# APPENDIX A

P,Q,UO

## THE IMHAUSEN STUDY

### Summary

The Imhausen study is a joint Australian/German effort examining the feasibility of direct and indirect coal liquefaction systems for installation in Australia. The study proposes a hydrogenation plant for producing 3 million tonnes (3.3 million tons) per year of motor fuel from Victoria lignite coal and a combined hydrogenation/Fischer-Tropsch plant for producing the same quantity of motor fuel from New South Wales bituminous coal. In the latter case it was necessary to use a combination process in order to achieve the diesel fuel specification since a hydrogenation plant could not produce sufficient diesel oil of the required density and cetane rating from the Australian bituminous coal.

The hydrogenation process assumed for the study is the German high-pressure hydrogenation process which has been developed from the I. G. Farben process. It will be tested in the 200 ton/day pilot plant at Bottrop starting in 1981.

The Imhausen study also examined several Fischer-Tropsch based plants.

Production costs for the combined high-pressure hydrogenation/Fischer-Tropsch, high-pressure hydrogenation, and Fischer-Tropsch cases were estimated. Results indicate that the following are the optimal ways of converting coal into motor fuels and liquefied gas:

- For Australian bituminous coal, only a combination of high-pressure hydrogenation/Fischer-Tropsch synthesis yields products which meet the required specifications. This combination also has the advantage that a considerable portion of ashy, inferior coal can be utilized as a raw material. This type of plant has the lowest production cost ($0.54/gal) and highest overall thermal efficiency (52.3%) of any of those considered in the study.

- For Australian lignite, the high-pressure hydrogenation process produces motor fuels which meet the specifications. It has a high thermal efficiency and has the lowest capital investment requirement of any of the lignite variations analyzed. This type of plant has the second lowest production cost ($0.55/gal) and second highest overall thermal efficiency (51.6%) of any of those which were included in the study.

However, the hydrogenation process requires washed coal whereas the Fischer-Tropsch process accepts run-of-mine coal, and it is not apparent that this has been taken into account in the Imhausen study. Extensive washing would add significantly to the cost of the coal prepared for the hydrogenation system.

## The Imhausen Report

The Imhausen report, "Optimization of a Combination of Coal Hydrogenation, Fischer-Tropsch Synthesis and Gasification for the Production of Motor Fuels," Research Report T-80-048, was prepared for the German Federal Ministry for Research and Technology (BMFT).

At the request of the BMFT, a proposal on the production of motor fuels from lignite and bituminous coal was presented in March 1976 to the Australian states of New South Wales, Queensland and Victoria. This proposal was compiled by a German consortium under the direction of Professor Dr. K.-H. Imhausen and was based on the Fischer-Tropsch synthesis process. This consortium is composed of the following German companies:

Imhausen-Chemie GmbH, Lahr
Lurgi Kohle and Mineraloltechnik GmbH, Frankfurt/Main
Rheinische Braunkohlenwerke AG, Cologne
Ruhrchemie AG, Oberhausen
Ruhrkohle AG, Essen
Salzgitter Industriebau GmbH, Salzgitter
Uhde GmbH, Dortmund.

In May 1977, the consortium suggested that instead of just Fischer-Tropsch synthesis, the combination of Fischer-Tropsch synthesis, coal hydrogenation and gasificaiton of the hydrogenation residue should be used for the conversion of coal to motor fuels. Reasons given for this suggestion are that this combination has substantial technical and economic advantages over the Fischer-Tropsch synthesis on its own and is based on modern German know-how.

Although the individual processes are already known, the combination of these processes in the suggested form is, technologically speaking, new ground. Therefore, the consortium suggested that the technical and economic aspects of this combination of processes be examined within the framework of a feasibility study. In order to have the necessary information and the most favorable approach available for this feasibility study, on February 1, 1978 the BMFT commissioned the consortium to begin by carrying out an optimization study.

After consultation with the Australian partner - the Department of National Development (DND) of the Australian government - and with the BMFT, it was decided that the optimization would be based on a plant with a capacity of $3 \times 10^6$ tonnes ($3.3 \times 10^6$ tons) of fuel and liquefied gas per annum, on the basis of lignite and bituminous coal, respectively. The breakdown of products should correspond to the given market requirements and consist approximately of the following:

45% synthetic petrol (gasoline)

45% diesel oil

10% liquefied gas.

It is possible to calculate both the Fischer-Tropsch synthesis process with a suitable gasification process and also coal high pressure hydrogenation with hydrogen production, hydrogenation residue gasification and hydrogenation gas treatment, and combinations of these, and to represent them in terms of particular variants.

The range of products, the coal and fresh water requirements as well as the by-products which cannot be converted into motor fuels were to be indicated for each variant, and the production costs, based on the estimated investment expenditure and at given price levels for coal, were to be established. Hypothetical assumptions which serve to simplify calculations without prejudicing the basis of comparison were admissible. Local conditions, environmental conservation, coal and water supplies, as well as the infrastructure were not taken into consideration. The study was based on the following analyses of coal for the hydrogenation and gasification processes and for the energy installations, representative of Australian lignite and bituminous coal.

| Lignite | Wt % |
|---|---|
| Carbon | 22.89 |
| Oxygen | 8.82 |
| Hydrogen | 1.62 |
| Nitrogen | 0.24 |
| Sulfur | 0.10 |
| Ash | 0.34 |
| Water | 65.00 |
| Calorific value, $H_u$ [Higher heating value (HHV)] | 1610 kcal/kg (2900 Btu/lb) |
| Calorific value, maf, $H_u$ [Higher heating value (HHV)] | 5950 kcal/kg (10,710 Btu/lb) |

| Bituminous coal | Wt % |
|---|---|
| C | 67.98 |
| O | 26.20 |
| H | 4.81 |
| N | 0.71 |
| S | 0.30 |

The study is also based on processes which are in the possession of the consortium partners, or which are available to the consortium partners. These are, in particular: (1) processes involving coal treatment, drying and briquetting; (2) Fischer-Tropsch synthesis; (3) liquid-phase hydrogenation of lignite and bituminous coal; (4) pressure gasification of lump lignite and bituminous coal; (5) pressure gasification of bituminous coal and hydrogenation residues; (6) pressure splitting of hydrocarbons; (7) processes for hydrogen production, gas cleaning, gas separation, and gas conditioning; (8) refining of coal oils by hydrogenation and splitting; (9) reforming of petroleum fractions; (10) hydrogenizing splitting of higher molecular n-paraffins; (11) isomerization and alkylation processes; and (12) processes for the purification of process effluents.

Further processing (upgrading) of the primary products from the Fischer-Tropsch synthesis and coal hydrogenation processes was included to achieve the following product quality levels:

| | |
|---|---|
| <u>Synthetic petrol (gasoline)</u> | |
| Density (sp.g.)$d_{15°}$ | Minimum 0.72 |
| ROZ (Research octane number) | Minimum 98 (0.15 ml TEL/l) |
| <u>Diesel fuel</u> | |
| Density (sp.g.)$d_{15°}$ | Minimum 0.815 Maximum 0.845 |
| Cetane rating | Minimum 50 |
| <u>Liquefied gas</u> | |
| Calorific value, $H_u$ [Higher heating value (HHV)] | Minimum 10,6700 kcal/kg (19,080 Btu/ft) |
| Butane content | Maximum 65% by weight |
| Methane/ethane | Maximum 5.5% by weight |

<u>Grid gas</u>

A mixture of methane and ethane/ethylene with a calorific value, $H_u$ [Higher heating value (HHV)], ranging between 8550 and 9600 kcal/$m_n{}^3$ (960 and 1080 Btu/ft$^3$), free of hydrogen, carbon oxides and nitrogen.

