The Reliability of Integrated Gasification Combined Cycle (IGCC) Power Generation Units

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Introduction

The Integrated Gasification Combined Cycle (IGCC) has for many years been regarded as a technology with considerable potential for power production from coal and other fuels at high energy efficiency and with greatly reduced emissions in comparison with conventional combustion technologies. The inherent ability to capture CO_2 with substantially reduced energy and cost penalties has increased the focus on IGCC in the context of various CO_2 reduction strategies.

Beginning in the mid-1990's, a number of IGCC plants were built and operated so that a base of experience has begun to develop. These plants have confirmed the exceptionally low (SO_x, NO_x, particulate matter and, if required, mercury) or less toxic (waste water and slag) emissions from this technology. They have also confirmed the expectations of improved thermal efficiency, even if parallel advances in other coal-based technologies have not allowed this to be translated into the competitive advantage originally contemplated.

However, the reliability and availability of demonstration IGCC's has not been as high as desired by the power industry or as actually achieved by gasification plants operating in the chemical and other industries. The success of IGCC in realising its potential is therefore also dependant on establishing the reasons for this reduced reliability and taking appropriate steps to improve it.

This paper presents two interlinked projects aimed at supporting the improvement of IGCC reliability. The one project comprises the extension of SPS's existing ORAP (Operational Reliability Analysis Program) reliability, availability and maintainability (RAM) tracking technology from its existing base in natural gas open and combined cycle operations into IGCC.

The other project is using the extended ORAP database to evaluate performance data from existing plants. The initial work has concentrated on evaluating public domain data on the performance of gasification based power and chemical plants. This is being followed up by plant interviews in some 20 plants to verify and expand the database on current performance.

1. Current Perceptions

1.1 The Importance of Reliability

Reliability is every bit as important to the economic success of a plant as the capital and operating expenditure (CAPEX and OPEX). This is illustrated in Figure 1. The cost of electricity (COE) was calculated for a base case (100%) and then sensitivities for the efficiency, the CAPEX and the availability performed. The chart shows that the cost of electricity is more sensitive to availability and CAPEX than to the heat rate. Note that that all calculations were made with a constant fuel price.

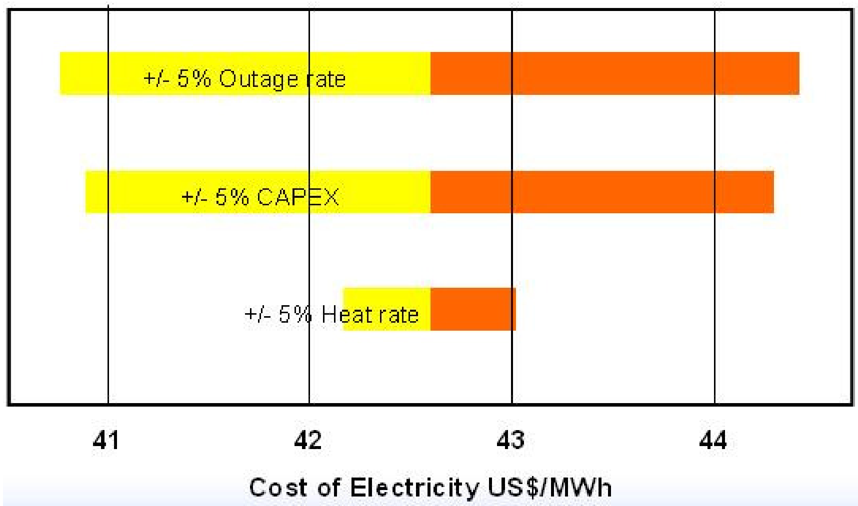

Figure 1 **Relative Influence of Availability, Investment and Efficiency on the Cost of Electricity**

The data in Table 1 shows availability and capacity factors for various type of power plant in North America over the period 1998 to 2002. The data has been gathered through the Generating Availability Data System (GADS) operated by the North American Electricity Reliability Council (NERC). As can be seen from these figures, availabilities for conventional PC boilers run just below 87%, natural gas fired CC plant at just under 90%.

