Fossil Fuels (Coal and Gas)*

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Abstract

In this module, the following topics are covered: 1) contributions of coal and gas to electricity generation and to carbon emissions, 2) the link between electricity generation and carbon emissions, 3) the challenges of sequestering carbon in geologic formations – chemical transformation, migration, and longevity

1 Learning Objectives

After reading this module, students should be able to

- outline the relative contributions of coal and gas to electricity generation and to carbon emissions
- understand the link between electricity generation and carbon emissions
- understand the challenges of sequestering carbon in geologic formations – chemical transformation, migration, and longevity

2 Introduction

At present the fossil fuels used for electricity generation are predominantly coal (45 percent) and gas (23 percent); petroleum accounts for approximately 1 percent (see Figure **Electricity Generation by Source** (Figure 1)). Coal electricity traces its origins to the early 20th Century, when it was the natural fuel for steam engines given its abundance, high energy density and low cost. Gas is a later addition to the fossil electricity mix, arriving in significant quantities after World War II and with its greatest growth since 1990 as shown in Figure **Growth of Fuels Used to Produce Electricity in the United States** (Figure 2) (EIA Annual Energy Review, 2009 (p. 6)). Of the two fuels, coal emits almost twice the carbon dioxide as gas for the same heat output, making it significantly greater contributor to global warming and climate change.

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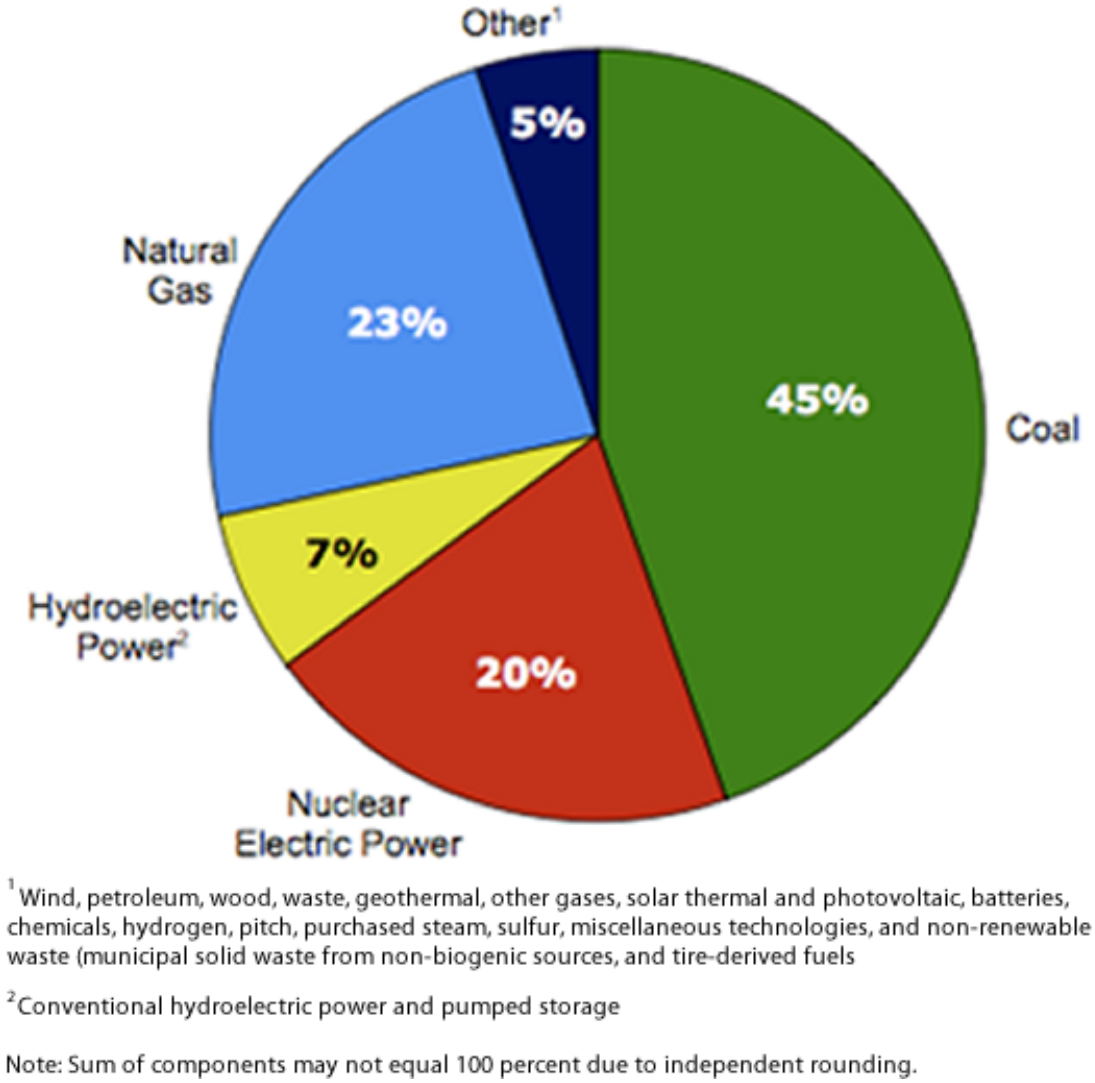

