TWO FARM BILL RESEARCH INITIATIVES PROMISE NEW MARKETS, TRANSMISSION, AND FIRMING STORAGE FOR DIVERSE, LARGE-SCALE, STRANDED RENEWABLES AS HYDROGEN AND AMMONIA

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ABSTRACT

Two research initiatives in the USA 07 Farm Bill, Senate floor passed version, promise an important thorough exploration of new sources and markets for hydrogen, and new transmission and firming storage systems, for diverse, large-scale, stranded renewable energy resources. As of 18 April 08, the Senate-House farm bill conference committee is meeting; whether these initiatives will be retained and funded is unknown.

Section 9019: RURAL NITROGEN FERTILIZER STUDY. Anhydrous ammonia (NH_3) would be produced from hydrogen produced from electricity generated by solar, wind, and other renewables, and from atmospheric nitrogen. NH_3 is a carbon-free transmission and storage medium for agricultural fertilizer, vehicle fuel, and distributed generation of combined heat and power (CHP), with high hydrogen energy density. It can be economically transported as a liquid in common steel pipelines, and stored in large, above-ground steel tanks; this infrastructure already exists. About 30,000 MW of nameplate renewable energy generation would be needed to produce USA's total present ammonia consumption, ~60% of which is imported. The internal combustion engine (ICE) runs on ammonia, at very high efficiency. This research initiative directs the Secretary of Agriculture to convene a task force to plan accelerated commercialization.

Section 9022: RESEARCH AND DEVELOPMENT OF RENEWABLE ENERGY. Directs funding to the "Colorado Renewable Energy Collaboratory" of NREL, University of Colorado, Colorado State University, and Colorado School of Mines. It could, in principle, include funding and intent to begin work on building a pilot plant hydrogen pipeline system, a Renewable Hydrogen Transmission Demonstration Facility, which would demonstrate the technical and economic feasibility of gathering, transmission, annual-scale firming storage, and delivery and end use of gaseous hydrogen (GH2) fuel, via pipelines and solution-mined salt caverns.

1. INTRODUCTION

Diverse, large-scale, stranded renewable energy resources ("renewables") can be gathered and delivered to distant markets without any expansion of the electricity transmission "grid". The world's richest renewable energy resources – of large geographic extent and high intensity – are stranded: far from end-users with no gathering and transmission systems to deliver the energy. The energy output of most renewables varies greatly, at time scales of seconds to seasons: the energy capture assets thus operate at inherently low capacity factor (CF); energy delivery to end-users is not "firm". New electric transmission systems, or fractions thereof, dedicated to renewables, will suffer the same low CF, and represent substantial stranded capital assets, which increases the cost of delivered renewable-source energy.

At gigawatt (GW) scale, renewable-source electricity from diverse sources, worldwide, can be converted to hydrogen and oxygen, via high-pressure-output electrolyzers, with the hydrogen pipelined to load centers (cities, refineries, chemical plants) for use as vehicle fuel, combined-heat-and-power generation on the retail side of the customers' meters, ammonia production, and petroleum refinery feedstock. The oxygen byproduct may be sold to adjacent dry biomass and / or coal gasification plants. New, large, solution-mined salt caverns in the southern Great Plains, and probably elsewhere in the world, can economically store enough energy as compressed gaseous hydrogen (GH2) to "firm" renewables at annual scale, adding great market and strategic value to diverse, stranded, rich, renewable resources. Figures 1 - 3. For example, Great Plains, USA, wind energy, if fully harvested and "firmed" and transmitted to markets, could supply the entire energy consumption of USA. If synergistically combined with solar energy, gathered, transmitted, and delivered as hydrogen, about 5 - 10,000 new solution-mined salt caverns would be required, at an incremental capital cost to the generation-transmission system of ~ 5 – 8 per cent, for this annual-scale firming of the entire USA energy supply. The salt cavern storage industry is also mature; several GH2 storage caverns have been in service for over twenty years; construction and O&M costs are well understood.

Alternatively, renewable-source hydrogen can be stored and transported as NH_3, which can be readily produced in an exothermic synthesis step following electrolysis using nitrogen (N2) from the air. NH_3 synthesis consumes energy comparable to compression of gaseous hydrogen, and less energy than liquefaction of hydrogen; it requires additional capital equipment and O&M costs for N2 supply and NH_3 synthesis. Figures 4 - 6.

Ammonia contains no carbon; has physical properties similar to propane; liquefies at ambient temperatures at about 10 bar or at -28 degrees C at 1 atmosphere. Liquid ammonia has over 50% more volumetric energy than liquid hydrogen; more than twice the volumetric energy of hydrogen gas at 700 bar.

