Ammonia as a Transportation Fuel and Fertilizer

Norm Olson –Iowa Energy Center

www.energy.iastate.edu

Iowa Energy Center

- Created by the Iowa Energy Act of 1990
- Conduct and sponsor research, demonstrations, training and educational programs in the areas of energy efficiency and renewable energy
- Main facilities/programs – Biomass Energy CONversion (BECON) Facility, Energy Resource Station (ERS), Alternative Energy Revolving Loan Program (AERLP)

Oil Experts See Supply Crisis in Five Years

International Energy Agency

July 10, 2007

Mid East

T Boone's Plan – Wind + NG

IT'S TIME TO STOP AMERICA'S ADDICTION TO FOREIGN OIL

America is in a hole and it's getting deeper every day. We import 70% of our oil at a cost of $700 billion a year - four times the annual cost of the Iraq war.

I've been an oil man all my life, but this is one emergency we can't drill our way out of. But if we create a new renewable energy network, we can break our addiction to foreign oil.

On January 20, 2009, a new President gets sworn in. If we're organized, we can convince Congress to make major changes towards cleaner, cheaper and domestic energy resources.

Someone Gets It

U.K. Will `Put the Brakes' on Imported Gas Supplies, (Update1)
By Kitty Donaldson
Sept. 22 (Bloomberg) -- U.K. Business Secretary John Hutton pledged to ``put the brakes'' on imported gas supplies by building new nuclear and coal-fired power stations.
New generating capacity is vital to secure future British energy needs, Hutton told the ruling Labour Party's annual conference in Manchester, England today. ``Our ambition must be more than weathering the economic storm unsettling the world,'' Hutton said. ``Above all, our ability to emerge stronger and fitter means dealing with one of the most important threats to our competitiveness, indeed our sovereignty as a nation, and that is the new international battle for energy security.''

OPEC - NOPEC

Crude Oil Rises After OPEC Agrees to Trim Excess Production
By Alexander Kwiatkowski

Sept. 10, 2008 (Bloomberg) -- Crude oil rose after OPEC urged its members to comply with output quotas, a move that would reduce supplies by 500,000 barrels a day. The Organization of Petroleum Exporting Countries agreed at a meeting last night in Vienna to a total production limit for 11 members of 28.8 million barrels a day, unchanged from previous targets. OPEC Secretary-General Abdalla El-Badri said this means it will trim ``oversupply'' by about 500,000 barrels a day. The International Energy Agency cut its forecast for global oil demand in 2008 and 2009 on lower U.S. consumption. ``They will do whatever they can to maintain prices above this $80-$100 range,'' Johannes Benigni, managing director of JBC Energy, said in a Bloomberg television interview today. ``If the market slides lower, you will hear more from them.''

U.S. Petroleum and Natural Gas

Oil rises on worries Gustav may strengthen

Oil prices rose above $119 a barrel Thursday on fears that Tropical Storm Gustav could strengthen on its way toward crude and natural gas rigs in the Gulf of Mexico and refineries in the Gulf area.

Royal Dutch Shell PLC said it's evacuating some 300 workers from offshore Gulf rigs, while BP PLC was also removing personnel from the region that's home to about a quarter of U.S. crude production and much of its natural gas.

Russian Petroleum

THE RISKS in Russia are large and could mushroom. The impact of the Yukos affair, combined with under-investment and the poor management of the Russian petroleum sector in general, is serious. PFC Energy estimates that Russian production, now 9.3 million BPD, will peak at just over ten million BPD in 2008. Without a huge infusion of capital, technology and management for further exploration and production, Russian production may hit a lower peak and begin declining sooner. Billions will also be needed to expand export capacity. Without a stable legal and operating environment, Russia will fail to meet its production targets. This in turn could damage the Russian economy and the prestige of the Putin Administration.

Wake Up Washington!

THE LEGALITY OF OPEC UNDER US ANTITRUST LAW AND EC COMPETITION LAW - ADENIKE O. ESAN

Abstract: The US and EC have well developed antitrust laws which have been used over the years to regulate both conducts occurring within and outside their respective territories. The extraterritorial application of both laws is not in doubt considering the avalanche of decided cases. One common denominator shared by these two competition regimes is their aversion and dislike for cartel practices, which are considered the worst kind of anticompetitive practices. Whilst OPEC prides itself as an intergovernmental organisation, it is trite that OPEC is considered an international cartel that wields so much power and influence globally. Particular conducts of OPEC are infringements under both the US antitrust law and the EC competition law and have been condemned from time to time. Incessantly the media is rife with calls and demands for OPEC to be sued but no such suit has ever been instituted within the framework of the US antitrust law or the EC competition law by the respective competition authorities. Meanwhile OPEC takes the view that its activities are justified and appropriate for the protection of its members' inalienable right over their exhaustible natural resources and for the purpose of effecting stabilisation in the global oil market.

No Turning Back

The day after we as a country decide to seriously pursue cost-effective energy independence, oil prices will plummet. A law must be put in place to effectively freeze imported oil prices at current levels and impose an energy tax on imported oil purchased below those levels. Sounds like a potential means to help pay off the national debt!

Stay the course even when the illegal cartel drops the price of crude oil in an attempt to halt the drive to U.S. Energy Independence. Did I mention the annual influx of $500 - $700 BILLION that will be spent on U.S. energy instead of imported petroleum!

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

Department of Defense Issues

DOD Energy Concerns

Lack secure and reliable sources of energy

- **Dependent on foreign oil**
- **Becoming dependent on foreign refined fuels**
- **Supply chain vulnerability**
- **Rely on mega-refineries**
- **Vulnerable to terrorist threats or natural disasters**
- **Need for cleaner fuels**
- **Need for Better Fuels**
- **Thermal stability, advanced engines, fuel cells**
- **Need for Fewer Fuels**
- **9+ Fuels presently in AOR**
- **Potential limits on deployments**
- **Possible conflict with EU rules**

"DoD intends to catalyze the commercial industry to produce clean fuels for the military from secure domestic resources using environmentally sensitive processes to enable a bridge to the future."

