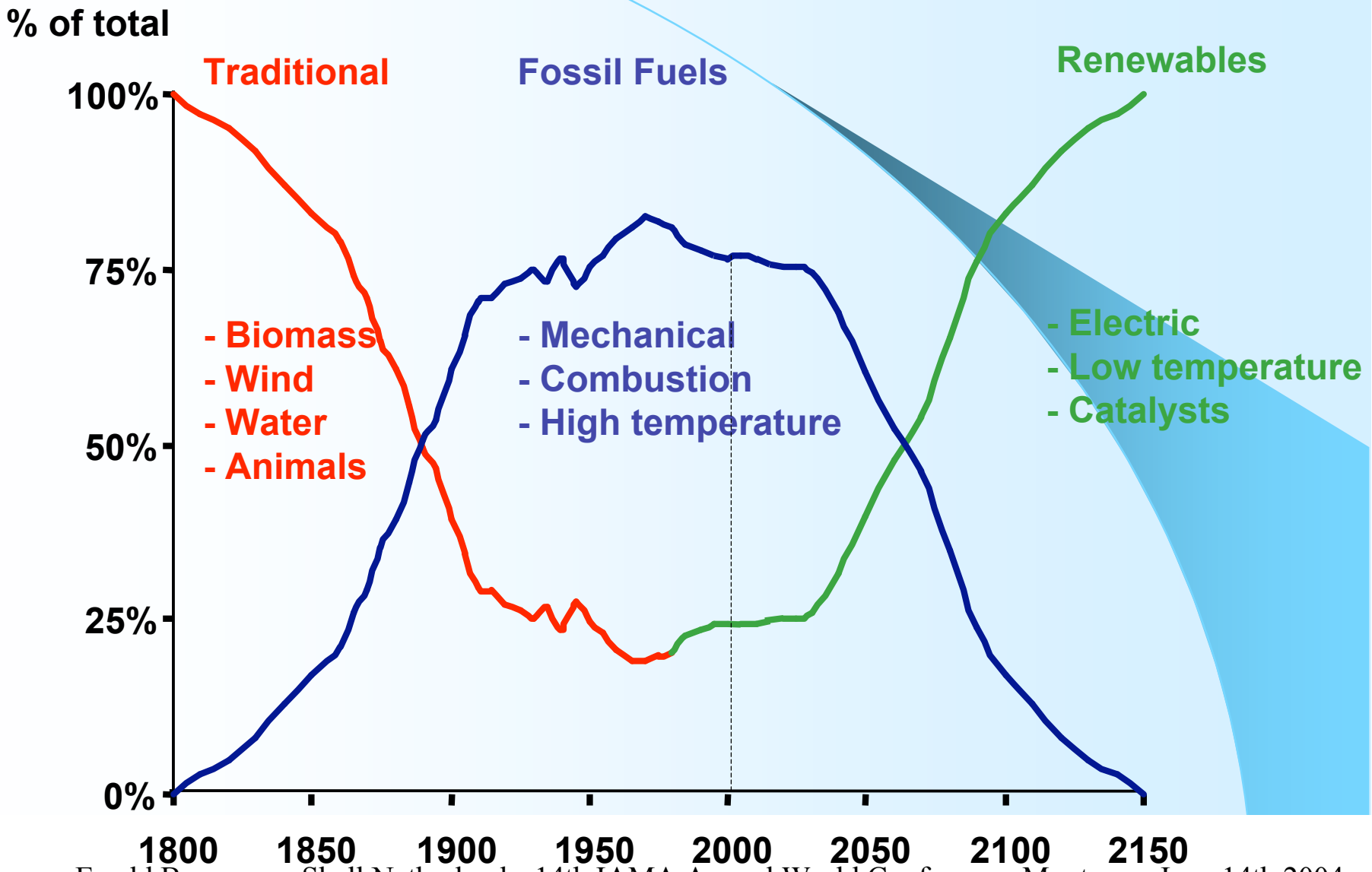
Ammonia as a Transportation Fuel

Meeting Purpose

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

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

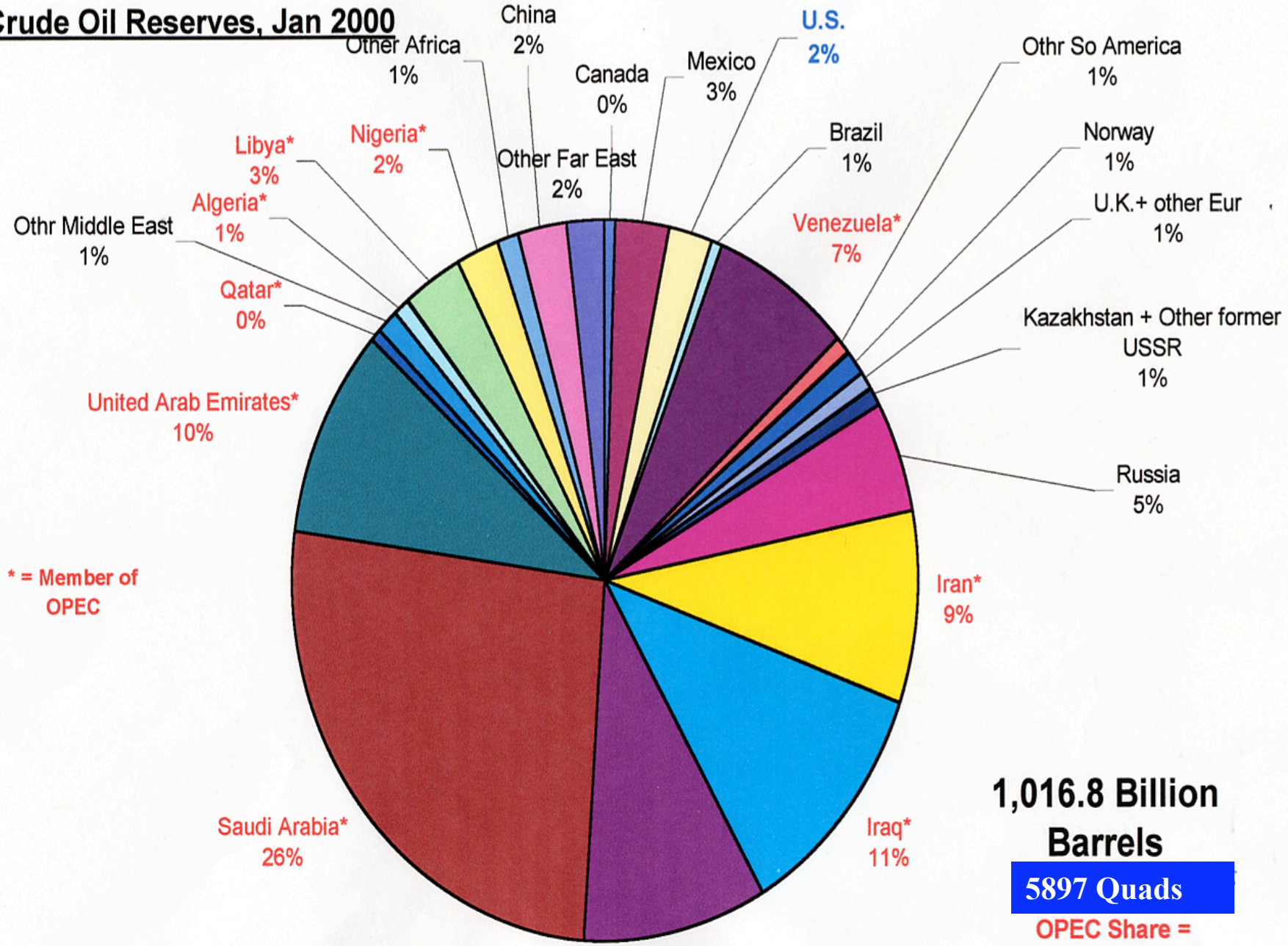
US imports over 60%

Iraq oil - the target for years