We consider producing NH_3 from wind using hydrogen from water electrolysis and nitrogen from the atmosphere, storing it in large-scale tanks, and delivering it either as nitrogen fertilizer or as fuel for vehicles and fuel cells, via pipeline, truck, rail, and barge, consistent with well-established global industry practice. Economical, large-scale storage of GH2 in deep, solution-mined salt caverns, and of NH_3 in liquid tank storage could firm Great Plains wind at annual scale, adding great strategic and market value.

The USA uses 15-20 million tons of NH_3 and NH_3-based fertilizer per year. Over half is imported from countries where fossil fuels (largely stranded natural gas (NG)) are used in the NH_3 production process, releasing enormous amounts of CO2 into the atmosphere. The USA Senate 07 Farm Bill included research initiatives for "renewable nitrogen fertilizer" and for "...storage and conversion technologies for wind- and solar-generated power..." , which could include both GH2 and NH_3, for both fertilizer and fuel.

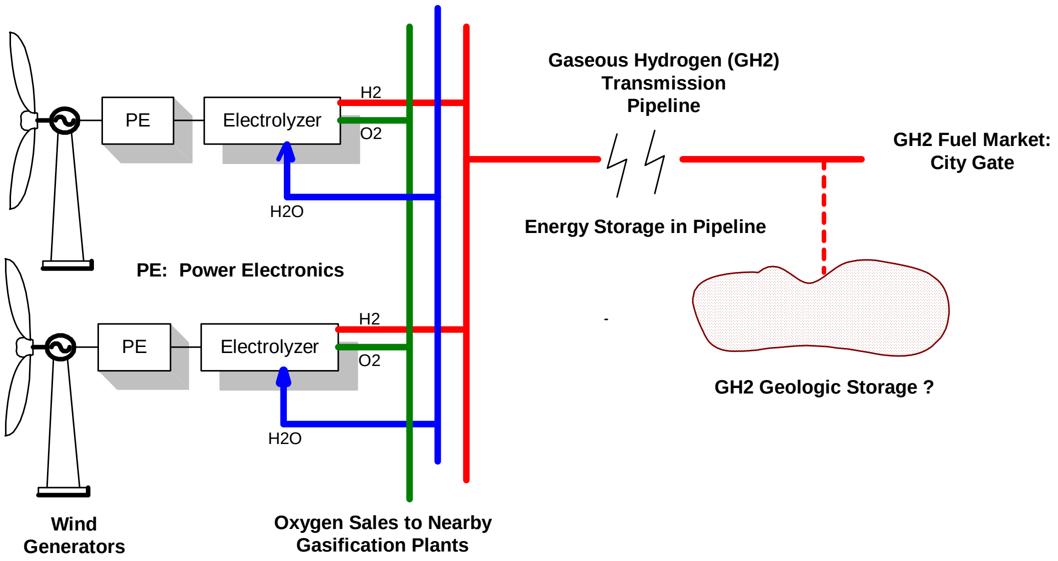


Figure 1. Generation, conversion, gathering, firming storage, and transmission of diverse renewable resources. Hydrogen can be transported and stored or used to make ammonia.

