Ammonia as a Transportation Fuel IV

San Francisco

October 15-16 , 2007

Norm Olson –Iowa Energy Center

www.energy.iastate.edu

Meeting Objectives

- Discuss Pro's and Con's of Ammonia as a Transportation Fuel
- Provide Facts to Help Enlighten Perspectives
- Report Progress
- Determine Next Steps

Oil Experts See Supply Crisis in Five Years

International Energy Agency

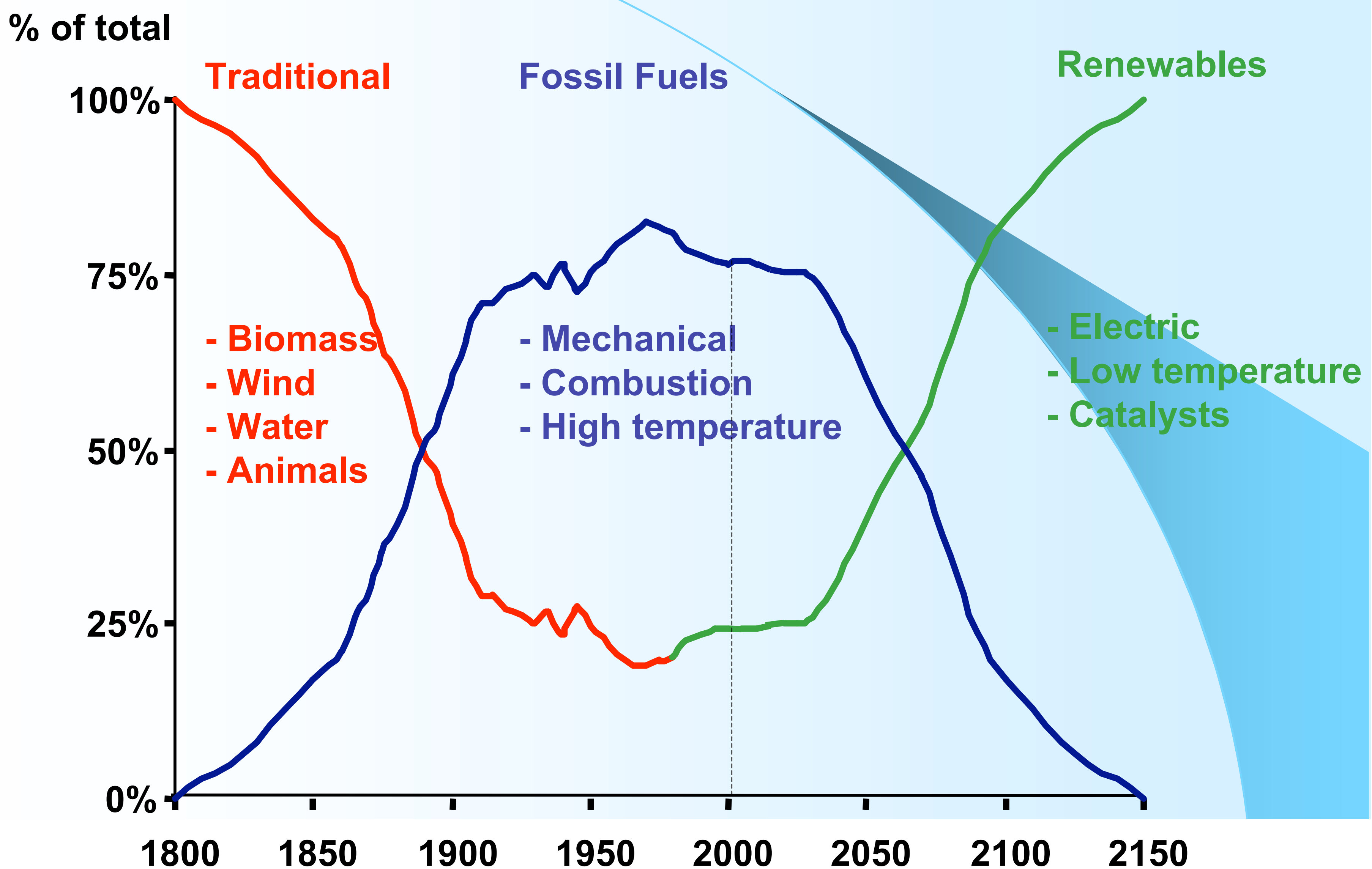
July 10, 2007

Energy Independence Goals

- Use U.S. Resources for U.S. Energy Needs
- Eliminate Petroleum Imports
- Provide a Bridge to Renewable Energy
- Protect the Environment
- Create U.S. Jobs/Improve Economy
- Eliminate Ammonia Imports

