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Experiences with Coal fired USC Boilers in Denmark

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1. The Basis for Coal Firing.

In Denmark coal fired utility power units have been a tradition for many years. As the country does not have any domestic coal resources the fuel basis has been imported coal from many different sources in the world. *Table 1* is a typical selection of coals used in Danish power stations. Since the 1950s the coal has been fired in pulverized fuel systems and normally after the direct firing principle, which means the coal dust is injected directly from the mill into the combustion chamber.

	Value as received	Unit
Net calorific value	23.0 – 30.0	MJ/Kg
Moisture	5 – 14	%
Ash	5 – 17	%
Volatiles	20 – 40	%
S	0.1 – 3	%
N	0 – 2	%
Hardgrove	45 – 80	Index

Table 1. Typical coals for use in Denmark

For a period of about 10 years from1963 oil prices were so low that Heavy Fuel Oil (HFO) became the most important fuel for power generation, but after 1973 coal has always given the lowest cost of electricity. Over the years the firing systems have been developed to high performances in terms of combustion efficiency and low NO_X emissions.

In the BWE Ultra Super Critical (USC) boilers the firing system comprises tangential firing with circular burners.

2. The USC power generation units

The steam cycle power plants in Denmark were of sub critical design up to around 1975. At that time the requirement for still higher overall efficiencies made it necessary to introduce super critical cycles (SC). The boilers for super critical designs would have to be of the once-through type, because of the high live steam pressure. BWE has for about 50 years been a Siemens Licensee for the Benson Boiler once-through design. Over this long period we have taken part in the development of that boiler type.

In *Figure 1* the red line indicates the planned and realised development of steam cycle Power units over time. It can be seen that the efficiency in the period from 1970 until 2001 has increased from 37 to 48 %. In 1980 the SC period began and this was after 1993

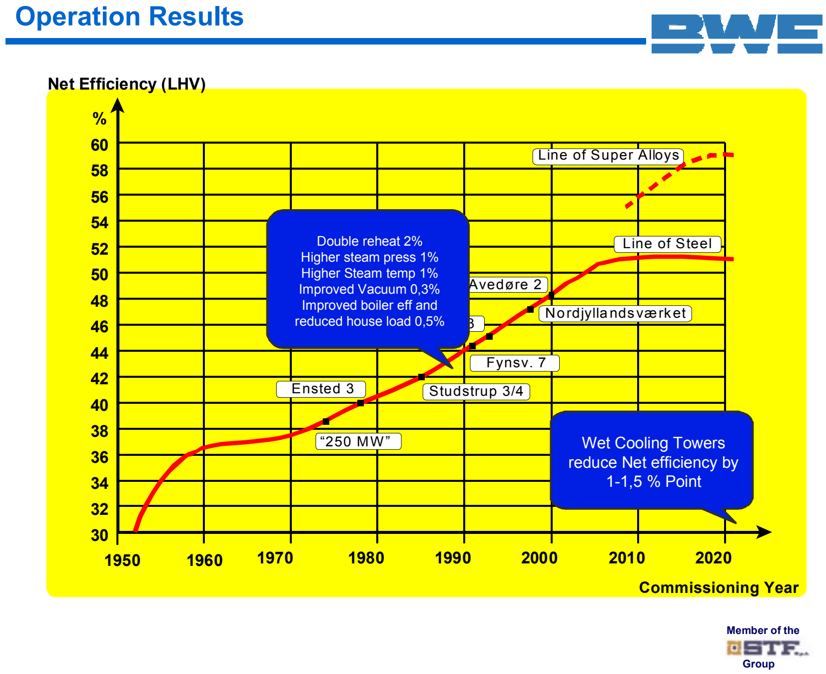

Figure 1. Development of steam power cycle

further transferred into the USC period where the live steam pressure raises higher than 275 bar. The red line can be seen as reflecting the possible achievement while using steel based materials. There is a maximum around 51% for the efficiency. However before reaching this limit we will have taken the step into using super alloy materials giving a new range for the overall efficiency.

From the number of units along the red line it can be understood that the development in the steam characteristics has been in a step-by-step mode. This was done to make sure the availability and reliability of these units were maintained at a high level.

3. Design features of the BWE USC boiler

The BWE coal fired USC boiler was developed from the beginning of the 1980s based on existing advanced sub critical design. The boiler plant commissioned in 1987 for the Walsum Power Station unit 9 represents this design basis. See *Figure 2.*

In the following you will find a short description of 3 boilers that will explain this development.

