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 CO_2 for every unit of electricity produced (about 1,200 tons of CO_2 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 CO_2 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 km^2 (while the resource lasts ~ decades), oil fields may yield 10 GW per km^2, and a bituminous coal field may yield 1 GW per km^2. Solar and geothermal power plants provide about 100 MW per km^2, 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 CO_2 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 CO_2 from what might be a fossil energy industry run mostly on gas.

Sustainable Use of Fossil Energy

AAPG – Houston

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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?"

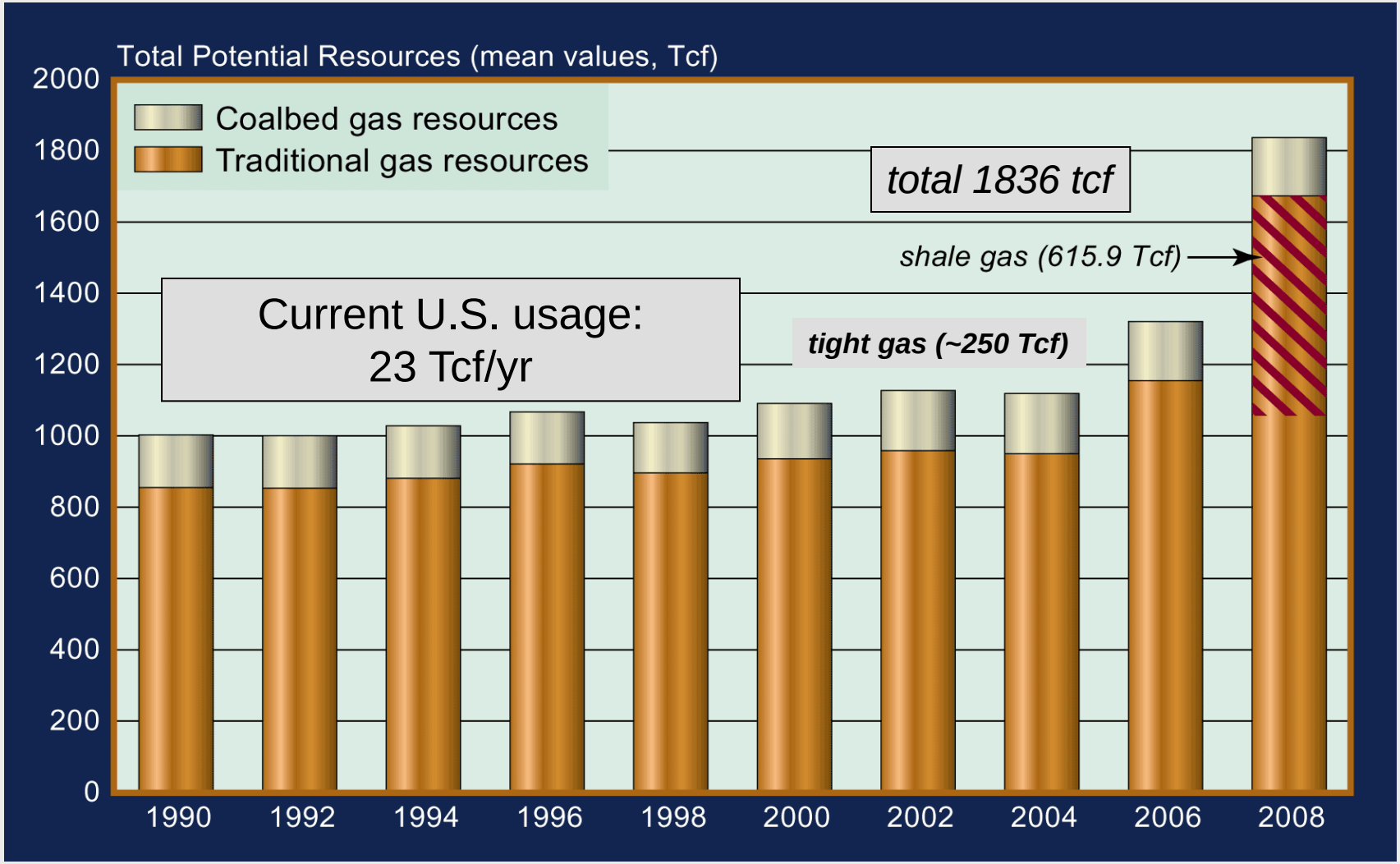
Proposed solutions: rapid acceleration of renewable energy and "next generation" (Gen 3, 4) nuclear power

Now: what is the role of natural gas along the path to sustainable energy?