Cost estimates were prepared separately for each plant variation, to an accuracy of ±25%. These represent a plant built under a turnkey contract in the Federal Republic of Germany and include the cost of engineering. Estimates are based on average 1978 prices in the Federal Republic of Germany.

The capital investment is defined as the sum of the costs of process installations, energy plants and secondary installations. Spare parts, catalysts, and chemicals as well as payment for licenses and know-how were not included in the capital costs unless specifically stated. Interest during the building, asesmbly and starting period was also not taken into consideration. Labor costs, insurance and operating costs during the assembly and starting period as well as coal requirements during the starting period were also excluded.

A uniform plant size of 2500 by 1500 m (9520 ft x 4920 ft = 1075 acres) with a capacity of 3 x $10^6$ tonnes (3.3 x $10^6$ tons) of motor fuel and liquefied gas per year were assumed. Land costs were not included.

Annual costs, based on capital investment, were projected as follows:

| Annual charge | Percentge of capital investment |
|---|---|
| Amortization and interest | 10.2 |
| Repair and maintenance | 3.5 |
| Taxes and insurance | 1.0 |
| Total | 14.7 |

The cost of coal was calculated on the basis of 5 DM/G cal ($0.72/$10^6$ Btu).

Total capital investments and coal consumption rates for the two types of plants considered for liquefying Australian bituminous coal are shown in Table A.1. Similar information for the three types of plants considered for liquefying Australian lignite is shown in Table A.2.

Production costs of liquid products from Australian bituminous coal and lignite are shown in Table A.3, and overall thermal efficiencies for the various plant configurations are shown in Table A.4.

The Imhausen study results indicate that the following are the optimal ways of converting coal into motor fuels and liquefied gas:

- For Australian bituminous coal, only the combination of high-pressure hydrogenation/Fischer-Tropsch synthesis yields products which meet the required specifications. This combination also has the advantage that a considerable portion of ashy, inferior coal can be utilized as a raw material. This type of plant has the lowest production cost ($0.54/gal) and highest overall thermal efficiency (52.3%) of any of those considered in the study.
- For Australian lignite, the high-pressure hydrogenation process produces motor fuels which meet the specifications. It has a high thermal efficiency and has the lowest capital investment requirement of any of the lignite variations analyzed. This type of plant has the second lowest production cost ($0.55/gal) and second highest overall thermal efficiency (51.6%) of any of those which were included in the study.

Table A.1. Investments and coal consumption rates for producing 3,000,000 tonnes (3,300,000 tons) of liquefied products per year from Australian bituminous coal

| Type plant | Total capital investment, $\$10^6$ | Annual coal consumption | |
|---|---|---|---|
| | | Tonnes | Tons |
| Fischer-Tropsch synthesis process | 2830 | $8.6 \times 10^6$ | $9.5 \times 10^6$ |
| Combined high-pressure hydrogenation/Fischer-Tropsch process | 2450 | $7.9 \times 10^6$ | $8.7 \times 10^6$ |

Table A.2. Investments and coal consumption rates for producing 3,000,000 tonnes (3,300,000 tons) of liquefied products per year from Australian lignite

| Type plant | Total capital investment, $\$10^6$ | Annual coal consumption | |
|---|---|---|---|
| | | Tonnes | Tons |
| Fischer-Tropsch synthesis process | 3425 | $41.0 \times 10^6$ | $45.1 \times 10^6$ |
| High-pressure hydrogenation process | 2630 | $37.0 \times 10^6$ | $40.7 \times 10^6$ |
| Combined high-pressure hydrogenation/Fischer-Tropsch process | 2970 | $39.0 \times 10^6$ | $42.9 \times 10^6$ |

Table A.3. Production costs of liquid products from Australian bituminous coal and lignite

| Type plant | Capital cost $/ton | Coal cost $/ton | Total cost $/ton | Total Cost $/gal |
|---|---|---|---|---|
| | | Bituminous Coal | | |
| Fischer-Tropsch synthesis process | 126 | 55 | 181 | 0.59 |
| Combined high-pressure hydrogenation/Fischer-Tropsch process | 109 | 50 | 159 | 0.52 |
| | | Lignite | | |
| Fischer-Tropsch synthesis process | 152 | 57 | 209 | 0.68 |
| High-pressure hydrogenation process | 117 | 52 | 169 | 0.55 |
| Combined high-pressure hydrogenation/Fischer-Tropsch process | 132 | 54 | 186 | 0.61 |

Table A.4. Overall thermal efficiencies[a] for the production of liquid products from Australian bituminous coal and lignite

| Type plant | Overall thermal efficiency, % |
|---|---|
| **Bituminous Coal** | |
| Fischer-Tropsch synthesis process | 46.0 |
| Combined high-pressure hydrogenation/Fischer-Tropsch process | 52.3 |
| **Lignite** | |
| Fischer-Tropsch synthesis process | 46.9 |
| High-pressure hydrogenation process | 51.6 |
| Combined high-pressure hydrogenation/Fischer-Tropsch process | Not available |

[a]Efficiencies are based on the heating value of the products divided by the heating value of the coal feed, including that used for steam and power generation.

# APPENDIX B

# COAL PROCESSING PROGRAM OF THE FEDERAL REPUBLIC OF GERMANY [E]

The stated aim of the West German national program is only partly in order to safeguard and develop indigeous supplies of fuels and feedstocks. The main objective, according to the Ministry of Research and Technology (BMFT), is to help German industry build a new high-technology industry for export ot the major coal producing countries of the world.

The coal processing program of the Federal Republic of Germany will not improve supplies of crude oil and natural gas immediately, but is expected to increasingly contribute to energy supplies towards the middle of the 1980's. It can be summarized as follows.

In 1974 the German federal government initiated the development of modern techniques for the processing of coal. As of early 1980, 650 million DM (about $370 million) had been invested by the BMFT (Ministry of Research and Technology) for this purpose. From 1977 to date seven pilot plants for coal gasification have started operation and another one is under construction. Table B-1 provides a survey of the seven coal gasification pilot plants, the largest of which processes 240 tonnes (264 tons) of hard coal daily. On the basis of discussions with industry, 14 projects for large scale processing of coal have been submitted by various enterprises. Coal gasification projects are listed in Table B-2, and coal liquefaction projects in Table B-3. These projects require, according to present estimates, an investment of about 13 billion DM (about $7.4 billion, price basis 1979) until 1993. Such an investment can only substitute a small percentage of the oil and natural gas imports. It provides, however, the basis for future exploitation of coal processing on a broad front.

The government plans to support what is believed to be every commercially significant coal conversion technology that has been identified. This accounts for one reason for funding so many projects. Other reasons given are that coal conversion is very difficult and that there are so many different kinds of coal.