- Walsum 9. Design basis
- NVV3. USC boiler with double reheat
- AVV2. USC boiler with single reheat

All these boilers are 400 MWe in size.

Walsum boiler (*Figure 2*)
In this boiler you will see a highly developed sub critical Benson boiler commissioned in 1987. The essential design principles have been carried on to the USC boilers, such as:

- Tower type boiler
- Spiralled tube walls in the combustion chamber
- Vertical tube walls in the top pass
- Tangential firing with circular burners
- 3 levels of air staging in the combustion air

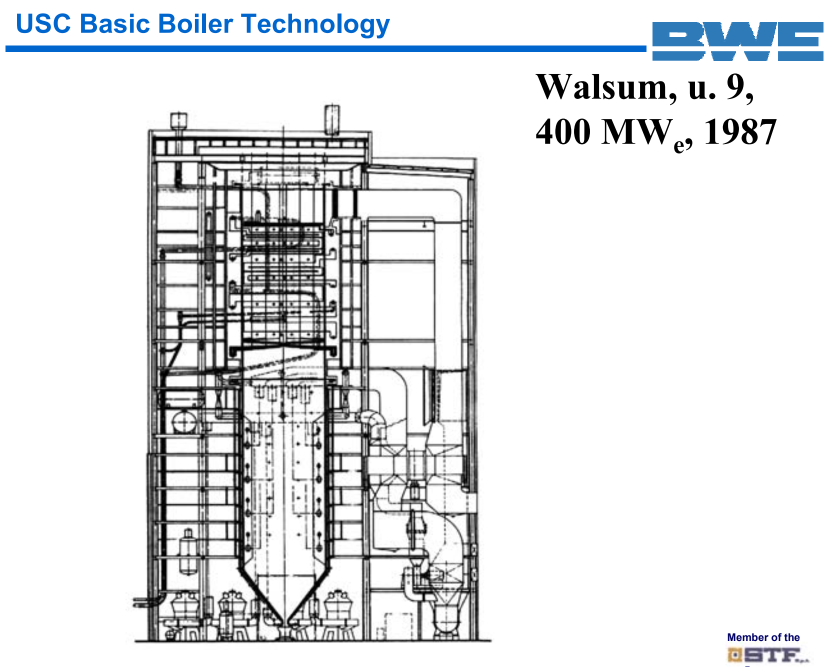

Figure 2. Walsum Power Station Unit no. 9

The tower design has proven to be a very efficient boiler type. The walls are 4 plane members that in a simple way are carrying a lot of the weight of the furnace and connected equipment. The tube bundles in the top pass are all hanging in one support system (vertical supporting tubes). In this way the boiler structure will respond in a simple manner to all transient phenomena coming from load changes or other dynamic processes. The tangential firing system is very efficient in minimising NO_X formation by means of 3 times air staging: 1. stage in the burner, 2. stage Over Burner Air (OBA), 3.

stage Over Fire Air (OFA). At the top of the boiler after the economiser the flue gas will be below 400°C and can be directed downwards in a steel duct, through the De-No_X catalyst in the high dust SCR system.

NVV3 boiler (*Figure 3*)
This boiler reflects to-days design of a USC boiler for solid fuels, commissioned in 1998. All the main design features from the Walsum boiler are used here. The boiler can