The Issues with Natural Gas

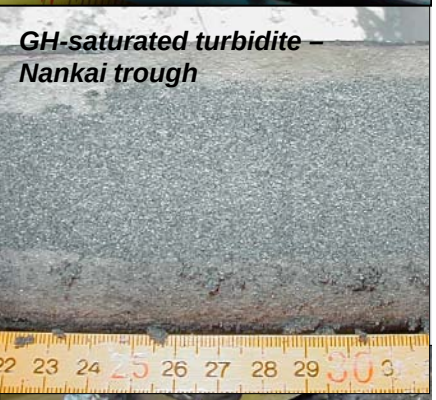
- Are supplies sufficient to replace coal and play a role as a transportation fuel?
- Are we (the U.S.) positioning ourselves to really use it?
- Is it really the fossil energy with the lowest carbon footprint?
- Can we really quantify the relative “environmental impacts” of different energy resources?

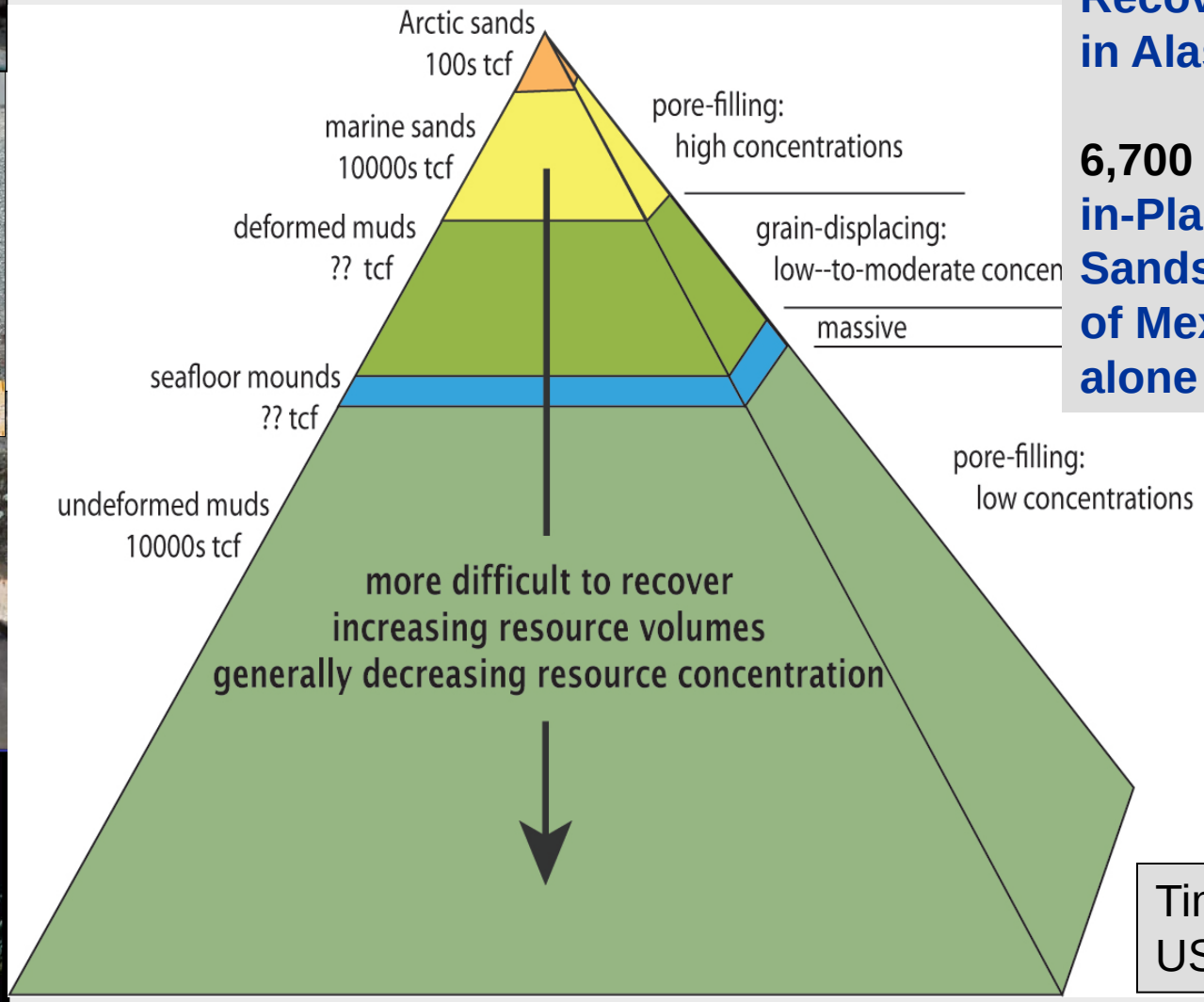
PGC U.S. Resource Assessments 1990-2008



Data source: Potential Gas Committee (2009)

