Supercritical Steam Power Plants - an Attractive Option for Malaysia

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Introduction

Forecast of a dramatic rise in natural gas (NG) prices, due within a short outlook of few years, causes coal to enjoy its resurgence once again.

In The 21st centaury the coal fueled power generation is expected to face new challenges. The biggest challenge is the concern over the global climate change.

A minor portion of reduction of green house gases (GHS) from coal use may be achieved through options like CO_2 trading or credits for investing in emissions reduction projects.

However, substantial reduction in emissions from coal fired power plants can be achieved only by employing most advanced and highly efficient modern power generation technologies.

Motivated by the urgent needs advanced technologies for coal fired power generation, clean coal technologies are undertaken worldwide, mainly in USA, Europe and in Asia.

Within recent tens of years, several progressive coal burning power generation technologies have been developed, of which are:

- Integrated Gasification Combined Cycle (IGCC)
- Pressurized Fluidized Bed Combustion (PFBC)
- Pressurized Fluidized Bed Combustion - Combined Cycle (PFBC-CC)

These technologies are broadly accepted internationally and researches as well as demonstration projects are preceded.

IGCC and PFBC technologies are described and discussed in our paper, **"Advanced Clean Coal Technology for Power Generation- An Opportunity for Southeast Asia"** which was presented at Malaysia Power 2003 conference in Kuala Lumpur.

This paper covers coal combustion with **s**upercritical steam **c**onditions (SC) and ultra-SC (USC) power generation technology (**later in this paper commonly named as SC technology**).

SC technology is a mature high efficient fossil power generation technique, which is being continuously developed worldwide and it is listed in the category of clean coal power generation technology class. This is justified due to efficient coal utilization at lover environmental pollution.

More than 500 SC power plants (status 2002), with total capacity above 300 GW, are operating mainly in Europe, USA, Japan and Russia (Figure 1).

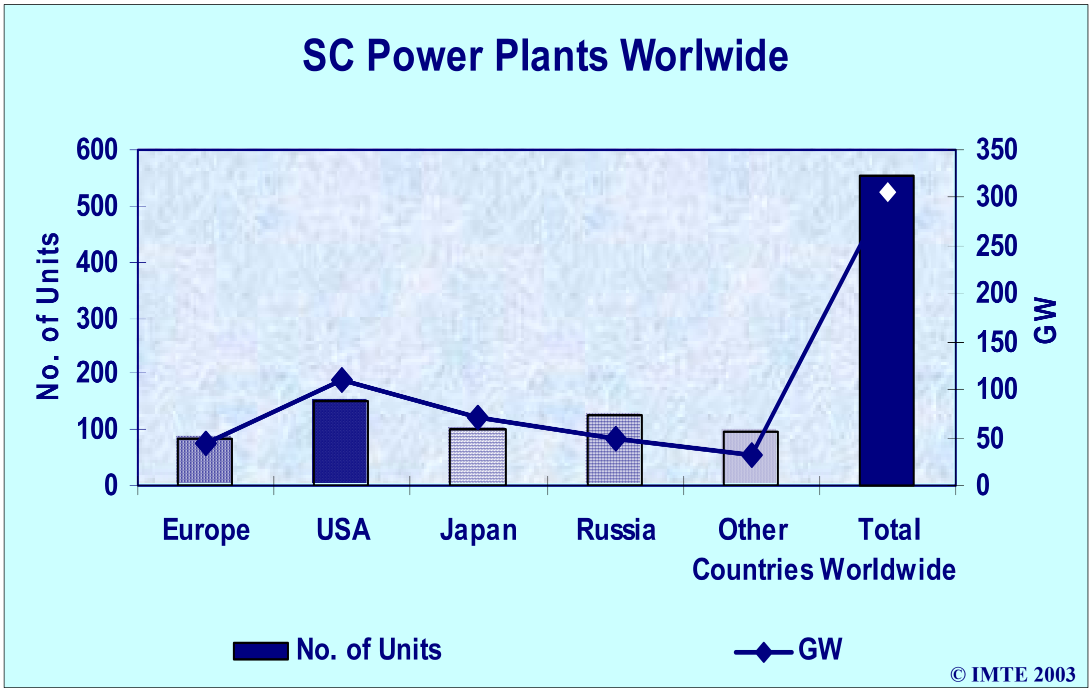

FIGURE 1
CAPACITY OF SC POWER PLANTS WORLDWIDE

Advanced SC designs can now be found at several Asian power plants, with are currently under construction in the People's Republic of China, South Korea and Taiwan with the capacity in range of 25 GW.

Emerging interest in advanced SC coal fired power plants has fueled development of new, cutting-edge technologies.

Power plants with record-breaking steam parameters approaching or exceeding levels of 300 bar and 600°C have been commissioned in the last decade or are under construction in Denmark, Germany and Japan.

Strange enough, this is not the case for the traditional developers of SC technology like Russia and the USA. In these two countries no further major growth of SC technology has been seen in the last decade.

Over the last 25 years, many SC units with relatively mild steam conditions of 240 bar / 565°C have been built in the former Soviet Union.

The first 100 MWe USC unit with operating conditions of 306 bar/650°C/565°C was already commissioned in Kashira, Russia in year 1966.

More than 150 SC power plants with combined installed capacity above 107 GW are in operation in the USA. Most of them came on-line prior to 1980. For example the most famous of them, Eddystone 1 that was commissioned in 1960, is still operating with remarkable steam parameters of 322 bar and 610°C.

A strong decline in 1980's decade came after this boom. Reasons for such decline were not only universal, like restructuring trends in the thermal power generation industry, but also ones cohering with "technological overheat".

SC industry was suffering more from the bullish expansion and uncontrolled increase in the unit size rather than from extreme pressures and temperatures themselves.

