneconomic multiple of the projected Henry Hub price for pipeline natural gas for the foreseeable future.

Conversion to Ammonia: The Distributed Generation Approach

Another group, a start-up, developed a proposal for the state of North Dakota to build and test a skid mounted mini-ammonia plant which could be located at the wellhead. The proposal was based upon a mini-ammonia plant developed in the Netherlands which is designed to use excess renewable electricity generated hydrogen to make ammonia. The proposal to North Dakota requested funding of about \$1 million, out of a total need of \$4 million, for the first unit. After some negotiations, the state approved the funding in September of 2012.

The size of the proposed distributed generation ammonia plant was 3,400 ton/year. This plant could operate with a natural gas flow of 100 MCF/day which is well within the flow rates of many wells currently flaring the gas. Unfortunately, the gas flow rates from the isolated wells are quite variable, much like wind generation of electricity. These uncertain flow rates make it very difficult to maintain the continuous operation which an ammonia plant needs for successful operation. Although the proposed equipment would be skid mounted, its portability will still require a considerable effort for relocation. Thus, the equipment set-up is not really suited for rapid deployment to follow different stranded gas sources as the source in use gets depleted.

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Finally, the projected cost per ton of ammonia produced from the mini-plant is considerably higher than that of merchant ammonia even with consideration of transportation costs.

Conclusion: Stranded gas does not have ammonia in its future for, at least, the near term.

1. The Resource: Bakken Stranded Gas

In less than a decade North Dakota has emerged as a major force in hydrocarbon production in the US. This surge in oil and gas production has been facilitated through directional drilling and hydraulic fracturing (fracking). The shale oil field extends through North Dakota, Montana and on into Saskatchewan. The major fraction of the resource lies in northwestern North Dakota as can be seen in Figure 1². The development and exploitation of this field has seen explosive growth over the past 6+ years. The interesting aspect of this growth is that it generally has not involved the oil majors, until lately.

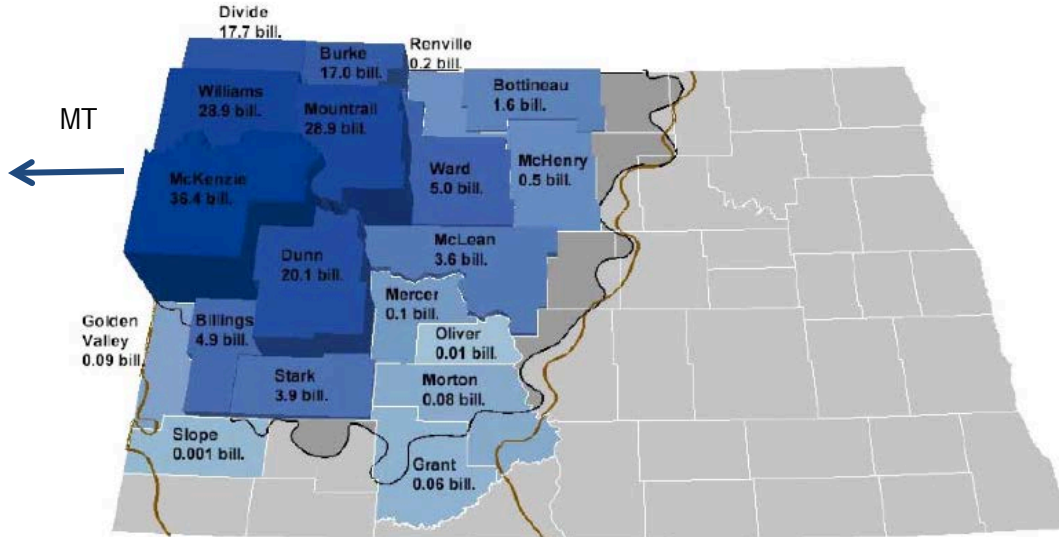


Figure 1: Three-Dimensional Visualization of the Bakken Field in North Dakota

A visualization of the rate of expansion of the oil recovery activity in the Bakken field can be appreciated by the data shown in Figure 2³; these show more than a 3-fold increase in oil

² <http://www.investingdaily.com/15159/bakken-shale-map-an-investors-introduction-to-the-formation>

³ <http://www.eia.gov/todayinenergy/detail.cfm?id=9030&src=email>

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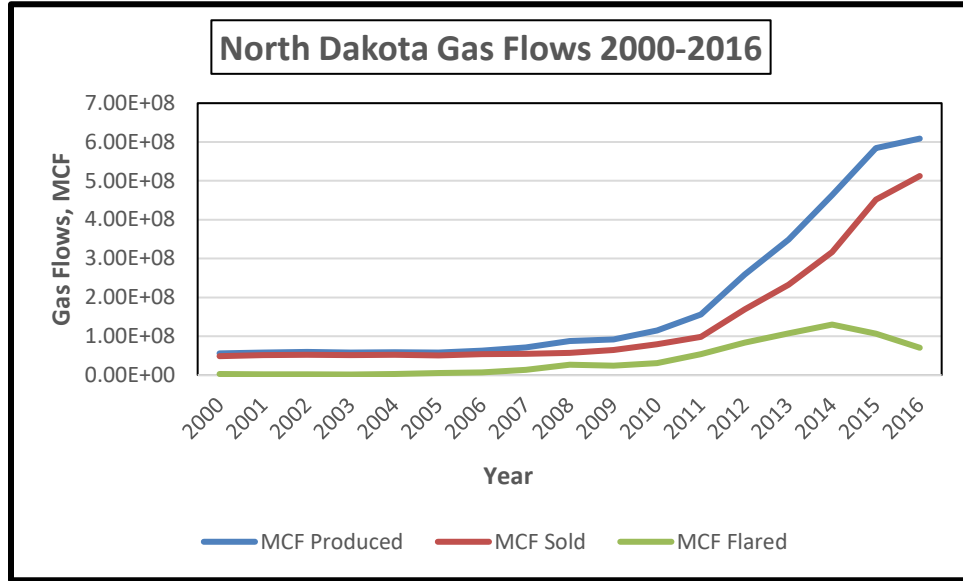


Figure 2: Annual North Dakota Gas Production: Jan 2010-Sept 2012

production over the past 2 ½ years. It is no surprise then that the expansion of the oil and gas resource recovery in North Dakota has outstripped the removal infrastructure (read pipelines) such that much of the crude is being shipped out of the basin by rail to refineries and pipeline access points. While this shipping method works for the liquid products, there is no usable transport mechanism for recovered gas values distant to a pipeline.

As a consequence, this unmovable gas is flared for safety and environmental concerns. That large quantities of the natural gas are flared can be seen in the view from space shown in Figure 3⁴. This figure also indicates the high activity areas for oil and gas operations and shows the large concentrations in northwest North Dakota. These gas resources are termed “stranded”. The hydrocarbon producing activities in North Dakota are carefully monitored by North Dakota’s Department of Mineral Resources (the Department).



Figure 3: The Dakotas from Space: Note the high Concentration of Gas Flares in ND

⁴ <http://thinkprogress.org/climate/2012/03/13/443979/north-dakotas-bakken-shale-boom-is-visible-from-space/>

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1.1 Estimation of Quantities of Available Stranded Gas

Before the exploitation of this stranded resource can attract the attention of potential users of the gas, the quantities of the stranded gas available for exploitation have to be established. Fortunately, the Department keeps a close watch on the hydrocarbon recovery activities in the state and documents the quantities of these resources which are recovered. The tracking of gas recovery and sale for the period from January of 2000 to present has already been shown in Figure 2.

Figure 2, a reprise of Figure A, shows that the quantity of stranded gas available in the second half of 2016 runs just under 1E+08 MCF⁵ per month. The volume of flared gas has been trending down in recent years in response to North Dakota's vigorous effort to reduce the quantity of flared gas.

1.2 Beneficial Use of the Stranded Gas

There is no doubt that the stranded gas in the Bakken field represents a wasted resource which should be put to beneficial use if economic pathways for its utility can be identified and verified. Several proposals have been suggested to make some beneficial use of the stranded gas. These include conversion of the gas to ammonia fertilizer either on a distributed approach or through the traditional large-scale ammonia plant.

The second potential use would be to convert the gas to hydrocarbon liquids using processes such as presented by the Fischer-Tropsch chemistry. The products would then be mixed with the crude oil or, if sufficiently upgraded, be used directly as fuels. However, extensive and expensive processing is required for GTL⁶ processes. As with ammonia production, the first step in the Fisher-Tropsch process is the conversion of methane to syn gas, a mixture of CO and hydrogen. This step requires over 60% of the capital expenditures for the whole plant.

The third option proposed is to use the gas, on-site, to generate electricity using either gas turbine technology or natural gas fired internal combustion engines. This approach is not as straightforward as it would appear, the stranded gas would require some prior processing to remove components that would be deleterious to the operation of the turbines or engines. This approach, in particular, could provide an opportunity for simple gas processing like PSA⁷ for straightforward gas cleaning. If the price is right, this approach could provide an opening for the PSA equipment supplied by Xebec, for example. This option and the natural gas to liquids option will be subjects of separate reports.

