Fuel Efficiency In Transportation Systems

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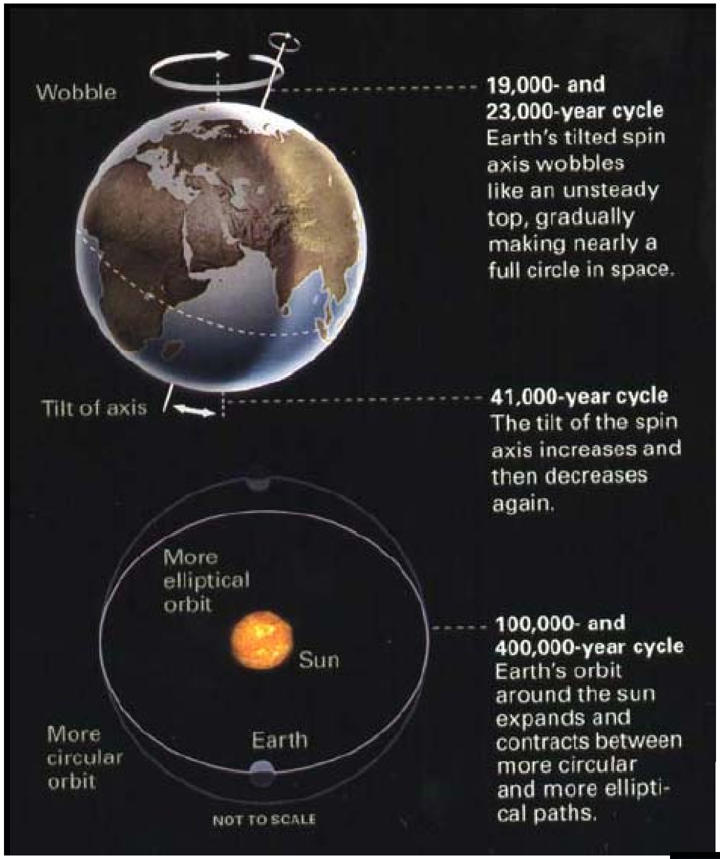
Outline of Lecture

- The Issue – Global Warming, Motivation for Transportation Efficiency
- Carbon Emissions by Light Duty Vehicles
- Alternate Engine Concepts
- Alternate Fuels
- Alternate Power Sources
- Role of Aerodynamic Efficiency

The Issue

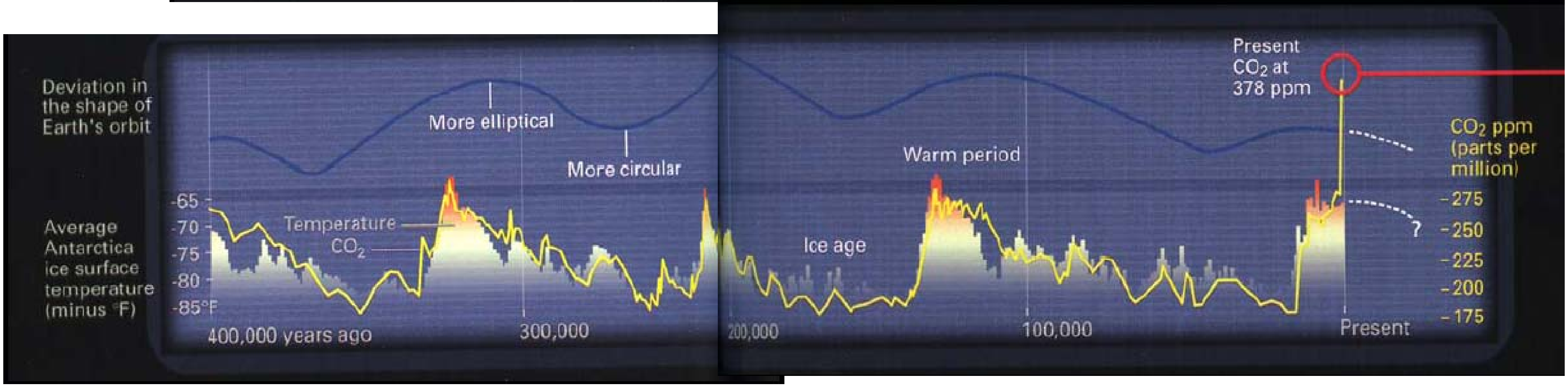


Milankovitch cycles

Caused by gravitational attraction between planets of the solar system and Earth due to changes in the eccentricity of the Earth's orbit, obliquity of the Earth's axis and precession of the Earth's axis of rotation.

- **Wobble Cycles 19,000 & 23,000 Yrs.**
- **Tilt Cycle 41,000 Yrs.**
- **Earth Orbit 100,000 & 400,000 Yrs.**

Below a chart showing CO_2 & temperature Of Antarctica Ice Surface by year.



National Geographic, September, 2004

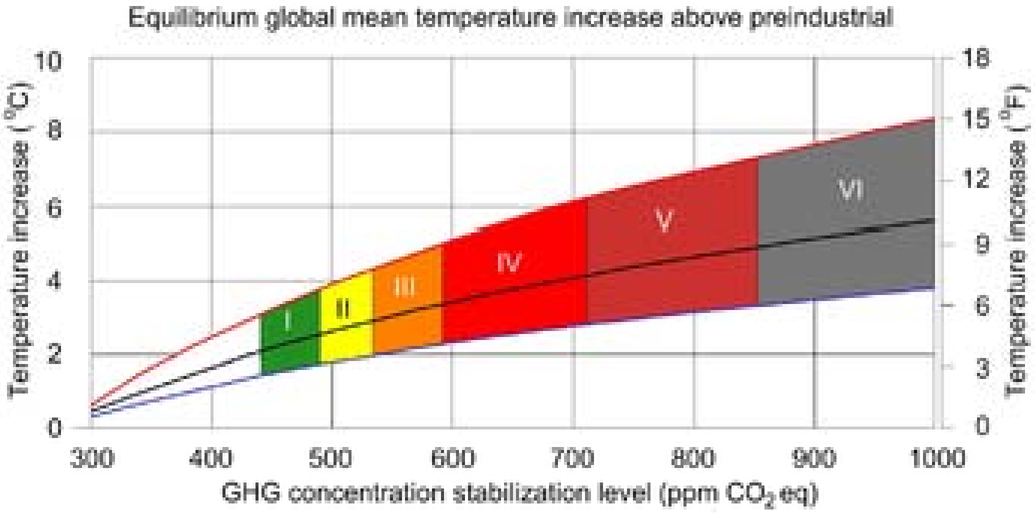
Greenhouse Gas Emissions

Note: Pre-Industrial Levels 260-280 ppm CO_2 eq.

Fossil Fuel Combustion Sources of CO_2 (% contributions for 2000–2004)

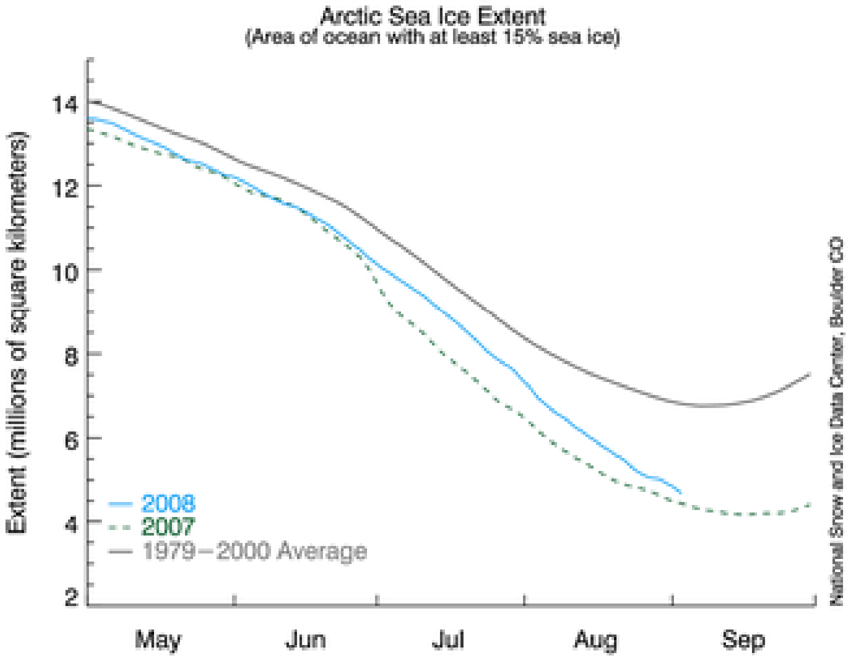
- Solid fuels (e.g. coal): 35%
- Liquid fuels (e.g. gasoline): 36%
- Gaseous fuels (e.g. natural gas): 20%
- Flaring gas industrially and at wells: <1%
- Cement production: 3%
- Non-fuel hydrocarbons: <1%
- Shipping and air transport: 4%

IPCC AR4, 2007

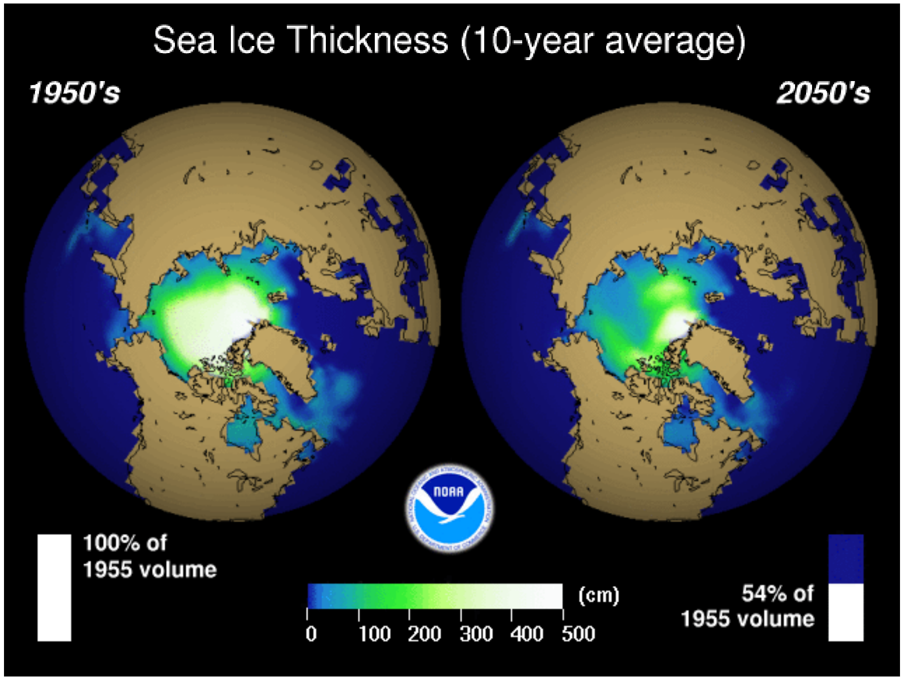


Source: Wikipedia, Global Fossil Fuel Emissions

Artic Sea Ice Extent & Thickness



NOAA Projected Artic Changes



In a typical year, the daily rate of ice loss starts to slow in August as the Arctic begins to cool. By contrast, in August 2008, the daily decline rate remained steadily downward and strong.

Source: National Snow & Ice Data Center

Quote From Tim Flannery:
“The Weather Makers: How Man Is Changing the Climate And What It Means for Life On Earth”

“To stay below the threshold for melting of the ice sheets in Greenland and West Antarctica, we need to reduce CO_2 emissions by 80% and achieve a diet of no more than 30 pounds of CO_2 per person per day.”

Carbon Emissions by Light Duty Vehicles

US Transportation Energy Book Data

(US Dept. of Energy, June 2008)

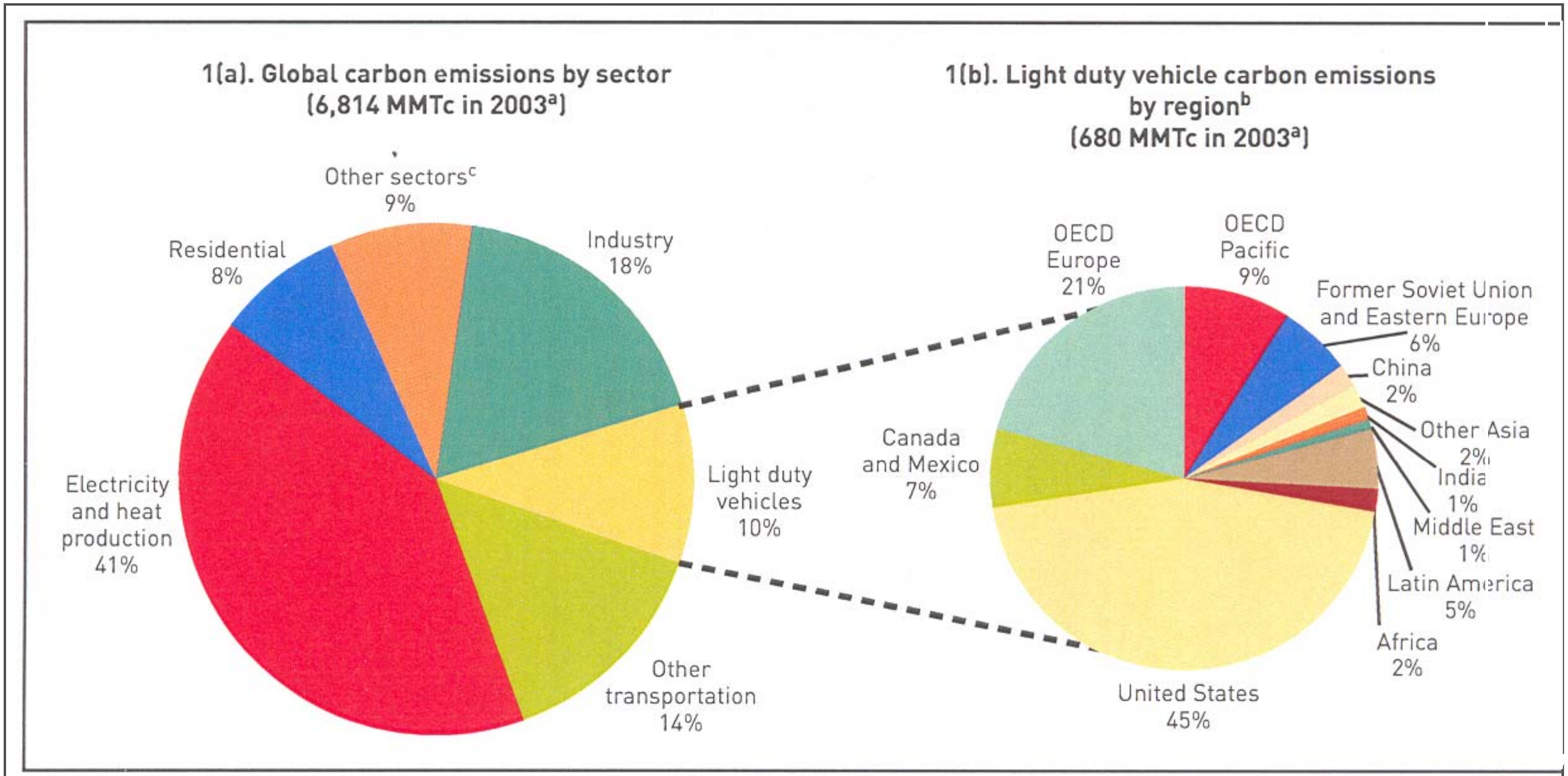
Transport Mode	Average Passengers Per Vehicle	Efficiency Per Passenger	
Vanpool	6.1	1322 BTU/mi	2.7 L/100 km (87 MPGe_{US})
Motorcycles	1.2	1855 BTU/mi	3.8 L/100 km (62 MPGe_{US})
Rail (Amtrak)	20.5	2650 BTU/mi	5.4 L/100 km (43 MPGe_{US})
Rail (Transit Light & Heavy)	22.5	2784 BTU/mi	5.7 L/100 km (41 MPGe_{US})
Rail (Commuter)	31.3	2996 BTU/mi	6.1 L/100 km (38 MPGe_{US})
Air	96.2	3261 BTU/mi	6.7 L/100 km (35 MPGe_{US})
Cars	1.57	3512 BTU/mi	7.2 L/100 km (33 MPGe_{US})
Personal Trucks	1.72	3944 BTU/mi	8.1 L/100 km (29 MPGe_{US})
Buses (Transit)	8.8	4235 BTU/mi	8.7 L/100 km (27 MPGe_{US})

Passenger Miles Per Gallon (PMPG)

Bicycling - 653 PMPG
Walking - 235 PMPG

Cruise Ship - 17 PMPG
Gulfstream G550 - 16 PMPG

Global Fossil Carbon Emissions by Economic Sector



1(a). Global carbon emissions by sector (6,814 MMTc in 2003^{a})

1(b). Light duty vehicle carbon emissions by region^{b} (680 MMTc in 2003^{a})

These estimates include only CO_2 emissions from fossil fuel use, and so exclude emissions from biofuel use or deforestation.

[a] Global emissions by sector are estimates for 2003 from IEA (2005). Global light-duty vehicle CO_2 emissions for 2003 are projections from WBCSD (2004).

[b] Light duty vehicle emission shares by region are estimates for 2000 from WBCSD (2004).

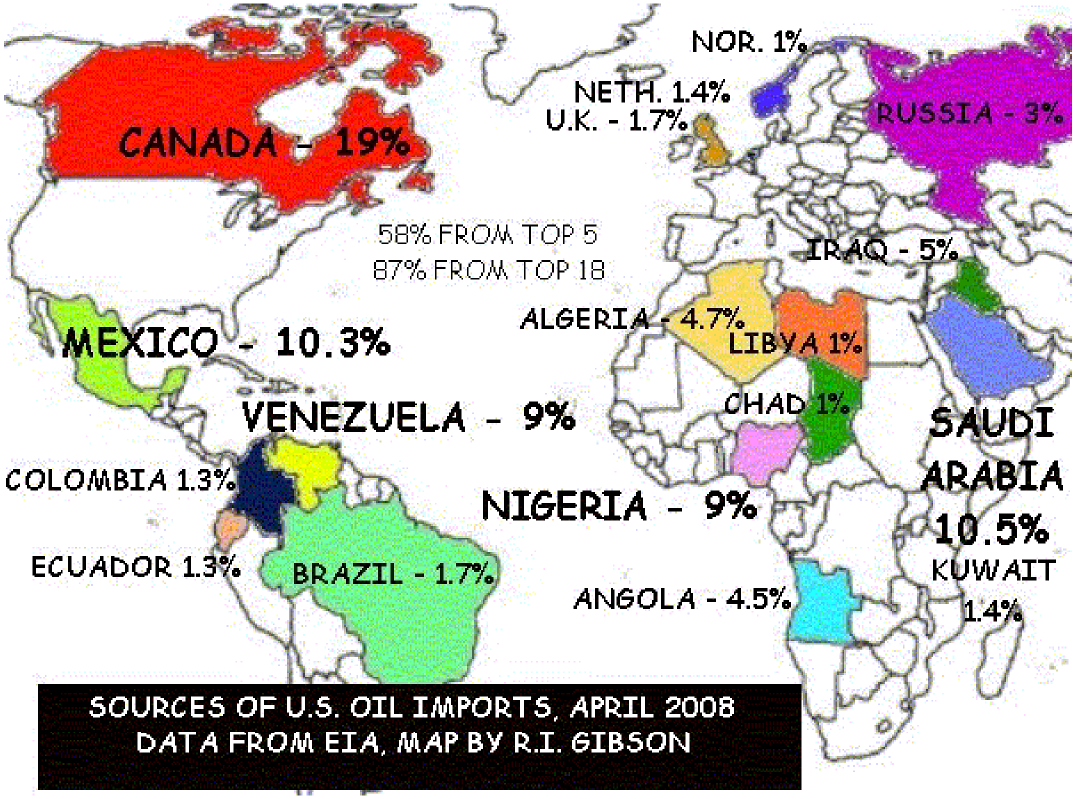
[c] Other sectors include commercial, public services, agriculture and energy industries other than electricity and heat production.

Source: DeCicco et. al., Global Warming on the Road

US Crude Oil Imports Per Day
25 Thousand Barrels in FY 2006

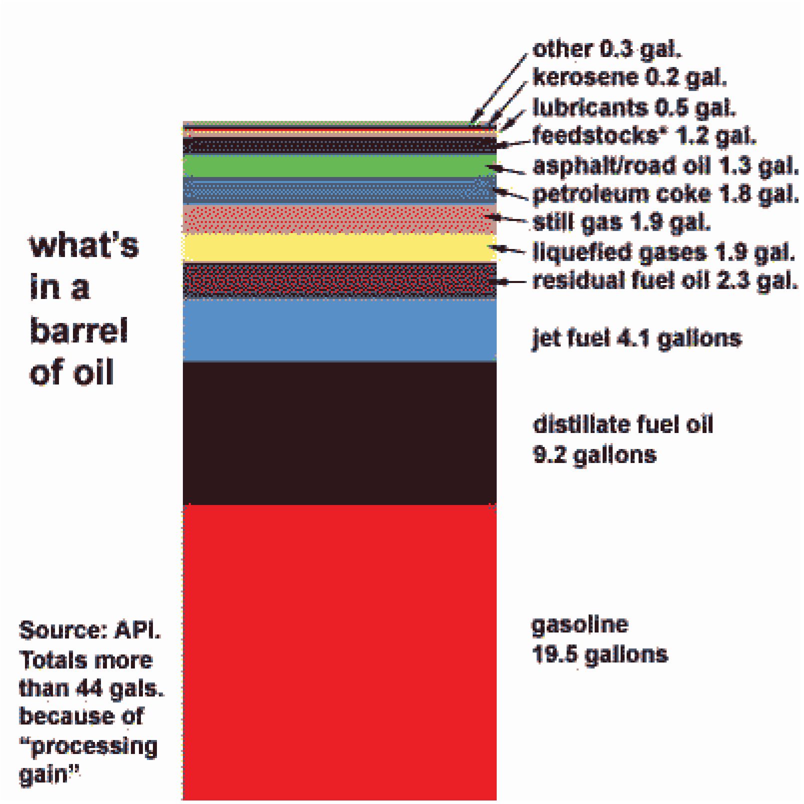
Sources of US Oil Imports

Note: US Produces 4 Million per Day



Source: Gibson Consulting

Product Distribution From a Barrel of Oil



Note: 42 gallons of crude oil per barrel

Consumption of Petro Products (Thousand Barrels Per Day)

	2003	2004	2005	2006
North America	**24207.13**	**25045.96**	**25220.97**	**25070.75**
Central & South America	**5195.683**	**5349.07**	**5481.752**	**5691.713**
Eurasia	**3910.225**	**4040.797**	**4158.806**	**4197.5**
Middle East	**5286.231**	**5539.414**	**5808.184**	**6065.3**
Africa	**2715.094**	**2819.461**	**2972.248**	**2984.93**
Asia & Oceania	**22158.91**	**23353.17**	**23940.05**	**24526.12**
World	**79660.39**	**82407.67**	**84004.87**	**84979.39**

Energy Information Administration

Factors Determining Auto Sector CO_2 Emissions

- Travel Demand (2.6 x 10^{12} miles/year)
- Fuel Use Rate (51 gallons/1000 miles)
- Fuel Carbon Content (5.3 pounds of carbon/gallon)

Note: FY 2004 US Auto Sector Results Where 314 MMTc Were Emitted

Source: DeCicco et. al., Global Warming on the Road

Amount of CO_2 Emitted Per Gallon

Code of Federal Regulations (40 CFR 600.113):

Gasoline carbon content per gallon: 2,421 grams
Diesel carbon content per gallon: 2,778 grams

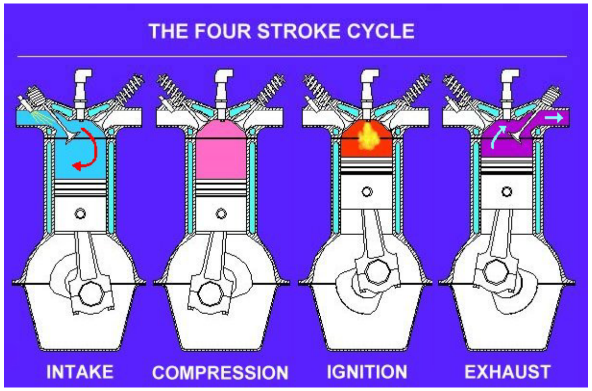
To calculate CO_2 emissions from a gallon of fuel, carbon emissions are multiplied by the ratio of the molecular weight of CO_2 (m.w. 44) to the molecular weight of carbon (m.w.): 44/12.