Before this decline, unit size had been gradually increasing from 200 MWe up to 500 MWe output within relatively short period between 1960 and 1975.

However, it is a fact that SC coal fired power plants with efficiencies of above 45% that produce less specific emissions (emissions per given power output) than subcritical power plants have a great future in the coal fired power generation industry.

This paper reviews the major technical and economical aspects of SC coal fired power plans in comparison with conventional technology, introduces selected SC power plants as well as discusses the opportunity for implementation of SC technology in Southeast Asia.

> Experience that takes account of SC power plant performance in USA, Europe, and Asia as well as in South Africa shows, that coal fired SC power plants are just a reliable as conventional, subcritical power plants.

Supercritical versus conventional

In order to increase coal based power generation efficiency, conventional coal fired power plants have to consistently improve steam parameters to higher levels.

Historically, it was widely foreseen that from the traditional 165 bar/538°C single reheat cycle, dramatic improvements in coal fired power plant performance could be achieved by rising the live steam pressure to levels above 310 bar and temperatures to levels in excess of 600°C.

In March 1957, the first SC unit was put into commercial operation in USA. After that, through more than 45 years of practices in many countries, through protracted struggles, the technology is unceasingly developed and gradually perfected.

What is supercritical? It is a thermodynamic expression describing the state of a substance (in our case water/steam) where there is no clear distinction between the liquid and the gaseous phase. Water reaches this state at a pressure above 221 bar (22.1 MPa).

The efficiency of each fueled power generation process describes how much of the energy that is fed into the process is converted into useful electrical energy. The greater the output of electrical energy for a given amount of energy input, the higher the efficiency.

If the energy input to the process is kept constant, the output can be increased by selecting the process parameters, in this case by elevating pressures and temperatures for the water-steam cycle.

Up to an operating live steam pressure of around 190 bar (19 MPa), the cycle is subcritical. This means, that there is a non-homogeneous mixture of water and steam in the evaporator part of the boiler.

In this case usually drum-type boilers are used, because the steam needs to be separated from water in the drum, before it is superheated and led into the turbine.

Above an operating live steam pressure of 221 bar (22.1 MPa), the cycle is supercritical (Figure 2).

The cycle medium is a single phase fluid with homogeneous properties and there is no need to separate steam from water in a drum. Once-through (OT) boilers are therefore used in SC cycles.

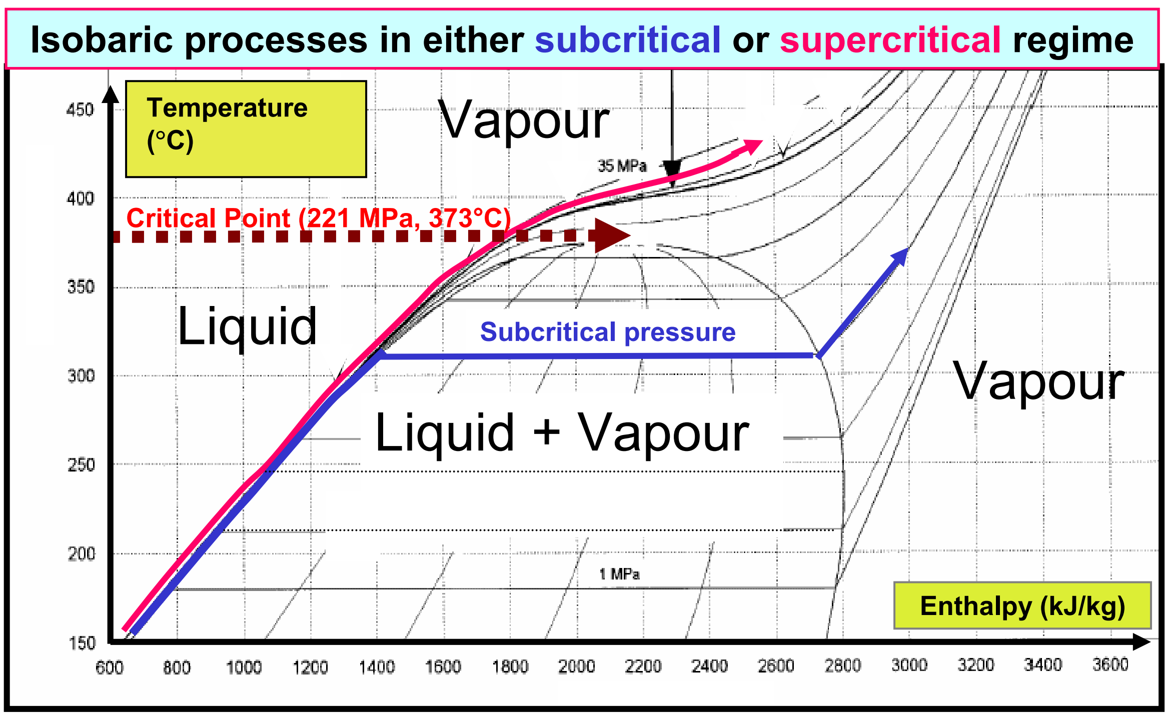

FIGURE 2
WATER – STEAM ENTHALPY DIAGRAM

Notorious reasons why not to build an SC plant were more-or-less related to the higher maintenance costs and lower operational availability and reliability compared to subcritical units.

Main concerns were related to the steam turbine control valve wear, to the thermal stress and turbine blade solid particle erosion problems as well as to more complicated start-up process.

SC units have a greater potential for turbine water induction through the main steam system compare to drum-type subcritical units.

They are more sensitive to feedwater quality. Full-flow condensate polishing, therefore, is required to protect the turbine from stress corrosion cracking.

However, SC units are more efficient. They employ OT-boiler technology and therefore have better operational dynamics.

Their ramp rates are higher, namely 7-8%/min compared to about 5%/min (for subcritical units) at higher loads.

