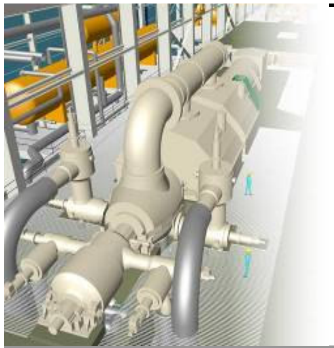

COALGEN 2006

Cincinnati - USA - August 16 - 18, 2006

CONTENT

Ultra-Supercritical Pulverized Coal Fired Power Plants

Miro R. Susta

IMTE AG Power Consulting Engineers

Switzerland

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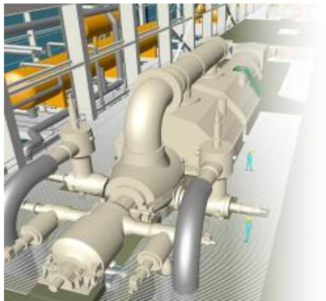


Main Concerns with Energy → Electricity Supply

- **Affordability**

  Investment - Technology – Fuel – O&M → Tariff

- **Reliability**

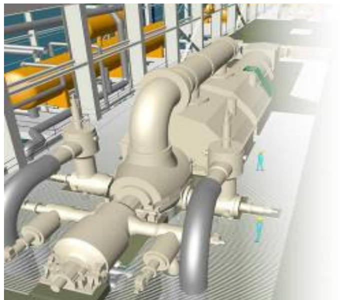
  Technology – Fuel – O&M → Availability

- **Accessibility**

  Grid Connections → Distribution Network

- **Environmental Acceptability**

  Technology – Fuel – O&M → Emissions



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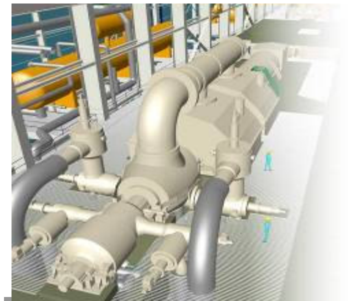
US Electricity Power Generation History

- ➢1896 ⇨ Niagara Falls Hydro Power Plant produced 3.7MW at 2.35kV / 25Hz
- ➢1903 ⇨ 1st Commonwealth Edison Power Plant ST produced 5MW (180psi/530ºF)
- ➢Beginning of 20th century;
  - ❖ 20 US¢/kWh or higher
  - ❖ Available only in the cities (lighting of streets, buildings, factories supply)
  - ❖ Not affordable for most of households
- ➢1900 – 1920 ⇨ ST operated at 1,200rpm (20Hz); Unit Capacity up to 65MW
- ➢1915 ⇨Establishment of ASME Code
- ➢1920 – 1935 ⇨ ST operated at 1,800rpm (30Hz); Unit Capacity up to 200MW
- ➢1935 – 1953 ⇨ ST operated at 3,600rpm (60Hz); Unit Capacity up to 200MW
- ➢1955 ⇨ 55% Power Generation from Coal; USA produced 42% World El. Power
- ➢1957 ⇨ 1st USC Power Plant, 120MW Philo 6 in Operation (4,500psi/1,100ºF)
- ➢1960 – 1963 ⇨ 1st Commercial Nuclear Power Plants produce Electric Power
- ➢1980 ⇨ Large STs reached Unit Capacity up to 1,300MW
- ➢1900 – 1980
  - ❖ kWh-Costs decreased every decade
  - ❖ Generating Capacity doubled every 8 – 12 years
- ➢End of 20th century ⇨ Golden Times for NG fired CCGT Power Plants
- ➢2006 ⇨ Overall Power Generation Capacity was 835GW (≈460GW from Coal)



Breaking News

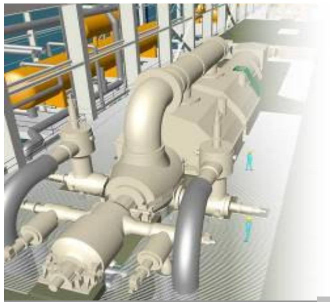
96,314GWh/Week

⇩

716 GW

(PLF 80%)

According to the Edison Electric Institute's weekly survey, US demand for electricity reached an all-time record 3 weeks ago amid a national heat wave as US utilities delivered 96,314 GWh of electricity for the week ending July 22, surpassing by more than 1%last year's record of 95,259 GWh.



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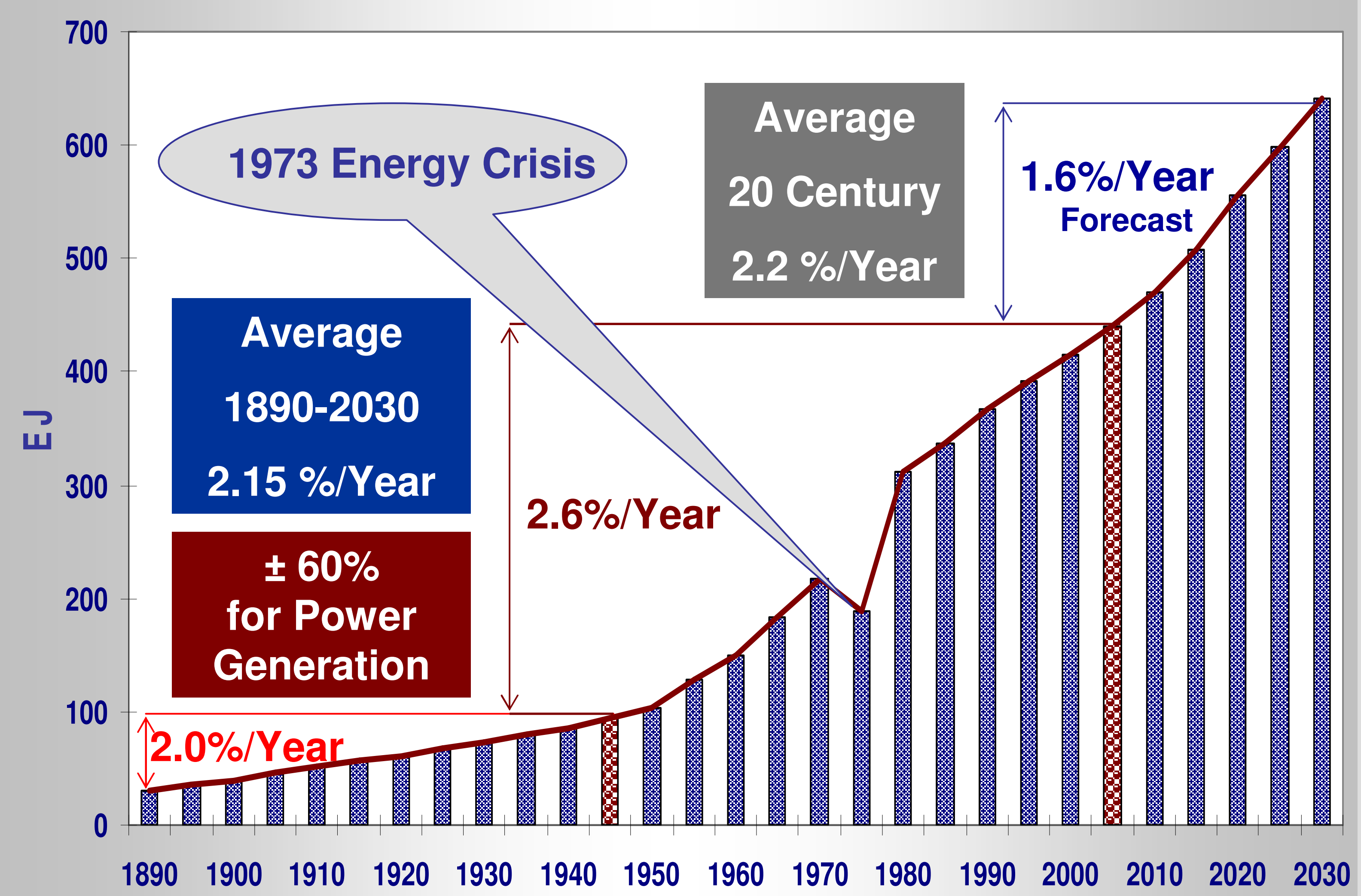
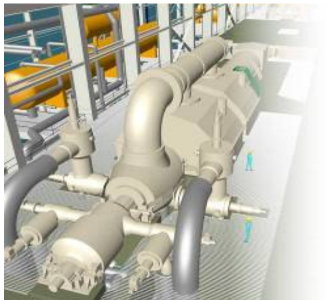
Worldwide Overall Energy Consumption



1Exajoule (EJ) =
10^{18} Joule
0.948 x 10^{15} Btu

Coalgen 2006



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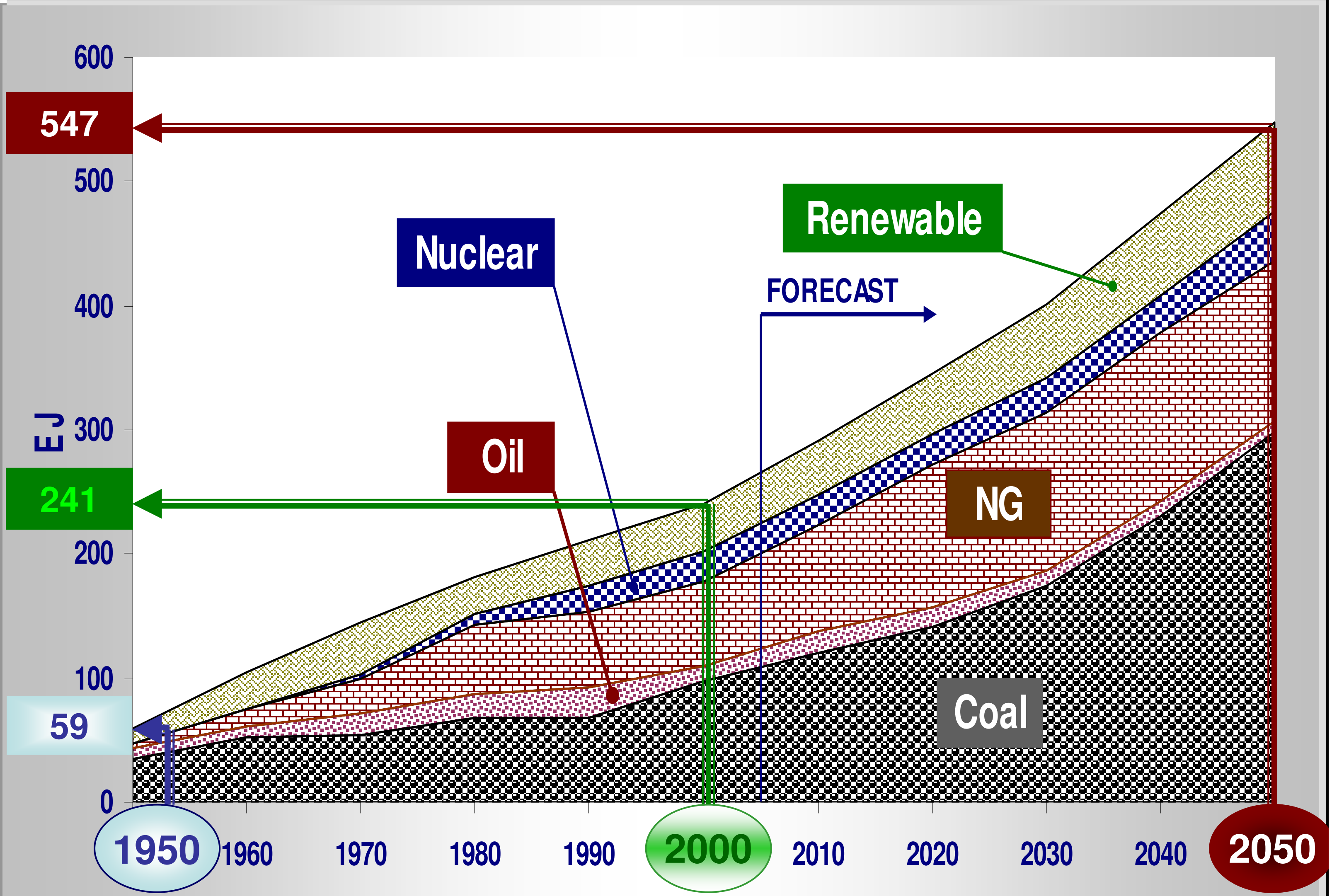
Worldwide Overall Energy Consumption for Power Generation

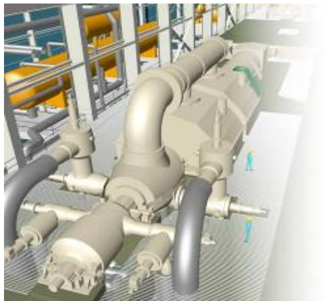
2050
Coal 54.5%
Oil 1.5%
NG 23.7%
Nuclear 7.3%
Renewable 13.0%

2000
Coal 40.5%
Oil 5.1%
NG 27.8%
Nuclear 10.1%
Renewable 16.8%

1950
Coal 59.6%
Oil 14.5%
NG 5.2%
Nuclear 0.0%
Renewable 20.7%

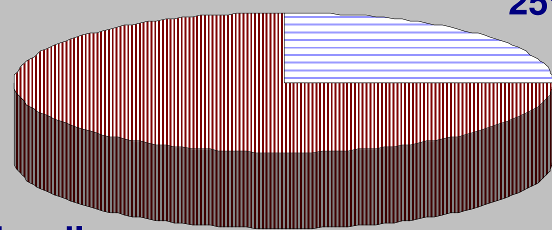


Coalgen 2006



Worldwide Power Generation Energy Sources

2006

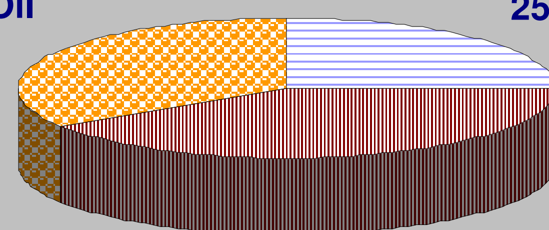


Others

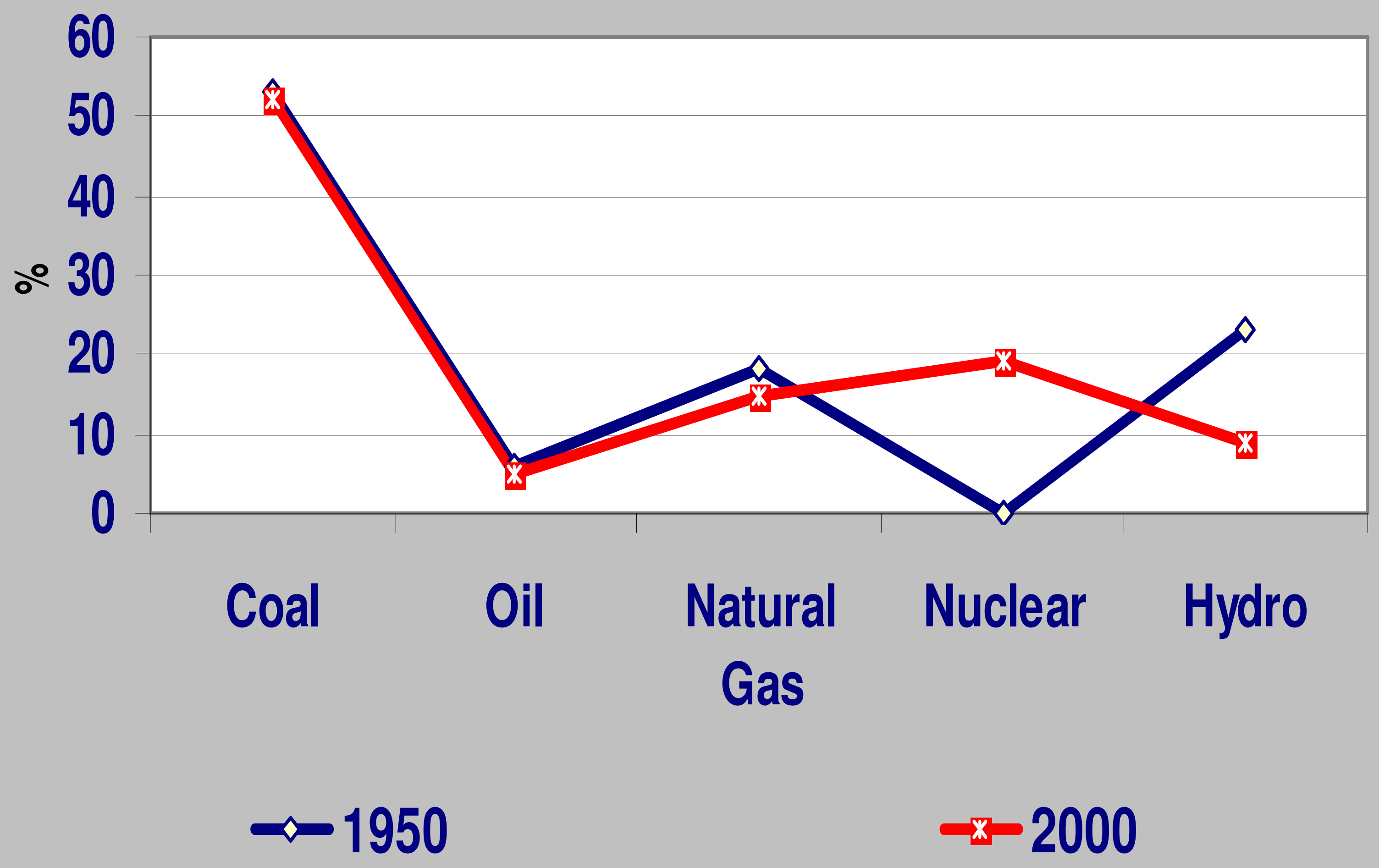
- ⇨ Nuclear
- ⇨ Geothermal
- ⇨ Hydro
- ⇨ Other Renewable

