Compressed Natural Gas (CNG) Motor Vehicle Fuel Specifications

May 19, 2010
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)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></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>MN*</td>
<td>98.7</td>
<td>101.9</td>
<td>95.3</td>
<td>95.31</td>
</tr>
<tr>
<td>WI*</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 Ehrenberg</th>
<th>1999 Topock</th>
<th>2009 Ehrenberg</th>
<th>2009 Topock</th>
</tr>
</thead>
<tbody>
<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 Ehrenberg</th>
<th>2009 Topock</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>
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<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>
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<tr>
<td>MN*</td>
<td>80</td>
<td>86.63</td>
<td>80</td>
<td>85</td>
<td>78</td>
<td>90</td>
</tr>
<tr>
<td>WI*</td>
<td>1352</td>
<td>1367</td>
<td>1352</td>
<td>1366</td>
<td>1385</td>
<td>1351</td>
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</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>
<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>
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<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%
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>Methane Number</th>
<th>75</th>
<th>78</th>
<th>80</th>
<th>89</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wobbe Level</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Wobbe Index</td>
<td>1363</td>
<td>1385</td>
<td>1353</td>
<td>1385</td>
<td>1347</td>
</tr>
<tr>
<td>Methane</td>
<td>% vol</td>
<td>85.3</td>
<td>86.5</td>
<td>87.1</td>
<td>88.8</td>
</tr>
<tr>
<td>Ethane</td>
<td>% vol</td>
<td>4.6</td>
<td>4.6</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Propane</td>
<td>% vol</td>
<td>6.1</td>
<td>6.2</td>
<td>5.7</td>
<td>5.8</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>% vol</td>
<td>4.0</td>
<td>2.7</td>
<td>4.0</td>
<td>2.2</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 – NOx Results

**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

![Graph showing NMHC results vs. Methane Number for different fuels.]

**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></td>
<td>Existing Reg(^a)</td>
<td>Proposed Reg(^b)</td>
<td>Existing Reg(^a)</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>
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<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>
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<td>0.001</td>
<td>18</td>
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<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>
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<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>
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</table>
III. HD Statistical Analysis – Results

<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></td>
<td>Existing Reg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Proposed Reg&lt;sup&gt;b&lt;/sup&gt;</td>
<td></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>
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<td>Riverside</td>
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<td>0.035</td>
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<tr>
<td>San Bernardino</td>
<td>66</td>
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<td>0.006</td>
<td>65</td>
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<tr>
<td>Ventura</td>
<td>32</td>
<td>0.004</td>
<td>0.004</td>
<td>42</td>
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<tr>
<td>Santa Barbara</td>
<td>29</td>
<td>0</td>
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<td>31</td>
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<tr>
<td>Kern</td>
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<td>12</td>
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<tr>
<td>Kings</td>
<td>18</td>
<td>0.001</td>
<td>0.001</td>
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<tr>
<td>Tulare</td>
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<td>0.008</td>
<td>0.007</td>
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<td>Fresno</td>
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<td>0</td>
<td>75</td>
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<tr>
<td>San Luis Obispo</td>
<td>15</td>
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<td>0</td>
<td>21</td>
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<tr>
<td>Imperial</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>29</td>
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<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>
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
IV. Light-Duty Vehicle Study (SwRI)

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>
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</thead>
<tbody>
<tr>
<td><strong>THC</strong></td>
<td>Emissions Decreased</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td><strong>NMHC</strong></td>
<td>Emissions Increased Max Effect + 0.002 g/mi (MN 68 fuel)</td>
<td>Emissions Increased Max Effect + 0.002 g/mi (MN 68 fuel)</td>
</tr>
<tr>
<td><strong>CO</strong></td>
<td>Emissions Increased Max Effect + 0.043 g/mi (MN 80 High WI)</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td><strong>NOx</strong></td>
<td>Emissions Decreased</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td><strong>CO2</strong></td>
<td>Emissions Increased up to 4.0 g/mi</td>
<td>No Fuel Effect</td>
</tr>
<tr>
<td><strong>FE</strong></td>
<td>No Fuel Effect</td>
<td>FE increased up to 0.7 mpg (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
Legacy CNG Engines in Operation

CARB Legacy Natural Gas Vehicle Population

Calendar Year

Population

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

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>Category</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>
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</table>
# 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>
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<tbody>
<tr>
<td>Methane</td>
<td>95.5</td>
<td>98.5</td>
<td>89.5</td>
<td>89.5</td>
<td>89.3</td>
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<tr>
<td>Ethane</td>
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<td>0</td>
<td>6</td>
<td>6</td>
<td>6</td>
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<tr>
<td>C3+</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
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</tr>
<tr>
<td>C6+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
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<tr>
<td>Inerts</td>
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<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

| MN*            | 108                  | 108                 | 82.36                           | 77.86                           | 72.83                         |
| WI*            | 1278.8               | 1333.5              | 1380.4                          | 1391.5                          | 1409                          |

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