

Ammonia as a Transportation Fuel II

Argonne National Labs

October 13-14, 2005

Norm Olson –Iowa Energy Center

www.energy.iastate.edu

Meeting Objectives

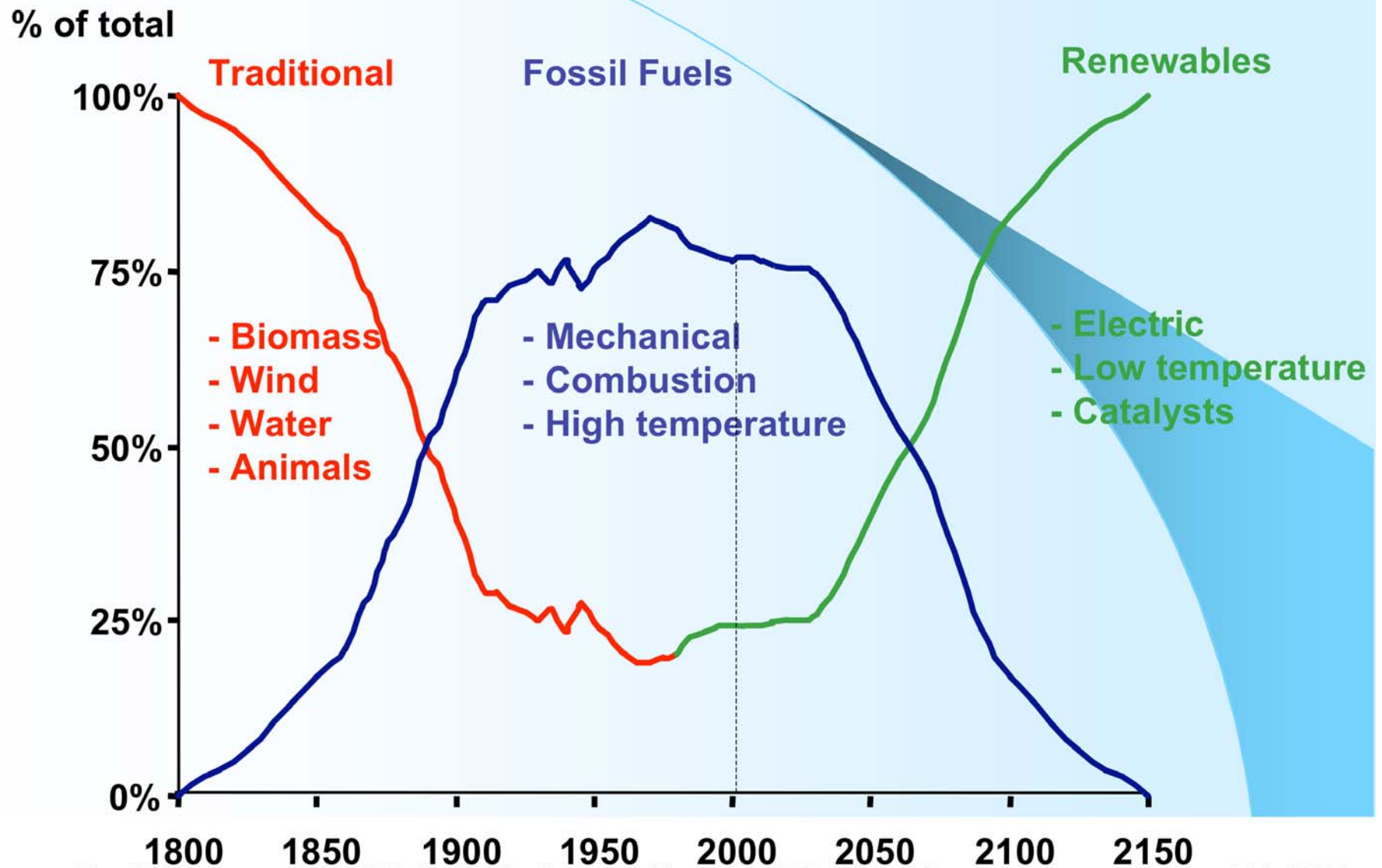
- Discuss Pro's and Con's of Ammonia as a Transportation Fuel
- Provide Facts to Help Enlighten Perspectives
- Determine Next Steps

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 Breunese, 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

