Efficiency Improvement Possibilities in CCGT Power Plant Technology

Manfred Greth & Miro R. Susta

IMTE AG

Power Generation Consulting Engineers

5416 Kirchdorf, Switzerland

From the History

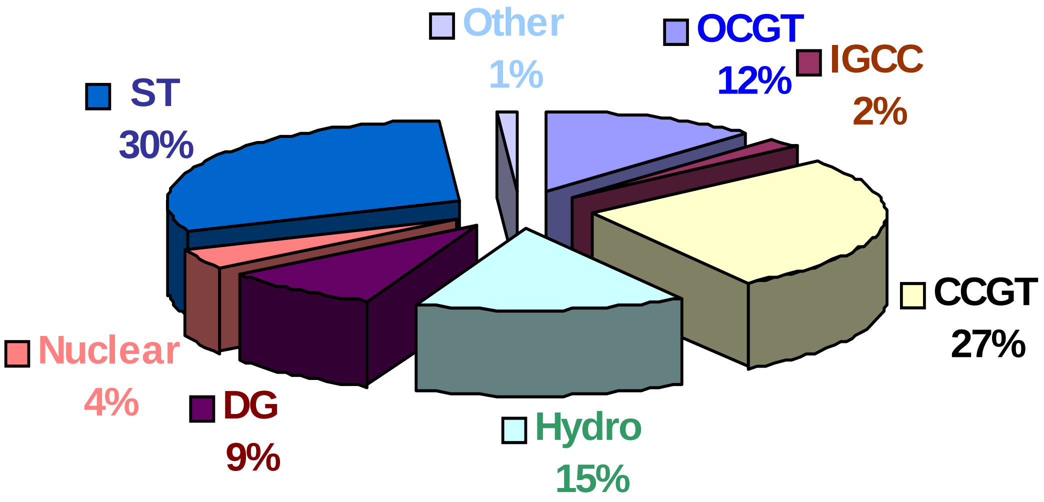
First Commercial Gas Turbine for Power Generation

Name / Location	City of Neuchatel, Switzerland
First Year of Commercial Operation	1939
GT Generator Power Output	4 MW
GT TIT	600 ° C
Thermal Efficiency	21 %

First Commercial CCGT for Power Generation

Name / Location	City of Dudelange, Luxembourg
First Year of Commercial Operation	around 1960
GT Generator Power Output	5.4 MW
GT TIT	650 ° C
GT Thermal Efficiency	21.5 %

POWER GENERATION MARKET SHARE



Status: 2000

MAIN GT TECHNOLOGICAL ELEMENTS RELATED TO GROWTH IN CCGT POWER PLANT EFFICIENCY

- ➓➢ Turbine Inlet Temperature (TIT) > 1400°C
- ➓➢ GT Exhaust Gas Temperature > 600°C
- ➓➢ Sustained Improvement in Special Cooling Techniques
- ➓➢ Further Progress in Metallurgy Status
- ➓➢ The Use of Ceramics
- ➓➢ Utilization of Improved Thermal Barrier Coatings
- ➓➢ Optimized Compressor and Turbine Aerodynamics
- ➓➢ Advanced Control System Technology

CCGT

Modern Gas Turbines with exhaust gas temperatures well above 600°C can benefit from higher pressure and temperature supercritical heat recovery steam generator technology.

