Proceedings of the HTR 2014
Weihai, China, October 27-31, 2014
Draft-Paper HTR2014-21208-Barnert.pdf

Substitute Energy Carriers from Refinement of Coal using HTR-Module

Heiko Barnert, Kurt Kugeler[1], Michael Will[2]
ARGE KT, Association Nuclear Technology
Marianne Hainisch Gasse 5-3, A-2500 Baden near Vienna, Austria
phone: +43-2252-252076, heiko.barnert@kabsi.at

[1]ARGE KT, Nordstraße25, D-52429 Juelich, Germany

[2]ARGE KT, Dorfstraße 28, D-51597 Morsbach, Germany

Abstract – *There is a revival of coal refinement in the world: a recent press article in Germany titled "The Renaissance of Coal Refinement". It reports about a large number of conventional plans and plants for coal refinement in many countries in the world, and in particular in China. Nuclear energy can be of assistance, in particular the High Temperature Reactor-Module, because it offers all needed process energies.. The status of the research, development, and demonstration, RDD, of technology is summarized, in particular of the former programs in Germany: The primary energy carriers were hard coal and lignite. The envisaged products were: Substitute Natural Gas, SNG, for the gas market, Hydrogen, H2, for a future H2-market, e.g. for airplane traffic, Liquid Fuels, as Substitute Gasoline, or as Energy Alcohol, e.g. Methanol CH3OH, in mixture with higher alcohols, for the car traffic and for home heating.*

I. INTRODUCTION

The competition between fossil primary energy carriers shows an interesting result: There is "The Renaissance of Coal Refinement" in many places of the world with conventional plans and plants, in particular in China [1]. Nuclear energy can be of assistance for this refinement, in particular with the High Temperature Reactor-Module, HTR-M, because it offers all needed process energies. These are electricity, high temperature process heat, and process steam of adjustable qualities in co-generation, as well as district heat. The status of the research, development, and demonstration, RDD, of the technology of refinement of coal, using nuclear energy of the HTR-M is summarized, in particular of the former programs in Germany: A lot had been achieved, this will be reported about in the following: But the efforts in Germany were terminated in 1992, because of the low prices of Oil and Natural Gas in these years before 1992.

II. REFINEMENT TECH

II.A. Basic Chemical Equations

Coal is a fossil energy carrier with the obviously largest reserves in comparison to oil and gas, this is an advantage. But it is a solid mixture of many substructures, and it contains sulfur, and other toxic matter, as well as ash.

There are in principle three summary chemical equations to describe the two process lines of
1) Steam Coal Gasification, SCG, and
2) Hydrogenating Coal Gasification, HCG:

1) $C+2\,H_2O = 2\,H_2+CO_2$ eq. (1): SCG

2a) $C+2\,H_2 = CH_4$ eq. (2): HCG
2b) $\underline{CH_4+2\,H_2O = 4\,H_2+CO_2}$ eq. (3): REF
2) $C+2H_2O = 2\,H_2+CO_2$ eq. (1): (a+b)

The above eq. (1), (2), and (3) are the most simplified form of description of the processing with the following symbols: C = coal, H_2O = steam, H_2 = Hydrogen, CH_4 = Methane and CO_2 = Carbon-Dioxide. A more precise formula for coal would be $C_1H_mO_n$ for 1 mol of C in a hypothetic molecule of coal.

The characteristic difference between the two process lines is the way to supply the required Heat Energy, which is equivalent to the Enthalpy Change ΔH of the respective reaction. The reactions 1) and 2b) are "endo-thermal" (ΔH > 0), they need to be heated, whereas reaction 2a), is "exo-thermal" (ΔH < 0), it needs to be cooled (done by the feed). Both process lines use coal in grinded form in a fluidized bed, and the characteristics is the fluidizing gas. This is in

1) SCG: steam of ca. 800 °C and ca.20 bar, and
2) HCG: hydrogen of ca. 600 °C and ca. 20 bar.

In process line 2) the fluidizing gas H_2 first needs to be produced by the Reforming process, REF. This is a well established catalytic process in refineries for the production of Hydrogen, H_2, from Methane, CH_4, and other hydrocarbons, but heated by high temperature combustion of surplus hydrocarbons. On that base the high temperature Helium heating for Reforming, REF, was developed.

In process line 1) the fluidizing steam is produces in a "Helium heated Steam Generator, SG", which has been demonstrated already in HTRs for electricity production with steam turbines, as in Ft. St. Vrain and THTR. For this reason the following processing schemes are described in the following in the order REF, HCG, and SCG.