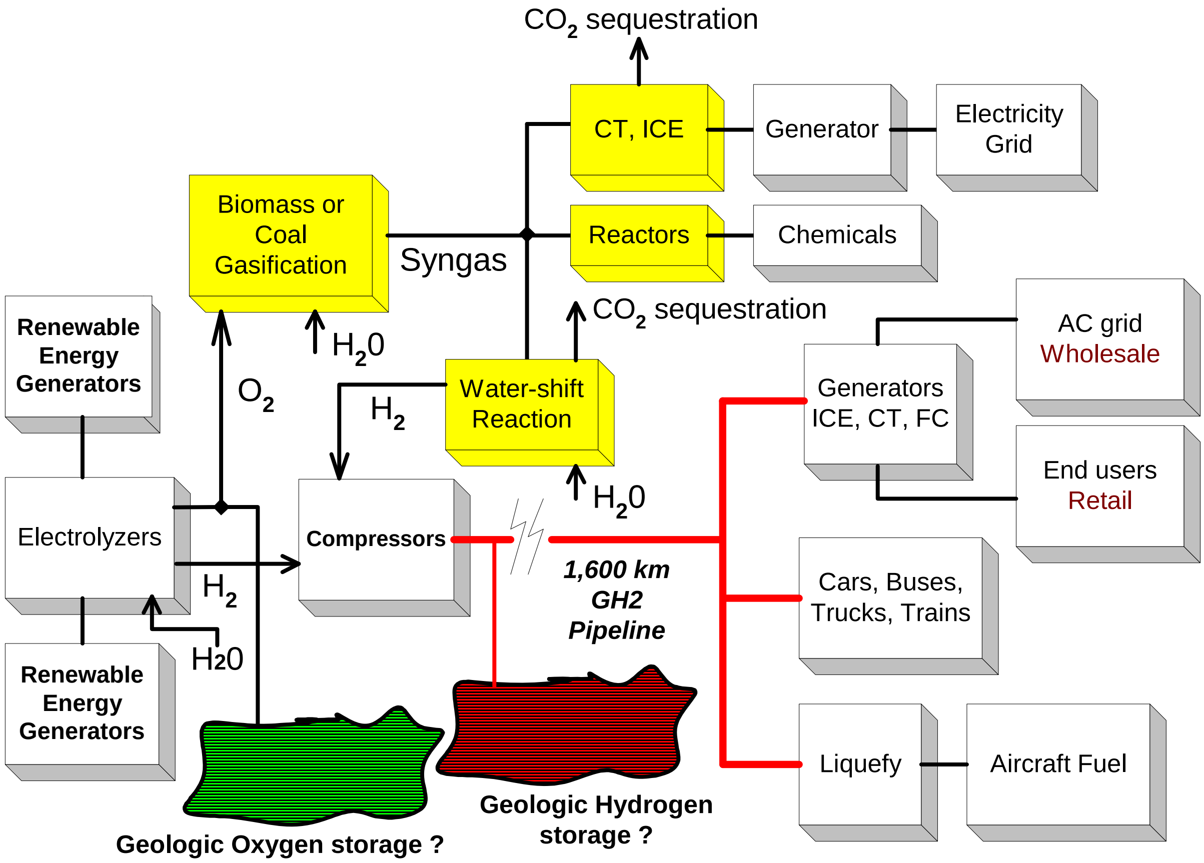


Figure 2. Hydrogen system options: compression and oxygen byproduct use at adjacent gasification plants. High-pressure-output electrolyzers could eliminate compressors.

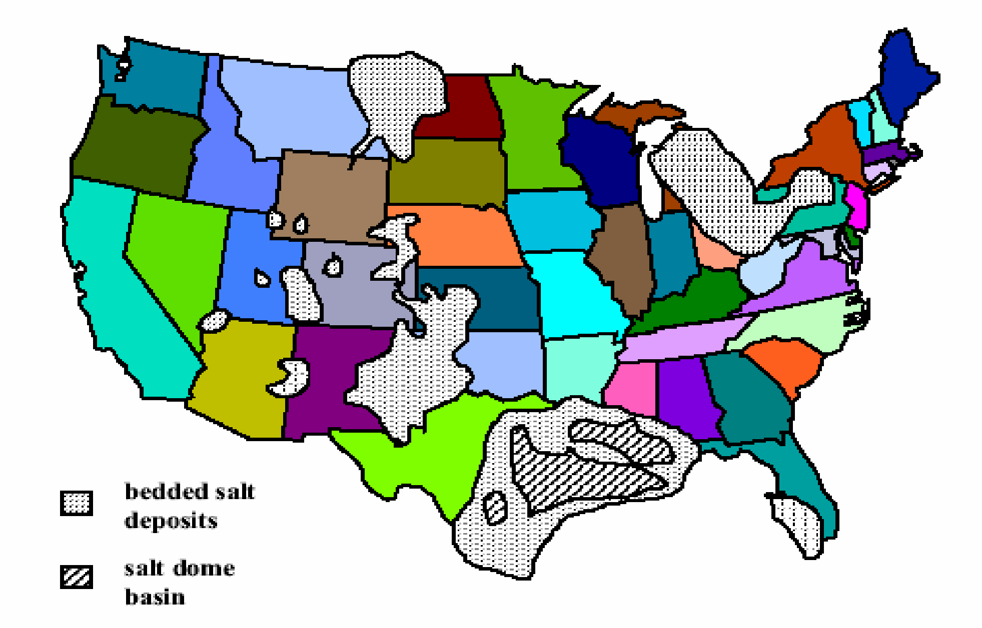
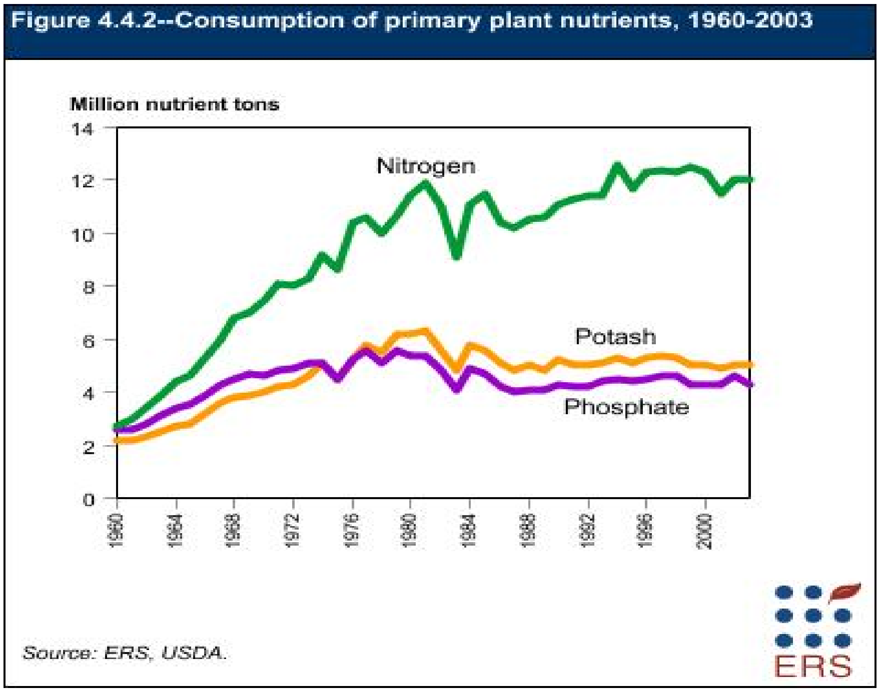


