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Date: 4/15/2005 4:27:24 PM
Subject: FW: IEEC Amendment No. 1 -- AQ Information Responses

As requested, enclosed is a Word version of the air quality information responses for IEEC Amendment No. 1 which were emailed to you as a PDF file earlier today. Also enclosed are the corresponding attachments which remain in PDF.

<<IEEC_AQ_CEC_Responses_rev3.doc>> <<CEC_Response_Attachments.pdf>>

CC: "Jenifer Morris" <jenifer@njr.net>, "Tom W. Andrews" <TAndrews@sierraresearch.com>, "Gary Rubenstein" <GRubenstein@sierraresearch.com>

INFORMATION REQUESTS

FOR DISCUSSION PURPOSES ONLY

Technical Area: Air Quality
Authors: Keith Golden, Will Walters, Brewster Birdsall

Revised Startup and Shutdown Emissions

BACKGROUND

Various power plant operators recently have sought license amendments due to inaccurate predictions of startup or shutdown emissions. Having accurate and sufficiently conservative estimates of these emissions is very important to staff because of the desire to avoid future amendments. Staff is interested in having a more detailed and technical explanation of startup and shutdown emission projections. Commissioners have also expressed interest in avoiding future amendments.

INFORMATION REQUEST

The following data requests pertain to the emission figures found on Table 3.1-2.

1. The NOx hourly startup or shutdown emission rate (for each turbine) is proposed to be revised from 80 lbs/hr to 408 lbs/hr. Provide all supporting assumptions, calculations, monitored data (and the source of that monitored data) that substantiate the 408 lbs/hr figure.

   RESPONSE: Supporting data has been provided to the CEC staff via e-mail for the cold start emission rates that serve as the basis for the proposed emission rates. These data are based on GE modeling of H-class turbine emissions during startups.

2. The CO hourly startup or shutdown emission rate (for each turbine) is proposed to be revised from 902 lbs/hr to 95 lbs/hr. Provide all supporting assumptions, calculations, monitored data (and the source of that monitored data) that substantiates the 95 lbs/hr figure.

   RESPONSE: Supporting data has been provided to the CEC staff via e-mail for the cold start emission rates that serve as the basis for the proposed emission rates. These data are based on GE modeling of H-class turbine emissions during startups. As described in the enclosed ASME Paper (GT2003-38193; Attachment AQ-2), the combustors used in the 7H turbine are sized sufficient to provide an adequate residence time for complete fuel combustion. This physical change in the combustors, as compared with *existing F-class turbines, results in lower CO levels throughout the turbine's operating range, including the low loads and transient conditions associated with turbine startups.*

3. The VOC hourly startup or shutdown emission rate (for each turbine) is proposed to remain the same at 16 lbs/hr for the H turbine. However, since the NOx and CO emission rates are being substantially revised, staff needs to know why the VOC emission rate is not being revised. Provide all supporting assumptions, calculations, monitored data (and the source of that monitored data) that substantiates the 16 lbs/hr figure.

   RESPONSE: Supporting data has been provided to the CEC staff via e-mail for the cold start emission rates that serve as the basis for the proposed emission rates. These data are based on GE modeling of H-class turbine emissions during startups. The 16 lbs/hr value proposed for the H-project, which is identical to the previously approved value, is more conservative than the 6 lbs/hr value predicted by GE. IEEC believes this level of conservatism is appropriate for this pollutant for this project.

4. The two turbine NOx start-up or shutdown emission rate is given as 550 lbs/hr. Provide all supporting assumptions and calculations that substantiates the 550 lbs/hr figure.

   RESPONSE: The 550 lbs/hr value presented in the amendment request was back-calculated based on modeling results to ensure that the simultaneous startup of two units would not result in a violation of state or federal air quality standards. IEEC planned on managing startups (staggered cold starts) to maintain compliance with this limit; it was anticipated that simultaneous hot and warm starts could be performed within this combined emission limit, as shown in the enclosed spreadsheets. However, as discussed in Response 36, a revised modeling analysis was performed that shows that simultaneous cold starts at a NOx emission rate of 408 lbs/hr per gas turbine is possible without exceeding the state ambient air quality standard for NO_2. Consequently, it is no longer necessary to limit the combined NOx emissions during startups to 550 lbs/hr. IEEC is proposing to delete the restriction on simultaneous startups, as discussed further below.

5. The per turbine NOx lbs/start emission figure is shown as 803 lbs/hr. Provide all supporting assumptions and calculations that substantiates the 803 lbs/hr figure.

   RESPONSE: The per-turbine startup NOx emission rate proposed for the project is 803 lbs/start, not 803 lbs/hr. This value is derived from GE's modeling of the 7H turbine's emissions during a startup, and reflects the *effectiveness of the SCR control technology. The spreadsheets detailing these calculations have been previously provided to the CEC staff.*

6. The per turbine CO lbs/start emission figure is shown as 300 lbs/hr. Provide all supporting assumptions and calculations that substantiates the 300 lbs/hr figure.

   RESPONSE: The per-turbine startup CO emission rate proposed for the project is 300 lbs/start, not 300 lbs/hr. This value is based on an estimated CO startup emission rate of 50 lbs/hr, which better reflects the potential mix of different types of starts, and the fact that the 95 lbs/hr maximum value is expected to be experienced during short periods, given the effectiveness of the oxidation catalyst (even during startups). This 50 lb/hr value is multiplied by the proposed maximum startup duration of six hours to determine the 300 lbs/start value.

7. The per turbine long term average NOx lbs/start emission figure is shown as 125 lbs/hr. Provide all supporting assumptions and calculations that substantiates the 125 lbs/hr figure.

   RESPONSE: This value was determined based on an engineering review of existing available F-class data (scaled as appropriate to reflect the larger size of the 7H turbines), combined with GE modeling of the 7H turbine emissions during cold, warm and hot starts. It should be noted that this value is used for estimating long-term (e.g., annual) NOx emission rates, and thus does not need to be as conservative as the short-term, not-to-be exceeded value of 408 lbs/hr.

8. The per turbine long term average CO lbs/start emission figure is shown as 50 lbs/hr. Provide all supporting assumptions and calculations that substantiates the 50 lbs/hr figure.

   RESPONSE: GE's modeling of CO emissions during startups of the 7H turbine predicts well under 50 lbs/hr for CO during startups, averaged over entire duration of startup (see data provided in response to Request 2). These values were rounded up to provide a conservative error margin.

9. The calculation of RTCs required during a "normal" year in Table A.1-7 does not appear to include any startups. Please describe the RTC requirements using a more-realistic operating schedule such as 400 hours per year per turbine in startup mode.

   RESPONSE: The calculation of RTCs required during a normal year is based on the worst case of several scenarios evaluated. As shown in the enclosed spreadsheet (Attachment AQ-9), base load operation at 8760 hours *per year results in higher emissions than cases that involve more startups and associated down-time periods.*

10. Please verify the anticipated startup durations. Table A.1-7 shows the duration of one hot startup as 1 hour and one cold startup as 6 hours, yet elsewhere the hot startup duration is anticipated to be 4 hours. Revised permit conditions (on p.3-21 of the amendment) indicate that the averaging time during a startup should be 3 hours.

    RESPONSE: One hour is the expected duration of a hot startup; however, no separate emission limits are requested for hot startups as compared with other types of startups. The anticipated maximum duration of all startups, except for cold steam turbine startups, is four hours. The averaging time for NOx emissions during a startup (three hours) is not a limit on the duration of a startup. This is the same averaging period established by the SCAQMD and the CEC in the recently-approved amendments for the Mountainview project.

<u>Dry Low NOx Combustor Performance</u>

BACKGROUND

The applicant claims that the combustor design being utilized for the H turbine is capable of limiting NOx emissions to 15 ppm corrected to 15% oxygen. The combustor performance is critical in the design of the SCR system and the requirement of meeting an out-the-stack NOx emission limit of 2 ppm (at 15% O2) averaged over one hour. In order for staff to be assured that the DLN combustor design can in fact meet a 15 ppm NOx level, staff needs additional information on the design of the H combustor and emissions data that validates the NOx emissions claim.

INFORMATION REQUEST

11. Staff is familiar with the F combustor can technology. Please describe any design differences between the F combustor and the H combustor that effects emissions performance.

    RESPONSE: The 7H turbine includes a number of advancements which enable the achievement of low emission rates and high efficiencies. These include changes to the combustor design to allow for increased residence times and more complete fuel combustion, and changes to the fuel nozzle and combustor designs to enable better control of the fuel/air mixture, and minimization of hot spots that can lead to NOx formation. These changes result in lower NOx and CO emissions than have been seen in the 7F turbines that have been previously reviewed by the CEC. The ASME paper included as Attachment AQ-2 describes these advancements in more detail.

12. Provide a discussion as to the normal operational start-up and shutdown profile and compare that profile for similarities and differences to the F combustor startup and shutdown profile.

    RESPONSE: There are no substantive differences in startup and shutdown sequences for the H-System turbine as compared with the F-class turbines, except for the fact that the H-System combustion turbine will come into compliance with its emission limits at a lower load than the F-class turbine.

13. Provide operational data, either at a commercial operation (Baglan Bay) or from test data that indicates the project would be likely to comply with the level of 15 ppm NOx during normal steady state operation.

    RESPONSE: The requested information will be provided under separate cover.

Partial Load Operation

BACKGROUND

Since this project will be subject to the unpredictability of the de-regulated market, it is possible that the each turbine train could be requested to be dispatched at loads less than full load. If that is the case, then it is important to understand at what loads the project can "safely" operate at and still meet the stringent emission permit limits.

INFORMATION REQUEST

14. Describe whether it is anticipated that each turbine train will be dispatched at less than full load (approx. 400 MW), and at what minimum load that each turbine train would be operated and still meet the emission limits of 2 ppm NOx, 3 ppm CO and 2 ppm VOC.

    RESPONSE: The above levels are expected to be achieved down to a combined cycle load of approximately 50% (equivalent to a combustion turbine load of approximately 42%). Additional information will be provided under separate cover.

Initial Commissioning Operation

BACKGROUND

A table was sent to staff via e-mail (March 15, 2005) that characterized the anticipated criteria pollutant emissions during the initial commissioning phase of operation. The applicant states the origin of the emissions are, "estimates are based on GE's proprietary computer model, and represent GE's best estimates of emissions during commissioning." Staff needs further information about how these emissions were derived so that staff can describe in their analysis the level of confidence they have about these emission figures.

INFORMATION REQUEST

15. Please describe the design of the "GE proprietary computer model" and how emissions are thus calculated as shown in the e-mail table received by CEC staff on March 15, 2005.

RESPONSE: GE's proprietary model for predicting turbine performance (including emissions) is referred to as the cycle deck. It consists of a series of individual component models that can be combined together to predict the performance of individual turbine components through a complete combined cycle power generation system. The individual building blocks of the model are developed from first principles, and are then confirmed through laboratory testing of individual components. Component integration is evaluated and tested in the same manner. Data from field units are added to a data base to enhance the models predictive capability over time. The specific model elements for the 7H turbine were originally derived from comparable model elements for the 7F turbine, supplemented with engineering data from laboratory tests of new components and systems. The predictions from the model were compared with measurements at the Baglan Bay facility in Wales, and the results were found to be reasonably consistent. Nonetheless, test data from the Baglan Bay facility have been used to further refine the model's predictive capabilities, and it is these refined results that form the basis of the predictions presented for IEEC.

16. Describe whether any of the emission figures from this table were from data actually collected at an operational facility (Baglan Bay) or whether all these figures were calculated from the computer model.

RESPONSE: Please see the response to Request 15.

17. Please provide a summary of any data collected at Baglan Bay that could be used to substantiate the anticipated commissioning emission rates and indicate that the project will be likely to comply with these rates.

RESPONSE: No commissioning emissions data are available from the Baglan Bay plant; however, the commissioning experience at Baglan Bay was incorporated in the development of the commissioning protocol for the IEEC project. GE believes that the commissioning emissions estimated for IEEC are conservative.

18. Please provide a summary of the commissioning emissions by phase.

RESPONSE: The commissioning program for this project is a characterization program, proprietary to GE, needed for initial deployment of *this equipment in the U.S. The following table summarizes the emitting modes associated with each phase of the commissioning period.*

Initial Commissioning test descriptions to address combustion emissions by phase					
No Load Tests	Aeromeachnical Validation	Aerothermal Validation	Performance & Off Design Testing	Final Combustion Testing	Compliance Testing
X1	X2	X3	X4	X5	X6
First Fire, Diffusion Comb Mapping, Comb PPM xfer tuning	Premix Xfer tuning, Premix CC full load	Premix Comb Mapping,	Premix	Emissions, Dynamics, Fuel/VGV variation	Grid and Emissions Compliance

The total estimated emissions for the entire commissioning period are believed to be more reliable than are the estimates for any individual phase of the commissioning period.

19. Please describe the activities that would take place during the following initial commissioning steps:
    - no load test
    - aeromechanical validation
    - aerothermal validation
    - performance & off-design testing
    - final combustion testing
    - compliance testing

    RESPONSE: Please see the response to Request 18.

20. Please describe how during "compliance testing," the highest hourly NOx emissions would occur (shown as 438 lbs/hour during run #X6.6 in the table sent March 15, 2005). Staff expects that during "compliance testing" the SCR system would be installed and operating and that the DLN combustors would be properly tuned resulting in significantly lower emissions.

    RESPONSE: The high NOx level estimated for this particular test is based on emissions during startup and at low loads (below 42% GT load).

21. Please indicate when, during the commissioning activities, the SCR system would be installed, tuned, and operated.

    RESPONSE: Installation of the SCR system is expected to be completed during the aeromechanical test phase of the commissioning activities, prior to approximately 50 hours of fired operation.

22. Please describe which of the commissioning activities would be completed with the SCR system operational.

RESPONSE: The SCR system is expected to be available for operation some time during the aeromechanical test phase of the commissioning activities. Subsequent to that time, the SCR system would be used during periods when the catalyst temperature is within proper operating range, although not necessarily to a degree sufficient to ensure compliance with the final operating limits.

PSD Delegation Issues

BACKGROUND

The Class I Area modeling analysis will need to be reviewed by the Federal Land Manager (FLM). Staff needs to obtain the FLM review findings to complete our modeling and LORS compliance analysis. The review of Class I impacts and coordinating FLM involvement were within the scope of the SCAQMD's original FDOC on this case because the U.S. EPA had delegated these PSD issues to the local district. Conversations with the engineer (Li Chen) as recently as March 18 indicate that SCAQMD expects U.S. EPA to process the PSD review of the amendment, and conversations with the U.S. EPA (Kathleen Stewart) indicate that SCAQMD will process the PSD review. The appropriate PSD review agency needs to be identified. Staff expects FLM involvement to be completed before making a determination that the amendment would comply with PSD requirements.

INFORMATION REQUEST

23. Please identify the PSD review agency and the anticipated schedule for completing the FLM review.

RESPONSE: The SCAQMD will be the PSD reviewing agency for the project. EPA issued a final partial PSD re-delegation agreement for the IEEC project on March 31, 2005. This redelegation authorizes the SCAQMD to issue the initial PSD permit for the project, as well as administrative changes prior to the commencement of operation. See the enclosed letter from EPA (Attachment AQ-23).

24. Please provide the contact name and phone number for the FLM personnel reviewing the amendment and describe how FLM involvement will be coordinated.

RESPONSE: The FLM reviews are being coordinated by Mike McCorison (626-574-5286) of the US Forest Service and John Notar (303-969-2079) of the National Park Service. A response from the FLMs is expected to be sent to the South Coast AQMD by mid-April.

25. Please explain whether a delay in FLM review could affect the timing of the final determination from SCAQMD.

RESPONSE: A delay in the FLM review beyond mid-April could potentially affect the timing of the final determination by the SCAQMD in a day-for-day slippage.

Construction Impacts

BACKGROUND

The amendment identifies an expanded area of disturbance during construction. It also identifies a slightly longer construction schedule. Staff anticipates that the inventory of construction equipment used for the larger combustion turbines will be different from those considered in the AFC. For example, larger cranes could be necessary. The amendment does not discuss the air quality impacts during construction.

INFORMATION REQUEST

26. Please provide either an updated construction air quality impacts assessment with dispersion modeling or describe how the changes in construction area, equipment, and schedule would affect the results of the original construction impacts assessment. Impacts at the fence-line and at the Romoland Elementary School are especially of concern.

RESPONSE: In response to the CEC's requests, IEEC has re-reviewed the construction schedule, equipment schedule, and laydown areas for the project, and has concluded, again, that the estimates provided for the original project remain valid as a worst case for the revised project configuration. The longer construction duration is anticipated to be offset by less intense activities at any individual point in time. The previously assumed construction equipment sizes and operation remain representative of those anticipated for the revised project. The difference in the sizes of the disturbed areas are principally related to increased, graveled laydown and parking areas and, hence, are not expected to result in significant changes to construction emissions.

27. Please verify that the project schedule can be met with the 12-hour per day limitation in AQ-SC6.

RESPONSE: IEEC confirms that it can continue to comply with the 12-hour per day limitation applicable to dust-moving activities in AQ-SC6.

Cumulative Assessment

BACKGROUND

The amendment does not discuss the air quality impacts of this project with other cumulative projects. A list of possible cumulative sources was sent to staff in an e-mail (March 11, 2005) and staff requested two small, nearby sources be added to the list in a reply e-mail (March 14, 2005).

INFORMATION REQUEST

28. Please provide a cumulative impacts discussion including dispersion modeling and the supporting modeling CD.

    RESPONSE: The cumulative impacts modeling analysis was provided to the staff on April 5, 2005.

Conditions of Certification and Dispersion Modeling

BACKGROUND

The dispersion modeling for NO_2 and CO appears to only include one turbine at a time uncontrolled, during commissioning or startup, with the exception of a combined 550 lb/hr NOx run. The amendment requests deletion of part of staff condition AQ-SC13 and all of AQ-SC14, which currently limit simultaneous commissioning and startups. The amendment also requests changes to conditions that are not explained.

INFORMATION REQUEST

29. Please provide a dispersion modeling analysis that illustrates the impacts of simultaneous commissioning of each turbine and an analysis of the turbines in simultaneous startup modes. Additionally, please explain why the short term emission rate of 408 lb/hr NOx would not occur simultaneously from both turbines during a simultaneous startup.

    RESPONSE: Worst case NOx impacts during commissioning were evaluated assuming one turbine operating at the worst case NOx emission rate for commissioning of 587 lbs/hr, plus one turbine operating at base load, fully controlled. There is no anticipated operation of two turbines simultaneously in commissioning with emissions higher than this level. As discussed in Responses 4 and 36, revised modeling was performed that shows compliance with ambient air quality standards during simultaneous cold starts at a NOx emission level of 408 lbs/hr per gas turbine for each gas turbine.

30. The startup emissions were modeled as a worst case 275 lbs/hour/turbine to equal 550 lbs/hour total. Please provide data to confirm that modeling with 408 lb/hr for one turbine and 142 lb/hour with another turbine would not provide the worst case modeling results.

RESPONSE: As discussed in Responses 4 and 36, revised modeling was performed that shows compliance with ambient air quality standards during simultaneous cold starts at a NOx emission level of 408 lbs/hr per gas turbine. Therefore, it is not necessary to perform additional modeling with regards to the NOx 550 lbs/hour combined limit.

31. Please describe why the amendment necessitates the proposed changes in AQ-SC13 and AQ-SC14.

RESPONSE: Changes to AQ-SC13 are requested for two reasons. First, the project configuration no longer includes duct burners, so references to duct burners are proposed to be deleted from this condition. Second, IEEC anticipates that there will be some overlap in commissioning activities between the two turbines. However, the maximum combined emissions from the two turbines during such an overlap will not exceed the levels evaluated in the modeling analysis discussed in Response 29. Enclosed as Attachment AQ-31 is proposed new permit language limiting the CO and NOx emissions during commissioning. IEEC requests the deletion of Condition AQ-SC14 because it has evaluated the potential impacts of having two turbines starting at the same time, and has found that such operation will not result in the violation of any state or federal ambient air quality standard.

32. Please describe why the amendment necessitates the proposed changes in AQ-26 and AQ-45.

RESPONSE: The requested changes to AQ-26 and AQ-45 are to be consistent with the most recent version of the ammonia monitoring conditions imposed by the SCAQMD.

Dispersion Modeling Approach

BACKGROUND

The modeling analysis of NO_2 impacts using ozone limiting method (OLM) uses 1981 meteorological data from Riverside and 1999 ozone data from Perris. The OLM analysis needs to use meteorological and ozone values that are from a consistent period and location. Additionally, the modeling analysis does not include any diesel engine emissions during startup or commissioning, and the NO_2 and CO emission rates used as input to the commissioning model runs seem arbitrary.

INFORMATION REQUEST

33. Please run startup and commissioning ISC_OLM using 1997 to 2001 March Air Force Base meteorological data and 1997 to 2001 Perris ozone data (staff can provide these data files).

    RESPONSE: IEEC objects to this request, as it did during the initial licensing proceeding, on the grounds that the March Air Force Base meteorological data have not been accepted by the South Coast AQMD for regulatory purposes. IEEC has no objection to the Staff performing this analysis, as it did in the original licensing proceeding.

34. Please describe why the project's three diesel engines would not operate during turbine commissioning or startup events, or remodel the commissioning and startup events with these engines operating.

    RESPONSE: IEEC does not anticipate that any of the three Diesel engines would be operated for testing purposes while the combustion turbines are either operating during commissioning or are starting up. All three engines are standby or emergency equipment, which would normally operate only during testing or power failures. Testing of this equipment will be scheduled such that it does not coincide with commissioning activities or startups.

35. Please tabulate the dispersion modeling inputs used in the analysis of commissioning impacts. The results shown for NO_2 in Table 3.1-6 do not appear to include both turbines operating simultaneously in commissioning mode, as requested in the revision to AQ-SC13, and the origin of the modeled CO emission rate (777 lb/hr) is not explained.

    RESPONSE: The modeling analysis for commissioning assumes that one turbine will be operated at the maximum expected hourly emission rate during commissioning, while the second would be operated at base load with full controls. Although some commissioning activities may be performed on the two engines in parallel, the maximum combined emissions will not exceed the levels evaluated. The 777 lbs/hr value is a worst-case value based on GE's modeling of emissions from the 7H turbine during the kinds of tests anticipated to be performed during the commissioning/characterization period.

36. The OLM analysis was performed with the ozone file set as "individual" rather than "source group," please explain why this is done even though source groups are used in the modeling analysis. We believe that this approach could double count the ozone conversion potential, so please make sure the ozone files are set as "source group" for all revised modeling runs.

    RESPONSE: As requested by the CEC staff, a revised modeling analysis was performed using source-group OLM rather than individual OLM. As *shown in Table 36-1, the maximum ambient 1-hr average NO_2 impacts decreased as a result of using the source-group OLM approach. A revised analysis was performed using the source-group OLM approach with both gas turbines simultaneously undergoing cold starts with a NOx emission rate of 408 lbs/hr per gas turbine. As shown in Table 36-2, this analysis shows that no ambient air quality standards are exceeded at a NOx emission rate of 408 lbs/hr per gas turbine. The electronic modeling files for this revised modeling analysis are included in an enclosed compact disk.*

Table 36-1
Comparison Between Individual and Source-Group OLM

Gas Turbine Operating Mode	NOx Emission Rate (lbs/hr per GT)	Maximum 1-Hr NO_2 Impact Using Individual OLM ($\mu g/m^3$)	Maximum 1-Hr NO_2 Impact Using Source-Group OLM ($\mu g/m^3$)
Gas Turbine Startups			
One GT in startup	275	293.4	186.1
Second GT in startup	275		
Gas Turbine Commissioning			
One GT in commissioning	587	194.4	188.1
Second GT in baseload	18.83		

Table 36-2
Revised Startup NOx Modeling Analysis

Gas Turbine Operating Mode	NOx Emission Rate (lbs/hr per GT)	Maximum 1-Hr NO2 Impact Using Source-Group OLM (ug/m3)	Background 1-Hr NO2 (ug/m3)	Total Impact (ug/m3)	State Standard (ug/m3)
One GT in startup	408	197.5	171	369	470
Second GT in startup	408				

Cooling and Emergency Equipment Changes

BACKGROUND

The amendment requests a change to the cooling tower flow rate limit in VIS-8. With this proposed limit, staff estimates that the exit velocity for this source would be about 8.2 m/s, yet the dispersion modeling submitted with the amendment and information in Table A.2-3 indicates a 10.2 m/s velocity. Overestimating the exit velocity causes the fence-line impacts to be underestimated. Staff needs to be sure the limits in VIS-8 match the input of the dispersion model.

INFORMATION REQUEST

37. Please provide calculations confirming the equivalency of the limits in VIS-8 and the modeled cooling tower exit velocity and, if necessary, rerun the dispersion model with the correct cooling tower exit velocity.

    RESPONSE: Enclosed as Attachment AQ-37 are the detailed calculations showing how the revised minimum cooling tower airflow rater per heat rejection rate of 28.4 kilograms per second per megawatt was calculated. As shown in these calculations, the cooling tower exhaust flow rate is 1,618,000 cubic feet per minute per cooling tower cell. This cooling tower exhaust flow rate matches the level shown in Table A.2-3 of the March 2005 Amendment to the CEC that shows the cooling tower exhaust flow rates used for the dispersion modeling.

BACKGROUND

The amendment would replace inlet air foggers with a chiller system. If evaporative cooling is used, the heat rejection portion of this chilled water system may be a source of drift or other emissions.

INFORMATION REQUEST

38. Please describe the chilled water system for inlet air and identify whether any small cooling tower would be used. If necessary, include this source of drift in the dispersion modeling analysis.

    RESPONSE: The chilled water system for inlet air rejects heat to the main cooling towers.

BACKGROUND

The amendment would replace a natural-gas fired emergency generator with two, much larger diesel power generators. There appears to be a discrepancy in the SOx emission calculations and the expected sulfur content of the diesel fuel. Staff expects that SCAQMD will require these units to be powered by ultra-low sulfur diesel (not exceeding 15 ppmw sulfur).

INFORMATION REQUEST

39. Please provide an emission calculation for SOx from the standby generator engines based on use of 15 ppmw sulfur fuel, or provide a discussion that supports use of 0.16 g/bhp-hr, as in Table A.1-5.

RESPONSE: Although the vendor data supplied for this engine was based on a 0.05% (500 ppmw) fuel sulfur limit, IEEC will comply with SCAQMD requirements that limit the sulfur content of Diesel fuel used in this engine to not more than 15 ppmw. The modeling was based on the original, vendor data and is conservatively higher than expected impacts.

ATTACHMENT AQ-2

Proceedings of ASME Turbo Expo 2003:
Power for Land, Sea, and Air
June 16–19, 2003, Atlanta, Georgia, USA

GT2003-38193

DRY, LOW EMISSIONS FOR THE 'H' HEAVY-DUTY INDUSTRIAL GAS TURBINES: FULL-SCALE COMBUSTION SYSTEM RIG TEST RESULTS

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I. ABSTRACT

The lean, premixed DLN2.5H combustion system was designed to deliver low NOx emissions from 50% to 100% load in both the Frame 7H (60 Hz) and Frame 9H (50 Hz) heavy-duty industrial gas turbines. The H machines employ steam cooling in the gas turbine, a 23:1 pressure ratio, and are fired at 1440 C (2600 F) to deliver over-all thermal efficiency for the combined-cycle system near 60%. The DLN2.5H combustor is a modular can-type design, with 14 identical chambers used on the 9H machine, and 12 used on the smaller 7H. On a 9H combined-cycle power plant, both the gas turbine and steam turbine are fired using the 14-chamber DLN2.5H combustion system. An extensive full-scale, full-pressure rig test program developed the fuel-staged dry, low emissions combustion system over a period of more than five years. Rig testing required test stand inlet conditions of over 50 kg/s at 500 C and 28 bar, while firing at up to 1440 C, to simulate combustor operation at base load. The combustion test rig simulated gas path geometry from the discharge of the annular tri-passage diffuser through the can-type combustion liner and transition piece, to the inlet of the first stage turbine nozzle. The present paper describes the combustion system, and reports emissions performance and operability results over the gas turbine load and ambient temperature operating range, as measured during the rig test program.

NOMENCLATURE

Modified Wobbe Index (MWI) = LHV $(Btu/FT^3)/(SG*T,R)^{0.5}$
Compressor Discharge Pressure = Pcd
Combustor Exit Temperature = $T_{3.95}$
Combustor Through-Flow = $W_{3.95}$

II. THE H SYSTEM™ STEAM – COOLED INDUSTRIAL GAS TURBINE

The subject combustion system was designed for operation in both the 60-cycle 7H application that employs 12 can-type combustion chambers, and the larger 50-cycle 9H system with 14 chambers. Both machines use an 18-stage axial compressor at a 23:1 pressure ratio, with a four-stage turbine on a single shaft. The first two stages of the turbine use a unique, closed-loop internal steam cooling system for both the turbine stators and the rotor buckets.

Development of the H combined-cycle gas turbines began in the mid-1990's. The 9H turbine has since been fielded and operated through an extensive Characterization Test at the Baglan Bay Energy Park outside Port Talbot, Wales. Matta (2000) describes the H combined cycle power plant completely in Reference 1. Figure 1 is a photograph of the 9H gas turbine just prior to the factory test at Greenville, South Carolina, USA.

The H System™ gas turbine, steam turbine, and generator operate in a "single shaft" arrangement, as shown in Figure 2, with the gas turbine, steam turbine, and generator shafts linked together end-to-end to form a single powertrain. The Baglan Bay power station, rated at 480 MW net output, is shown in Figure 3.

Figure 1 – 9H Gas Turbine prior Factory Testing (Non-DLN Combustion System)

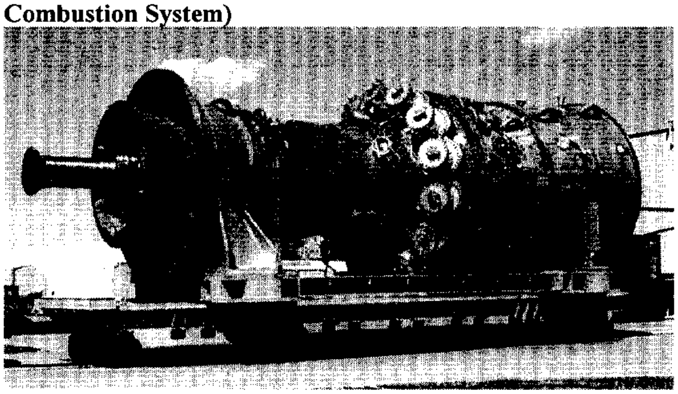


Figure 2 – 9H Power Plant Arrangement

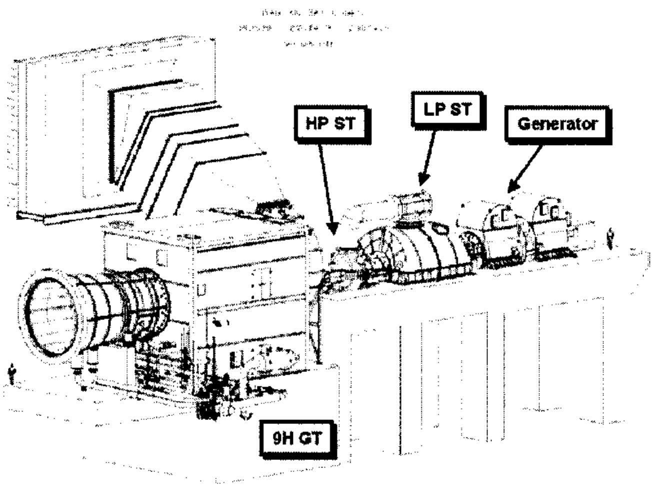
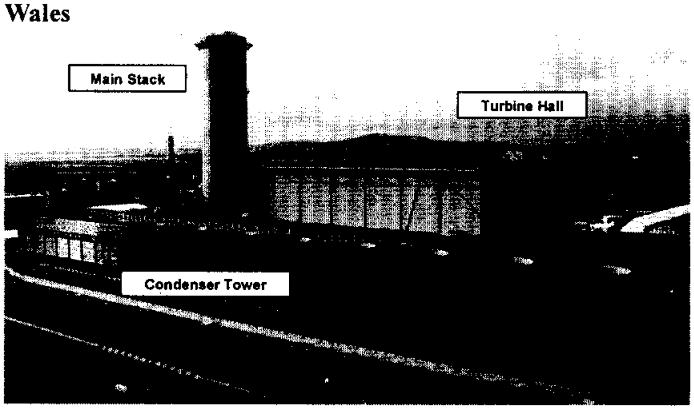


Figure 3 – 480 MW Baglan Bay Power Station, Port Talbot, Wales



The subject combustion system was designed for use in both the 7H and 9H gas turbines, with the total number of chambers used (12 and 14, respectively) being the only difference. The subject rig test program was conducted with just one of these identical chambers, with the test stand designed to reproduce the internal flow path geometry of the either the 7H or the 9H gas turbines.

Table 1 – Combustion System Performance Comparison for the H IGT's

Parameter	Units	7H	9H
Combined-Cycle Output (59F Day)	MW	400	480
C - C Output per Chamber	MW/Chamber	33	34
NOx emissions Target	ppmvd @15% O2	9 ppm	25 ppm
Pressure Ratio		23.5	23.2
Turbine Rotor Inlet Temperature	Deg F (C)	2600 (1440)	2600 (1440)
Max Fuel Temperature	deg F (C)	440 (227)	440 (227)
Quantity of Combustion Chambers		12	14
Gas Premixers per Chamber		5	5

The first application of the DLN2.5H combustion system was in the 9H gas turbine at the Baglan Bay site, first – fired in November, 2002, and operated at 100% combined – cycle load in premixed combustion mode in January, 2003.

III. COMBUSTOR OPERATING CONDITIONS AND PERFORMANCE OBJECTIVES

Gas turbine performance and combustor inlet conditions at 100% gas turbine load for the 7H and 9H are given in Table 1 for comparison. Combustor inlet conditions from the gas turbine cycle were used to set up the rig test program. The initial NOx emissions target for the 9H system at Baglan Bay is 25 ppm (dry, corrected to 15% Oxygen). The system has demonstrated less than 15 ppm NOx on the same oxygen basis at full-load conditions during the initial field test. Carbon Monoxide (CO) and Unburned Hydrocarbons (UHC) were targeted at less than 5 ppm. Emissions objectives are achieved over the ambient temperature range from 0 to 104 F (-18 to 40 C), from 50% to 100% gas turbine load, and without steam or water injection for NOx emissions control. The fuel Modified Wobbe Index (MWI) range for premixed operation on the 9H unit at Baglan Bay is 40.6 +/- 5%, although a range of more than 20% (lower and higher fuel temperatures) has been demonstrated in rig testing and during the initial field test of the gas turbine without impacting lean premixed operability.

At the power station, water heated by the gas turbine exhaust is used in a fuel/water heat exchanger to increase the gas fuel temperature from ambient up to 440 F (227 C). Fuel performance heating permits low-grade exhaust energy to be re-introduced into the cycle, reducing the heat rate. Day (2001) describe heated fuel design considerations for industrial turbines. A gas-fired, oil bath type fuel heater was used to produce the required fuel temperatures for the rig test program.

In addition to the emissions and operability requirements, part life and reliability consistent with 24,000 fired-hour replacement intervals for the major components and an 8000-hour Hot Section Inspection (HSI) interval was specified for initial operation. Field experience and data from the heavily instrumented prototype 9H gas turbine at Baglan Bay will permit validation of the combustor reliability analysis. The present paper will focus primarily on aerothermal performance of the system.

IV. DLN 2.5H COMBUSTOR HARDWARE

The discussion below describes the combustion system as a whole, followed by more detailed descriptions of the individual components. For the 9H machine, fourteen combustion chambers are arranged around the perimeter of the compressor discharge casing, as shown in Figure 4. Other than the casing and liner modifications required for the accessories (spark plugs, flame detectors, water wash drains, etc.), the combustor components for all 14 chambers are identical.

Figure 4 – 9H Chamber Arrangement, Forward Looking Aft.

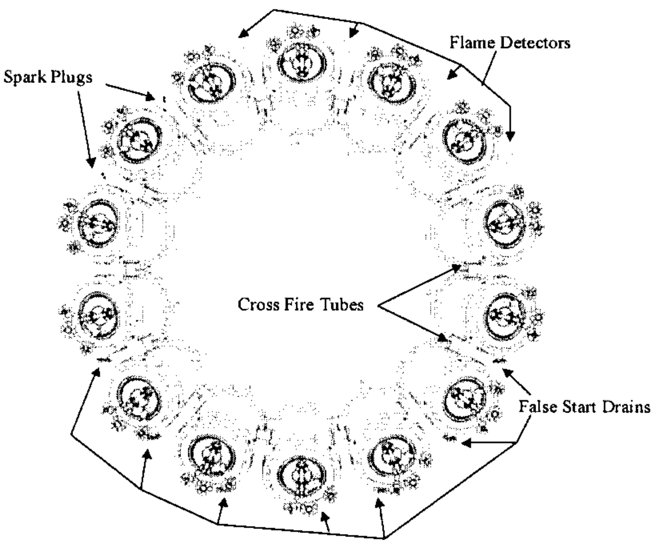


Figure 5 – DLN2.5H Combustor Cross-Section

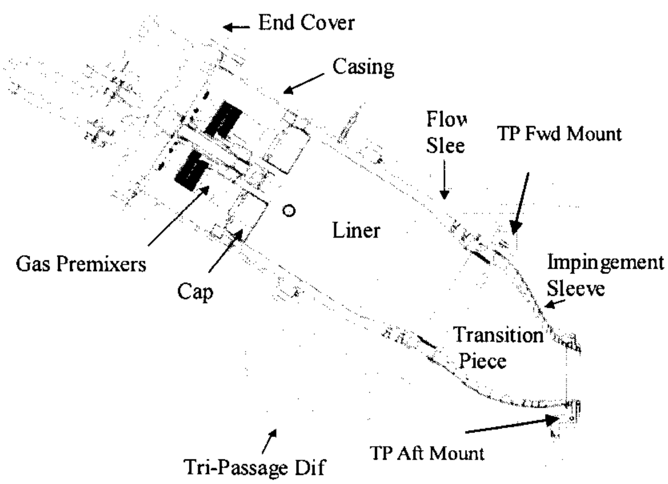


Figure 5 shows a cross-section taken through a single combustion chamber, including parts of the compressor discharge casing and turbine casing of the gas turbine.

The tri-passage annular diffuser is shown at the bottom of the cross-section. Air delivered from the compressor is directed through the diffuser into the large plenum formed by the casing. The tri-passage diffuser permits improved static pressure recovery without excessive length, minimizing the distance between the final compressor stage and the first turbine stage and the mechanical penalties associated with rotor size and weight. The diffuser also turns and distributes the air flow for more uniform feed of the liner and transition piece cooling features.

A majority of the compressor discharge air flows through the impingement sleeve, around the transition piece body, and through additional orifices in the flow sleeve, cooling the transition piece by enhanced convection, and flowing into the annular space between the outside of the combustion liner and the inside of the flow sleeve. In addition to the impingement cooling, a series of turbulator ribs on the outside of the liner enhance the heat transfer between the compressor discharge air and the liner. Bunker et. al. (2002) provide a complete description of the transition piece and liner convective cooling approach, common to most of GE's DLN combustors including the H system. Discharging into the plenum formed between the hot side of the end cover and the cold side of the cap, the combustion air flows through the inlet flow conditioner screens on the upstream end of each gas nozzle, to be premixed with natural gas, while the remainder flows through cooling features in the combustor cap. The combustion process takes place in the cylindrical zone immediately downstream of the cap. Crossfire tubes permit flame to travel from one chamber to the next only during the initial ignition process. Some details of the individual components are provided below.

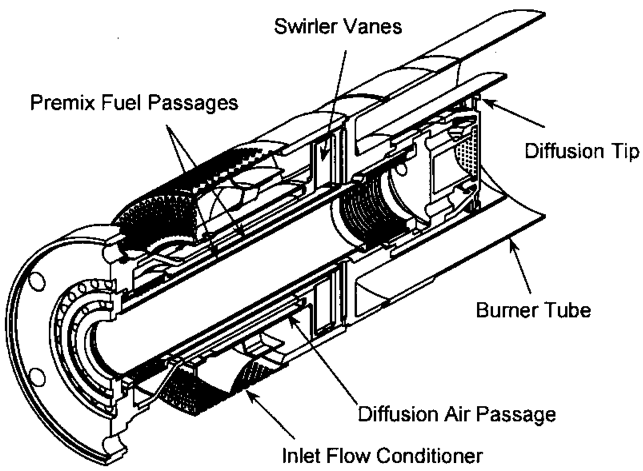
Fuel Nozzle Assembly

The fuel nozzle assembly consists of the 5 identical gas premixers mounted on the end cover. The end cover serves as both a pressure boundary, when bolted on to the cylindrical casing, and as a fuel gas manifold, connecting the four independent gas circuits to the individual fuel passages in each gas premixer. As shown in Figure 5, each endcover is equipped with gas inlet flanges to permit the gas fuel manifolds to communicate with the gas circuits in the premixers mounted on the opposite side of each endcover. The cap assembly also bolts on to the hot side of the endcover. The endcover material is SS347.

Fuel Gas Nozzles

The fuel gas nozzles used on the 9H combustion system are key to meeting goals for operability and emissions. Each gas nozzle has a single diffusion gas circuit, and two premixed circuits, supplied from the end cover manifolds via orifices in the mounting flange.

Figure 6 – DLN2.5H Gas Nozzle



As shown in Figure 6, each nozzle consists of an inlet flow conditioner, a large air swirler with hollow vanes for mixing the fuel with air, a "burner tube" downstream of the air swirler, and a diffusion tip. The burner tube OD seals against the floating collars in the combustor cap, minimizing leakage of air around the premixer. The diffusion tip is fueled only at part load, as explained below. A majority of the air enters the combustor through the inlet flow conditioners, or 'IFC's' on the five nozzles, so that a fuel-lean mixture can be created upstream of the reaction zone. The slight pressure drop across the IFC washes out the impact of wakes and stagnation zones upstream of the gas nozzle air swirlers. Fuel gas is introduced via two independent premix gas circuits, which supply fuel to the premixing annulus downstream of the Inlet Flow Conditioner (IFC) through ports machined in the hollow main air swirler vanes. Variation of the fuel split between the two circuits determines the equivalence ratio distribution in the premixing annulus. At this point, the mixture is flammable, and the mixing process must take place smoothly, without any wakes or stagnation zones that might contribute to flashback, autoignition, or other premature reaction upstream of the combustion liner. The DLN2.5 gas nozzles employ a diffusion tip, located at the centerline of each gas premixer assembly, immediately upstream of the burner tube exit. The purpose of this tip is to produce a well-anchored, high temperature diffusion flame during machine operating modes when stable operation, rather than low NOx, is the prime driver.

The diffusion tip is also supplied with compressor discharge air for a small air swirler to enhance stability, and for cooling portions of the tip exposed to the reaction zone. The air is supplied through the annulus between the ID of the IFC assembly and the OD of the nozzle stem.

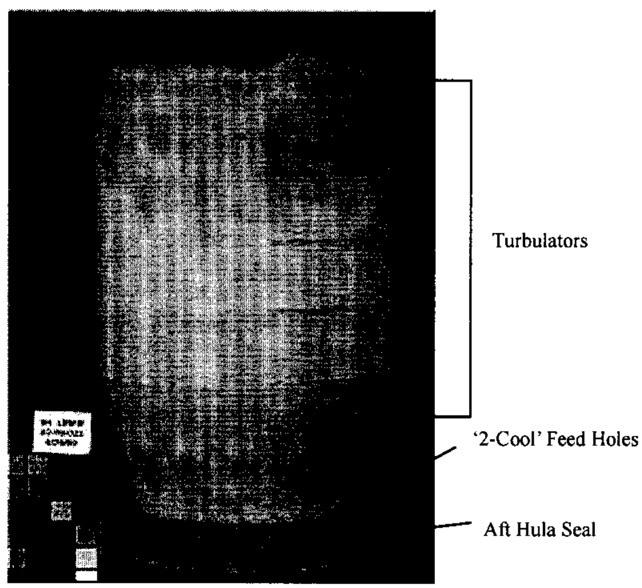
Combustion Liner Cap Assembly

The combustor cap assembly provides an interface between the burner tubes on the five gas nozzles and the combustion liner. The cap is exposed to flame radiation and convection, and must be film-cooled. The assembly consists of a cylinder with a flange on one end, and the cap attached on the other, as shown in Figure 5. Rather than bolting to a boss on the forward casing, or being attached directly to the liner, the DLN2.5H cap is mounted on the inner side of the end cover. Several relatively thin support struts are used to support the OD of the cap, minimizing the blockage in the annulus between the outside of the cap and the flow sleeve. The forward half of the cap OD supports a metal leaf spring seal that limits air leakage between the cap and liner, while allowing the two parts to float relative to one another as the liner heats up and moves axially and radially. The liner cap itself is a double-wall construction, with an effusion-cooled plate on the side exposed to the flame, and a parallel bulkhead just upstream. Floating collars provide the seal interface between the nozzle burner tubes and the cap, and are captured under the bulkhead. The collars can move freely in the plane of the cap, but cannot rotate through 360 degrees, to avoid wear during operation.

Combustion Liner

The DLN2.5H combustion liner is cylinder at the cap end, tapering to match the transition piece after a short conical section. The liner is made from a Nimonic alloy. As described by Ritter (1998), the patented '2-Cool' sealing feature is used at the aft-end of the liner to support the hula seal area. The '2-Cool' arrangement provides enhanced cooling of the part of the liner under the hula seal, and some film cooling of the transition piece immediately downstream, for better dimensional control of the important seal interface between the liner and TP at operating temperature.

Figure 7 – 9H Liner (Thermal Paint Test)



Other than some local film cooling around the crossfire tube collars and a small amount of leakage through the forward hula-seal at the cap, the liner depends entirely on convective cooling and ceramic thermal barrier coating (TBC) for protection from the flame. Figure 7 shows a picture of the liner, taken following a thermal paint test.

Transition Piece

The transition piece, or "TP", is a complex duct assembly for conducting the flow of combustion products from the circular cross-section at the combustion liner exit to the turbine nozzle sector at the aft end. A carefully designed impingement shield fits over the TP body to provide highly effective impingement cooling of the hot gas path, minimizing the need for any film cooling that would impact emissions. The transition piece body is made from a creep-resistant nickel-based super-alloy. The inside surface of the transition piece is flame sprayed with thermal barrier coating to reduce body metal temperatures. The transition piece mounts are designed to support the component against the aerodynamic and mechanical loads. The TP forward mount supports the transition piece assembly on the outer radial side, and the aft mount uses two large bolts centered by a pin of similar diameter to load the inner radial portion of the TP against the front face of the turbine nozzle inner support ring. All of the transition piece mounting interfaces use specifically designed material couples to prevent wear at the contact surfaces as a result of normal vibration. The inner radial, outer radial, and side seals between the transition piece aft frame and turbine nozzle are the 'cloth' type. Coarse cloth woven from steel wire is inserted in-between the TP frame and the turbine nozzle to prevent the pressure loss across the combustion system from driving an excessive amount of compressor discharge air through the TP/turbine nozzle interface. Any air that bypasses the combustion system in this fashion increases the combustor fuel/air ratio, the reaction temperature, and the NOx emissions. The inner and outer radial cloth seals deflect to permit relative movement between the TP and the steam-cooled first stage turbine nozzle without increased leakage.

V. FUEL STAGING AND DLN OPERATION

Davis (1996) and Vandervort (2000) discuss the evolution of Dry Low NOx (DLN) combustion systems as applied to "F" class industrial gas turbines. Like other lean-premixed combustion systems, the DLN 2.5 H combustor uses complex gas injectors to 'premix' the fuel and air prior to combustion and produce a charge in each chamber that is uniformly lean. The lean mixture burns at a lower reaction temperature (approximately 1600 C, ~2900 F), minimizing NOx formation in the flame. However, since the lower reaction temperature could have a negative impact on combustion efficiency, producing carbon monoxide (CO) and partially burned fuel (UHC) in the exhaust, the combustor must also be designed to minimize the formation of these other pollutants. Consequently, the combustion chambers are sized to provide excess residence time to consume all of the fuel completely, and with a minimum of film cooling to prevent quenching of the combustion reaction on or near cooled surfaces. Combustor 'dynamics', 'combustion noise', or 'pressure oscillations' are also a consequence of lean premixed combustion. Excessive combustor dynamics can cause fatigue damage and contact surface wear, reducing hot gas path component life. In addition, the combustor must operate reliably from ignition through 100% load, over a wide range of ambient temperatures. Thus, operability is the final major design constraint, along with emissions and dynamics. The combustor cannot operate with acceptable stability and efficiency in fully lean premixed mode at part-speed and low load. Consequently, additional, independently controlled fuel circuits are used in each chamber to permit operation in 'diffusion' and 'piloted premix' modes that emphasize stability at the expense of higher NOx emissions, as well as the fully premixed operating mode:

- **Diffusion Mode**: Diffusion pilot circuits in the outer 4 of the 5 gas nozzles in each chamber.
- **Piloted-Premix Mode**: Diffusion pilot circuits and outer premixed circuits
- **Premixed Mode:** Center nozzle premixed circuit and outer premixed circuits

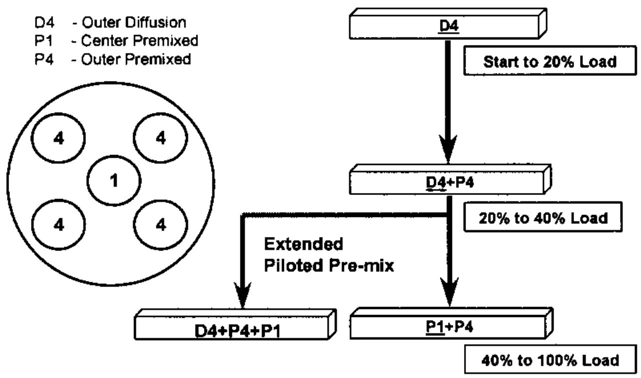
Performance characteristics in each mode are discussed in the section on rig test results below. Ascent to full-load operation is diagrammed in Figure 8. Fuels 'splits' (the percentage of the total fuel flow in a particular circuit) are based on relative metering valve positions during gas turbine operation, and were measured during rig testing. Although all seventy fuel nozzles are identical, and interchangeable, only the premix circuit is fueled at the center position in the array.

Dormant fuel circuits are purged with compressor discharge air. During an unplanned "load rejection" from premixed operation at full load, the combustor operates briefly with only the 14 center premix circuits fueled. This mode is required in order to shed 100% of the shaft power in just a few seconds following a 'breaker open' event. There is insufficient time to stop purge and resume fuel flow to the diffusion circuits, and the amount of fuel flow must be cut by almost a factor of ten in less than five seconds to avoid over-speed of the rotor. At the same time, the combustion chambers must stay lit to permit a rapid return to spinning reserve. The four independent fuel circuits are described below:

DLN2.5H Fuel Circuits

D4: feeds the diffusion gas circuits at the tip of each of the four outer gas nozzles, producing a hot, stable diffusion flame for ignition through part-load operation in 'diffusion' mode. In piloted premix mode, between 15 and 20% of the total fuel is supplied to the diffusion pilots, providing much greater stability

Figure 8 - Fuel Staging During Start and Loading



than a 100% premixed flame, but lower NOx emissions than if all the fuel were supplied through the diffusion circuits.

P1: supplies the outer premixed circuit in the center nozzle. This is the only circuit that can be supplied in the center position. Fuel through this circuit is injected and mixed with compressor discharge air upstream of the flame front. P1 is typically used in concert with the P4 premixed circuit, supplying about 20% (one fifth) of the fuel in premixed mode, at and above 40% load. The P1 circuit is also used during a 'breaker open' load rejection event mentioned above.

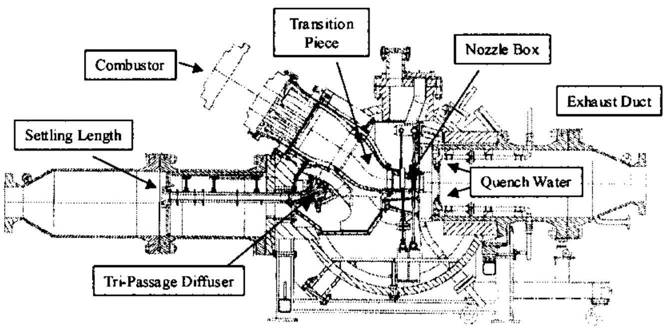
P4: supplies the premixed circuits in the four outer gas nozzles, providing about 80% of the fuel (4/5ths) in premixed mode. Like P1, the P4 fuel is supplied through ports in the nozzle, mixing the fuel with compressor discharge air upstream of the flame front. When the load is at 20%, transfer into piloted premix is initiated by fueling the P4 and D4 circuits simultaneously. P4 is reduced to zero flow immediately following a 'breaker open' or load rejection event.

B4: supplies an additional premixed circuit in the four outer gas nozzles. The B4 fuel circuit is smaller than the P1 or P4 circuits in terms of capacity, and was designed to flow between 5 and 10% of the total fuel, exclusively in piloted premix or full premix mode. B4 provides an additional 'knob' to turn if needed to mitigate combustor dynamics, and could also be used to add additional volumetric capacity for lower MWI fuels. B4 was not needed to achieve the emissions and operability goals during initial field testing at Baglan Bay.

VI. DLN2.5H COMBUSTOR PERFORMANCE TEST RIG

The DLN2.5H combustor was developed and validated using a pressure vessel designed to reproduce the gas turbine flow path from the compressor discharge to the first stage turbine nozzle inlet for a single combustion chamber. The rig was designed according to the ASME Boiler and Pressure Vessel Code for duty at up to 31 bar and 485 C to accommodate both the current 7H and 9H combustor inlet conditions and future growth. An annotated cross-section of the rig is shown in Figure 9, with an early version of the 9H combustion liner installed.

Figure 9 - DLN 2.5H Combustor Rig Cross-Section



The production version of the combustion system was installed for the subject test program, including the hardware described above. An air-cooled 'nozzle box' assembly with 49 platinum-rhodium thermocouples arranged on 7 water-cooled rakes was used in place of the turbine nozzle. About 15% of the rig inlet air flow is used in cooling the nozzle box. Separate cold-flow tests are conducted to determine the nozzle box effective flow area, and the flow area of the frame cooling and transition piece aft seals. The combustor bypass flows are then calculated as a function of inlet conditions to determine the combustor air flow. Rig internal pressure was set by manipulating a 'blast-gate' back pressure valve located several feet downstream of the exit flange, as well as by changing the upstream pressure, temperature, and air flow rate.

Instrumentation for the production performance validation included the 49 exit thermocouples sensing the exhaust gas temperature at station 3.95, inlet temperature, pressure, and air flow, exit pressure, and exhaust gas emissions. Fuel flow was separately metered in each of the four fuel legs using standard ASME square-edged orifices. The total fuel flow was also measured upstream. Fuel temperatures were also recorded in each leg. A boost compressor was used to deliver fuel pressures up to 55 bar, with fuel temperatures from ambient to 260 C supplied using an oil bath type heater. Non-vitiated stand inlet air flows over 50 kg/sec were supplied by a series of up to five air compressors, metered through a venturi type flow meter, with stand inlet temperatures up to 490 C supplied by a natural gas fired heat exchanger.

Secondary air flows required for purging the dormant fuel gas circuits were supplied from the main air header and metered separately. The test liner was equipped with an additional two-inch port and floating collar assembly to accommodate the window barrel of an air-cooled CCD television camera for viewing the structure of the flame while the test was running. (Cooling air for the camera was exhausted externally, and did not impact combustor operation.) The field of view allowed parts of all five burner tubes to be viewed for several inches downstream of the cap. A 9 mm port through the liner, located at top-dead center, was also provided for sensing dynamic pressure levels. A high response piezo-electric pressure transducer was attached to a sensor tube via a tee compression fitting that was also connected to several feet of copper cooling air tubing.

VII. RIG TEST RESULTS

The behavior of the DLN2.5H system is dependent on the combustor inlet conditions, operating mode, and reference temperature, which in turn depend on gas turbine parameters, such as the ambient temperature, compressor inlet guide vane (IGV) setting, and the load. The fuel staging schedule was developed by rig testing the 9H production hardware using a matrix of combustor inlet conditions representing a wide range of gas turbine ambient temperatures, IGV settings, loads, and fuel temperatures. More than 540 data readings were taken over a 9-month period using the production hardware.

The resulting operating mode schedule is designed to simultaneously optimize the exhaust emissions (NOx, CO, and unburned hydrocarbons) and the operability (lean blowout margin) while minimizing combustor dynamic pressures. An additional objective was to minimize the number of mode steps and fuel circuits required to operate the combustion system.

Rig test results are discussed below for each combustor operating mode, along with the primary gas turbine operating considerations in that mode. Recall that Figure 8 shows the operating modes and fuel circuits used during the loading process. Table Two shows typical combustor performance over the load range, including inlet conditions, fueling mode, emissions, and dynamic pressures. Each column describes a different operating condition. In each mode, the fuel splits were optimized during rig testing to deliver either minimum emissions or additional operating margin. Results at the same load, but on either side of the staging process, are given in adjacent columns, and illustrate the effect on NOx as steadily more fuel is premixed. At base load rig inlet conditions with all but 15% of the total fuel premixed, over 150 ppm NOx was measured, while in premixed mode with the split optimized, NOx was measured less than 15 ppm. Figure 10 shows typical NOx and carbon monoxide emissions measured over the load range for a 15 C day ambient temperature at sea level.

Diffusion Mode Test Results

In addition to combustor operability, exhaust emissions, and dynamic pressures, the fuel staging schedule must consider stable, reliable operation of the power plant as a whole. For example, from a cold start, the shaft line requires several holds during part-speed operation for 'warm up' of the HRSG so that cooling steam can be provided to the steam turbine. 'D4' diffusion mode is used up to approximately 20% gas turbine load to provide reliable ignition and good lean stability margin throughout the start and initial loading process. Two chambers are provided with pressure-retracted spark plugs for redundancy.

Figure 10 - NOx and CO Emissions over the Load Range, ISO Day

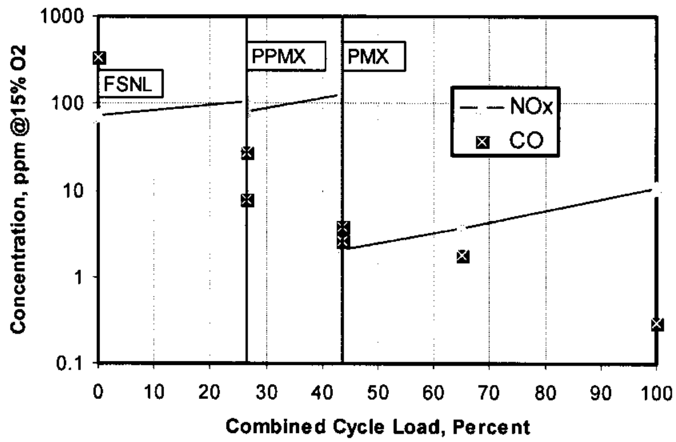


Figure 11 - DLN2.5H Combustor Ignition Characteristics

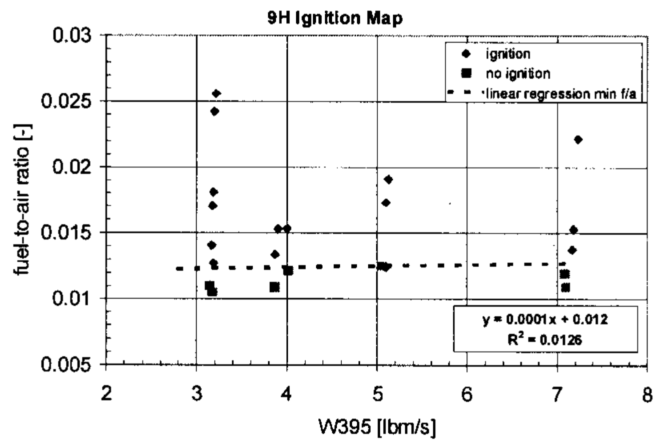


Figure 12 - Lean Stability Margin During the Acceleration Process

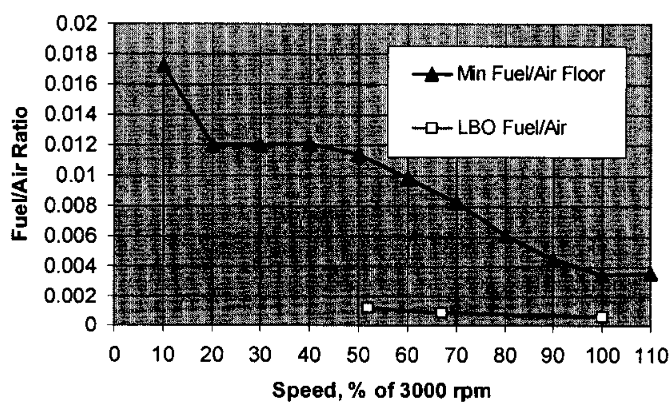


Table 2 - Typical Rig Data Over the Gas Turbine Load Range

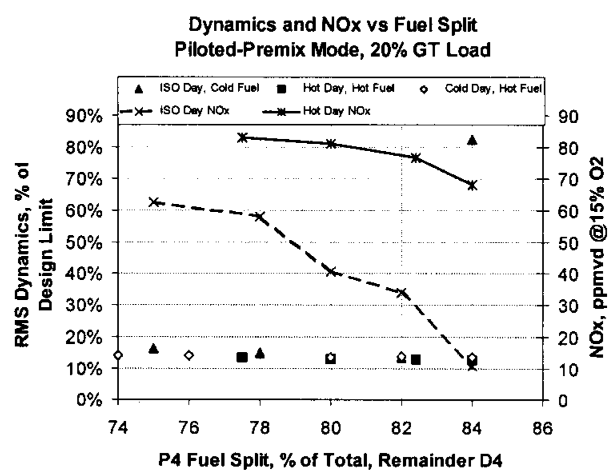
Parameter	FSNL	Max Diffusion	Piloted PMX Xfer	Max PPMX	Premix Transfer	65% Load PMX	Base PPMX	Base PMX	Base PPMX Cold Fuel
% Plant (CC) Load	0	26.5	26.5	43.6	43.6	65%	100%	100%	100%
Inlet Pressure, bar	8.47	10.29	10.29	12.06	12.06	16.24	23.52	23.52	23.52
Fuel/Air Ratio, % FSFL	27.2%	72.0%	72.0%	95.0%	95.0%	98.2%	100.0%	100.0%	100.0%
Diffusion Split, % Total	100%	100%	20%	20%	0%	0%	15%	0%	70%
P1 Split, % Total	0	0	0	0	20%	20%	15%	20%	30%
P4 Split, % Total	0	0	80%	80%	80%	80%	70%	80%	0%
Total Premixed Fuel, %	0	0	80%	80%	100%	100%	85%	100%	30%
Fuel Temperature, C	201	208	208	215	215	224	227	227	27
NOx, ppm dry, 15% O2	71.0	106.0	81.1	125.0	2.1	3.7	157.2	10.5	243.0
CO, ppm dry, 15% O2	335	27	8	< 5	< 5	< 5	< 5	< 5	< 5
UHC, ppm dry, 15% O2	255	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
RMS Dynamics, % Limit	11.4%	32.5%	23.9%	16.5%	28.3%	29.8%	30.1%	33.0%	34.8%

During the gas turbine start sequence, the generator is used as a motor to drive the shaft line up to 16% speed, and fuel is provided to the four diffusion circuits in all 14 chambers. The ignition fuel flow was developed in rig tests by setting a range of inlet pressures, temperatures, and flows representative of different gas turbine ambient conditions at start, and identifying the minimum fuel/air ratio which would result in ignition of the diffusion tip nearest the igniter and light-around to the other three diffusion tips on the endcover. The in-combustor camera permitted full light-around to all four tips to be verified. Figure 11 plots ignition characteristics for the DLN2.5H combustor. During initial tests of the prototype gas turbine in Wales, the 9H ignition and cross-firing sequence took less than two seconds, validating the rig test results. In addition to reliable ignition, the combustor must provide stable operation during the initial acceleration process up to full speed. Lean stability boundaries for all operating modes were identified during rig testing by holding inlet conditions constant as fuel flow was reduced, and measuring the fuel/air ratio at blow out. Weak extinction fuel/air ratios derived from rig testing and fuel/air requirements based on models of the gas turbine cycle were related to combustor inlet conditions using a common transfer function. The 'air loading' correlating parameter = air flow/($Pcd^{1.75}$*exp(Tcd/540) can be used to correlate LBO limits (Lefebvre, 1998). Figure 12 compares the blowout fuel/air ratio to the gas turbine operating fuel/air ratio during a start up to full-load. Diffusion mode exhaust emissions are directly proportional to flame temperature, with relatively high CO and UHC emissions at warm-up, and NOx peaking above 125 ppm, dry corrected to 15% oxygen at the transfer point into piloted-premix.

Piloted – Premixed Mode Test Results

"Piloted-Premix" (PPMX) modes combine the D4 circuit with one or more of the premixed fuel circuits. Once the gas turbine has reached 20% load, a fuel 'transfer' to piloted premix operation results in 80% of the fuel routed through the P4 circuit, with the remaining 20% in the D4 diffusion circuit. A matrix of transfer points and fuel schedules were evaluated during rig testing and the 20/80 D4/P4 split at 20% load was found to offer the best combination of lean stability, dynamics, and exhaust emissions. The transfer is accomplished well after the acceleration to full speed, breaker closure, and the air/steam turbine cooling transients. Combustor inlet conditions at the transfer point have reached levels that easily support a stable, partially premixed flame. Emissions and dynamics results for piloted-premix mode as a function of fuel split are given in Figure 13. Dynamic pressure measurements are RMS values (overall amplitudes integrated over all frequencies), given as a percentage of the design limit. Data was taken while operating the rig at the 20% gas turbine load operating condition. In this mode, typically at least 80% of the fuel is premixed, and the NOx decreases steadily as the P4 split is increased. Hot-Day NOx was lower across the split range because the overall fuel/air ratio was lower for the same T3.95. Dynamic pressures were low across the split range, with the content spread out over the frequency spectrum. Dynamics increased sharply (by a factor of 7) between 82 and 85% P4 with cold fuel, however.

Figure 13 – NOx and Dynamics vs. D4/P1 Fuel Split, Piloted Premix Mode



Fuel temperature impacts the pressure drop across the gas ports, permitting interaction between the combustion process and the instantaneous fuel supply rate. The fuel split trends were similar at the 43% load premix transfer condition in piloted premix mode, although NOx levels increase 15 to 20% because of the higher reaction temperatures at the 43% load operating condition.

The diffusion pilots provided by the D4 circuit gave the system excellent lean stability in piloted-premix mode, even with 80% of the fuel premixed. The weak extinction fuel/air ratio for the 20/80 D4/P4 fuel split at the diffusion-to-piloted premix transfer operating condition was measured at 0.0085, less than 50% of the minimum operating fuel/air ratio at that condition. The combustor will stay alight in piloted premixed mode at T3.95 temperatures 1000 F below the minimum operating temperature for PPMX mode, providing ample operability margin. The weak extinction fuel/air ratio in diffusion and piloted-premix operating modes was not a function of fuel temperature in the range between 80 and 440 F (27 to 227 C) tested.

Premixed Mode Test Results

Premixed transfer is accomplished by pre-filling the manifold supplying the P1 circuits on the 14 endcovers, and then opening the P1 circuit steadily as the D4 fuel is switched off and purged. The transfer process takes less than one minute. Fuel supply valves in the gas control module are carefully sequenced to avoid loss-of-flame or output power swings during the transient, which occurs at 43% gas turbine load (roughly 200 MW) on an ISO day at sea level. The premixed fuel split schedule was refined by measuring the exhaust emissions and dynamic pressure levels while systematically adjusting the fuel split to three premixed gas circuits on the endcover. Figure 14 shows NOx and dynamic pressures for premixed operation at the 43% load operating condition, just after premix transfer. NOx emissions are minimized near an 'even' fuel split, as expected, with each of the five premixers on the endcover supplied with nearly the same amount of fuel. NOx was minimized near 19.5/80.5 P1/P4 fuel split, suggesting that the center premixer is supplied with slightly less compressor discharge air than the outer premixers as a result of its position at the center of the nozzle array. The outer nozzles block the air flow to the center nozzle, so that a perfectly even fuel/air ratio at the exit of all five nozzles requires slightly less fuel at the center premixer. Dynamic pressures were low across the split range. Figure 15 is a similar plot of NOx and dynamics results at Base Load operating conditions for Cold Day (-18C), ISO Day (15 C) and Hot Day (40 C) ambient temperatures. Although combustor inlet temperatures vary over a wide range between the ambient extremes, the gas turbine control system maintains the temperature rise (T3.95 – Tcd) across the combustor, contributing to the near constant NOx results at a particular fuel split regardless of gas turbine inlet conditions. The figure also shows very low dynamic pressures across the split range, allowing a fuel split setting considering only minimum NOx.

Figure 14 – NOx and Dynamics for Premixed Operation at 43% Load

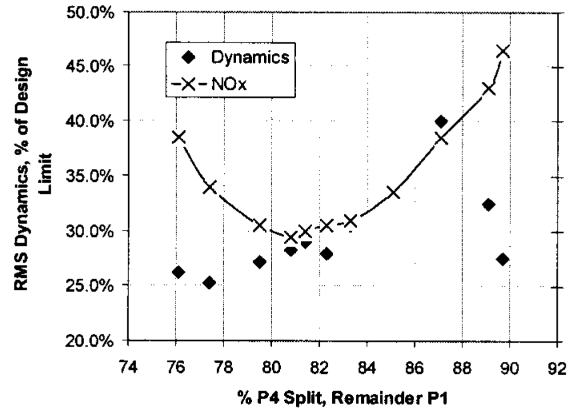


Figure 15 - NOx and Dynamics for Premixed Operation at Base Load

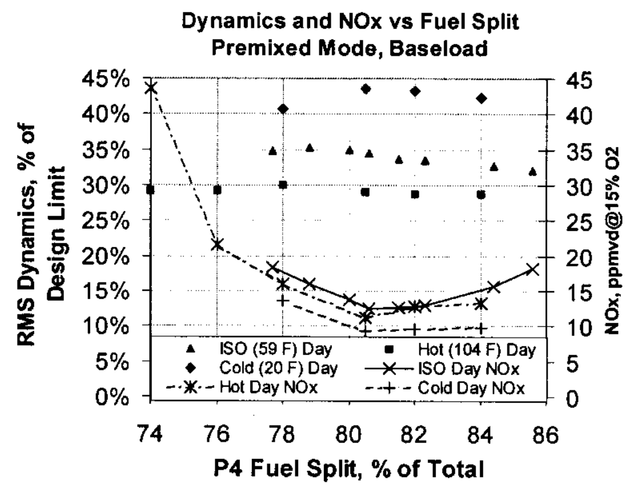


Figure 16 - NOx Emissions vs. T3.95 Ratio with Optimum P1/P4 Fuel Split

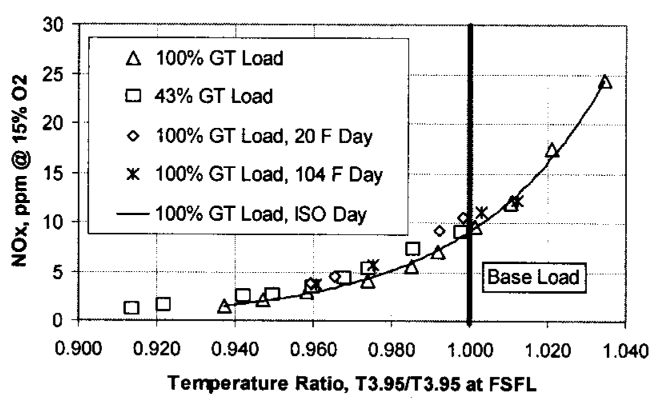
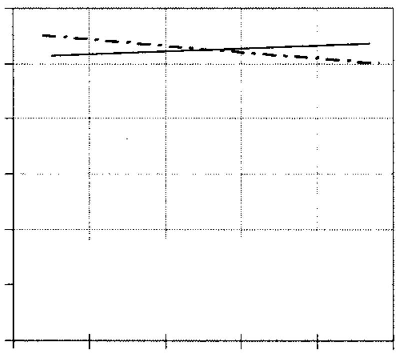


Figure 17 - Lean Stability Capability in Premixed Mode



From: "Jenifer Morris" <jenifer@njr.net>
To: "Connie Bruins" <Cbruins@energy.state.ca.us>
Date: 4/18/2005 4:49:21 PM
Subject: Air Quality Follow Up Informational Responses

Connie,

The responses that we provided on Friday included reference to information that we would provide under separate cover. Attached is the responses to AQ-13 and AQ-14.

Thanks,

Jenifer

Jenifer Morris
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CC: "Jim McLucas" <JMcLucas@Calpine.com>, "Mike Hatfield" <MiHatfield@calpine.com>, "Ken Kohl" <kenneth.kohl@ps.ge.com>, "Tom Andrews" <TAndrews@sierraresearch.com>, "Gary Rubenstein" <GRubenstein@SierraResearch.com>

INFORMATION REQUESTS

FOR DISCUSSION PURPOSES ONLY

Technical Area: Air Quality
Authors: Keith Golden, Will Walters, Brewster Birdsall

Dry Low NOx Combustor Performance

BACKGROUND

The applicant claims that the combustor design being utilized for the H turbine is capable of limiting NOx emissions to 15 ppm corrected to 15% oxygen. The combustor performance is critical in the design of the SCR system and the requirement of meeting an out-the-stack NOx emission limit of 2 ppm (at 15% O2) averaged over one hour. In order for staff to be assured that the DLN combustor design can in fact meet a 15 ppm NOx level, staff needs additional information on the design of the H combustor and emissions data that validates the NOx emissions claim.

INFORMATION REQUEST

13. Provide operational data, either at a commercial operation (Baglan Bay) or from test data that indicates the project would be likely to comply with the level of 15 ppm NOx during normal steady state operation.

    RESPONSE: Enclosed as Attachment AQ-13 is a summary of the Baglan Bay 2004 quarterly emission data that confirms the equipment is able to consistently comply with a NOx level of 15 ppm during normal steady state operation.

Partial Load Operation

BACKGROUND

Since this project will be subject to the unpredictability of the de-regulated market, it is possible that the each turbine train could be requested to be dispatched at loads less than full load. If that is the case, then it is important to understand at what loads the project can "safely" operate at and still meet the stringent emission permit limits.

INFORMATION REQUEST

14. Describe whether it is anticipated that each turbine train will be dispatched at less than full load (approx. 400 MW), and at what minimum load that each turbine train would be operated and still meet the emission limits of 2 ppm NOx, 3 ppm CO and 2 ppm VOC.

RESPONSE: The above levels are expected to be achieved down to a combined cycle load of approximately 50% (equivalent to a combustion turbine load of approximately 42%). Enclosed as Attachment AQ-14 is a data summary for the Baglan Bay facility that shows NOx, CO, and VOC emission levels at minimum load operation. At these gas turbine emission levels, compliance with the permit limits of 2 ppm NOx, 3 ppm CO, and 2 ppm VOC is expected when the SCR and oxidation catalyst control is taken into account.

ATTACHMENT AQ-13

Baglan 2004 Quarterly Reports						
	NOX	Quarterly mean	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
		mg/Nm3	24.53	24.39	24.4	20.47
		ppmv*	12.64	12.57	12.57	10.55
	CO	Quarterly				
		mean	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
		mg/Nm3	3.45	0.966	1.04	0.86
		ppmv*	2.92	0.82	0.88	0.73

Notes:

* Converted to ppmv based on standard molar volume of 23.7 m3/Kg-mole (at 60 deg. F) and molecular weights for NOx and CO of 46 Kg/Kg-mole and 28 Kg/Kg-mole, respectively.

ATTACHMENT AQ-14

Baglan 2005 Jan/Feb from CEMS

		9H MW (Mean)	9H Nox (Mean) ppmvd	9H CO (Mean) ppmvd
Base Load	Mean	485.89	10.57	1.44

		9H MW	9H Nox ppmvd	9H CO ppmvd
Partial Load > 50%	Shutdown	342.1	14.3	5.6
	Cold Startup	351.3	9.8	5.9

PPM to PM transfer in Apr 2003

		9H MW	9H Nox ppmvd	9H CO ppmvd
Comb Mode Xfer	PPM	227.0	103.0	0.4
	PM	234.0	13.5	0.4