II.B. Helium Heated Reformer, REF

The reforming, REF, [2] is described by two reactions, "Main" and "Shift (water gas)", Fig. (1):

1) $CH_4+H_2O = 3\ H_2+CO$, r =1 Main eq. (4)
2) $CO + H_2O = H_2+CO_2$, r =2 Shift eq. (5).

Figure 1 shows the relative progress of the reactions Main and Shift as function of temperature at 40 bar (4 MPa) pressure and at a steam/methane ratio at start of 3.1: The progress is 80% for r = 1, and 28 % for r = 2 per equation-reactions (eq.4 and 5). The steam/methane ratio of 3.1 avoids the formation of soot. The purpose is the "Main" reaction to produce Hydrogen, H_2, and Carbon-Monoxide, CO, from Methane, CH_4 and from Steam, H_2O. The "Shift" reaction is a side reaction. It increases the H_2 production and produces Carbon-Dioxide CO_2, one of the two final sinks in chemical energy conversion; the other one is water, H_2O.

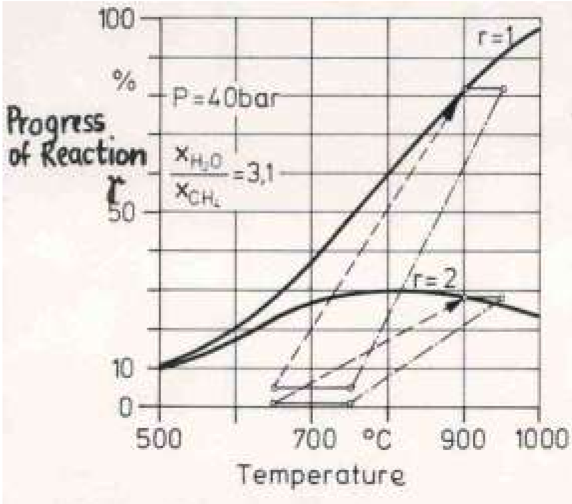

Fig.1: Progress of the two reactions in the Helium heated Reformer, REF as functions of temperature at 40 bar (4 MPa),
lines r=1 and r=2: chemical equilibrium of both reactions, dashed lines: reactions paths of r=1 and r=2, see text, dot-dashed lines: Helium temperature change from 950 °C to 750°C.

Fig 2: Photo of Tube Bundle of the "Helium heated Reformer, REF". Look from the entry side of high temperature Helium of 950°C upwards in the direction of the helium flow, guided by baffles. This baffle-bundle was tested first. Later the double-tube bundle was also tested.

Figure 2 is a photo [2] of the Tube Bundle of the baffle-variant of the "Helium heated Reformer, REF". The baffles are plates to guide the helium flow from inside to outside and reverse, while moving upwards for increased heat transfer. The photo also shows thermo-couples at the lower end of the reformer tubes for temperature measurement at the helium inlet. The feed enters the tubes at top and flows done in counter current to the outside helium. The reaction happens at the catalyst, which is located inside the tubes. The product gases leaf via an internal pipe inside of each tube from bottom to top. This internal pipe acts -together with the outside Helium- as the heater for the incoming feed. For length compensation the lower end of the pipe is formed as a screw line, therefore it is call "pig tail" The non-reacted stem and methane are separated from the product and recycled.

Two types of Reformer Bundles have been proposed, developed and tested in semi-technical scale, the baffle- and double-tube-variant, in the Large Scale Test Facility "EVA-ADAM-II" at the Research Center Juelich, FZJ, Figure 3, [2].

Fig. 3: Photo of Large Scale Test Facility "EVA and ADAM-II", for semi-technical demonstration of "Helium heated Steam Reformer, REF", called EVA, as well as for Methane production from Synthesis Gas (H2 and CO), called ADAM, operated in "Loop Configuration" to simulate the system "Nuclear Long Distance Energy, NLE", at Research Center Juelich, FZJ, near the city of Juelich, west of Cologne, east of Aachen.

Figure 3 shows the "EVA-ADAM-II" Plant, which demonstrated successfully the function of the system "Nuclear Long Distance Energy", NFE, by operating in "Loop Configuration". The idea is to transport heat energy from a nuclear reactor over longer distances by the transportation of the reactions partners of the reactions "Main" and "Shift", eq. (4) and eq. (5). At the Reactor these reactions run forward, EVA, and at the heat consumer, ADAM; –a town station- these reactions run backwards. For the transportation the gases were cooled down to ambient temperature. The town station ADAM converts the incoming heat energy into steam and district heat. The abbreviation EVA comes from the small scale test facility, which was operated before, with its name "Single Tube Experimental Facility", in German: Einzelrohr-Versuchs-Anlage", EVA; the word "ADAM" was introduced just because the two fames names in the bible.