Figure 3. “Domal” and “bedded” salt deposits; some are useful for cavern storage of GH2.



Source: ERS, USDA.

Figure 4. Primary agricultural fertilizer consumption. “Nitrogen” is anhydrous ammonia and other products made from it: urea, ammonium nitrate, ammonium sulphate.

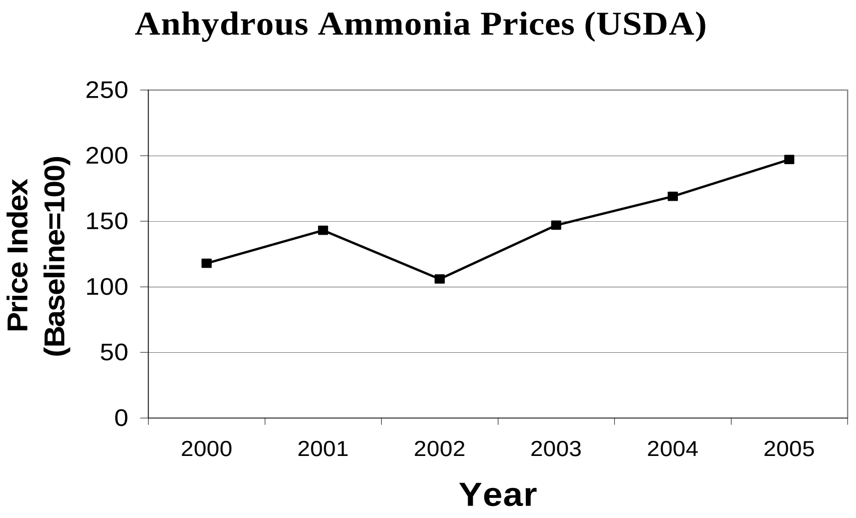


Figure 5. High nitrogen fertilizer prices increase cost pressure on farmers and present a new market for indigenous renewables, reducing our imports, now at ~60% of consumption.