Table B-1. Pilot plants for coal gasification completed and under construction

| No. | Operator or parent company | Process | Plant site | Primary product(s) | Coal type and feed rate | Total cost | Government funding | Status or plans |
|---|---|---|---|---|---|---|---|---|
| 1 | Rheinische Braunkohlen Werke AG | High temp. Winkler fluidized bed gasification | Frechen | Synthesis gas | Brown (lignite) (1 t/hr) | 32 million DM ($18 million) | 65% (BMFT)[a] | Planning and construction 1974-1978. Operational 1978. Experimental phase 1978-1981. |
| 2 | Rheinische Braunkohlen Werke AG | Hydrogenizing coal gasification | Wesseling | SNG | Brown (lignite) 15 t/hr | 150 million DM ($85 million) | 75% (BMFT)[a] | Planning and construction 1979-1983. Operational 1982. Experimental phase 1982-1983. |
| 3 | Ruhrkohle AG Ruhrchemie AG | Texaco gasification | Oberhausen-Holten | Synthesis gas 10,000 $Nm^3/hr$ (353,000 $ft^3/hr$) | 6 t/hr | 48 million DM ($27 million) | 60% (BMFT)[a] | Operational 1978. Experimental phase from 1978 on. |
| 4 | Ruhrkohle AG, Ruhrchemie AG, Stelag AG | Lurgi fixed-bed pressurized gasification | Dorsten | Synthesis gas, town gas, SNG | Hard 7 t/hr | 150 million DM ($85 million) | 75% (BMFT)[a] | Operational Sept. 1979. Experimental phase 1979-1983. |
| 5 | Shell AG | Shell-Koppers pressurized coal dust gasification | Harburg | Synthesis gas 10,000 $Nm^3/hr$ (353,000 $ft^3/hr$) | Hard 6 t/hr | 100 million DM ($57 million) | None | Operational 1979. Experimental phase from 1979 on. |
| 6 | Saarbergwerke AG | Saarberg-Otto gasification | Volklingen | Synthesis gas, SNG | Hard 10 t/hr | 71 million DM ($40 million) | 75% (BMFT)[a] | Operational Dec. 1979. Experimental phase from 1979 on. |
| 7 | PVC (Flick) Sophia Jacobs | Fixed bed gasification | Huckelhoven | Synthesis gas 2500 $Nm^3/hr$ (88,000 $ft^3/hr$) | Hard 1.5 t/hr | 25 million DM ($15 million) | 80% (NRW)[b] | Operational March 1979. Experimental phase from 1979 on. |

[a]BMFT = Ministry for Research and Technology.
[b]North-Rhine Westphalia.

Table B-2. Coal gasification projects

| No. | Operator or parent company | Process | Plant site | Primary product(s) | Coal type and feed rate | Status or plans |
|---|---|---|---|---|---|---|
| 1 | Ruhrkohle AG<br>Ruhrgas AG | Lurgi fixed bed pressurized gasification | Ruhrgebeit | SNG<br>($1.5x10^9$ $m^3/yr$)<br>($6x10^6$ $ft^3/hr$) | Hard<br>($3x10^6$ t/yr)<br>(9000 tons/day) | Planning 1980-82<br>Construction 1981-1984<br>Operation from 1984 |
| 2 | Ruhrkohle AG<br>Ruhrchemie AG | Texaco coal dust gasification | Oberhausen-Holten | 50% synthesis gas, 50% SNG<br>$0.7x10^9$ $m^3/yr$<br>($3x10^6$ $ft^3/hr$)<br>(total) | Hard<br>$0.4x10^6$ t/yr<br>(1200 tons/day) | Planning 1980-82<br>Construction 1981-1984<br>Operation from 1984 |
| 3 | Shell | Shell-Koppers coal dust gasification | Depends on type of coal used | Synthesis gas<br>$0.6x10^9$ $m^3/yr$<br>($2x10^6$ $ft^3/hr$) | Hard<br>0.3 x $10^6$ t/yr<br>(900 tons/day) | Planning 1980-81<br>Construction 1981-83<br>Operation from 1983 |
| 4 | Texaco | Texaco coal dust gasification | Rheinpreussen Noers-Neerbeck power station | Synthesis gas<br>(medium-Btu gas)<br>$0.65x10^9$ $m^3/yr$<br>($3x10^6$ $ft^3/hr$) | Hard<br>$0.36x10^6$ t/yr<br>(10 tons/day) | Planning 1980-83<br>Construction 1983-85<br>Operation from 1985 |
| 5 | PVC<br>(Flick Gruppe) | Fixed bed gasification | Hückelhoven (Sophia Jacob mining area) | SNG<br>$1.1x10^9$ $m^3/yr$<br>($4x10^6$ $ft^3/hr$) | Hard<br>$0.5x10^6$ t/yr<br>(1500 tons/day) | Planning 1980-81<br>Construction 1982-84<br>Operation 1985 |
| 6 | Saarbergwerke | Kombi process with Saarberg-Otto gasification | Saarland | Synthesis gas<br>(medium-Btu gas)<br>for a 60 MW combined-cycle power station | Hard<br>$0.4x10^6$ t/yr<br>(1200 tons/day) | Planning 1980-83<br>Construction 1983-84<br>Operation from 1985 |

Table B-2, continued

| No. | Operator or parent company | Process | Plant site | Primary product(s) | Coal type and feed rate | Status or plans |
|---|---|---|---|---|---|---|
| 7 | Rheinische Braunkohlen Werke AG | High temp. Winkler fluidized bed gasification | Herrenrath | Synthesis gas $1x10^9$ $m^3/yr$ ($4x10^6$ $ft^3/hr$) | Crude brown $2.25x10^6$ t/yr (7000 tons/day) | Planning 1982-85<br>Construction from 1982<br>Operation from 1984 |
| 8 | Rheinische Braunkohlen Werke AG | Hydrogenizing coal gasification | Rhenish coal district | SNG $0.7x10^9$ $m^3/yr$ ($3x10^6$ $ft^3/hr$) | Crude brown $5.0x10^6$ t/yr (15,000 tons/day) | Planning 1984-87<br>Construction 1987-90<br>Operation from 1990 |
| 9 | Korf | Saarberg-Otto gasification | Undecided | Reducing gas for direct reduction of iron ore | Hard $0.1x10^6$ t/yr) (300 tons/day) | Planning 1980-83<br>Construction 1983-84<br>Operation from 1985 |
| 10 | VEW | Partial gasification with air, without pressure | VEW power stations Gersteinwerk Lippe and Emsland | Coke and gas for an 800 MW combined-cycle power station | Hard $1.0x10^6$ t/yr (3000 tons/day) | Planning 1980-83<br>Construction 1983-85<br>Operation from 1985 |
| 11 | Thyssengas | Methanizing in a single fluidized bed | Oberhausen-Holten | SNG $0.1x10^9$ $m^3/yr$ ($0.4x10^6$ $ft^3/hr$) | Synthesis gas from the Ruhr-Kohle/Ruhr-chemie project | Planning 1980-83<br>Construction 1984-85<br>Operation from 1985 |

Table B-3. Coal liquefaction projects

| No. | Operator or parent company | Process | Plant site | Primary product(s) | Coal type and feed rate | Status or plans |
|---|---|---|---|---|---|---|
| 1[a] | Ruhrkohle AG | I.G. Farben process as modified by Ruhrkohle | Ruhrgebiet | $2x10^6$ t/yr of liquid products, propellants, benzene (about 40,000 bbl/day) | Hard $6x10^6$ t/yr (18,000 tons/day) | Planning 1980-83 Construction 1983-93 Operation from 1986 |
| 2[a] | Veba Oel | Modified I. G. Farben process | Undecided | $2x10^6$ t/yr of liquid products, propellants, heating oil, chemical raw materials | Hard (or heavy oil) $6x10^6$ t/yr (18,000 tons/day) | Planning 1980-83 Construction 1984-87 Operation from 1987 |
| 3 | Saarbergwerke AG | I. B. Farben process as modified by Saarbergwerke | Saarbegiet | 800,000 t/yr of hydrogenated benzene (about 19,000 barrels/day) | Saar flaming coal $2x10^6$ tyr (6000 tons/day) | Planning 1980-82 Construction 1983-86 Operation from 1987 |
| 4 | Rheinische Braunkohlen Werke AG | I. G. Farben process as modified by Rheinische Braunkohlen Werke | Rhenish brown coal area | 400,000 t/yr of propellants, chemical raw materials (about 9000 barrels/day) | Crude brown $3.5x10^6$ t/yr (11,000 tons/day) | Planning 1985-88 Construction 1988-91 Operation from 1992 |

[a]Ruhrkohle and Veba Oel are working jointly on the 200 t/d Bottrop coal liquefaciton pilot plant and are negotiating the possibility of also linking these two projects.

