Gasification

Jacobs Engineering

Swinging to Peak

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SWINGING TO PEAK

1 Abstract

Gasification/Combined Cycle (GCC) Power Stations are twice as costly to build as Natural Gas/Combined Cycle (NGCC) Power Stations because they produce and treat their own fuel gas as well as generate electricity. This means that GCC Power Stations are regarded primarily as a base-load contributor to the grid. The fact is that GCC can be used for the basis of a dual purpose base load/peak power supplier through its ability to store feedstock and co-product on site.

The principle of making a buffer by-product such as crude methanol or compressed air (for storage in underground salt domes) has been studied at length. The stored buffer by-product would then be used to generate power at peak periods of demand. The economics are disappointing. This is because the peak electricity generated from the buffer by-product suffers a double penalty of efficiency loss thus making the extra electricity very expensive - even for peaking.

A new concept of "swing" has been developed by the Authors in which the primary products and by-products of gasification are used to simultaneously manufacture two co-products each of marketable quality. One, electricity, is sold instantaneously whilst the other is stored as a liquid for bulk dispatch. For peaking, gasification products are partially "swung" from the manufacture of liquid product to generate additional electricity. In this way, a financially attractive arrangement of fossil fuel, electricity and co-product supply contracts can be struck.

The paper discusses how the best combination of marketable products was developed and describes the proprietary flowscheme which minimises the overall capital cost by using commercially available technology.

2 Introduction

Over the past few years, a new standard has been set for low investment, low product cost and exceptional cleanliness for power generation by natural gas fired, combined cycle plant (NGCC).

Gasification Combined Cycle (GCC) can match NGCC in the cost of electricity and cleanliness. However, the investment level is twice that of NGCC which means that generators expect a much higher return to offset the greater commercial risk.

GCC is better than NGCC in its ability to accept a wider range of feedstock. It can also provide a variety of cash products in addition to electricity. Nevertheless, none of this is any advantage for power generation if natural gas is available at the right price.

Many NGCC owners have improved their commercial position by purchasing gas on a "take or pay" basis to obtain lower prices. This can transform technically flexible plant into power stations which have to be base-load of commercial necessity.

The operation of the new NGCC power stations underline the preference of private power investors for base load demand and they have not helped the distributors’ need for variable capacity. Peaking power is becoming scarce and expensive but the commercial incentives to maintain standby generating capacity may be insufficient to meet a future peak demand.

3 Peaking Technology

Peaking demand for electricity generally refers to the diurnal peaks which occur in the morning and, more especially, in the early evening. Peak demand is often a high multiple of base load but persists only for a few hours. Regulating authorities pay premium prices for peak electricity and this "cream" revenue is attractive.

Ideally, peaks in demand would be met by a plant capable of competitive base load electricity generation which could also produce a significant margin of additional output at little extra unit cost. As implied above, most NGCC Power Stations cannot provide this as the cost of an extra "on demand" feedstock supply would result in prohibitively high cost peaking electricity.

In the past, dedicated low cost, low efficiency plant such as open cycle gas turbines have been used to provide peak generation capacity. Open cycles can be expensive to operate as, for environmental reasons, they have to use high cost low sulphur liquid fuels. This is because there is an absence of low cost natural gas at periods of peak demand. The price paid for peak power is therefore high with respect to base load electricity.

An alternative to purchasing expensive low sulphur standby fuels is to manufacture one's own source of peak fuel supply. This would be an intermediate product/feedstock made at times of surplus and therefore low cost electricity.

The classic scheme is the pumping of water uphill to a reservoir for later peak generation as hydro-electricity. Pumped water is particularly suitable for peaking as the same equipment can be used both for filling the reservoir and for power generation. The two modes of operation will not be required simultaneously.

The Dinorwic and Ffestiniog schemes in North Wales in the UK are good examples of hydro power peaking. However these two high capital cost schemes were instituted during a period of state ownership of the UK power generation industry and a similar scheme today would be unlikely to attract private investors because of the long payback time. Such schemes also need careful consideration in respect of environmental impact and the effect on the local population.

Current thinking is to incorporate a system of peaking within the original Power Station design whereby a proportion of the instantaneous output can be "put aside" for the future as a readily accessible store of high density energy. An essential feature is for as much of the plant as possible to operate at a steady and constant throughput. This optimises the capital expenditure on the main part of the plant and minimises the capital tied up in redundant capacity i.e. those sections operating at full capacity only at peaking times.