Table 1 **NERC GADS Data 1998-2002 [from DellaVilla, 2004]**

	Service Factors (%)	**Capacity Factors (%)**	**Availability Factor (%)**
Gas-fired boilers	46.7	28.9	86.3
Oil-fired boilers	42.2	27.6	86.3
Coal-fired boilers	82.3	69.9	86.9
Aero-derivatives	4.6	2.9	91.9
Single Cycle GTs	5.0	4.3	91.1
Combined Cycle GTs	61.3	49.9	89.9

Looking at Table 2, which shows data evaluated from the ORAP database, one can see that the best performing group of natural gas fired combustion turbines achieve an availability of 94.5%. These figures put the 90% target typically required for IGCCs into perspective. This target is clearly ambitious, which as a development goal is certainly correct. On the other hand the data from existing coal-fired plants operating with conventional technologies shows that it may not be an absolute criterion for every application.

Table 2 **ORAP Data 1999-2004**

	Service Factor (%)	**Capacity Factor (%)**	**Availability Factor (%)**
Aeroderivative			
Utility	37.0	34.0	92.3
Non-Utility	50.6	47.9	94.0
E-Class			
Utility	16.4	13.1	92.5
Non-Utility	67.5	59.4	94.5
F-Class			
Utility	60.8	52.7	88.5
Non-Utility	54.8	48.0	91.3

1.2 Availability Reporting

The regular reports to Technology Conferences on the status of four IGCC demonstration units (Buggenum, Polk, Puertollano and Wabash) typically show annual on-stream times of around 80%. At the same time other operators show equally regular on-stream times of 96 to 98% (e.g. BP, Gelsenkirchen [Laege and Pontow, 2002] and Eastman Chemicals, Kingsport [Mook, 2004]). Although the latter two plants operate in the chemical rather than the power sector, and although these plants have specific features, which certainly contribute to higher availability (liquid feed at BP, spare reactor at Eastman), even a cursory reading of the available literature is sufficient to show that these features alone by no means supply a satisfactory explanation for the performance difference.

Published reports on plant operations vary considerably in their depth of detail. At the level of management statistics recent reports have been oriented towards the standard procedures developed by the Gasification Technologies Council, but at a more detailed level there is no common, agreed basis so that statistical evaluation of outage time becomes more difficult.

Furthermore there are a number of plants known to the author, where plant availability factors of over 90% are attained. These are however mostly commercial operations for which little public domain data is available.

2. The ORAP Database System

2.1 The Existing Process and Methodology

Strategic Power Systems, Inc. ® (SPS), is an information technology and reliability engineering company that tracks reliability and availability information through ORAP® (the Operational Reliability Analysis Program). ORAP is the largest most comprehensive reliability database in the energy market focused on gas turbines in both simple and combined cycle operation. The data reflects the operating experience of over 2,000 gas and steam turbines worldwide, across all manufacturers, product lines, and duty cycles. Further, the data represents the performance capability of both mature and advanced technologies.

ORAP is an automated system for monitoring the Reliability, Availability, and Maintainability (RAM) of both combustion (gas) and steam turbine driven plants, with the emphasis on the total plant, including condensate and feed water systems, power distribution, heat recovery steam generators, electrical generators, driven equipment, and all mechanical and electrical balance of plant systems. Standard Equipment Codes, developed by SPS under an EPRI contract, are the basis for the uniform reporting system across all product lines and OEMs. These codes provide reporting uniformity across all equipment types, providing a basis for combining or segmenting data at a component level across equipment manufacturers, size ranges, or other valid criteria. Additionally, ORAP is capable of obtaining data using the European KKS standard.

