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Strategic Planning on Clean Utilization of Coal Complied with Domestic Energy Transition

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ABSTRACT

In the 21st century, the mainstay of energy production will remain predominant with fossil fuels; while coal is the most abundant reserve, accounting for over 50% of global resources that may last for more than 110 years, at the current mining production levels worldwide. However, increased concentrations of carbon dioxide (CO_2) and pollutants in the environment are inevitable unless energy systems reduce the emissions to the atmosphere. Furthermore, mitigation of greenhouse gas (GHG) emissions has been essential to sustainability, and requires various portfolios. It is foreseen that substantial reduction of human dependence on coal is impossible today, but it is possible to make it cleaner. In other words, clean coal technologies (CCT) will allow us to continuously utilize world's coal resources. According to the statistics of IEA (International Energy Agency), the top ranking three categories in CO_2 mitigation portfolio are renewables, end-use efficiency, and CCS (carbon capture and storage); while clean utilization of coal can make significant contribution to the last two options above, and will be the major focus of this paper. Taiwan is an isolated island with dense population and limited natural resources. In 2015, the dependence on imported energy in Taiwan is 97.53%, mainly fossil fuels. The share of electricity generation by coal remains 44.58%, and the CO_2 emissions from domestic coal power account for about one-third of the present national total. Hence, clean utilization of coal resides in a high-priority issue in Taiwan. The "Greenhouse Gas Reduction and Management Act" has been issued in Taiwan since June 2015, which sets the target to reduce GHG emissions to 50% of the 2005 level by 2050. It means that lower carbon-containing sources or advanced low-carbon energy technologies will be major options to mitigate CO_2 emission. From the perspectives of energy security, environmental protection and economic development, extensive viewpoints and development trends are addressed in this work. Moreover, progressive bullet points are proposed to implement clean utilization of coal. In summary, CCT, utilizing coal in a sustainable way and minimizing its impacts to the environment, will be the ideal candidate for the economy to create more value with less input.

Keywords: Coal utilization, Clean coal technologies (CCT), Efficiency, Gasification, Emissions

1. BACKGROUND OBSERVATION

In the 21st century, the mainstay of energy production will remain predominant with fossil fuels; while coal is the most abundant reserve that may last for more than 110 years, as shown in Fig. 1, at the current mining production levels worldwide [BP, 2016]. Coal accounts for over 50% of global resources, supplies 29% of global primary energy, and provides 41% of world electricity generation [Dubiński, 2015]. Among the abundant reserves of coal, the ratio of high-rank coal (HRC) to low-rank coal (LRC) is 53% : 47%, while the mining amount of HRC is about 6 times larger than that of LRC. Hence, it is feasible that LRC will become the prime energy source in

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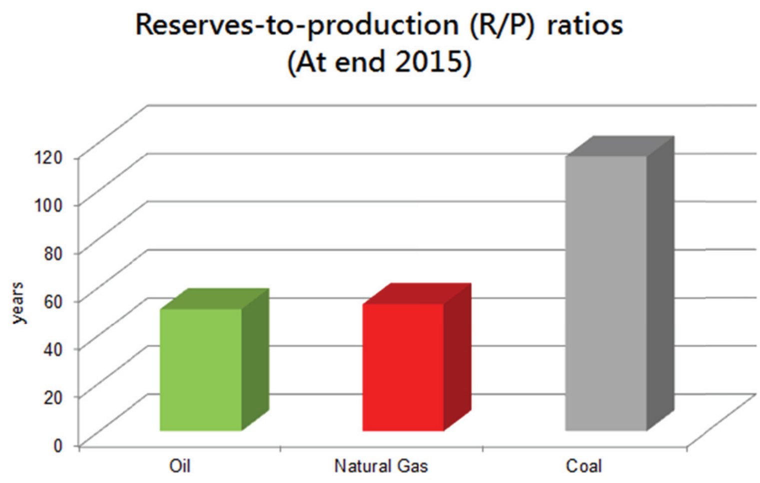


Fig. 1. Fossil fuel reserve.
Source: BP, 2016.

the future. Consequently, capability of adapting feedstock variety becomes a critical issue, since high substitutability of energy sources can enhance energy security. For example, gasification features the capability of utilizing LRC, biomass, pet-coke, MSW (municipal solid waste), etc., which gives potential to the future.

However, increased concentrations of carbon dioxide (CO_2) in the environment are inevitable unless energy systems reduce the carbon emissions to the atmosphere. Furthermore, utilization of coal has been persistently accused of severe environmental impact with pollutants, such as NOx, SOx, particulate, etc. Hence, clean coal technologies (CCT) will be major issues for continuous utilization of world's coal reserve.

1.1 International Status and Trend

Both US and EU leaders promote that "Once in a Generation Opportunity to Build," regarding the utilization of fossil fuel. The US Perspectives state that fossil energy remains a dominant share (68%) of US power in 2040. Furthermore, the climate action plan consists of three major items, i.e., Mitigation, Adaption, & International Partnerships [Smouse, 2015]. Similarly, the IEA (International Energy Agency) Perspectives illustrate various scenarios [Lipponen, 2015]. It is remarked that fossil fuels still have a 44% share in 2050, and are an important part of global energy supply in the 2DS (2 degree scenario); in addition, it is predicted that CCS (carbon capture and storage) will take off after 2025 in the 2DS.

Further details of global energy outlook for regional and country groupings are summarized in the annual report of Energy Technology Perspectives (ETP) [IEA, 2015]. Decarbonising the electricity systems of emerging economies is a daunting challenge in the 2DS. Electricity demand growth between 2012 and 2050 skyrockets in OECD (Organisation for Economic Co-operation and Development) non-member economies – averaging 131% growth and as high as nearly 300% – driven primarily by emerging economies. Coal's contribution to electricity generation is particularly high in China (76%), India (71%) and South Africa (94%). Between 2002 and 2012, coal accounted for 56% of the increase in electricity generation in OECD non-member economies. In the 2DS, coal's share in electricity generation is projected to decline over the next two decades in China, India and South Africa, but rise in parts of Southeast Asia, including Indonesia, Thailand, Malaysia and the Philippines.

