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The Past, Present and Future of Nuclear Power in Taiwan

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Introduction

Nuclear power is a mature technology that has been used effectively and successfully for more than 50 years. Faced with increasing energy demands, concerns over climate change and dependence on overseas supplies of fossil fuels, many countries have turned to nuclear power. Nuclear power provides countries with energy security and generates power without emission of polluting products or greenhouse gases (GHG). Furthermore, the safety record of nuclear power is superior to that of other major energy sources. Undoubtedly, nuclear power will play a major role in future power generation.

Taiwan is a country that lacks domestic energy resources and nuclear power is a viable energy option. Its government's interest in nuclear power dates back to 1955. The world oil crisis in the early 1970s led to the first phase of Taiwan's nuclear energy development, in which four nuclear power plants (NPPs) with eight units were planned and consequently built. The building of the first three nuclear power stations went smoothly and since then nuclear energy has made a significant contribution to Taiwan's economic growth. In 2007, NPPs produced 38.96 TWh of electricity, accounting for 19.3 per cent of the total electricity generation and 7.97 per cent of primary energy supply in Taiwan. In 2008, the total installed nuclear capacity was 5144 MWe, or 13.5 per cent of Taiwan's installed electricity generation capacity. The cost of nuclear power is NT$0.63 per kilowatt hour (kWh), which also includes a contribution of NT$0.17/kWh to nuclear waste management and the decommissioning of plants, and it is significantly lower than that of electricity from fossil-fuelled power plants. The fourth NPP (units 7 and 8 of the Taiwan Power Company – TPC) was proposed and approved by the government in 1980. Its construction, however, did not start until August 1999. Ten years later, it was still not completed. Over the past 20 years, the building of the Lungmen Nuclear Power Station has been one of the major public controversies and a centre of debate by the two rival political parties in Taiwan, Kumintang (KMT) and the Democratic Progressive Party (DPP). After it took

over as government in May 2000, the DPP adopted 'A Nuclear-Free Homeland' as a major government policy. The Legislative Yuan passed the Basic Environment Act on 11 December 2002. Article 23 of the Act states: 'The government shall establish plans to gradually achieve the goal of becoming a nuclear-free country.'

Two developments, the price hiking of fossil fuel starting in 2004 and the Kyoto Protocol which became effective in February 2005, convinced policy makers around the world to think seriously of the 'nuclear option'. In 2008, the newly elected KMT government acknowledged the importance of nuclear energy to the future economic development of the country. In the closing ceremony of the 2009 National Energy Conference of Taiwan, Prime Minister Dr Chao-Shiuan Liu stated that nuclear power was an important energy resource that would help the country achieve its goal of building a 'low-carbon homeland'.

This chapter discusses the experience gained and lessons learned in the development of nuclear power in Taiwan.

The necessity of nuclear power

The world's population stands at around 6.6 billion and it is estimated that this number will rise to 9 billion by 2050. A burgeoning world population will require vast amounts of energy to provide fresh water, energise factories, homes and transportation, and support infrastructure for nutrition, education and heath care. Statistics show that 1.4 billion people (or 20 per cent of the world's population) in developed countries consume 80 per cent of the world's resources, while 1.6 billion people have no access to electricity and 2 billion more have only limited access. Numbers of the same scale apply to clean water as world water tables fall under the demands of expanding human consumption. As a remedy, large-scale desalination of seawater is the only solution. The process is energy-intensive and this will compound global energy demand. It is generally believed that in less than ten years the energy consumption of developing nations will equal that of countries we now refer to as 'developed'.

A tremendous amount of energy is required to support the continuing development of human civilisation. In 2007, over 81 per cent of the world's primary energy supply (12,029 million tonnes of oil equivalent, Mtoe) was derived from fossil sources (IEA 2009b). It is estimated that global energy consumption will be doubled by 2050. Fossil reserves are limited and, more importantly, the burning of fossil fuel generates carbon dioxide. Climate change is real and the energy sector accounts for 84 per cent of global CO_2 emissions and 64 per cent of the world's greenhouse gas emissions. The consensus is that containing the Earth's atmosphere to no more than 450 parts per million (ppm) of carbon dioxide is necessary if we want to avoid catastrophic disasters. 'Meeting a 450 Scenario requires a fundamental change in our approach to producing and consuming energy, whether it is

re-orienting our power generation mix away from fossil fuels and towards nuclear and renewables, maximizing the efficiency of our vehicles, appliances, homes and industries, or developing revolutionary technologies for the future, almost all potential sources of lower emission will need to be tapped' (IEA 2009b: 168).

Renewable energies, such as solar, wind, tidal and geothermal, all have roles to play in future energy supply. Energy conservation and improving energy efficiency will also help deal with climate change. But none of these tools can alter the fact that nuclear power offers the one available technology that can energise a thriving economy without destructive environmental impacts.

Status of nuclear power worldwide

The world's first civilian NPP, with a capacity of 6 MWe, reached its criticality at Obninsk in the former Soviet Union on 1 June 1954. The first pressurised water reactor with rated power of 60 MWe began its commercial operation at Shippingport Pennsylvania, USA, in 1957 (IAEA 1997). Today, 70 years after the discovery of nuclear fission and about 50 years after the operation of the first nuclear power reactor, there are 439 reactors in operation in 30 countries. The total installed capacity is 372 GWe. The total amount of electricity generated was 2,719 TWh in 2007, which is about 16 per cent of the world's total electricity generation and about 6 per cent of its primary energy consumption (IEA 2009a: 15–16). Civil nuclear power reactors have accumulated more than 12,600 reactor-years of operation experience. At the beginning of 2010, 57 reactors of 53,505 MWe are under construction in 15 countries (IAEA 2010a).

The installation of nuclear capacity rose relatively quickly in the early years, from less than 1,000 MWe in 1960 to 100,000 MWe in the late 1970s, and over 310 GWe by the end of the 1980s. It rose by only 18 per cent between 1989 and 2008 to 371 GWe (Table 8.1). Indeed, more than two-thirds of all nuclear plants ordered after January 1970 were eventually cancelled (IAEA 1997).

Nuclear power is a controversial issue and anti-nuclear advocates express their multiple concerns ranging from: the fear of possible nuclear accidents,

Table 8.1 Reactors in operation in the world

	1960	**1970**	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2008**
No. of units	15	84	169	245	363	416	434	435	441	438
GWe	0.9	19.0	72.7	135.3	248.1	320.5	342.2	350.6	368.1	371.6

Source: IAEA (2009: 21).

radiation leaks, nuclear proliferation, and nuclear waste production, transport and final storage. The Three Mile Island incident of 1979 and the disaster of the Chernobyl nuclear power plant in 1986 played important roles in stopping the construction of new plants and in triggering the actions to start nuclear power phase-outs in several countries. Nevertheless, the 1973 oil crisis had a significant impact on energy policies in countries such as France, Korea and Japan, which relied heavily on imported primary energy for electric generation. The shares of nuclear power in the electricity generation in these countries were 77 per cent, 35.3 per cent and 27.5 per cent, respectively, in 2007.

After a long period of decline in the construction of NPPs, lately there has been a renewed interest in nuclear energy. Concerns about energy security and climate change are the two main reasons for the renewed interest. In 2002, the parliament in Finland decided to grant a licence for the construction of a fifth nuclear power station. This was the first such decision to build a new NPP in Western Europe for more than a decade. Many countries in Asia, such as Japan, China and India, are more active in expanding their nuclear energy.