Background Information

The Fossil Fuel Era



Source: Ewald Breunesse, Shell Netherlands, 14th IAMA Annual World Conference, Montreux, June 14th 2004

aljazeera.net

Increasing dependence on oil imports
By Ahmad al-Quni
Sunday 10 August 2003, 12:43 Makka Time, 9:43 GMT

http://english.aljazeera.net/NR/exeres/2CDA8F31-A5D7-4071-B12D-1B804E1C15EE.htm

Per Capita Consumption (BPY): US - 28, China - 2

US imports over 60% of Petroleum (2004)

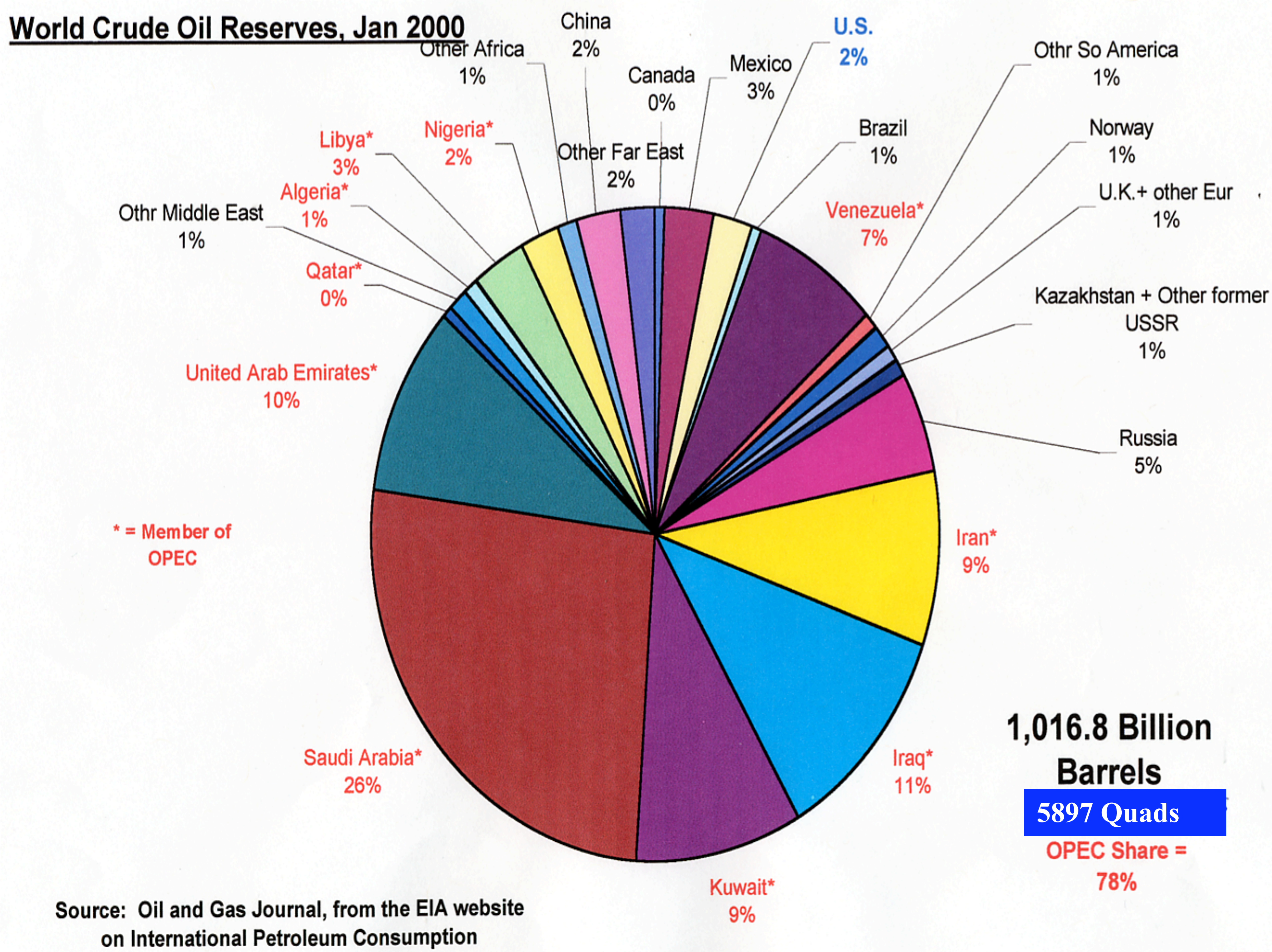
Iraq oil - the target for years ***By Ahmad Quni***

Really?!

