

ALTERNATIVES FOR TRANSPORTATION ENERGY

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Current Transportation Energy is Not Sustainable for the Long Term

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Huge Petroleum Consumption

Leads to:

- Potentially Destructive CO₂ Production
- Economic Security-Balance of Payments
- Energy Security-Maintaining Needed Supply

Sustainable Petroleum Consumption ?

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- Currently about 300 billion gallons per year total
- About 100 billion imported from OPEC
- Almost 100 billion imported from Non-OPEC
- Slightly over 100 billion produced in U.S.
- Resulting in ~ 141 billion gallons of gasoline
 - ~ 63 billion gallons of diesel and fuel oil
 - ~ 25 billion gallons of jet fuel

Sustainable CO₂ Production?

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- 1990 total ~ 5 billion metric tons per year
- 2007 total ~ 6 billion metric tons per year
 - 2.6 Petroleum-based
 - 2.2 Coal-based
 - 1.2 Natural Gas-based
- 2007 By end-use:
 - 2.3 Electricity production
 - 2.0 Transportation
 - 1.0 Industrial
 - 0.4 Residential
 - 0.3 Commercial
- 2007 By petroleum end-use:
 - 1.2 Gasoline
 - 0.5 Diesel
 - 0.25 Jet fuel

Sustainable Dollars?

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- Imported Crude and Petroleum Products
 - 2007 ~ \$360 billion per year
 - 2008 ~ \$625 billion per year

- Typical Consumer Gasoline Cost
 - 2007 ~ \$1675 per year
 - 2008 ~ \$2300 per year

- This takes ~ \$125 billion per year away from consumer discretionary spending.

What are Potential Approaches to Sustainability?

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1. Reduced consumption of petroleum-based fuels for transportation systems continuing to use them.
2. Replace or supplement petroleum fuels with biofuels (ethanol, biodiesel, etc.).
3. Replace or supplement petroleum fuels with hydrogen.
4. Utilize electric or plug-in hybrid vehicles which transfer transportation energy to the energy sources for producing electricity.

What About Natural Gas?

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- Plentiful and inexpensive in the short term, **BUT--**
- about 21% is imported (mostly Canada).
- to displace OPEC oil imports (about 1/3 of total) 7×10^{12} SCF of ng \sim almost 1/3 of current consumption.
- only $\sim 150,000$ LDVs (mostly fleet) in the U.S. use cng. \sim Virtually no high-pressure infrastructure.

Natural Gas (Continued)

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- cng is an excellent clean-burning LDV fuel, **BUT—**
- onboard storage-energy density at 250 bar (3600 psi) is about 1/3 that of gasoline. This means very large tanks and/or reduced range.
- there is in the U.S. an excellent low-pressure ng infrastructure but less than 800 cng refueling stations.
- there were 164,292 refueling stations in 2007.* Tens of thousands of cng-capable stations would be needed to support widespread cng vehicles.
- about 100,000,000 LDVs would have to be manufactured or converted to displace OPEC oil.

- *DOE/EERE fact #548.

What About Ethanol?

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- Ethanol is an excellent clean-burning fuel and about 9 billion gallons were produced in 2008, **BUT—**
- that is less than 5% of gasoline energy.
- thus far almost all has been produced from corn.
- corn-based ethanol can adversely affect food prices – corn directly, animal feed and other crops indirectly.
- it requires about $\frac{3}{4}$ of the resulting ethanol energy to produce it.
- it also requires about 2-1/2 gallons of fresh water per gallon of ethanol for processing.

Ethanol (Continued)

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- Cellulosic ethanol is promising, **BUT—**
- there are over a dozen cellulosic projects underway involving many processes and feedstocks with no clear winners.
- [†] there is no obvious feedstock
- -- too much removal of corn stover (over about $\frac{1}{4}$) could have serious consequences.
- --there are already many demands for wood and wood residues.
- --there are few harvests and virtually no current market for switchgrass.

What About Biodiesel?

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- Biodiesel (prepared properly) is an excellent fuel which burns cleaner than petroleum diesel (except for No_x), **BUT—**
- only about 650 million gallons were made in 2008 and less than half of that was used in the U.S. for fuel.
- if the entire soy crop was used to make biodiesel, it would amount to only about 6% of the diesel/fuel oil production.
- part of the cost recovery is the production (a by-product) of glycerin which could reach market saturation.

Problems, Needing Solutions, for all Approaches

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- Reduced petroleum-based fuel consumption:
- Smaller, lighter, lower-performance vehicles without compromising safety or mission capabilities.
- Advanced diesels without significant increases in vehicle or fuel costs, including extensive internal/external, exhaust treatment.
- Greater use of hybrid systems but with better, less expensive power batteries or some other storage such as ultracapacitors.
- Wider use of battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) which will likely require better and less expensive energy batteries to be successful.