The nuclear renaissance has revived debates about nuclear waste and safety issues. Some developing countries that plan to go nuclear have very poor industrial safety records and problems with political corruption. Most countries with nuclear power do not have a final solution for the disposal of nuclear spent fuel. Burying the spent fuel deep underground is the common solution, but no such long-term waste repositories yet exist. Some anti-nuclear advocates also raise concerns that the expansion of nuclear power will lead to a significantly increased risk of nuclear weapons proliferation and nuclear terrorism.

Status of nuclear power in Taiwan

Taiwan is a highly populated island country, with around 0.3 per cent of the world's population living on 0.6 per cent of the world's land. It consumes around 1 per cent of the world's total energy and 1.3 per cent of electricity. In 2007, electricity consumption per capita in Taiwan was 10,216 kWh, 3.7 times that of the world average and 21 per cent higher even than the OECD's average (IEA 2009a). The primary energy resources of power generation are 43.35 per cent coal, 21.39 per cent gas, 19.30 per cent nuclear, 5.86 per cent co-generation and 5.76 per cent oil. Almost all energy consumed in Taiwan is imported and hydro makes up the rest, but hydro heavily depends on weather conditions (Table 8.2).

The total amount of carbon emissions in Taiwan was 276 million tonnes in 2007 and its per capita emission 12 tonnes, three times the world's average (IEA 2009a). According to the International Energy Agency (IEA), Taiwan ranks 22nd for the total amount of CO_2 emissions and ranks 16th in CO_2

Table 8.2 Energy mix in Taiwan

Year	Oil (%)	Coal (%)	Nuclear (%)	Natural gas (%)	Hydro (%)
1990	55.4	23.3	13.9	3.8	3.47
1995	54.3	26.2	11	5.8	2.7
2000	50.9	31.1	9.1	6.8	2.1
2005	51.3	31.9	7.3	8.0	1.45

Source: Bureau of Energy, Ministry of Economic Affairs (2008).

emission per capita. In 2008, Taiwan ranked number one in the world in relation to its annual increase rate of CO_2 emission per capita.

In 2008 Taiwan had a total installed nuclear capacity of 5,144 MWe, accounting for 13.5 per cent of the total generating capacity. This was a significant decline from the peak in the mid-1980s when nearly 50 per cent of the country's total electricity was from NPPs (personal communication with Taipower staff). The Taiwan Power Company (Taipower) owns and operates six nuclear units and has another two under construction and both were expected to be commissioned in 2010 (Table 8.3):

Table 8.3 Nuclear power plants in Taiwan

Name	Type of reactor	Capacity (MWe)	Date of commissioning
Chin Shan 1	BWR	636	16 November 1977
Chin Shan 2	BWR	636	19 December 1978
Kuosheng 1	BWR	1019	21 May 1981
Kuosheng 2	BWR	985	29 June 1982
Maanshan 1	PWR	956	9 May 1984
Maanshan 2	PWR	921	25 February 1985
Lungmen 1	BWR	1350	Under construction
Lungmen 2	BWR	1350	Under construction

Note: BWR: boiling water reactor; PWR: pressurised water reactor.
Source: IAEA (2010b).

The capacity factor of these six operating units over the past five years is 88.5 per cent. The generation cost of nuclear power was 0.63 NT$/kWh in 2005, which included a contribution of 0.17 NT$/kWh to the nuclear waste management and decommission of the plant. About 16 per cent of the total cost was on nuclear fuel, of which 55 per cent was for purchasing uranium ore.

The fourth nuclear power project (Lungmen) started construction in August 1999 and ten years later, it is still not completed. Indeed, the project has been heavily debated for the past 20 years by the two rival political

parties – KMT and DPP. This ill-fated project provides a valuable lesson for countries that are interested in developing nuclear power: that public acceptance and consensus among political parties are crucial for a successful deployment of nuclear power. The difficulties in the construction of the Lungmen nuclear power station of Taiwan are discussed later in this chapter.

Development of nuclear power in Taiwan

Taiwan launched its nuclear programme in 1955 after it signed a bilateral agreement with the USA on the peaceful use of atomic energy. The Atomic Energy Council, Taiwan (AEC) was established in the same year at a ministerial level, under the Executive Yuan, to coordinate the affairs related to nuclear energy and the government initiated a plan to construct a research reactor at National Tsing Hua University located at Hsin Chu, Taiwan. Nuclear development in Taiwan was government-led and government-financed as was the case in South Korea. All six nuclear reactors in operation now were constructed and completed under the authoritarian regime. The anti-nuclear movement emerged at the same time as the democratic movement spread across the island and since then nuclear power projects have been subject to increasing public scrutiny. Indeed, they have been one of the most contentious issues between the two rival political parties.

Taipower is a state-owned public utility, responsible for the production and distribution of electricity in Taiwan. Nearly two-thirds of Taiwan's power stations are owned by Taipower. In 1955, Taipower established an Atomic Power Research Committee, which was responsible for collecting information on nuclear power, sending experts to foreign countries to gain an understanding of the latest developments in nuclear power, exploring the possibility of building a nuclear industry in Taiwan, and drafting and executing training programmes. Deploying nuclear power is a complicated issue. The historical lessons in Taiwan's development of nuclear power are presented in the following sections.

Building the manpower required for the deployment of nuclear power

The Atomic Power Research Committee of Taipower initiated a long-term training programme in order to acquire the manpower required for the deployment of nuclear power long before the construction of the first NPP. Between 1968 and 1981, Taipower sent 583 experienced plant construction engineers and fossil power plant staff to foreign countries to learn how to build and operate NPPs. The host institutes of the training programme included universities, vendors of nuclear steam supply system (NSSS) and nuclear power utilities. Later, the training programme was transplanted back to Taiwan. The Department of Nuclear Engineering of National Tsing Hua University played a major role in setting up the domestic training programme of nuclear engineers.

National Tsing Hua University was re-established in Taiwan in 1955 and the major focus of the university at the time was nuclear science and engineering. The university created the first research nuclear reactor in the country. The Institute of Nuclear Science (master programme) was founded in 1956, which was the first academic unit at the university. The construction work for the Tsing Hua Open-Pool Reactor (THOR) began in December 1959 and the first self-sustained nuclear chain reaction was reached on 19 April 1961. This was the country's first step towards the nuclear era. The university established undergraduate and master's programmes in the Department of Nuclear Engineering in 1964 and 1970, respectively, and doctoral programmes in 1980. In 1992, the Institute of Nuclear Science evolved into the Department of Nuclear Science to include undergraduate education. Because of the stagnation of nuclear power around the world, and in Taiwan itself, the Department of Nuclear Engineering was changed to the Department of Engineering and System Science (ESS) in 1997 and the name of the Department of Nuclear Science was changed to the Department of Biomedical Engineering and Environmental Sciences in 2006. In response to the nuclear renaissance and the renewed interest in the country for nuclear power, the university re-established the Institute of Nuclear Engineering and Science in 2007.

The graduates of these programmes have played a major role in the nuclear development in Taiwan. Most of the managerial positions in the nuclear branch of Taipower and in the regulatory body (the AEC) of government are held by the alumni of the department. Human capital is the key to a successful nuclear energy programme in all countries wishing to develop and expand nuclear energy programmes.