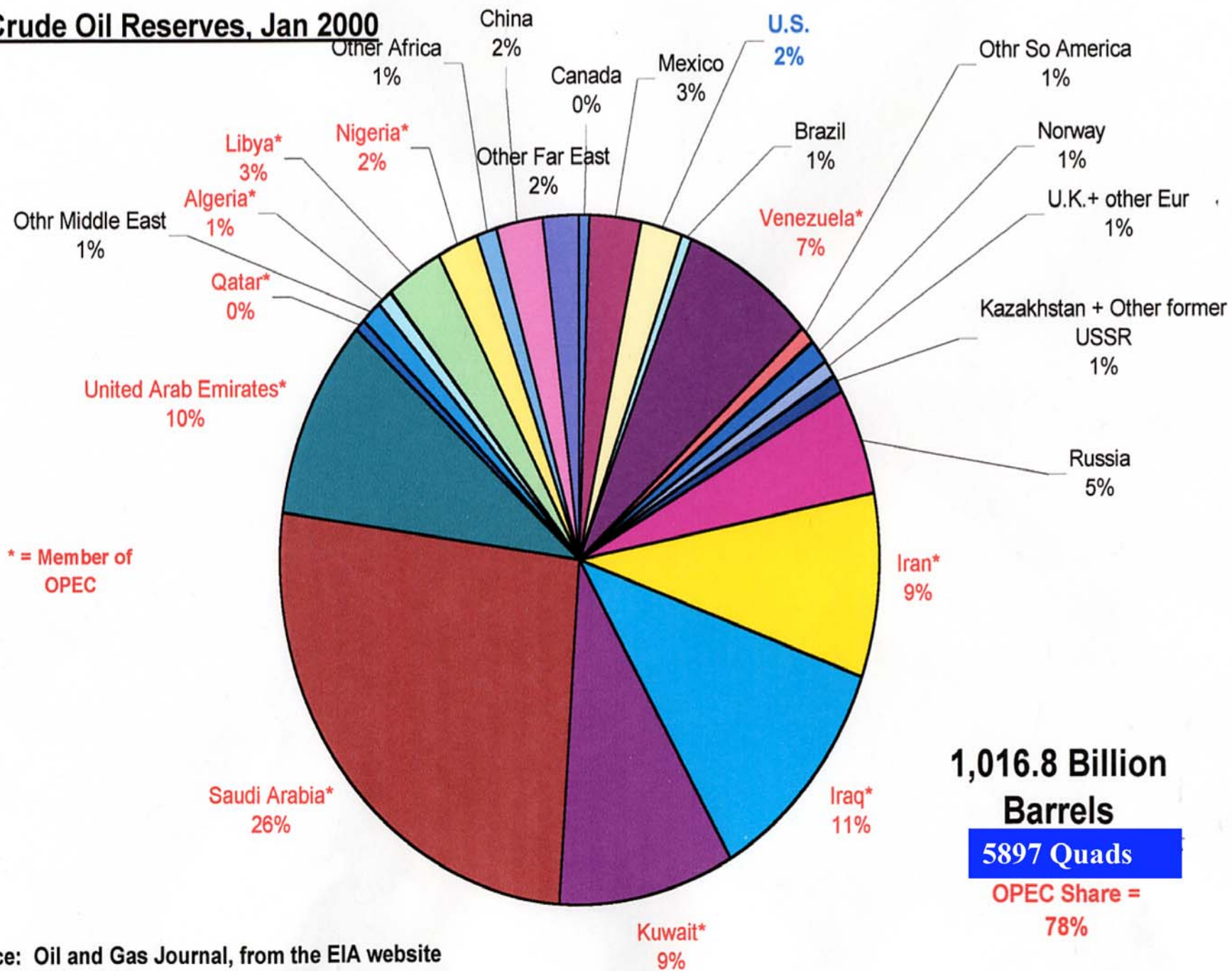
US imports over 60% of Petroleum (2004)

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

Oil Reserves

The background is a solid blue gradient. A thin, light blue curved line starts from the top left and arcs towards the right. A light blue triangle is positioned on the right side, pointing towards the center.