The remainder of this report will discuss the first proposal, conversion of the stranded gas to ammonia. North Dakota, in addition to its oil production, is an agricultural state which produces both wheat and corn. The corn crop is a major consumer of nitrogen fertilizers which are produced from ammonia. Natural gas is the most favored starting material for ammonia production with low cost methane making the process especially favored. A discussion of the ammonia production technology and its use in the agriculture of corn is presented in the supporting information section.

⁵ MMCF = million ft³ of gas at 1 atm & 60F (by convention)

⁶ GTL = gas-to-liquids

⁷ PSA = pressure swing absorption, a physical separation process

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2. Stranded Gas to Ammonia Fertilizer

2.1 An Overview: Importance of Ammonia in Agriculture

The high yields of necessary food crops obtained from the “Green Revolution” and the newer crop hybrids are dependent on high levels of (mostly) synthetic fertilizers. The production of fertilizers has become of increasing importance in a world which is experiencing population food needs that exceed any possible growth in arable land. The fertilizer needs for a few of the world’s top food crops are shown in Figure 4⁸. Except for cotton, the crops in this figure are harvested as seeds which are the actual “food” in the food crops. Seeds contain protein and protein requires nitrogen. The harvesting of “seeds” removes nitrogen from the soil which has to be replaced regularly to maintain the required yields of the food crops⁹.

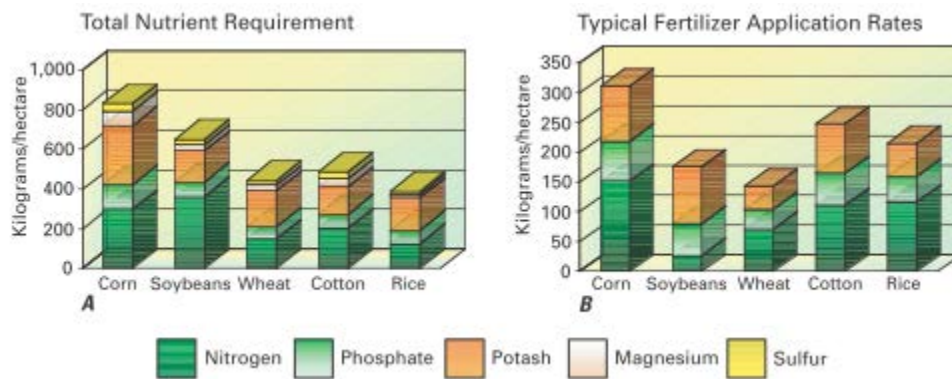


Figure 4: Chart shows: A, total nutrient requirements for major crops. B, typical application rates for major crops.

Nitrogen is needed by all of the grain crops and requires annual applications to replace the nitrogen removed by the crop. Annual applications of the other nutrients are not always necessary and are determined for each season by soil analysis before application is considered. For corn, much of the phosphorous and potash taken up by the plant remains in the stover, stalks and cobs, after harvest. Leaving the stover in the field reduces the amounts of phosphorous and potash which need to be applied in the next season.

2.2 Corn Nitrogen Needs¹⁰

The following section expands on the quantification of actual nutrient needs of the corn crop. As the fertilizer needs are a complex aggregation of crop nutrient need, previous crops grown in the rotation, crop residues left in the field and economics. In this section the focus is on nitrogen as the surrogate example of the greater fertilizer use for agriculture.

⁸ Fertilizers - Sustaining Global Food Supplies, USGS Fact Sheet FS-155-99, September 1999

⁹ Nitrogen replacement is also required for cotton as this crop is harvested with its seeds. The seeds do for part of the food chain as they are pressed for oil with the press cake then used for animal feed.

¹⁰ This section is needed to establish the validity of the stranded gas to ammonia processes proposed by N-Flex LLC. The numbers in their proposal may not be realistic for the application.

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The economics of corn farming are closely tied to achieving the desired yields of 200+ bushels¹¹/acre, which, in turn, are related to the nitrogen available to the crop. Considerable nitrogen is contained in the corn grain, which is removed with the crop (and in the stover if the stover is also collected). The removed nitrogen needs to be replaced if the next corn crop is to have the desired high yields around the 200 bu/acre range. The question then is how much nitrogen was removed?

A, more or less, consensus summary of nutrient removal amounts for the major Corn Belt crops is given in Table 1¹². From this Table it can be calculated that our 200 bu/acre corn

Crop	Unit	Removal, lb/unit ¹				
		N	P ₂ O ₅	K ₂ O	Mg	S
Alfalfa	ton	51	12	49	5.4	5.4
Corn grain	bu	0.90	0.38	0.27	0.09	0.08
Corn stover	bu	0.45	0.16	1.1	0.14	0.07
Corn stover	ton	16	5.8	40	5.0	3
Corn silage	bu	1.6	0.51	1.2	0.33	0.18
Corn silage	ton	9.7	3.1	7.3	2.0	1.1
Soybean grain	bu	3.8	0.84	1.3	0.21	0.18
Soybean stover	bu	1.1	0.24	1.0	0.22	0.17
Soybean stover	ton	40	8.8	37	8.1	6.2
Soybean hay	ton	45	11	25	9	5
Wheat grain	bu	1.5	0.60	0.34	0.15	0.1
Wheat straw	bu	0.7	0.16	1.2	0.1	0.14
Wheat straw	ton	14	3.3	24	2	2.8

¹Moisture for reported units is based on marketing conventions or on a hay or wet silage basis. Values are limited to Northcentral regional publications whenever possible.

Table 1: Average Nutrient Removal Rates for Crops in the Northcentral Region

yield resulted in a removal of 180 lbs/acre of nitrogen in the grain. Further removal of nitrogen will occur if any of the stover is harvested. For example, if 50% of the stover were removed, an additional 45 lb of nitrogen per acre would be removed, for a total of 225 lbs N/acre.

Failure to replace the nitrogen can result in diminished corn yields as shown in Figure 5, below. The nitrogen replacement is not as simple as, in this case, putting 225 lb/acre of nitrogen onto the field. As noted above, the amount of nitrogen to be applied is a function of the previous crop, the cost of the fertilizer and the expected sale price of the corn.

¹¹ One bushel of corn is stated to be 56 lbs. One acre at 200 bu/acre will yield 11.2 tons of corn. This value converts to 25 tonnes/hectare (1 hectare = 2.47 acres).

¹² Plant Nutrition Today, Fall 2008, No 4. www.ipni.net/pnt

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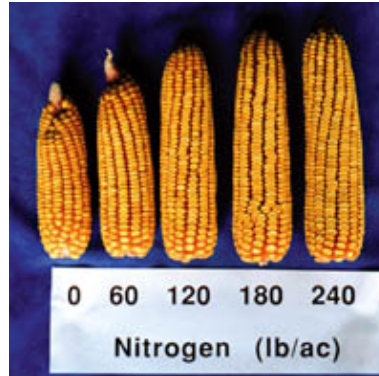


Figure 5: Corn Yield Response to Nitrogen¹³

A main consideration arising from crop rotation planning is that the “normal” sequence of corn-soybeans-corn (SC) is being replaced by corn-corn (CC) in many areas in the Corn Belt owing to the draw of the ethanol market. Soybeans are legumes and, as such, they do add nitrogen to the soil in spite of their large nitrogen withdrawal, in the seed, compared to corn, about 4 x that of corn¹⁴ (See Figure 4). Soy is a major source of plant protein, so this large nitrogen withdrawal should not be surprising.

The difference in the SC rotation versus a CC rotation in approximately identical locations is shown in Figure 6¹⁵. The figure compares SC with CC over a span of several years showing corn yield against nitrogen fertilization levels. It also indicates the EONR point (Economic Optimum Nitrogen Rate) for each situation. As anticipated the SC rotation required a lower nitrogen application to achieve the same corn yield.

Figure 6 shows that (in 2004) the SC rotation gave a corn yield of about 240 bu/acre at a N application of about 110 lb N/acre. In contrast, the CC field (for 2004) needed about 185 lb N/acre to get a slightly lower corn yield of about 230 bu/acre. Part of this lowered yield could be owing to a higher survival rate for the corn root parasite over just 1 winter compared to 2 winters with the SC rotation.

Why the importance of corn? Truly, corn is an amazing plant. Only 15 to 20 lb dry matter/acre is planted in the spring as seed, and in only four months, these seeds build an energy-capturing factory that produces nearly 20,000 pounds of dry matter/acre and generates 500 to 1,000 new seeds for each seed that was planted¹⁶. The growth stages for the remarkable corn plant are shown in Figure 7. Below ground, the total length of the corn root system can reach 30,000 to 40,000 miles/acre.

¹³ <http://agronomyday.cropsci.illinois.edu/2001/tours/nitrogen-need/index.html>

¹⁴ The comparison is not that direct, a corn bushel is 56 lb, and a soybean bushel is 60 lb.

¹⁵ Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn, www.extension.iastate.edu/Publications/2015.pdf page 17.

