Petroleum and the Environment: an Introduction

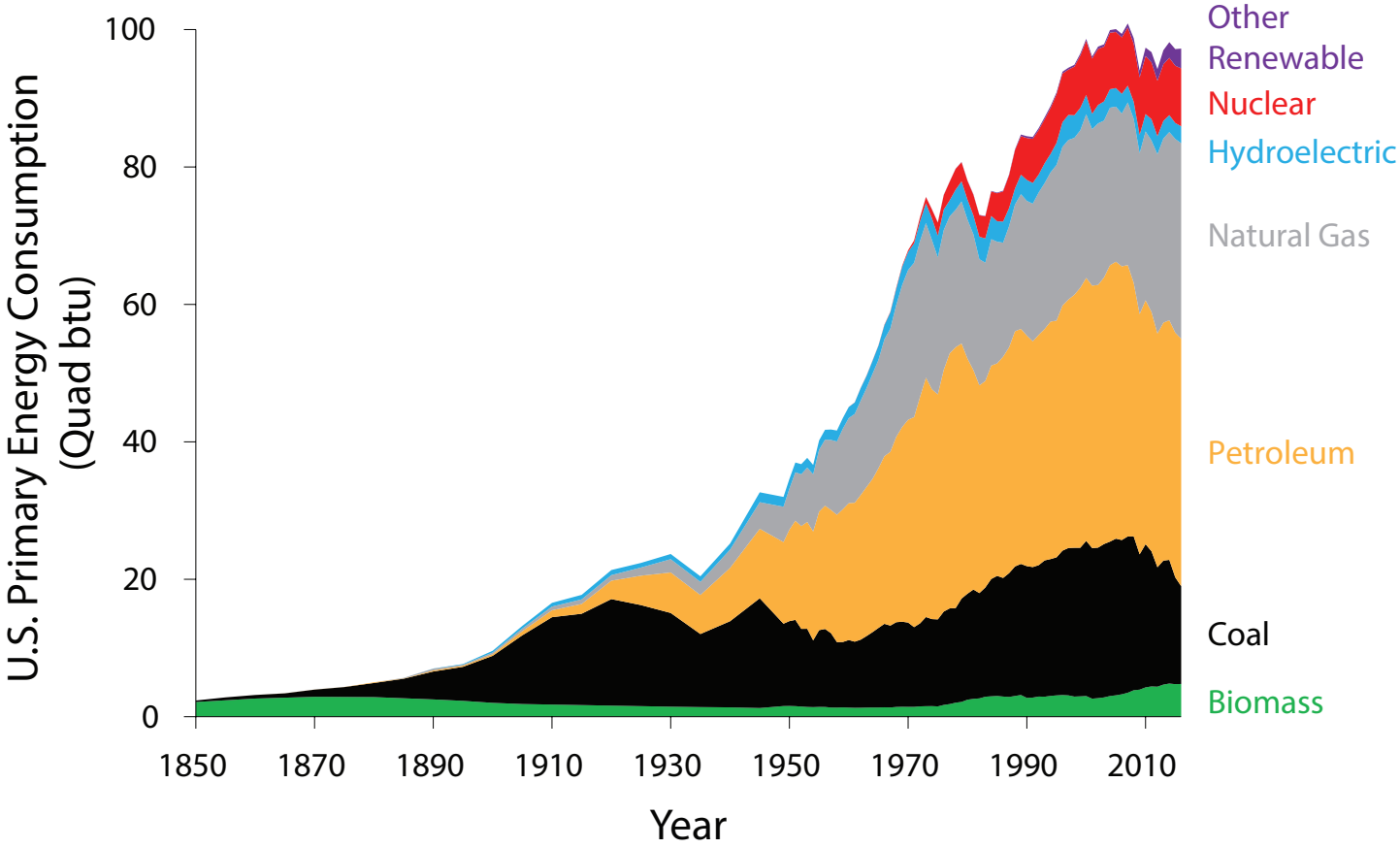
Relationships between oil and gas and the environment in historical context

Introduction

When oil and gas were first extracted and used on an industrial scale in the 19th century, they provided significant advantages over existing fuels: they were cleaner, easier to transport, and more versatile than coal and biomass (wood, waste, and whale oil). Diesel and gasoline derived from oil revolutionized the transportation sector. Through developments in chemical engineering, oil and gas also provided the raw materials for a vast range of useful products, from plastics to fertilizers and medicines. By the 20th century, oil and gas had become essential resources for modern life: as both fuel and raw material, the versatility and abundance of oil and gas helped to facilitate unprecedented economic growth and improved human health around the world.

