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

Background

CNG Specifications

Hydrocarbons	Methane (min.)	88 mol%
	Ethane (max.)	6 mol%
	C3+higher (max.)	3 mol%
	C6+higher (max.)	0.2 mol%
Other Specs.	Hydrogen (max.)	0.1 mol%
	Carbon Monoxide (max.)	0.1 mol%
	Oxygen	1.0 mol%
	Inert Gases	1.5 - 4.5 mol%
	Sulfur (max.)	16 ppmv
	Water, Particulates, Odorant	

Background

California Public Utilities Commission Pipeline Specifications
(Ex. SoCalGas Rule 30)

WI	1279 - 1385
Heating Value	990 - 1150
CO_2 (max)	3% vol
H_2S (max)	4 ppm
H_2O (max)	7 lbs/MMSCF
Inerts (max)	4% vol

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

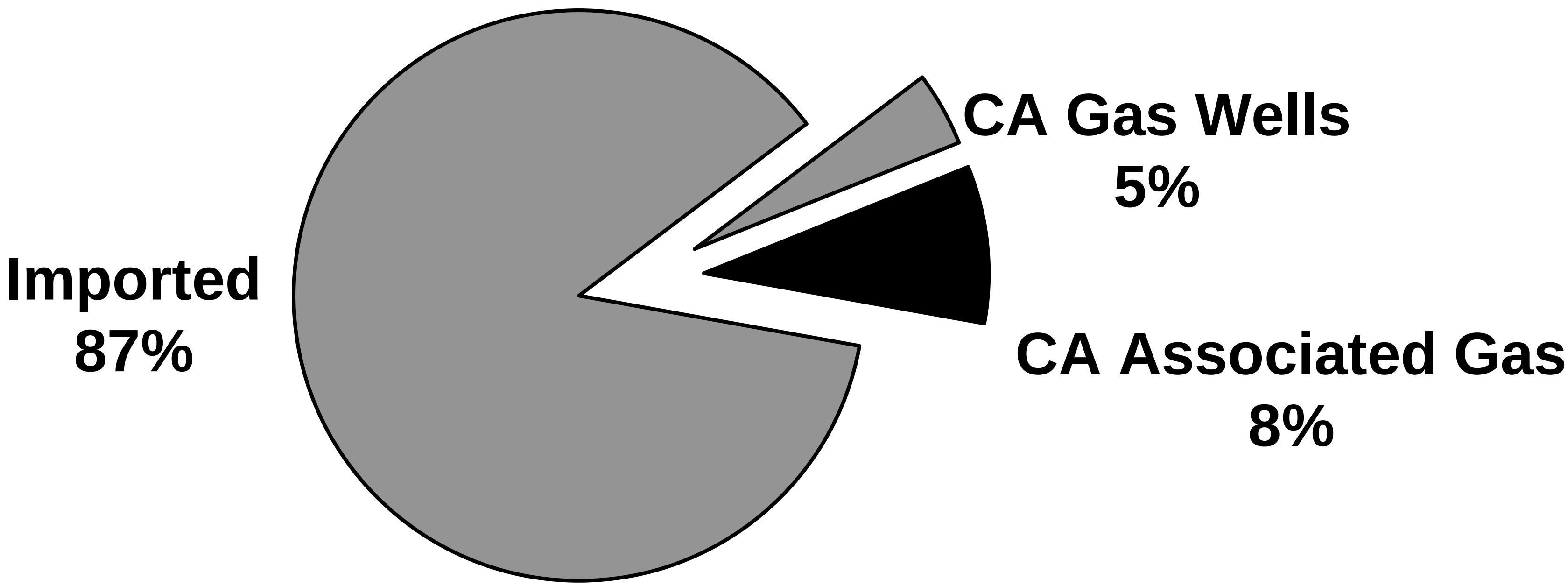
Background

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



Note: Does <u>not</u> 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

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

Background

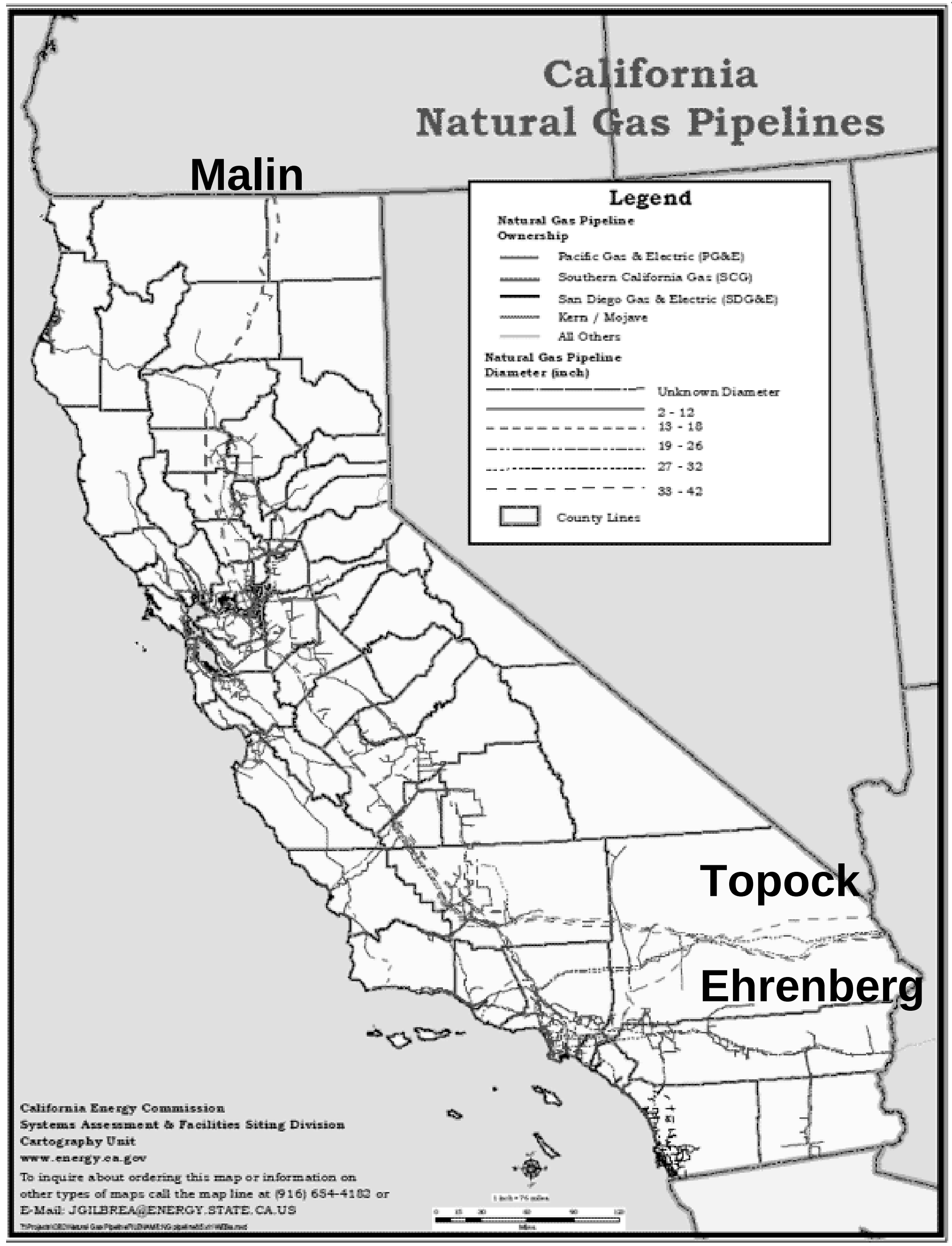
Imported Pipelined Gas Quality Fuel Composition – Northern CA

	1999		2009	
	Malin	**Topock**	**Malin**	**Topock**
Methane	94.9	96.12	95.93	95.86
Ethane	3.15	1.69	2.17	1.79
C3+	0.20	0.27	0.33	0.57
C6+	0.01	0.01	0.01	0.02
Inerts	1.65	1.9	1.55	1.75
MN*	98.7	101.9	95.3	95.31
WI*	1340.1	1333.4	1341.13	1335.64

* MN and WI are not a part of CARB specifications

Source: PG&E 1997-2000, 2008-2009

California Natural Gas Pipelines