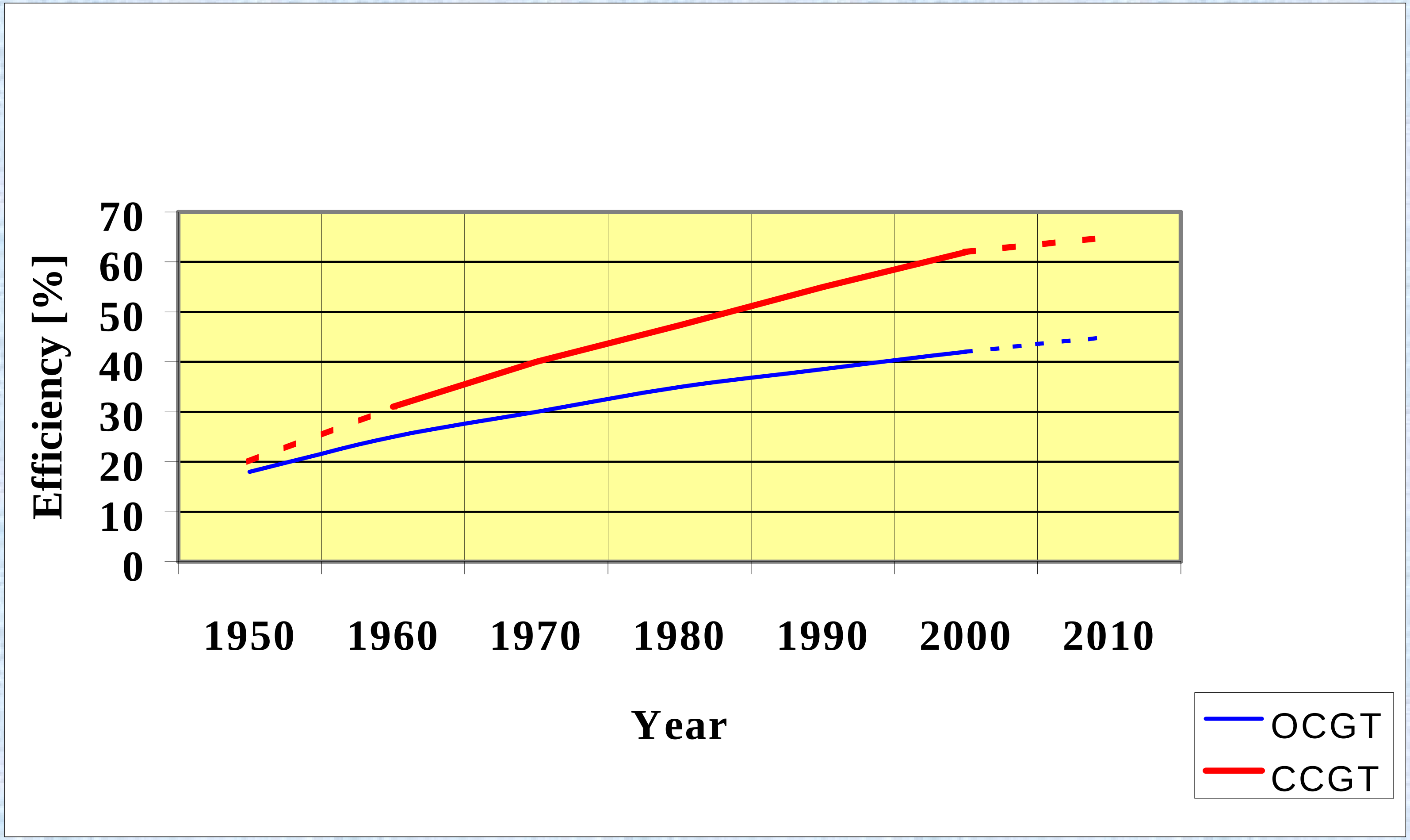
Commercial implementation of supercritical technology in the water-steam cycle within the frame of CCGT power plant is a reality.

Once-through single-pass Benson boiler using high nickel alloys for high pressure and temperature components might be employed.

Main Driving CCGT Power Plant Development Factors

⑩❶	**High Operational Efficiency**	→	**Approaching 60 %**
⑩❷	**Low Specific EPC Installation Costs**	→	**< 500 – 650 US$/kW**
	(CCGT Block in the range of 100 – 700 MW)		
⑩❸	**Relatively Short Installation Period**	→	**< 2 Years**
⑩❹	**Environmentally Friendly of all**		
	the Fossil-Fired Power Plants	→	**NOx < 25 ppm**
⑩❺	**Low Space Requirement**	→	**< 150 m^2 / MW**