Despite rapid advances in renewable energy technologies, in 2016 oil and gas accounted for two thirds of U.S. energy consumption[1] and over half of all the energy consumed worldwide.[2] Annual U.S. oil and gas production is expected to increase beyond 2040.[3] Developments in policy, technology, and public opinion may change this trend, but oil and gas will likely play a fundamental role in U.S. and global energy production and consumption for much of the 21st century.

How can the environmental and public health risks of the energy sector be minimized while ensuring a consistent and abundant energy supply? An important step in addressing environmental and health concerns is understanding the risks and the options



Sources of energy used in the United States, 1850-2016. "Other Renewable" includes solar, wind, and geothermal energy. Image credit: American Geosciences Institute. Data source: Energy Information Administration.[4,5]

available to reduce them. In this series, 24 factsheets and case studies provide an overview of the many intersections between the oil and gas industry and the environment. Specific attention is paid to: (1) environmental and human health issues in the exploration, production, refining and processing, and transportation of oil and natural gas; and (2) some of the technologies, management practices, and regulations that can help to address these issues.

A Note on Climate Change

The combustion of fossil fuels (coal, oil, and natural gas) releases large quantities of carbon dioxide (and other greenhouse gases) into the atmosphere, which has a wide range of environmental impacts. The full extent of these impacts is not yet known, but they include rising global temperatures, ocean acidification, sea level rise, and a variety of other impacts on weather, natural hazards, agriculture, and more, many of which are likely to increase into the future.[10,11,12] While agriculture and land use change also emit carbon dioxide and other greenhouse gases (especially methane), fossil fuels, especially coal and oil, produce the majority of anthropogenic (human-caused) emissions of greenhouse gases on a global scale.[13]

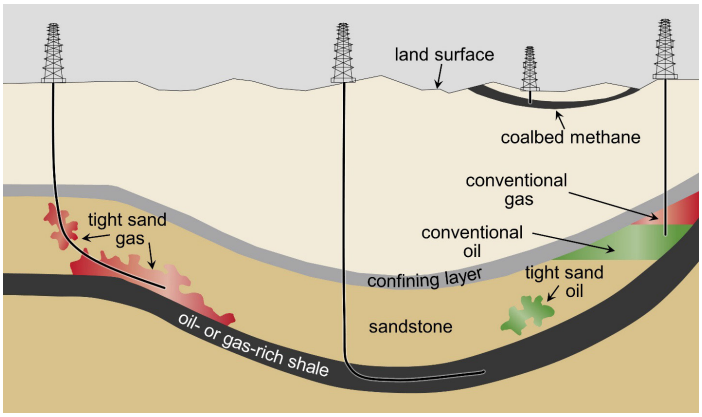
Since peaking in 2007, U.S. emissions of greenhouse gases have decreased largely due to changes in electric power generation (decreased electricity demand and decreased use of coal for electricity generation in favor of natural gas and, more recently, renewables).[14] With continued changes in how energy is generated and used, emissions from the energy sector as a whole may continue to decrease. Meanwhile, there are actions that can be taken to reduce the carbon emissions from the oil and gas sector, such as reducing gas leaks, using less energy-intensive exploration and production techniques, and capturing and storing carbon emissions. These efforts are addressed throughout this series where relevant to each subtopic. For those interested in learning more about climate change and its relationship to the combustion of fossil fuels as an energy source, a selection of resources is provided at the end of this introduction.