Figure 1: Electricity Generation by Source Chart shows U.S. electricity generation by source. *Source: U.S.* [1] *Energy Information Administration, Annual Review, 2009, p. 228 (Aug. 2010)*[2]

[1] http://205.254.135.24/totalenergy/data/annual/pdf/aer.pdf
[2] http://205.254.135.24/totalenergy/data/annual/pdf/aer.pdf

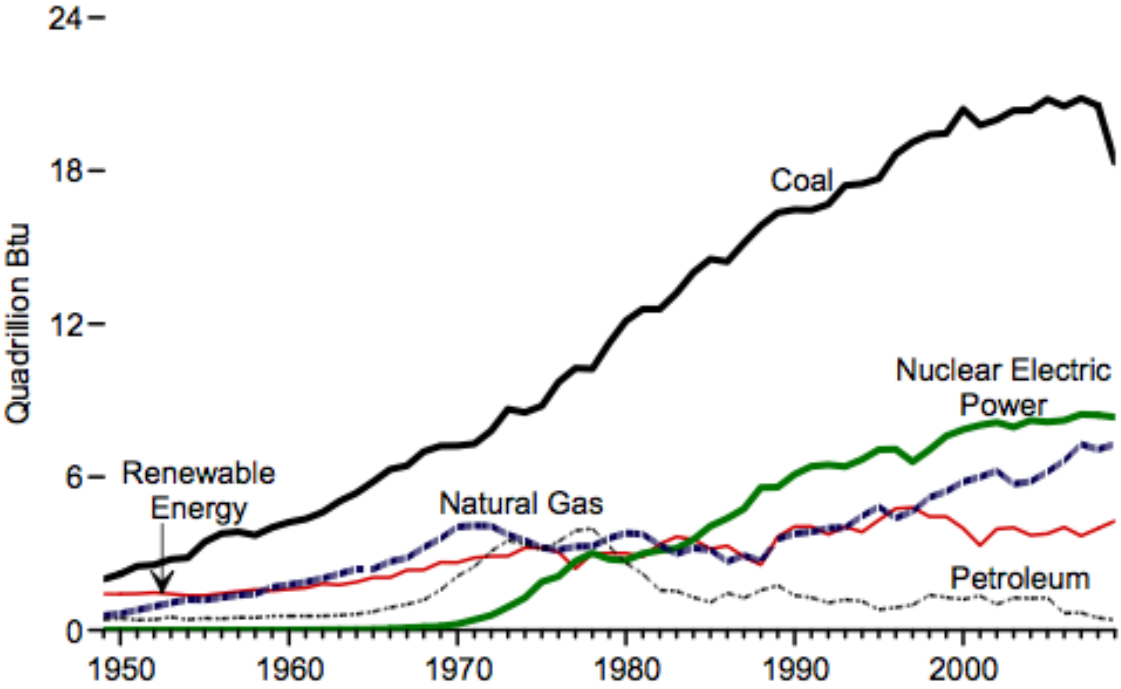

Figure 2: Growth of Fuels Used to Produce Electricity in the United States Graph shows the growth of fuels used to produce electricity in the United States from 1950 to 2009. *Source: U.S. Energy Information Administration, Annual Energy Review 2009, p. 238 (Aug. 2010)*[3]