Saudi Oil Exec: Only 18% of World's Crude Reserves Tapped
Wednesday, September 13, 2006

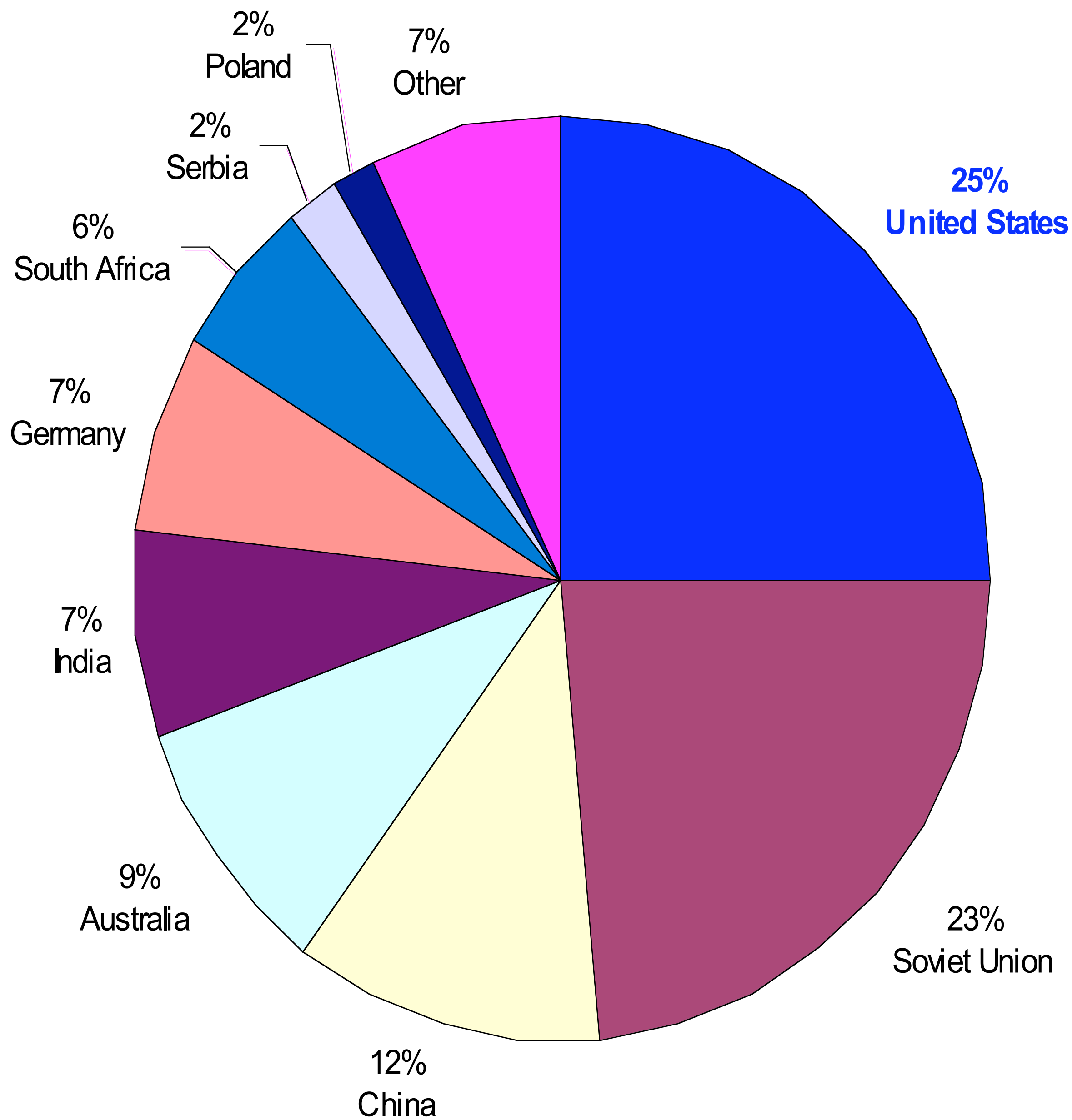
VIENNA, Austria — The world has tapped only 18 percent of the total global supply of crude, a leading Saudi oil executive said Wednesday, challenging the notion that supplies are petering out. Abdallah S. Jum'ah, president and CEO of the state-owned Saudi Arabian Oil Co., known better as **Aramco**, said the world has the potential of 4.5 trillion barrels in reserves — enough to power the globe at current levels of consumption for another 140 years.

