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Progress toward Commercialisation of EGPT: A New Technique for Realising Carbon-Free Energy Regeneration and CO_2 Savings

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ABSTRACT

The EGPT (Expanding Gas Power Transformation) concept has progressed from early investigations in 2008 to the situation today where commencement of pilot plant installations is imminent. Patents relating to the technology have been awarded and are in force in the great majority of countries with significant natural gas consumption.

The possibility of generating power from natural gas pressure letdown has been noted in numerous communications dating back at least to the 1970's. A brief overview of the methods put forward to exploit this resource is presented. Despite the number of proposals which have been put forward with the objective of harnessing this resource, the vast bulk of letdown stations still use the traditional recipe based on the J-T regulator valve with boiler preheat of the incoming gas stream.

The factors which have impeded the development of pressure letdown energy are examined from both technical and commercial perspectives. The main obstacle from a technical standpoint is identified as the need for much increased gas heating when the gas is expanded at high efficiency for power production. From a commercial standpoint there are two principal impediments: the capital cost and the operating cost of a power producing pressure letdown station when compared to the standard configuration. A third source of technical and commercial difficulty has been the complexity of some of the arrangements proposed and the need for extraneous equipment and consumables at the pressure letdown site.

Like most of the other methods proposed to exploit gas expansion energy, EGPT makes use of an expander-generator. Unlike any of the other methods proposed, the EGPT approach makes use of ambient thermal energy upgraded by a new type of heat pump using a transcritical cycle to produce the necessary gas warming at high efficiency. Independent investigations of the concept carried out in three different countries by different teams have reported similar and highly positive findings. The studies indicate that the EGPT system has potential for cost effective applications ranging from small low-pressure letdown stations producing tens of kilowatts up to large high-pressure stations producing up to tens of megawatts.

All applications of EGPT technology generate carbon-free power, avoid wasteful consumption of gas and provide substantial reductions in CO_2 emissions. In some particular cases additional synergies provide even more benefits. The particular merits of applications at gas fired power stations where EGPT can provide inlet air cooling and at island letdown stations where EGPT installations could provide power for hydrogen production are examined.

The paper concludes with an overview of progress toward pilot plant installations to demonstrate the technical and commercial performance of an exciting new clean energy technology.

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1. INTRODUCTION

Pressure reduction in natural gas pipelines is usually accompanied by a wasteful consumption of gas. Gas generally emerges cooled from the throttling valve as a result of the Joule-Thomson process. This cooling is generally undesirable, and in most cases it is counteracted by warming the gas stream prior to its depressurisation...most commonly by burning a small portion of the gas in transit. Use of the throttling process to reduce pressure generally makes gas heating necessary. In addition, pressure reduction by throttling valve also destroys the opportunity to recover the very substantial quantity of expansion energy available from high pressure natural gas streams.

The potential for energy regeneration in natural gas pressure letdown stations has been widely appreciated in the industry for at least four decades. A broad spectrum of methods for exploiting this resource has been described. A generator-coupled gas expander is used in virtually all of the methods proposed. The differences in the proposed methods are found in the treatment of the thermal aspects of the process. These approaches are summarised and the challenges faced by each of them are noted.

The Expanding Gas Power Transformation (EGPT) approach to the problem puts forward an innovative method capable of dealing with many of the problems which have thus far inhibited any substantial commercialisation of pressure letdown energy regeneration. The salient technical features of the EGPT approach are summarized. The steps taken toward commercialisation are chronicled and the near term outlook for further advancement of the technology is presented.

2. NATURAL GAS PRESSURE LETDOWN: AN ENERGY RESOURCE WORTH DEVELOPING

Gas expansion energy is available in any situation in which gas pressure is reduced as part of a continuous process. The worldwide network of natural gas pipelines with its myriad pressure reduction stations presents what is in all likelihood the largest single opportunity for gas expansion energy regeneration. Estimates of the ultimate resource size have been made in earlier studies[1] using the global total natural gas consumption[2] and an assumed three-stage pressure letdown sequence to a final pressure of approximately 6bar. Assuming isentropic expansion and pre-expansion heating sufficient to maintain the exiting gas temperature at 4ºC, a theoretical wheel power figure of almost 40GW is obtained from the global natural gas consumption figures of recent years. When this figure is derated to allow for realistic energy conversion efficiencies, to exclude unsuitable pressure letdown sites and to allow for a plausible market uptake of the technology, the potential for carbon-free energy generation from gas expansion energy is still of the order of 5GW.