In detail Figure 3 shows the building for the Reformer, REF, the Steam Generator, SG, and the electrical heater on the left side of the photo, the pipe work for the simulation of the transportation of the cold gasses in the center, and the production of heat by the backwards reaction in the cylinder type structure at the right side if the photo. The electrical heater has an input of electricity of ca. 10 MW. The plant has operated successfully over years, and different types of catalysts have been tested.

In these operational periods both types of "Helium Heated Reformers, REF", the "Baffle"-REF and the "Double-Tube"-REF have been tested successfully in large (semi technical) scale.

The results of the reactions can be formulated as the sum of the two reactions. Typical examples with rounded stochiometric coefficients are:

$CH_4 + 1.1\ H_2O + (3\ H_2O) =$
$2.64\ H_2 + 0.47\ CO + 0.30\ CO_2 + 0.23\ CH_4$, eq. (6)

It should also be mentioned that with this reformer process Carbon Dioxide can be consumed and thereby can be split. An example from long operation test is:

$CH_4 + 0.4\ H_2O + 0.3\ CO_2 + (1.6\ H_2O + 1.7\ CO_2) =$
$1.94\ H_2 + 1.07\ CO + 0.23\ CH_4$, eq. (7)

Of course, both reactions were working without the formation of soot. The values in brackets in eq. (6): ($3\ H_2O$) and in eq. (7): ($1.6\ H_2O + 1.7\ CO_2$) are needed as feed materials to "push" the chemical equilibrium into the required direction of the reaction. This means that the values in brackets need to be recycled.

II.C. Hydrogenating Coal Gasification, HCG

The Hydrogenating Coal Gasification, HCG, [3], [4], [5] is in principle a two step process, because hydrogen is typically not easily available. The formulation of the two principle reactions depends also on the required product. In eq, (1) to (3) hydrogen as the product has been taken for simplicity. But a more interesting product is Methane CH_4, so called Substitute Natural Gas, SNG. Therefore this product is chosen in the following:

1) $2\ H_2O + CH_4 = 4\ H_2 + CO_2$, eq. (8): REF
2) $2\ C + 4\ H_2 = 2\ CH_4$, eq. (9): HCG
3) $2\ C + 2H_2O = CH_4 + CO_2$ eq. (10): sum

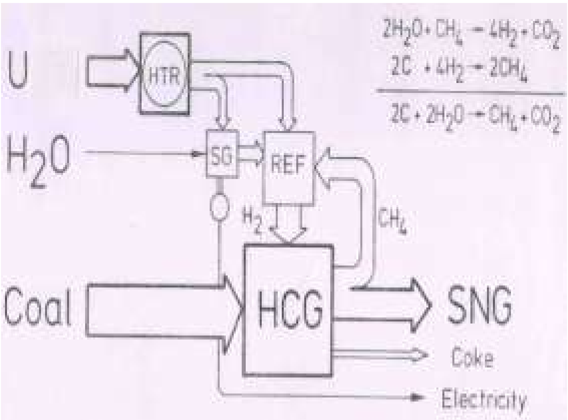

Fig. 4: Energy flow diagram of the "Hydrogenating Coal Gasification, HCG": The coal is converted in "HCG" with Hydrogen, H_2, into Methane, CH_4; about half of that is recycled to the Reformer, REF, to produce the needed Hydrogen, H_2

Figure 4 shows the supply HTR heat to the Reformer, REF, and to the Steam Generator, SG. The Reformer REF converts the recycled CH_4 into the needed hydrogen to gasify the coal. The gasification process in HCG is a fluidized bed reaction. There is no need of HTR heat for the gas generator, because the reaction is "exo-thermal", the need to cool it, this typically is done by the feed.

In more precise formulation younger coal, "Lignite", is $CH_{0.89}O_{0.28}$, per 1 mol of C in the Lignite. The over-all reaction equation is e.g.

$CH_{0.89}O_{0.28} + 0.75\ H_2 + (2.2\ H_2) =$ eq. (11)
$0.53\ CH_4 + 0.07\ CO + 0.02\ CO_2 + 0.35\ CH_{0.1}$,

The main product is Substitute Natural Gas, 0.53 CH_4, the side product is Fine Coke, 0.35 $CH_{0.1}$. An additional product is electricity.

The value in brackets in eq. (11): (2.2 H_2) is needed as feed materials to "push" the chemical equilibrium into the required direction of the chemical reaction. This means that the values in brackets need to be recycled. This is not a big difficulty, since there is anyhow the need of a separation of gases.

