KENNEDY SPACE CENTER
POLYGENERATION FACILITY

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ABSTRACT

This is a report on the status of the polygeneration feasibility study conducted by the Kennedy Space Center (KSC). Polygeneration is an innovative approach to reducing cost per flight for the Shuttle by reducing propellant and other costs. Cost of LH2 is expected to be adversely affected by sharp increases in natural gas pricing as well as other costs such as electricity and transportation. The polygeneration concept is to produce liquid hydrogen (LH2) for the Shuttle and gaseous nitrogen (GN2), electricity and thermal energy to meet KSC requirements by means of an integrated coal gasification plant. Conclusions of the initial feasibility study will be presented as well as the status of on-going activities.

INTRODUCTION

As the Space Shuttle develops into an operational space transportation system, cost of operations, and more specifically, cost per flight, begin to take on added significance. Although in terms of capability, the Shuttle has no peers, competition is already on the horizon in the area of commercial launch services. This is coming from the Europeans presently, and possibly the Japanese in the not too distant future. NASA has concentrated a good portion of its resources over the last ten years to develop the capability gained with Space Shuttle, and is now, as has been planned, changing its focus. While the challenge of developing the Shuttle hardware, in the R&D sense, has been met with outstanding success, the next task of turning the Shuttle into an efficient and cost-effective operational system for carrying payloads into and out of space is no less of a challenge. Much of the emphasis on operational efficiency at KSC is in the area of improving procedures and hardware related directly to processing the Space Shuttle. However, cost reductions and strategies for limiting future cost increases in other areas are also possible.

Cost reductions at Kennedy Space Center (KSC) can be achieved in two areas. One is institutional costs; the other is Shuttle program costs. Institutional cost reduction programs such as the energy conservation program have been in place at KSC for several years. This program has been very successful, achieving a 37% reduction in energy consumption in 1982 (1973 base year). This has been accomplished thru conventional conservation means. Continued energy cost and/or usage reduction will require more unconventional and capital intensive techniques. One such area could be a cogeneration system for supplying electrical and thermal energy for the launch complex area.

Shuttle program cost reductions can span many areas. One area of concern is propellants, especially liquid hydrogen (LH2) for the Shuttle main engines. LH2 is currently produced in a natural gas steam reforming plant in Louisiana and transported to KSC by vacuum-insulated tanker trucks. Natural gas prices have been increasing rapidly in some areas even in the face of stabilizing oil prices. These rising costs are a result of implementation of the Natural Gas Policy Act of 1978 which is decontrolling the price of various categories of new gas and deep gas. The result has been spiraling costs for natural gas in some areas as the cost of the gas reaches market clearing prices. The net effect of this is a very confusing short term picture for natural gas prices. The long term picture, however, is somewhat clearer. As natural gas reaches a cost per BTU parity with fuel oil, and economic recovery dries up the oil glut, energy prices can be expected to average real increases of about 3-4% above inflation.

This is not good news for the cost of liquid hydrogen for the Shuttle. Every launch of the Shuttle will require 485,000 gallons of LH2 after accounting for boiloff, transfer and loading losses. The cost of this hydrogen will be directly affected by the cost increases of natural gas.

A primary consideration, therefore, in avoiding these projected increases in KSC's cost for LH2 and possibly realizing actual cost reductions, will be concentrated in looking for an alternate feed stock for production of hydrogen. The most attractive alternative, when considering long term availability, cost, and transportation, is coal. Presently coal is selling for approximately half the cost of natural gas on a BTU basis. The long term outlook for coal is for reasonably stable cost growth at or near the rate of inflation. In terms of long term cost, coal appears to be attractive compared to natural gas.

Other important considerations in the overall cost of LH2 are electricity and transportation costs. Electricity is an important factor in the cost to liquefy the hydrogen and represents almost 25% of the delivered price of LH2 for KSC. Transportation is equally important in the cost of LH2 to KSC. The cost to deliver LH2 in tanker trucks from Lousiana also accounts for approximately 25% of its delivered cost plus a small percentage of product loss due to boiloff during transfer operations at KSC.