Comparing to subcritical power plants, SC power plants can maintain higher efficiency at rather low load.

On the other hand, conventional drum-type boilers have bigger material requirements because of the thick-wall drums, and also the water/steam inventory.

Fuel prices are taking ever higher economy weight. Markets of the countries, where fuel cost is a higher fraction of the total cost, more efficient SC units offer a more favourable cost-of-electricity comparison and lower emissions than subcritical units. SC plant reduces carbon emissions relative to the same size of subcritical coal unit.

And at last but not least, the expected life cycle costs of SC power plants are lower than those of subcritical power plants.

In the second half of last decade SC technology clearly prevailed over the conventional one in the OECD countries.

In this period, more than 20 GWe of new installed SC capacity against merely 3 GWe subcritical one were installed here.

Various collaborative programs like THERMIE 700 EUROPE, COST 522 EUR, EPRI 1403-50 USA or CRIEPI push the technical envelope of this important clean-coal technology.

In the non-OECD countries, however, the rating for the same period was vice-versa. Only 5% out of new installed capacity was based on SC technology in the second half of last decade.

While the rapid introduction of very large plants in the USA in the early 70s created problems in the availability, due to forced outage, of these plants, feedback from other operators is very positive.

The following diagram (Figure 3) illustrates that availability of SC power plants is equal or even higher than those of comparable conventional (subcritical) power plants.

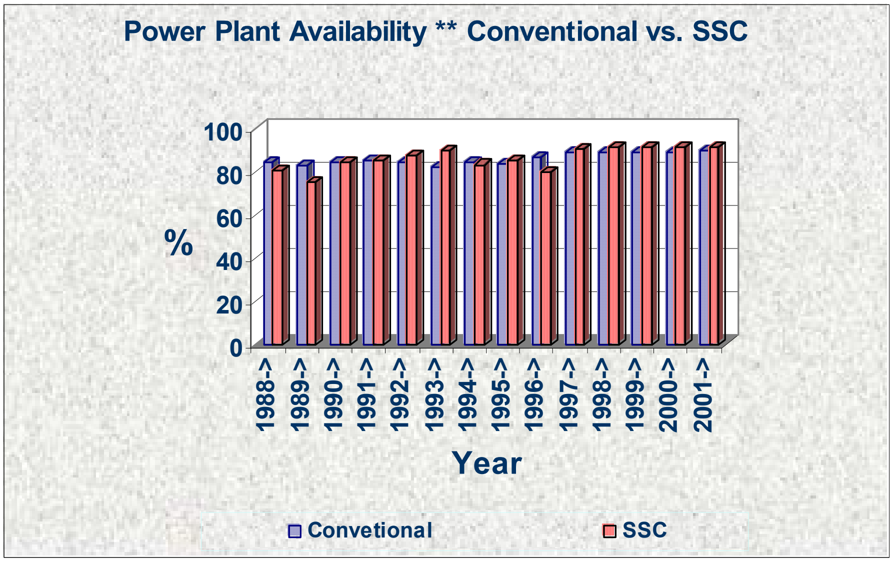

FIGURE 3
COAL FIRED ST POWER PLANT AVAILABILITY SC VS. SUBCRITICAL

The following Table 1 indicated basic data comparison between 580°C/700°C SCC and conventional coal fired power plant.

Plant Type	Price (US$/kW)	S-Pressure (MPa)	S-Temperature (°C)	A-Consumption (%)	Efficiency (%)	CO_2 (g/kWh)	SO_2 (g/kWh)
Conventional	1100	165	538 / 538	4-6	< 40.0	≈ 855	≈ 2.4
580°C - SC	1300	290	580 / 580 / 580	5-7	> 42.0	≈ 780	≈ 2.2
700°C - SC	1350	365	700 / 700 / 700	6-8	> 48.0	≈ 710	≈ 2.0

TABLE 1
COMPARISON PARAMETERS SC VS. SUBCRITICAL

Increased live steam pressure to levels above 300 bar leads to higher auxiliary power consumption and to loss of thermal flexibility, comparing to conventional (subcritical) systems.

The following diagram (Figure 4) illustrates the relative thermal efficiency gain for a variety of main and supercritical reheat steam conditions and boiler material improvement (using Benson type boilers) for single reheat unit compared to the conventional (subcritical) 167bar/538°C/538°C cycle.

As shown in this diagram, steam temperatures above 700°C are possible, using more expensive nickel based alloys. Such USC cycles might achieve thermal efficiency of around 48-50% and higher.

Limitations on achievable steam parameters are set by creep properties of construction materials for high temperature boiler sections, live steam piping and other components, as well as high temperature corrosion resistance of superheater and reheater materials.