Recent Focus: Hydrate Gas in Sands





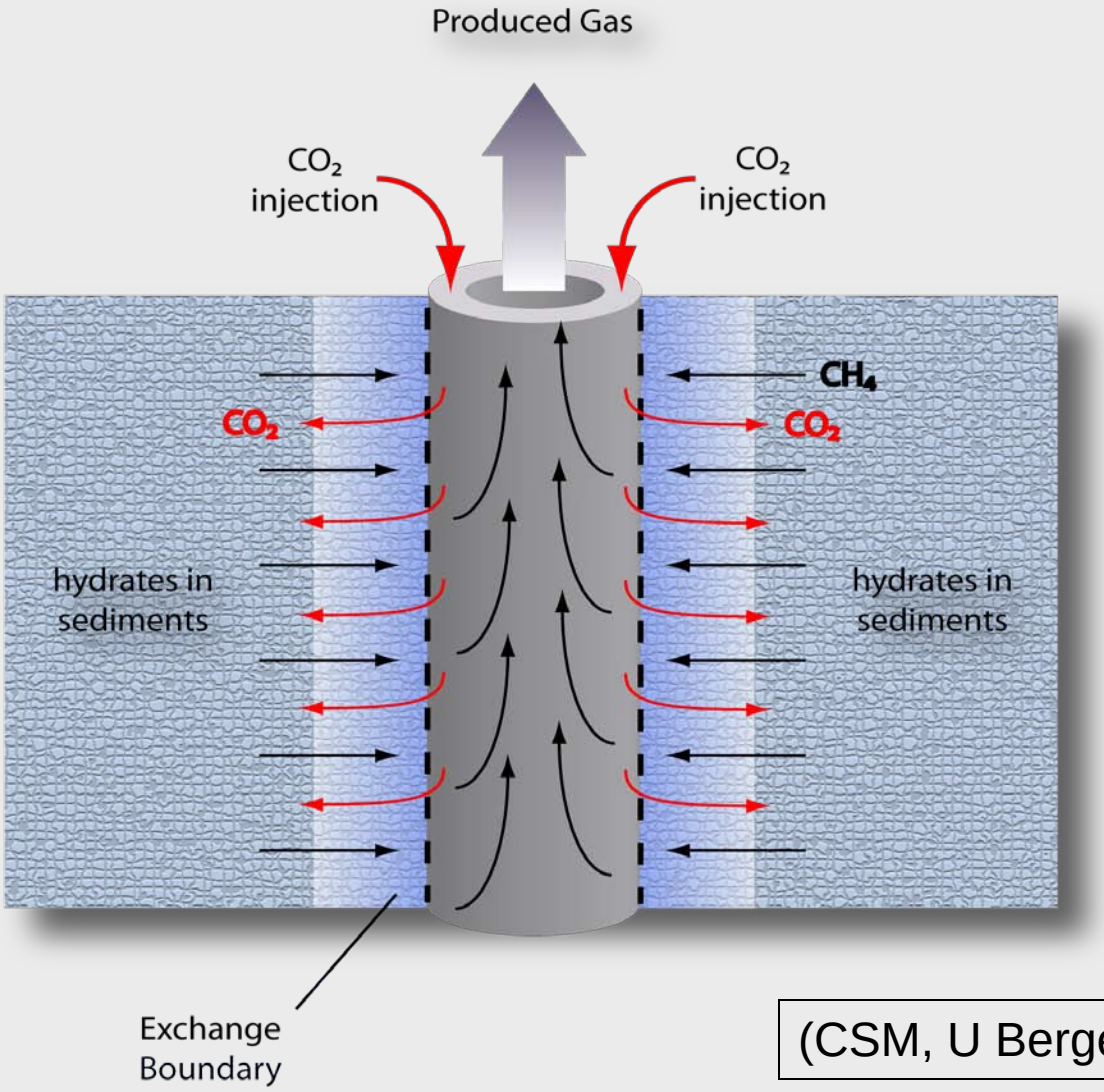
2008 DOI Assessments

85 Tcf Technically-Recoverable in Alaska