¹⁶ Reference 6, page 6

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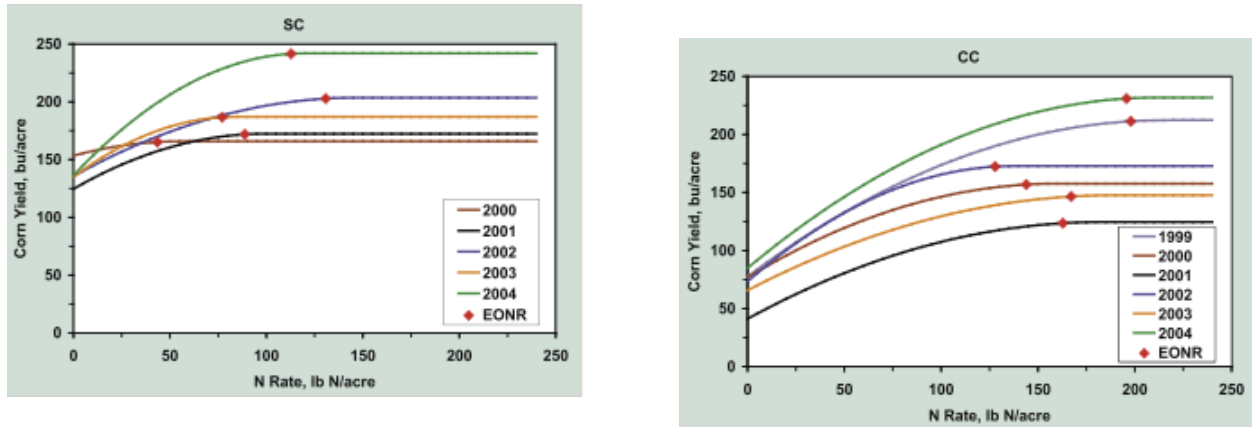


Figure 6: Variation in EONR (0.10 price ratio¹⁷) and corn yield in different years for SC (left) and CC (right) at the same site in Ames, IA.

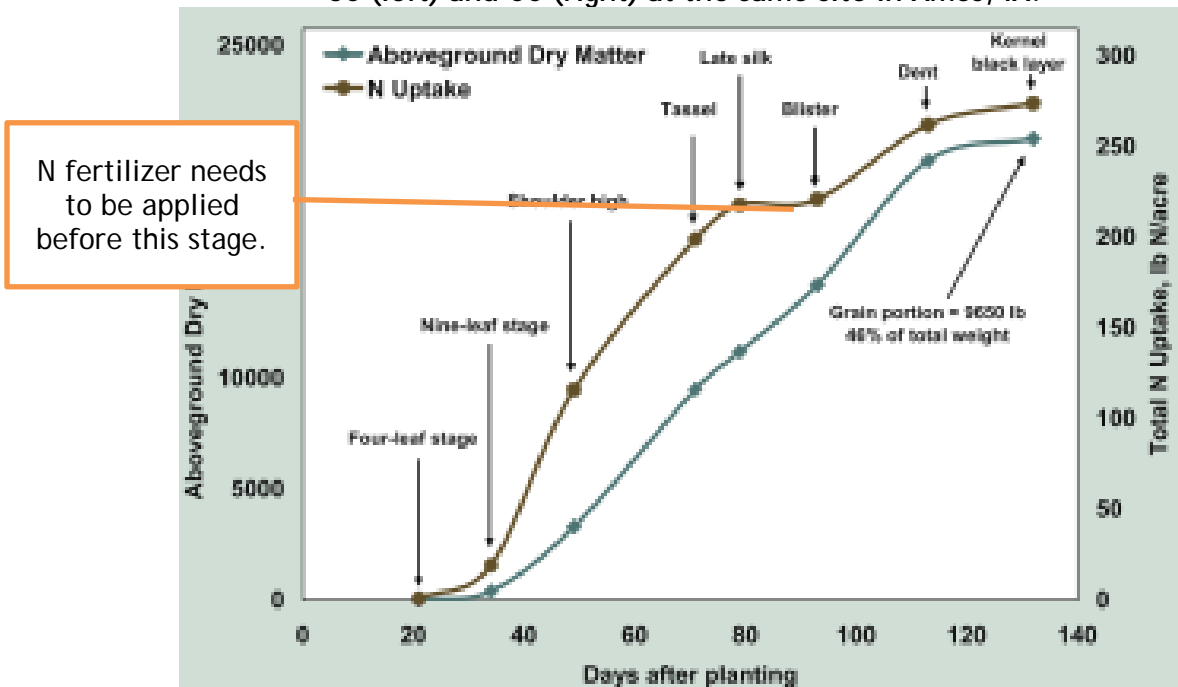


Figure 7: Corn above ground dry matter accumulation and N uptake for a 204 bu/acre corn crop

So, depending on the previous crop, nitrogen application to a corn field will range between 100+ to 200 lb N/acre. The nitrogen application can be split between planting and 60-70 days later but before tasseling. Thus 1,000 acre planting of corn could use up to 200 tons of ammonia in a growing season.

¹⁷ The price ratio is the ratio of the price of N per lb divided by the selling price of corn. At \$805 per ton for ammonia and \$7.50 corn this number is 0.07.

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2.3 Ammonia Market Potential for Corn

2.3.1 Corn Plantings

The previous section established the need for nitrogen fertilizers for corn agriculture. The next question then becomes: how much corn is planted in the US? The answer can be seen in Figure 8 as supplied by the USDA¹⁸. Figure 8 shows that in this crop year about 97 million acres of corn were planted and about 88 million acres were harvested. Crop year 2012 was very difficult for corn owing to a persistent and wide spread drought. Yet, this reduced crop still managed to come in with an average yield of 122 bu/acre¹⁹.

Million acres

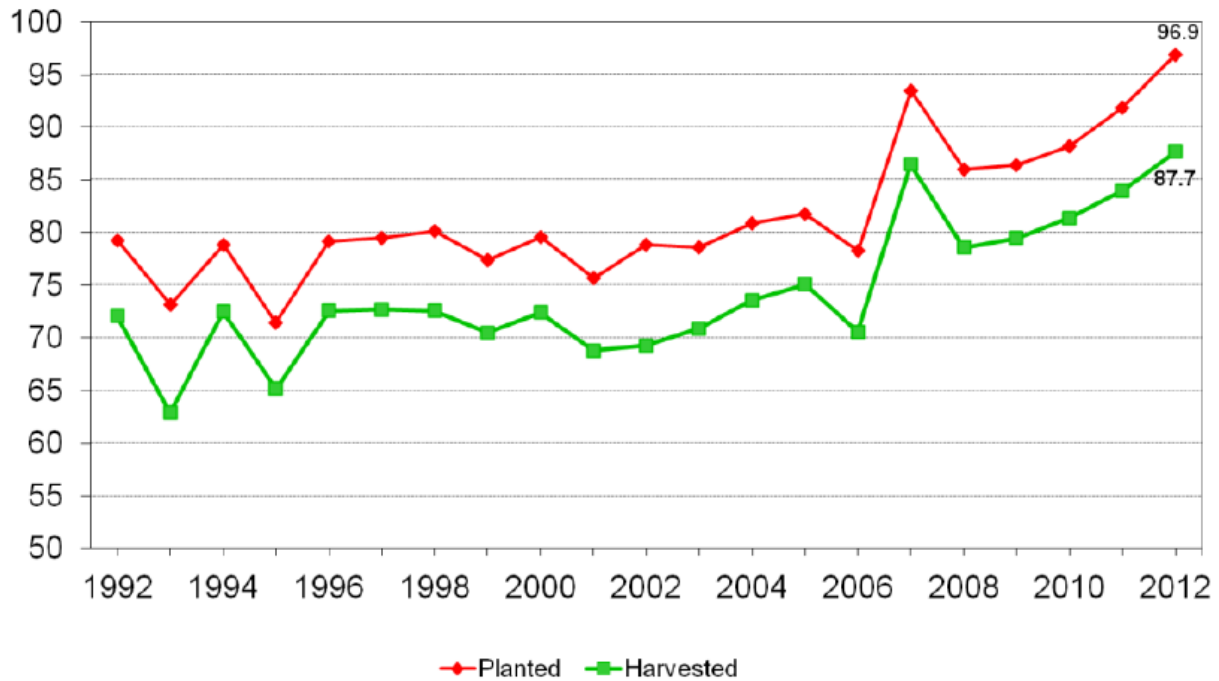


Figure 8: US Corn Acreage Planted & Harvested 1992-2012

The 96.9 million acres at 122 bu/acre delivered about 2.7 million tons of corn. As an estimate, say 150 lb N²⁰/acre was applied for this crop year. The demand for ammonia for this crop year was then about 8.7 million tons. This number is an estimate to cover all forms of nitrogen which includes urea and urea-ammonium nitrate. Looking a little closer to Bakken's home, North Dakota, the corn plantings are seen to be clustered in the southeast, see Figure 9²¹. The locations for the 5 operating ethanol plants are also indicated in Figure 10. While the corn crop in North Dakota is smaller than that achieved in the traditional "Corn Belt" states it still is of sufficient size to support some local ammonia production.

¹⁸ http://www.nass.usda.gov/Charts_and_Maps/Field_Crops/index.asp

¹⁹ WASDE 11-09-2012

²⁰ 150 lb N/ acre would translate to about 180 lb ammonia per acre as ammonia is 82% N by weight.

