Impacts of Potential Revisions to CNG Fuel Standard

California Air Resources Board

May 19, 2010

Steven Moore, SDAPCD

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

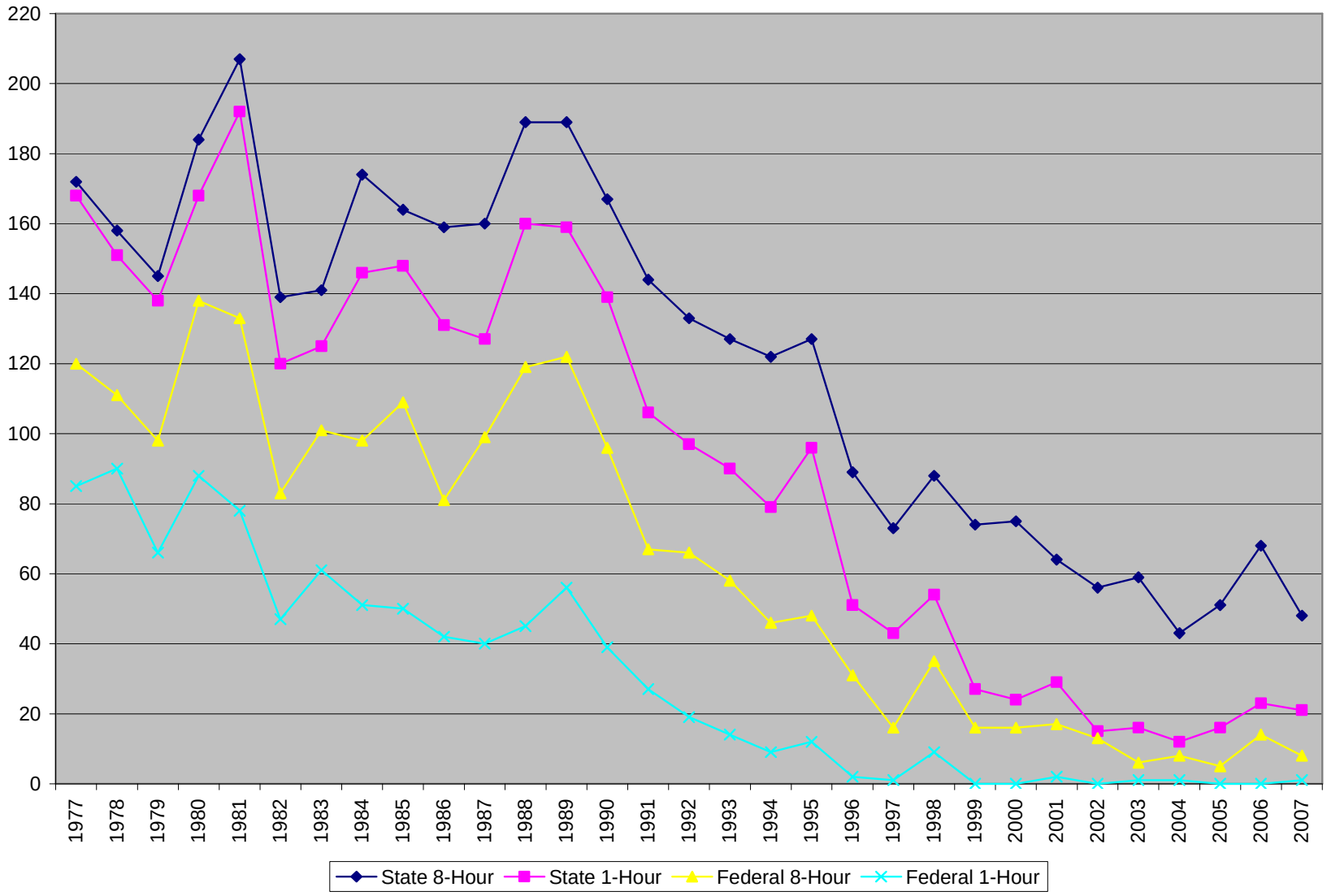
District Goals

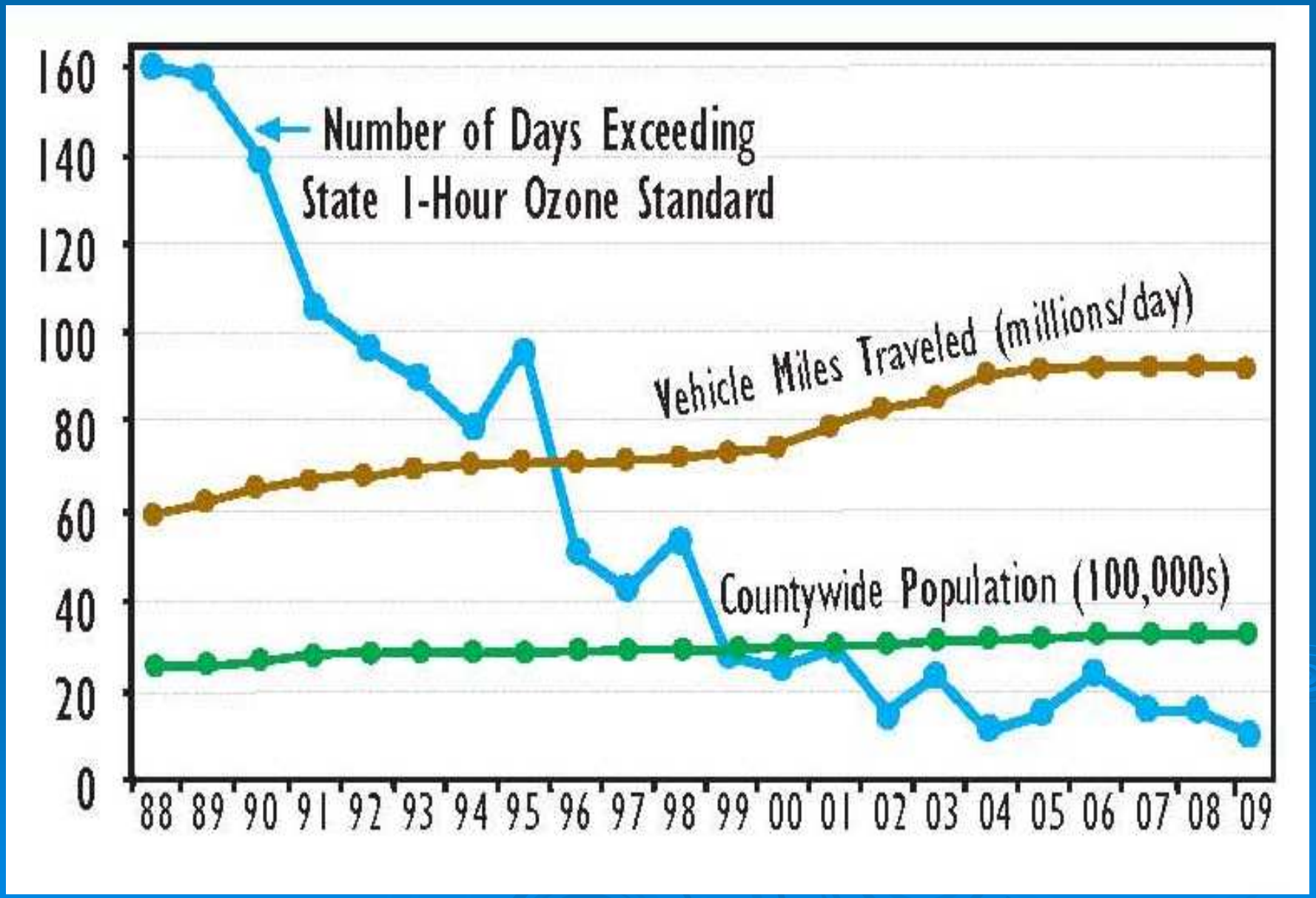
- *Protect air quality*
- *Attain & maintain (no backsliding) the state and federal ambient air quality standards*
- *Mitigate any emission increases resulting from changes in source of gas supply*
- *Compliance of permitted sources*

San Diego Attainment Status

Pollutant	Federal	State
Carbon Monoxide	Attainment	Attainment
Nitrogen Dioxide	Attainment	Attainment
Sulfur Dioxide	Attainment	Attainment
Lead	Attainment	Attainment
Particulate Matter	Attainment	Non-Attainment
Ozone	Non-Attainment	Non-Attainment