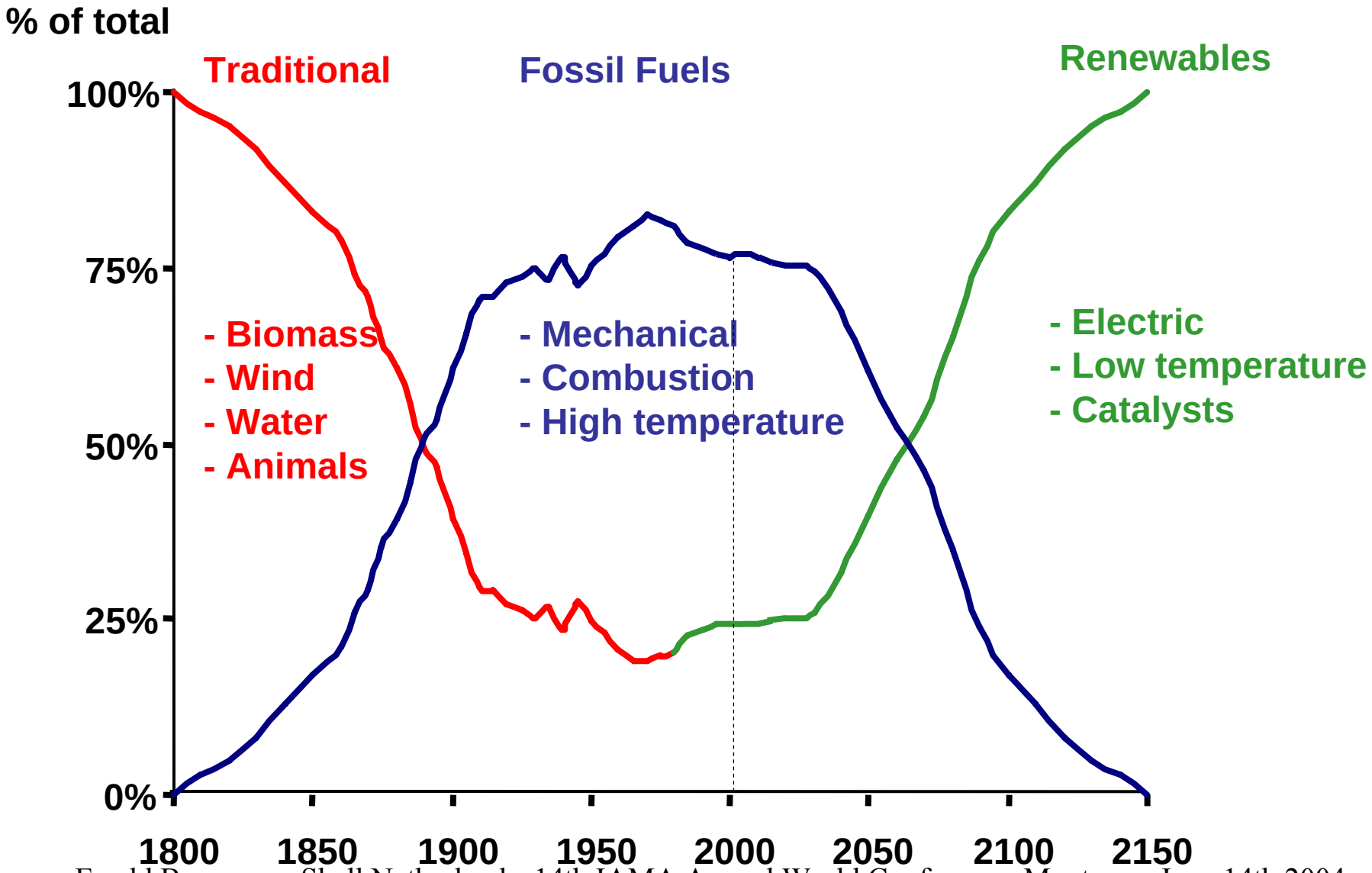
Theodore K. Barna, Ph.D., Assistant Deputy Under Secretary of Defense - Advanced Systems and Concepts

Background Information

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

The Fossil Fuel Era



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

Know The Competition

Natural Gas – Russia & OPEC have largest reserves, U.S. has 3% of proven reserves. Liquid at -278F. Can't be made from wind, solar, nuclear, etc. Extensive infrastructure.

Petroleum - U.S. has 2% of proven reserves. OPEC has nearly 70% of proven reserves. Extensive infrastructure. Environmental issues, no commercially available CO2 sequestration technology.

Coal – Abundant U.S. resource. Proven, cost-effective CO2 sequestration . Cost effective source of a variety of liquid transportation fuels. Environmental issues but better than petroleum with commercially available technologies.

Hydrogen – Made from any raw energy source. Storage and delivery infrastructure barriers are insurmountable in the near to mid-term.

Alcohols – Can be made from biomass and fossil fuels. Some storage and delivery infrastructure. Can't be made from wind, solar, nuclear, etc. U.S. is a major producer.

Ammonia – Made from any primary energy source, high performance in all types of prime movers, no CO2, cost effective, huge world- wide storage and delivery infrastructure, safer than gasoline and propane as a transportation fuel.

Fuels Comparison Chart

	CNG/LNG	Gasoline Diesel	Alcohols	Hydrogen/ Ammonia	Advanced Batteries
Existing Delivery Infrastructure	NG – good LNG - poor	Excellent	Poor/Fair	Very poor/ Excellent	Poor
Safety	Fair	Fair	Fair	Fair/Fair	Excellent
Major Sources	Russia OPEC	OPEC	Any Ag. Region	Any/Any	Any
GHG at Exhaust	Fair	Poor	Good	Excellent/ Excellent	Excellent
Delivered Cost	Fair/Good	Fair	Fair	Poor/ Good (coal)	Fair/Good
End Use Flexibility	Good	Fair	Fair	Good/ Excellent	NA
SI, CI, FC, Burner Wind, Solar, OTEC Nuclear, etc.	No	No	No	Yes/Yes	Yes

