Renewable and Sustainable Energy Reviews (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Opportunities and challenges of gas hydrate policies with consideration of environmental impacts

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ARTICLE INFO

Keywords:
Gas hydrate
Policy
Environment impact
Ocean Energy
Sustainable development

ABSTRACT

Gas hydrates are crystalline compounds formed by gas molecules captured inside a water framework, which are substantially stored beneath the seafloor and permafrost regions at a stable condition of high pressure and low temperature. It is suggested as a potentially alternative form of energy, of which the reserves are even larger than the gross reserves of all the proved conventional fossil fuels incorporating coal, oil and natural gas. Intense research activities throughout the world are focusing on the exploration and exploitation of these enormous energy resources. However, changes of hydrate volumes and morphologies during exploitation and the resulting weakening of the sediment mechanical strength may likely trigger catastrophic seafloor instability. Besides, the permafrost ablation experienced in the Arctic could also induce potential methane gas released from the hydrates into the atmosphere and most likely exert certain impacts on the climate change. To date, most researches focus on the technical solutions to the total resource estimation, reservoir exploration, mining technologies, and physical properties of hydrate sediments. Yet, limited documents are found to illuminate the worldwide efforts on national policies proposed to promote the secure and efficient utilisation of this source of energy. Herein, the special attentions are placed on the opportunities and challenges of gas hydrate policies with consideration of environmental impacts to push forward the global developments of the renewable and sustainable energy resources.

1. Introduction

In 1778, Joseph Priestley observed gas hydrates by bubbling sulphur dioxide in the 0 °C water at an atmospheric pressure. However, he did not give name to the observed crystals as hydrates [1]. First documented by Davy in 1811, the development of hydrates studies stagnated for about a century till 1934, when Hammerschmidt found severe operational problems in the United States transportation pipelines of natural gas [2,3]. Then breakdowns during gas transport were occurring due to blockages of pipes caused by the hydrate formation under high pressures [4]. Dehydration of gas prior to shipping by heating the pipelines to temperatures above hydrate formation point could solve hydrate-problem [5]. In 1980s, hydrates started to arouse worldwide interest as large amount of hydrate reservoirs have been discovered; the interest remained growing substantially in 1990s, with numbers of publications released and ever-increasing funds invested. Consequently, the first gas hydrate conference was held in the U.S. in 1991 which was jointly hosted by the U.S. Department of Energy, the U.S. Geological Survey and the Naval Research Laboratory [6]. Currently, intense research activities are being conducted concerning resource exploration [7,8], mining technology [9], physical properties [10], as well as engineering application of gas hydrate techniques [11,12].

Gas hydrate is a vast energy source stored underneath the ocean seabed and permafrost. Nowadays, the global energy supply is dramatically relying on the conventional oil, natural gas and coal. Nearly 85.9% out of the total global energy supply is of fossil origin, yet with merely 9.6% of them originating from renewable resources [13]. Unfortunately, the non-renewable fossil fuels cannot meet the globally increasing energy demands as a result of growing populations, expanding industries and rising economics [14]. Therefore, a diversification of energy sources is crucially significant and highly required

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http://dx.doi.org/10.1016/j.rser.2016.11.269
Received 16 May 2015; Received in revised form 8 November 2016; Accepted 29 November 2016
1364-0321/

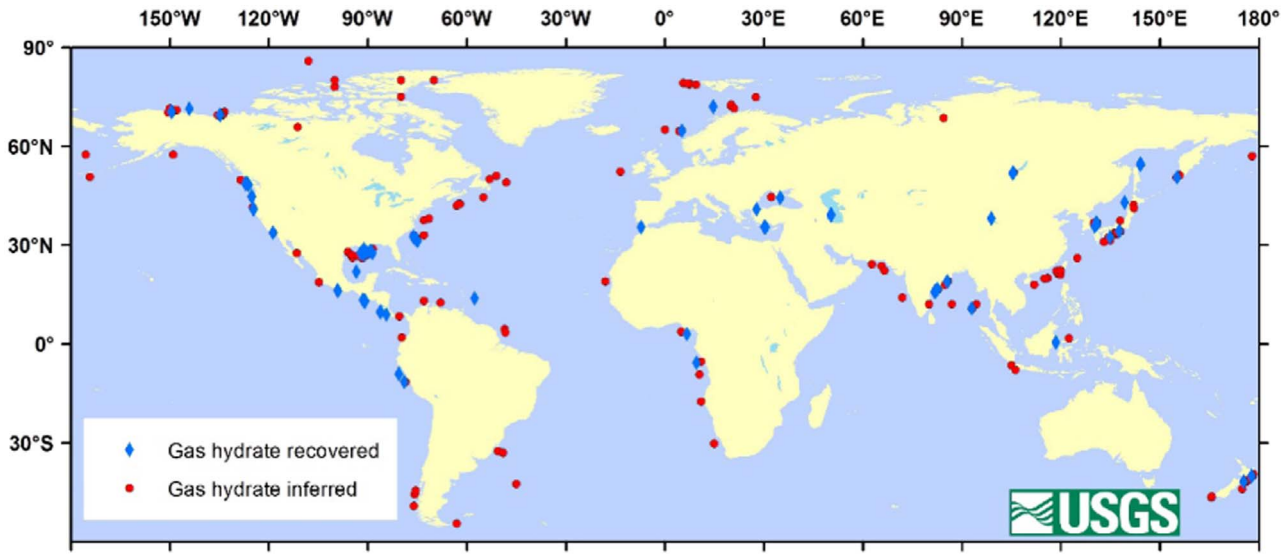

Fig. 1. Worldwide locations of known and inferred gas hydrate [21]. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