By Ahmad Quni

Oil Reserves

World Crude Oil Reserves, Jan 2000



1,016.8 Billion Barrels

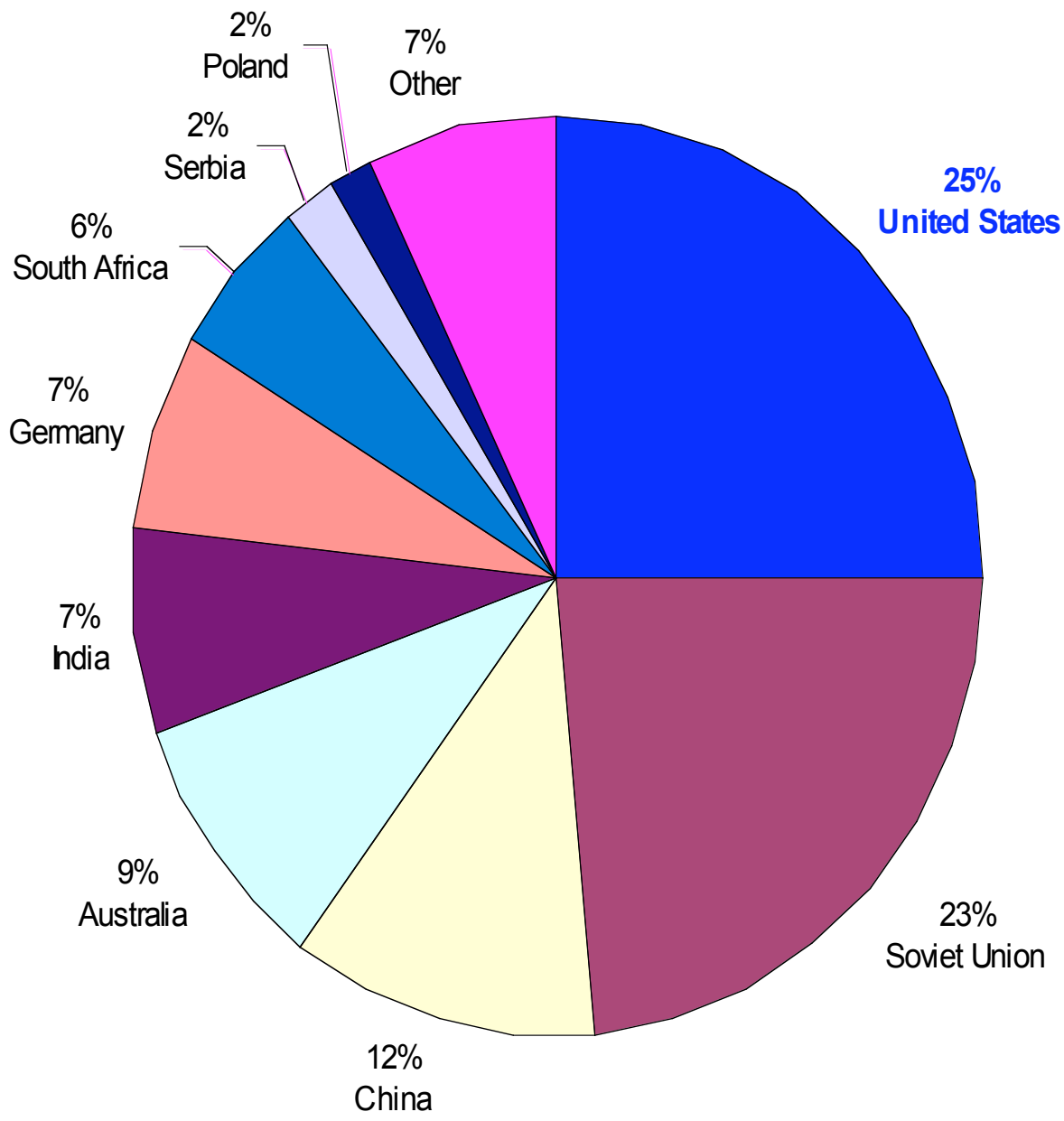
5897 Quads

OPEC Share = 78%

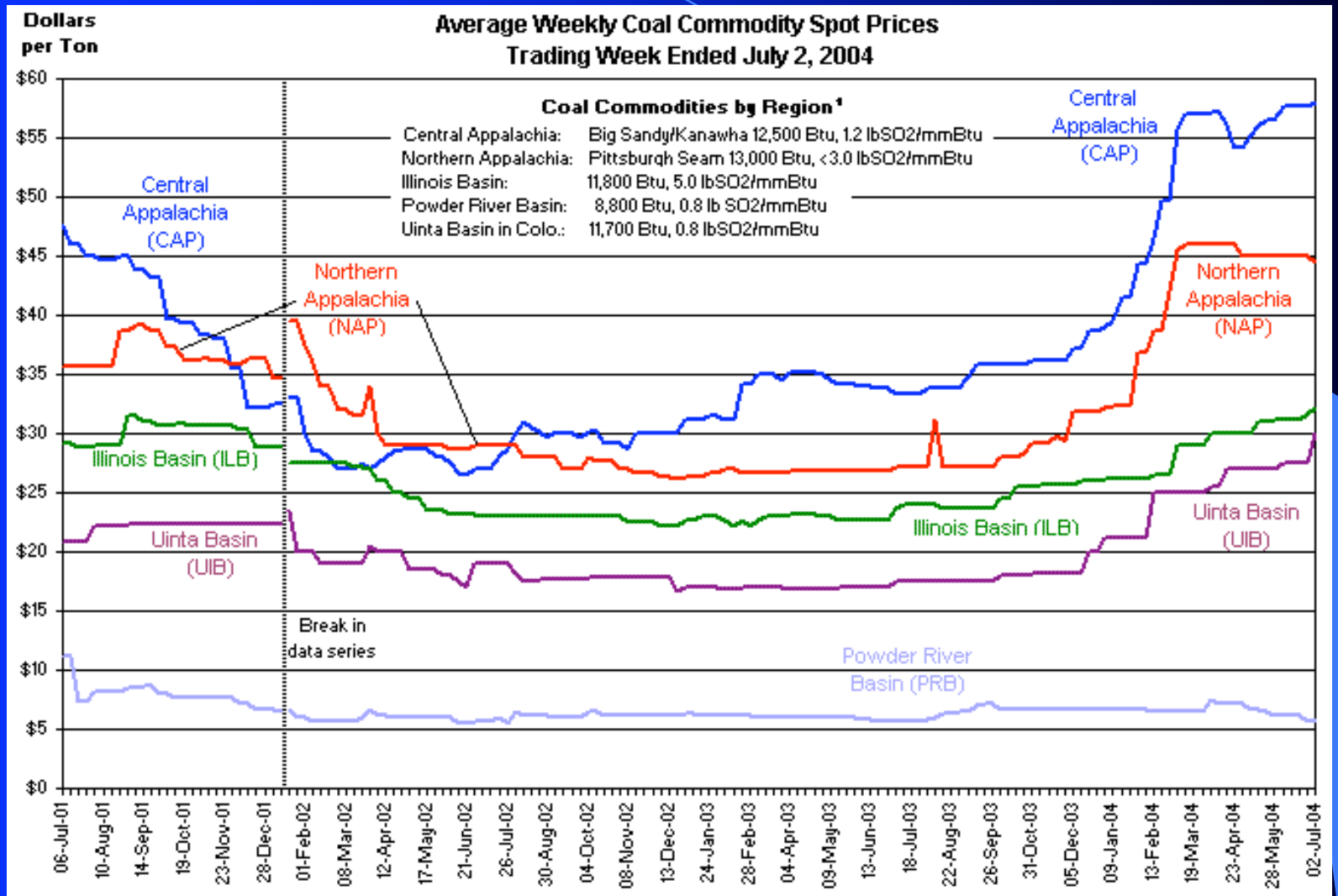
Source: Oil and Gas Journal, from the EIA website on International Petroleum Consumption