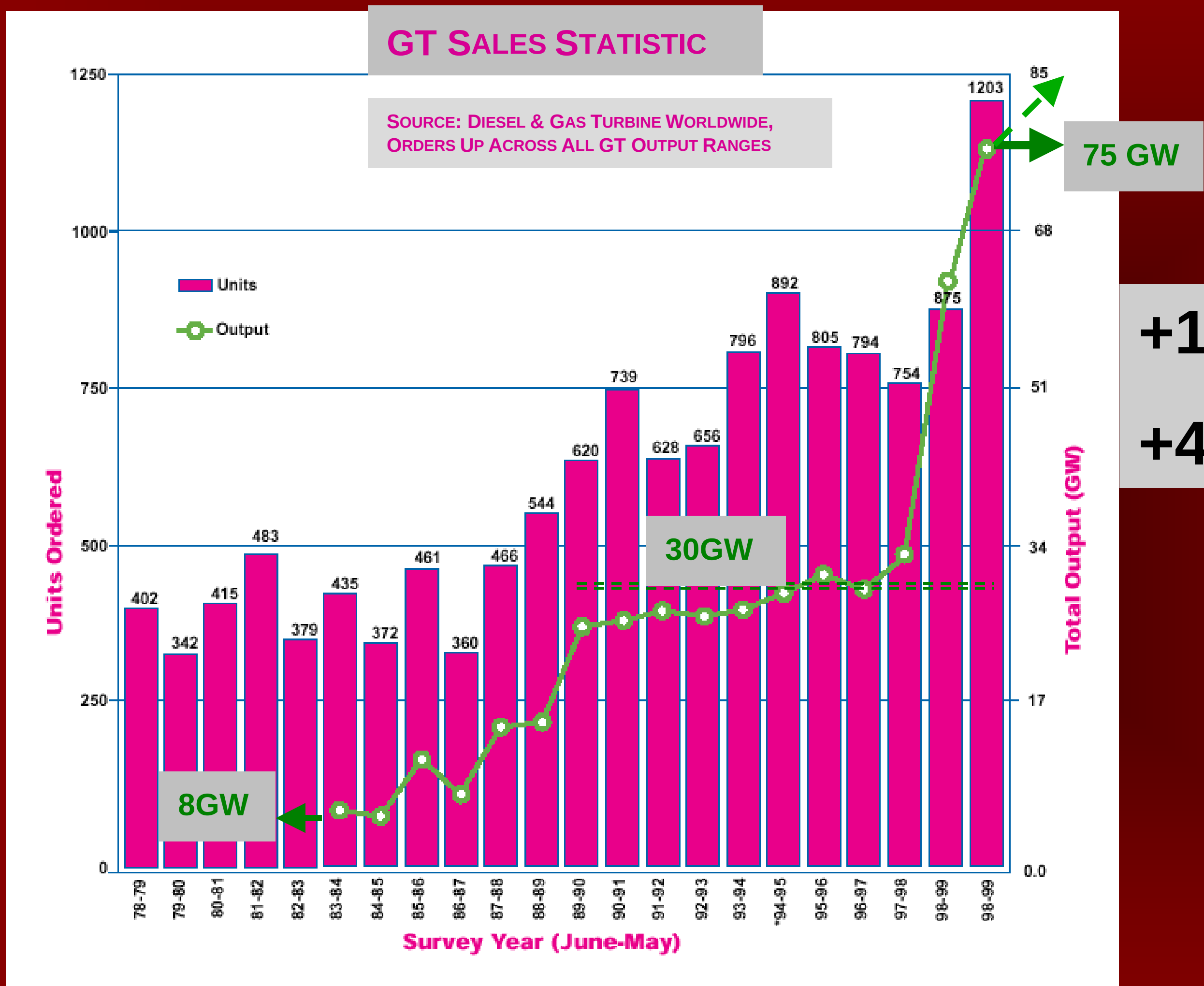
Development of OCGT and CCGT Efficiency



Performance Specifications of Large Advanced Heavy Frame GTs

(ISO Conditions & Natural Gas Fuel-LHV & Generator Terminals)

Manufacturer	GT Type	Power Output MW	Efficiency %	Pressure Ratio	Exhaust Mass Flow kg/s	Estimated TIT °C	Exhaust Temperature °C	Frequency Hz
Alstom Power	GT24	179	39.5	30	391	1300	640	60
	GT26	262	40.3	30	562	1300	640	50
GE Power Systems	7001G	240	39.5	23	558	1430	572	60
	9001G	282	39.5	23	685	1430	583	50
Siemens Westinghouse Power Corp.	501F	185	37.0	15	456	1350	596	60
	501G	254	39.0	19	553.4	1427	590	60
	94.3A	260	38	17	640	1190	562	50
Mitsubishi Heavy Industries	501F	181	38.6	16	453	1350	607	60
	701F	265	39.9	17	651	1350	596	50
	501G	250	40.4	20	567	1500	586	60
	701G	328	41.3	21	737	1500	587	50



+120% → 2 Years

+400% → 10 Years

Turbine Inlet Temperature (TIT)

TIT Increase → Improvement of Cycle Efficiency

TIT Increase → Increase of Specific Power Output (kJ/kg)

Main Objectives

To raise TIT without damaging or reducing a design life of GT components.

