SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

CONTRACTED STUDY AGREEMENT REG / POL / 1

"CONCEPTS AND TOOLS FOR STRATEGIC REGIONAL SOCIO-ECONOMIC CHANGE POLICY"

STUDY REPORT

PART 2

POLISH CASE STUDY REPORT

COORDINATOR, IIASA: A. KOCHETKOV
COORDINATOR, SRI PAS: A.STRASZAK

ZTS/ZPZC/ZTSW 1-36/85

WARSAW 1986

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II. REGIONAL STRATEGIC ENERGY POLICIES IN VIEW OF THE GENERAL FUEL-ENERGY SYSTEM DEVELOPMENT ALTERNATIVES

by Wiesław Ciechanowicz

II.1. Introduction

The subject of this chapter is to consider how the lignite basin infrastructure of Bełchatów could be utilized in the future when the lignite resources are depleted.

This productive, and, to some extent, also social infrastructure has been developed as a result of expansion of the national fuel-energy system. Therefore it is not only possible, but quite justified to look for the future Bełchatów basin strategic policy within the future national fuel-energy system expansion that will result from the possible solutions of future energy problems, these solutions being determined most probably by the competition of coal, to be better utilized, and other energy sources, as well as of the impacts of these solutions on the national economy (Fig. II.1).

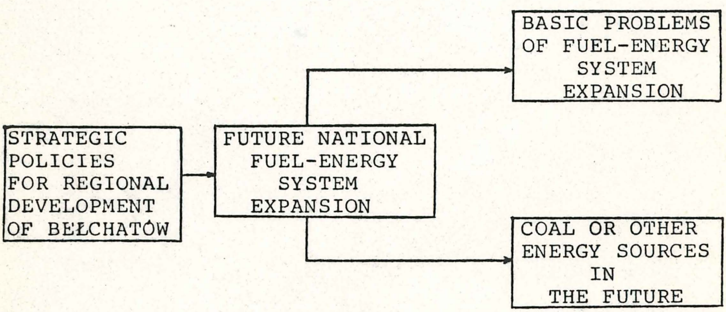

Fig. II.1. Energy-wise framework of regional case study analysis.

Bearing in mind the above the sequence of problems considered will be the following:

1. the basic problems of fuel-energy system expansion,
2. coal or other energy sources in the future,
3. remarks on the strategic policies for regional development of Bełchatów.

Main emphasis will be placed on the 2-nd of the above problems, which involves determination of the possible future solutions to energy problems.

II.2. <u>The basic problems of fuel-energy system expansion</u>

The basic problems of expansion of the fuel-energy system are presently:

1. energy conservation, understood as rational management of fuel and energy utilization,
2. utilization of non-conventional energy resources,
3. substitution of oil and natural gas
4. the mounting desire to preserve our environment.

To solve any of these problems the non-conventional technologies are required, which, in turn, necessitates financial expenditures to be provided on research, development and investments. It involves particularly coal conversion processes or broader-scale utilization of non-conventional energy sources. Therefore, the problem of competition of coal and other energy sources ought to be clarified.

II.3. <u>Coal and other energy sources in the future</u>

Bearing in mind the previous statement that the solution of energy problems lies in the non-conventional technologies the question arises:

<u>what are the impacts of non-conventional technology choices on economy?</u>

To answer this question a number of problems have to be considered, involving:

- scale of the problem,
- consequences of expansion,
- priority of introducing non-conventional technologies,
- decision constraints

all that with respect to separate national economy sectors and regions as well as to the whole of the national economy.

This means that the general question mentioned above should be split into the component questions to be answered separately at the first stage of considerations.

The energy content of world oil and gas resources constitute respectively 3% and 1% as compared to the energy content of world coal resources. This is the reason why our attention will be turned to coal as the fossil fuel to be utilized in the future. Therefore the first component questions are the following ones:

1. what should be done in order to have coal utilized better by the main direct coal consumers, such as electricity, industry and heat residential sectors?
2. what should be done in order to utilize coal in a converted form as hydrocarbons so as to substitute oil and gas?

The risk of bearing the expenses of the coal technology development suggests the third component question, that is:

3. which energy sources could turn out in the future to be the rivals and which allies of coal for direct coal consumers and oil-gas substitute production?

Our explanation shall be performed by answering a number of subsequent questions within each of these three questions.

II.3.1. Question 1: What should be done in order to better utilize coal?

To answer this question the following issue will be considered: What is the essence and mechanisms of energy conservation for the main direct coal consumers, i.e.

- coal fired power plants,
- industry,
- heat residential receivers.

The essence of energy conservation for these direct coal consumers is better utilization of useful work within the thermodynamic processes. This leads to the mechanisms of energy conservation, which should in fact be seen as non-conventional technologies, presented below for the sectors considered in subsequent sections.

II.3.1.1. Coal fired power plant sector

The mechanisms of energy conservation in this sector are, see Fig. II.2:

- lowering of combustion temperature,
- introduction of basic steam Rankine cycle:
  - topping cycle,
  - bottoming cycle.