In addition to its sheer size, this renewable energy resource has a number of attributes which are highly desirable indicators of prospective commercial viability.

1. High duty factors. Many pressure letdown stations have high year round utilization. This is in part due to the fact that gas distribution networks are designed to be cost effective from the outset. Also the fact that natural gas is an energy utility ensures that the infrastructure which carries it will stay in regular use.
2. Advantageous time domain coupling between the resource (gas flow) and the electricity demand. This correlation, especially pronounced where cooling forms a substantial part of electricity demand, makes power derived from gas expansion easy to accommodate on the electricity grid. This advantage is more readily apparent in contrast to conventional wind power which has little correlation with typical diurnal activity patterns.

3. Favourable geographical dispersion. Natural gas pressure letdown stations are, by and large, located near industrial and residential user concentrations. Access to the electrical grid is generally easier and other options for storage or conversion of the generated power are most readily implemented.
4. Pipeline industry standardisation. The transnational nature of much of the natural gas pipeline transport and distribution network ensures that the infrastructure has a high degree of similarity. An important consequence of this is that the design of equipment for this application can be focused on a series of factory built modular assemblies which can be used to cater for a large part of the worldwide market.

In view of the above generally favourable attributes of this energy resource it is natural to enquire why its development has not progressed more rapidly to date.

3. CURRENT APPROACHES TO HARNESSING GAS EXPANSION ENERGY

The one element common to all of the approaches under active development is the generator–coupled gas expander. In the majority of cases the expander is a radial inflow turboexpander. Screw expanders and other expansion devices have been applied, particularly to small systems where turboexpanders may be either unavailable or are difficult to justify on economic grounds.

The expander-generator is the element needed to extract mechanical work from the expanding gas flow. However, this is not the only technical problem to be solved. Any power-producing expansion of a compressible fluid gives rise to an intense chilling of the gas over and above the Joule-Thomson cooling which accompanies the more common throttling process used in conventional pressure letdown stations. For the same reasons that J-T cooling is routinely counteracted by preheating the gas stream with combustion derived heat, the severalfold more intense chilling which accompanies high efficiency turboexpansion must also be offset by an appropriate supply of heat. It is the approach taken to deal with the concomitant thermal problem that most often differentiates among the various methods used to exploit gas expansion energy.

3.1 Post-expansion heating

Delaying the gas warming operation until after the expansion process has one major advantage, namely that the local ambient environment can be used to provide much of the required heat input without fuel consumption. This advantage is accompanied by a number of adverse effects, including gas stream problems and equipment complexity.

A typical city gate pressure letdown station will often have a working pressure ratio between 2.5 and 3.5. A pressure reduction of this size in a high efficiency expander can produce exit gas temperatures as low as -60ºC. Such temperatures can produce condensation of heavier hydrocarbons as well as formation of hydrates. They can also pose hazards for any nonmetallic components in the adjoining portions of the pipework. Letdown energy recovery strategies using post-expansion heating may require multiple pressure reduction steps to mitigate the problem of low exit gas temperatures. Depending on the gas composition at the station under consideration, these systems may also provide for dosing of the gas stream with condensation inhibitors. Subsequent post-warming recovery of the inhibitors may also be required. The effect of dealing with all these undesired side effects is a complicated support structure, a likely ongoing requirement for consumables at the site and substantial added capital cost.

The final point to be noted in this connection is that the motive power obtainable from the expanding gas stream using post-expansion heating is considerably less than when using preheating. A discussion and illustration of this effect is given in Ref. 1.

3.2 Preheating using gas boiler or waste heat

This configuration is the closest to the standard boiler and throttle valve pressure letdown arrangement. In this configuration the preheater is upsized to provide the considerably higher temperature needed to counteract the cooling accompanying power producing pressure letdown. Compared to a conventional pressure letdown station, this arrangement could consume between three and seven times as much gas to maintain the same exit gas temperature. The additional gas consumption is a requisite for the harvesting of the gas expansion energy. The ratio of the power produced to the preheating power input is not to be interpreted simply as a thermal conversion efficiency since the gas stream pressure drop is an essential ingredient in the process. The subtlety of this point is illustrated by the discussion of it in some detail[3] in a recent publication.