Recent Developments

Oil and gas exploration, production, and use have radically changed since the beginning of the 21st century. The use of horizontal drilling with hydraulic fracturing to access previously uneconomic oil and gas deposits led to unprecedented increases in oil and gas production: from 2006 to 2015, U.S. natural gas production increased by 40%,[6] while from 2008 to 2015, U.S. oil production increased by 88%.[7] This growth in production has led to commensurate growth in oil and gas transportation, processing and refining, use in agriculture and manufacturing, and energy exports.[8,9]

However, the recent growth in oil and gas production has increased or renewed some longstanding concerns over their impact on the environment, while also giving rise to some new concerns. Areas of major change and/or public concern include:

- **Hydraulic fracturing ("fracking")** – this technique of fracturing rocks to extract oil and gas has been used since the 1940s, but its combination with horizontal drilling to extract oil and gas from shale led to a surge in hydraulic fracturing starting around 2005. The widespread use of hydraulic fracturing has raised questions about the large amount of water used in the process, which may compete with other fresh water demands in some areas, and has motivated research into alternative fluids. Hydraulic fracturing has also highlighted the issue of groundwater



Schematic showing the various types of oil and gas deposits. Recent advances in directional (especially horizontal) drilling and hydraulic fracturing have led to substantial increases in production from shale as well as tight oil and gas sandstone. Image credit: U.S. Environmental Protection Agency.[15]

protection, partly due to concerns over the fracturing process itself and partly due to the use of toxic chemicals in some hydraulic fracturing fluids. This adds a new element of concern to a longstanding problem: old or poorly constructed wells may leak a variety of fluids if the cement or steel portions of the well are compromised, whether they are hydraulically fractured or not. Identifying instances and sources of groundwater contamination is an ongoing challenge for research scientists, regulators, and industry.

- **Induced earthquakes** – many human activities can trigger earthquakes, including geothermal energy production, filling up reservoirs behind dams, and groundwater extraction.[16,17] Oil and gas operations can trigger earthquakes through two main processes: underground wastewater injection and hydraulic fracturing. The largest induced earthquakes from oil and gas operations have been caused by the underground injection of large volumes of wastewater extracted along with oil and gas ("produced water").[18] This water is often too salty to release into surface waterbodies so it is instead injected deep underground, where it can increase the likelihood of earthquakes on existing faults. Hydraulic fracturing very rarely causes noticeable earthquakes, but it has triggered some small but noticeable earthquakes in parts of the United States and Canada.[19] Some states, particularly Oklahoma and Kansas, have observed a decrease in induced seismicity since 2015 due to decreased oil production (and therefore less wastewater in need of disposal) and new regulations constraining wastewater injection volumes and rates.[20]

- **Land use** – advances in horizontal drilling mean that wells don't need to be placed directly above a resource, so the location of well sites can be planned to reduce their surface impact, and multiple wells can be drilled in different directions from a single site. However, the boom in horizontal drilling and hydraulic fracturing has led to increased oil and gas activity in many areas, including some areas that had previously had little activity, resulting in increased overall land disturbance in some parts of the country.

- **Methane emissions** – the surge in U.S. natural gas production has led to natural gas replacing coal as the largest source of electricity in the United States.[21] Burning natural gas releases less carbon dioxide than coal, so in this sense the transition from coal to natural gas has had a positive environmental impact. However, methane, the main component of natural gas, is itself a potent greenhouse gas, so any leaks during natural gas production and distribution will partially offset this benefit. Improved monitoring of methane emissions, targeted repair and replacement of equipment, and potential regulations all play a role in minimizing methane leaks.

- **Heavy oil and oil sands** – some of the largest oil resources in the world consist of thick, heavy oil that is extracted and processed with specific, energy-intensive techniques. In the United States, California has long produced heavy oil from the Kern River Oil Field outside Bakersfield,[22] but the largest heavy oil producers are Venezuela and Canada. In Canada, a significant proportion of oil production comes from oil sands (also known as "tar sands"), which are a mixture of clay, sand, water, and bitumen (a very thick oil). Canadian oil sand production has increased substantially since 2005. Deeper oil sand deposits are commonly extracted by heating the oil, which thins it so that it can flow up through a well. Shallower deposits are extracted by open-pit mining of the oil sands, which are then processed to remove the oil. Regardless of the production technique, oil sand production is energy-intensive and therefore results in higher overall emissions of carbon dioxide and combustion-related air pollutants. Open-pit mining of oil sands in particular presents additional environmental concerns, such as risks to air and water quality from dust and waste ponds.