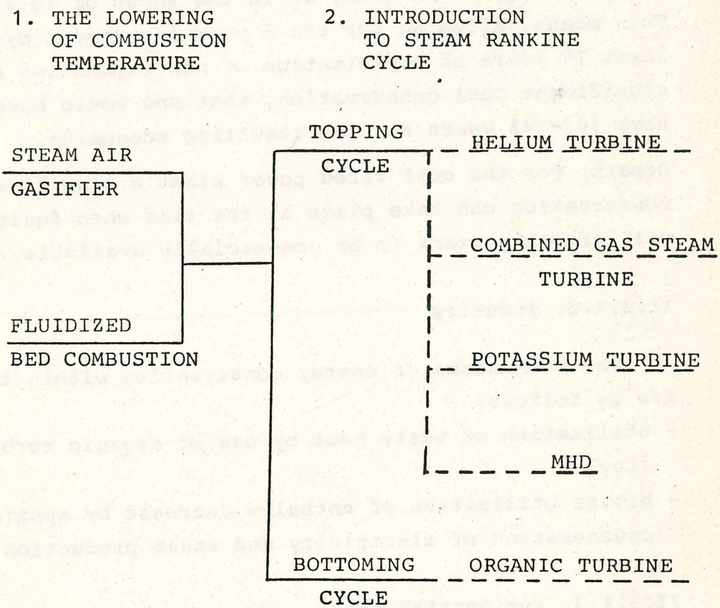

Fig. II.2. The mechanisms of energy conservation in electric energy sector.

To practically implement these mechanisms we must introduce into the processes the following non-conventional technologies:

for lowering of the combustion temperature:

- steam/air gasifier, or

- fluidized bed combustion technology,

for topping cycle

- potassium turbine applied together with fluidized combustion technology,
- combined gas steam turbine applied together with steam/air gasifier,
- MHD generators,

for bottoming cycle

- organic turbine.

The time required for research and development, depending on technology to be used, is in the range of 10-25 years. This means, allowing for the 5 year investment cycle and at least 15 years of exploitation of new capacities for significant coal conservation, that one would have to wait some 30 - 45 years for the resulting economies.

Remark. For the coal fired power plant a significant energy conservation can take place at the time when fusion energy will probably start to be commercially available.

II.3.1.2. Industry

The mechanisms of energy conservation within this sector are as follows:

- utilization of waste heat by use of organic turbine technology,
- better utilization of enthalpy decrease by application of cogeneration of electricity and steam production technology.

II.3.1.3. Residential heat

The mechanism of energy conservation within this sector is:

- better utilization of enthalpy decrease through application of technology of cogeneration of electricity and steam.

The considerations presented above complete the answer to question 1, indicating that the key to better utilization of coal are the non-conventional technologies.

II.3.2. Question 2: What should be done in order to utilize coal in a converted form as hydrocarbons?

To answer this general question we will consider the following more detailed subquestions.

2.1. When oil runs out which substitute could dominate within the transport sector?

2.2. What are the main requirements and constraints of coal conversion?

2.3. What are the more convenient hydrogen and methanol production methods?

II.3.2.1. Answer to subquestion 2.1: when oil runs out which substitute could dominate within the transport sector.

Cars and aircrafts need a portable, highly concentrated source of energy, and not heavyweight batteries or exotic fuel stores. On the road, petrol is unbeatable. As an energy store petrol packs twice its nearest rival i.e. methanol. Methane in the form of liquefied natural gas has to be cooled to -163 ^{o}C. Hydrogen poses even bigger problems. Being the smallest atom of all if leaks through anything. Hydrogen gas has only a third the energy of methane. Forget the idea that it could be used in liquid form. Hydrogen will not liquefy until it has been cooled down to -253 ^{o}C. Hydrogen gas can be stored chemically in the form of a hydride of exotic metals like lanthanum, titanium, zirconium and magnese. To contain the energy equivalent of a 40 dm^3 (approx. 10 gallons) petrol tank would cost several thousand dollars.

Bearing in mind the above the answer to the subquestion is the following:

There is a great possibility that the converted coal can turn out to be the dominating substitute within transport sector in the future. But not necessarily fossil coal. The substitution can involve the non-fossil coal contained e.g. in CO_2 in the atmosphere.

II.3.2.2. The answer to subquestion 2.2: what are the main requirements and constraints of coal conversion?

Let us review alternative technologies for the following endproducts:

- methane,
- liquid fuels.

Methane

Synthetic methane can be obtained using the following technologies (see Fig. II.3):

1. high caloric value (CV) catalytic gasification,
2. high CV gasification by use of nuclear heat,
3. hydrogasification.

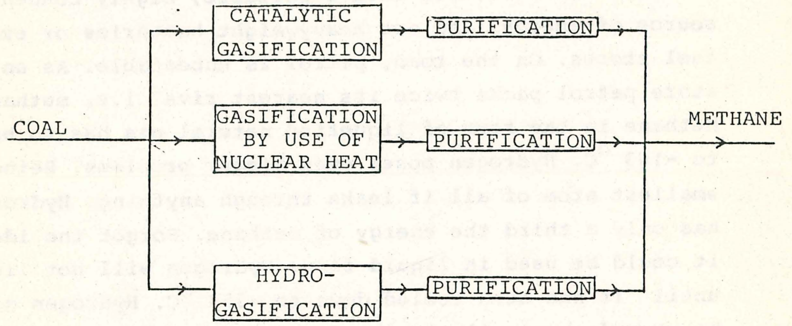

Fig. II.3. Coal-methane technologies.