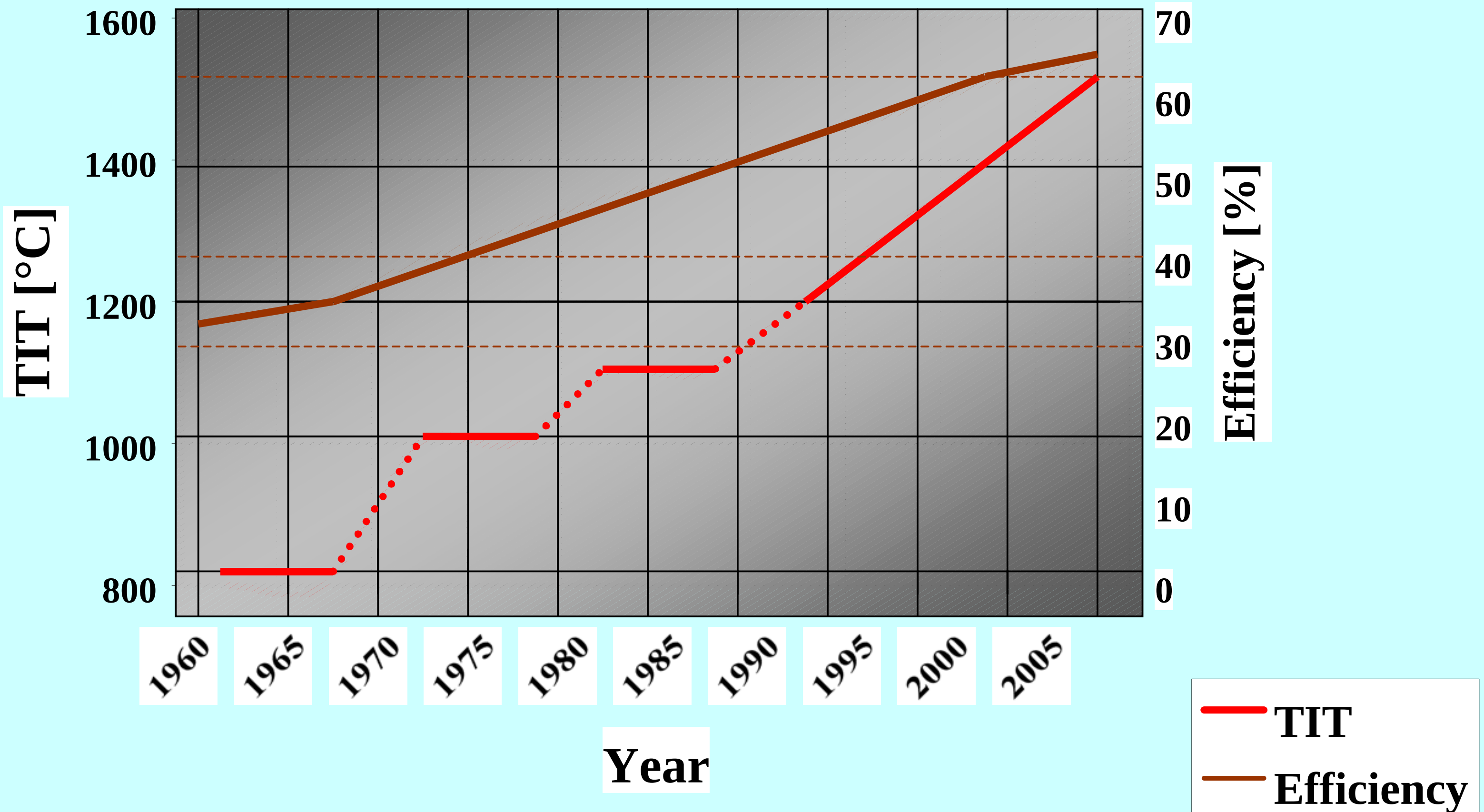
The main limiting factor is the ability of the GT blades and vanes, rotor and stator materials as well as combustor materials to withstand high temperatures during the entire design life time period.