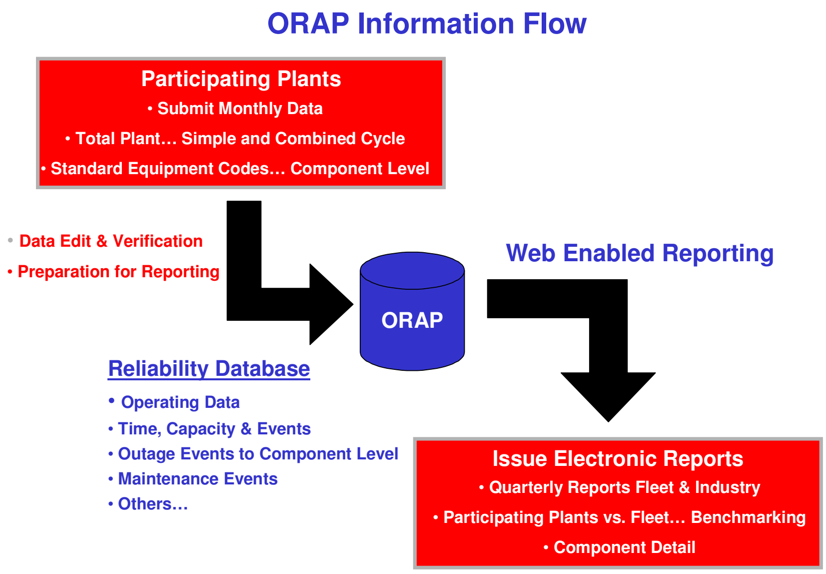

Figure 2 ORAP Information Flow

This product breakdown structure or equipment taxonomy is essential for recording event data (either/or forced or planned outages at the component level). Further, SPS ensures that the ORAP system adheres to industry measurement standards of RAM (i.e. IEEE 762 and ISO 3977-9). The information available in ORAP covers various applications, duty cycles, and plant arrangements for both simple and combined cycles.

Data from participating plants is submitted to SPS on a monthly basis, or in some cases on a "real time" basis, for engineering review and data validation, data acceptance according to relevant industry standards, and incorporation in the ORAP database. This process is illustrated in Figure 2.

An important aspect of the data collection process is to obtain event data (forced and scheduled outages) at the right level of detail to support an understanding of the causes of unavailability/unreliability. Standard event types, based on IEEE 762, were created and used by ORAP. ORAP data is collected and reported from the "bottom-up". In other words, ORAP allows the engineer to see the impact of a component failure – including shared equipment, up to the system, up to the plant. This level of detail is essential for effective reliability analyses.

The ORAP information system then converts the data into RAM statistics such as: detailed system and component outage factors, failure rates, starting unreliability, service factors, time to repair, and other outage factor information. Additionally, ORAP provides outage description details, outage causes, failure modes, and corrective actions taken (as supplied by the plant operator). This information provides the basis for assessing plant, system, and component RAM performance, as well as, for developing RAM values to assess improvement. It should be noted that the data reported to the SPS ORAP system from various utility and co-generator participants is reviewed for accuracy, verification, and then entered into the database. The information is not modified by SPS unless the participating customer concurs with and accepts the recommended change. SPS engineers work with each participant to ensure data accuracy and completeness. This ensures that SPS ORAP data reflects the specific operational, failure, and maintenance history for each component in the database, and therefore, the availability and reliability performance measurements are valid indicators of unit experience and capability.

2.2 Extension of ORAP to IGCC

SPS is currently extending the coverage of the ORAP System to IGCC Plants. Since the infrastructure for tracking RAM data on the combined-cycle plant at the component level already exists, the extension of ORAP to the entire IGCC plant only requires that the Gasification Plant equipment be reviewed, and Equipment Breakdown Structure Codes developed for this equipment. At this point, initial EBS Codes for the gasification plant equipment have been developed, to at least the system level. These codes are further being refined down to the component level.

The ORAP Process and the codes developed provide the means for entering and evaluating the RAM Data on IGCC and Gasification equipment developed as part of this assessment. In addition, the ORAP Process as described above will be extended to IGCC Plants to provide a means of tracking RAM Performance on an ongoing basis. All of the event information that has been extracted through a review of public domain literature has been entered into the ORAP System.

3. Historic Analysis Project

3.1 Project Goals

The aim of the project is to gather data from a representative selection of IGCC and other gasification plants and prepare a systematic evaluation of reliability data down to the component level. The database and evaluation aim to provide realistic guidance on expected availability to all parties involved in future projects (investors, technology and engineering suppliers, financiers and authorities). The aim is to highlight systematic weaknesses and/or avoidable problem areas.

3.2 Project Methodology

The project is being executed in four stages:

i.) Data capture of public domain or other readily accessible information on the reliability performance of existing IGCC and other gasification plants. The data is stored in the ORAP databank. Evaluations from the databank at this stage are performed specifically to prepare the questionnaires required for the second stage. This part of the project is now complete.

ii.) In the second stage, which began late last year, interviews are conducted with the operators of IGCC and other gasification plants. This involves clarification and validation of the data from the first stage and well as gathering data not available in the public domain.

iii.) The full, validated data will be evaluated to determine the contribution of different parts of the plant to reliability statistics, both at the unit and component level.

iv.) It is planned that the statistical data on plant failures be used as input to develop an expected availability for one or more typical IGCC configurations.