Fossil

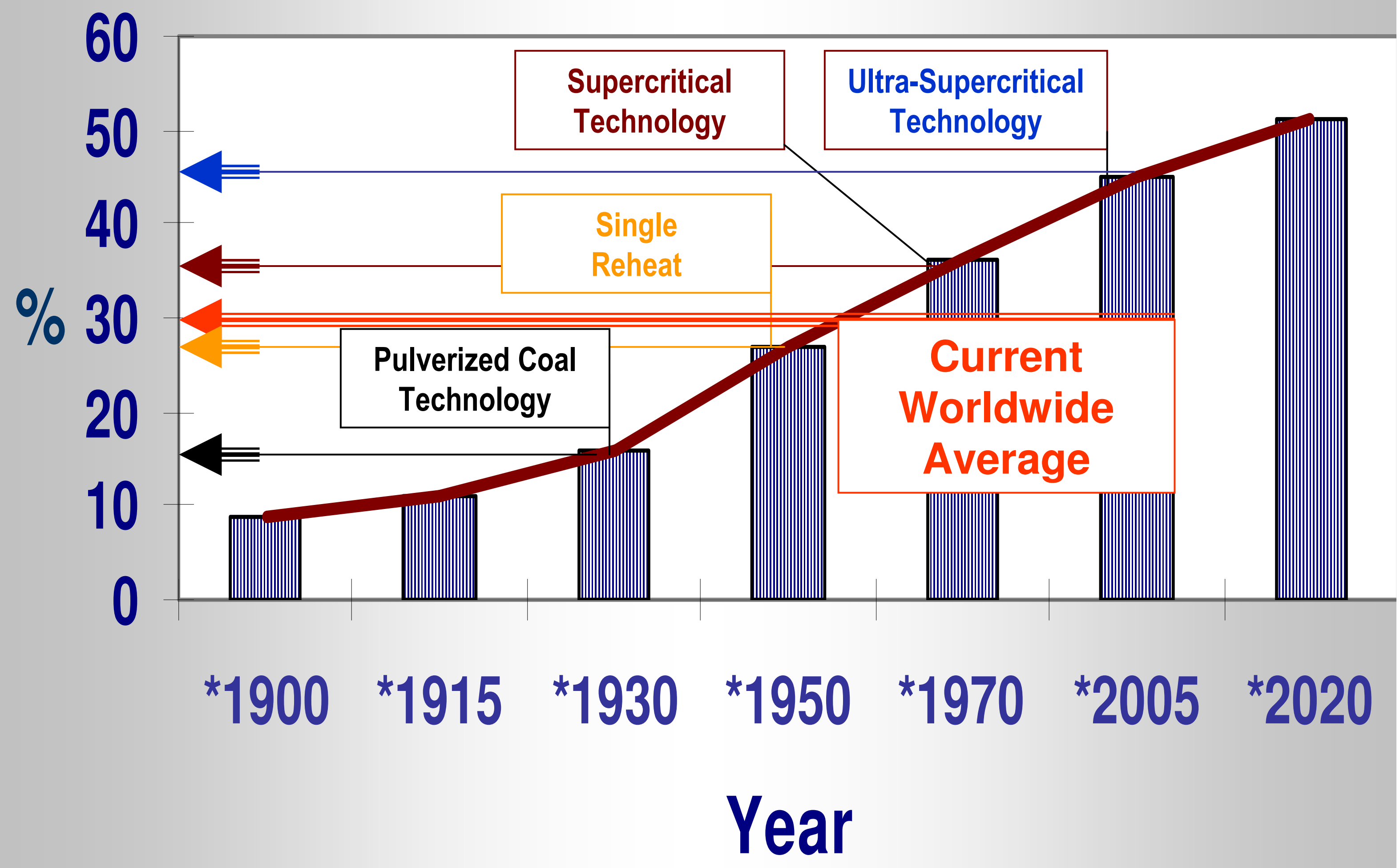
- ⇨ Coal
- ⇨ Natural Gas
- ⇨ Fuel Oil



USA Power Generation Energy Sources



Coal Fired Power Generation Efficiency Evolution



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Worldwide Present & Projected Future Coal Reserves

1 Short Ton=

0.907 M Ton

Reserves in 2005

1,000 Billions Short Tons

Annual Consumption (2005)

4 Billions Short Tons

250 Years

Projected Reserves in 2030

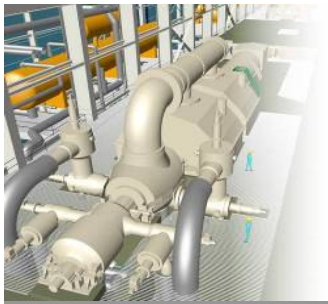
30% Efficiency Scenario

138 Years

Projected Reserves in 2030

40% Efficiency Scenario

190 Years



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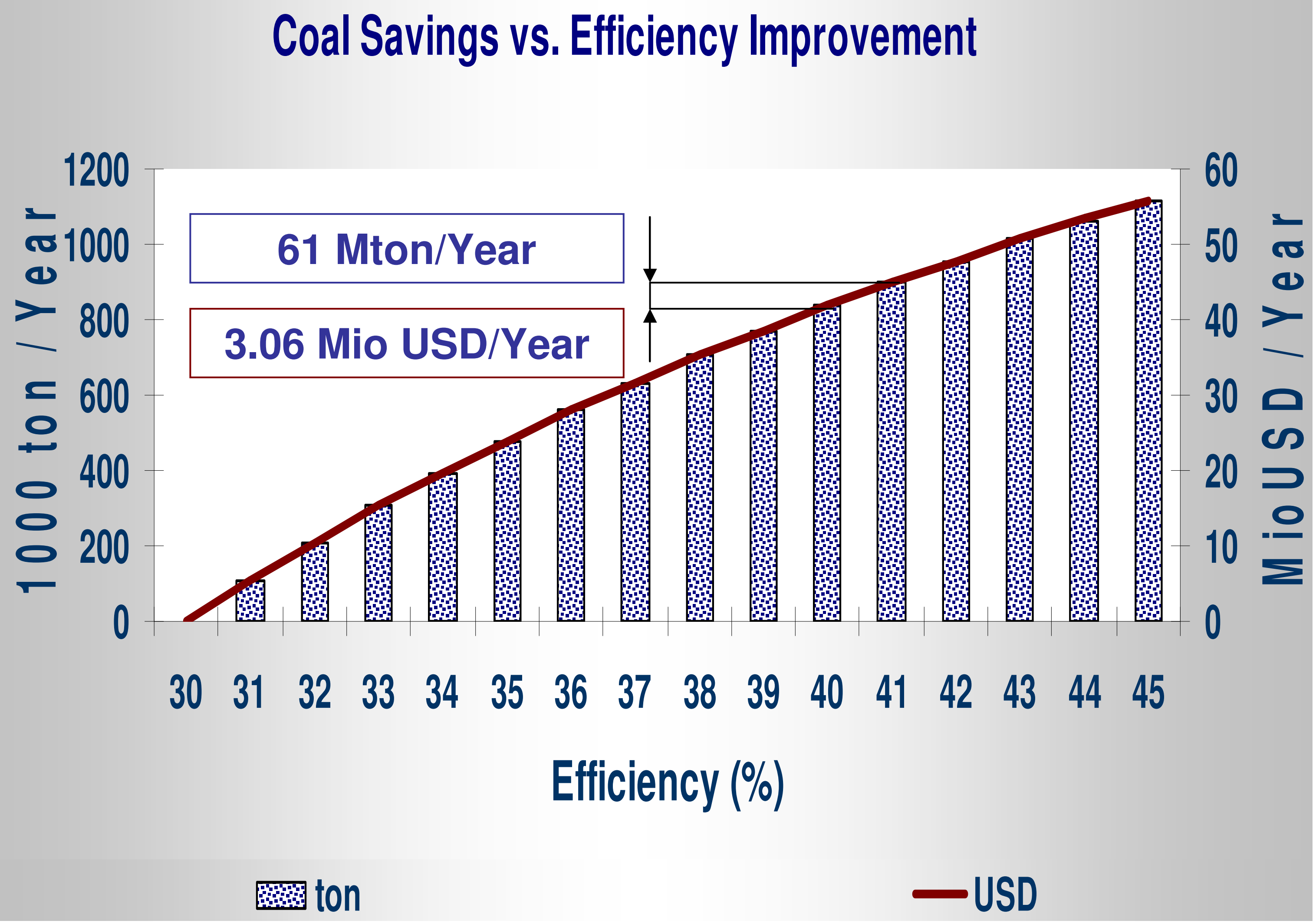
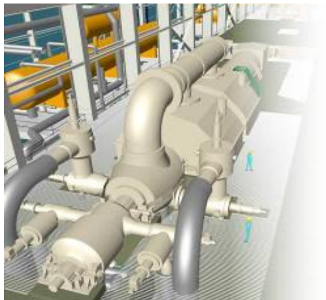
1,000MW**10,800Btu/lb (6,000kcal/kg)

50USD/ton (2.1USD/MioBtu)**PLF=80%

1% Improvement
40%→41%



Coalgen 2006



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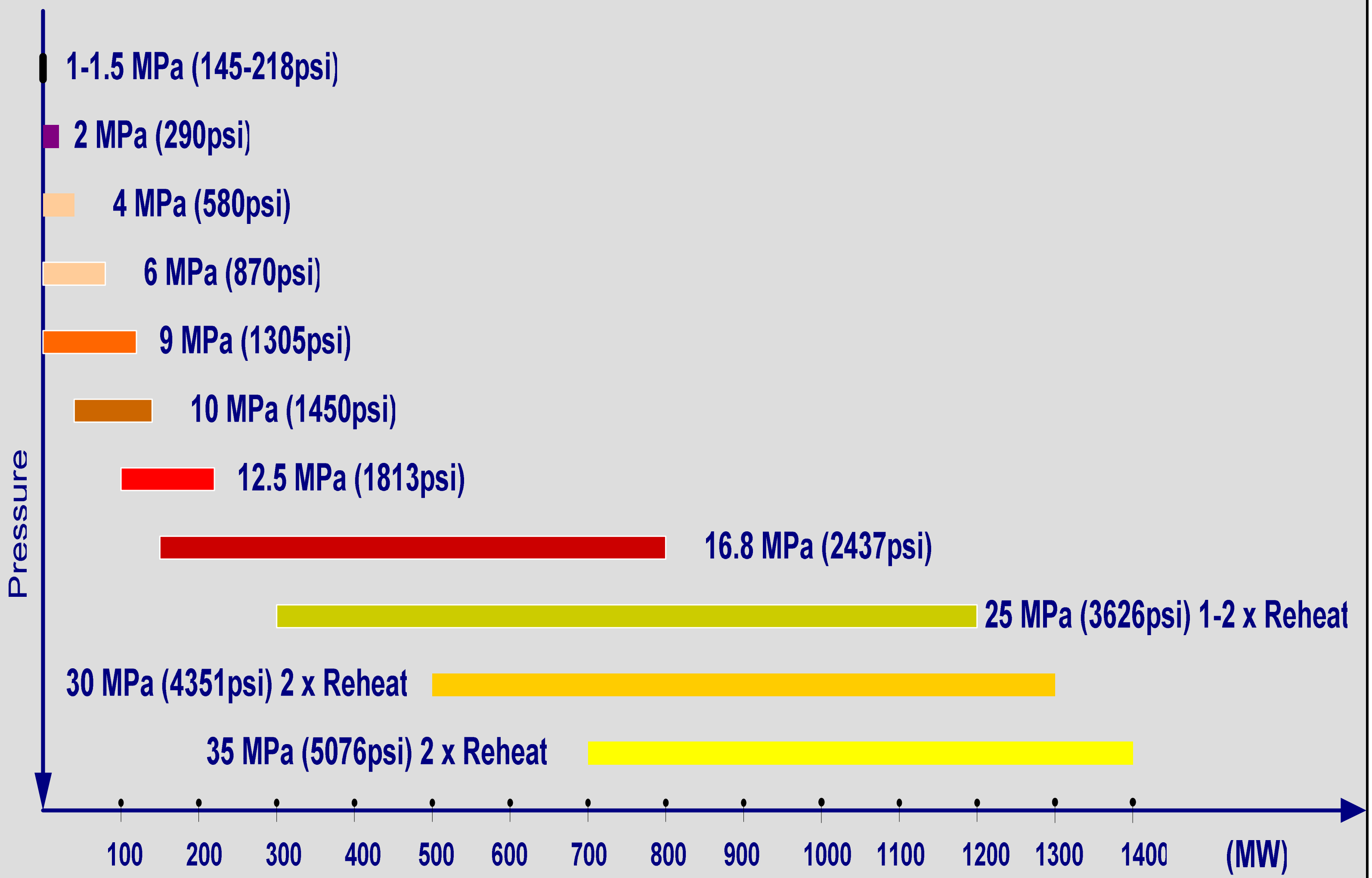
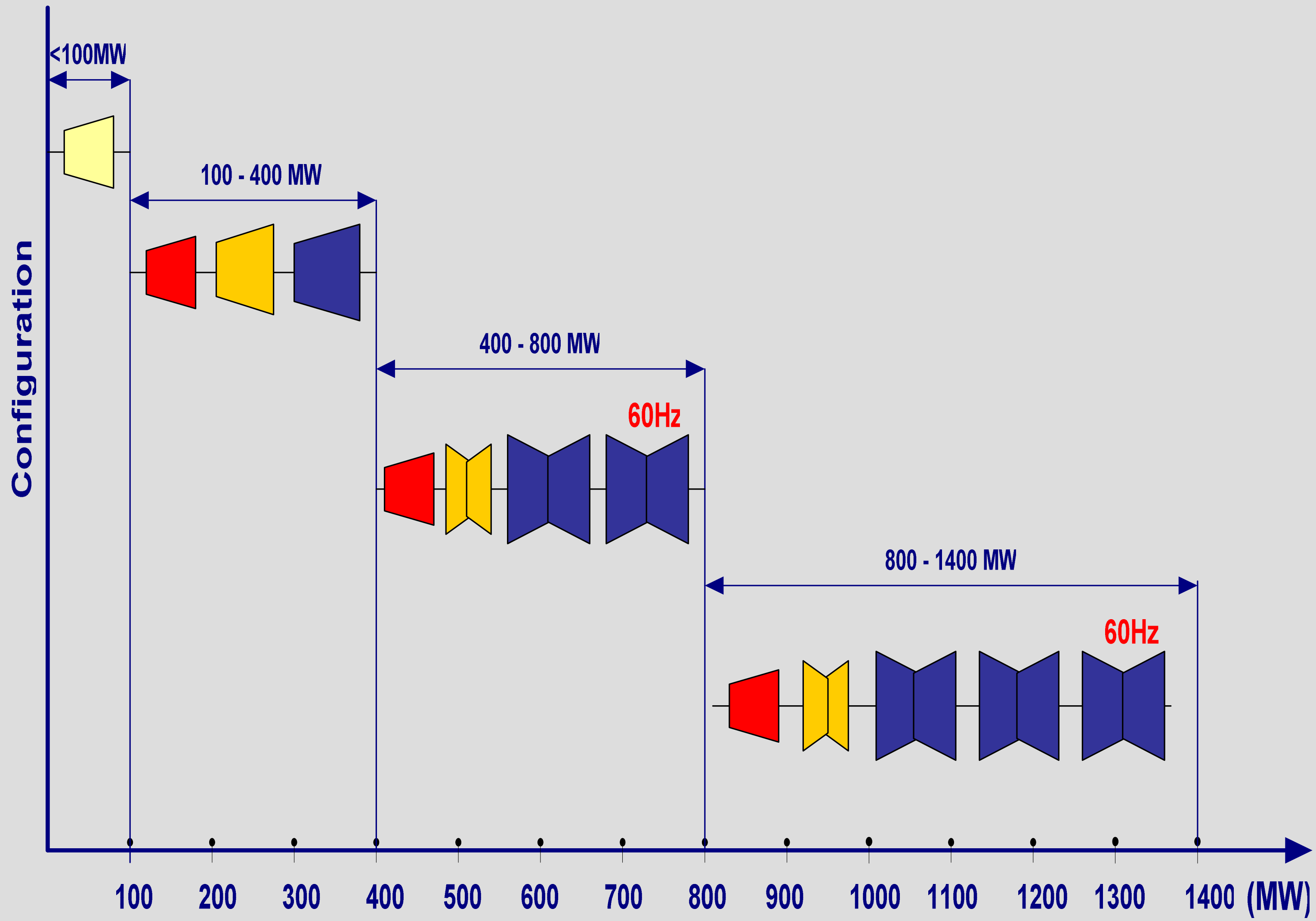
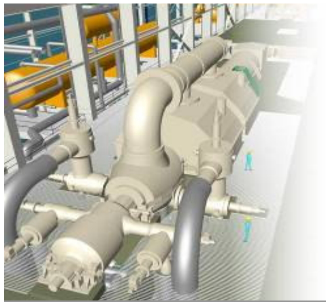
Evolution of ST Unit Size