Building nuclear power plants

In the early 1960s, Taipower incorporated nuclear power in its long-term planning for power grid construction. The site selection process of an NPP was initiated in 1965. With the assistance of experts from the International Atomic Energy Agency (IAEA) and an engineering consulting company from the USA, several potential sites were identified. In the first phase of the nuclear power development plan, it was decided that four plants and eight nuclear units were to be built. Each site would be able to host more than two units. In total, around 20 units were planned for the four selected sites. The construction of the first nuclear power station in Taiwan, Chinshan, started in November 1970. The Atomic Power Research Committee of Taipower evolved into the Division of Atomic Power in 1972. Construction on the second, Kuosheng, and the third, Maanshan, nuclear power stations was started in August 1975 and April 1978, respectively. A fourth NPP was proposed in May 1980 and was approved soon after by the government. The project, however, was postponed following the economic slow-down after the second oil crisis in 1982 and the consequent decline in electricity demand.

Table 8.4 Schedule and budget of Taipower's nuclear power plants

Unit 1		**Chinshan**	**Kuosheng**	**Maanshan**
Date of commercial operation	Scheduled	Mar 1975	Apr 1980	Feb 1984
	Actual	Dec 1978	Dec 1981	Jul 1984
Budget Billion NT$	Original	12.80	21.96	35.77
	Actual	29.62	63.04	97.44

Source: Personal communication with Taipower.

Table 8.5 Median construction time span in the world, 1976–2008

	1976–80	**1981–85**	**1986–90**	**1991–95**	**1996–2000**	**2001–05**	**2006–08**
World	74	99	95	103	146	64	80
Taiwan	64	72					

Source: IAEA (2009: 23).

Like many nuclear power projects around the world at the time, the nuclear power projects in Taiwan also suffered significant schedule delays and an escalation of the costs (Table 8.4).

Construction time delay in Taiwan was nearly as bad as the world average (Table 8.5), but the cost overrun raised serious concerns. Furthermore, the construction schedule delays for the fourth plan (Lungmen) until 2009 were already double the construction time span in other parts of the world.

There are several major players in the construction of NPPs: owners, vendors of NSSS, vendors of turbines and generators, suppliers of key components, an engineering consulting company that is responsible for the detailed design of the plant, constructors, the company in charge of project control and management (PCM) and the regulatory agency of the government. Any developing country that is considering nuclear power must be aware that the risk – the construction of a nuclear power station will not be completed on schedule and on budget – is very high. The experience and capability of the company in charge of PCM play a vital role in the success of a project.

Operation of nuclear power plants

Operating an NPP requires a great deal of experience and the power industry has had to come to terms with these difficulties. One lesson learned from the Three Mile Island accident in 1979 is that better management of nuclear plants is vitally important for their safe operation. Safety measures must ensure that a plant shuts down automatically if there is a malfunction of the sub-system or if there is any violation of normal procedures.

The capacity factor of a nuclear plant is the most important factor in determining the generation cost of a plant. Continuing operation of a nuclear

Table 8.6 World average factors of nuclear power plants, 1990–2008

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008
%	72.9	77.7	83.6	85	84.6	81.7	84	84	83.9	82.6	80.8

Source: IAEA (2009).

plant is the key to its safety and therefore efficiency. This explains the steady increase in capacity factor in all NPPs around the world after the Chernobyl disaster in 1986. From 1990 to 2008, the world's nuclear generation capacity expanded by 51 GWe (23 per cent, due to both the net addition of new plants and the up rating of some established ones) and electricity production rose by 708 TWh, an increase of 37.5 per cent (IAEA 2009: 19). The relative contributions to this increase were new construction (36 per cent), power up rating (7 per cent) and increase in capacity factor (57 per cent). Indeed, the world average utilisation rate of NPPs increased from merely 73 per cent in 1990 to 81 per cent by 2008 (Table 8.6). Almost one-third of the world's reactors have capacity factors of more than 90 per cent, and more than two-thirds are higher than 75 per cent, compared with about 25 per cent of NPPs operating above that level in 1990.

In Taiwan, the capacity factor of the six nuclear power reactors improved from about 70 per cent in the mid-1980s to the current 90 per cent. Other indicators can be used to measure the performance of an NPP including the number of scrams (emergency shutdowns of a nuclear reactor), the collective dose (a measure of the total amount of effective dose multiplied by the size of the exposed population), the amount of low-level waste generated, and the fuel reliability. The number of scrams dropped from the peak of 30 in 1984 to only one in 2004 and 2–3 in the last two years.

The significant improvement in Taipower's operation of nuclear plants over the years can be attributed to pressure from anti-nuclear advocates and organisations. Taipower has implemented several initiatives to promote a safety culture among workers and engineers in the nuclear sector. The philosophy and strategy for operating an NPP and a fossil power plant are very different. The campaign for better industrial safety, radiation safety and nuclear safety is a never-ending process. To control nuclear power requires new managerial concepts and a new working culture.

Management of low-level radioactive waste

The operation and decommissioning of NPPs generate low-level radioactive wastes. Various applications of radiation – such as industrial, medical and research – also generate nuclear wastes. Low-level radioactive wastes need to be isolated for several hundred years. Technically, long-term storage of low-level radioactive waste is available and feasible. There are 74 low-level waste repositories in operation in 34 countries. Nevertheless, politically the

site selection process is a controversial and time-consuming issue and public acceptance is the dominant factor in making a final decision.

Up to 2008, Taiwan had accumulated 188,434 drums (55 gallons) of low-level waste, with 90 per cent of the waste generated from NPPs. The waste drums are either stored in an interim storage facility located on Orchid Island or in a warehouse on the site of the NPPs. Orchid Island, with a size of 45.7 square kilometres, is located in the Pacific Ocean 91 degrees south-east of Taitung. It has 4,183 residents (2009 February). Most of the residents (77 per cent) are Aborigines. The decision to construct an interim storage facility of low-level waste at Orchid Island was made in the late 1970s and the facility began operation in 1982. The government chose Orchid Island as the location on which to build the interim storage of low-level waste because there is a deep oceanic trench in the region and the geology of Orchid Island is suitable for building the final disposal repository. At the time, dumping solidified low-level nuclear waste into the ocean was not formally forbidden by international law.

In the 1990s, local residents and anti-nuclear activists organised protests against using the island as a deposit site for nuclear wastes. The shipment of low-level waste to the site was made in 1996. Closing the facility and shipping out all the waste were two of the issues debated during the construction of the fourth NPP. Taipower once promised to ship the low-level waste out from Orchid Island by 2002, but it broke the promise because it failed to secure a potential repository site at a small island near the coast of mainland China.

It is estimated that to store the total amount of low-level nuclear wastes from NPPs of Taipower would require an area of 1 square kilometre for the repository. For a highly populated island, this becomes a difficult challenge. Taipower, under the supervision of AEC Taiwan, initiated a process to identify potential sites for the final repository, and would like to have a repository built by 2016.

Over the past 20 or so years, Taipower and AEC have spent a great deal of effort finding a site for the repository of low-level waste. Various criteria were set by a special committee for the site selection processes. From the initial three potential sites, the government chose two sites for submission to a referendum of local residents in June 2010. Without support from other branches of the government and politicians of the ruling party, the site selection of a low-level waste repository is a process that never ends. Site selection for nuclear waste deposit is more political than technical or economic in nature.