Therefore, any approach to reducing KSC costs for LH2 should consider these three primary factors:

a. Feedstock
b. Electricity
c. Transportation

KSC has been studying an innovative concept for reducing it's cost of LH2 and other institutional costs. This concept is called polygeneration. It is a derivative of cogeneration which became popular in the 60's and 70's. With cogeneration, electrical and thermal energy production is combined to achieve overall higher process efficiencies. The polygeneration concept expands on this by producing multiple energy streams by means of an integrated coal gasification process. In this particular application, the output streams which are of interest are:

a. Medium BTU Gas
b. Liquid Hydrogen
c. Electricity
d. Thermal Energy
e. Byproduct Gaseous Nitrogen

During the course of the initial feasibility study conducted by KSC, it became evident that this concept has potential applications in many other industries, such as the petrochemical and power industries. The nature of the coal gasification gas clean-up process is that it allows simultaneous utilization of high sulfur coal and reduction of sulfur compound emissions to the air significantly below federal and state requirements. With proven reserves of coal which can last for centuries, this is a very significant capability. In addition, the sulfur that is removed during the clean-up process is in the form of pure sulfur which is marketable.

PROJECT DESCRIPTION

Figure 1 shows the typical polygeneration plant layout, the input/output streams, and how they will be integrated with existing KSC facilities and systems.

The gasification and gas cleanup system gasifies the input coal and cleans up the output gas to produce a clean medium BTU gas composed primarily of carbon monoxide (CO) and hydrogen (H2). It has a BTU content of approximately 300 BTU's per standard cubic foot (SCF) as compared to natural gas which has about 1000 BTU's/SCF. This MBTU gas can be used as a hydrocarbon feedstock for producing pure hydrogen and can also be combusted, similar to natural gas, in a combustion turbine for producing electrical power. In addition, depending on the particular gasification process used, the gas stream exits the gasifier at a temperature of 2500 - 2700 degrees Fahrenheit. It is possible to recover the thermal energy in this gas stream by means of a waste heat recovery system. This system can then provide thermal energy for facility use or steam to a combined cycle generation plant.

Coal gasification processes use either air, oxygen, or oxygen enriched air. Using oxygen in the gasification process has several advantages. It increases the BTU content of the output gas stream since the nitrogen content of air is not present to dilute the output gas. In addition, carrying the nitrogen would only serve to increase the quantity of output gas and would require downstream unit processes to be oversized to handle the larger gas stream. Additional processes would also have to be added to remove the GN2 downstream in order to produce the purity hydrogen required. For these reasons, oxygen is provided by means of a cryogenic air separation plant. In addition to providing oxygen for the coal gasification process, large quantities of pure gaseous nitrogen are available as a byproduct from the air separation plan which can be used at KSC to meet existing requirements for nitrogen purge gas.

The medium BTU gas stream coming from the gasifier can now be used both as a feedstock for making liquid hydrogen and as a gas turbine fuel. Its composition will be primarily carbon monoxide and hydrogen with some carbon dioxide (CO2). This composition gas is an excellent feedstock for making hydrogen by means of the water shift reaction. The water shift reaction in simplified form is as follows:

$$CO + H_2O \rightarrow H_2 + CO_2$$

The CO_2 can be separated and the hydrogen purified by a number of commercial processes which leaves a pure hydrogen stream which is fed to a standard hydrogen liquefaction plant, and then pipelined or transported to the LH_2 storage tanks at LC-39A/B for use by the Space Shuttle.

The medium BTU gas, as mentioned earlier, also can be used directly as a gas turbine fuel. Use of medium BTU gas in gas turbines is not common in the United States, but commercial experience is good in Europe. Existing "off-the-shelf" designed U.S. gas turbines can use medium BTU gas with relatively minor combustor mods to accommodate higher mass flows and combustion temperatures. The high temperature gas turbine exhaust can be used in a heat recovery steam generator along with the steam generated by the gasifier waste heat system to produce superheated steam. The superheated steam can be expanded thru a steam turbine for producing electrical power. This arrangement is referred to as an integrated gasification combined cycle (IGCC) power plant. Thermal energy from the steam cycle may also be used for facility heating and air conditioning. The electricity produced in the IGCC plant can serve not only the large power needs of the air separation plant and liquid hydrogen plant but also part or all of the KSC facilities power requirements.