6,700 Tcf Gas-in-Place in Sands in Gulf of Mexico alone

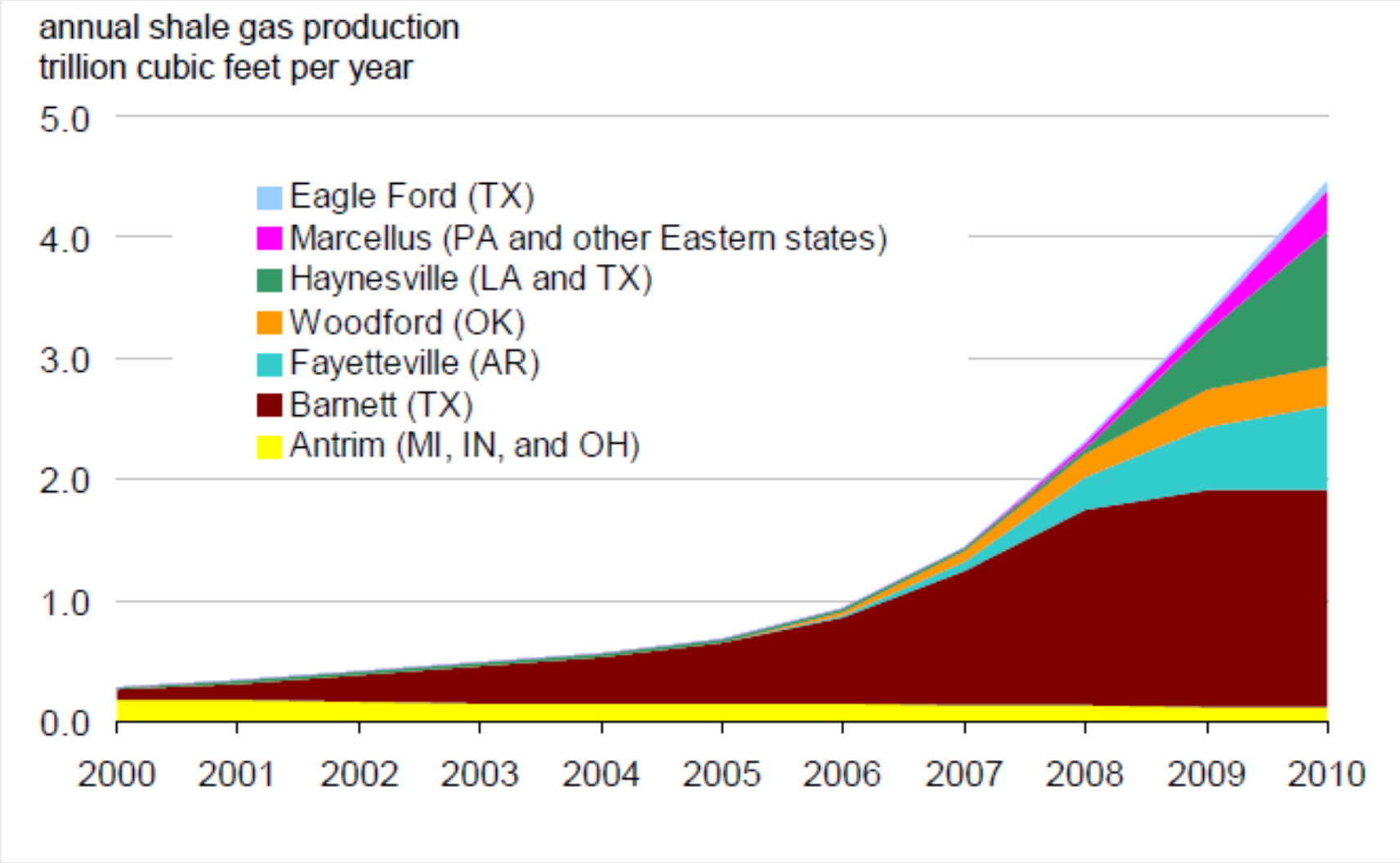
Tim Collett
USGS

In-Situ CO_2 Sequestration with CH_4 Exchange in Gas Hydrate