Management of spent fuel

One challenge all countries wishing to develop nuclear energy programmes must face is what to do with the spent fuel discharged from nuclear power reactors, which needs to be managed with great care. The spent fuel

contains a large amount of uranium and plutonium that are valuable energy resources. Reprocessing spent fuel was abandoned in the 1970s in the USA because of the economic costs and concerns about nuclear proliferation. The American government opted for the open ('once-through') cycle. The spent fuel was not processed and currently is stored on site. It was proposed to build a permanent geologic repository facility in the Yucca Mountain in Nevada, and the facility was scheduled to become operational in 2020. However, the project has encountered significant delays. Currently, the amount of spent fuel already discharged in the USA is approaching the legal capacity of Yucca Mountain and the Obama Administration announced officially that the Yucca Mountain site would not be put into operation.

France, on the other hand, chose the 'closed fuel cycle' at the beginning of its nuclear programme. The closed fuel cycle strategy allows the extraction of remaining fissile material (uranium and plutonium) from the spent fuel and the recovered fissile materials are then recycled. At the same time, the volume and radio-toxicity of the ultimate waste are significantly reduced. The nuclear fuel cycle policies adopted by Japan, Switzerland, Russia, India and China chose to reprocess their spent fuels, while many other countries have adopted a 'wait and see' strategy and store the spent fuel for an indefinite period.

Of the 10,000 tonnes of heavy metal discharged annually from nuclear power reactors around the world, only approximately 30 per cent has currently been reprocessed. The total amount of spent fuel cumulatively generated worldwide by the beginning of 2004 was close to 340,000 tonnes of heavy metal, of which only 90,000 tonnes has been reprocessed. The annual discharge amount is estimated to increase to 11,500 tonnes of heavy metal by 2010.

Projections are that the world energy demand will more than double by 2050, and the expansion of nuclear energy is key to meeting this demand while reducing pollution and the emission of GHG. Early in 2006, the USA decided to revise its back-end policy of nuclear power and to consider recycling as part of its nuclear strategy through a US Department of Energy (DOE) Global Nuclear Energy Partnership (GNEP) initiative. GNEP aims for a system of industrial services and supplies guaranteed to support the fully controlled expansion of nuclear power across the world, which complies with non-proliferation requirements. Through this initiative, the US Administration confirms that nuclear power must play a major role in meeting the growing demand for energy around the world. It also constitutes recognition of treatment and recycling, which aims to recover the energy content of spent fuels and minimise the amount of final high-level waste as a solution for the sustainable development of nuclear power. On 21 May 2007, five countries with major nuclear power programmes (China, France, Japan, Russia and the USA) agreed on a joint statement of principles on the GNEP. This joint statement affirms a common vision of 'expansion

of nuclear power, realising its contribution to sustainable development and assistance in meeting the worldwide growing energy demand'. In June 2009, the US DOE announced that it is no longer pursuing domestic commercial reprocessing, and had largely halted the domestic GNEP programme of the USA. Nevertheless, they indicated that research would continue on proliferation-resistant fuel cycles and waste management.

Taiwan adopted nuclear power technology from the USA. When nuclear power was first introduced, the policy makers envisioned that the USA would take back the spent fuel for reprocessing. Because there is great uncertainty in pursuing a closed fuel cycle, the Taiwan government decided to dispose of the spent fuel directly in a repository. Taipower started a long-term, multi-phase research and development programme for the final disposal of nuclear spent fuel in May 1986. In accordance with the Nuclear Materials and Radioactive Waste Management Act 2002, Taipower submitted a Programme Plan for Final Disposal of Spent Nuclear Fuel to the AEC in 2004. The AEC approved the plan in July 2006. According to this plan, the spent fuel disposal programme would be carried out in five phases:

- Potential host rock characterisation and evaluation (2005–17).
- Candidate site investigation and confirmation (2018–28).
- Detailed site investigation and testing (2029–38).
- Repository design and licence application (2039–44).
- Repository construction (2045–55).

Currently, all the spent fuel assemblies are stored in the spent fuel pools of an NPP. At the end of September 2007, the total inventory of spent fuel amounted to 13,666 fuel assemblies, containing about 2787 tonnes of uranium generated and stored on site. The spent fuel pool capacities of the two earlier boiling water reactor (BWR) plants are not large enough to cover the 40-year operation of the plants. For Chinshan NPP, it was expected that the pools would lose full core offload capability by March 2010. The interim storage of spent fuel in dry storage casks is planned for these plants. The construction of the dry storage cask facility faces strong opposition from local municipal government, local residents and anti-nuclear advocates. The licence for the construction is in the hands of the governor of the local municipal government (Taipei County), which demanded Taipower and AEC specify a firm target date to ship out spent fuel before the construction permit was granted. The continued operation of the existing facilities is jeopardised by the lack of a clear plan for nuclear spent fuel management that can be trusted by the public.

The back-end fund of nuclear power

The nuclear back-end fund covers the cost of the final disposal of low-level waste: packaging; transport; interim storage and final disposal or

reprocessing of spent fuel; decommissioning of Taipower's nuclear facilities; and disposal of decommissioning waste. The nuclear back-end fund for Taiwan was established in 1986 and is being managed by an ad hoc committee under the Ministry of Economic Affairs, which consists of 13 members from government organisations and academic institutes. The total cost of six operating units was estimated to be NT$275 billion (about US$8.3 billion) at the currency value of 2001. Of the estimated cost, 60 per cent is associated with the interim storage and final disposal or reprocessing of spent fuel, and this estimated cost will be updated periodically. The rate of the back-end fund was NT$ 0.17/kWh in 2009, and can be adjusted annually so that it would adequately accommodate cost inflation. As of the end of June 2009, the total amount of the fund topped NT$196.2 billion (about US$5.9 billion).

Regulatory agency

The Atomic Energy Council (AEC) was founded in 1955 at the ministerial level under the Executive Yuan and is the sole authority within the central government directly overseeing atomic energy-related affairs. The council members consist of ministers of different branches of central government and scholars from universities. The primary mission of AEC is to protect public health and safety, and the environment from the effects of radiation from nuclear materials and facilities. The organisations of the AEC consist of the Department of Planning, the Department of Nuclear Regulation, the Department of Radiation Protection, the Department of Nuclear Technology, the Radiation Monitoring Centre, the Fuel Cycle and Materials Administration and the Institute of Nuclear Energy Research (INER). The missions of these organisations are developing and enforcing regulations, conducting R&D of nuclear technology, protecting against natural and man-made ionising radiation, overseeing the handling and final disposal of nuclear waste and coordinating international cooperation on nuclear energy. The National Nuclear Emergency Response Centre, led by the AEC minister, oversees offsite nuclear emergency preparedness and management, while the facility operator (Taipower) takes charge of the on-site mission. The Fuel Cycle and Materials Administration of AEC is the government organisation in charge of the management of nuclear waste.

INER is a national research institute and is the technical arm of the regulatory agency. INER has more than 1,000 employees and also plays a role in the technical support for the operation of the Taipower NPP.

Taiwan adopted its nuclear power technology from the USA, and its regulatory system is consequently directly transplanted from the USA. In the early days of the development of nuclear power in Taiwan, AEC did not have sufficient manpower and capabilities to conduct the review of the 'Preliminary Safety Analysis Report', to issue the construction permit and review the 'Final Safety Analysis Report' and to issue the operation licence. The

review work was contracted out to US engineering consulting companies. In the early 1980s, after four to five years of commercial operation of the first nuclear power unit, the Department of Nuclear Regulation of AEC gradually built up the capabilities and manpower required for the oversight of the safe operation of NPPs. Consequently, the nuclear industry is probably the most regulated industry worldwide. The confidence and trust of the public in the governmental nuclear regulatory agency is a crucial factor in the public acceptance of nuclear power. In the debate over nuclear power, the capabilities of the agency and the transparency of the regulatory processes are always the concerns of anti-nuclear advocates.