In the case of GCC Power Stations, this would mean that the Air Separation Unit or ASU, Gasification Unit and Gas Treatment Unit including waste heat recovery and sulphur removal should be operated at full capacity and at a steady rate at all times.

There are two general forms of storage:

- **Intermediate**
  in which part or all of the process flowscheme is diverted to manufacture an intermediate by-product which is then stored and used specifically as a fuel augmenter for peaking.

- **Co-Product**
  in which electricity and another finished product are co-produced from the same quantity of basic gasification gas and this fuel/synthesis gas "swung" between the two co-products to follow the benefits of peaking prices.

3.1 Intermediate Peaking

Traditionally, intermediate products, which can be stored and reused as a fuel supplement, have been the focus for providing peaking power in a GCC system. The subject continues to be extensively studied and developed in the USA.

One scheme involves a series, or once through, production of methanol. This requires the virtually total removal of sulphur from all the syn/fuel gas to protect the sulphur sensitive methanol synthesis catalyst.

Another scheme is the use of so called HAT (Humid Air Turbine) cycles to reduce the capital cost of the GCC. This may be combined with the underground storage of compressed air as an intermediate to final power production. HAT cycles rely on the development of a new and very specific range of gas turbines - or at least a unique combination of at present unmatched gas turbine compressors and expanders.

Different and additional equipment has to be used to produce the intermediate product. More importantly, the consequent two stage production of electricity means a double penalty of thermal efficiency loss. This raises the cost of this form of peak electricity.

3.2 Co-Product Peaking

Instead of an intermediate product, an alternative parallel product can be co-produced enabling plant production to be "swung" from the alternative to power during periods of peak demand.

At least 50% of the investment cost of a GCC plant lies in the generation and treatment of the fuel gas to be fed to the power island. If it can be guaranteed that whatever the demand for electricity, all this gas will be used to make electricity plus a profitable co-product, then the gas production unit can be operated at a steady and optimum throughput. This principle of output optimisation requires an alternative co-product which:

- Has at least an equivalent market price to electricity.
- Can be stored and sold on a daily average basis (unlike electricity, which has to be sold instantaneously).
- Can be produced using the GCC fuel gas as syngas.
- Can be made in a process capable of large and rapid changes in throughput without deleterious effect on either operating parameters, equipment, catalyst life or quality of product

Such co-products are methanol and ammonia in today's markets and possibly DME (Dimethyl Ether) and Fischer-Tropsch oils in the future.

Synthesis loops for these products are extremely flexible in operation and quite large diurnal fluctuations in output can be accommodated within the normal recommended tank storage capacity on site.

4 Commercial Philosophy

The profitable marketing of two co-products from the same plant can be a complex matter as the specific market for each product is unlikely to be in phase with the other. For example, a summer turn-down in electricity prices may not necessarily coincide with a balanced strengthening of the co-product chemical price.

However power peaking plants are designed specifically to take advantage of diurnal rather than seasonal fluctuations in demand and not to respond to and take advantage of any long-term market price trends in one product or the other.

To be competitive with other manufacturers of the co-product and therefore to be financially attractive, the alternative co-product to electricity has, quite simply, to cost less to produce than by conventional processes.

Examining the two leading candidates i.e. methanol and ammonia, the conventional single product manufacturing routes are summarised below:

Methanol

Feedstock	Gas Generation	Gas Treatment	Chemical Manufacture	Storage
Sulphur-Free Natural Gas	Catalytic Reforming with Steam	Some CO Shift	Synthesis Loop, Distillation	Atmospheric Storage Tanks
Coal or Oil	Gasification (With ASU)	Some CO Shift, Total Sulphur Removal	As above	As above

Ammonia

Feedstock	Gas Generation	Gas Treatment	Chemical Manufacture	Storage
Sulphur-Free Natural Gas	Catalytic Reforming with Steam/Air	CO Shift, CO_2 Removal, Methanation	Synthesis Loop	Refrigerated or Pressurised Storage Tanks
Coal or Oil	Gasification (With ASU)	CO Shift, CO_2 Removal, Total Sulphur Removal, Methanation, Nitrogen added from the ASU	As Above	As Above

Most conventionally produced methanol and ammonia is synthesised from gases produced from the reforming of natural gas. This low cost source of clean syngas generally outweighs the advantage of using a cheaper but dirty oil or coal feedstock. These admittedly lower cost feedstocks have to undergo relatively expensive gasification with oxygen followed by removal of impurities from the syngas. The subsequent process and cost of the actual synthesis of methanol and ammonia is the same whatever the source of the syngas.

