Understanding the Energy Challenge:
It Takes More Than Science

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Saturday Physics for Everyone
University of Illinois Department of Physics
December 01, 2012
My Introduction to Energy Issues
The Energy Challenge Outline

• What is the energy challenge?
• Supply and demand in the US and the world
• Some points of reference
• Some energy issue examples
• Closing comments and summary
What is the energy challenge?
The Energy Challenge

- Energy is crucial to modern society
- Fossil fuels linked to climate change
- Insecurity of current oil supply
- Increased demand from developing economies
- Energy needs of undeveloped world
- Increased world population
Energy is crucial to modern society
Power Consumption per Capita vs GDP per Capita

From D. MacKay, Sustainable Energy without the Hot Air, Fig 18.4.
Highly Recommended

“…the aim of this book is to help you figure out the numbers and do the arithmetic so that you can evaluate policies…”

http://www.withouthotair.com/
Free pdf download - $31.55 from Amazon
Fossil fuels linked to climate change
Land Surface Temperature and CO$_2$ Concentration Since 1850
Comparison of Models:
Global Mean Surface Temperature Anomalies

- Anthropogenic and Natural Forcings
  - Observations
  - Models

- Events:
  - Santa Maria
  - Agung
  - El Chichon

Year:
- 1900
- 1920
- 1940
- 1960
- 1980
- 2000

Temperature anomaly (°C)
Comparison of Models:

Global Mean Surface Temperature Anomalies

Graph showing temperature anomaly (°C) over years with labeled events: Santa Maria, Agung, El Chichon, and Pinatubo.
USDA Plant Hardiness Zone Map 2012

1990 zone 5 – zone 6 boundary in southern Illinois
Worldwide GHG Emissions and Energy Use

From D. MacKay, Sustainable Energy without the Hot Air, Fig I.12.
Insecurity of current oil supply
Distribution of World Oil Reserves

From Prof. S. Marshak, January, 2011 EaSE presentation
“But with only 2 percent of the world’s oil reserves, oil isn’t enough. This country needs an all-out, all-of-the-above strategy that develops every available source of American energy. A strategy that’s cleaner, cheaper, and full of new jobs.”

President Obama, State of the Union address, January 25, 2012.
Crude Oil Prices 1861 - 2009

BP Statistical Review of World Energy (June, 2010)
Increased demand from developing economies
World Energy Consumption, 1990-2035 (quadrillion Btu or quads)

International Energy Agency, 2011 Outlook, Figure 1
Energy Consumption in the United States, China, and India, 1990-2035 (quads)
Population growth

from UN Department of Economic and Social Affairs, World Population to 2300 (2004)
Energy supply and demand
Many Measures Are Commonly Used

- distinguish energy from power
- very large numbers
- many use the “quad” $10^{15}$ Btu
- oil barrels or bbl (42 US gal)
- coal tons (2,000 lbs) or tonnes (1,000 kg)
- natural gas $10^{12}$ ft$^3$ or therms
- electricity kWh
U.S. Energy Flow, 2010
(Quadrillion Btu)

Total
98.0 quads =
3270 GW y =
254 kWh / person / d

Energy Information Agency, Annual Energy Review 2010, Fig 1.0 (October, 2011)
U.S. Primary Energy Consumption by Source and Sector, 2010 (Quadrillion Btu)

Source

- Petroleum: 36.0 (37%)
- Natural Gas: 24.6 (25%)
- Coal: 20.8 (21%)
- Renewable Energy: 8.0 (8%)
- Nuclear Electric Power: 8.4 (9%)

Total = 98.0

Percent of Sources

- Petroleum: 71
- Natural Gas: 33
- Coal: 20
- Renewable Energy: 29
- Nuclear Electric Power: 100

Percent of Sectors

- Transportation: 94
- Industrial: 41
- Residential & Commercial: 76
- Electric Power: 100

Energy Information Agency, Annual Energy Review 2010, Fig 2.0 (October, 2011)

Energy Information Agency, Annual Energy Review 2010, Fig 10.0 (October, 2011)
USA Electricity Generation (2010)