TIT Historical Development

1939	→	600 °C	→	$\Pi \approx 5$	→	≈ 100 kJ/kg
1947	→	650 °C	→	$\Pi \approx 6$	→	≈ 120 kJ/kg
1965	→	800 °C	→	$\Pi \approx 8$	→	≈ 150 kJ/kg
1970	→	860 °C	→	$\Pi \approx 10$	→	≈ 200 kJ/kg
1975	→	950 °C	→	$\Pi \approx 10 – 12$	→	≈ 250 kJ/kg
1985	→	1100 °C	→	$\Pi \approx 12 – 14$	→	≈ 320 kJ/kg
1995	→	1200 °C	→	$\Pi \approx 16 – 18$	→	≈ 380 kJ/kg
2000	→	1400 °C	→	$\Pi \approx 18 – 30$	→	≈ 450 kJ/kg

With regard to cycle efficiency the optimal TIT lies in the region of 1400°C - 1600°C at compressor pressure ratio between 20 and 40 for compressors without intercooling and 40 – 60 for intercooled compressors, at specific GT power output of 400-500 kJ/kg.

Figure 3
TIT vs. CCGT Efficiency



Exhaust gas temperature

Higher TIT → Higher Exhaust Gas Temperature (EGT)

High EGT → High Value Heat Energy for the Bottoming Water-Steam Cycle of the CCGT.

- EGT of the most advanced GT models > 600°C.
- This makes possible that the steam bottoming cycle goes supercritical.

Improvements in Hot Gas Path Cooling Techniques

Technological improvements in GT cooling technologies have come largely from aircraft technology.

Cooling technology has progressed in a series of discrete steps as advanced production techniques and finite element analysis computer codes allowed ever more intricate and tortuous cooling paths to be built into GT rotors, stators, blades, vanes and combustion systems.

Improvements to Film Cooling.

GT Closed Circuit Steam and Mist Cooling can easily maintain TIT in the range of 1500°C - 1600°C.

For example, by eliminating combustor cooling air from a steam cooled combustion chamber wall, all the combustion air can be introduced into the primary combustion zone in order to maintain the flame temperature at acceptable level i.e. not higher than the flame temperature of "lower" rated unit without steam cooling.

Progress in Metallurgy Status

- **Material properties have improved through advanced material production methods such as directionally solidified metals and crystallization to the extent that "single crystal" turbine blades can be made.**
- **Because materials usually break across the interface of two crystals, single crystal casting makes parts inherently stronger and corrosion-resistant.**
- **Use of ceramic materials shall also contribute to GT performance economics.**
- **Si_3N_4, is a candidate ceramic material for the high-temperature components but it is much more brittle than metals, while its thermal expansion coefficient is almost one-fourth that of typical heat-resistant alloys.**
- **The “ceramic” GT using the key technologies, such as monolithic ceramics may be the CCGT prime movers leading this technology to OCGT efficiencies in the range of 45% and above.**

High Insulation Thermal Barrier Coating Systems (HITBC)

- PROBLEM: HIGH TEMPERATURE CORROSION OF GT HOT GAS PATH COMPONENTS CAUSES PITTING OR CRACKING, RESULTING IN COSTLY MAINTENANCE AND DOWNTIME.
- THE USE OF GT HOT GAS PATH COMPONENTS WITH A HITBC MAKES IT POSSIBLE TO RAISE THE TURBINE INLET TEMPERATURE AND THE BASE LOAD RATING WITHOUT DETRIMENT TO THE SERVICE LIFE.
- THE MAIN OBJECTIVE OF HITBC IS TO PROVIDE AN ENHANCED THERMAL INSULATION CAPABILITY FOR THE PROTECTION OF GT HOT GAS PATH COMPONENTS, MAINLY FOR GAS TURBINE BLADING AND GAS TURBINE COMBUSTORS.
- THE FURTHER DEVELOPMENTS FROM HITBC WILL ALLOW TO INCREASE THE GT TIT WHICH WILL BRING FAR REACHING BENEFITS TO GT WEIGHT, PERFORMANCE ECONOMICS AND COMPONENT LIVES.
- AT THE PRESENT BOTH PLASMA AND HVOF (HIGH VELOCITY OXY FUEL) COATINGS ARE WIDELY APPLIED TO THE MOST STRINGENT INDUSTRY STANDARDS.
- PLASMA COATINGS ARE GENERALLY APPLIED FOR THERMAL-BARRIER-TYPE COATINGS TO PRIMARILY COMBUSTION COMPONENTS SUCH AS LINERS, BASKETS, TRANSITION PIECES AND ALSO TO STATIONARY VANES.
- HVOF IS USED FOR THE COATING OF TURBINE HOT-SECTION ROTATING BLADING AND ALSO STATIONERY VANES.