Fig. 5: Photo of Pilot Plant of "Hydrogenating Coal Gasification, HCG", with a fluidized bed gas generator to convert Lignite, $CH_{0.89}O_{0.28}$, with Hydrogen, H_2, into mainly Methane, CH_4, at industry site of Rhein-Braun Company, close to the city of Wesseling, near Bonn, south of Cologne. This Pilot Plant was started after the successful operation of a semi-technical plant.

Figure 5 shows the Pilot Plant of HCG, the largest plant in the whole program, with an input of 9.6 t/h of dry Lignite , lower heating value of 9 350 kJ/kg. The raw Lignite has 51.5 % water, 7 % ash, and 0.4 % Sulfur, all weight%. These numbers of the raw Lignite give an indication that the gasification process can be seen at the same time as a purification process to provide "clean" substitute secondary energy carriers to the customer.

The production of Fine Coke from Lignite is very useful, because it is almost sulfur-free and concentrates the ash components. It is a valuable fuel for any combustion applications.

II.D. Steam Coal Gasification, SCG

The Steam Coal Gasification, SCG, [3], [6], [7] is a one step process: it follows mainly eq. (1).

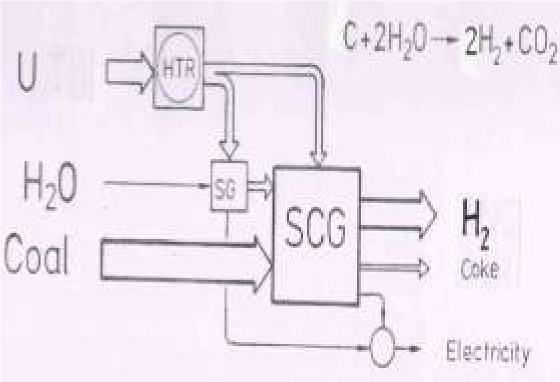

Fig. 6: Energy flow diagram of the "Steam Coal Gasification, SCG": the coal is converted in SCG with Steam H_2O mainly into Hydrogen, H_2, Fine Coke, and Carbon-Dioxide, CO_2.

Figure 6 shows the supply of HTR heat to the Gas Generator, SCG, and to the Steam Generator, SG. The Steam Coal Gas Generator, SCG, is a fluidized bed reactor. The medium for the fluidization of the grinded coal is steam. The transportation and feeding of that coal is done with steam of the same quality.

In more precise formulation older coal, so called "Hard Coal", is $CH_{0.74}O_{0.06}$ per 1 mol of C in the Hard Coal. The over-all reaction equation for 50 % partial gasification and in non-catalytic operation is e.g.

$$CH_{0.74}O_{0.06} + 0.44\ H_2O + (1\ H_2O) = \quad \text{eq. (12)}$$
$$0.44\ H_2 + 0.15\ CH_4 + 0.1\ CO + 0.2\ CO_2 + 0.55\ CH_{0.25}$$

The main product is Hydrogen, H_2, the side energy products are Methane, CH_4, Carbon-Monoxide, CO, Fine Coke, $CH_{0.25}$, and some Electricity. The side product gases can be converted in additional Hydrogen, H_2, by Reforming, or Hydrogen, H_2, and the other C-gases can be converted into additional Methane, CH_4, that is Substitute Natural Gas, SNG. The Fine Coke, $CH_{0.25}$, has an ash content of ca. 14 weight%. It is a valuable product in the energy market, because it is "cleaned". The above given numbers are valid for "German Gasflamm-Kohle, so-called Westerholt Hard Coal, named after a nearby city, northern Ruhr area. The characteristic data are of the raw coal are: 28 000 kJ/kg lower heating value, 9 % water, 7 % ash, and 1.3 % Sulfur, all weight%.

The application of catalysts has also been tested. It turned out that this application produces a lot of difficulties, because the catalyst is going to be consumed, since it gets mixed with the ash and enlarges the need of purification of the waste-water.