Greater Use of Biofuels:

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- Biofuels are going to be very important for our energy future, **BUT—**
- Biofuels from food crops can increase food prices and might cause a net *increase* (e.g., by clearing trees to plant more crops) in CO₂ production.
- Biofuels are not likely to replace a significant fraction of transportation petroleum fuels. For example,
 - -- if the entire U.S. soybean crop was converted to biodiesel, it would correspond to about 6% of the diesel/ fuel oil production.
 - -- if the entire sugarcane production of Brazil was converted to ethanol and imported to the U.S., it would amount to only about 5% of the gasoline fuel energy.

How About Wind and Solar for Renewable Electricity for PHEVs and BEVs?

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- Solar is still non-competitive for commercial electricity production and accounts for only 2/100 of one percent.
- Wind is an excellent resource for power generation, **BUT—**
- in 2008 provided less than 1.3% of electrical energy.
- Grew by 17,500 MWh from 2007 to 2008 (about 4/10 of 1% of total electrical energy demand).
- it would require about 7 MWh for each full-function PHEV or BEV.
- all wind energy in 2008 would support about 7 million vehicles ~ about 3% of LDV fleet.

Wind and Solar (Continued)

- There are many possible sites for Class 4 (7.5 to 8.0 m/s), Class 5 (8.0 to 8.8 m/s), or Class 6 (8.8 to 11.9 m/s) at 50 meters height, **BUT—**
- many are in remote areas with rough terrain and/or limited nearby transmission lines.
- many are in areas where NIMBY would be a problem.
- few are near major population areas.

What about Hydrogen Vehicles and Fuel Cells ?

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- Very limited (marketable) H₂ production capacity. Almost all current H₂ is produced from natural gas or as a by-product and used in mfg processes.
- All H₂ production (except by-products) require a feedstock, and generally more energy is input to make it than is available from the resulting H₂.
- Fuel cell technologies (best way to use H₂ in vehicles) are making great progress, but are not ready for mass production.
- As yet, no practical means of storing needed H₂ (~5 kg.) onboard vehicles. Compressed gas works but tanks are heavy and costly.
- Coal is the most abundant feedstock (besides water) but carbon capture and sequester (CCS) is essential and is far from ready.
- Using electricity from the grid to produce H₂ (about 50% of power is from coal) could dramatically increase grid-based CO₂.

Hydrogen and Fuel Cells (Continued)

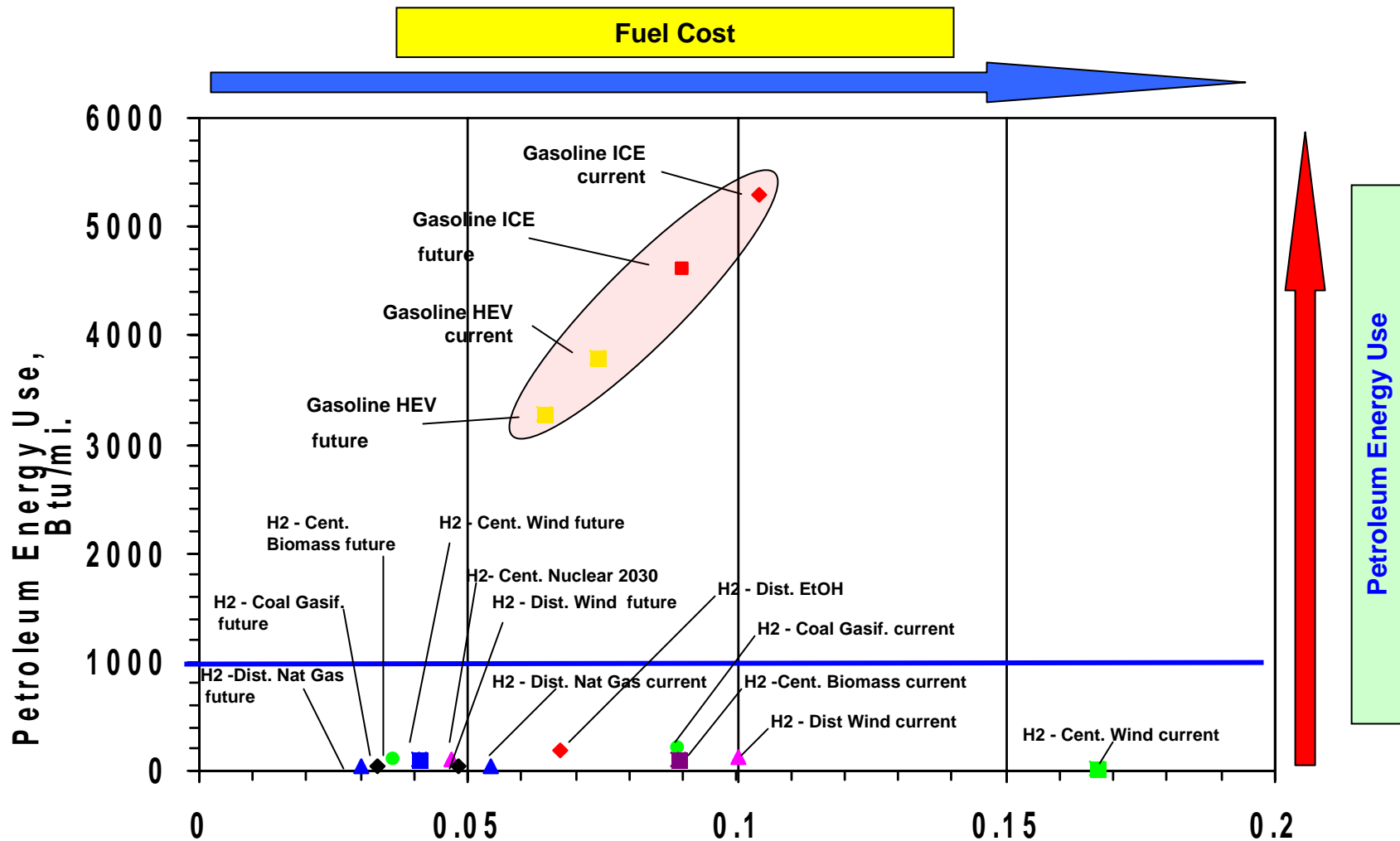
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- Great progress has been made in all areas, **BUT—**
- projected fuel cell costs are more than double DOE targets for 2010 (~ +\$3000 for 80 kW).
- projected hydrogen storage costs are 4x to 6x DOE 2010 targets (~ +\$5000 for 5 kg).
- demonstrated fuel cell durability is less than half 2010 target of 5000 cycles.
- projected hydrogen costs are \$3 to \$5 per gge.
- there is virtually no infrastructure for hydrogen as a vehicle fuel.