3 The Future of Gas and Coal

The future development of coal and gas depend on the degree of public and regulatory concern for carbon emissions, and the relative price and supply of the two fuels. Supplies of coal are abundant in the United States, and the transportation chain from mines to power plants is well established by long experience. The primary unknown factor is the degree of public and regulatory pressure that will be placed on carbon emissions. Strong regulatory pressure on carbon emissions would favor retirement of coal and addition of gas power plants. This trend is reinforced by the recent dramatic expansion of shale gas reserves in the United States due to technology advances in horizontal drilling and hydraulic fracturing ("fracking") of shale gas fields. Shale gas production has increased 48 percent annually in the years 2006 – 2010, with more increases expected (EIA Annual Energy Outlook, 2011 (p. 6)). Greater United States production of shale gas will gradually reduce imports and could eventually make the United States a net exporter of natural gas.

The technique of hydraulic fracturing of shale uses high-pressure fluids to fracture the normally hard shale deposits and release gas and oil trapped inside the rock. To promote the flow of gas out of the rock, small particles of solids are included in the fracturing liquids to lodge in the shale cracks and keep them open after the liquids are depressurized. Although hydraulic fracturing has been used since the 1940s, is technologically feasible, economic, and proven to enhance gas an oil recovery, it faces considerable environmental challenges. In aquifers overlying the Marcellus and Utica shale formations of northeastern Pennsylvania and upstate New York, methane contamination of drinking water associated with shale gas extraction has been reported

[3] http://205.254.135.24/totalenergy/data/annual/pdf/aer.pdf

(Osborn, (p. 6)Vengosh, Warner, & Jackson, 2011 (p. 6)). The public reaction to these reports has been strong and negative, prompting calls for greater transparency, scientific investigation and regulatory control to clearly establish the safety, sustainability and public confidence in the technique. See Module **Environmental Challenges in Energy, Carbon Dioxide, Air and Water** for more on the process of hydraulic fracturing and its associated risks.