Oil Reserves

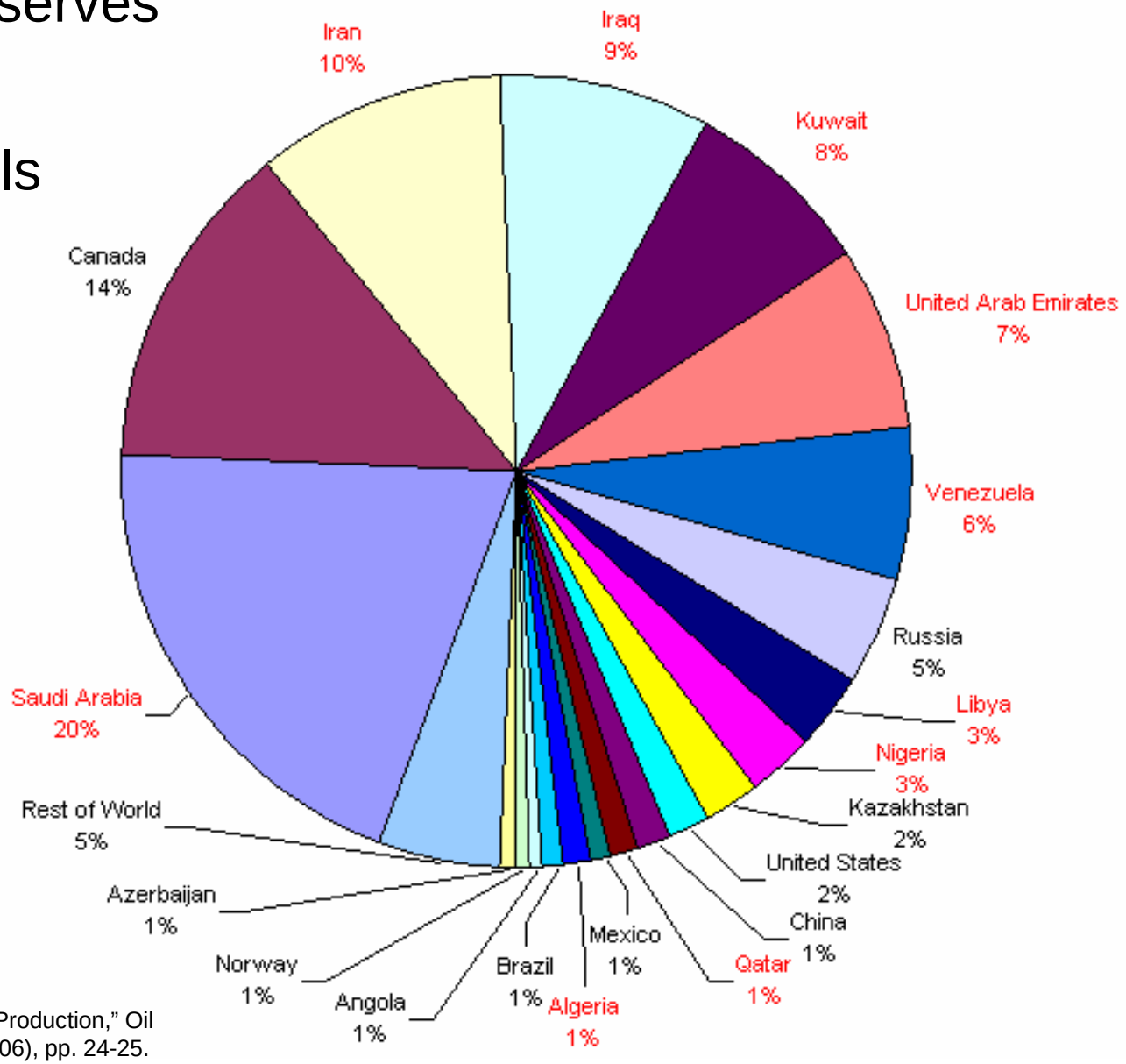
World Crude Oil Reserves Jan 2007

1,317.4 billion barrels
7,749 quads

(Coal: 22,171 quads)

(NG: 5.500 quads)

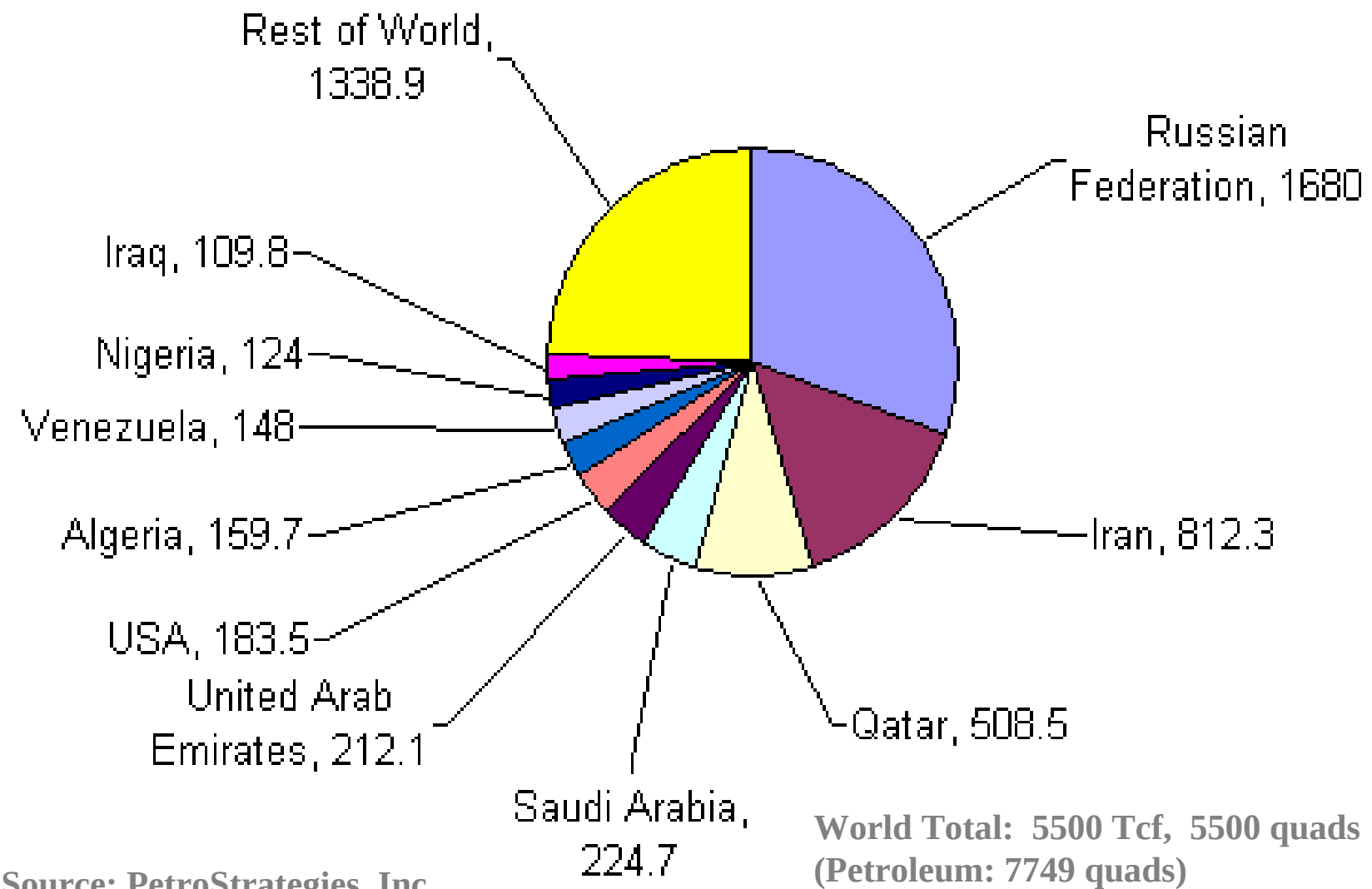
OPEC Share (68%)



Compiled from “Worldwide Look at Reserves and Production,” Oil & Gas Journal, Vol. 104, No. 47 (December 18, 2006), pp. 24-25.

Natural Gas Reserves

World Natural Gas Reserves, Tcf



Source: PetroStrategies, Inc.