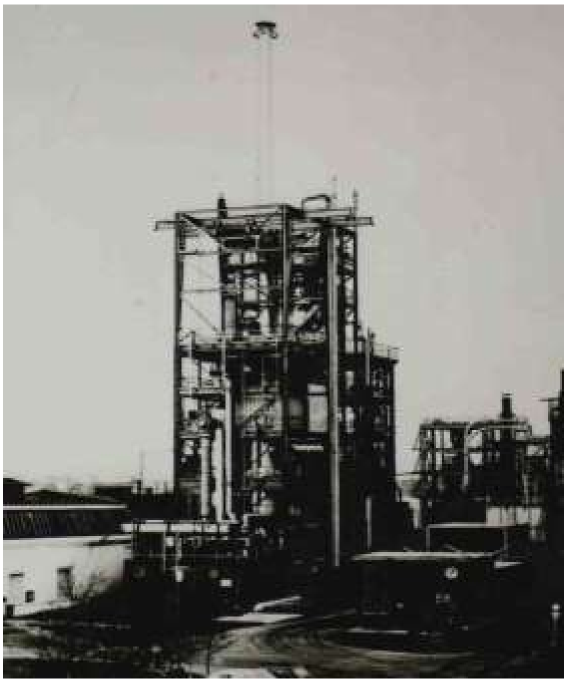

Fig. 7: Photo of Semi-technical Plant for "Steam Coal Gasification, SCG" with the "Helium heated Fluidized Bed Gas Generator" to convert coal with steam H_2O into mainly Hydrogen H_2 and Carbon-Monoxide, CO, at the Research Institute of Bergbau-Forschung, of Ruhrkohle AG, city of Essen, near Duesseldorf.

Figure 7 shows the Semi-technical Plant for Steam Coal Gasification, SCG, with a throughput of 200 kg/h Carbon to be gasified in the "Helium heated Fluidized Bed Gas Generator with the fluidizing Steam. The Helium is heated electrically. Tests with helium of 900 °C and 950°C have been made. The maximum wall temperature of the heat transfer bundle is ca. 860°C at 950 °C Helium temperature. The operating pressure is about 20 bar (2MPa) at both sides of the wall.

At the beginning of the development work in the project "Prototype Plant Nuclear Process Heat, PNP, the component design was directed for large plants and unit sizes. This policy was extended after the invention of the HTR-Module, [7]: it became possible to think about unit sizes for PNP-Applications with a heat input of 170 MW_t, that is the combined heat consumers REF plus SG, respectively SCG plus SG.

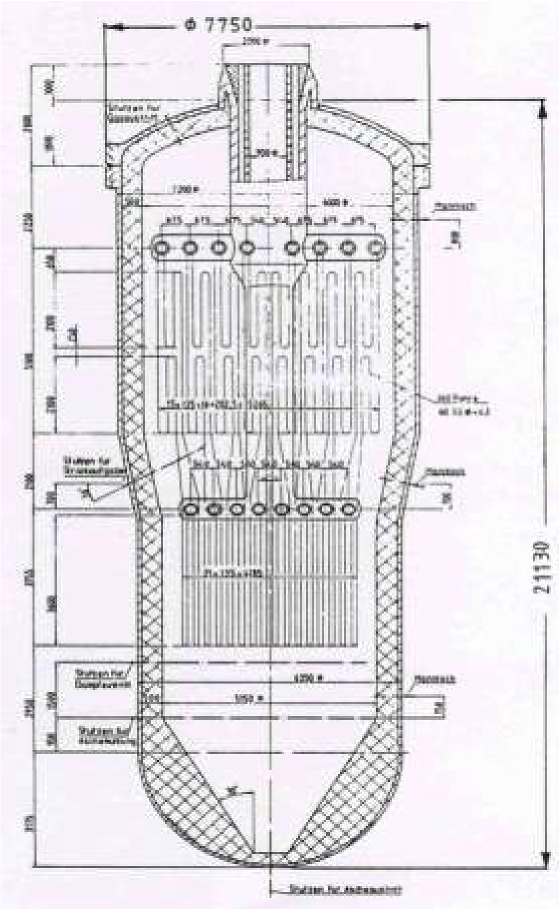

Fig.8: The latest design of a Primary Helium heated Steam Coal Gasification, SCG, gas generator of vertical design in the unit size for one HTR-Module-Process Heat Reactor with a thermal output of 170 MW, an Intermediate Heat Exchanger was not considered to be necessary, mainly because of very low over pressure.

Figure 8 shows the most modern design proposal for a Steam Coal Gasification, SCG, gas generator with steam driven fluidized bed gasification in vertical arrangement for non-catalytic processing in partial gasification in the unit size to be applicable for an HTR-Module, made by Bergbauforschung, Mannesmann-Anlagenbau and FZJ [8]. The Helium enters and leaves at top in co-axial tubing. The grinded coal enters via steam jet from the left side. The fluidizing steam enters below the heat transfer bundles from the left. The gas products leave at top beside the Helium connection. The Fine Coke leaves at bottom after it is cooled. The upper part of the volume is the pyrolyses zone and the lower part is for gasification. Meanwhile this type of gas generator has been tested with wood chips. This opens the perspective on any biomass, including manure, as the future source for the C-atom to produce Energy Alcohol [9].