Furthermore, Australia is a country endowed with massive coal and gas resources, which have resulted in deriving approximately 85% of its electricity from fossil fuels [Zapantis, 2016]. Fossil fuel energy powers Australia's economy. Australia is the world's largest exporter of coal and is about to become the world's largest exporter of Liquefied Natural Gas (LNG); moreover, the market share in 2015 of Taiwan coal import from Australia was about 46% [Hsu, 2016]. Currently, Australia's energy policy undertakes reform approaches, including integration of renewable energy and technology into national electricity market, increase in energy productivity (defined as the ratio of economic output to energy used) and efficiency performance, etc. The former is promoted by the program of Renewable Energy Target (RET), which encourages new deployment to achieve 23.5% of electricity from renewable energy by 2020. On the other hand, the latter is implemented by National Energy Productivity Plan (NEPP), which aims at 40% improvement of energy productivity by 2030 [Lambie, 2016].

1.2 Domestic Development

In WCA (WORLD COAL ASSOCIATION) database, Taiwan is the 5th largest coal import country worldwide, as shown in Table 1 [WCA, 2016], which imports 85% coal from Indonesia and Australia. Majority of imported coal is for power generation [USCC, 2015]; however, COE (cost of electricity) is the 3rd and 4th lowest globally for household & industry, respectively [TPC, 2016].

Only 16% public in Taiwan know energy import is greater than 90%; but, less people know the related economic figures. Fossil fuel import expenditure per GDP (Gross Domestic Product) (2012) accounted for 14.47%, which is 2.24 times higher than that in OECD [USCC, 2014]. Energy import dependency reached 97.75%, while energy import cost exceeded national annual income in 2014, as seen in Fig. 2 [BOE, 2015]!

Table 1. Top 7 coal import nations in 2013

Country	Total *of which*	Steam	Coking
PR China	292Mt	229Mt	63Mt
India	239Mt	189Mt	50Mt
Japan	188Mt	137Mt	51Mt
South Korea	131Mt	97Mt	34Mt
Chinese Taipei	**67Mt**	**60Mt**	**7Mt**
Germany	57Mt	47Mt	10Mt
UK	41Mt	35Mt	6Mt

Source: WCA, 2016.

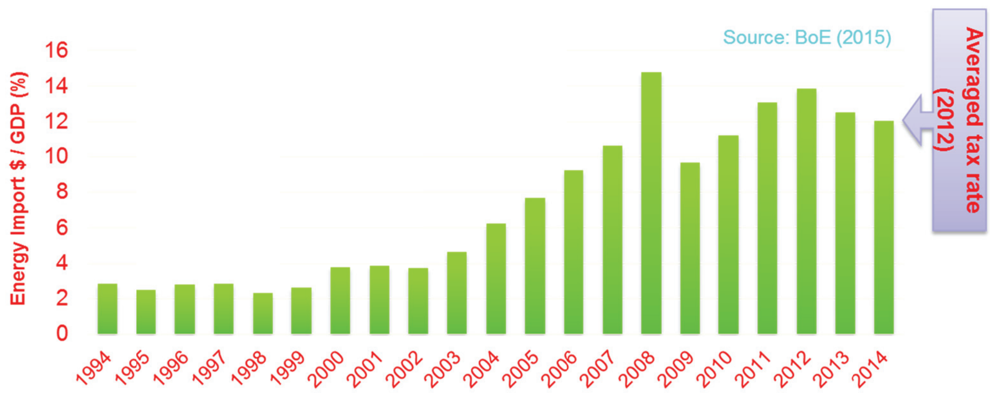
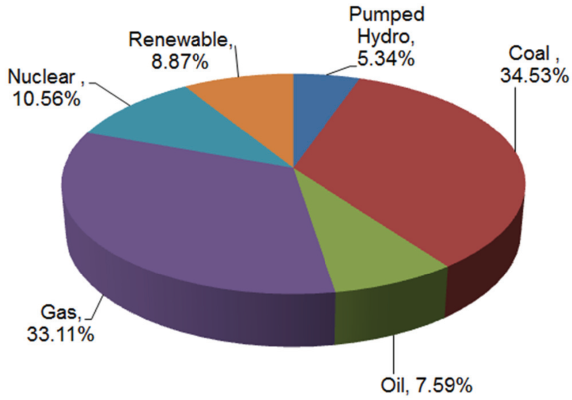
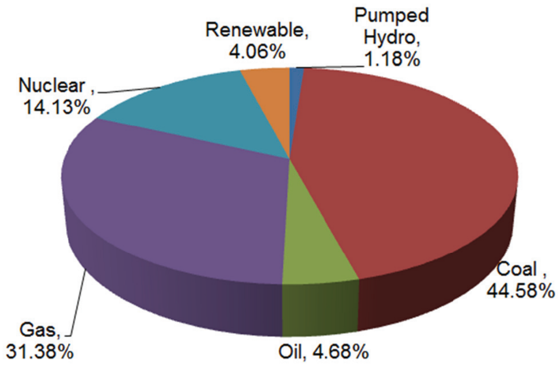


Fig. 2. Fossil fuel import expenditure in Taiwan.
Source: BOE, 2015.

The Power System Portfolio (PSP) of Taiwan indicated that coal was utilized as mainstream for electricity. In 2011, the installed capacity of coal power was 18,014.70 MW (36.95% of total PSP), while the electricity generated by coal was about 124,759 GWh (49.47% of total) [BOE, 2012]. Moreover, CO_2 emission by coal was about 118.9 MT (77.5% of total in power sector). On the other hand, a relatively lower capacity factor of NGCC (natural gas combined cycle) plants was encountered. The installed capacity of NGCC was 15,861.30 MW (32.54% of total PSP), while the capacity factor (CF) of NGCC approached 49% [TPC, 2011]. For Peak load, the design value is around 35%; in other words, the aforementioned value for NGCC has surpassed the usual design target, but is still lower than the counterpart of coal power. Nevertheless, about 6~8 GW of NGCC installed capacity are under inactive situation. The PSP of Taiwan gradually evolves to higher share of natural gas in recent years; nevertheless, coal was still predominant for electricity generation. The most updated data available for 2015 are shown in Fig. 3 [BOE, 2016].



(a) Power Install Capacity



(b) Electricity Generation

Fig. 3. Power System Portfolio (PSP) of Taiwan in 2015.
Source: BOE, 2016.

Evolution of electricity generation portfolio in Taiwan is shown Table 2 [BOE, 2016]. The PSP has been consistently shifted from coal toward natural gas (NG) at a gradual pace ever since; however, in 2016 a dramatic reform of PSP is proposed under the scheme called “520 Energy Transition,” which will be illustrated in a later section.