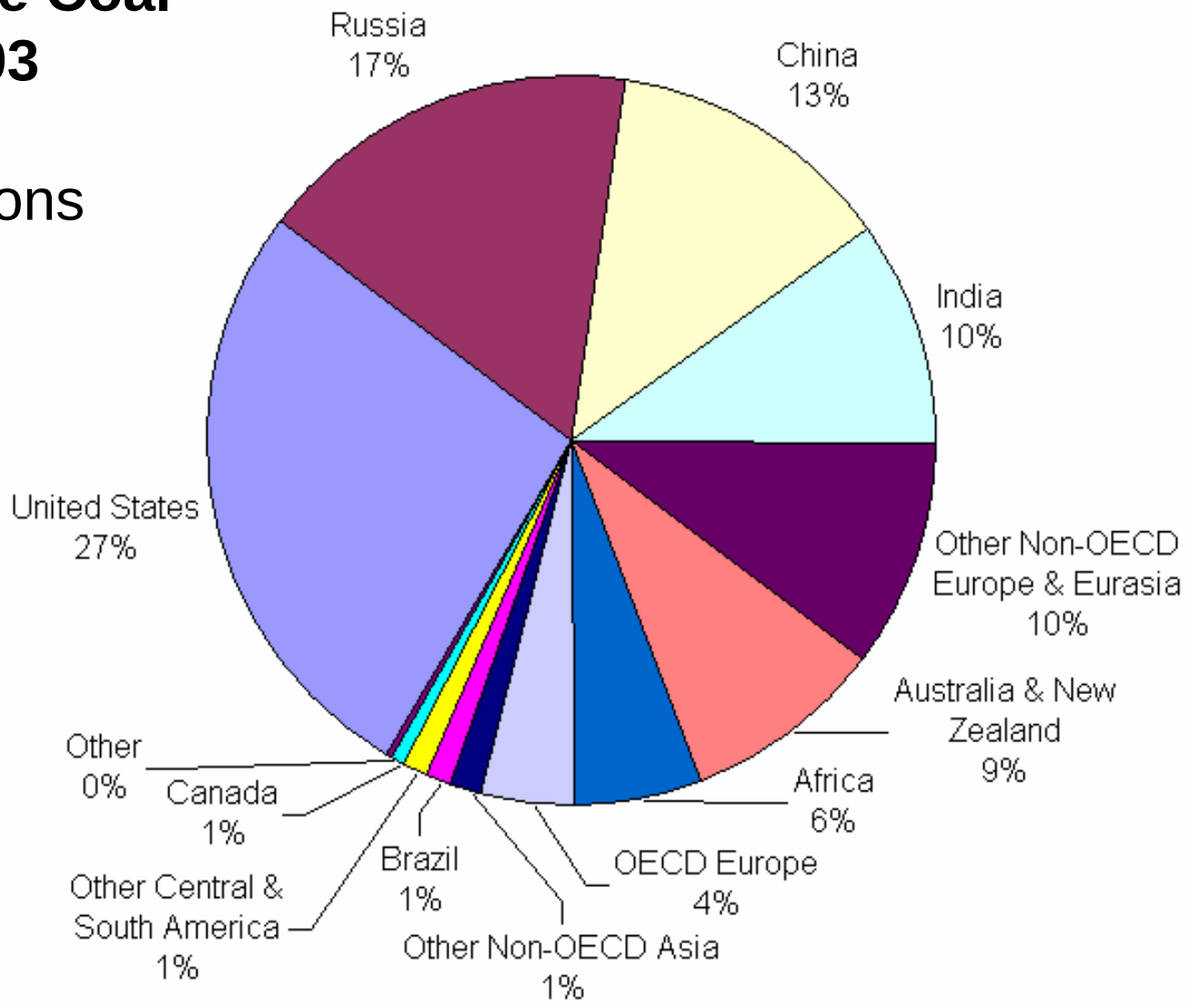
World Total: 5500 Tcf, 5500 quads
(Petroleum: 7749 quads)
(Coal: 22,171 quads)

Coal Reserves

World Recoverable Coal Reserves, Jan 2003

997.7 billion short tons
22,171 quads

Oil: 7,749 quads
NG: 5.500 quads



USDoE - EIA, unpublished data, Coal Reserves Database (April 2007). World Energy Council, 2004 Survey of Energy Resources, Eds. J. Trinnaman and A. Clarke (London, UK: Elsevier, December 2004).

The Perfect 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
- Is environmentally friendly
- Can be used in any prime mover (i.e. diesel engines, fuel cells, SI engines, gas turbines, etc.)

The Worst Possible Transportation Fuel

- Can only be produced from fossil fuels.
- Requires huge direct and indirect incentives/subsidies (i.e. military protection of supply lines)
- Production, storage and delivery systems are susceptible to substantial disruption via terrorist activity and/or natural disaster (e.g. hurricane, earthquake, etc.)
- Environmentally unfriendly, huge air and water pollution .
- Cannot be readily used in fuel cells

Who Planned This Mess?

Ammonia Basics 1

- Ammonia (NH3) can be produced from any raw energy source, including all fossil, renewable and nuclear sources.
- Ammonia is cost competitive with gasoline as a transportation fuel
- Ammonia has extensive, worldwide transportation and storage infrastructure already in place
- Ammonia is very environmentally friendly when used as a transportation fuel and produces only N2 and H20 at the tailpipe with low-cost emissions controls.
- Ammonia has been successfully demonstrated in SI engines, CI engines, and fuel cells.