By Source Category, 2010

- Fossil Fuels: 2.9 trillion kilowatt-hours
- Nuclear Electric Power: 0.8 trillion kilowatt-hours
- Renewable Energy: 0.4 trillion kilowatt-hours

By Source, 2010

- Coal: 45%
- Natural Gas: 24%
- Nuclear Electric Power: 20%
- Hydroelectric Power: 6%
- Other: 6%

Energy Information Agency, Annual Energy Review 2010, Fig. 8.2a (October, 2010)
Ameren Illinois

Sources of electricity supplied for the 12 months ending September 30, 2011 for Ameren Illinois

- Hydro power 1%
- Natural gas-fired power 5%
- Nuclear power 14%
- Wind power 4%
- Other resources 1%
- Coal-fired power 75%

AmerenIP, Facts On Energy
Some points of reference
Reference point 1

Hubbert Model

“Peak Oil”
NUCLEAR ENERGY AND THE FOSSIL FUELS

BY

M. KING HUBBERT

CHIEF CONSULTANT (GENERAL GEOLOGY)

PUBLICATION NO. 95

SHELL DEVELOPMENT COMPANY

EXPLORATION AND PRODUCTION RESEARCH DIVISION

HOUSTON, TEXAS

JUNE 1956

To be published in
Drilling and Production Practice (1956)
American Petroleum Institute
Hubbert Data 1956

Figure 2 - World production of crude oil. Figure 5 - United States production of crude oil.

NB: the rate of oil extraction in the world and in the U.S. is increasing.
Hubbert Data 1956

GROWTH RATE: 7.9% / yr
DOUBLING PERIOD: 8.7 YEARS

Figure 10 - Crude-oil production in the United States plotted on semilogarithmic scale.
Hubbert Prediction 1956

Figure 21 - Ultimate United States crude-oil production based on assumed initial reserves of 150 and 200 billion barrels.

Peak oil prediction between 1965 -1970
Oil Production Did Peak in 1973

U. S. Annual Oil Production

Data from Energy Information Agency Annual Energy Outlook August 2010
Oil Production through September, 2012

U.S. Field Production of Crude Oil

Source: U.S. Energy Information Administration

Graph from Energy Information Agency
http://www.eia.gov/dnav/pet/hist/leafhandler.ashx?n=pet&s=mcrfpus1&f=m
Reserves, Resources and Occurrences

Fossil Fuels in Human History

![Diagram showing fossil fuel use over time with years BCE and CE marked.]
Reference point 2

Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies
S. Pacala and R. Socolow

SCIENCE 305(2004)968
AUGUST 13, 2004
Present Worldwide Emissions, Business as Usual, and Flat Emission Target

- **2000 Gt C in 2000**
- **mix of fossil fuels over sectors**
- **2000 Gt C in 2000**
- **business as usual 14 Gt C in 2054**
- **flat emissions 7 Gt C in 2054**

![Bar charts showing emission projections for 2000 and 2054]
Two Emissions Projections
Business as Usual and 500 ppm CO$_2$ Peak

What is a Wedge?

Wedge: a strategy to avoid 25 GtC of emissions from BAU over the next 50 years.
Is There a Silver Bullet?
Some Possible Stabilization Wedges
Requirements by 2055

• Efficient use of fuel, e.g. $2 \times 10^9$ cars @ 60 mpg
• Efficient use of electricity (25% reduction overall)
• Coal plants at 60% rather than 40% efficiency
• Replace 1400 GW of coal with natural gas ($\times 4$)
• Add CCS to 800 GW of coal plants (3,500 Sleipners)
• Wind from $10^6$ 2 MW wind turbines ($\times 50$)
• PV from 10% efficient cells on $2 \times 10^4$ km$^2$ ($\times 700$)
• Replace 700 GW coal with nuclear ($\times 3$)
• Clean ethanol from $250 \times 10^4$ km$^2$ ($\times 100$ Brazil)

“At the international climate meetings in Copenhagen next month, Mr. Obama will tell the delegates that the United States intends to reduce its greenhouse gas emissions “in the range of” 17 percent below 2005 levels by 2020 and 83 percent by 2050, officials said.”
CO₂ Emissions from Energy Consumption