Coal Reserves

World Recoverable Coal Reserves - January 1999



US Coal



[1]Prior 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."

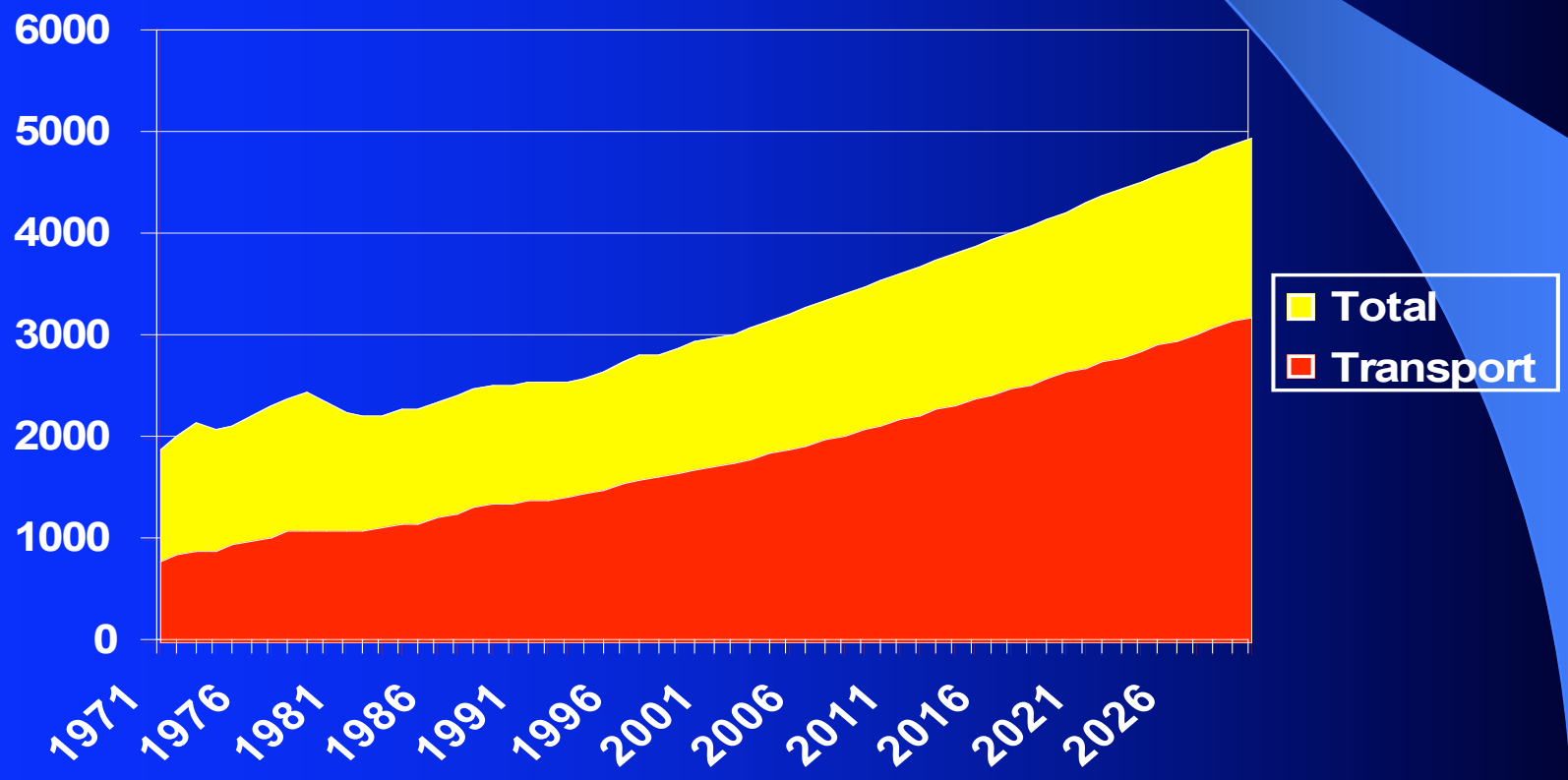
Status of the Hydrogen Economy: Does Hydrogen Have a Practical Future as a Transportation Fuel?

World Federation of Scientists
Energy PMP
19 August 2003

Carmen Difiglio, Ph.D.
International Energy Agency

World Oil Consumption 1971-2030

(Final Consumption - Mtoe - Historic Data + WEO 2002)