CO_2 emissions from a gallon of gasoline = 2,421 grams X 0.99 X (44/12)= 8,788 grams = 8.8 kg/gallon = 19.4 pounds/gallon.

CO_2 emissions from a gallon of diesel = 2,778 grams X 0.99 X (44/12)= 10084 grams = 10.1 kg/gallon = 22.2 pounds/gallon.

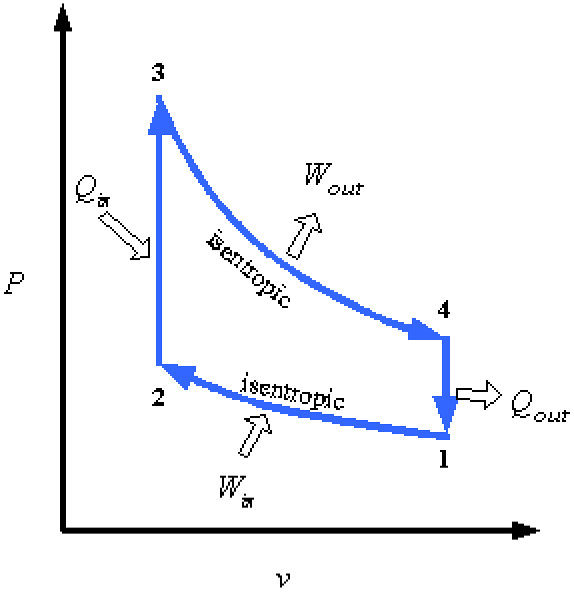
Conventional Automotive Engine Cycles

4-Stroke Engine Concept



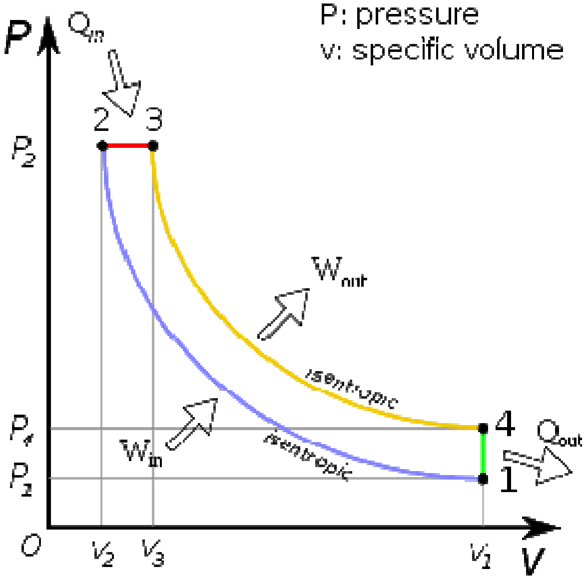
The four-stroke engine was first patented by Eugenio Barsanti and Felice Matteucci in 1854. The two-stroke cycle was Patented by Dugald Clerk In 1878.

Idealized Thermo Cycle
4-Stroke SI Engine



Otto Cycle Pv Diagram, Nicolaus Otto, 1876

Idealized Thermo Cycle
4-Stroke CI Engine



Diesel Cycle Pv Diagram, Rudolph Diesel, 1892

Obert, Internal Combustion Engines, 1970
Cycle Pad Design Library

Ideal Otto Cycle

Stoichiometric Combustion of Gasoline with AIR

$$C_8H_{18} + 12\tfrac{1}{2}O_2 + 47N_2 \rightarrow 8CO_2 + 9H_2O + 47N_2$$

$$Q_{Arev} = c_v\left(T_3 - T_2\right)$$

$$Q_{Rrev} = c_v\left(T_1 - T_4\right)$$

$$\eta_t = \frac{Q_A + Q_R}{Q_A} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{r_v^{\gamma-1}}$$

Note: r_v is the engine compression ratio

Example: r = 8, Ta = 540^0R, Pa = 14.7 psia

$$\eta_t = 1 - \frac{1}{r_v^{\gamma-1}} = 1 - \frac{1}{8^{0.4}} = 0.565$$

or 56.5%

Factoring in transmission & drive train overall gas power auto efficiency 17%

Obert, Internal Combustion Engines, 1970

Ideal Diesel Cycle

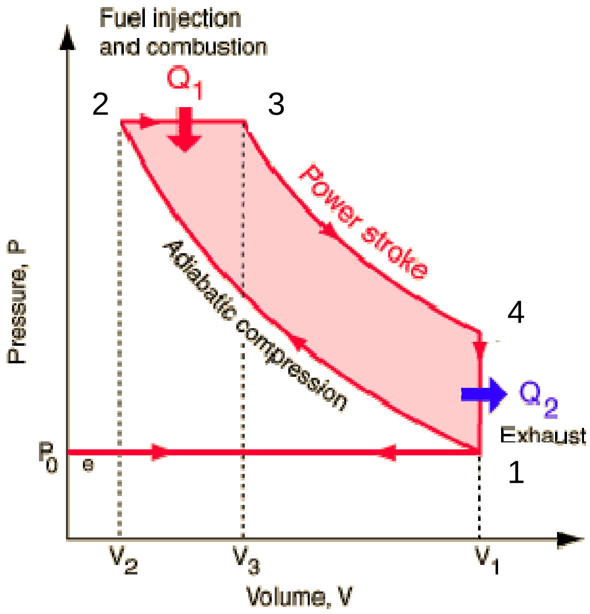
$$Q_{Arev} = c_v\left(T_3 - T_2\right)$$

$$Q_{Rrev} = c_v\left(T_1 - T_4\right)$$

Since, $$\left(\frac{T_3}{T_2}\right)^{\gamma} = \left(\frac{T_4}{T_1}\right)$$

$$\eta_t = \frac{Q_A + Q_R}{Q_A} = 1 - \left(\frac{1}{\gamma}\right)\left(\frac{T_4 - T_1}{T_3 - T_2}\right) = 1 - \frac{1}{r_v^{\gamma-1}}\left[\frac{r^{\gamma} - 1}{\gamma\left(r - 1\right)}\right]$$

$r = 25$, $\eta_t = 0.264$



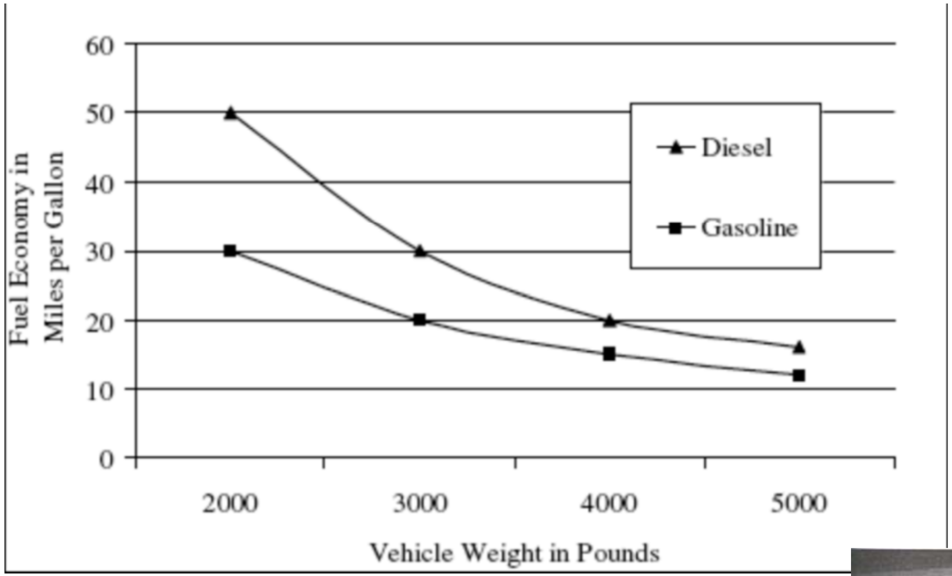
A diesel engine takes in just air, compresses it and then injects fuel into the compressed air. The heat of the compressed air lights the fuel spontaneously.

Note1: 147000 BTU/gal of Diesel
125000 BTU/gal of Gasoline

Note2: Diesel is 30 to 35 % more efficient than gas powered vehicles, but strongly dependent on vehicle load.

Obert, Internal Combustion Engines, 1970

Fuel Economy of Gasoline & Diesel



Crown's Diesel Repair Manuel

Note:

Rudoff Diesel Originally Envisioned Running His Engine on Vegetable Oil

The Volkswagen Jetta with 1.9 liter turbo direct injection Diesel engine gets 50 mpg on the highway.

Source: From the fryer to the fuel tank
By Joshua Tickel,
ISBN 0-9707227-0-2, 2003

Alternate Engine Concepts

Turbine Powered Auto's

1963 Chrysler Turbine

1959 Plymouth Turbine

George J. Huebner, Jr., Executive Engineer—Research, with gas-turbine powered Plymouth

1964 Chrysler Turbine Car Specifications

- **130 horsepower at 3,600 rpm; 425 lb-ft of torque at zero rpm!**
- **Weight: 410 lb - 25 inches long, 25.5 inches wide, 27.5 inches tall.**
- **Fuel requirements: diesel, unleaded gas, kerosene, JP-4, others. No adjustments needed to switch from one to the other.**
- **Compressor: centrifugal, single-stage compressor with 4:1 pressure ratio, 80% efficiency, 2.2 lb/sec air flow.**
- **First stage turbine: axial, single-stage, 87% efficiency, inlet temperature 1,700 degrees F.**
- **Second-stage turbine: axial, single-stage, 84% efficiency, max speed 45,700 rpm.**
- **Exhaust temperature at full power: 500 ^{0}F.**
- **A 400 ^{0}F increase in inlet temperature would mean a 40 per cent increase in specific output improve fuel economy over 20 per cent.**

Advantages of Automotive Gas Turbines

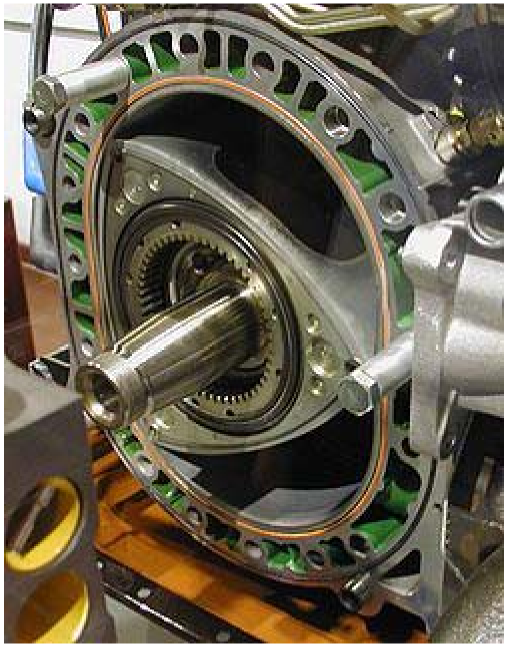
- Maintenance is considerably reduced
- Engine life-expectancy is much longer
- The number of parts is reduced 80%
- Tuning-up is almost eliminated
- Low-temperature starting difficulties are eliminated
- No warm-up period is necessary
- Antifreeze is not needed
- Instant heat is available in the winter
- The engine will not stall with sudden overloading
- Engine operation is vibration-free
- Operates on wide variety of fuels
- Oil consumption is negligible
- Engine weight is reduced
- Exhaust gases are hot but clean
- Can be used as a gas generator for electric hybrid.

Issues Associated With Gas Turbines

- High fuel consumption at idle due to high RPM.
- Throttle lag from idle as engine spools up.
- High temperature exhaust gas.
- Very high noise source.
- Expensive parts to replace.

Pistonless Rotary Wankel Engine

Wankel Engine in Deutsches Museum in Munich, Germany



The Good News:

•Wankel has higher power output / unit weight.

- Better fuel/air mixing.
- More even combustion.

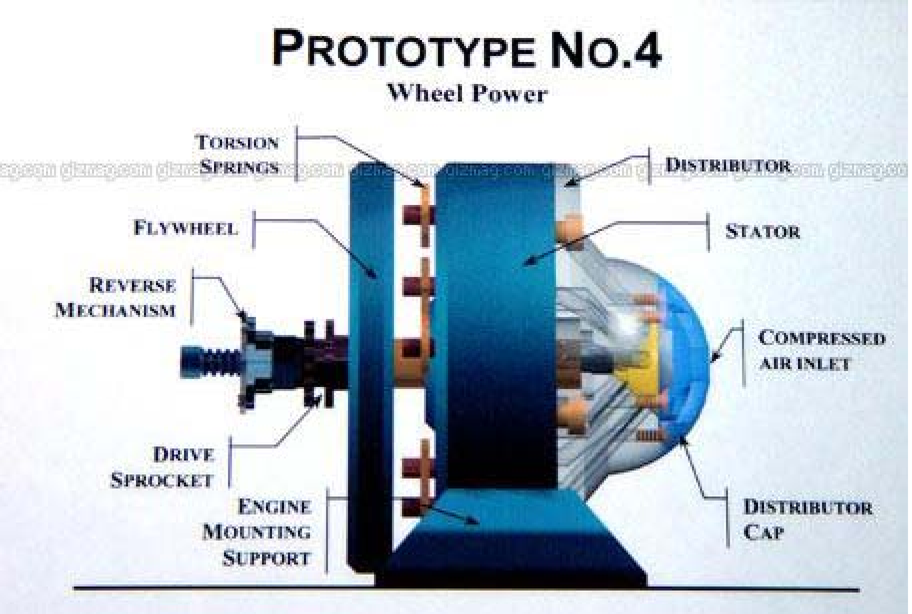
The Bad News:

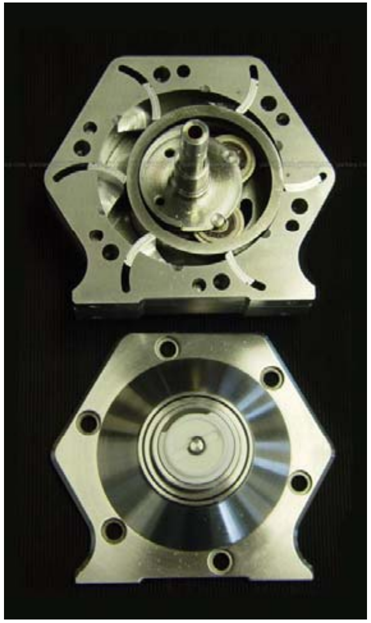
- Rotating seals reduces engine compression ratio.
- Larger fraction of unburned fuel lowers efficiency.
- Excess noise due to rotating seals.

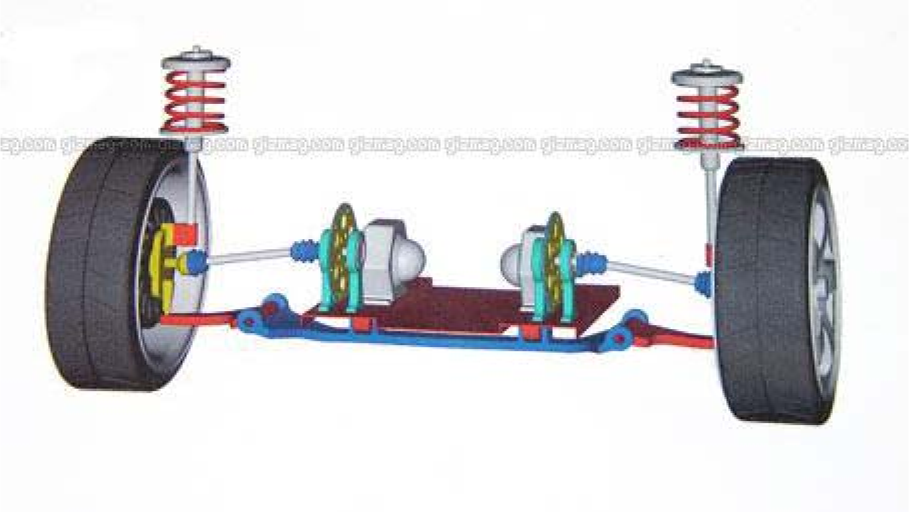
Mazada RX-8 Powered by a Wankel Engine

Source: Kevin Reed, Why Wankel Engine is not Famous

Di Pietro Rotary Air Engine







Engineair's Ultra-Efficient Rotary Compressed-Air Motor Applications

EngineAir Motor Prototype
Motor Weight: 28.6 Lbs.

Example Products

Note: Each front wheel driven by separate motors

Compressed Air Car

December 2, 2004 French engineers have designed a low consumption and low pollution engine for urban motoring that runs on compressed air technology. The CATS (Compressed Air Technology System) "air car" from Motor Development International is a significant step for zero-emission transport, delivering a compressed air-driven vehicle that is safe, quiet, has a top speed of 110 km/h and a range of 200 km. Costing next to nothing to run, the Zero Emission Vehicle (ZEV) range which includes a pick-up truck and van - is set for release in early 2005.

Compressed Air Concept

Typical Piston Engine

EcoGeek

ecogeek.org
brains for the earth

Air car ready for production

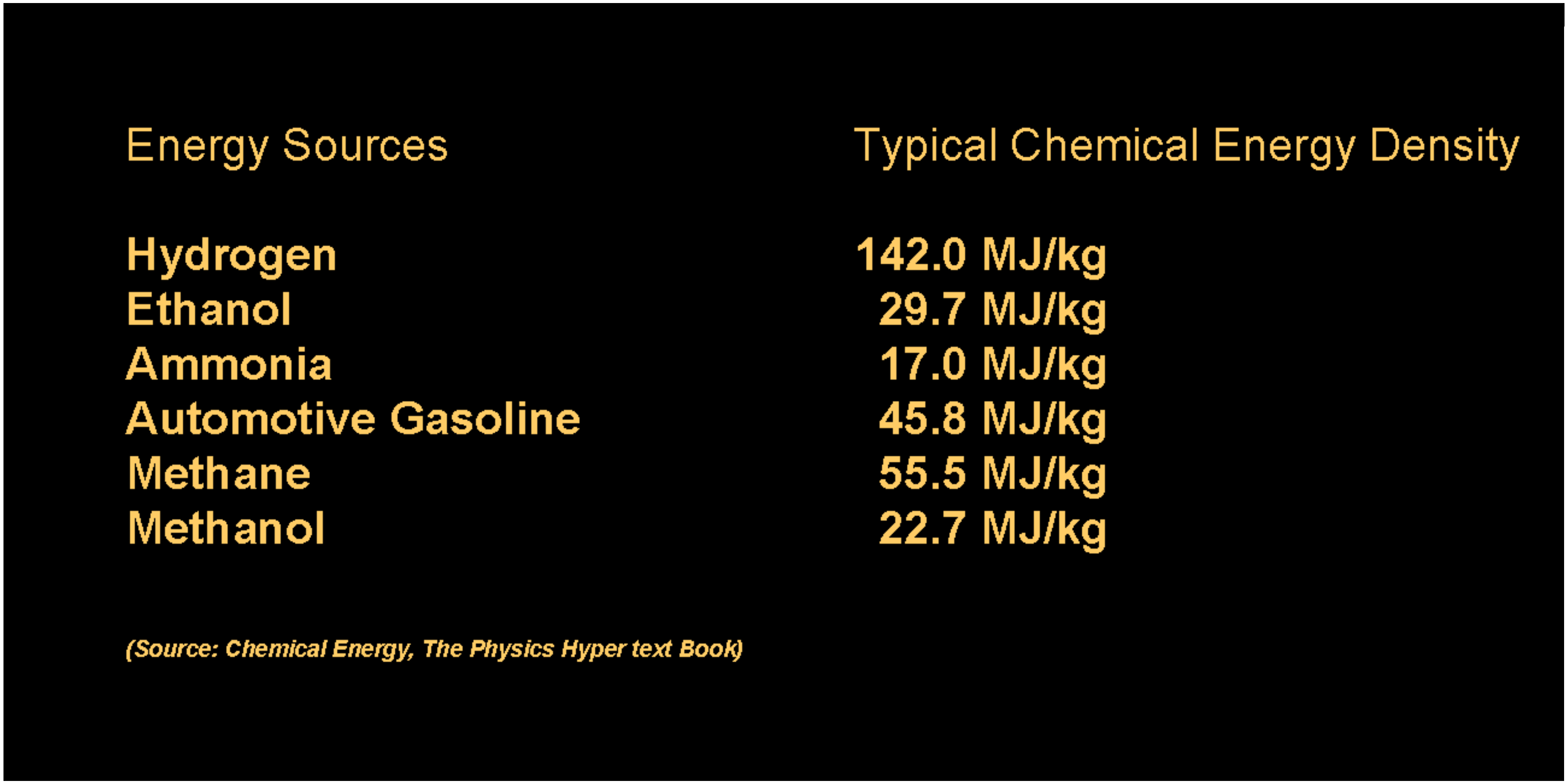
By Bob Ewing Posted Fri Jul 13, 2007 8:07am PDT

The world's first commercial compressed air-powered vehicle is rolling towards the production line. The Air Car, developed by ex-Formula One engineer Guy Nègre, will be built by India's largest automaker, Tata Motors.