Source: CEC

Background

Imported Pipelined Gas Quality Fuel Composition – Central & Southern CA

	1999		2009	
	Ehrenberg	**Topock**	**Ehrenberg**	**Topock**
Methane	TBD	TBD	95.77	96.38
Ethane	TBD	TBD	1.96	1.55
C3+	TBD	TBD	0.5	0.44
C6+	TBD	TBD	0.03	0.02
Inerts	TBD	TBD	1.73	1.61
MN*	TBD	TBD	100	101
WI*	TBD	TBD	1337.37	1335.37

* MN and WI are not a part of CARB specifications

Source: SoCalGas 1997-2000, 2008-2009

Background

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

Background

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

Background

Associated Gas Fuel Composition

	Fresno	Kern	Kings	Santa Barbara	San Luis Obispo	Ventura
Methane	86.19	93.83	86.19	91.28	88.42	92.48
Ethane	8.35	1.84	8.35	4.08	5.41	4.22
C3+	2.43	2.76	2.43	2.78	4.23	1.39
C6+	0.02	0.07	0.02	0.04	0.04	0.02
Inerts	3.01	1.49	3.01	1.83	1.88	1.89
MN*	80	86.63	80	85	78	90
WI*	1352	1367	1352	1366	1385	1351

NOTE: North American Pipeline Gas Composition
Methane %: 95-96, MN: 95-100, WI: 1330-1345

Background

In-State Production vs. CNG Specs

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

*   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

Background

Potential LNG Imports Gas Quality Fuel Composition

	Tangguh	Malaysia	Sahkalin
Methane	96.3	91.23	93.765
Ethane	2.6	4.3	3.45
C3+	0.7	4.36	2.53
C6+	0	0	0
Inerts	0.4	0.12	0.26
MN*	101.4	79.0	90.2
WI*	1372	1422	1397