The government expects that industry will carry out these projects of coal processing within its own competence and at its own responsibility, carrying a large part of the risks and costs. It will, however, support industry in all respects. The government will promote all preliminary projects for the realization of the coal processing program, as far as the timely start of these projects makes this necessary. The sum of 70 million DM (about $40 million) needed for this purpose during 1980 and 1981 is available. The land Nordrhein-Westfalen is financing three preliminary projects. Other enterprises, expecting subsidies later, have started preliminary projects without public assistance.

The preliminary projects are the first step towards the realization of large-scale plants. They will enable the companies to prepare basic plans for technical lay-out, site erection and environmental problems, time tables, costs and economics of the individual projects. By means of the preliminary projects the costs and risks of larger plants can be established with reasonable accuracy. The preliminary projects provide the companies with the basis for their decisions to build, and the federal government with the basis for its decision to give further public assistance.

The essential preliminary project results for coal gasification will probably be ready by the end of 1980 and for liquefaction by mid-1981.

How demonstration plants will be funded has not yet been decided. A mixture of measures will probably be used, including help with capital investments, guarantees on product price, and tax exemptions for products of coal conversion.

Parallel to the efforts in the country, the federal government is also involved in the processing of coal through international cooperation. Thus, the Federal Republic of Germany is, for instance, working together with Japan and the USA, participating in demonstration projects for the liquefaction of coal in the USA (total costs $1.4 billion).

Large-scale coal processing plants may give rise to environmental problems, which could conflict with the protection of the environment. Active protection of the environment is therefore essential. Special efforts must be made in this respect to prevent detrimental effects at the sites for coal processing plants, especially in the coal fields. This can be achieved by extending district heating and natural gas pipelines, as well as by replacing outdated coal burning power stations with modern power stations. This will also provide an impulse for further investment. When planning further individual projects, special emphasis will be put on the protection of the environment.

Apart from reducing dependence on energy imports, processing of coal can increase production and employment in industry and can open up a new field for continuous investment.

Owing to the increasing efforts at crude oil substitution, the interest in coal processing can become world-wide. The construction of modern reference plants will strengthen the competitiveness of German industry, increase its export chances, and thus provide more production and employment.

By such exports, combined with German investment in foreign coal mining and processing plants, it is possible to expand and secure the provision of energy and raw materials for the German economy.

As envisaged at present, the German national coal plan aims at converting 10-15 milion tonnes (11-17 million tons) of coal into oil or gas annually by the end of the century.

Two factors are seen as setting the upper limit for Germany's efforts at coal conversion. One is the siting of plants which some believe will prove at least as troublesome as the siting of nuclear plants today. The other is what the government sees as an upper limit to the amount of coal Germany can be expected to produce. For lignite (brown coal) the present level of 130 milllion tonnes (140 million tons) a year is probably the limit, because it is expected that the public will not tolerate further expansion of massive open-pit mining activities. The present level of 85-90 million tonnes (94-100 million tons) a year of deep-mined hard coal can probably be increased slightly, according to Ruhrkohle, perhaps to 100 million tonnes (110 million tons). More may become available through a lower output of German steel in the future. Beyond that, any increase in the use of German coal for conversion to synfuels would depend upon the pace at which nuclear plants could replace coal-burning plants for electricity generation.

Processing of coal is at present not yet economical in the Federal Republic of Germany; however, the production of synthetic gas from brown coal is close to becoming economical. Liquid products and substitute natural gas from German hard coal cost today two to four times as much as crude oil products or natural gas. Even when coal is imported, the liquid products still cost twice as much. This cost relationship may shift in favor of coal towards the middle of the eighties when the first large-scale plant will be in operation.

Compared with coal processing, the replacement of heavy heating oil in industry and power stations by coal and the conversion of the heavy heating oil freed in this manner to gasoline and light heating oil is the quicker and economically more favorable way. This potential of about 20 million tonnes/yr (22 million tons/yr) must therefore also be emphasized.

Germany is supporting one further possibility for increased coal production, although it is given no more than an outside chance. The FRG is sharing the cost of a joint research venture with Belgium into underground gasification of coal at great depth, about 5000 ft. The aim is high-pressure gasification of the coal to yield a substitute natural gas.

# APPENDIX C

## COMPARATIVE MATERIALS IDENTIFICATIONS FOR DIFFERENT COUNTRIES

One of the complicating factors in a materials assessment of foreign technology is differences in materials identification from country to country and the variations in code requirements for materials acceptability and design for such items as pressure vessels in each country. Any comment on the code requirements is outside of the context of this assessment. However, it should be noted that in general, while the design methodologys and even the materials property allowables within each code may vary, the net result is equivalent in terms of safety, operating restrictions and functional reliability. Thus the chief difficulty is one of a comparative identification of materials from one country to another.

At the time this assessment was initiated there was no readily available source of information for comparative identification. To assist in this effort and the continuing assessments we were asked to prepare such a chart. To a limited extent this has been done and is presented here in Table C.

The limitations of such a listing of comparative standard specifications are worthy of note. While they are generally adequate for an assessment of this type they are at best a guide to required information for any design material choice. All materials specifications have compositional ranges and many have production process as well as forming and heat treatment requirements to provide specified materials properties. Thus, a true comparison requires a detailed technical review of the comparative specifications and a subsequent matching to the materials requirements for the specific code being used in the component design. This is evident from the number of specifications existent in the United States addressing similar materials. Only a limited number of U.S. specifications are listed in the table including the Unified Numbering System (UNS) number to assist the readers in identifying other U.S. specifications by reference to the publication "Unified Numbering System for Metals and Alloys" published in January 1975 by the Society of Automotive Engineers, Inc.[15] Often a material is identified by the manufacturers number or code and this must subsequently be compared to the appropriate materials specification for the country. Dealing with this complication must be on a case-by-case basis in any assessment. Because of the difficulty in obtaining even limited, comparative references the materials listing was restricted to those metallic materials commonly in use in the petrochemical industry and proposed for coal conversion applications. The list was developed from a number of published reports[1,4] and consultation with others involved in coal conversion materials development. The listing is far from being a complete listing of potentially applicable alloys but addiional specification comparisons are possible by reference to two recent publications[5,6,7] which were used in developing this table. Only the six largest metal producing countries are listed in the table but this can be extended to other countries in many cases by reference to the ASM publication.[5] This publication provides only limited data on product form, alloy composition and product mechanical compositions so the prior concerns on required in-depth review of the identified specifications would be required for design use comparisons.