The Air Car uses compressed air to push its engine's pistons. It is anticipated that approximately 6000 Air Cars will be cruising the streets of India by 2008. If the manufacturers have no surprises up their exhaust pipes the car will be practical and reasonably priced. The CityCat model will clock out at 68 mph with a driving range of 125 miles.

Alternate Fuels

Potential Fuels



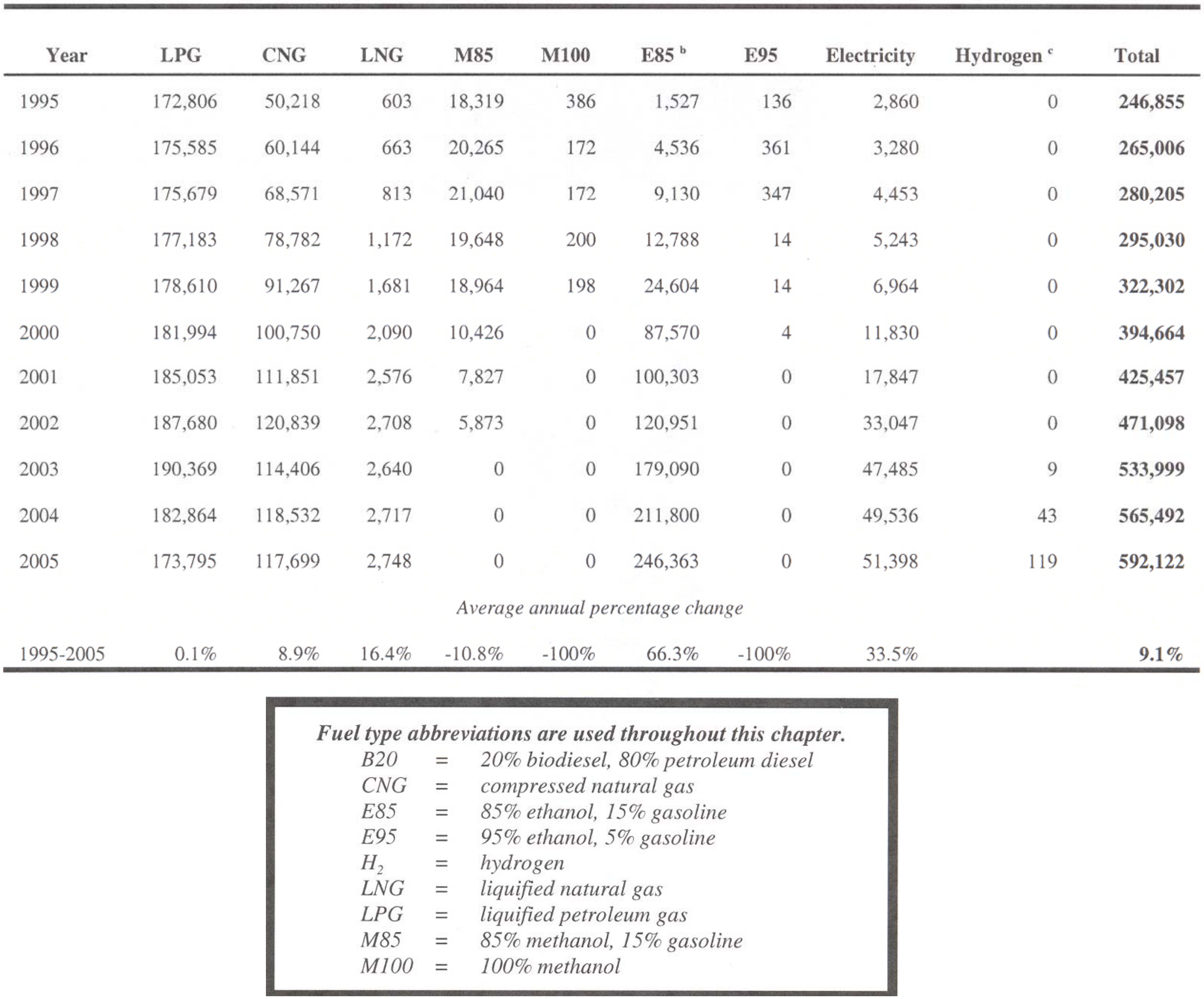
Energy Sources	Typical Chemical Energy Density
Hydrogen	**142.0 MJ/kg**
Ethanol	**29.7 MJ/kg**
Ammonia	**17.0 MJ/kg**
Automotive Gasoline	**45.8 MJ/kg**
Methane	**55.5 MJ/kg**
Methanol	**22.7 MJ/kg**

(Source: Chemical Energy, The Physics Hyper text Book)

Energy Density in Watt-Hour/Liter

Material	Volumetric	Gravimetric
Diesel	10942 Wh/l	13762Wh/kg
Gasoline	9,700 Wh/l	12,200 Wh/kg
LNG	7,216 Wh/l	12,100 Wh/kg
Propane	6,600 Wh/l	13,900 Wh/kg
Ethanol	6,100 Wh/l	7,850 Wh/kg
Methanol	4,600 Wh/l	6,400 Wh/kg
Liquid H2	2600 Wh/l	39,000 Wh/kg
150 Bar H2	405 Wh/l	39,000 Wh/kg
Lithium	250 Wh/l	350 Wh/kg
Nickel Metal Hydride	100 W·h/L	60Wh/kg
Lead Acid Battery	40 Wh/l	25 Wh/kg
Compressed Air	17 Wh/l	34 Wh/kg

Estimates of Alternate Fuel Vehicles In Use



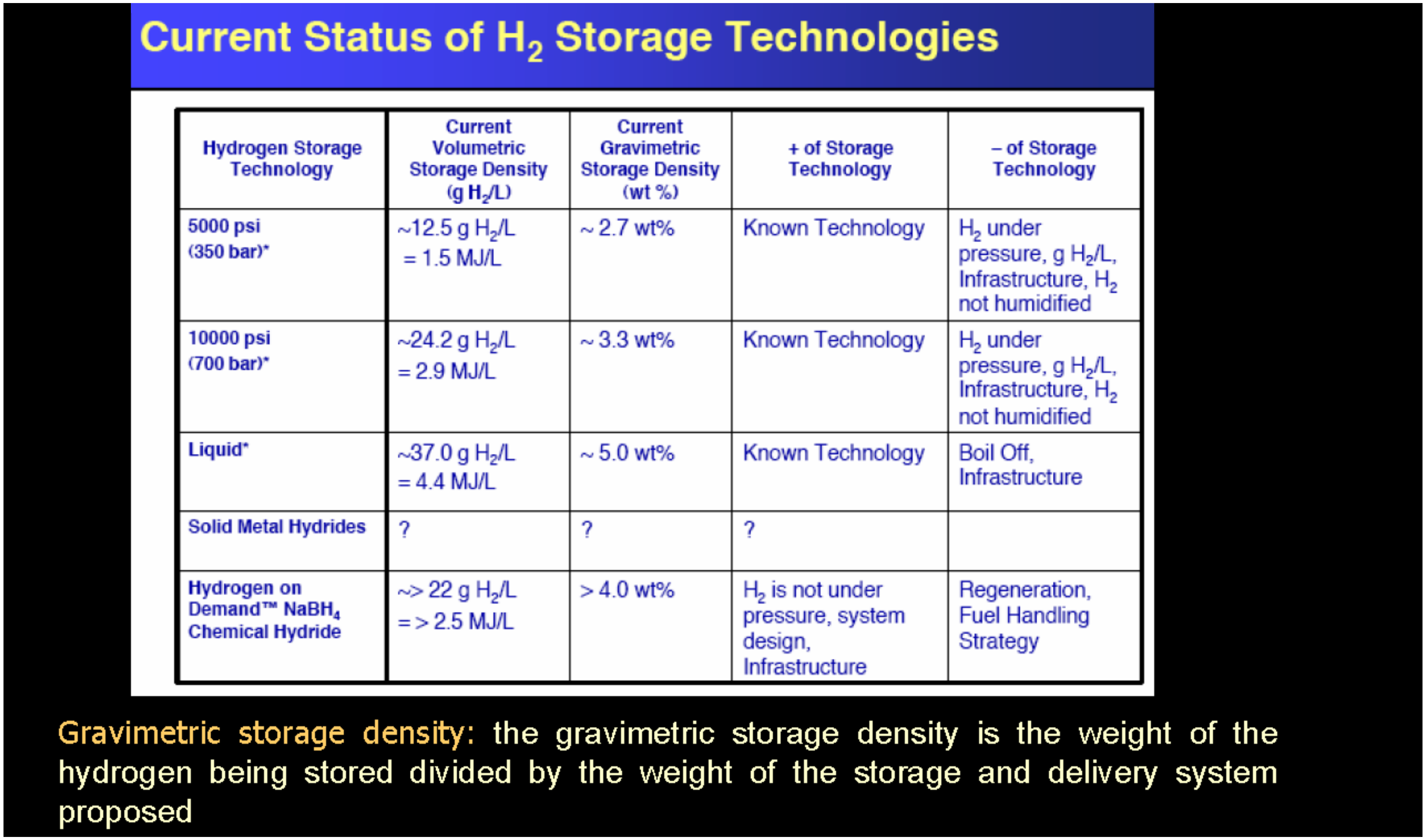
Year	LPG	CNG	LNG	M85	M100	E85 [b]	E95	Electricity	Hydrogen [c]	Total
1995	172,806	50,218	603	18,319	386	1,527	136	2,860	0	**246,855**
1996	175,585	60,144	663	20,265	172	4,536	361	3,280	0	**265,006**
1997	175,679	68,571	813	21,040	172	9,130	347	4,453	0	**280,205**
1998	177,183	78,782	1,172	19,648	200	12,788	14	5,243	0	**295,030**
1999	178,610	91,267	1,681	18,964	198	24,604	14	6,964	0	**322,302**
2000	181,994	100,750	2,090	10,426	0	87,570	4	11,830	0	**394,664**
2001	185,053	111,851	2,576	7,827	0	100,303	0	17,847	0	**425,457**
2002	187,680	120,839	2,708	5,873	0	120,951	0	33,047	0	**471,098**
2003	190,369	114,406	2,640	0	0	179,090	0	47,485	9	**533,999**
2004	182,864	118,532	2,717	0	0	211,800	0	49,536	43	**565,492**
2005	173,795	117,699	2,748	0	0	246,363	0	51,398	119	**592,122**
						Average annual percentage change				
1995-2005	0.1%	8.9%	16.4%	-10.8%	-100%	66.3%	-100%	33.5%		**9.1%**

Fuel type abbreviations are used throughout this chapter.

B20 = 20% biodiesel, 80% petroleum diesel
CNG = compressed natural gas
E85 = 85% ethanol, 15% gasoline
E95 = 95% ethanol, 5% gasoline
H_2 = *hydrogen*
LNG = liquified natural gas
LPG = liquified petroleum gas
M85 = 85% methanol, 15% gasoline
M100 = 100% methanol

Hydrogen

Issue: Achieve Adequate Stored Energy In An Efficient, Safe and Cost Effective System



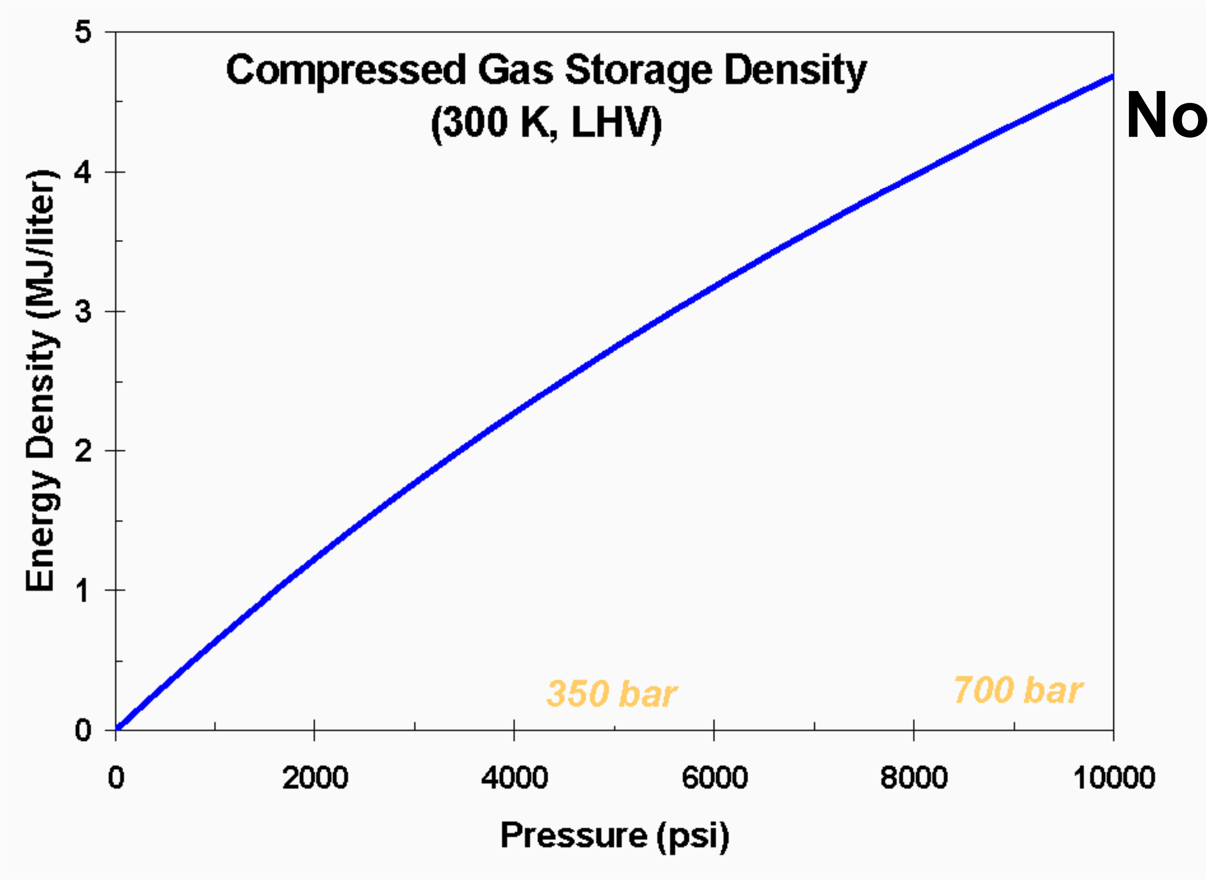
Current Status of H_2 Storage Technologies

Hydrogen Storage Technology	Current Volumetric Storage Density ($g\ H_2/L$)	Current Gravimetric Storage Density (wt %)	+ of Storage Technology	– of Storage Technology
5000 psi (350 bar)*	~12.5 g H_2/L = 1.5 MJ/L	~ 2.7 wt%	Known Technology	H_2 under pressure, g H_2/L, Infrastructure, H_2 not humidified
10000 psi (700 bar)*	~24.2 g H_2/L = 2.9 MJ/L	~ 3.3 wt%	Known Technology	H_2 under pressure, g H_2/L, Infrastructure, H_2 not humidified
Liquid*	~37.0 g H_2/L = 4.4 MJ/L	~ 5.0 wt%	Known Technology	Boil Off, Infrastructure
Solid Metal Hydrides	?	?	?	
Hydrogen on Demand™ $NaBH_4$ Chemical Hydride	~> 22 g H_2/L => 2.5 MJ/L	> 4.0 wt%	H_2 is not under pressure, system design, Infrastructure	Regeneration, Fuel Handling Strategy

Gravimetric storage density: the gravimetric storage density is the weight of the hydrogen being stored divided by the weight of the storage and delivery system proposed

Source: Oak Ridge National Laboratory Hydrogen Storage Workshop, May 2003

Compressed Gas



Note: Gasoline 13 MJ/L

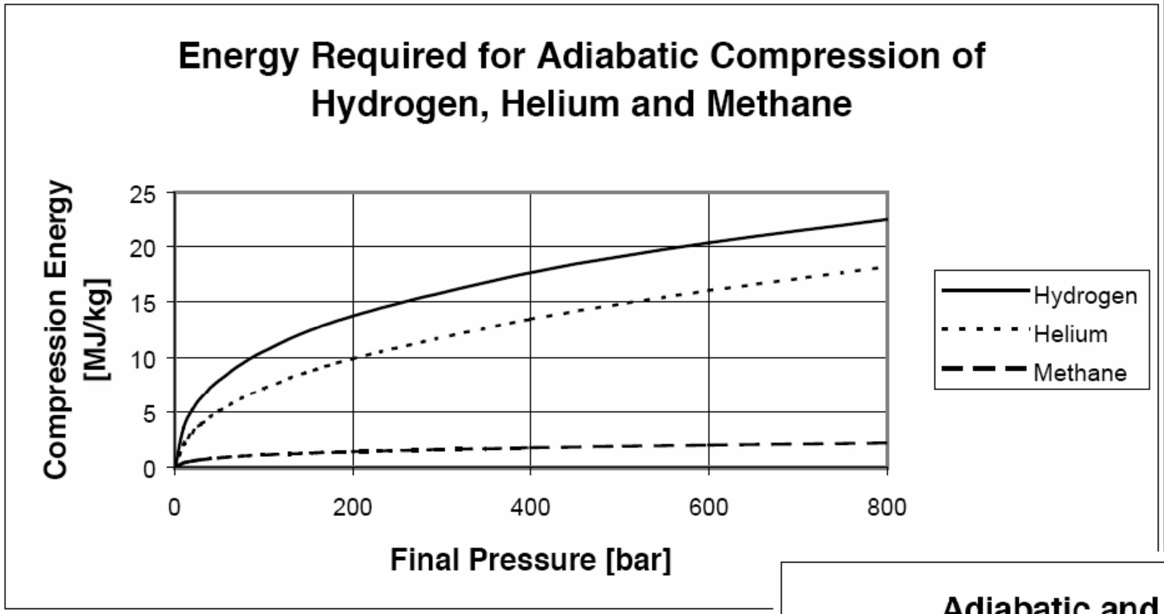
Pressures > 700 bar

- Stronger, lighter composite tanks (cost)
- Hydrogen permeation
- Non-ideal gas behavior

Gaseous Hydrogen Storage

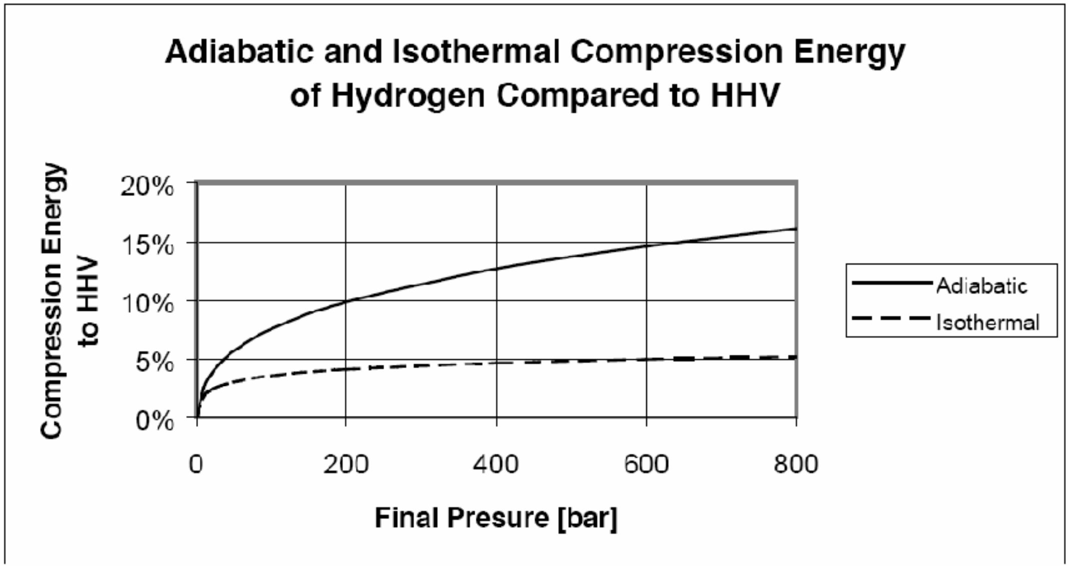
Work required to compress a gas from Baldur Eliasson and Ulf Bossel:

W = [n/(n -1)] Po Vo [(P_1/Po) (n-1)/n - 1]


Energy Required for Adiabatic Compression of Hydrogen, Helium and Methane

Hydride storage of hydrogen may be compared to the compression of hydrogen

Higher Heating value of Hydrogen: 142 MJ/kg


Adiabatic and Isothermal Compression Energy of Hydrogen Compared to HHV

Compressed Gas Cylinders

Carbon fiber wrap/polymer liner tanks are lightweight and commercially available.

weight	specific energy
6 wt.%	7.2 MJ/kg
7.5 wt.%	9.0 MJ/kg
10 wt.%	12 MJ/kg

Energy density is the issue:

Pressure	Gas density	System density
350 bar	2.7 MJ/L	1.95 MJ/L
700 bar	4.7 MJ/L	3.4 MJ/L

Liquid Storage - Requires Cryogenic Systems

- Equilibrium temperature at 1 bar for liquid hydrogen is ~20 K.
- Estimated storage densities[1]

Berry (1998)	4.4 MJ/liter
Dillon (1997)	4.2 MJ/liter
Klos (1998)	5.6 MJ/liter

- Issues with this approach are:
  - dormancy.
  - energy cost of liquifaction.