III. OBJECTIVES AND RESULTS OF “PNP”

III.A. Partners of the PNP-Project

The Project “Prototype Plant Nuclear Process Heat, PNP” was founded by the three partners Bergbauforschung (Research Institute of Hard Coal Industry), Rheinische Braunkohlen-Werke AG (for Lignite), und Kern-Forschungs-Anlage, KFA, *now Research Center Juelich,FZJ,* in Juelich in 1972. In 1976 an extended contract was made and two additional partners from the reactor industry joint the co-operation. These partners were: Gesellschaft für Hochtemperatur-Technik GmbH, GHT, a daughter company of the Siemens Group, and Hochtemperatur-Reaktor-Bau GmbH, HRB, a daughter company of the former BBC Group.

The PNP-Project was terminated at 1992-June-30. *The following text was formulated in 1992 to inform the government authorities, it was first published in [9], and it was reviewed for “HTR-2014” at 2014-March. Extensions are in italic print.*

The Partners at termination of PNP were:

Forschungs-Zentrum Juelich GmbH, FZJ, former Kernforschungsanlage Juelich KFA,
in Juelich,
GHT Gesellschaft für Hochtemperatur-Technik mbH, in Bergisch-Gladbach,
Hochtemperatur-Reaktorbau GmbH,
in Mannheim,
DMT Gesellschaft für Forschung und Prüfung mbH, former Bergbauforschung, in Essen, and
Rheinische Braunkohlenwerke AG,
in Cologne.

This RDD Program PNP was supported by the respective Ministries of the Federal Government of Germany and the States Government of North Rhine-Westfalia, [2], [3], [4], [5], [6], [7], [8].

III.B. Objectives

a) to develop a high temperature reactor for high values of the gas outlet temperature (950°C) for the application as a source for process heat to be applied in processes of coal refinement, including the components for heat transfer, being necessary for this purpose, and
b) to develop and to demonstrate components and pilot plants for the process of Steam Gasification and for the process of Hydrogenating Gasification of coal.

III.C. Results in General

A) The technical feasibility of a "Nuclear Process Heat Plant for the Refinement of Coal" has been established: The main parts "High Temperature Reactor for Process Heat Production" and "Refinement of Coal" have sufficiently been developed and demonstrated for the realization of a prototype plant. This means: The objectives of the project have been achieved. Nevertheless the costs of the plant are guessed to be much higher than originally expected.

B) The economical competitiveness of the nuclear process heat plant for the refinement of coal is in comparison to the conventional alternatives of coal refinement in principle achievable, if potential improvements can be realized. But the economical competitiveness of the refinement of coal in total does not exist anymore under market conditions since the end of the oil crisis.

C) The process of the refinement of coal using nuclear energy contributes to the fundamental goals "security of energy supply", "diversification of the resources" and "environmental friendliness"

III.D. Results in Detail

1) The development of the High Temperature Reactor for the production of high temperature heat with high values of the outlet temperature of the coolant Helium (950°C) for the application as source for Process heat is conceptually accomplished to a very large extend: Several concepts of reactors have been established ready for construction.

2) The fuel element being envisaged for application in the HTR process heat production is the "Pebble Type Fuel Element, Low Enriched Uranium, Coated Particle with TRISO Coating". These fuel elements have been successfully qualified in mass tests in AVR reactor in Juelich.

3) The technical feasibility of the production of process heat in a nuclear reactor in the form of high temperature helium of 950 °C has successfully been demonstrated by the operation of the AVR in Juelich for many years of operation in its life span of 20 years from 1969 to 1988. This result has been reconfirmed by the project "Reconstruction of the AVR into a Process Heat Plant" (this has not been realized), also with respect to the license-ability. At the beginning and at the end of the operation the helium outlet temperature was less, e.g.750°C (tests) and about 850°C (after the melt-wire measurement).

4) Components for the high temperature helium transportation are qualified: Examples are the successful test for Hot Helium Ducts, including insulation and liners in the scale 1:1 test facilities "Component Experimental Loop" (Komponenten-Versuchs-Kreislauf KVK, Siemens-Interatom, Bergisch-Gladbach) and in the Experimental Plant ADI (HRB, Experimental Facilities, Juelich).

5) Verifications on safety of an HTR for Process Heat Production have successfully accomplished. Examples are the "Explosion Test with Hydrogen" (Siemens- Interatom, Bergisch-Gladbach) and "Earthquake Test on the Systems with Pebble Bed Core", including Support Structures (earthquake test facility MAVIS, former SAMSON, HRB, Juelich), as well as experimental work on "Retention of Tritium" (FZJ Juelich and others more).

6) The technical feasibility of components of HTR for process heat production in Industrial Scale has been supported by the Operation of the demonstration plant THTR-300 in Schmehausen with valuable experiences (also of negative kind). The operation of the THTR-300 was finished already in 1989, also due to political difficulties.