* MN and WI are not a part of CARB specifications

Source: 2009 Publicly Available Gas Quality Data

Background

Imports vs. CNG Specs

	LNG Imports	CARB Spec
Methane	84.83 - 96.33	88 – 98.5
Ethane	2.6 - 13.39	0 - 6
C3+	0.7 - 4.30	0 - 3
C6+	0 - 0.04	0 - 0.02
Inerts	0 - 0.4	1.5 - 4.5
MN*	75.09 - 101.4	81[**] - 108
WI*	1372 - 1424.5	1280 - 1385

* 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

Assessment

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

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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

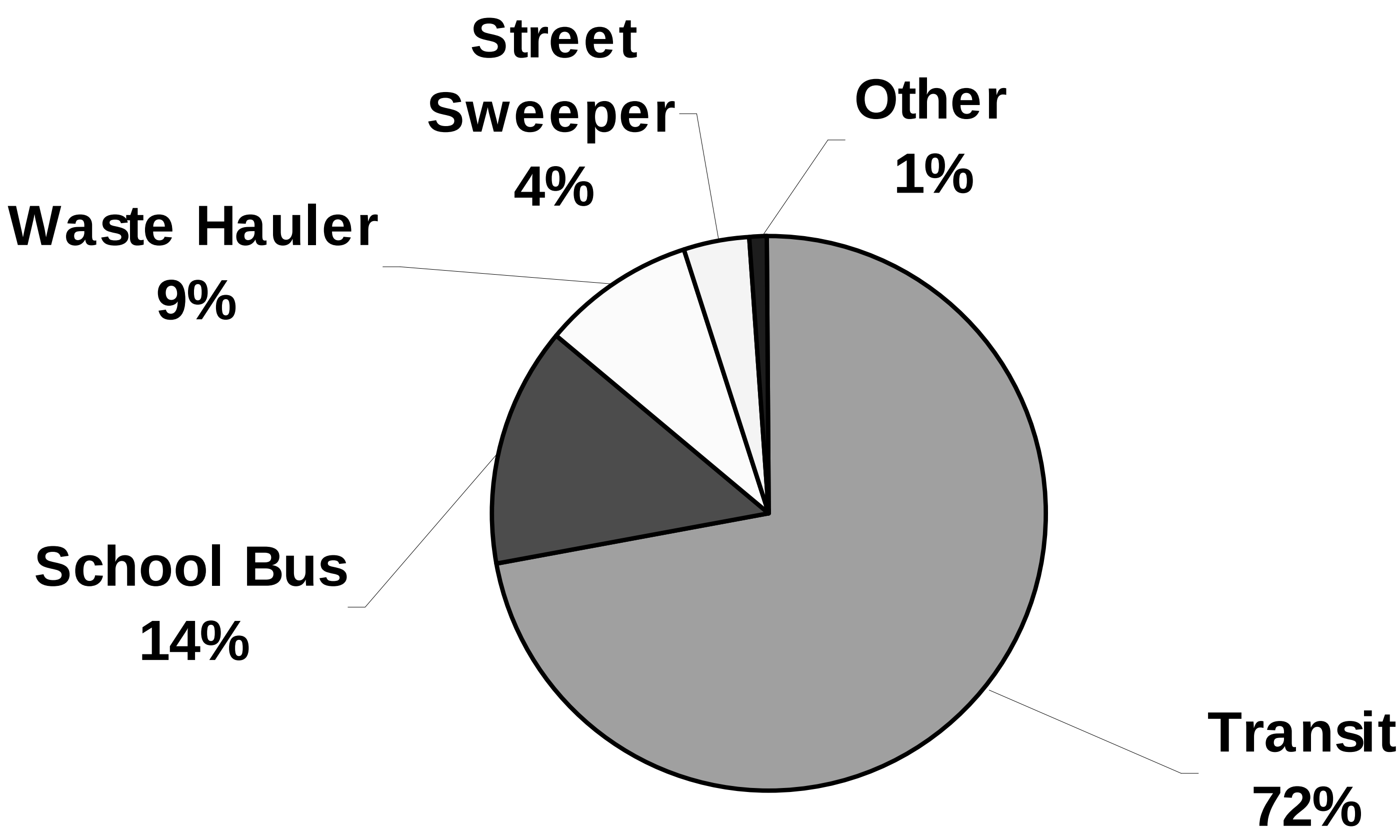
- Compile inventory of all HD CNG engines in 2008 and estimate changes over time