NB: CO₂ emissions plotted. U.S. pledge is 1.2 P&S wedge.
83% Reduction Goal Requires Zero(!!!) Electricity, Transportation and Heating Emissions

“Now, clean energy breakthroughs will only translate into clean energy jobs if businesses know there will be a market for what they're selling. So tonight, I challenge you to join me in setting a new goal: **by 2035, 80% of America's electricity will come from clean energy sources.** Some folks want wind and solar. Others want nuclear, clean coal, and natural gas. To meet this goal, we will need them all - and I urge Democrats and Republicans to work together to make it happen.“

NB: White House briefing notes state that “currently, 40% of our electricity comes from clean energy sources.”

EIA AER 2010 Fig. 8.2a and Table 8.2a show 30.7% from nuclear, hydro, and renewables.
• “…open more than 75% of our potential offshore oil and gas resources…”
• “American oil production is the highest that it’s been in eight years.”
• “…we relied less on foreign oil than in any of the past 16 years.”
• “We have a supply of natural gas that can last America nearly 100 years…”
• “..it was public research dollars, over the course of 30 years, that helped develop the technologies to extract all this natural gas out of shale rock…”
President Barack Obama
The State of the Union Address
January 29, 2013

• Mr. Speaker, Mr. Vice President, members of Congress, distinguished guests, and fellow Americans…

• …

• …

• …

• …

• …

• Thank you…
Reference point 3

The Stern Review on
The Economics of Climate Change
HM Treasury
October, 2006
The IPCC Models the Earth-Atmosphere Energy Flux Balance

**Diagram Description:**
- **Reflecting Solar Radiation:** 107 Wm⁻² (Reflected by Clouds, Aerosol and Atmospheric Gases 77, Reflected by Surface 30)
- **Incoming Solar Radiation:** 342 Wm⁻²
- **Emitting by Atmosphere:** 165 Wm⁻²
- **Outgoing Longwave Radiation:** 235 Wm⁻²

**Energy Flow:**
- **Absorbed by Surface:** 168, 30
- **Evapotranspiration:** 78
- **Thermals:** 24
- **Latent Heat:** 24
- **Greenhouse Gases:** 324
- **Back Radiation:** 324

**FAQ 1.1, Figure 1.** Estimate of the Earth’s annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth’s surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).
The Stern Review Models the Entire World Economy for the Next 100 to 200 Years!

- Business-as-usual decreases world GDP by 5% to 20% over next two centuries
- Costs for stabilization at 500-550 ppm CO$_2$e are centered on 1% of GDP
- Benefits of strong, early action on climate change outweigh the costs
- Policy must include a tax carbon
“The choice of an appropriate discount rate is particularly important for climate-change policies because most of the impacts are far in the future. The approach in the DICE model is to use the estimated market return on capital as the discount rate. The estimated discount rate in the model averages 4 percent per year over the next century. This means that $1,000 worth of climate damages in a century is valued at $20 today.”
CLIMATE SUMMIT

WHAT IF IT’S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?

- Energy Independence
- Preserve Rainforests
- Sustainability
- Green Jobs
- Livable Cities
- Renewables
- Clean Water, Air
- Healthy Children
- Etc. Etc.
Energy Issue Examples

Energy Economics
Estimated Levelized Total System Cost of New Generation Resources, 2016

Source Energy Information Agency  Annual Energy Outlook 2011
Estimated Capital Cost of New Generation Resources, 2016

Source: Energy Information Agency Annual Energy Outlook 2011
Energy Issue Examples

Ethanol
Corn Harvested Acres 2007
Corn Ethanol Issues

- Positive (?) energy benefit
- Reduction (?) of direct greenhouse gas emissions
- Increase of greenhouse gas emissions due to indirect land use change
- Food versus fuel
Federal Renewable Fuel Standards Mandate Ethanol Usage

RFS 1: Energy Policy Act of 2005

US gasoline consumption
~130 billion gallons / year
ANL GREET
Greenhouse Gases, Regulated Emissions and Energy Use in Transportation
Gasoline and Ethanol Life Cycle Analysis Comparison

