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World natural gas endowment as a bridge towards zero carbon emissions

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ABSTRACT

We use a global energy market (GEM) model to show that natural gas has the potential to help stabilize global carbon emissions in a span of about 50–100 years and pave the way towards low and zero carbon energy.

The GEM provides a close fit of the global energy mix between 1850 and 2005. It also matches historical carbon and CO_2 emissions generated by the combustion of fossil fuels. The model is used then to forecast the future energy mix, as well as the carbon and CO_2 emissions, up to the year 2150.

Historical data show relative decarbonization and an increase in the amount of hydrogen burned as a percent of fossil fuel use between 1850 and 1970. The GEM indicates that with a larger contribution of natural gas to the future energy market, the burned hydrogen percentage will increase. This decarbonization will help to advance economic and environmental sustainability.

1. Introduction

Energy services are a vital need and are indispensable for human well-being. Significant challenges exist, ranging from energy security to environmental quality. Historically, economic growth has been primarily fuelled by coal and oil. As the world economy continues to expand over the long term, natural gas has the potential to play a significant role in satisfying energy demand and acting as a bridge towards renewables [1]. Increased use of gas will help to reduce dependency on oil and coal, which may result in increased energy security and reduced environmental impact. Thus, the aim of this paper is to analyze the role of natural gas, on a global scale, in providing a sustainable global energy future. In particular, this paper provides projections related to natural gas and its association to the energy mix, decarbonization, and carbon emissions.

The themes of this paper support the work of experts visualizing a bright future for natural gas as a transition fuel [e.g. 1–7]. Common forecasting models for estimated energy demand include IEA MARKAL [8] and the IAEA MAED [9]. For a comparative study of energy demand models, see [10]. Reserve estimates are presented annually in the British Petroleum Statistical Review of World Energy [11] and by the U.S. Energy Information Administration [12]. Estimates of resources are periodically assessed by the United States Geological Survey [13] and the German BGR [14].

Recent natural gas estimates indicate marketable resources of 2074 trillion cubic feet (tcf) in the United States [15], and 700 to 1300 tcf in Canada [16], are much larger than previously assessed. The same holds true for the world when natural gas in conventional, tight, shale and coalbed reservoirs is taken into account [17,18].

The endowment in these four types of reservoirs is estimated at 45,000 tcf split into 15,000 tcf in conventional reservoirs; 15,000 in tight gas reservoirs; 10,000 in shale gas reservoirs; and 5000 in coalbed reservoirs.[1]

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[1] GFREE research team, Schulich School of Engineering, University of Calgary, Canada. GFREE is a target-oriented research program developed in attempts to increase natural gas rates and recoveries from low permeability formations. The program uses an integrated approach that includes geoscience (G), formation evaluation (F), reservoir drilling, completion and stimulation (R), reservoir engineering (RE), and economics and externalities (EE).

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Endowment refers to the sum of known volumes of hydrocarbons (cumulative production plus remaining reserves) and undiscovered volumes [13]. We estimate that cumulative gas production for the world until 2005 is approximately 2776 tcf. Thus, the 'future endowment' (i.e. endowment minus cumulative production) suggests that at current rates of natural gas production of 106 tcf/year [11], the resource would last for 398 years. Table 1 presents a summary of alternative conventional and unconventional fossil endowments and the time they would last depending on various assumed production growth rates.

In addition to more comfort and convenience, the large gas endowment can help pave the way towards environmental sustainability. As we demonstrate, natural gas use could help stabilize carbon and CO_2 emissions within 50 to 100 years and eventually lead to a zero carbon energy economy in which renewables dominate the energy mix.

2. The global energy market (GEM) model

The GEM model is based on a previous logistic substitution model that provided a good match of the energy mix from approximately 1850 to 1970 [19,20]. After 1970, the actual historical data deviated from the logistic model. The GEM model takes this deviation into account while providing a good fit of all the historical data.

Fig. 1 shows world primary energy consumption and substitution starting in the year 1850. The black curves correspond to actual historical data taken from [21]. The color symbols represent the best fit using theoretical values calculated with the GEM model, which is based on a binary technology substitution model given by [19,20]:

$$\frac{f}{1-f} = \exp(\alpha t + \beta) \tag{1–1}$$

where f is market share of a competitor, t is time, and α and β are parameters. Fisher and Pry define y_{FP} as,

$$y_{FP} = \frac{f}{1-f} \tag{1–2}$$

Eq. (1–1) indicates that a semilogarithmic plot of y_{FP} versus time should result in a straight line with a slope equal to α and intercept equal to β. We modified Eq. (1–1) when we observed deviations from the straight line for the energy sources discussed in this study. The deviations included slight or severe increases or decreases in f. We handle the deviations empirically by incorporating a severity exponent, S, and a parameter, ψ, in Eq. (1–1)[22]. The modified equation takes the form [23]:

$$y_{AA} = \frac{\exp(\alpha t + \beta)}{\psi + (1-\psi)\left[1 - \exp\left(-\frac{y_{FP}}{y_{CO}}\right)\right]^S} \tag{1–3}$$

where y_{CO} is a constant determined from the match of the historical data and the theoretical energy fraction is given by:

$$f = \frac{y_{AA}}{1 + y_{AA}} \tag{1–4}$$

As an example, the filled magenta squares in Fig. 2 show $[f/(1+f)]$ values of the measured contribution of natural gas to the global energy market versus time. Time zero in the lower horizontal scale corresponds to the year 1850 (shown in the upper horizontal scale). The measured data form an approximate straight line starting in 1906 (56 years in the lower scale) that deviates from linearity around 1968 (118 years in the lower scale). From the straight line, the values of α and β are determined to be approximately 0.057 and 8.1, respectively. Other parameters are determined from the trend that deviates from linearity, and are as follows: $\psi = 0.052$, $y_{co} = 3.61$and $S = 1.30$. Finally, the fraction f is calculated from Eq. (1–4) and is plotted in Fig. 2 (shown by the symbol 'X').

Table 1
Life expectancies.

1	2	3	4			5
Commodity	Future[a] volumes	2007–2009[b] average annual production	Life expectancy in years,[c] at various[c] growth rates in production			Average annual growth[d] in production, 1979–2009 (%)
			0%	2%	5%	
Conventional gas, tight gas, shale gas, coalbed	4.22E+16	1.06E+14	398	110	61	2.51
Conventional oil	3.50E+12	2.96E+10	118	61	39	0.67
Heavy oil, oil sands, oil shale	2.30E+13	2.96E+10	777	140	74	-

Notes:
[a] Conventional oil, heavy oil, oil sands and oil shale in barrels; conventional gas, tight gas, shale gas and coalbed in cubic feet.
[b] Average annual production comes from British Petroleum (2010).
[c] Life expectancies estimated by this study.
[d] Average annual growth in production calculated from British Petroleum (2010).