Wider Use of Electric or Plug-in Hybrid Vehicles

- Batteries with enough energy for plug-in hybrids, and especially for BEVs, are still expensive, heavy, and have not demonstrated desired cycle life.
- Existing grid excess energy could theoretically support replacing up to about 73 million vehicles (about 1 / 3 of the current light duty vehicle fleet) with off-peak recharging. However, practically, the replacement of probably not more than about 10-20% of current vehicles could be supported.

Petroleum Energy Use vs. Fuel Cost for Technologies with Current Gasoline Prices



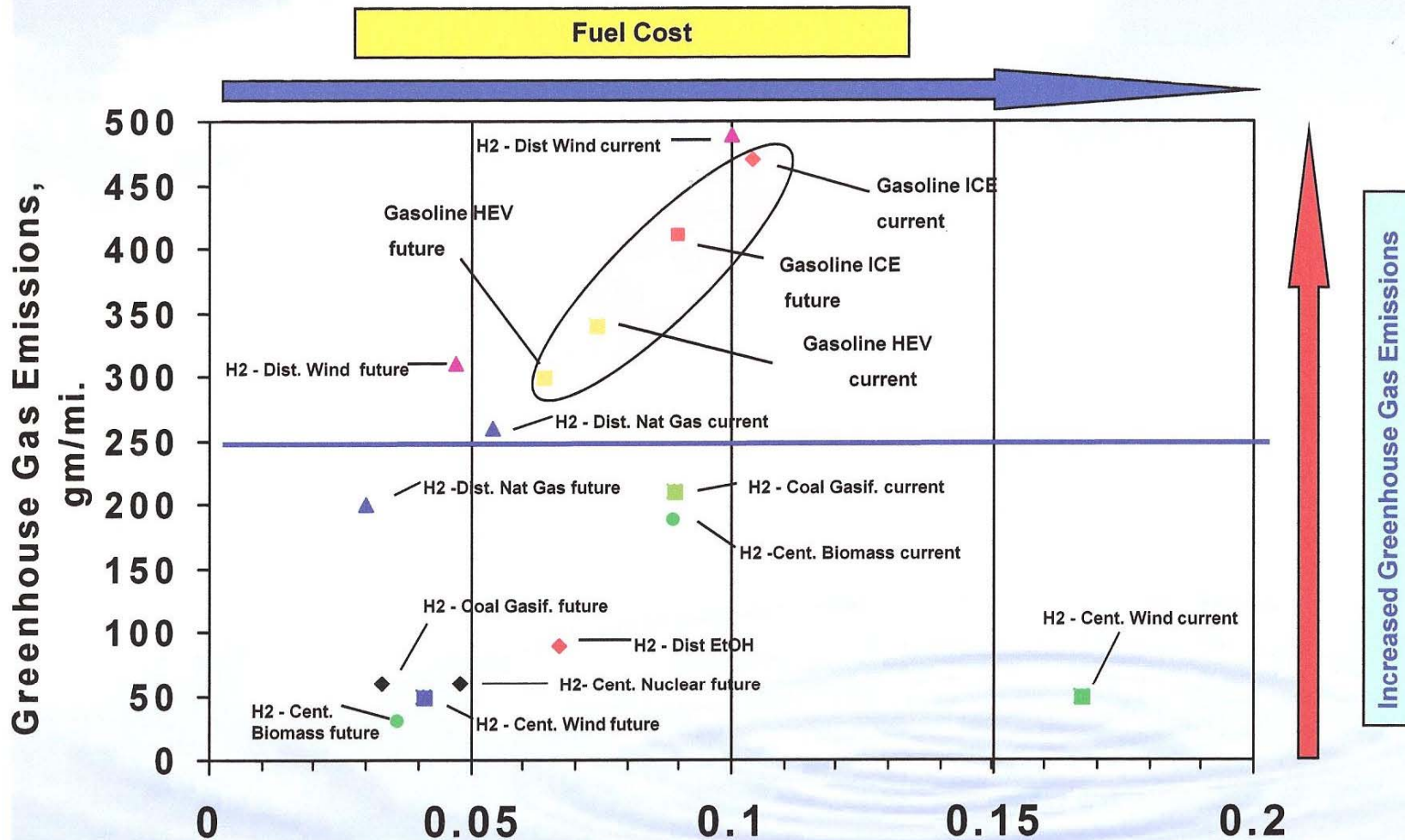
Assumption:

• The energy cost data was based on the EIA 2005 AEO High "A" case including the gasoline price (untaxed). Gasoline price based on \$2.5/gal.

Fuel Cost, \$/mi.

- The hydrogen costs were obtained from the H2A model.
 - The petroleum use was obtained from the GREET model.
- Source: Argonne National Laboratory.

GHGs vs. Fuel Cost for Technologies with Current Gasoline Prices



Assumption:

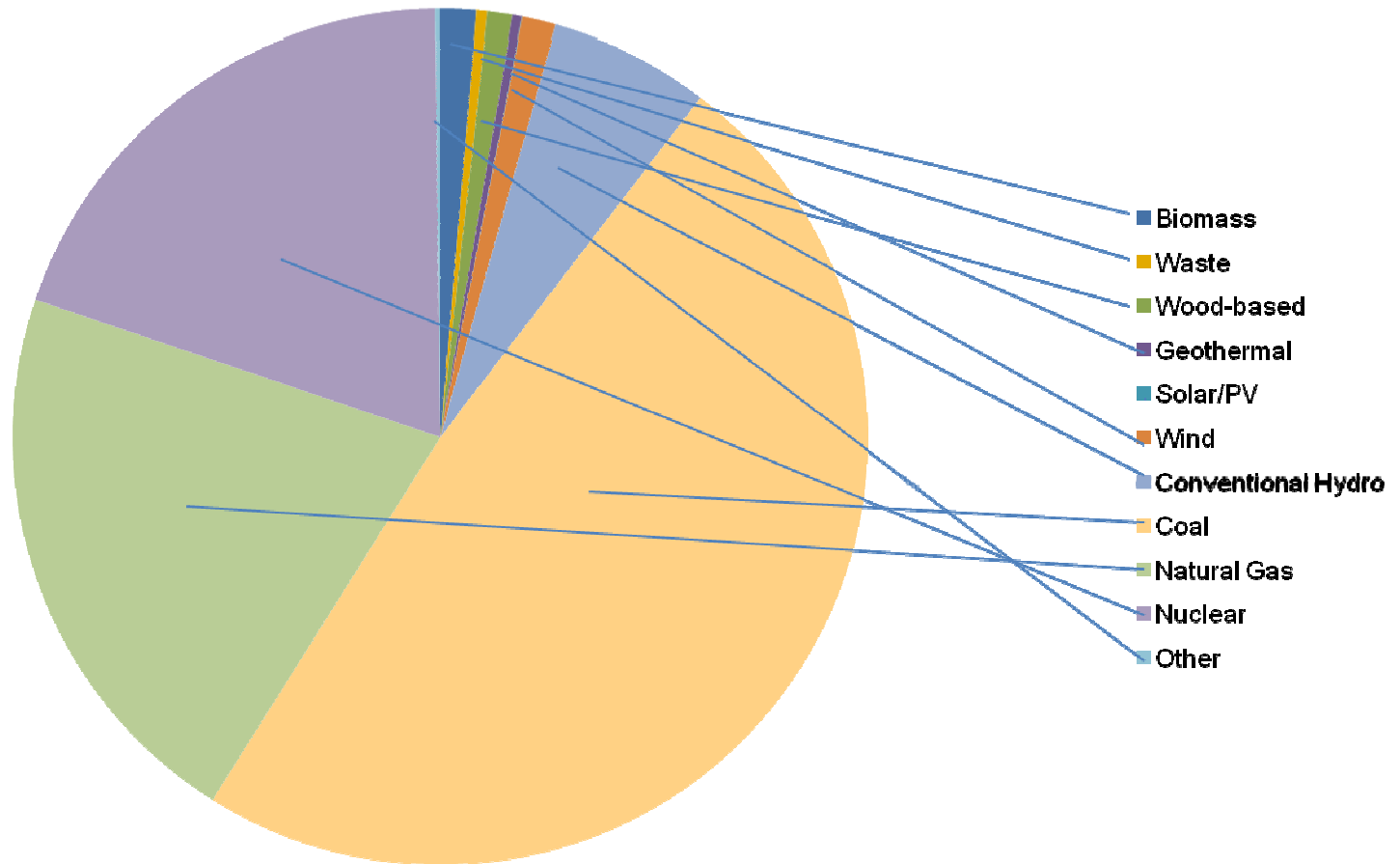
20 The energy cost data was based on the EIA 2005 AEO High "A" case. The gasoline price (untaxed) is \$2.50/gal.