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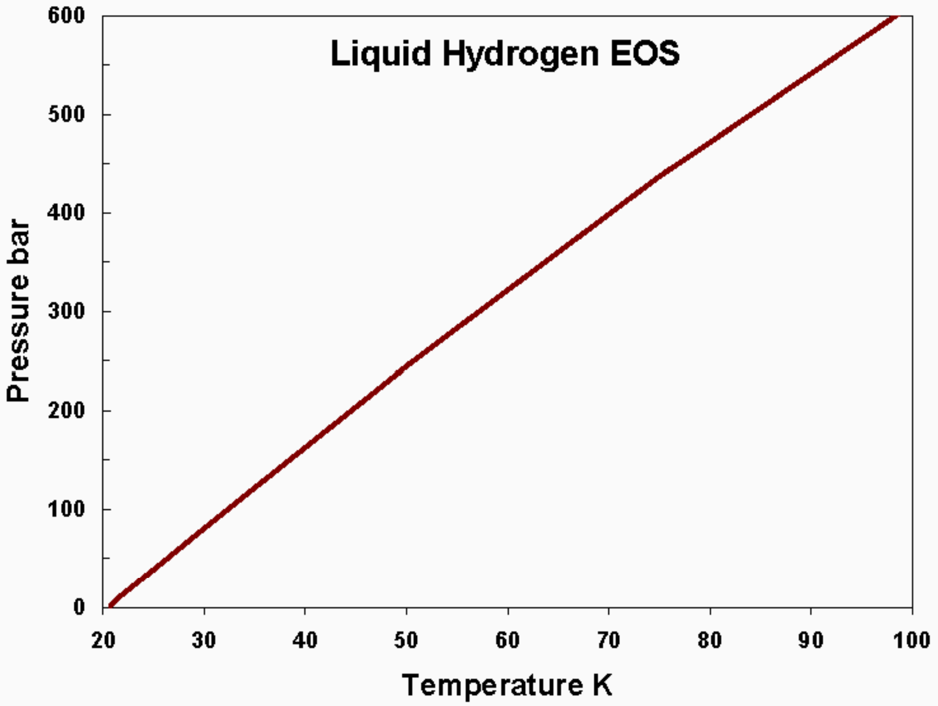
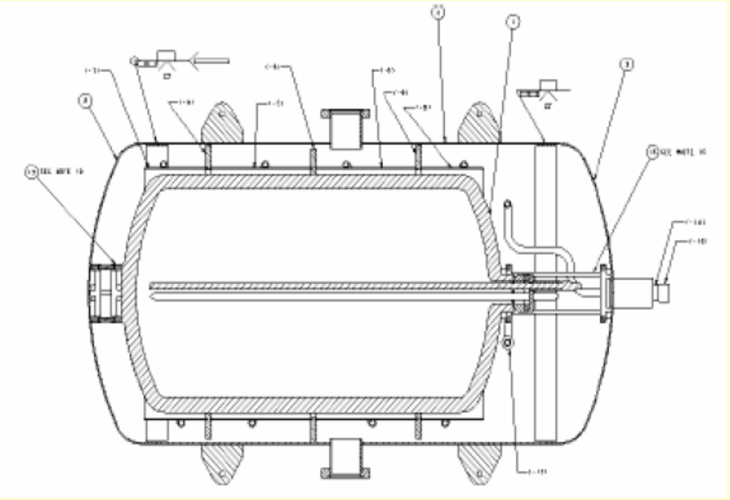
[1] **J. Pettersson and O Hjortsberg, KFB-Meddelande 1999:27**

High Pressure Cryogenic Tank

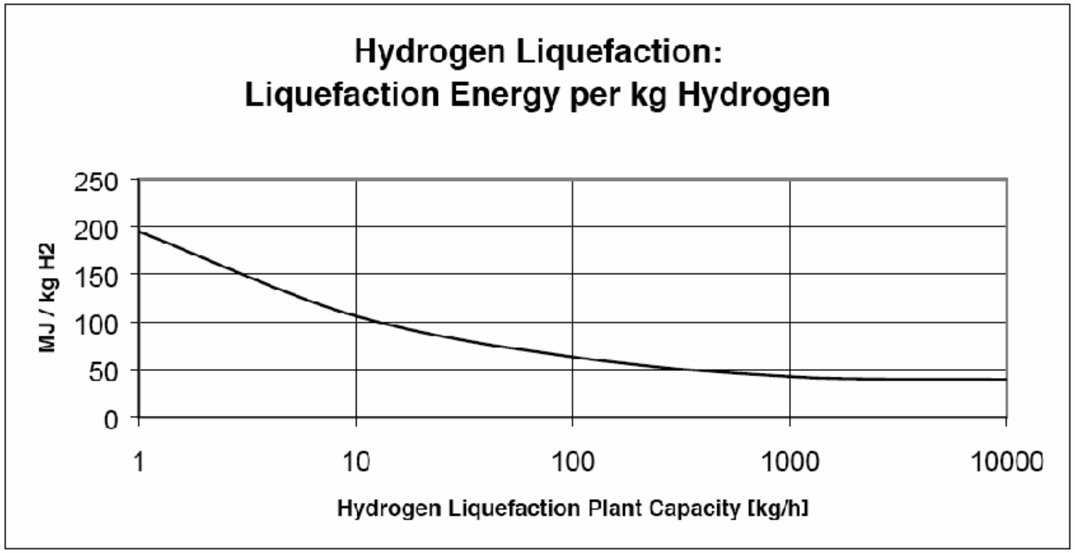




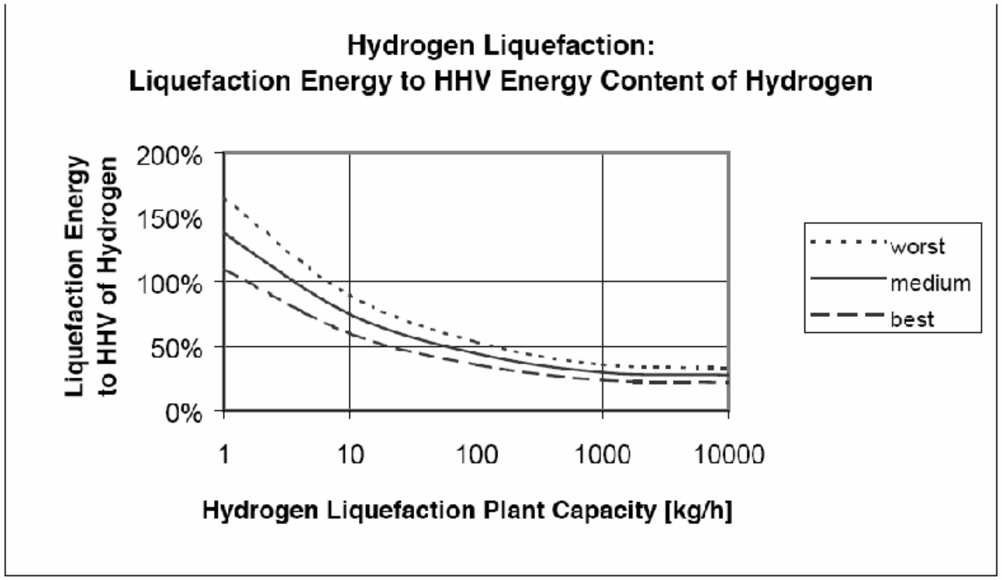
S. Aceves, et al 2002

Estimated energy density:
4.9 MJ/L (Berry 1998)

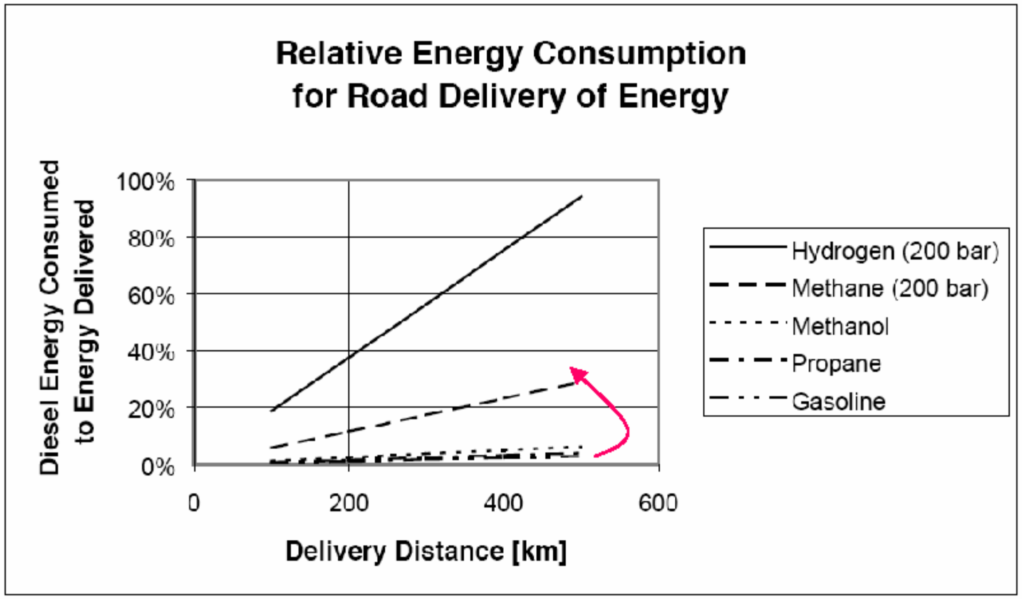
Hydrogen Storage - Liquefaction

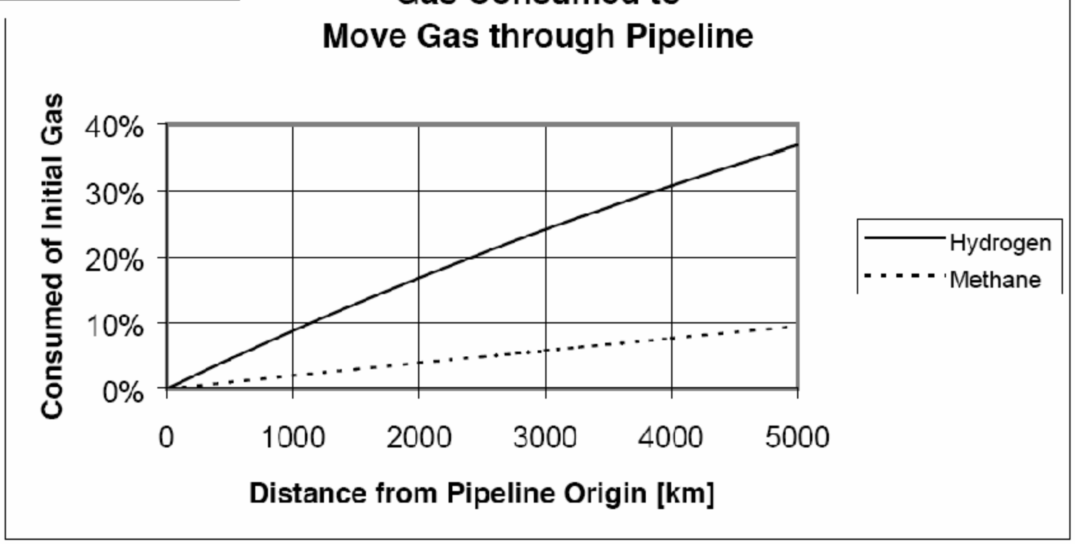


Total energy requirement for liquefaction of 1 kg of H_2



Hydrogen Delivery Pipelines

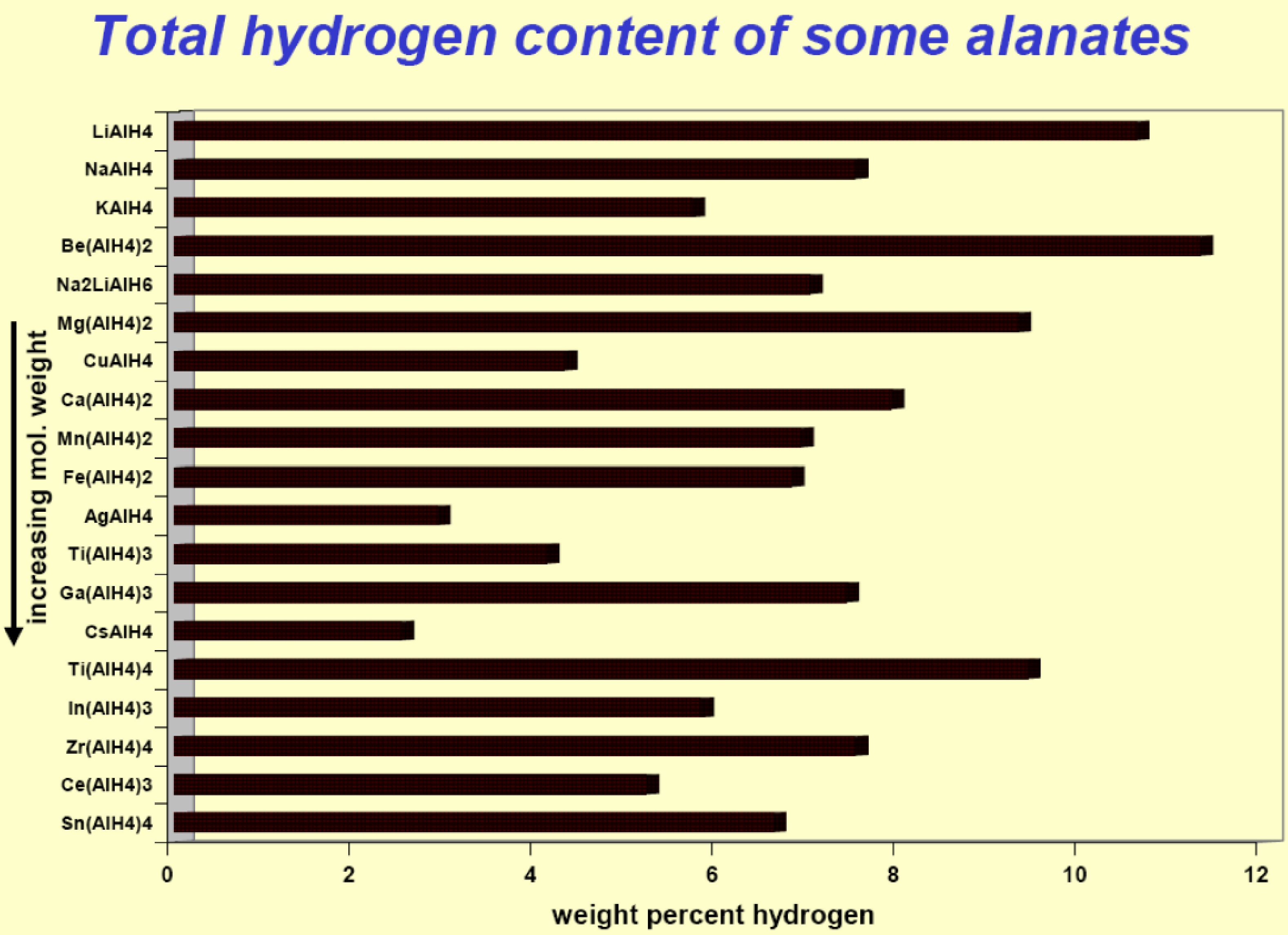

Relative Energy Consumption for Road Delivery of Energy


Gas Consumed to Move Gas through Pipeline

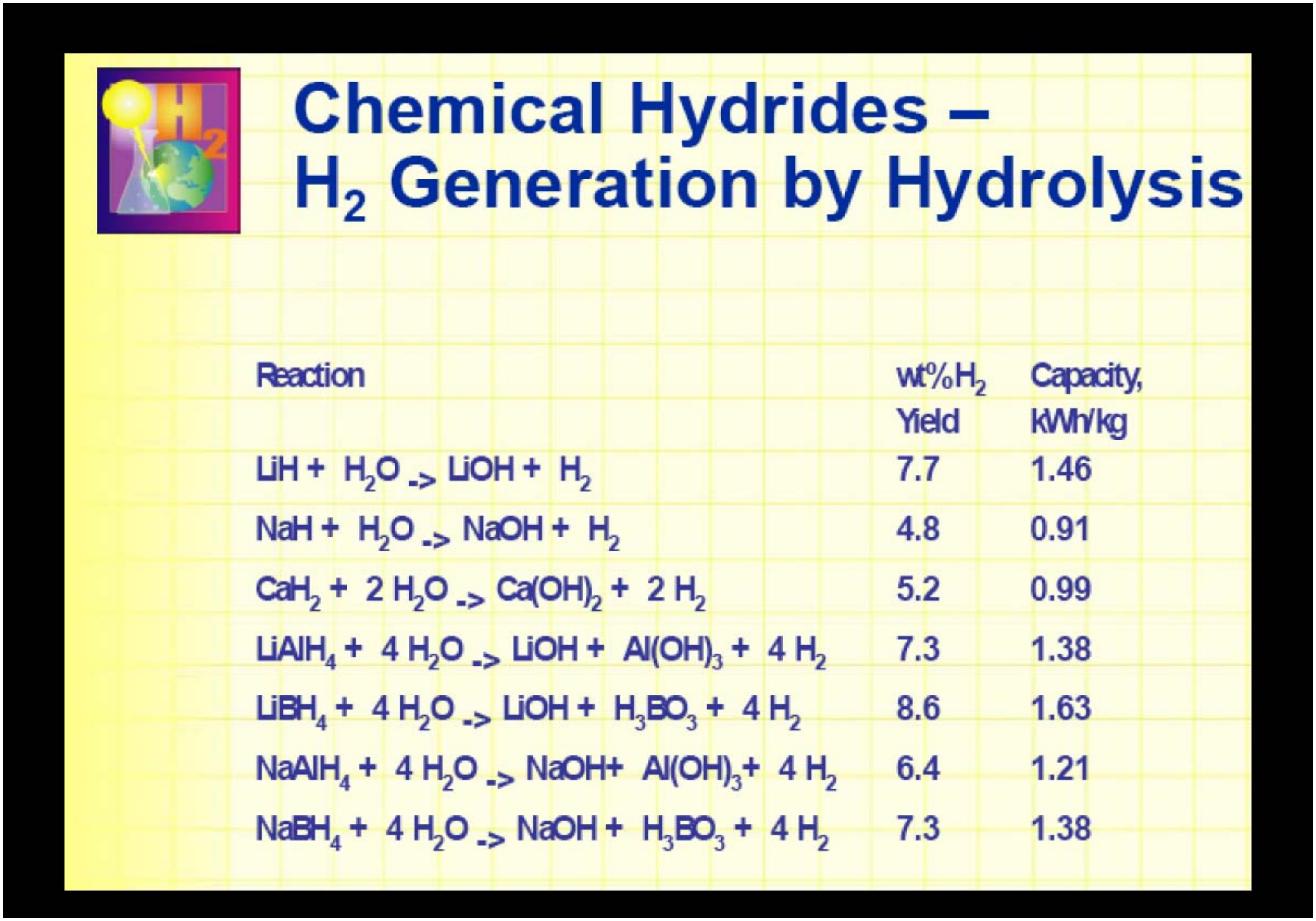
Hydrides – Chemically Bond Hydrogen In A Solid Material

- This storage approach should have the highest hydrogen packing density.
- However, the storage media must meet certain requirements:
  - reversible hydrogen uptake/release
  - lightweight with high capacity for hydrogen
  - rapid kinetic properties
  - equilibrium properties (P,T) consistent with near ambient conditions.
- Two solid state approaches
  - hydrogen absorption (bulk hydrogen)
  - hydrogen adsorption (surface hydrogen) including cage structures

Alanates


Total hydrogen content of some alanates
LiAlH4
NaAlH4
KAlH4
Be(AlH4)2
Na2LiAlH6
Mg(AlH4)2
CuAlH4
Ca(AlH4)2
Mn(AlH4)2
Fe(AlH4)2
AgAlH4
Ti(AlH4)3
Ga(AlH4)3
CsAlH4
Ti(AlH4)4
In(AlH4)3
Zr(AlH4)4
Ce(AlH4)3
Sn(AlH4)4
increasing mol. weight
0
2
4
6
8
10
12
weight percent hydrogen