Oil Reserves

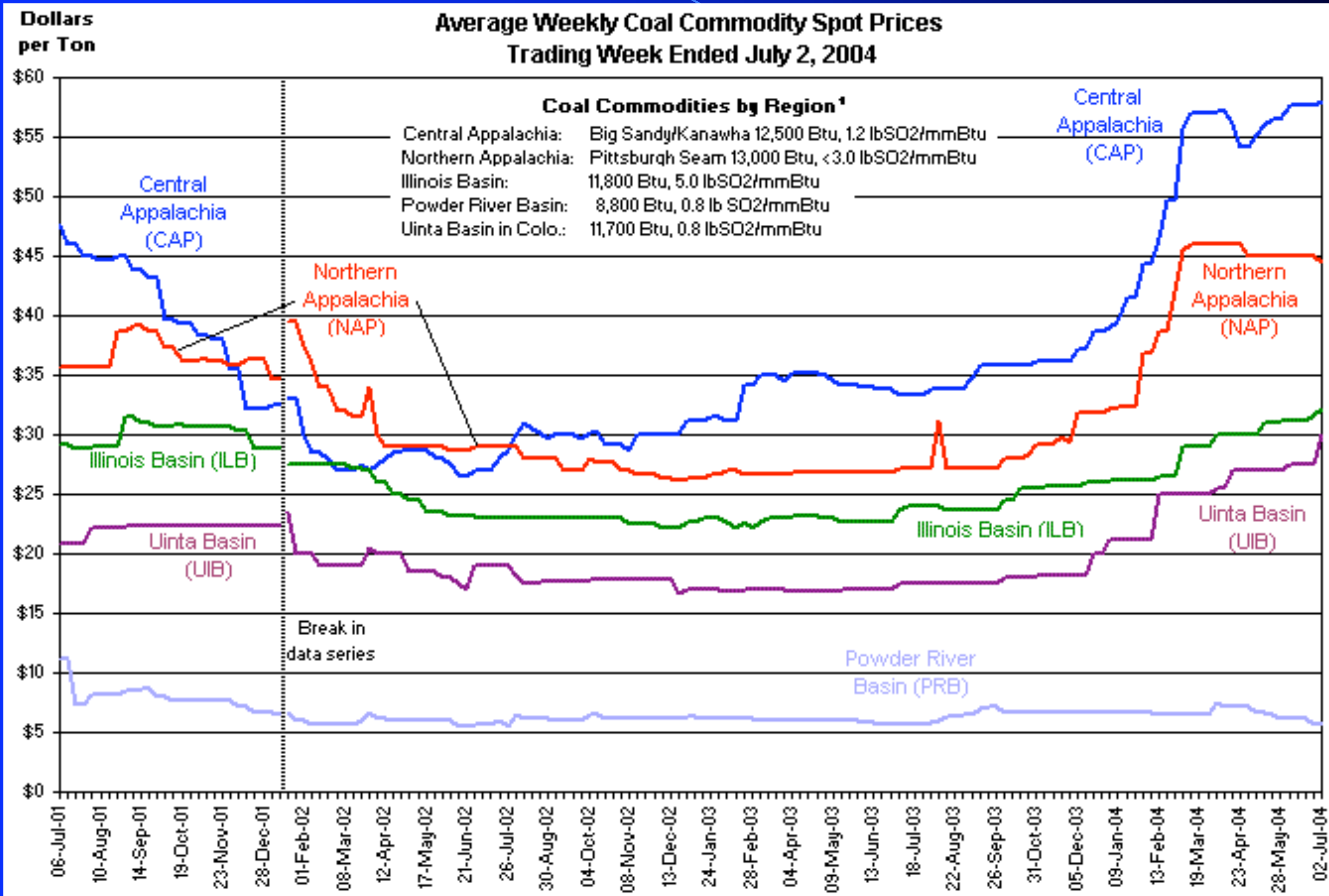

World Crude Oil Reserves, Jan 2000
Other Africa 1%
China 2%
Canada 0%
Mexico 3%
U.S. 2%
Othr So America 1%
Libya* 3%
Nigeria* 2%
Other Far East 2%
Brazil 1%
Norway 1%
Algeria* 1%
Othr Middle East 1%
U.K.+ other Eur 1%
Venezuela* 7%
Qatar* 0%
Kazakhstan + Other former USSR 1%
United Arab Emirates* 10%
Russia 5%
* = Member of OPEC
Iran* 9%
1,016.8 Billion Barrels
5897 Quads
Saudi Arabia* 26%
Iraq* 11%
OPEC Share = 78%
Kuwait* 9%
Source: Oil and Gas Journal, from the EIA website on International Petroleum Consumption

Coal Reserves

World Recoverable Coal Reserves - January 1999



US Coal



¹Prior to January 11, 2002, EIA averaged 12-month "forward" spot prices for several coal specifications; after that date, coal prices shown are for a relatively high-Btu coal selected in each region, for delivery in the "prompt" quarter. The "prompt quarter" is the next calendar quarter, with quarters shifting forward after the 15th of the month preceding each quarter's end.

Source: with permission, selected from listed prices in Platts Coal Outlook, "Weekly Price Survey."

Hydrogen Sources

- Renewables
- Fossil Fuels
- Nuclear

Renewable Energy Options

- Wind
- Solar
- Hydro
- OTEC
- Biomass
- Others

Enough Biomass?