7) The qualification of the metallic materials for high temperature applications is very advanced: For the materials of the Steam Reformer, *REF,* and the Intermediate Heat Exchanger, *IHX,* the prognostic lifetime of more than 100,000 hours have been achieved. The newly developed material for the Helium-Heated Gas Generator, *SCG,* of the process of Steam Coal Gasification withstands very hard corrosion conditions in the gasification of coal.

8) Methods for the Concept Design and the Detailed Design, as well as the production of Licensing Documents for the components of high temperature heat transfer and high temperature heat consuming apparatus have been developed completely.

9) The development and demonstration of the process of Steam/Methane-Reforming with a Helium-Heated Reformer has successfully been performed. Two variants of the Helium flow, the Baffle-, and Tube- Variant, have successfully been tested in pilot-scale in the Large Scale Test Facility EVA-ADAM-II, (FZJ Juelich), *[2]*.

10) The development and demonstration of the Helium Intermediate Loop for the transfer of high temperature heat from the primary into the secondary loop has been performed successfully. Two variants of the Helium flows for the

intermediate heat exchange, the Helix- and the U-Tube- Variant, have successfully been tested in the Large Scale Experimental Plant "Component Experimental Loop" (Komponenten- Versuchs-Kreislauf, KVK, Siemens-Interatom, Bergisch - Gladbach) together with the Hot Helium Ducts and Hot Helium Fittings.

11) The development and demonstration of the process of the "Hydrogenating Coal Gasification", *HCG*, in experimental facilities in the Semi-Technical Scale and in the Pilot-Scale (Union Kraftstoff, Wesseling) have been successfully performed. The process has been developed mainly for Lignite, the applicability for Hard Coal has also been tested successfully, *[2], [3], [4], [5]*.

12) The development and demonstration of the process of Steam Coal Gasification, *SCG,* has been performed successfully in an experimental facility in the Semi-Technical Scale (Deutsche Montan Technologie, DMT, former Bergbau-Forschung, Essen): the process has been developed for Hard Coal in the main, *[2], [3], [6]*.

13) Assessments of the technical feasibility and the economical competitiveness of the processes for the refinement of coal using nuclear energy have been performed in the year 1987 (RBW assessment, *[5]* ROeG study, *[6]*). Both studies confirm the technical feasibility. On the economical competitiveness the following is stated:

For the Hydrogenating Coal Gasification, *HCG*, *[5]:* "The product costs are remarkable higher than the market prices of today and also above the conventional alternatives, with the conclusion that an economical competitiveness may be achieved only in the long term".

For the Steam Coal Gasification, *SCG [6]:* The cost value of the processes applying nuclear energy are higher than those of the conventional processes, and there is a potential to decrease the costs" but without the possibility to be cheaper than the conventional alternatives: However, it had also be shown that it would be necessary to have an optimal coupling between the HTR and the heat producing process", *[7], [8]*.

14) The R&D work for the improvement and the securing of the technical feasibility and the economical competitiveness, and for the preparation of the market penetration of coal refinement using nuclear energy: "Development of concepts and assessment" (1989-1992) have identified potentials of improvement: With these improvements the economical competitiveness of nuclear process heat for the refinement of coal in comparison to conventional alternatives has been achieved: the best value is 75% of conventional alternatives: But the economical competitiveness of coal refinement as a whole is not achieved in comparison to the market conditions after the end of the oil price crisis for the moment *(1992), [7], [8]*.

15) The license-ability of nuclear heat application for coal refinement has been evaluated in 1980 by the Assessment Committee of the Bundesminister des Inneren, BMI, (Federal Ministry of the Interior) and has received a positive vote: "requirements can be fulfilled and proofs can be made". This vote has been revitalized by the evaluation in the frame of the project "Modification of the AVR into a Process Heat Plant" in 1984. The Primary-Helium-heated Reformer, *REF,* fulfills all requirements being important in a licensing process.

16) The environmental friendliness of nuclear coal gasification with respect to emissions from the coal refinement process has been proven by the experimental plants: the products specific emissions of carbon-dioxide, CO_2, of the nuclear coal refinement is in comparison to the conventional alternatives smaller by the factor of 1.5 to 1.8. With the nuclear coal refinement the "CO_2-disadvantage" of coal in comparison to oil and gas can be diminished.