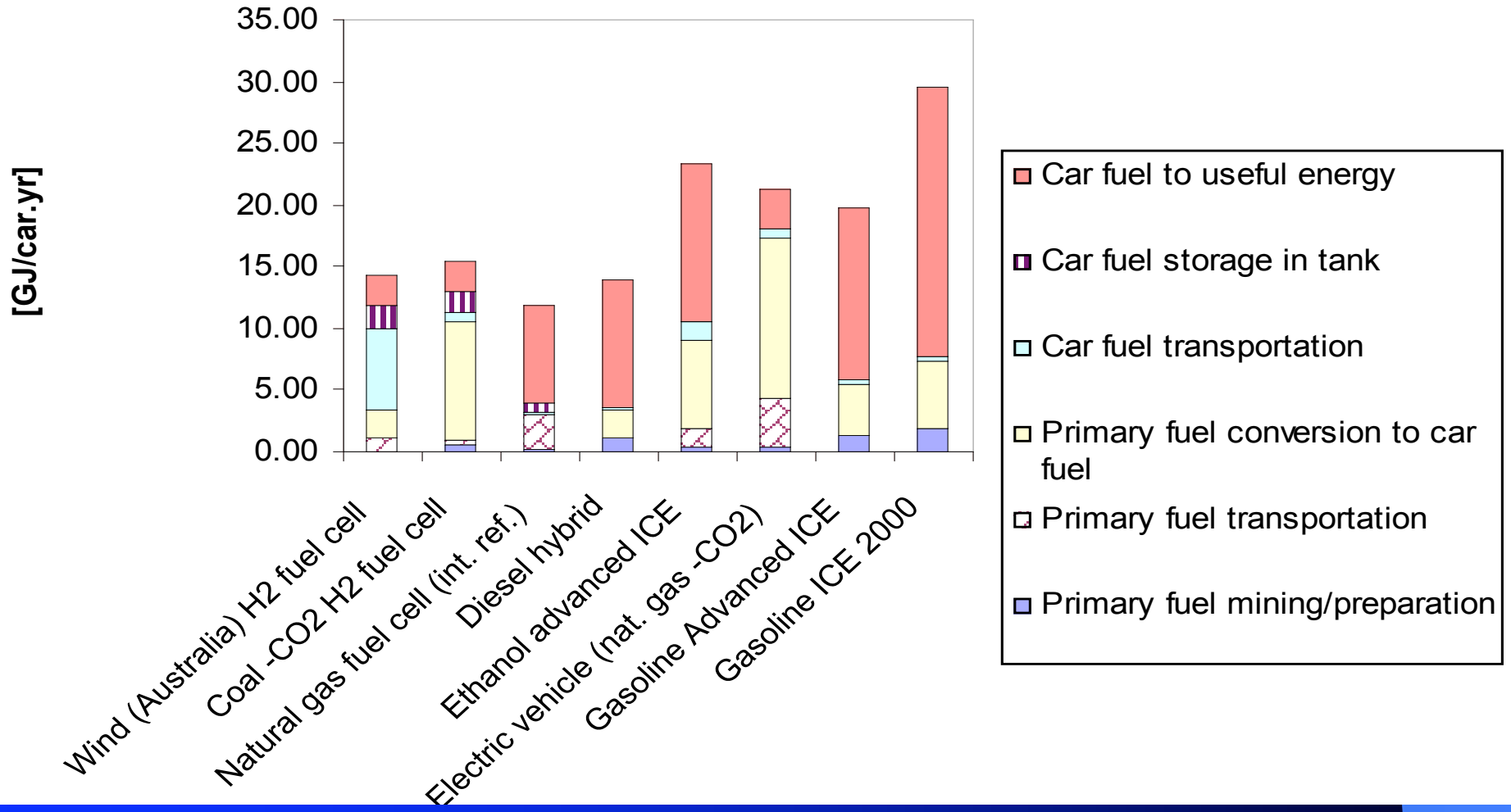
Alternative Hydrogen Transport Technologies

- Alternative Sources of Hydrogen
  - Coal with & without CO_2 capture & storage
  - Gas with & without CO_2 capture & storage
  - Electrolysis of water with CO_2-free electricity
  - Co-generation in HTGR
  - Biomass production
- Vehicle Technologies
  - Advanced ICE optimised for H_2
  - Hybrid ICE optimsed for H_2
  - Fuel Cell

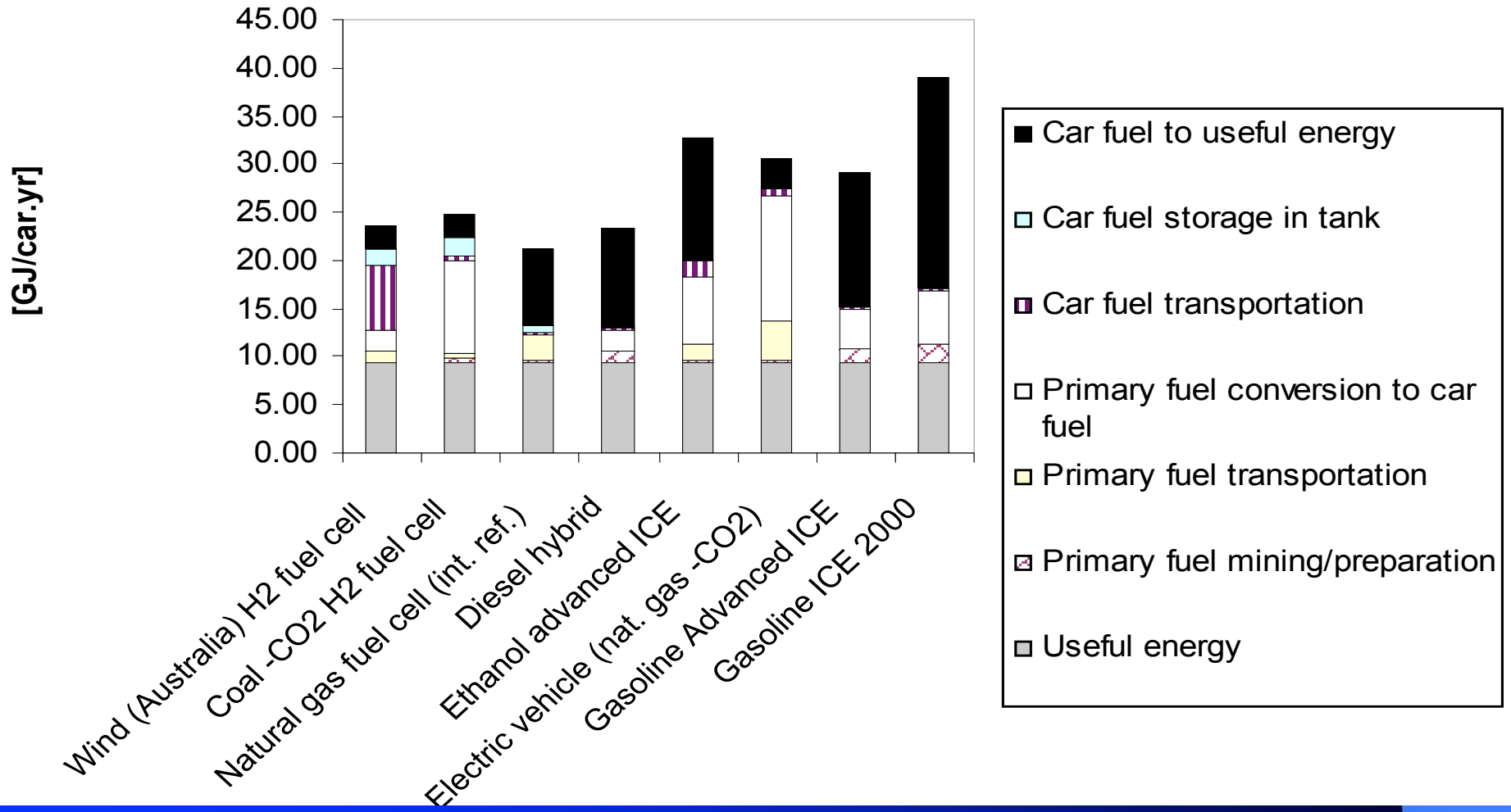
Energy Use

- Energy use can occur at every step in the "full-fuel-cycle" chain:
  - primary fuel mining and preparation
  - primary fuel transport
  - conversion to car fuel
  - car fuel transportation
  - car fuel storage
  - conversion of car fuel to useful energy