The interrelated requirements of coal gasification, liquid hydrogen production, electrical and thermal energy production and KSC's somewhat unique needs for these products naturally lend themselves to an integrated polygeneration plant as described. The synergism inherent in this approach to LH_2 production, combined with IGCC and the lower cost of coal as a primary feedstock, provides a unique opportunity for reduction in the three primary cost factors of producing LH_2. This offers the potential for significant cost savings for KSC and the Space Shuttle program.

The initial feasibility study conducted by KSC established the technical and economic feasibility of the polygeneration concept. These findings were based on a set of groundrules which were established to focus and guide the study. These groundrules will be discussed below in terms of their relationship to the study.

In order to begin to size the plant, detailed requirements were needed for KSC's demand for the various products. These were defined in terms of 1988 requirements and full Shuttle launch rate as follows:

Electricity (peak usage - both substations)	34.6 MW
Liquid Hydrogen (18 launches/yr average) (24 launches/yr peak)	24,000 lbs/day
Gaseous Nitrogen (average)	3.7×10^6 SCFD
Thermal Energy (Utility Annex only)	17.3 MW (59×10^6 BTU/hr)

In order to keep the polygeneration plant reasonably sized, both technically and financially, an initial groundrule was established for the Feasibility Study that only KSC requirements would be considered for initial sizing. This would limit the upper bounds of the plant to the requirements listed above. This provided a starting place and more detailed cost/economic trades will have to be run to look at requirements beyond these. Expanding electrical generating capacity to include, possibly, Cape Canaveral AFS might be attractive, when taking into account the Public Utilities Reglatory Policy Act (PURPA). The PURPA legislation requires that public utilities buy back excess power generated by small power producers (such as industrial plants) at a rate equivalent to the utilities avoided cost of power. Other areas which should obviously be considered would be providing LH_2 to meet most or all of NASA's eastern U.S. requirements. Although KSC will be the primary user of LH_2, other NASA requirements such as NSTL are also significant.

Another groundrule established which might seem obvious at first but needed to be emphasized, was that the priority products from the polygeneration plant are LH_2 and GN_2, respectively. The polygeneration plant is primarily a Space Shuttle liquid hydrogen plant. Integration of other products offers economies of scale and increased efficiency; however, reliable and cost-effective hydrogen production must be first priority. The Shuttle program must be able to rely on this plant for its liquid hydrogen. Secondly, once the polygeneration plant goes on line, its GN_2 product will also become critical. Since the GN_2 will be used at KSC to purge hazardous areas, to eliminate explosion hazards, and provide inert atmospheres, the supply of GN_2 is very critical to ongoing operations. Since the electrical and thermal energy generated by the polygeneration plant can be more easily supplied from supplemental back-up sources, they can be considered as second priority products. The key here is to integrate the plant very carefully such that the high priority products will have sufficient supply reliability.

One of the most important technical groundrules established was that the polygeneration plant design will not attempt to advance the state-of-the-art for any process or system. The objective of the polygeneration approach is one of cost savings both for KSC and the Shuttle program. Therefore, plant design based upon proven and mature technology, to the greatest extent possible, is requisite for meeting this objective. A technology assessment was conducted which confirmed that this requirement is almost entirely achievable (see Figure 2). One area of concern is the high degree of integration inherent in the plant. A high degree of integration can add complexity which may lower the overall reliability and availability of the plant. In terms of products, the polygeneration plant could be termed a "first-of-a-kind" plant which may also carry some inherent risk. However, all processes can be considered commercially proven, or commercially available, at the design start for this project, thereby reducing the overall project risk.

Another important technical groundrule relates to the coal to be used. Coal, unlike natural gas and, to some extent, oil, is very heterogeneous. It cannot be described in terms of a chemical formula and its properties can be very different between regions, mines, seams, and even within the same seam. Depending on application, some of these properties may be more critical than others. For this reason, it is common in coal-using industries to select a coal and design processes around that coal. In many cases these industries also have either equity or interest in coal resources and for that reason choose to use a specific coal. Since this is not KSC's situation, it is to our advantage to optimize coal selection along with other aspects of the plant. For this reason we established the groundrule that the plant should be capable of operating on high sulfur, high caking eastern coals. Most eastern coals fall into this category. This groundrule will allow the plant to be optimized based on the coals which are the most readily available to Florida. It may be advantageous for KSC to use high sulfur coal because of its historically lower cost, and the possibility of marketing the pure sulfur byproduct. However, this would have to be compared to the increased cost of the sulfur recovery process.