Construction of the Lungmen nuclear power station

Background information

The fourth NPP, Lungmen nuclear power station of Taiwan, is located on the northeastern coast of Taiwan. It is about 20 kilometres southeast of Keelung City and 40 kilometres east of Taipei City. The entire site property is about 480 hectares. The building of the fourth nuclear power project (units seven and eight of Taipower) was proposed and approved by the government in 1980. After the Chernobyl nuclear disaster of 1986, Legislator Yuan (congress) voted to freeze the budget for the construction. In the same year, the opposition DPP was founded. DPP made nuclear energy a political issue and stated that the party would not support the construction of any new NPPs in Taiwan. Since then, the fourth NPP has become the major focus of the political struggle between the ruling party KMT and the opposition party DPP.

In 1992, the Legislative Yuan passed a resolution, reinstating the budget for the construction of the plant. In May 1994, Gongliao residents (the village where the plant is located) had their first referendum, with 96.45 per cent voting against building the plant. Anti-nuclear advocates organised a large-scale rally to protest about the government decision. In May 1996, a proposal to halt the construction of the plant was successfully passed in the Legislative Yuan, with a majority vote of 76. In June of the same year, the Executive Yuan sent a request to the Legislative Yuan asking for reconsideration. In October 1996, the Legislative Yuan passed the motion of the reconsideration, by 83 votes. The Preliminary Safety Analysis Report of Lungmen nuclear power station was submitted to the AEC on 16 October 1997. The construction permit of Lungmen nuclear power station was issued on 17 March 1999, and the first concrete was poured on 31 March 1999.

The Lungmen nuclear power project, which employs an advanced boiling water reactor (ABWR), is a two-unit facility. The rated electric power is 1,350 MWe per unit. The rated thermal power level is 3,926 MWt and the design power level is 4,005 MWt. General Electric Nuclear Energy Division and its associates are responsible for the design of the NSSS. Mitsubishi Heavy

Industries (MHI) is responsible for providing the turbine generator and related auxiliary systems, including the related control systems and instrumentation. Engineering support is provided by Stone & Webster (S&W). Taipower maintains control over and oversight of the design engineering process. The completion of the project was delayed several times and still not completed by early 2010.

Re-evaluation of the fourth nuclear power plant project

The DPP won the presidential election on 18 March 2000, and Shui-Bian Chen became President of the Republic of China. The 'termination of the construction of the 4th NPP' was one of President Chen's promises during the election campaign. On 26 May 2000, the new Minister of Economic Affairs, Hsin-Yi Lin, announced that he would organise a committee to reassess the feasibility of the fourth NPP project. The members of the Re-evaluation Committee of the fourth NPP project consisted of 18 members, of which six were from the government agency, two were from the Legislative Yuan and the rest were invited experts from universities, research institutes and industry.

The Re-evaluation Committee of the fourth NPP project held 13 meetings between 16 June and 15 September 2000. Each meeting lasted for six to seven hours and the topics covered included the worldwide trend of nuclear energy development, safety, risk and emergency planning of NPPs, nuclear waste; decommissioning, environment and ecological impacts of nuclear power, alternatives to the fourth NPP, the cost of its power generation, the social impacts, government policies on economics, energy and the environment, and the future of the fourth NPP project. At the first meeting of the Re-evaluation Committee, all the members agreed that the committee would not vote to determine the future of the fourth NPP project. The primary responsibility of the committee was to provide the necessary information for the government to make the final decision. The meeting was broadcast live on the Internet and was video-taped for broadcast on public television at a later date.

After the discussion of the first topic, it became clear that it would be difficult to reach consensus among the committee members who already had strong opinions about nuclear power. It was then decided that members of the committee would be split into two groups to write their separate reports and recommendations. One group was in favour of the continuing construction of the fourth NPP and the other group was in favour of its termination. After a long discussion in the final meeting, the committee members reached the following agreement:

1. The construction of the NPP is a controversial issue. It is not a simple issue of power demand and supply. It is a complicated problem related to the government policies on energy supply, economic development and

environmental protection. It is also a social and a political issue. The issue will have an impact on national security too.
2. The continuing construction or the termination of the fourth NPP project should not jeopardise the sufficient and the stable supply of electric power, which is a necessary condition for the economic development and a comfortable daily life for citizens.
3. In solving the problem of the lack of domestic energy resources, the government should adopt policies for diversified energy development, which include promotion of energy saving, promotion of increasing energy efficiency (power generation and consumption), promotion of the use of renewable energy resource, adjustment of industrial structure and deregulation of the electric power industry. These policies are consistent with the international requirements on sustainable development and environmental protection.
4. The final disposal of nuclear waste is an existing problem and should be treated in a responsible manner.

This ambiguous agreement of the Re-evaluation Committee of the fourth NPP project had no impact on the decision of the government in the cancellation of the fourth NPP project. The meetings of the Re-evaluation Committee gave the anti-nuclear and pro-nuclear groups a chance to argue about (but not really discuss) the related issues of nuclear power.

Suspension of the construction of the fourth NPP

On 29 September 2000, Minister Lin of the Ministry of Economic Affairs announced that he had recommended to Premier Tang that the construction of the fourth NPP should be terminated. The suggestion put great pressure on Premier Tang who favoured the completion of the project and Premier Tang resigned on 3 October 2000. The resignation of Premier Tang was a strong indication that the government had decided to terminate the construction of the fourth NPP.

On 27 October 2000, the leader of KMT, Tzn Lien, and President Chen met to discuss how to relax the tension that existed between the ruling DPP and opposition parties. Tzn Lien was the former Vice-President and a Presidential candidate representing KMT in the March 2000 election. The meeting was considered by the public and the media to be a major breakthrough in relations between the DPP and KMT, and certainly it was hoped that the meeting would end the long standoff between the parties. In the meeting, Tzn Lien suggested that the government should complete the construction of the fourth NPP and since the newly constructed NPP is safer and better than the old plants, the old NPPs in Taiwan could be replaced by the fourth NPP.

Almost immediately after the meeting, Chun-Hsiung Chang, the new Premier, announced in a press conference that the Executive Yuan had

decided to terminate the project. In the announcement, Premier Chang said that safety concerns in the NPP were one of the major reasons the project was terminated. He believed that nuclear waste was a problem without a solution and halting the development of nuclear power was a worldwide trend. He also pointed out that the termination of the fourth NPP would not cause power shortages during the next seven years and that the power generated by the fourth NPP could be replaced with a gas-fired plant built by independent power producers. The day after the announcement, Taipower stopped all construction activities on the site and notified General Electric (GE) that the project was 'suspended'.

The announcement of Premier Chang surprised the public and greatly increased the tension between the ruling DPP and the opposition parties. The media used the phrase 'the explosion of a political atomic bomb' to express the impact of the announcement on the political stability of the country.

Resumption of the construction of the fourth NPP

Taipower is a government-owned company. The budget for the fourth NPP project had been approved by the Legislative Yuan. The opposition parties argued that, from a constitutional point of view, the Executive Yuan did not have the right to cancel the project. In order to justify that the Executive Yuan had this right, it asked the Grand Justice of Judicial Yuan to interpret the Constitution in the Constitution Court on 10 November 2000.