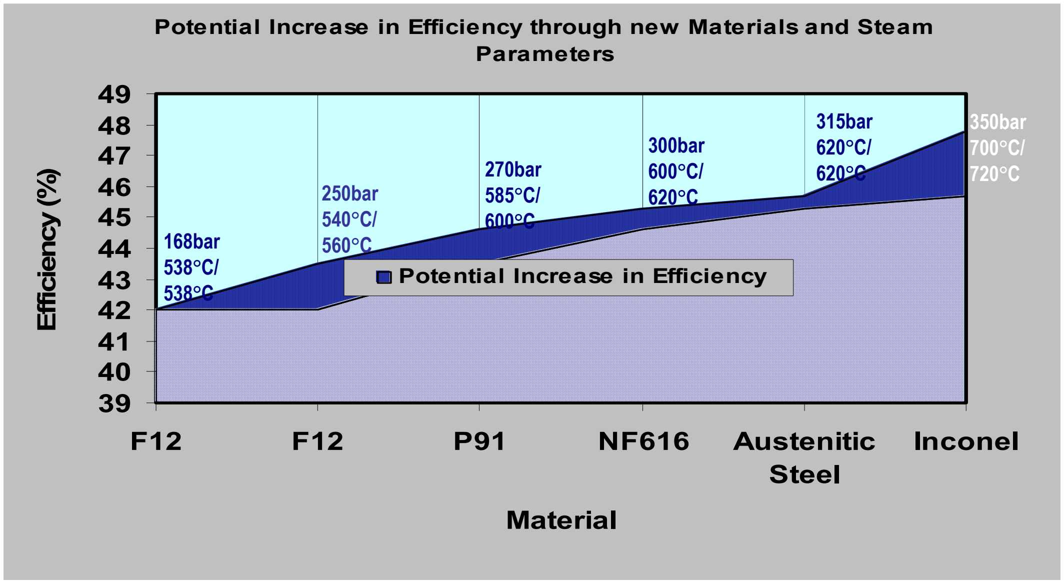

FIGURE 4
POTENTIAL INCREASE IN THERMAL EFFICIENCY

Higher steam temperatures make the change from ferritic steel to austenitic steel and inconel unavoidable.

Both, conventional (subcritical) and SC technology is commercially available in wide range of size. Compared with conventional power plant, SC technology with its improvement in efficiency and consequently lower specific flue gas throughput is cleaner method of electricity generation. Conventional technology provides great coal flexibility. Higher temperatures encountered in SC units' makes corrosion more critical, thus coals with slugging or corrosion potential are less suitable for SC plants. State-of-the-art SC power plants have an efficiency of about 46% and satisfy current emission standards worldwide.

Supercritical state-of-the-art

As already stated in this paper, compared to conventional (subcritical) coal fired power plants, SC coal fired technology is one example of a "clean coal" technique that burns coal more efficiently and with fewer emissions.

This is an emerging technology with limited construction history worldwide, although it has been used more extensively in countries such as USA, Russia, Japan, Germany, Italy and Denmark.

The following Table 2 illustrates some selected projects representing state-of-the-art SC technology with reputable efficiencies that have already been commissioned, or are currently under construction:

Power Plant Name	Country	Power Output (MW)	Live Steam Parameters (kPa / °C / °C)	Efficiency (%)	Commercial Operation
Schwarze Pumpe	Germany	2 x 800	250 / 544 / 562	41.0	1992
Staudinger Unit	Germany	500	250 / 540 / 560	43.0	1993
Lippendorf	Germany	2 x 800	268 / 554 / 554	42.4	2000
Niederaussem	Germany	1000	275 / 580 / 600	45.2	2002
Boxberg	Germany	1000	266 / 545 / 581	43.0	2000
Nordjyllaend	Denmark	410	285 / 580 / 580	47.0	1998
Esbjerg 3	Denmark	415	250 / 560 / 560	45.3	1992
Studstrupvaerket	Denmark	400	270 / 540 / 540	42.0	1985
Fynsvaeket – 7	Denmark	420	250 / 540 / 540	43.5	1991
Hemweg-8	Netherlands	700	250 / 535 / 563	44.0	1994
Isogo 1 & 2	Japan	2 x 500	245 / 600 / 600	46.0	2001
Misumi 1	Japan	600	250 / 605 / 600	46.0	2001
Tachibanawan-2	Japan	3 x 700	250 / 600 / 610	47.0	2000
Waigaoqiao	China	2 x 900	279 / 542 / 562	42.7	2004
Yonghungdo	S. Korea	2 x 800	246 / 566 / 566	43.5	2004

TABLE 2
SELECTED SC POWER PLANTS IN OPERATION OR UNDER CONSTRUCTION

At present, the ultimate stage of development is fixed to live steam conditions up to 37.5 kPa / 700°C / 720°C (e.g. JOULE / THERMIE Program).

Depending on the steam conditions and other process parameters (cooling method, ambient conditions, etc), thermal efficiencies in the range 50% are expected.

Technological Features of Supercritical Boilers & Steam Turbines

SC plants have typically been built according to the “split package / multi-contract principle” in which a project is divided into several packages put out to tender individually.

Following this model, two distinguished parties of suppliers (or their consortia) are playing their particular role.

One is responsible for the boiler island package, the other one is covering the turbine-generator island package and related auxiliary systems.

It will therefore be useful to discuss the technological features of the boiler and the steam turbine separately.

Boilers

Standard SC boiler is OT-boiler equipped with spiral wound furnace pipes. Steepness of the loops (angle of inclination) is one of its important design parameters. The spiral tube design has a good record of more than 30 years' experience.

However, spiral loop is expensive in manufacturing. The primary drawback to the spiral tube design is the hardware needed to support the spiral tubes bunch.

As it is well-known, physical principle of supercriticality is very simple. Water substance has its critical point defined by pressure and temperature coordinates of 22.1 kPa and 373.2°C, respectively. At the critical point liquid and vapor phase converge to equal density and evaporation heat converges to zero.

Beyond the critical point natural boundary between liquid and vapor phases disappears (liquid water is abruptly changed to steam). Internal circulation system, based on the density difference between liquid water and steam (common to all drum boilers) is becoming no more applicable.

The only way how to overcome this challenge, is a OT-boiler system. OT system is simple for physical understanding, yet difficult in the detailed engineering design that would operate properly.

Overheating of tubes must be prevented. Adequate cooling effect inside the pipes must be guaranteed throughout their whole length. It means that thermohydraulic regime defined by the heat flux (kW/m^2) and mass flux ($kg/m^2/s$) must be maintained within certain boundaries of subtle and fragile equilibrium.

This is not always easy to follow in a system equipped with standard smooth pipes.

However, latest design of OT boiler (Benson type) created within the EU-sponsored programme Thermie 700, developed by Siemens, is based on horizontal furnace and internally rifled vertical pipes. Internal rifling is a microspiral grooved within the tubes.