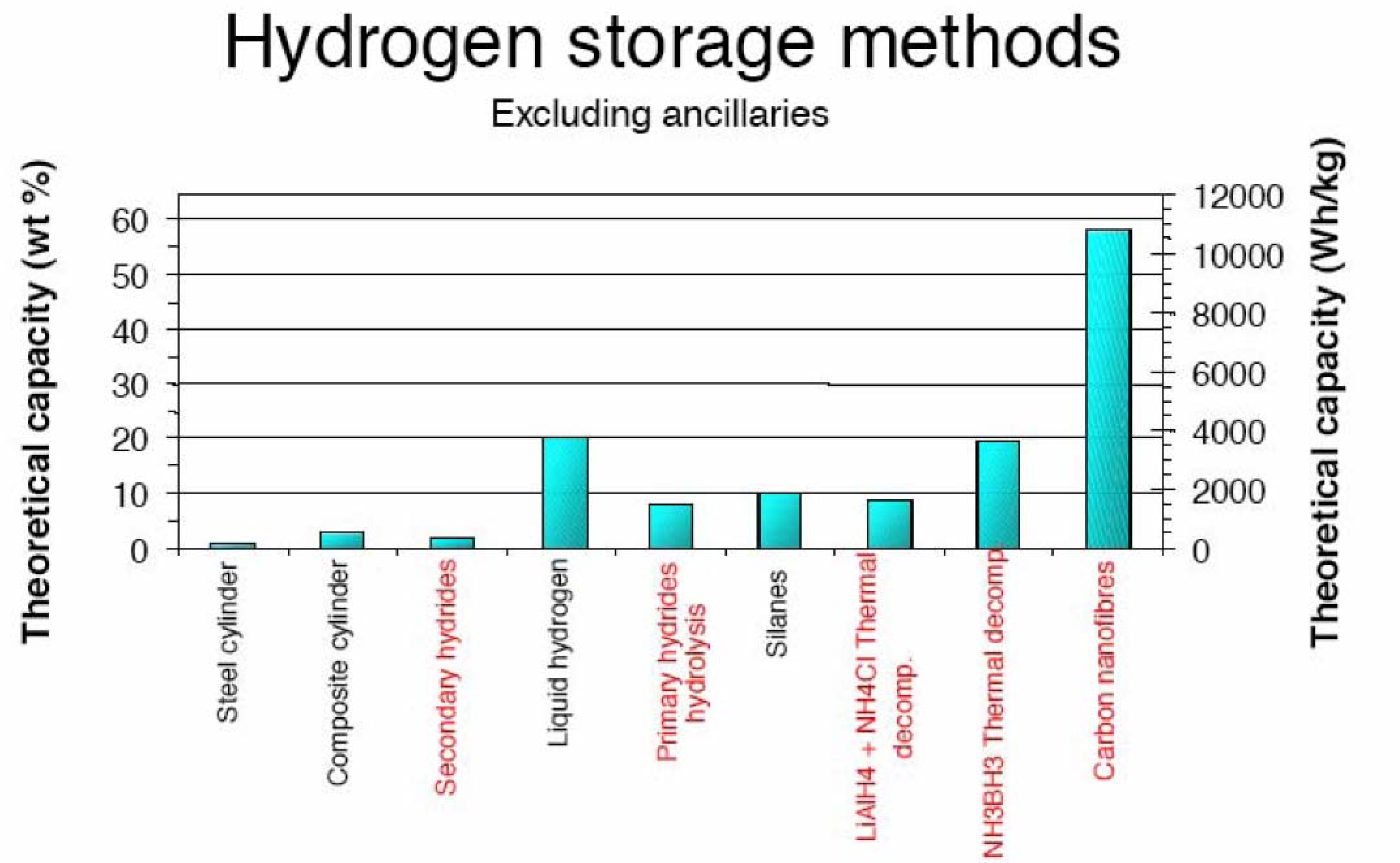
Complex Hydrides



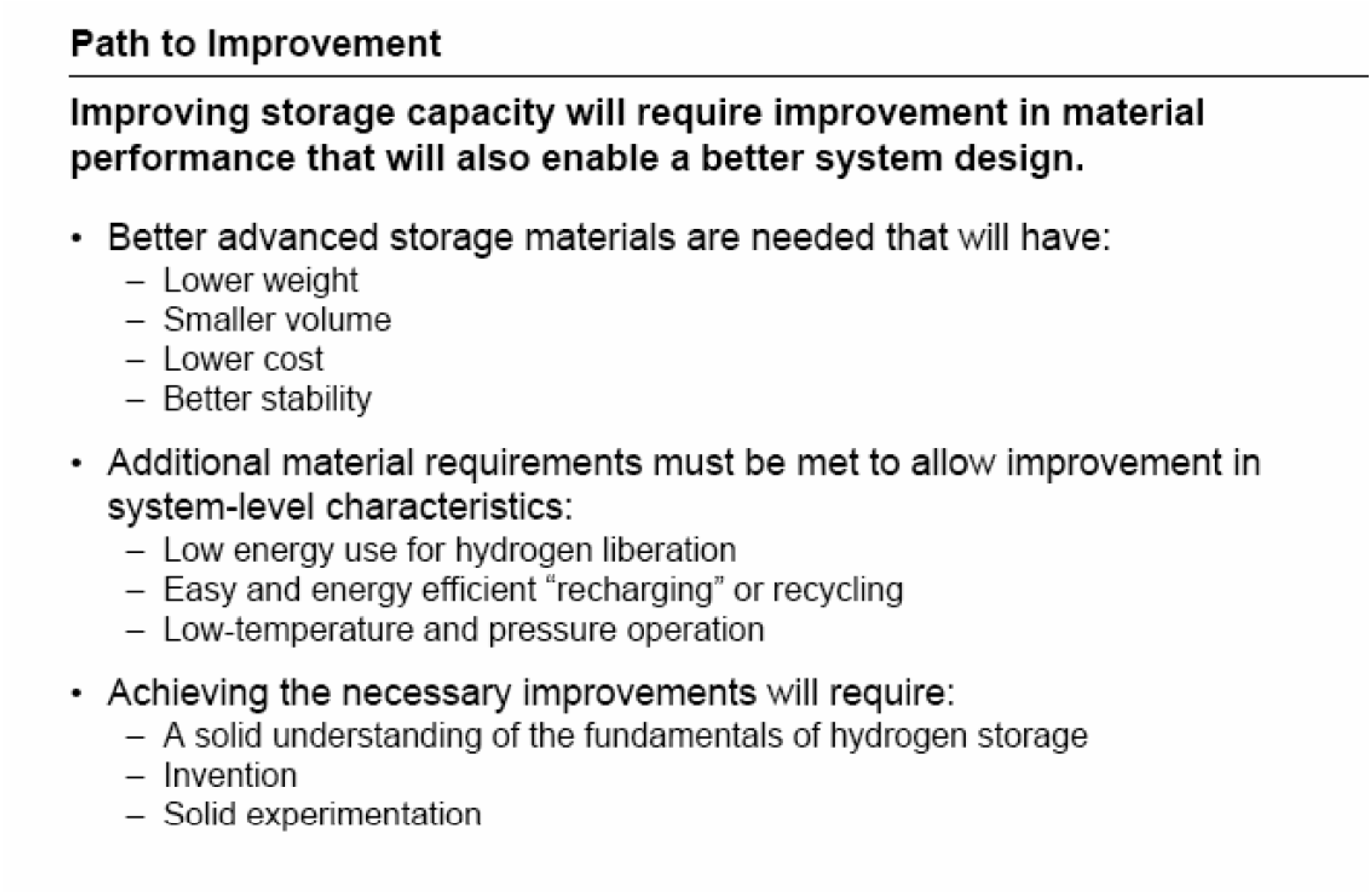
Chemical Hydrides – H_2 Generation by Hydrolysis

Reaction	wt% H_2 Yield	Capacity, kWh/kg
$LiH + H_2O \rightarrow LiOH + H_2$	7.7	1.46
$NaH + H_2O \rightarrow NaOH + H_2$	4.8	0.91
$CaH_2 + 2\ H_2O \rightarrow Ca(OH)_2 + 2\ H_2$	5.2	0.99
$LiAlH_4 + 4\ H_2O \rightarrow LiOH + Al(OH)_3 + 4\ H_2$	7.3	1.38
$LiBH_4 + 4\ H_2O \rightarrow LiOH + H_3BO_3 + 4\ H_2$	8.6	1.63
$NaAlH_4 + 4\ H_2O \rightarrow NaOH + Al(OH)_3 + 4\ H_2$	6.4	1.21
$NaBH_4 + 4\ H_2O \rightarrow NaOH + H_3BO_3 + 4\ H_2$	7.3	1.38

Storage Methods



Improvements



Path to Improvement

Improving storage capacity will require improvement in material performance that will also enable a better system design.

- Better advanced storage materials are needed that will have:
  - Lower weight
  - Smaller volume
  - Lower cost
  - Better stability
- Additional material requirements must be met to allow improvement in system-level characteristics:
  - Low energy use for hydrogen liberation
  - Easy and energy efficient “recharging” or recycling
  - Low-temperature and pressure operation
- Achieving the necessary improvements will require:
  - A solid understanding of the fundamentals of hydrogen storage
  - Invention
  - Solid experimentation

US DOE Targets

DOE Technical Targets: On-Board Hydrogen Storage

	Units	Target	Status Physical Storage	Status Chemical Storage
Storage Weight Percent	%	6	5.2	3.4
Energy Efficiency	%	97	94	88
Energy Density	W-h/L	1100	800	1300
Specific Energy	W-h/kg	2000	1745	1080
Cost	$/kW-h	5	50	18
Operating Temperature	ºC	-40–50°C	-40–50°C	-20–50°C
Start-Up Time To Full Flow	sec	15	<1	<15
Hydrogen Loss	scc/hr/L	1.0	1.0	1.0
Cycle Life	Cycles	500	>500	20-50
Refueling Time	min	<5	TBD	TBD
Recoverable Usable Amount	%	90	99.7	>90

Flex Fuels

- Flexible fuel vehicles (FFVs) are designed to run on gasoline or a blend of up to 85% ethanol (E85). Except for a few engine and fuel system modifications, they are identical to gasoline-only models.
- FFVs have been produced since the 1980s, and dozens of models are currently available. Since FFVs look just like gasoline-only models, you may have an FFV and not even know it. To determine if your vehicle is an FFV, check the inside of your car's fuel filler door for an identification sticker or consult your owner's manual.
- FFVs experience no loss in performance when operating on E85. However, since a gallon of ethanol contains less energy than a gallon of gasoline, FFVs typically get about 20-30% fewer miles per gallon when fueled with E85.

Ethanol Production

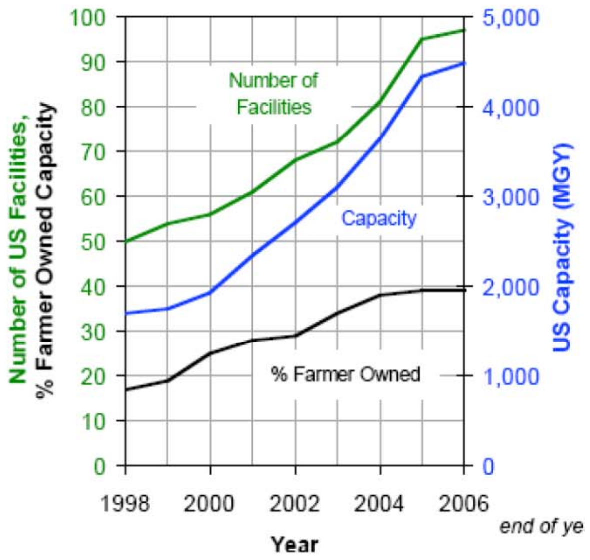
Million Gallons Per Year

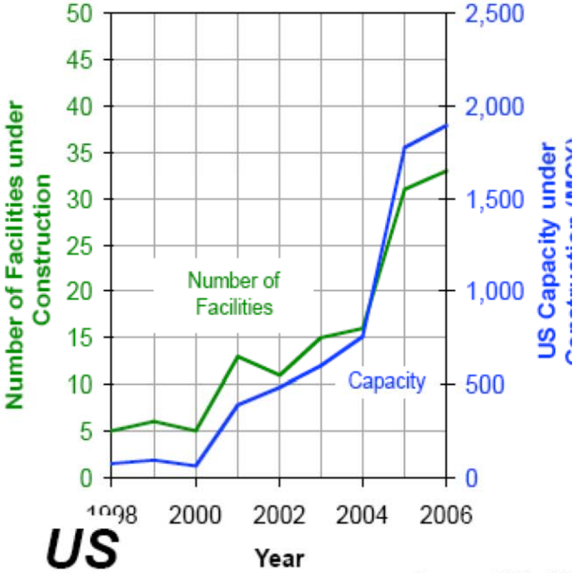
Country	2004	2005
U.S.	3,535	4,264
Brazil	3,989	4,227
China	964	1,004
India	462	449
France	219	240
Russia	198	198
South Africa	110	103
U.K.	106	92
Others	1,187	1,573
Total	**10,770**	**12,150**

States in US with Ethanol Plants (2006): 21

>1.4 billion bushels of corn used in US for ethanol, 13-16% of US corn crop. Also used 15% of grain sorghum crop. 18% of corn crop projected by 2010. 10% ethanol blend nationally would require 50% of current corn crop (5 billion bushels)

9 million metric tons of distillers grains



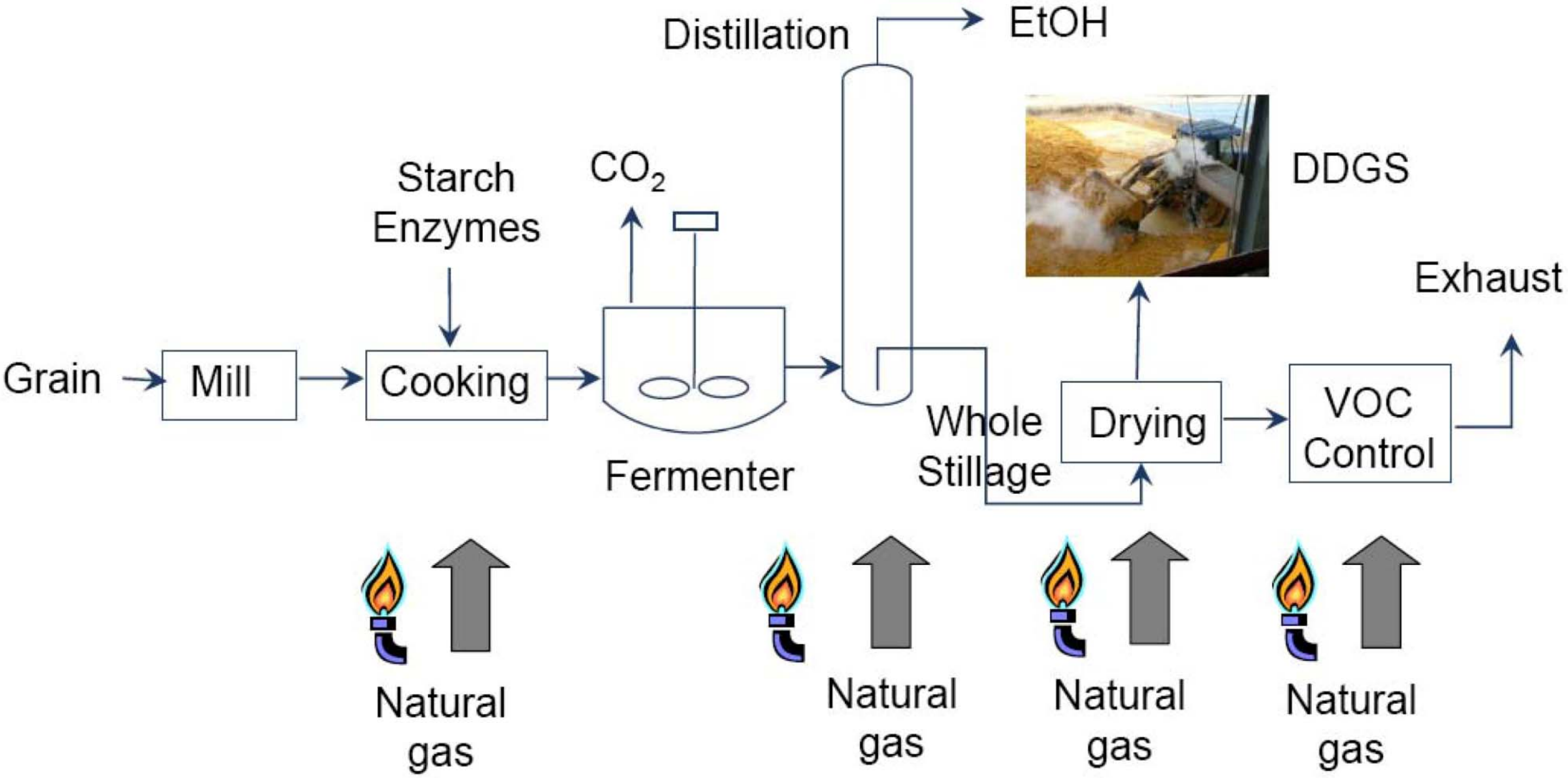


US

Source: RFA, 20

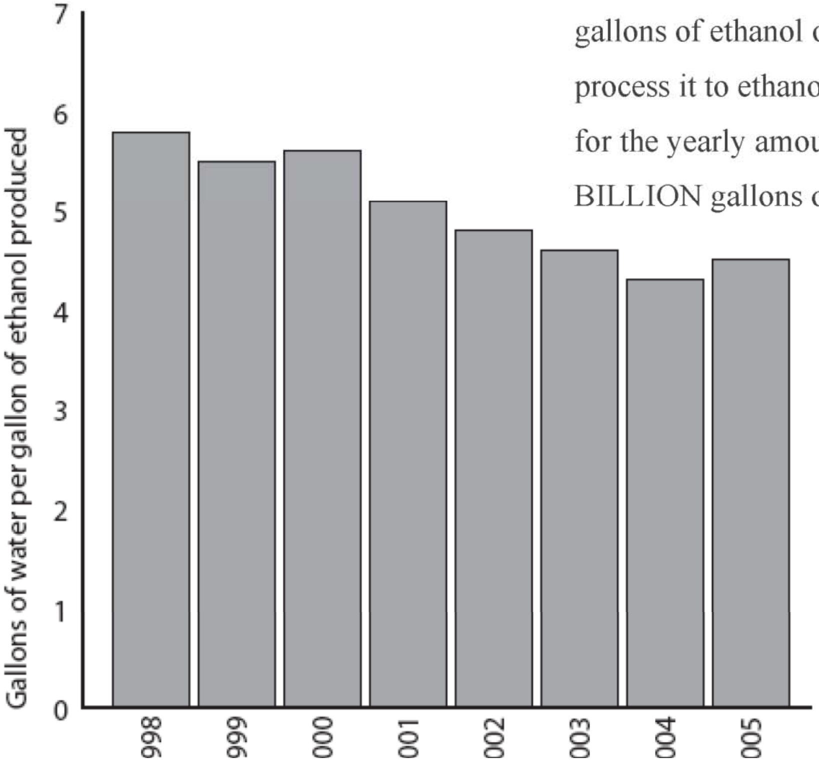
Source: Bryan M. Jenkins, UC Davis, Clean Tech. Workshop, 1/30/2007.

Ethanol Plant Energy Consumption



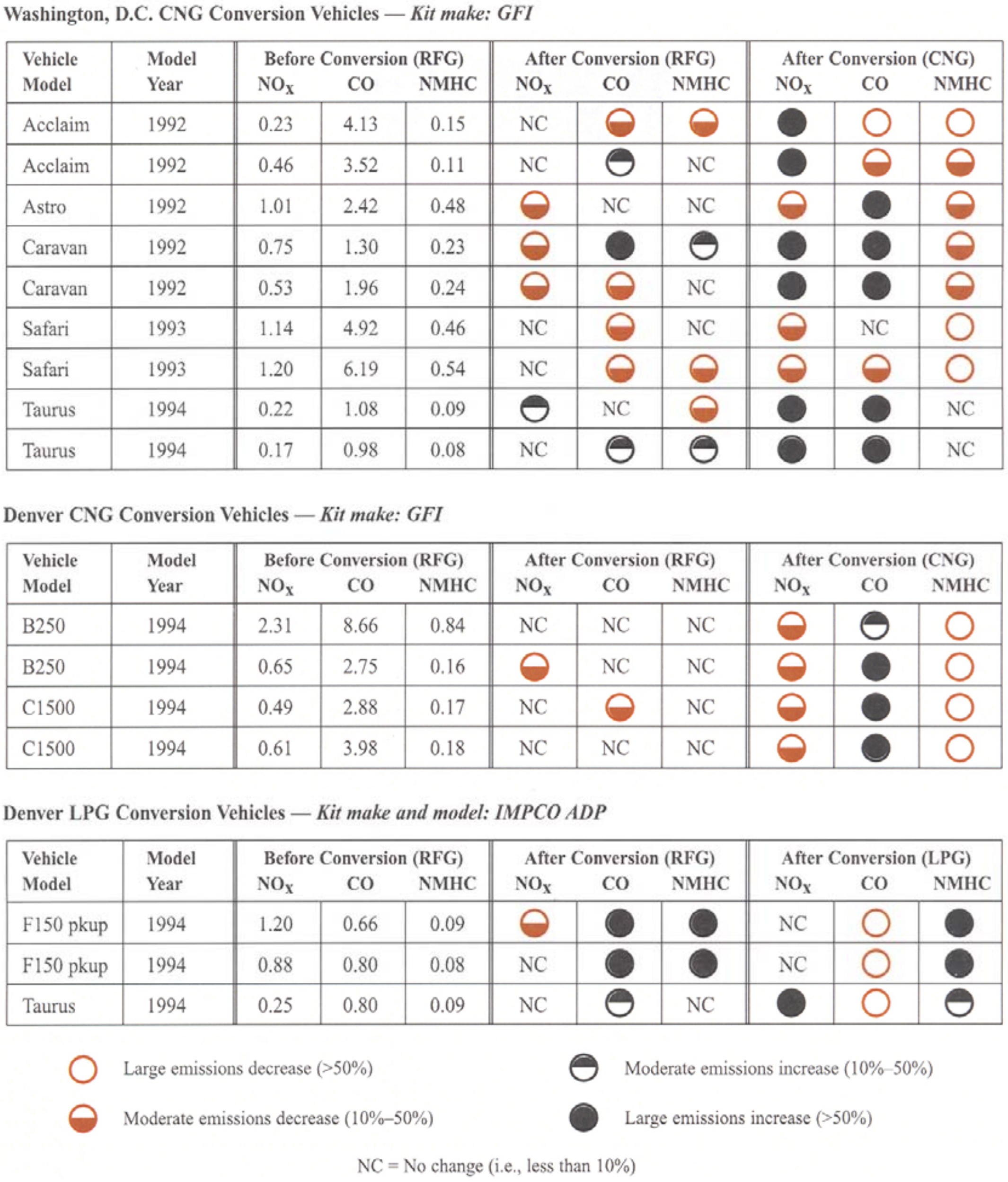
Ethanol Plant Water Consumption

It would take 1,215 gallons of water per acre of corn for the conversion process. The yield per acre of corn to ethanol is 405 gallons. That's per year. So how much would it take to run our country for just one day on ethanol? Here are the numbers, 32,035,500 gallons of ethanol or 791,000 acres of corn, 96,106,500 gallons of water and that is just to process it to ethanol. We still have not touched the amount of water it takes to grow it. So for the yearly amount of water required for an ethanol only market is 34,982,766,000. 35 BILLION gallons of water!



Water use by Ethanol plants, Institute for Agriculture and Trade Policy, Minnesota 2006.