World Crude Oil Reserves, Jan 2000

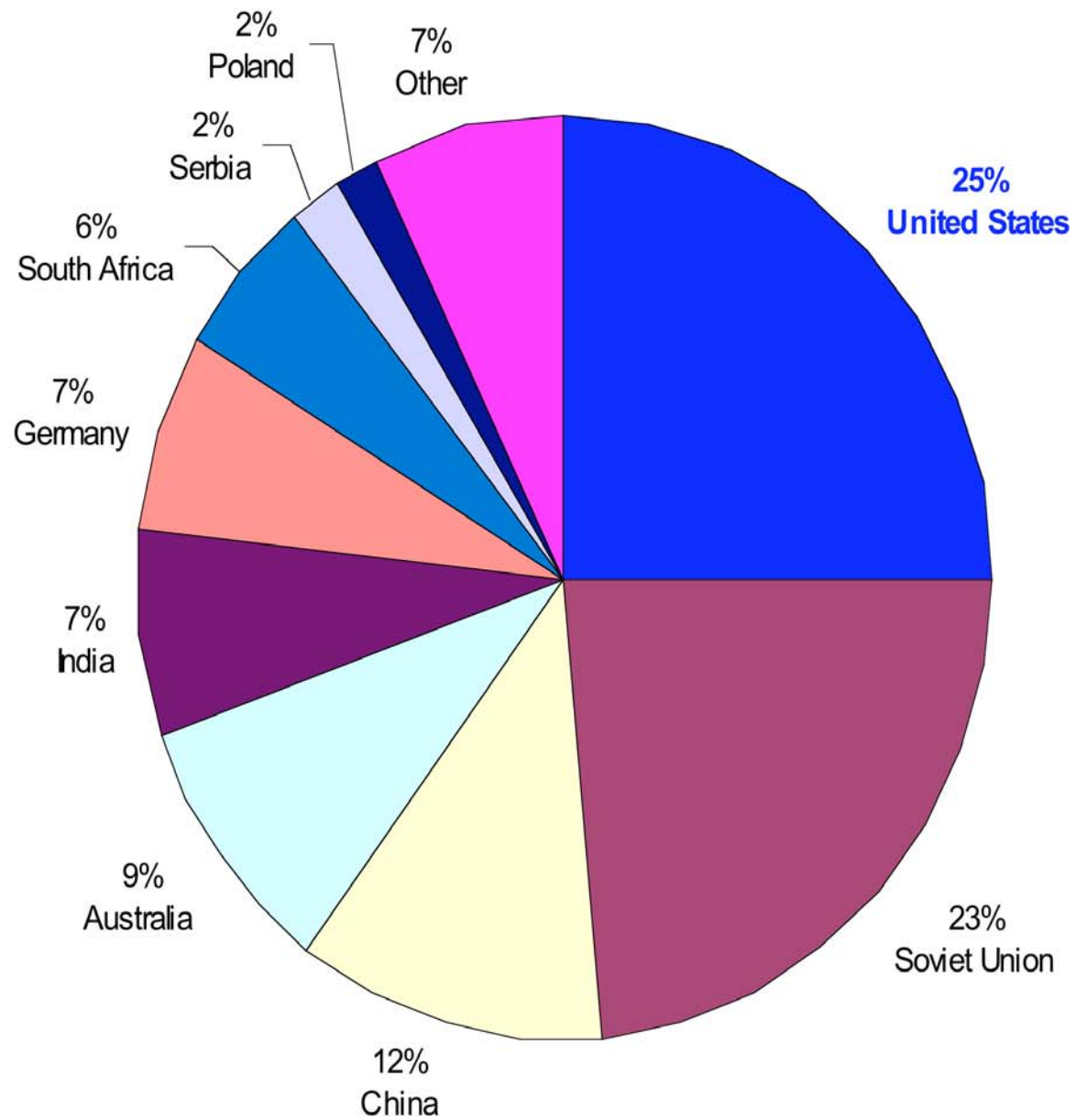


Source: Oil and Gas Journal, from the EIA website on International Petroleum Consumption