Statistics of GDP and energy consumption are usually implemented to characterize prosperity and sustainability. Comparison of indices per countries is shown in Fig. 4, which is derived from open data of IEA and World Bank that are sorted by this work. The abscissa quantifies the prosperity

Table 2. Evolution of electricity generation portfolio in Taiwan

Type [%]	Coal	NG	Nuclear	Renewables	Pumped Hydro.	Others (Oil, CHP)
Y2010	49.9	24.6	16.8	3.6	1.2	3.8
Y2011	49.47	25.84	16.70	3.56	1.15	3.27
Y2012	49.01	26.89	16.14	4.24	1.17	2.54
Y2013	48.06	27.55	16.50	4.28	1.26	2.35
Y2014	46.94	28.97	16.30	3.80	1.20	2.79
Y2015	44.6	31.4	14	4.1	1.2	4.7

Source: BOE, 2016.

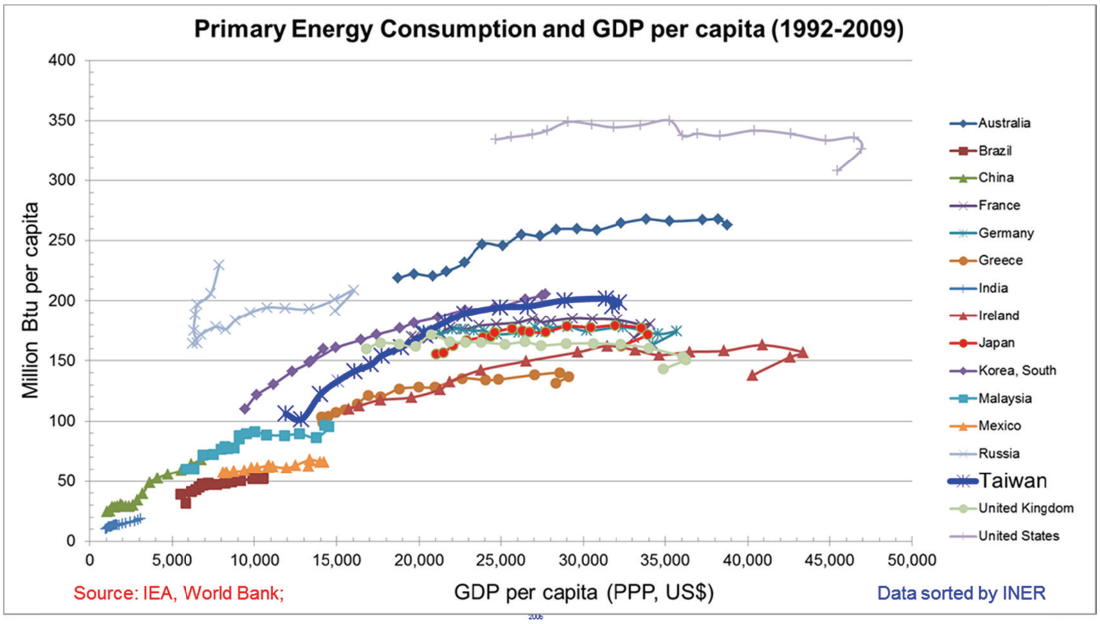


Fig. 4. Statistics of GDP and energy consumption.
Source: Figure prepared by this work.

by PPP (purchasing power parity), for which the higher values give more prosperous life; while the ordinate defines the sustainability via energy consumption per capita, with which the lower indices represent better sustainability. It is clearly seen that there is room of improvement for Taiwan.

2. STRATEGIC PLANNING

Burning carbon has brought us (most of us) out of darkness, but it is inevitably posed environmental concerns. It is foreseen that substantial reduction of human dependence on coal is impossible today, but it is possible to make it cleaner. In other words, clean coal technologies (CCT) will allow us to continuously utilize world's coal resources.

The elements of full chain for CCT cover the whole spectrum of coal production (mining), processing and utilization. Typical CCT in mining includes underground coal gasification (UCG), methane capture, new processing technologies for ultra-clean coal (UCC), dewatering lower rank coals (e.g., brown coals), etc. Clean coal processing technologies cover coking, gasification, coal to liquid (CtL), coal to gas (CtG), etc., as well as hydrogen economy. For coal utilization, advanced coal combustion, efficiency improvement, emission mitigation, etc., are critical issues [Dubiński, 2015]. In summary, CCT provides essential and critical pathways to sustainable environment!

2.1 Technological Schemes

Figure 5 illustrates environmental perspective of various power generation technologies [Chyou *et al.*, 2016]. BACT (Best Achievable Control Technology) concept exhibits superior performance in terms of environmental benignity.

Thermodynamic principles of power generation from fossil fuel mainly implement Brayton cycle for gas turbine (GT) and Rankine cycle for steam turbine (ST). Steam plants (pulverize coal, PC) utilize only Rankine cycle, for which the efficiency mainly depends on the steam condition of the boiler. Figure 6 presents the potential of thermal efficiency improvement with

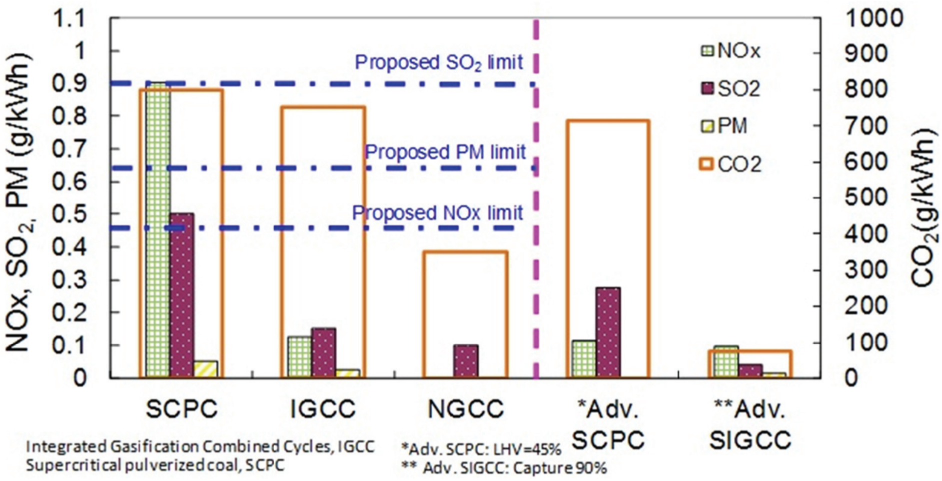


Fig. 5. Environmental perspective of various power generation technologies.
Source: Chyou *et al*., 2016.