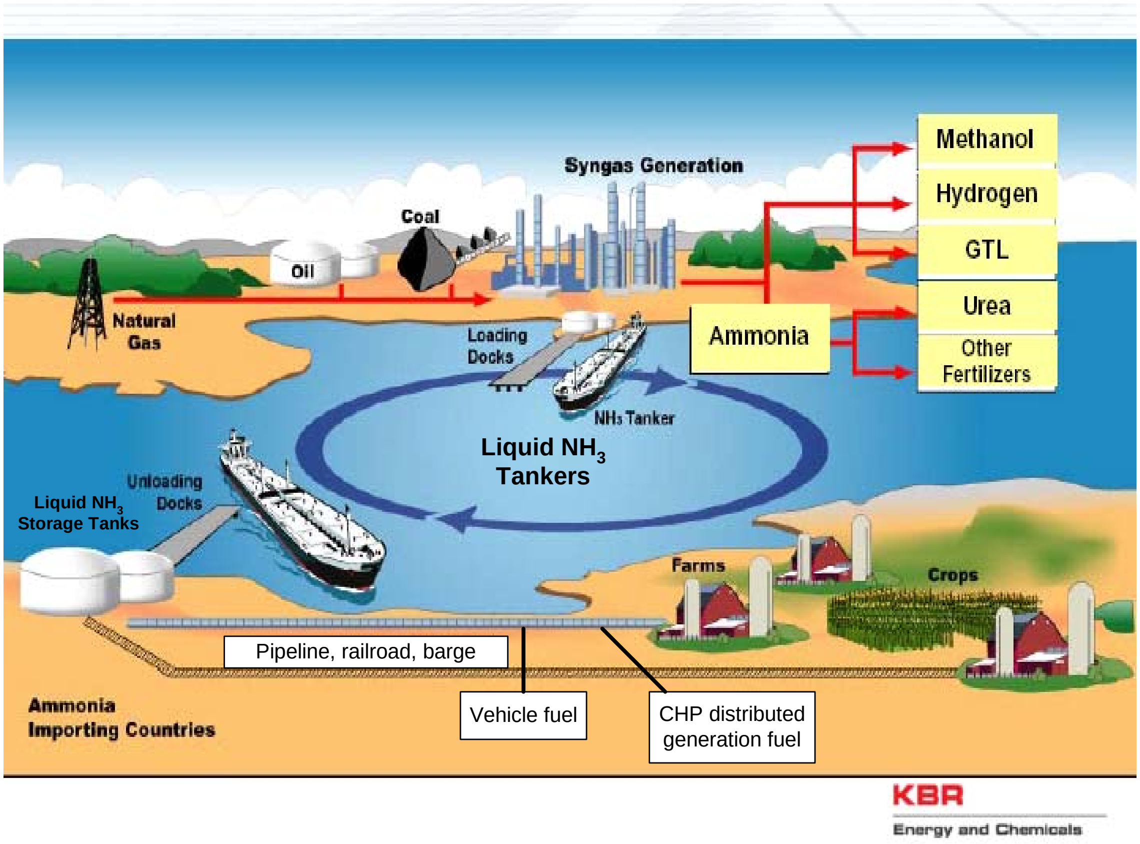


Figure 6. The global ammonia economy. Liquid NH_3 is exported from plants fed by low-cost, stranded fossil fuels. Indigenous wind-source NH_3 may displace fossil-source imports. The future NH_3 fuel market may be larger than the fertilizer market.

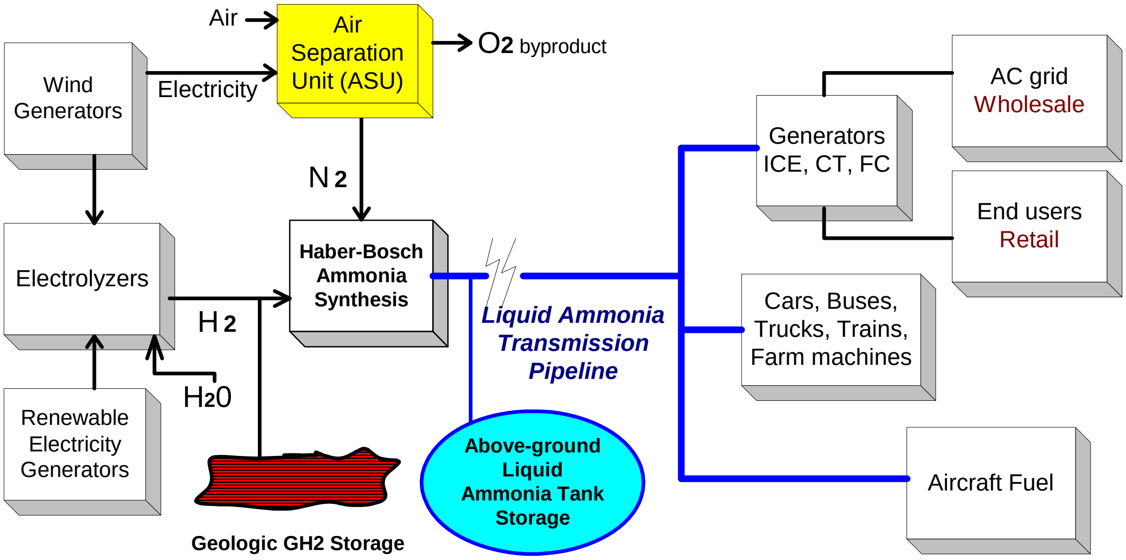


Figure 7. NH_3 production, transmission, and firming storage system. Low-cost, large-scale, high-pressure GH2 storage probably requires deep domal or bedded salt formations for solution mining of large caverns. GH2 storage allows the ASU and synloop to operate at high CF, without the difficult dynamic range required to follow renewable energy generation output variations. Without large scale GH2 storage, high efficiency conversion of the wind energy to NH_3 may require novel technical solutions.

Figure 8. Clipper Windpower 2.5 MW turbines in background with liquid anhydrous ammonia (NH_3) nitrogen fertilizer “nurse tanks”, ~5 m^3 each. Wind-generated electricity can be locally converted to NH_3 for fertilizer and fuel, without expansion of the electricity transmission grid. September ’07, NE Iowa.

2. ANHYDROUS AMMONIA (NH_3) AS A HYDROGEN AND ENERGY CARRIER

Figures 7 - 8. The entire energy output of the stranded windplant is converted to GH2 via electrolysis of water in electrolyzers. High-pressure-output electrolyzers directly feed the transmission pipeline at ~100 bar, for delivery to distant city gate wholesale merchant markets. Byproduct oxygen may be sold to adjacent coal and dry biomass gasification plants. No pilot plant has been built. Part or all of the hydrogen could also by delivered to NH_3 synthesis plants

In the Twentieth Century Norway, Iceland, Peru, and Zimbabwe produced hydrogen for NH_3 synthesis from surplus hydropower via electrolysis, entirely for agricultural nitrogen fertilizer. But, lower-cost hydrogen from steam methane reforming (SMR) of NG displaced this electrolytic hydrogen by the 1980's. Electrolyzer manufacturers are now improving energy conversion efficiency and reducing capital costs, anticipating new interest in GH2 and NH_3 fuels, driven by higher NG prices and the transmission and firming storage needs of diverse, large-scale, carbon-emission-free renewables.