Days Exceeding Air Quality Standards for Ozone




160
140
120
100
80
60
40
20
0
Number of Days Exceeding
State 1-Hour Ozone Standard
Vehicle Miles Traveled (millions/day)
Countywide Population (100,000s)
88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09

Significance of Emissions

Emission Increase	Stationary Source Requirements and District Mandates
10 lbs/day	BACT
0.07 tons per day (25 tons per year)	LAER and Offsets at a major source
0.1 tons per day	New rule to address source category
0.01–0.1 tons per day	Potential new rule to address source category

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*

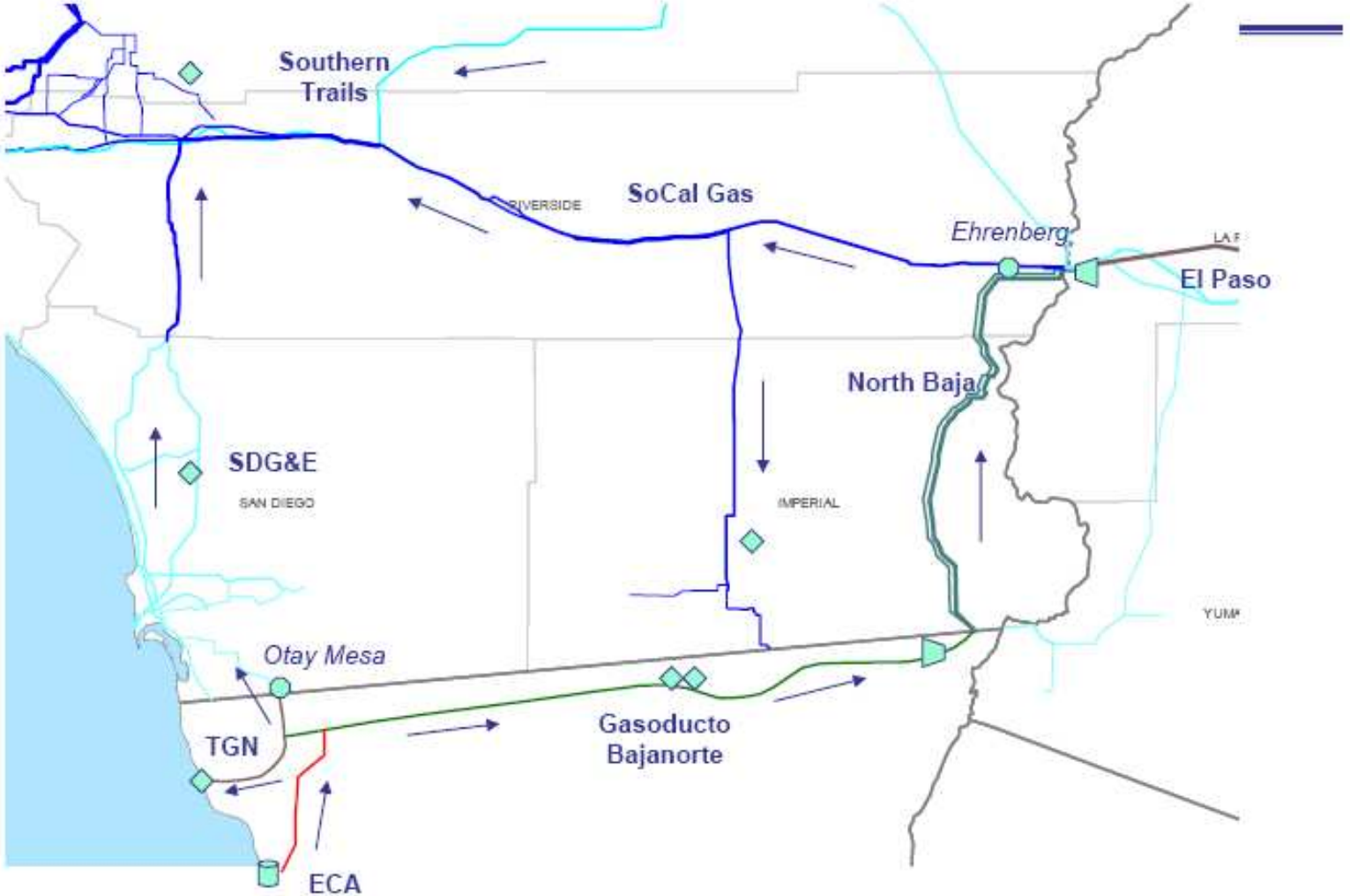
Potential Implications of Revision to CNG Standards