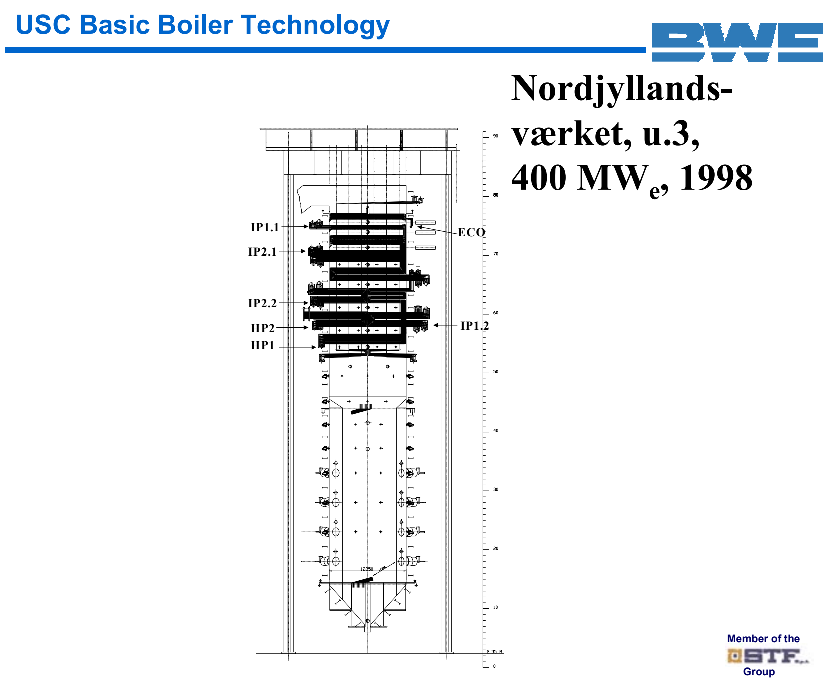

Figure 3. USC boiler for NVV3

manage the whole load range on coal or HFO, but it runs normally on coal.For optimisation of the power cycle the system incl. the boiler has double reheat.This is rather simple to do in a tower boiler. Figure 4 is the boiler flow chart. The plant is a CHP (Combined Heat and Power) unit.

The boiler island represents a fully equipped system with

- ESP (ElectroStatic Precipitator for fly ash)
- FGD (Flue Gas Desulphurisation)
- SCR (Selective Catalytic Reduction of NO_X)

In that way the boiler is operating without any pollution of the local environment.

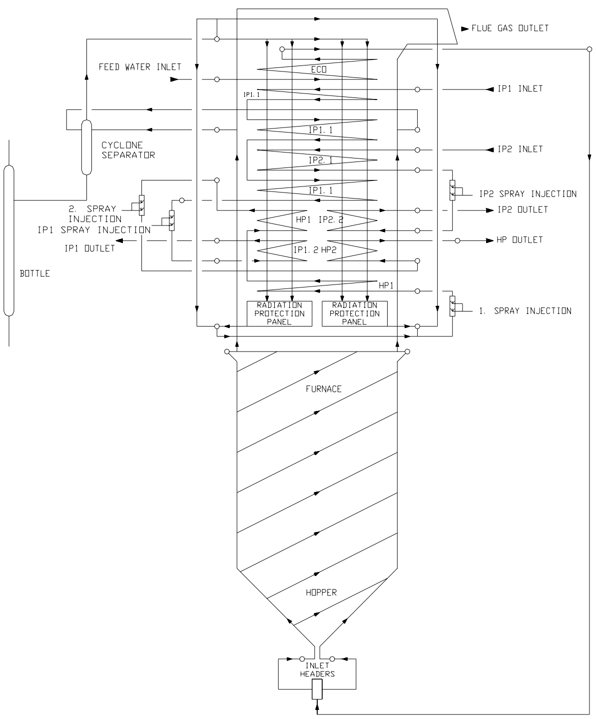

Figure 4. Boiler Flow Chart. NVV 3

Overall efficiencies, 1987 - 2001

Plant Name	KWW	FV 7	NVV 3	AVV2
Commissioning	1987	1991	1998	2001
Plant size [MW_e]	400	350	400	400
Fuel (C/O/HFO/G)	C	C/HFO	C/HFO	G/HFO
HP steam [bar]	200	250	290	305
- - [°C]	540	540	582	582
IP1 steam [bar]	40	58	80	74
- - [°C]	540	540	580	600
IP2 steam [bar]	-	-	23	-
- - [°C]	-	-	580	-
Efficiency [%]	42	44	47	49

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Table 2. Development of Efficiency

AVV2 boiler (*Figure 5*)
Like the NVV3 unit this boiler is a top modern USC boiler designed for solid fuels and commissioned in 2001. This boiler has single reheat and can be operated on Coal, HFO, Natural Gas and Wood Pellets.