The criteria for economic success, therefore, is to co-produce syngas for methanol or ammonia from coal or oil in a gasification peaking plant at a lower total cost (feed cost plus processing cost) than from natural gas in a conventional single product plant.

5 Design Philosophy

Having established possible co-products which can be stored and marketed, a design has to be developed which delivers each of the two products at a competitive cost for all modes of operation. This means that the preparation and treatment of the gas has to be effectively the same for both products as well as low in cost.

The chemical synthesis unit should minimise the amount of equipment left operating at lower than design output when production is swung away from chemicals to power.

This philosophy was followed by Jacobs Engineering in the design of peak power flowschemes developed for electricity plus methanol or ammonia co-production.

5.1 Co-Product Methanol (See Figure 1)

Gasification is carried out at high pressure (>60 bar) as the resultant syngas is then at a sufficient pressure to carry out methanol synthesis without gas compression. The high gasification pressure is also conducive to the use of Jacobs Engineering Clean Power Generation (CPG^{SM}) technology for power generation.

The process is as follows:

1. Gas Production

   Raw gas is produced at > 60 bar in Water Quench Gasification Units. Total gas production is maintained at a constant output and the raw gas split in a fixed proportion of approximately 2:1 into a fuel gas and a syngas stream respectively.

2. Syngas Treatment

   The syngas stream is cooled, partially shifted and the sulphur content reduced to below 30 ppm. The bulk of the CO_2 formed by shifting is then absorbed by washing with a liquid physical absorbent such as Selexol™. This will also remove further sulphur. Any peak demand for swing gas is then split out of the syngas for feeding to the fuel gas. Final sulphur removal from the syngas is carried out with a solid absorbent before entry to the methanol synthesis loop.

3. Fuel Gas Treatment

   The larger fuel gas stream is cooled and its sulphur content reduced to below 30 ppm. After the addition of any swing gas from the methanol syngas stream the fuel gas is expanded to the required gas turbine inlet pressure. The expanded fuel gas is used to strip CO_2 from the liquid physical absorbent used to wash the methanol syngas. After water saturation using waste heat from gasification, the fuel gas then passes to the CCU and to the open cycle peak power gas turbines (this use of waste heat from a high pressure quench gasifier is patented as a Jacobs CPG^{SM} or Clean Power Generation process).

4. Product Swing

   A typical combination would be 400 MW of electricity coupled with 1500 MTPD of methanol, swinging, as called upon, to 500 MW coupled with only 1000 MTPD.

5. Purges and Waste Heat Steam

   Purge gas and waste heat steam from the methanol synthesis are used to supplement power production.

The special features of this scheme are:

- The whole of the gas production, cooling and treatment from gasification up to the limits marked X----X in Figure 1 operates at a constant and steady rate at all conditions of output and swing.

- The displacement of CO_2 from syngas to fuel gas is kept at a constant and steady rate at all conditions of normal operation and swing. This system requires no energy input other than circulating pump power and has no need for a premature discharge of CO_2 to atmosphere.

- The methanol make-up syngas remains at a steady and optimum composition at all conditions of normal operation.

- The bulk of the necessary sulphur removal is carried out by liquid absorption within a single system and the very low level sulphur required by the synthesis catalyst applies only to that gas finally committed for methanol production.

- The fuel gas CV changes by less than 2% throughout the whole range of swing.

- Although synergetic, the power and methanol sections of the plant can be independently costed, operated and maintained even to the extent of either the methanol or electricity production units being totally shut-down for limited periods (e.g. for maintenance etc.).

This concept of co-product electricity and methanol, nevertheless, has a major drawback. That is the difficulty in obtaining a long term offtake contract for the methanol which would be the equivalent to a UK power industry "Contract for Difference" for electricity. Long term offtake contracts for both electricity and methanol would be essential to obtain the necessary financing needed in order to satisfy a reasonable return on investment.

