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A National Renewable Ammonia Architecture

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Update May 15, 2009. *Please note that an updated expanded version has been published on the strandedwind website. An Oil Drum summary of the new version can be found here.*

This white paper describes the current manufacture and uses of ammonia as well as describing a path forward to a fully renewable future for this vital fertilizer ingredient. The primary author and editor is Neal Rauhauser, known on TOD SacredCowTipper, with assistance in its development rendered by Dave Bradley, known as nb41, Bryan Lutter, known as CropDuster, Larry Bruce, and others.

Ammonia Production Methods Today

It can be argued that ammonia is perhaps the most critical manmade substance to the existence of human society. Without continuing agricultural growth, the world's expanding population faces famine and the concomitant breakdown of civil society. The expansion of population and modern society is based on fertilizer driven agriculture...and modern nitrogen fertilizer is ammonia. Traditional agricultural strategies of slash and burn, fallow fields and crop rotation were gradually replaced in the 19th century by fertilizer from the mining of nitrates and harvesting of guano deposits. At the dawn of the 20th century, the end was in sight for Chilean nitrate deposits and there was growing concern that a worldwide famine would ensue. The discovery of ammonia synthesis by Fritz Haber and subsequent commercialization by Carl Bosch in 1910 freed the human race of the need to worry about a source of nitrogen fertilizer for a century.

The Haber Bosch process requires only pure nitrogen, pure hydrogen, and a high pressure reactor with a catalyst in order to produce ammonia. The nitrogen is free for the taking from the air but hydrogen, no matter what method we use to obtain it, involves the use of energy. The primary sources for the hydrogen used in ammonia manufacture today are natural gas and coal. There are an increasing number of petroleum coke projects in development, and a handful of remaining hydroelectric facilities built forty to sixty years ago.

Natural gas is the cleanest high volume production method used today, generating only about two tons of carbon dioxide for every ton of ammonia produced. Just as oil fields deplete, natural gas resources are being depleted as well. The year 2007 saw the closure of the Agrium facility in Kenai, Alaska due to natural gas depletion, the impending conversion of Rentech's East Dubuque facility to coal from natural gas, and the Farmland Chemicals plant from Lawrence, Kansas resuming operation after being dismantled and reconstructed in its new location in natural gas rich Oman.

Natural gas supplies are certain to decline in the long term...and in the short term the price will be unpredictable. Coal is plentiful, petroleum coke is also readily available, but the carbon in these fuels is used in a gasification process to strip hydrogen from water will result in a tremendous expansion of CO_2 emissions. Coal based production emits about four tons of carbon dioxide per ton of ammonia and petroleum coke produces a bit more than that. All planned new production both domestically and globally seems to be coal gasification based. Carbon dioxide figures are uncertain as plant efficiency can have significant (25% or more) influence on overall output, but they are a good first approximation for estimates of national or global scope.

Global Ammonia Production Emissions

Global ammonia production is about 69% natural gas and 29% coal. One petroleum coke system is in operation today and three legacy hydroelectric facilities nearing end of life contribute about 1.5% of the total global production of 131 million tons.

The 90 million tons of ammonia produced annually with natural gas release 180 million tons of carbon dioxide. The 38 million tons of ammonia produced with coal released an estimated 152 million tons of carbon dioxide. The total 332 million tons of emissions are 7.3 % of the estimated 4,500 million tons of worldwide emissions of CO_2.

Given that natural gas supplies are fragmented and depleting quickly it is reasonable to assume that existing natural gas based ammonia plants could be converted to coal gasification in an emergency. Should this happen ammonia related carbon dioxide emissions would climb to 524 million tons which would equal 11.6% of the 4,500 million tons humans already add to the atmosphere.

Ammonia In Domestic Agriculture

Fully half of all human protein comes from man made ammonia. Plants require nitrogen to produce protein and ammonia is the only viable source for large scale nitrogen applications. The United States uses about 18.5 million tons of ammonia annually from the global production of 131 million tons. 90% of this is used in agriculture. Over the last forty four years of statistics corn has averaged nearly 44% of the total, wheat almost 14%, and the remaining 42% of agricultural use is spread among all other crops.

American farmers planted 86 million acres of corn and 65 million acres of wheat in 2008.Corn fertilization averaged 170 pounds of ammonia per acre and wheat received 72 pounds per acre. Yields averaged 154 bushels per acre for corn and 36 bushels per acre for wheat.