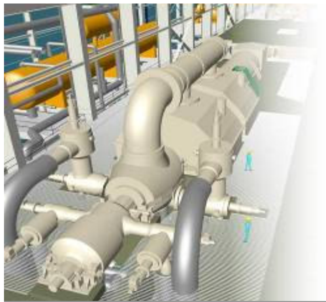


ST Unit Configuration





Supercritical Water-Steam Cycle Technology



Supercritical is a thermodynamic expression describing the state of a fluid above a certain pressure when there exists no clear distinction between the liquid and gaseous phases.

> 22.064 MPa (3,200 psi)

> 374.81 ºC (706.66 ºF)

One of the primary means of increasing the efficiency of steam power plants is to increase live steam pressures to super- or ultra-supercritical conditions.

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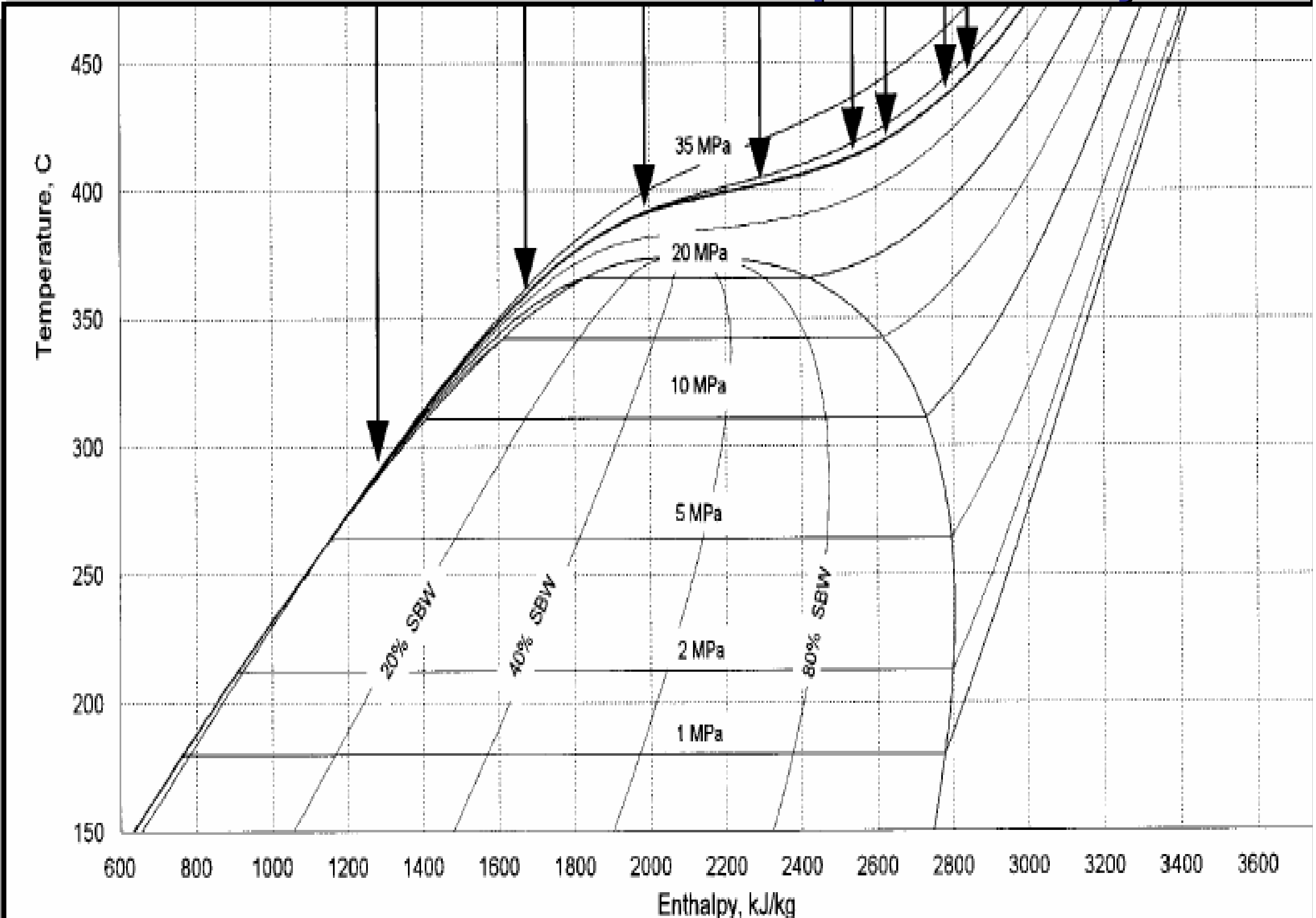
Heat Transfer Subcritical vs. Supercritical Cycle



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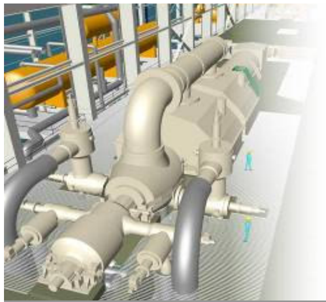
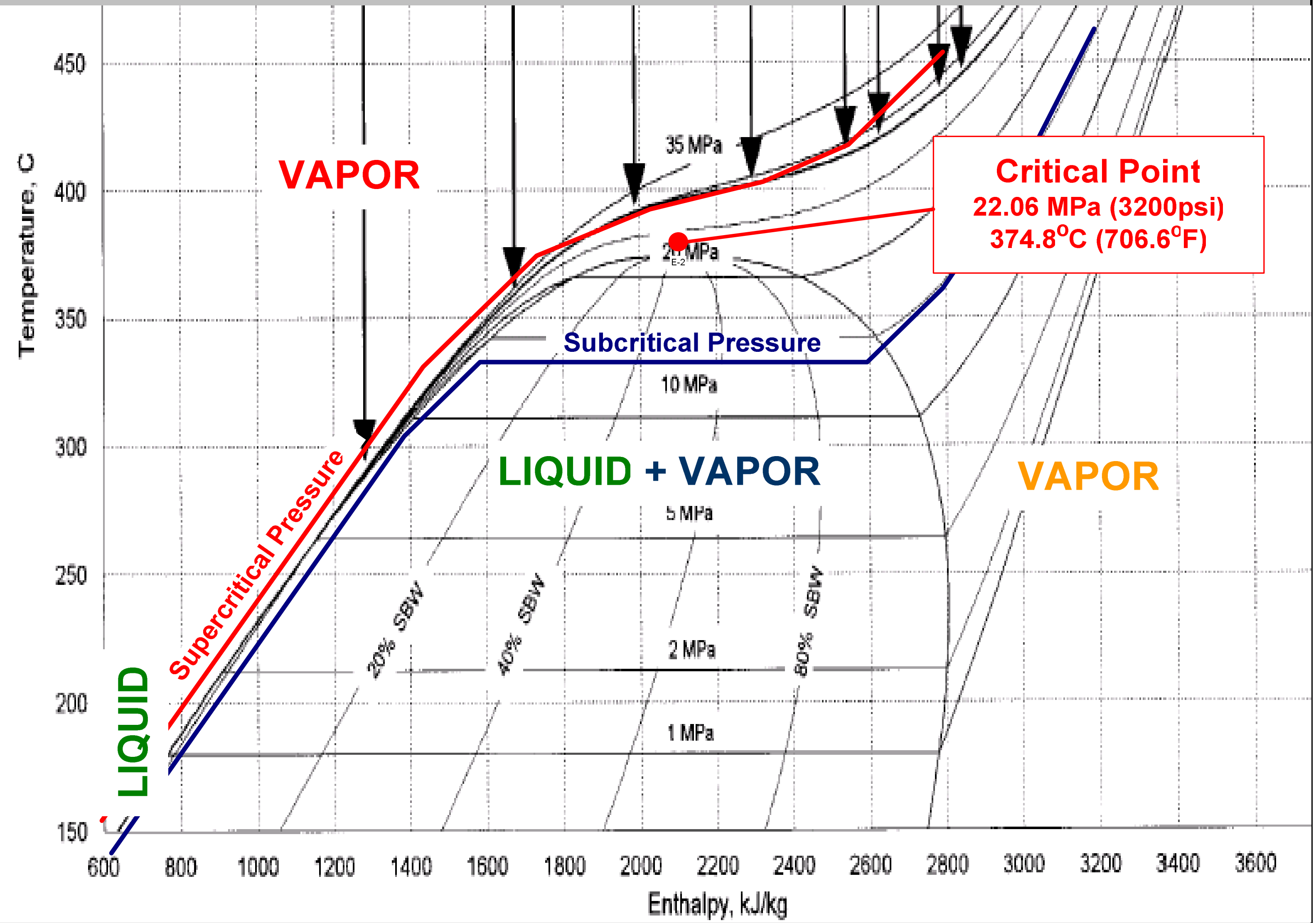


Heat Transfer Subcritical vs. Supercritical Cycle



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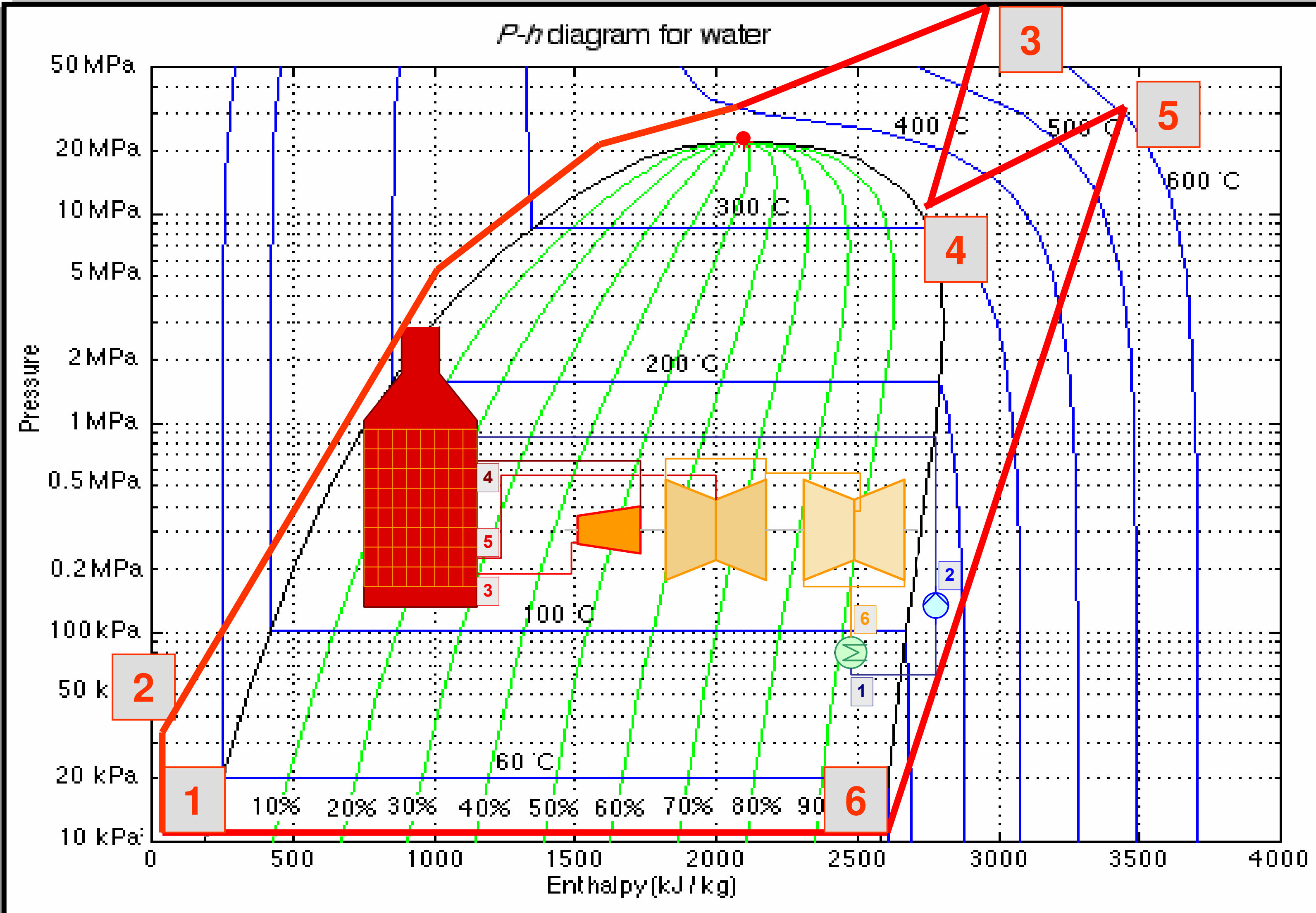
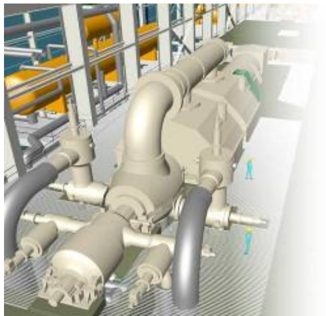