Well-to-Wheel Energy Losses



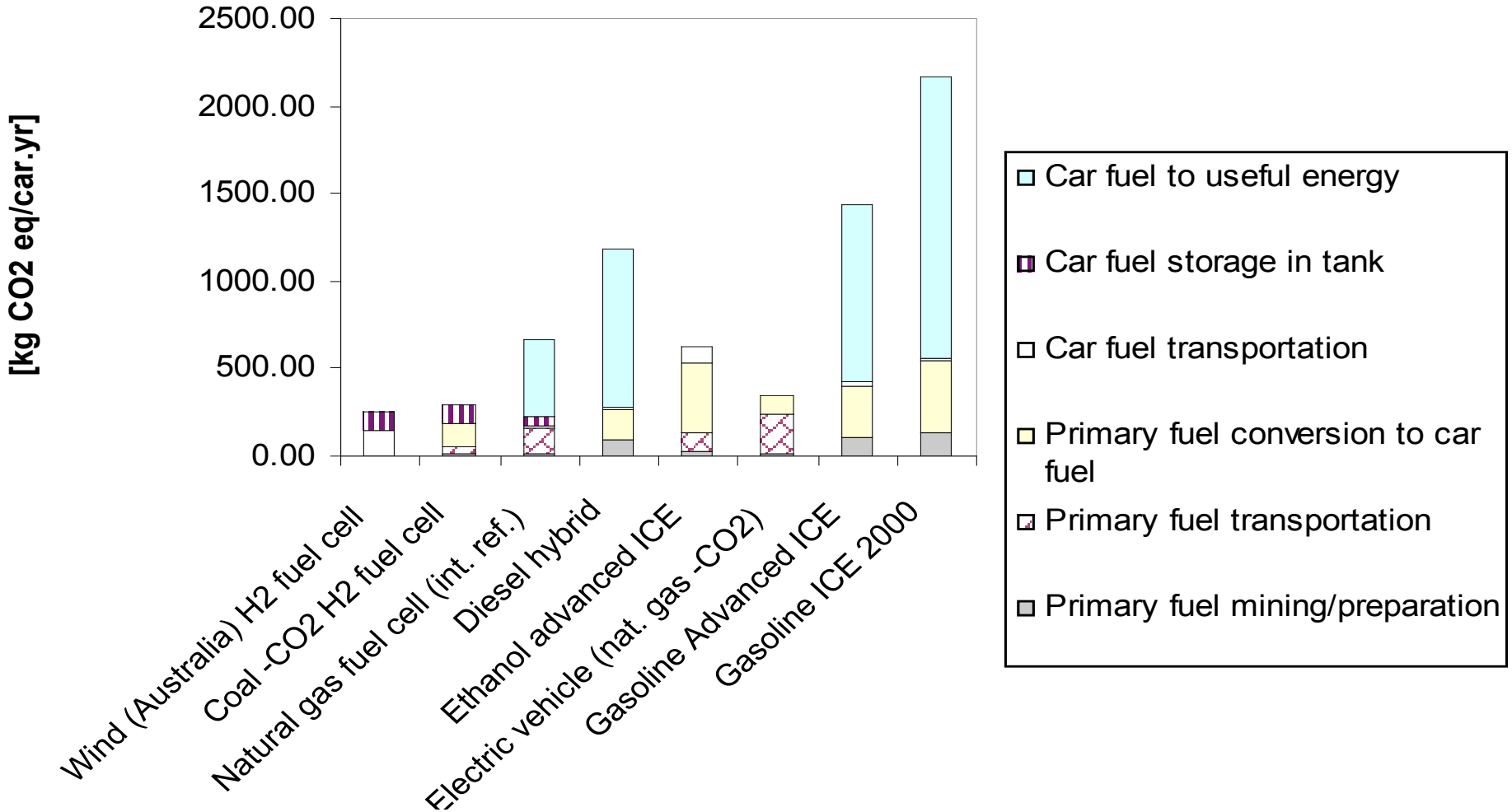
Well-to-Wheel Energy Use



Observations - Energy Use

- Fuel cells and electric vehicles provide large improvements in the efficient use of car fuel.
- These savings are partly offset by increased energy use in primary fuel transportation, conversion to car fuel and on-board storage.
- Natural gas fuel cells (on board reforming) and diesel hybrids both have very low well-to-wheel energy losses.

Well-to-Wheel GHG Emissions



Future Delivered Fuel Supply Costs

($/GJ unless otherwise indicated)

	Gasoline or Diesel	Nat Gas	H_2: NG-CO_2	H_2: Coal-CO_2
Current Cost (reference)	5-7	3-4	8-12	12-15
Fuel/Elec Cost	$25-29/bl	3-4 (LNG import)	3-5 (LNG import)	1-2
Feedstock Cost	4.4-5.1	3-4	3.8-6.3	1.3-2.7
Production Costs	2.0-2.8	NA	1.2-2.7	4.7-6.3
Distribution Costs	<1-1	<1-1	2	2
Delivered Costs	6-9	3-5	7-11	8-11

Future Delivered Fuel Supply Costs

($/GJ unless otherwise indicated)

	H_2:Gsftn Biomass	H_2: On-S Wind	H_2: Off-S Wind	H_2: Solar Thermal
Current Cost (reference)	NA	NA	NA	NA
Fuel/Elec Cost	2-5	3-4 (cents/kWh)	4-4.5 (cents/kWh)	6-8 (cents/kWh)
Feedstock Cost	2.9-7.1	10-13	13-18	20-26
Production Costs	5-6	5	5	5
Distribution Costs	2-5	2-5	2-5	2-5
Delivered Costs	10-18	17-23	22-30	27-35

Future Delivered Fuel Supply Costs

($/GJ unless otherwise indicated)

	H_2: Solar PV	H_2: Nuclear	H_2: CHP HTGR
Current Cost (reference)	NA	NA	NA
Fuel/Elec Cost	12-20 (cents/kWh)	2.5-3.5 (cents/kWh)	
Feedstock Cost	39-65	8.2-11	
Production Costs	5	5	8-23
Distribution Costs	2-5	2	2
Delivered Costs	47-75	15-20	10-25

The Transition Period

- Chicken or the Egg Problem no. 1:
  - Consumers reluctant to H_2 purchase vehicles without widespread availability of H_2 refueling.
  - Fuel marketers reluctant to invest in H_2 refueling without adequate numbers of customers.
- Chicken or the Egg Problem no. 2:
  - Investors reluctant to build H_2 capacity in anticipation of uncertain vehicle sales .
  - Auto manufacturers reluctant to build large numbers of H_2 vehicles without assured H_2 supplies *and* distribution.