The economic viability of this type of system is critically dependent on the relative prices of gas and electricity. While the gas to power conversion efficiency may be comparable to or even better than that of modern CCGT plants, the capital cost per kW will be considerably higher and the amortization time can be expected to be correspondingly longer than for a large thermal power plant. The environmental credentials of this type of system will be similar to those of CCGT plants since fuel is consumed to produce power. Although the efficiency of this type of plant can be quite high it would be incorrect to describe the power produced as carbon-free electricity.

A similar arrangement is one in which the preheat needed for gas stream warming is provided by cost-free waste heat. In this situation there is no fuel taken from the gas stream. Instead there is the site-specific situation which requires a suitable coupling of the letdown station to the waste heat source. Here the necessary heat flux is free of cost, but a bespoke arrangement must be put in place to avail of it. The effect of this on the overall economics of the installation must be evaluated for each and every installation of the type which arises. This arrangement would normally have no greenhouse gas emissions associated with the electrical power produced. If a premium is placed on carbon-free power this could improve the prospects of systems using waste heat. The chances of finding a reliable, available and readily accessible source of heat are likely to be small enough to ensure that this option will remain a very limited part of the market.

3.3. Preheating with CHP

The most actively pursued development route is one in which the thermal problem is solved by siting an auxiliary Combined Heat and Power unit at the pressure letdown station. The basic idea is to use the waste heat produced by the CHP unit to supply the necessary gas preheating. The result is an ensemble which produces gas expansion power and CHP power with no surplus or shortfall of heat. The result is a considerably larger power output than the expander-generator alone and a cancellation of the thermal deficit. This approach has been investigated using a number of different types of auxiliary power units including reciprocating engines, microturbines and fuel cell units.

More fuel is consumed in this type of system than in one using direct combustion preheating. At the same time more power is produced by the combined output of the two sources than of the expander-generator alone. A system in which the thermal surplus and the thermal deficit are matched will have a power output roughly double that of the gas expansion generator alone. The capital cost of the aggregate installation is clearly expected to be substantially larger than for the directly heated arrangement described in the preceding section.

The energy and environmental effectiveness of the system will depend on the fuel and power prices which apply and the performance of the CHP units used. Both CHP fuel efficiency and per-kW cost figures tend to improve with increasing unit size. This tends to favour the application of this technology to large pressure letdown stations. A detailed simulation of the performance of a system of this type has been carried out[4] using actual flow and pressure data from a selected letdown station. The environmental performance of the system will depend on the type of fuel used and the CHP efficiency.

4. EXPANDING GAS POWER TRANSFORMATION (EGPT)

The EGPT process is an innovative approach to the exploitation of gas expansion energy which preserves the carbon-free status of the energy produced. It is instructive to compare and contrast this technology with each of the previously described approaches.

Like the post-heating method, EGPT makes use of ambient thermal energy to provide gas warming. In contrast EGPT uses preheating and thereby avoids the major difficulties associated with the post-expansion heating method, including the reduction in power generation.

EGPT shares the simplicity of the direct combustion preheating method but avoids its major drawback, namely the large consumption of fuel gas and associated greenhouse gas emissions. EGPT energy is completely green, there is no fuel burned at the letdown station. The site CO_2 emissions are zero during normal operation of the system and the overall effect of the system in operation is CO_2 negative.

Like the CHP method, EGPT makes use of an auxiliary thermodynamic assembly to deal with the heat deficit produced by turboexpansion. In the EGPT formula the auxiliary assembly is a heat pump using a transcritical cycle to upgrade ambient heat at high efficiency to the temperatures needed to counteract turboexpansion cooling. Instead of burning a fossil fuel to provide motive energy and heat, the EGPT process uses a portion of the expansion-generated power to supply the heat pump. There is no fuel diverted from the gas stream or supplied to site from other sources. Again, there are absolutely no greenhouse gas emissions from the EGPT system in normal operation and the surplus energy produced by it has zero carbon content.