Fuel Cost, \$/mi.

- The hydrogen costs were obtained from the H2A model.
- The greenhouse gas emissions were obtained from the GREET model.

ENERGY SOURCES FOR ELECTRIC POWER GENERATION

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Classes of Wind Power Density

Ref:

DOE/NREL

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Classes of Wind Power Density at Heights of 10 m and 50 m ^(a)

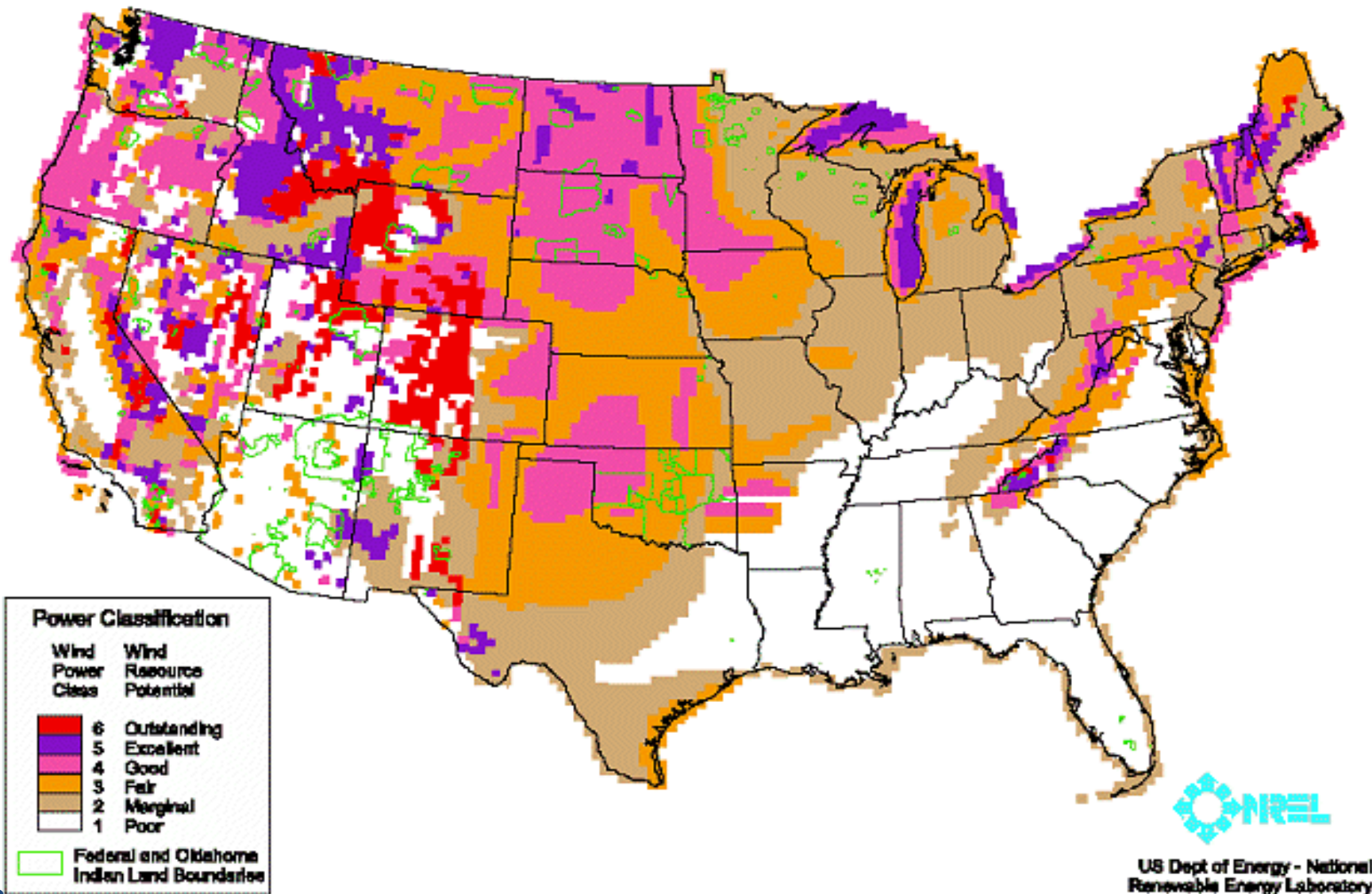
Wind Power Class [*]	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m ²)	Speed ^(b) m/s (mph)	Wind Power Density (W/m ²)	Speed ^(b) m/s (mph)
	0	0	0	
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1,000	9.4 (21.1)	2,000	11.9 (26.6)

