Development of cogeneration and district energy (CDE) networks in South-east Asia

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Abstract

Over the last decade, natural gas has increasingly become the most favourite fuel for South-East Asia's power and industry sectors. The world produces around 20% of electricity using natural gas as fuel. But the dependence of South-East Asia, and particularly Thailand, on natural gas is significantly higher, over 40% and 70% of total generation capacity, respectively. Considering the fact that natural gas is a much cleaner fuel than coal or fuel oil and an important feedstock for the chemical industry, national governments have favoured its development by investing in pipelines and energy-efficient combined-cycle power plants.

However, there is a major concern about the high cost of electricity from natural gas whose prices have seen very large fluctuations during the recent years. Moreover, countries in the region are faced with the problem of rapid hike in electricity demand associated with the population and economic growth. As cities expand and new settlements are created to accommodate the growing urban population, national authorities are unable to cope with the need for expanding generation capacity and distribution network. Similar challenges are also being faced by the new industrial zones being created to facilitate the development of industrial activities.

In the past, most of the energy utilities were national monopolies and there was no scope for the private sector to invest and widen the energy sector. Thanks to the progressive policies of national governments, private sector can now play an active role and reduce the financial burden of the State-owned energy companies. The inherent constraints of the past can be dealt with effectively through the provision of energy services at the points of use by using technological solutions that allow to maximize the conversion efficiency through combined heat and power generation or cogeneration, and to eliminate the losses associated with transmission and distribution of grid electricity through district energy networks.

This paper shares some examples of the industrial and commercial applications of cogeneration and district energy (CDE) in South-East Asia.

Keywords

Natural gas, cogeneration, South-east Asia, vapour absorption cooling, district energy network

Introduction to cogeneration and district energy network

The demand for energy services in the buildings and factories is mostly in the form of either electricity or thermal energy. Fossil-fuel based electricity is generally produced in centralized

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mega-scale coal or oil fired power plants with an average efficiency of below 40 percent. Almost two-thirds of energy in the fuel is rejected as low-grade heat into the surroundings. Further, as this centrally-generated electricity is transmitted over hundreds of kilometres before it can be distributed to the end-users, around 15-20 percent of the energy is lost in the electricity network, depending on how well the electrical system is designed and operated. Thus, the overall efficiency of power supply in Asian countries is around 30 percent or so.

On the other hand, the thermal energy needed by end-users is produced on-site by using fuels in devices such as boilers or furnaces, incurring losses in the range of 15 to 20 percent during the conversion process. Moreover, the conversion facility is often sized to meet the peak demand of the site whereas the actual demand may vary considerably with time. This results in higher initial investments and low operating efficiencies.

Technological progresses as well as the availability of cleaner fuels such as natural gas, either liquefied or in pipeline, have made it possible for the combined generation of electricity and thermal energy (widely known as cogeneration or Combined Heat and Power - CHP), at the premises of the end-user, thus reducing the overall primary energy demand by as much as 25 to 40 percent. Cogeneration is therefore considered as one of the most attractive supply-side solutions to reduce the demand for fossil fuels while the world continues its pursuit of a carbon-neutral future.

As shown in Figure 1, the CDE networks are ideally suited for new commercial complexes or industrial estates because they can be well integrated into the infrastructure plans right at the designing stage. As there is no need for putting up boilers, chillers, smokestacks or cooling towers in individual buildings or factories, this provides greater opportunity and flexibility to the architects for adopting designs that are aesthetically more pleasing to their potential clients.