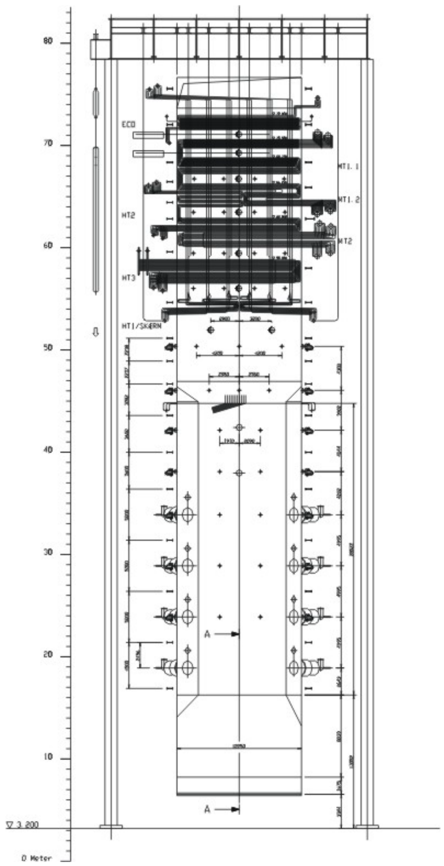

Figure 5. USC boiler for AVV2

The boiler has not yet been running on coal (no approval). However, the whole coal firing system is used for handling, grinding and burning wood pellets. On this fuel the boiler has 70% capacity. On all other fuels mentioned the capacity is 100%.

A comparison of these 3 boilers can be seen on *Table 2*. The development from subcritical to ultra super critical conditions can be seen on the live steam pressure. At the same time the steam temperatures have been increased. The achievement coming from these changes is clearly seen in the overall efficiences. Besides the obvious influence on the cost of electricity the efficiency improvement also means a dramatic reduction of harmful emissions. This is why the USC technology is called a clean coal technology (CCT).

4. Operation of Nordjyllandsværket Unit 3 (NVV3)

The unit entered commercial operation in September 1998 and it has now, April 2003, recorded 35000 hours. Almost all these hours the boiler has been running on coal. In the commissioning some minor adjustments in the boiler were identified and executed in the summer 1999. Since then the boiler has been operating satisfactorily and with an availability higher than 90 %. The emissions are within required limits and the byproducts gypsum and flyash are of high quality meaning they have a good market value.The high steam characteristics have not given cause to any special problems and the double reheat system is easy to handle in daily operation.

Operation Results

Generator output	411	MW
Auxiliary Power consumption incl. DeNOx- and DeSOx plant	26	MW
Auxiliary Power consumption excl. DeNOx- and DeSOx plant	23	MW
400 kV output to grid, DeNOx- and DeSOx plant in operation	385	MW
400 kV output to grid, without DeNOx- and DeSOx plant in operation	388	MW
Turbogenerator, heat rate, based on gen. output	6.736,6	kJ/kWh
Boiler efficiency	94,2	%
Power plant, heat rate, based on gen. output	7.151,4	kJ/kWh
Gross calorific value of coal	26	MJ/kg
Specific coal consumption, based on gen. output	275	g/kWh
Specific coal consumption, based on 400 kV output to grid	293	g/kwh
Thermal efficiency, based on 400 kV output to grid	47,2	%

Operational data, power production only
100% load, condensing mode, 10 c cooling water.

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Figure 6. Operation in condensing mode. NVV3

Figures 6 and 7 are recorded results from daily operations. It should be observed the plant is a Combined Heat and Power plant (CHP). *Figure 6* is giving the results from power production only while *Figure 7* reflects simultaneous generation of heat and power. In the power production mode the thermal efficiency achieved is 47.2 % while the CHP mode realises 90 %.

Operation Results

Generator output	339,5 MW
Auxiliary Power consumption incl. DeNOx- and DeSOx plant	26,5 MW
Auxiliary Power consumption excl. DeNOx- and DeSOx plant	23,5 MW
400 kV output to grid, DeNOx- and DeSOx plant in operation	313 MW
400 kV output to grid, without DeNOx- and DeSOx plant in operation	316 MW
District heating output	422 Mj/s
Turbogenerator, heat rate, based on gen. output	8150,3 kJ/kWh
Boiler efficiency	94,2 %
Power plant, heat rate, based on gen. output	8652,1 kJ/kWh
Gross calorific value of coal	26 MJ/kg
Specific coal consumption, based on gen. output + DH output	148 g/kWh
Specific coal consumption, based on 400 kV output to grid + DH output	154 g/kwh
Thermal efficiency, based on 400 kV output to grid +DH output	90 %

Operational data, combined heat and power production
100% load, back pressure mode, 4 c cooling water.