Ammonia Basics 2

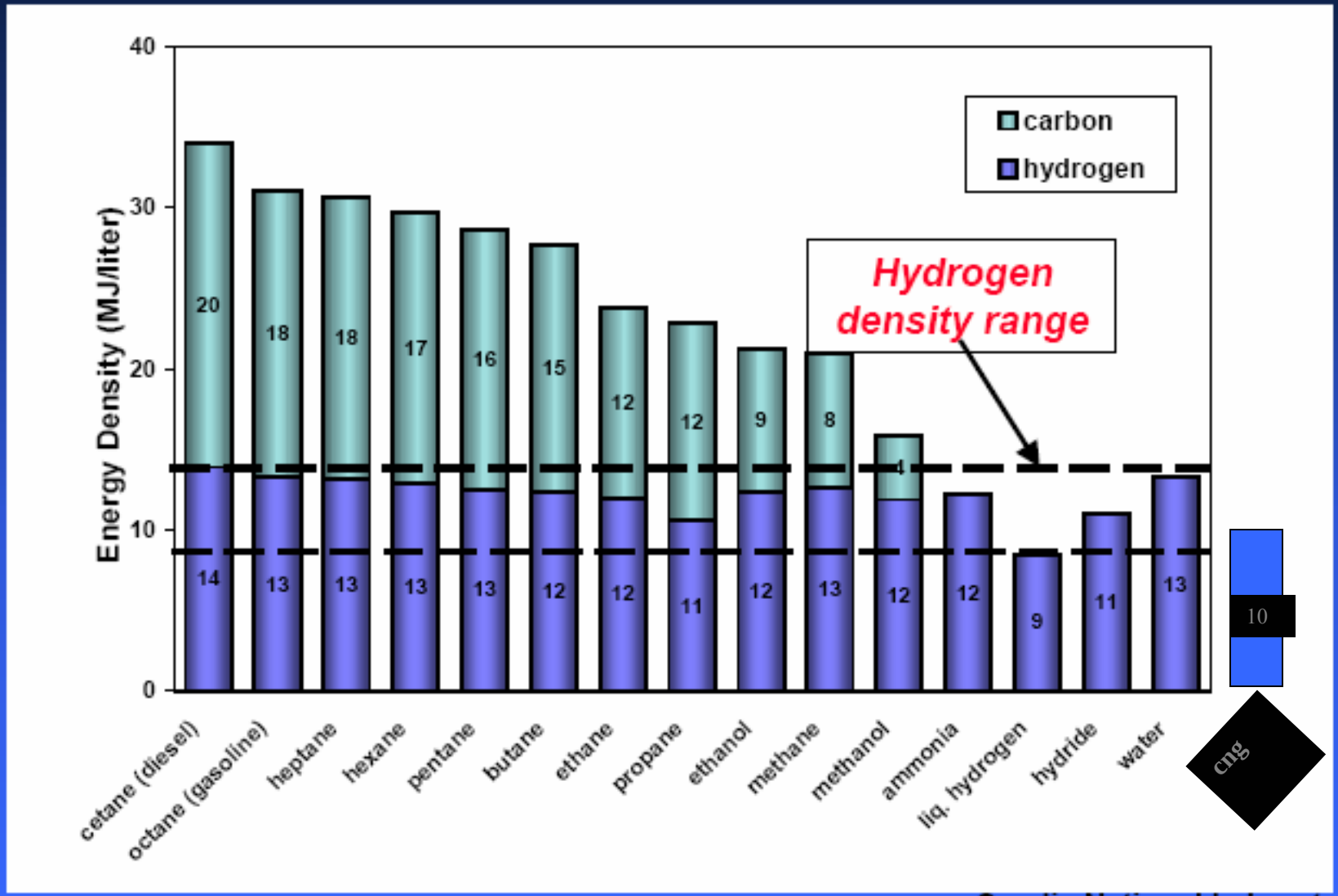
- High U.S. cost is due to high cost of U.S. natural gas
- The U.S. imported over 50% of it's nitrogen fertilizer for the first time in 2004
- Ammonia high cost partially due to highly seasonal nature of use (inefficient use of infrastructure)
- Ammonia has been produced from coal in Beulah, North Dakota for decades. China has huge coal to ammonia capacity.

Dakota Gasification

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

Sequestering carbon dioxide since 2000. 200+ mile pipeline. Enhanced oil recovery.

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

	$/MMBtu
• Ammonia - $200/metric ton*	$10.01
• Methanol - $0.79/gallon*	$13.68
• Ammonia - $350/short ton (coal)	$19.26
• Gasoline - $2.50/gallon	$21.92
• Ethanol - $2.20/gallon	$28.93
• Gasoline - $3.50/gallon	$30.69
• Wind NH3-$1000/short ton (estimate)	$55.02