The Grand Justice announced their decision on 15 January 2001. In the announcement, the Grand Justice did not say that the Executive Yuan had no right to terminate a project approved by the Legislative Yuan; nevertheless, the new government did have the right to change major national policy. However, the Executive Yuan had to 'report' to the Legislative Yuan about its decision and ask for approval. The Grand Justice also made three suggestions as to how to solve the constitutional crisis surrounding the construction of the fourth NPP. Following the suggestions of the Grand Justice, on 30 January 2001, Premier Chun-Hsiung Chang presented a formal report to the Legislative Yuan.

In the report, Premier Chang mentioned that the ultimate goal of the government was to close down all NPPs in Taiwan and, therefore, the construction of the new NPP should be terminated. The slogan used was 'a nuclear-free homeland'. The legislators in the opposition parties insisted that the construction of the fourth NPP was approved by a constitutional process. Therefore, they concluded, the continued construction of the plants should be unconditional. The DPP was the minority party in the Legislative Yuan.

On the second day after the report was handed down, the Legislative Yuan voted on the issue and asked the Executive Yuan to resume the construction of the plant. The decision of the Legislative Yuan ignited another round of

arguments among the politicians of the DPP and opposition parties that created a deadlock between the Executive Yuan and the Legislative Yuan on the issue. Finally, President Chen compromised. After several rounds of negotiation a memorandum was signed by the Executive Yuan and the Legislative Yuan. According to the memorandum, the Executive Yuan would resume construction of the fourth NPP and would send an 'Energy Bill' related to the nuclear energy issues to the Legislative Yuan for approval. The memorandum also stated that 'A nuclear-free homeland' was the consensus among all the political parties. After the memorandum was signed, Premier Chang announced the resumption of the construction of the fourth NPP on 14 February 2001 (Wang 2006).

Upon receiving the agreement Taipower notified all the contractors and demanded a resumption of the construction work immediately. In the announcement, Premier Chang also stated that the first nuclear unit of Taipower (Chinshan 1) would be closed down at the end of 2011, by which time the unit would have been in operation for 32 years.

Knowing that his decision would be challenged by the supporters of the DPP, President Chen promised that a public vote on the fourth NPP would be held in conjunction with the election due at the end of year. If the public voted in favour of termination of the project the fourth NPP would be officially cancelled. To prepare for the public vote on the issue, President Chen asked the Executive Yuan to propose a law to allow a public vote on the major national policies. The opposition parties argued that the new law should not apply to the construction of the fourth NPP and the Legislative Yuan would not pass the law if the Executive Yuan insisted upon it.

The Executive Yuan threatened that the vote would be set at the election held at the end of the year, even without the new law in place. The anti-nuclear advocates organised a demonstration on 24 February to protest against the decision and asked for the right to vote on the issue. In response to the request, the Executive Yuan organised a special committee to assess the impact if a public vote on the issue was carried out during the election at the end of the year. After a lengthy debate, the special committee suggested on 31 July that the issue of the construction of the fourth NPP should not be put to the vote at the election. The committee was worried that a negative public vote on the issue might inflict another major blow to the fragile economy of the country. However, this decision implied that President Chen had broken his promise to the supporters of the DPP.

Impact of suspension on the project

Construction work on the fourth NPP was suspended for 111 days between 27 October 2000 and 14 February 2001. There were two major consequences of the suspension on the project – a delayed construction schedule and the cost involved.

This impacted on the schedule as the original target date of the commercial operation of the first unit of Lungmen project was 16 July 2004. However, the date of the commercial operation was pushed back to 16 December 2004 due to the delay in obtaining the construction permit from AEC. The construction was eventually commenced on 14 February 2001. Taipower revised its completion date to 15 July 2006. According to the revised schedule, the 111 days of work suspension caused a delay of 576 days in the commercial operation. For some contractors, the workforce designated to the project was dissolved during the work suspension. The staff of the General Electric Nuclear Energy Lungmen task force was reduced from 300 to 100 upon receiving notice of the project suspension. It took time to organise a new team and to put the project back on track. The design and procurement processes of the project were also delayed significantly because Taipower was forbidden to decide on the contractor and supplier of the major auxiliary components during the period of the re-evaluation. It was believed that the possibility of holding a public vote on the issue at the end of 2001 also played a role in the severe delay in the schedule. The contractors remained sceptical that the government had given up the idea of terminating the fourth NPP. Consequently, the confidence and morale of the staff of Taipower and of the contractors was extremely low for a long time.

Taipower is a government-owned utility and the high-ranking managers of the company are appointed by the government. Consequently, it was politically incorrect for them to pay a great deal of attention to a project that was not favoured by the government. For the period between 2001 and 2007, Taipower had five Board chairmen and none of them visited the construction site during this period.

Since the resumption of construction, the date of commercial operation of the plant has been rescheduled twice. In December 2005, Taipower submitted an application to the Ministry of Economic Affairs to postpone the fuel loading date to October 2008 and the commercial operation date to 15 July 2009. The date of the commercial operation was revised again in February 2009. The latest target date for the fuel loading and commercial operation of unit 1 is 15 December 2010 and 2011, respectively.

There was a budgetary impact as well. The total budget approved by the Executive Yuan for the fourth NPP at the beginning of the project was NT$169.73 billion. The costs were allocated for two 1,000 MWe units and estimated based on a currency exchange rate of 1:27 and an annual inflation rate of 4.5 per cent. The cost included the construction, the first fuel loading and interest during the construction. The budget was revised to NT$208.21 billion during the re-evaluation. The escalation of the cost was due to the change in power level from 1,000 MWe to 1,350 MWe and the depreciation of the NT dollar. It was estimated by the Ministry of Economic Affairs that the loss through termination of the fourth NPP was between NT$75.1 and NT$90.3 billion.

At the beginning of 2001, the Legislative Yuan passed a budget of NT$3.49 billion to cover the costs during the period of suspension from 27 October 2000 to 15 February 2001. The cost due to the interest payment during this period was NT$0.555 billion. The cost of construction management during the period was NT$0.255 billion and the compensation to local contractors and foreign contractors was NT$0.565 billion and NT$2.114 billion, respectively.

Since the suspension caused a significant delay in the construction of the fourth NPP project, the contractors demanded compensation for the extra costs. The actual losses of the contractors are difficult to estimate and verify. Taipower negotiated with each individual contractor about the compensation for the losses due to the schedule delay. The actual amount of compensation each contractor received was confidential so the public would not know the total cost of the 111 days suspension of the construction of the fourth NPP.

The cost of the project also escalated significantly not only because of the delay in construction, but also because of inflation and the price hike of raw material around 2003. The approved budget before the suspension was NT$208.2 billion, but this figure was revised in December 2005 to NT$233.5 billion. It was revised again in February 2009 to NT$273.5 billion.

Another cost of the delay in the commercial operation of the fourth NPP was the fuel cost of the replacement power. The actual cost of fuel, of course, depended on the fuel prices at the time. According to figures in the report prepared by Taipower for the Re-evaluation Committee, the average fuel costs of coal and natural gas will be NT$1.368/kWh and NT$3.395/kWh, respectively, over the next 25 years. Assuming the capacity factor of the plant will be around 80 per cent, a rough estimation of the cost of the replacement power for six years will be between NT$77.6 and NT$192.7 billion.