It makes the medium inside the pipes to rotate along its trajectory and to throw the cooling medium droplets against the pipe walls via excentrical force (induced swirl). Cooling effect is boosted considerably in this manner.

Also the furnace corners are easier to form. The lower overall pressure loss results in life-cycle savings in feed pump power compared with a spiral wound design, which requires an auxiliary support system.

One of the latest references for the improved design of vertical piping has become the first 300 MW unit at 1200 MW Yaomeng Power Plant in China. This project is actually retrofit with an OT-boiler, low mass flux, vertical tubing. This has been under development by Mitsui Babcock with Siemens PG for more than 15 years.

Nevertheless, Benson boilers with vertical piping are not new. They were popular for more than 70 years. Since 1930, the furnace tubing has generally been configured in a spiral configuration with the tubes welded together to form membrane walls. Up to date more than 1000 Benson boilers have been installed worldwide.

In 1980 Sulzer developed a concept that used internally ribbed tubes (applied in 2x700 MW Kawagoe, Japan). Full load mass flow density for this boiler is 1600-2000 kg/m^2/s. Benson boilers are also flexible in operation, minimum Benson boiler output can be as low as 20%.

> Before 1920 there were serious explosions of drum boilers as the result of material and manufacturing defects. Inventor of the first OT boiler, Mark Benson proposed boiler with evaporation to occur at the critical point, when water instantaneously turns into dry steam of equal volume.
>
> In 1922 he was awarded a patent. Siemens-Schuckert-Werke acquired this patent in 1924 and developed this kind of boiler for practical use. The first OT Benson boiler was placed in operation in the late 1920s in Berlin. In those days power plants employing drum-type boilers generally operated at 20 bar / 325°C.
>
> Benson yielded 40% higher efficiency and 20% lower investment costs. In 1933 Siemens-Schuckert-Werke closed down their own manufacturing operations and granted licences to miscellaneous manufacturers.

Boiler design technology is currently following the trend of ever higher creep rupture stress material. Such are steels P91 to P92, austenitic steels 18-8 to 18-25 like Super 304H, Esshete 1250 as well as the high nickel alloys like Inconel 718 as shown in Figure 4.

The extra costs of using nickel based alloys can be partly compensated by reduction in the amount of material, because of thinner pipe walls and smaller dimensions of machinery.

Also austenitic steel slightly reduces the wall thickness. Despite of its unfavourable physical properties (thermal coefficient & conductivity) compare to ferritic/martensitic steel, this material is able to follow changing temperatures during accelerated start-up of the turbine. This is why austenitic steels are used for superheater pipes.

Furnace walls need high-temperature creep-resistant feritic steel. T23 & T24 are probable candidates.

Reheat temperature is usually higher (typically by 15-20°C) than main live steam temperature, but because the reheat pressure is typically by 4-times lower than main live steam pressure, lower quality material may be used for reheat systems and components.

Present ultimate stage of development which was fixed by JOULE/THERMIE program to live steam conditions up to 37.5 kPa / 700°C / 720°C.

Onerous conditions like these require application of expensive high nickel alloys. However, proportionally reduced hight of the vertical piping system minimizes the amount of expensive high nickel.

SC boiler size reduction (reduction of material quantiry and amaller construction site) may appear to become the decisive factor for even more intensive expansion of SC technology, because this particular problem of extremely high cost of special steels and alloys was traditionally the main obstacle with even wider application of SC technology.

History and outlook of high temperature materials development is shown in Table 3.

Live steam		When	What
Pressure (bar)	Temperature (°C)		
<250	<520	Since early 60's	X20
<300	<560	Since late 80's	P91
<330	<620	Start 2002	P92
350-470	700-720	Start 2010	Super Alloys

TABLE 3
COAL FIRED POWER GENERATION-TEMPERATURE & MATERIAL DEVELOPMNET

Currently, steam conditions are limited by material to 300bar, 600°C, and 620°C corresponding to 46% efficiency.

Even higher, 47%, efficiency is demonstrated at the Nordjyllaendsvaerket SC power plant in Denmark (Table 2), yet in extremely favourable cold cooling sea water conditions.

Classic SC Technology supporting Programmes

- EU Brite Euram (European Union)
- COST (34 European member countries)
- EPRI (USA)
- DOE (USA)
- Thermie (European Union)
- Convoy (Denmark)
- KEMA (The Netherlands)
- EPDC (Japan)
- CRIEPI (Japan)

For example, the achievement of the goals of EPRI program shall produce the capability to construct and operate a boiler to USC conditions of 760°C and 35 MPa.

The objective task of an other program supported by DOE is to develop new-generation corrosion-resistant Mo-Si alloys for use as hot components in advanced fossil energy conversion and combustion systems in order to improve the thermal efficiency and to increase the service life of hot components exposed to corrosive environments at temperatures as high as 1600°C.

Emerging demand for SC technology indicates that long-term operational performance has largely erased concerns about SC plant reliability.

Steam Turbines

Steam turbines (ST) for SC duty are an extra category among the family of steam turbines. Typical feature of modern SC turbines is relatively high capacity (300 MWe - up to 1300 MWe).

They are robust, heavy duty and highly sophisticated machines. Observing the main philosophy of SC plants, which is based on high efficiency, these STs are highly efficient with adiabatic efficiency up to 95%.

Internal design of ST technology has undergone a long evolutionary development. Using CFD (Computational Fluid Dynamics) software, hydrodynamic regime and blade shaping has been processed on the basis of 3-dimensional (3-D) analysis, or advanced three dimensional analysis (3-DS). In this way a complete range of new high-efficiency 3-DS ST blading has been developed.

Adopting the new design philosophy, Siemens now claims to have developed a new type of blading, which in addition to the 3-D blade shape, allows also the reaction of each stage to be set on individual basis.

Known as 3-DV (3-D blading with variable stage reaction), the new variable reaction design is based on an extension of Siemens' existing, well-proven 3-DS blading.