4.1 EGPT Application Strategies

Full economic development The application strategy adopted at the outset in the great majority of cases is to identify the equipment complement which will result in the fullest development of the energy regeneration potential at the PLD station being studied. Depending on the actual load pattern of the station, a maximum output equipment selection may or may not be the economically optimum solution for the site. The criterion most often used to carry out this exercise is the net present value (NPV) of the project. The quantities involved in making this determination are illustrated in Figure 1.

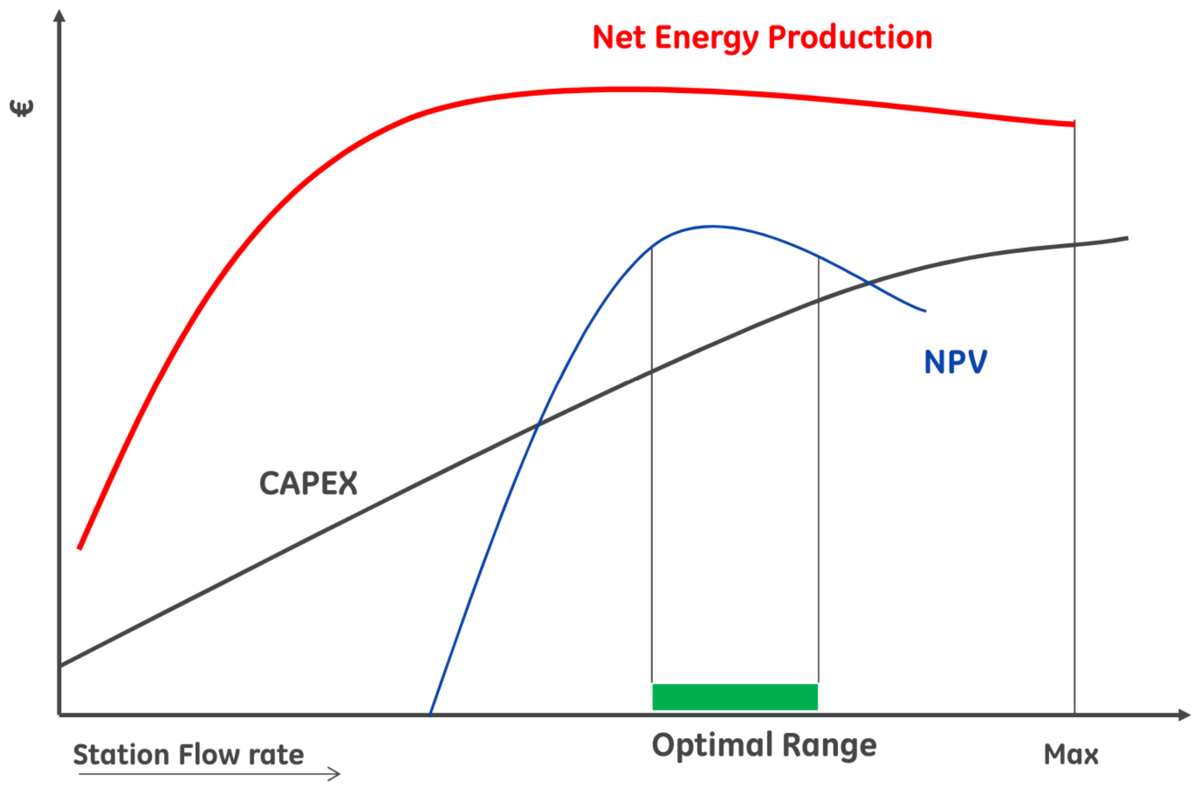

Figure 1: Selection of Optimum Equipment Complement

This general approach will be the strategy adopted in the great majority of applications.

Island mode development There are situations where full economic development of the gas expansion resource may not be appropriate. One such situation is where it may not be possible to export the surplus generated power to the grid. This could arise in the case of an isolated PLD station not served by any electricity supply, or by a supply far too small to accommodate the prospective export of power. The first option in this situation is to use a downsized EGPT system designed to generate only enough power to cater for the site electrical load. While this is a straightforward exercise in technical terms, it may or may not result in an economically attractive application. If an island mode development is found to be economically viable then the downsized EGPT option can offer an elegant way to arrive at a zero energy PLD station.

