Sustainable Use of Fossil Energy*

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Abstract

Finding common measures to compare and contrast multiple environmental impacts of fossil and renewable energy is challenging. A quantitative comparison of emissions by resource may be a good place to start. Power plants burning lignite coals emit by far the largest amount of CO₂ for every unit of electricity produced (about 1,200 tons of CO₂ per GWhr of electricity). Bituminous coals emits about 2/3’s as much, natural gas about 1/3. Renewable energy resources range from a high of 100 tons per GWhr of electricity down to 10 tons for some wind systems. Therefore, if the goal is simply to reduce emissions - at all costs - the choice is easy: with only renewable (and nuclear) energy systems, we may reduce CO₂ emissions by more than two orders of magnitude for the same output of power.

Another measure is power density: how much land (or sea) area does it take to produce electricity from different resources? The densest power resource of all, oil shale, may yield 100 GW per km² (while the resource lasts ~ decades), oil fields may yield 10 GW per km², and a bituminous coal field may yield 1 GW per km². Solar and geothermal power plants provide about 100 MW per km², wind perhaps 10, and biomass less than 1. Therefore, if one looks at optimizing the future global power supply from a land use perspective, the choice is very different: by using the most dense hydrocarbon accumulations on earth, the acreage used for power production would be five orders of magnitude less than the ‘worst’ renewable energy systems, for the same power output.

These numbers imply that climate stabilization without costly competition for arable land requires creative strategies for CO₂ emissions reductions from fossil fuels. One such strategy is fuel shift from coal to natural gas, with its attendant lower emissions during combustion and much lower energy cost during production and shipping. Another is to decarbonize the planet’s huge volume of unconventional fossil energy resources (oil shale, shale oil, heavy oils, tight gas, shale gas, CBM, hydrates). Research is already underway on microbial, genetic engineering and catalytic approaches to break the long...
molecules of these unconventional hydrocarbons and produce only the lightest components: light oils and natural gas, and dramatically reduce the carbon footprint relative to current practices. There will still be a need for CCS technologies, to capture and store the CO₂ from what might be a fossil energy industry run mostly on gas.
Sustainable Use of Fossil Energy

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The Changing Focus

10 years ago, the discussion moved on from “is there global warming?” to “what do we do about it?”

Proposed solutions: rapid acceleration of renewable energy and “next generation” (Gen 3, 4) nuclear power

Now: what is the role of natural gas along the path to sustainable energy?
The Issues with Natural Gas

- Are supplies sufficient to replace coal and play a role as a transportation fuel?
- Are we (the U.S.) positioning ourselves to really use it?
- Is it really the fossil energy with the lowest carbon footprint?
- Can we really quantify the relative "environmental impacts" of different energy resources?
Current U.S. usage: 23 Tcf/yr

Total Potential Resources (mean values, Tcf)

- Coalbed gas resources
- Traditional gas resources

**total 1836 tcf**

- Shale gas (615.9 Tcf)
- Tight gas (~250 Tcf)

Data source: Potential Gas Committee (2009)
Recent Focus: Hydrate Gas in Sands

- GH-saturated fractured clays – Bay of Bengal
- Massive GH seafloor mound – Gulf of Mexico
- GH-saturated turbidite – Nankai trough
- GH-Saturated conglomerate – NW Canada (Mallik)

Recent Focus:
Hydrate Gas in Sands

2008 DOI Assessments

- 85 Tcf Technically- Recoverable in Alaska
- 6,700 Tcf Gas-in-Place in Sands in Gulf of Mexico alone

Tim Collett
USGS
In-Situ CO$_2$ Sequestration with CH$_4$ Exchange in Gas Hydrate

(CSM, U Bergen, USGS)
Shale Gas Production is Growing Fast

Source: Annual Energy Outlook 2011, EIA.
And is Expected to Continue Growing…
... Also Internationally

Shale gas production in the United States has grown from 0.39 TCF in 2000 to 4.87 TCF in 2010 (14%)

Shale Gas Expected to account for 46 percent of U.S. natural gas production in 2035

Total shale resource base estimate of 6,622 TCF for the United States and the other 32 countries assessed.