3.3 Operating Plants

The total number of IGCC's is still very limited worldwide, even if one extends the definition to include any syngas fuelled combined cycle unit. On the other hand there are many gasification plants in the chemical and refining industries, which are of a size suitable to feed an IGCC in the range 150-450 MW. The validity of the statistical results can be improved by including some of these plants in the study. The authors have identified 25 plants, which are considered suitable for inclusion. These comprise:

- 14 IGCC's, of which 8 have solid and 6 liquid feedstock. A number of these plants are polygeneration units, where part of the syngas is used for purposes other than as gas turbine fuel.
- 11 other gasification plants, (3 solid, 8 liquid feed) most of which produce ammonia or methanol. These plants will extend the data base in the air separation, gasification and gas treatment areas. An additional feature of these plants is that many of them include a CO_2 removal step, and in those cases with on-site urea production, further compression of the CO_2 to about 150 bar.

Contact with these plants to secure their participation in the project is ongoing. Some visits have already taken place.

4. Some First Impressions

Already with an analysis of the public domain literature it is possible to draw some preliminary conclusions. In what follows a number of the principle units in the IGCC are highlighted. These analyses have been made purely on the basis of public domain data, principally as outlined in the literature citations list at the end of this paper.

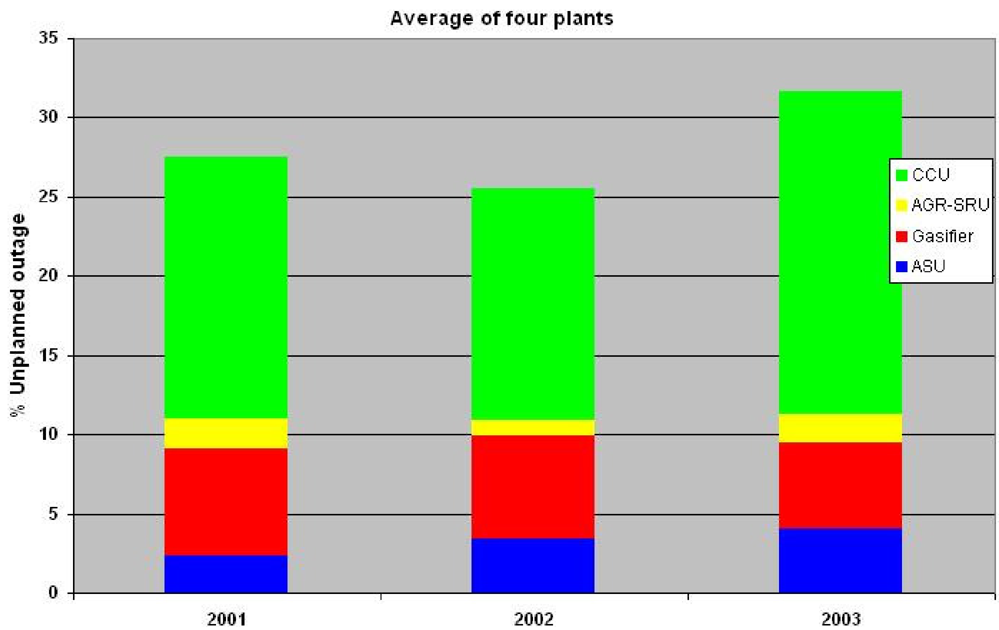

Figure 3 Overall outage time by main plant section

The best set of data (in the statistical sense) over a reasonable period which is available in the public domain is that over the three-year period 2001-2003. The four plants mentioned in section 1.2 above reported at a consistent level of detail over this period. The results are consolidated in Figure 3, which divides the average outage time for these four plants each year into the four major subsections of the IGCC plant, namely ASU, gasification, gas treatment (acid gas removal and sulphur recovery) and combined cycle unit. The outage time is expressed as a percentage of 8760 hrs.

The most remarkable feature of this result is the high contribution to overall outage time contributed by the combined cycle unit. These four main sections are commented upon individually.