Figures 4 - 6. Anhydrous ammonia (NH_3) is an essential fertilizer, which has led to vastly increased agricultural consumption over the last century. Fritz Haber, the German inventor of the first industrial process to "fix" nitrogen from the air in the ammonia molecule, won the Nobel Prize in 1918. The USA annually consumes 15-20 million tons of nitrogen fertilizers, as NH_3 or as products made from NH_3. Worldwide annual consumption is approximately 130 million tons.

NH_3 made from wind-generated electric energy, water, and atmospheric nitrogen is a potential major market and delivery pathway for wind energy, worldwide. A reasonable "market share" of 6 million tons per year (tpy) of NH_3 would require the full output of about 20,000 MW of nameplate wind generation, at 40% CF (Total installed USA wind capacity in April 2007 was about 12,000 MW).

Figures 7 - 8 illustrate the opportunity for indigenous conversion of wind energy, where it is generated, to N-fertilizer, where it is consumed, without expansion of the electricity transmission grid. Figure 6 illustrates the global ammonia fertilizer economy, now operating primarily on natural gas and coal. A few decades ago the USA produced all its ammonia from abundant, low-cost, North American NG, releasing the byproduct CO2 to Earth's atmosphere. That NG is now too costly, so the USA imports over half its NH_3 . Future CO2 emissions will probably be limited and costly. Several proposed new domestic coal-source NH_3 plants will suffer a worse CO2 management problem than NG-source plants. Four annual conferences have tracked this evolution in the ammonia industry and the new opportunities in both supply and demand, including renewable-energy-source ammonia (RE- NH_3).

Extensive markets and transmission and storage infrastructure currently exist for NH_3. Figure 9. If wind-source NH_3 is competitive in price and simply displaces fossil-source NH_3, whether from domestic fossil sources or imported, the existing delivery infrastructure would be adequate for delivering the wind-generated ammonia, since the demand is the same, with these exceptions:

1. A new gathering NH_3 pipeline system will be needed;
2. NH_3 use as vehicle and distributed generation (DG) – CHP fuel would increase total NH3 demand.

3. NH_3 PRODUCTION PROBLEMS REQUIRE RESEARCH

Figures 1, 2, and 7. We accept that wind generators will typically operate at 40% capacity factor (CF). This inflicts a similar low CF on the electrolyzers, ASU, and ammonia synthesis process loop ("synloop"), resulting in large stranded capital asset costs for these downstream components, unless we have large-scale GH2 energy storage between electrolyzers and synloop.

Furthermore, the ASU and synloop have limited static and dynamic capacity range and ramp rates, i.e. “turndown”, thus limited ability to operate effectively or efficiently at low wind generator power output, and to respond to rapid variations in wind power output. NH_3 cost minimization will probably require windplant nameplate capacity to be greater than electrolyzer, ASU, and synloop nameplate capacities, with some consequent curtailment of high-output wind generation.

These CF and turndown problems could compromise overall system efficiency and economics. One solution would be new NH_3 synthesis technologies that could “track” the time-variable wind power and maintain efficient production. See “Potential new technologies ...”, below. This problem might be greatly reduced in Texas and other places where salt geology is available for constructing high-pressure, solution-mined storage caverns to firm the GH2 supply to the NH_3 synloop.

Figures 4 and 7. In the absence of such large-scale GH2 storage, these problems may require the NH_3 plant to remain “always on”, which could result in low average efficiency, or require that a new ammonia synthesis technology – more tolerant of turndown -- be developed. For the ASU, ionic membrane separation has inherently better turndown capability than cryogenic separation, for N2 production.

4. 2007 FARM BILL LANGUAGE

The US Senate floor passed version of the 07 Farm Bill essentially includes these features which, if they became law and were funded, could provide major new sources and markets for hydrogen:

Section 9019: RURAL NITROGEN FERTILIZER STUDY

- Anhydrous ammonia (NH_3) made from renewable-source hydrogen + atmospheric N2
- USA consumes ~15 million tons of NH_3 per year; <60% imported, from offshore natural gas
- Potential: H2 demand for NH3 synthesis = 3 million tons / year
- NH3 is a high-density hydrogen carrier, storage medium, and fuel
- Internal combustion engines and combustion turbines run well on NH3
- “Assess feasibility... identify alternative processes... program recommendations”
- “... report to Congress... no later than 18 months from the first meeting of the Task Force”
- “... identify the key technical and economic barriers to producing commercial-scale quantities of nitrogen fertilizer from renewable energy sources”
- Appropriation: Senate Farm Bill recommends authorization $1 M