Coalgen 2006



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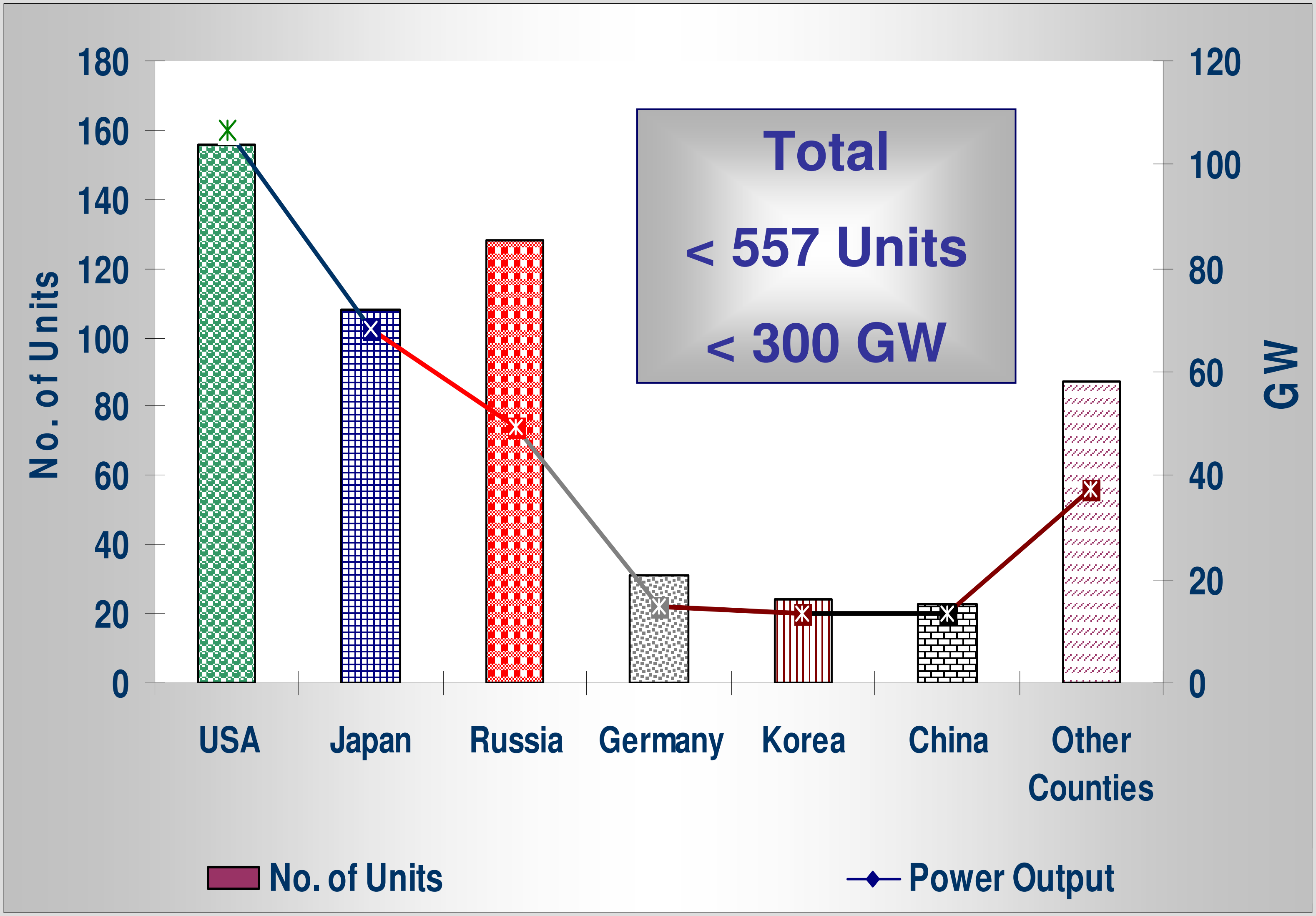
Number and Capacity of SC/USC Power Plants



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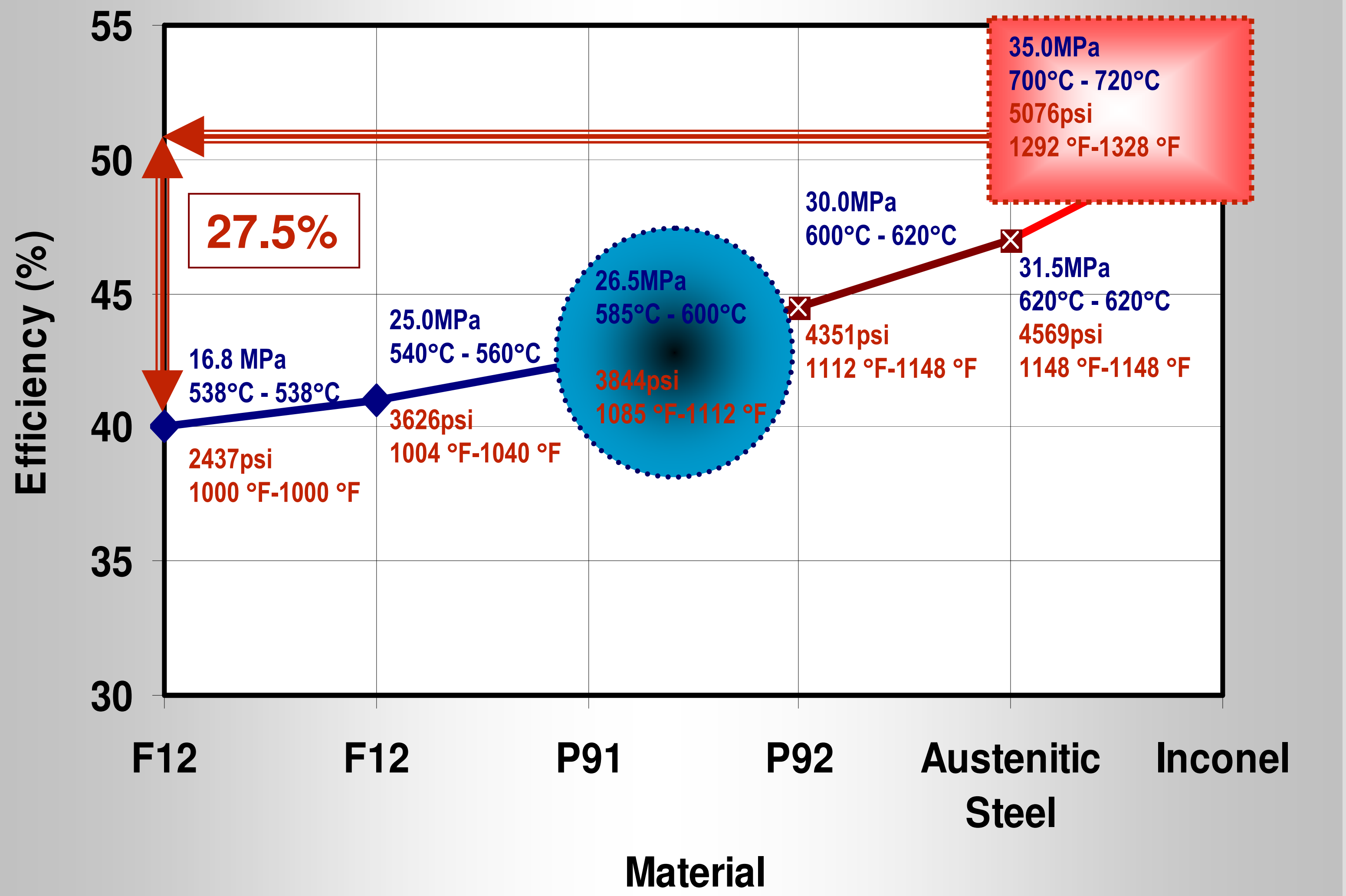
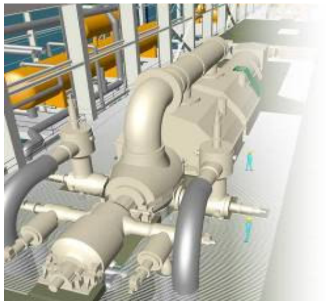
Potential in Increase of Net Efficiency



Coalgen 2006



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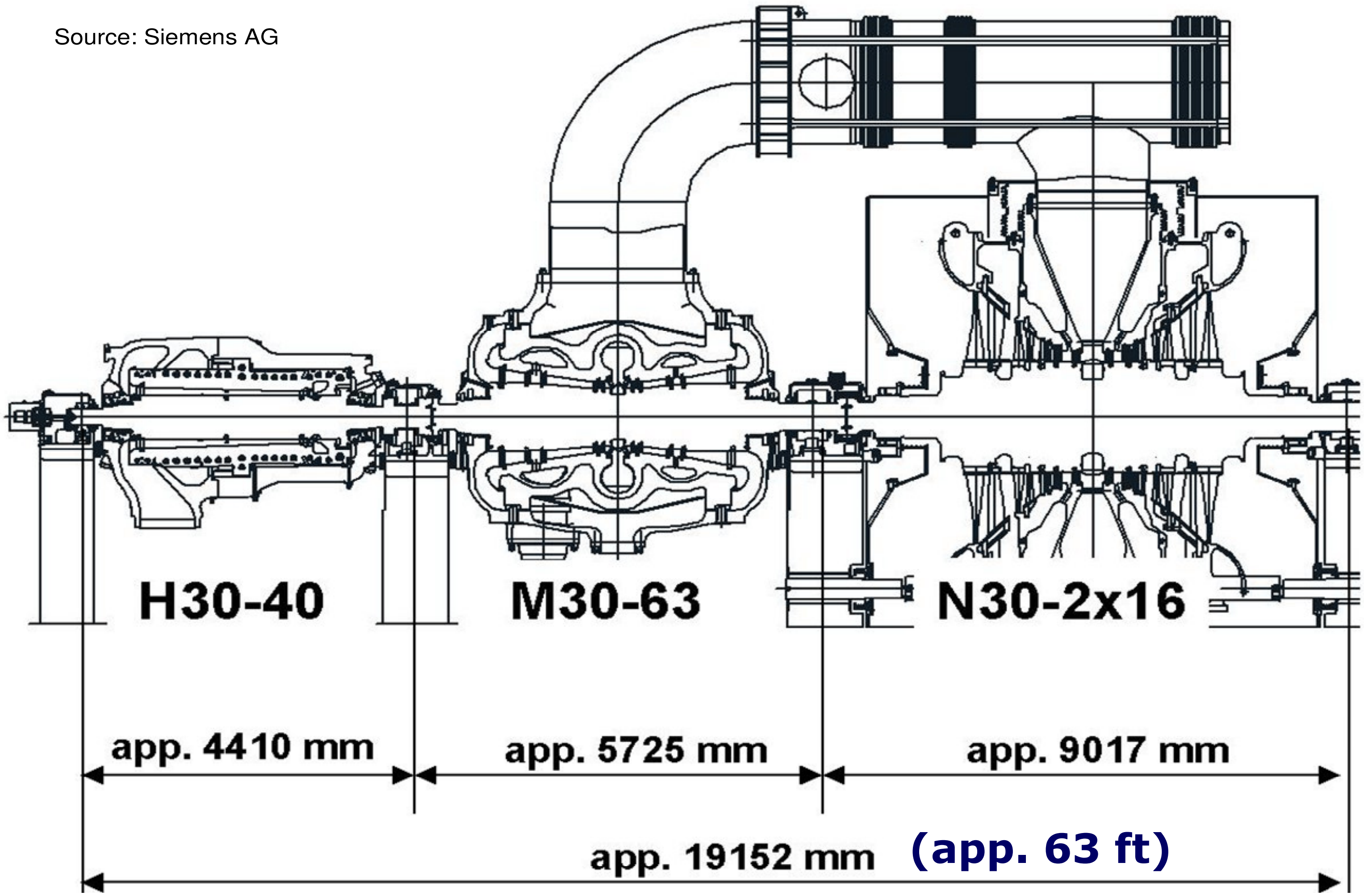
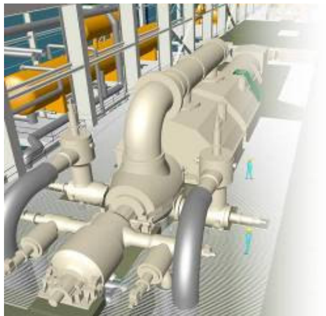
50Hz RPP – Main Parameters

➢ Plant Gross Capacity	600 MW
➢ Plant Net Capacity	552 MW
➢ Live Steam Pressure	28.5 MPa → 4134 psi
➢ Live Steam Temperature	600 ºC → 1112 ºF
➢ Reheat Pressure	6.0 MPa → 870 psi
➢ Condenser Pressure	4.5 kPa → 0.653 psi
➢ Feed Water Temperature	303 ºC → 578 ºF
➢ Reheat Temperature	620 ºC → 1148 ºF
➢ Heat Rate$_{NET/LHV}$–Efficiency	7,433.8 Btu/kWh – 45.9 %
➢ Boiler Type	OT-Benson
➢ ST Type	3 Casing – Single Reheat 1SF HP-1DF IP-1DF LP

$600MW_{GROSS}$ 3-Casing (50Hz) USC Steam Turbine

Source: Siemens AG





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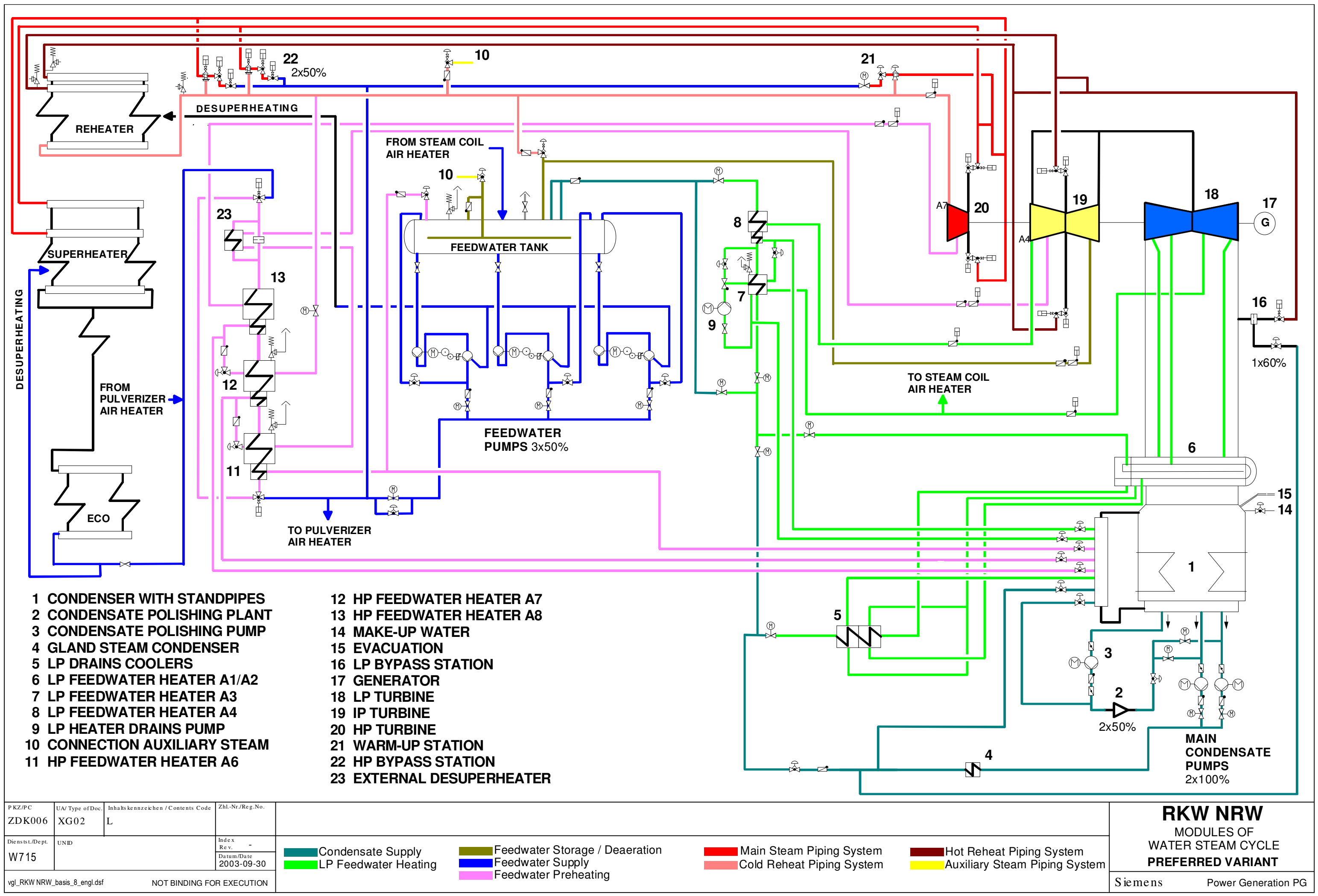
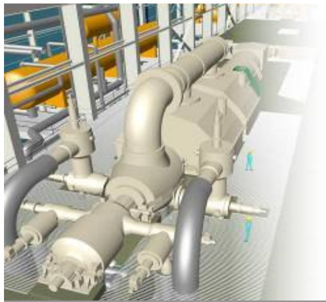
50 Hz RPP – Water Steam Cycle Diagram