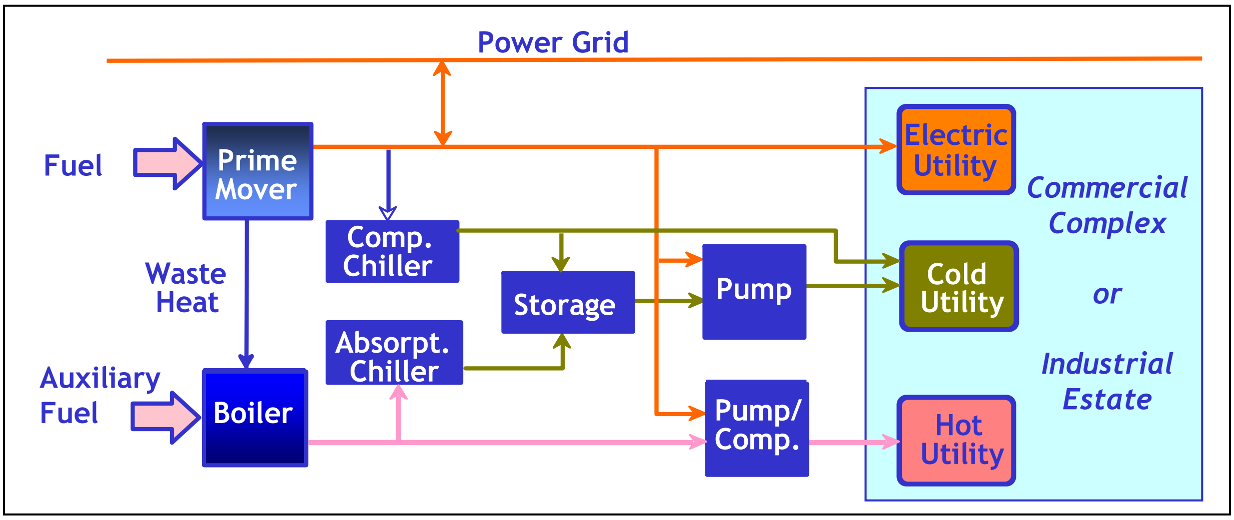

Figure 1: Schematic presentation of cogeneration and district energy (CDE) network

In addition to its efficiency and cost-effectiveness, some of the other advantages of the CDE networks include:

- Economy of scale: the combination of the varying energy service needs of a large number of clients allows setting up a facility which is modular in design and can achieve a good economy of scale.

- Wider spectrum of users: the CDE network satisfies the energy service needs of a variety of clients with different characteristics and functions; it can be expanded to even those users for whom an individual cogeneration system cannot be technically and financially justifiable.

- Better reliability and availability: with the ability to retain qualified engineers and technicians, the cogeneration and CDE networks can ensure increased reliability and availability of utility services to match well with the demands of the end-users.

- Ease of operation for the clients: since heating and cooling services are delivered to customer's building or factory, they no longer have to worry about boilers or chillers, fuel purchasing, handling and storage, and the safety aspects associated with them.

- Better environment: by avoiding the combustion of fuel in many smaller and less efficient boilers, and adopting more efficient plants that adhere to stringent emission controls, the cogeneration site becomes environmentally sound while helping clients to honour their environmental commitments.

Driving forces for cogeneration in Asia

The concept of cogeneration is not new to Asia. For example, cogeneration was practiced in traditional sugar mills to produce electricity for mechanical drives and the thermal energy was recovered to be used for producing sugar from the cane juice. But there was little incentive for the development of cogeneration in a bigger scale.

Most electricity companies were government monopolies and national policies were framed to favour utility power generation. The development of technology was heavily biased towards bigger systems to achieve economy of scale, hence there were not much efforts made by manufacturers to invest in research and development to produce smaller power generating systems. Moreover, the price of electricity was kept quite low to make it more affordable; this was possible because the capital investment for setting up power plants was mobilized by the government and fuel was supplied to the power plants at below-market rates.

Along with the economic liberalization in the late eighties and early nineties, South-east Asian economies had to confront a rapid rise in the demand for energy to fuel the economic growth. Faced with the challenge to finance the energy infrastructure needed to cope with the phenomenal growth in energy demand, some governments were forced to make policy changes, starting with the opening up of the energy sector to private players so that adequate financing could be mobilized for creating sufficient generating capacity to cope with the demand. The price of electricity was rationalized to reflect the marginal generation cost and to promote energy demand management. In the mean while, technology was maturing to meet the demand for small-scale decentralized power and cogeneration projects which were being promoted by industrialized economies as a means for improving competitiveness and curtailing the emission of greenhouse gases.

Deregulation of the power sector provided the thrust towards revitalization of the cogeneration concept, and gave an excellent opportunity for cogeneration to flourish. Thanks to the policies formulated to encourage small power producers to produce and sell electricity to the national power grid at acceptable rates, private investors opted for small to medium sized cogeneration projects, primarily to meet the heat and power demands of individual industrial and commercial facilities. Based on location, environment and small-scale advantages, such projects were able to not only meet the captive demand but sell surplus power at highly attractive rates.

The technology of cogeneration had matured by then and generating devices of all capacities and designs were readily available in the market. Moreover, the region had established a large and growing industrial base from which cogeneration projects could be easily developed. With the formulation of favourable policies and regulatory framework, and rational pricing mechanism, cogeneration was guaranteed to bring economic and environmental benefits both at micro and macro levels.