Section 9022: RESEARCH AND DEVELOPMENT OF ALTERNATIVE ENERGY

- Directs program and funds to Colorado Renewable Energy Collaboratory: NREL, UC Boulder, Colorado State University, Colorado School of Mines
- Energy crops, biofuels, storage and conversion, fuel cell technologies
- “Develop storage and conversion technologies for wind- and solar-generated power for small-scale and utility-scale generation facilities...”
- “Research fuel cell technologies for use on farm, ranch, and rural applications... ”
- Could include hydrogen pipeline transmission and firming storage in solution-mined salt caverns
- Appropriation: Senate Farm Bill recommends authorization of $225 M

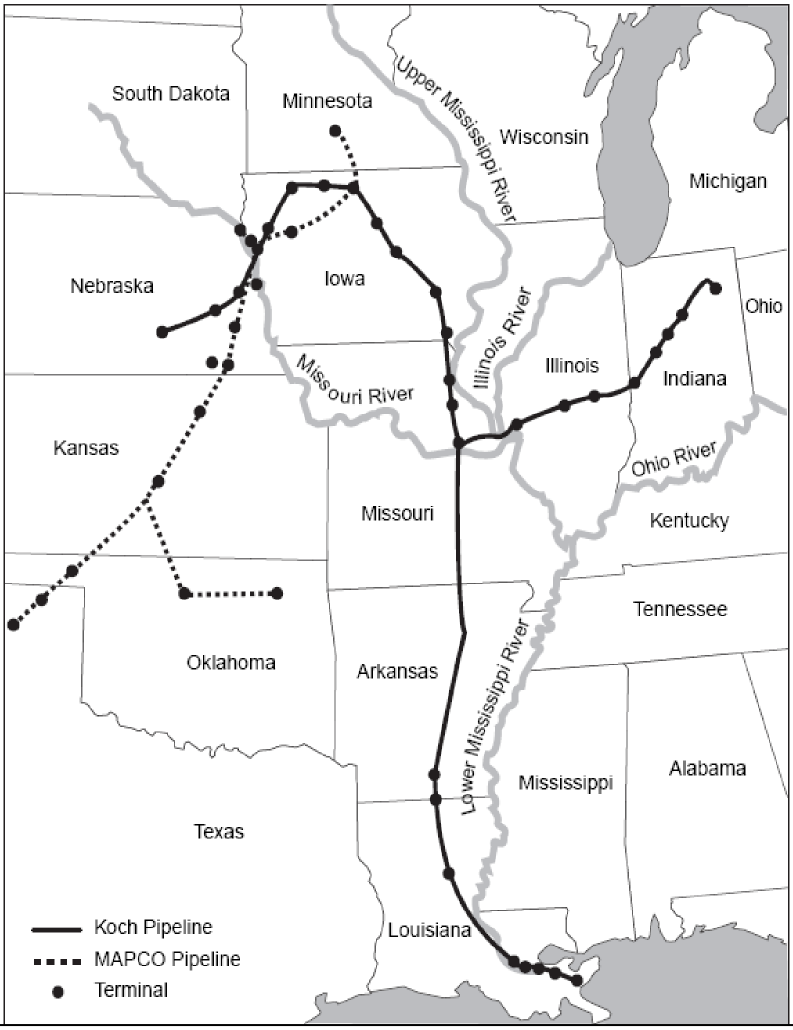
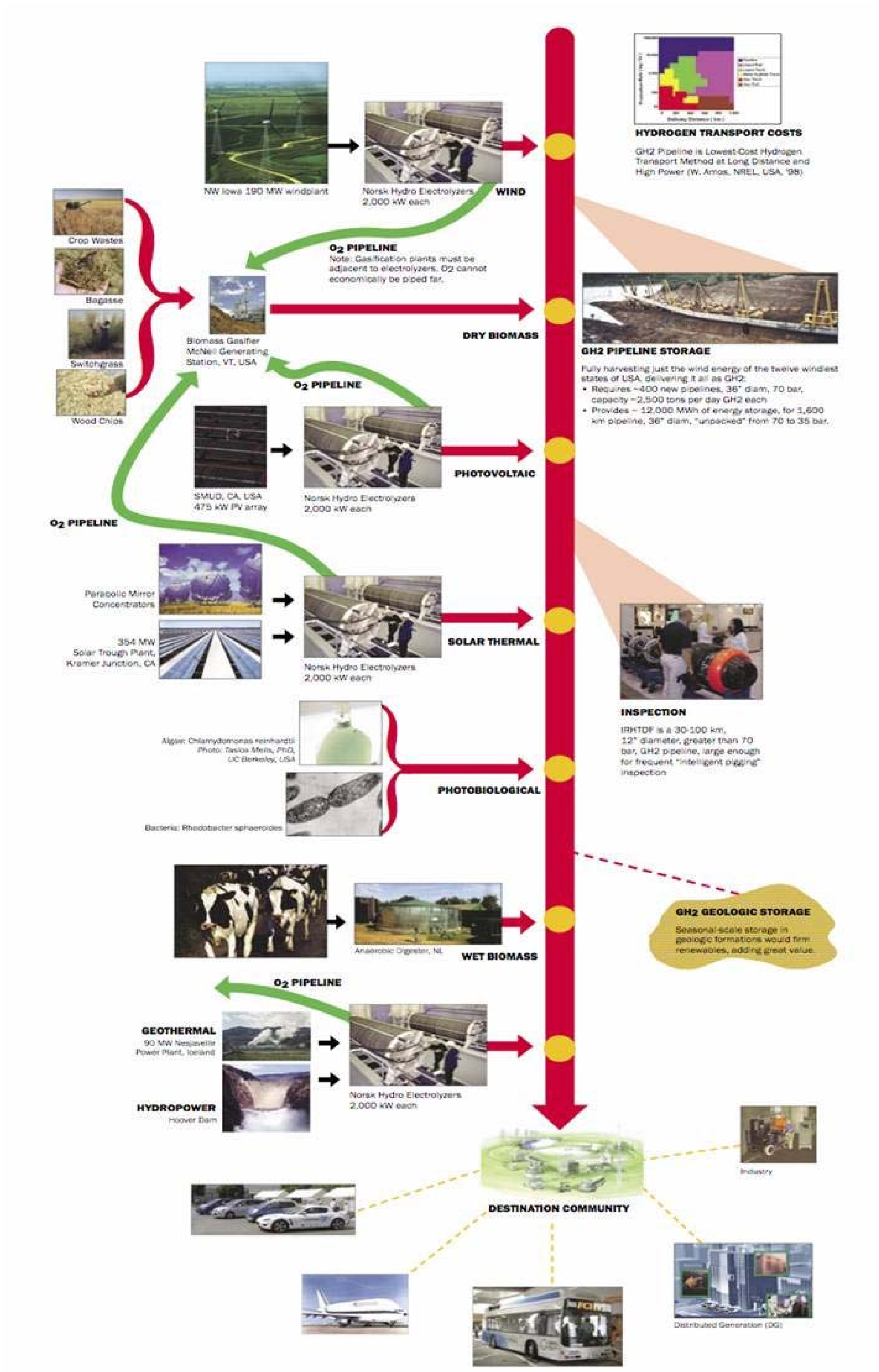