Public acceptance of the project

A number of polls have been conducted to gauge public opinion of the suspension and resumption of the construction of the fourth NPP. In the poll made by MunSangPoh via the Internet on 12 April 2000, 38.8 per cent of the population said that construction of the fourth NPP should be continued if there were no better alternatives. If the site of the fourth NPP could be used to build a gas-fired power plant, 55.55 per cent of the population agreed that the construction of the fourth NPP should be stopped. Conversely, 22.22 per cent of the population disagreed. If the phase-out of nuclear power implied a higher rate of electric power, 40.7 per cent of the population would accept, but 51.85 per cent of the population would not accept.

In the poll conducted by TVBS (a cable TV station) on 4 May 2000, 43 per cent of the population did not feel confident that Taipower had the

ability to handle an NPP accident. Also, 51 per cent of the population did not want to live near an NPP.

The poll results published in *China Times* on 8 May 2000 showed that about 30 per cent of the population living close to the site (near Keelung City and Taipei County) wanted to terminate the construction of the fourth NPP. About 10–20 per cent of the population living in other areas wanted to terminate the construction.

A poll conducted by the DPP on 18 September 2000 showed that more than half the population favoured the termination of construction of the fourth NPP, if they were offered alternatives to avoid power shortages.

In a poll conducted by KMT in 2000 immediately after Minister Lin suggested terminating the construction of the fourth NPP, 52 per cent of the population living in Taipei County favoured construction of the fourth NPP and 31 per cent of the population were against it. Immediately after Premier Chang announced suspension of the fourth NPP in 2001, six polls were conducted. The results of a poll carried out by *United Daily News* showed 56 per cent of the population was worried that the suspension of the fourth NPP would cause a power shortage in the near future. Only 22 per cent of the population believed Premier Chang's decision to suspend the fourth NPP would not cause a power shortage. The results also showed that the decision made by the Executive Yuan damaged the popularity of President Chen.

The poll results in *China Times* indicated that attitudes towards nuclear power depended on the level of education of the respondents. Sixty per cent of those with only primary education supported the decision of the Executive Yuan to terminate the project, while only 40 per cent of those with a higher education were against the decision. As shown in the results of a poll made by the DPP, under given conditions the termination of the fourth NPP would not cause a power shortage, and 58 per cent of the population supported the decision of the Executive Yuan to terminate the construction of the fourth NPP. A poll carried out by TVBS showed that 47 per cent of the population felt that the decision of the Executive Yuan was made based on the interests of the DPP. Only 31 per cent of the population thought that the decision was based on the interests of the public. As shown in the poll made by KMT, the public were worried that termination of the construction of the fourth NPP would cause: (1) a recession of the economy (33.4 per cent); (2) political instability (22.4 per cent); (3) an increase in the unemployment rate (11 per cent); (4) a negative impact on the stock market (8 per cent); and (5) a loss of competitiveness in the country (8 per cent).

After the Executive Yuan announced the resumption of construction of the fourth NPP, a poll carried out by *China Times* showed that 52 per cent of the population thought that members of the DPP should support the government decision, while 19 per cent suggested that members of the DPP should continue to fight for the termination of the construction. The poll conducted by the Environment Protection Quality Foundation showed that

a narrow majority (52 per cent) thought that a public vote should be taken to determine the fate of the fourth NPP.

In short, the results of a range of polls demonstrate that about 40–60 per cent of the public supported the project while 20–40 per cent were against. In all polls, except that conducted by the DPP, there were always more people supporting the project than were against it. The margin was between 9–37 per cent. One major concern was whether other alternatives to the fourth NPP would be able to provide sufficient electricity needed for the continuing economic growth. The final disposal of nuclear waste was also an issue. Finally, a majority of people thought the public should have the right to make the final decision on the fate of the fourth NPP.

Promotion of 'A nuclear-free homeland' by the DPP's government

In a memorandum signed by the Executive Yuan and the Legislative Yuan to resume the construction of the fourth NPP, it was stated that 'A nuclear-free homeland' was the consensus among different political parties. When he announced the resumption of construction of the fourth NPP, Premier Chang also said that the first nuclear unit of Taipower would be closed down at the end of 2011. As required by the memorandum, the Executive Yuan had to propose an 'Energy Bill', addressing the issue. This bill was drafted by the Energy Commission of the Ministry of Economic Affairs. The name of the bill was 'The Law of Premature Closedown of the Existing NPPs'.

The first draft of 'The Law of Premature Closedown of the Existing NPPs' specified that three existing NPPs of Taipower would be closed down sequentially starting at the end of 2011, under the conditions that: (1) the reserve power on the electric grid would be no less than 15 per cent in the next seven years; (2) the increase in electricity demand in the next seven years is no more than 15 per cent; and (3) the closedown of the nuclear unit would not affect the national commitment to international agreements, especially in relation to climate change. It was also specified in the legislation that the government would allocate funds (1) to cover the deficiencies in the back-end foundations; (2) to make up the loss of Taipower; and (3) to compensate those employees who would lose their jobs due to the premature closedown, according to the relevant labour laws.

Taipower was obligated to write a report to address the above issues too. The report was reviewed by a special committee organised by the Ministry of Economic Affairs and members of the committee had the right to make the final decision on the premature closedown of NPPs. However, the Minister of Economic Affairs could veto the decision. If the decision of the committee was vetoed by the Minister, the committee members would have to reconsider their decision. If the members disagreed with the Minister a second time, the Minister of Economic Affairs had to follow the suggestion of the committee.

The first draft of the legislation was approved by the Ministry of Economic Affairs and sent to the Executive Yuan. After being reviewed by the Executive Yuan, it was sent to the Legislative Yuan for approval. However the bill has been sitting in the Legislative Yuan for a considerable time and has never been put on the agenda.

The Legislative Yuan did manage to pass the Basic Environment Act on 11 December 2002. In Article 23 of the Act, it states that: 'The government shall establish plans to gradually achieve the goal of becoming a nuclear-free country. The government will also strengthen nuclear safety management and control, protections against radiation, and the management of radioactive materials and monitoring of environmental radiation to safeguard the public from the dangers of radiation exposure.'

Finally, 'A nuclear-free homeland' became a major government policy. The Executive Yuan had organised the Nuclear Free Homeland Commission to consolidate and coordinate related issues. The Commission was composed of nine members from non-governmental sectors (including experts and scholars in fields such as law, economics and social sciences) and eight government officials representing the Executive Yuan's Atomic Energy Council, the Environmental Protection Administration, the Department of Health, the Ministry of Economic Affairs, the Ministry of the Interior, the Ministry of Education, the Ministry of Justice and the Government Information Office. The Commission drafted a strategic plan to implement the policy. The Commission is divided into eight workgroups, each responsible for specific nuclear-free implementation related matters. The eight workgroups are the Energy Structure Adjustment Workgroup, the Clean Energy Promotion Workgroup, the Nuclear Power Plant Phase-out Workgroup, the Nuclear Waste Management Workgroup, the Nuclear-Free Homeland Legislation Workgroup, the Fourth Nuclear Power Plant Monitoring Workgroup, the Nuclear-Free Homeland Promotion Workgroup and the Nuclear-Free Homeland Education Workgroup. After eight years of cultivation, 'A nuclear-free homeland' had finally become a slogan that resonates with the public.

