Renewable and Sustainable Energy Reviews 30 (2014) 1–28

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Natural gas from shale formation – The evolution, evidences and challenges of shale gas revolution in United States

Qiang Wang [a,b,*], Xi Chen [a], Awadhesh N. Jha [c], Howard Rogers [d]

[a] State Key Laboratory of Desert and Oasis Ecology, Western Research Center for Energy and Eco-Environmental Policy, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[b] Ecological Complexity and Modeling Laboratory, Department of Botany and Plant Sciences, University of California, Riverside, CA 92521, USA
[c] School of Biological Sciences, Plymouth University, PL4 8AA, United Kingdom
[d] Oxford Institute for Energy Studies, United Kingdom

ARTICLE INFO

Article history:
Received 16 August 2012
Received in revised form
17 August 2013
Accepted 24 August 2013

Keywords:
Natural gas from shale formation
Energy revolution
Environmental challenge
Best practices
US shale gas

ABSTRACT

Extraction of natural gas from shale rock in the United States (US) is one of the landmark events in the 21st century. The combination of horizontal drilling and hydraulic fracturing can extract huge quantities of natural gas from impermeable shale formations, which were previously thought to be either impossible or uneconomic to produce. This review offers a comprehensive insight into US shale gas opportunities, appraising the evolution, evidence and the challenges of shale gas production in the US. The history of US shale gas in this article is divided into three periods and based on the change of oil price (i.e., the period before the 1970s oil crisis, the period from 1970s to 2000, and the period since 2000), the US has moved from being one of the world's biggest importers of gas to being self-sufficient in less than a decade, with the shale gas production increasing 12-fold (from 2000 to 2010). The US domestic natural gas price hit a 10-year low in 2012. The US domestic natural gas price in the first half of 2012 was about $2 per million British Thermal Unit (BTU), compared with Brent crude, the world benchmark price for oil, now about $ 80–100/barrel, or $14–17 per million BTU. Partly due to an increase in gas-fired power generation in response to low gas prices, US carbon emissions from fossil-fuel combustion fell by 430 million ton CO_2 – more than any other country – between 2006 and 2011. Shale gas also stimulated economic growth, creating 600,000 new jobs in the US by 2010. However, the US shale gas revolution would be curbed, if the environmental risks posed by hydraulic fracturing are not managed effectively. The hydraulic fracturing is water intensive, and can cause pollution in the marine environment, with implications for long-term environmental sustainability in several ways. Also, large amounts of methane, a powerful greenhouse gas, can be emitted during the shale gas exploration and production. Hydraulic fracturing also may induce earthquakes. These environmental risks need to be managed by good practices which is not being applied by all the producers in all the locations. Enforcing stronger regulations are necessary to minimize risk to the environment and on human health. Robust regulatory oversight can however increase the cost of extraction, but stringent regulations can foster an historic opportunity to provide cheaper and cleaner gas to meet the consumer demand, as well as to usher in the future growth of the industry.

Contents

* Corresponding author at: State Key Laboratory of Desert and Oasis Ecology, Western Research Center for Energy and Eco-Environmental Policy, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China. Tel.: +86 991 788 5420.
E-mail address: qiangwang7@gmail.com (Q. Wang).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.08.065

1. Introduction

1.1. Introduction of US shale gas revolution

The biggest energy story that has happened in the 21st century so far is the extraction of natural gas from shale rock formations in the United States [1–19]. The combination of horizontal drilling and hydraulic fracturing enables the extraction of huge quantities of natural gas from impermeable shale formations, which were previously thought to be either impractical or uneconomic [4,20,21]. The extraction of shale gas has transformed the US energy landscape. About 10 years ago, the decline of conventional natural gas output indicated that the US's economically recoverable natural gas reserves were in long term decline [22–24]. However, extraction of natural gas from shale formation has not only offset the decline of conventional gas output, but has resulted in the growth of total natural gas production. The US is estimated to possess a 100-year supply of natural gas at current consumption rates [1,5,11]. In addition, partly due to shale gas replacing coal-fired power plant generation, the International Energy Agency (IEA) reported that carbon dioxide from fossil fuel consumption in the US has fallen by 430 million ton from 2006 to 2011 (7.7%), the largest reduction of all countries or regions surveyed [25]. Despite its far greater efforts to tackle climate change, the carbon reduction in the European Union (EU) is less than that of the US, partly because of an increase in coal-fired power generation in response to Europe's high gas price, the failure of its emissions trading policies and the phasing out nuclear energy [25–27].

Many other countries, such as China [28], India [29], Poland [30], South Africa [31], Australia [32], Ukraine [33], and UK [34,35], are at the early stages of evaluating their shale gas resources. Many of these countries are attempting to cope with the growing energy demand while attempting to reduce their dependence on imported fossil fuel. Most notably, China, the world's biggest energy consumer [36] and the world's largest shale gas resource holder [37], has set an aggressive plan to follow America to boost its shale gas output from near zero in 2012 to 6.5 billion m^3/year by 2015 and to 80–100 billion by 2020, or a quarter of its total gas consumption [28,38–40].

However, the rise of shale gas has raised environmental concerns [1,3,41–47]. Hydraulic fracturing has been criticized for polluting water [41,42,45,48–56], emitting more greenhouse gas caused by fugitive methane [57–62], causing detrimental health impacts [46,63,64] and even to cause earthquakes [65–67]. If the shale gas industry does not work harder to address environmental safety, sustainability and health impacts, the revolution risks being limited or even halted [68–73].

Table 1
A selected of references of evolution, evidence and challenges of US shale gas revolution.

Item	References		
	Official reports	Academic papers	News analyses
Evolution	E.g. [74–82]	E.g. [32,52,58,61,83–98]	E.g. [1,5,7,10,31,69,70,99–103]
Evidences	E.g. [21,68,104–106]	E.g. [3,8,11,13–15,18,24,30,32,46,49,50,55,57,61,87,107–134]	E.g. [7,9,26,29,39,135–140]
Challenges	E.g. [4,37,78,82,141–147]	E.g. [3,42,43,46,52–55,58–60,64,86,91,93,99,107,108,114,120,121,125,148–177]	E.g. [5,10,31,40,69,101–103]