Fertilization rates are given in ammonia equivalents. Depending on the crop, producer preference and availability, ammonia can be applied in various compounds. Actual usage by volume of nitrogen was anhydrous ammonia (59%), urea (27%), a mixture of urea and ammonium nitrate known as UAN (9%), and the remainder were various specialty forms of fixed nitrogen such as ammonium phosphate compounds.

Properly fertilized wheat will yield fifty to sixty bushels an acre while alternating fallow cultivation methods will struggle to produce just a little more than half that amount. Protein content is also a concern – hard red spring wheat will have up to 17% protein when fertilized and as little as 9% if not. Many farmers didn't fertilize in the fall of 2008 due to the difference between grain price and ammonia price which may mean a 50% reduction in total yield and a a 40% reduction in protein in what is harvested. If this has happened to farmers in all of the large wheat exporting nations, and we believe it has, it's a recipe for collapsing governments all over the developing world.

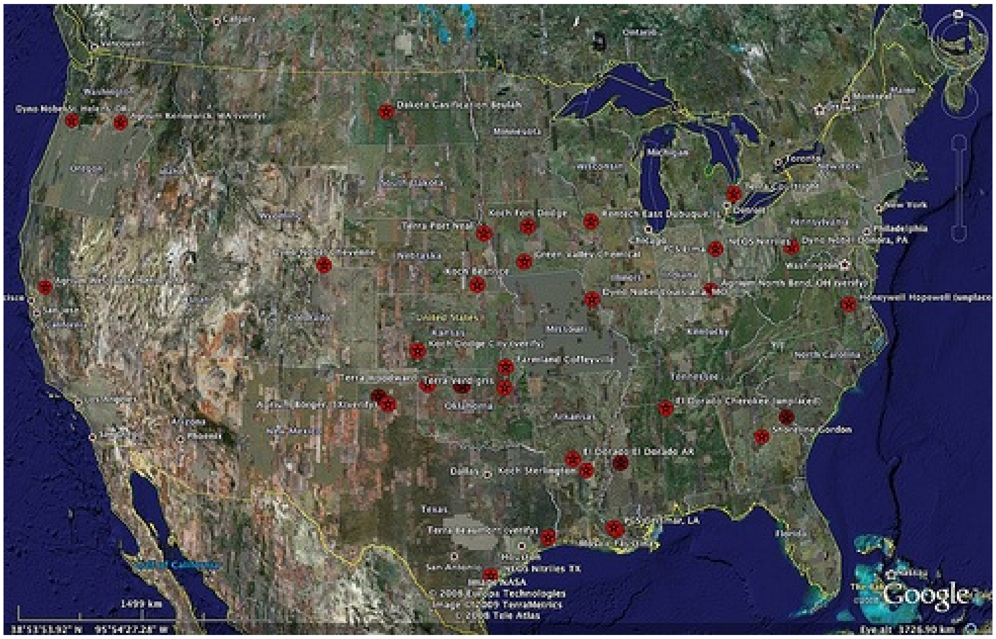
The corn crop is raised primarily for its starch content and protein is not closely tracked. A sudden reduction in ammonia based fertilizer input here will have the same yield effect as is seen with wheat – a sudden plunge to about half of the current average.

Domestic Ammonia Production Facilities

These 29 locations are ammonia plants either operating or, in the case of the recently idled Agrium Kenai facility, in good enough condition to be returned to service. Many of these plants are not purely ammonia production but instead operate in conjunction with follow on fertilizer manufacturing or are involved in the production of derivative industrial products such as nitric acid. All capacity figures are in thousands of tons of ammonia per year.