²¹ See reference 9 for path

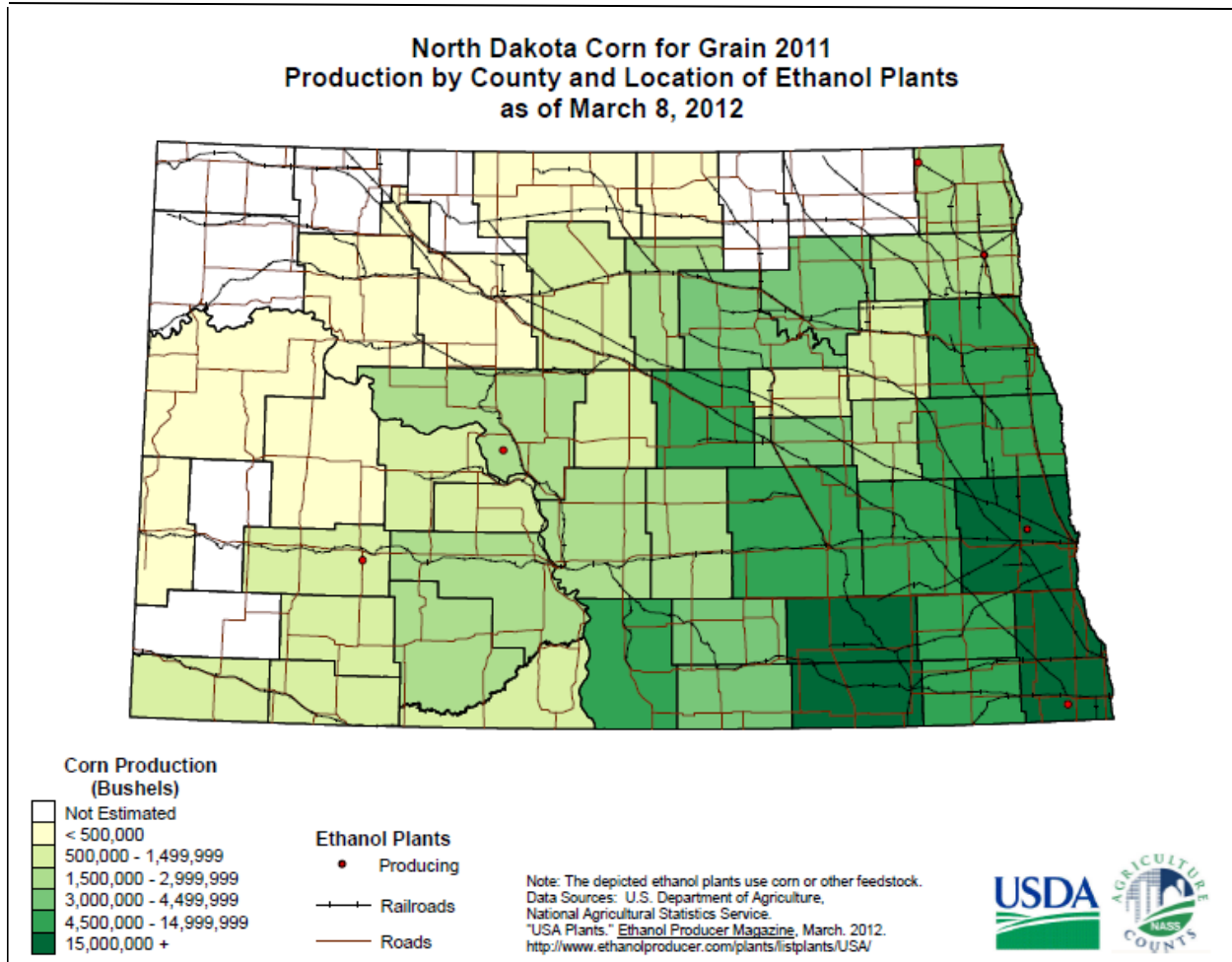


Figure 9: Corn Production in North Dakota for 2011

2.3.2 Ammonia Sources and Usage in the US

Now that we know that nitrogen fertilizers are essential for corn agriculture with a large market potential. There are several questions that need answering: What is the actual market size and usage in the US? Where the plants for domestic production, what are their capacities and where are the distribution centers? The USGS supplies the needed answers. Table 2 gives the salient data for ammonia in the US showing production, exports, imports and consumption²². Table 3 identifies the prominent domestic producers of ammonia and shows the plant locations and name plate capacities. The capacities as stated assume 340 operating days per year. In 2010 the plants, on average, operated at 70% capacity.

²² <http://minerals.usgs.gov/minerals/pubs/commodity/nitrogen/>

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Table 2: Baseline Statistics for Ammonia Production and Use in the US 2010 Data

SALIENT AMMONIA STATISTICS ^{1, 2}					
(Thousand metric tons of contained nitrogen unless otherwise specified)					
	2006	2007	2008	2009	2010
United States:					
Production	8,190	8,540	7,870	7,700	8,290 ^P
Exports	193	145	192	16	35
Imports for consumption	5,920	6,530	6,020	4,530	5,540
Consumption, apparent ³	14,000	15,000	13,500 ^r	12,300	13,800 ^P
Stocks, December 31, producers	201	157	302	167	165
Average annual price, free on board gulf coast ⁴ dollars per short ton	302	307	590	251	396
Net import reliance as a percentage of apparent consumption ⁵	41	43	41	38	40 ^P
Natural gas price, wellhead, average price ⁶ dollars per thousand cubic feet	6.39	6.25	7.97 ^r	3.67 ^r	4.16 ^e
World:					
Production ^e	125,000 ^r	131,000	130,000	127,000 ^r	131,000
Trade ⁷	15,900	15,800	15,500 ^r	14,400 ^r	14,800 ^e

^eEstimated. ^PPreliminary. ^rRevised.

The domestic ammonia plants are located close to the hydrocarbon sources used in the steam reforming operations that generate the hydrogen for reaction with nitrogen to produce the ammonia. For the most part they are located outside of the “Corn Belt”. There are, however, 2 large pipelines devoted to transport of ammonia from the production locations to the usage locations. A map of the pipelines and terminals is shown in Figure 10 courtesy of Koch Industries. (It also shows the Koch Industries plant locations, the yellow stars.) The next section describes the Haber - Bosch process as practiced today.

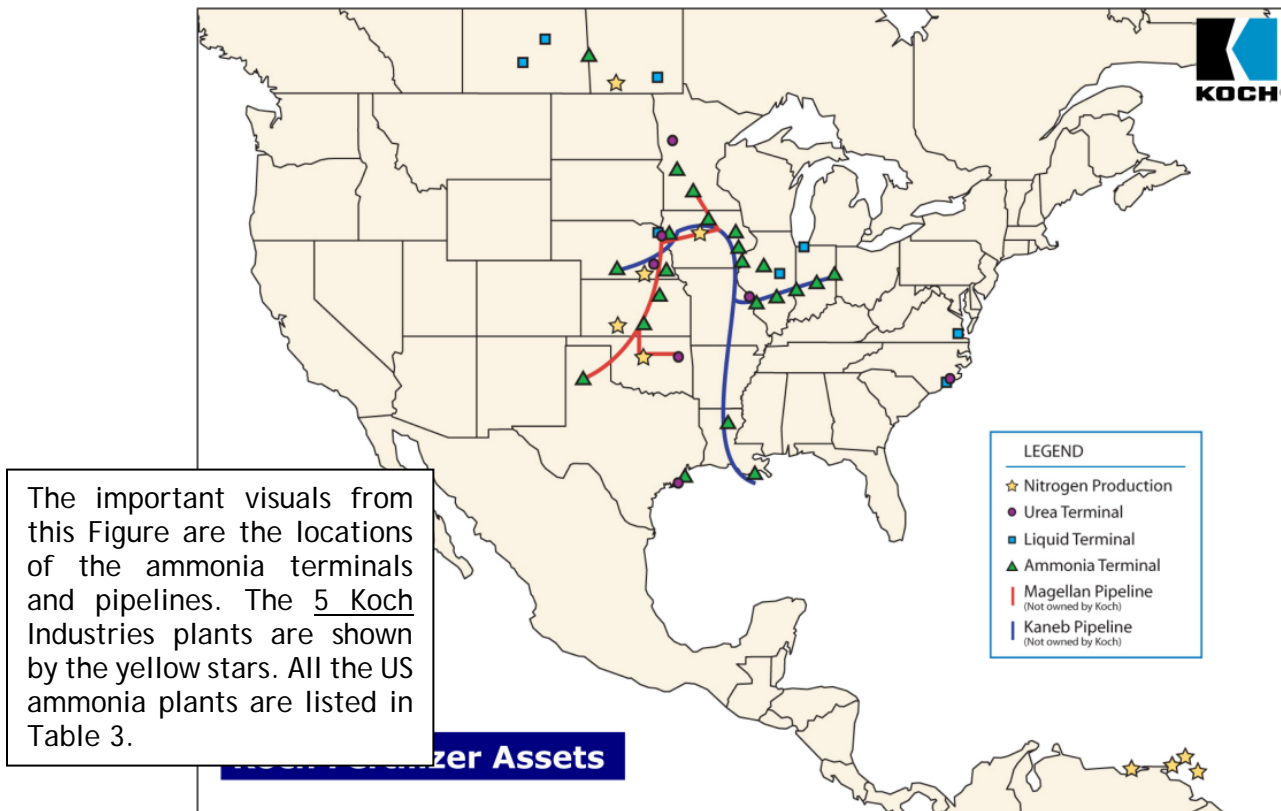


Figure 10: Ammonia Pipelines and Terminals in the US (Source: Koch Industries)

