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Power-to-gas based subsurface energy storage: A review

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ABSTRACT

The Renewable energy power generation capacity has been rapidly increasing in China recently. Meanwhile, the contradiction between power supply and demand is becoming increasingly more prominent due to the intermittence of renewable energies. On the other hand, on the mitigation of carbon dioxide (CO_2) emissions in China needs immediate attention. Power-to-Gas (PtG), a chemical energy storage technology, can convert surplus electricity into combustible gases. Subsurface energy storage can meet the requirements of long term storage with its large capacity. This paper provides a discussion of the entire PtG energy storage technology process and the current research progress. Based on the comparative study of different geological storage schemes for synthetic methane, their respective research progress and limitations are noted. In addition, a full investigation of the distribution and implementation of global PtG and CO_2 capture and storage (CCS) demonstration projects is performed. Subsequently, the opportunities and challenges of the development of this technology in China are discussed based on techno-economic and ecological effects analysis. While PtG is expected to be a revolutionary technology that will replace traditional power systems, the main issues of site selection, energy efficiency and the economy still need to be adequately addressed. Additionally, based on the comprehensive discussion of the results of the analysis, power-to-gas and subsurface energy storage implementation strategies, as well as outlook in China are presented.

1. Introduction

In terms of the environment, the content of carbon dioxide in the atmosphere has grown by 40% since extensive use of fossil fuels for approximately 250 years [1]. The resulting global climate change has brought severe challenges to the survival and development of human society. In response, more than 170 national leaders gathered at the United Nations Headquarters in New York to sign the Paris Agreement on April 22, 2016, and committed to working to limit the increase in the global average temperature to below 2 °C. The agreement came into effect on November 4, 2016. As a responsible country, China promised to control CO_2 emissions so that the peak will be reached by 2030, with efforts to achieve the emissions peak sooner, if possible. In 2030, CO_2 emissions per unit of gross domestic product (GDP) should be decreased by 60–65% compared to 2005. In addition, the proportion of non-fossil energy accounting for primary energy consumption should be increased to approximately 20%. To achieve these challenging goals, the current energy structure transformation is inadequate. Coordinated deployment and great efforts are required [2,3]. Studies have shown that carbon dioxide capture and storage (CCS) constitute one of the most effective technical tools for global greenhouse gas emission reductions [4]. The Paris Agreement also reaffirms that it will be difficult for humans to limit the increase in the global average temperature within 2 °C without CCS [5,6]. However, pure CCS technology is only a non-profit environmental technology, which is costly with low economic efficiency. Therefore, the integration of the effective utilization of CO_2 is a new idea [7].

As is well known, energy is the basis for determining social progress and economic development. Over the years, the rapid development of fossil fuels, such as oil and coal, has contributed to the development of the world pattern, and the environmental pollution problem has become increasingly serious. At present, renewable energy development is particularly important due to the dual pressures from fossil energy shortage and the deteriorating ecological environment. Because of the cleanliness and unlimited utilization of renewable energy power generation technology, such as hydropower, wind power, and PhotoVoltaics (PV), it is considered to be the most likely alternative to fossil energy [8–11]. Currently, more than twenty countries have

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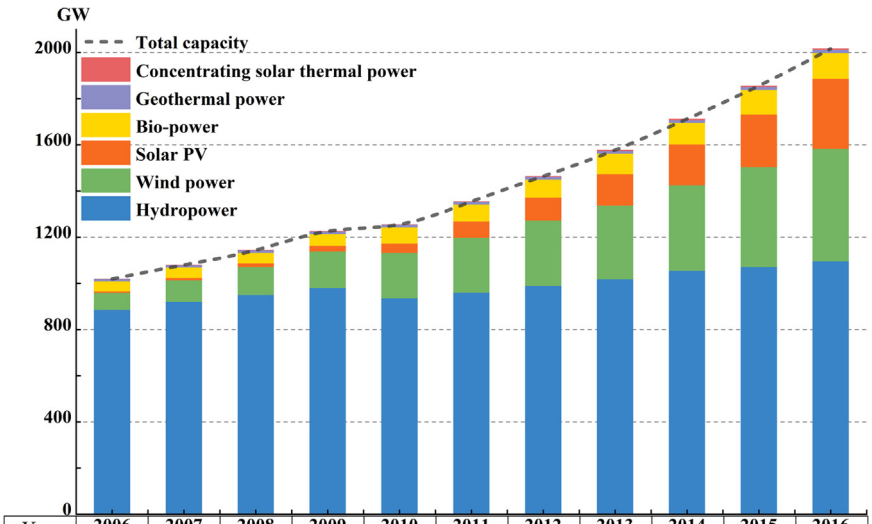
Nomenclature