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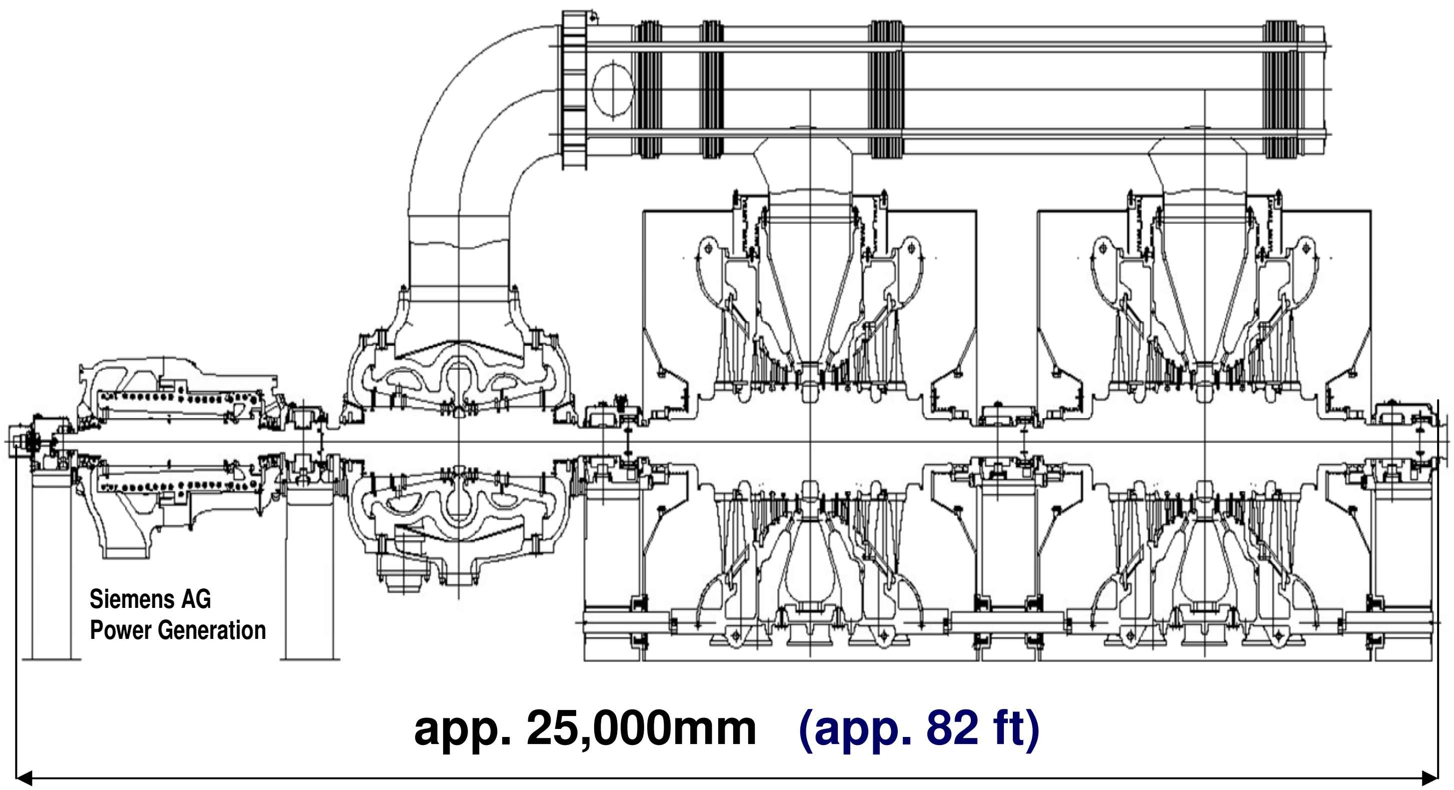
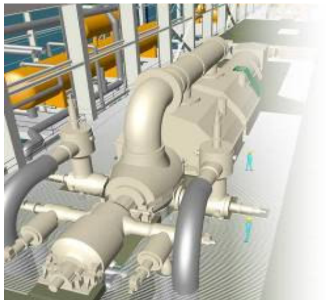
60Hz Varioplant – Main Parameters

Plant Gross Capacity	800 MW
Plant Net Capacity	725 MW
Live Steam Pressure	28.5 MPa → 4134 psi
Live Steam Temperature	600 ºC → 1112 ºF
Reheat Pressure	6.0 MPa → 870 psi
Condenser Pressure	4.5 kPa → 0.653 psi
Feed Water Temperature	303 ºC → 578 ºF
Reheat Temperature	610 ºC → 1130 ºF
Heat Rate$_{NET/LHV}$–Efficiency	7435 Btu/kWh – 45.8 %
Boiler Type	OT-Benson
ST Type	4 Casing – Single Reheat 1SF HP-1DF IP-2DF LP

Coalgen 2006

800MW$_{GROSS}$ 4-Casing (60Hz) USC Steam Turbine





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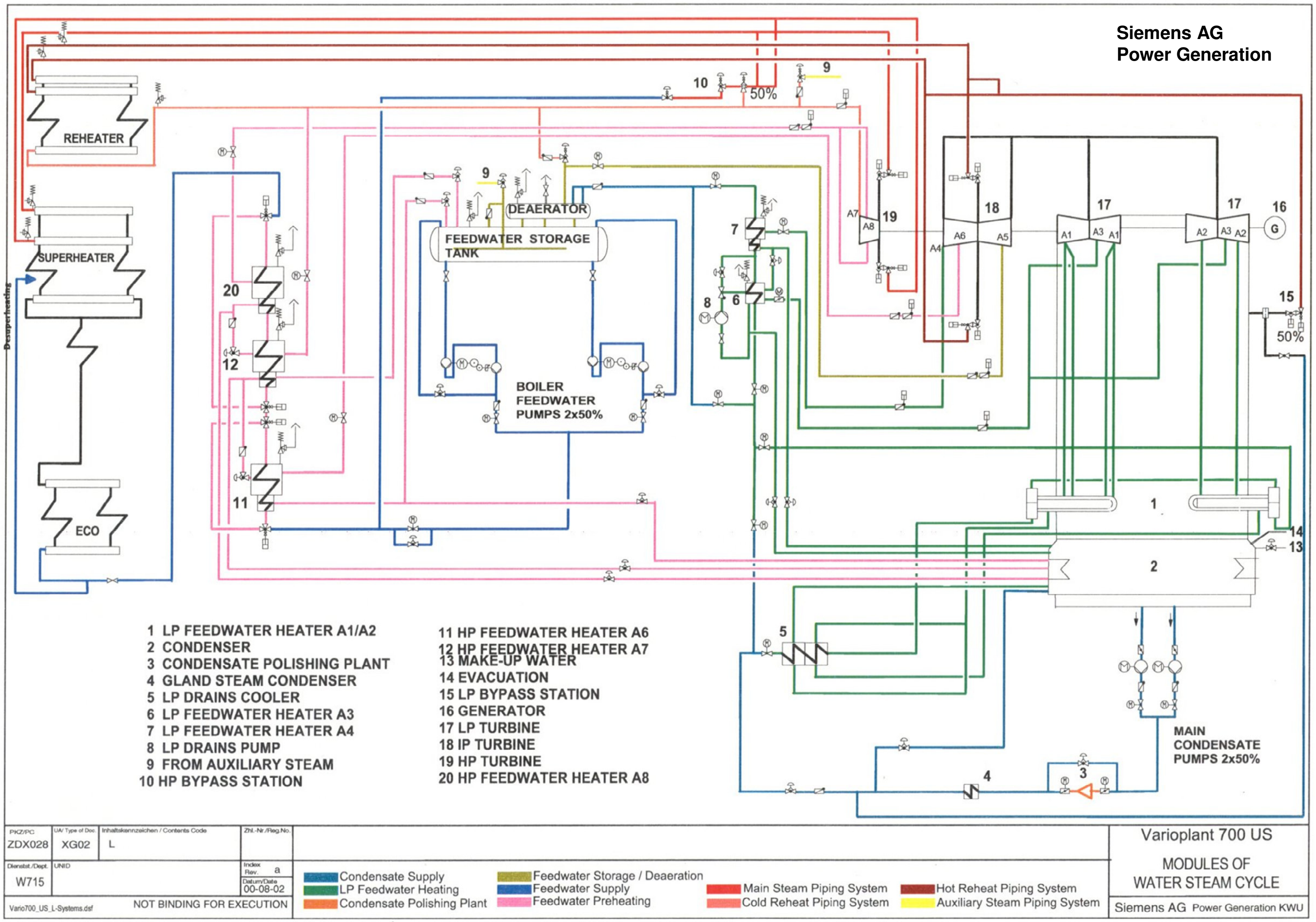
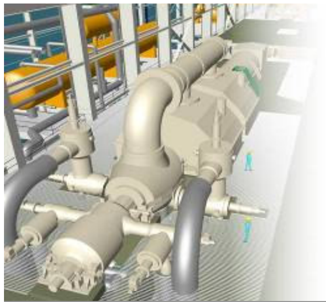
60 Hz Varioplant – Water Steam Cycle Diagram





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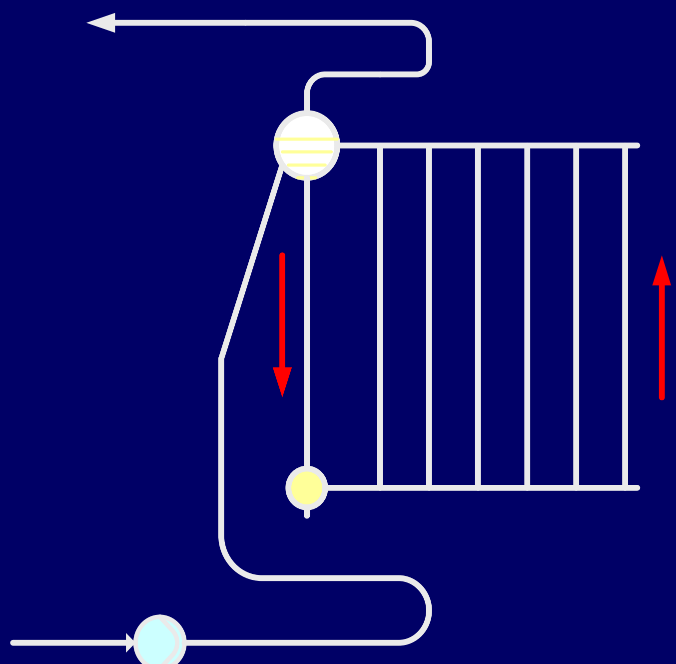
Drum vs. OT Boiler

Drum Type Boiler

Operational Pressure

1.0 – 18.0 MPa

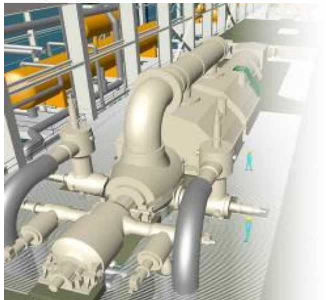


OT Type Boiler

Operational Pressure

2.0 – 40.0 MPa

Coalgen 2006



Drum vs. OT Boiler

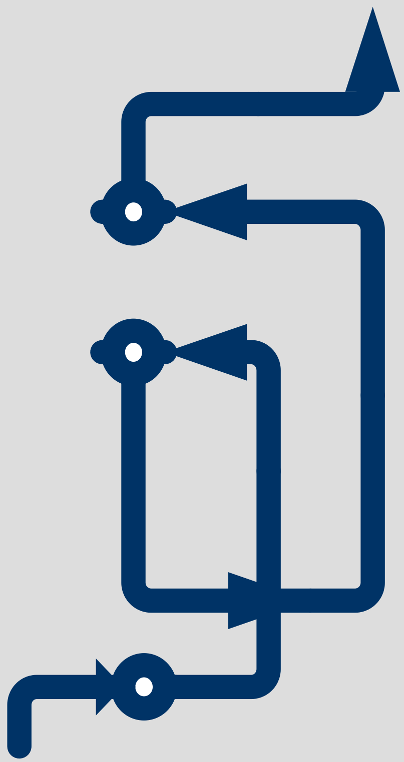
Drum Boiler

- Restricted to Sub-Critical Pressures
- Low Efficiency at Part Load
- Long Start-up Times
- Thick Walled Components (HP Drum) →Higher Thermal Stresses
- Feed Water Flow Control by Drum Water Level Control
- Lower Load Transients (4-5%)

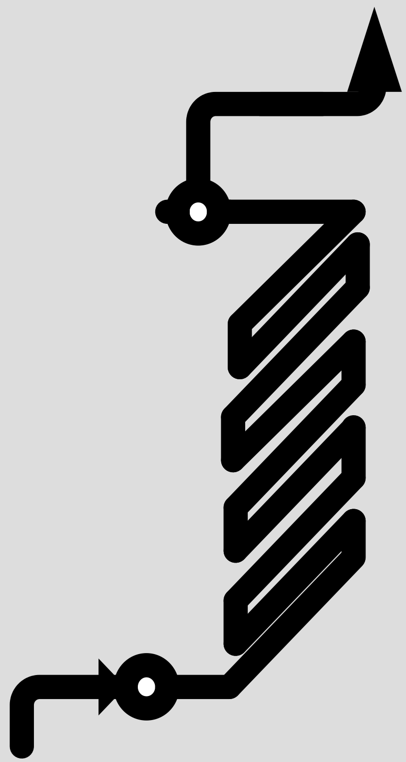
OT Boiler

- Both Sub- & Super-Critical Pressures
- Highest Efficiency at Part & Full Load
- Short Start-up Times
- Thermoelastic Construction →Lower Thermal Stresses
- Feed Water Flow Control by after Evaporator Temperature / Enthalpy Control
- Higher Load Transients (6-8%)

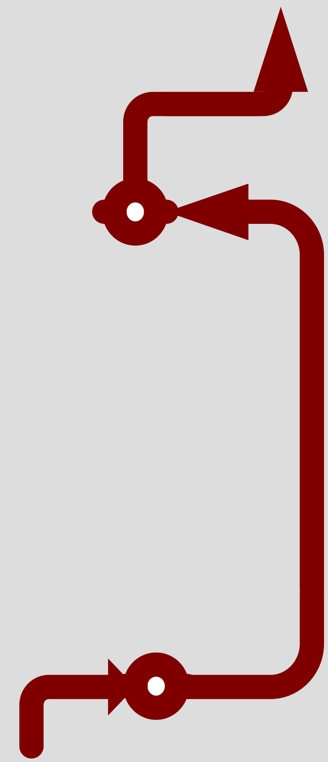
OT Boiler Furnace Arrangements



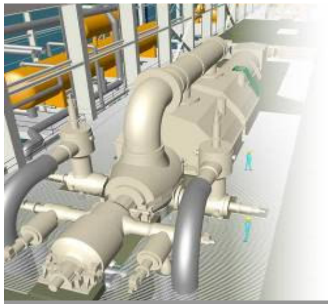
Vertical Tube Arrangement High Mass Flux



Spiral Tube Arrangement High Mass Flux

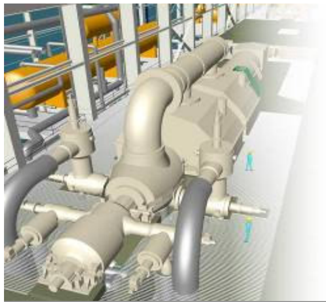


Advanced Vertical Tube Arrangement Low Mass Flux



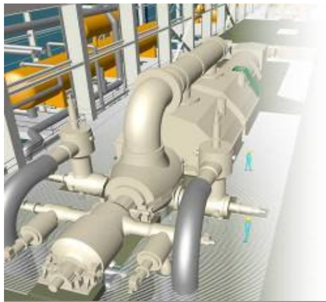
Advantages of Vertical vs. Spiral Arrangement

- Cheaper Manufacture & Assembly
- Maintenance Friendly
- Part Load up to 20% at highest Main Steam Temperatures
- Reduced Slagging of Furnace Walls
- Lower Evaporator Pressure Loss
- Lower Auxiliary Power Requirement
- Simple Start-up System.



