NH3 – The Key to Energy Independence, Economic Recovery and National Security

Norm Olson  P.E.

NH3 VI

October 12 – 13, 2009

Kansas City, Missouri
Oil Experts See Supply Crisis in Five Years

International Energy Agency

July 10, 2007
IEA Economist Says World Oil Reserves Less Than Estimated

*United Press International 9/7/2009*

World oil supplies will pass their peak production sooner than expected, creating conditions for a global energy catastrophe, a French energy economist says. Higher crude prices brought on by sharply growing demand, coupled with a stagnation or decline in supply, could shove any recovery off-course, said Fatih Birol, chief economist at the International Energy Agency in Paris. Birol told The Independent that the public and many governments are ignoring reports that the oil is running out faster than predicted. Birol said global production likely will peak in about a decade, 10 years sooner than most governments have estimated.

In an assessment of more than 800 oil fields in the world, Birol found most of the biggest fields already have peaked, and the rate of decline in oil production is running at nearly twice the pace calculated just two years ago, the newspaper said. In addition, chronic under-investment by oil-producing countries likely will result in an "oil crunch" within the next five years, jeopardizing any hope of a recovery from the global economic recession, Birol said. "One day we will run out of oil. It is not today or tomorrow, but one day we will run out of oil and we have to leave oil before oil leaves us, and we have to prepare ourselves for that day," Birol said. "The earlier we start, the better, because all of our economic and social system is based on oil, so to change from that will take a lot of time and a lot of money and we should take this issue very seriously."
Mid East
China has been widening its lead over the U.S. as the world's top auto market, with September sales jumping 78 percent over a year earlier, boosted by tax cuts and government stimulus spending. China's total sales hit 9.66 million vehicles in the first nine months of the year, up 34 percent from a year earlier and are forecast to top 12 million units for the year. Previously only Japan and the U.S. have exceeded 10 million vehicles in annual output.

Copyright © 2009 The Associated Press.
Energy Independence Goals

- Use Local Resources for Local Energy Needs
- Eliminate Petroleum Imports
- Provide a Bridge to Renewable Energy
- Protect the Environment
- Create Local Jobs/Improve Economy
- Eliminate NH3 Imports
Background Information
The Fossil Fuel Era

- Biomass
- Wind
- Water
- Animals

- Mechanical
- Combustion
- High temperature

- Electric
- Low temperature
- Catalysts

% of total

Source: Ewald Breunesse, Shell Netherlands, 14th IAMA Annual World Conference, Montreux, June 14th 2004
Oil Reserves
World Crude Oil Reserves
Jan 2007
1,317.4 billion barrels
7,749 quads
(Coal: 22,171 quads)
(NG: 5,500 quads)

OPEC Share (68%)

Natural Gas Reserves
World Total: 5500 Tcf, 5500 quads
(Petroleum: 7749 quads)
(Coal: 22,171 quads)

Source: PetroStrategies Inc.
Coal Reserves
World Recoverable Coal Reserves, Jan 2003

997.7 billion short tons
22,171 quads

Oil: 7,749 quads
NG: 5,500 quads

The Ideal Transportation Fuel

• Can be produced from any raw energy source (i.e. wind, solar, biomass, coal, nuclear, hydro etc.)  Don’t exclude wind, solar, hydro and nuclear energy as potential transportation fuel sources!!!

• Is cost effective

• Has significant storage and delivery systems already in place

• Environmentally friendly

• Can be used in any prime mover (i.e. diesel engines, fuel cells, SI engines, gas turbines, etc.)

• Has a proven, acceptable safety record

• Produced in the U.S.
NH3 Basics 1

- NH3 can be produced from any raw energy source, including all fossil, renewable and nuclear sources.
- NH3 is normally cost competitive with gasoline as a transportation fuel.
- NH3 has extensive, worldwide transportation and storage infrastructure already in place.
- NH3 is very environmentally friendly when used as a transportation fuel and produces only N2 and H2O at the tailpipe with low-cost emissions controls.
- Ammonia has been successfully demonstrated in SI engines, CI engines, fuel cells and burners. Ammonia can replace natural gas, propane, gasoline and diesel fuel.
NH3 Basics 2

- The U.S. imported over 50% of its nitrogen fertilizer for the first time in 2004 and continues to import increasingly more than it produces domestically.
- Ammonia high cost partially due to highly seasonal nature of use (inefficient use of infrastructure).
- NH3 has been produced from coal in Beulah, North Dakota for decades and with CO2 capture since 2000. China has huge coal to NH3 capacity.
- NH3 cost 2009: $125 - $325 per metric tonne.
Alternative Fuel Candidates

Algae – will algae-based biodiesel displace all other fuels?