^a Vertical extrapolation of wind speed based on the 1/7 power law.

^b Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation.

* Note: Each wind power class should span two power densities. For example, Wind Power Class = 3 represents the Wind Power Density range between 150 W/m² and 200 W/m². The offset cells in the first column attempt to illustrate this concept.

Figure 13. Wind Resource Potential



US Dept of Energy - National Renewable Energy Laboratory

Energy Sources for Electric Power

Ref: Energy

Information Administration for CY 2008

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Energy Source	Thousands of MWh	Percent of Total
Biomass	55,875	1.4
Waste	17,086	0.4
Wood-Based	38,789	0.9
Geothermal	14,859	0.36
Solar/PV	843	0.02
Wind	52,025	1.3
Conventional Hydro	248,085	6.0
<u>Total Renewable</u>	427,562	10.4
Coal	1,994,385	48.5
Natural Gas	876,948	21.3
Nuclear	806,182	19.6
Other	5,182	0.2
<u>Total All Sources</u>	4,110,259	

What is Being Done and Where is Funding?

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- Auto Industry/Alliances have done, and funded, extensive research but now may be in survival mode.
- Federal Government, especially DOE, has funded and/or is now funding many related programs, including:
 - PNGV and FreedomCAR Vehicle Programs
 - Fossil Fuel, Solar, and Wind Energy Programs
 - Hydrogen and Fuel Cell Program
 - Carbon Capture and Sequester (CCS) Program
 - Research at National Laboratories
 - Research at Universities
 - Centers of Excellence
- Some State Governments, such as California, have been providing funds.

DOE Related Budget Summary

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For FY 2004 to 2009

□ Vehicle Technologies	\$1,186,824,000
FreedomCAR	\$738,862,000
21 st Century Truck	\$297,913,000
□ Hydrogen/Fuel Cells	\$1,420,391,000
EERE	\$1,061,305,000
Fossil Energy	\$116,034,000
Nuclear Energy	\$74,963,000
Science	\$171,089,000

Some Possible Long-Term Options

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- Advanced ICEs Fueled with Biofuels Made from Non Food-Competitive Feedstocks.
- Electric/PHEV Vehicles Using Clean Electricity Produced from Renewable (or Perhaps Nuclear) Sources.
- Fuel Cell Vehicles Operating on Hydrogen Made from Renewable Feedstocks or Water and Clean Electricity.
- It Will Probably Take All of the Above !!

BACKUP SLIDES

Typical Wind Site Velocity Durations

Ref:

Fundamentals of Wind Energy, N. P. Cheremisinoff

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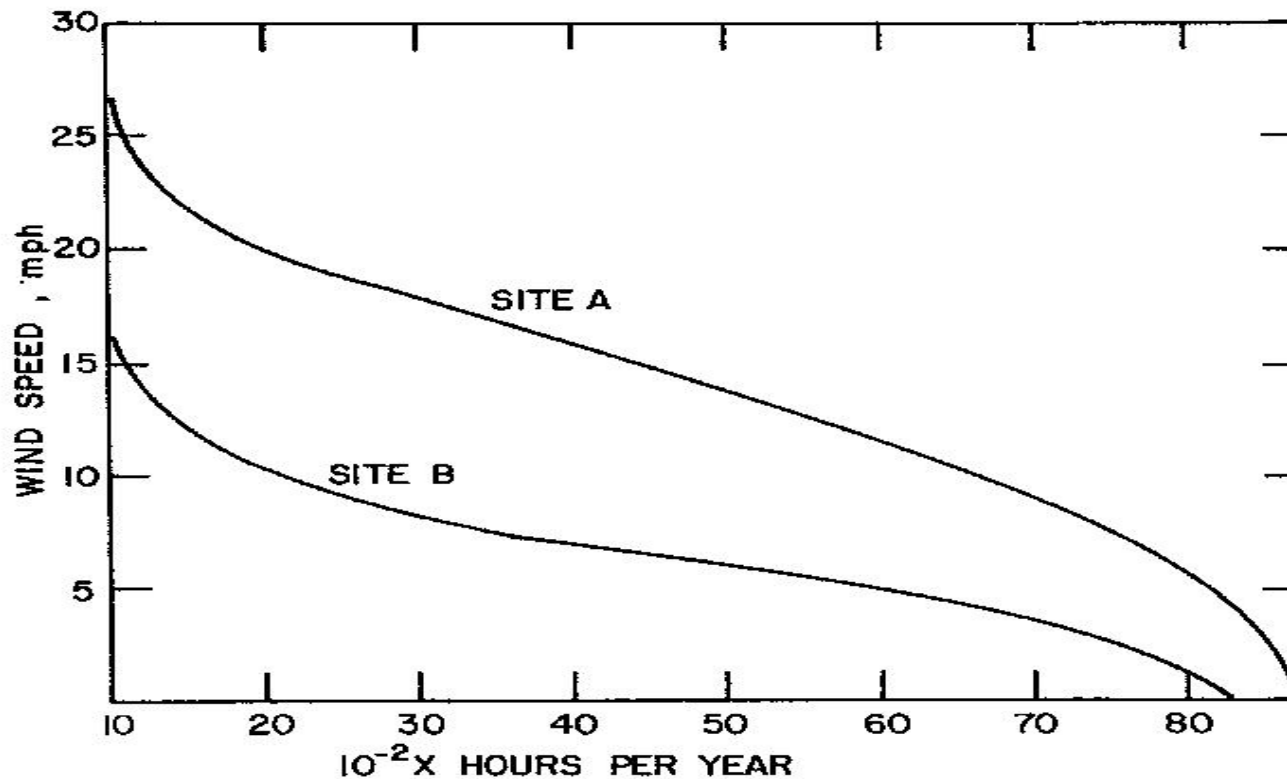


Figure 4-2. Typical annual average velocity duration curves for different geographical sites.

Wind Speed Probability Functions

Ref:

Putnam's Power From The Wind, Second Edition, G.W. Koepl

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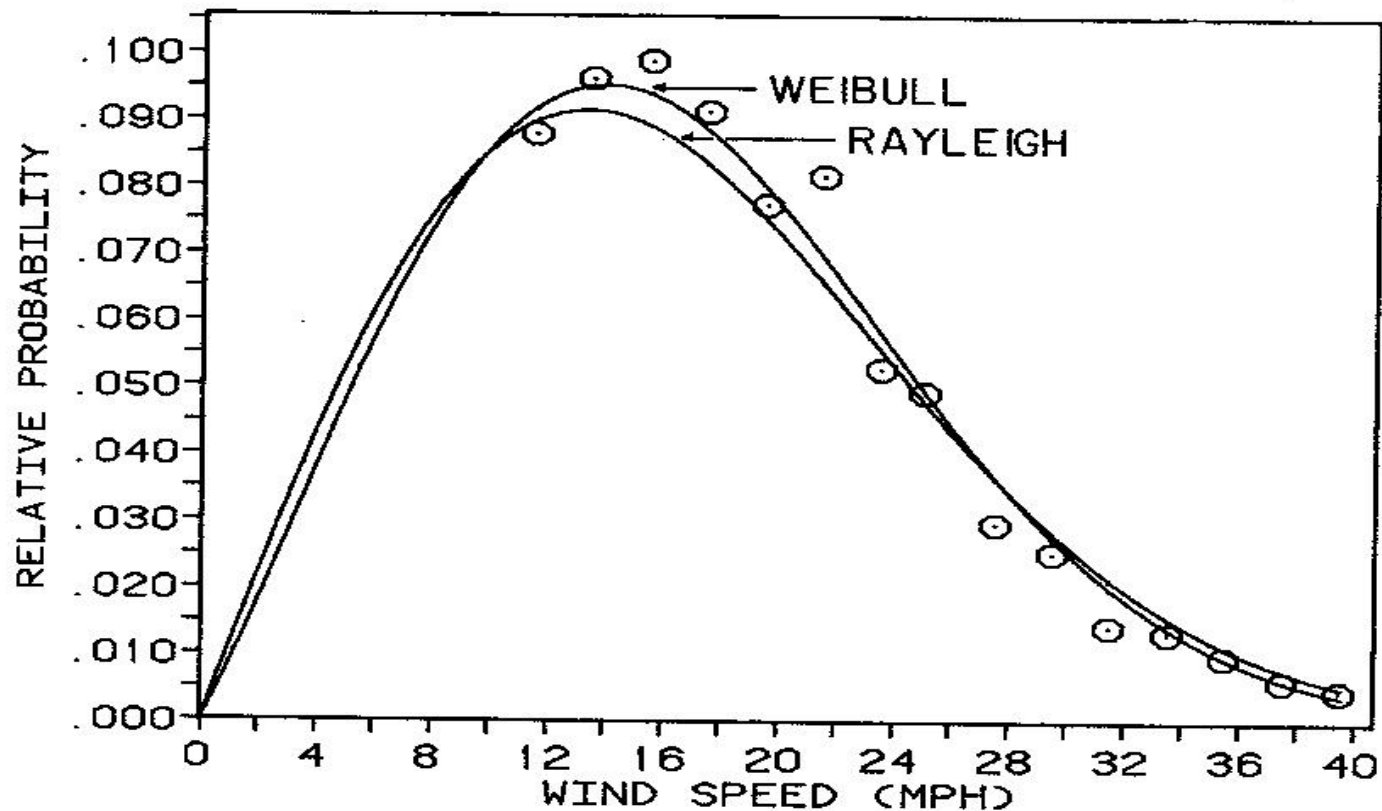