2002 Consumption	Quads
Petroleum	38.11
Natural Gas	23.37
Coal	22.18
Nuclear	8.15
Renewable	5.25
Corn potential (including stalk, 10 bil. bu.)	8.40

Solar, Wind, Biomass

Technology	Converter Efficiency	Capacity Factor	Maximum Packing	Land per Year for: km2/GW	m2/GWh
Flat-Plate PV	10-20%	20%	25-75%	10-50	5000 - 25,000
Wind	Low to 20%	20%	2-5%	100	140,000
Biomass	0.1% total		High	1000	500,000

Source:

http://www.nrel.gov/docs/fy04osti/35097.pdf

Fossil Fuel Hydrogen Sources

- Petroleum
- Natural Gas
- Coal

Dakota Gasification

Over 20 years of producing natural gas, ammonia and other valuable chemicals from US coal.

Al Lukes - $4.50 Nat. Gas from new coal gasification plants.

China

- # new plants
- Chart of chemicals produced

Europe

The Homepage of
the R&D Component of
the European Commission
Clean Coal Technology
Programme

euro-cleancoal.net

Chemistry

From Coal

C + H2O ------ CO + H2

CO + H2O ------ CO2 + H2

From Natural Gas

CH4 + H2O ----- CO + 3H2 (Steam Reforming)

CO + H2O ------ CO2 + H2

Ammonia

N2 + 3H2 ----- 2NH3

Performance

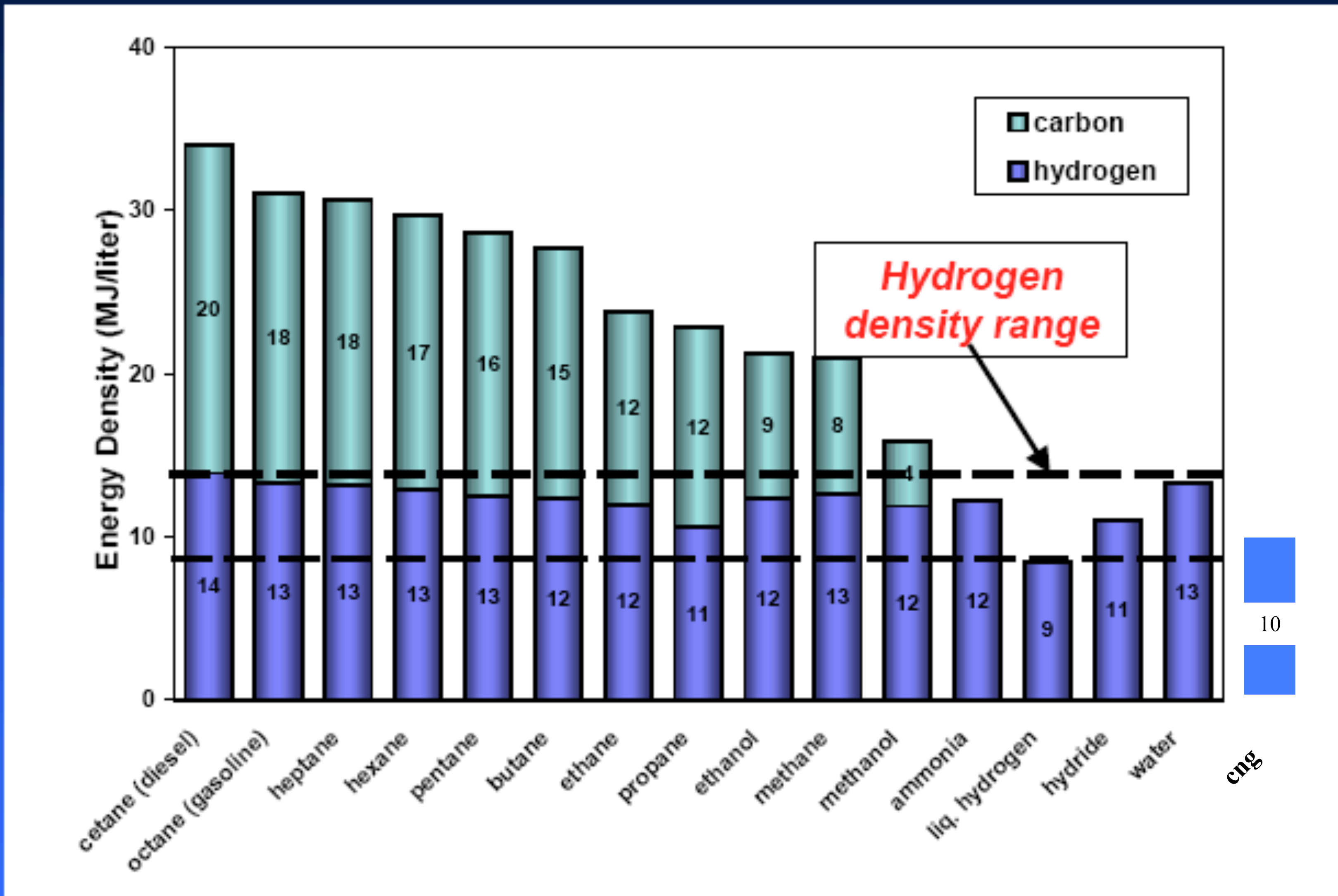
The Perfect Transportation Fuel

- Can be produced from any raw energy source (i.e. wind, solar, biomass, coal, nuclear, hydro etc.)
- Is cost effective
- Has significant storage and delivery systems already in place
- Is environmentally friendly
- Can be used in any prime mover (i.e. diesel engines, fuel cells, SI engines, gas turbines, etc.)