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

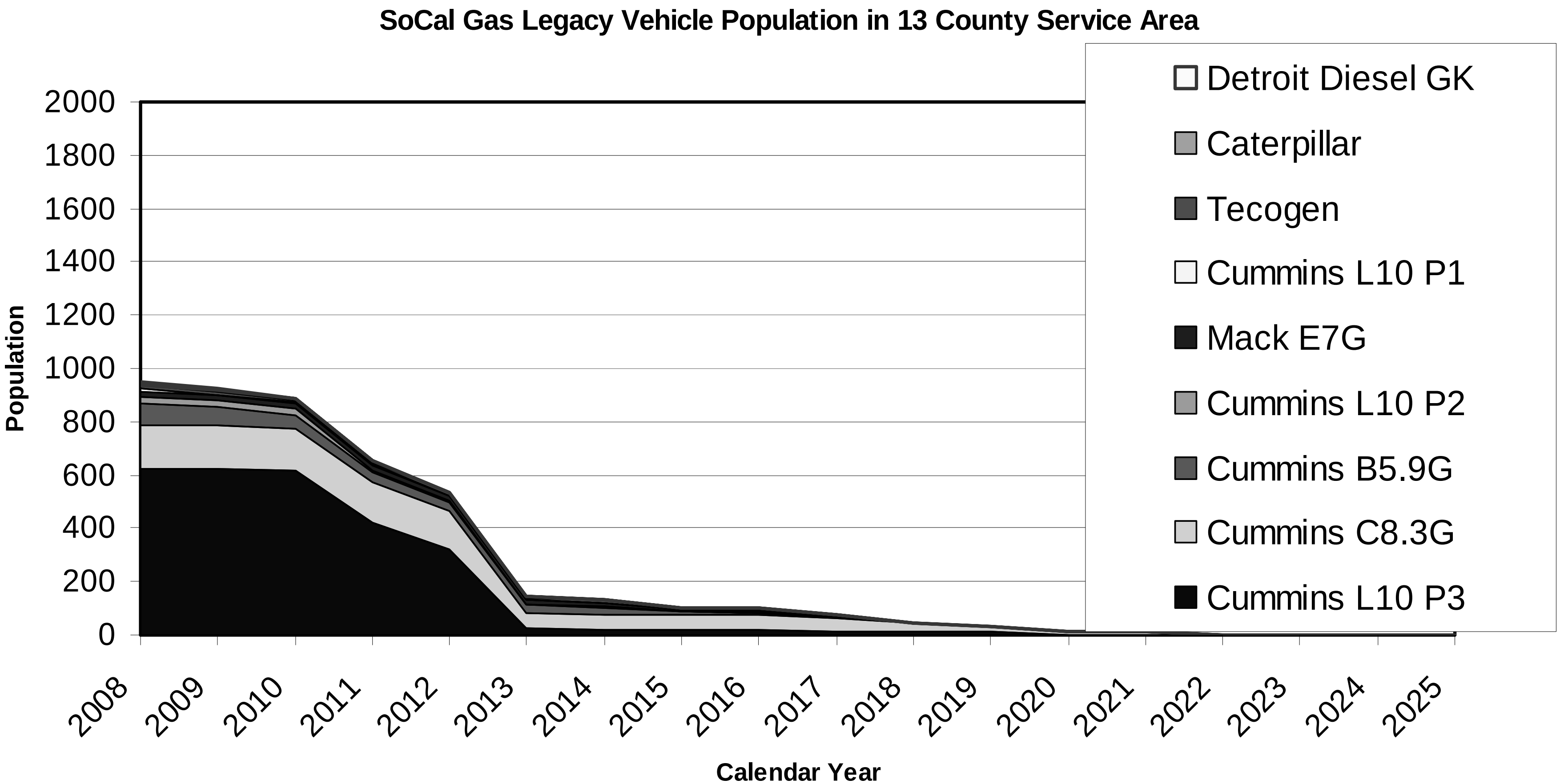
I. HD CNG Vehicle Report - Results

2008 Heavy-Duty CNG Engine Fleet Types



I. HD CNG Vehicle Report - Results

"Legacy Fleet" CNG Engines in Operation Through 2025



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

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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 2. TARGET CNG COMPOSITIONS SUPPLIED BY SCG

Methane Number		*75*		*78* [1]		*80*		*89*	*100*		
Wobbe Level		Low	High	Low	High	Low	High	-	Low	Mid	High
Wobbe Index		1363	1385	1353	1385	1347	1385	1333	1302	1337	1375
Methane	% vol	85.3	86.5	87.1	88.8	88.3	90.3	90.5	93.7	95.6	97.7
Ethane	% vol	4.6	4.6	3.2	3.2	2.2	2.2	4.0	1.5	1.5	1.5
Propane	% vol	6.1	6.2	5.7	5.8	5.5	5.7	2.0	0.8	0.8	0.9
Nitrogen	% vol	4.0	2.7	4.0	2.2	4.0	1.9	3.5	4.0	2.1	0.0

[1] Methane number 78 fuel was tested with the 1998 model year Cummins C Gas engine only.