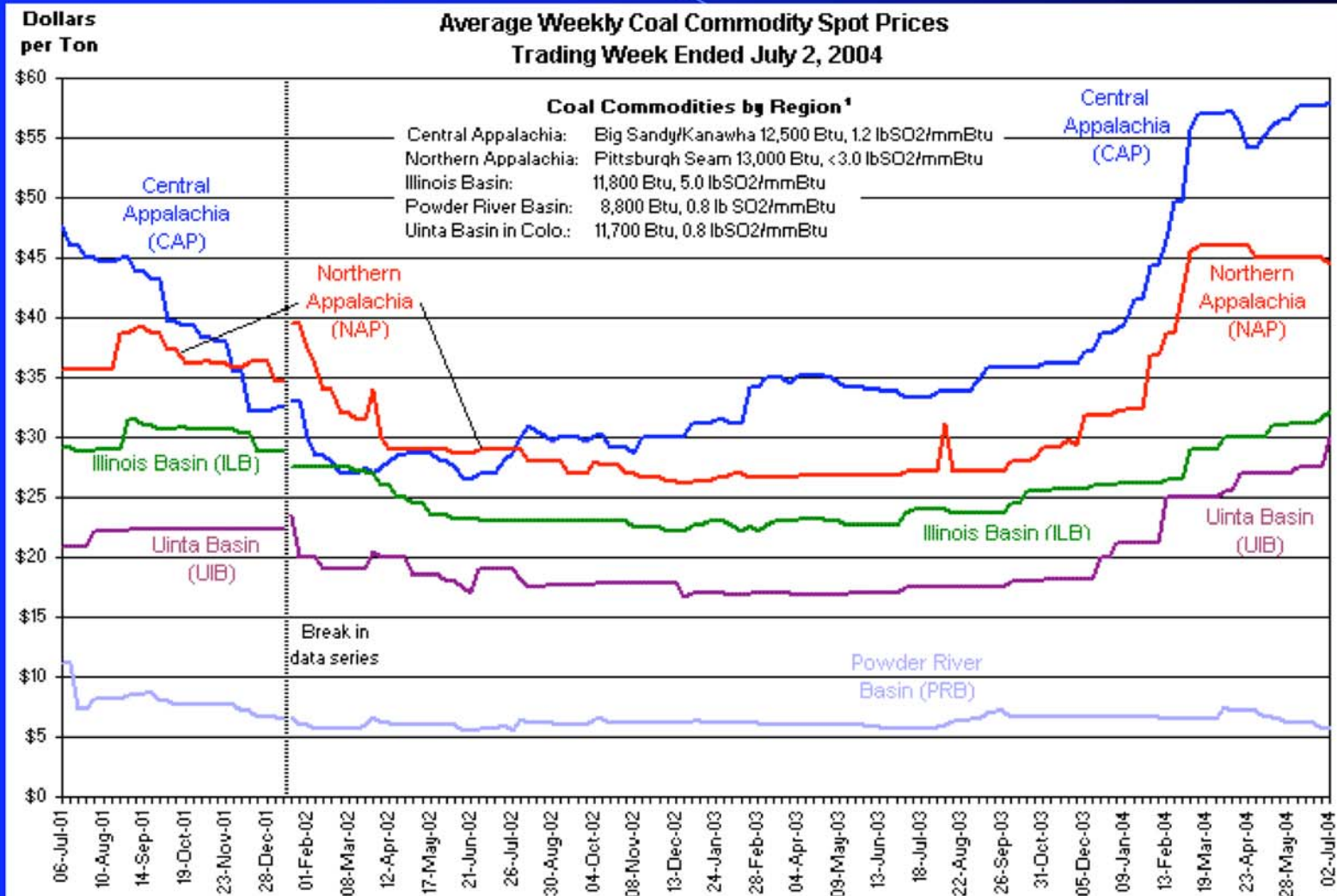
Coal Reserves

The background is a solid blue gradient. A thin, light blue curved line starts from the top left and arcs towards the right. A light blue triangle is positioned on the right side, pointing towards the center.

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