*

Future Compatibility

Hydrogen + Nitrogen

Ammonia

Storage & Delivery – Pipeline, Barge, Truck, Rail

Stationary Power

Fertilizer

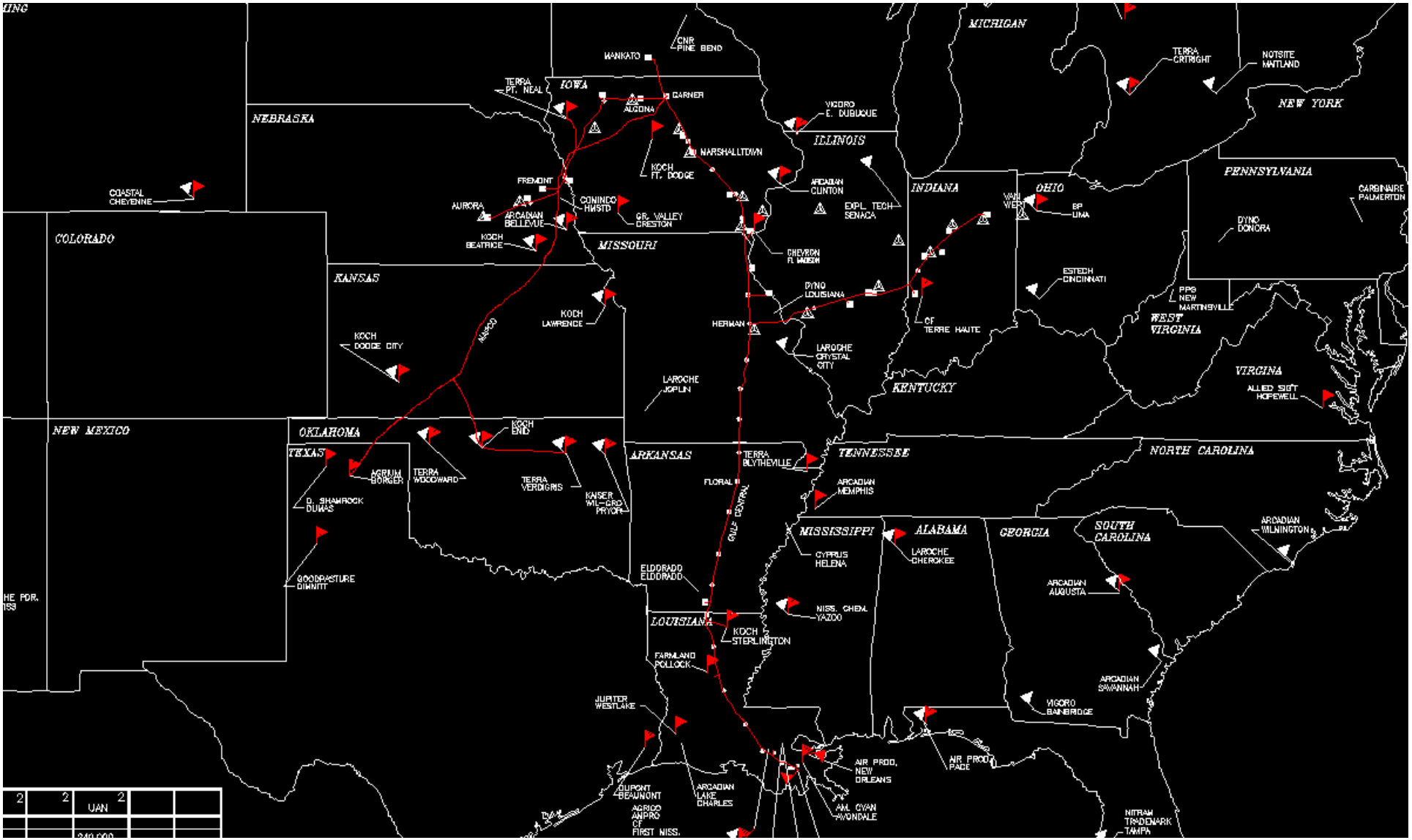
Transportation

Delivery Infrastructure

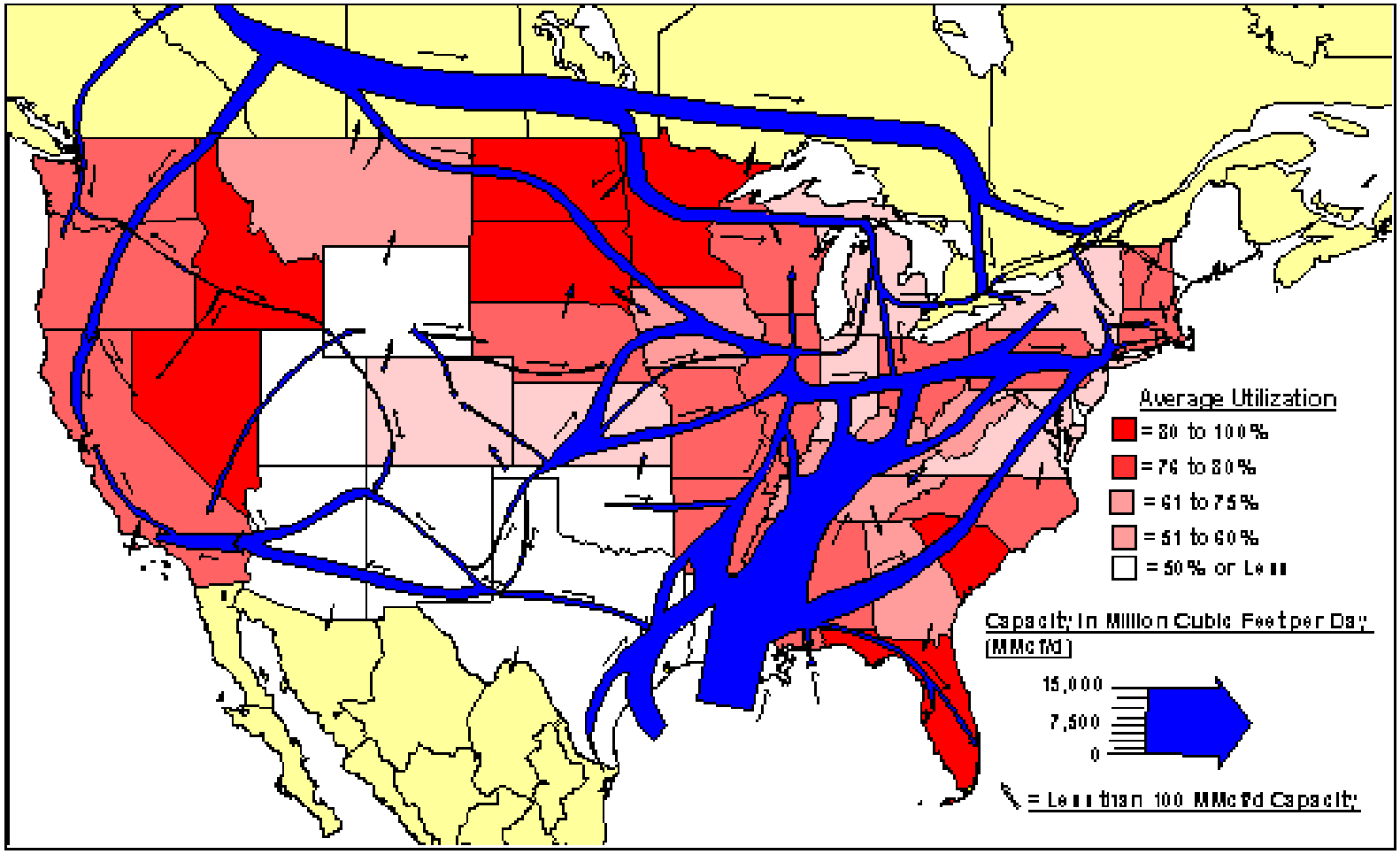
Ammonia Storage & Transport

NH3 vs H2 Delivered Energy Balance

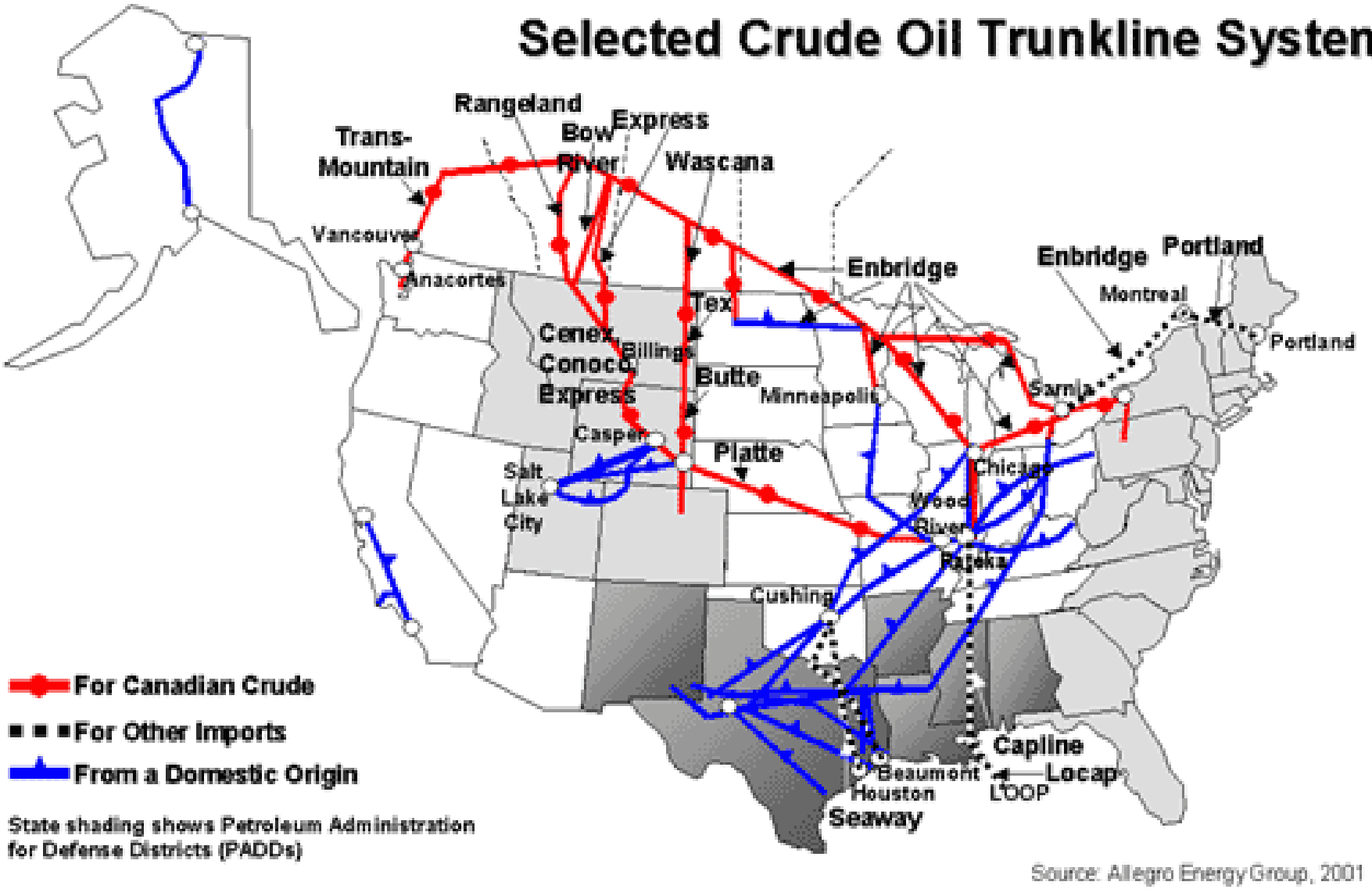
Ammonia Pipeline



Natural Gas Pipelines

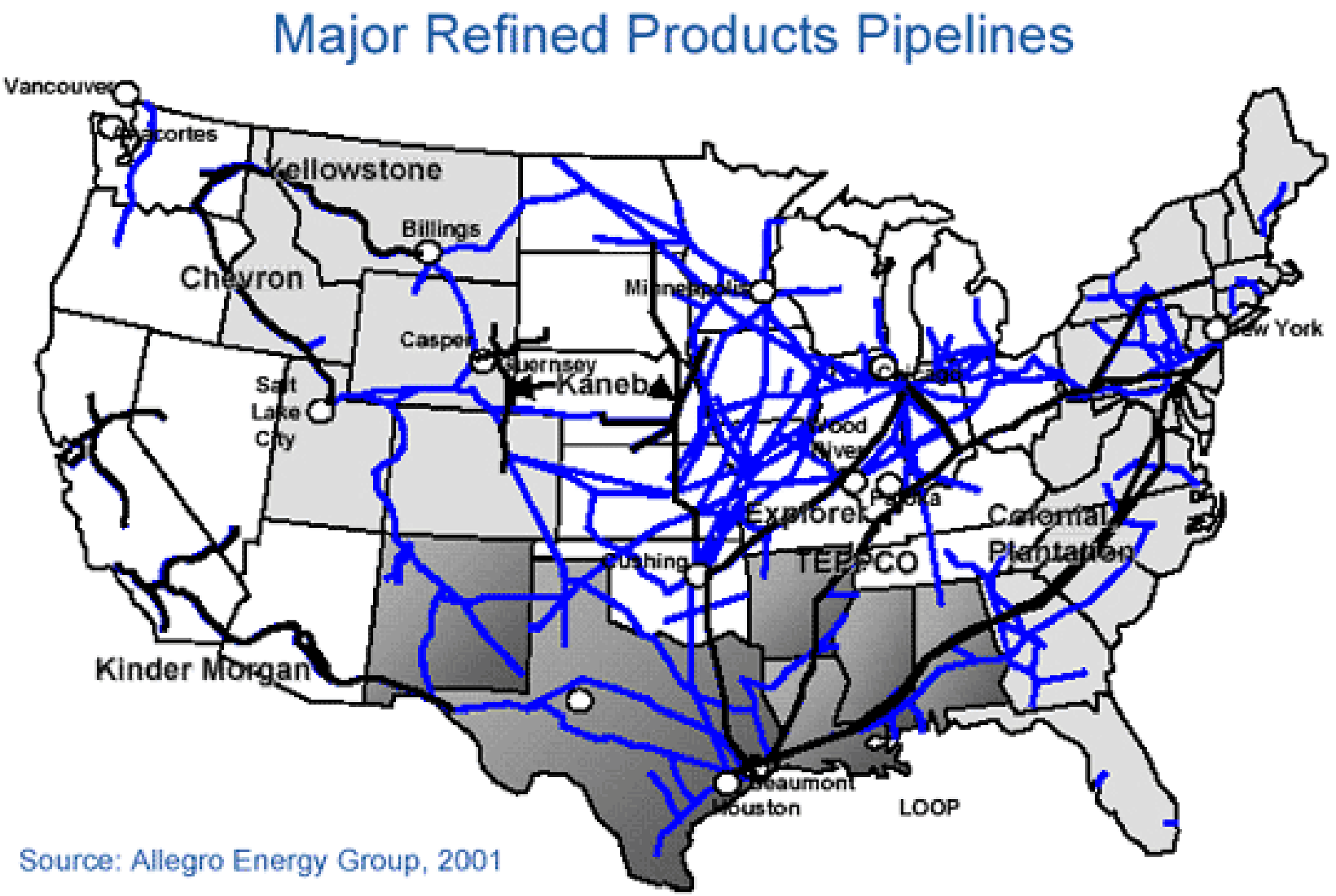


Crude Oil Pipelines

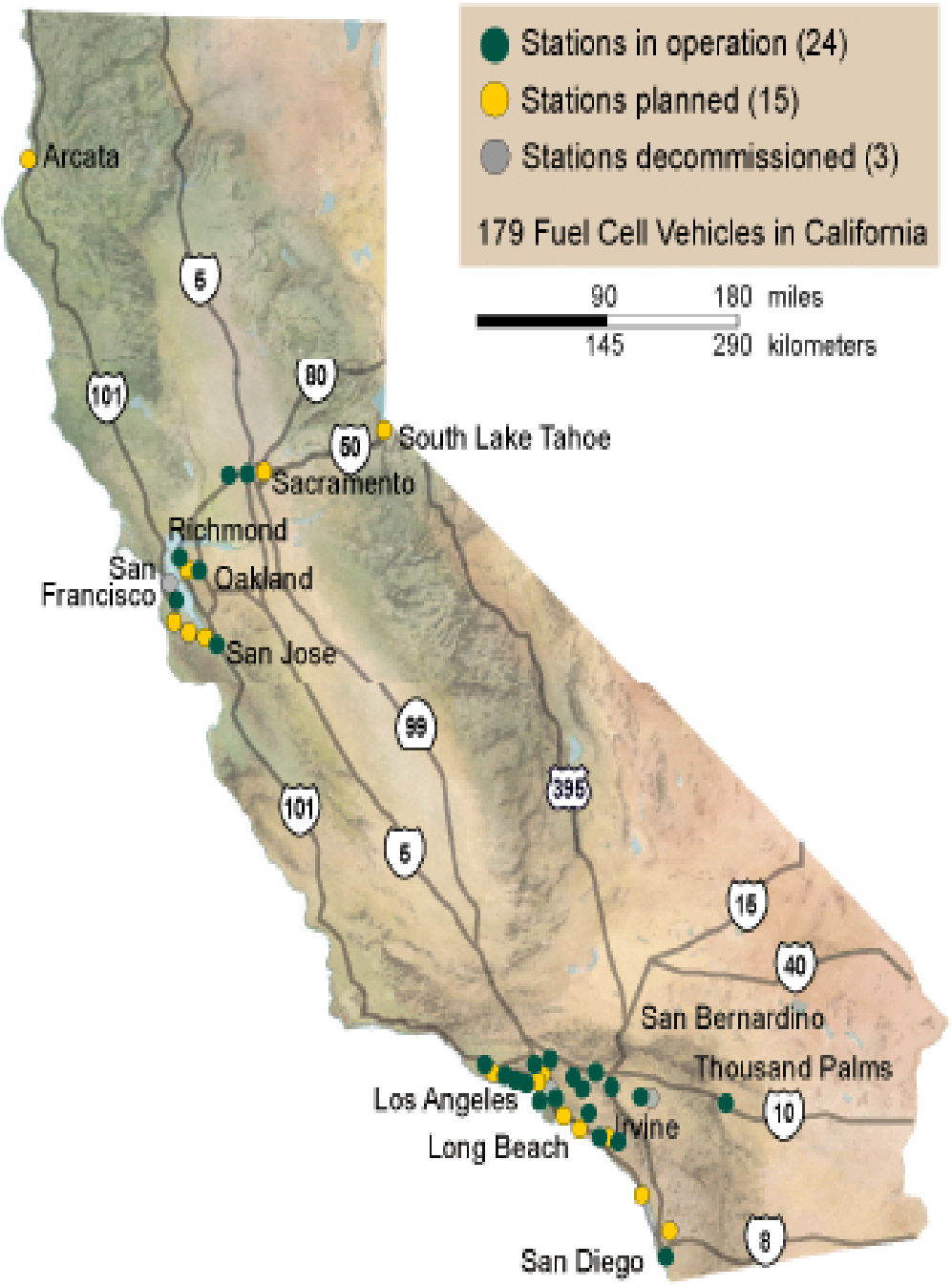


Source: Allegro Energy Group, 2001

Refined Products Pipelines



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 Refueling

Original Photo:
Clean Fuels Inc.

Iowa Power Fund Proposal

IEC NH3 Power Fund Proposal

Click to edit Master title style

Click to edit Master text styles

Second level

Third level

Fourth level

level

Wind Turbine

Electrolyzer

H2

Nitrogen Generator

Anaerobic Digester (Existing)

CH4

Methane Reformer/ Water Shift Unit

H2

Ammonia Synthesis Unit(s)

NH3

NH3 Refueling Station

Ammonia Storage

Diesel Engine
SI Engine
Fuel Cell

Burner

Fertilizer

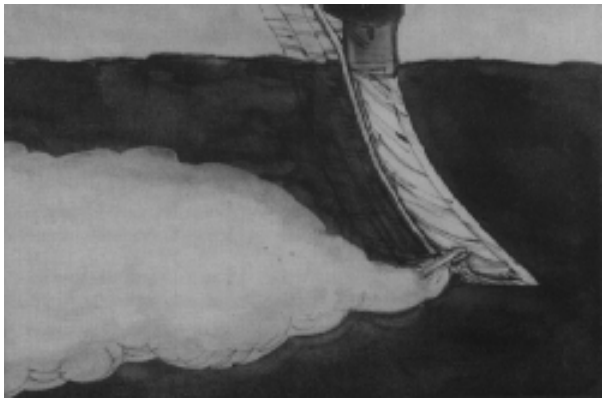
CRA Study – NH3, Propane, Gasoline

- Iowa Energy Center Funded Effort – December 2008 targeted completion date.

IEC Ammonia RFP

- 13 Responses