## Table C.1 Comparative Standards Specifications

| | United States (ASTM) Standard | Designation | Note | United Kingdom (BS) Standard | Designation | Note | France (NF) Standard | Designation | Note |
|---|---|---|---|---|---|---|---|---|---|
| **PLATE AND SHEET** | | | | | | | | | |
| **Carbon Steel Low Strength** | | | | | | | | | |
| Structural | A283 | Gr A | | 4360 | | | A35-501 | A33-2 | |
| Notch Ductile for Tankage | A131 | Gr A | | | | | | | |
| | A131 | Gr B | | 2762 | ND1 | | | | |
| **Carbon Steel Intermediate Strength** | | | | | | | | | |
| (Carbon-Manganese Alloys) | A285 | Gr A | | 1501-151 | GR 23A | | A35-205 | A52C2 | |
| | A515 | 60 | | 1501-161 | GR 28A | | A36-205 | A42-C2 | |
| | A516 | 60 | | 1501-224 | GR 28A | | A36-205 | A42P2 | |
| **Carbon Steel High Strength** | | | | | | | | | |
| (Carbon-Manganese Alloys) | A299 | | | 1501-221 | GR32 | | A36-205 | A52C1 | |
| | A515 | 70 | | 1501-221 | GR32C1A | | A36-205 | A52C2 | |
| | A516 | 70 | | 1501-224 | GR32C1A | | A36-208 | A52P2 | |
| **FERRITIC ALLOYS** | | | | | | | | | |
| Mn - Ni | A203 | Gr D | | 1501-Pt2 | 503 | | A36-208 | 35 Ni 285 | |
| Mn - 0.5 Mo | A204 | Gr A | | 1501-Pt2 | 240 | | | | |
| Mn - 0.5 Mo (N) | A302 | Gr A | | | | | A36-206 | 18 MD 4.05 | |
| Mn - 0.5 Mo Ni (N) | A302 | Gr C | | | | | | | |
| Mn - 0.5 Mo (Q,T) | A533 | Gr A | | | | | A36-206 | 15 MDV 4.05 | |
| Mn - 0.5 Mo Ni (Q,T) | A533 | Gr B | | | | | | | |
| Mn - 0.5 Mo Ni (Q,T) | A533 | Gr C | | | | | | | |
| 0.5 Cr - 0.5 Mo (Cl 1-A; Cl 2 N&T) | A387 | Gr 2 | | 1501 | 620 Gr A | | A36-206 | 15 CD 2.05 | |
| 1.0 Cr - 0.5 Mo (Cl 1-A; Cl 2 N&T) | A387 | Gr 12 | | 1501-Pt2 | 620 Gr 31 | | A36-206 | 15 CD 4.05 | |
| 1.25 Cr - 0.5 Mo (Cl 1-A; Cl 2 N&T) | A387 | Gr 11 | | 1501-Pt2 | 621 | | | | |
| 5.0 Cr - 0.5 Mo | A387 | Gr 5 | | 1501 | 625 | | A36-206 | 10 CD 5.05 | |
| 3.0 Cr - 1.0 Mo | A387 | Gr 21 | | | | | | | |
| 2.25 Cr - 1.0 Mo (Cl 1-A; Cl 2-N&T) | A387 | Gr 22 | | 1501-Pt2 | 622 Gr 31 | | A36-206 | 10 CD 9.10 | |
| 2.25 Cr - 1.0 Mo (Q,T) | A542 | Cl 1 | | | | | | | |

## Comparative Standards Specifications (Cont'd)

| | Federal Republic of Germany (DIN) Standard | Designation | Note | Russia (GOST) Standard | Designation | Note | Japan (JIS) Standard | Designation | Note |
|---|---|---|---|---|---|---|---|---|---|
| **PLATE AND SHEET** | | | | | | | | | |
| **Carbon Steel Low Strength** | | | | | | | | | |
| Structural | 17100 | UST34-1 | | 380 | ST3KP | | G3101 | SS34 | |
| Notch Ductile for Tankage | 17100 | RST42-1 | | | | | G3106 | SM41A | |
| | 17100 | RST42-2 | | | | | G3106 | SM41B | |
| **Carbon Steel Intermediate Strength** | | | | | | | | | |
| (Carbon-Manganese Alloys) | 17155 | HI | | 5520 | 12K | | | | |
| | 17155 | HII | | | 16K | | G3103 | SB42B | 1 |
| | 17135 | AST41 | | 5520 | 18K | | G3118 | SGV42 | 1 |
| **Carbon Steel High Strength** | | | | | | | | | |
| (Carbon-Manganese Alloys) | 17155 | 19Mn5 | | | | | G3115 | SPV36 | |
| | 17155 | 19Mn5 | | | | | G3103 | SB49 | |
| | 17135 | AST52 | | | | | G3118 | SGV49 | 1 |
| **FERRITIC ALLOYS** | | | | | | | | | |
| Mn - Ni | VDEH SEW680 | 10 Ni 14 | | | | | G3129 | SL3N26 | |
| Mn - 0.5 Mo | VDTUV201 | 16 Mo 5 | | | | | G3103 | SB46M | |
| Mn - 0.5 Mo (N) | | | | | | | G3119 | SBV1A | |
| Mn - 0.5 Mo Ni (N) | | | | | | | G3119 | SBV2 | |
| Mn - 0.5 Mo ($O_2T$) | | | | | | | G3120 | SBV1A | |
| Mn - 0.5 Mo $Ni^2$ ($O_2T$) | | | | | | | G3120 | SQV2A | |
| Mn - 0.5 Mo Ni ($O_2T$) | | | | | | | G3120 | SQV3A | |
| 0.5 Cr - 0.5 Mo (Cl 1-A; Cl 2 N&T) | | | | | | | G4109 | SCMV1 | |
| 1.0 Cr - 0.5 Mo (Cl 1-A; Cl 2 N&T) | 17155 | 13 Cr Mo 44 | | | | | G4109 | SCMV2 | |
| 1.25 Cr - 0.5 Mo (Cl 1-A; Cl 2 N&T) | | | | | | | G4109 | SCMV3 | |
| 5.0 Cr - 0.5 Mo | VDTUV1207 | 12 Cr Mo 19-5 | | 5632 | 15X5M | | G4109 | SCMV6 | |
| 3.0 Cr - 1.0 Mo | | | | | | | G4109 | SCMV5 | |
| 2.25 Cr - 1.0 Mo (Cl 1-A; Cl 2-N&T) | SEW 610 | 10 Cr Mo 9-6 | | | | | | | |
| 2.25 Cr - 1.0 Mo ($O_2T$) | | | | | | | G4109 | SCMV4 | |