- *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

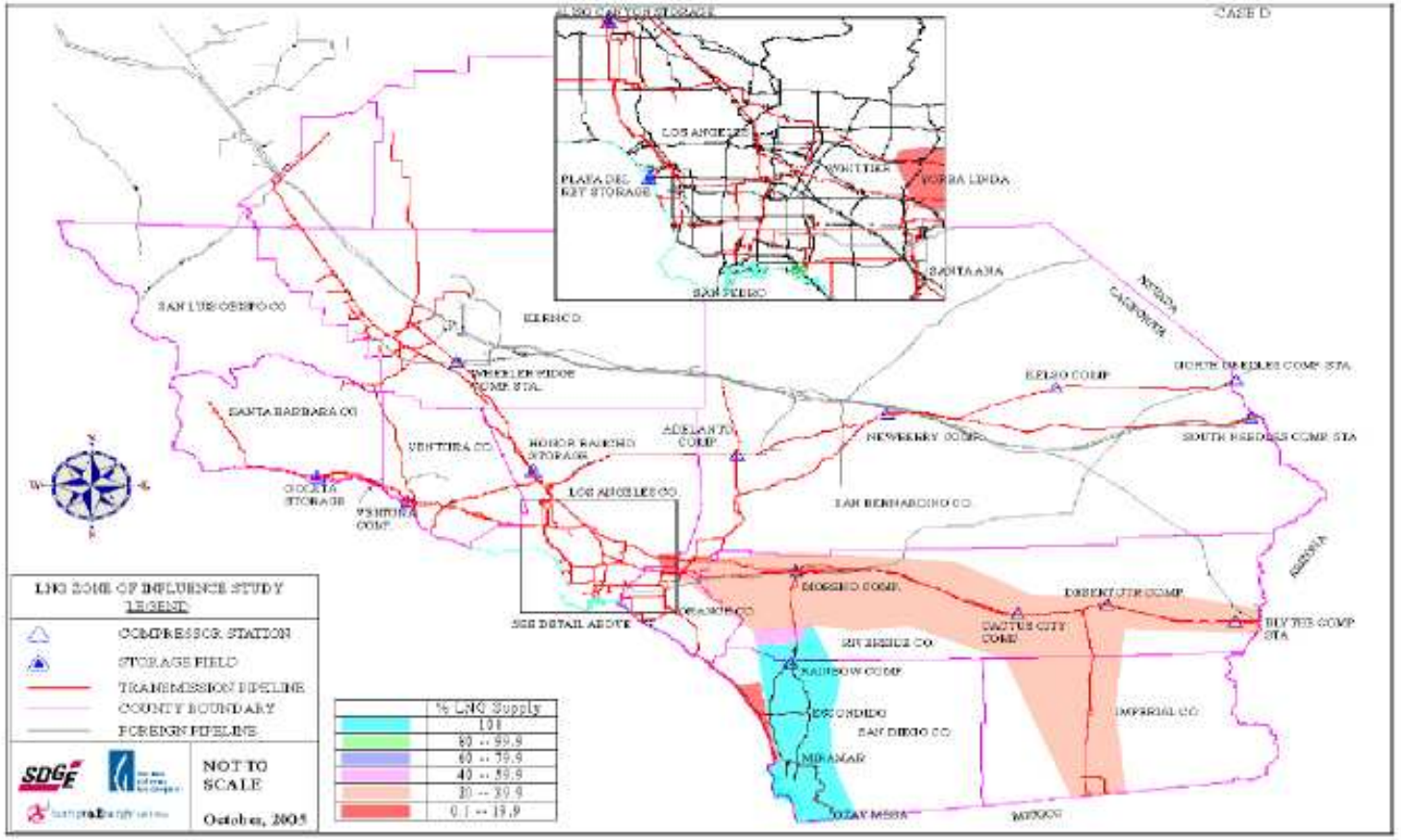
- *Revision to gas quality standard could immediately allow large amounts of LNG use—up to 400 MMscf/day in San Diego and 400 MMscf/day elsewhere in S. CA*
- *San Diego current maximum gas consumption about 400 MMscf/day*