Chemical reaction schemes for these technologies are described as follows:

1. High CV catalytic gasification -

gasification	$2C + 2H_2O \rightarrow 2H_2 + 2CO$
gas shift	$CO + H_2O \rightarrow H_2 + CO_2$
methanization	$CO + 3H_2 \rightarrow H_2O + CH_4$
net reaction	$2C + 2H_2O \rightarrow CO_2 + CH_4$

2. Nuclear heat application, steam methane reforming -

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$
$$2C + 4H_2 \rightarrow 2CH_4$$

net reaction $$2C + 2H_2O \rightarrow CO_2 + CH_4$$

3. Hydrogasification

$$C + 2H_2 \rightarrow CH_4$$
$$C + 2H_2O \rightarrow CO_2 + 2H_2$$

net reaction $$2C + 2H_2O \rightarrow CO_2 + CH_4$$

It can be seen that in all the considered coal-based technologies for one molecule of methane produced, two atoms of carbon are consumed and one molecule of CO_2 is produced as a useless byproduct.

CO_2 production is the result of the hydrogen production by use of the shift reaction. This means that in order to avoid CO_2 production we need external hydrogen.

Only high CV catalytic gasification is in the demonstration plan stage. Its thermodynamic efficiency is expected to be 71.6%.

Remaining technologies, whose reactions were given here, are in the pilot plant stage.

Liquid fuels

The three principal routes by which synthetic liquid fuels can be produced from coal are, see Fig. II.4:

1. indirect liquidfraction,
2. direct liquidfraction,
3. pyrolysis.

1. Within indirect liquidfraction we can distinguish two cycles of technologies which are presented below.

1 cycle: Lurgi reactor - methanol synthesis - Mobil process of high octane gasoline production

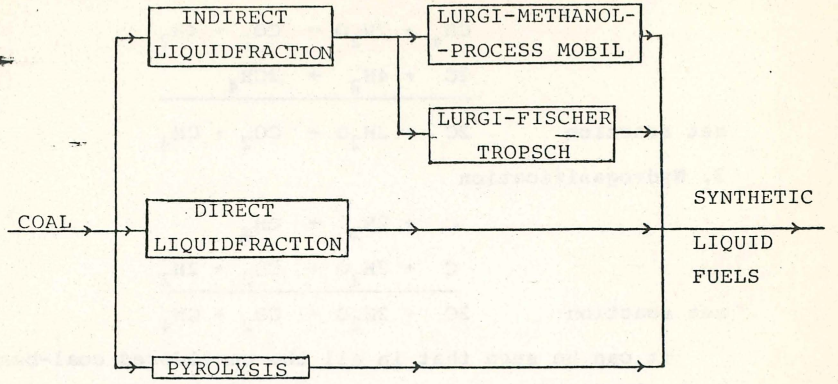

Fig. II.4. Coal-liquid fuels technologies.

Reactions:

reactor Lurgi output - $CO + 2H_2$ - synthesis gas,

methanol synthesis

$$CO + 2H_2 \rightarrow CH_3OH$$

Mobil process

$$CH_3OH \rightarrow -CH_2- + H_2O$$

The synthesis gas production gives CO_2 as the hydrogen by--production.

Technological cycle would be close to be commercially available if suitable fuel cost relations existed. With a gasifier efficiency 70% the overall efficiency to gasoline is expected to be 48%.

2 cycle: Lurgi reactor - Fischer-Tropsch synthesis, which is carried out according to net reaction

$$2CO + H_2 \rightarrow -CH_2- + CO_2$$

Its net efficiency is of the order of 45%. This technology cycle is in operation in Republic of South Africa, due to low costs of coal mining.

2. The direct liquidfraction methods utilize 30% of calorie value of coal which participate in coal liquidfraction processes. This technological development is in the pilot plant stage.

3. In the pyrolysis method the pyrolysis process is the first stage of process which produces synthetic gas and liquid fuels. This technological development is in the pilot plant stage.

Remarks:

Production of gas and oil substitutes from coal requires a source of hydrogen because the ratio of hydrogen atoms to carbon atoms in coal is too low. All coal gasification processes currently under development use the gas shift reaction as the basis for producing hydrogen.

For every molecule of methane produced two atoms of carbon are consumed and one molecule of CO_2 is produced as useless byproduct. This implies that the carbon source in coal will be consumed twice as fast as in natural gas if the natural gas supply is substituted by synthetic gas.

The consequence of release of CO_2 into atmosphere would be the ecological "greenhouse effect". The prevailing view is that a two-fold increase in the atmospheric CO_2 concentration would substantially alter global weather patterns.

For most coal gasification schemes, the energy required for the endothermic gas shift reaction is also supplied by burning coal, resulting in even more coal, approximately 30% consumed as feed stock.

If an external source of hydrogen were available, the contents of carbon in coal could be hydrogened, at least theretically, to any hydrocarbon desired without unnecessary waste of carbon by producing CO_2.