Hydrogen Carriers

- Liquefied Hydrogen (H_2) 100%
- Compressed Hydrogen (H_2) 100%
- Natural Gas (CH_4) 25.0%
- Ammonia (NH_3) 17.6%
- Ethanol (C_2H_6O) 13.0%
- Methanol (CH_4O) 12.5%

Energy densities (LHV) for fuels in liquid state



 From George Thomas, BES workshop 5/13/03

Freedom Car Targets w/ 2005 NH3 Comparison

Parameter	Units	2007	2010	2015	NH3 (2005)
Spec. Energy	kWh/kg	1.5	2	3	3.0
Energy Density	kWh/L	1.2	1.5	2.7	2.7
Storage Cost	$/kWh	6	4	2	2.1
Fuel Cost	$/gal. Gas equiv	3	1.5	1.5	1.7*

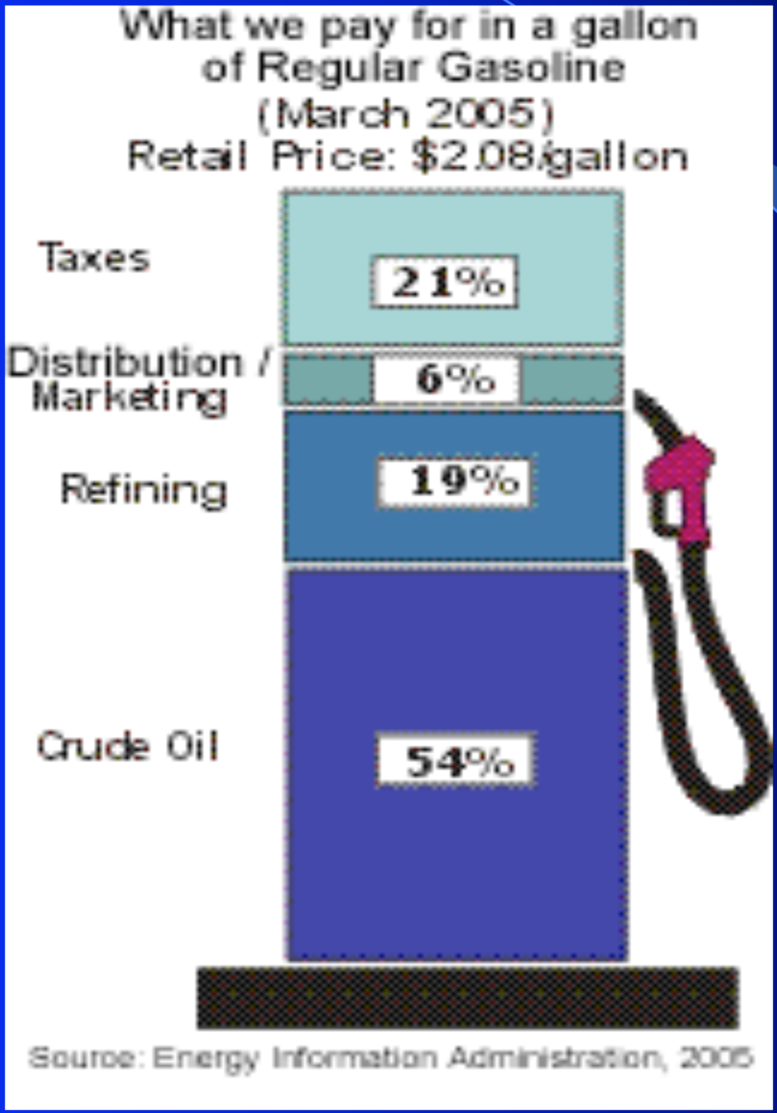
*$280/ton ammonia

Fuel Costs

- **June 2003 Chemical Market Reporter***

	$/MMBtu
Ammonia - $200/metric ton*	$10.01
Gasoline - $1.20/gallon	$10.52
Methanol - $0.79/gallon*	$13.68
Ammonia - $270/short ton	$14.86
Ethanol - $1.25/gallon* ($2.70, 9/05)	$16.44
Gasoline - $2.00/gallon	$17.54
Wind - $0.035/kwh x 2 (electrolyzer)	$20.51
Gasoline - $2.50/gallon	$21.92
Ethanol - $2.70/gallon (9/05)	$35.51