Energia Costa Azul & Pipelines to California



ECA Terminal Start Up Presentation, Sempra LNG

Costa Azul Zone of Influence for Rollout Planning

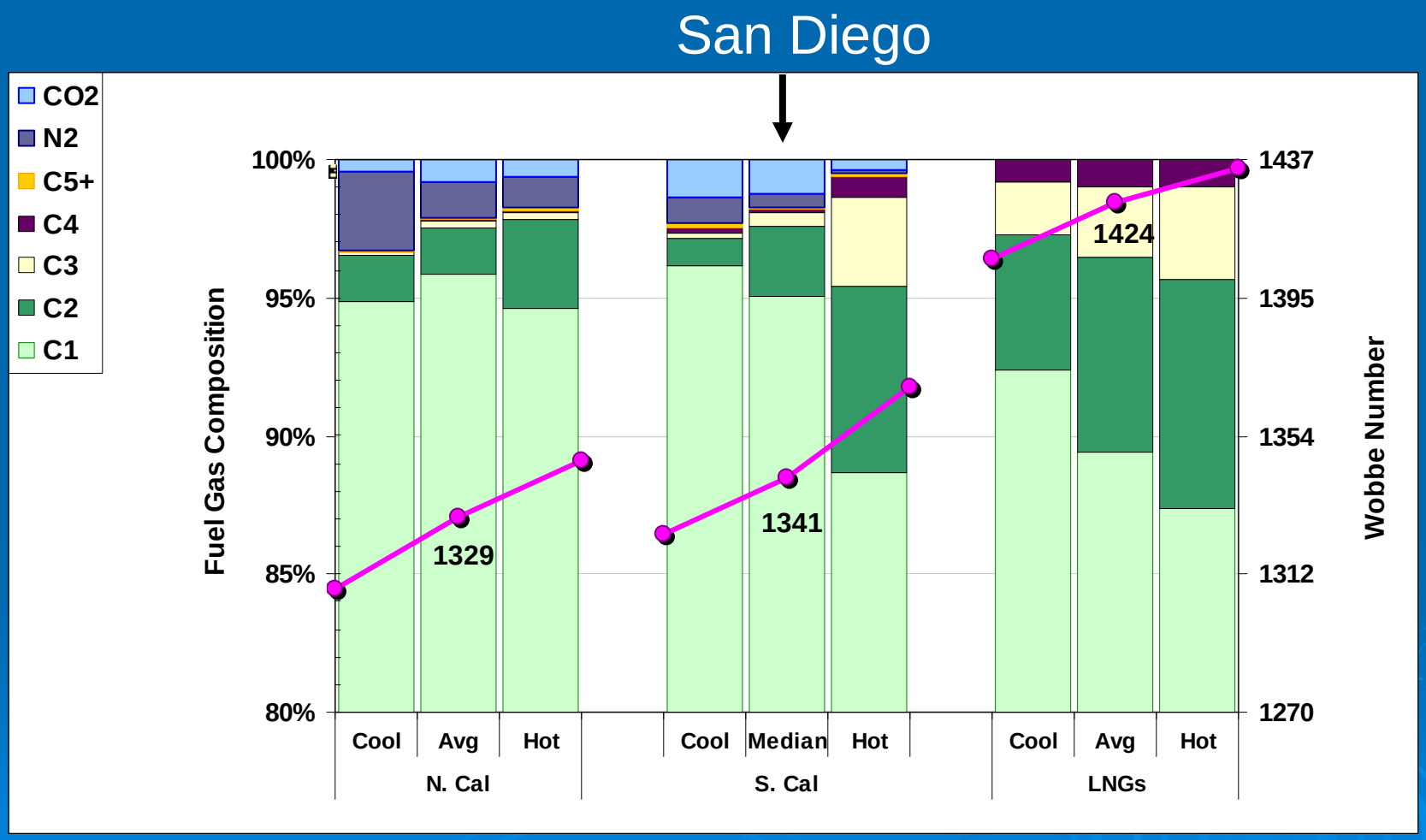


Zone of Influence Study, Exhibit 151, admitted December 16, 2005

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. x 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)*
  - *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 through out 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*
- *$WI = HHV/(\text{specific gravity})^{0.5}$*
- *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)*