Bearing in mind the above we conclude:

I. The main requirement of coal conversion is external hydrogen availability.

II. The main constraint of coal conversion is the ecological effect of emitting CO_2 into atmosphere.

II.3.2.3. Answer to subquestion 2.3: What are the more convenient hydrogen and methanol production methods?

Hydrogen

A source of hydrogen other then the gas shift reaction, can be water decomposition,

Energy can be provided for water decomposition in the form of:

- work,
- heat,
- neutron energy,
- pairs of above.

To these forms of energy provision the following water decomposition methods correspond:

- electrolysis,
- termochemical cycle,
- radiolysis,
- pairs of above.

Efficiency of electrolysis of water

Even though the electrical efficiencies of current low-temperature electrolysis processes are high (70%), the overall efficiency is limited by the efficiency of electric power generation. Therefore the efficiency of water electrolysis is limited to perhaps 30 to 35 percent.

Thus, any method of hydrogen production with overall efficiencies greater than that attained by the electrolysis of water will have important economic advantages, see Fig. II.5.

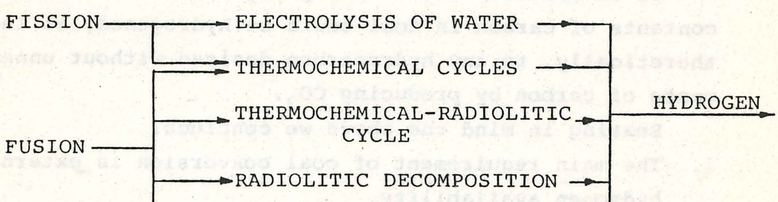

Fig. II.5. Nuclear energy-hydrogen technologies.

Direct decomposition of water

The direct decomposition of water, in which the energy is provided only in the form of heat, according to reaction

$$H_2O \rightarrow H_2 + \frac{1}{2} O_2 \qquad 5450\ ^oK$$

requires 5450 ^oK. Such temperature cannot be industrially achieved.

Thermochemical cycles

The temperature bottoming is possible by use of two or more steps-cycles, endothermic and exothermic. Suitable substances which react with water participate in these cycles.

Appropriate examples can be provided by decomposition of CO_2

$$CO_2 \rightarrow CO + \frac{1}{2} O_2 \qquad 3340\ ^oK$$

and shift reaction

$$CO + H_2O \rightarrow H_2 + CO_2 \qquad 750\ ^oK$$

This cycle cannot be implemented if heat is not provided to the CO_2 decomposition process. The reason is the requirement of very high temperature source.

Another example is the Schulten methanol cycle, which consists of the following four reactions:

$$CH_4 + H_2O \rightarrow 2H_2 + CO + H_2$$

$$2H_2 + CO \rightarrow CH_3OH$$

$$CH_3OH + SO_2 + H_2O \rightarrow H_2SO_4 + CH_4$$

$$H_2SO_4 \rightarrow H_2O + SO_2 + \frac{1}{2}O_2$$

The maximum required temperature is 927 ^oC. This cycle can be implemented by use of nuclear heat.

Preliminary estimates of this process thermal efficiency were in the range 40% - 45%. Net efficiency, when nuclear heat is applied, is expected to be 37.5%.

A number of thermochemical cycles as well as electrolytic - thermochemical cycle have been discovered, for which the upper limit of temperature is 1000 ^oC. The efficiency can be expected to be in the range of 40%.

Remark:

To increase the hydrogen production efficiency with respect to the water electrolysis process a high temperature source is required. This source can be implemented by the High Temperature Reactor. This means that in order to increase the hydrogen production efficiency the nuclear fissile energy is required.

Radiolytic decomposition

In the radiolysis process it is theoretically possible to use neutrons to be produced as fission fragments of fission reactors or by the fusion reaction.

The fundamental difficulty in the use of fission fragments directly is, of course, contamination of the process fluid.

In the fusion reactors the radiolysis of H_2O or CO_2 to produce respectively H_2 or CO on a commercial scale would be based on utilization of the 14 Mev neutrons. Review of the experimental data for H_2O or CO_2 radiolytic decomposition indicates relatively low efficiencies of conversion compared to other processes discussed previously.

Remarks:

On the basis of considerations here presented we can forward the following general conclusions, of importance for technology choice:

1. Any method of hydrogen production with overall efficiencies greater then water electrolysis (30 - 35%) will have important economic advantages.
2. Utilization of fission energy in the form of high temperature heat would enable achievement of the 40% - 45% efficiency of hydrogen production, constrained by temperature level of HTGR* equal 927 $^{\circ}$C.

Let us look at the potential of fusion reactors as energy sources at temperatures in the range of 1377 to 1827 $^{\circ}$C.

Hydrogen from high-temperature electrolysis of steam

Fusion appears as a very promising energy source for synthetic fuels. Very high temperatures can be generated in fusion blankets for production of hydrogen from decomposition of water.