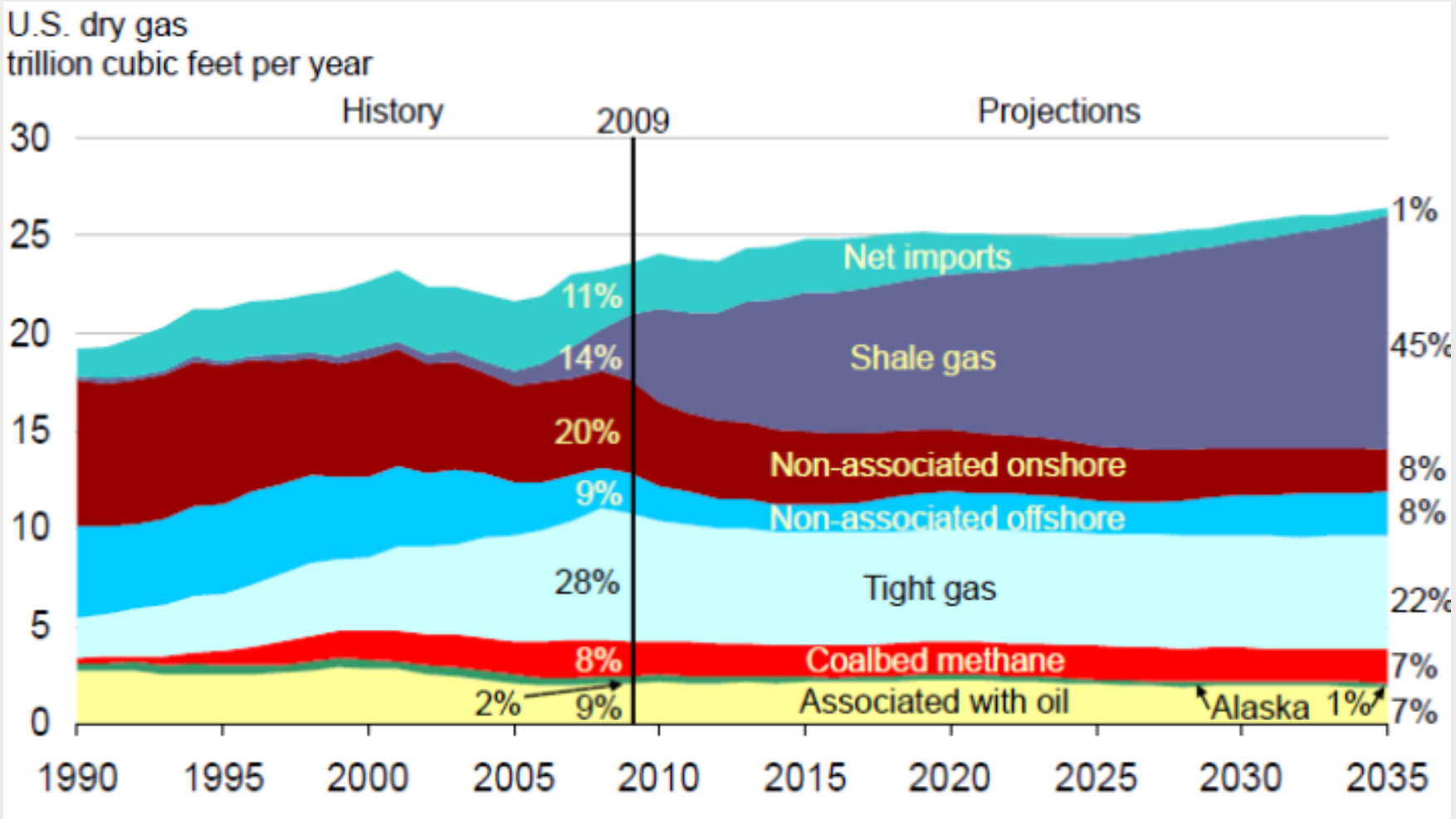
(CSM, U Bergen, USGS

Shale Gas Production is Growing Fast



Source: Annual Energy Outlook 2011, EIA.