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

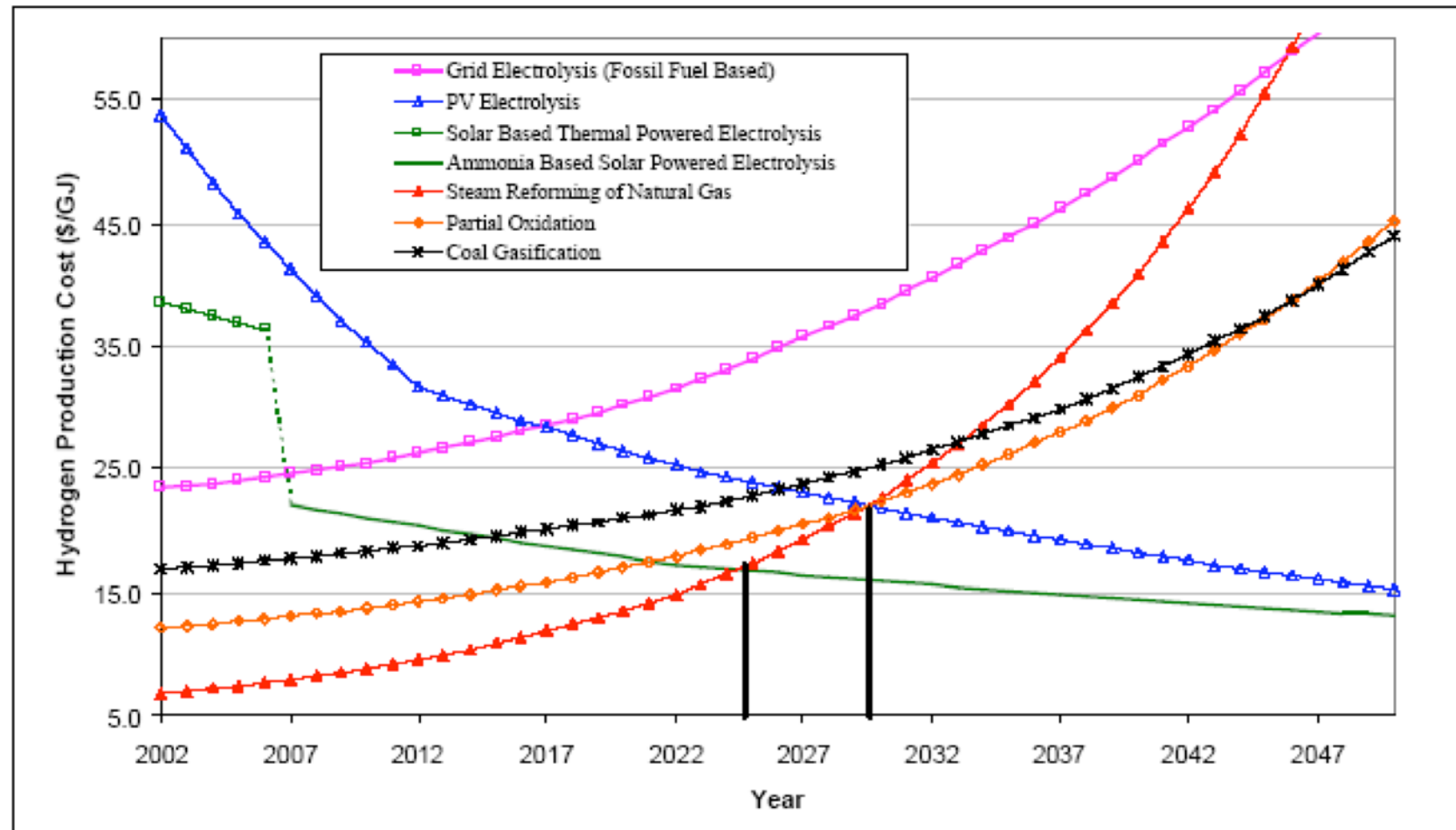
Technology	Converter	Capacity	Maximum	Land per Year for:	
	Efficiency	Factor	Packing	km ² /GW	m ² /GWh
Flat-Plate PV	10-20%	20%	25-75%	10-50	5000 - 25,000
Wind	Low to 20%	20%	2-5%	100	140,000
Biomass	0.1% total		High	1000	500,000