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Figure 7. Operation in CHP mode. NVV3

5. Operation of Avedøreværket Unit 2 (AVV2)

This unit has been doing commercial operation since 2001. Until April 2003 it has performed 11500 operating hours split on the 3 possible fuels Natural Gas, HFO and Wood Pellets. The boiler operation has been going well and the performance has been as expected. The boiler is installed as a part of a complicated total technical solution involving a biomass fired boiler and 2 gasturbines. As mentioned the USC boiler gives the basis for 400 MW power production, but with the biomass boiler and the gasturbines in operation the total power production will amount to 570 MW. For the future the USC boiler is fully equipped for firing coal when approval will be given.

6. Conclusion

The USC technology is now well established in Denmark. The expected advantages in terms of reduced cost of electricity at a high availability have been verified. Consequently the development will be going on in the future.

Future steam parameters

Plant Name		NVV 3	AVV2	Future I	Future II
Commissioning		1998	2001	2010	2020
HP steam	[bar]	290	305	335	400
- -	[°C]	582	582	610	700
IP1 steam	[bar]	80	74	93	112
- -	[°C]	580	600	630	720

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Table 3. Future steam parameters

Table 3 is demonstrating what can be expected for the steam parameters of the future. In future I is presented what could be realised in 2010 by using steel based materials. In future II you will see what can be developed on the long term, as it is now going on within the joint European project AD 700. *Table 4* demonstrates what efficiencies can be expected from these new steam parameters.

USC Basic Boiler Technology BWE

Future efficiencies

Plant Name	NVV 3	AVV2	Future I	Future II
Commissioning	1998	2001	2010	2020
Unit efficiency [%]	47	49	>50	52-55

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Table 4. Future efficiencies

BWE is participating in the AD 700 boiler development. A steam temperature of 700ºC can only be realised after development of socalled super alloys. In the AD700 working groups, different problems are being investigated and the material requirements are being identified.

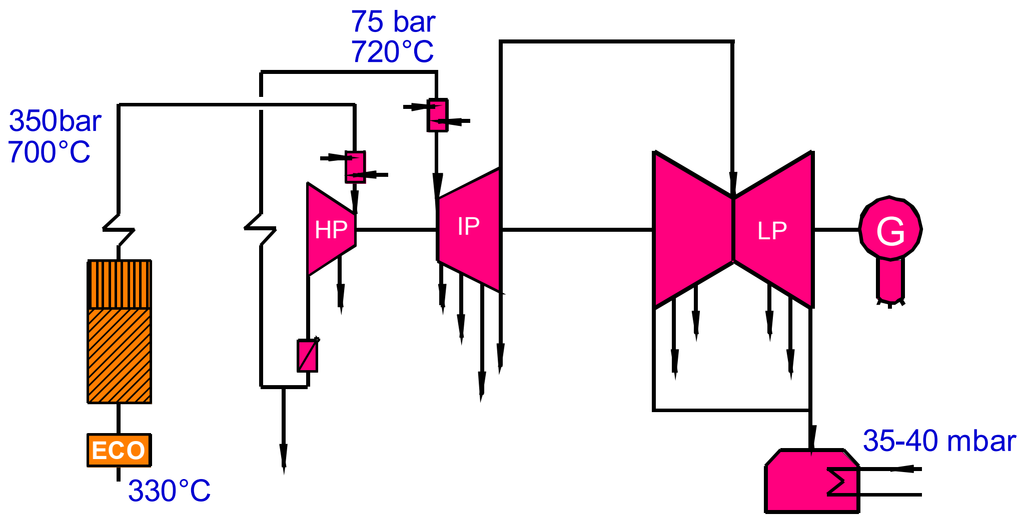

Figure 8. Future USC plant at 700°C live steam temperature. Inland location.

In *Figure 8* you will see a proposal for a 700°C plant in a single reheat version. Such plant could be operating commercially in 2020 provided the necessary materials can be made available. The development program is very expensive and the EU commission has been giving an essential part of the funding for the first 2 phases of AD 700. Hopefully this funding will continue until a full scale, i.e. 400 MW demonstration unit has been established.

This development is still intended for coal fired versions of the technology. *Figures 9 and 10* demonstrate the need for new coal fired capacity after 2010. The problem is of a global nature. The problem with CO_2 - emission will also have to be handled under a global aspect, however seen from an available resource viewpoint it will be necessary to find a way for still having coal as the most important fuel for power generation also in the next 30 years. This has been found necessary in many independent investigations.