Owner	Location	Capacity
Agrium	Borger-TX	490
Agrium	Kenai-AK	280
Agrium	Kennewick-WA	545
CF Industries	Donaldsonville-LA	2040
Coffeyville Resources	Coffeyville-KS	375
Dakota Gasification	Beulah-ND	363
Dyno Nobel	Cheyenne-WY	174
Dyno Nobel	St. Helens-OR	101
Green Valley	Creston-IA	32
Honeywell International	Hopewell-VA	530
Koch Nitrogen	Beatrice-NE	265
Koch Nitrogen	Dodge City-KS	280
Koch Nitrogen	Enid-OK	930
Koch Nitrogen	Fort Dodge-IA	350
Koch Nitrogen	Sterlington-LA	1110
LSB Industries	Cherokee-AL	159
LSB Industries	Pryor-OK	300
Mosaic Company	Donaldsonville-LA	508
PCS Nitrogen	Augusta-GA	688
PCS Nitrogen	Geismar-LA	483
PCS Nitrogen	Lima-OH	542
PCS Nitrogen	Memphis-TN	371
Rentech Energy	East Dubuque-IA	278
Terra Industries	Beaumont-TX	231
Terra Industries	Donaldsonville-LA	360
Terra Industries	Port Neal-IA	336
Terra Industries	Verdigris-OK	953
Terra Industries	Woodward-OK	399
Terra Industries	Yazoo City-MS	454
Total		13945

U.S. Ammonia Facilities Excluding Alaska



This is a link to the Google Earth file that was used to produce the map image you see. Clicking individual site markers will lead to the given company's web page associated with the site, should I have been able to locate one. Koch and Terra are particularly forthcoming regarding what their plants actually produce.

Domestic Ammonia Economics

Domestic ammonia production was 10.7 million tons in 2007 and the USGS states that plants were running at 84% capacity, I list the Agrium Kennewick facility which is easily locatable both via Google Earth and web searches but it did not make the USGS plant list for that year. Capacity and production figures are not exact and I attribute this to overall market instability – plants were on and off based on commodity prices.

2007 imported ammonia totaled 7.9 million tons. Major suppliers were Trinidad (55%), Russia (21%), and Canada (12%). The price at port is stated to be $339/ton indicating a transfer of $2.7 billion overseas. 2008 prices were dramatically higher and wealth transfer was perhaps double this amount.

Trinidad, supplier of over half of our total imports, had reserves of 30.7 trillion cubic feet (~17 Tcf proven, 7.8 Tcf probable, 5.9 Tcf possible) of natural gas in 2004 and usage was just under a trillion cubic feet a year. Many additional industrial plants meant to use the inexpensive gas and labor in this Caribbean country were planned to come online between 2008 and 2010. A 2004 IMF study indicates that Trinidad would exhaust its reserves within ten years of these plants becoming active. The global economic recession should slow domestic industrial consumption but liquid natural gas exports will ensure an ongoing drawdown of reserves. Russian exports are subject to rising geopolitical tensions. TOD contributor Jon Freise has published a report indicating that Canadian natural gas is on a path to negative EROI within the next six years.

The three largest ammonia import sources are all under different stresses and will all fail within at most a decade, cutting the United States off from 88% of current imports. This alone will amount to a reduction in ammonia supplies in the continental United States of about 36%. Domestic natural gas fueled manufacturers face similar issues.

National Ammonia Independence

The United States can and must achieve national ammonia independence by a mix of refurbishing existing plants and construction of new renewable production facilities.

Existing facilities could produce about 14 million tons of ammonia annually and would require 2.5 million tons of hydrogen to do this. This hydrogen, current produced from a mix of natural gas and coal gasification could be replaced with electrolytically produced hydrogen.

Using current electrolyzers 6,300 two megawatt units would be required and assuming 8,760 hours of operation annually 12,500 megawatts of continuous power would be needed to fully replace hydrogen derived from fossil fuels. A scheme to buffer renewably produced hydrogen output would enhance the flexibility of such a configuration but at this time the best buffer seems to be just getting on with the process of making ammonia. Even so, the Louisiana ammonia plants may have access to nearby salt domes which would allow the creation of solution mined caverns capable of storing large volumes of hydrogen, a configuration that would naturally complement the large amount of wind resources available on the Texas plains.

Imports total 7.9 million tons. Based on business planning done by Third Mode Energy we calculate that this volume of production could be covered by 7,900 megawatts of continuous power and a $25 billion investment in Haber Bosch style plants. Assuming $0.04/kwh electricity resulting in an annual cost of $2.8 billion the physical plant costs could be recouped in ten to fifteen years given the ammonia pricing we saw in 2008. Hydroelectric or nuclear are the only clean power sources steady enough to drive this process today. We believe there is a simple route to a system that would work with a hybrid wind and base load power source but this likely uneconomical; why would anyone build a wind driven plant to run 85% of the time and only achieve 40% of capacity when the same equipment could be installed near a hydroelectric facility and produce 100% of the time?