Optimized Compressor and Turbine Aerodynamics

- For example, optimized number of compressor stages with variable-pitch guide vanes to optimize flow across the profile.
- Application of brush and abradable coating seals to reduce internal leakage between rotating and stationary parts.
- To reduce blading skin friction to improve blade airfoil surface characteristics.
- Introduction of higher loaded airfoils (sub- to transonic profiles).

Advanced Control System Technology

WHAT SHOULD BE DONE:

- Improving sensors and control systems.
- Developing a suite of novel sensors that would measure combustor flame temperature and hot-gas-path components directly. For example, today's GTs control TIT indirectly – by measuring the exhaust gas temperature and the heating value of the fuel, then mathematically calculating the peak combustor temperatures.
- To assess wear of GT components within the hot gas path in real time, without shutting down the GT.
- All novel concepts in OCGT and CCGT control technology shall incorporate condition monitoring and fault tolerance.
- The system reliability must be defined in terms that include the process controlled philosophy (i.e., the OCGT and CCGT) and not simply the controlling components.
- Fault tolerant considerations for both the instrumentation points and the control system shall be addressed by means of an expert system coupled with a modelling system.
- In the subject control system, an online, background running hybrid expert system shall compare real time input data from instruments to calculated thermodynamic and mechanical parameters.

Additional Tools for Optimisation of CCGT Cycle

- Minimize the irreversibility of the HRSG by raising steam in the HRSG at pressures closer to the optimum → An increase of above 6 – 7 % CCGT efficiency comes from changing from single to triple pressure steam system.
- Employ supercritical-high pressure steam cycle.
- Optimise the balance between the HRSG efficiency and the steam turbine thermal efficiency → The balance may be struck by designing for a relatively high HRSG efficiency and accepting a somewhat lower steam turbine thermal efficiency, for a net gain of CCGT efficiency.
- Minimize overall heat loss and maximize the CCGT efficiency → Minimize the HRSG flue gas temperature.
- Fuel preheaters using low-grade waste heat from HRSG cycle also contributes to heat loss reduction, however the efficiency increase will not exceed 0.5 – 0.8 %, which is rather low compared to system complexity and additional costs.