Energy Storage Another option which can be considered in cases where export of power to the grid is impractical or unprofitable is to use the surplus power for the generation of hydrogen. This rapidly developing technology may offer a number of ways to monetize the surplus energy. If an economically feasible way can be found to market the carbon-free hydrogen it may become possible to carry out a full economic development at sites where grid export of the surplus clean energy is not an option.

PLD Stations supplying gas fired power plants Letdown stations serving gas-fired power plants can provide an additional benefit to the site: free cooling. If the pressure ratio at the PLD station serving the power plant is substantial, the refrigeration capacity of the EGPT heat pump can supply a considerable portion of the chilling needed for turbine inlet air cooling. The net effect of combining an EGPT system with turbine inlet air cooling is to effectively add the power used to drive its heat pump to the output of the power plant. This happens because the heat pump offsets all or part of the refrigeration needed for turbine inlet air cooling. This benefit can provide a significant enhancement to the economic performance of an EGPT system installed on a power plant PLD station which requires inlet air cooling.

4.2 Feasibility Investigations and progress toward commercialisation

Independent studies of the EGPT configuration have been conducted by its developers and by industry specialist groups in recent years. Research teams based in Ireland, Italy and Denmark have looked at the technical and commercial potential of this new technique for saving on heating fuel and producing carbon free electricity. The studies were carried out initially by EGPT and subsequently by GE Oil&Gas[5] under a cooperation agreement to commercialise the technology. A totally separate study was conducted by the Danish Gas Technology Centre[6].

Each group focused its analysis primarily on the gas transmission/distribution infrastructure and regulatory situation in its respective home market. The results obtained in all of these investigations produced highly positive results. Economic analyses indicate prospective economic payback periods ranging from about 7 down to 3 years when applied to sites with favourable flow patterns. The spread in the economic viability figures was primarily due to variations and uncertainties in the prices applicable to the carbon-free surplus power produced by the installation.

A useful way to segment the market for pressure letdown (PLD) station energy regeneration systems is to examine the three broad pressure domains in which they operate. A three-zone breakdown of the relevant pressure domain is illustrated schematically on a pressure-enthalpy diagram for methane in Figure 2 below. This segmentation is not strictly defined in terms of specific pressure values since national and regional practices vary. It is presented to allow the gas expansion energy market to be viewed as a composite of several distinct subsections.