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Table 3: Domestic US Producers of Ammonia in 2010

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 2010 ¹		
(Thousand metric tons per year of ammonia)		
Company	Location	Capacity ²
Agrium Inc.	Borger, TX	490
Ditto	Kennewick, WA ³	180
CF Industries Holdings, Inc.	Donaldsonville, LA	2,490
Ditto	Port Neal, IA	336
Ditto	Verdigris, OK	953
Ditto	Woodward, OK	399
Ditto	Yazoo City, MS	454
Coffeyville Resources Nitrogen Fertiliz	Coffeyville, KS	375
Dakota Gasification Co.	Beulah, ND	363
Dyno Nobel Inc.	Cheyenne, WY	174
Ditto	St. Helens, OR	101
Eastman Chemical Co.	Beaumont, TX ³	231
Green Valley Chemical Corp.	Creston, IA	32
Honeywell International Inc.	Hopewell, VA	530
Koch Nitrogen Co.	Beatrice, NE	265
Ditto	Dodge City, KS	280
Ditto	Enid, OK	930
Ditto	Fort Dodge, IA	350
Ditto	Sterlington, LA ³	1,110
LSB Industries, Inc.	Cherokee, AL	159
Ditto	Pryor, OK ³	210
Mosaic Co., The	Faustina (Donaldsonville)	508
PCS Nitrogen, Inc.	Augusta, GA	688
Ditto	Geismar, LA ³	483
Ditto	Lima, OH	542
Ditto	Memphis, TN ³	372
Rentech Energy Midwest Corp.	East Dubuque, IL	278
Total		13,300

2.3.3 Ammonia Synthesis Today

The direct synthesis of ammonia from the elements, nitrogen and hydrogen, was demonstrated by Fritz Haber²³ in the period from 1904-1908 and received a patent. In 1910 Fritz Haber began working with Carl Bosch at what is now BASF to engineer the process for production. The first plant ran at about 30 Mt/day. A modern ammonia plant runs in excess of 2,500 MT/day.

²³ Fritz Haber is the only chemical engineer to receive the Nobel Prize for chemistry. He also, personally, supervised the use of poisonous chlorine gas in the WWI on the western front.

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The process consists of several chemical processes, steam reforming (SR) of hydrocarbons to make hydrogen, methane is the preferred material; purification of the SR product to remove water, carbon monoxide and carbon dioxide (catalyst poisons), and; reaction of the purified hydrogen with nitrogen over an iron based catalyst to produce the ammonia. The SR process is run to have complete conversion of the methane. The ammonia formation reaction, Reaction1, is reversible and under thermodynamic control. While product yields of this reaction



are high, >95%, per pass conversions are only about 15-20% so recycle is an important part of the process.

Among the major suppliers of the ammonia technology are Haldor Topsoe, KBR, Uhde (ThyssenKrupp) and the Casale Group. Their processes all have the same unit operations as noted above. The process flow diagram for the Haldor Topsoe version is shown in Figure 11.

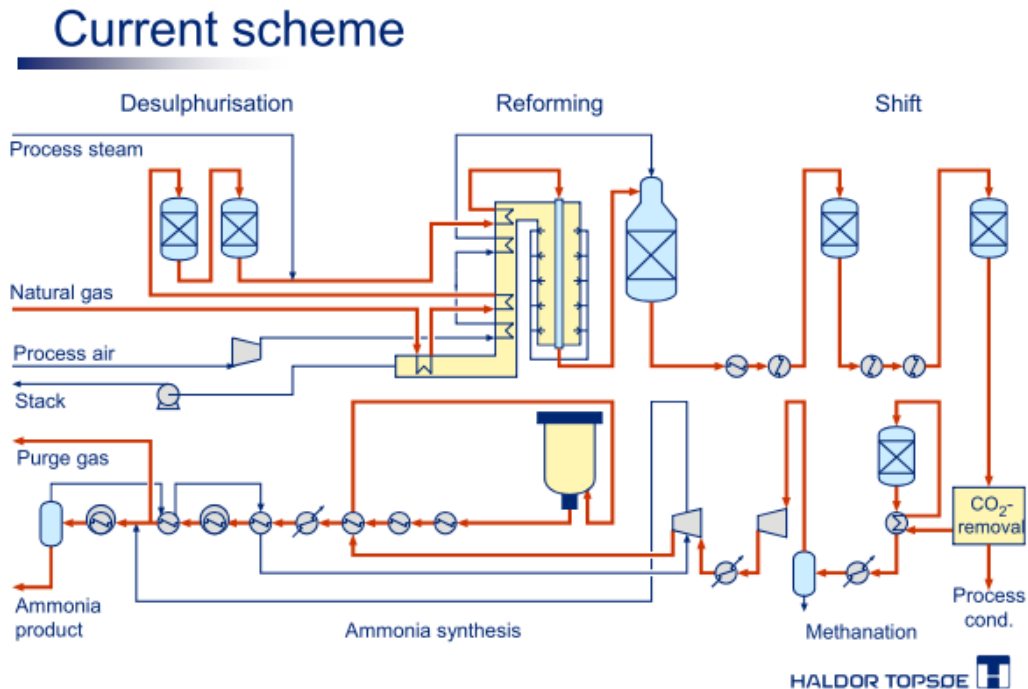


Figure 11: The Haldor Topsoe Ammonia Synthesis Process

In addition to the steam reforming of methane to produce the hydrogen and the ammonia synthesis reactor, the process also requires an air plant to supply oxygen to the reformer and nitrogen to the ammonia reactor. Also note that there is a methanation reactor to remove all traces of CO and CO₂ from the hydrogen stream as these 2 species are catalyst poisons.

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Both Topsoe²⁴ and Casale²⁵ give the same energy consumption for the ammonia process at about 6.5 Gcal/MT²⁶ NH₃. With this information an overall process efficiency can be calculated as follows:

$$6.5 \text{ Gcal/MT NH}_3 \times 4.1868 \text{ J/cal} = 27.2 \text{ GJ/MT NH}_3$$

$$\text{Using the LHV}^{27} \text{ for the ammonia} = 1,000 \text{ kg} \times 18.6 \text{ MJ/kg} = 18.6 \text{ GJ/MT NH}_3$$

$$\text{Efficiency} = 18.6 \text{ GJ/MT NH}_3 / 27.2 \text{ GJ/MT NH}_3 = 68\%$$

The processes are designed to minimize thermal losses throughout the plant. Given that 2 of the plant providers state the same energy consumption value for the process, it would be safe to assume that their plants (as well as the others) are optimized to achieve this efficiency level.

2.3.4 Ammonia Production and the Bakken Stranded Gas

The proposal to locate ammonia production facilities in North Dakota are expected to be favorable to North Dakota's agriculture as there is now only one operating ammonia plant²⁸ in North Dakota. Ammonia is a high-volume usage fertilizer and transportation costs are a good part of the fertilizer expense to the farmer in North Dakota. There are 2 proposals for ammonia production in North Dakota hoping to get a benefit from the Bakken stranded gas.

The first proposal is for a traditional large ammonia process facility has been proposed by North Plains Nitrogen. The addition of another large ammonia producer would be expected to lower the fertilizer costs to farmers in the northern Great Plains.

Update: North Plains Nitrogen remains alive although plant construction has not yet begun. The company still is working to secure the necessary funding to launch. The project was first announced in 2013, and leaders had hoped to have the plant running sometime this year (2017). The total project cost, however has risen and is now estimated at about \$2.5 billion. Asked how much longer the CEO felt the project would continue to wait for investment, the CEO replied "indefinitely" was too strong a word, but expressed confidence in the project nonetheless²⁹.

A second proposal involves a distributed generation approach which has been proposed by a start-up company named N-Flex LLC or Agcelerator LLC depending on the publication. The headquarters of this group are in New York City with another office in South Dakota. The organization of this company is almost as interesting as their concept for the distributed production of ammonia using small scale, semi-portable units. This operation no longer appears to be around.

²⁴ www.topsoe.com

²⁵ www.casale.ch/group/ammonia-casale/company.html

²⁶ Here MT = metric ton

²⁷ www.spg-corp.com/clean-energy-power-generation.html

²⁸ http://www.dakotagas.com/Products/Product_Profiles/index.html Dakota Gas makes syn gas by steam reforming of coal. One of its products is ammonia on a 1,000 tonnes/day level. A modern natural gas ammonia plant operates with a capacity in excess of 2,000 tonnes/day.

²⁹ <http://www.westfargopioneer.com/news/4207720-nd-fertilizer-plant-works-woo-investors-amid-economic-headwinds>

3. The Large-Scale Approach: North Plains Nitrogen

North Plains Nitrogen³⁰ (NPN) is a consortium of corn growers looking to raise a seed fund of \$15 million to develop the plans for the >\$1 billion plant in North Dakota. A feasibility study³¹ has been prepared and funded in part by a grant from the North Dakota Department of Commerce. The driving force for this ammonia plant is a consortium of farmers under the umbrella of the Northern Corn Development Corporation³². The state (of North Dakota) gave the group a \$100k award for a feasibility study for the project. (See the Update, above.)