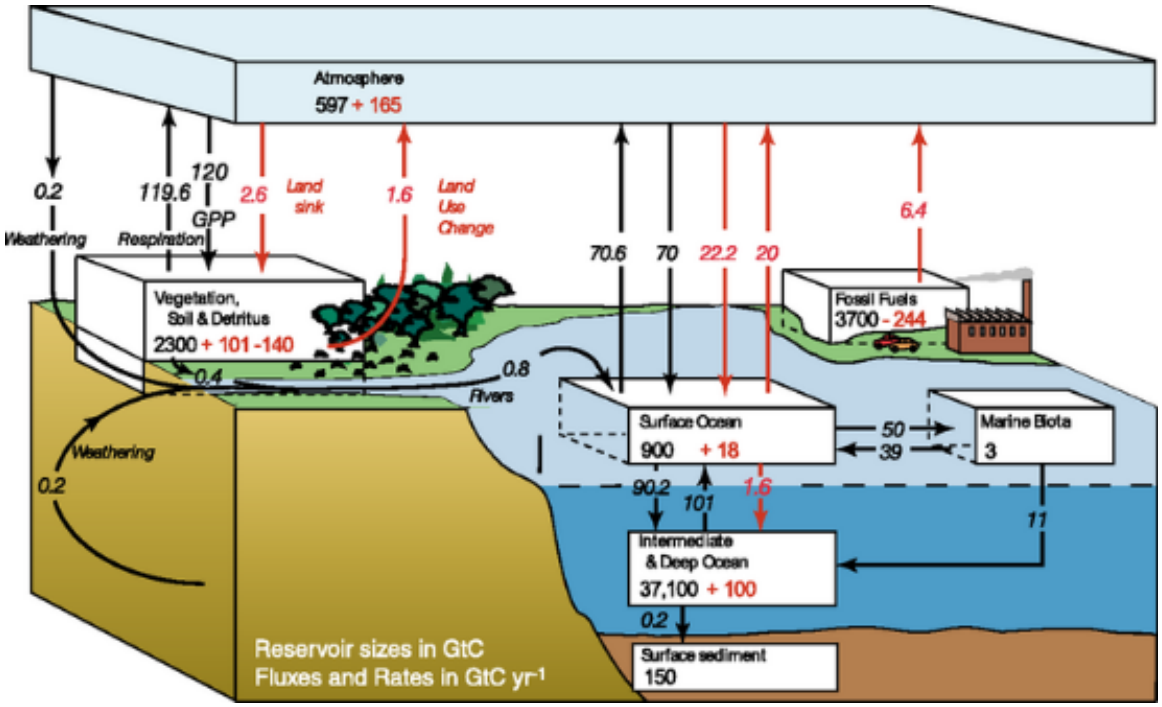

Figure 3: Global Carbon Cycle, 1990s The global carbon cycle for the 1990s, showing the main annual fluxes in GtC yr−1: pre-industrial 'natural' fluxes in black and 'anthropogenic' fluxes in red. *Source: Climate Change 2007: The Physical Science Basis:* [4]*Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, figure 7.3*[5]

Beyond a trend from coal to gas for electricity generation, there is a need to deal with the carbon emissions from the fossil production of electricity. Figure **Global Carbon Cycle, 1990s** (Figure 3) shows the size of these emissions compared to natural fluxes between ocean and atmosphere and from vegetation and land use. The anthropogenic fluxes are small by comparison, yet have a large effect on the concentration of carbon dioxide in the atmosphere. The reason is the step-wise dynamics of the carbon cycle. The ultimate storage repository for carbon emissions is the deep ocean, with abundant capacity to absorb the relatively small flux from fossil fuel combustion. Transfer to the deep ocean, however, occurs in three steps: first to the atmosphere, then to the shallow ocean, and finally to the deep ocean. The bottleneck is the slow transfer of carbon dioxide from the shallow ocean to the deep ocean, governed by the **great ocean conveyor belt** or **thermohaline circulation** illustrated in Figure **Great Ocean Conveyor Belt** (Figure 4). The great ocean conveyor belt takes 400 − 1000 years to complete one cycle. While carbon dioxide waits to be

[4]http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch7s7-3.html
[5]http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch7s7-3.html

transported to the deep ocean, it saturates the shallow ocean and "backs up" in the atmosphere causing global warming and threatening climate change. If carbon emissions are to be captured and stored (or "sequestered") they must be trapped for thousands of years while the atmosphere adjusts to past and future carbon emissions (Lenton, 2006 (p. 6)).