And is Expected to Continue Growing…



EIA 2011

… Also Internationally

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

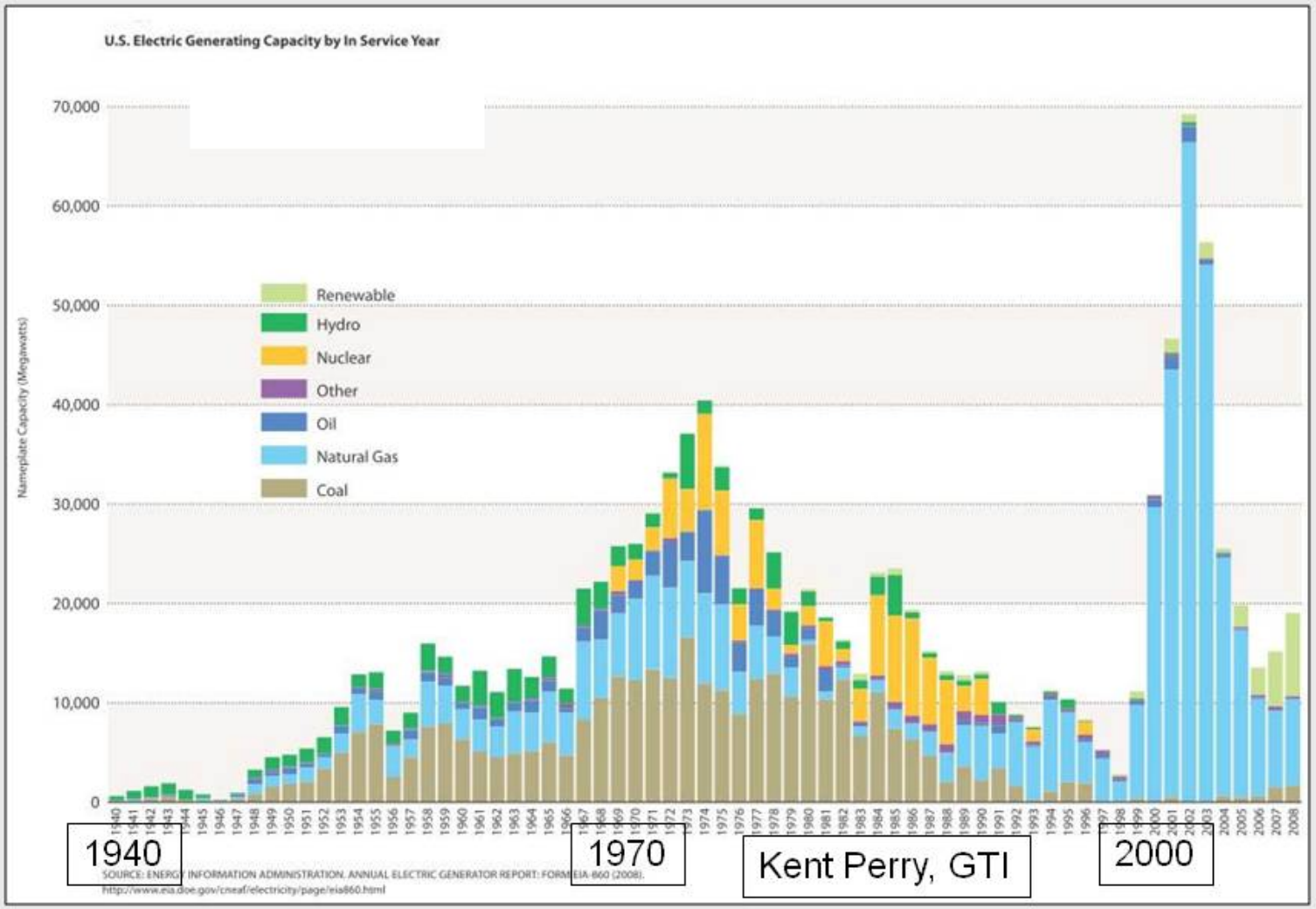
Shale Gas Expected to account for 46 percent of U.S. natural gas production in 2035

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)