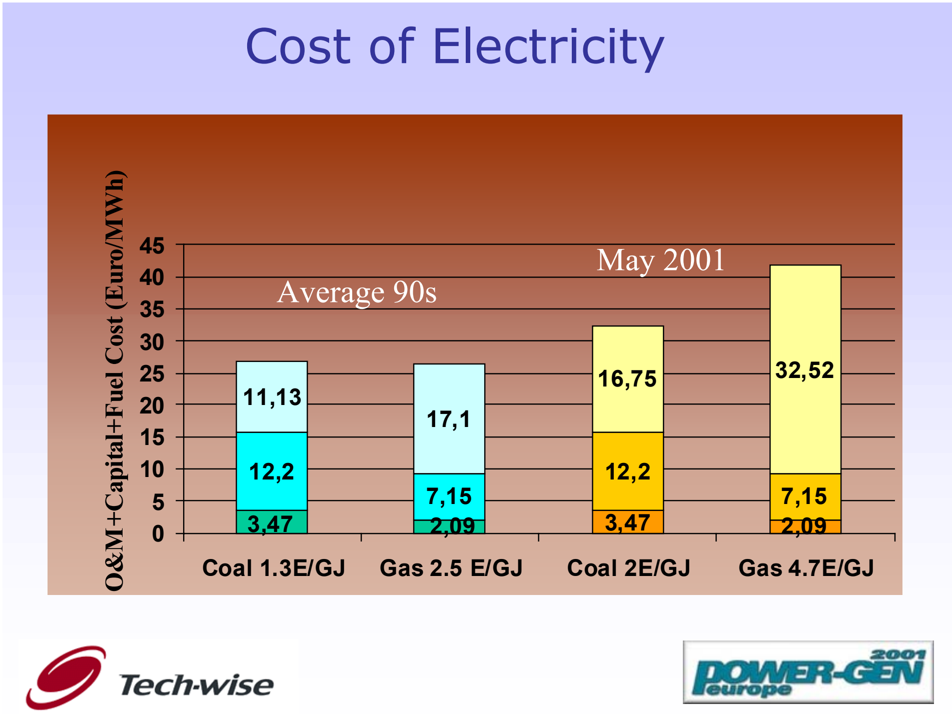

Figure 9. Cost of electricity.

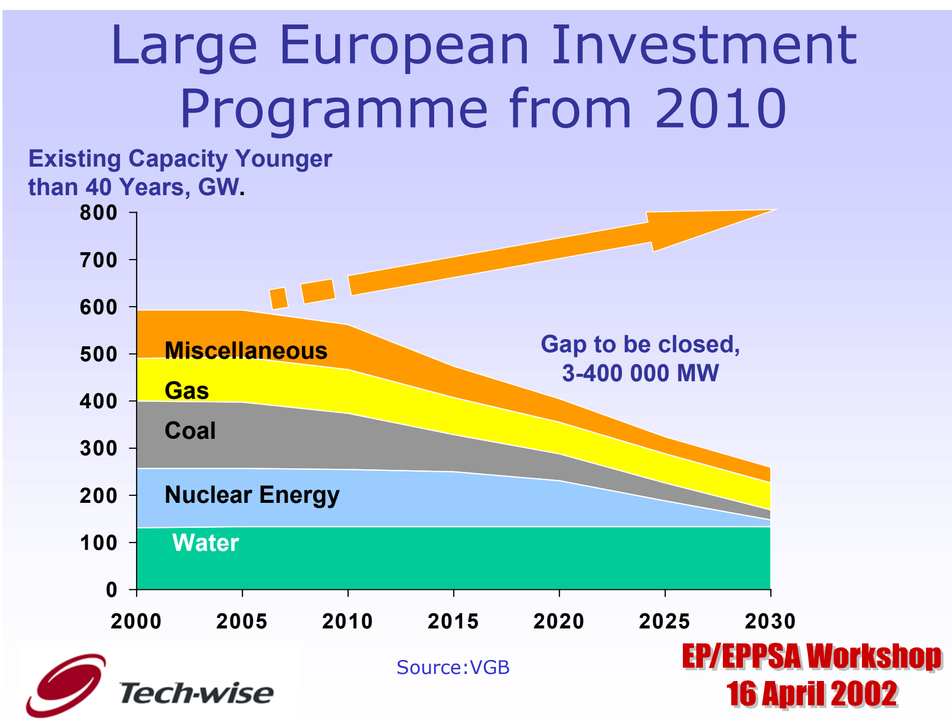

Figure 10. Power Generation Capacity Planning