*High Temperature Gas-cooled Reactor

The most promising appears to be the process of high temperature electrolysis (HTE) of steam. Depending on HTE cell temperatures and overall power cycle efficiency, overall synthetic fuel efficiency is expected to be in the range of 50 to 70 percent. In Brookhaven National Laboratory (BNL) the HTE process technology has been successfully demonstrated on a relatively small scale and can be demonstrated on the pilot scale.

The high temperature electrolysis of steam is one of the most promising ways of fusion energy utilization in the synthetic hydrocarbon production in the future.

Another way is the radiolytic-electrolytic cycle.

Fusion energy to be utilized in the process of radiolytic-electrolytic decomposition may appear not only to be the hydrogen source but also an interesting approach to the problem of providing a renewable supply of liquid hydrocarbon fuels. A very attractive possibility is to derive raw materials only from air and water, that is, the source of supply can be the carbon dioxide in the atmosphere and the hydrogen from water. The following advantages would be obtained:

1. Elimination of deep coal mining hazards.
2. Elimination of ecological problems of strip mining.
3. Elimination of sulfur and trace element pollution problems due to burning of fossil fuels.
4. Maintenance of the CO_2 balance in the atmosphere and the possible greenhouse effect avoided.
5. Plants will no longer be restricted to sites close to large deposits of fossil fuels.

By analogy to photosynthetic-fuel cycle there may arise the fusion energy-methanol cycle. The first converts solar energy to cellulose (wood) as a result of CO_2 and H_2O reaction, namely

$$n\,CO_2 + n\,H_2O \xrightarrow[\text{energy}]{\text{solar}} C_nH_{2n}O_n + n\,O_2$$

and shift reaction gives

$$C_nH_{2n}O_n + n\,O_2 \rightarrow n\,CO_2 + n\,H_2O + \text{heat}$$

Fusion energy - methanol cycle includes

- radiolytic decomposition

$$CO_2 \xrightarrow[\text{energy}]{\text{fusion}} CO + \frac{1}{2}O_2$$

- electrolytic decomposition

$$2H_2O \xrightarrow[\text{energy}]{\text{fusion}} 2H_2 + O_2$$

- methanol synthesis

$$CO + 2H_2 \rightarrow CH_3OH$$

then applying the Mobil process we can get high octane gasoline.

In BNL the economic evaluation of presented approach has been performed. For production of 189 000 bbl/d in one plant 1 GJ should cost 2 units. For 63 000 bbl/d in one plant the cost of 1 GJ has been estimated on the level of 3.5 units. At that time (1974) these levels were comparable with the gasoline price (3.05/GJ). Conclusion was, that utilization of fusion energy for provision of independent source of liquid fuels has an economically interesting potential.

Now let us answer subquestion 2.3.

1. The more convenient hydrogen production method will be the high temperature electrolysis of steam by use of fusion energy. The expected efficiency can be by some 50% higher than the efficiency which could be obtained by use of nuclear fission energy. That is, in the case of hydrogen as well as synthetic hydrocarbon productions fusion energy can appear as a rival of fissile energy.
2. Very promising method of methanol production, and therefore synthetic liquid fuel production, could be fusion energy - - methanol cycle. In this method the raw material would be the nonfossil coal. The source of this coal is atmospheric CO_2.

II.3.3. <u>Question 3: Which energy sources could turn out to be the rivals and which - allies of coal in the future?</u>

The energy sources other than coal to be considered are:

- solar and wind energy,
- nuclear fission,
- nuclear fusion.

In order to answer this question we will consider the following subquestions, namely:

<u>Subquestion 3.1.</u>: To which extent the solar and wind energy could turn out to be allies or rivals of coal?

<u>Subquestion 3.2.</u>: What can turn out to be the limiting factor in the growth of nuclear fission energy?

<u>Subquestion 3.3.</u>: What can be the possible nuclear system choices?

<u>Subquestion 3.4.</u>: What are the perspectives of nuclear system development after year 2020?

II.3.3.1. Answer to subquestion 3.1.: <u>Solar and wind energy as allies or rivals of coal</u>

The solar and wind energy can be utilized by respective application of:

- central solar thermal power plant or solar collectors, (as well as satellite power plant in the case of highly industrialized countries),
- rotor wind generators or wind generator farm.

The solar and wind energy can not become rivals of coal in our country because they will not be able to satisfy anticipated power demand in the desired time intervals.

On the other hand there are possibilities of applying them:

- to produce hydrogen by use of water electrolysis technology,
- to supplement the basic energy sources, which would satisfy the power demand requirement, for electricity and heat residential production.

Besides coal it is the nuclear fission energy that would satisfy the power demand requirement by the condition that there would not be limiting factors in the growth of this energy. That is the subject of subquestion 3.2.

II.3.3.2. Answer to subquestion 3.2.: what is the limiting factor in the growth of commercially available nuclear fission energy.

Supply of uranium 235 at reasonable prices will be the limiting factor in the growth of fission nuclear energy systems if the breeders are not introduced at the beginning of next century. Breeder reactor is a device which produces the fissile materials, Pu-239, U-233, from the fertile materials U-238, Th-232, respectively.

This means that the development of nuclear energy production system whose elements would be burners of fissile fuel and breeders of fissile fuel from fertile materials, will be the limiting factor of nuclear fission energy growth.