Methanol is bought and sold mainly as a commodity as the optimum single manufacturing plant capacity (say 2500 - 3000 MTD) cannot be taken by a single methanol consuming plant. Hence there is an active methanol market and a considerable volume of "spot" trading.

Ammonia plants, on the other hand, are often paired with downstream ammonia fed plants, such as urea, which can consume the whole output of the upstream ammonia plant. The ammonia consumption rates of such downstream plants are high compared to the consumption rates of typical methanol fed plants. Therefore the acquisition of a long-term offtake contract for ammonia is considered a good possibility - if an appropriate site can be found.

5.2 Co-Product Ammonia (See Figure 2)

An 1100 t/d ammonia from coal plant has been in commercial operation in Ube, Japan, since 1984. The Authors have now designed a peak power flowscheme for electricity/ammonia co-production.

In common with the features of the electricity/methanol scheme discussed above, this:

- uses the same equipment to produce both fuel gas and syngas

- exposes a minimum of redundant equipment when production is swung from ammonia to power

- generates the peaking electricity in add-on open cycle gas turbines This reduces extra capital cost and enables the main Combined Cycle Unit (CCU) to be optimised for continuous operation at full output. In other words, the peak electricity is generated over and above the output of the CCU.

The process is as follows:

1. Gas Production

   Raw gas is produced at > 60 bar from Water Quench Gasification Units. Total gas production is maintained at a constant output.

2. Total Gas Treatment

   The raw gasification stream is cooled, shifted and the sulphur content reduced to below 50 ppm (See Section 5.3). The gas is then expanded to gas turbine fuel pressure (20-30 bar).

   The gas expander is used to control its own downstream pressure which is vitally important as this provides a fast response gas supply to both the CCU and peak-power gas turbines (essential for grid control) as well as ensuring a steady supply for the PSA unit.

3. Fuel Gas Treatment

   Fuel gas taken from the exhaust of the expander is saturated with water using waste heat from gasification, and the fuel gas then passes to the CCU (this use of waste heat from a high pressure quench gasifier is patented as the Jacobs CPG^{SM} or Clean Power Generation process).

4. Syngas Treatment

   The syngas stream is also taken from the exhaust of the gas expander at 20-30 bar and passed to a PSA (Pressure Swing Adsorption) unit to produce pure hydrogen for ammonia synthesis. PSA off-gases are fed to the CCU as gas turbine afterburn.

   Pure nitrogen from the ASU is compressed to 20-30 bar, added to the hydrogen to produce a stoichiometric syngas mixture which is then compressed to ammonia synthesis pressure.

5. Product Swing

   The fuel gas for the open cycle peak power gas turbines is taken from the feed to the PSA unit. Pure nitrogen is used to suppress flame temperature and hence NO_x formation in the gas turbine combustors (it should be noted that this technique has been patented by Air Products – US Patent 5,081,845).

   A typical combination would be 400 MW of electricity coupled with 1600 MTPD of ammonia, swinging, as called upon, to 520 MW coupled with only 800 MTPD of ammonia.

6. Waste Heat Steam

   Waste heat from the ammonia synthesis loop is used to supplement power production.

The special features of this scheme are:

- The whole of the gas production, cooling and treatment from gasification up to the limits marked X----X in Figure 2 operates at a constant and steady rate at all conditions of output and swing.
- The CCU remains at steady and optimum operation at all conditions of normal operation.
- With the exception of the nitrogen compressor, the syngas compression system is standard, taking a hydrogen/nitrogen mixture at 20-30 bar pressure and compressing it up to loop pressure.
- The ammonia synthesis unit is an optimised stoichiometric loop with only trace impurities and hence no need for a continuous gas purge of inerts. The product requires no further treatment such as the distillation that is required for raw methanol synthesis product.
- Although synergetic, the power and ammonia sections of the plant can be independently costed, operated and maintained even to the extent of either the ammonia or electricity production units being totally shut-down (e.g. for maintenance etc.).