Producing Ethanol (EtOH) from Corn:
- 0.78 million Btu
- Fossil Energy Input
- Solar Energy
- Corn Farming
- Fertilizer Production
- Natural Gas
  - Production
- Diesel Fuel
  - Transportation
- EtOH Production
- Coal
  - Natural Gas
  - Electricity
- Animal Feeds
  - 1 million Btu of EtOH at Refueling Stations

Producing Gasoline from Petroleum:
- 1.23 million Btu
- Fossil Energy Input
- Petroleum Recovery
- Diesel Fuel
  - Natural Gas
- Electricity
- Petroleum Transportation
- Residual Oil
  - Natural Gas
  - Electricity
- Petroleum Refining
- Refinery Gas
  - Natural Gas
  - Coal
  - Electricity
- 1 million Btu of Gasoline at Refueling Stations
- Other Petroleum Products
Rough Energy Accounting

- **Fossil energy input**
  - 1.0 MMBTU gasoline requires 0.2 MMBTU
  - 1.0 MMBTU ethanol requires 0.8 MMBTU

- **Total energy input**
  - 1.0 MMBTU gasoline requires 0.2 MMBTU
    - 0.2 = 0.2 (fossil input)
  - 1.0 MMBTU ethanol requires 1.2 MMBTU
    - 1.2 = 0.8 (fossil input) + 0.4 (sunlight)

MMBTU is $10^6$ BTU
Corn Solar Conversion Efficiency

Champaign County corn production = 150 \textit{bu} / a / y

corn to ethanol conversion = 2.77 gal / bu

ethanol energy content = 84,300 \textit{Btu} / gal

gasoline energy content = 125,000 \textit{Btu} / gal

corn solar energy conversion = \fbox{0.31 \textit{W} / \textit{m}^2}

Champaign County average insolation = 195 \textit{W} / \textit{m}^2

UI proposed 20 acre solar farm = 10.8 \textit{W} / \textit{m}^2
Ethanol Is a Quantitative Failure
Biofuels Need a Breakthrough

U.S. gasoline consumption
19.8 Mbbl per day of oil equivalent

gasoline consumption avoided
through ethanol production
0.8 Mbbl per day oil equivalent
Alternative Fuel Stock
Miscanthus at University of Illinois
Experimental Plot

From D. MacKay Sustainable Energy without the Hot Air, Figure 6.10
Chemtex Crescentino, IT
Cellulosic Ethanol Plant

Capital cost 100M$
Design nameplate capacity 15 Mgal/y @ $1.30/gal
Construction completed late 2012
US project planned for Clinton, NC
Energy Issue Examples

Wind
USA on-shore wind resource map

Annual Average Wind Speed at 80 m

(260 ft)

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>m/s</th>
<th>mph</th>
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<tbody>
<tr>
<td>&gt; 10.0</td>
<td>9.0</td>
<td>20.2</td>
</tr>
<tr>
<td>10.0 - 9.5</td>
<td>7.0</td>
<td>15.7</td>
</tr>
<tr>
<td>9.5 - 9.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>9.0 - 8.5</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>8.5 - 8.0</td>
<td>4.0</td>
<td>9.0</td>
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<tr>
<td>8.0 - 7.5</td>
<td>4.0</td>
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<td>4.0</td>
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<td>7.0 - 6.5</td>
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<td>4.0</td>
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<td>5.5 - 5.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>5.0 - 4.5</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>4.5 - 4.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>&lt; 4.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>
USA off-shore wind resource map

Figure 2. U.S. offshore wind speed estimates at 90-m height

From DOE National Offshore Wind Strategy February 2011
U.S. Source of Electric Generation 1950-2010

Electricity Net Generation

from DOE EIA Annual Energy Outlook 2011, Table 8.2a
U.S. Wind Power in 2010

Figure 4. Location of Wind Power Development in the United States
State RPS Policies and Non-Binding Renewable Energy Goals

Existing High Voltage Transmission
Clean Line Energy projects four 3.5 GW, 765 kV DC transmission lines
Hourly Wind Power Time Series of a 1.5 MW Wind Turbine in North Dakota