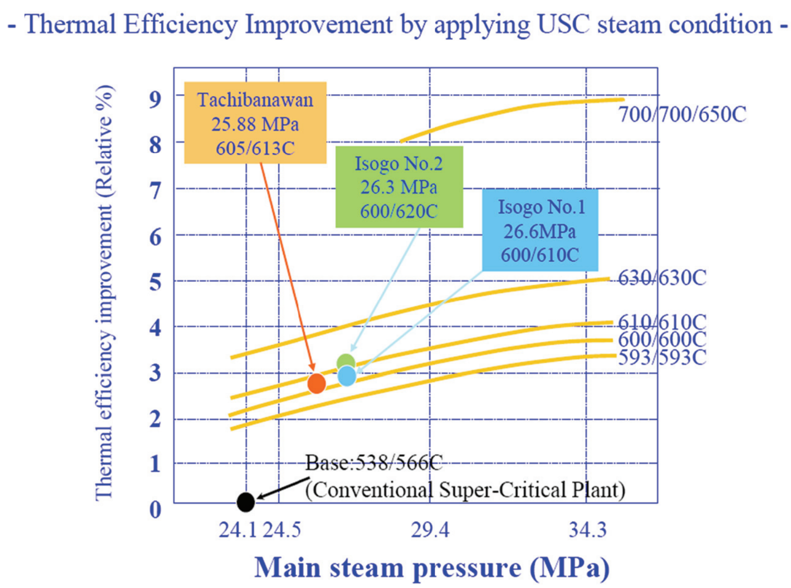


Fig. 6. Potential of thermal efficiency improvement with the steam condition.
Source: Chyou *et al*., 2012.

the parameters of temperature and steam pressure. It is clearly explained efficiency enhancement trend by applying USC (ultra-supercritical) steam condition. Furthermore, combined-cycle plants combine topping Brayton cycle and bottoming Rankine cycle, and the efficiency of both cycles can be improved. Figure 7 indicates the net plant efficiency of thermal power, in which the improvement of NGCC and IGCC (integrated gasification combined cycle) is mainly governed by the TIT (turbine inlet temperature) to GT that can enhance the performance in both the topping and bottoming cycles [Chyou, 2012]. For IGCC, system integration exhibits another dimension for efficiency enhancement.

Gasification-based system concept features multiple feedstock possibilities (e.g. coal, pet-coke, biomass, municipal solid waste (MSW), etc.) and flexible products via gasification process (electricity, chemicals, steam, H_2, etc.). Fraction

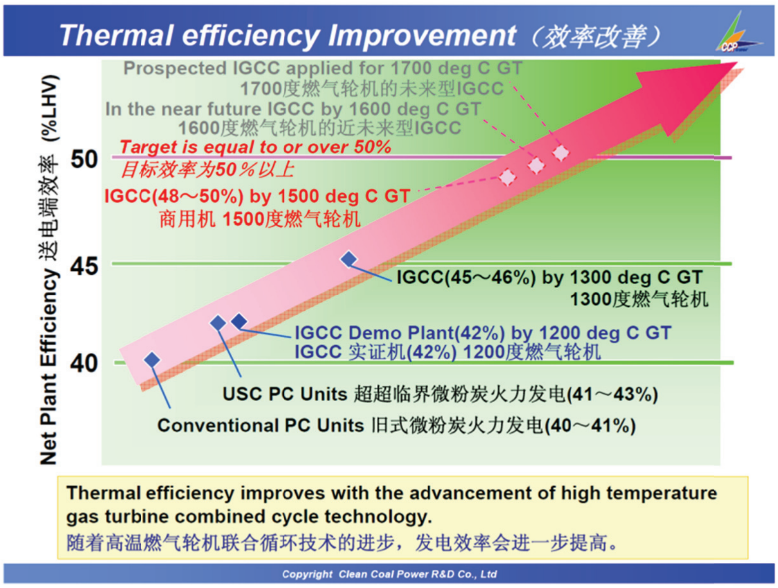


Fig. 7. Plant efficiency of thermal power.
Source: Chyou *et al*., 2012.

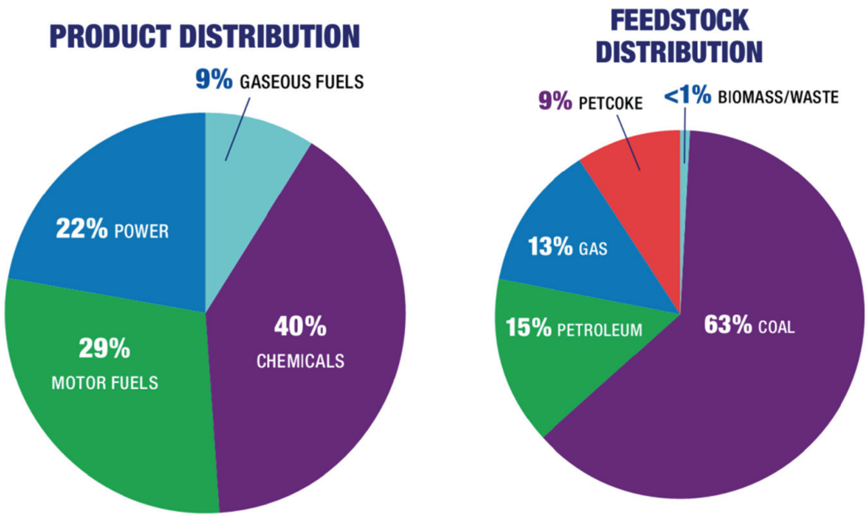


Fig. 8. Fraction of syngas utilization worldwide.
Source: GTC, 2013.

of syngas utilization worldwide is shown in Fig. 8. Major products are chemicals, while power occupies one-fourth. More than half of syngas is produced from coal [GTC, 2013].