5.3 Selexol™ Unit for Electricity/Ammonia

Outline Description:

Untreated gas enters the system and is combined with a gas stream from the overhead of the CO_2 Stripper and the Rich Flash. This combined stream is sent to the H_2S Absorber, where most of the H_2S and COS are removed as well as some CO_2 and H_2. These gases are removed by contact with Pre-Loaded Selexol™ solution (i.e. rich in CO_2 content), which is sent into the top of the H_2S Absorber. The Selexol™ solution at the bottom of the H_2S Absorber is now termed rich solution. This rich solution is pumped through the Lean/Rich Exchanger, via the Rich Solution Pump, to increase its temperature and recover energy from the reboiler. The rich solution is sent to the top of the CO_2 Stripper, where CO_2, H_2 and other gases are recovered by stripping with a nitrogen/hydrogen mixture. This stripping gas is ammonia syngas taken from the ammonia syngas compressor.

This system reduces the sulphur content of all the product gas to less than 50 ppm sulphur, whilst maximising CO_2 slip in order to increase the amount of power produced by the expander. In fact, the anticipated CO_2 slip is approaching 98%.

At < 50 ppm sulphur, the expanded gas is more than suitable for gas turbine fuel exhausting to atmosphere without the need for further SO_x reduction.

5.4 PSA Hydrogen Purification

Pure hydrogen for ammonia production is extracted in the PSA unit which also reduces the oxides of carbon and the remaining sulphur content below the level demanded by the ammonia synthesis catalyst.

The PSA process for hydrogen purification is based on the capacity of adsorbents to adsorb more impurities at high gas-phase partial pressure than at low partial pressure. Impurities are adsorbed in an adsorber at high partial pressure and then desorbed at lower partial pressure. The impurity partial pressure is lowered by "swinging" the adsorber pressure from the feed pressure to the off-gas pressure, and by using high-purity hydrogen purge. The process operates on a cyclic basis. Multiple adsorbers are used in order to provide constant feed, product and off-gas flows. Each adsorber undergoes the same process steps in the same sequence, but the steps are staggered with respect to time. The PSA process has significant advantages, carbon oxides and sulphur compounds are removed to very low (ppm) levels in a single step process, the hydrogen product is available at close to feed pressure, the pressure drop between feed and product being less than 1 bar and the process is very flexible to changes in feed capacity and composition.

The sulphur content of the PSA off-gas fed as afterburn to the gas turbine are such as not to exceed total permitted emission levels when combined with the sulphur in the gas turbine exhaust.

6 Optimisation

Both schemes (for electricity/methanol and for electricity/ammonia) have been simulated by the Authors and mass balances produced (not attached to this paper). The designs appear robust and flexible.

In the case of the ammonia option especially, there is a large potential for optimisation. The general guide lines for optimisation are:

1. Minimise the extra equipment needed to achieve co-production.
2. Minimise the operating redundancy of the extra equipment i.e. the equipment dedicated to the manufacture of only one co-product is to be minimal.
3. Maximise the proportion of plant operating at optimum and constant throughput.
4. Minimise the interaction between the co-product flowschemes.
5. Keep all operating parameters of each co-product flowscheme within the normally permitted values when swinging.
6. Ensure that the swing procedure is fast and can be fully automatically controlled.

There are also some specific optimisation considerations for the ammonia option such as:

- The optimum pressure at which the nitrogen for ammonia synthesis can be made available from the ASU for compression to syngas compressor suction pressure.
- The optimum pressure for feeding gas to the PSA unit.
- The waste heat steam system.

7 Anticipated Performance

The overall anticipated performance for the developed electricity/ammonia swing plant is as follows:

	Normal Operation	**Peaking Operation**
Coal Consumption (GJ/hr)	5700	5700
Net Electricity Output (MW)	400	520
Net Ammonia Output (MW)	1600	800

A detailed steam balance has not yet been completed and the net electricity output assumes that the recovery of waste heat for conversion to power is balanced by the internal power requirements (mainly gas compression) plus the ASU requirements including air and oxygen compression.

8 Commercial Benefits

The commercial benefits of swing cannot be assessed solely from the mass balances developed to produce this Paper. An energy balance and estimated capital cost is required plus, of course, market predictions of the future costs and prices of the feedstocks and co-products.

Preliminary investigations by the Authors suggest that the benefit obtained by swinging at peak periods is up to 2% higher revenues in the current UK power supply environment. This margin may become wider with future peaking trends.

A further benefit of the scheme could be the availability of low cost ammonia to those remote from pipeline gas.

Hydrogen for ammonia synthesis is produced at marginal cost, constituting 40% of total hydrogen produced at normal operation to 20% at peaking power.

Pure nitrogen for ammonia synthesis is available from the ASU and requires only compression.

