NETL Investigation of LNG Interchangeability Issues

Presented to the
California Stakeholders'
Technical Committee Meeting
January 10, 2006

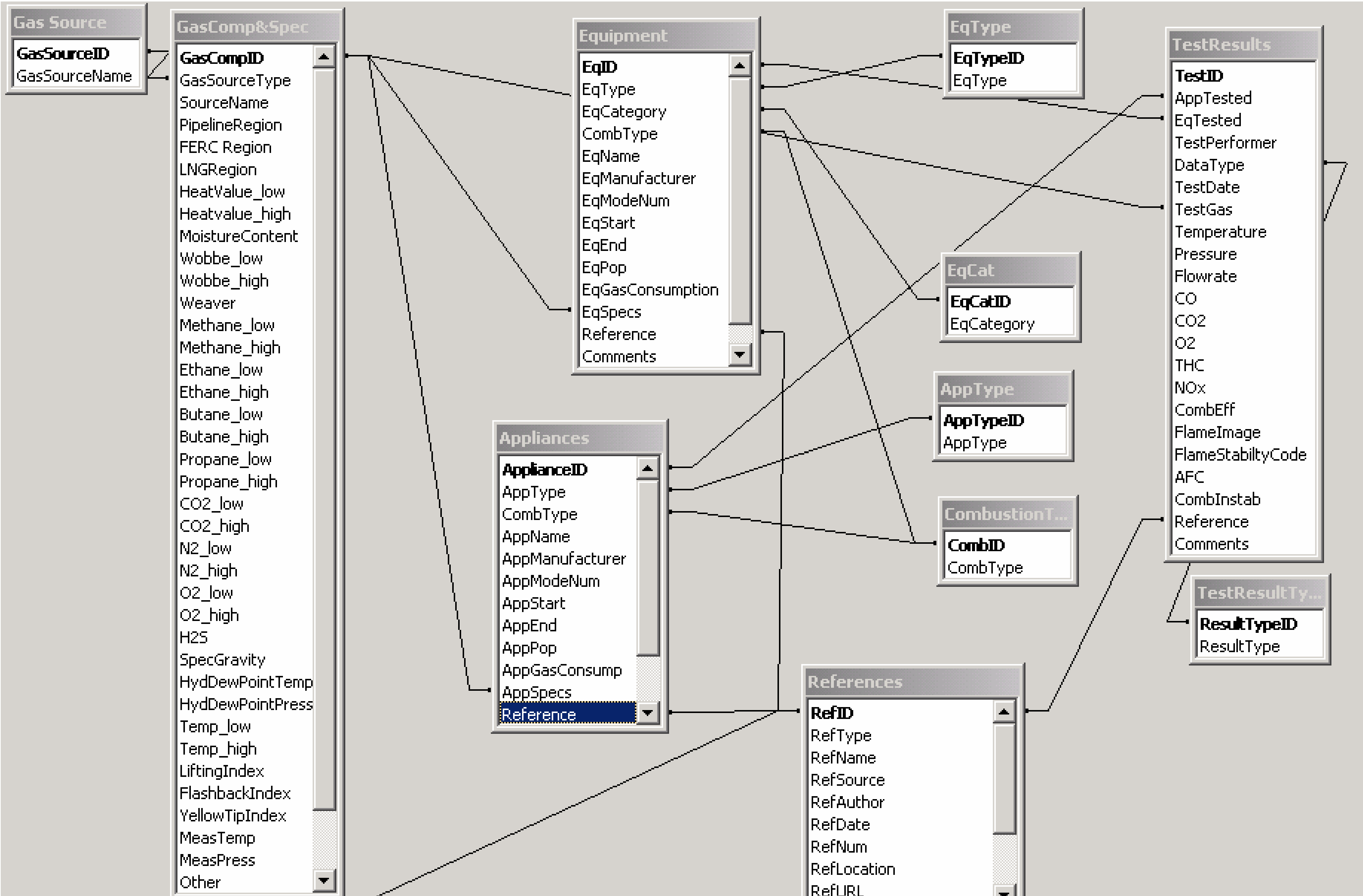
The National Energy Technology Laboratory

Overview of NETL effort

- **Evaluation of *mixing* in the gas infrastructure (Dave Huckaby)**
  - Requested for commissioners, etc.
- **Development of a database (Chris Nichols)**
  - Gas supply characteristics.
  - Data and fuel specs from appliances.
  - Data and fuel spec for turbines.
  - Data and fuel spec for recip engines.
- **Summary of appliance data analysis (Geo Richards)**
  - No plans for additional work at NETL.
- **Status of reciprocating engine data review (Mike McMillian)**
  - Not yet certain what testing is needed.
- **Status, plans, and progress on turbines (Geo Richards)**
  - Review limited public data.
  - Describe technical issues.
  - Describe NETL progress and plans.

LNG Interchangeability Database

- **Microsoft Access relational format**
- **Four main tables for data:**
  - Appliances
  - Equipment
  - Gas Compositions and Specifications
  - Test Result Data


Gas Source
GasSourceID
GasSourceName
GasComp&Spec
GasCompID
GasSourceType
SourceName
PipelineRegion
FERC Region
LNGRegion
HeatValue_low
Heatvalue_high
MoistureContent
Wobbe_low
Wobbe_high
Weaver
Methane_low
Methane_high
Ethane_low
Ethane_high
Butane_low
Butane_high
Propane_low
Propane_high
CO2_low
CO2_high
N2_low
N2_high
O2_low
O2_high
H2S
SpecGravity
HydDewPointTemp
HydDewPointPress
Temp_low
Temp_high
LiftingIndex
FlashbackIndex
YellowTipIndex
MeasTemp
MeasPress
Other
Equipment
EqID
EqType
EqCategory
CombType
EqName
EqManufacturer
EqModeNum
EqStart
EqEnd
EqPop
EqGasConsumption
EqSpecs
Reference
Comments
EqType
EqTypeID
EqType
TestResults
TestID
AppTested
EqTested
TestPerformer
DataType
TestDate
TestGas
Temperature
Pressure
Flowrate
CO
CO2
O2
THC
NOx
CombEff
FlameImage
FlameStabiltyCode
AFC
CombInstab
Reference
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EqCategory
AppType
AppTypeID
AppType
Appliances
ApplianceID
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CombType
AppName
AppManufacturer
AppModeNum
AppStart
AppEnd
AppPop
AppGasConsump
AppSpecs
Reference
CombustionT...
CombID
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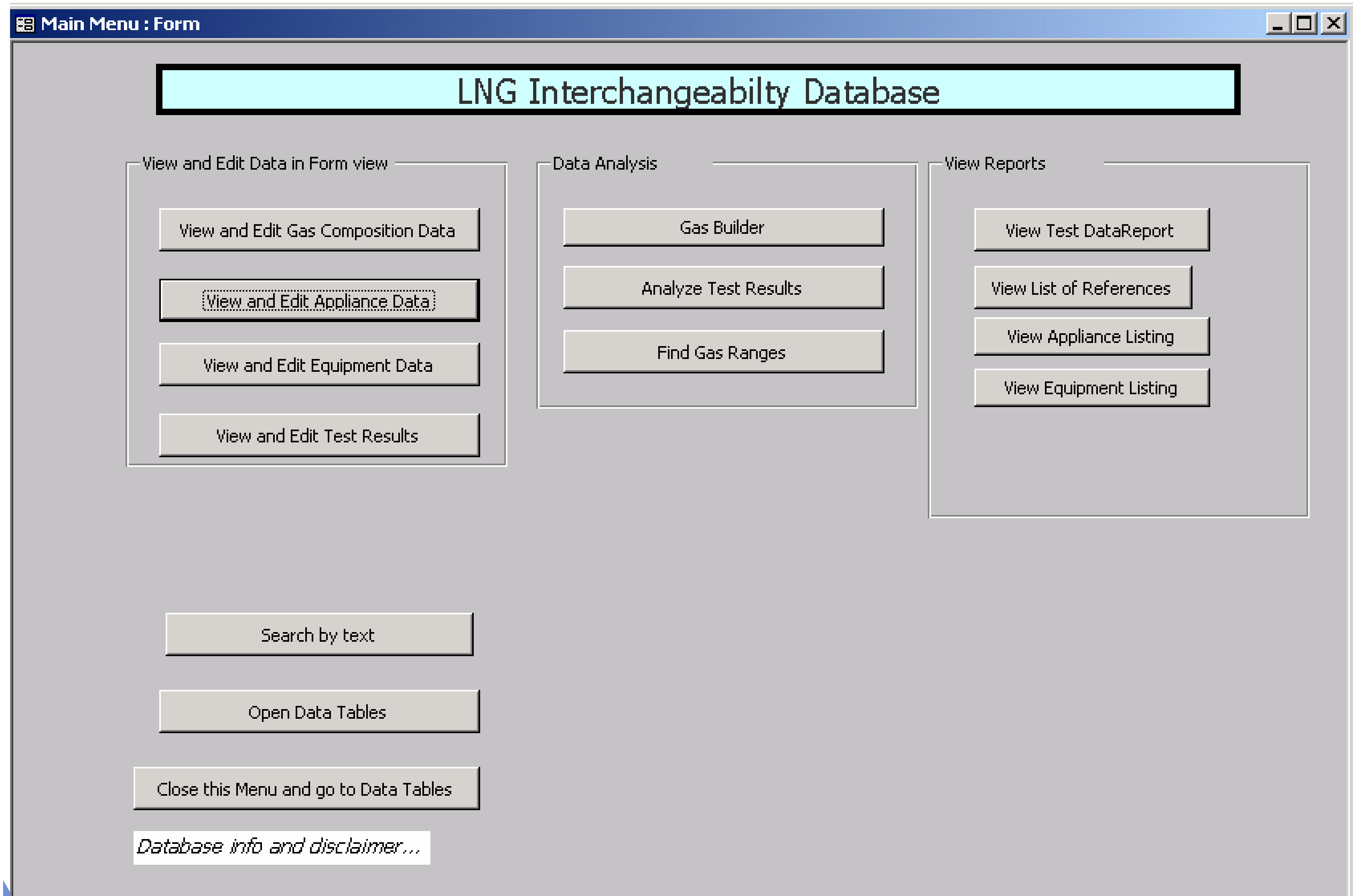
Main Menu : Form
LNG Interchangeabilty Database
View and Edit Data in Form view
View and Edit Gas Composition Data
View and Edit Appliance Data
View and Edit Equipment Data
View and Edit Test Results
Data Analysis
Gas Builder
Analyze Test Results
Find Gas Ranges
View Reports
View Test DataReport
View List of References
View Appliance Listing
View Equipment Listing
Search by text
Open Data Tables
Close this Menu and go to Data Tables
Database info and disclaimer...

GasComp&Spec : Table

GasSourceType	SourceName	HeatValue_low	Heatvalue_high	MoistureConten	Wobbe_low	Wobbe_high	Methane_low	Methane_high
Test Gas	GTI Adj1	1026.56	1026.56		1356.69	1356.69	0.97	0.97
Test Gas	GTI Adj2	1033.96	1033.96		1350.29	1350.29	0.95	0.95
Test Gas	GTI Adj3	1047.99	1047.99		1337.51	1337.51	0.91	0.91
Test Gas	GTI Sub1	1047.86	1047.86		1380.14	1380.14	0.96	0.96
Test Gas	GTI Sub2	1102.51	1102.51		1406.34	1406.34	0.89	0.89
Test Gas	GTI Sub3	1132.23	1132.23		1424.99	1424.99	0.89	0.89
Test Gas	GTI Sub4	1133	1133		1425.28	1425.28	0.85	0.85
Test Gas	GTI Sub5	1161.78	1161.78		1441.61	1441.61	0.87	0.87
Test Gas	GTI Sub6	1168.28	1168.28		1444.16	1444.16	0.86	0.86
Test Gas	GTI Test Pipeline NG	1023.28	1023.28		1327.92	1327.92	0.92	0.92
Test Gas	GTI Test Mixture	1159.54	1159.54		1408	1408	0.84	0.84
LNG	BG-Trinidad loading v	0	0	0	0	0	95.59	97.54
LNG	BG-Algeria Bethouia	0	0	0	0	0	87.14	92.06
LNG	BG-Malaysia loading	0	0	0	0	0	89.26	91.79
LNG	BG-Nigeria loading v	0	0	0	0	0	91.87	92.86
LNG	BG-Egypt - Damietta	0	0	0	0	0	97.48	97.98
LNG	BG-Egypt - Idku loac	0	0	0	0	0	97.49	97.91
LNG	BG-Oman loading va	0	0	0	0	0	88.38	88.54
LNG	BG-Qatar loading val	0	0	0	0	0	89.67	89.81
LNG	BG-Australia loading	0	0	0	0	0	86.08	87.78
LNG	Woodside Expected	1070	1135	1	1339	1339	88	95
Test Gas	Gas #1 (baseline)	1022	1022	0	1271	1271	96.08	96.08
Test Gas	Gas #2	974	974	0	1437	1437	96	96
Test Gas	Gas #3	1150	1150	0	1375	1375	87.03	87.03
Test Gas	Gas #4	1150	1150	0	1375	1375	84.92	84.92
Test Gas	Gas #4a	1150	1150	0	1376	1376	84.45	84.45
Test Gas	Gas #5a	1099	1099	0	1303.41	1303.41	90.85	90.85
Test Gas	Gas #1 (baseline 0.1	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]

Record: 1 of 137

gasFinder : Form

Gas Finder

BTU

Within [ ] **% of** [ ] **BTU**

Between [ ] **and** [ ] **BTU**

Wobbe

Within [5] **% of** [1400]

Between [ ] **and** [ ]

Gases Matching Criteria

Name:	GasSourceType	BTU Low	BTU High	Pipeline Region	Wobbe Low	Wobbe High	
Shell LNG-Arzew	LNG	1127.09	1127.09		0	1380.5	
Shell LNG-NW Shelf	LNG	1142.9	1142.9	N/A	0	1434.1	
Shell LNG-Idku	LNG	1032.6	1032.6	N/A	0	1371.5	Specification
Shell LNG-NLNG	LNG	1088.51	1088.51	N/A	0	1401.8	Measured at
Shell LNG-Oman	LNG	1134.95	1134.95	N/A	0	1425.7	
Shell LNG-Ras Laffan	LNG	1100	1100	N/A	0	1414	
Shell LNG-Trinidad	LNG	1042.7	1042.7	N/A	0	1378.4	Measured at
GTI Adj1	Test Gas	1026.56	1026.56		1356.69	1356.69	
GTI Adj2	Test Gas	1033.96	1033.96		1350.29	1350.29	
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GTI Test Mixture	Test Gas	1159.54	1159.54		1408	1408	
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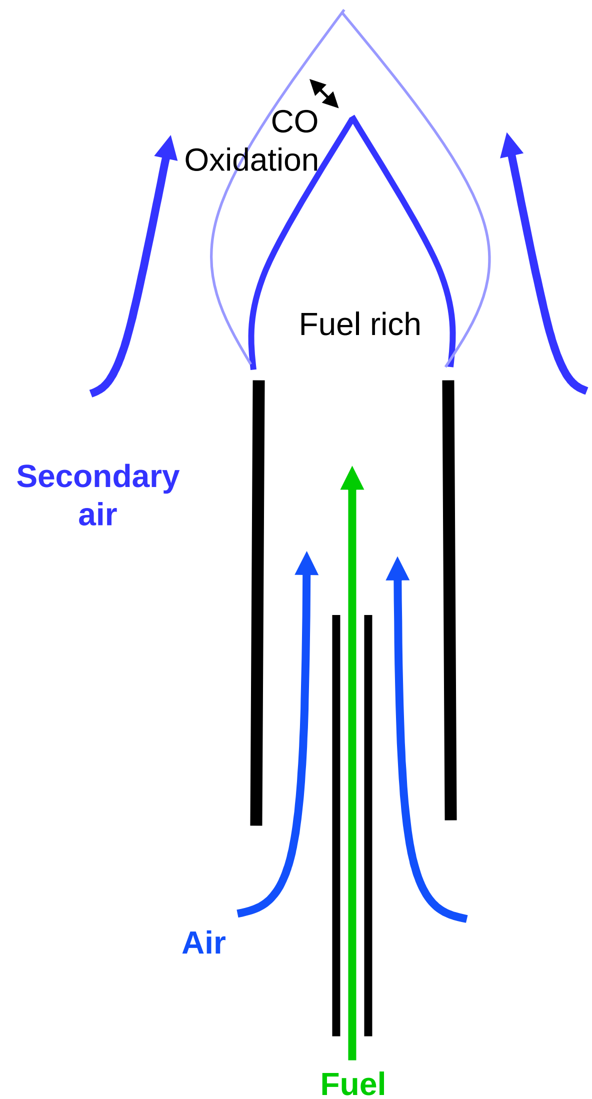
How appliances operate

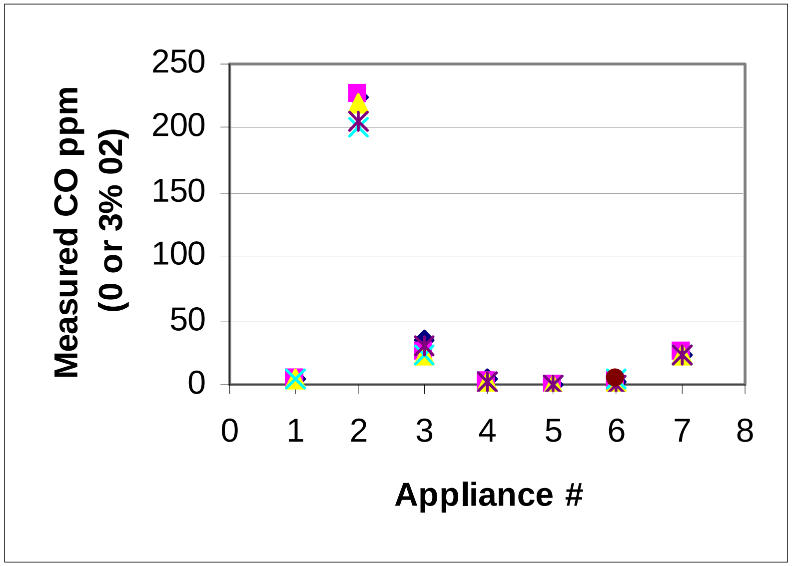
- **Non-powered combustion: fuel entrains air**
  - What happens if the fuel changes at constant Wobbe?
    - Look at propane-air systems already in use.
  - What happens if the Wobbe changes due to fuel shifting?
    - The fuel rich zone gets richer for higher Wobbe.
    - More CO to oxidize by secondary air.



Appliance data

- Phone discussions with propane air operators
- Public data from So Cal Web Site
- Data from GRI report

CO data from So Cal Gas tests
Fuel blends 1 – 4 in different appliances



Summary of CO data from GRI tests

	CO range w/Wobbe	Effect of dilution on CO
Oven2	Increase 130 –>340	decrease 210 –>120
Furnance	Increase 175->230	decrease 230 ->170
Range top1	decrease 160 –> 100	decrease 300 – 260
Radiant burner	decrease 700 –>500	slight increase 700 –> 720
Oven1	none	slight increase (30 – 45?)
Unvented heater	none	none
Dryer	none	none
Unvented fireplace	none	none
Water heater1	none	not recorded
Water heater2	none	none
Range top2	none	none

Table A.1 Data from GRI-03/0159. Taken directly from data in section six "Appliance Summaries" Numbers are taken from the trend lines presented; the data spread was considerable in some cases and leads to inconsistencies between dilution test results and the Wobbe trend numbers. The CO values are at 0% O2. The Wobbe range was 1355 -> 1435 btu/scf.

Summary of appliance data

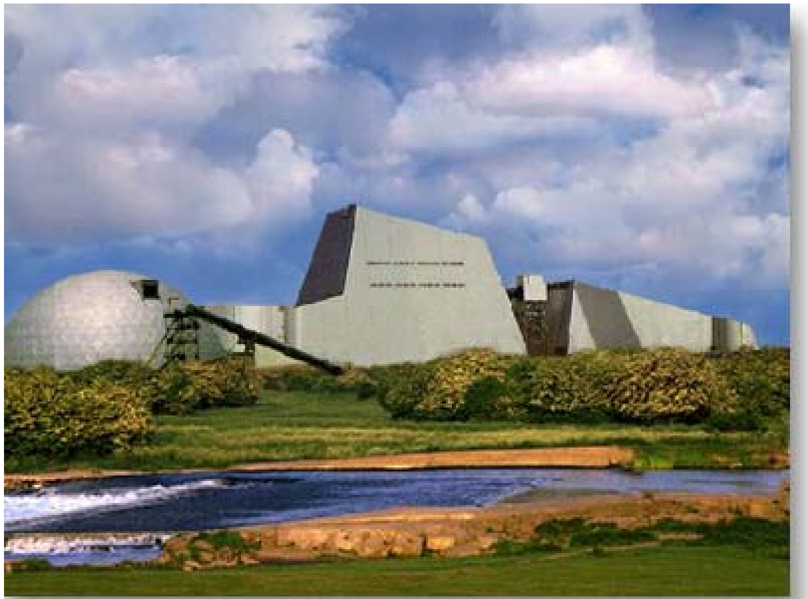
- **How many appliances need to be tested to reach a conclusion?**
- **Suggestion:**
  - Review European/Japanese field data – any problems?
  - Document performance of propane/air systems in use domestically.
- **NETL will not do additional work on this topic:**
  - Discussion with Marla Mueller, Technical Lead, Air Quality Research Program, PIER Environmental Area, California Energy Commission

Reciprocating Engines

- **Analysis of literature is still in progress.**
- **We know, with certainty, that emissions will be affected by fuel composition.**
  - Have discussed with Colorado State University
  - Have reviewed open literature
  - Have reviewed fuel spec from some engine OEMs
- **A possible approach:**
  - Small scale engine test at NETL
  - But, how to generalize?
- **Adding gas variation to NETL rig**
  - Gas blending is smaller, low pressure
  - Cannot do diesel injection
  - Can get excellent emissions data

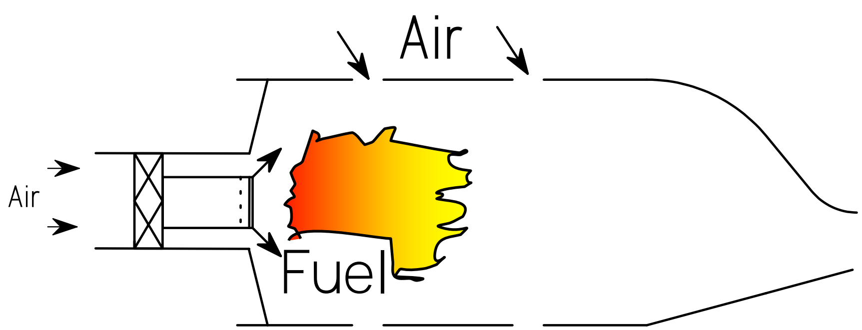
Dynamics in low-emission turbines

- **Current fleet of low-emission turbines**
  - Combustion dynamics limits NOx performance, combustor life.
  - Combustion dynamics limits fuel tolerance.
- **Future power plants**
  - Desire *greater* fuel flexibility
    - Variable coal syngas (IGCC), H_2 + NG blends

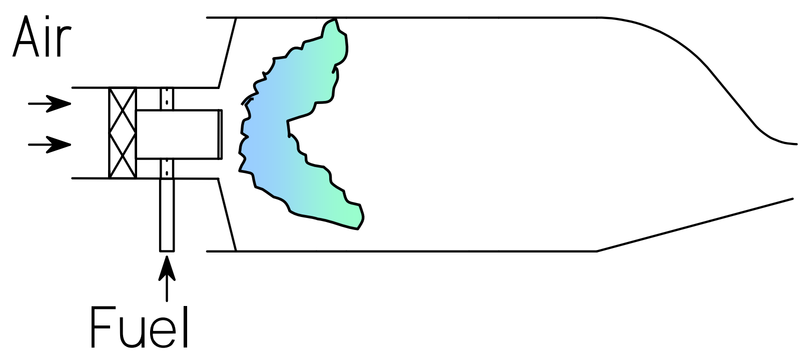


An important distinction

- **Emissions have been dramatically reduced from natural gas fired gas turbines:**
  - 1990 diffusion flame combustor ~ 100ppmv @15% 02
  - 2000 premix combustor < 10 ppmv @ 15% 02
- **The focus of this technical presentation is premix dry low-NOx**
  - Older diffusion systems: effect of hotter fuel is somewhat expected (NOx up)
  - Exact changes in emissions will depend on the engine



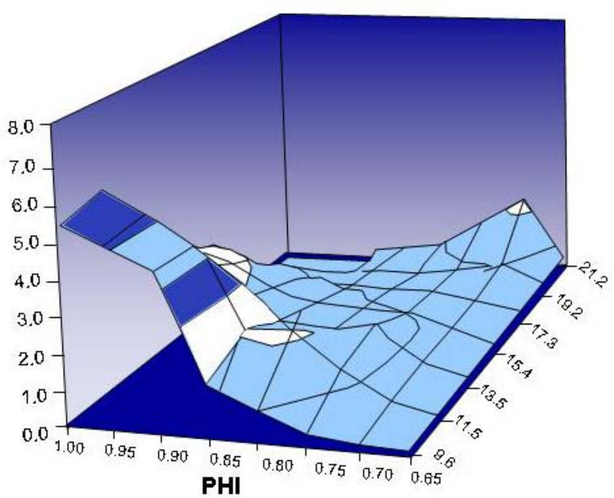
Diffusion flame produces stoichiometric combustion temperatures (hot!). This produces NOx



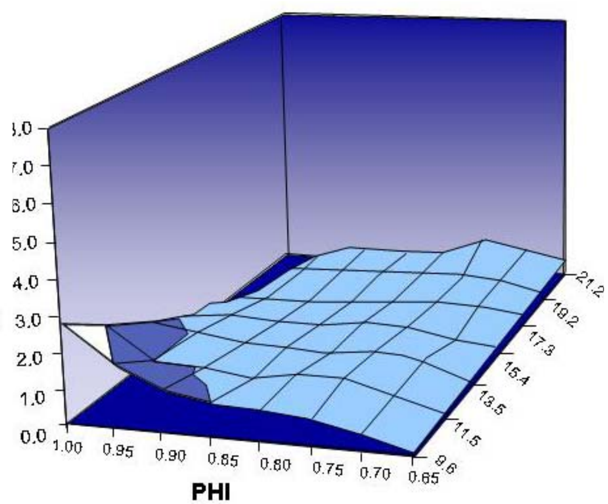
Premixed flame avoids stoichiometric combustion temperatures (cool!). This prevents NOx

Fuel composition effect on dynamics

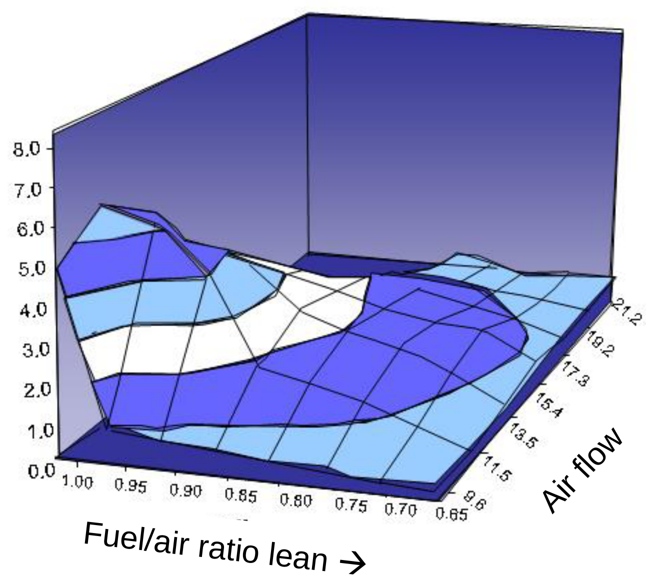
- **Lab scale combustor, atmospheric pressure**
- **Plots show stability maps (RMS pressure = height at various fuel/air ratio, flow rate)**



Natural gas (NG)



NG + 25% H_2 vol.



Propane

Summary and discussion points

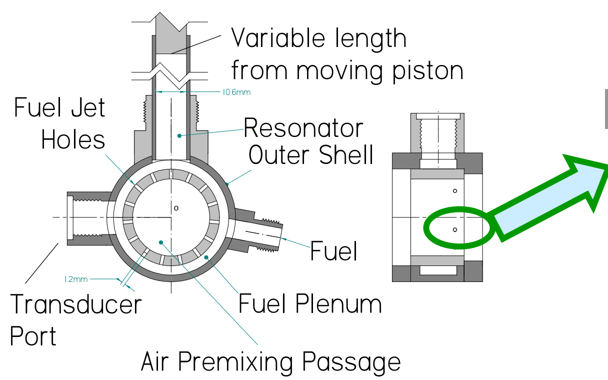
- **Combustion dynamics are a *potential* complication of rapid, significant fuel composition changes.**
  - Ambiguous public information on fielded engines (how much of a change is significant?)
  - Lab data identifies a connection between fuel composition and dynamics.
  - Predicting fuel composition effects depends on the engine; not a single way to describe the effect.
- **What about other issues for gas turbines?**

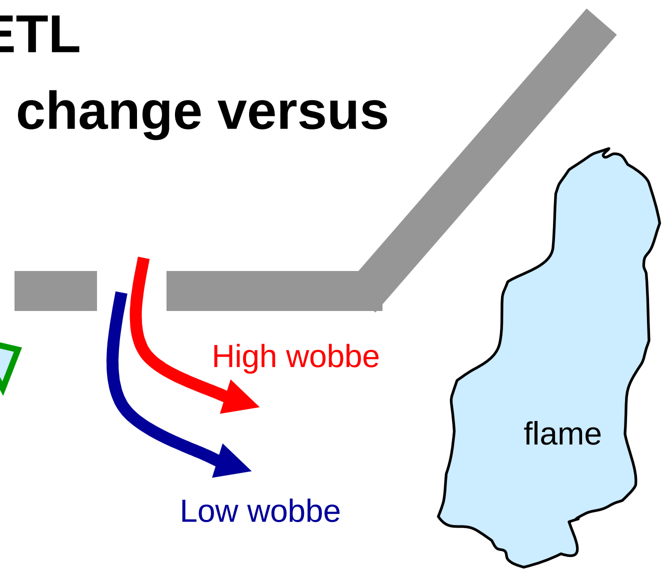
Combustion issues for turbines

- **Flashback**
- **Blowoff**
- **Autoignition**
- **Chemical effects on emissions**
- **Physical effects on emissions**
- **Dynamics**
  - Effect on fuel system impedance
  - Effect on dynamic flame response

Physical effects on emissions

- **Low NOx emissions require fuel/air premixing**
- **Premixing affected by injector pressure drop**
- **Unlike burners, appliances, pressure drop is dependant variable on power setting**
  - For a given power setting, $\Delta p \sim 1/(\text{Wobbe})^{\mathbf{2}}$ ← Squared!
- **How significant is this?**
  - **General analysis in progress at NETL**
  - **Should determine effect of Wobbe change versus impact.**

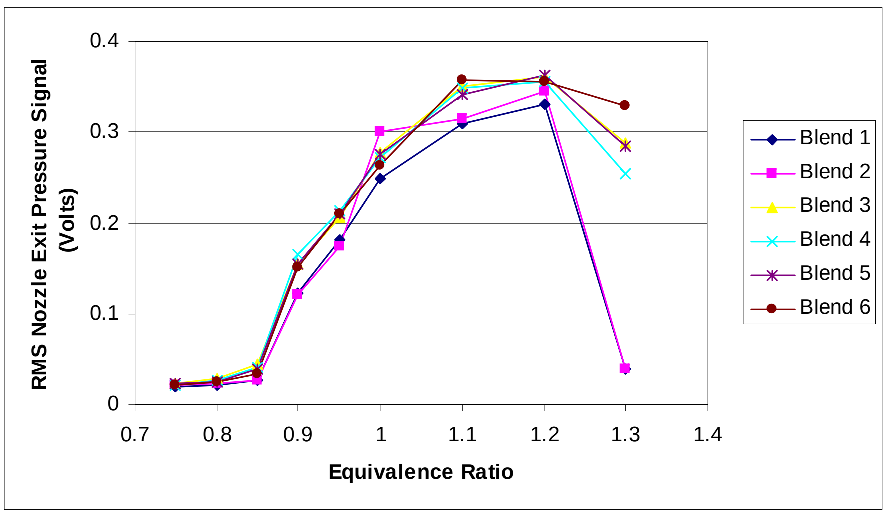


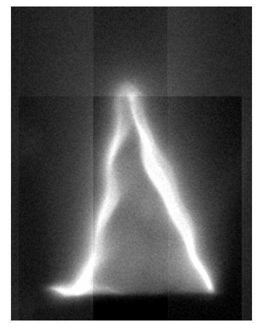


Flame response effects

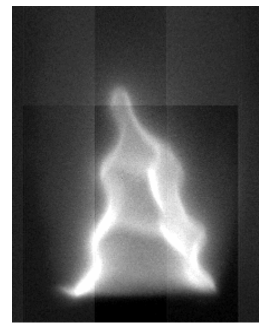
- **Two issues:**
  - Chemistry and diffusive effects on the reaction front.
  - Position and flame anchoring changing dynamic feedback timing.
- **Current lab burner studies shown.**
  - Must compliment with tests covering turbulent flames, _turbine_ operating conditions

Blend #	*1*	*2*	*3*	*4*	*5*	*6*
Methane %	**100**	**96.2**	**87.1**	**86**	**90**	**85**
Ethane %	**0**	**3.4**	**10.7**	**9**	**5**	**15**
Propane %	**0**	**0.43**	**2.1**	**5**	**5**	**0**

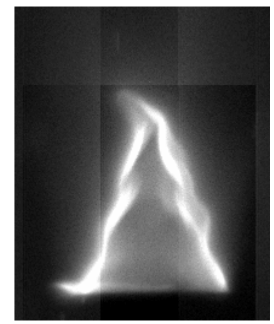




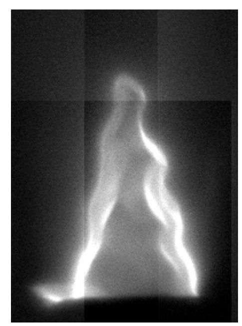
Blend 1



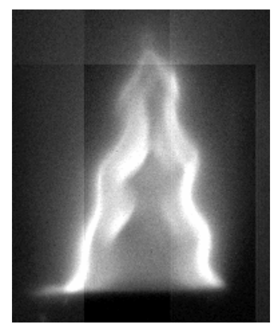
Blend 2



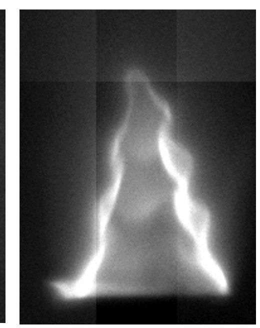
Blend 3



Blend 4



Blend 5



Blend 6

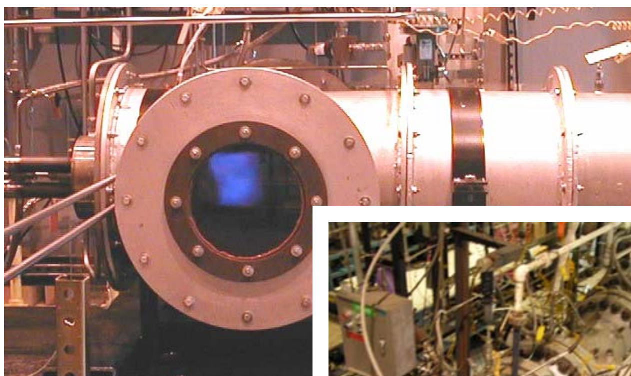
Plans or work addressing the issues

1. **Flashback – insignifcant?**
2. **Blowoff – insignificant?**
3. **Autoignition – insignificant?**
4. **Chemical effects on emissions – small?**
5. **Physical effects on emissions - uncertain**
6. **Dynamics**
   - Effect on fuel system impedance
   - Effect on dynamic flame response

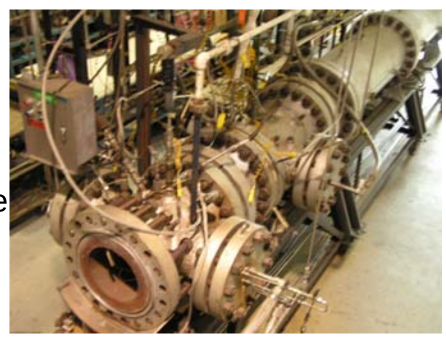
1. **Affirm during testing.**
2. **Affirm during testing.**
3. **Affirm based on literature and test data.**
4. **Affirm during testing, and resolve model predictions (brown plume issue open?)**
5. **Quantify based on analysis, tests TBD.**
6. **Dynamics**
   1. Effect on fuel system impedance - define significance based on literature, analysis, tests.
   2. Effect on dynamic flame response – define significance based on literature, analysis, tests

Summary of NETL approach for turbines

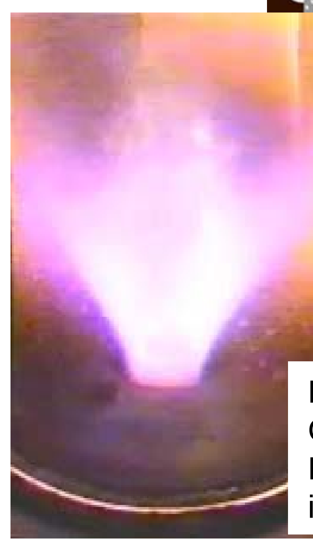
- **Lab scale bunsen studies already in progress to define flame response versus fuel type**
- **Atmospheric pressure turbine combustion tests starting now**
  - Baseline on natural gas
  - Switch to propane/N2 to evaluate issues
- **High-pressure combustion tests to validate atmospheric pressure findings an address other issues:**
  - Emissions, flame stability

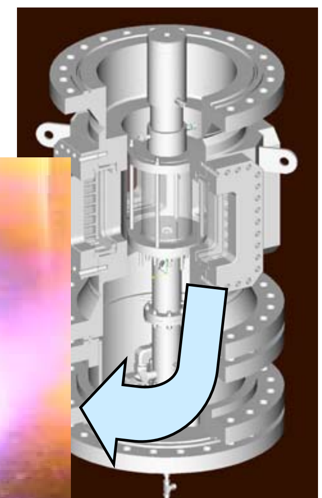


Atmospheric pressure combustor for screening studies



Full-size gas turbine combustor For changes in stability





Full –size optical Gas turbine combustor For emissions, changes in flame anchoring

One other activity

- **NETL is investigating options for how to measure gas composition:**
  - Real time (<1s), faster than GC approach.
  - Small and cheap compared to GC.
  - No clear options identified yet:
    - Optical methods too complicated
    - Sound speed methods proposed by others limited
    - Ideas being sought from local academic sensors groups

Deliverables

- **Database available to public**
- **Gap analysis: a report stating what we know versus what we need to know.**
  - Appliances discussed here
  - Recip engines is still in progress
  - Turbines presented here
- **Quantify the magnitude of fuel effects in gas turbines *based on data:***
  - Hypothesis:
    - *Flashback, autoignition, and blow-off not significant*
    - *Emissions changes <u>due to chemistry</u> small*
    - *Emissions change dominated by physical effects and dynamic margin changes*
  - Suggest how engine tests and operation will be sensitive to fuel composition
    - *E.g., if you know an engine is sensitive to fuel temperature, can you make a statement about fuel composition?*
    - *Emphasize: this is a research question!*
- **What we won't deliver**
  - The fuel spec across the country can be x% changed without any problems
    - *Need to look at the specific engine*