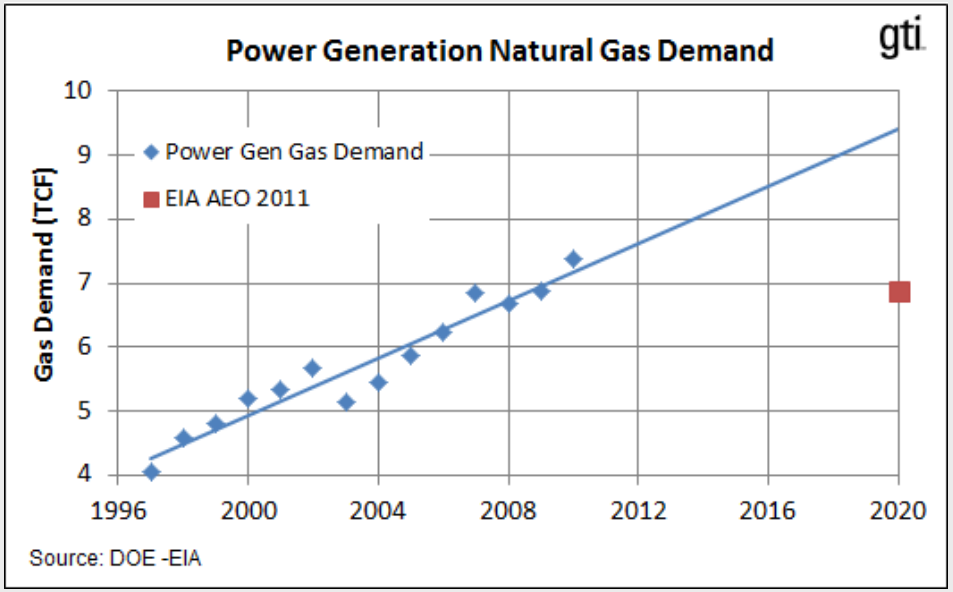
EIA April 6, 2011

Installed U.S. Electric Generating Capacity by Service Year



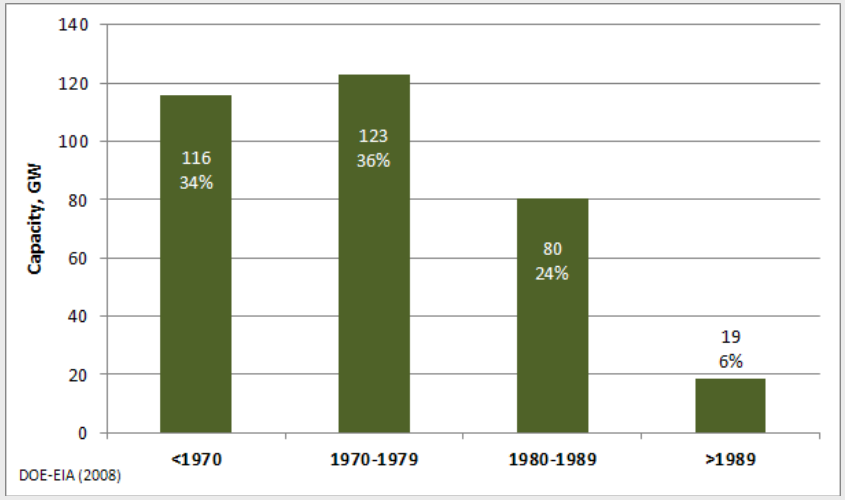
Notes by Presenter: Following a wave of electric industry deregulation in the latter part of the 1990s and early 2000s, there was a wave of investment in low-cost gas turbine power systems. This was further supported by low natural gas prices. There was a clear over-investment in gas turbine capacity.

Outlook for Natural Gas Power Generation

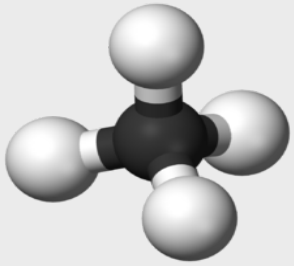


Natural gas use for power has grown steadily for 15 years. Trend will continue upward during the coming decade due to favorable supply & prices, coupled with a large fleet of aging coal plants nearing retirement. EIA's latest projection are likely well below what 2020 levels will be if gas prices are sustained. Over 9 Tcf seems to be a more realistic outlook.

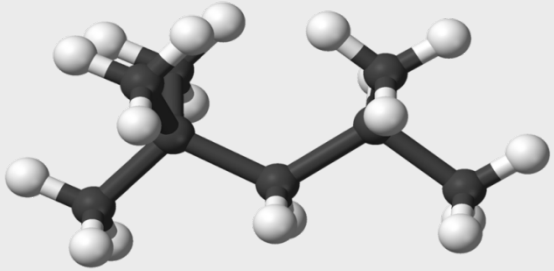
34% of coal plants are over 50 years old and 70% are over 40 years old. Under increasing pressure from EPA regulations.



CO_2 Emissions from Gas



Methane – CH_4
Primary constituent of natural gas



Iso-octane – C_8H_{18}
Typical molecule in gasoline

Combustion Chemistry 101

During combustion, energy is liberated as H is oxidized to H_2O and C is oxidized to CO_2

The more H relative to C the more energy is liberated per unit CO_2

In **methane H/C ratio is 4:1**. The CO_2 release per MJ = 1.2 mol

In **petroleum the H/C ratio is ~ 2:1**. In iso-octane the CO_2 release per MJ = 1.6 mol

In **coal the H/C ratio is ~ 1:1**
The CO_2 release per MJ = 2.0 mol

CO_2 Emissions – Comparisons of Electricity Generation

Using Life Cycle Assessment
2004 World Energy Council[1]

Emissions include direct (stack emissions); and indirect (other stages - transport, production, parts manufacturing, etc.)