Challenges of NGCC system in Taiwan mainly reside in the supply and cost of LNG (liquefied natural gas). Unstable supply of LNG has been one of the major concerns in Taiwan for years (Fig. 9). There is insufficient capacity of LNG stations, with operation buffer of 10D~2W for Taiwan Power Company (TPC) only (Table 3). Furthermore, lack of long-term LNG contracts might cause deficiency of gas supply. Domestic unit price of imported LNG is substantially higher than that of coal. LNG price is far more expensive than the NG counterpart of international market. For example, LNG import price has exceeded 13 USD/MMBtu since 2011, and the long-term LNG contract with Australia (20 years from 2013) costs 14.5 USD/MMBtu [Chyou, 2012]. Current LNG

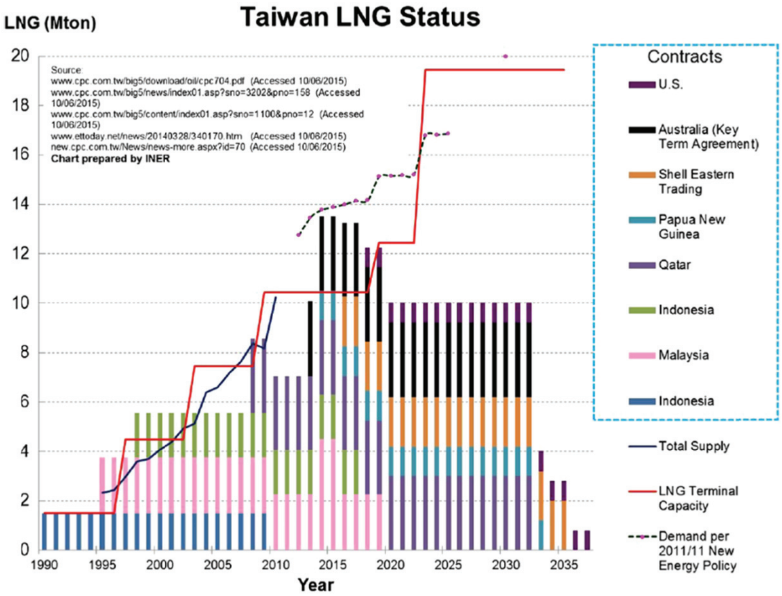


Fig. 9. Supply of LNG in Taiwan.
Source: Chyou, 2012; Recent data amended by this work.

Table 3. Reserve of different fuel in Taiwan

Fuel	Safety Reserve (Day)		Energy Density (kWh/unit)
	Statutory	Actual	
Coal	30	34	2,070/Ton
Gas	15	12.2	0.1/M^3
Oil	90	140	580/Barrel

Source: Chyou, 2012.

price has dropped below 10 USD/MMBtu, due to shale gas entering energy markets. However, lower reserve of imported LNG and possible cost fluctuation of LNG later might pose concerns for energy security in Taiwan.

To circumvent the aforementioned challenge, strategic planning for the establishment of "Regional Gasification Center/Park" would be a possible option. It is proposed to establish "Regional Gasification Center/Park" near LNG stations and coal harbors, including poly-generation coal gasification plants. Options for poly-generation and/or SNG (synthetic natural gas) integrate energy supply with industrial demand, promote integrated regional energy utilization, and enhance overall energy saving efficiency. It can also deliver supplementary gas source to nearby NGCC plants, to activate idled NGCC capacity.

2.2 Climate Change Issues

There have been diversified opinions about "Global Warming," whether it's on-going reality, scam of the century, or somewhat real but might be exaggerated? On October 26, 2015, an article in Scientific American (SA) revealed that Exxon knew about Climate Change almost 40 years ago [SA, 2015]. A new investigation shows that the oil company understood the science before it became a public issue and spent millions to promote misinformation. Exxon was aware of climate change, as early as 1977, 11 years before it became a public issue. Nevertheless, it is important to focus on the reality of Climate Change phenomena! Recently, the data from NASA turned to a stunning message: "Blowing away heat records," as shown

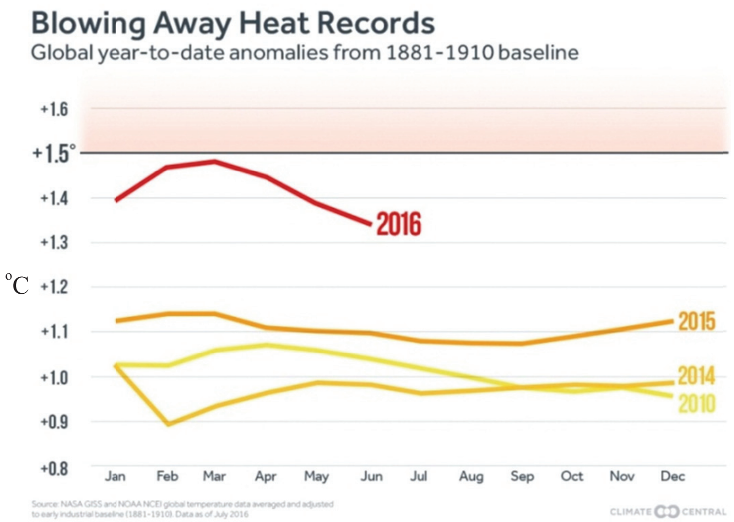


Fig. 10. Blowing away heat records.
Source: SA, 2016a.

in Fig. 10 [SA, 2016a]. July 2016 was the hottest month our planet has seen since we started recording temperatures 136 years ago [SA, 2016b]. Numerous information sources have been available in public domain, to which interested readers can refer for further phenomena and mitigation measures [e.g., WP, 2015; IPCC, 2014].

To mitigate emissions of "Greenhouse gases (GHGs)," worldwide efforts for environmental protection have been concluded in the "Kyoto Protocol," which had been activated since February 16, 2005. However, the first "commitment period" of the Kyoto Protocol was expired at the end of 2012.

After numerous negotiations among countries, consensus was finally achieved in the 21st Conference of the Parties (COP21) held in Paris, Dec. 2015. Prior to the conference, 146 national climate panels publicly presented draft national climate contributions (then called "Intended Nationally Determined Contributions", INDCs). These suggested commitments (now called NDCs) were estimated to limit global warming to 2.7 degrees Celsius (^{o}C) by 2100 [UNFCC, 2015a]. The expected key result was an agreement to set a goal of limiting global warming to less than 2^{o}C compared to pre-industrial levels. The agreement calls for zero net anthropogenic greenhouse gas emissions to be reached during the second half of the 21st century. In the adopted version of the Paris Agreement [UNFCC, 2015b], the parties will also "pursue efforts to" limit the temperature increase to 1.5^{o}C [Sutter & Berlinger, 2015]. Outline of international climate actions has been summarized by EPA [Chien, 2016].

Domestically, the GHG Reduction and Management Act has been issued in Taiwan since June 2015. This legitimated action set an ambitious goal for GHG mitigation in 2050, in accordance with the NDC as the intermittent control measures (Fig. 11) [Chien, 2016]. Hence, deep de-carbonization pathways projects (DDPP) should be widely assessed for implementation.