4.1 Air Separation Units

Oxygen is the lifeblood of any gasification process, so that it goes without saying that a high reliability of the ASU is required. Generally in the industrial gas industry these units provide a reliability of over 99% and an overall availability of over 98%. Figure 4 shows the performance of some air separation units in IGCC service over the last few years as documented in various conference papers [McDaniel and Hornik, 2000 and 2002;, Keeler, 1999, 2002 and 2003; Mendez-Vigo, 2001, 2003 ; Wolters, 2003; Yamaguchi, 2004]. Clearly these general industry figures have not been consistently achieved in these plants and with this performance from the ASU the overall availability suffers dramatically.

There are a number of lessons to be learned from these failures. In two cases there was a failure of the rotor of the air compressor. In both cases there was no spare rotor on site, so that the damaged part had to be returned to Europe from Japan and the USA respectively for repair. This cost in both cases an outage of about three weeks. These outages could have reduced to about one week if a spare rotor had been available on site as an "insurance spare", a concept adopted by a number of plants, with which the author has been associated. The cost is estimated at around US $ 600 000.

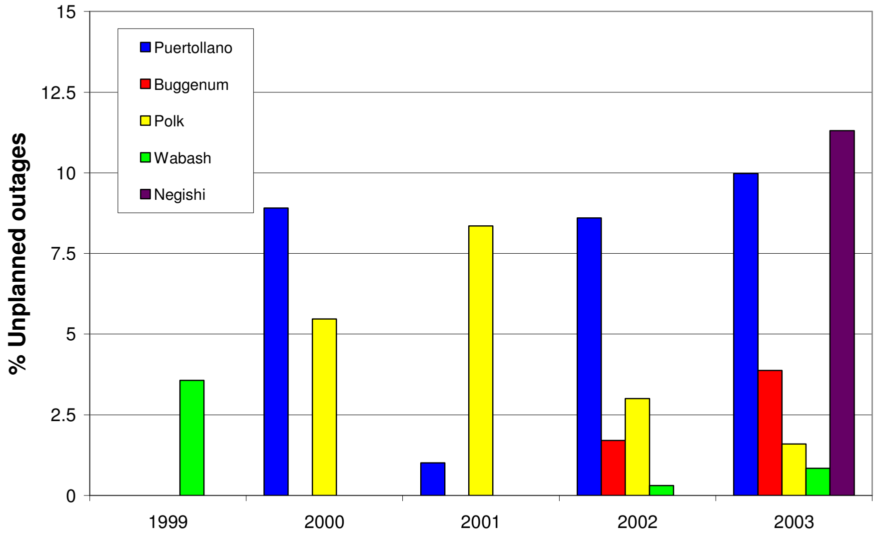

Figure 4 Outages of Air Separation Units

In two other cases, there was a leakage inside the cold box, which necessitated entry and repair. This required in both cases removing the perlite to make the repair and replacing it afterwards. This is also a task requiring around three weeks in all. In one of these cases the problem was traced to faulty welding on an instrument line. In another case known to one of the authors the leakage was from a flange located inside the perlite area. Such failures will tend to occur during the early years of a plant's life. Obviously weld failure is a residual risk, whatever precautions are taken. Nonetheless there are a number of possibilities to minimize the potential for leakages after filling the perlite. Flanges, which are subjected to tension when put into the cold, operating state, can be designed out of the perlite area and located in a special chamber. This chamber can be insulated with a fibre insulation material, which permits much easier and quicker entry for repair, thus reducing the outage time. Again such a precaution is standard in those plants with which the author is familiar.

4.2 Gasification Area

Figure 5 shows the average unplanned outage for the gasification area, which has been taken as encompassing the typical licensor scope of feed system (whether slurry or dry feed), the gasifier itself, slag removal and disposal, syngas cooling, particulate removal (again wet or dry) and the black water circuit. The figure shows the same three year period with data averaged over the four plants considered. Each of the subsections is shown up separately in the histogram.