II.3.3.3. Answer to subquestion 3.3.: what are the possible nuclear system choices?

The breeder which has been under development through last 25 years is Liquid Metal Fast Breeder Reactor, LMFBR. The obstacles for commercial availability of LMFBR are determined by the following aspects:

1. safety,
2. economics,
3. weapons proliferation,
4. social acceptance.

The estimated cost of the prototype breeder, planned for Clinch River, Tennessee, has escalated from USD $700 \cdot 10^6$ in 1972 to well over USD $2 \cdot 10^9$ in 1978, equivalent to a capital cost in excess of USD 5300 per kW. Futhermore, expected costs for the breeder fuel cycle have risen to the point where significant savings from the more efficient use of uranium resources can no longer be depended upon.

Bearing in mind the above the question arises: what are the other possible nuclear system choices?

They are the following:

1. accelerator breeder,
2. fusion breeder called hybrid reactor,
3. synergetic muon catalized "COLD" fusion breeder.

Description of nuclear processes

The accelerator breeder is thought as a special purpose accelerator designed for neutron production in the target and associated fissile breeding in the blanket surrounding the target according to the following course of reactions occurrin therein; in standard notation:

$Fi + n \rightarrow \nu n$	Fission reactor
$p + Z \rightarrow \nu n$	Accelerator target
$Fe + n \rightarrow Fi$	Blanket surrounding accelerator target

The hybrid reactor can, on the other hand, be described by the following scheme:

$T + D \rightarrow n + He$	Fusion core
$\left\{\begin{array}{l} Fe + n \rightarrow Fi \\ Li + n \rightarrow T + He \end{array}\right\}$	Fusion blanket

The above concepts may be viewed as systems characterized by the selective integration of three technologies:

1. fission,
2. fusion,
3. accelerator.

Fission and accelerator are commercially available. Fusion is presently in the technology development stage.

The synergetic concept based on the principle of muon catalized "COLD" fusion in a deuterium - tritium mixture is presently on the scientific stage of development. COLD means here the range of temperatures up to 1000 ^{o}K.

The proton accelerator is used to produce muons which thereupon enter a D-T chamber to initiate a series of fusion reactions during the lifetime of muon. The reaction couplings may be represented by the following reaction scheme:

$$p + Z \rightarrow \nu\mu$$

$$\mu + D + T \rightarrow \mu + n + He$$

$$Fe + n \rightarrow Fi$$

The development stage

The accelerator breeder, AB consists of:

1. proton acceleator,
2. uranium thorium target which can be considered as a subcritical assembly,
3. balance of plant.

The total cost of development of an AB is estimated at roughly USD $100 \cdot 10^6$ (1982) and completion is expected for 2015-2025.

AB are:

- safe as being subcritical assemblies,
- economically competitive with any other proposed means of fissile fuel production.

Current projections suggest that commercialization of fusion reactors will not be reached before 2020. But hybrid concept is an approach alternative to pure fusion that could shorten the time required for commercialization. A reactor of this type would operate at less then breakeven, producing copious quantities of high energy neutrons that are required to produce fissile materials.

It is very speculative to estimate the development cost of the hybrid reactor. One should mention only that the financial commitment of nations to fusion exceeds presently two billion dollars a year.

The muon serves as a catalyst, permitting the fusion reaction to proceed rapidly and at "COLD" temperatures up to 1000 ^{o}K. The present status of studies of the muon catalysis allows us to believe that in the nearest future a complete theretical and experimental description will be achieved for this extremely beautiful phenomenon. Currently, research groups are working on this problem in many national and international scientific centers: in such countries as USSR, USA, Canada and Switzerland.

The information presented above shows that in the worst case the breeder technology would be commercially available around the year 2020. One can expect that from that time on there will be no constraints on the fissile nuclear energy expansion if this energy source is the winner in the competition with other energy sources.

Moreover, by using high energy neutrons the development of fusion energy can importantly contribute to solution of the radioactive waste problem haunting fission reactors. In this way fusion energy could become in future the ally of fission energy.

Neutrons, being the products of D - T reaction, which is expected to be implemented by fusion devices such as:

1. magnetic fusion confinement represented by tokamak and mirror reactor,
2. inertial fusion confinement with laser fusion and particle beams reactors,

are the very source of many problems associated with the civil use of nuclear energy. These problems can be classified as follows: radioactivity, reactor design problems, direct and latent nuclear weapons proliferation, material problems, wall limits, life-time of reactor components. These considerations lead us to subquestion 3.4.

II.3.3.4. Answer to subquestion 3.4.: what are the perspectives of nuclear system development after year 2020?

The problem of D-T fusion utilization, mentioned above, motivates careful investigation of nuclear systems which would enable minimization of the appearance of neutrons in the first place i.e. in the power generating process. This suggests the use of nuclear fuels which are neutron-free in their primary reactions and which are also radioactivity free. Up till now two solutions to this problem are known.

One of the problem solutions is the (D, ^{3}He) fuel which participates in the fusion reaction

$$D + {}^3He \rightarrow {}^4He + p$$

There is a concept of symbiotic fusion-fission systems, see Fig. II.6, consisting of:

1. the core of the system to be visualized as a large, 1000 to 5000 MW, D-D fusion reactor, and

two types of core satellites, namely

2. small D - ^{3}He fusion reactor satellites in the 1 to 10 MW range, and
3. fission reactor satellites which can be built and operated

at any reasonable size from GW to small size units in the kW range as the pool-type reactors.