Adding the identified shale gas resources to other gas resources increases total world technically recoverable gas resources by over 40 percent to 22,600 TCF (includes Europe, Asia, South and North America, Africa and Australia)

EIA April 6, 2011
Notes by Presenter: Following a wave of electric industry deregulation in the latter part of the 1990s and early 2000s, there was a wave of investment in low-cost gas turbine power systems. This was further supported by low natural gas prices. There was a clear over-investment in gas turbine capacity.
Natural gas use for power has grown steadily for 15 years. Trend will continue upward during the coming decade due to favorable supply & prices, coupled with a large fleet of aging coal plants nearing retirement. EIA's latest projection are likely well below what 2020 levels will be if gas prices are sustained. Over 9 Tcf seems to be a more realistic outlook.

34% of coal plants are over 50 years old and 70% are over 40 years old. Under increasing pressure from EPA regulations.
CO₂ Emissions from Gas

**Combustion Chemistry 101**

During combustion, energy is liberated as H is oxidized to H₂O and C is oxidized to CO₂.

The more H relative to C the more energy is liberated per unit CO₂.

- In methane the H/C ratio is 4:1. The CO₂ release per MJ = 1.2 mol.
- In petroleum the H/C ratio is ~ 2:1. In iso-octane the CO₂ release per MJ = 1.6 mol.
- In coal the H/C ratio is ~ 1:1. The CO₂ release per MJ = 2.0 mol.
Notes by Presenter: So – the transformation to a low emission global energy system is easy – no? Just switch to renewables.
Notes by Presenter: This is a review of published estimates of LC GHG Emissions for electricity generation technologies from all over the world. NG typically been seen as about half GHG emissions as coal (LC and non-LC perspectives), but there is wide variability in previous estimates stemming from differences in technology (combined cycle vs. simple cycle vs. LNG), assumed performance characteristics, LCA modeling assumptions, etc.

However, this is being challenged (Propublica, Prof. Howarth, etc.), the argument being GHG emissions from NG production have been underestimated to-date.

GHG emissions matter to the atmosphere and also for policies that aim to protect against climate change, for instance Obama’s proposed Clean Energy Standard, where the credit for using NG to displace coal electricity is important to determine accurately.
An Often-Ignored Environmental Factor: Power Density by Resource, W/m²

<table>
<thead>
<tr>
<th>Resource</th>
<th>Power Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil shale</td>
<td>$10^4 - 10^5$</td>
</tr>
<tr>
<td>Oil and gas fields</td>
<td>$10^3 - 10^4$</td>
</tr>
<tr>
<td>Coal fields</td>
<td>$10^{2.5} - 10^4$</td>
</tr>
<tr>
<td>Solar thermal plants</td>
<td>$10^{1.5} - 10^2$</td>
</tr>
<tr>
<td>Geothermal</td>
<td>$10^{1.5} - 10^2$</td>
</tr>
<tr>
<td>Solar PV plants</td>
<td>$10^{1.5} - 10^2$</td>
</tr>
<tr>
<td>Wind</td>
<td>3 - 5</td>
</tr>
<tr>
<td>Biomass</td>
<td>$10^{-1} - 1$</td>
</tr>
<tr>
<td>Hydro ...</td>
<td>$10^{-1} - 10^{1.5}$</td>
</tr>
</tbody>
</table>

Renewable energy has its own great environmental challenges

Modified from Science, Special Section, 13 August, 2010

Notes by Presenter: In 2008 one of our very high-level political leaders called for the U.S. to commit to produce 100% of our electricity from renewable energy resources within 10 years. Energy scientists have dubbed that “The Great Energy Delusion”.
Conclusions – Answers?

• Are supplies sufficient to replace coal and play a role as a transportation fuel? Yes.

• Are we (the U.S.) positioning ourselves to really use it? No.

• Is it really the fossil energy with the lowest carbon footprint? Probably.

• Can we really quantify the relative “environmental impacts” of different energy resources? Doubtful.