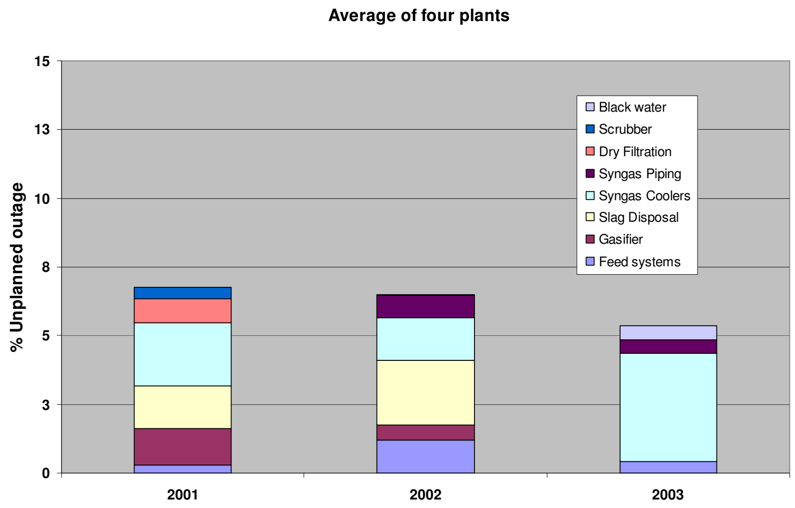

Figure 5 Forced Outages Attributable to Gasification

Interestingly the reactor itself is a relatively minor player – although for the refractory lined systems it will show up more heavily when planned outage is added in. On the other hand, the syngas cooler has been the most persistent item in this area. Further analysis has shown leakage and fouling to be roughly equal contributors to outage time.

4.3 Acid Gas Removal and Sulfur Recovery

In contrast to the ASU and Combined Cycle Plants, the Acid Gas Removal and Sulfur Recovery Units present have caused little loss of production. The Figure 6 shows the overall average of 1-2% for four plants.

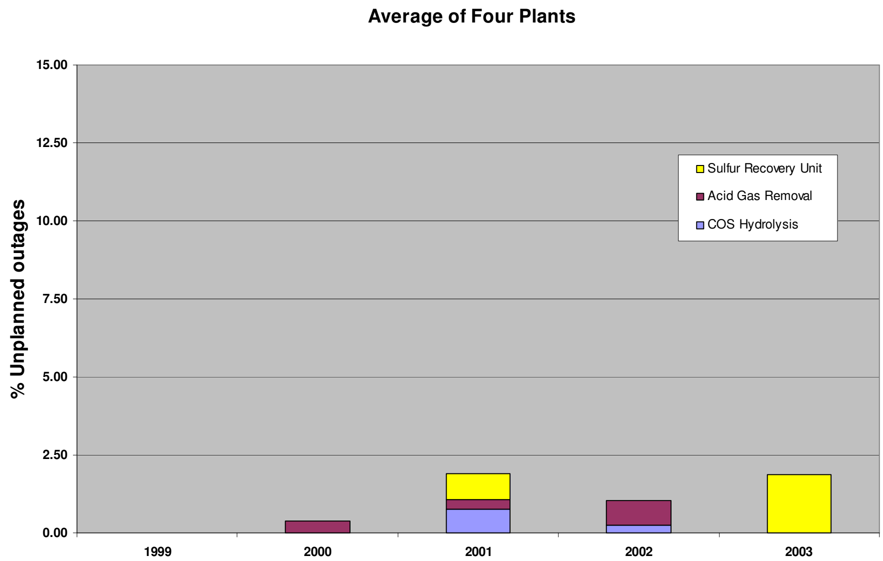

Figure 6 Outages Attributable to Acid Gas Removal and Sulfur Recovery

This includes a number of “lessons learned”, which should allow the production losses to be further reduced. Typical is the effect of formic acid carry over from the COS Hydrolysis into the AGR. Heat stable salts are formed causing corrosion in the system. This has been countered by the installation of ion exchange units to remove the heat stable salts. The increase in outage time in 2003 is largely due to a tubesheet failure in the Claus Unit of one plant that caused a 6.7% loss of production there. This was due to a recognized design error.

4.4 Combined Cycle

Figure 7 shows a similar report on lack of availability for the combined cycle plants. Note that this diagram is not complete since data has not been published for all these plants every year. Nonetheless there is enough information to demonstrate that a substantial portion of the lack of availability of existing IGCCs is attributable to the combined cycle unit (CCU) or power block. More important is to note that none of the production loss shown is attributable to the use of syngas as fuel. Earlier problems associated with this issue were resolved before the time period considered.