II. SwRI HD Study – NOx Results

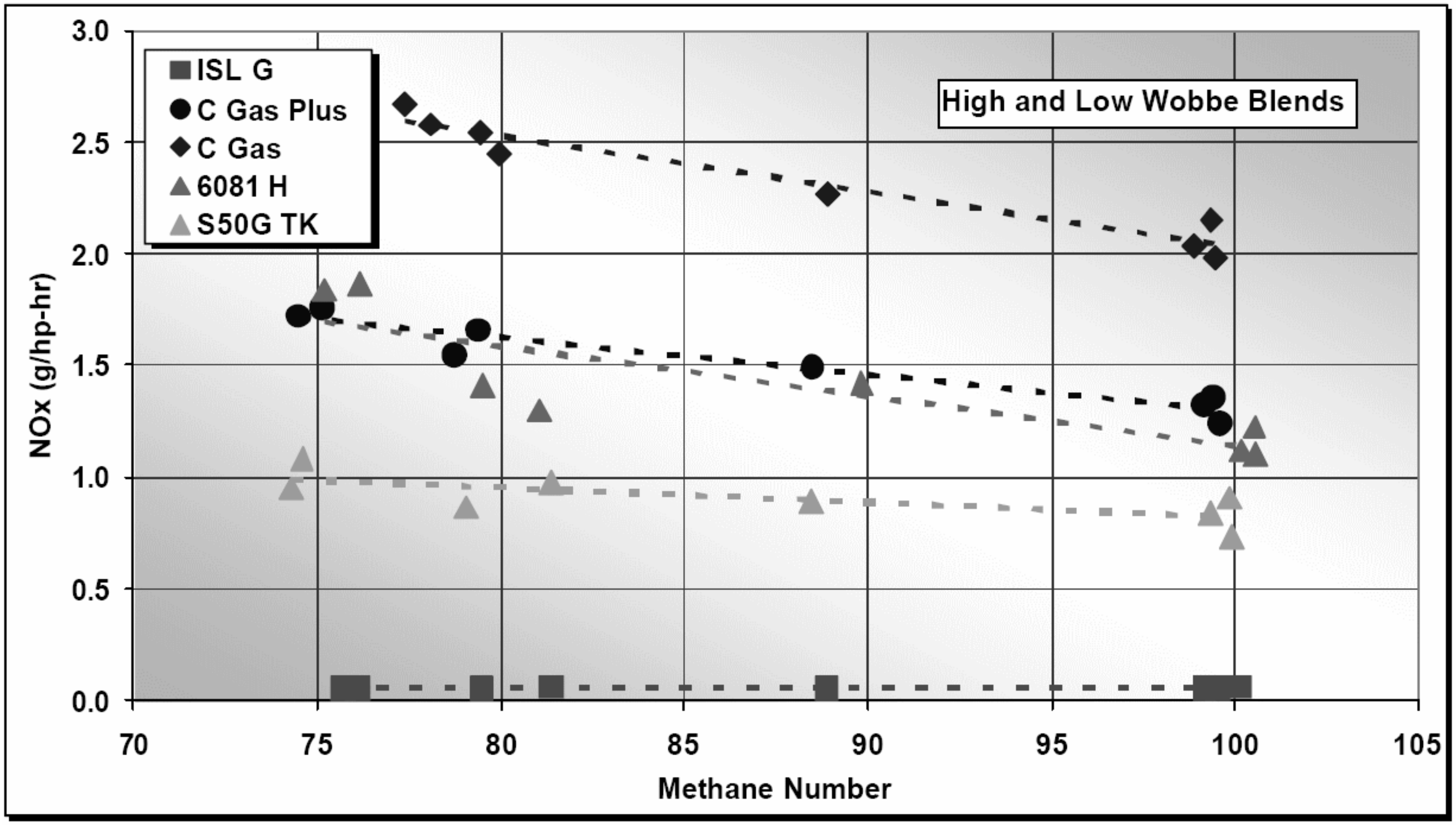

FIGURE 94. HOT-START AVERAGE BRAKE-SPECIFIC NO_X RESULTS VERSUS TEST FUEL METHANE NUMBER FOR ALL TEST ENGINES AND FUELS

II. SwRI HD Study – NMHC Results

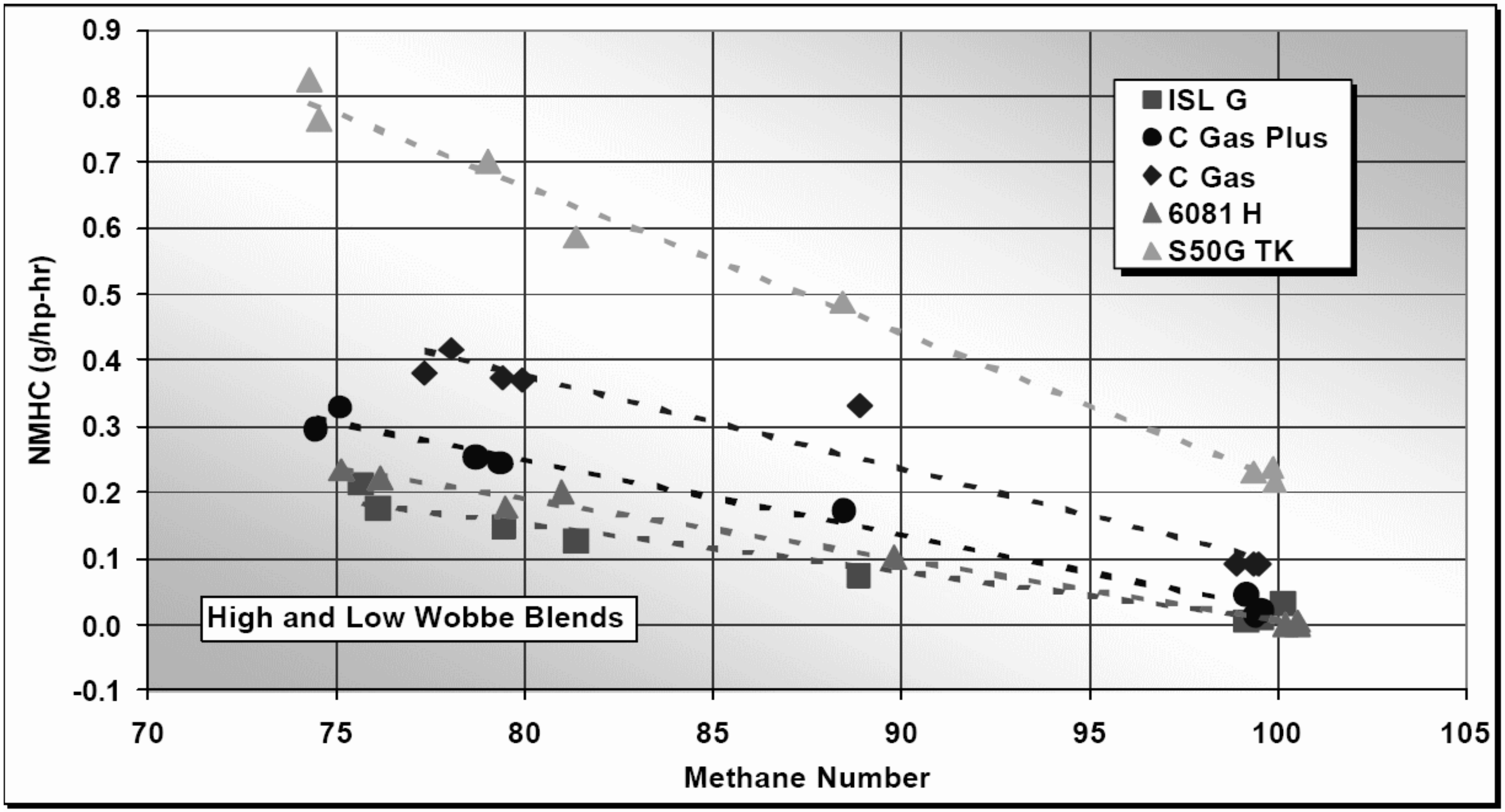

FIGURE 95. HOT-START AVERAGE BRAKE-SPECIFIC NMHC RESULTS VERSUS TEST FUEL METHANE NUMBER FOR ALL TEST ENGINES AND FUELS

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

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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)						
		NOx Change			NMHC Change	
County	Total NOx Inventory	Existing Reg[a]	Proposed Reg[b]	Total NMHC Inventory	Existing Reg[a]	Proposed Reg[b]
San Diego	166	0.144	0.133	152	0.076	0.068
Los Angeles	482	0.346	0.325	336	0.381	0.340
Orange	136	0.067	0.062	117	0.085	0.076
Riverside	83	0.075	0.070	62	0.153	0.137
San Bernardino	91	0.019	0.018	72	0.038	0.034
Ventura	44	0.009	0.008	47	0.005	0.004
Santa Barbara	38	0.001	0.001	35	0.000	0.000
Kern	58	0.003	0.003	14	0.002	0.002