Immediate construction of renewable ammonia facilities based on the very well known Haber Bosch process should begin at once but funds must be directed to promising new synthesis methods as well. Solid state ammonia synthesis (SSAS) promises capital costs that are half of the Haber Bosch systems, power costs that are perhaps 25% less, and the ability to build plants a tiny fraction of the size of a Haber Bosch plant, making it suitable for use with power sources as small and as variable as a single utility scale wind turbine.

Renewable Electric Sources

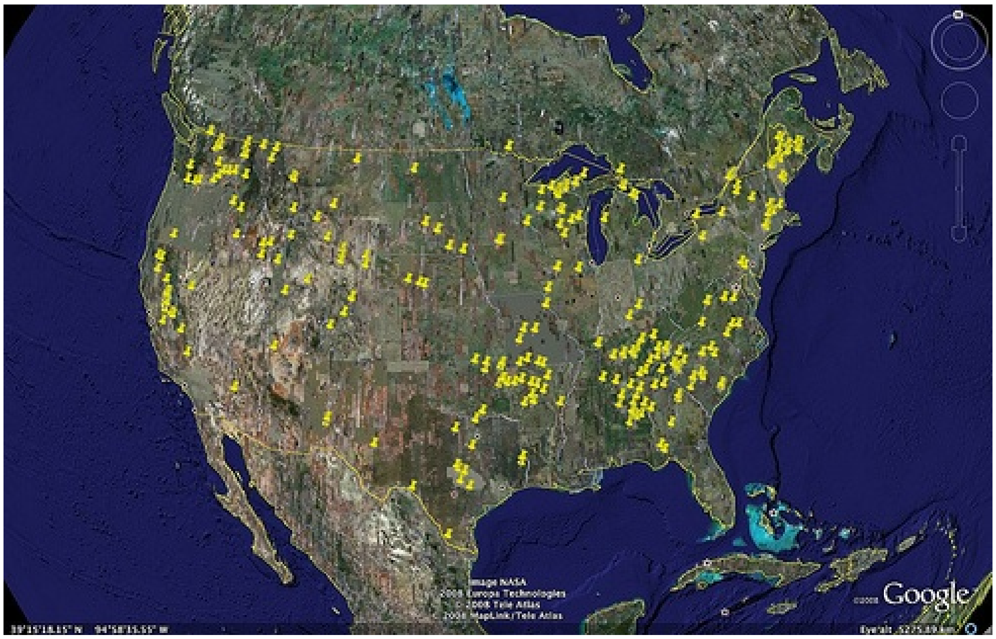
Ammonia can be produced by a completely carbon free process that releases no greenhouse gases. What is needed is renewably generated electricity at a relatively low cost, air and water.

Hydroelectric power for ammonia.

The United States Department of the Interior maintains a national inventory of dams – a database of over 8,800 locations in the United States with information regarding their purpose.

This map and associated Google Earth file show 352 locations with either an impoundment in excess of eight square miles or a run of river installation. There is a negative correlation between good cropland and the elevation changes needed for good hydroelectric power. Hydroelectric power in the $0.02/kwh to $0.04/kwh range will yield ammonia in the $350 to $500/ton range.