3. SUSTAINABLE DEVELOPMENT

Carbon management issues associated with climate change are so complicated. Hence, there is no single category of technology can accomplish the task alone; rather, portfolios of various options

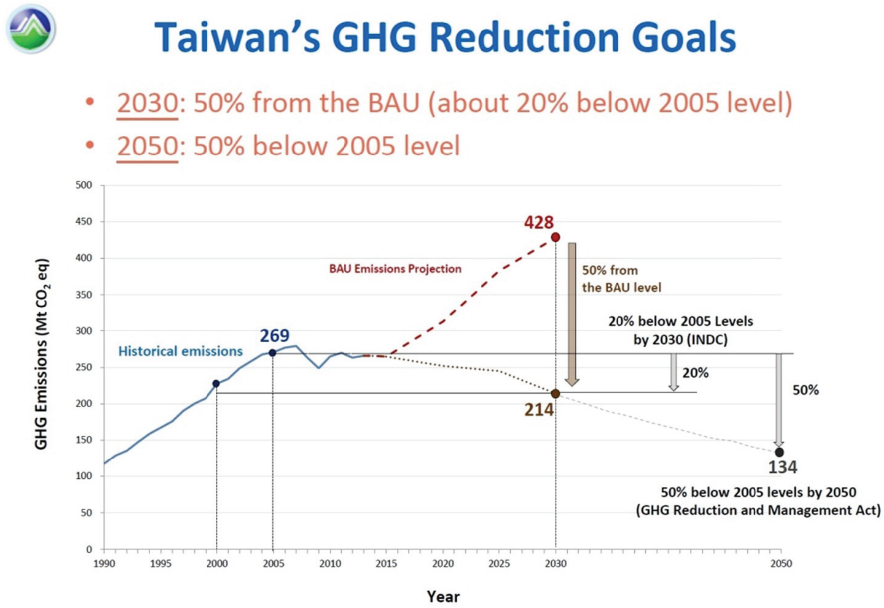


Fig. 11. GHG mitigation goal in Taiwan.
Source: Chien, 2016.

should be implemented. Similar to western legends, there is no silver bullet as way of killing werewolves or other supernatural beings.

3.1 R&D Measures

Following synergy of "*Abenomics*," three bullets should be implemented:

Bullet 1: Coal is still indispensible, both in Taiwan and worldwide.
(1) Coal facilitates preservation of energy security;
(2) Coal provides stable and affordable sources.

Bullet 2: HELE (High efficiency, low emission) technologies are crucial for clean utilization of carbonaceous fuel.
(1) *BAT (Best Available Technology)* improves efficiency and carbon footprint;
(2) *BACT* mitigates pollutant emissions.

Bullet 3: Energy industry is the prime mover for national development.

3.1.1 Bullet 1: Coal is still indispensible

Coal is still indispensible, according to new planning of Power Generation Portfolio in Taiwan. Since the inauguration of new government on 20 May 2016, the so-called "520 Energy Transition" has become a norm, which aims to achieve more "greener" energy by 2025. In the next ten years, renewables will be pushed up to ~20% of the electricity generation portfolio; more specifically, the installation capacity will occupy 53.1%, while the electricity generation account for 18.5%. Coal will be substantially reduced, but still remain at 27% of the electricity generation portfolio.

Table 4. "520 Energy Transition"

Type [%]	Coal	NG	Nuclear	Renewables	Pumped Hydro.	Others (Oil, CHP)
Y2015	44.6	31.4	14	4.1	1.2	4.7
Y2025	27	50	-	20	1	2

Source: CT, 2016.

Detailed figures of the transition are illustrated in Table 4 [CT, 2016]. Moreover, TPC's (Taiwan Power Company) power developing plan aims at retiring "ancient" coal- and oil-power, so newer advanced units offer better efficiency and lower COE.

Referring to ETP 2015, while generation from wind and solar technologies has grown annually at double-digit rates over the last ten years, electricity demand growth has largely been satisfied by fossil fuels. Addressing CO_2 emissions from thermal power plants fired with fossil fuels requires concerted action. In some cases, switching to lower carbon generation should be pursued, e.g., to electricity generation from gas or non-fossil sources, which is the scenario proposed by the "520 Energy Transition" in Taiwan. Nevertheless, energy security is one of the most critical issues to be addressed, which in turn makes coal as an essential part of domestic energy portfolio, though its share is projected to be declined.

Coal is still indispensible, according to future fossil energy demand and generation worldwide. US maintain a major coal fleet: coal-fired plants have been retarded since 2008; however, even with robust NG growth, coal will level off after 2018 [Smouse, 2015]. German coal fleet still dominates its power portfolio, in which renewables have been growing steadily since 2000, but coal-fired plants have maintained as a major portfolio ever since [Nieh, 2016]. Japan re-embraces coal power, which opens up its power retail market in April 2016, and plans to build 43 coal-fired plants or 20.5 GW of capacity [PEI, 2016a].

3.1.2 Bullet 2: HELE technologies are crucial

According to Japan EPA, HELE technologies emit 20-25% less CO_2/MWh than the average existing power station, and consume less fuel and emit fewer local pollutants [PEI, 2016b]. In addition, advanced gas turbine (AGT) is a candidate for future CCT. The J-type AGT employs TIT approaches ~1,700°C, and the efficiency surpasses 60+% (low heating value, LHV) with NG. Several multi-national original equipment manufacturers in Japan, US, Germany, etc., have devoted to developing world leading technologies in the fields of HELE and CCT. For example, an advanced poly-generation concept based on fuel gasification technology has been proposed, which allows stepwise integration of fossil and renewable energy and possibly up to 90% CO_2 reduction.

Figure 12 shows the evolution of power generation technology [Nieh, 2016]. In addition, analysis models of poly-generation process have been established at INER (Institute of Nuclear Energy Research) [Chen *et al*., 2012], with which the evaluation of integrated systems illustrates benefits of poly-gen plants. Comparing with IGCC reference plant, efficiency enhancement might be achieved through options of AGT, high-HV (heating value) coal, poly-gen., etc. Furthermore, carbon fixation in process (e.g., poly-gen with DME (dimethyl ether) exhibits another benefit for the latter option, as shown in Fig. 13.