Figure 9. Existing NH_3 pipelines and storage terminals. Storage is in refrigerated, liquid, above-ground steel tanks of 10 – 60,000 tons each.



O_2 PIPELINE
Note: Gasification plants must be adjacent to electrolyzers. O_2 cannot economically be piped far.

HYDROGEN TRANSPORT COSTS
GH2 Pipeline is Lowest-Cost Hydrogen Transport Method at Long Distance and High Power (W. Amos, NREL, USA, '98)

GH2 PIPELINE STORAGE
Fully harvesting just the wind energy of the twelve windiest states of USA, delivering it all as GH2:
- Requires ~400 new pipelines, 36" diam, 70 bar, capacity ~2,500 tons per day GH2 each
- Provides ~ 12,000 MWh of energy storage, for 1,600 km pipeline, 36" diam, "unpacked" from 70 to 35 bar.

INSPECTION
IRHTDF is a 30-100 km, 12" diameter, greater than 70 bar, GH2 pipeline, large enough for frequent "intelligent pigging" inspection

GH2 GEOLOGIC STORAGE
Seasonal-scale storage in geologic formations would firm renewables, adding great value.

Figure 10. Proposed pilot plant, the International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF), which could be combined with an ammonia pipeline transmission demonstration facility.

5. CONCLUSION

Two research initiatives in the USA 07 Farm Bill promise thorough exploration of new markets, and new transmission and firming storage systems, for diverse, large-scale, stranded renewable energy resources. As of 18 April 08, the Senate-House farm bill conference committee is meeting; whether these initiatives will be retained and funded is unknown.

We suggest building pilot plants, as in Figures 7 and 10. Although hydrogen and ammonia have been proposed as transmission and firming storage media for GW-scale wind energy, no pilot plant exists for confirming the system costs and efficiencies we estimate here. Hydrogen is promising as a clean-burning energy carrier. Modern electrolyzers can produce large volumes of high-pressure hydrogen from water, ready for pipeline transmission and / or ammonia synthesis, from renewable energy sources. Hydrogen's extremely low volumetric energy density requires its compression or liquefaction to increase energy density, which consumes a significant fraction of the energy contained in the hydrogen. Gaseous hydrogen (GH2) transmission and firming storage has been explored elsewhere, so we focus on anhydrous ammonia (NH3) here, and its comparison with energy transmission by electricity and hydrogen.

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