The actual degree of cogeneration development varied widely from one country to another. There were several determining factors, including the level of economic and industrial development, status of power sector in terms of demand versus supply, availability of fuels, electricity pricing, government policies on the role of private sector in energy supply, and local climatic condition. In this context, the lead taken by Malaysia and Thailand to promote cogeneration is noteworthy. By realizing the potential energy saving role of cogeneration, both countries concentrated their efforts to ensure the availability of natural gas in pipelines closer to the clients who had potential to make best use of both electricity and thermal energy in their facilities.

Further policy changes were initiated in both Malaysia and Thailand to allow cogenerators to not only sell electricity to the electricity grid but also sell electricity and thermal energy directly to third parties. This led to the growth of bigger capacity cogeneration plants that could meet the total energy needs of a cluster of industrial as well as commercial facilities so that the later could focus their full attention on their core business without worrying about the reliability of fuel and energy supply. By cumulating the demands of a greater number of clients located either in an industrial estate or urban centre, it was possible to size the system better and operate it optimally to match the varying electrical and thermal energy needs at all times. The production facility set up in the vicinity of a group of end-users could minimize the power transmission and distribution losses while thermal energy distributed through district energy network could simultaneously meet the heating and cooling demands of the clients.

Japan’s cogeneration experience

Japan has played a role model for the development of cogeneration in South-east Asia. As a country that is heavily dependent on imported primary energy to meet the energy services, Japan has mastered the cogeneration technology, including the commercialization of large-capacity and efficient vapour absorption chillers, and has widely adopted district heating and cooling networks.

By creating city gas networks, Japan could promote cogeneration extensively as an energy saving resource in the industrial, commercial, medical and public facility sectors. Cooling systems operating on cogenerated heat were incorporated into the design of shopping centres, offices, school and hospitals due to such factors as their energy efficiency, compactness, ease of maintenance and their economical attractiveness.

Japan was a pioneer in popularizing gas powered CDE networks thanks to which an entire district or a community of housing could have its heating and cooling requirements provided by the installation of a suitably sized plant in the basement area of a single building within the confines of the area of supply (Figure 2).

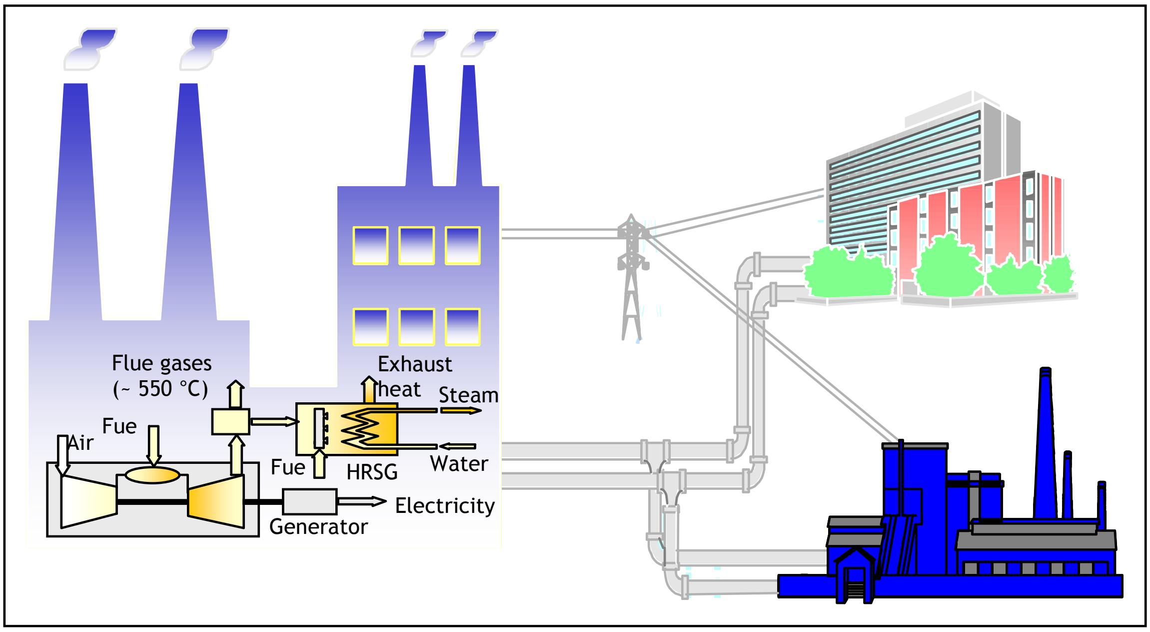

Figure 2: Schematics of CDE network promoted in Japan

In the past, the demand for gas was considerably higher in winter months for space heating applications. On the other hand, more electricity was needed in summer months for space cooling applications. Gas cooling systems were particularly effective because of their ability to alleviate peak electricity demand during summer months. As a result, the large seasonal variations in the gas demand have been minimized. Thanks to the growth of decentralized cogeneration and district cooling, the overall demand for natural gas has fallen over the years.