Kings	29	0.001	0.001	18	0.000	0.000
Tulare	45	0.016	0.014	45	0.015	0.013
Fresno	110	0.001	0.000	82	0.000	0.000
San Luis Obispo	21	0.001	0.001	23	0.001	0.001
Imperial	37	0.000	0.000	30	0.000	0.000
13-County Total	**1340**	**0.683**	**0.636**	**1033**	**0.756**	**0.675**

III. HD Statistical Analysis – Results

Maximum Theoretical Change in 2018 NOx and NMHC Emissions (TPD)						
		NOx Change			NMHC Change	
County	Total NOx Inventory	Existing Reg[a]	Proposed Reg[b]	Total NMHC Inventory	Existing Reg[a]	Proposed Reg[b]
San Diego	113	0.011	0.01	133	0.063	0.056
Los Angeles	330	0.05	0.045	277	0.35	0.312
Orange	95	0.06	0.055	102	0.075	0.067
Riverside	55	0.038	0.035	55	0.137	0.122
San Bernardino	66	0.007	0.006	65	0.026	0.023
Ventura	32	0.004	0.004	42	0.005	0.004
Santa Barbara	29	0	0	31	0	0
Kern	48	0	0	12	0.001	0
Kings	18	0.001	0.001	17	0	0.001
Tulare	31	0.008	0.007	42	0.013	0.012
Fresno	72	0	0	75	0	0
San Luis Obispo	15	0	0	21	0.001	0
Imperial	29	0	0	29	0	0
13-County Total	**933**	**0.179**	**0.163**	**901**	**0.671**	**0.597**