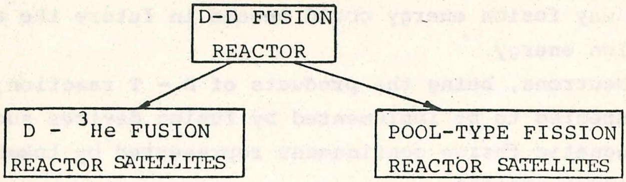

Fig. II.6. Concept of symbiotic fusion-fission system,

The symbiotic reactor systems could produce electricity and thereby they could provide electricity and also low temperature heat for localized space heating. In the far future they could turn out to be rivals of coal in the heat residential sector.

The second problem solution appears to be the potential possibility of implementing the "clear" nuclear energy source. This idea is hidden in the utilization of elementary particles - muons as catalysts in fusion of proton and boron ^{11}B.

The fusion process represented by

$$p + {}^{11}B \rightarrow 3\alpha + 8.7 \text{ Mev}$$

has long been recognized as the most appealing advanced fuel fusion reaction. The reasons for this are three - fold:

1. the reaction is neutron free,
2. identical monoenergetic reaction products are released,
3. terrestrial resources of fuels appear sufficient.

Such an approach will obviate the need for high temperatures and therefore also eliminate the associated radiation losses.

The above considerations complete the answer to subquestion 3.4.

II.3.5. <u>Answer to question 3</u>

Summarizing, on the basis of presented considerations we may now assume that the following stages of nuclear energy development are possible from the point of view of theoretical technical, and partly also economic aspects:

1. nuclear systems producing fissile materials, such as LMFBR or AB, are available,
2. D-T fusion reactors are commercially available,
3. muon catalized "COLD" fusion is accessible.

Within these development stages we will try to answer question 3 with respect to:

- electricity and heat residential production,
- synthetic fuel production.

Stage 1

The answer to the question whether fissile nuclear energy can turn out to be the rival or ally of coal in the electricity and heat residential production sectors will depend mainly upon the two following factors:

- production cost relations,
- availability of coal.

The fissile nuclear energy ought to be coal ally in the synthetic fuel production under the condition that HTGR becomes commercially available on time. If this condition is not satisfied the coal-based synthetic fuel technology could be the winner with appropriate ecological consequences. To weaken these consequences one would be obliged to apply external hydrogen in the synthetic hydrocarbon production.

In the stage 1 assumed availability of nuclear systems means the availability of equipment being able of producing fissile materials. When fusion reactors are not taken into consideration as nuclear systems, there remain LMFBR or accelarator breeder. At the moment there is no answer when, if ever, could LMFBR be commercially available. If accelerator breeders are applied then on could expect no limit in the fissile energy growth probably after 2020 year.

Stage 2

The competition of fusion energy with fissile energy or coal would be somehow related to the kind of technologies used for synthetic fuel production. We can distinguish among them the following two:

1. high temperature electrolysis of steam,

2. fusion energy - methanol cycle.

In the first case fusion energy would be the ally of coal. By applying this technology as bypass production large quantities of medium temperature steam would be obtained. This means that fusion energy could turn out simultaneously to be the rival of fission energy in the electricity production sector.

The second technology would make the fusion energy to be the rival of coal as well as of fission energy.

On the other hand if fissile energy is applied then fusion energy could be the ally of fission energy solving two main fission energy problems:

- fissile material breeding,
- radioactive waste management.

Stage 3

The muon catalized fusion could offer less sophisticated technology then D-T fusion reactors. As a consequence the "COLD" fusion energy could be developed not only by the very highly industrialized economies but also by medium industrialized economies.

There is a possibility of using muon catalized fusion for the fissile material breeding, too. This means that it could turn out to be the ally both of coal and fission energy, particularly in the medium industrialized economies.

II.4. Remarks on the strategic policies for regional development of Bełchatów

Five scenarios of nonconventional technology utilization within energy sector are discussed.

In all the scenarios considered it is assumed that the main energy system expansion problem is the development of synthetic hydrocarbon production.

For each scenario we will distinguish those nonconventional technologies which, we assume, will be introduced to national economy energy system with first and second priority. It will be the basis for answering the question of choice of Bełchatów future strategic policies.

Scenario 1

The national economy energy system

We assume that:

x the most efficient nonconventional technology for hydrocarbon production will be used,

which is equivalent to the assumption that

x the fusion reactors will be available to apply the high-temperature electrolysis of steam.

By these assumptions we have the following set of first priority technologies to be introduced to the energy system, namely:

1. hydrogen production by the high-temperature electrolysis of steam in the blanket of mirror reactor,
2. methane production by hydrogasification of coal,
3. methanol synthesis,
4. Mobil M-gasoline process, in which methanol is converted to high octane gasoline,
5. technology of tryt breeding from lithium as a consequence of fusion reactor utilization.