The popularity of gas cogeneration and its wide scale use is mainly due to its ability to achieve high total energy efficiency, in the range of 70-90%. Energy is more effectively and affordably used for a variety of applications through cogeneration by employing both gas engines and gas turbines:

1. Electricity: generated for use in lighting and power supply
2. Hot water and steam: by the use of heat exchangers, waste heat and thermal energy from chilled water are recovered and used for steam generation and the heating of water. This is commonly used in hotels and hospitals.
3. Space conditioning: recovered energy is used to provide space heating and/or cooling.
4. Manufacturing: heat recovered in the form of steam or hot water is used in manufacturing processes.

Thanks to the high energy efficiency, cogeneration technology in Japan has achieved very high market penetration over the last two decades. In 1991, there were 426 gas-based installations with a total generation capacity of 440 MW, mainly to cater to the energy needs of residential buildings. By the year 2000, the number had increased to 1,400 and the aggregated installed capacity stood at 1,689 MW. The aggressive role played by the gas company to compete with the electricity utilities and the tremendous progress in technology to harness the energy in a clean and environment-friendly manner within the city centre have resulted in a phenomenon growth of small-scale gas-powered cogeneration systems during the recent years. This can be witnessed by the fact that by 2009, there were 96, 626 cogeneration systems in operation with a total installed capacity of 4,487 MW. Within a span of 7-8 years, the average capacity of the cogeneration plant has dropped from over 1 MW to less than 50 kW [1].

With the advent of next generation energy systems such as fuel cell cogeneration, new avenues are being sought to further reduce the overall energy demand and lower the carbon dioxide emissions. Smart energy networks are designed that are able to optimize the operation of energy supply and demand for both electricity and heat, by using renewable energy, waste heat in the city, cogeneration systems, information technologies, and the exchange of heat and electricity among multiple consumers.

Japan has positively influenced other countries in the region such as South Korea, China, Malaysia and Thailand to adopt similar schemes to meet the overall energy demands for office complexes, shopping malls, hotels, hospitals, airports, etc. Likewise, a country like Thailand has learnt from how European countries like Denmark and Netherlands could meet with the increasing energy demands for industrial and domestic applications with limited investment and no additional fuel costs thanks to the adoption of energy-efficient decentralized cogeneration and distribution networks. Several industrial estates in Thailand have adopted the concept and benefitted immensely over the last couple of decades.

Examples are given below to illustrate the recent evolutions of commercial and industrial applications in Malaysia and Thailand, respectively.

Examples of gas based CDE networks in Malaysia

Realizing the fact that CDE networks were ideally suited for new commercial complexes as they can be well integrated into the infrastructure plans right at the designing stage, Malaysia's national oil company PETRONAS established a subsidiary gas district cooling company (GDC) in July 1993. Gas supply network was created to meet the future demands of buildings and industries [2].

The KLCC (Kuala Lumpur City Centre) is a development project for urban renewal, covering an area of 40 hectares. The project was aimed at transforming the city's core business area into working place with ecologically balanced and culturally enriched environment. The KLCC awarded a contract to GDC in 1994 to develop the first CDE plant in Malaysia on "build, own and operate" basis. The plant commenced commercial operation at KLCC in 1996.