Source:

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



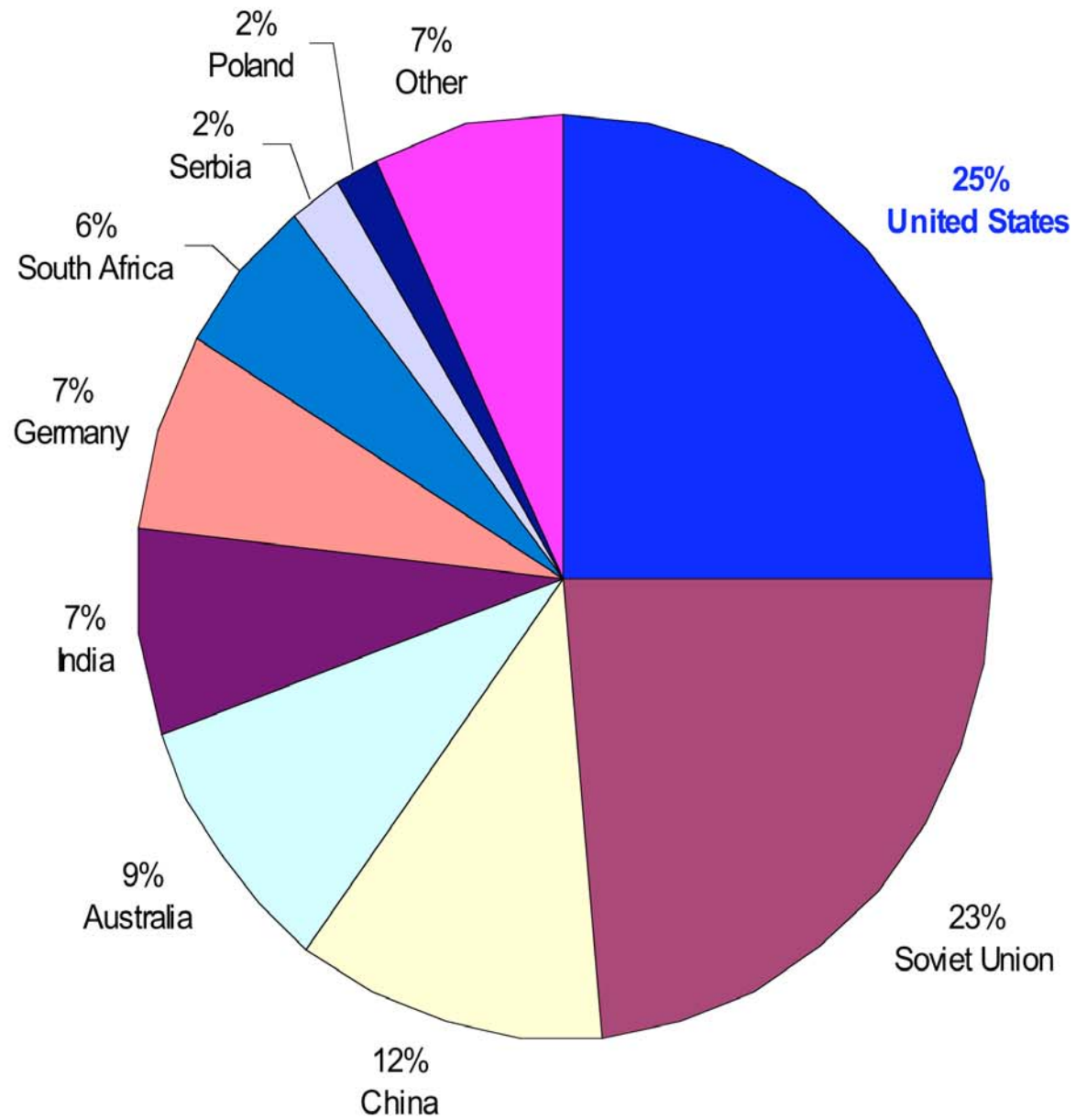
Scenario 1 Results



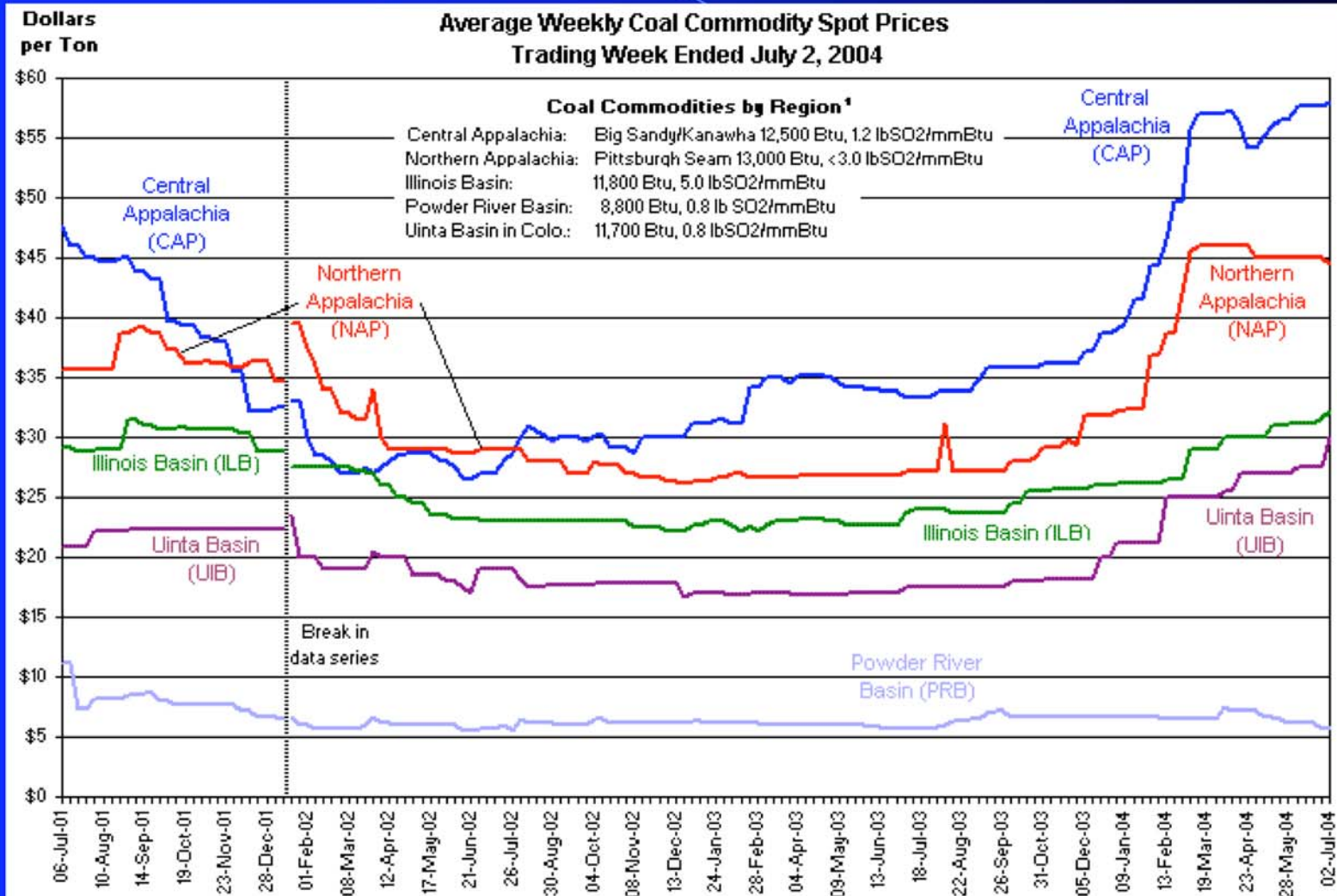
Fossil Fuel Hydrogen Sources

- Petroleum
- Natural Gas
- Coal

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."

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.