Emission Test Results From Aftermarket Conversions



Washington, D.C. CNG Conversion Vehicles — *Kit make: GFI*

Vehicle Model	Model Year	Before Conversion (RFG) NO_x	CO	NMHC	After Conversion (RFG) NO_x	CO	NMHC	After Conversion (CNG) NO_x	CO	NMHC
Acclaim	1992	0.23	4.13	0.15	NC	◒	◒	●	○	○
Acclaim	1992	0.46	3.52	0.11	NC	◓	NC	●	◒	◒
Astro	1992	1.01	2.42	0.48	◒	NC	NC	◒	●	◒
Caravan	1992	0.75	1.30	0.23	◒	●	◓	●	●	◒
Caravan	1992	0.53	1.96	0.24	◒	◒	NC	●	●	◒
Safari	1993	1.14	4.92	0.46	NC	◒	NC	◒	NC	○
Safari	1993	1.20	6.19	0.54	NC	◒	◒	◒	◒	○
Taurus	1994	0.22	1.08	0.09	◓	NC	◒	●	●	NC
Taurus	1994	0.17	0.98	0.08	NC	◓	◓	●	●	NC

Denver CNG Conversion Vehicles — *Kit make: GFI*

Vehicle Model	Model Year	Before Conversion (RFG) NO_x	CO	NMHC	After Conversion (RFG) NO_x	CO	NMHC	After Conversion (CNG) NO_x	CO	NMHC
B250	1994	2.31	8.66	0.84	NC	NC	NC	◒	◓	○
B250	1994	0.65	2.75	0.16	◒	NC	NC	◒	●	○
C1500	1994	0.49	2.88	0.17	NC	◒	NC	◒	●	○
C1500	1994	0.61	3.98	0.18	NC	NC	NC	◒	●	○

Denver LPG Conversion Vehicles — *Kit make and model: IMPCO ADP*

Vehicle Model	Model Year	Before Conversion (RFG) NO_x	CO	NMHC	After Conversion (RFG) NO_x	CO	NMHC	After Conversion (LPG) NO_x	CO	NMHC
F150 pkup	1994	1.20	0.66	0.09	◒	●	●	NC	○	●
F150 pkup	1994	0.88	0.80	0.08	NC	●	●	NC	○	●
Taurus	1994	0.25	0.80	0.09	NC	◓	NC	●	○	◓

○ Large emissions decrease (>50%)

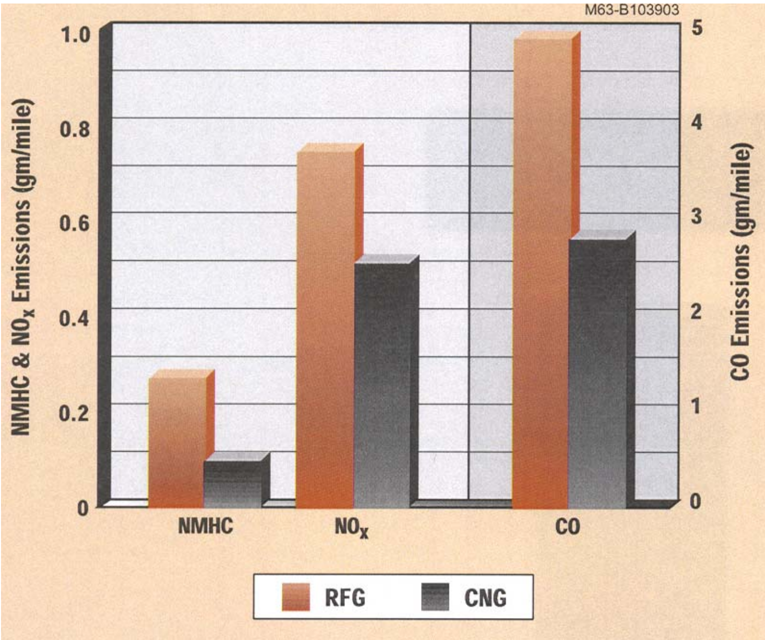
◒ Moderate emissions decrease (10%–50%)

◓ Moderate emissions increase (10%–50%)

● Large emissions increase (>50%)

NC = No change (i.e., less than 10%)

OEM Dodge RAM B250 Van



Source: NREL

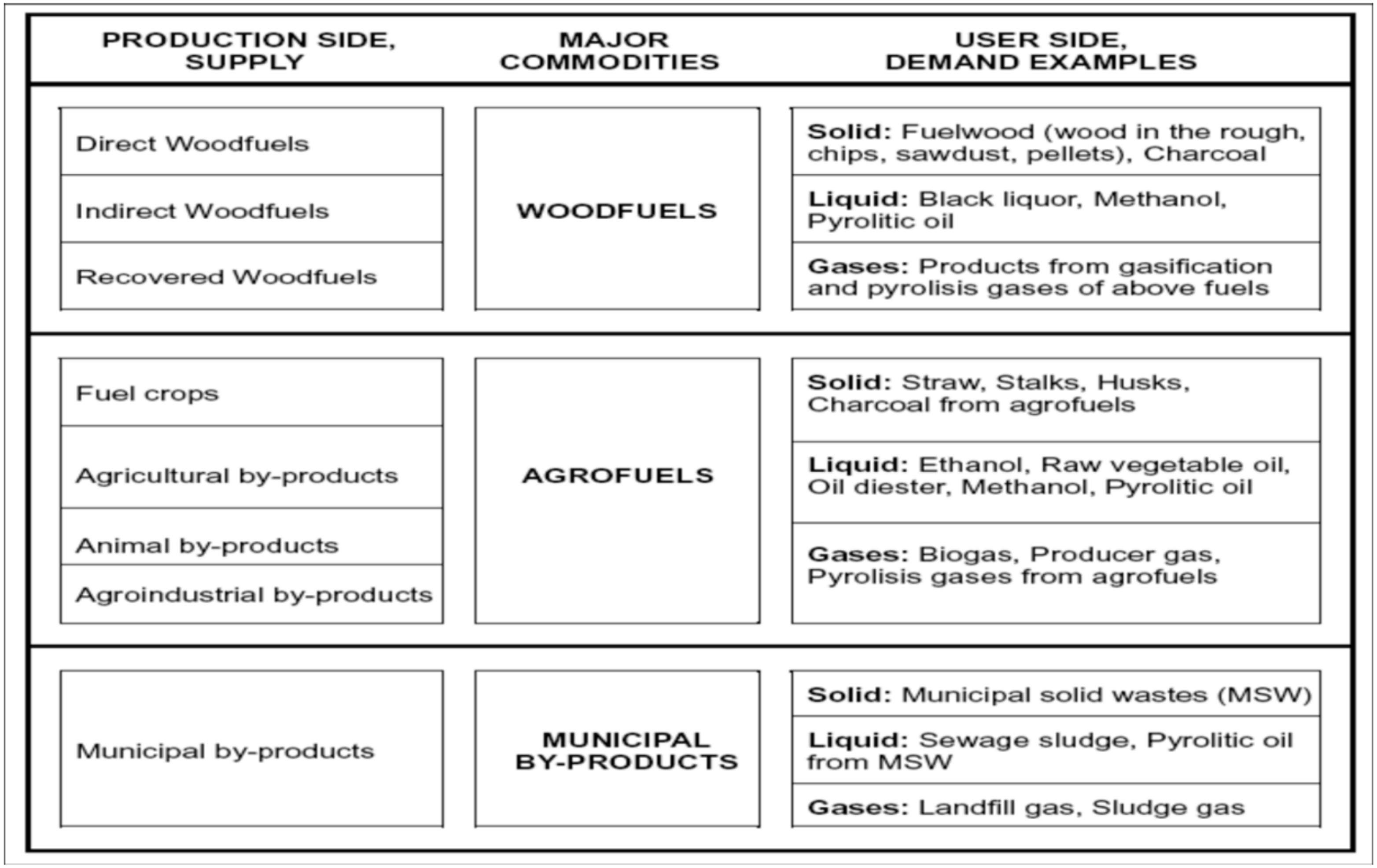
Biofuels In Transportation

Combination of biomass gasification (BG) and Fischer-Tropsch (FT) synthesis is a possible route to produce renewable transportation fuels (biofuels).

Fischer-Tropsch Used to Form Alkenes
With Either Iron or Cobalt as Catalysts

$$(2n+1)H_2 + nCO \rightarrow C_nH_{(2n+2)} + nH_2O$$

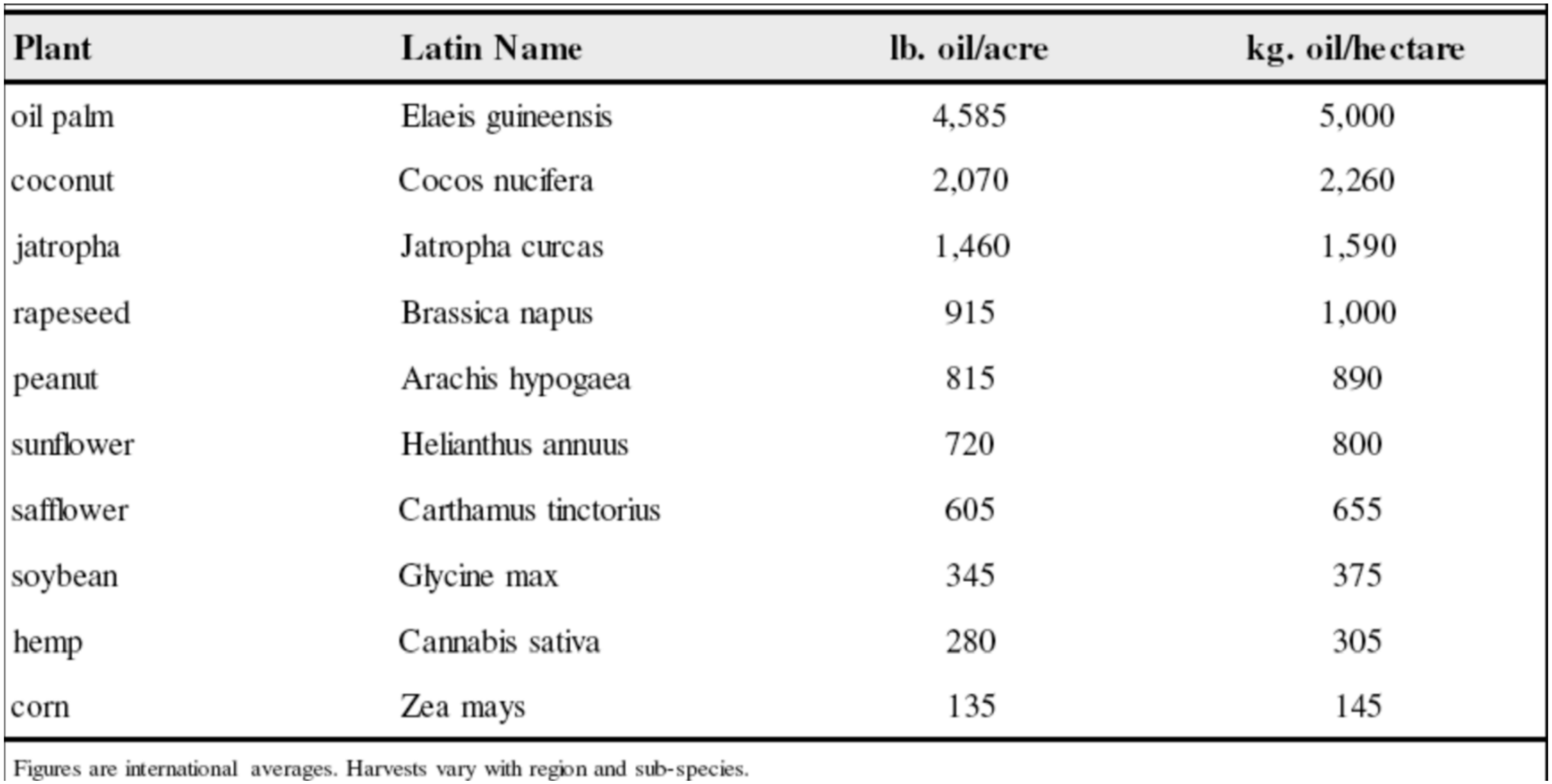
Biofuel Classification



PRODUCTION SIDE, SUPPLY	MAJOR COMMODITIES	USER SIDE, DEMAND EXAMPLES
Direct Woodfuels	WOODFUELS	**Solid:** Fuelwood (wood in the rough, chips, sawdust, pellets), Charcoal
Indirect Woodfuels		**Liquid:** Black liquor, Methanol, Pyrolitic oil
Recovered Woodfuels		**Gases:** Products from gasification and pyrolisis gases of above fuels
Fuel crops	AGROFUELS	**Solid:** Straw, Stalks, Husks, Charcoal from agrofuels
Agricultural by-products		**Liquid:** Ethanol, Raw vegetable oil, Oil diester, Methanol, Pyrolitic oil
Animal by-products		**Gases:** Biogas, Producer gas, Pyrolisis gases from agrofuels
Agroindustrial by-products		
Municipal by-products	MUNICIPAL BY-PRODUCTS	**Solid:** Municipal solid wastes (MSW)
		Liquid: Sewage sludge, Pyrolitic oil from MSW
		Gases: Landfill gas, Sludge gas

Source: World Energy Book, 2006, Chapter 10

Oil Crop Production

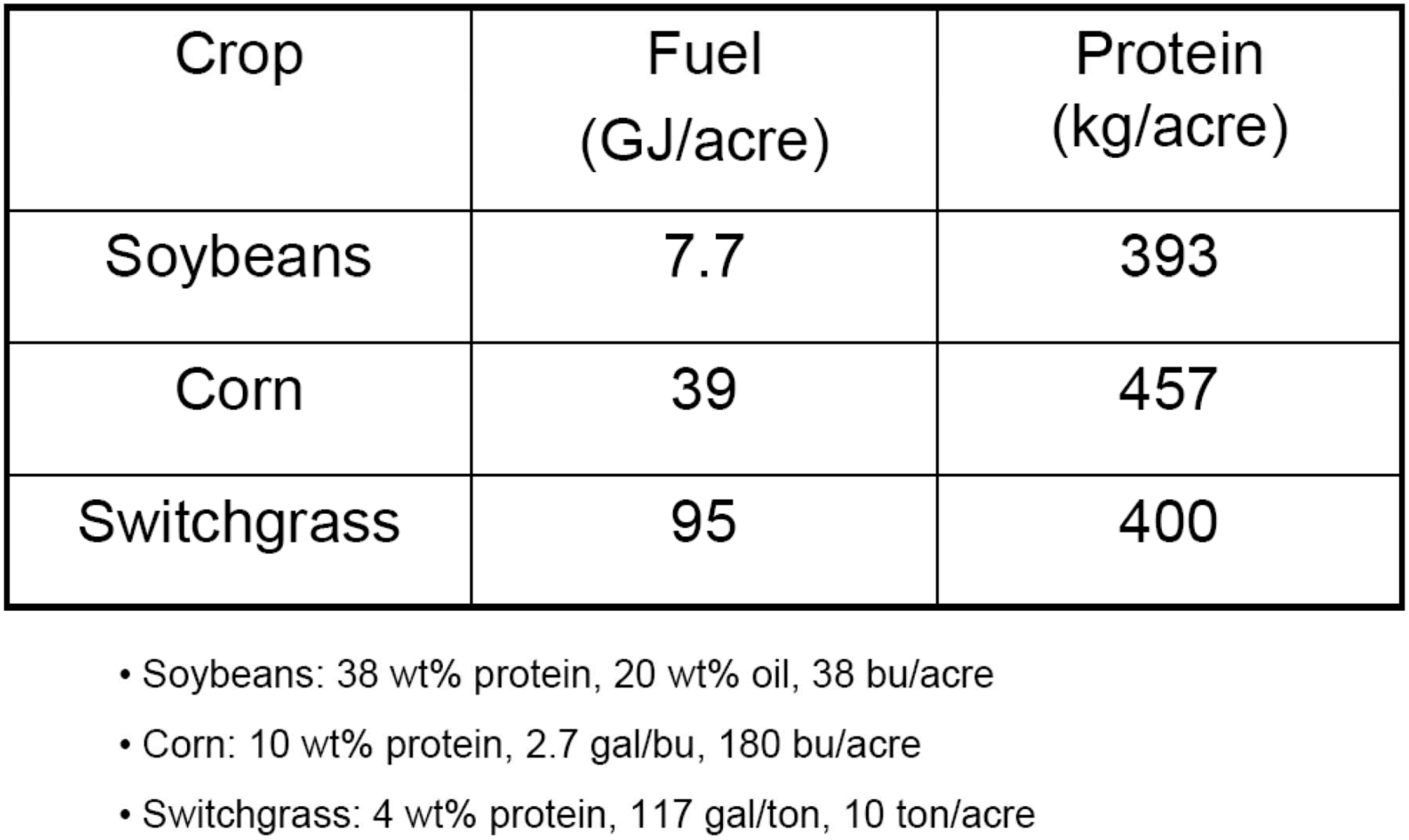


Plant	Latin Name	lb. oil/acre	kg. oil/hectare
oil palm	Elaeis guineensis	4,585	5,000
coconut	Cocos nucifera	2,070	2,260
jatropha	Jatropha curcas	1,460	1,590
rapeseed	Brassica napus	915	1,000
peanut	Arachis hypogaea	815	890
sunflower	Helianthus annuus	720	800
safflower	Carthamus tinctorius	605	655
soybean	Glycine max	345	375
hemp	Cannabis sativa	280	305
corn	Zea mays	135	145

Figures are international averages. Harvests vary with region and sub-species.

Source: From the fryer to the fuel tank by Josha Tickel, ISBN 0-9707227-0-2, 2003

Fuel Crops



Crop	Fuel (GJ/acre)	Protein (kg/acre)
Soybeans	7.7	393
Corn	39	457
Switchgrass	95	400

- Soybeans: 38 wt% protein, 20 wt% oil, 38 bu/acre
- Corn: 10 wt% protein, 2.7 gal/bu, 180 bu/acre
- Switchgrass: 4 wt% protein, 117 gal/ton, 10 ton/acre

Biodiesel Vs. Petroleum Based Diesel

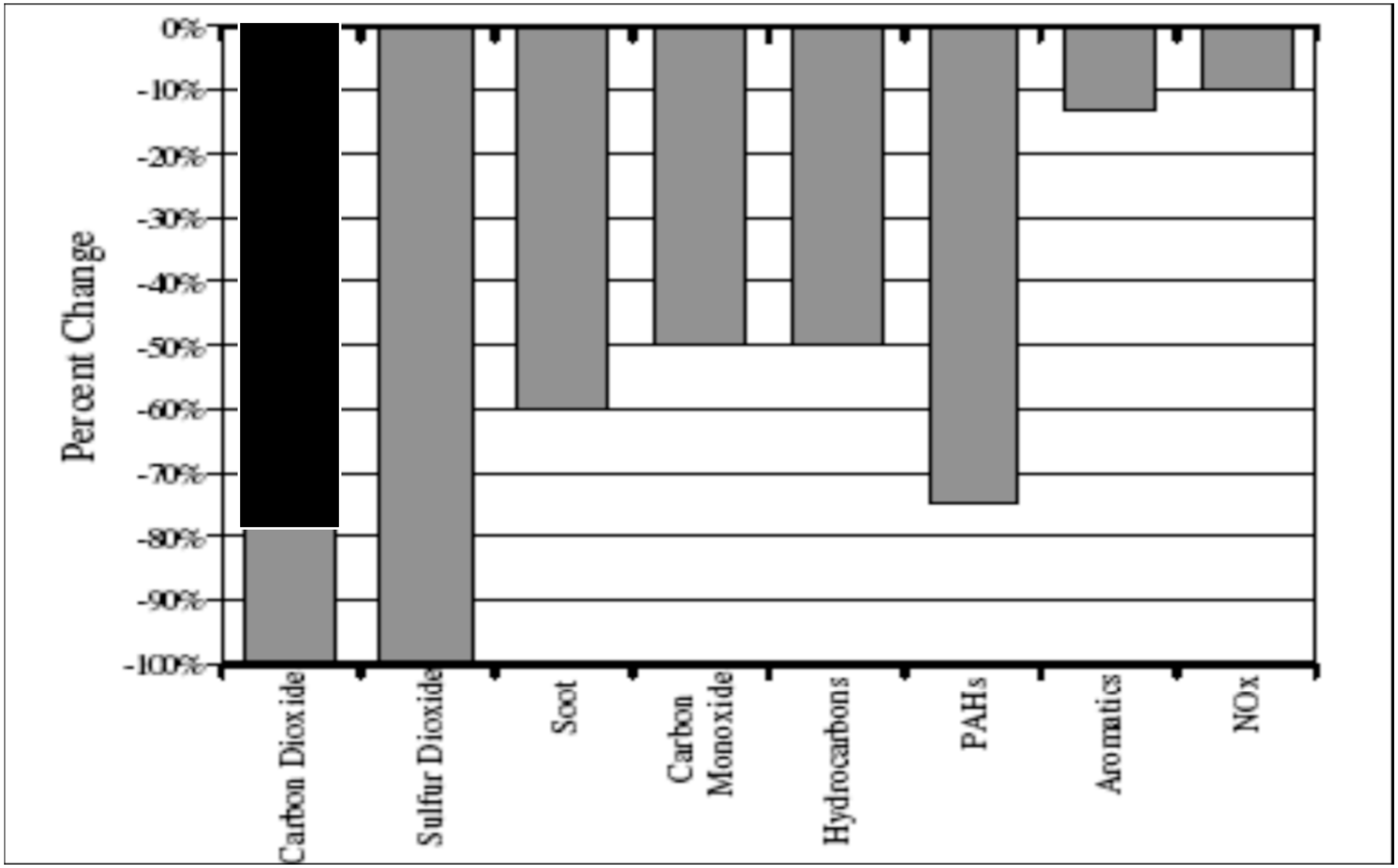
Advantages	Disadvantages
Domestically produced from non-petroleum, renewable resources	Use of blends above B5 not yet warrantied by auto makers
Can be used in most diesel engines, especially newer ones	Lower fuel economy and power (10% lower for B100, 2% for B20)
Less air pollutants (other than nitrogen oxides) and greenhouse gases	Currently more expensive
Biodegradable	More nitrogen oxide emissions
Non-toxic	B100 generally not suitable for use in low temperatures
Safer to handle	Concerns about B100's impact on engine durability

Notes: Diesel Engine is 30-35% More Fuel Efficient Than Similar Sizes Gasoline Engine.

Ultra Low Sulfur Diesel (ULSD) lowers particulates and combats NOx emissions.