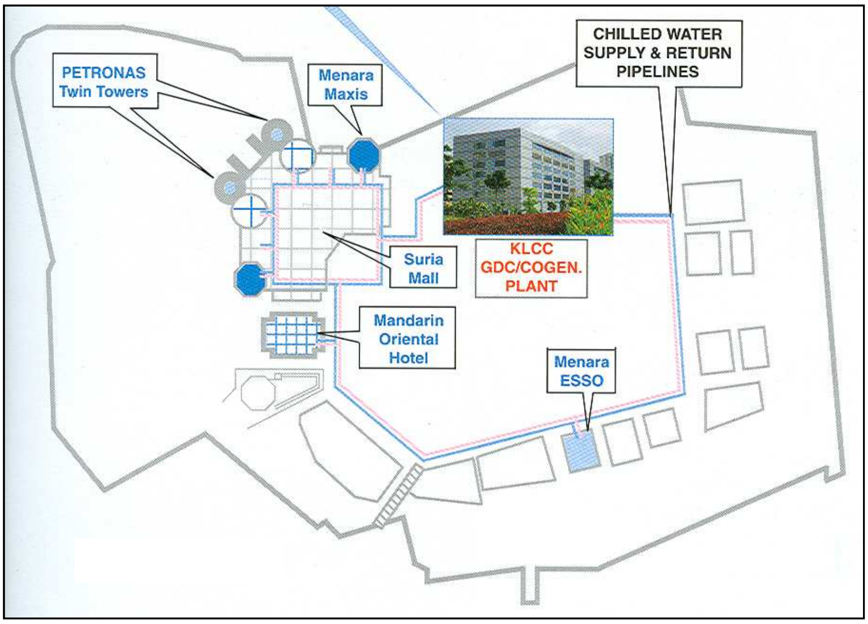

Figure 3: Cogeneration and district cooling network in KLCC

The cogeneration facility includes 4 gas turbine generators with a cumulative capacity 25.8 MW. Exhaust gases from the gas turbines are passed through 4 heat recovery steam generators to produce 58.8 tons of steam per hour. This steam is used in a steam turbine centrifugal chiller to produce 15,000 RT of cooling. The remaining 15,000 RT of cooling is obtained by using 3 electrical centrifugal chillers. Chilled water (supply at 4.4-6.4ºC and return at 14.4ºC) is circulated in a 4 km underground network of pipes to all the buildings in KLCC, including the world renowned Petronas Twin Towers, several multi-storey offices, hotels and commercial centres (Figure 3).

Malaysia's new international airport, known as KLIA (Kuala Lumpur International Airport), is the largest airport in Southeast Asia. Covering an area of 10,000 hectares, KLIA was inaugurated in July 1998 about 60 km from Kuala Lumpur. In 1995, KLIA awarded a 20-year concession for CDE facility on a Build-Operate-Transfer basis. Constructed between 1995 and 1997, this plant was the first facility to be completed in KLIA. The cogeneration system consists of 2 gas turbine generators with a total capacity of 40 MW. The exhaust gases from the turbines are passed through two heat recovery steam generators to produce 80 tons of steam per hour. There are 12 steam fired vapour absorption units with a cumulative capacity of 30,000 RT. In addition, 3 auxiliary boilers are installed to generate up to 90 tons of steam per hour. There is scope for further expansion in the power generating and cooling supply capacity as and when the need arises. Though natural gas is the main fuel used at this plant, the plant is designed to operate on aviation fuel as alternative. The cogeneration plant supplies chilled water (supply at 7ºC and return at 14ºC) to the core facilities at the airport and other privatized facilities which include a hotel.

The Malaysian Federal Government's new Administrative Centre, known as Putrajaya, is located at about 25 km from Kuala Lumpur. Covering a total area of 4,581 hectares of former plantation land, it is being developed as an "intelligent city in a garden". Putrajaya has several precincts that are being developed in a phased manner over a period of 20 years (Figure 4). Accordingly, a number of CDE units of varying capacities will be commissioned as and when the expansion takes place.