**Comparative Standards Specifications (Cont'd)**

| | United States (ASTM) | | | United Kingdom (BS) | | | France (NF) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Standard | Designation | Note | Standard | Designation | Note | Standard | Designation | Note |
| **PLATE AND SHEET (CONT.)** | | | | | | | | | |
| 7.0 Cr – 1.0 Mo (Cl 1-A; Cl 2-N&T) | A387 | Gr 7 | | | | | | | |
| 9.0 Cr – 1.0 Mo (Cl 1-A; Cl 2-N&T) | A387 | Gr 9 | | | | | | | |
| 0.5 Mo – Ni, Cr, V ($Q_2T$ – in US; NF in UK) | A543 | Gr B | | 1501 | Gr 281 | | | | |
| 12 Cr – 1.0 Mo, Ni, W, V (Sandvik HT 9) | A240 | 410S | | | | | | | |
| 13 Cr | A240 | 410S | | | | | A35-573 | Z6C13 | |
| 18 Cr – 2 Mo (444) | A240 | 18 CR 2 Mo | | | | | | | |
| 26 Cr – 1 Mo (446) | A240 | XM 27 | | | | | | | |
| 29 Cr – 4 Mo (447) | A240 | S44700 | | | | | | | |
| **AUSTENITIC ALLOYS** | | | | | | | | | |
| 18 Cr – 8 Ni | A240 | 304 | | 1501-Pt3 | 304 S15 | | A35-573 | Z6CN18-09 | |
| 18 Cr – 8 Ni | A240 | 304L | | 1501-Pt3 | 304 S12 | | A35-573 | Z2CN18-10 | |
| 18 Cr – 8 Ni-N (304N) | A240 | XM21 | | 1501-Pt3 | 304 S65 | | A36-209 | Z5CN18-10Az | |
| 18 Cr – 11 Ni – Ti | A240 | 321 | | 1501-Pt3 | 321 S12 | | A35-572 | Z6CNT18-10 | |
| 18 Cr – 11 Ni – Cb | A240 | 347 | | 1501-Pt3 | 347 S17 | | A35-573 | Z6CNNb18-10 | |
| 18 Cr – 11 Ni – 2 Mo | A240 | 316 | | 1501-Pt3 | 316 S16 | | A35-572 | Z6CND17-12 | |
| 18 Cr – 12 Ni – 2 Mo | A240 | 316L | | 1501-Pt3 | 316 S12 | | A35-573 | Z2CND17-12 | |
| 18 Cr – 12 Ni – 2 MoN | A240 | 316N | | 1501-Pt3 | 316 S62 | | | | |
| 20 Cr – 11 Ni | A167 | 308 | | | | | | | |
| 23 Cr – 13 Ni | A167 | 309 | | | | | | | |
| 25 Cr – 20 Ni (310) | A167 | 210 | | 1501-Pt3 | 310 S24 | | | | |
| 19 Cr – 13 Ni – 3 Mo | A240 | 317 | | 1501-846 | | | | | |
| 19 Cr – 13 Ni – 3 Mo | A240 | 317L | | | | | A35-573 | Z2CND19-15 | |

## Comperative Standards Specifications (Cont'd)

| | Federal Republic of Germany (DIN) Standard | Designation | Note | Russia (GOST) Standard | Designation | Note | Japan (JIS) Standard | Designation | Note |
|---|---|---|---|---|---|---|---|---|---|
| **PLATE AND SHEET (CONT.)** | | | | | | | | | |
| 7.0 Cr - 1.0 Mo (Cl 1-A; Cl 2-N&T) | | | | 5632 | 12KKAVF | | | | |
| 9.0 Cr - 1.0 Mo (Cl 1-A; Cl 2-N&T) | | | | | | | | | |
| 0.5 Mo - Ni, Cr, V ($O_2T$ - in US; NF in UK) | | | | | | | | | |
| 12 Cr - 1.0 Mo, Ni, V, V (Sandvik HT 9) | | X20CrMoWV121 | | | | | | | |
| 13 Cr | 17440 | X7Cr13 | | | | | G4304 | SUS21HP | |
| 18 Cr - 2 Mo (444) | | | | | | | | | |
| 26 Cr - 1 Mo (446) | | | | 5632 | 15KH25T | | G4312 | SUH446 | |
| 29 Cr - 4 Mo (447) | | | | | | | | | |
| **AUSTENITIC ALLOYS** | | | | | | | | | |
| 18 Cr - 8 Ni | 17440 | X5CrNi189 | | 5632 | 08KH18N10 | | G4304 | SUS304 | |
| 18 Cr - 8 Ni | 17440 | X2CrNi189 | | | | | G4304 | SUS304L | |
| 18 Cr - 8 Ni-N (304N) | 17440 | X2CrNiN1810 | | | | | | | |
| 18 Cr - 11 Ni - Ti | 17440 | X10CrNiTi189 | | 5632 | 08KH18N10T | | G4304 | SUS321 | |
| 18 Cr - 11 Ni - C6 | 17440 | X10CrNiBb189 | | 5632 | 08KH18N12B | | G4304 | SUS347 | |
| 18 Cr - 11 Ni - 2 Mo | 17440 | X5CrNiMo1812 | | | | | G4304 | SUS316 | |
| 18 Cr - 12 Ni - 2 Mo | 17440 | X2CrNiMo1810 | | 5632 | 03KH17N14M2 | | G4304 | SUS316L | |
| 18 Cr - 12 Ni - 2 MoN | 17440 | X2CrNiMoN1812 | | | | | | | |
| 20 Cr - 11 Ni | | | | | | | | | |
| 23 Cr - 13 Ni | | | | 5632 | 20KH23N13 | | G4312 | SUH309 | |
| 25 Cr - 20 Ni (310) | | | | 5632 | 20KH23N18 | | G4312 | SUH310 | |
| 19 Cr - 13 Ni - 3 Mo | | X5CrNiMo1713 | | | | | G4304 | SUS317L | |
| 19 Cr - 13 Ni - 3 Mo | 17440 | X2CrNiMo1816 | | | | | G4304 | SUS317L | |

## Comparative Standards Specifications (Cont'd)

| | United States (ASTM) | | | United Kingdom (BS) | | | France (NF) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Standard | Designation | Note | Standard | Designation | Note | Standard | Designation | Note |
| **Patented Alloys (Examples)** | | | | | | | | | |
| (Incoloy 800) 32 Cr - 21 Ni | B409 | | | | | | | | |
| (Incoloy 800H) 32 Cr - 21 Ni | B409 | | | | | | | | |
| (Incoloy 825) 42 Cr - 21 Ni - 3 Mo - 2 Cu | B163 | | | | | | | | |
| (Incoloy 600) 76 Ni - 15 Cr | B443 | | | | | | | | |
| (Incoloy 625) 61 Ni - 22 Cu - 9 Mo - 4 Nb | B333 | | | | | | | | |
| Hastelloy B | A296 | | | | | | | | |
| Hastelloy C | | | | | | | | | |
| Hastelloy F | | | | | | | | | |
| Hastelloy G | | | | | | | | | |
| Hastelloy C-276 | | | | | | | | | |
| Haynes Alloy 20 MOD | B574 | | | | | | | | |
| Carpenter 20 | | | | | | | | | |
| Carpenter 20 Cb 3 | | | | | | | | | |
| **Forgings for Pressure Vessels and Components** | | | | | | | | | |
| Carbon Steel Intermediate Strength | | | | | | | | | |
| Carbon - Manganese Alloys | A266 (1) | | | | | | | | |
| Carbon Steel High Strength | | | | | | | | | |
| C - Mn | A105<br>A266 (2&3)<br>A541 (1) | Gr 1 | | 1503-161 | Grade B | | A33-101 | AF42 | |

## Comperative Standards Specifications (Cont'd)

| | Federal Republic of Germany (DIN) Standard | Designation | Note | Russia (GOST) Standard | Designation | Note | Japan (JIS) Standard | Designation | Note |
|---|---|---|---|---|---|---|---|---|---|
| **Patented Alloys (Examples)** | | | | | | | | | |
| (Incoloy 800) 32 Cr - 21 NI | | | | | | | 4901 | NCF2 | |
| (Incoloy 800H) 32 Cr - 21 NI | | | | | | | | | |
| (Incoloy 825) 42 Cr - 21 NI - 3 Mo - 2 Cu | | | | | | | | | |
| (Incoloy 600) 76 Ni - 15 Cr | | | | | | | 4901 | NCF1 | |
| (Incoloy 625) 61 Ni - 22 Cu - 9 Mo - 4 Nb | | | | | | | | | |
| Hastelloy B | | | | | | | | | |
| Hastelloy C | | | | | | | | | |
| Hostelloy F | | | | | | | | | |
| Hastelloy G | | | | | | | | | |
| Hastelloy C-276 | | | | | | | | | |
| Haynes Alloy 20 MOD | | | | | | | | | |
| Carpenter 20 | | | | | | | | | |
| Carpenter 20 Cb 3 | | | | | | | | | |
| **Forgings for Pressure Vessels and Components** | | | | | | | | | |
| Carbon Steel Intermediate Strength | | | | | | | | | |
| Carbon - Manganese Alloys | | | | | | | | | |
| Carbon Steel High Strength | | | | | | | | | |
| C - Mn | 17M04C22 | | | | | | G3102 | S200 | |