3-DV combines the benefits of both, multistage reaction blading and low reaction impulse blading, because it offers greater design freedom. This allows further significant improvements in blading and consequently in overall efficiency.

Stage reaction is the degree to which enthalpy drop of a particular stage of blading is divided between rotating and stationary part. Mathematically it is defined as follows:

$$\text{Stage Reaction} = \frac{\text{Enthalpy drop of rotating row}}{\text{Enthalpy drop of the whole stage}}$$

The reaction of each stage is set individually and may vary between 10% and 60%. According to this classification character of individual stage can be labelled as either "reaction stage" or "impulse stage".

Reaction stages: The symmetry in enthalpy drop allows the same profile to be used for both blade rows. The pressure differential across the rotor blades is rather high and exerts a large axial thrust on the rotor. In order to compensate axial thrust, a dummy balance piston is required in single flow designs. A reaction stage has stage reaction of up to 60%.

Impulse stages turbines have zero stage reaction. Consequently, the total stage enthalpy is converted to kinetic energy in the stator row, while the rotor row merely deflects the steam without further acceleration. Flow is asymmetrical.

Until now, blades and vanes have been based on either an impulse or reaction design philosophy with the same degree of reaction applied to all stages.

This imposes an immediate constraint setting a limit to the design target when aiming for the highest level of efficiency.

However, if 3-D blade is designed for each specific application, the distinction between impulse or reaction blading is lost.

To reduce windage losses, modern SC turbines have the rotor blades fully shrouded by internal shroud blading (ISB).

Usually, only the last stage blade (LSB) row in the low pressure (LP) ST-section is free-standing, because of the high centrifugal forces acting in that area.

The exhaust diffuser provides for pressure recovery of the exhaust steam so that the exit pressure from that blading can be lower than the condenser pressure.

The result of modern advanced SC-ST technology is the highest recorded gross thermal efficiency of 49% that has been claimed by Mitsubishi Heavy Industries (MHI) SC power plant.

MHI apply in their 1050 MWe (reportedly the biggest and most efficient SC turbine ever built) the longest 46in (1170 mm) LSB.

Advanced material application, especially of titanium for the LSB with lower density allows longer blades to be used and thus the exhaust annulus area to be increased.

Advanced materials to be used for SC turbine components are of higher quality grade compare to the conventional steam conditions of 538°C.

High pressure SC steam turbine materials - comparison of 600°C class applied by MHI to conventional 538°C class is shown in Table 4.

Main steam temperature	600°C	538°C
Rotor	New 12 Cr forging	Cr-Mo-V forging
Nozzle chamber	12 Cr cast steel	2 ¼ Cr – 1 Mo cast steel
Inner casing	12 Cr cast steel	1 ¼ Cr – ½ Mo cast steel
No.1 blade ring	12 Cr cast steel	1 ¼ Cr – ½ Mo cast steel
No.2 blade ring	2 ¼ Cr – 1Mo cast steel	1/2 Cr – ½ Mo cast steel
Outer casing	2 ¼ Cr – 1Mo cast steel	1 ¼ Cr – ½ Mo cast steel
Rotating blade	Refractory alloy (R-26)	12 Cr forging
Main steam stop valve	9 Cr forging	2 ¼ Cr – 1Mo forging
Main steam governing valve	9 Cr forging	2 ¼ Cr – 1Mo forging

Table 4

Configuration of turbines depends on the MW capacity application range, approximately as follows (Figure 5 – 10).

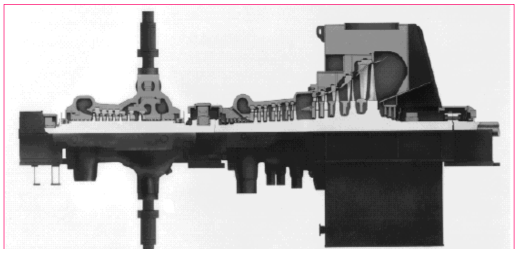

Figure 5
Two-casing, single-flow ST, with double-shell HP inlet, < 300 MW

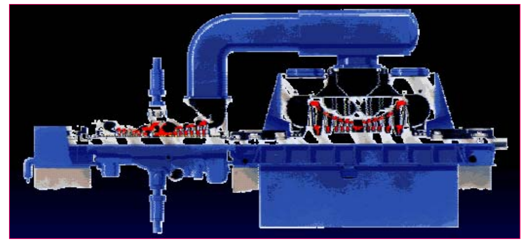

Figure 6
Two-casing, double-flow ST 300 – 500 MW, 170 bar / 565°C / 565°C

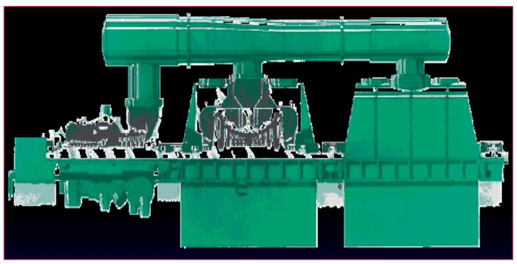

Figure 7
Three-casing, four-flow ST 500 - 700 MW, 170 bar / 565°C / 565°C

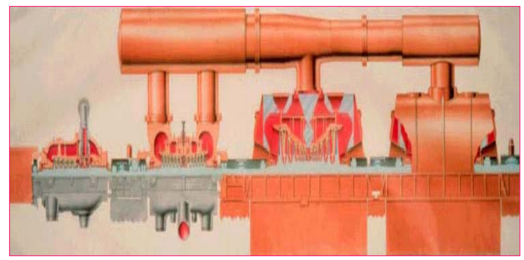

Figure 8
Four-casing, four-flow ST 700 - 900 MW, 245 bar / 565°C / 565°C

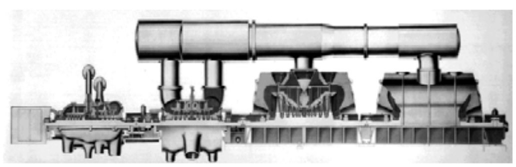

Figure 9
Four-casing, four-flow, with double reheat, 900 - 1200 MW, 310 bar

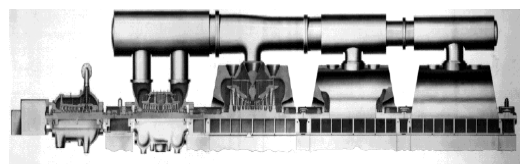

Figure 10
Five-casing, six-flow, with single reheat, > 1200 MW, 310 bar

Does Supercritical Technology suit to Malaysia's Power generation Environment?