Gasoline Costs – March 2005



Future Compatibility

Hydrogen + Nitrogen

Ammonia

Storage & Delivery – Pipeline, Barge, Truck, Rail

Stationary Power

Fertilizer

Transportation

Economic Impacts

Current (2003) Imports: ~ 13 million bpd

= $114 billion/year @ $24/bbl, $228 billion @ $48/bbl

2003 Gasoline Consumption – 8,756,000 bbl/day

15.3 x 10^{15} Btu/year = 850 million ton/year ammonia

1250 new plants @ 650,000 ton/year each

$562 billion investment @$450 million/plant

375,000 new jobs

$5 billion annual new tax revenue/year (employees only)

Delivery Infrastructure

Typical New Infrastructure

Filling Stations – fuel tanks,

Chicago Stations (20)

Delivery (cold or pressurized?)

Natural Gas/Petroleum Pipeline retrofit?

One fuel (+pilot) simplifies fuel infrastructure.

Simplified refineries and formulations

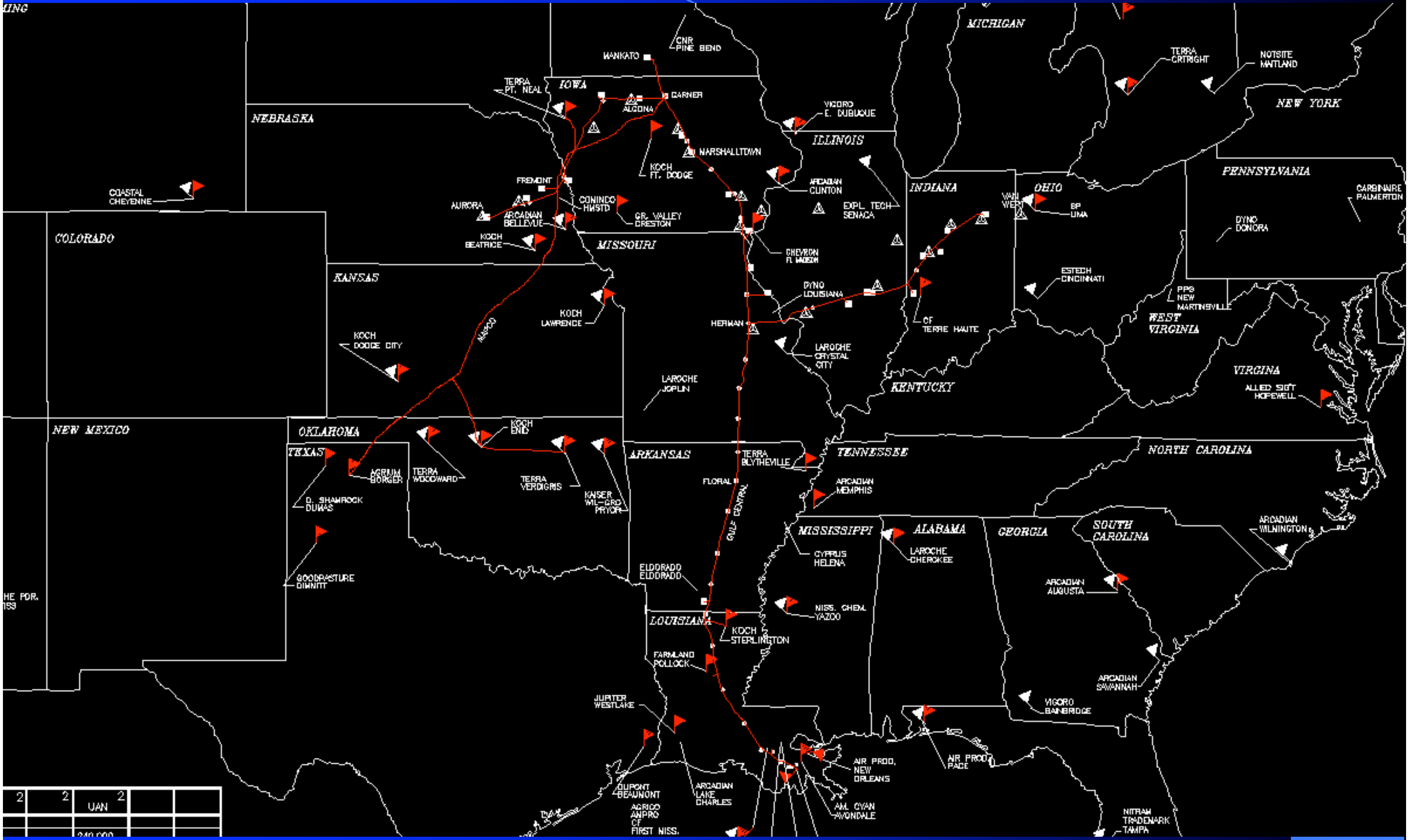
California Hydrogen Stations

http://www.fuelcellpartnership.org/fuel-vehl_map_print.html

Iowa Hydrogen Refueling Stations

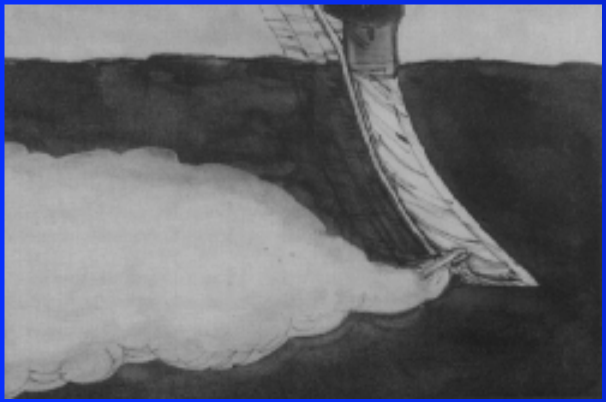
Over 800 retail ammonia (the "Other Hydrogen") outlets currently exist in Iowa.

Ammonia Pipeline



Ammonia Storage & Transport

Anhydrous Application



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)
- Direct Ammonia Fuel Cells
- Gas Turbines
- Gas Burners

Health And Safety

- "Safety assessment of ammonia as a transportation fuel", Nijs Jan Duijm, Frank Markert, Jette Lundtang Paulsen, Riso National Laboratory, Denmark, February 2005

US DOT Statistics 1993-2003

Chemical	#Incidents	Fatalities	Rel. Freq.
Gasoline	3936	82	5.3x
LPG	915	9	2.5x
Anhyd. Ammonia	1016	4	--

Scapegoat?

Ammonia	NH_3
Ephedrine and Pseudoephedrine	$C_{10}H_{15}NO$
Methamphetamine	$C_{10}H_{15}N$

VOC's + NOx + O2 + Sunlight = ozone = smog+

NOx + H2O + ammonia = ammonium nitrate = smog-

If the NOx doesn't form ammonium nitrate it goes to ozone (worse)

Fossil fuels (the source of NOx) are the problem, <u>not</u> ammonia

Ammonia is actually used to clean up NOx emmissions at coal plants

Ammonia Toxicity Ratings