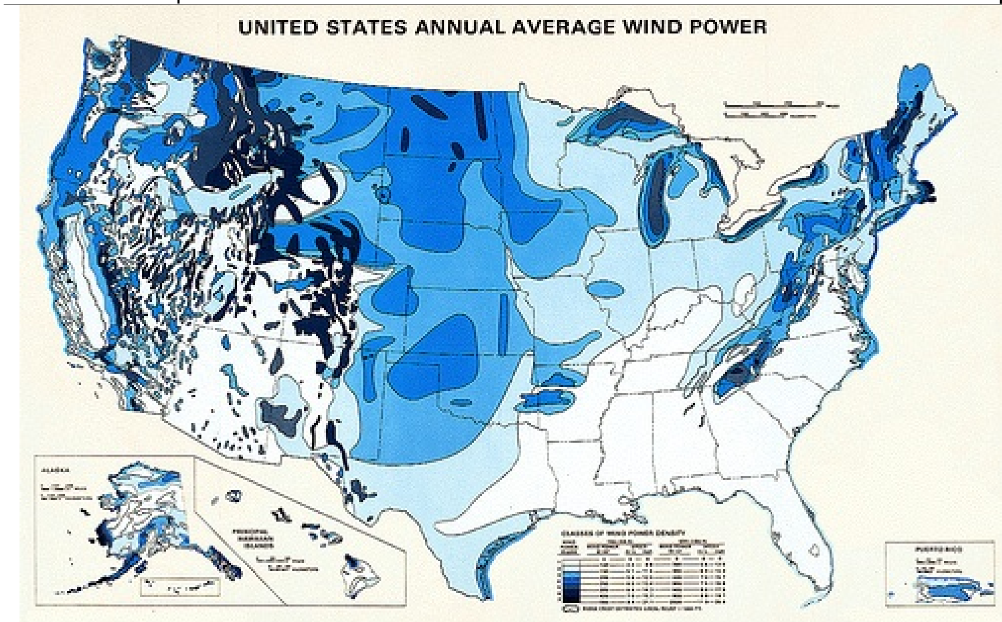
Run Of River Or Impoundments Greater Than 5,120 Acres



Wind power for ammonia

There is excellent correlation between national wind resources and the wheat growing states of North Dakota, South Dakota, and Kansas. The corn growing states of Iowa, Illinois, Kansas, Nebraska, and Minnesota have good wind resources in their own right and usable rail links to the wind rich Dakotas. Assuming the wind intermittency problem can be remedied, either by the mastery of the solid state ammonia synthesis process or the creation of a grid footprint large enough to ensure continuous production, a wind energy based ammonia production industry can be envisioned. 7,900 2.5 megawatt turbines each with a 40% capacity factor would produce the electricity needed to cover the anticipated import deficit.

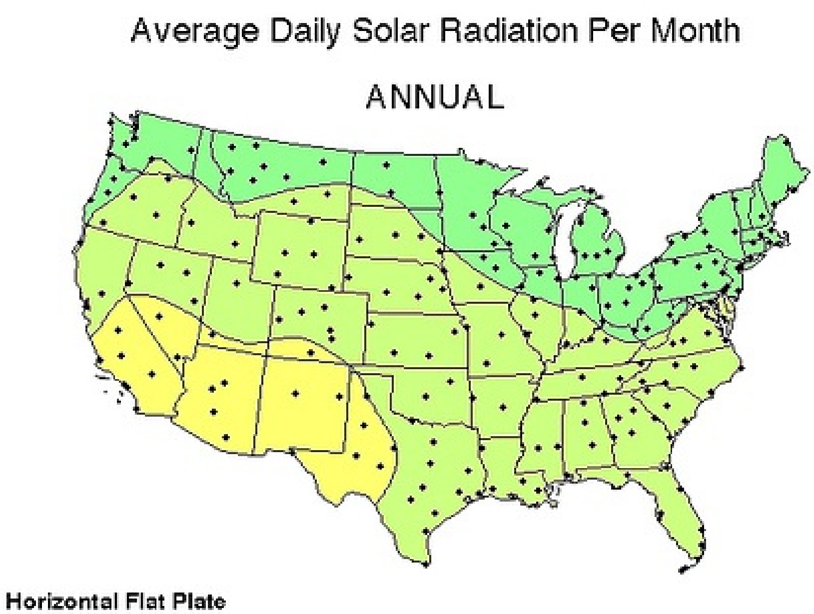
National Wind Energy Map



Solar power for ammonia

Solar PV costs are too high for ammonia production based on current technology, but solar ammonia has potential.. A clever concentrated solar storage process using ammonia is in the pilot phase at the Australian National University but at this time there is no commercially deployable ammonia synthesis solution tuned for the sunny, relatively windless American southwest. A concentrated effort to develop such a thing would permit ammonia manufacture in that region, creating a domestic bilateral energy/food circuit in place of a similar trade arrangement with less friendly parts of the world.

National Solar Energy Map



Conclusions

As this report is based on public information in the midst of tremendous stress on farmers, cooperatives, and lending institutions in agricultural areas, it is certain to have missed some of the details. The big concern is that the foundations of it are correct and defensible. We look forward to the insightful comments from TOD's community.