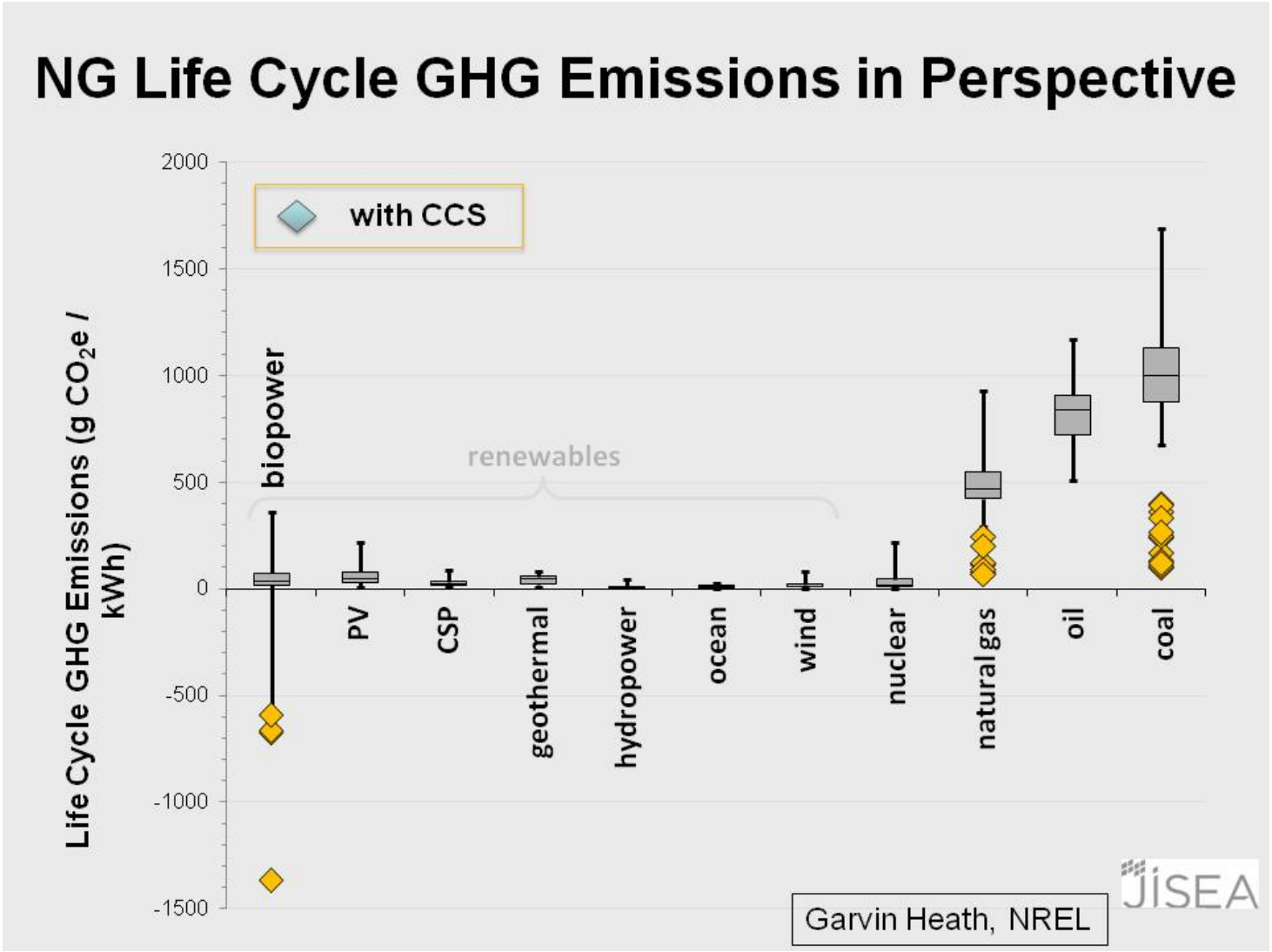
Tons of carbon dioxide equivalent per GWh of electricity generated

Fuel type	Efficiency %	CO_2eq (T/gWh)
Lignite	31 – 37	1140 – 1370
Coal	33 – 44	820 – 1080
Heavy oil	37 – 40	650 – 840
Natural gas CC	47 – 55	363 – 485
Solar PV	5 – 38	43 – 104
Hydro	51 – 73	6 – 120
Wind	21 – 35	7 – 15
Nuclear	82 – 89	3 – 40
Geothermal		23 – 82

[1]London-based council (formed in 1924), running the tri-annual world energy congresses (members from R&D groups, industry, government agencies)

Similar data from: NREL; Univ. Wisconsin; International Atomic Energy Commission; IEA; INL; many others.

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/m^2

Oil shale	10^4 - 10^5
Oil and gas fields	10^3 – 10^4
Coal fields	$10^{2.5}$ -10^4
Solar thermal plants	$10^{1.5}$ -10^2
Geothermal	$10^{1.5}$ -10^2
Solar PV plants	$10^{1.5}$ -10^2
Wind	3 - 5
Biomass	10^{-1} -1
Hydro …	10^{-1} -$10^{1.5}$

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.