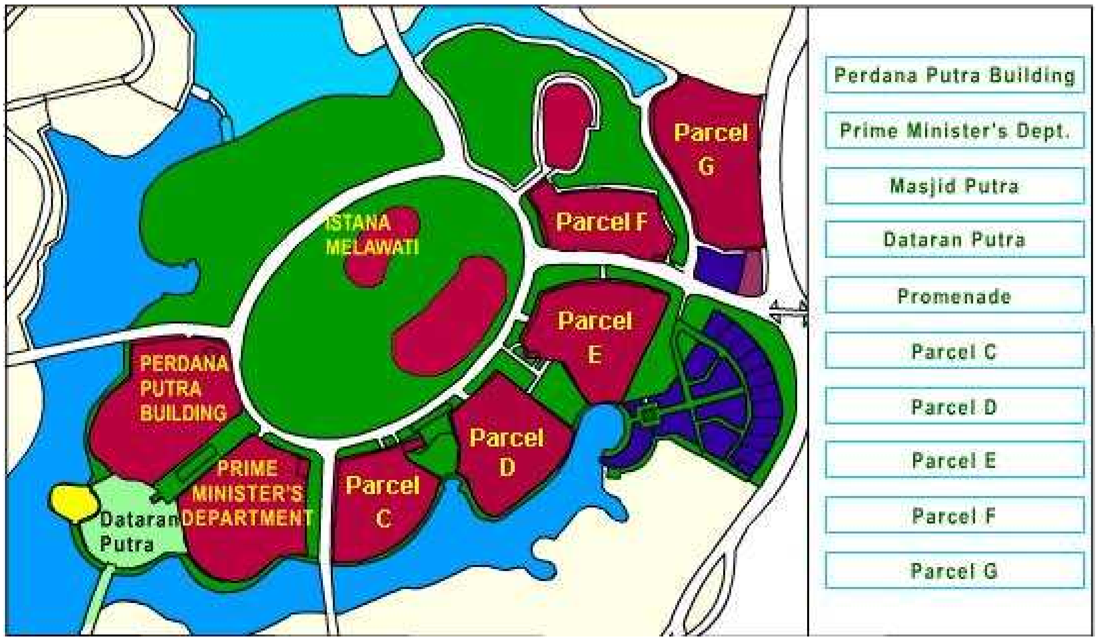

Figure 4: Several precincts being developed in Putrajaya

The first CDE facility was constructed in 1997-98 in the Government Precinct. It is configured to have two gas turbine generators, each with a capacity to produce 4 MW electricity. The exhaust gases from the turbine are channelled through two heat recovery steam generators with a capacity of 21.4 Ton of steam per hour. Three different types of chillers are employed to provide 22,500 Refrigeration Tons (RT) of cooling (2 electrical centrifugal chillers of 1,250 RT each; 5 steam fired vapour absorption chillers of 2,500 RT each; 5 direct fired vapour absorption chillers of 1,500 RT each). Since most buildings in the Government Precinct function during the daytime, a thermal energy storage facility of 9,000 RTh capacity has been installed to store the excess cooling at night and use during the day peak period.

The second CDE plant designed with a power generating capacity of 10 MW and cooling capacity of 33,000 RT is located in Precinct 2 on Core island. Chilled water from this plant is supplied (supply at 7.5ºC and return at 14.5ºC) to 3 Precincts covering Government buildings, cultural, commercial, sports and recreational facilities.

Examples of gas based CDE networks in Thailand

The CDE concept took concrete shape in Thailand following the announcement of the new Government policy in 1992 that encouraged participation of private operators in power generation and distribution business. To cater to the energy utility requirements of the petrochemical plants in the Map Ta Phut Industrial Estate of Rayong, CDE facilities were developed in three phases. During a period of 7 years (1993-2000), the cumulative capacity of the three phases amounted to 814 MW of power, 770 tons of steam per hour, 2,110 m^3 of clarified water per hour, and 660 m^3 of demineralised water per hour. Electricity generated by the CDE plants is sold to industrial customers as well as the national power utility. High-pressure steam at 40-45 bar and 400ºC and medium pressure steam at 12-15 bar and 250ºC are delivered to factories through large over-ground pipelines. Steam metering stations are set up to control the steam condition and calculate the thermal energy delivered for billing purpose.

In the first phase, only high-pressure steam, clarified water and demineralised water were produced by using natural gas as primary source of energy. The plant started commercial operation in July 1994. Soon after, the second phase was commissioned in October 1996. In this phase, a combined cycle cogeneration scheme was retained, including 6 gas turbine generators of 35 MW capacity each, and 2 steam turbine generators of 50 MW each. The gas turbines are primarily fuelled by natural gas with diesel oil as back up. Depending on the steam requirement of the factories in the industrial estate, the plant is designed to extract up to 320 tons of steam from the backpressure turbines. In addition, the plant has also a capacity to produce and supply 900 m^3 of clarified water per hour and 280 m^3 of demineralised water per hour to the factories. The DG system has an electrical efficiency of 45 percent in combined cycle mode and an overall efficiency of around 70 percent in cogeneration mode.

A new "hybrid" technology was adopted for the development and construction of the third phase to mitigate the risk and to avoid the dependence on a single type of fuel. The hybrid system utilizes both natural gas and high quality clean bituminous coal, thus guaranteeing fuel supply at all times. In the hybrid cycle, the flue gas from the gas turbine is used to reheat steam and water in the Heat Recovery Units. The reheated steam is returned to the medium-pressure section of the steam turbine while the heated water is sent to the coal fired Circulating Fluidized Bed (CFB) boiler, where it is further heated to produce high pressure steam for electricity generation and sale of excess steam to the industrial customers. Figure 5 shows an overall view of the CDE unit installed close to the port for facilitating the off-loading of imported coal [3].