The 19 day outage in Wabash in 2000 is an unusual case since this was caused by expansion issues in the HRSG [Payonk, 2000]. The bulk of the outage time at both Wabash and Polk can be attributed to fleet problems associated with the early F technology machines [Holt, 2004]. Note that the data included for Wabash are estimates based on 90% of reported “Syngas not required” data, since detailed information on the CCU is not publicly available. This serves to underline the importance of the plant interviews in the second phase of the project, which are required to ensure a correct interpretation of the published data.

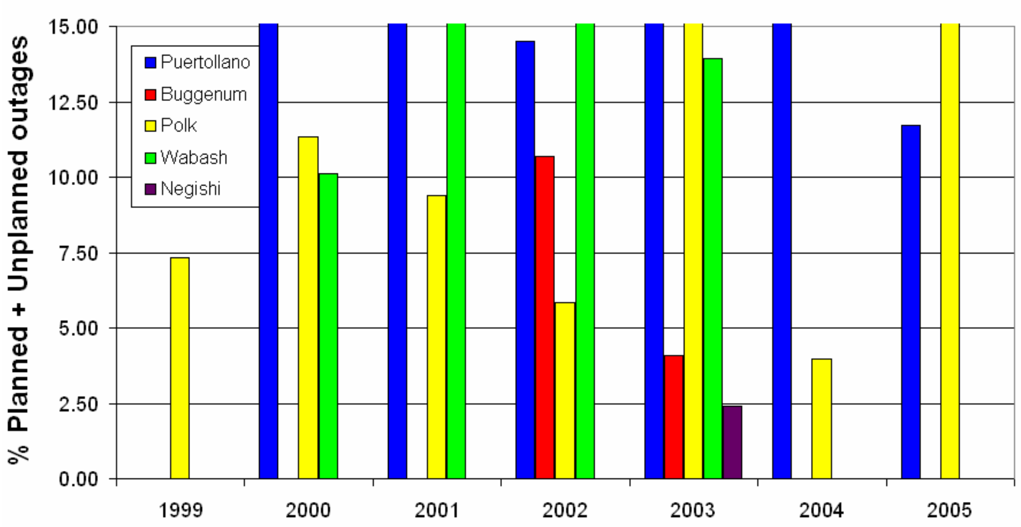

Figure 7 Outages Attributable to Combined Cycle

During the last year, we see continued production losses from the combined cycle section of the IGCC. In Polk damage to the air compressor rotor of the combustion turbine has caused an outage of 100 days [McDaniel, 2005]. In Puertollano there was a transformer failure in November 2004 which caused substantial loss of production continuing into 2005 [Garcia Peña, 2005].

Looking at the above, one might gain the impression that the CCU are an inherent weak point in the system. In one sense that may be true, in as much as they require more scheduled maintenance than the chemical processes such as ammonia or methanol synthesis. Because of this the chemical pants will always show slightly better figures than power plants. However the gap need not be anything like that described in the introduction. This is demonstrated by the performance of three oil-based IGCC units in Italy. The progress in availability as recorded in the public domain is illustrated in Figure 8 [Collodi, 2003 and Arienti, 2005].

Already during their second year of operation the gas turbines at both ISAB and Sarlux were running at over 80% on stream on an output basis. On a time basis the Sarlux on stream factor was actually over 90% in its second year. After some important modifications Falconara was running at over 90% in its fourth year. This is clearly not possible without the appropriate availability from the gas turbine. Interestingly enough, each of the three gas turbines in these plants is from a different manufacturer. The one thing they do have in common though is that they all have “E” class machines.