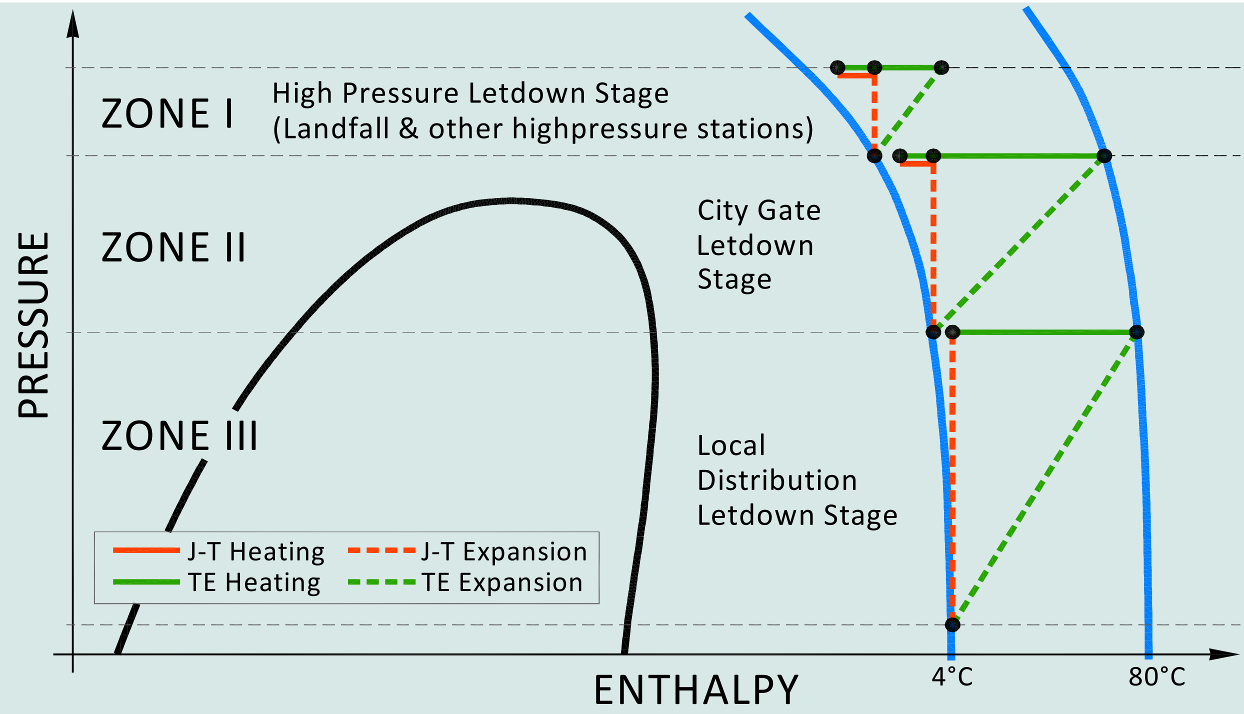

Figure 2: Natural Gas Pressure Letdown Zones

Zone I stations generally have the highest flow rates and the most stable short term flow patterns. Inlet pressures are typically upwards of 100Bar and letdown pressure ratios typically around a factor of 2. Stations of this type tend to be sited at the landfall end of a subsea pipeline or at the terminus of a high pressure pipeline supplying gas from a remote field. This kind of station could provide gas expansion energy resources in multiples of 5 megawatts. These favourable attributes must be set against the fact that such stations are relatively few in number and do not lend themselves readily to standard module solutions. Applications of this type will usually require specific engineering design input and site-specific subassemblies.

Zone II stations are often described as city gate stations. These stations are, as the name implies, usually found close to major load centres. This type of letdown station could serve an urban residential area, a large industrial user, or some combination of the two. Inlet pressures range between 50Bar and 70Bar with pressure letdown ratios generally between 2 and 3.5. This type of PLD station may have a wide range of flow rates and offer gas expansion energy potentials in the decade between 250kW and 2.5MW. This type of station is far more numerous than the Zone I type and is likely to be a promising type of candidate for standardised preassembled solutions.

Zone III stations are those which carry out the last pressure reduction for which the harvesting of gas expansion energy can be realistically contemplated. These stations are by far the most numerous on any network. Gas flows are small and may have large fluctuations. Stations subject to large fluctuations are unlikely to be candidates for energy recovery systems. The inlet pressures at which they work may be between 40Bar and 20Bar with letdown pressure ratios ranging between 5 and up to 10. Leaving gas pressures are usually in the range of 4 to 6Bar. The scope for gas expansion energy regeneration ranges from about 120kW down to as little as 20kW per site. Gas preheating is often considered unnecessary in conventional throttling PLD stations if inlet pressures are below about 20Bar due to the very small degree of J-T cooling encountered (Refer to Fig 2 above). Fully preassembled modular units are essential for addressing this market segment. The other relevant consideration is the energy conversion efficiency available for equipment in this size range. Quoted expander isentropic efficiencies are more commonly in the region of 65% rather than the 85% achievable with larger equipment.

The feasibility investigations noted above have focused on different gas pressure zones. The study by DGC concentrated on the small PLD stations on distribution networks, mostly located in Zone III. The GE O&G investigations have taken as their primary focus the city gate range of Zone II while the EGPT high level studies examined Zones I and II. Taken together, the preliminary studies carried out to date indicate that the technology is applicable and has positive economic prospects over most of the pressure range used in gas transmission and distribution.

The pertinent conclusions emerging from these investigations may be summarised as follows:

1. Expander-generator units covering the full range of flows at pressure letdown stations are available from commercial sources.
2. Transcritical heat pump units with thermal outputs up to approximately 2MW are available from commercial sources.
3. The principal components currently available commercially offer adequate capacity to cater for the requirements of letdown Zones II and III with minimal requirements for multiple modules. Zone I applications are likely to require multiple heat pump modules.
4. The most important single determinant of economic viability of the system is the price applied to the exportable carbon-free energy produced by the system. The EGPT configuration is the only preheat system which supplies genuine carbon-free power from gas expansion..
5. Investigations across an entire national gas distribution system have established that 35-40% of small scale PLD stations are technically suitable for EGPT installations.
6. A technical-economic evaluation tool has been developed to allow hourly PLD station pressure and flow data to be combined with expander-generator characteristics and heat pump performance in order to select the optimum equipment complement and predict economic performance. The system is illustrated schematically in Figure 3 below.