Figure 5: Third phase of the CDE installation in Map Ta Phut industrial estate

The CDE experience of Map Ta Phut Industrial Estate has been successfully replicated in several industrial estates in Thailand. The CDE developments in industrial zones form part of the Thai government's Small Power Producer (SPP) program which requires the CDE facility to sell up to 90 MW of electricity to the national power grid and export their thermal energy in the form of steam or hot water to industrial users in the area to improve the plant's overall efficiency. Presently, seven gas combined-cycle cogeneration power plants are under development in/near industrial zones located in different provinces of Thailand. These CDE facilities have power output capacities of around 110 to 120 MW and are expected to commence operation in 2012-2013. Each power plant has signed agreements to purchase natural gas from the national company PTT and to sell 90 MW of electric power to the national electricity utility company EGAT; the remaining electric power, steam and/or chilled water will be sold directly to customers in their respective vicinities.

During the designing stage of the new international airport of Bangkok, a decision was taken to set up a CDE facility to reduce the overall energy consumption and improve the reliability of energy services. For this purpose, a strategic partnership was built among three important players involved in electricity generation, natural gas supply and electricity distribution, in order to form a new company named District Cooling System and Power Plant Co. Ltd. (DCAP) in April 2003 [4].

On the basis of the load calculations and optimization of the energy performance of the airport during the designing stage, it was estimated that 66 MW of electricity would be required to meet the overall energy demand of the airport, including 12,500 RT for cooling with a demand for 16 MW of electricity. The CDE plant was designed such that it would produce the 50 MW of electricity required by the airport for all purposes other than air conditioning, and the waste energy recovered from a combined-cycle cogeneration unit will be effectively used in vapour absorption machines to meet all the air conditioning loads of the airport and the surrounding buildings such as the airport hotel and the catering building of Thai Airways.

The final CDE configuration retained after the completion of the feasibility study consisted of 2 units of 22 MW gas turbine generators, two units of 42.5 T/h of heat recovery steam generators, and one unit of 12.5 MW back-pressure steam turbine operating with the steam generated from the waste heat of the gas turbines. The low-pressure steam exiting the steam turbines is piped to three different areas of the airport complex to be used for cooling in double-effect vapour absorption cooling units or for direct heating applications in the hotel and the catering building. In order to improve the reliability of energy supply to the airport complex, the energy system of the airport would continue to function by having access to the stand-by electricity supplied by the power utility, the auxiliary boilers operating with diesel as backup fuel, and the stand-by chillers in case of the disruption of natural gas supply or the shut-down of the cogeneration unit (Figure 6).