The second priority technologies would then be as follows:

1. nonconventional coal fired power plant technologies,
2. solar energy technologies to be utilized for low temperature heat production,
3. wind energy technology,
4. organic turbines.

The strategic policy for Bełchatów

Because technology 1 of the first priority set requires large quantities of water it may turn out convenient to localize this technology at the Bełchatów basin if the mine pits are filled with water soon enough. Therefore, the potential regional development of the Bełchatów power centre would be the following:

1. installation of fusion reactor for hydrogen production,
2. utilization of the medium-temperature heat, being the by-pass production,
3. installation of coal hydrogasification technology, under assumption that coal will be transported to the Bełchatów region.

Advantage of strategic policy - utilization of water resources and Bełchatów infrastructure when lignite resources are depleted*.

Disadvantage of strategic policy - requirement of coal transportation.

Scenario 2

The national economy energy system

The expansion direction of the national economy energy system for scenario 2 is assumed to be the same as in the case of scenario 1, except for technology 3, i.e. methanol synthesis. Namely, in scenario 2 methanol is assumed to be produced by use of 3' - fusion energy - methanol cycle technology.

The strategic policy for Bełchatów

We assume that technology 3' will be located in the Bełchatów region. Then the possible regional development is determined by:

x installation of fusion reactor for methanol production,

Advantage of strategic policy:

- application of only one technology to utilize water resources and infrastructure,
- no requirements for coal transportation,
- possibility of decreasing the expected energy deficit of national economy because of utilization of the nonfossil coal resources.

Scenario 3

National economy energy system

It is assumed that the basic primary energy carriers used will be:

- coal, and
- fissile nuclear energy.

From this assumption there results the following set of first priority technologies:

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*being disadvantageous when there is not enough water (ed.)

1. high temperature reactors,
2. accelarator breeders,
3. methane production by use of the nuclear heat coal gasification technology,
4. methanol synthesis,
5. Mobil process technology,
6. fluidized bed combustion,
7. nonconventional coal fired power plant technology.

<u>Second priority technologies</u>:

1. solar energy technologies to be utilized for low temperature heat production,
2. wind energy technology,
3. organic turbines.

<u>Strategic policy for Bełchatów</u>

Because of water availability at Bełchatów it is most convenient to locate there:

- high temperature reactor,
- methane production by nuclear heat coal gasification technology.

<u>Advantage of strategic policy</u> - utilization of water resources and infrastructure. i.e. the same as in the case of scenario 1.

<u>Disadvantage of scenario 3</u>:

- requirement of coal transportation to Bełchatów region,
- lower efficiency of hydrocarbon production in comparison with scenario 1, which means that
- more coal should be transported for the same final hydrocarbon production in comparison with scenario 1.

<u>Scenario 4</u>

<u>National economy energy system</u>

It is assumed that the basic primary energy carriers will be:

- coal,
- fissile nuclear energy utilized for electricity and medium-temperature heat production by use of Light Water Reactors.

The set of first priority technologies are:

1. hydrogen production by the electrolysis process and wind energy,
2. hydrogasification of coal,

3. methanol synthesis,
4. Mobil process,
5. fluidized bed combustion,
6. nonconventional coal fired power plant technologies.

Strategic policy for Bełchatów

The Bełchatów basin is not a windy region. Therefore in order to locate coal gasification technology there hydrogen should be transported to this region. On the other hand there is small probability that hydrogen transport technology will be available in the future.

Bearing in mind the above the only strategic policy for Bełchatów in the future seems to be utilization of Bełchatów infrastructure for:

- fluidized bed combustion,
- nonconventional technology of coal fired power plant under assumption that coal will be transported to the Bełchatów basin.

Advantage of scenario 4 - utilization of water resources and infrastructure, the same as in the case of scenario 1, 2 and 3.

Disadvantage of scenario 4 - requirement of coal transportation to Bełchatów region, i.e. the same as in the case of scenario 1 and 3.

Scenario 5

National economy energy system

Assumption: the basic primary energy carriers will be coal and fissile nuclear energy as in the case of scenario 4.

The set of first priority technologies:

1. technology cycle: Lurgi reactor - methanization,
2. technology cycle: Lurgi reactor - methanol production - synthetic gasoline production using the Mobil process,
3. fluidized bed combustion,
4. nonconventional coal fired power plant technology.

Strategic policy for Bełchatów

Because of water availability it is proposed to locate technology cycle at Bełchatów

- Lurgi reactor - methanization - methanol production.

<u>Advantage of scenario 5</u> - same as in the case of scenarios 1, 3, 4.

<u>Disadvantage of scenario 5</u>:

- requirement of coal transportation,
- more core should be transported for the same final production quantity in comparison with scenarios 3 and 1.

FINAL REMARK

All proposed scenarios for Bełchatów future strategic policy, based upon the general framework of technical possibilities, make it possible to utilize the potential water resources as well as infrastructure. From among the scenarios outlined only scenario 2 does not require transportation of coal.

The actual choice of the Bełchatów expansion scenario will depend mainly upon:

- the possibility of international cooperation in developing the fusion energy technology,
- the impacts of the nonconventional energy technologies chosen on economy,
- national economic conditions.

STUDY REPORT

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