A primary objective of the initial feasibility study was to define a preliminary process description for the polygeneration plant. Based on KSC requirements and the stated groundrules, this preliminary concept was developed and is represented in block diagram form in Figure 3. Below is a brief description of the unit processes involved.

1. Air Separation - This is a typical cryogenic air distillation plant which will be producing gaseous O_2 and N_2 as products. GN_2 purity will be to KSC requirements and GO_2 purity to the gasifier will be optimized between 95-99% based on downstream process requirements.

2. Gasifier - Gasifies the coal by means of the partial oxidation process that produces a medium BTU gas which is primarily CO and H_2. A second-generation high-temperature, pressurized entrained flow gasification process was assumed in the feasibility study. This process has a very good efficiency and is essentially free of higher hydrocarbons such as methane (CH_4) which are unwanted for producing the final product - hydrogen. Typical composition of the product gas is shown in Figure 3.

3. Heat Recovery - The product gas stream will exit the gasifier at about 2500-2700 degrees Fahrenheit. Heat recovery from this gas stream occurs in two sections. First is the radiant boiler section which lowers the gas temperature sufficiently to allow the molten slag droplets from the coal to solidify before they reach the convective boiler section. Generally, high pressure saturated steam is produced in the radiant section and low pressure steam is generated in the convective section.

4. Acid Gas Removal - There are several commercially available processes for the removal of H_2S and COS from the gas stream. Generally, these processes either chemically or physically absorb the acid gases from the process stream and then release them thru a regeneration process.

5.&6. Sulfur Recovery/Tail Gas Unit - H_2S gas removed in AGR must be further processed to an acceptable form. This is done in the sulfur recovery unit where the H_2S is oxidized to elemental sulfur and water and the sulfur is discharged in pure form suitable for marketing. COS generally is not removed in this process and must be treated first in a tail gas unit where COS is converted to H_2S and then recycled to the sulfur unit.

7. Gas Stream Splitting - It is the combination of processes 4, 5, and 6 which make coal gasification such an attractive

choice for using coal in an environmentally acceptable way. These processes will allow total sulfur removal from the product gas such that emission from this plant should be well below EPA emission requirements. The product gas which leaves AGR is essentially sulfur free and will burn very similar to natural gas. Out of AGR the gas stream must be split with a portion going to the hydrogen plant and a portion going to the gas turbine generator.

8. Shift Conversion - CO is reacted with steam (H_2O) in the presence of a catalyst producing H_2 and CO_2. Therefore, out of the shift conversion process both the H_2 and CO_2 content of the gas is increased.

9. Pressure Swing Adsorber - This unit is used to purify the H_2 gas stream by removing the CO_2 and other impurities such that 99.99% pure H_2 is available for liquefaction.

10. H_2 Liquefaction - the pure H_2 gas stream will be liquefied in a conventional liquefaction plant with the output going to on-site storage tanks prior to transport to the storage tanks at LC-39 A/B

11. Gas Turbine Generator - A portion of medium BTU gas will be combusted in a gas turbine to produce a portion of the electricity generated in the plant.

12. Heat Recovery Steam Generator (HRSG) - The hot exhaust from the gas turbine will be exhausted through the HRSG, superheating the steam coming from the gasifier heat recovery system.

13.&14. Steam Turbine Generator - Super heated steam will be expanded through the steam turbine to produce electricity. One or more extraction stages can be utilized to provide heat to the KSC High Temperature Hot Water system.

The simplified block diagram and description of the processes presented above provides a brief overview of the polygeneration plant. Several processes such as coal handling and preparation, waste water systems and slag handling and disposal, although very important in terms of overall plant concept, were not presented.

The initial feasibility study has been completed and the results have been briefed to NASA Headquarters. Our conclusions were threefold:

a. Technology - All technology for this application is commercially available with most being commercially proven.

b. Economics - The economics of coal gasification/polygeneration at KSC to provide LH_2, GN_2, electricity and thermal energy look attractive for reducing Shuttle operational costs. This can be accomplished either by a NASA or private industry funded plant.

c. Implementation - Prior to an implementation decision or funds commitment for design, a more detailed study should be performed by an outside study contractor with expertise in process engineering of similar plants.