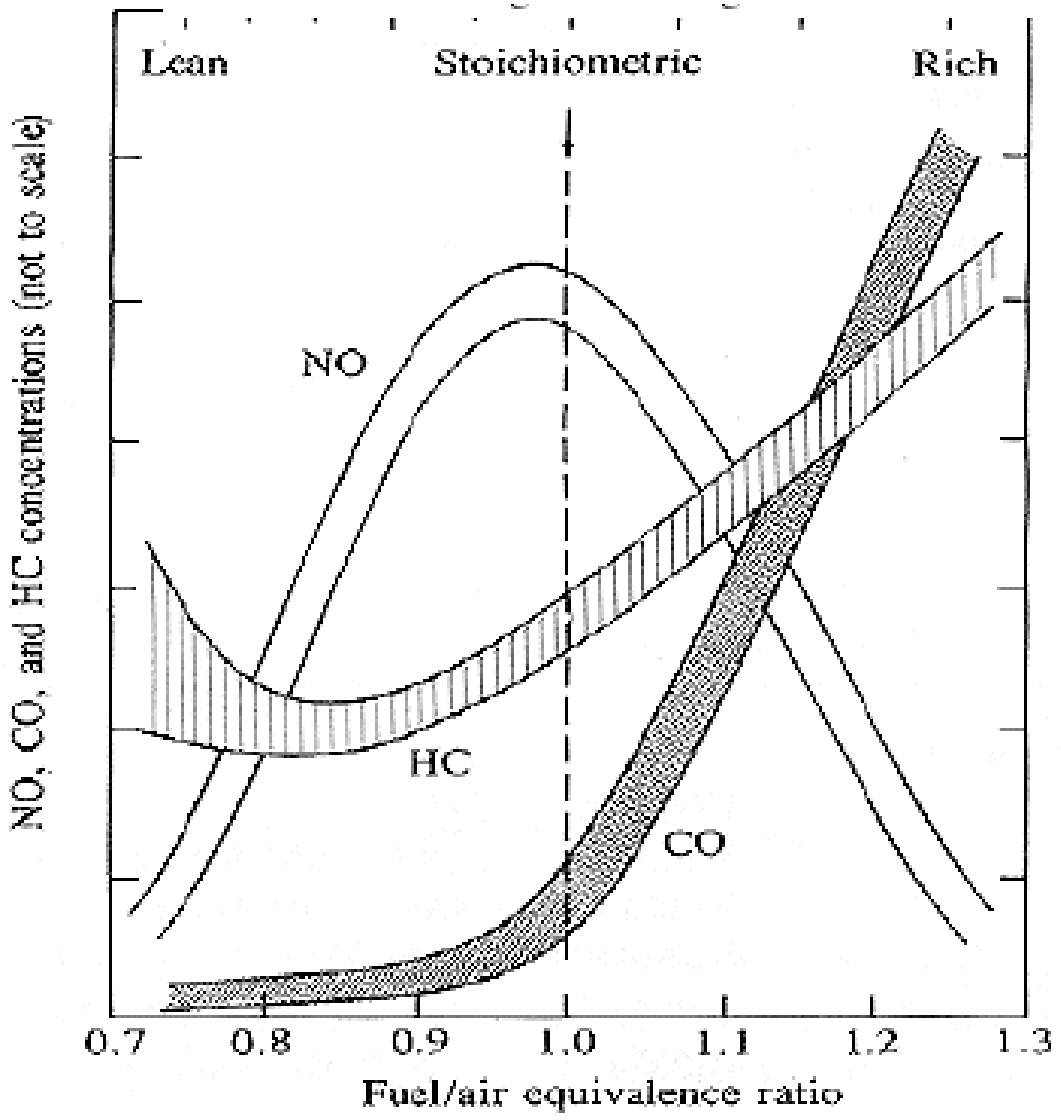
Wobbe Index and Emissions

- *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 effect 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, φ, is (fuel/air)/(stoichiometric fuel/air)*
- *φ < 1 is lean (more air than needed for complete combustion)*
- *φ > 1 is rich (less air than needed for complete combustion)*
- *Peak combustion temperature at or near φ = 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