CAES	Compressed air energy storage
CAPEX	Capital expenditure
CCGT	Combined cycle gas turbine
CCS	Carbon dioxide capture and storage
CCUS	Carbon dioxide capture, utilization and storage
CH_4	Methane
CIS	Commonwealth of independence states
CNPC	China national petroleum corporation
COE	Costs of electricity
CO_2	Carbon dioxide
DSM	Demand side management
EGS	Enhanced geothermal system
EOR	Enhanced oil recovery
ERI	Energy research institute
EWR	Enhanced water recovery
GDP	Gross domestic product
H_2	Hydrogen
IGU	International gas union
NDRC	National development and reform commission
NEA	National energy administration
OPEX	Operational expenditure
PEM	Polymer electrolyte membrane
PHS	Pumped hydro storage
PtG	Power-to-gas
PV	Photovoltaics
RMB	Renminbi, i.e. Chinese yuan
SINOPEC	China petroleum & chemical corporation
SNG	Synthetic natural gas
UGS	Underground gas storage
WEPP	West-east pipeline project
kWh	kilowatt-hour
MWh	Megawatt-hour
PWh	Petawatt-hour
TWh	Terawatt-hour
GW	Gigawatt
MW	Megawatt
km	Kilometers
m^3	Cubic meter
€	Euro
TJ	Terajoule
GJ	Gigajoule

achieved a high proportion of renewable generation to total power generation, including Iceland (100%), Norway (96%), Brazil (85%), New Zealand (73%), and Colombia (70%) [12]. Installed capacity in the world has increased from 1.02 billion kilowatts in 2006 to 2.02 billion kilowatts in 2016, with an average annual growth rate of approximately 8%, as shown in Fig. 1 [13,14].

China has made a solid step in the field of renewable energy. As of the end of 2016, renewable energy power generation installed capacity, including wind power and solar power installed capacity in China, is ranked first in the world (258 GW). As shown in Fig. 2 [14], total installed capacity in China has exceeded 1/4 that of the world.

The current transformation of energy in China is mainly focused on the increase in clean low-carbon energy. The 13th Five-Year Plan in China indicated that the proportion of non-fossil energy consumption needs to increase to more than 15%, the proportion of natural gas consumption needs to increase to approximately 10%, and the proportion of coal consumption needs to be reduced to 58% or less [15]. In addition, the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC) of China organized a study of high proportion renewable energy development scenarios and paths for China in 2015. The study suggests that renewable energy is the fundamental way to achieve alternatives to fossil fuels, where wind power and solar power will be important pillars of the future power supply. In the energy scenarios with a high proportion of renewable energy, the total electricity generation in China will be 15.2 PWh by 2050, renewable energy generating capacity will reach 86% of the total



Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total (GW)	1019.4	1079.8	1144.2	1225.7	1255.3	1355	1464.2	1577.5	1712.2	1855.7	2016.3
	0.4	0.4	0.5	0.7	1.1	1.6	2.5	3.4	4.4	4.7	4.8
	10	10.4	10.7	11	11.2	11.4	11.7	12.1	12.8	13	13.5
	43	45	46	51	70	74	78	88	93	106	112
	7	10	16	24	40	70	99	137	177	228	303
	74	94	121	159	198	238	283	319	370	433	487
	885	920	950	980	935	960	990	1018	1055	1071	1096

Fig. 1. 2006–2016 global renewable energy power generation capacity [13,14].