Impacts of Potential Revisions to CNG Fuel Standard

California Air Resources Board

May 19, 2010

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Introduction
San Diego Concerns

- Potential emission impacts from LNG
- All emission impacts must be addressed
  - Gas distribution emissions, stationary source emissions, vehicle emissions
- Emission impacts must be accurately estimated
- Impacts are adequately mitigated
- Possible safety issues, if any, from LNG use are considered
Outline

- Background
- District concerns
- Characterizing & Quantifying Emission Impacts
- Possible Safety Concerns
- Emission Estimates & Mitigation
- Conclusion
Background
District Goals

- Protect air quality
- Attain & maintain (no backsliding) the state and federal ambient air quality standards
- Mitigate any emission increases resulting from changes in source of gas supply
- Compliance of permitted sources
## San Diego Attainment Status

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Federal</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>Attainment</td>
<td>Attainment</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>Attainment</td>
<td>Attainment</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>Attainment</td>
<td>Attainment</td>
</tr>
<tr>
<td>Lead</td>
<td>Attainment</td>
<td>Attainment</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Attainment</td>
<td>Non-Attainment</td>
</tr>
<tr>
<td>Ozone</td>
<td>Non-Attainment</td>
<td>Non-Attainment</td>
</tr>
</tbody>
</table>
Days Exceeding Air Quality Standards for Ozone
# Significance of Emissions

<table>
<thead>
<tr>
<th>Emission Increase</th>
<th>Stationary Source Requirements and District Mandates</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 lbs/day</td>
<td>BACT</td>
</tr>
<tr>
<td>0.07 tons per day (25 tons per year)</td>
<td>LAER and Offsets at a major source</td>
</tr>
<tr>
<td>0.1 tons per day</td>
<td>New rule to address source category</td>
</tr>
<tr>
<td>0.01–0.1 tons per day</td>
<td>Potential new rule to address source category</td>
</tr>
</tbody>
</table>
District Concerns
Potential Implications of Revision to CNG Standards

- **LNGs do not comply with current standards**
  - Less than 1.5% inerts
  - More ethane (C2) and/or propane and butane (C3+) than standard

- **LNG has higher C2 and C3+ than historical San Diego supply and most of the supply in the rest of CA**
Potential Implications of Revision to CNG Standards

- Revising gas quality standards removes barrier to LNG-derived natural gas being supplied to San Diego, Imperial County and SCAQMD

- Operational LNG terminal in Baja California with 1000+ MMscf/day capacity

- Energia Costa Azul or ECA terminal—owned by Sempra, parent company of SDG&E and SoCal Gas
Potential Implications of Revision to CNG Standards

- Revision to gas quality standard could immediately allow large amounts of LNG use—up to 400 MMscf/day in San Diego and 400 MMscf/day elsewhere in S. CA
- San Diego current maximum gas consumption about 400 MMscf/day
Energia Costa Azul & Pipelines to California
Costa Azul Zone of Influence for Rollout Planning
Liquefied Natural Gas (LNG) vs Historical Natural Gas

- San Diego natural gas composition has been very stable over many years.
- Natural gas derived by revaporizing LNG has a significantly different gas composition from historic pipeline (base) natural gas.
LNG vs. CA Historic Natural Gas

Source: Gas Technology Institute
Emission Concerns

- Combustion equipment can be tuned to operate well over a wide range of gas compositions.

- However, evidence shows that some combustion devices tuned and/or expected to operate on historic gas have significantly increased NOx emissions on LNG.
Emissions Concerns

- All combustion equipment in the county could be affected
- Device operation may otherwise be relatively unaffected
- Little incentive to retune to new gas
- Market forces can cause rapid and unanticipated changes in gas quality
Emission Concerns

- LNG has higher VOC content than historic natural gas
- Potential significant increase in emissions from fugitive VOC leaks from gas transmission and distribution system expected
- Potential increased VOC emissions from combustion devices
Impact from CA Producer Gas

- Limited amounts of gas and areas affected (San Diego-little, if any)
- Historical gas in area gas system already same quality
- Combustion devices tuned to existing supply
- Typically don’t have rapid, unanticipated changes in gas quality
Quantifying and Characterizing Emission Impacts
Characterizing Emission Increases

- $E_{baseline} = E.F. \times Activity$
- $\Delta E = E_{baseline} \times [EI(x)/EI(x_{baseline}) - 1]$
- $EI$ is an emission index based on testing (e.g., NOx ppmv)
- $x$ is a parameter that characterizes the change in $EI$ with gas quality
Characterizing Emission Increases

Some assumptions

- Activity (e.g., total annual heat input) is approximately constant (i.e., small changes in efficiency)
- \( \frac{EI(x)}{EI(x_{baseline})} \) is constant with changing baseline emissions (e.g., decreasing control efficiency)
- Representative \( x \) (or \( x \)'s) to quantify increase
- Test population is applicable to population of devices
Stationary Source Emission Testing

- **Residential appliances**
  - SoCal Gas—NOx, CO, safety
  - LBNL (CEC sponsored) —NOx, CO, PM
  - AHRI—NOx and CO not published
  - PG&E and East Coast utilities—results not publicly available

- **Industrial/commercial equipment**
  - SoCal Gas, GTI (CEC sponsored)
  - LNG event SoCal Gas, SDG&E, SDAPCD
Vehicle Emission Testing

- SWRI Fuel Composition Testing Using DDC Series 50G Natural Gas Engines, 2006
- SwRI Heavy-Duty Natural Gas Engine Study, 2009
- SwRI Light-Duty Natural Gas Vehicle Study, 2010
- CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010 DRAFT
Characterizing Combustion Equipment
Combustion Categories

- **Premixed**—turbulent or laminar
  - Ideally same fuel/air ratio everywhere in flame
  - Low-NOx burners often lean-premixed

- **Conventional**—turbulent nonpremixed (diffusion flame)
  - Fuel/air ratio varies throughout the flame
  - Typical of nonregulated devices

- **Partial premix (double flame)**—appliances
Important Nonresidential Combustion Equipment

- Conventional burners (San Diego unpermitted commercial/industrial)

- Premixed lean-burn (SCAQMD unpermitted commercial/industrial)

- Permitted equipment usually $O_2$ or load following (permitted equipment)

- Add-on SCR with CEMS feedback—no significant NOx increases observed so far
Wobbe Index
Wobbe Index

- Common measure of effect of natural gas composition on combustion equipment
- $WI = \frac{HHV}{(\text{specific gravity})^{0.5}}$
- HHV and specific gravity at STP
- Measure of fuel heat input to a combustor through an opening with a fixed size (constant fuel T & P)
Wobbe Index and Emissions

- For natural gas fuels metered through a fixed opening and with a fixed air supply, fuel to air ratio is directly proportional to the Wobbe Index.

- Once tuned, changes in fuel/air ratio can strongly affect emissions.

- Wobbe Index for most LNG is higher (1385 is PUC limit) than for historic San Diego pipeline gas (about 1335).
Equivalence Ratio

- Equivalence ratio, $\phi$, is $\frac{\text{fuel/air}}{\text{stoichiometric fuel/air}}$
- $\phi < 1$ is lean (more air than needed for complete combustion)
- $\phi > 1$ is rich (less air than needed for complete combustion)
- Peak combustion temperature at or near $\phi = 1$
- NOx emissions are very sensitive to temperature
Increasing Wobbe

Source: Gas Technology Institute
NOx Formation

- **Thermal NOx**
  - Categorized as NOx occurring outside of flame zone where combustion primarily occurs (usually a very narrow flame zone)
  - Increases very rapidly with temperature

- **Prompt NOx**
  - Occurs within the flame zone
  - Different NOx creation mechanisms may dominate
Most commercial and residential equipment can not easily or routinely adjust fuel or air flow.

- Lean-premix devices are especially sensitive.
- Devices with diffusion flames may be less sensitive.
Large Industrial Equipment

- Operational controls that may compensate for changes in Wobbe Index are common but not universal
  - Fuel adjustment for load following
  - Air adjustment with O$_2$ trim systems

- Mitigates emission increases from Wobbe Index increases
Beyond the Wobbe Index

- Ethane and propane have higher adiabatic flame temperatures than methane at the same fuel to air ratio
- Ethane and propane have higher flame speeds than methane at the same fuel to air ratio
- Combustion chemistry details
Characterizing NOx Emission Impacts
Wobbe and Non-Wobbe Impacts

- Wobbe Index expected to be important for devices without fuel/air controls
- Non-Wobbe effects expected to dominate in devices with fuel/air controls or operating at very low NOx levels (i.e., at low temperatures)
Wobbe Effects on NOx
Source: Southern California Gas Company, Gas Quality and Research Study, Appendix G
Non-Wobbe Effects on NOx
Prompt NOx, Lean Premixed Combustion

Replotted from Bachmaier F. et al., Combust. Sci. Tech., 7, 77 (1973)
Fuel Effect Lean Premix—Low Swirl

Equivalence Ratio

NOx, ppmv @ 15% O2

Fuel Effect Lean Premix Burner--Low Swirl

Based on linear fit of log(NOx) vs phi, phi > 0.65

Other Data with Non-Wobbe NOx Emission Increases

- SWRI lean-burn engine testing, 2006 and 2009
- Dual fueled lean-burn engine, McTaggert-Cowan, et al., 2010
  - Nonpremixed
Tests with No Significant Emission Increase

- Low-pressure (33 Torr) laminar flame, Pillier, L., et al., 2005
Conclusions—Characterizing NOx Emissions

- Can’t rely on Wobbe Index alone
- Especially if fuel/air ratio is controlled
- Testing must cover wide range of gas compositions
Characterizing VOC Emission Impacts
Characterizing VOC Combustion Emissions

- Very limited testing (SWRI on engines)
- Increase in emissions expected to be related NMHC in fuel
- Ethane $\Rightarrow$ ethene and acetylene
- Propane & Butane $\Rightarrow$ propane, butane, propene, ethene, acetylene
- Large relative increases possible because of large relative change in NMHCs
Plot of data from SwRI Heavy-Duty Natural Gas Engine Study, 2009.
Plot of data from SwRI Heavy-Duty Natural Gas Engine Study, 2009.
Relative VOC Increase DD TK Engine--Based on Linear Fit to SWRI Test Results

Based on fit of data from SwRI Heavy-Duty Natural Gas Engine Study, 2009.
Relative VOC Increase ISLG--Based on Linear Fit to SWRI Test Results

Plot of data from SwRI Heavy-Duty Natural Gas Engine Study, 2009.
Gas Supply System VOC
Emissions from LNG

- **Leaks of natural gas from supply system**
  - Supply piping, residential meters, industrial meters, system regulating/metering system, compressors, etc

- Assuming same mass leak rate of natural gas, VOC emissions proportional to wt% VOC in the natural gas

- May be very significant
VOC Content of LNGs Compared to Existing San Diego Natural Gas

<table>
<thead>
<tr>
<th>Location</th>
<th>VOC Content, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD Baseline</td>
<td>0.0%</td>
</tr>
<tr>
<td>Tangguh, Indonesia</td>
<td>2.0%</td>
</tr>
<tr>
<td>Sakhalin Island</td>
<td>8.0%</td>
</tr>
<tr>
<td>Malaysia</td>
<td>12.0%</td>
</tr>
</tbody>
</table>
Transmission and Distribution

Emission Estimates

- Current estimate relies on AGA and INGAA emission factors ultimately based on data collected in the 1990s
- Updated emission factors may be useful in refining emission estimates
Conclusions—Characterizing VOC Emissions

- Weight fractions of ethane, propane, and butane are the important parameters
PM10 (Soot) Emissions

- **Sooting tendency**
  - Butane > Propane > Ethane > Methane

- *No observed trend with composition in SWRI engine testing or LBNL appliance testing*

- *Probably because all test were done on lean-burn and/or premixed devices*
PM Emissions from a Dual Fueled Engine

Toxics

- **Limited known tests**
  - SWRI engine tests—(full spectrum)
  - LBNL appliance tests—formaldehydes

- **Limited testing or so far as shown little correlation with fuel composition**

- **Devices tested all or partially premixed**

- **Dual-fueled engine test indicates that nonpremixed (i.e., diffusion flames) may show increases in PAHs and BTEX**
Testing Comments
LNG Event Testing

- “LNG Event” commissioning of Sempra’s Energia Costa Azul (ECA) liquefied natural gas (LNG) terminal in Baja, California
- Large influx of LNG-derived natural gas on May 9, 2008, into San Diego
Testing During LNG Event

- District source tests of permitted equipment using reference methods
- SoCal Gas and SDG&E testing of permitted and a few nonpermitted devices
  - Separate from, but coordinated with, District testing
  - Used portable analyzer
- Collection of CEMS data
LNG Event Natural Gas Composition

- **Ethane**
- **Propane**
- **Butanes**
- **Pentanes**
- **C6+**
- **CO2**
- **N2**

**Base Natural Gas** — WI = 1342

**LNG** — WI = 1382
Limitations

- Gas Composition tested did not fully capture the potential emission increases
- Low C3+
- Non-Wobbe effects not captured for Nox
- VOC increase not representative of other LNG compositions
Other Issues

- Equipment tested self-selected

- Some equipment may not be representative of inventory

- Equipment specific issues
LNG Event Testing—Assessing Potential Compliance Issues

- *District source tests and CEMS data showed no compliance problems for equipment tested*
  - However, even small increases may be an issue for some sites

- *SoCal Gas/SDG&E testing showed two potential exceedences of NOx limits*
  - Lean burn engine—tuning resolved
  - Boiler—2 ppmv, but exceeded by 1 ppmv on base gas
## SWRI Engine Testing

<table>
<thead>
<tr>
<th>Engine</th>
<th>Engine Type</th>
<th>Controls</th>
<th>Status When Procurred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cummins ISL G</td>
<td>Rich-Burn</td>
<td>3-Way Catalyst</td>
<td>New</td>
</tr>
<tr>
<td>Cummins C Gas Plus</td>
<td>Lean-burn</td>
<td>Oxidation Catalyst</td>
<td>New</td>
</tr>
<tr>
<td>Cummins C Gas</td>
<td>Lean-burn</td>
<td>Oxidation Catalyst</td>
<td>New</td>
</tr>
<tr>
<td>Detroit Diesel TK</td>
<td>Lean-burn</td>
<td>None</td>
<td>Used</td>
</tr>
<tr>
<td>John Deere 6081H</td>
<td>Lean-burn</td>
<td>Oxidation Catalyst</td>
<td>Used—about 15% Life</td>
</tr>
</tbody>
</table>
In use emission increases need to be considered when using test results on new engines to estimate actual emission increases.

<table>
<thead>
<tr>
<th>Engine</th>
<th>Emissions Relative to New Emissions @ 435,000 miles</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>NOx</td>
</tr>
<tr>
<td>HHD Lean-Burn</td>
<td>1.07</td>
</tr>
<tr>
<td>LHD Rich-Burn</td>
<td>5.58</td>
</tr>
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</table>

Relative Increase based on Table 2 from EPA 420-R-01-033, MOBILE 6 Emission Factors for Natural Gas Vehicles, April 2001.
Safety
Safety Concerns?

- Large WI change from tuning level known to increase CO from some appliances
- Previous (available) US testing has not shown a problem (SoCal Gas and LBNL)
- Draft results of recently concluded AHRI tests may indicate a possible issue
AHRI Testing

- AHRI—an industry organization for appliance manufacturers—tested a large number (about 80) currently manufactured appliances
- Measured CO levels for WI increase slightly higher than generally expected increase from LNG in CA (4.5% vs. 4%)
- Used industry standard safety test procedures
AHRI Testing

- **Standard appliance test procedures**
  challenges appliance with overfiring

- **Overfiring test provides a margin of safety**
  to account for:
  - Gas quality variation, ambient condition changes, manufacturing variations, poor maintenance, etc.
AHRI Draft Results

- Observed CO increases exceed safety standards when devices overfired (mostly)
- One interpretation is that most devices may perform satisfactorily with change to high Wobbe gas, but safety margin may be reduced
- Once again issue is change in gas quality from the expected gas quality used to tune the appliance
Maximum CO Increase Among All Devices Tested--Overfire Test

- **Baseline Gas (1345 Wobbe) - Overfire**
- **High Wobbe (1405 Wobbe) - Overfire**

Uncertainties

- Draft results—no conclusions from AHRI, no details of devices tested publicly available
- Not clear how appliances tested (and those failing) relate to installed appliance base in CA
Preliminary Emission Estimates

- San Diego emissions
- Based on expected worst case LNG-derived natural gas (Malaysian)
- Emission increase relative to historical natural gas
- Still undergoing review by stakeholders
### Annual Average Emission Increase

<table>
<thead>
<tr>
<th>Category</th>
<th>NOx, tpd</th>
<th>VOC, tpd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Transmission &amp; Distribution</td>
<td>0</td>
<td>&gt;5</td>
</tr>
<tr>
<td>District Inventoried Combustion Sources</td>
<td>0.12</td>
<td>0.27</td>
</tr>
<tr>
<td>Residential Appliances</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Unpermitted Commercial &amp; Industrial Equipment</td>
<td>0.35</td>
<td>0.03</td>
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<tr>
<td>Transit &amp; School Busses, 2010</td>
<td>0.13</td>
<td>0.06</td>
</tr>
<tr>
<td>Transit &amp; School Busses, Future</td>
<td>≈ 0</td>
<td>0.14</td>
</tr>
<tr>
<td>TOTAL, 2010</td>
<td>0.67</td>
<td>5.41</td>
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</table>
## Peak Summer Day Emission Increase

<table>
<thead>
<tr>
<th>Category</th>
<th>NOx, tpd</th>
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<tbody>
<tr>
<td>Gas Transmission &amp; Distribution</td>
<td>0</td>
<td>&gt;5</td>
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<tr>
<td>District Inventoried Combustion Sources</td>
<td>0.17</td>
<td>0.50</td>
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<tr>
<td>Residential Appliances</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Unpermitted Commercial &amp; Industrial Equipment</td>
<td>0.33</td>
<td>0.02</td>
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<tr>
<td>Transit &amp; School Busses, 2010</td>
<td>0.15</td>
<td>0.07</td>
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<tr>
<td>Transit &amp; School Busses, Future</td>
<td>≈ 0</td>
<td>0.16</td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.68</td>
<td>5.62</td>
</tr>
</tbody>
</table>
District Position on Mitigation

- Mitigation required for all emission increases not just vehicle emissions
- Mitigation based on emission increases relative to historical gas composition
- Ideally, control gas quality to significantly reduce or eliminate emission increases and compliance issues
  - Remove excess C2 and C3+
  - N2 injection (only addresses Wobbe Index)
Conclusions
Some Conclusions

- Potentially significant emission impacts from LNG based on preliminary analysis
- Emission impacts not solely related to Wobbe Index
  - Methane No., C3+ wt%, C2 and C3+ vol %
- More research required to quantify impacts
Critical Gas Quality Emission Research Needs

- Updated emission factors for gas transmission and distribution
- Emissions from nonpremixed (diffusion flame) commercial industrial/equipment with and w/o fuel/air controls—NOx, CO, VOCs, PM, toxics
- Potential non-Wobbe effects on NOx from industrial equipment
- NOx and VOC emissions from industrial lean-burn engines
Overall Conclusion

- Emission increases from LNG-derived natural gas are counterproductive for attainment of ambient air quality standards
- More research and information needed to fully assess potential impacts basin-wide
- Revision of CNG Fuel Standards would facilitate LNG importation
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