- **Transportation and spills** – increases in oil and gas production and consumption require enhanced transportation infrastructure. About 90% of crude oil and refined products, and essentially all natural gas, are transported through millions of miles of (mostly underground) pipelines. Spills of crude oil and refined products represent less than 0.001% of the total amount transported, but this small percentage amounts to millions of gallons spilled each year.[23] Most spills are small but some can have significant local impacts and require extensive and expensive cleanup efforts.

- **Offshore drilling** – advances in offshore drilling technology have allowed oil and gas to be produced in increasingly deep water. These extreme conditions pose particular technological and environmental challenges. For example, in 2010, a defective well in the Macondo prospect of the Gulf of Mexico caused the largest marine oil spill in history and killed 11 workers on the Deepwater Horizon drilling rig. Since this spill, regulations and industry practices have changed substantially to reduce the environmental risks of offshore oil and gas production, but many concerns remain.

The Purpose of This Series

This series of factsheets and case studies discusses developments in the topics listed above, as well as some less visible topics, such as the importance of data, non-fuel products of oil and gas, the positive and negative impacts of refining and processing, and the many factors that determine the location of a well. Our aim is to provide an overview of the many ways in which the oil and gas industry interacts with people and the environment, including major risks and hazards; progress that has been made in addressing these issues; and how the geosciences, technology, and regulations are used in attempts to balance the need for abundant, affordable energy with the need to protect and preserve environmental and human health.

The information provided herein represents the most current reliable information available to the authors at the time of publishing (Spring 2018). Data relating to petroleum and the environment change through time: government statistics may be updated weekly, monthly, annually, or less frequently; research on aspects of energy and the environment is regularly published in peer-reviewed journals; and regulations affecting energy exploration, production and use are developed and/or legally contested in an ongoing but slow process. Details that are more likely to change in the near future or are associated with substantial uncertainty are indicated. Every attempt has been made to provide references and recommend additional resources that are freely available online, to allow the interested reader to dive deeper into each topic. Not all topics have been covered in the same level of detail: for some topics for which high-quality, accessible resources are freely available (e.g., oil spills in marine settings), the reader is directed toward these existing resources for further information.

References & More Resources

For a complete listing of references, see the "References" section of the full publication, *Petroleum and the Environment*, or visit the online version at: www.americangeosciences.org/critical-issues/petroleum-environment

Petroleum and the Environment (2018) is a completely rewritten update of AGI's 2003 publication, *Petroleum and the Environment*. You can access the 2003 publication at https://www.agiweb.org/environment/publications/petroleum.pdf

Additional resources are provided in each of the 24 sections of this series where they are most topically relevant. Below is a selection of resources that relate to petroleum and the environment but are not provided elsewhere in this series.

Intergovernmental Panel on Climate Change – Fifth Assessment Report. http://www.ipcc.ch/report/ar5/

U.S. Environmental Protection Agency – Global Greenhouse Gas Emissions Data. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

International Energy Agency - World Energy Flows Sankey Diagram. https://www.iea.org/Sankey/

Institute of Physics (2008). The Role of Physics in Improving the Efficiency of Electricity Generation and Supply. https://www.iop.org/publications/iop/2008/file_38218.pdf

World Resources Institute – Resource Watch. https://resourcewatch.org/

International Energy Agency (2017). CO_2 Emissions from Fuel Combustion 2017. http://www.iea.org/bookshop/757-CO2_Emissions_from_Fuel_Combustion_2017

Raimi, D. (2017). The Fracking Debate: The Risks, Benefits, and Uncertainties of the Shale Revolution. Columbia University Press, 280 pp.