Europe

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

euro-cleancoal.net

Chemistry

From Coal



or



From Natural Gas



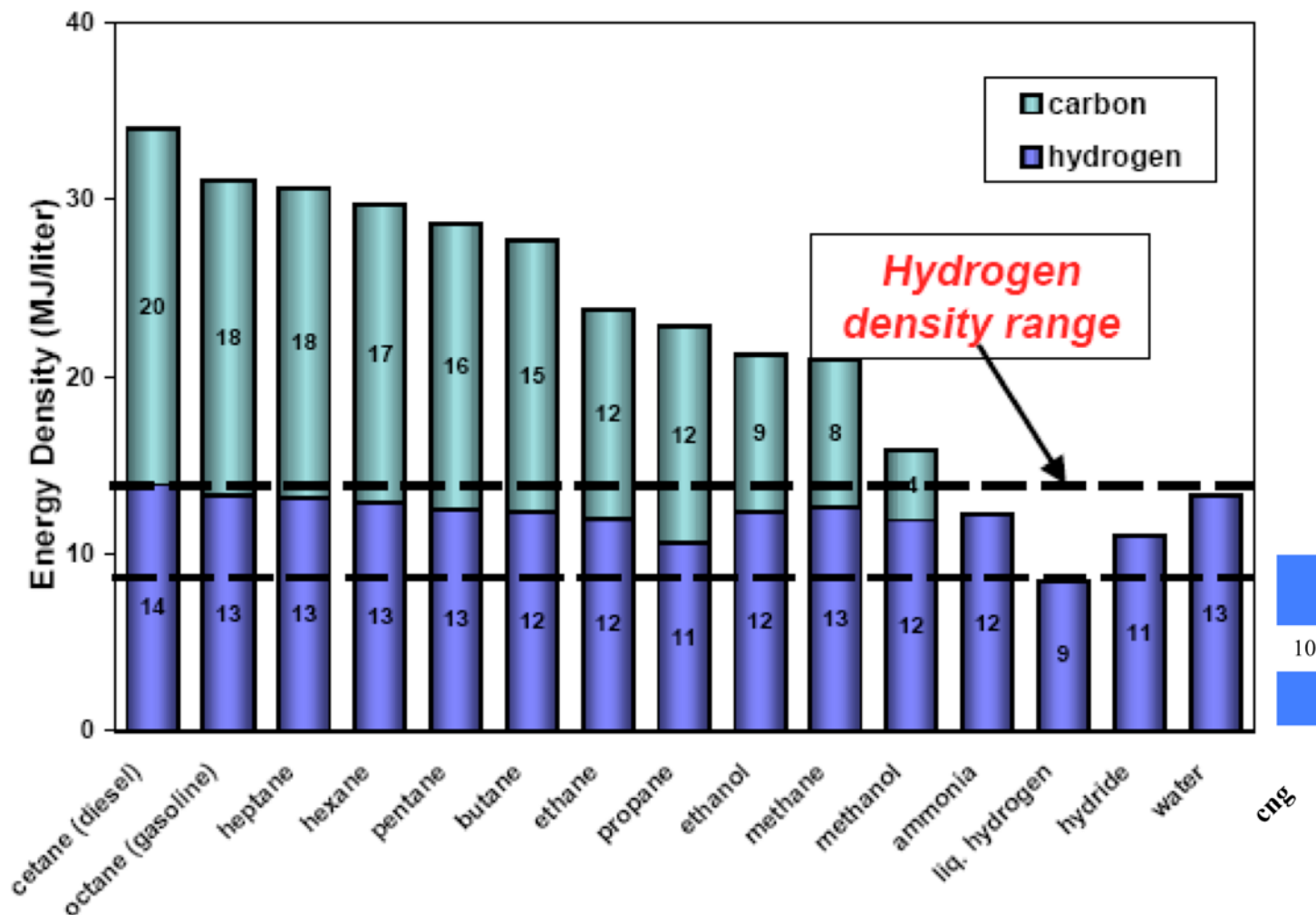
Performance

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Hydrogen Carriers

- Liquefied Hydrogen (H_2) 100%
- Compressed Hydrogen (H_2) 100%
- Natural Gas (CH_4) 25.0%
- Ammonia (NH_3) 17.6%
- Ethanol ($\text{C}_2\text{H}_6\text{O}$) 13.0%
- Methanol (CH_4O) 12.5%

Energy densities (LHV) for fuels in liquid state



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	3.1
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