The total current (2002) power generating capacity installed in Malaysia is around 14.6 GW (Peninsular Malaysia 12.9 GW, Sarawak 0.9 GW, Sabah 0.8 GW) with maximum power demand (2002) of around 10.8 GW.

The present generation fuel mix is 66% NG, 13% hydro, 6.8% oil and 14% coal. The remaining 0.2% is light diesel oil and biomass fuel.

Malaysian five fuel policy, oil, NG, coal, hydro and renewable energy, avoids any over-dependence on any one source.

The present power plant mix is: OCGT and CCGT power plants firing NG and oil, conventional ST power plants firing coal, NG or oil, hydro power plants and small biomass fueled plants (mainly steam and hot water boilers).

Present fuel split and fuel split expected in year 2020 is shown in Figure 11 and 12.

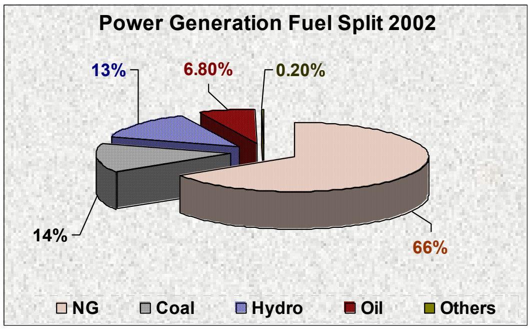

Figure 11

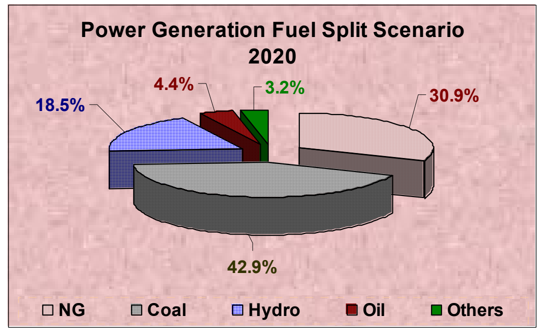

Figure 12

Although TNB and several IPPs place great emphasis on efficient NG-fired power plants, there are several coal fired power plants in operation, under construction as well as in planning stage.

The Government forecasts demand to grow by between 8% and 10% annually. If demand does in fact grow at approximately 8% per year, this will mean that around 1 GW power generation capacity has to be installed every year in Malaysia.

In 2002, the national annual energy requirement for power generation was about 16’000 kiloton’s oil equivalent (ktoe).

Considering 8% annual grow, country’s energy requirements for power generation is expected to increase to about 57’000-60’000 ktoe per annum in 2020, in other terms the expected power demand in 2020 is to be in the region of about 38 – 40GW.

This will require putting up a huge additional power generation infrastructure. Very important question is how Malaysia can meet this growing power generation requirement in terms of primary energy resources in the future.

Due to very limited reserves, oil is not expected to have a major role in base load power generation in the future. The dependence on oil in power generation sector will be reduced in the foreseeable future, however, in log term thinking oil may be maintained as important fuel for emergency power generation purposes.

Another very important primary energy source in Malaysia is NG. During last ten years many NG fueled CCGT power plants (≈5.5 GW) were planted by Independent Power Producers (IPPs) in Malaysia.

This brought the NG fueled power generation capacity to above 8 GW. It is a fact that Malaysia does not have that much of NG to continue increasingly cover country’s power generation needs by NG.

Since NG has other important uses (e.g. petrochemical, chemical and fertilizer industries), the current NG resources have to be well preserved. As such it is necessary for the country to reduce the use of NG in the power generation.

What would be the candidate to take NG role in power generation industry? Due to very long transmission distances and other related problem, accessible hydro resources in Malaysia are rather limited. The total hydro potential of the country is in the order of 29 GW of which only about 2 GW has been utilized to date.

There is a huge hydro potential in Sarawak, but there are also many technical and commercial restrains related to the transmission of electric power generated in Sarawak to Peninsula Malaysia.

Other renewable energies (solar, wind, biomass) will not play major role in the foreseeable period and nuclear energy is not in line with Government's five fuel policy, it may be some time before Malaysia can seriously consider the inclusion of nuclear energy in the overall fuel mix.

The answer to above question is simple. The future fuel for power generation in Malaysia beside of hydro power is coal.

Malaysia has some coal reserves, most of it in Sarawak, but they are rather small. However coal is available in large quantities worldwide and its price is relatively stable.

Total world proven recoverable coal resources amount to 985'000 million metric tons (more than 25% located in Asia and about 8% in Australia).

The current worldwide coal consumption is 4'400 millions metric tons per annum. Even if an average consumption increases 5% each year, the proven coal resources are sufficient to cover coal consumption for more than 110 years.

Also other, clean coal technologies (refer also to our paper "**Advanced Clean Coal Technology for Power Generation-An Opportunity for Southeast Asia"**) are now available to generate electricity from coal with acceptable environmental effects.