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

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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

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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		
	FTP Composite	**UC Drive Cycle**
THC	Emissions Decreased	No Fuel Effect
NMHC	Emissions Increased Max Effect + 0.002 g/mi (MN 68 fuel)	Emissions Increased Max Effect + 0.002 g/mi (MN 68 fuel)
CO	Emissions Increased Max Effect + 0.043 g/mi (MN 80 High WI)	No Fuel Effect
NOx	Emissions Decreased	No Fuel Effect
CO2	Emissions Increased up to 4.0 g/mi	No Fuel Effect
FE	No Fuel Effect	FE increased up to 0.7 mpg (MN 80 High WI)

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

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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

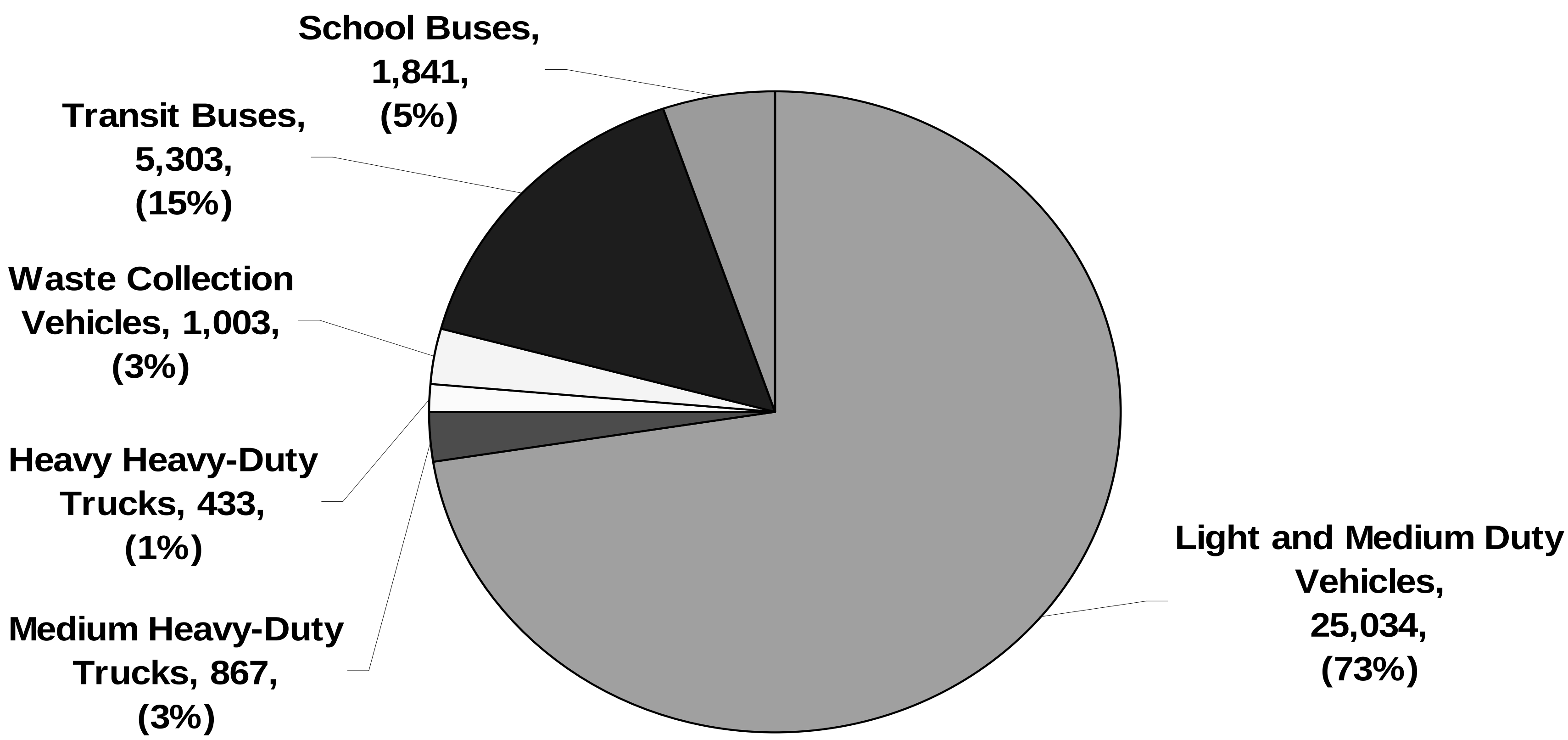
VI. CE-CERT HD and LD

- 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

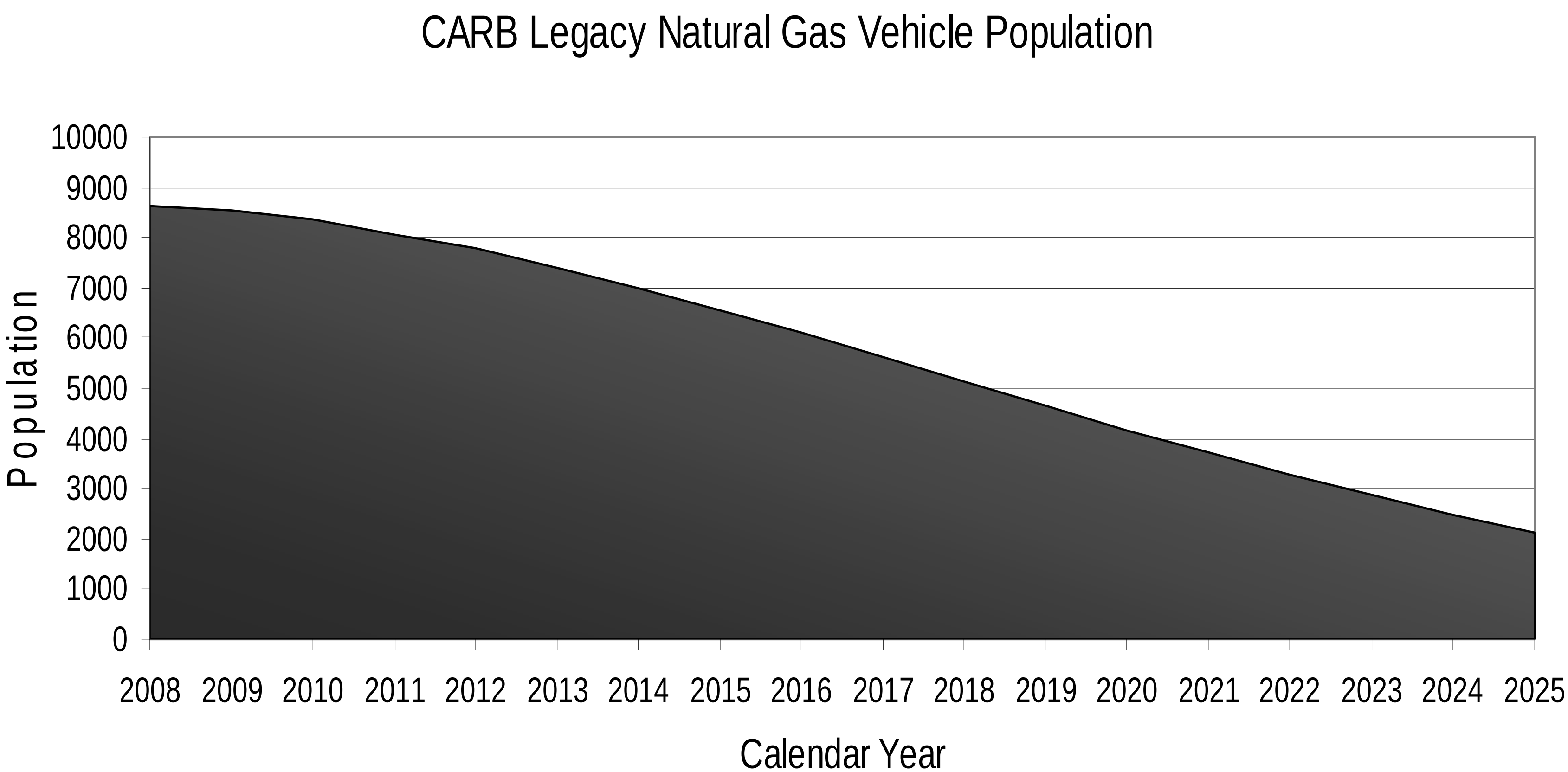
- Test fuels based on range of MN, WI and various fuel compositions