Dilemma (pro and con) of carbon management issues has been encountered worldwide. On the PRO side, USDOE (United States Department of Energy) illustrates that if targeting well below 2°C global temperature increase, CCS will be needed for energy and industrial sectors, and negative emissions [Der, 2016]; similarly, IEA's perspective indicates that CCS will contribute 14+% of CO_2 mitigation portfolio per ETP 2015 [Lipponen, 2015]. Contrarily on the CON side, US government funding for commercial-scale CCS projects seems to be not likely in the near-term [Der, 2016]; while

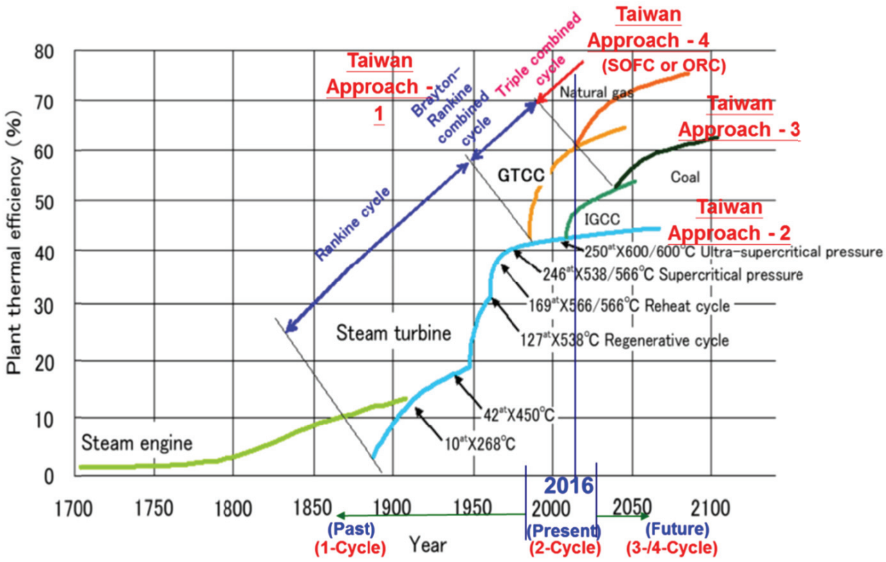
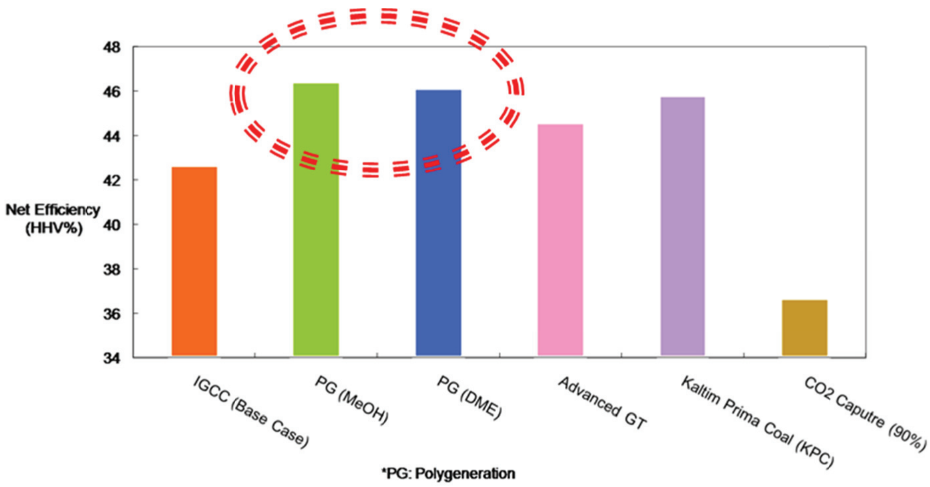
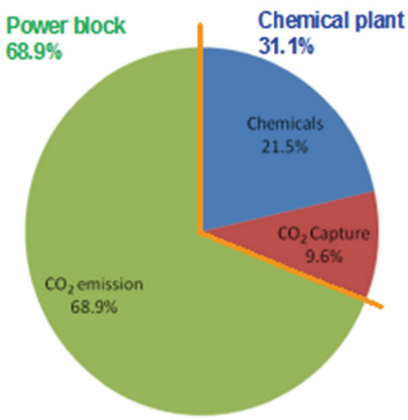


Fig. 12. Evolution of power generation technology.
Source: Nieh, 2016.



(a) Efficiency



(b) Carbon fixation in process

Fig. 13. Benefit analysis of Poly-gen plants.
Source: Chen *et al.*, 2012.

EU countries (e.g., Germany, United Kingdom, etc.) have suspended CCS demo projects indefinitely [The Telegraph, 2015]. Nevertheless, for the sake of sustainable development, precaution measures have to be pursued; from a progressive viewpoint, carbon capture ready (CCR) status will be a prerequisite at present, in order to implement transition to carbon capture, utilization and storage (CCUS) practice in the future.

3.1.3 Bullet 3: Energy industry is the prime mover

Energy industry is the prime mover, according to new planning of Power Generation Portfolio in Taiwan. Currently, the government is promoting the "5+2" Flagship Program to attract innovative technological R&D projects. Among the above program, green energy technology (GET) is one of the original five categories, and cyclic economy (petro-chemical) represents the other one of additional two strategic industries. To comply with the policy, an integrated conceptual process, namely "Green Refinery Applied To Cyclic Economy/Eco-system *(GREAT Cyc-Eco)*," has been proposed (Fig. 14). This concept integrates the aforementioned GET and cyclic economy. The aim of this concept is to forge a consistent key linkage from raw feedstock to end applications, and to promote next-generation GET industry through innovation. It exhibits the features to emulate the paradigm of refinery, execute a series of conversion processes in operating platforms, and trigger transition of domestic industry. Focusing on the above key linkage processes, it is also possible to incorporate external sources (e.g. renewables), and integrate through smart systems; then, industry eco-systems and sustainable living cycles complied with the concept of cyclic economy would be achieved.