The extra equipment required to make the syngas for the ammonia includes a PSA unit, an afterburner for the offgas and nitrogen compression. The syngas compression is standard and the synthesis loop requires no purge.

Unlike methanol production, the ammonia product does not require distillation.

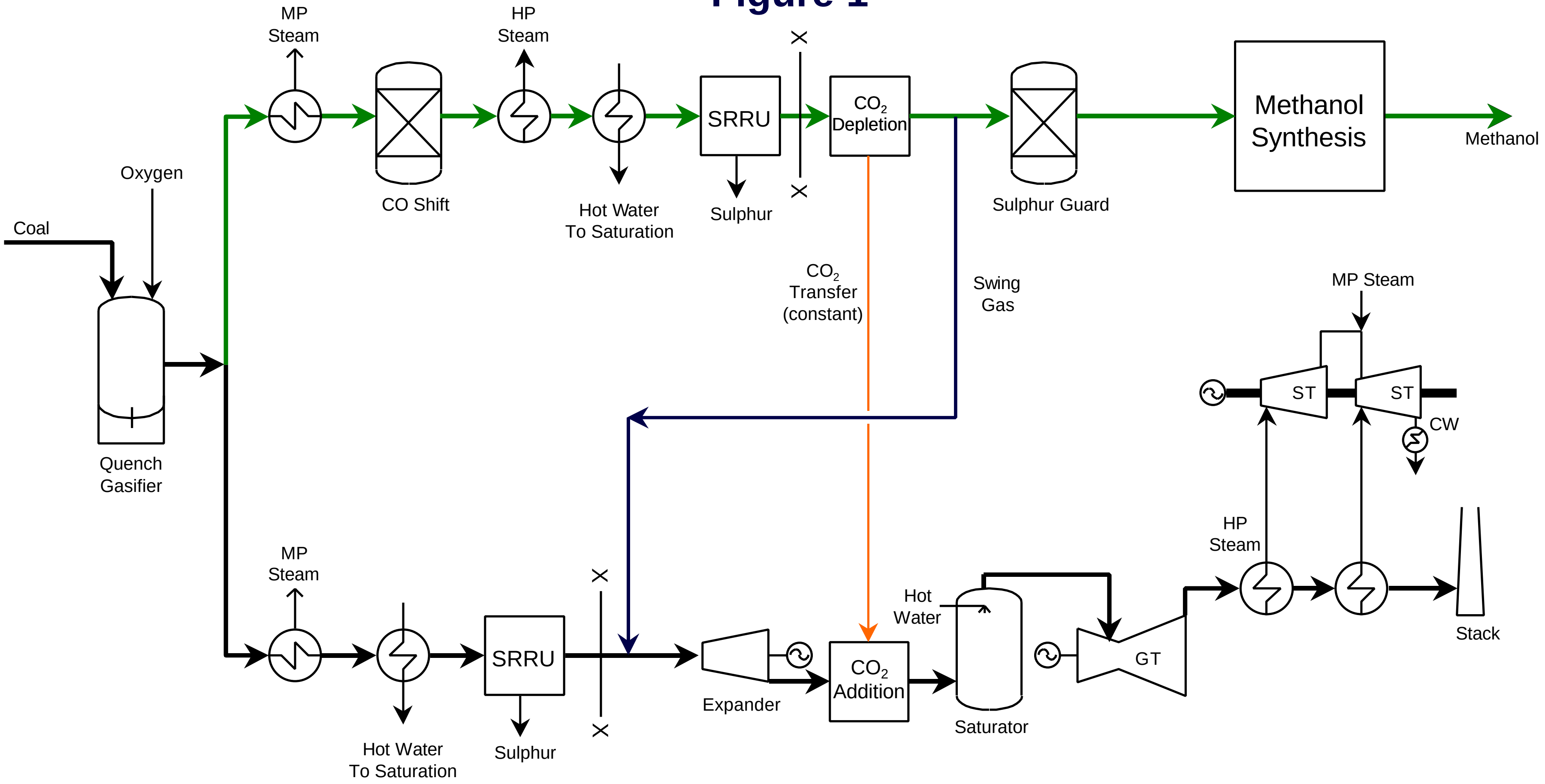
9 Conclusions

The paper presents an attractive means of using low-grade feedstock to supply both low cost and reliable peaking power and a competitively priced chemical normally produced from natural gas.