Fig. 2-1. Measured, Rayleigh, and Weibull wind speed probability distributions based on five years of data at the Grandpa's Knob test site. Each distribution corresponds to a mean wind speed of 7.33 m/s (16.39 mph).

DOE Vehicle Technologies Budgets

Activity	Funding (\$ in thousands)					FY2009 Approp.	FY2010 Request
	FY2004 Approp.	FY2005 Approp.	FY2006 Approp.	FY2007 Approp.	FY2008 Approp.		
Hybrid Electric Systems	0	0	0	0	94,135	125,709	164,661
Vehicle Systems	13,875	13,004	13,056	13,006	0	0	0
Hybrid & Elec. Propulsion	43,390	44,066	43,997	59,240	0	0	0
Adv. Combustion Eng R&D	52,736	48,480	42,746	48,346	44,591	40,800	57,600
Materials Technology	38,622	36,042	35,269	29,044	39,636	39,903	54,905
Fuels Technology	15,887	12,419	13,709	18,413	17,836	20,122	25,122
Technology Integration	0	0	0	0	16,350	46,704	30,514
Technology Introduction	4,802	4,944	6,250	15,031	0	0	0
Innovative Concepts	494	494	495	500	0	0	0
Tech/Prog Mgt. Support	2,095	1,877	2,475	0	0	0	0
Biennial Peer Reviews	494	0	990	0	495	0	500
Cong. Dir. Activities	0	0	24,255	0	0	0	0
TOTAL	172,395	161,326	183,242	183,580	213,043	273,238	333,302
Freedom CAR	86,653	85,282	96,549	126,773	153,448	190,157	
21st Century Truck	76,339	70,055	45,267	42,021	34,544	29,687	

Doe Hydrogen/Fuel Cell Budgets

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HYDROGEN AND FUEL CELL BUDGETS: FY 2004 - 2010

	Funding (\$ in thousands)						
	FY 2004 Approp.	FY 2005 Approp.	FY 2006 Approp.	FY 2007 Approp.	FY 2008 Approp.	FY 2009 Approp.	FY 2010 Request
EERE Hydrogen/Fuel Cells	144,881	166,772	153,451	189,511	206,241	200,449	68,213
Fossil Energy (FE)	4,879	16,518	21,036	21,513	24,088	25,000*	16,400*
Nuclear Energy (NE)	6,201	8,682	24,057	18,855	9,668	7,500	0
Science (SC)	0	29,183	32,500	36,388	36,509	36,509	36,509**
DOE TOTAL	155,961	221,155	231,044	266,267	276,506	269,458	121,122
Department of Transportation (DOT)	555	549	1,411	1,420	1,425	1,800	1,800
TOTAL	156,516	221,704	232,455	267,687	277,931	271,258	122,922

* Includes funding for R&D plus program direction. Fossil Energy also plans \$58M for SECA in FY10.

** The Office of Science also plans ~\$14M for Biological and Environmental Research in FY10.

Some Research Needs

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□ For Vehicles:

- Reduced materials costs to allow greater use of lighter/stronger materials such as carbon fiber, magnesium, and aluminum
- More efficient components such as A/C, PS, AT, tires, etc.
- Better power/energy management

□ For Fuels:

- New liquid hydrocarbon fuels, possibly from coal (with CCS)
- Affordable and plentiful non-food-based biofuels
- More efficient hydrogen production from acceptable feedstocks
- A national hydrogen infrastructure
- Better options for on-board hydrogen storage

□ For Power Systems:

- Fuel Cells ready for mass production
- Advanced batteries ready for HEVs, BEVs and PHEVs
- Lower cost, higher performance power electronics
- Alternatives to rare-earth-based, permanent magnet drive motors