IV. SUMMARY

The Project "Prototype Plant Nuclear Process Heat, PNP" for the Refinement of Coal in Germany was operative from 1972 to 1995. It established the technical feasibility of the refinement of coal for the two types of coal: Lignite and Hard Coal. This was achieved by Research, Development and Demonstration, R&D&D, on the two process lines:
1) Steam Coal Gasification, SCG, and
2) Hydrogenating Coal Gasification, HCG,
respectively on three fundamental process steps
a) Helium heated Reformer, REF,
b) HCG Gas Generator, and
c) Helium heated SCG Gas Generator.
HCG has been demonstrated in Pilot Plant Scale, SCG in Semi-Technical Scale.
Remark:
In the late 80ies it was difficult to reach economical competitiveness in coal refinement, because the crude oil price had dropped from 40 (max. in first oil prize crises, 1976) to 12 \$(1986)/ barrel; today it is about 100 \$ (2014)/barrel.
With the nuclear coal refinement the "CO_2-disadvantage" of coal in comparison to oil and gas can be diminished.

REFERENCES

[1] Georg Kueffner, Frankfurter Allgemeine Zeitung, FAZ, 8. Jan. 2014, „Die Renaissance der Kohlevergasung“; Düngemittel, Treibstoff und Kohlenmonoxid zur Methanerzeugung; Saubere IGCC-Technik,
Title in English: The Renaissance of Coal Refinement, Fertilizer, Gasoline, Carbon-Monoxide for Methane Production, Clean Integrated Gasification Combined Cycle-, IGCC-Technology.

[2] Udo Boltendahl, Ralph Harth: Wärmetransport auf kaltem Wege, Projekt ADAM & EVA, Kernforschungsanlage Juelich GmbH, Rheinische Braunkohlenwerke AG, Sonderdruck „bild der wissenschaft“, Nr. 4,1980;
Title in English: Transport of Heat Energy using Cold Gases.

[3] Projekt PNP-1981: Referenzkonzept der Proto-Typ-Anlage Nukleare Prozesswärme, PNP, Gesamtanlage und Kraftwerk, Februar 1981; Title in English: Reference Concept of Prototype Plant Nuclear Process Heat, PNP, Total Plant plus Power Station.

[4] Projekt PNP-1987: Arbeiten zur Festlegung des Anlagenkonzepts HTR und Hydrierende Kohle-Vergasung, HKV, Rheinische Braunkohlenwerke AG, (RBW-Bewertung, Juli 1987);
Title in English: Evaluations on the Definition of the Concept of the Plant: „High Temperature Reactor plus Hydrogenating Coal Gasification Plant“, (RBW Assessment).

[5] Projekt PNP-1989:Abschlussbericht zur Entwicklung eines Röhrenspaltofens (RSO) für die Prototypanlage Nukleare Prozesswärme, Partner BASF AG, Interatom GmbH, L+C Steinmüller GmbH, Systemführer: GHT Gesellschaft für Hochtemperatur-Technik mbH, Juli 1989;
Title in English: Final Report on the Development of a Reformer, REF, for the Prototype Plant Nuclear Process Heat.

[6] Ruhrkohle Öl und Gas GmbH im Auftrag der Ruhrkohle AG: Studie zur Kohlevergasung mit nuklearer Prozesswärme, RÖeG-Studie, April 1987;
Title in English: Ruhrkohle Öl and Gas Gmbh on behalf of Ruhrkokle AG: Study on Gasification of Coal using Nuclear Process Heat.

[7] Project PNP-1992: Schlussbericht über die F+E-Arbeiten zur Verbesserung und Absicherung der technischen Auslegung und der Wirtschaftlichkeit und zur Vorbereitung der Markteinführung der nuklearen Kohleveredlung „Konzept-Entwicklung und -Bewertung 1989-1992. Partner DMT-Gesellschaft für Forschung und Prüfung mbH, (vormals Bergbauforschung GmbH), Forschungszentrum Jülich GmbH, Siemens AG, Bereich Energieerzeugung KWU/GHT (Gesellschaft Hochtemperatur-Technologie mbH), Juni 1992,
Title in English: Final Report on R+D Work on Improvement and Confirmation of the Design and Economics, as well as on the Preparation of the Market Introduction of Nuclear Coal Gasification „Concept Development and Assessment”, 1989-1992.

[8] Heiko Barnert, Jasbir Singh, Hans-Ferdinand Niessen, Helmut Neis, Hans Hohn, Potentialstudie zur Kohleveredlung durch Wasserdampf-Kohlevergasung (WKV) mit Hochtemperaturreaktor-(HTR)-Wärme, Jül-2131, Mai 1987, ISSN 0366-0855;
Title in English: Study on the Potential of the Refinement of Coal by Steam Coal Gasification using HTR heat.

[9] Heiko Barnert, Energy Alcohol from Plant Biomass plus High Temperature Heat, the CO_2-Neutral, Environment Benign, and Consumer Friendly Future Alternative, Jül-3089, July 1995, ISSN 0944-2952.

End of References
End of Paper.