## Comperative Standards Specifications (Cont'd)

| | United States (ASTM) | | | United Kingdom (BS) | | | France (NF) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Standard | Designation | Note | Standard | Designation | Note | Standard | Designation | Note |
| **Ferritic Alloys** | | | | | | | | | |
| Mn - 0.5 Mo | A182 | F1 | | | | | | | |
| | A336 | F1 | | | | | | | |
| Mn - 0.5 Mo, Ni | A541 | 3 | | | | | | | |
| Mn - 0.5 Mo, Ni, Cr | A508 | 3 | | | | | | | |
| 0.5 Mo, Ni, Cr | A508 | 2 | | | | | | | |
| | A541 | 2 | | | | | | | |
| | A592 | F | | | | | | | |
| 1 Cr - 0.5 Mo | A336 | F12 | | | | | | | |
| | A182 | F12 | | 1503-620 | | | 15CD4-5 | | |
| 1.25 Cr - 0.5 Mo | A182 | F11 | | 1503-621 | | | 15CD5-05 | | |
| 2.0 Cr - 0.5 Mo, Ni | A508 | 4&5 | | | | | | | |
| 2.25 Cr - 1.0 Mo | A182 | F22 | | 1503-622 | | | 12CD9-10 | | |
| | A336 | F22 | | | | | | | |
| 3.0 Cr - 1.0 Mo | A336 | F21 | | | | | | | |
| 5.0 Cr - 0.5 Mo | A182 | F5 | | 1503-625 | | | Z12CD5 | | |
| | A336 | F5 | | | | | | | |
| 9.0 Cr - 1.0 Mo | A182 | F9 | | | | | Z10CD9 | | 2 |
| **Austenitic Alloys** | | | | | | | | | |
| 18 Cr - 8 Ni | A182 | F304L | | 1503-304S30 | | | Z2CN1810 | | 2 |
| 18 Cr - 8 Ni | A182 | F304H | | 1503-801 | | | Z6CN1810 | | |
| 18 Cr - 8 Ni, Ti | A336 | F8 | | | | | | | |
| 18 Cr - 8 Ni, Ti | A192 | F321H | | | | | | | |
| 18 Cr - 9 Ni, Ti | A336 | F8T | | | | | | | |
| 18 Cr - 8 Ni, Cb | A182 | F347H | | 1503-821 | Grade Nb | | Z7CNNb18-11 | | |
| | A336 | F8C | | | | | | | |
| 16 Cr - 12 Ni - 2 Mo | A182 | F316L | | 1503-316S30 | | | Z2CND17-12 | | 3 |
| 16 Cr - 12 Ni - 2 Mo | A192 | F316H | | 1503-316S50 | | | Z6CND17-12 | | |
| 16 Cr - 12 Ni - 2 Mo | A336 | F8M | | | | | | | |

## Comparative Standards Specifications (Cont'd)

| | Federal Republic of Germany (DIN) Standard | Designation | Note | Russia (GOST) Standard | Designation | Note | Japan (JIS) Standard | Designation | Note |
|---|---|---|---|---|---|---|---|---|---|
| **Ferritic Alloys** | | | | | | | | | |
| Mn - 0.5 Mo | 16Mo5 | | | | | | G3213 | SFHV12B | |
| Mn - 0.5 Mo, Ni | | | | | | | | | |
| Mn - 0.5 Mo, Ni, Cr | | | | | | | | | |
| 0.5 Mo, Ni, Cr | | | | | | | | | |
| 1 Cr - 0.5 Mo | 16CrMo44 | | | | | | G3213 | SFHV22B | |
| 1.25 Cr - 0.5 Mo | | | | | | | G3213 | SFHV23B | |
| 2.0 Cr - 0.5 Mo, Ni | | | | | | | | | |
| 2.25 Cr - 1.0 Mo | 10CrMo910 | | | | | | G3213 | SFHV24B | |
| 3.0 Cr - 1.0 Mo | | | | | | | | | |
| 5.0 Cr - 0.5 Mo | VdTuV1207 | 12CrMo19 5 | | | | | G3213 | SFHV25 | |
| 9.0 Cr - 1.0 Mo | X12CrMo91 | | 1 | | | | G3212 | SFHV26B | |
| **Austenitic Alloys** | | | | | | | | | |
| 18 Cr - 8 Ni | 17440 | 2CrNi18 9 | | | | | G3214 | SUSF304L | |
| 18 Cr - 8 Ni | 17440 | 5CrNi18 9 | | | | | G3214 | SUSF304H | |
| 18 Cr - 8 Ni, Ti | | | | | | | | | |
| 18 Cr - 8 Ni, Ti | | | | | | | | | |
| 18 Cr - 9 Ni, Ti | | | | | | | | | |
| 18 Cr - 8 Ni, Cb | | 10CrNiNb18 9 | | | | | | | |
| 16 Cr - 12 Ni - 2 Mo | 17440 | 2CrNiMo18 10 | 4 | | | | G3214 | SUSF316L | |
| 16 Cr - 12 Ni - 2 Mo | | 5CrNiMo18 10 | | | | | G3214 | SUSF316H | |
| 16 Cr - 12 Ni - 2 Mo | | | | | | | | | |

**Comparative Standards Specifications (Cont'd)**

| | United States (ASTM) | | | United Kingdom (BS) | | | France (JIS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Standard | Designation | Note | Standard | Designation | Note | Standard | Designation | Note |
| **CASTINGS** | | | | | | | | | |
| Carbon Steel Intermediate Strength C-Mn | A216 | WCA | | 1504-161 | | | | | |
| Carbon Steel High Strength C-Mn | A216 | WCB | | 1504-161 | | | | | |
| Ferritic Alloys | | | | | | | | | |
| 1.25 Cr - 0.5 Mo | A217 | WC6 | | 1504-621 | | 5 | 35CD4 | | |
| 2.25 Cr - 1.0 Mo | A217 | WC9 | | 1504-622 | | 5 | | | |
| 5.0 Cr - 1.0 M | A217 | C5 | | 1504-625 | | 5 | | | |
| 9.0 Cr - 1.0 M | A217 | C12 | | 1504-629 | | 5 | | | |
| Austenitic Alloys | | | | | | | | | |
| 18 Cr - 8 Ni | A351 | CF8 | | 1504-801 | | | Z6CN1910 | | |
| 18 Cr - Ni, Ti | | | | | | | | | |
| 18 Cr - 8 Ni, Cb | A351 | CF8C | | 1504-821 | | | | | |
| 16 Cr - 12 Ni - 2 Mo | A315 | CF8M | | 1504-845 | | | Z6CND18-12-2 | | |
| **PIPE AND TUBES** | | | | | | | | | |
| Carbon Steel | | | | | | | | | |
| Low strength (Forged) | A369 | FPA | | | | | | | |
| Intermediate Strength (Seamless) | A106 | Gr B | | 3602 | HFS-410 | | | | |
| (Forged) | A369 | FP B | | | | | | | |
| High Strength | A106 | Gr C | | 3602 | HFS-460 | | | | |
| Ferritic Alloys | | | | | | | | | |
| C - 0.5 Mo (Seamless) | A335 | P 1 | | | | | | | |
| 1.0 Cr - 0.5 Mo (Seamless) | A335 | P 12 | | 3604 | HFS-620 | | | | |
| 1.25 Cr - 0.5 Mo (Seamless) | A335 | P 11 | | 3604 | HFS-621 | | 12CD505 | | |
| 2.25 Cr - 0.5 Mo (Seamless) | A335 | P 22 | | 3604 | HFS-6222 | | 12CD9.10 | | |
| 2.25 Cr - 0.5 Mo (Forged) | A369 | FP 22 | | | | | | | |
| 5.0 Cr - 0.5 Mo (Seamless) | A335 | P 5 | | 3604 | HFS-625 | | Z12CD5 | | |
| 5.0 Cr - 0.5 Mo (Forged) | A369 | FP 5 | | | | | | | |
| 9.0 Cr - 1.0 Mo (Seamless) | A335 | P 9 | | 3604 | HFS-629 | | | | |
| 9.0 Cr - 1.0 Mo (Forged) | A369 | FP 5 | | | | | | | |