Corresponding NFPA Index	Toxicity Rating	Descriptive Term	LD_{50} (wt/kg) single oral dose rates	LC_{50} (ppm) 4 hours inhalation rate
4	1	Extremely Toxic	< 1 mg	< 10
3	2	Highly Toxic	1-50 mg	10-100
2	3	Moderately Toxic	50-500 mg	100-1000
1	4	Slightly Toxic	500-5000 mg	1000-10,000
0	5	Practically non-toxic	500-15,000 mg	10,000-100,000
	6	Relatively Harmless	> 15,000 mg	> 100,000
		Ammonia - NH_3	LD_{50} = 350	LC_{50} = 2000

The NFPA rating for ammonia is 3 taking into account the physical stress of emergency people. The actual NFPA health ratings based solely on the actual LD_{50} and LC_{50} numbers would be 2 and 1 respectively. Since we are most concerned with inhalation risks, the NFPA rating based on actual test data for ammonia should be 1 or “slightly toxic”.

NFPA Classifications

Substance	Health	Flammability	Reactivity
Ammonia	3 ?!	1	0
Gasoline	1	3	0
Benzene, Ethyl benzene	3	3	0
MTBE	1 ?!	3	0
Natural gas, Methane	1	4	0
Hydrogen	0	4	0
LPG	1	4	0
Methanol, Ethanol ?, Toluene, Hexane	2	3	0

NFPA ratings span from 0 to 4 (0 = no special hazards, 4 = severe hazards). Based on actual test data, the NFPA Health rating for ammonia should be 1 (as an inhalation risk). It is interesting to note that gasoline gets a Health Rating of 1, yet many of it's significant components have Health Ratings of 2 and 3.

Progress

- Irrigation pump demonstration with SI engine
- Over 50% efficiency demonstrated in an IC engine
- Direct ammonia fuel cell
- Wind to ammonia demonstration funded
- 95% ammonia, 5% diesel, full power, LOWER NOx!!!
- New ammonia synthesis technologies

Summary

- **Ammonia Meets Most 2015 Freedom Car Targets Today**
- **Ammonia Has a Very Extensive, Worldwide Delivery and Storage Infrastructure Already in Place**
- **Only H2 and NH3 Have No Tailpipe Greenhouse Gas Emissions**
- **Only H2 and NH3 Can be Made From Electricity and Water (+air for NH3)**
- **Ammonia From Fossil Fuels Now**
- **Ammonia From Renewables in the Near Future**
- **Diesel and Spark-Ignition IC Engines Now**
- **Fuel Cells in the Future**
- **Ammonia Looks Very Good Now and in the Future**
- **Ammonia is Safer Than Gasoline and Hydrogen**