Hydrogen Sources

- Renewables
- Fossil Fuels
- Nuclear

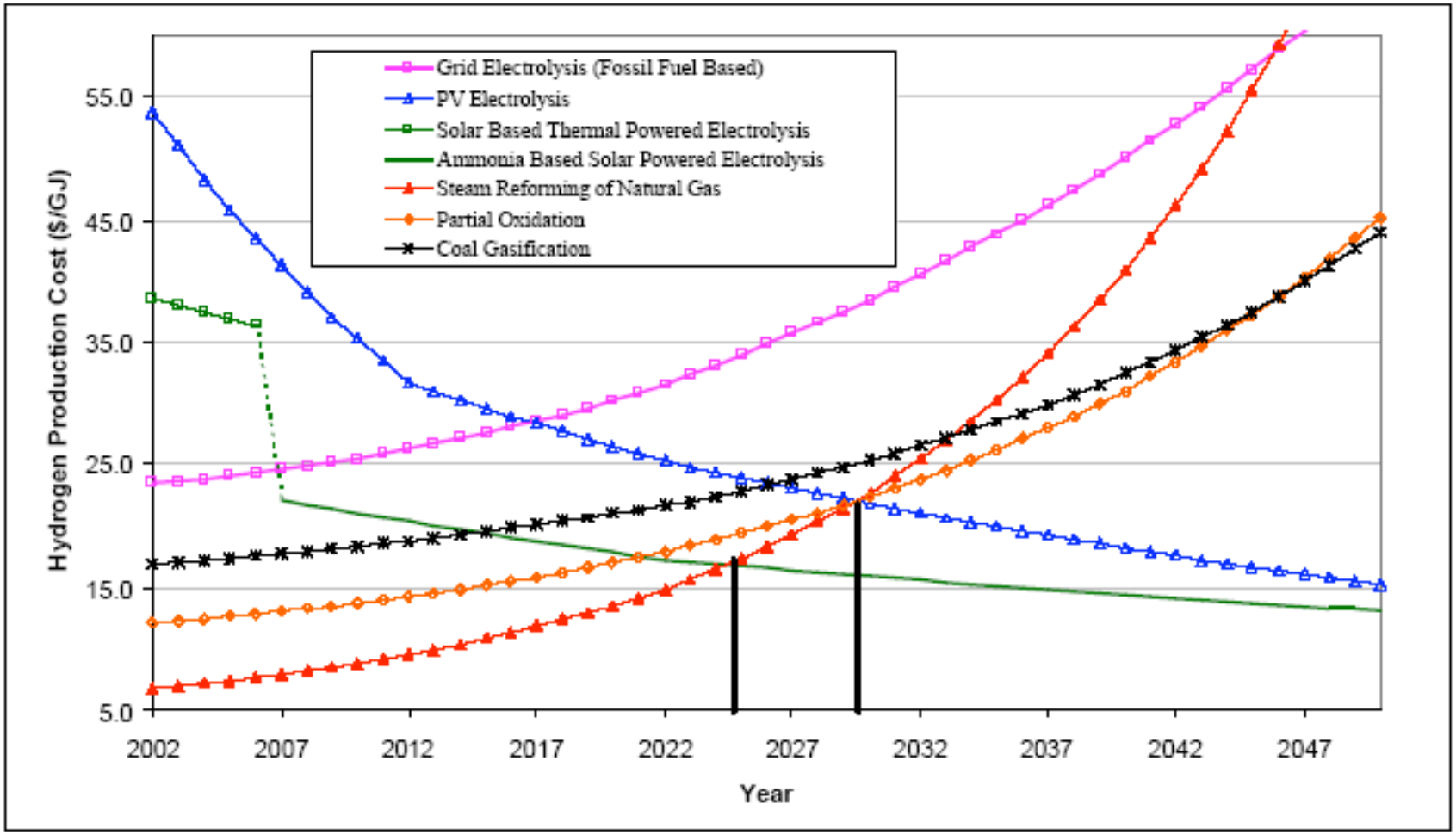
Renewable Energy Options

- Wind
- Solar
- Biomass

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

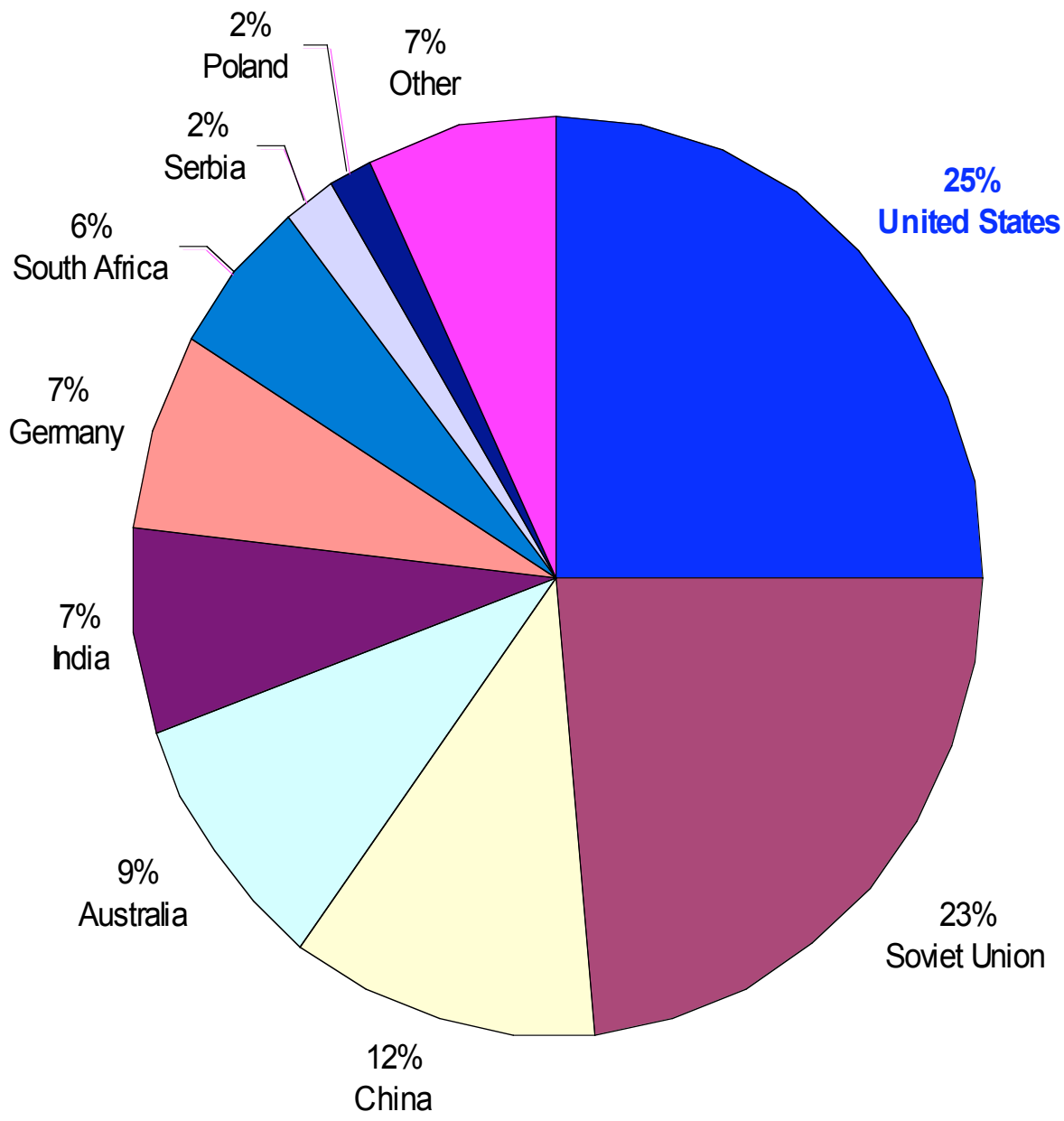
Scenario 1 Results



Fossil Fuel Hydrogen Sources

- Petroleum
- Natural Gas
- Coal

World Recoverable Coal Reserves - January 1999