The feasibility study was performed by personnel in the department of Agribusiness and Applied Economics at the North Dakota State University³³. This study started out focused on the use of the stranded gas but was expanded to include “conventional” (read pipeline) natural gas in the course of the study. The full charge of the study was:

- Determining the most profitable facility size, location, and configuration for a natural gas nitrogen fertilizer production facility in North Dakota.
- Calculating the financial returns and capital requirements of gas-based nitrogen fertilizer production.
- Identifying possible business structures for the fertilizer production facility.

The initial thrust of the study was to determine the feasibility and economics of using the Bakken stranded gas for ammonia production. The report included an analysis of the availability of the stranded gas as well as cost associated with its collection to obtain necessary industrial useful quantities of the gas.

3.1 Economics of Capturing and Collecting Stranded Gas for Any Process

The reviewers estimated, based on a report on stranded gas in Russia³⁴, that it would be quite costly to collect the stranded gas through a scheme proposed in the referenced report. The total cost for getting the stranded gas could come up to around \$7.57/MMBTU. This value assumes \$0.57/MMBTU to the wellhead producer for capture; a processing cost of \$3/MMBTU; and, a pipeline connection cost of \$4/MMBTU.

This cost runs above the current costs that the evaluators used for pipeline gas based upon the Henry Hub spot price of around \$3/MMBTU. Further, the most recent projections for the Henry Hub spot price published by EIA shown in Figure 12³⁵ indicate that the Henry Hub spot price for natural gas will remain below the above estimate for stranded gas of \$7.57. From the numbers in Figure 12, it is fairly clear that there is no economic incentive to use the stranded gas for production of ammonia at the centralized facility.

³⁰ <http://northernplainsnitrogen.com>

³¹ http://northernplainsnitrogen.com/PDF/APUC_NDSU_Final_Report_Ammonia_Plant.pdf

³² www.reuters.com/article/2012/09/26/us-column-kemp-usfertilizer-idUSBRE88POP620120926

³³ “Economics of using Flared vs Conventional Natural Gas to Produce Fertilizer: A Feasibility Study September 2012. <http://agecon.lib.umn.edu/>

³⁴ http://siteresources.worldbank.org/INTGGFR/Resources/pfc_energy_report_appendices.pdf

³⁵ http://www.eia.gov/forecasts/archive/aeo11/images/figure_86-lq.jpg

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With this finding the feasibility study was expanded in scope to consider if the proposed centralized ammonia facility could be economic using conventional (pipeline) natural gas. In their development of the cost issues involved in the construction of a centralized ammonia plant they made series of assumptions which are summarized in Table 4. There is, at least, one problem with the data shown in Table 4 and that is with the entry giving the natural gas requirement of 33 MMBTU/ton of ammonia.

This value indicates an acceptance of a plant efficiency out of step with the modern ammonia plants described above. The efficiency here is:

$$33 \times 10^6 \text{ BTU/ton} \times 1055.1 \text{ J/BTU} = 34.8 \times 10^3 \text{ MJ/ton NH}_3$$

$$1\text{-ton NH}_3 \times 907 \text{ kg/ton} \times 18.6 \text{ MJ/kg (LHV)} = 16.9 \times 10^3 \text{ MJ}$$

$$\text{Efficiency} = 16.9 \times 10^3 \text{ MJ} / 34.8 \times 10^3 \text{ MJ} = 48\%$$

The 48% efficiency is considerably less than the 68% efficiencies quoted by both Haldor Topsoe and Casale, see above.

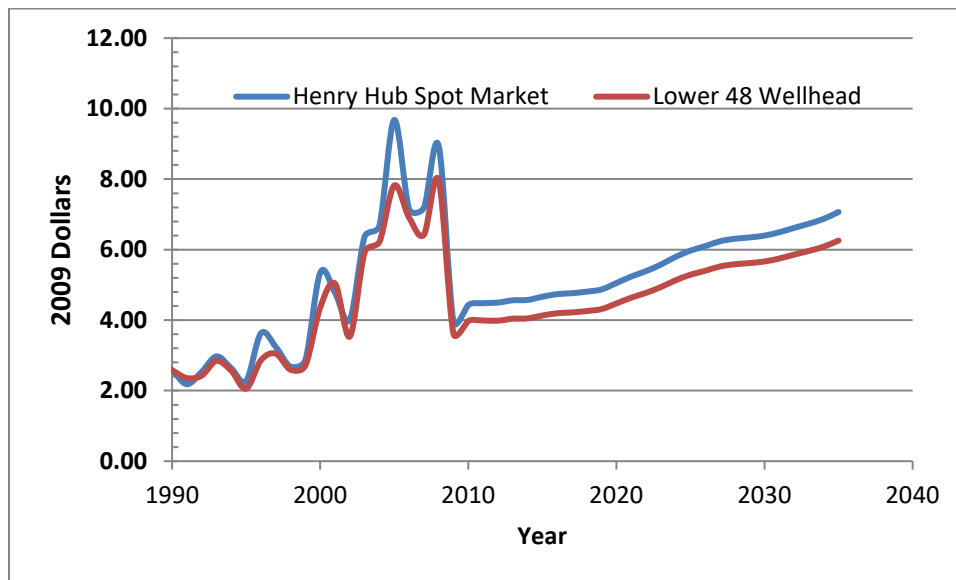


Figure 12: Annual Averaged Henry Hub Spot Prices & Wellhead Prices (Lower 48) for the Period 1990-2035

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Natural Gas Cost (\$/MMBtu)	5
Plant Efficiency Rate (%)	100
Electricity Cost (\$/kWh)	0.06
Electricity Requirement for Small Plant (kWh/ton)	950
Electricity Requirement for Large Plant (kWh/ton)	100
O&M Cost for Small Plant (\$/ton)	40
O&M Cost for Large Plant (\$/ton)	30
Natural Gas Requirement (MMBtu/ton)	33
Real Discount Rate (i) (%)	8
Lifetime Financing (n) (years)	20
Number of Operating Days	340

Table 4: Baseline Assumptions Used in Estimating Ammonia

Production Cost Issues

The study did go forward and calculate the capital costs for several differently sized ammonia plants. While these calculations are skewed owing to their lower than “normal” operating efficiencies, they are more or less uniformly displaced. Nevertheless, it is informative to look at their results as they give a competitive picture of ammonia plant realizations for North Dakota. Their results and additional comments are given in Table 5.

Plant Size		Capital Cost		Comments
Tons/year*	Tons/day	Total \$ Millions	<i>Capital Cost \$ millions per ton/day</i>	
3,400	10	24	2.4	<i>N-Flex LLC portable plant</i>
50,000	≈150	138	0.92	
516,000	1,500	630	0.42	<i>Near Great Plains capacity</i>
1 million	3,000	968	0.32	<i>≈A Haldor-Topsoe plant*</i>
1.5 million	4,400	1,261	0.29	<i>“The \$ billion plant”</i>
(* 340 day-year)				

Table 5: Cost Estimates for Various Sizes of Ammonia Plants³⁶

The 10 ton/day plant matches the plant size proposed by N-Flex LLC for distributed, portable plants, described in the next section. The proposed 1,500 ton/day plant approximates the capacity of the Great Plains coal gasification plant in operation in Beulah, North Dakota. The 3,000 ton/day plant is slightly larger than the plants featured by either Haldor-Topsoe or Casale. The 4,400 ton/day plant fits size promoted in the PR releases of Northern Plains Nitrogen consortium funding the feasibility report.

The feasibility report also included a reduction of the data to include a calculation of the levelized cost of ammonia production for each of the various sizes of ammonia plant given in

³⁶ Italicized values are added in this report.

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Table 5. Their calculations are given in Table 6. Several comments are in order on the Table 6 entries. The 3,400 ton/year plant has a cost basis that puts it outside of commercial consideration, *vide infra*. The 516,000 ton/year plant approximates the Great Plains plant in operation in Beulah, North Dakota. The 1 million ton/year plant is slightly larger than plants provided by Haldor Topsoe or Casale, so this size can be considered in contention for good practice of current technology. The largest plant would require a considerable engineering effort to bring on-line as it is larger than current plants. The choice of plant size would be dependent on a competitive position with present ammonia pricing. This comparison is given in the next section.

	Ammonia Plant Size (tons per year)				
	3,400	50,000	516,000	1 Million	1.5 Million
	\$/ton of Ammonia				
Capital Cost	721	281	124	99	86
Natural Gas Cost	165	165	165	165	165
Electricity Cost	57	57	6	6	6
O&M Cost	40	40	30	30	30
Total Ammonia Cost	983	543	325	300	287

Table 6: Baseline Levelized Cost for Ammonia Production by Plant Size

Anhydrous ammonia prices remain relatively high and are moving higher even though natural gas³⁷ prices remain at record low prices. Recent reporting of the cost structures for ammonia and natural gas prices are shown in Figure 13³⁸. The Gulf ammonia prices are a bit over \$550/ton. The process would be higher in North Dakota owing to transportation costs from the Gulf. The effect of transportation can be seen in the current pricing structure for fertilizers in Illinois, Figure 14.

³⁷ Natural is the defining variable cost item in ammonia manufacture.