## Comperative Standards Specifications (Cont'd)

| | Federal Republic of Germany (DIN) | | | Russia (GOST) | | | Japan (JIS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Standard | Designation | Note | Standard | Designation | Note | Standard | Designation | Note |
| **CASTINGS** | | | | | | | | | |
| Carbon Steel Intermediate Strength C-Mn | 17245 | GS-C25 | | | | | G5102 | SCW42 | |
| Carbon Steel High Strength C-Mn | 17245 | GS-C30 | | | | | G5102 | SCW49 | |
| **Ferritic Alloys** | | | | | | | | | |
| 1.25 Cr - 0.5 Mo | 17245 | GS-22CrMo54 | 4 | | | | G5151 | SCPH21 | |
| 2.25 Cr - 1.0 Mo | vdTUV173 | GS-12CrMo9 10 | 2 | | | | G5151 | SCPH32 | |
| 5.0 Cr - 1.0 M | vdTUV153 | GS-12CrMo19 5 | 2 | | | | G5151 | SCPH61 | |
| 9.0 Cr - 1.0 M | | GS-12CrMo9 | 2 | | | | | | |
| **Austenitic Alloys** | | | | | | | | | |
| 18 Cr - 8 Ni | | G-X6CrNi18 9 | 2 | | | | SCS13 | | 1 |
| 18 Cr - Ni, Ti | | | | | | | | | |
| 18 Cr - 8 Ni, Cb | | G-X7CrNiNb18 9 | 2 | | | | SCS21 | | 1 |
| 16 Cr - 12 Ni - 2 Mo | | G-X6CrNiMo18 10 | 2 | | | | SCS14 | | 1 |
| **PIPE AND TUBES** | | | | | | | | | |
| **Carbon Steel** | | | | | | | | | |
| Low strength (Forged | | | | | | | | | |
| Intermediate Strength (Seamless) (Forged) | 17175 | ST 45.8 | | 5654 | 20 | | G3456 | STPT 42 | |
| High Strength | | | | 8731 | ST 5 (380) | | G3456 | STPT 49 | |
| **Ferritic Alloys** | | | | | | | | | |
| C - 0.5 Mo (Seamless) | vdTUV201 | 16Mo5 | | | | | G3458 | STPA 12 | |
| 1.0 Cr - 0.5 Mo (Seamless) | 17175 | 13 Cr Mo 44 | | 8731 | 15 XMM | | G3458 | STPA 22 | |
| 1.25 Cr - 0.5 Mo (Seamless) | | | | | | | G3458 | STPA 23 | |
| 2.25 Cr - 0.5 Mo (Seamless) | 17175 | 10 Cr Mo 910 | | | | | G3458 | STPA 24 | |
| 2.25 Cr - 0.5 Mo (Forged | | | | | | | | | |
| 5.0 Cr - 0.5 Mo (Seamless) | vdTUV1207 | 12 Cr Mo 19.5 | | 550 | 15KHMS(20072) | | G3458 | STPA 25 | |
| 5.0 Cr - 0.5 Mn (Forged) | | | | | | | | | |
| 9.0 Cr - 1.0 Mo (Seamless) | | x 12 Cr Mo 91 | | | | | G3458 | STPA 26 | |
| 9.0 Cr - 1.0 Mo (Forged | | | | | | | | | |

## Comparative Standards Specifications (Cont'd)

| | United States (ASTM) | | | United Kingdom (BS) | | | France (NF) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Standard | Designation | Note | Standard | Designation | Note | Standard | Designation | Note |
| **AUSTENITIC ALLOYS** | | | | | | | | | |
| 18 Cr - 8 Ni (Seamless) | A376 | TP 304 | | 3605 | 304S18 | | | | |
| 18 Cr - 8 Ni (Forged) | A430 | FP 304 | | | | | | | |
| 18 Cr - 8 Ni - N (Seamless) | A376 | TP 304N | | | | | | | |
| 18 Cr - 8 Ni - N (Forged) | A430 | FP 304N | | | | | | | |
| 18 Cr - 8 Ni - Ti (Seamless) | A376 | TP 321 | | 3605 | 321S18 | | | | |
| 18 Cr - 8 Ni - Ti (Forged) | A430 | FP 321 | | | | | | | |
| 18 Cr - 8 Ni - Nb (Seamless) | A376 | TP 347 | | 3605 | 347S18 | | | | |
| 18 Cr - 8 Ni - Nb (Cast) | A451 | CF8C | | | | | | | |
| 16 Cr - 12 Ni - 2 Mo (Seamless) | A376 | TP 316 | | 3605 | 316S18 | | | | |
| 25 Cr - 20 Ni (Seamless) | A376 | TP 310 | | | | | | | |

## Comparative Standards Specifications (Cont'd)

| AUSTENITIC ALLOYS | Federal Republic of Germany (DIN) Standard | Designation | Note | Russia (GOST) Standard | Designation | Note | Japan (JIS) Standard | Designation | Note |
|---|---|---|---|---|---|---|---|---|---|
| 18 Cr - 8 Ni (Seamless) | 2462 | X5CRNI189 | | 9940 | OXH19N10 | | G3459 | SUS 304 TP | |
| 18 Cr - 8 Ni (Forged) | | | | | | | | | |
| 18 Cr - 8 Ni - N (Seamless) | | | | | | | | | |
| 18 Cr - 8 Ni - N (Forged) | | | | | | | | | |
| 18 Cr - 8 Ni - Ti (Seamless) | 2462 | X10CrNiTi189 | | 9940 | OKH18N10T | | G3459 | SUS 321 TP | |
| 18 Cr - 8 Ni - Ti (Forged) | | | | | | | | | |
| 18 Cr - 8 Ni - Nb (Seamless) | 2462 | X10CrNiNb1810 | | 9940 | OKH18N12B | | G3459 | SUS 347 TP | |
| 18 Cr - 8 Ni - Nb (Cast) | | | | | | | | | |
| 16 Cr - 12 Ni - 2 Mo (Seamless) | 2462 | X5CrNiMo1810 | | | | | G3459 | SUS 316 TP | |
| 25 Cr - 20 Ni (Seamless) | | | | 9940 | OKH23N18 | | G3459 | SUS 310S TP | |

Note 1 Recognize minimum lower tensile and yield strength of substitute steel in design or specify minimum tensile and yield strength per ASTM.

Note 2 Specify mechanical properties, test and inspection in accordance with ASTM.

Note 3 Specify ASTM dimensional requirements, tolerances and inspection.

Note 4 Test and inspect the product to ASTM specification except for chemical analysis and mechanical properties of the steel.

Note 5 Hydrotest to ASTM A 217.

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