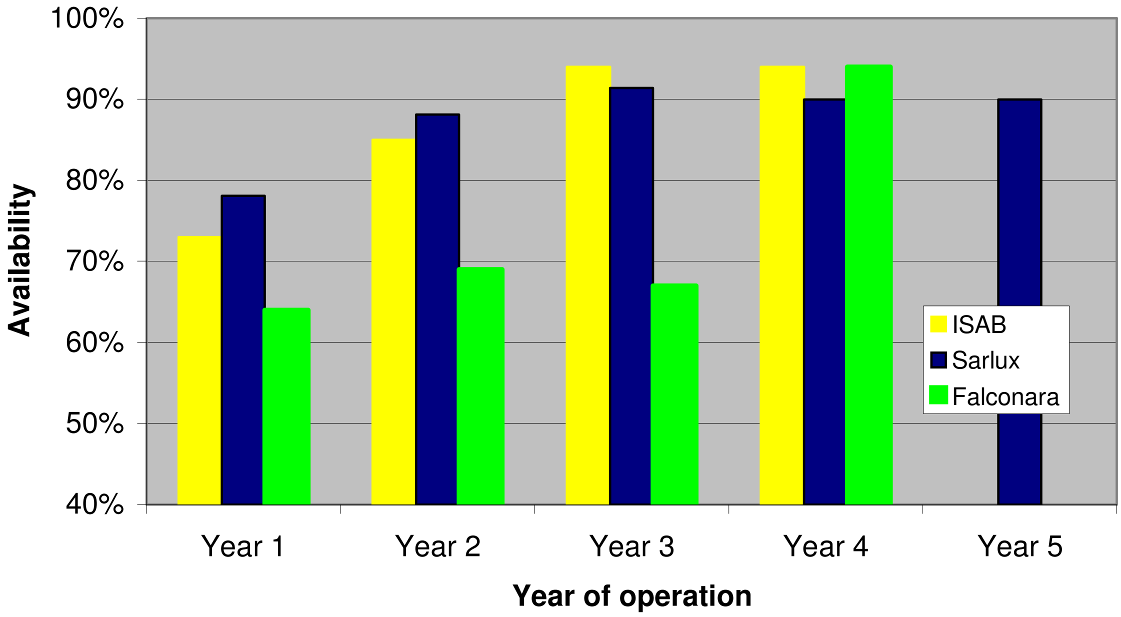

Figure 8. Availability ramp up in Italian IGCCs
(Sources: Collodi, 2003 and Arienti, 2005, Allevi, 2006, Jaeger, 2006)

ORAP evaluation of natural gas based machines has shown that the introduction of new, advanced technologies into gas turbines is not without its own availability risks. As can be seen from Table 2, the availability of the F class machines is about 3 – 4 points lower than E class machines [DellaVilla, 2004].

Given the economic importance of reliability for an IGCC discussed earlier, this raises the question as to whether it might be better for IGCCs to remain with E class turbine reliability despite the efficiency penalty involved. In one sense this would obviously be a retrograde step, but the mere thought is a challenge to OEM and operators alike to bring the F class availability closer to the benchmark set by the E class machines.

4.5 Preliminary Observations

One result of this analysis would appear to be surprising, namely the high contribution to outage time caused by units, which are generally considered "standard". On the other hand the surprise may not need to be so great. Over the years one of the authors has observed a tendency in both project execution and in operation and maintenance to concentrate resources onto units perceived to be "difficult" or "critical" to the extent that one might almost begin to talk about "neglect" of the "standard" units [Higman, 1994]. As one can see from the above, everything – even the instrument air supply – must considered critical and nothing can be left to chance.

From the public discussion it is clear that much effort is being put into improving the availability of gasification processes, even to the extent of including spare gasifiers in the line up. The current work shows that unless due attention is paid to the infrastructure into which the gasifier is built, these efforts will be wasted. In many cases the infrastructural improvement can be achieved without any great research and development, but it will require attention to detail at every stage of the life of a project.

5. Project Schedule and Status

This project is currently being conducted by the authors on an unfunded basis. The schedule is therefore relatively extended. Evaluation of public domain data is largely complete. Nearly 200 events from this evaluation are now in the ORAP data bank. Some plant interviews have already been conducted. More are planned between now and the end of the year. The full evaluation, report and prediction model are planned to be completed late 2006. Preliminary information is being made available at suitable conferences such as the present one over the intervening interval.

6. Conclusions

Improved reliability is the key to improving the economics of the IGCC, provided this can be achieved without excessive increase in CAPEX. The purpose of the current project is to analyse the IGCC as a complete system. The ORAP database provides the basis for this analysis.

Interim results show that considerable loss of availability in existing IGCC plants arises in areas outside the core gasification unit. In areas such as air separation considerably better performance has been demonstrated in the industrial gas industry and could be achieved in an IGCC as well. Early deployment of advanced gas turbine technologies has contributed to lower availabilities than desired in some existing IGCC plants.

An important result of the work so far is the recognition that the efforts for improvement in reliability must be put into the IGCC system as a whole. Focus on a single subsystem such as gasification – however important – is insufficient for the success of the overall IGCC concept. It is hoped that the system-wide approach of the two projects described will make a contribution towards achieving that success.

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