Low Mass Flux Design (LMFD)

- Current OT boilers use Furnace Tube Mass Fluxes (FTMF) designs >1,500-1,800kg/m^2s → 1,106,190-1,327,430lb/ft^2h
- FTMF levels below 1,000-1,200kg/m^2s → 737,460-884,950lb/ft^2h (LMFD) minimize the furnace dynamic pressure losses
- Thermo-hydraulic behavior of the LMFD becomes similar to natural circulation boilers.

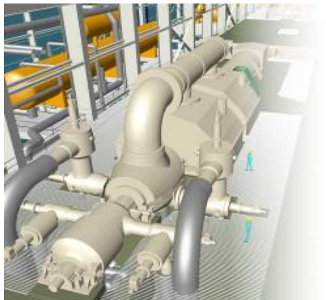


Low Mass Flux Design (LMFD)

Combination Vertical Tube Arrangement with Low Mass Flux Design

⇩

Highly Efficient & Reliable Boiler with Outstanding Operating Characteristics at any Load from 20% part Load up to Design Base Load.



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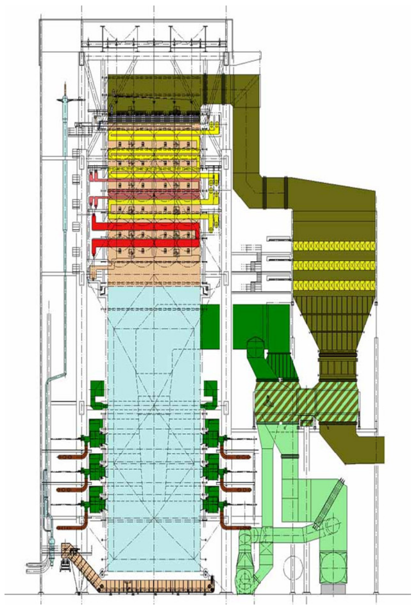
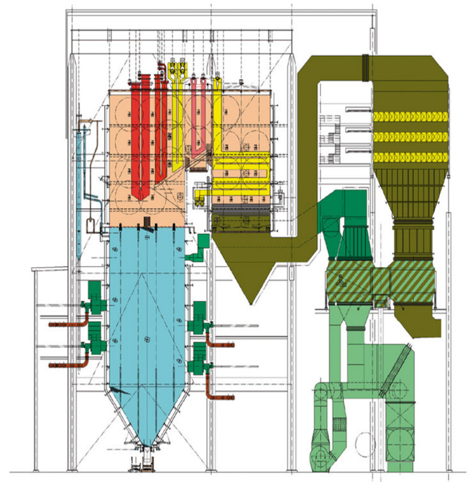
OT Boiler Design Alternatives

Tower Boiler



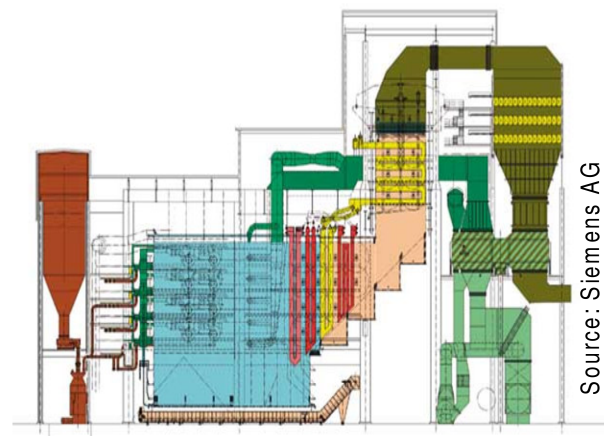
Floor space: 2,975 m²
Volume: 166,000 m³
Efficiency: 95%

Two-Pass Boiler



Floor space: 4,164 m²
Volume: 197,000 m³
Efficiency: 95%

Horizontal Boiler



Floor space: 4,600 m²
Volume: 209,000 m³
Efficiency: 95%

Source: Siemens AG

Concept study reference power plant North Rhine-Westphalia (RPP NRW), Project 85.65.69 – T-138, VGB PowerTech e.V., 2004

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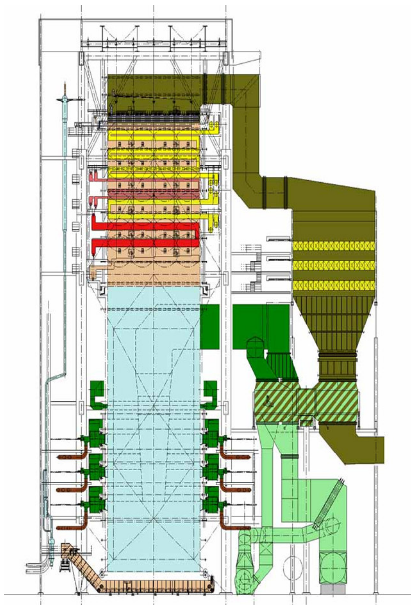
OT Boiler Design Alternatives



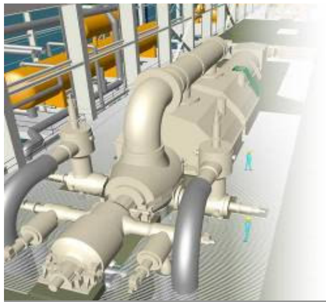
Floor space: 2,975 m^2
Volume: 166,000 m^3
Efficiency: 95%

Tower Boiler →

Lowest Steel & Pressure Parts & Floor Space Requirement.

Allows Multilevel Coal Feeders.

High Hight.



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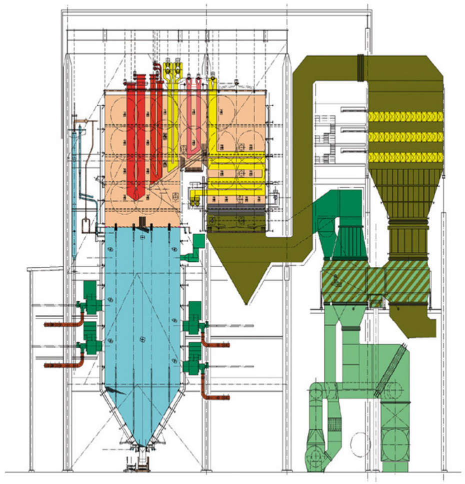
OT Boiler Design Alternatives



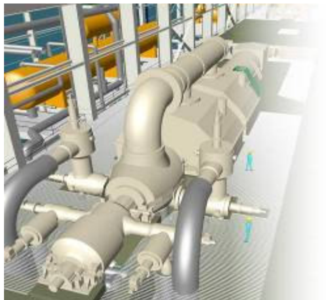
Floor space: 4,164 m²
Volume: 197,000 m³
Efficiency: 95%

Two-Pass Boiler →

High Steel, External Piping, Pressure Parts & Floor Space Requirement.

Short Assembly Time.

Low Height.

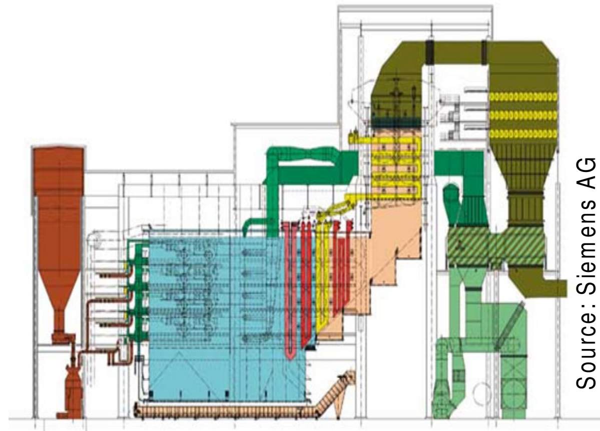


OT Boiler Design Alternatives

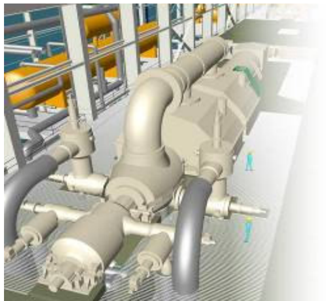
Horizontal Boiler →

Lowest External Piping Requirement, High Steel & Floor Space Requirement.

Low Height.



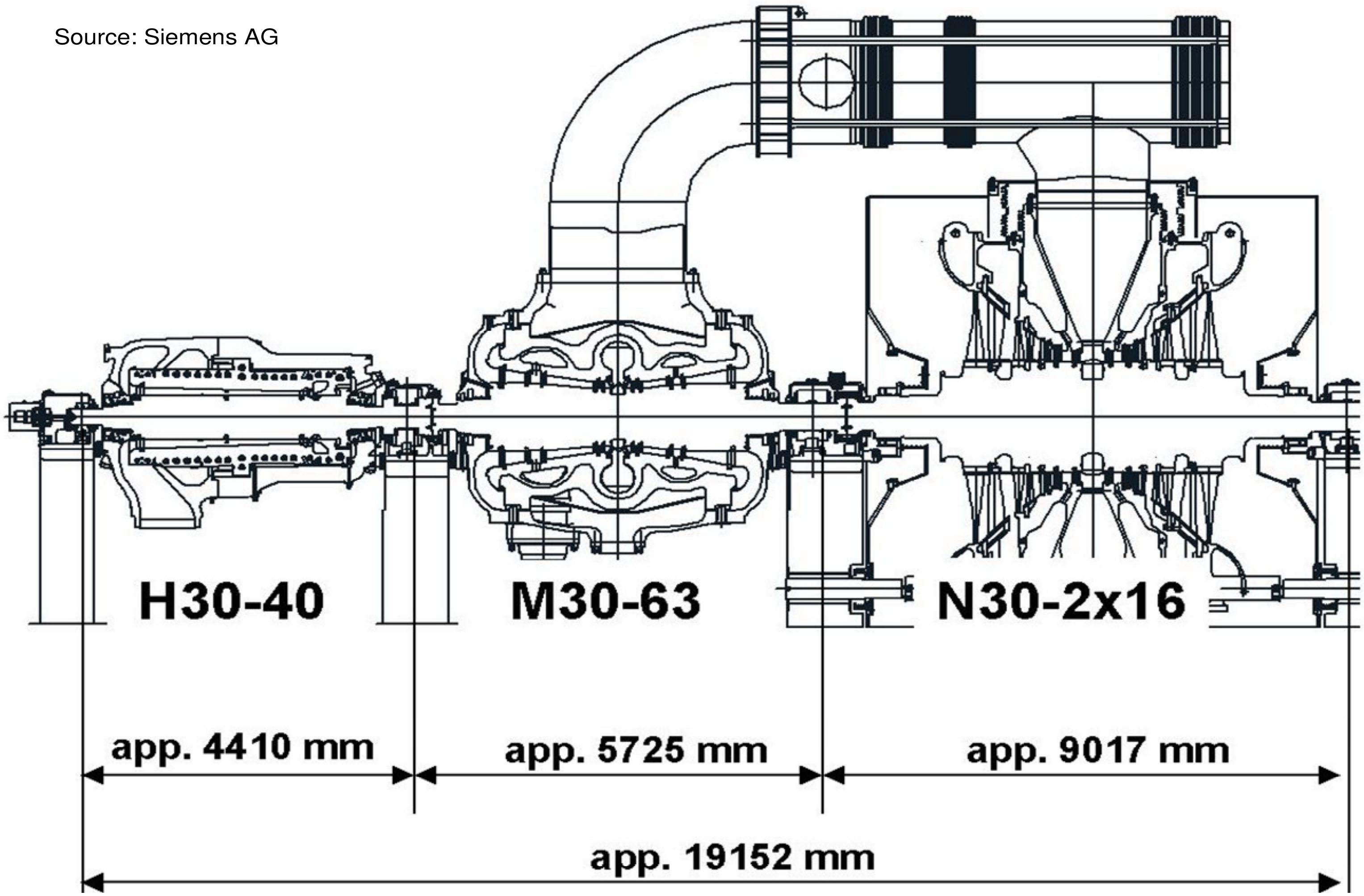
Floor space: 4,600 m^2
Volume: 209,000 m^3
Efficiency: 95%

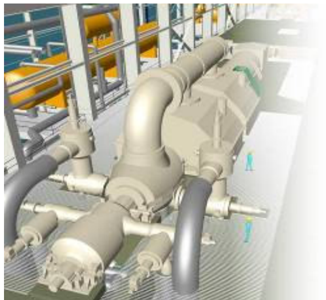


Boiler Temperature & Material Development

Live Steam Pressure MPa (psi)	Live Steam Temperature °C (°F)	Date	Material	Equivalent to
<20.0 (<2900)	<520 (<968)	Since Early 60's	X 20	Cr Mo V 11 1
<25.0 (<3626)	<540 (<1004)	Since Early 80's	P 22	2 ¼ Cr Mo
<30.0 (<4351)	<560 (<1040)	Since Late 80's	P 91	9Cr – 1Mo
<33.0 (<4786)	<620 (<1148)	Since 2004	P 92	X10CrWMoVNb9-1 EUROPE STBA29-STPA29 JAPAN
<35.0 (<5076)	<700 (<1292)	Start 2010	Super Alloys	CCA 617 - IN 740 – Haynes 230 – Save 12

$600MW_{GROSS}$ 3-Casing (50Hz) USC Steam Turbine





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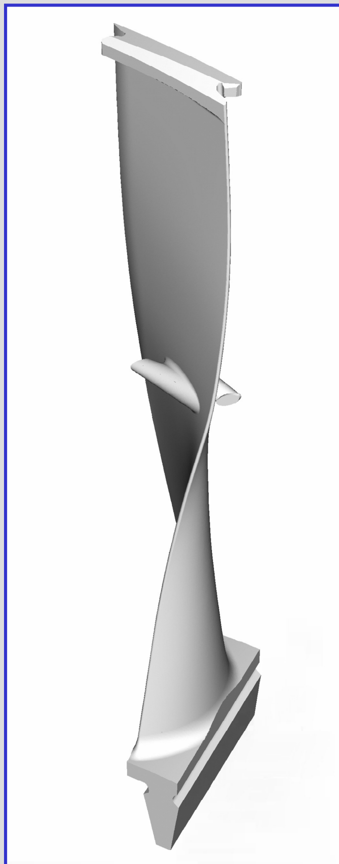
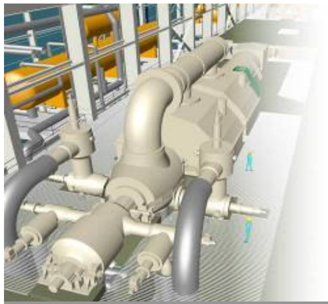
Design Features (50Hz) 16m² Last Stage Blade



➢ Rotor Diameter	1,900 mm (74.8'')
➢ Blade Length	1,400 mm (55.0'')
➢ Speed at Blade End	738 m/s (1,435 knot)
➢ Mach No at Blade End	2.24
➢ Blade Connection	Shroud & Snubber
➢ Blade Material	Titanium