Individual turbine highly intermittent and variable. Some smoothing for entire wind farm. More smoothing for entire region.
Example of Solar Insolation Variability and Wide Area Aggregation

NB: No solar power before 6 AM and after 7 PM

DOE Atmospheric Radiation Measurement at Southern Great Plains site
Wind Power Interconnection Regions Study

Red dots indicate existing wind farms
2009 Wind Power Duration Curve
(one hour resolution)

for aggregated regions
13% of capacity available 90% of the time
Energy Issue Examples

Energy Storage
Motivation for Energy Storage

- Energy demand varies on many time scales – daily, weekly, seasonally
- Energy supply, especially solar and wind, also varies on various time scales
- Energy storage decouples supply and demand
- Energy storage provides peak capacity without additional equipment
Pacific Gas and Electric Company
Helms Pumped Hydro Storage Plant

From Manho Yeung, Pacific Gas and Electric Company
Proposed Norton, OH
Compressed Air Energy S Facility

Required Storage Volume to Generate 300 MW (12 Hours Pumping, 12 Hours Generation)

0.28 million m³ of Compressed Air

7 million m³ of Water

From Dr Chris Bullough ALSTOM Power Technology Centre
From APS Energy Future Think Efficiency (September, 2008)
Energy Issue Examples

Efficiency
Efficiency Successes in Appliances

Figure 23
Impact of standards on efficiency of 3 household appliances

- Gas furnaces
- Central air conditioners
- Refrigerators

Effective dates of national standards
Effective dates of state standards

Index (1972 = 100)

Efficiency in Lighting

100 W Light Bulb Equivalent

- Incandescent – 100 W
- Halogen – 50 W
- Compact fluorescent – 26 W
- LED – 13 W

Suppose all 112 million U.S. households replaced one 100 W incandescent light bulb with an LED light bulb. At four hours per day usage, a savings of 14 TWh per year would be obtained, compared to total electricity usage of 4,100 TWh per year. One light bulb change is 0.3% effect.
Efficiency in Windows

- Solar Radiation
- Convection and Conduction
- Thermal Radiation
- Infiltration
Ideal Window from Energy Efficiency Point of View

From Stephen Selkowitz APS Conference, Berkeley, March 2008
Efficiency in Insulation

Figure 1. Places in the home where insulation should be applied
### Table 11.1. R-Values of building materials

<table>
<thead>
<tr>
<th>Material</th>
<th>$R_{SI}$</th>
<th>$R_{Eng}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood siding shingles</td>
<td>0.15</td>
<td>0.9</td>
</tr>
<tr>
<td>Stucco, 1 cm</td>
<td>0.014</td>
<td>0.1</td>
</tr>
<tr>
<td>Plywood, 1 cm</td>
<td>0.09</td>
<td>0.5</td>
</tr>
<tr>
<td>Softwood, 1 cm</td>
<td>0.09</td>
<td>0.5</td>
</tr>
<tr>
<td>Concrete block, 30 cm (12″)</td>
<td>0.2</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Brick/cm</strong></td>
<td><strong>0.014</strong></td>
<td><strong>0.1</strong></td>
</tr>
<tr>
<td>Gypsumboard, 1 cm</td>
<td>0.06</td>
<td>0.3</td>
</tr>
<tr>
<td>Hardwood floor, 1 cm</td>
<td>0.06</td>
<td>0.3</td>
</tr>
<tr>
<td>Carpet</td>
<td>0.11</td>
<td>0.6</td>
</tr>
<tr>
<td>Asphalt roof shingles</td>
<td>0.08</td>
<td>0.5</td>
</tr>
<tr>
<td>Wood roof shingles</td>
<td>0.17</td>
<td>1.0</td>
</tr>
<tr>
<td>Insulation, 10 cm (4″)</td>
<td>2.3</td>
<td>13</td>
</tr>
<tr>
<td>Insulation, 15 cm (6″)</td>
<td>3.3</td>
<td>19</td>
</tr>
<tr>
<td>Polystyrene, 1 cm</td>
<td>0.35</td>
<td>2.0</td>
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<tr>
<td>Polyurethane, 1 cm</td>
<td>0.44</td>
<td>2.5</td>
</tr>
<tr>
<td>Gas-filled panels, 2.5 cm (1″)</td>
<td>2.5</td>
<td>14</td>
</tr>
<tr>
<td>Gas-filled panels, 10 cm (4″)</td>
<td>5–10</td>
<td>28–56</td>
</tr>
<tr>
<td>Straw bale, 40 cm (16″)</td>
<td>6–9</td>
<td>33–50</td>
</tr>
<tr>
<td>Glass, 3 mm (0.12″)</td>
<td>0.005</td>
<td>0.03</td>
</tr>
<tr>
<td>Convection</td>
<td>0.04–0.02</td>
<td>0.2–1</td>
</tr>
<tr>
<td>Radiation</td>
<td>0.2ε</td>
<td>1ε</td>
</tr>
</tbody>
</table>