The KSC recommendation to NASA Headquarters was to have KSC initiate a contractor performed study with three primary objectives:

a. Further develop the polygeneration technical concept.

b. Establish best, worst, and most probable economic scenarios on which to evaluate the plant.

c. Establish NASA/private industry options for ownership/operations of the plant with corresponding framework for implementation.

NASA Headquarters accepted KSC's recommendation and authorized KSC to initiate the study. A request for proposals has been released to industry, proposals have been received, and the study contract is expected to be awarded by March 15, 1983. This study will take seven months to complete and at its conclusion the results will be combined with the results of on-going in-house studies related to polygeneration and the environmental analysis for presentation to NASA Headquarters. A decision on whether to proceed with the project will be made subsequent to this. Design, procurement, construction and start-up of the polygeneration plant would take 4-4-1/2 years after a decision to proceed, based on NASA budgeting and funding.

SUMMARY

KSC has completed an initial evaluation of the polygeneration concept and concluded that significant cost savings are possible by using this concept to produce LH_2 for the Shuttle and GN_2, electricity and thermal energy for KSC. The technology is either mature, or is approaching maturity. However, some risk may result from this unique first-of-a-kind facility. A detailed feasibility study by an outside study contractor will be awarded by March 15, 1983, to evaluate the

technology, economics, and implementation options of the polygeneration concept.

We feel that commercial application of this latest generation technology at KSC can not only reduce costs, but also provide an important demonstration of technology which can be vital to our nation's energy independence through environmentally attractive usage of our abundant coal resource.