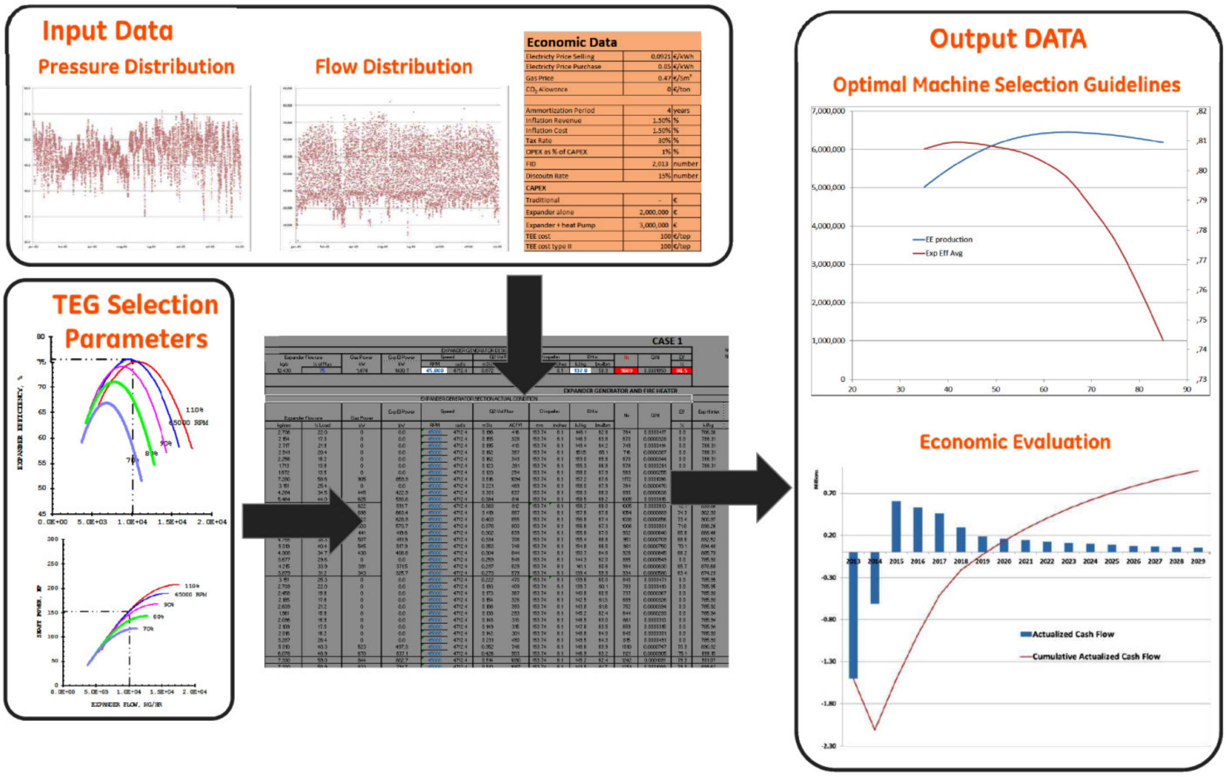

Figure 3: Hour by Hour Performance Tool

7. Analyses carried out for technically promising PLD stations have shown calculated payback periods ranging from 3 to 4 years when clean energy premiums apply. These payback periods are roughly doubled when no clean energy premium is available.
8. An additional economic incentive for the EGPT system will arise whenever reductions in CO_2 emissions are monetized. These reductions arise both from savings in avoided preheating gas consumption and from the displacement of conventional electricity by carbon-free energy from gas expansion via the EGPT process.

The next step in the commercial development of the EGPT process is the realization and testing of the technology in a series of commercial pilot installations at sites selected with the detailed evaluation tool now available. This evaluation process is now underway for a number of candidate sites already identified in preliminary surveys. Active ongoing efforts to identify additional sites with promising development prospects are progressing in concert with GE Oil&Gas under a cooperation agreement to bring the EGPT technology to the gas transmission/distribution market.

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