The most important feature is that none of the units or proposed operating regimes are novel. The whole concept of swing could be implemented without the need to develop any new processes or equipment.

JACOBS SWING TECHNOLOGY FOR METHANOL / POWER

Figure 1



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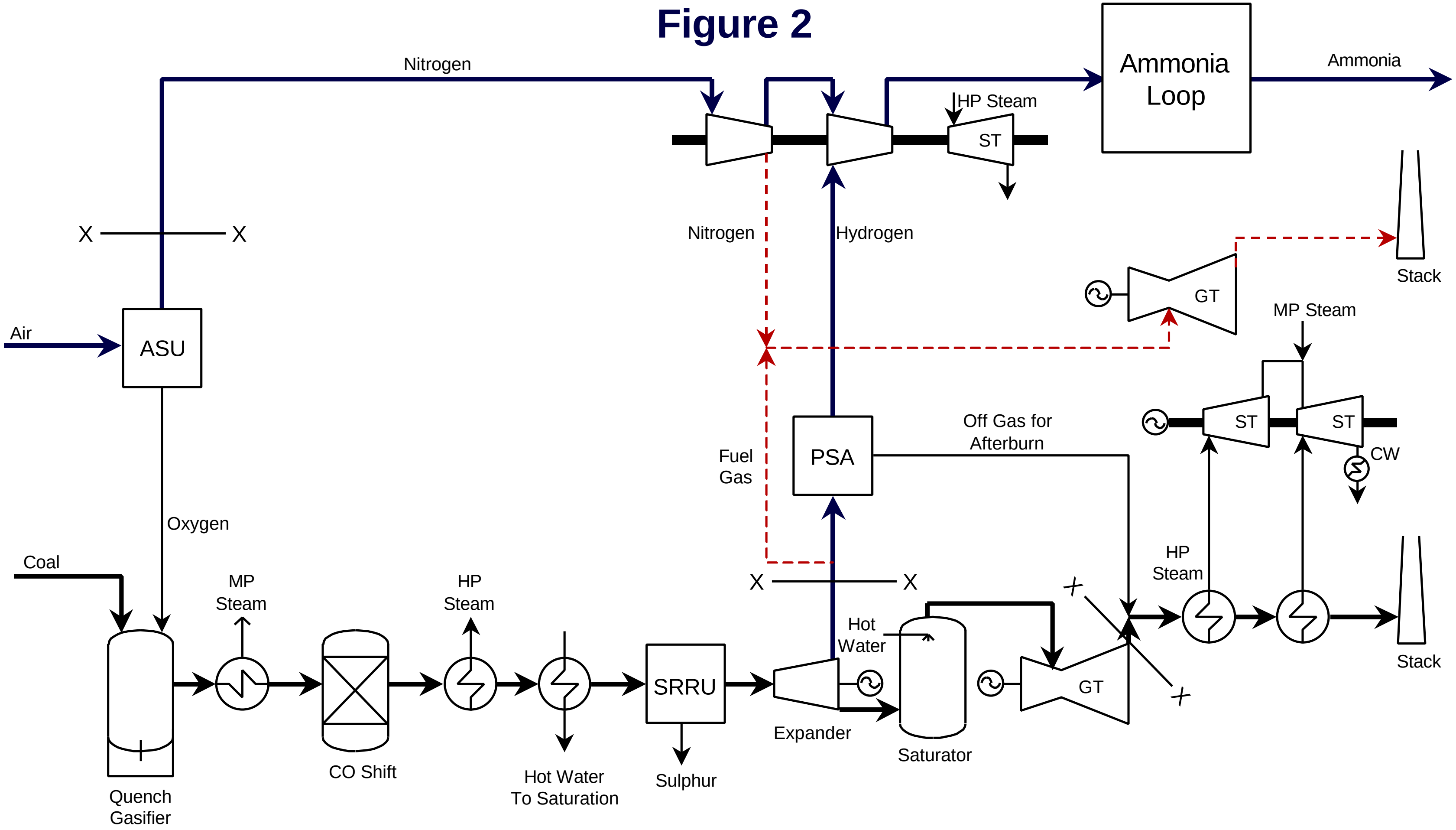
JACOBS SWING TECHNOLOGY FOR AMMONIA / POWER

Figure 2



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