All figures cited were originally gathered and reported by www.fueleconomy.gov

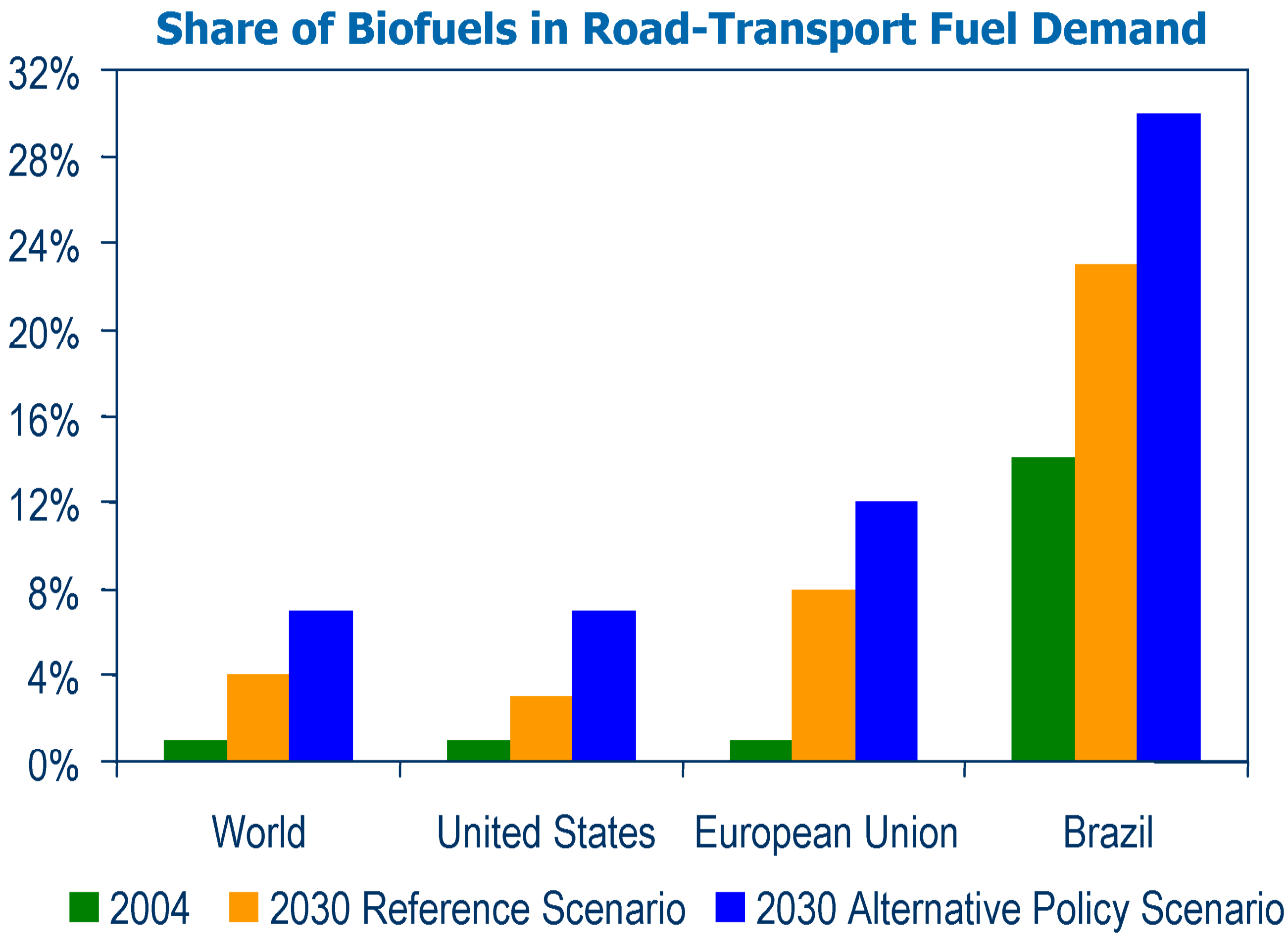
Biodiesel vs Diesel Emissions



PAH – Polycyclic Aromatic Hydrocarbons

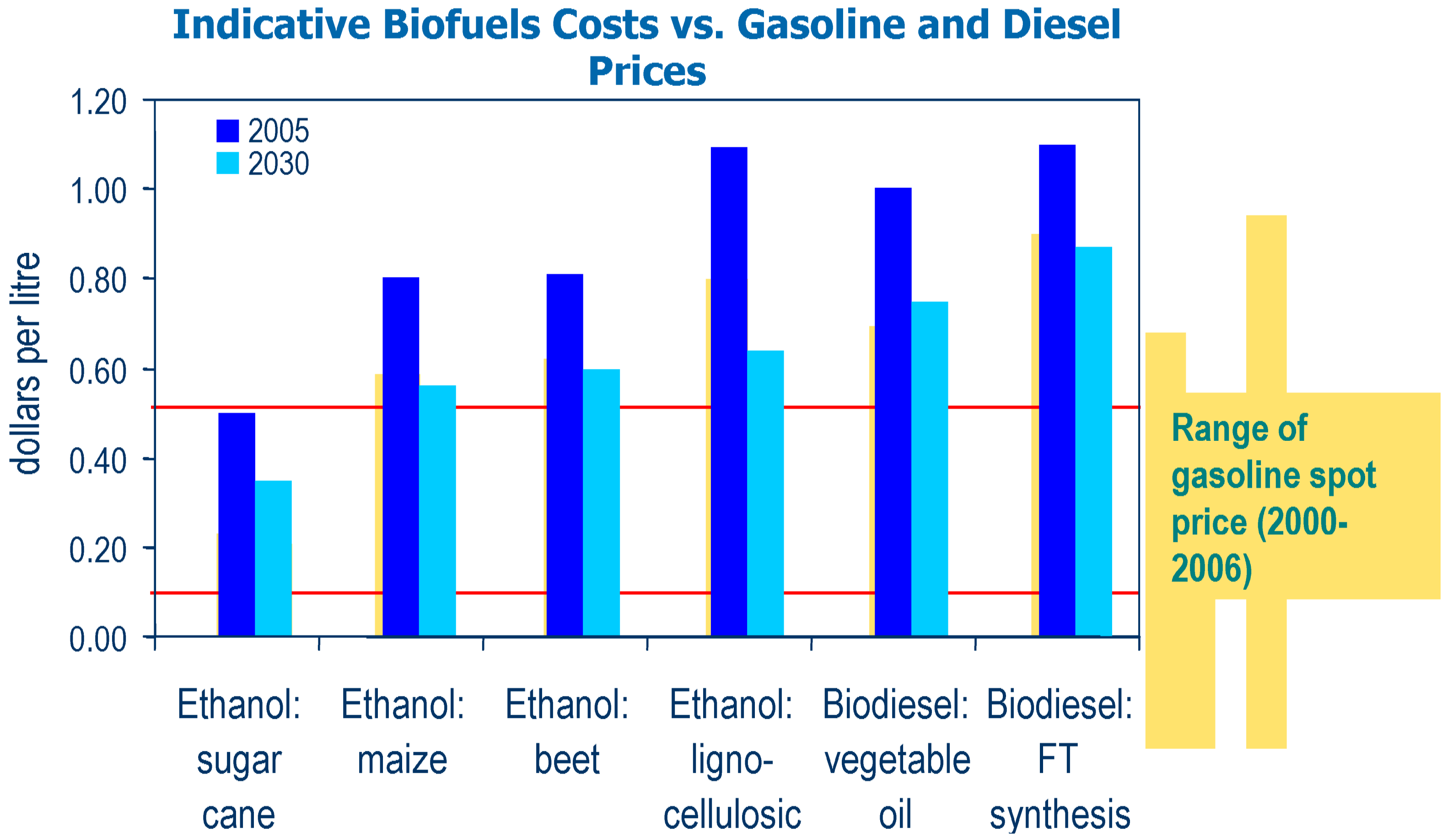
Source: From the fryer to the fuel tank by Josha Tickel, ISBN 0-9707227-0-2, 2003

Outlook for Biofuels



Dr. Roberto Schaeffer, Climate Change in Brazil, UNDESA, Nov. 2007

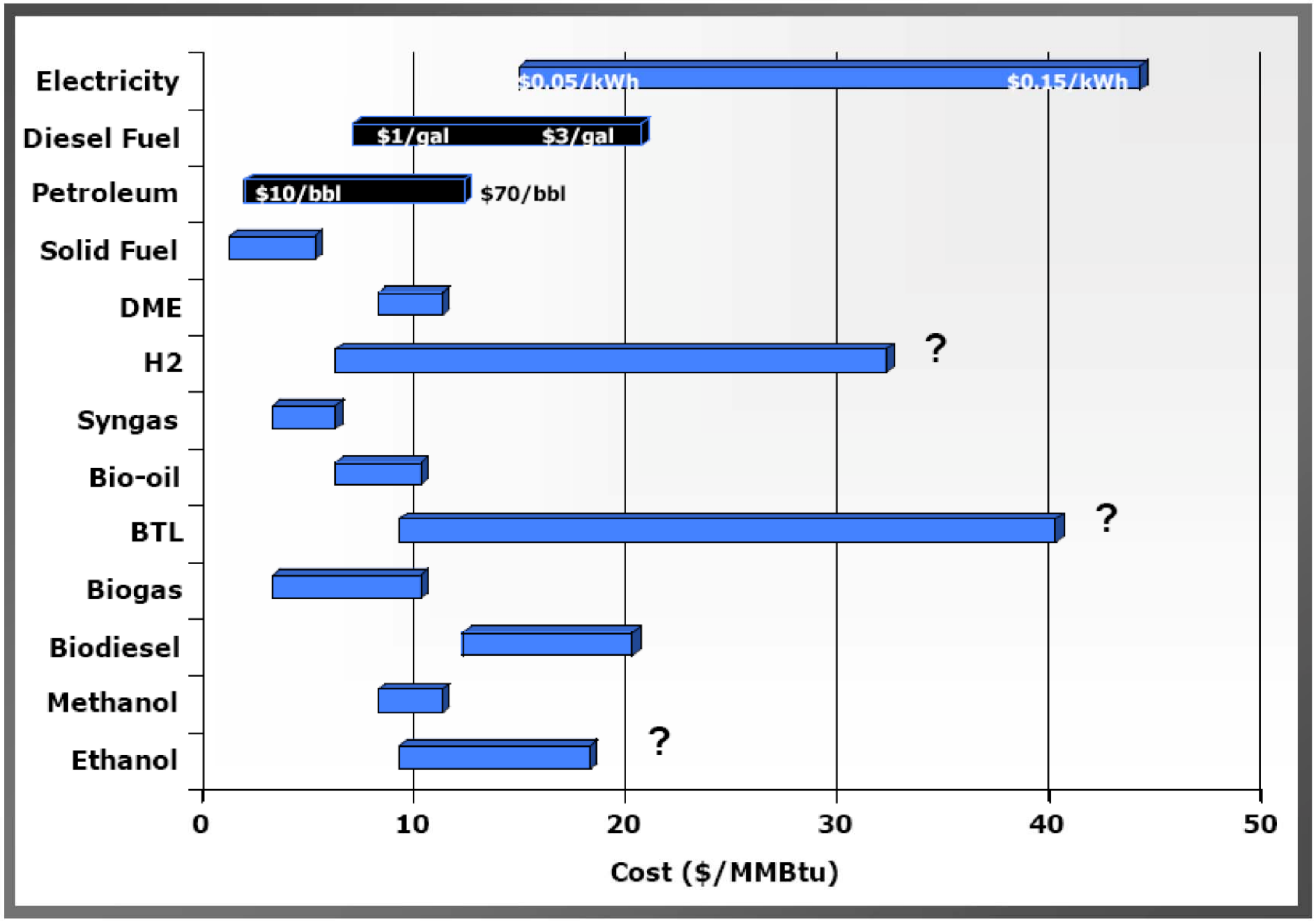
Biofuels Supply Costs



Significant production cost reductions are expected especially for 2nd – generation ligno-cellulisic ethanol.

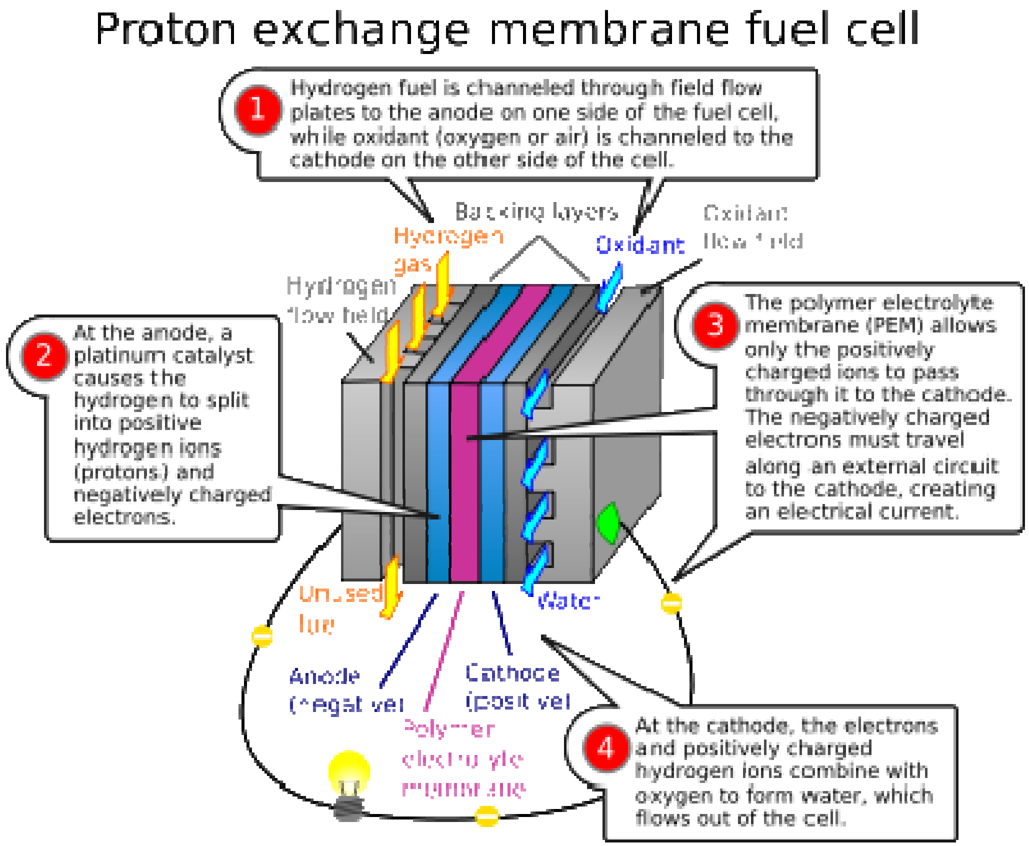
Dr. Roberto Schaeffer, Climate Change in Brazil, UNDESA, Nov. 2007

Production Costs and Prices



Alternate Power Sources

Fuel Cells



Proton exchange membrane fuel cell

1 Hydrogen fuel is channeled through field flow plates to the anode on one side of the fuel cell, while oxidant (oxygen or air) is channeled to the cathode on the other side of the cell.

2 At the anode, a platinum catalyst causes the hydrogen to split into positive hydrogen ions (protons) and negatively charged electrons.

3 The polymer electrolyte membrane (PEM) allows only the positively charged ions to pass through it to the cathode. The negatively charged electrons must travel along an external circuit to the cathode, creating an electrical current.

4 At the cathode, the electrons and positively charged hydrogen ions combine with oxygen to form water, which flows out of the cell.

Costs:

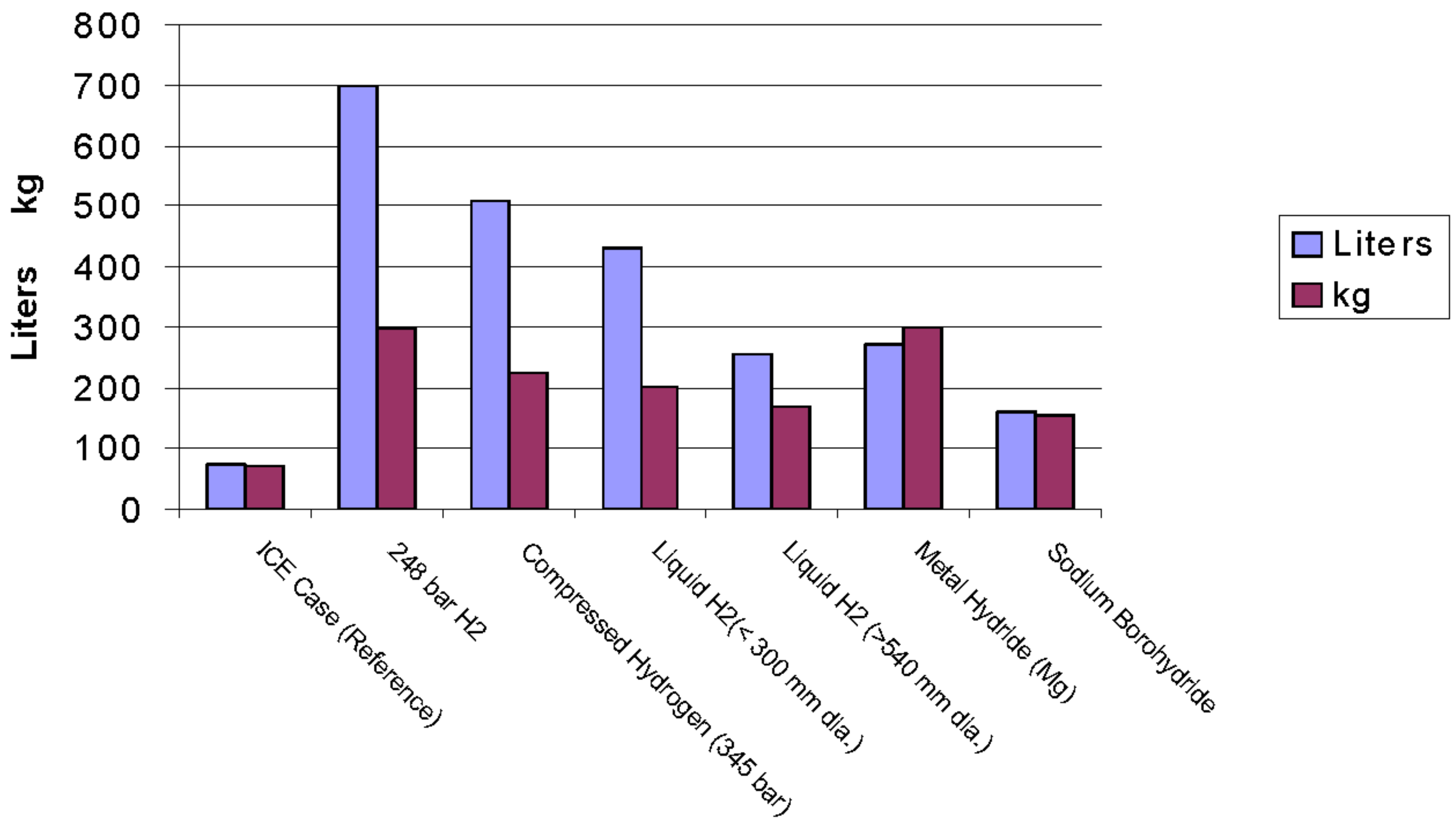
In 2002, typical cells had a catalyst content of US$1000 per kilowatt of electric power output. In 2008 UTC Power has 400kw Fuel cells for $1,000,000 per 400kW installed costs. The goal is to reduce the cost in order to compete with current market technologies including gasoline internal combustion engines.

Honda FCX Clarity

Hydrogen Fuel Port

Fuel Cell Electric Vehicle Storage System

Comparative Volumes and Weights of a FCEV Hydrogen Storage System (Capable of 560 km (350 mi) Range – Compact Sedan)

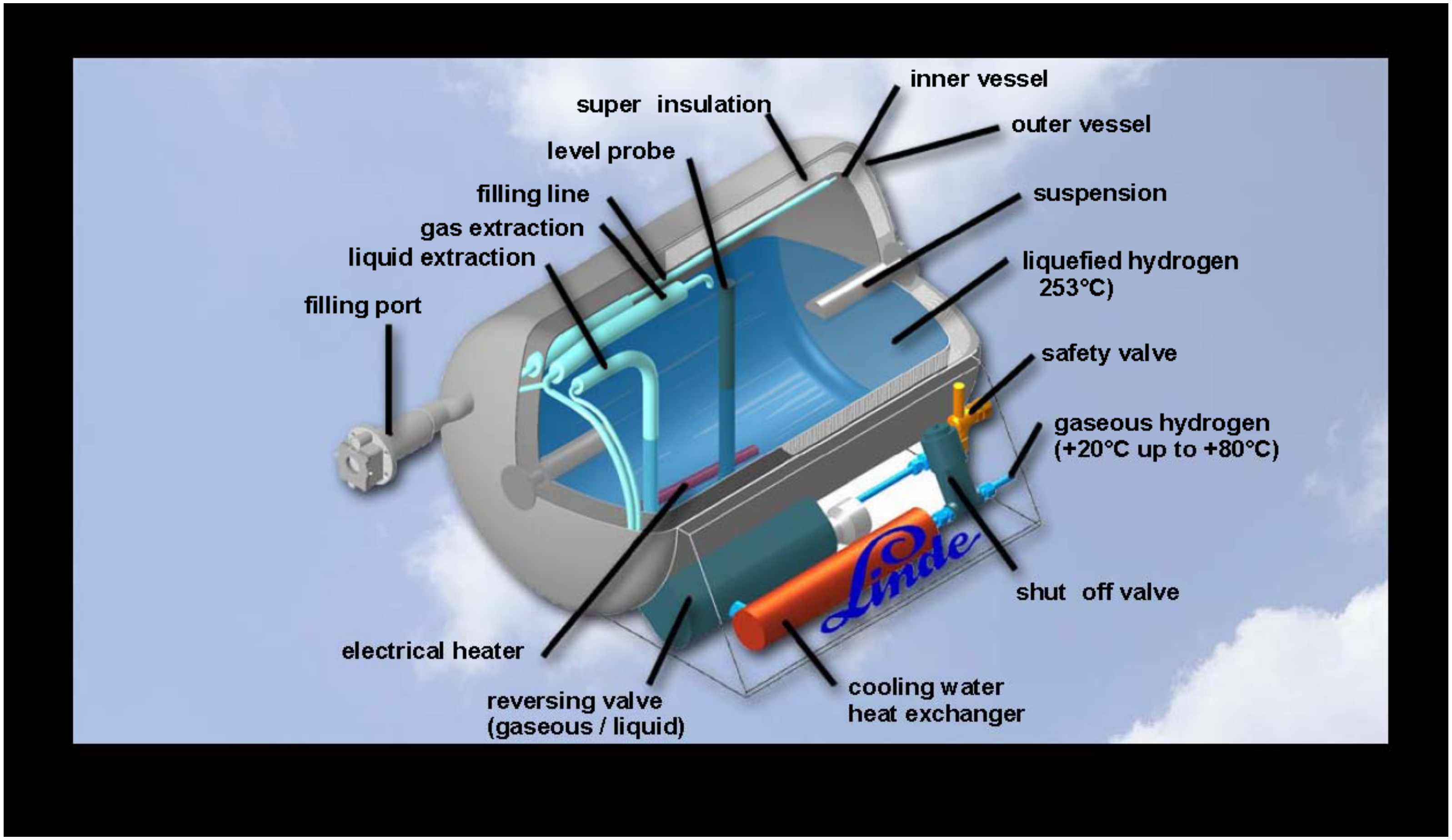


Storage Systems

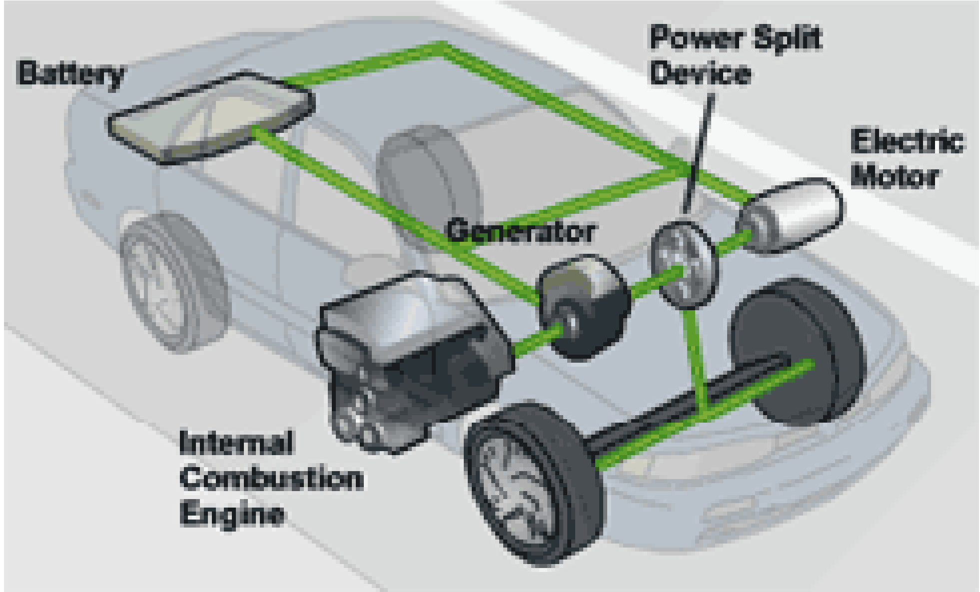
	System Weight	System Volume	Extraction Complexity	System Cost	Fuel Cost	Dormancy	Safety
Compressed Gas (5,000 psi)	🟢	🟡	🟢	🟢	🟢	🟢	🟡
Cryogenic Liquid H2	🟢	🟢	🟡	🟢	🟡	🟡	🟡
Cryo - Liquid Compressed H2	🟢	🟢	🟡	🟢	🟡	🟡	🟡
Rechargeable Metal Hydride	🔴	🟢	🟡	🟢	🟢	🟢	🟢
Carbon Adsorbtion	🟡	🟢	🟡	🟢	🟡	🟢🟡	🟢🟡
Chemical Hydride	🟢	🟢	🔴	🟡	🔴	🟢	🟡