³⁸ Weekly Fertilizer review for December 5, 2012. DAP + diammonium phosphate
<http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1393>

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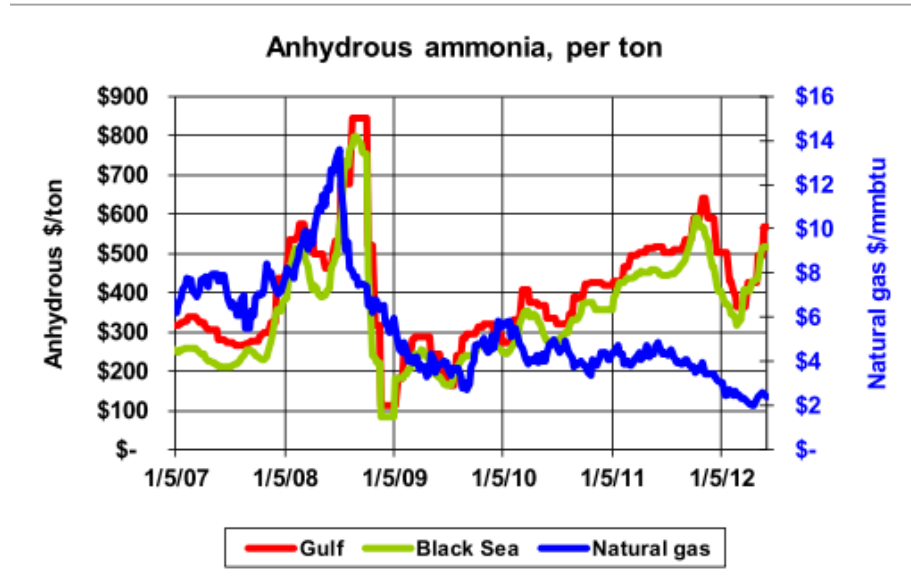


Figure 13: December Comparative Prices for Ammonia and Natural Gas

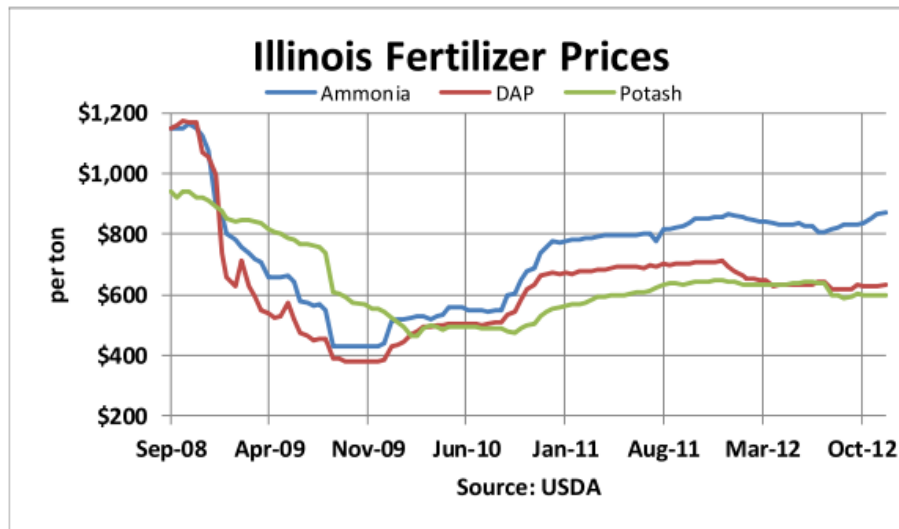


Figure 14: Illinois Fertilizer Prices 2008-2012

The transportation situation is not as simple as it would appear by comparison of the data in Figures 13 and 14. Transportation of ammonia need not be moved directly from the Gulf as there are ammonia production facilities and pipeline terminals in neighboring states to North Dakota. Nonetheless, it is clear from Table 6 that ammonia plant sizes equal to or greater than the 516,000 ton/year capacity should be profitable.

3.2 Summary: Large Scale Ammonia Plant Approach

The data would indicate that a reasonably large-scale ammonia plant sited near an existing natural gas pipeline should be a profitable enterprise in North Dakota or close thereto. The attractiveness of such a venture is re-enforced by the projections of continuing low natural gas

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process. However, the Northern Plains Nitrogen consortium would have to raise the considerable capital to fund a completely green field ammonia operation. As a *de novo* organization entering the ammonia production world they may be at a competitive disadvantage compared to veteran organizations in the business. Any competitive advantage that North Plains Nitrogen could hope to have would have to be evaluated considering the information in the next paragraph.

The low and probably sustained natural gas prices have not gone unrecognized by companies already in the ammonia business. Recently several companies have announced that they are re-starting existing ammonia plants especially in the natural gas rich areas in Louisiana³⁹ and neighboring states. Also, several new plant ventures have been announced in Louisiana, one by CF Industries; in the upper Mississippi River valley by Egypt's Orascom Construction Industries⁴⁰; CHS. Inc., a MN co-operative is planning a \$1 billion plant in ND (let's hope they're not eying stranded gas); also, both Norway's Yara and Canada's Agrium are planning plant expansions in North America.

Conclusion: The projected fairly long term low stable prices for natural gas should provide domestic ammonia producers a price advantage over nitrogen fertilizer imports in the coming years. This cost advantage could open the field for new producers especially those lying close to farming operations outside the present ammonia pipeline infrastructure particularly in the northern plains. These areas will become more favorable for corn agriculture as the climate change effects keep moving the growing zones northward. A more quantitative economic analysis would be required using one or more of the premier ammonia technology suppliers.

4. The Distributed Approach: N-Flex LLC (Agcelerator LLC)

Note: The following section needs to be considered as a case study rather than a concrete business proposal and/or plan as the company does not appear to be in existence any longer. Notice was given in April of 2014 that the enterprise has collapsed.⁴¹

4.1 Distributed Generation of Ammonia from Stranded Gas

4.1.1 N-Flex LLC, The Company

N-Flex LLC⁴², a New York based start-up, applied to the State of North Dakota for financial support for a project⁴³ designed to use stranded gas to produce ammonia on-site. The company presented a proposal to the state for a \$1.1 million grant as part of a \$4 million project to produce ammonia using skid mounted equipment. The proposal was evaluated by the state and a written report was issued⁴⁴. The proposal received a grade of 65% and was returned to the proposers for more information. It appears that the funders were satisfied and N-Flex received the \$1 million grant.

³⁹ Potash Corp at its plant in Geismar LA

⁴⁰ <http://cen.acs.org/articles/90/i46/Big-Bet-Nitrogen-Fertilizer.html>

⁴¹ <http://www.naturalgasintel.com/articles/97955-fertilizer-as-flaring-cure-flames-out-in-north-dakota>

⁴² Also listed as Agcelerator, this report will use N-Flex LLC as the interested entity

⁴³ <https://cms.oilresearch.goc/image/cache/G027-09.pdf>

⁴⁴ <https://www.dmr.nd.gov/ogr/Secure/ReviewSummary.aspx?ProjectId=389&Submitted=1>

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The company's management includes a boutique venture capitalist⁴⁵; a financial person, located in New York; a chemical engineer from the Netherlands, associate of the ammonia technology company; a retired executive from CR Industries, a major ammonia producer; an executive from Arysta North America, a crop science company; and, a chemical engineer out of Chevron with expertise in flared gas. There is no doubt that the company has the management expertise to carry through on the project.

The company's proposed project budget is shown in Table 7. The 18-month budget is shown for a couple of reasons: 1: It probably does not represent either a realistic dollar amount or reasonable timeline. There does not appear to be any recognition of the severity of winter weather in North Dakota. 2. The equipment procurement for skids designed and built in the Netherlands is probably reasonably costed as the developer is on the team. However, this issue, while perfectly reasonable given the state of the technology... (It is new folks.) was one of the strongest objections made by the reviewers on the proposal. This could lead to some harsher criticisms from the clients (the State) if schedules slip, as they will.

Associated Gas to Ammonia Production							
18 Month Project: Capture and convert well gas into ammonia on a distributed basis							
Project Associated Expense	Total	NDIC	%	Accelerator Cash	%	Accelerator In-Kind	%
N-Flex Unit Equipment	\$ 3,100,000	\$ 1,100,000	35%	\$ 2,000,000	65%	\$ -	0%
Shipping Equipment	\$ 50,000	\$ 0	0%	\$ 50,000	100%	\$ -	0%
Gas/Liquid Treatment Equipment	\$ 400,000	\$ 0	0%	\$ 400,000	100%	\$ -	0%
Site permits / preparation	\$ 25,000		0%	\$ 25,000	100%		
Installation / Adjustment	\$ 25,000		0%	\$ 25,000	100%		
Operator & Maintenance	\$ 100,000	\$ -	0%	\$ 100,000	100%	\$ -	0%
Engineering and Mgmt. Consultants	\$ 100,000	\$ -	0%	\$ 100,000	100%	\$ -	0%
Internal staffing	\$ 200,000	\$ -	0%	\$ -	0%	\$ 200,000	100%
TOTAL	\$ 4,000,000	\$ 1,100,000	27.5%	\$ 2,700,000	67.5%	\$ 200,000	5%

Table 7: N-Flex' Budget for Ammonia Technology Demonstration

4.1.2 The Proposed Technology

The company has formed a joint venture with Proton Ventures BV (Proton) of the Netherlands. Proton Ventures is a company that proposes to use renewable energy, wind energy, to electrolyze water to produce hydrogen. In Proton's case, it is proposed to use the hydrogen to make ammonia. The proposed process is designed to store "excess" wind energy as ammonia, which is a useful fertilizer commodity.