- **0.5 for 1 cm**
- **0.1 for 1 cm**
- **1.0 for 1 cm**
Energy Issue Examples

Transportation
U.S. Transportation Sector

[Figure 4]
Energy and transportation in the U.S.
U.S. transportation energy consumption by mode in 2005.

- Light vehicles: 63%
- Air: 9%
- Water: 5%
- Pipeline: 3%
- Rail: 2%
- Heavy duty road: 17%
- Motorcycles: 1%

Source: Davis and Diegel, 2006

[Figure 5]
U.S. miles per gallon

- Cars
- Both
- Light trucks

Sources: U.S. Environmental Protection Agency, National Highway Traffic Safety Administration

From APS Energy Future Think Efficiency (September, 2008)
Where Does The Energy Go?

Largest losses are in the engine.

From APS Energy Future Think Efficiency (September, 2008)
Tata Motors/Motor Development International
Compressed Air Car (CAC)
Energy Storage for CAC

- 86 gal tank (327 l) at 4500 psi (310 bar)
- fiberglass or carbon fiber 80 lbs (~35 kg)
- compressed air 0.18 MJ/l (0.37 MJ/kg)
- lead acid 0.14 MJ/l (0.090 MJ/kg)
- lithium ion 0.90 MJ/l (1.26 MJ/kg)
- gasoline 35 MJ/l (48 MJ/kg)
Nissan Leaf
Electric Vehicle (EV)
Nissan Leaf Monroney Sticker
Compare EV to CV

\[
MPGe_{\text{fuel-to-wheel}} = \frac{1}{[Wh/mi]} \times U_{\text{gasoline}} \times \varepsilon_{\text{electricity}}
\]

\[
= \frac{100\, mi}{34\, kWh} \times \frac{33.7\, kWh}{gal} \times 0.303
\]

\[
= 99\, mpg \times 0.303 = 30\, mpg \quad (\text{EV})
\]

\[
MPGe_{\text{fuel-to-wheel}} = MPGe_{\text{tank-to-wheel}} \times \varepsilon_{\text{gasoline}}
\]

\[
= 30\, mpg \times 0.830 = 25\, mpg \quad (\text{CV})
\]
Closing Comments
Fossil fuels will be available for many decades at higher economic and environmental cost.
An impossible task is only very, very difficult.

Wedge: a strategy to avoid 25 GtC of emissions from BAU over the next 50 years.
Ethanol Is a Quantitative Failure
Biofuels Need a Breakthrough

U.S. gasoline consumption
19.8 Mbbl per day of oil equivalent

gasoline consumption avoided
through ethanol production
0.8 Mbbl per day oil equivalent
Conservation and Efficiency

The greenest energy is the energy that you do not use.
In *Sustainable Energy - without the hot air*, David MacKay admonishes us that we stop saying “no” to everything, and we must start say “yes” to something.
I would admonish us that we have to start saying “yes” to enough.
Summary

• U.S. energy sources are dominantly from fossil fuels. These sources will / must / can change.
• U.S. energy consumption is inefficient. This pattern will / must / can change.
• Physics is valuable in the analysis of both energy generation and usage, but
• Economics, regulation, and policy must be understood or, at least, acknowledged.