🟢 Good 🟡 Acceptable 🔴 Problem

LH2 Tank Configuration



Hybrids



Hybrid Features:

- Regenerative braking
- Electric motor drive/assist
- Automatic start/shutoff
- Great gas mileage

Source: Alternate Fuel Vehicle

Available & Planned Hybrids

Manufacturer	Model	Type	Available
Chrysler	Aspen HEMI Hybrid	SUV	2008
Dodge	Durango HEMI Hybrid	SUV	2008
Ford	Fusion Hybrid	Midsize Car	2008
Mercury	Milan Hybrid	Midsize Car	2008
Ford	Edge Hybrid	SUV	2008-10
Ford	Five Hundred Hybrid	Large Car	2008-10
Lincoln	MKX Hybrid	SUV	2008-10
Mercury	Montego Hybrid	Large Car	2008-10
Mercedes-Benz	ML450 Hybrid	SUV	2009
Mercedes-Benz	S400 BlueHybrid	Large Car	2009-10
BMW	X6	SUV	2010
Porsche	Cayenne Hybrid	SUV	2010
Honda	Fit Hybrid	Small Station Wagon	2010-15

Three new hybrids for 2009

Cadillac Escalade Hybrid

Chevrolet Silverado 15 Hybrid

GMC Sierra 15 Hybrid

Sources: J.D. Power-LMC; Energy & Environmental Analysis (EEA), Inc.; manufacturer web sites. Updated 9/6/2006.

All Electric Tesla Car

Now in Production

The 2008 Tesla Roadster:
- 100% electric
- 0 to 60 mph in 3.9 seconds
- 13,000 rpm redline
- 135 mpg equivalent
- 220 miles per charge*
- less than 2¢ per mile*

What's New?

Tesla Motors begins regular production of 2008 Tesla Roadster. **read the press release ➤**

Jay Leno's Garage, 2008 Tesla Roadster - Batteries are included **view the video ➤**

Mythbuster Blog: The Tesla Roadster is not a Converted Lotus Elise. **learn more ➤**

Tesla Motors completes all regulatory approvals and sets schedule to begin production. **read the press release ➤**

Our Press

Tesla Motors is making headlines in places like:

- *USA Today*
  Tesla: Little electric roadster that could
- *Bloomberg*
  Tesla Boosts Funding to Start Electric-Car Assembly
- *Motor Trend*
  First Drive: 2008 Tesla Roadster

more headlines ➤

Awards

- *PRWeek*
  Honorable Mention: **Corporate Branding Campaign** & **Technology Campaign of the Year 2008**
- *TechCrunch*
  TechCrunchie for Best Clean Tech Startup 2007
- *Wired*
  Autopia 2007 Car of the Year
- *INDEX*
  INDEX Award 2007
- *BusinessWeek*
  Best Product Design of 2007, Ecodesign
- *CarDomain*

Noteworthy

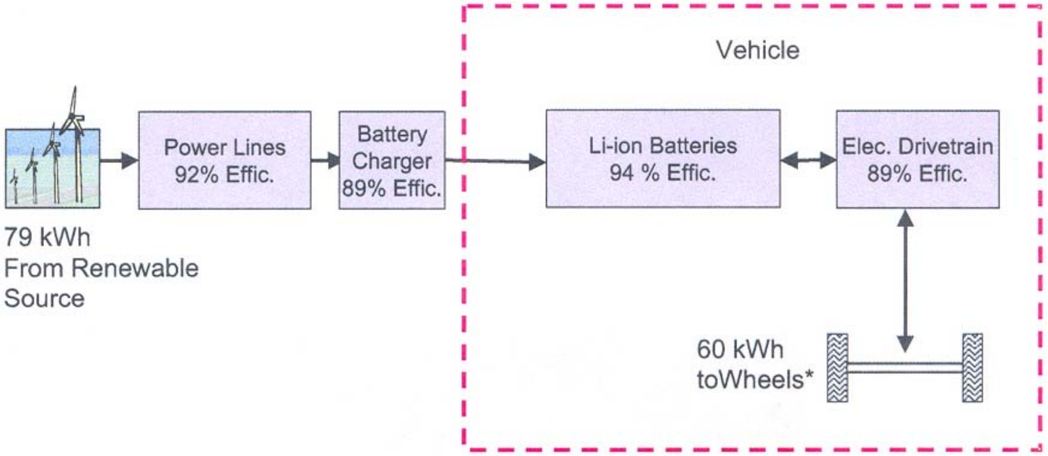
Tesla Motors wait list for the 2009 Roadster. **learn more ➤**

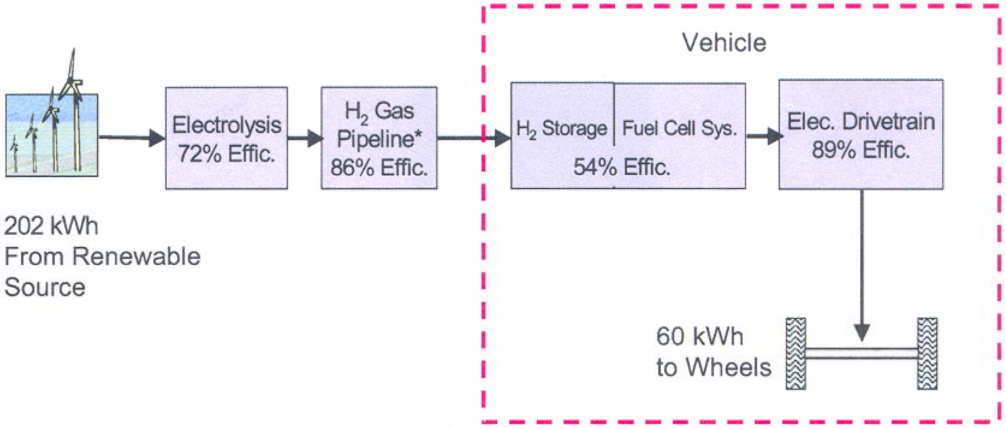
How long does it take to charge the Tesla Roadster? How fast is it? And, most importantly, how do I buy one? These questions and more answered in our FAQs. **find answers➤**

http://www.teslamotors.com/ (1 of 2) [4/14/2008 1:26:42 PM]

Well To Wheel Energy Pathways

Battery Electric Vehicle





Fuel Cell Vehicle

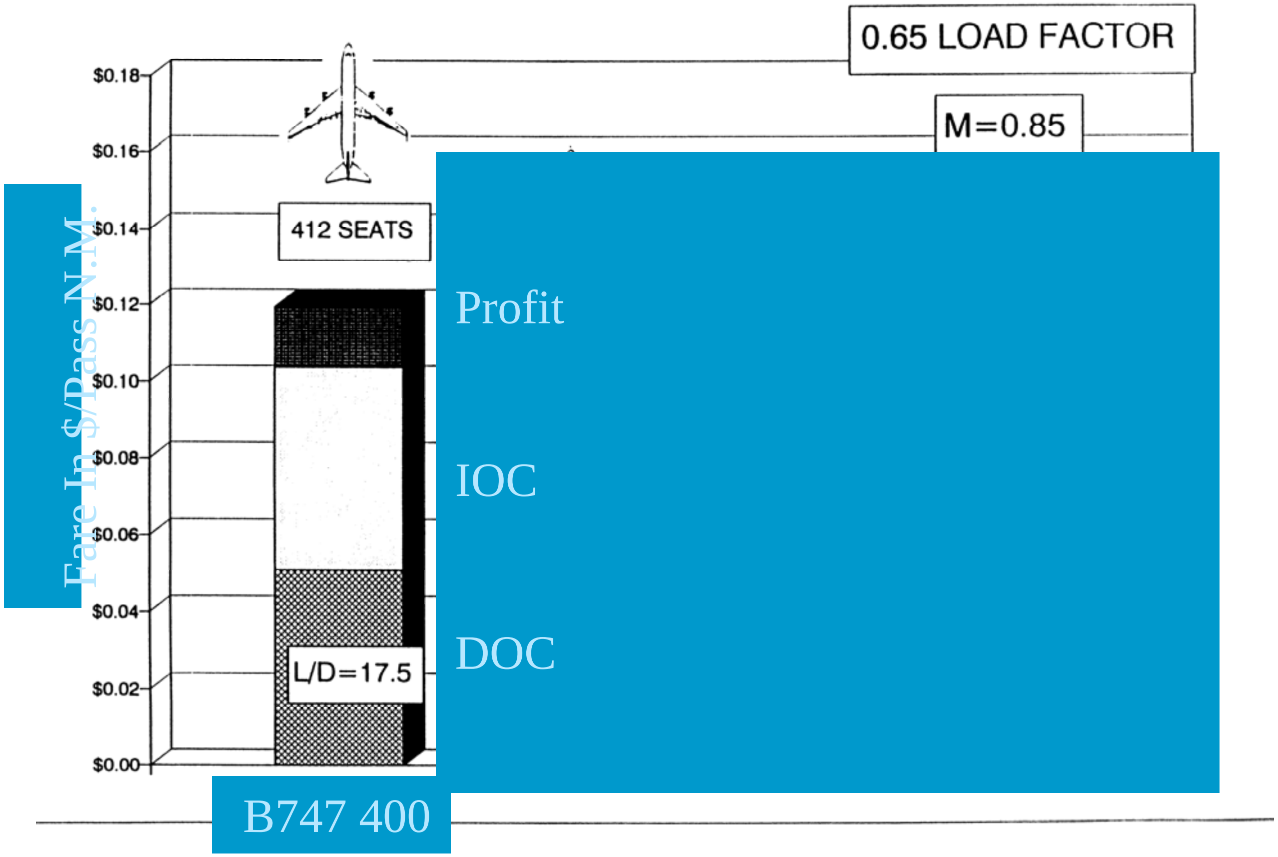
Source: Eaves & Eaves, A cost comparison of fuel-cell and battery electric vehicles, J. Pwr Sources, 130 (2004) 208-212

Factors Affecting New Airplane Launch Decisions

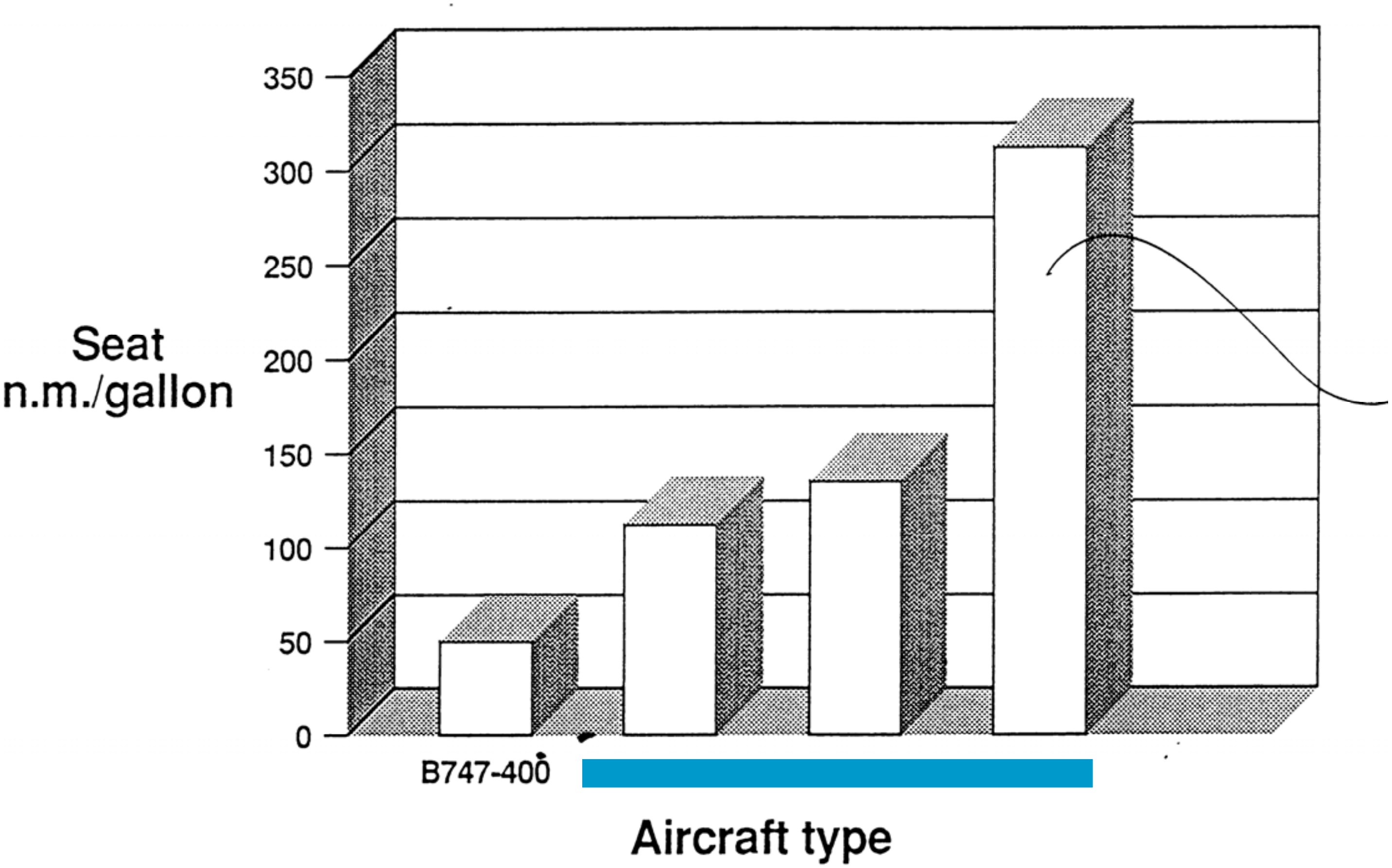
- Economics - International Market Competition
  - Aircraft Cost/Efficiency/Productivity
  - Airport Gate / Runway Productivity

- Additional Constraints
  - Energy Efficiency
  - Emissions
  - Noise
  - Safety

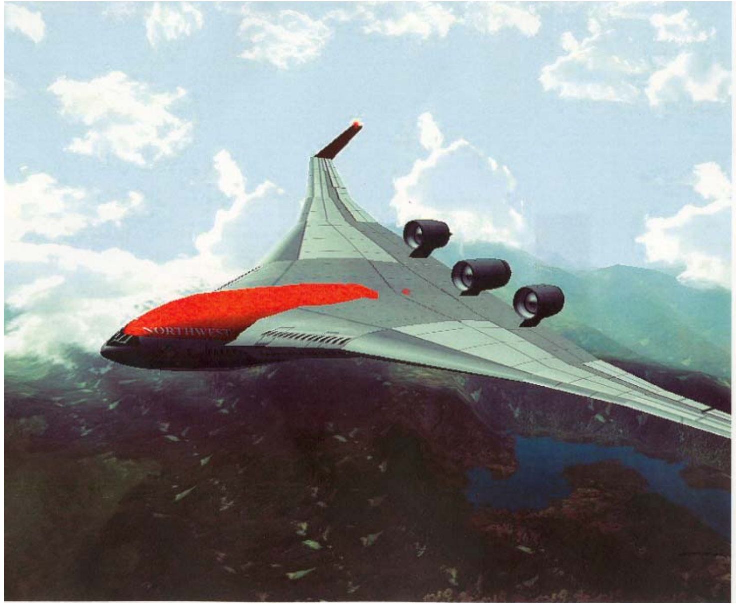
Factors Influencing Airplane Ticket Price
5500 Nautical Mile Stage Length



Aircraft Fuel Cost



Blended Wing Body Concept



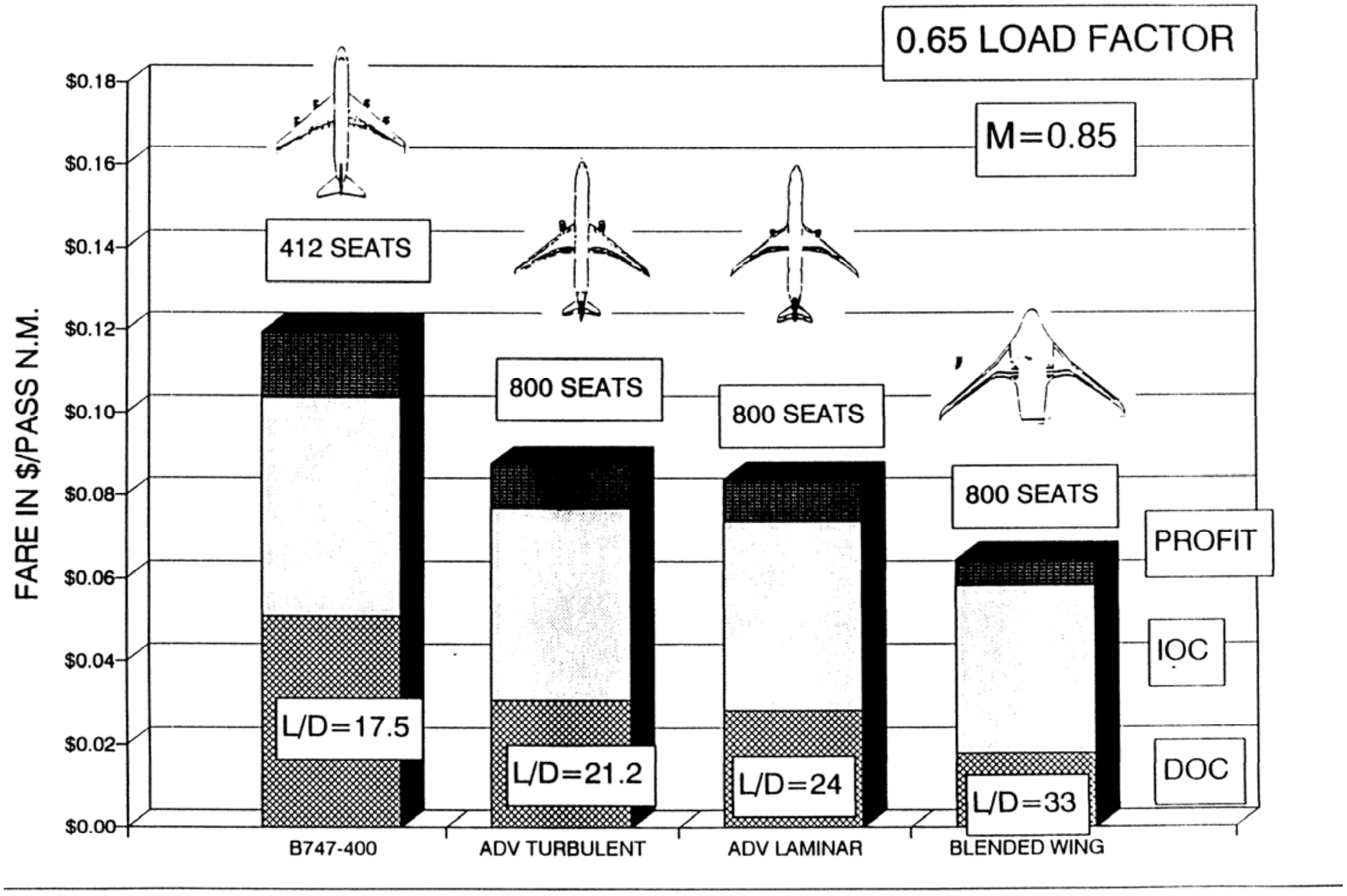
Benefits:

- **20-25 % Less Fuel**
- **10-15% Less Weight**
- **10-15% Lower DOC**

Challenges:

- **Propulsion/Airframe Integration**
- **Aero-Structural Integration**
- **Aerodynamics**
- **Controls**

Subsonic Aircraft Comparison
5500 Nautical Mile Stage Length



Estimated Fuel Economy