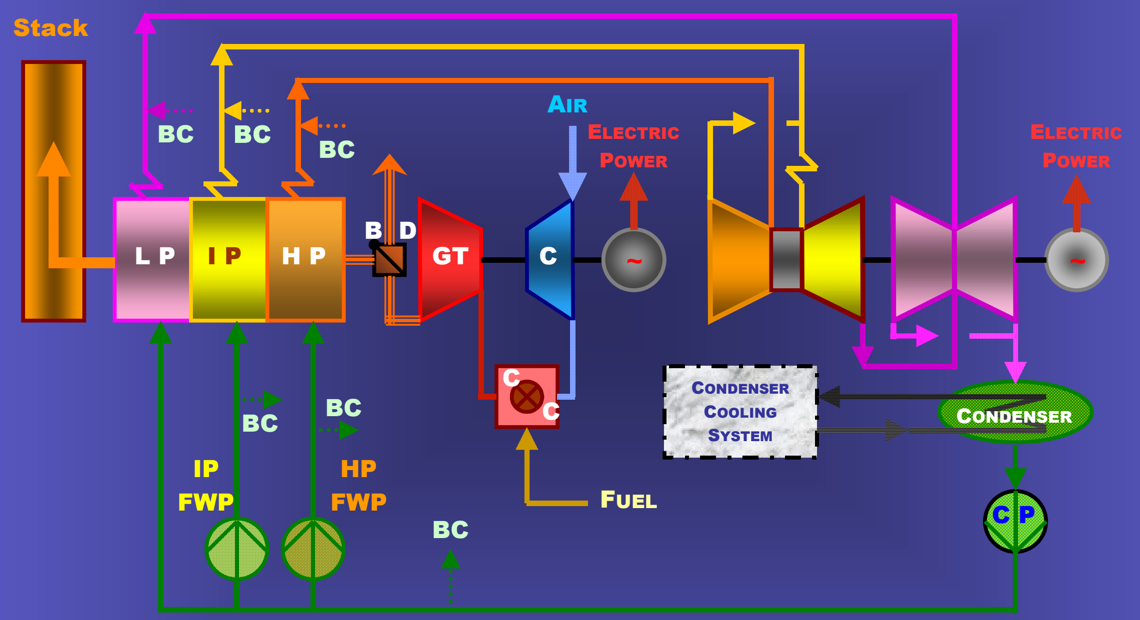
Combination of above "tools" with latest generation of future large GTs can push the magic, and most probably the top, efficiency towards 70% to 75% targeted by US Department of Energy's Vision 21 program which is aiming for a goal this challenging figure for CCGT power plants in the 21st-century.

Performance Specifications of Advanced CCGT Units

(ISO Conditions-Base Load & Natural Gas Fuel-LHV & Generator Terminals)

Manufacturer	CCGT Model Designation	Total CCGT Output MW	Thermal Efficiency %	GT Number & Model	Power Output GT MW	Power Output ST MW	Frequency Hz
Alstom Power	KA 24-1	260	56.6	1 - GT24	176	84	60
	KA26-1	378	57.0	1 - GT26	258	120	50
GE Power Systems	S107FB	280	57.3	1-MS7001FB	181	99	60
	S109FA	391	56.7	1-MS9001FA	252	139	50
	S 107H	400	60.0	1-MS7001H	**MONO-BLOCK**		60
	S 109H	480	60.0	1-MS9001H	**MONO-BLOCK**		50
Siemens Westinghouse Power Corp.	2.W501F	561	55.8	2 - W501F	2x182	197	60
	1S.W501G	365	58.0	1 - W501G	250	115	60
	GUD2.94.3A	705.0	57.3	2 - V94.3A	2x256	282	50
Mitsubishi Heavy Industries	M501F	281	56.7	1 - M501F	178	103	60
	M501G	371	58.0	1 - M501G	247	124	60
	M701F	398	56.9	1 - M701F	262	136	50
	M701G	484	58.2	1 – M701G	324	160	50

Typical Triple Pressure HRSG with Reheat Steam Cycle



SUMMARY - CONCLUSIONS

✷ The technological innovation in CCGT power generation systems has been strongly influenced by new market conditions and vital changes as a result of spreading liberalization and deregulation accompanied by competitive forces as well as with manufacturers R&D spending.

✷ It is expected that the CCGT efficiency parameters in the class of large heavy duty GTs with 180 MW and above may achieve the level between 62% and 65% by the year 2015.

✷ A very good chance to reach such challenge has the combination of advanced GT technology with supercritical, reheat steam bottoming cycle. However, this is again very much depending on the future design and also price development in the HRSG industry.

✷ With the advent of new technologies like inter-cooled aeroderivative CCGT, the Kalina cycle, advanced fuel cells in CCGT efficiencies up to 70% may be achieved in the next decades.

✷ By enabling GTs to operate much closer to their design limits, it may be possible to significantly increase the marginal capacity of both, OCGT and CCGT systems – meaning cost savings for power producers and more electric power at lower prices for consumers.

✷ As next-generation turbine power plants evolve, the GTs will be required to operate at higher-pressure ratios and hotter TIT conditions leading to an increase of NO emissions, but the goal is to cut emissions by 50% or more compared to state-of-the-art lean premixed GT combustors.

✷ The combination of both, the advanced technology and experienced O&M provider can beat all records in the power generation technology.


Powergen Asia 2001
Malaysia
Thank You for Your attention
IMTE AG Switzerland * IMTE Sdn. Bhd. Malaysia