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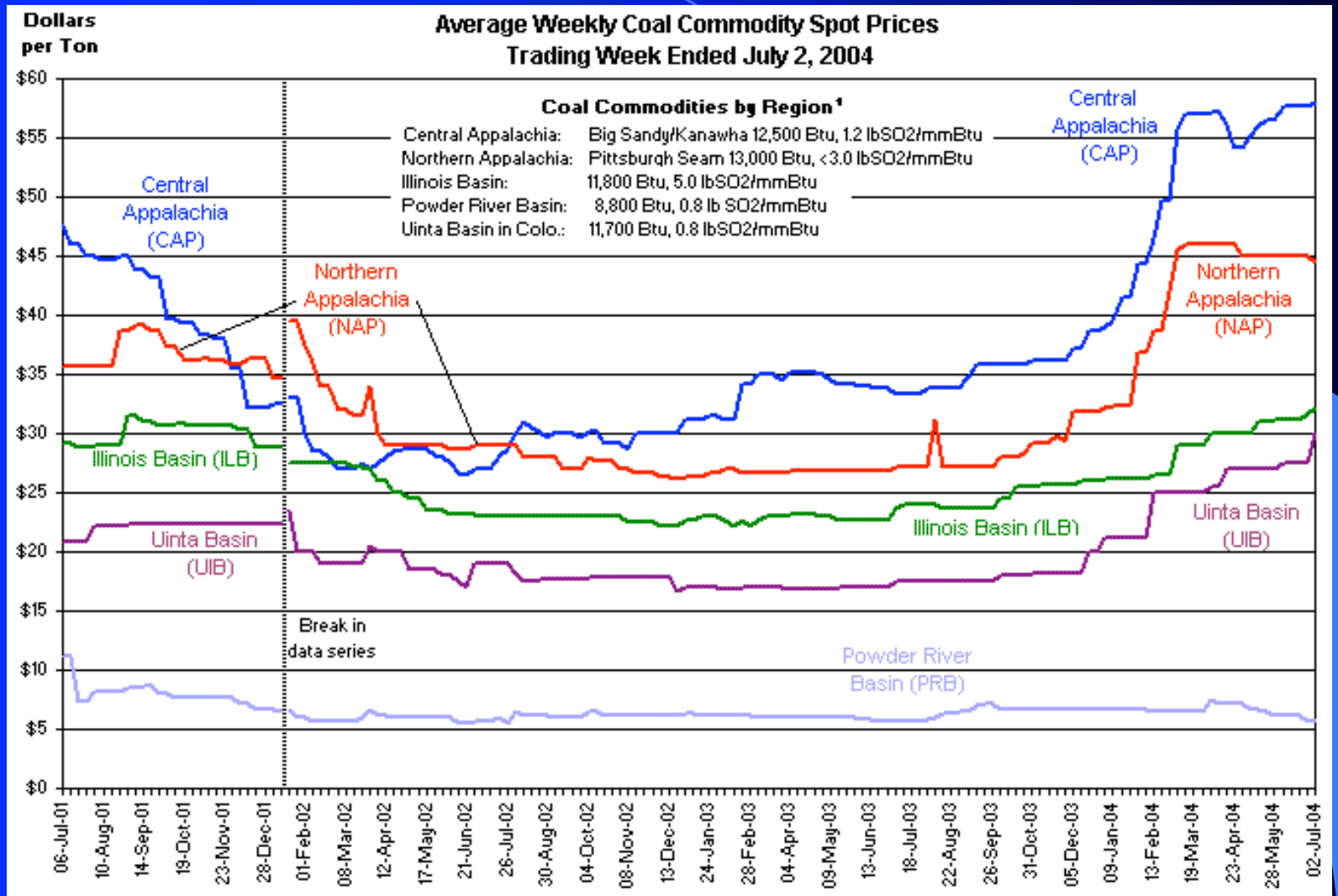

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Dakota Gasification

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.

Chemistry

From Coal

$C + H_2O$ ------ $CO + H_2$

$CO + H_2O$ ------ $CO_2 + H_2$

$CO + 3H_2$ ----- $CH_4 + H_2O$ (Natural Gas)

$N_2 + 3H_2$ ----- $2NH_3$ (Ammonia)