The economic perspective of nuclear power

The relative cost of electricity generation from coal, gas and nuclear plants varies considerably depending on location. In general, nuclear power is cost-competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels. The generation costs from various types of fuels vary considerably. According to Taipower, in 2007 the cost of its coal-fired electricity was NT$1.18/kWh; it was NT$0.63 for nuclear, NT$2.57 for wind, NT$3.32 for combined cycle and the average generation cost is NT$1.79/kWh. The generation cost of nuclear power is significantly lower (35 per cent of the average and half of that of thermal generation) than other types in Taiwan predominantly because much of its energy sources are

imported. For example, Taipower burned 53.5 million tonnes of coal and 10,377 Mega-M^3 of natural gas in 2005. For a country that relies heavily on imported energy, the transportation and storage of vast amounts of fossil fuel required for power generation are serious concerns in terms of national energy security. The energy released by the fission of 1 kilogram of uranium released in a typical reactor is equivalent to about 22,000 kilograms of coal. It is therefore quite common that an NPP stores the nuclear fuel required for the next fuel cycle on-site and a plant can be operated continuously at least for 18 months without having to change the fuel rods. Due to a lack of storage facilities, the reserves of liquefied natural gas (LNG) in Taiwan nowadays can last for no more than seven days. This means a great cost saving for nuclear power companies.

The construction cost of NPPs is high and fuel costs for nuclear power are only a minor portion of the total generating cost. Therefore, the impact of global energy price fluctuation on the generation cost of nuclear power will be relatively small. In Taiwan, the generation cost of coal increased from NT$0.83 in 2003 to NT$1.18/kWh in 2007, an increase of 42.2 per cent. The corresponding costs of purchasing fossil fuel for these two years are NT$87.0 and NT$188.6 billion, respectively, an increase of more than 200 per cent. This quantum jump is due to the price increase of fossil fuel that began in 2003–04. During the same period, the generation cost of nuclear power decreased by 1 NT cent due to an improvement of the capacity factor. The total amount of power produced by Taipower in 2003 and 2007 was 136.10 and 154.62 TWh, respectively, an increase of 13.6 per cent. Nuclear energy could at least stabilise, if not help lower, the average power generation cost.

Yet, there is high risk involved in building an NPP. Its intensive up-front capital investment means that it is subject to changes in interest rates, exchange rates, discount rates and macroeconomic conditions. Long delays in construction often add increased uncertainties to the cost of nuclear energy. The Lungmen nuclear power station of Taipower is a good example of an unexpected rise in costs with long delays and rescheduling.

Operating nuclear power units also involve financial risks. For example, the Niigata Chuetsu Offshore Earthquake that occurred on 16 July 2007 caused an emergency shutdown of all nuclear units of the Kashiwazaki Kariwa nuclear power station, a plant with seven units and installed capacity of 7,965 MWe. All units were successfully brought to a safe shutdown, but there was some minor leakage of radioactive material from the spent fuel pool and some minor fire hazards. The ground acceleration at the site during the earthquake exceeded the designed safety standards. Even though there was no damage to the plant components and, theoretically, the plant itself was safe to operate, all the units were idle for a long period after the earthquake. This resulted in a huge financial cost to the utility.

Because Taipower is a government-owned utility, the price of electricity is strictly regulated by the Executive Yuan. The electricity price is often used

Table 8.7 Profit before tax of Taipower

	2001	2002	2003	2004	2005	2006	2007
Billion NT$	23.67	31.31	31.76	8.47	1.23	−2.82	−31.24

Source: Taipower, 'Annual Reports', various years.

by the government as a policy vehicle to keep the inflation in a range that is considered acceptable by the public. Therefore, fluctuation of the global energy prices often is not translated into domestic electricity prices. In 2007, for example, Taipower had to absorb the losses of more than NT$100 billion just to keep the electricity price stable (Table 8.7).

Nuclear renaissance in Taiwan

Dr Ying Jeou Ma won the presidential election in March 2008 and KMT took over the government. The Executive Yuan of the newly elected government announced its Sustainable Energy Policy on 5 June 2008, which would promote the diversification of energy resources; increase the weighting of low-carbon energy in the energy portfolio; and keep nuclear power as a viable option for energy supply. The power generated from low-carbon primary energy resources would increase to about 55 per cent by 2025. The Ministry of Economic Affairs announced its Energy Security Strategy Plan on 28 August 2008. It specified that the government would expand renewable energy and nuclear power from a current 9 per cent to 18 per cent by 2025. The tentative goal for the CO_2 emission reduction is to the level of 2008 between 2016 and 2020, and to the level of 2000 by 2025.

Following these announcements, the government convened the 2009 National Energy Conference to solicit public opinions on the future of the government's energy policy. The Steering Committee of the conference decided the four main topics to be covered were: (1) sustainable development of energy security; (2) energy resource management and improvement of energy efficiency; (3) energy pricing and deregulation of the energy market; and (4) energy technology and industry development. Experts from research institutes and scholars from universities were invited to prepare the background information for the sub-topics of each group. The background information was presented at the conference to lead the discussion.

Between 19 February and 3 March 2009 regional conferences were held in the northern, central, southern and eastern parts of the county. They were open to the public and each conference lasted for two days. All four topics were discussed. The public responses and suggestions were recorded and documented. Then groups were formed to discuss the sub-topics and then closed-door meetings were held with only invited government officials,

scholars from research institutes and universities, and representatives from non-governmental organisations. These group meetings were chaired by high-ranking government officials. Sometimes, cross-group meetings were organised too. In April 2009, a national energy conference was held to bring the delegates, responses and recommendations together. The Prime Minister Dr Chao-Shiuan Liu delivered a speech at the opening of the conference and attended the last session.

At the National Energy Conference, nuclear power was discussed and recommendations were presented:

- To extend the lives of the existing NPPs.
- To build six more nuclear reactors at existing sites and the first would be commercialised in 2020.
- To increase the share of nuclear energy in the total installed capacity to 20–25 per cent by 2025 and 30 per cent beyond 2025.
- To strengthen the public acceptance of nuclear power.
- To promote the safety of nuclear power operation through international cooperation.
- The government to be heavily involved in the identification of the repository site of low-level nuclear waste.
- To seek regional cooperation on spent fuel and high-level radioactive waste (HLW) management.

A number of concerns were also raised at the Conference. They include:

- Cross-generation justice regarding nuclear energy development.
- Safety concerns of nuclear energy development.
- Lack of trained engineers in operating NPPs.
- Lack of ability to manage nuclear wastes.
- Proper load management of NPPs.
- Costs of nuclear power.
- Government subsidies to nuclear energy.
- CO_2 emission from nuclear energy.
- Environmental consequences of nuclear energy.
- Renewable energy versus nuclear energy development.
- LNG as a better alternative to nuclear energy.

It seemed that at the end of the conferences, delegates, many of whom were anti-nuclear advocates, rejected all the recommendations made by group meetings on nuclear energy development. The newly elected government acknowledged the importance of nuclear power to the future economic development of the island. Taipower has developed concrete plans for nuclear energy expansion. A feasibility study is underway for a new NPP. According to Taipower, the total installed generation capacity of Taiwan will

have to expand from the current 38.1 GW to 67.1 GW by 2025 to meet the rising demands. To ensure adequate energy supplies and to reduce greenhouse gas emissions; a portion of new power plants will have to be nuclear. For Taiwan, nuclear would be cheaper than LNG-fired generation capacity.

Despite these developments, the public remains sceptical about nuclear energy. Other major challenges include the following: to find innovative ways to raise the initial capital investment; to meet the environmental target set in the Basic Environment Act; to resolve disputes with anti-nuclear movements; and to formulate an acceptable policy on the management of nuclear spent fuel.

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