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 (including residential furnaces)

Health And Safety

- Iowa Energy Center funded comparative risk assessment study completed by end of 2008.
- “Safety assessment of ammonia as a transportation fuel”, Nijs Jan Duijm, Frank Markert, Jette Lundtang Paulsen, Riso National Laboratory, Denmark, February 2005
- WWI (Fritz Haber)
- Terrorists
- Ammonia plant operators
- Ammonia safety is an engineering issue. It can be made to be as safe as is necessary. It is safer than propane and gasoline as a transportation fuel.

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, not ammonia

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

Progress

- Flex fuel (gasoline/ammonia) vehicle successfully driven from Michigan to California (NH3 Car)
- Over 50% efficiency demonstrated in a SI engine (HEC)
- Irrigation pump demonstration with SI engine (HEC)
- Direct ammonia fuel cell bench-scale demonstration (Howard U.)
- Wind to ammonia demonstration funded, construction underway (U. Minn. Morris)
- 95% ammonia, 5% diesel, 110% rated power in a John Deere diesel engine (IEC/ISU)
- New ammonia synthesis technologies undeer development.
- Ammonia trademarked as “The Other Hydrogen” (HEC)
- Comparative risk assessment report commissioned. December 2008 projected completion date. (IEC)
- Ammonia Fuel Network (AFN) website established
- Focused RFP for ammonia research/demonstration issued (IEC)

Economic Impacts

T Boone Pickens - $700 Billion new U.S. industry.

Summary 1

- **Ammonia meets most 2015 Freedom Car targets today**
- **Ammonia has a very extensive, worldwide transportation and storage infrastructure already in place. Hydrogen infrastructure is negligible and too costly to ever implement.**
- **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**
- **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 all fuel applications**

Summary 2

- **Ammonia from coal, natural gas and nuclear energy now**
- **Ammonia from renewables in the near future (Including wind, solar, OTEC and hydro!)**
- **NH3 diesel (CI) and spark-ignition (SI) engines now**
- **Direct NH3 fuel cells in the near future**
- **Ammonia is not a toxic chemical! It is the most commonly used fertilizer in the U.S. and is used on most corn ground.**
- **Any known transportation fuel has some associated safety risks but ammonia is safer than gasoline, propane and hydrogen when used as a transportation fuel.**
- **Ammonia looks very good now and in the future**
- **It's time to get politically connected and become better promoters**