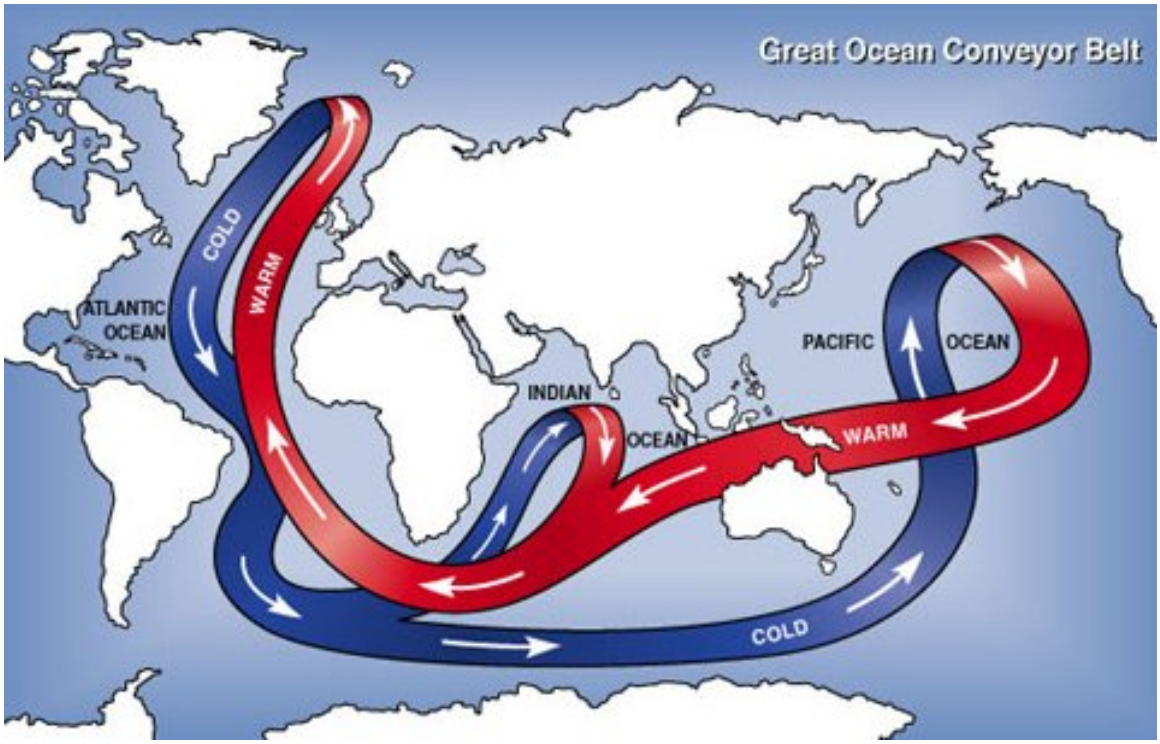

Figure 4: Great Ocean Conveyor Belt The great ocean conveyor belt (or thermohaline current) sends warm surface currents from the Pacific to Atlantic oceans and cold deep currents in the opposite direction. The conveyor belt is responsible for transporting dissolved carbon dioxide from the relatively small reservoir of the shallow ocean to much larger reservoir of the deep ocean. It takes 400 - 1000 years to complete one cycle. *Source: Argonne National Laboratory*[6]

Sequestration of carbon dioxide in underground geologic formations is one process that, in principle, has the capacity to handle fossil fuel carbon emissions (Olajire, 2010 (p. 6)); chemical reaction of carbon dioxide to a stable solid form is another (Stephens & Keith, 2008 (p. 6)). For sequestration, there are fundamental challenges that must be understood and resolved before the process can be implemented on a wide scale.

The chemical reactions and migration routes through the porous rocks in which carbon dioxide is stored underground are largely unknown. Depending on the rock environment, stable solid compounds could form that would effectively remove the sequestered carbon dioxide from the environment. Alternatively, it could remain as carbon dioxide or transform to a mobile species and migrate long distances, finally finding an escape route to the atmosphere where it could resume its contribution to greenhouse warming or cause new environmental damage. The requirement on long term sequestration is severe: a leak rate of 1 percent means that all the carbon dioxide sequestered in the first year escapes in a century, a blink of the eye on the

[6] http://www.anl.gov/Media_Center/Frontiers/2003/d8ee.html

timescale of climate change.

4 Summary

Coal (45 percent) and gas (23 percent) are the two primary fossil fuels for electricity production in the United States. Coal combustion produces nearly twice the carbon emissions of gas combustion. Increasing public opinion and regulatory pressure to lower carbon emissions are shifting electricity generation toward gas and away from coal. The domestic supply of gas is increasing rapidly due to shale gas released by hydraulic fracturing, a technology with significant potential for harmful environmental impact. Reducing the greenhouse gas impact of electricity production requires capturing and sequestering the carbon dioxide emitted from power plants. Storing carbon dioxide in underground geologic formations faces challenges of chemical transformation, migration, and longevity.

5 Review Questions

Question 1
The United States' electricity supply is provided primarily by coal, natural gas, nuclear, and hydropower. How safe are these fuel supplies from interruption by international disasters, weather events or geopolitical tension?

Question 2
Natural gas reserves from shale are increasing rapidly due to increased use of hydrofracturing technology ("fracking"). The increased domestic resource of shale gas has the potential to provide greater energy security at the expense of greater environmental impact. What are the long-term costs, benefits, and outlook for tapping into domestic shale gas reserves?

Question 3
Anthropogenic carbon emissions are small compared to natural exchange between ocean and atmosphere and fluxes from vegetation and land use. Why do anthropogenic emissions have such a large effect on the concentration of carbon dioxide in the atmosphere?

Question 4
One proposal for mitigating carbon emissions is capturing and storing them in underground geologic formations (sequestration). What scientific, technological and policy challenges must be overcome before sequestration can be deployed widely?

6 References

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[7] http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf

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Glossary

Definition 1: carbon sequestration
The storage of carbon dioxide underground in geologic formations consisting of depleted oil and gas wells, unmineable coal beds, and deep saline aquifers.

Definition 2: great ocean conveyor belt (or Termohaline Current)
The current spanning the Pacific, Antarctic, Indian and Atlantic Oceans that carries warm surface water to the cold deep ocean and takes 400-1000 years to complete one cycle.

[8] http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf