Compressed Natural Gas (CNG) Motor Vehicle Fuel Specifications

May 19, 2010

California Environmental Protection Agency

Air Resources Board
Overview

- Background
- Current Situation
- Studies and Results
- Possible Considerations
- Next Steps
Background
Alternative Fuels Regulations

- ARB alternative fuel regulations, 1992
  - Title 13, CCR, §2290 - 2293.5
- Includes compressed natural gas (CNG) specifications
  - Title 13, CCR, §2292.5
- Last discussed in 2005
# CNG Specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (min.)</td>
<td>88 mol%</td>
</tr>
<tr>
<td>Ethane (max.)</td>
<td>6 mol%</td>
</tr>
<tr>
<td>C3+higher (max.)</td>
<td>3 mol%</td>
</tr>
<tr>
<td>C6+higher (max.)</td>
<td>0.2 mol%</td>
</tr>
<tr>
<td>Hydrogen (max.)</td>
<td>0.1 mol%</td>
</tr>
<tr>
<td>Carbon Monoxide (max.)</td>
<td>0.1 mol%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1.0 mol%</td>
</tr>
<tr>
<td>Inert Gases</td>
<td>1.5 - 4.5 mol%</td>
</tr>
<tr>
<td>Sulfur (max.)</td>
<td>16 ppmv</td>
</tr>
<tr>
<td>Water, Particulates, Odorant</td>
<td></td>
</tr>
</tbody>
</table>
California Public Utilities Commission
Pipeline Specifications
(Ex. SoCalGas Rule 30)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI</td>
<td>1279 - 1385</td>
</tr>
<tr>
<td>Heating Value</td>
<td>990 - 1150</td>
</tr>
<tr>
<td>CO₂ (max)</td>
<td>3% vol</td>
</tr>
<tr>
<td>H₂S (max)</td>
<td>4 ppm</td>
</tr>
<tr>
<td>H₂O (max)</td>
<td>7 lbs/MMSCF</td>
</tr>
<tr>
<td>Inerts (max)</td>
<td>4% vol</td>
</tr>
</tbody>
</table>

Source: Rule No. 30 Southern California Gas Company
Current Situation

- North American pipelined gas generally meets CARB specifications
  - A portion of potential LNG supplies generally exceeds specifications
- A portion of in-state gas does not meet current CARB specifications
California Natural Gas Supplies

- **Imported via Interstate Pipeline** 87%
  - Southwest 41%
  - Midwest 24%
  - Canada 22%

- **California Production** 13%
  - Central/Southern CA 8%
  - Northern CA 5%

Source: CEC 2007
92% of CA Current Supply Generally Meets CNG MV Specifications

- Imported: 87%
- CA Gas Wells: 5%
- CA Associated Gas: 8%

Note: Does not include potential LNG shipments

Source: CEC 2006
Primary Reasons for Off-Specification Natural Gas

- Associated gas
  - Byproduct of oil production
  - Produced from gas fields in Southern and Central CA
- Potential imports of LNG

Background
Gas Quality Trends

- **Imported Pipelined Gas**
  - Slight variation of gas quality over time

- **Potential LNG Imports**
  - May cause decrease in pipeline gas quality

- **In-state Production**
  - Slight degradation of gas quality over time
# Imported Pipelined Gas Quality

## Fuel Composition – Northern CA

<table>
<thead>
<tr>
<th></th>
<th>1999 Malin</th>
<th>1999 Topock</th>
<th>2009 Malin</th>
<th>2009 Topock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>94.9</td>
<td>96.12</td>
<td>95.93</td>
<td>95.86</td>
</tr>
<tr>
<td>Ethane</td>
<td>3.15</td>
<td>1.69</td>
<td>2.17</td>
<td>1.79</td>
</tr>
<tr>
<td>C3+</td>
<td>0.20</td>
<td>0.27</td>
<td>0.33</td>
<td>0.57</td>
</tr>
<tr>
<td>C6+</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Inerts</td>
<td>1.65</td>
<td>1.9</td>
<td>1.55</td>
<td>1.75</td>
</tr>
<tr>
<td><strong>MN</strong></td>
<td>98.7</td>
<td>101.9</td>
<td>95.3</td>
<td>95.31</td>
</tr>
<tr>
<td><strong>WI</strong></td>
<td>1340.1</td>
<td>1333.4</td>
<td>1341.13</td>
<td>1335.64</td>
</tr>
</tbody>
</table>

*MN and WI are not a part of CARB specifications

California Natural Gas Pipelines

Source: CEC
## Imported Pipelined Gas Quality Fuel Composition – Central & Southern CA

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th></th>
<th>2009</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ehrenberg</td>
<td>Topock</td>
<td>Ehrenberg</td>
<td>Topock</td>
</tr>
<tr>
<td>Methane</td>
<td>TBD</td>
<td>TBD</td>
<td>95.77</td>
<td>96.38</td>
</tr>
<tr>
<td>Ethane</td>
<td>TBD</td>
<td>TBD</td>
<td>1.96</td>
<td>1.55</td>
</tr>
<tr>
<td>C3+</td>
<td>TBD</td>
<td>TBD</td>
<td>0.5</td>
<td>0.44</td>
</tr>
<tr>
<td>C6+</td>
<td>TBD</td>
<td>TBD</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Inerts</td>
<td>TBD</td>
<td>TBD</td>
<td>1.73</td>
<td>1.61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>MN*</td>
<td>100</td>
<td>101</td>
</tr>
<tr>
<td>WI*</td>
<td>1337.37</td>
<td>1335.37</td>
</tr>
</tbody>
</table>

* MN and WI are not a part of CARB specifications

Associated Gas
Generally Does Not Meet CNG Specifications

- Heavy in non-methane hydrocarbons
- Exceeds ethane and C3+ specifications
- Higher energy content that may cause engine problems
Associated Gas Production Areas Primarily in Southern & Central CA

- San Joaquin Valley (SJV)
  - Fresno, Kern, Kings, Tulare
- South Central Coast (SCC)
  - Ventura, Santa Barbara, San Luis Obispo
- South Coast Basin
  - Los Angeles, Orange, San Bernardino

Source: Department of Conservation 2001
## Associated Gas Fuel Composition

<table>
<thead>
<tr>
<th></th>
<th>Fresno</th>
<th>Kern</th>
<th>Kings</th>
<th>Santa Barbara</th>
<th>San Luis Obispo</th>
<th>Ventura</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>86.19</td>
<td>93.83</td>
<td>86.19</td>
<td>91.28</td>
<td>88.42</td>
<td>92.48</td>
</tr>
<tr>
<td>Ethane</td>
<td>8.35</td>
<td>1.84</td>
<td>8.35</td>
<td>4.08</td>
<td>5.41</td>
<td>4.22</td>
</tr>
<tr>
<td>C3+</td>
<td>2.43</td>
<td>2.76</td>
<td>2.43</td>
<td>2.78</td>
<td>4.23</td>
<td>1.39</td>
</tr>
<tr>
<td>C6+</td>
<td>0.02</td>
<td>0.07</td>
<td>0.02</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>Inerts</td>
<td>3.01</td>
<td>1.49</td>
<td>3.01</td>
<td>1.83</td>
<td>1.88</td>
<td>1.89</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MN*</th>
<th>WI*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80</td>
<td>1352</td>
</tr>
<tr>
<td></td>
<td>86.63</td>
<td>1367</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>1352</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>1366</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>1385</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>1351</td>
</tr>
</tbody>
</table>

**NOTE:** North American Pipeline Gas Composition  
Methane %: 95-96, MN: 95-100, WI: 1330-1345
## In-State Production vs. CNG Specs

<table>
<thead>
<tr>
<th></th>
<th>In State</th>
<th>CARB Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>86.19 - 93.83</td>
<td>88 – 98.5</td>
</tr>
<tr>
<td>Ethane</td>
<td>1.84 - 8.35</td>
<td>0 - 6</td>
</tr>
<tr>
<td>C3+</td>
<td>1.39 - 4.23</td>
<td>0 - 3</td>
</tr>
<tr>
<td>C6+</td>
<td>.02 - .07</td>
<td>0 - 0.02</td>
</tr>
<tr>
<td>Inerts</td>
<td>1.49 - 3.01</td>
<td>1.5 - 4.5</td>
</tr>
<tr>
<td>MN*</td>
<td>78 - 90</td>
<td>81** - 108</td>
</tr>
<tr>
<td>WI*</td>
<td>1351 - 1385</td>
<td>1280 - 1385</td>
</tr>
</tbody>
</table>

* MN and WI are not a part of CARB specifications
** MN 81 is the practical low value, MN 72 is the theoretical low value
Potential LNG Imports Generally Do Not Meet Specifications

- Potentially exceeds ethane and C3+ specifications
- May not meet inert specifications
- Higher energy content may cause engine problems
# Potential LNG Imports Gas Quality

## Fuel Composition

<table>
<thead>
<tr>
<th></th>
<th>Tangguh</th>
<th>Malaysia</th>
<th>Sahkalin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>96.3</td>
<td>91.23</td>
<td>93.765</td>
</tr>
<tr>
<td>Ethane</td>
<td>2.6</td>
<td>4.3</td>
<td>3.45</td>
</tr>
<tr>
<td>C3+</td>
<td>0.7</td>
<td>4.36</td>
<td>2.53</td>
</tr>
<tr>
<td>C6+</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Inerts</td>
<td>0.4</td>
<td>0.12</td>
<td>0.26</td>
</tr>
</tbody>
</table>

**MN**

<table>
<thead>
<tr>
<th></th>
<th>Tangguh</th>
<th>Malaysia</th>
<th>Sahkalin</th>
</tr>
</thead>
<tbody>
<tr>
<td>MN*</td>
<td>101.4</td>
<td>79.0</td>
<td>90.2</td>
</tr>
<tr>
<td>WI*</td>
<td>1372</td>
<td>1422</td>
<td>1397</td>
</tr>
</tbody>
</table>

* MN and WI are not a part of CARB specifications

Source: 2009 Publicly Available Gas Quality Data
# Imports vs. CNG Specs

<table>
<thead>
<tr>
<th></th>
<th>LNG Imports</th>
<th>CARB Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>84.83 - 96.33</td>
<td>88 – 98.5</td>
</tr>
<tr>
<td>Ethane</td>
<td>2.6 - 13.39</td>
<td>0 - 6</td>
</tr>
<tr>
<td>C3+</td>
<td>0.7 - 4.30</td>
<td>0 - 3</td>
</tr>
<tr>
<td>C6+</td>
<td>0 - 0.04</td>
<td>0 - 0.02</td>
</tr>
<tr>
<td>Inerts</td>
<td>0 - 0.4</td>
<td>1.5 - 4.5</td>
</tr>
<tr>
<td>MN*</td>
<td>75.09 - 101.4</td>
<td>81** - 108</td>
</tr>
<tr>
<td>WI*</td>
<td>1372 - 1424.5</td>
<td>1280 - 1385</td>
</tr>
</tbody>
</table>

* MN and WI are not a part of CARB specifications
** MN 81 is the practical low value, MN 72 is the theoretical low value
Discussion
Assessment of the Current CNG Specifications
Current CNG Specifications

- Supports Low-Emission/Clean Fuels Program and Regulations
- Reflects quality of imported and in-state produced NG at time when specs were established
- Based on available technologies at that time
- Developed in consultation with industry and other interested parties
Disadvantages of the CNG Specifications

- Some in-state and LNG supplies do not comply
- Current engine technologies have evolved
- Limits availability of on-spec CNG fuel in some areas in CA
- Restricts expansion of the NGV market
- No trading within HC specs
CNG Studies and Results
CNG Studies and Test Programs

I. SoCalGas and SDG&E Heavy-Duty CNG Vehicle Report, 2008

II. SwRI Heavy-Duty Natural Gas Engine Study, 2009

III. Sierra Research Statistical Analysis of SwRI HD Natural Gas Engine Study, 2009

IV. SwRI Light-Duty Natural Gas Vehicle Study, 2010

V. Sierra Research Statistical Analysis of SwRI LD Natural Gas Vehicle Study, 2010

VI. CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010
CNG Studies and Test Programs

I. SoCalGas and SDG&E Heavy-Duty CNG Vehicle Report, 2008

II. SwRI Heavy-Duty Natural Gas Engine Study, 2009

III. Sierra Research Statistical Analysis of SwRI HD Natural Gas Engine Study, 2009

IV. SwRI Light-Duty Natural Gas Vehicle Study, 2010

V. Sierra Research Statistical Analysis of SwRI LD Natural Gas Vehicle Study, 2010

VI. CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010
I. Heavy-Duty CNG Vehicle Report
(SoCalGas & SDG&E)

Comprehensive survey, inventory and assessment of all HD CNG engines in operation in 13 counties at end of 2008

Objective

- Compile inventory of all HD CNG engines in 2008 and estimate changes over time

Assumptions

- Test engines classified as MD or HD CNG engines used not including LD OEM
- “Legacy fleet” vehicles defined as engines that cannot operate on sub-MN 80 fuel
I. HD CNG Vehicle Report - Results
2008 Heavy-Duty CNG Engine Fleet Types

- Transit: 72%
- School Bus: 14%
- Waste Hauler: 9%
- Street Sweeper: 4%
- Other: 1%

Studies and Results
I. HD CNG Vehicle Report - Results

“Legacy Fleet” CNG Engines in Operation Through 2025

SoCal Gas Legacy Vehicle Population in 13 County Service Area

- Detroit Diesel GK
- Caterpillar
- Tecogen
- Cummins L10 P1
- Mack E7G
- Cummins L10 P2
- Cummins B5.9G
- Cummins C8.3G
- Cummins L10 P3
I. ARB Staff’s Observations

- Information based on 2008 survey
  - Scope specific to SoCalGas and SDG&E service territories (13 counties)
  - Engine expected life based on operator feedback
  - Does not include LD OEM vehicles
- “Legacy fleet” vehicle definition - vehicle engine cannot run on MN < 80
  - Based on manufacturer specs
CNG Studies and Test Programs

I. SoCalGas and SDG&E Heavy-Duty CNG Vehicle Report, 2008

II. SwRI Heavy-Duty Natural Gas Engine Study, 2009

III. Sierra Research Statistical Analysis of SwRI HD Natural Gas Engine Study, 2009

IV. SwRI Light-Duty Natural Gas Vehicle Study, 2010

V. Sierra Research Statistical Analysis of SwRI LD Natural Gas Vehicle Study, 2010

VI. CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010
II. Heavy-Duty Engine Study
(Southwest Research Institute - SwRI)

Objective
Test five HD natural gas engines for emissions and engine performance impacts using fuels of varying MN and WI

Test Engines
1. 2007 Cummins ISL G
2. 2006 Cummins C Gas Plus
3. 2005 John Deere 6081H
4. 1999 Detroit Diesel Series S50G TK
5. 1998 Cummins C Gas
II. SwRI Heavy-Duty Engine Study

Test Fuels
- MN of the NG blends ranged from MN 75 to MN 100. Both high and low WI blends were tested at each MN.

<table>
<thead>
<tr>
<th>TABLE 2. TARGET CNG COMPOSITIONS SUPPLIED BY SCG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Methane Number</strong></td>
</tr>
<tr>
<td><strong>Wobbe Level</strong></td>
</tr>
<tr>
<td><strong>Wobbe Index</strong></td>
</tr>
<tr>
<td>Methane % vol</td>
</tr>
<tr>
<td>Ethane % vol</td>
</tr>
<tr>
<td>Propane % vol</td>
</tr>
<tr>
<td>Nitrogen % vol</td>
</tr>
</tbody>
</table>

1 Methane number 78 fuel was tested with the 1998 model year Cummins C Gas engine only.
II. SwRI HD Study – NO\textsubscript{x} Results

![Graph showing NO\textsubscript{x} results for different fuel blends and methane numbers.]

**FIGURE 94. HOT-START AVERAGE BRAKE-SPECIFIC NO\textsubscript{x} RESULTS VERSUS TEST FUEL METHANE NUMBER FOR ALL TEST ENGINES AND FUELS**
II. SwRI HD Study – NMHC Results

**FIGURE 95. HOT-START AVERAGE BRAKE-SPECIFIC NMHC RESULTS VERSUS TEST FUEL METHANE NUMBER FOR ALL TEST ENGINES AND FUELS**
II. SwRI HD Study – Results

- NOx and NMHC increased as MN decreased for older engines
- PM showed no significant trends for all engines
- CO increased as MN decreased for some engines
- Fuel consumption increased with lower WI fuels
- Slight changes in engine performance
- No engine knock or auto ignition
II. SwRI HD Study – Results (cont.)

- Changes in MN resulted in significant emission variation for some pollutants
- WI had a slight effect on some regulated emissions
II. ARB Staff’s Observations

- Tested fuels ranged in MN
  - MN tested: MN 75, 78, 80, 89, 100
  - High and Low WI tested at each MN

- Test engines serviced and repaired before emissions testing
CNG Studies and Test Programs

I. SoCalGas and SDG&E Heavy-Duty CNG Vehicle Report, 2008

II. SwRI Heavy-Duty Natural Gas Engine Study, 2009

III. Sierra Research Statistical Analysis of SwRI HD Natural Gas Engine Study, 2009

IV. SwRI Light-Duty Natural Gas Vehicle Study, 2010

V. Sierra Research Statistical Analysis of SwRI LD Natural Gas Vehicle Study, 2010

VI. CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010
III. Statistical Analysis of SwRI HD Engine Study
(Sierra Research Inc)

Objectives
- Identify statistically significant relationships between MN, WI, engine emissions

Assumptions
- CNG fuel used at the lowest MN and highest WI under the:
  - Current prescriptive CARB CNG regulations (MN 72.4, WI 1385)
  - Performance-based CNG regulation proposed by SoCalGas and SDG&E (MN 75, WI 1385)
### III. HD Statistical Analysis – Results

#### Maximum Theoretical Change in 2008 NOx and NMHC Emissions (TPD)

<table>
<thead>
<tr>
<th>County</th>
<th>Total NOx Inventory</th>
<th>NOx Change</th>
<th>Total NMHC Inventory</th>
<th>NMHC Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing Reg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Proposed Reg&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Existing Reg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Proposed Reg&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>San Diego</td>
<td>166</td>
<td>0.144</td>
<td>0.133</td>
<td>152</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>482</td>
<td>0.346</td>
<td>0.325</td>
<td>336</td>
</tr>
<tr>
<td>Orange</td>
<td>136</td>
<td>0.067</td>
<td>0.062</td>
<td>117</td>
</tr>
<tr>
<td>Riverside</td>
<td>83</td>
<td>0.075</td>
<td>0.070</td>
<td>62</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>91</td>
<td>0.019</td>
<td>0.018</td>
<td>72</td>
</tr>
<tr>
<td>Ventura</td>
<td>44</td>
<td>0.009</td>
<td>0.008</td>
<td>47</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>38</td>
<td>0.001</td>
<td>0.001</td>
<td>35</td>
</tr>
<tr>
<td>Kern</td>
<td>58</td>
<td>0.003</td>
<td>0.003</td>
<td>14</td>
</tr>
<tr>
<td>Kings</td>
<td>29</td>
<td>0.001</td>
<td>0.001</td>
<td>18</td>
</tr>
<tr>
<td>Tulare</td>
<td>45</td>
<td>0.016</td>
<td>0.014</td>
<td>45</td>
</tr>
<tr>
<td>Fresno</td>
<td>110</td>
<td>0.001</td>
<td>0.000</td>
<td>82</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>21</td>
<td>0.001</td>
<td>0.001</td>
<td>23</td>
</tr>
<tr>
<td>Imperial</td>
<td>37</td>
<td>0.000</td>
<td>0.000</td>
<td>30</td>
</tr>
<tr>
<td><strong>13-County Total</strong></td>
<td><strong>1340</strong></td>
<td><strong>0.683</strong></td>
<td><strong>0.636</strong></td>
<td><strong>1033</strong></td>
</tr>
</tbody>
</table>
### III. HD Statistical Analysis – Results

#### Maximum Theoretical Change in 2018 NOx and NMHC Emissions (TPD)

<table>
<thead>
<tr>
<th>County</th>
<th>Total NOx Inventory</th>
<th>NOx Change</th>
<th>Total NMHC Inventory</th>
<th>NMHC Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing Reg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Proposed Reg&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Existing Reg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Proposed Reg&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>San Diego</td>
<td>113</td>
<td>0.011</td>
<td>0.01</td>
<td>133</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>330</td>
<td>0.05</td>
<td>0.045</td>
<td>277</td>
</tr>
<tr>
<td>Orange</td>
<td>95</td>
<td>0.06</td>
<td>0.055</td>
<td>102</td>
</tr>
<tr>
<td>Riverside</td>
<td>55</td>
<td>0.038</td>
<td>0.035</td>
<td>55</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>66</td>
<td>0.007</td>
<td>0.006</td>
<td>65</td>
</tr>
<tr>
<td>Ventura</td>
<td>32</td>
<td>0.004</td>
<td>0.004</td>
<td>42</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>Kern</td>
<td>48</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Kings</td>
<td>18</td>
<td>0.001</td>
<td>0.001</td>
<td>17</td>
</tr>
<tr>
<td>Tulare</td>
<td>31</td>
<td>0.008</td>
<td>0.007</td>
<td>42</td>
</tr>
<tr>
<td>Fresno</td>
<td>72</td>
<td>0</td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Imperial</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td><strong>13-County Total</strong></td>
<td><strong>933</strong></td>
<td><strong>0.179</strong></td>
<td><strong>0.163</strong></td>
<td><strong>901</strong></td>
</tr>
</tbody>
</table>

---

5/18/2010
III. Statistical Analysis of SwRI HD Engine Study – Results

Results
- Slight increase of NMHC and NOx from present
- Maximum theoretical increase of NMHC and NOx under current CARB specs is larger than increase under performance-based reg (MN 75/80 and WI 1385)
- The magnitude of impacts decline over time

Conclusion
- Performance regulation based on MN 75/80 and WI 1385 does not have potential to increase emissions above levels that could already occur under existing CARB specs
III. ARB Staff’s Observations

- Potential impacts based on theoretical limit
  - Lowest MN and highest WI under current CNG specs (MN 72.4, WI 1385)
- MN and WI were not evaluated as independent variables
CNG Studies and Test Programs

I. SoCalGas and SDG&E Heavy-Duty CNG Vehicle Report, 2008

II. SwRI Heavy-Duty Natural Gas Engine Study, 2009

III. Sierra Research Statistical Analysis of SwRI HD Natural Gas Engine Study, 2009

IV. SwRI Light-Duty Natural Gas Vehicle Study, 2010

V. Sierra Research Statistical Analysis of SwRI LD Natural Gas Vehicle Study, 2010

VI. CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010
Objective

- Determine the emissions and fuel economy (FE) for six CNG fuel blends on a test vehicle over the FTP-75 and UC driving cycles
IV. SwRI LD Vehicle Study

Test Vehicle
- 2003 Honda Civic GX

Test Fuels
- Six test fuels blends of varying MN (68-89) and WI (1333-1390) were produced by SwRI as specified by SoCalGas
- Fuel blends represent worst-case NG scenarios under theoretical standards as well as typical fuel compositions found in the region
IV. SwRI LD Vehicle Study - Results

- Average FTP-75 NOx emissions were 50% of the certification standard
- CO emissions were about 10% of the certification standard
- NMHC results were well below the NMOG standard
IV. ARB Staff’s Observations

- LD vehicle technologies can operate on various fuel blends with minimal impacts
  - Consistent with expectations
CNG Studies and Test Programs

I. SoCalGas and SDG&E Heavy-Duty CNG Vehicle Report, 2008

II. SwRI Heavy-Duty Natural Gas Engine Study, 2009

III. Sierra Research Statistical Analysis of SwRI HD Natural Gas Engine Study, 2009

IV. SwRI Light-Duty Natural Gas Vehicle Study, 2010

V. Sierra Research Statistical Analysis of SwRI LD Natural Gas Vehicle Study, 2010

VI. CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010
V. Statistical Analysis of SwRI LD Vehicle Study
(Sierra Research Inc)

Objective

- Analyze the data obtained from the LD Vehicle Test Program
### V. LD Statistical Analysis - Results

#### Summary of Findings on Emissions and Fuel Economy Changes Due to CNG Fuel Formulation

<table>
<thead>
<tr>
<th></th>
<th>FTP Composite</th>
<th>UC Drive Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>THC</td>
<td>Emissions Decreased</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td>NMHC</td>
<td>Emissions Increased</td>
<td>Emissions Increased</td>
</tr>
<tr>
<td></td>
<td>Max Effect + 0.002 g/mi (MN 68 fuel)</td>
<td>Max Effect + 0.002 g/mi (MN 68 fuel)</td>
</tr>
<tr>
<td>CO</td>
<td>Emissions Increased</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td></td>
<td>Max Effect + 0.043 g/mi (MN 80 High WI)</td>
<td></td>
</tr>
<tr>
<td>NOx</td>
<td>Emissions Decreased</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td>CO2</td>
<td>Emissions Increased</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td></td>
<td>up to 4.0 g/mi</td>
<td></td>
</tr>
<tr>
<td>FE</td>
<td>No Fuel Effect</td>
<td>FE increased up to 0.7 mpg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(MN 80 High WI)</td>
</tr>
</tbody>
</table>
V. Statistical Analysis of LD Vehicle Study – Results

Findings
- Analysis found some instances of statistically significant relationships between MN, WI, and vehicle emissions
  - MN generally had a greater impact on emissions than WI

Conclusion
- The variations in NG quality had little impact on emissions from the vehicle studied
V. ARB Staff’s Observations

- Test fuels ranged in MN
  - MN tested: MN 68, 75, 80, 89
  - High and Low WI tested at each MN
CNG Studies and Test Programs

I. SoCalGas and SDG&E Heavy-Duty CNG Vehicle Report, 2008
II. SwRI Heavy-Duty Natural Gas Engine Study, 2009
III. Sierra Research Statistical Analysis of SwRI HD Natural Gas Engine Study, 2009
IV. SwRI Light-Duty Natural Gas Vehicle Study, 2010
V. Sierra Research Statistical Analysis of SwRI LD Natural Gas Vehicle Study, 2010
VI. CE-CERT HD & LD Natural Gas Engine and Vehicle Study, 2010
VI. CE-CERT HD and LD Natural Gas Engine and Vehicle Study (CEC, CE-CERT)

Objective

- Address impacts of using broader range of NG compositions, such as those expected with greater introduction of LNG
VI. CE-CERT HD and LD

- Overall Test Program:
  - Light-Duty Testing
    - CNG Vehicle Testing – 2 test vehicles, 4 test fuels
  - Heavy-Duty Testing
    - CNG Vehicle Testing – 3 test vehicles, 5 test fuels
    - LNG Engine Testing – 1 test engine, 3 test fuels

- Status - Testing to be completed
  - Discuss at next CNG public meeting
III. ARB Staff’s Observations

- Test fuels based on range of MN, WI and various fuel compositions
  - MN 83 – 96
  - WI 1330-1436
  - High/Low Ethane
- Engines and vehicles tested as-is
2008 CA Natural Gas Vehicle Population

Source: 2008 DMV

- School Buses, 1,841, (5%)
- Transit Buses, 5,303, (15%)
- Waste Collection Vehicles, 1,003, (3%)
- Heavy Heavy-Duty Trucks, 433, (1%)
- Medium Heavy-Duty Trucks, 867, (3%)
- Light and Medium Duty Vehicles, 25,034, (73%)
Legacy CNG Engines in Operation

Studies and Results

CARB Legacy Natural Gas Vehicle Population

Calendar Year

Population

0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000
Discussion
Consider Changes to the CNG Fuel Regulation?
Disadvantages of the CNG Specifications

- Relatively inflexible
  - Does not allow trading within HC specs
- Some in-state and LNG supplies do not comply
- Current engine technologies have evolved and can use a broader range of NG compositions
- Limits availability of on-spec CNG fuel in some areas in CA
- Restricts expansion of the NGV market
Possible Approaches

- Adopt alternative performance based standards?
  - Potential performance metrics: MN and WI
- Others?
Potential Advantages of Performance Approach

- Increases flexibility
  - Allows trading within HC spec
- Increase of compliant fuels without loss of benefits
Potential Metrics for Performance Approach

- Methane Number (MN)
- Wobbe Index (WI)
Methane Number (MN)

- Similar to Octane Number
- Experimentally derived relationship between fuel composition and engine performance (knock)
- Established index to prevent engine knock
- Some engine manufacturers require minimum MN
Methane Number (MN)

- **Equation:**
  - \[ MN = 1.624 \times \text{MON} - 119.1 \]
  - \[ \text{MON} = (20.17 \times \frac{\text{H/C}^3}{\text{C}} - 173.55 \times \frac{\text{H/C}^2}{\text{C}} + 508.4 \times \frac{\text{H/C}}{\text{C}} - 406.14) \]
  - \[ \frac{\text{H/C}}{\text{C}} = (\text{mol} \% \text{ Hydrogen} / \text{mol} \% \text{ Carbon}) \]

Source: SwRI 1992
Wobbe Index

- Measure of fuel interchangeability with respect to energy content and metered air/fuel ratio
  \[ \text{Wobbe Index} = \frac{\text{Higher Heating Value}}{\sqrt{\text{relative density}}} \]

- Changes in Wobbe Index affect the engine’s metered air/fuel ratio and power output
# CNG Specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (min.)</td>
<td>88 mol%</td>
</tr>
<tr>
<td>Ethane (max.)</td>
<td>6 mol%</td>
</tr>
<tr>
<td>C3+higher (max.)</td>
<td>3 mol%</td>
</tr>
<tr>
<td>C6+higher (max.)</td>
<td>0.2 mol%</td>
</tr>
<tr>
<td>Hydrogen (max.)</td>
<td>0.1 mol%</td>
</tr>
<tr>
<td>Carbon Monoxide (max.)</td>
<td>0.1 mol%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1.0 mol%</td>
</tr>
<tr>
<td>Inert Gases</td>
<td>1.5 - 4.5 mol%</td>
</tr>
<tr>
<td>Sulfur (max.)</td>
<td>16 ppmv</td>
</tr>
<tr>
<td>Water, Particulates, Odorant</td>
<td></td>
</tr>
</tbody>
</table>

## Considerations
## CNG Specifications with possible MN and WI

<table>
<thead>
<tr>
<th></th>
<th>High CH4 High Inerts</th>
<th>High CH4 Low Inerts</th>
<th>Max C2 and Min Inerts (C3 only)</th>
<th>Max C2 and Min Inerts (C3 Equal)</th>
<th>Max C2, C3, &amp; C6 Min Inerts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Methane</strong></td>
<td>95.5</td>
<td>98.5</td>
<td>89.5</td>
<td>89.5</td>
<td>89.3</td>
</tr>
<tr>
<td><strong>Ethane</strong></td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>C3+</strong></td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>C6+</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Inerts</strong></td>
<td>4.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>MN</strong></td>
<td>108</td>
<td>108</td>
<td>82.36</td>
<td>77.86</td>
<td>72.83</td>
</tr>
<tr>
<td><strong>WI</strong></td>
<td>1278.8</td>
<td>1333.5</td>
<td>1380.4</td>
<td>1391.5</td>
<td>1409</td>
</tr>
</tbody>
</table>

* MN and WI are not a part of CARB specifications

Note: CPUC pipeline specifications allow WI 1385 in the pipeline
What is the Best Approach?

- Should an alternative performance standard be adopted?
  - Appropriate to use Methane Number (MN)?
  - Appropriate to use Wobbe Index (WI)?
  - Appropriate to use both MN and WI?

- Tiered Approach
  - Time frame for implementation?

- Any other approaches?
Discussion
Next Steps
Next Steps

- Evaluate comments
- Develop proposals based on comments
- Evaluate proposals
  - Pros/Cons
  - Impacts
- Discuss at next public meeting
Schedule

- Public Meeting: May 19, 2010
- Comments due by: June 3, 2010
- Additional Meetings: July – Aug 2010
- Board Hearing: Fall 2010
Contact Information

Floyd Vergara  
Manager, Industrial Section  
(916) 327-5986  
fvergara@arb.ca.gov

Aubrey Sideco  
Lead Staff, Industrial Section  
(916) 324-3334  
asideco@arb.ca.gov

Stephen d’Esterhazy  
Industrial Section  
(916) 323-7227  
sdesterhaz@arb.ca.gov

Cody Livingston  
Off-Road Diesel Analysis Section  
(916) 324-0585  
clivings@arb.ca.gov

http://www.arb.ca.gov/fuels/altfuels/cng/cng.htm
Thank You