Electric Vehicles – will all-electric vehicles eliminate the need for liquid transportation fuels?

Alcohol Fuels – will cellulosic alcohol fuels meet all of our transportation fuel needs?

Natural gas – Does T. Boone really have the best solution?

Propane – nice fuel, limited quantities.

DME – a dark horse candidate?

NH3 Hydrogen – a formidable candidate
Algae – will algae-based biodiesel displace all other fuels? Probably not, especially natural gas, propane, gasoline, nuclear and certainly not coal (with CO2 sequestration). Algae produces protein (high value), oil (high value), carbohydrates (low value). NH3 could be made from the low value carbohydrates. Fuel cells run “better” on NH3 than on biodiesel. All current existing sources of fats, oils, and grease are very small compared to the demand for diesel fuel. Food vs. fuel issues can be a problem if non-algae sources of oil (e.g. soybean oil, canola oil, etc.) are used.
Electric Vehicles:
+very efficient use of electricity
- charging infrastructure for quick charge costly (could change out battery pack
- charging time
- energy density, cost and life expectancy problems
Energy Densities

- Diesel
- Lithium Ion Battery
- NH3

Wh/l vs. Wh/kg
Alcohols – With the exception of methanol, alcohols are difficult to produce in a cost-effective fashion from cellulose, coal or other carbon/hydrogen sources. Corn to alcohol has some fairly significant opposition due to the “food vs. fuel” issue. Alcohols can not be produced from wind, solar, OTEC, nuclear or other similar important future energy sources. Any land that can produce significant amounts of cellulosic biomass could also produce significant amounts of food.
Natural Gas - Natural gas can not be produced from wind, solar, OTEC, nuclear or other similar important future energy sources. Can be made with existing, commercially available technologies from cellulosic biomass and coal. Expensive to store and transport (LNG at -278 degrees F). Compared to coal and petroleum, there is not as much natural gas available. Russia has the largest reserves. Extensive pipeline system already in place.
Propane - Propane can not be produced from wind, solar, OTEC, nuclear or other similar important future energy sources. No commercial production from cellulosic biomass or coal. Stores easily as a liquid. Limited amounts available worldwide. Usually co-produced with natural gas.
NH3 - Unlike all other alternative fuel candidates (except electricity) NH3 can be produced from wind, solar, OTEC, nuclear or other similar important future energy sources. Easily produced from cellulose using commercially available technologies (i.e. thermal gasification, anaerobic digestion) biomass and coal. China has a huge, existing coal to NH3 industry. Stores easily as a liquid at slightly milder conditions than propane. Proven performance in pipelines and natural gas pipelines converted to transport NH3 would gain 50% additional energy shipping capacity. NH3 can perform in all types of engines (with modifications) and direct NH3 fuel cells promise to be low-cost, efficient and robust.
Energy densities (LHV) for fuels in liquid state

- Jet (diesel)
- Octane (gasoline)
- Heptane
- Hexane
- Pentane
- Butane
- Ethane
- Propane
- Ethanol
- Methane
- Methanol
- Ammonia
- Liquid hydrogen
- Hydride
- Water
- CNG

Hydrogen density range

From George Thomas, BES workshop 5/13/03
## Freedom Car Targets w/ 2005 NH3 Comparison

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spec. Energy</td>
<td>kWh/kg</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>Energy Density</td>
<td>kWh/L</td>
<td>1.2</td>
<td>1.5</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Storage Cost</td>
<td>$/kWh</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>Fuel Cost</td>
<td>$/gal. Gas equiv</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
<td>1.7*</td>
</tr>
</tbody>
</table>

*$280/ton ammonia
In Tampa, the January (2009) contract price is expected to be agreed next week with little change from the current level of $125/tonne CFR expected.

*June 2003 Chemical Market Reporter
NH3 will normally cost less than gasoline (per million BTU) due to the fact that NH3 is currently made from coal and natural gas, both of which cost significantly less than petroleum per million BTU.