Before looking into IGCC & PFBC, Malaysian power industry should make a serious consideration for implementation of SC technology. The fundamental principles and advantages of SC technology have already been elucidated in this paper.

Since coal is a primary energy that is available at reasonable price and in order to achieve power generation security at reasonable and competitive prices, coal contribution to power plant mix has to be increased.

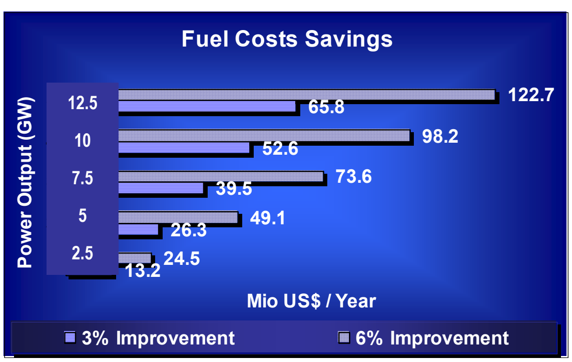

Figure 13
Fuel Cost Saving

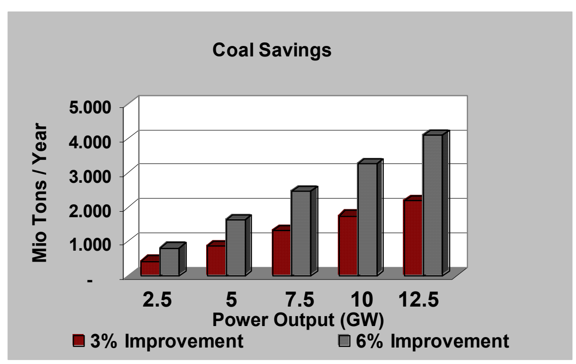

Figure 14
Reduction of Coal Consumption

On the other side, coal is an imported fuel, therefore it has to be used efficiently and the power generation scene will not be complete if other considerations such as power generation efficiency are not widely discussed.

For example average 3-6% efficiency improvement by introduction SC technology in comparison to subcritical power generation technology can save annually up to 3 millions metric tons of coal (Figure 14) or between 50 and 100 Mio US$ (Figure 13) per each 10 GW power generation capacity.

Basic data used for this calculation: Coal LHV = 28'000 MJ/ton, average yearly load factor 85%, 30 US$/ton coal.

There are many challenges to be faced in the country's power generation sector - in sourcing the energy, in terms of keeping its price down and in reducing its effects on the environment as Malaysia is moving towards 2020.

It is important that all of these issues are properly addressed in order for the country to maintain its growth and economy.

Conclusions & Constraints

The early problems experienced with the first and second generation of SC and USC power plants is underway to be overcome.

Currently, SC and USC power plants with steam conditions up to 300 bar, 600°C / 620°C have been matured and become high efficiency commercialized technology.

The largest commercial units with capacity of 1300 MW have reached ambitious efficiency of 47%.

This is indicating that SC and USC coal fired power plants will have broad prospects of development in this centaury, and in conjunction with conventional desulphurization and denitrification further perfected, will still combine to give high efficiency and clean coal firing power generation technology.

Outlook for coal fired SC power plant technology is very positive and its further growth lies ahead. Intensity of this growth will depend on the following factors:

- On a worldwide basis, the prospect for SC / USC technology is extremely good, especially in rapidly developing markets such as Asia.
- Overall reliance of thermal power generation on coal; that has very positive outlook due to very restricted NG and huge coal reserves.
- Competitive influence of other technologies , like IGCC and PFBC; especially IGCC has biggest chances to beat SC technology (mainly in tough markets of OECD countries, however, in the rest of the world, SSG technology has better chances compare to IGCC in the medium term outlook).
- Availability factor; SC power plants have attained similar or even higher availability factor as subcritical power plants.
- Power plant efficiency is increased with higher steam parameters. It is generally considered that SC power plants will have about 2-3% and than USC about 3-6% higher efficiency than subcritical power plants. If conventional, subcritical, 5 GW replaced with SC or USC power plants 1-2 Mio tons of coal can be saved ever year.

- Load regulating characteristics; SC power plants can maintain relatively high efficiency at rather low load.
- Environment effect; due to lower specific (tons/MWh) coal consumption the emissions of CO_2, SO_2 and NOx are proportionally reduced.
- Life cycle costs of SC power plants are lower than those of subcritical power plants.

On the other side there are some constrains related to coal fueled SC and USC technology that are summarized in the following:

- ✓ If SC & USC power generation technology is to become one of the preferred choice in new power plant construction, it has to become economic against the alternative technologies such as subcritical coal-fired conventional power plants and NG-fired CCGT power plants;
- ✓ Regulating and safety systems (mainly for USC) related to multiple reheating systems to be further improved;
- ✓ Advanced austenitic stainless steels for use as superheater and reheater tubing are available for service temperatures up to 650°C and possibly 700°C. Ni base superalloys would be needed for higher temperatures. None of these steels have been approved by the ASME Boiler Code Group so far;
- ✓ Higher strength materials are needed for upper water walls of boilers with steam pressure of 24 MPa (240 bar) and higher;
- ✓ Better opportunity for manufacturing of components for SC & USC coal fired power plants in developing countries should be created;

Coal fired SC power generation technology is matured and advanced technique that can be favorably compared with well proven subcritical power generation technology.

Up to date many SC power plants worldwide have achieved satisfactory commercial operation experiences.

Due to much higher steam parameter and multistage reheating systems, the efficiency of SC and USC power plants is distinctly increased, and will have broad development prospect.

In the medium to long term, as NG becomes a more scarce fuel and prices increase, and in conjunction with further economic improvements in clean coal technologies, SC / USC technology can expect to receive a renaissance as a feasible option for new large scale coal fueled power generation plants.

New technologies have an impact on everything — from environmental quality to costs that consumers will ultimately have to pay.