⁴⁵ Paul Batcheller sits on the board of ZeaChem, a biofuel company which just started a cellulosic ethanol plant in OR. Also on this board are Erik Strasser, our friend from Mohr Davidow and Martin Lagod, our friend from Firelake.

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Proton⁴⁶ has adapted the Casale ammonia process for small scale skid mounted units for production of 120 kg/hour of ammonia or roughly 3+ ton⁴⁷/day or about 1,000 ton/year. This amount of ammonia should be able to cover about 10,000 acres at 200 lb/acre for a growing season. Since the ammonia is applied, at most, 2 times in a season, considerable ammonia storage facilities would have to be included at each generation point.

This mini-ammonia plant has been designed to work with electrolytic hydrogen, an easier starting material for ammonia synthesis compared to natural gas. With natural gas the skid would need to include unit operations for sulfur removal, gas liquids separation⁴⁸ compressor, the methane steam reformer unit, and a methanation reactor to remove last traces of CO and CO₂ before feeding into the reactor with nitrogen to form ammonia. These additional unit operations add complexity to the skid operation. While, this approach has been stated in Proton's presentations, there is no indication that the package has been assembled and operated.

4.1.3 The N-Flex Arithmetic: Does it work?

The N-Flex LLC proposal⁴⁹ proposes to build 3.3 ton/day ammonia mini-plants using an estimated 142 MCF⁵⁰/day gas stream, which, when stripped of the natural gas liquids, propane and butane, results in a methane feed stream of 100 MCF/day. This 100 MCF/day stream would be then used to feed the mini-ammonia plant. Does this arithmetic work?

First, 140 MCF/day is reduced to 100 MCF/day by removal of NGLs (butane & propane) then:

Energy in to ammonia system⁵¹

$$100 \times 10^3 \text{ ft}^3/\text{day} \times \text{m}^3/35.3 \text{ ft}^3 = 2.83 \times 10^3 \text{ m}^3/\text{day} \times 35.22 \text{ MJ/m}^3 = \approx 100 \times 10^3 \text{ MJ}$$

Energy recovered as ammonia

$$3.3 \times 2,000 \text{ lb/day} \times \text{kg}/2.2 \text{ lb} = 3.0 \times 10^3 \text{ kg} \times 18.6 \text{ MJ/kg (LHV)} = 56 \times 10^3 \text{ MJ}$$

Thus, the process runs at approximately 56% efficiency, at best.

As proposed, the N-Flex LLC stranded gas to ammonia system would operate with an efficiency around 50%. Given that the resource would be wasted (flared) without this recovery process, the technology looks like it has some potential to make a positive impact for North Dakota. Note, however, all of the carbon contained in the process gas is still released as CO₂.

⁴⁶ H. Vrijenhoef et, al., 8th Annual Ammonia Fuel Conference, Portland, OR 2011.

⁴⁷ Short ton, 2,000 lbs

⁴⁸ The gas liquids, propane and butane, would not need removal as they are also allowable feed for the steam reformer. However, as they have an economic value greater than the methane (and ethane) feed, their separation probably pays for itself.

⁴⁹ <https://cms.oilresearch.nd.gov/image/cache/G027-09.pdf>

⁵⁰ MCF = 1,000 ft³ of gas

⁵¹ These sample calculations are estimations. The MCF values for natural gas are for gas at 60 F and 14.73 psi (1 atm); the SI numbers assume 0 C and 1 atm (101.325 kPa).

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4.1.4 Reliability of Stranded Gas as a Fuel Source

The concept of using the stranded gas on a distributed basis assumes that the stranded locations can provide a steady and reliable source of the gas. We know that the total flow of the stranded gas is quite large although decreasing with time, see Figure 2, above. However, does this still large flow translate down uniformly to the individual sites where a N-Flex unit would be sited? It would appear from the data that the individual gas sources in the Bakken field have production curves which look like the very familiar generation profile from a collection of many individual wind generators, see Figure 15⁵².

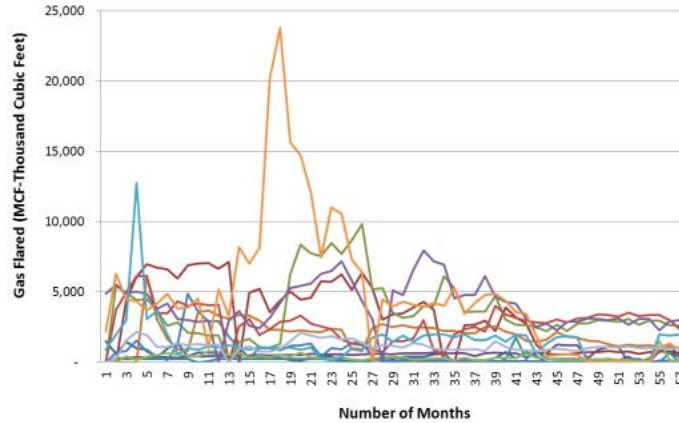


Figure 15: Flare Gas Flows Based on 13 Oil Well Observations

Though an individual gas well, at a given time, may produce the quantities of gas needed by the N-Flex ammonia module, an individual well's flow stream is neither steady nor reliable over time. All of the gas production outputs at the wells shown in Figure 15 drop to fairly low levels as the production process proceeds over the many months. While the N-Flex technology is meant for distributed operation, the equipment required is not terribly portable as indicated by the N-Flex conceptualization of the system as shown in Figure 15⁵³ even if, as N-Flex contends, that the actual skids would be smaller. Portability to chase producing wells would be an logistical issue and a permitting nightmare.

⁵² Reference 30, page 5

⁵³ Reference 41, page 10

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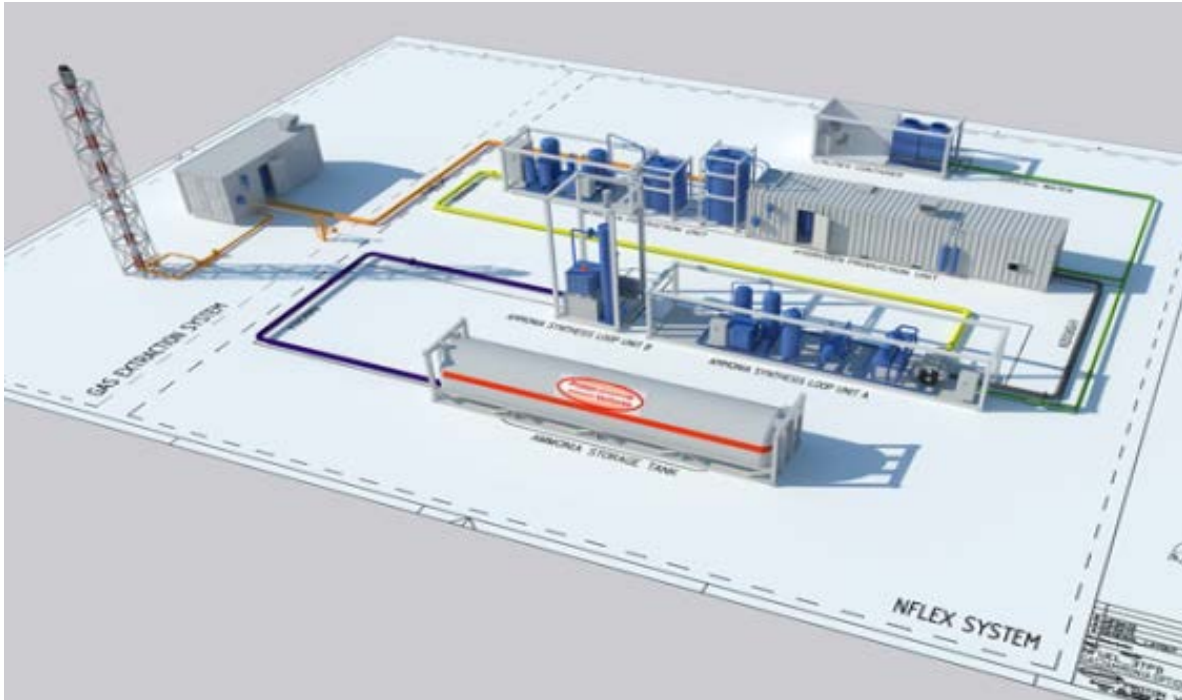


Figure 16: Conceptualization of the N-Flex Distributed Ammonia Mini-plant

Conclusion: The concept of using a distributed processing technology to beneficially use the stranded gas at the well heads in the Bakken field is viscerally satisfying. However, it would appear that the chaotic nature of gas production at an individual well site may not support the installation of the processing equipment for sufficient time to be productive or profitable.

Further, there does not appear to be any economic data provided to get an idea of the costs involved in fielding the process equipment. The only number for an ammonia plant of this size has been provided by the feasibility study done for the large fixed site operation discussed above. Table 6 puts the cost of ammonia produced at a plant having a production of 3,400 tons/year at \$983/ton of ammonia produced. This value is up to several hundred dollars higher than the present price of the ammonia. This looks like it is a non-starter.