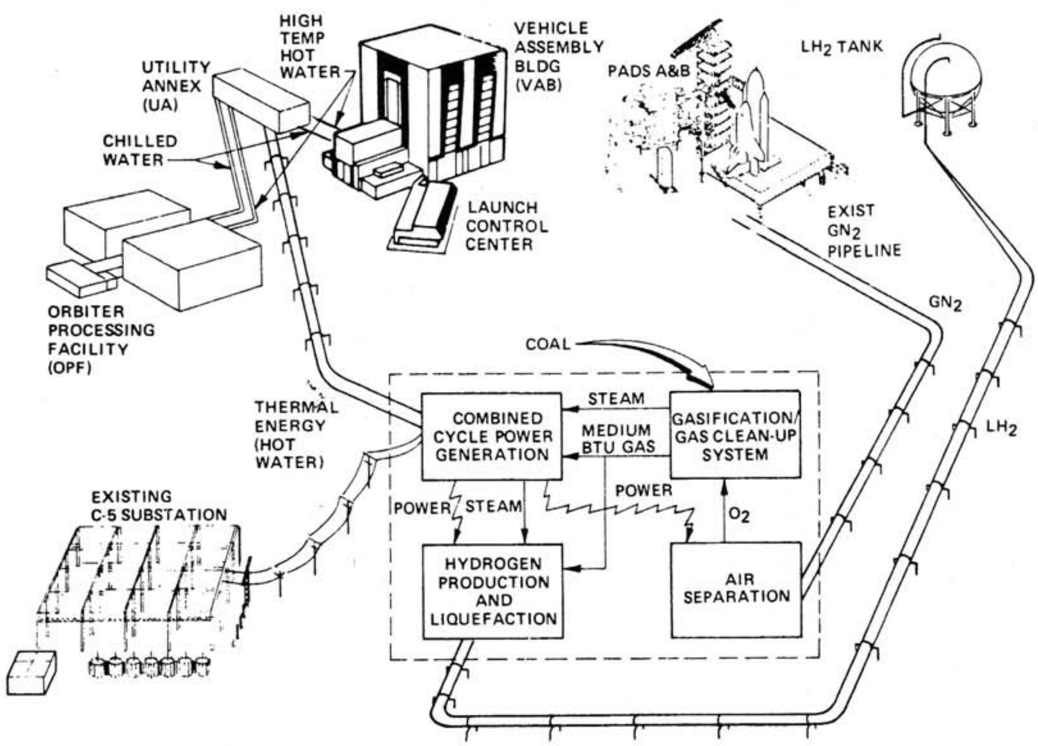

Figure 1. Typical Polygeneration Plant Layout

SYSTEM TECHNOLOGY ASSESSMENT

● COAL HANDLING & GASIFICATION	
● COAL HANDLING	CP
● COAL PREPARATION & FEEDING	CP
● GASIFIERS	CA/CP
● INITIAL GAS CLEANUP & COOLING	CA/CP
● SOLID WASTE RECYCLING/DISPOSAL	CP
● GAS CLEANUP	
● ACID GAS REMOVAL	CP
● SULFUR RECOVERY	CP
● TAIL GAS TREATMENT	CP
● AUXILIARIES	
● PLANT POWER	CP
● INSTRUMENTATION & CONTROL	CP
● COOLING WATER SYSTEMS	CP
● STEAM DISTRIBUTION	CP
● WASTE WATER TREATMENT	CP
● COMBINED CYCLE POWER GENERATION	
● STEAM TURBINES	CP
● COMBUSTION TURBINES	CA/CP
● HEAT RECOVERY STEAM GENERATOR	CP
● AIR SEPARATION PLANT	CP
● H_2 LIQUEFACTION	
● SHIFT CONVERTER	CP
● H_2 PURIFIER	CP
● H_2 LIQUEFIER	CP
● SYSTEM AND PLANT INTEGRATION	?

KEY: CP = COMMERCIALLY PROVEN, CA = COMMERCIALLY AVAILABLE

Figure 2. System Technology Assessment

TYPICAL
POLYGENERATION FACILITY

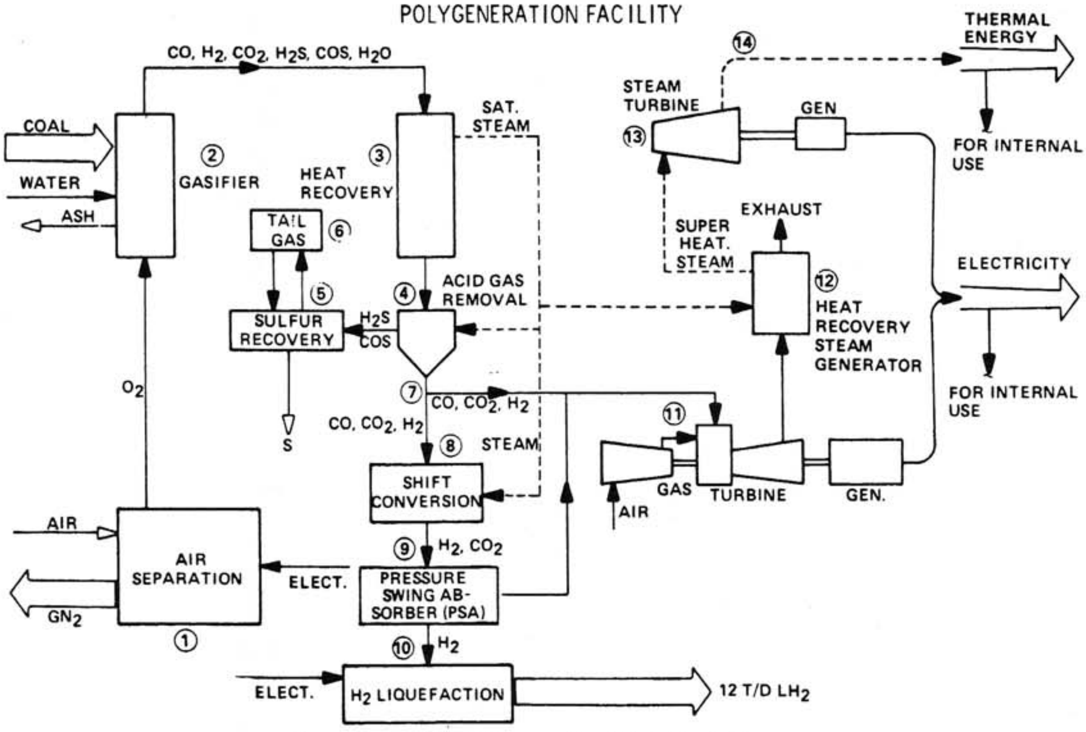

Figure 3. Typical Polygeneration Plant Block Diagram