  - MN 83 – 96
  - WI 1330-1436
  - High/Low Ethane
- Engines and vehicles tested as-is

2008 CA Natural Gas Vehicle Population



Source: 2008 DMV

Legacy CNG Engines in Operation



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:
  - $MN = 1.624 * MON – 119.1$
  - $MON = (20.17 * H/C^3 – 173.55 * H/C^2 + 508.4 * H/C – 406.14)$
  - H/C = (mol % Hydrogen / 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

Considerations

CNG Specifications

Hydrocarbons	Methane (min.)	88 mol%
	Ethane (max.)	6 mol%
	C3+higher (max.)	3 mol%
	C6+higher (max.)	0.2 mol%
Other Specs.	Hydrogen (max.)	0.1 mol%
	Carbon Monoxide (max.)	0.1 mol%
	Oxygen	1.0 mol%
	Inert Gases	1.5 - 4.5 mol%
	Sulfur (max.)	16 ppmv
	Water, Particulates, Odorant	

CNG Specifications with possible MN and WI

	High CH4 High Inerts	High CH4 Low Inerts	Max C2 and Min Inerts (C3 only)	Max C2 and Min Inerts (C3 Equal)	Max C2, C3, & C6 Min Inerts
Methane	95.5	98.5	89.5	89.5	89.3
Ethane	0	0	6	6	6
C3+	0	0	3	3	3
C6+	0	0	0	0	0.2
Inerts	4.5	1.5	1.5	1.5	1.5
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