Wholesale price per million Btu for fuels October 2009:
- Coal (spot) - $0.52 (PRB), $1.73 (ILB);
- Natural Gas - $4.90;
- Gasoline - $17.28

NH3 is a great use for stranded natural gas since NH3 is so cost effective to transport. Much cheaper than LNG and CNG.
Future Compatibility

Hydrogen + Nitrogen

Ammonia

Storage & Delivery – Pipeline, Barge, Truck, Rail

Stationary Power

Fertilizer

Transportation
NH3 is in the top three chemicals shipped worldwide.
Ammonia Storage & Transport
U.S. Ammonia Pipeline

3000 Miles Total

- Koch Pipeline
- MAPCO Pipeline
- Terminal
NH₃ and Gaseous H₂ Transport

- 736 t/day H₂
  - 104,350 GJ/day

- H₂ (104 bar)

- 1,531 t/day H₂
  - 217,065 GJ/day

NH₃ Synthesis

- 2.22 kWhₑ/kg H₂
  - 10,580 GJ
  - -4.9% (loss)

NH₃ Pipeline

- 12”, 1k mile H₂ Pipeline

- 12”, 1k mile
  - H₂ Comp.
    - 690 bar
    - 4.16 kWhₑ/kg H₂
      - 19823 GJ
      - -19.0% (loss)
    - 1.85 kWhₑ/kg H₂
      - 8815 GJ
      - -8.5% (loss)

- 75,712 GJ
  - 72.5% eff.

- 184,507 GJ
  - 84.9% eff.

Assume: H₂/NH₃ used to gen. kWhₑ @ 55% Eff.
NH₃ and Cryogenic H₂ Storage

2,664 t H₂
377,701 GJ

H₂ (104 bar)

H₂ Liquefaction
- 10.0 kWhₑ/kg H₂
- 165,313 GJ
- 44.7% (loss)

Liquid H₂ Storage
- 1.82 kWhₑ/kg H₂
- 8672 GJ
- 2.3% (loss)

203,716 GJ
53.9% eff.

NH₃ Synthesis
- 2.22 kWhₑ/kg H₂
- 18,409 GJ
- 4.9% (loss)

NH₃ Liquefaction
- 0.03 kWhₑ/kg H₂
- 432 GJ
- 0.1% (loss)

NH₃ Storage
- 0.18 kWhₑ/kg H₂
- 2597 GJ
- 0.6% (loss)

320,636 GJ
84.9% eff.

Assume: H₂/NH₃ used to gen. kWhₑ @ 55% Eff.
NH₃ vs. Natural Gas

Convert CH₄ to NH₃ at well head, sequester CO₂ in natural gas well to extend well production and use natural gas pipeline (with modifications) to ship NH₃

1.5 times more energy capacity when transporting NH₃ than CH₄ for a given pipeline size

More efficient energy transport
Iowa Hydrogen Refueling Stations

Over 800 retail ammonia (the “Other Hydrogen”) outlets currently exist in Iowa.
Anhydrous ammonia expands into a gas as it is injected into the soil where it rapidly combines with soil moisture.
End Use Applications

• Spark-Ignition Internal-Combustion Engines (w/ethanol)
• Diesel Engines (w/biodiesel and/or DME)
• Direct Ammonia Fuel Cells
• Gas Turbines
• Gas Burners (including residential furnaces)
Economic Impacts

T Boone Pickens – “$700 Billion new U.S. industry.”

Using NH3 as the main fuel will allow any country to produce its own transportation fuel and create a large number of high quality, long-term jobs. The wild price fluctuations that have made long-term investments in energy products will no longer be a problem and allow sound, long-term investments to be made.
Ammonia meets critical 2015 Freedom Car targets today

Ammonia has a very extensive, worldwide transportation and storage infrastructure already in place. With relatively minor modifications, existing oil and natural gas pipelines could be converted to transport NH₃

Only H₂ and NH₃ have no tailpipe greenhouse gas emissions (with controls)

Only H₂ and NH₃ can be made from electricity and water (+air for NH₃)

Ammonia can replace diesel fuel, gasoline, natural gas and propane in most fuel applications

NH₃ is the world’s most hydrogen dense chemical by volume, ~50% greater than liquid hydrogen. Results in outstanding green energy storage capability.
NH3 from coal, natural gas and nuclear energy now
NH3 from renewables in the near future (Including wind, solar, OTE and hydro!)
NH3 diesel (CI) and spark-ignition (SI) engines now
Direct NH3 fuel cells in the near future
NH3 is not a toxic chemical! It is an very prevalent, naturally occurring chemical
Any known transportation fuel has some associated safety risks but NH3 is as safe as gasoline and safer than propane when used as a transportation fuel.
NH3 looks very good now and in the future
Hydrogen produced stored, delivered and utilized in the form of NH3 is the best choice for cost-effective, near-term energy independence for many countries.