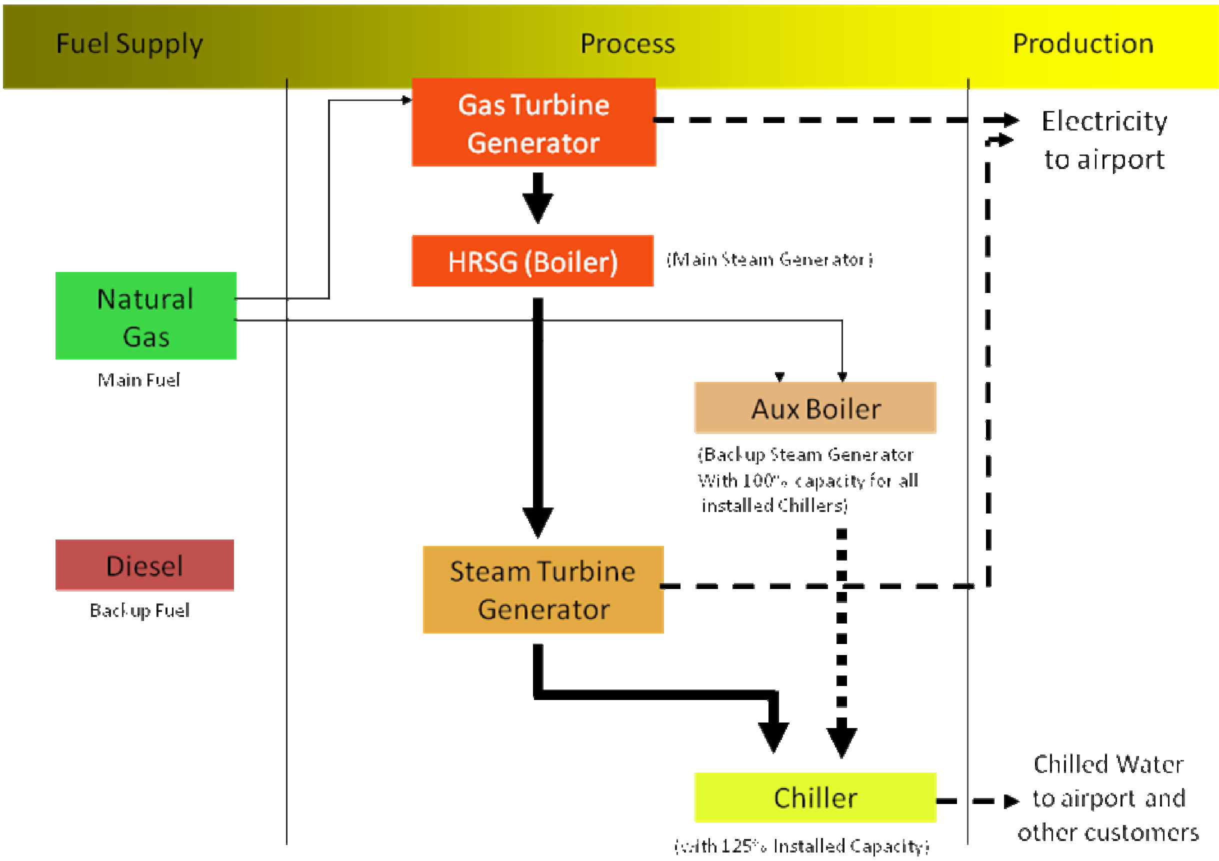

Figure 6: The CDE configuration for Bangkok Airport to ensure reliable energy supply

The future of cogeneration and district energy in South-east Asia

The above examples demonstrate the lead taken by Malaysia and Thailand in adopting CDE as a measure to enhance the overall energy efficiency, thus improving the country's energy security and contributing positively to address the climate change issues. Policy makers in both countries have realized the specific benefits that can be accrued from CDE and have actively supported such developments by creating appropriate regulatory and economic environment and removing barriers to the development of cogeneration, such as non-transparent and inconsistent procedures for the participation of non-utility players in generating and selling electricity to the power grid, technical hurdles of interconnection and high charges, securing a fair price for the export of cogenerated electricity to the grid. Considering the fact higher up-front investments are necessary to set up decentralized CDE networks, suitable incentive measures have been extended to encourage private sector investment by making the projects financially attractive. Industries and commercial clients find it attractive to purchase energy services from CDE networks because of the economic advantages and the ease of availability of the different forms of energy from a single provider closer to their operation site.

Though similar potentials exist in other regional countries like Indonesia and Vietnam, there are several bottlenecks for their realization. Many of the existing policies are not conducive for the promotion of CDE. Typical barriers can be classified into the following four categories:

1. Regulatory: Lack of consideration of cogeneration as an option for the power sector development; restriction on private power generation or the sale of privately generated electricity to the power grid; treatment of cogeneration on taxation regime; lack of incentives for cogeneration as a means to reduce national greenhouse gas emissions
2. Technical: non-availability of natural gas grid near potential sites with important industrial and commercial client base; interconnection with the electric utility
3. Economic/financial: cost of fuel purchased in bulk for cogeneration not the same as the price at which it is supplied to the utility-based power generating facilities; low price of electricity sold to the utility grid; high cost of electricity purchased from the grid; use of system charges and procedures, including the high stand-by costs
4. Awareness: inadequate awareness of the different stakeholders: policy makers do not realize the multiple benefits of CDE at the micro and macro level, potential developers are not always aware of the different financing options, and the potential clients underestimate the direct benefits.

As East-Asian region continues to grow rapidly, there is increased pressure to develop new urban districts for decongesting the overcrowded city centres, and to create infrastructure for well-planned industrial estates for matching with the high growth in the industrial sector. At the same time, the threats of climate change are real and need to be addressed seriously by the national decision makers. Those countries lagging behind in the development of CDE can learn from their neighbours as well as from the best practices and examples around the world in order to lift the existing barriers and secure the benefits from the healthy growth of cogeneration and district energy in their cities and industrial complexes.

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