Source: Siemens AG



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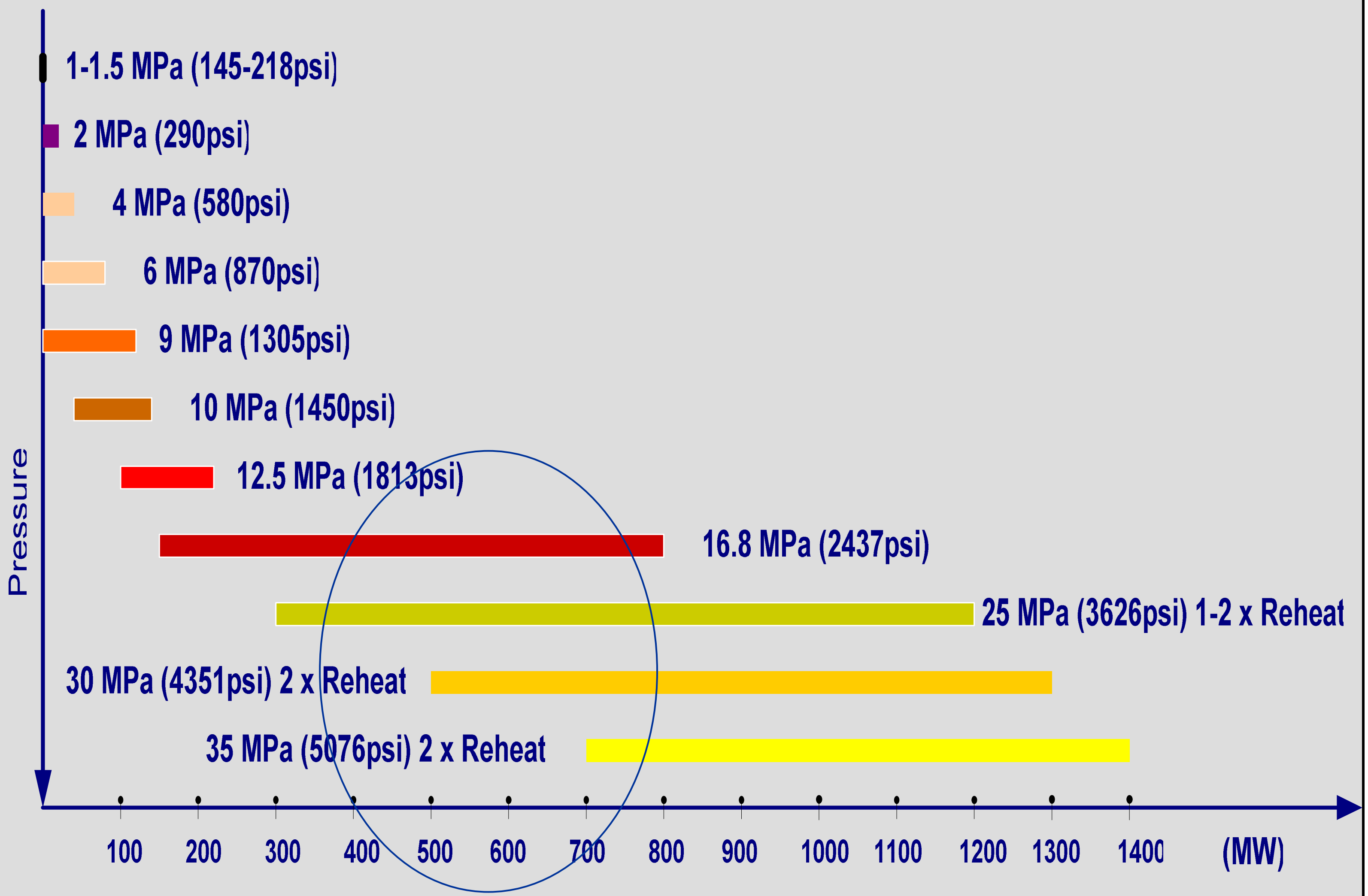
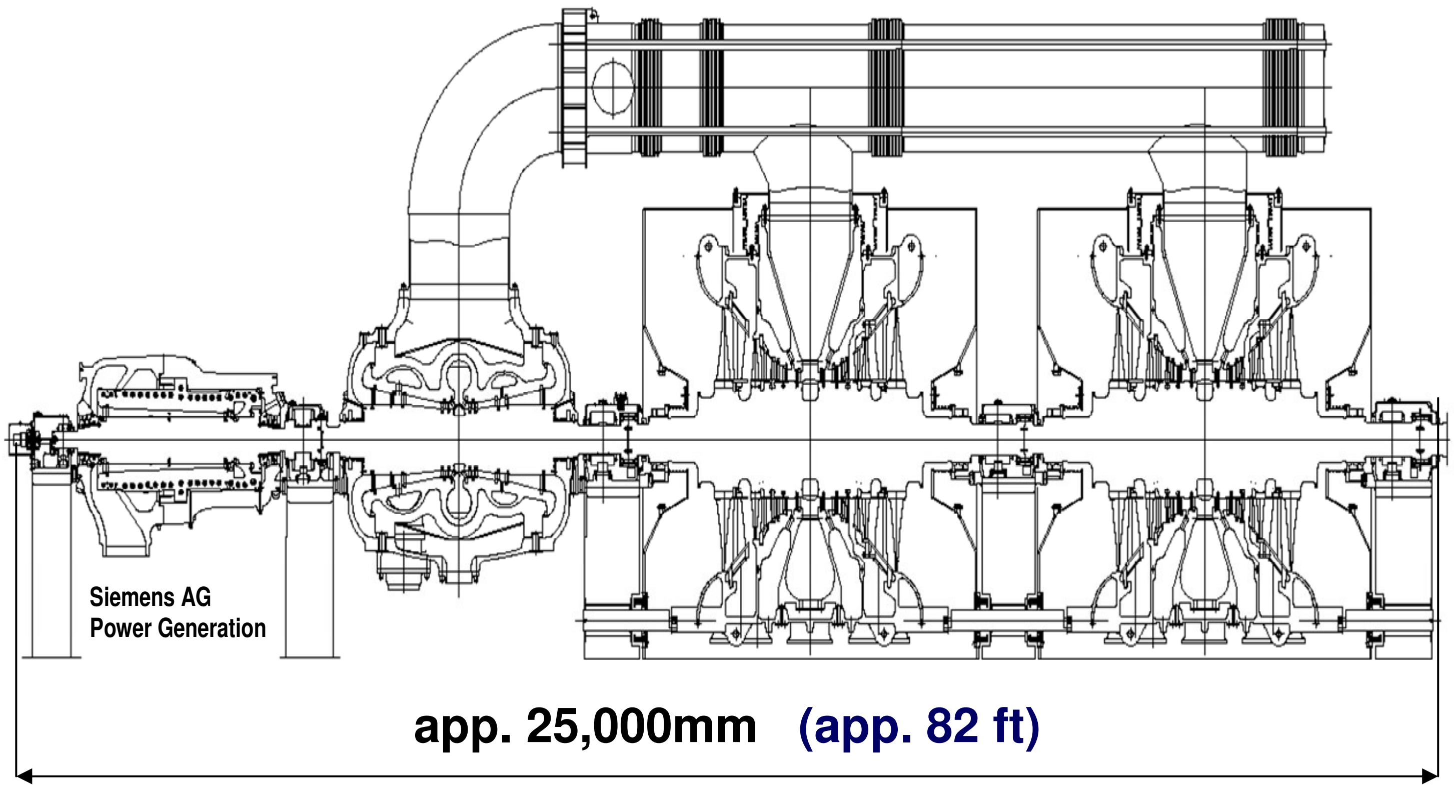
ST Unit Size

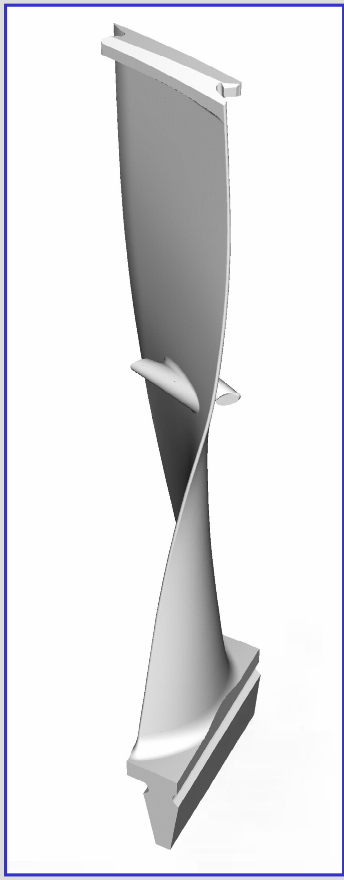


Coalgen 2006

800MW$_{GROSS}$ 4-Casing (60Hz) USC Steam Turbine

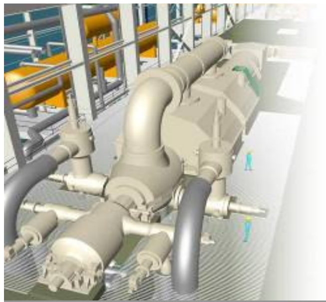


Design Features (60Hz) 10.3 m^2 Last Stage Blade



➢ Rotor Diameter	1,700 mm (67.0'')
➢ Blade Length	1,067 mm (42.0'')
➢ Speed at Blade End	722 m/s (1,403 knot)
➢ Mach No at Blade End	2.18
➢ Blade Connection	Shroud & Snubber
➢ Blade Material	Titanium

Source: Siemens AG



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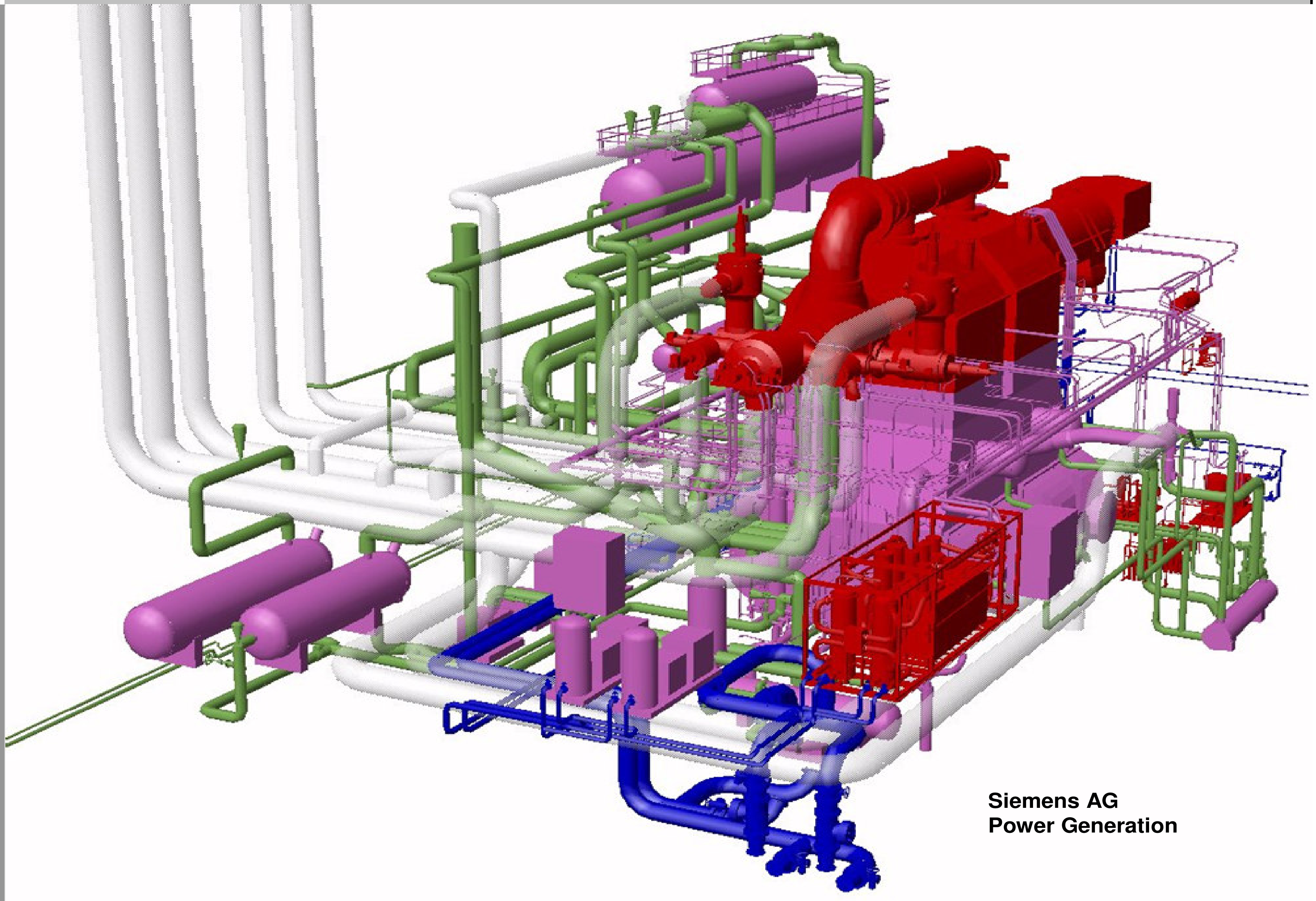
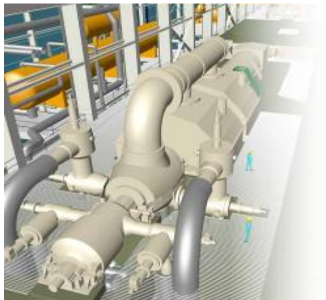
60Hz SSP-600 ** 3-D Model of Turbine Island



Siemens AG
Power Generation

Coalgen 2006



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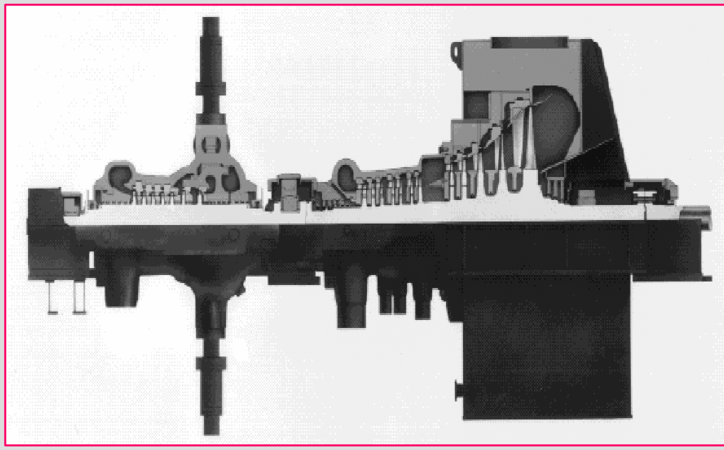
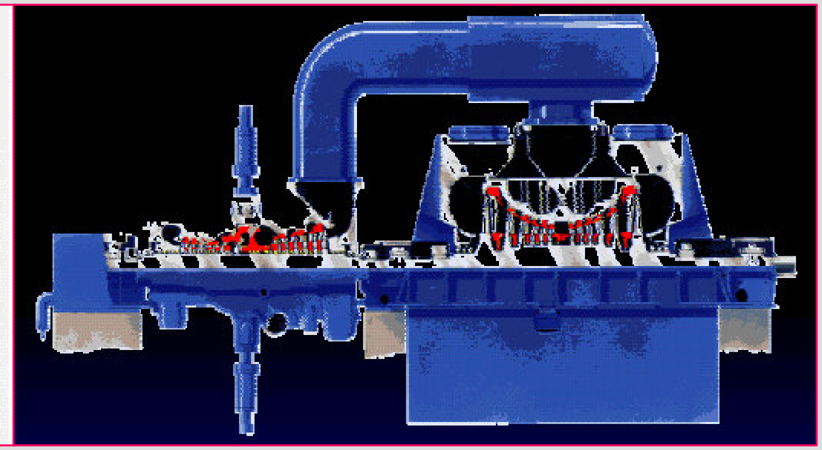
ST Common Configurations