Scenario of low-carbon energy industry, complied with COP21 and GHG Reduction and Management Act in Taiwan, will be illustrated in the following. Strategy to promote viable industry includes stepwise options that BAT & BACT improve efficiency and emissions, and enabling technologies offer potential long-term benefit. Progressive developing plans eventually would lead to DDPP in the long run: (1) Advancing "existing" coal power via USC + CCSU (carbon capture, storage and utilization);

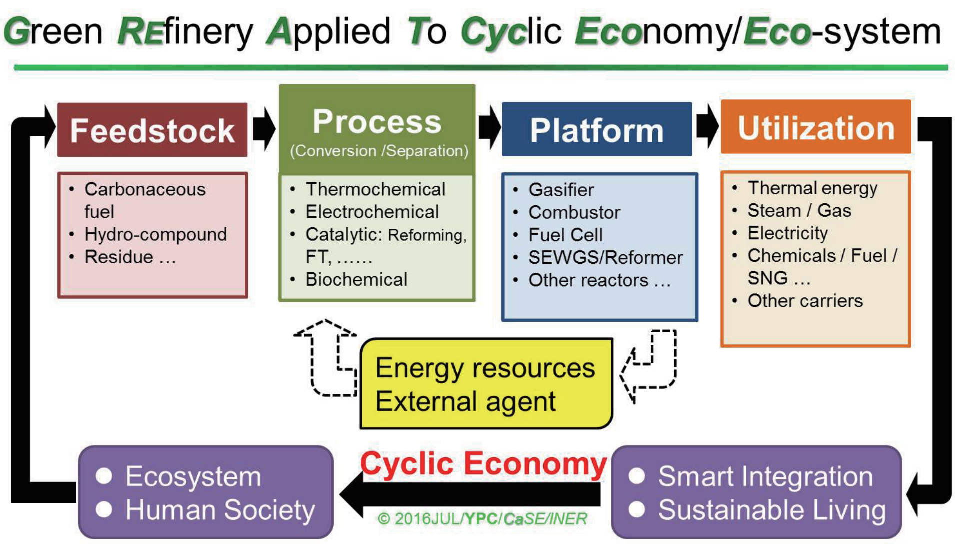


Fig. 14. Green Refinery Applied To Cyclic Economy/Eco-system.
Source: Figure prepared by this work.

(2) Commissioning gasification industry for poly-generation with Syngas/SNG + CCSU for power & petro-chemicals; and (3) Developing advanced triple- and quadruple-cycle systems integrated with deep de-carbonization pathways (long-term goals!).

New coal plants should exhibit high efficiency and low emissions, for which USC would be a near-term CCT option to retire ageing and less efficient coal units, as illustrated in Fig. 6. Although PC boilers have been widely operated with LRC in many countries, e.g., Germany, Australia, Poland, etc., domestic steam plants are all fed by HRC, which corresponds to the quality of imported coal. On the other hand, gasification features multiple feedstock flexibility, while syngas characteristics vary with operating conditions, type and quality of feedstock, etc. Hence, syngas conditioning process provides an option for tuning the properties to be complied with the requirements of downstream poly-generation applications. Moreover, pipeline would be most favourable for transporting gaseous fuel, e.g., NG, syngas, SNG, etc. However, such kind of infrastructure has not yet been available in Taiwan for importing gas from oversea sources; then, liquefaction turns out to be the option, which results in high overhead cost. Hence, it is feasible to commission gasification facilities for poly-generation in land as a mid-term CCT option.

3.2 Spiritual Thinking

There has been discussion about who is responsible for climate change, for which IEA perspectives indicate that climate change is caused by seven billion key individuals [Lipponen, 2015]. According to ETP 2014, the top ranking three categories in CO_2 Mitigation portfolio are Renewables (34%), End-use efficiency (33%), and CCS (14%). Energy conservation indeed offers appreciable potential. However, substantial adaption of living style would be needed! For renewables, integration of smart system turns out to be essential: i. e., Peak shaving (off-peak utilization), Load shifting (distribution managing), Storage system investing, COE escalating, etc.

4. SUMMARY & VISION

The so-called "520 Energy Transition" aims to achieve more "greener" energy by 2025, then substantial deployment of renewables to the electricity generation portfolio has become a norm. Extensive assessments on energy outlook and development trends in Taiwan are illustrated in this work, from the viewpoints of energy security, environment protection and economic growth. Furthermore, mitigation of greenhouse gas (GHG) emissions requires various portfolios; while clean utilization of coal can make significant contribution to the aforementioned options, and is the major focus of this paper. In summary, clean utilization of coal is essential for sustainable development and its implementation through progressive bullet points are proposed as follows: (1) coal is still indispensible, (2) HELE (high efficiency, low emission) technologies are crucial, and (3) energy industry is the prime mover for national development. It is expected that the statements addressed above can provide as reference to future domestic strategy, which will achieve green energy solutions as well as preserve national competitiveness.

Energy technology is an inter-disciplinary expertise that relies on seamless integration of all stakeholders. "Green" Energy Technology fulfils both environmental protection and economic development, as well as preserves sustainable development, for the "Global Village": More specifically, gasification-based technology is an essential and critical option, while HELE is crucial for clean utilization of carbonaceous energy resources. Finally, a statement in recent US Presidential campaign would be quotes as the vision of such complicated issues: "I Believe in Science! I believe that climate change is real and that we can save our planet while creating millions of good-paying clean energy jobs."

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因應國內能源轉型煤炭潔淨利用之策略規畫

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摘 要

在本世紀中，化石燃料仍是人類社會能源供應之主流；其中以煤炭為大宗，其蘊藏量佔地球資源50%以上，預估可使用超過110年。煤炭供給29%全球初級能源，其總發電量佔比高達41%。然而，大氣中二氧化碳(CO_2)濃度攀升無可避免，除非能源系統降低其碳排放。此外，煤炭利用向來被視為環境衝擊的主要元兇，排放大量的污染物，如NOx、SOx、懸浮微粒等。當前可預見人類對煤之依賴不可能大幅戒絕，但可使其潔淨利用；換言之，淨煤技術將容許我們持續使用地球的煤炭資源。溫室氣體減量須經由各類技術組合方可克竟全功，而煤炭潔淨利用可提供重要貢獻，亦為本文之主題。台灣為人口稠密、資源缺乏之島國。在2015年，我國進口能源依存度為97.53%，而44.58%發電量來自燃煤，其二氧化碳排放占總量比例達三分之一。有鑑於此，煤炭潔淨利用實為一項必須高度優先關注之議題。我國於2015年正式通過「溫室氣體減量及管理法」，條文中明確規範我國溫室氣體長期減量目標為2050年的溫室氣體排放量要降為2005年的50%以下。可預期我國產業對於淨碳能源之應用亦將有大量之需求出現。因此，以永續方式利用煤炭並將環境衝擊減少到最低限度之淨煤技術將是絕佳選項；預期可以利用較少的投資創造更大之經濟價值，以確保邁向一個永續之未來。

關鍵詞：煤炭利用、淨煤技術、效率、氣化、排放

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