[15]. Methane hydrates, with their high energy density, purity and enormous reserves, are suggested to be an alternative energy source in terms of sustainable development and require further efforts around the world, in particular the national or even global policy supports.

Many countries have designated policies or programs on gas hydrate investigations [8]. In 2000, U.S. enacted the first public law in the world to promote researches on gas hydrate. The Methane Hydrate Research and Development Act of 2000 commenced the following National Methane Hydrate Program. In Japan, the "Research Consortium for Methane Hydrate Resources in Japan", known as MH21, was established in July 2001. These programs aimed at the resource identification, estimation, exploration and exploitation of gas hydrates, with cooperative efforts involving the government, industry and institutions. In particular, some international collaboration was achieved with foreign scientists involved to study gas hydrate on site. For example, a drilling test was conducted in the Mackenzie delta of northern Canada with the collective work from Japan, the Geological Survey of Canada and U.S.; India and U.S. also collaborated to explore gas hydrate in Mumbai, India. However, limited work is found on a comprehensive discussion on the opportunities and challenges in gas hydrate policies considering environment impacts, which will have some implications for the long-term development and strategy of this potential source of energy.

Gas hydrate may make a significant difference in the energy structure after efforts on the commercialisation. The reserves underneath the seabed and permafrost would be potentially huge to likely support the global energy supply for another century. However, limited global collaborations are made on the study of environment impacts of gas hydrates, possible effects on the climate change for instance. Methane contributes 21 times larger than carbon dioxide in the global warming effect [16], the release of which into the sea water and the atmosphere would likely result in negative impacts on the marine ecosystem and the climate. In April 2009, the Hotspot Ecosystem Research and Man's Impact on European Sea (HERMIONE) was established to study the deep-sea ecosystem. This is an international multidisciplinary project funded by the European Commission's Seventh Framework Program to study the mechanism of how climate change affects the ecosystem. Besides, the Intergovernmental Panel on Climate Change (IPCC) places high attentions on the issues of climate change which is attributed to gas hydrate instability. The issues of methane release triggered by the climate change have been mentioned in the third and fourth assessment reports in 2001 and 2007. The methane concentration in air has reached 1803 PPB in the fifth assessment reports. Yet, few studies focus on the potential eco-hazard of gas hydrates to the atmosphere and marine system, which should be paid sufficient attention prior to a commercial utilisation of the resources.

In this study, policies on global gas hydrate research and development are briefly reviewed with consideration of environment impacts. National programs and international cooperation in the United States, Japan, India, China, as well as Malaysia are also introduced. Attentions are placed on the opportunities and challenges of gas hydrate investigations around the world as well. This work would have some implications for insights of global gas hydrate researches, and provide guidance to future development on the sustainable energy sources.

2. Worldwide occurrence of gas hydrate

Gas hydrates are widespread in sea sediments hundreds of meters below the sea floor along the continental margins, as well as in the Arctic permafrost. About 95% of the Atlantic regions, 85% of the Pacific regions and 96% of the Indian Ocean areas contain gas hydrates [17]. Kvenvolden et al. from the United States Geological Survey (USGS) predicted that about 90% of land regions and 27% of marine areas are favourable for the formation of gas hydrates [18].

The occurrence of gas hydrate is strongly dependent on factors including temperature, pressure and constituent components. As a result, the occurrence of gas hydrate is restricted to sediments in polar and deep oceanic regions. In Polar Regions, gas hydrate exists in permafrost at both onshore and offshore of the continental shelves. In deep oceanic regions, gas hydrate occurs in sediment of slopes along continental margins where cold bottom water and high pressure are naturally present [19,20]; the worldwide locations of known and inferred gas hydrate occurrence are illustrated in Fig. 1[21]. The blue marks denote locations of natural gas hydrate that have been recovered while the red ones indicate locations with inferred gas hydrate. It is noticeable that many recovered gas hydrate is located in the Pacific Ocean, probably due to the sound environment for the formation of gas hydrate.

Bohannon et al. tried to characterise the likelihoods for the resource estimation [22]. A scale exceeding 1000 GtC (1 Gt=1 billion tonnes) of methane hydrate is in the category of high confidence. Medium confidence of methane hydrate inventory is ranging from 1000 to 10,000 GtC (equivalent to approximately 2,000–20,000 trillion cubic meters of natural gas) [22]. As a comparison, the worldwide inventory of fossil fuels is approximately 5000 GtC [19]. In China, the resource