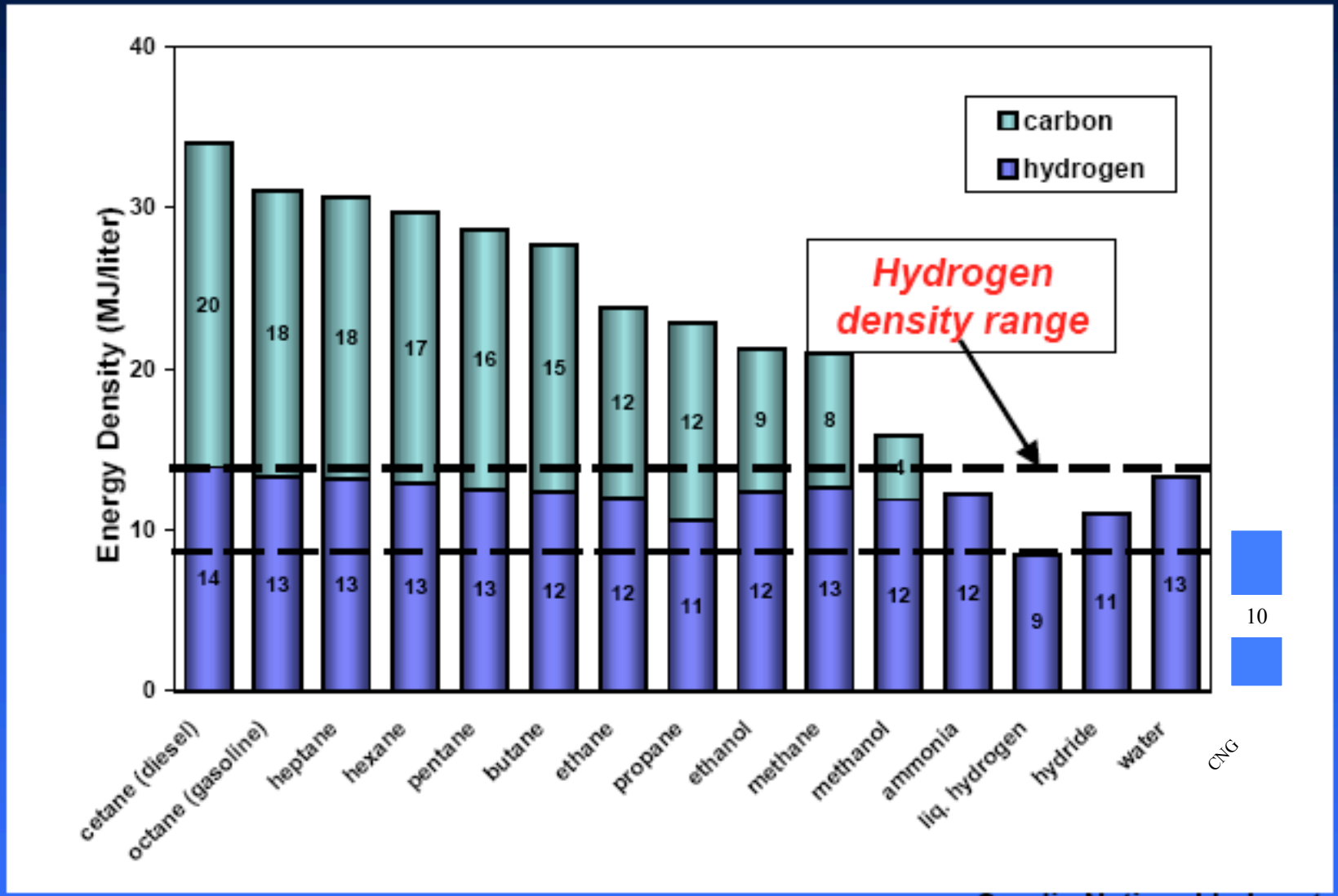
From Natural Gas

$CH_4 + O_2$ ----- $CO_2 + 2H_2$

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

Fuel Costs

- June 2003 Chemical Market Reporter*

- Ammonia - $200/metric ton* - $10.01/MMBtu
- Gasoline - $1.20/gallon - $10.52/MMBtu
- Gasoline - $1.50/gallon - $13.15/MMBtu
- Methanol - $0.79/gallon* - $13.68/MMBtu
- Ammonia - $270/short ton - $14.86/MMBtu
- Ethanol - $1.25/gallon* - $16.44/MMBtu

FreedomCAR Targets (2005)

	Target	Ammonia
Storage System Cost ($/kWe hr net)	$6	$2.93
Specific Energy (kW hr/kg)	1.5	5.8
Energy Density (kW hr/L)	1.2	3.4
Fuel Cost ($/gge @pump)	$3.00	$1.69
Hydrogen % of Storage System Wt.	6%	5.6%

Future Compatibility





Hydrogen + Nitrogen

Ammonia

Storage & Delivery – Pipeline, Barge, Truck, Rail

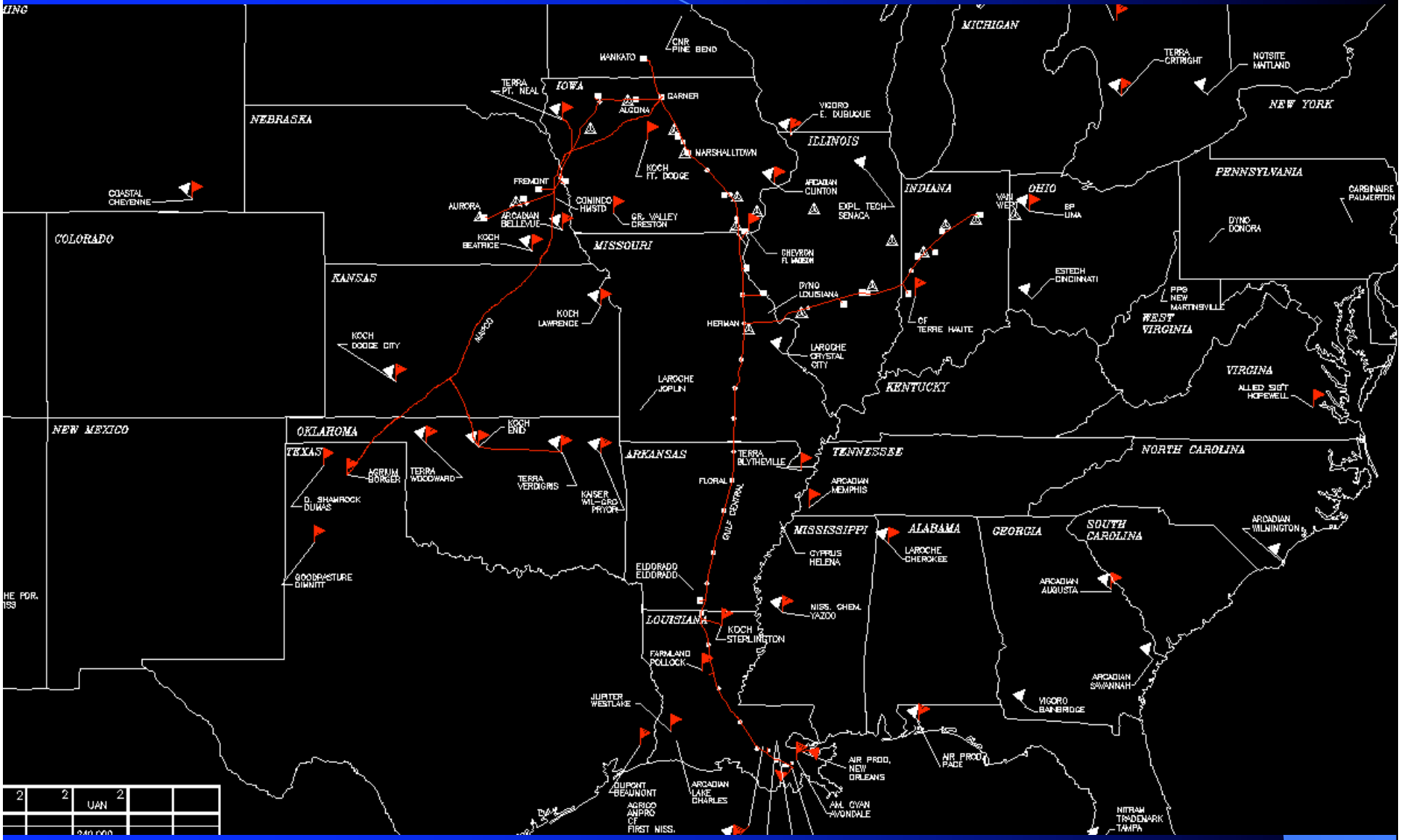
Stationary Power

Fertilizer

Transportation

Delivery Infrastructure

Ammonia Pipeline



Ammonia Storage & Transport

US DOT Statistics 1993-2003

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

Europe

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

euro-cleancoal.net

Economic Impacts

Current 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 new tax revenue/year (employees only)

Summary

- Ammonia vs. Natural Gas vs. Hydrogen
- Fossil Fuels Now
- Renewables in the Future
- IC Engines Now
- Fuel Cells in the Future
- Ammonia Looks Pretty Good Now and in the Future
- Next Steps?