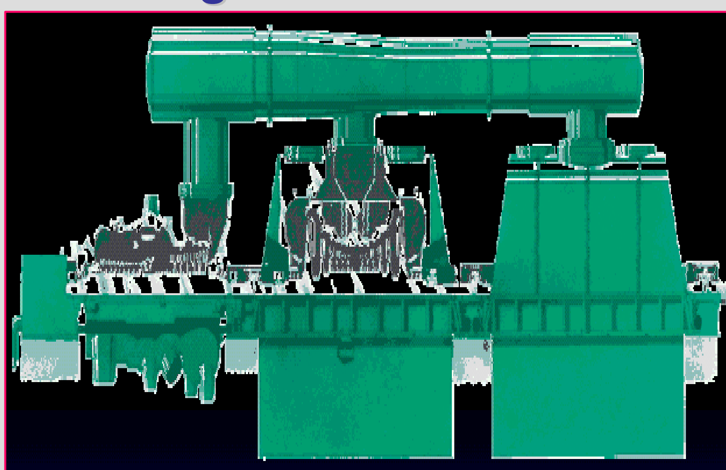
Double Shell * 1-Flow <50MW



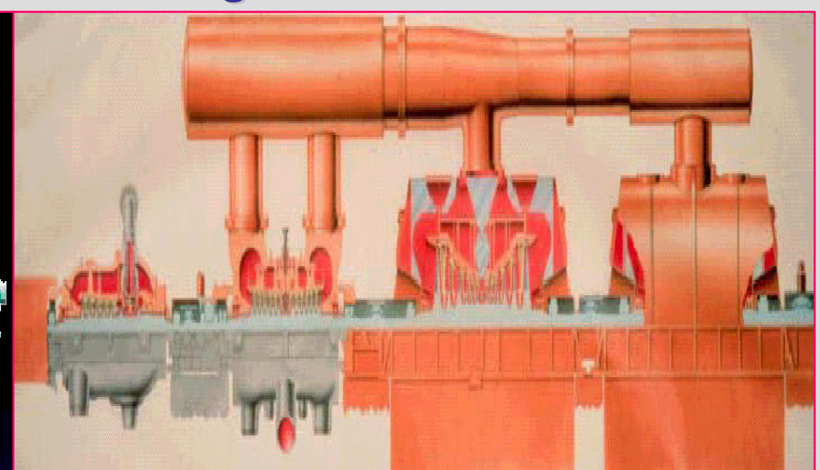
2-Casing * 2-Flow 300-600 MW

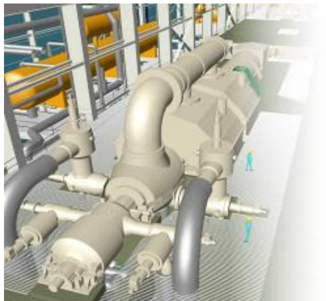


3-Casing * 4-Flow 400-700 MW



4-Casing * 4-Flow 700-1000 MW

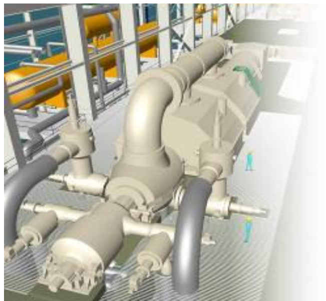




ST Material Development (50Hz)

Steam Temperature	≤560℃	≤620℃	≤700℃
Rotor	1Cr Mo V forging 12Cr Mo V Nb N 26Ni Cr Mo V11 5	9-12Cr W Co forging 12Cr Mo W V Nb N	IN 625 / IN 740 CCA 617 Haynes 230
Nozzles Valves	Cr Mo V Cast 10Cr Mo V Nb	9-10% Cr (W) Cast12Cr W (Co)	CCA 617 IN 625 / IN 714
Inner Casing Shells	1-2 Cr Mo Cast Cr Mo V Cast 9Cr 1 Mo V Nb (up to 590°C)	9-12% Cr (W) Cast12Cr W (Co)	CCA 617 IN 625 IN 740 (up to 760°C)
Blading	10Cr Mo V Nb N Titanium (last rotor row)	9-12% Cr W Co Titanium (last rotor row)	Wrought Ni-Base Titanium (last rotor row)
Bolting	9-12% Cr Mo V NI 80A; IN 718	9-12% Cr Mo VIN 718	Nimonic105 / 115 / 718Allvac 718 Plus Waspaloy

Pos	Power Plant Name	Country	Power Output MW_{GROSS}	Live Steam MPa /°C /°C (psi /°F /°F)	COD
01	Council Bluffs	USA (IA)	790	25.5 / 565 / 565 (3690/1050/1050)	2007
02	Weston 4	USA (WI)	500	36.2 / 580 / 580 (3800/1076/1076)	2007
03	Comanche 3	USA (CO)	750	26.2 / 570 / 570 (3800/1055/1055)	2009
04	Elm Road 1 & 2	USA (WI)	2 x 600	26.2 / 570 / 570 (3800/1055/1055)	2009
05	Iatan 2	USA (MO)	900	25.5 / 585 / 585 (3686/1085/1085)	2010
06	Genesee 3	Canada	495	25.0 / 570 / 568 (3626/1058/1054)	2005
07	RPP NRW_{60Hz}	USA	800	28.5 / 600 / 610 (4134/1112/1130)	2010
08	Lippendorf	Germany	934	26.7 / 554 / 583 (3873/1029/1081)	1999
09	Boxberg 1	Germany	907	26.6 / 545 / 581 (3860/1013/1078)	2000
10	Niederaussem	Germany	1027	27.5 / 580 / 600 (3989/1076/1112)	2003
11	RPP NRW_{50Hz}	Germany	600	28.5 / 600 / 620 (4134/1112/1148)	2008
12	Boa 2 Neurath	Germany	2 x 1100	26.0 / 595 / 595 (3771/1103/1103)	2010
13	Nordjylland 3	Denmark	411	29.0 / 582 / 580 (4206/1080/1076)	1998
14	Avedoere 2	Denmark	450	30.0 / 580 /600 (4351/1076/1112)	2002
15	Schwarze Pumpe	Germany	2 x 800	26.8 / 547 / 565 (3742/1017/1078)	1996
16	Tachibana-Wan	Japan	1050	25.9 / 600 / 610 (3756/1112/1130)	2000
17	Hitachi-Naka 1	Japan	1000	25.4 / 604 / 602 (3684/1119/1116)	2003
18	Isogo 1	Japan	600	28.0 / 605 / 613 (4061/1121/1135)	2002
19	Misumi	Japan	1000	25.0 / 600 / 605 (3626/1112/1121)	1998
20	Wangqu	PR China	2 x 600	27.5 / 571 / 569 (3989/1060/1056)	2007
21	Waigaoqiao	PR China	2 x 900	27.9 / 542 / 562 (4047/1008/1044)	2004
22	Zouxian IV	PR China	2 x 1000	27.0 / 600 / 600 (3916/1112/1112)	2008
23	Huaneng	PR China	4 x 1000	26.5 / 600 / 600 (3844/1112/1112)	2008
24	Cogan Creek	Australia	700	26.0 / 540 / 560 (3626/1004/1040)	2008



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Boxberg 907 MW USC Power Plant - Germany

26.6 MPa

545 / 581 ºC

3860 psi

1013 / 1078 ºF

Photographs courtesy of Siemens Power Generation AG

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Niederaussem 1027 MW USC Power Plant - Germany

27.5 MPa

580 / 600 ºC

3989 psi

1076 / 1112 ºF

Photograph courtesy of Siemens Power Generation AG

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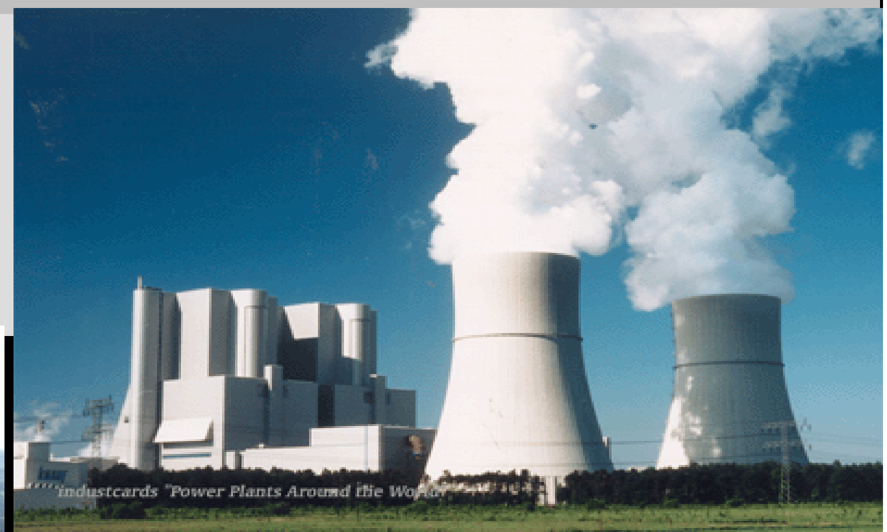
Schwarze Pumpe 2x800 MW USC Power Plant - Germany

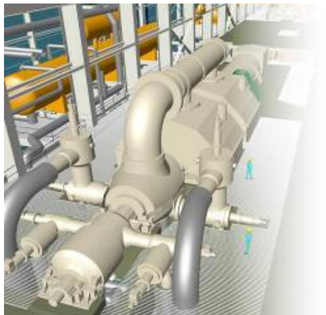
26.8 MPa

547 / 565 ºC



3742 psi

1017 / 1078 ºF



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Tachibana-Wan 1050 MW SC Power Plant - Japan

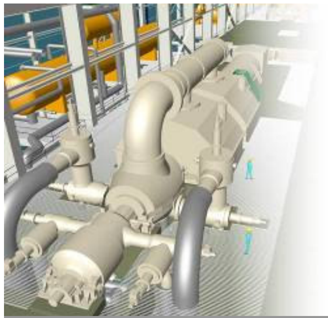
Photographs courtesy of IHI Ltd

25.9 MPa

600 / 610 ºC

3756 psi

1112 / 1130 ºF

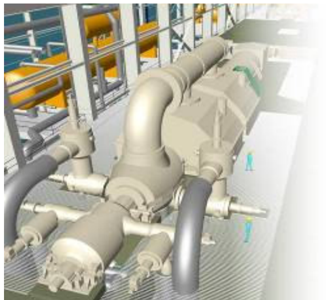


Shin-Isogo 600 MW USC Power Plant - Japan

28.0 MPa
605 / 613 ºC

4061 psi
1121 / 1135 ºF

Photographs courtesy of Hokuriku Electric Power Co & Siemens Power Generation AG



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Misumi 1000 MW SC Power Plant - Japan

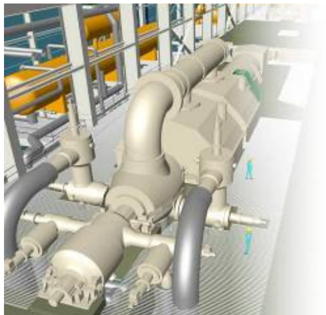
25.0 MPa

600 / 605 ºC

3626 psi

1112 / 1121 ºF

Coalgen 2006



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Waigaoqiao 2x900 MW USC Power Plant–PR China

27.9 MPa

542 / 562 ºC

4047 psi

1008 / 1044 ºF

Photographs courtesy of Siemens Power Generation AG

Coalgen 2006

Huaneng Yuhuan 4x1000 MW USC Power Plant – PR China

26.5 MPa

600 / 600 ºC

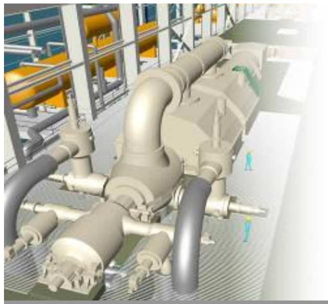
COD

2008

3844 psi

1112 / 1112 ºF

Photographs courtesy of Ministry of Construction PR China



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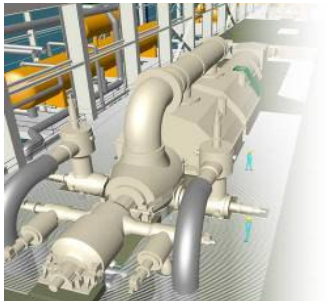
Kogan Creek 700MW SC Power Plant - Australia

Photograph courtesy of Siemens Power Generation AG

Coalgen 2006



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Kogan Creek 700MW SC Power Plant - Australia

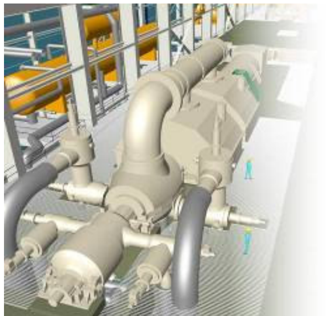
26.0 MPa / 540ºC / 560ºC

⇩

3,626 psi / 1004ºF / 1040ºF

Photograph courtesy of Siemens Power Generation AG

Coalgen 2006



Summary

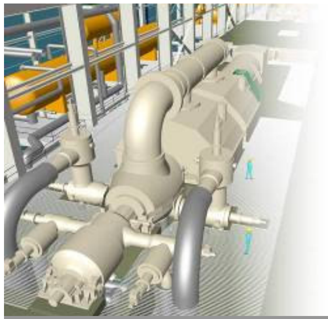
&

Conclusions

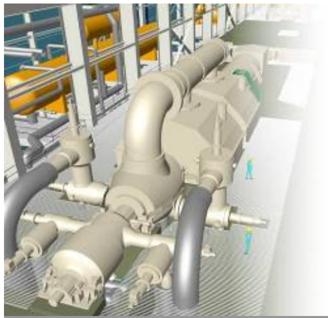
Most of the coal fired power plants to be build worldwide during next decades will be of:-

IGCC Technology; and

Pulverized Coal Fired SC/USC Technology



- Both IGCC and SC & USC Technologies are enjoying a steeply growing market share.
- However, IGCC market specifically, is not following this bullish trend yet- Reason is higher investment costs than the cost of SC & USC Technology.



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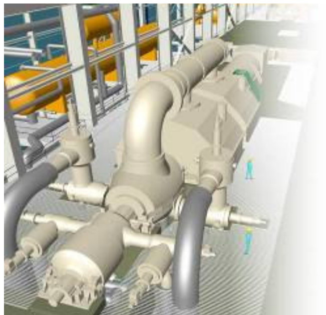
SC & USC Power Generation Technology will gain superiority over conventional (sub-critical) power plants from the following reasons:-

Higher Efficiency

Excellent Load Behavior

Compactness

Environmental Friendliness



Current SC pulverized coal based power plants are working with net efficiencies in the range of:-

44 - 46%

7,755 - 7,420Btu/kWh

Options to increase efficiency above

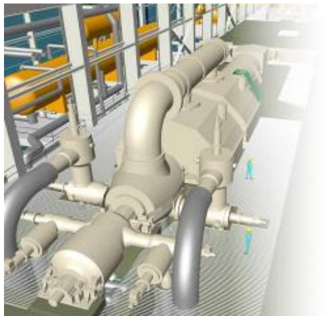
50 %

6,824 Btu/kWh

in

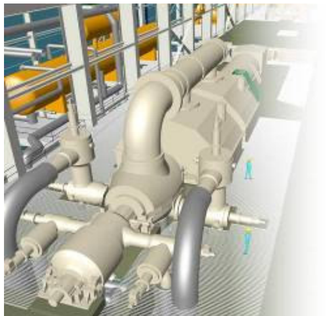
USC Power Plants

rely on elevated steam conditions as well as on future improved process and component quality.



Steam conditions up to
30 MPa/600°C/620°C
4351psi/1112°F/1148°F
are achieved using steels with
12 % Cr content

Steam conditions up to
31.5 MPa/620°C/620°C
4567psi/1148°F/1148°F
can be achieved with Austenite
steels.



Nickel-based alloys may permit

35MPa/720℃/720℃

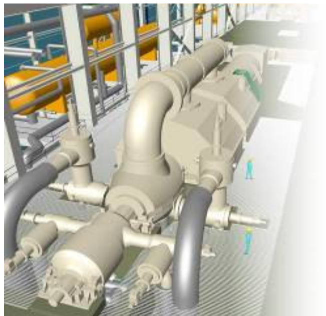
5076psi/1328℉/1328℉

yielding efficiencies of:-

50 - 52%

6,825-6,562Btu/kWh

in around 2020.



Overall outlook for pulverized coal-fired SC/USC power plant technology is promising and its further growth lies ahead.

Intensity of this growth will depend on the following factors:

- Worldwide acceptance of USC technology
- Further development of NG vs. Coal price
- Reduction of investment & life cycle costs
- Further Improvement of availability & reliability
- Efficiency improvement
- Further reduction of specific emissions.

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

THANK YOU

IMTE AG

Power Consulting Engineers, Switzerland

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