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

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

1250 new plants @ 650,000 ton/year each

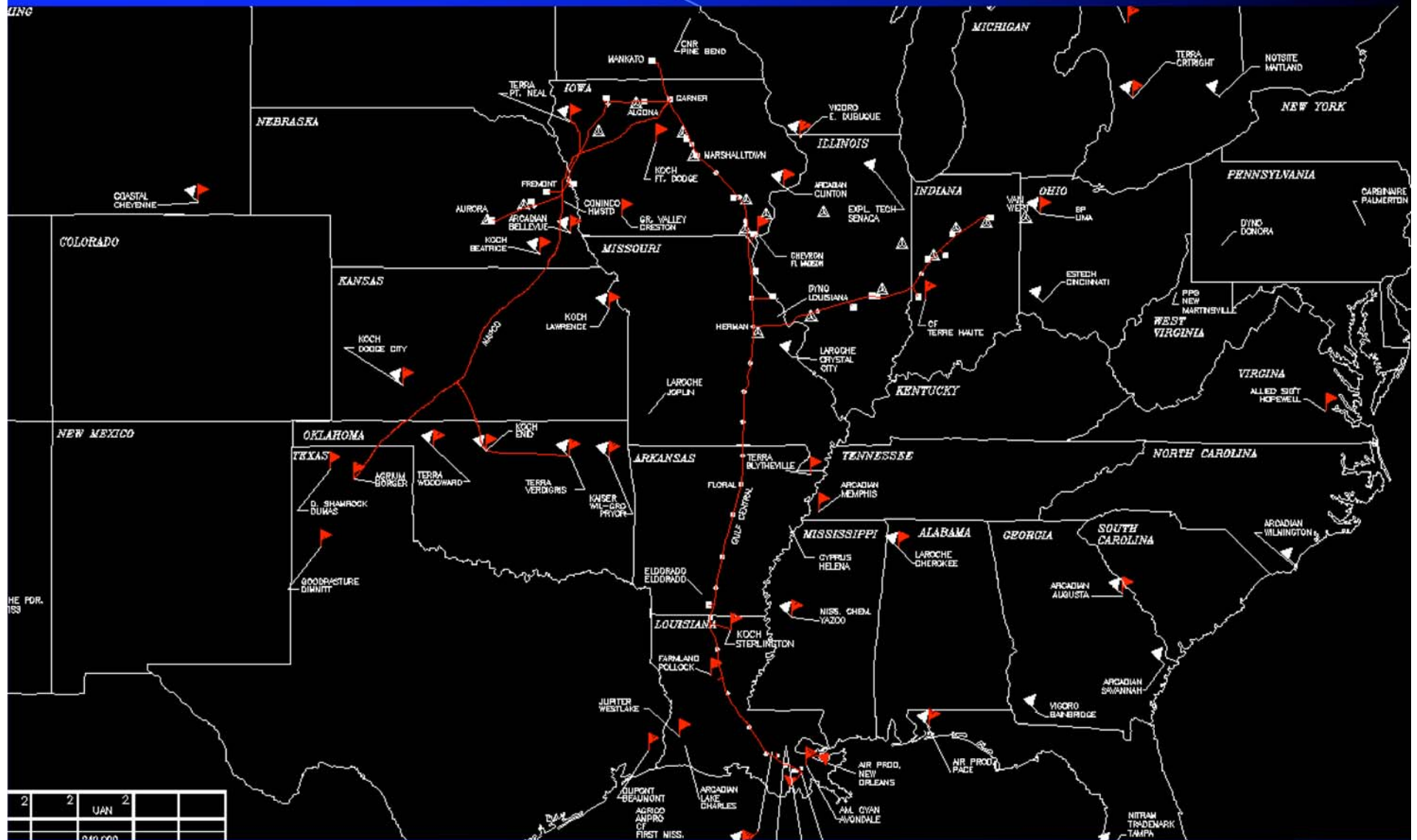
\$562 billion investment @\$450 million/plant

375,000 new jobs

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

Delivery Infrastructure

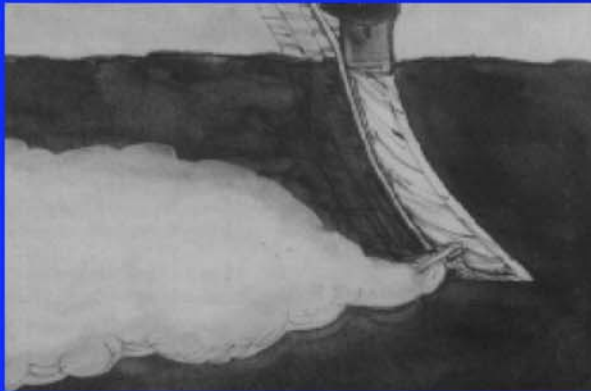
Ammonia Pipeline



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

The background is a solid blue gradient. A curved, lighter blue shape starts from the top left and sweeps towards the bottom right, creating a dynamic visual element. The text "Health And Safety" is centered in the upper half of the image.

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

$\text{C}_{10}\text{H}_{15}\text{NO}$

Methamphetamine

$\text{C}_{10}\text{H}_{15}\text{N}$

$\text{VOC's} + \text{NO}_x + \text{O}_2 + \text{Sunlight} = \text{ozone} = \text{smog} +$

$\text{NO}_x + \text{H}_2\text{O} + \text{ammonia} = \text{ammonium nitrate} = \text{smog-}$

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

Fossil fuels are the problem, not ammonia

Ammonia is actually used to clean up NO_x emissions 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 LD₅₀ and LC₅₀ 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 its significant components have Health Ratings of 2 and 3.

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**