Wobbe Index and Emissions

- *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

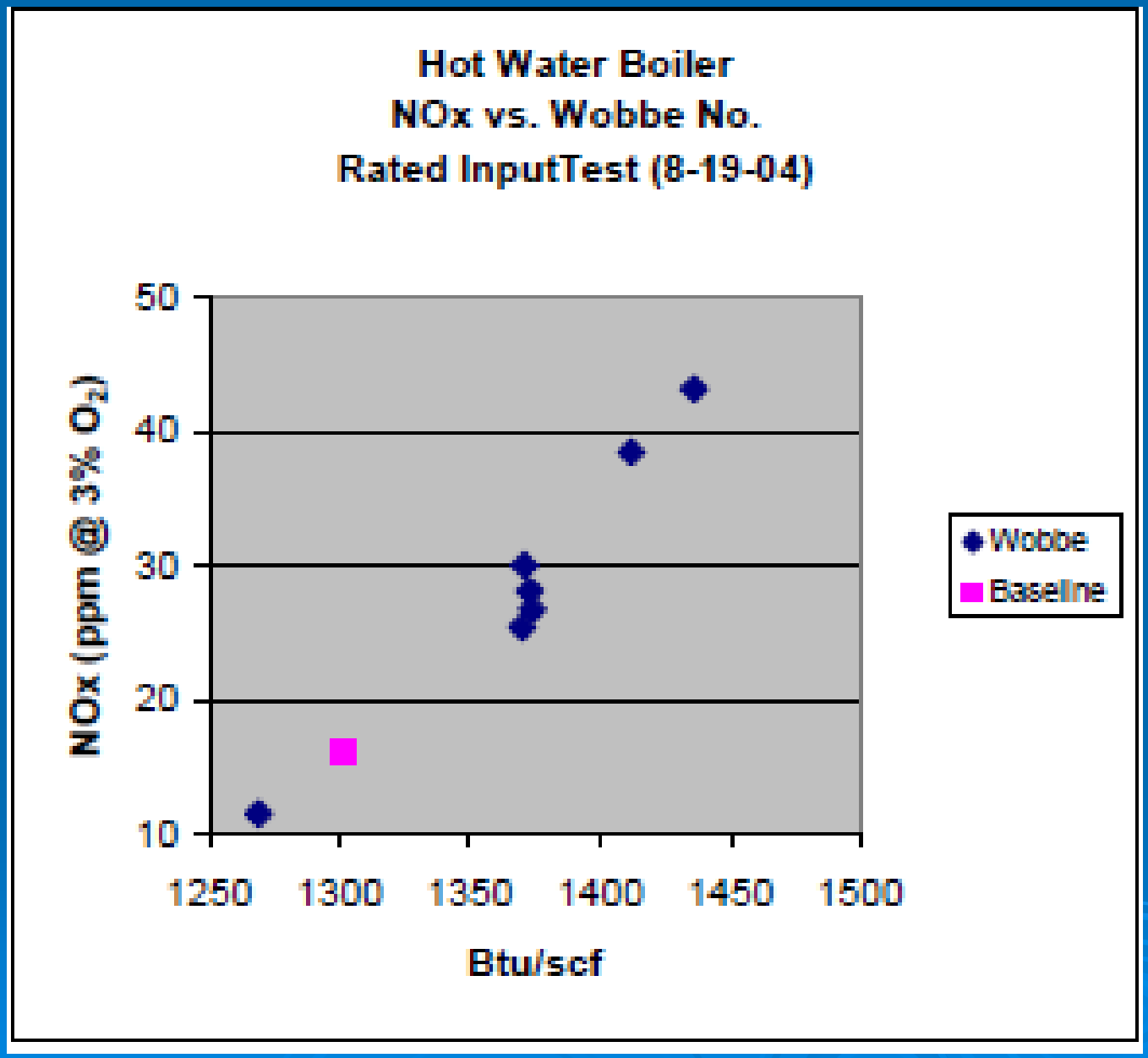
- *Ethane and propane have higher adiabatic flame temperatures than methane at the same fuel to air ratio*
- *Ethane and propane have higher flame speeds than methane at the same fuel to air ratio*
- *Combustion chemistry details*

Characterizing NOx Emission Impacts

Wobbe and Non-Wobbe Impacts

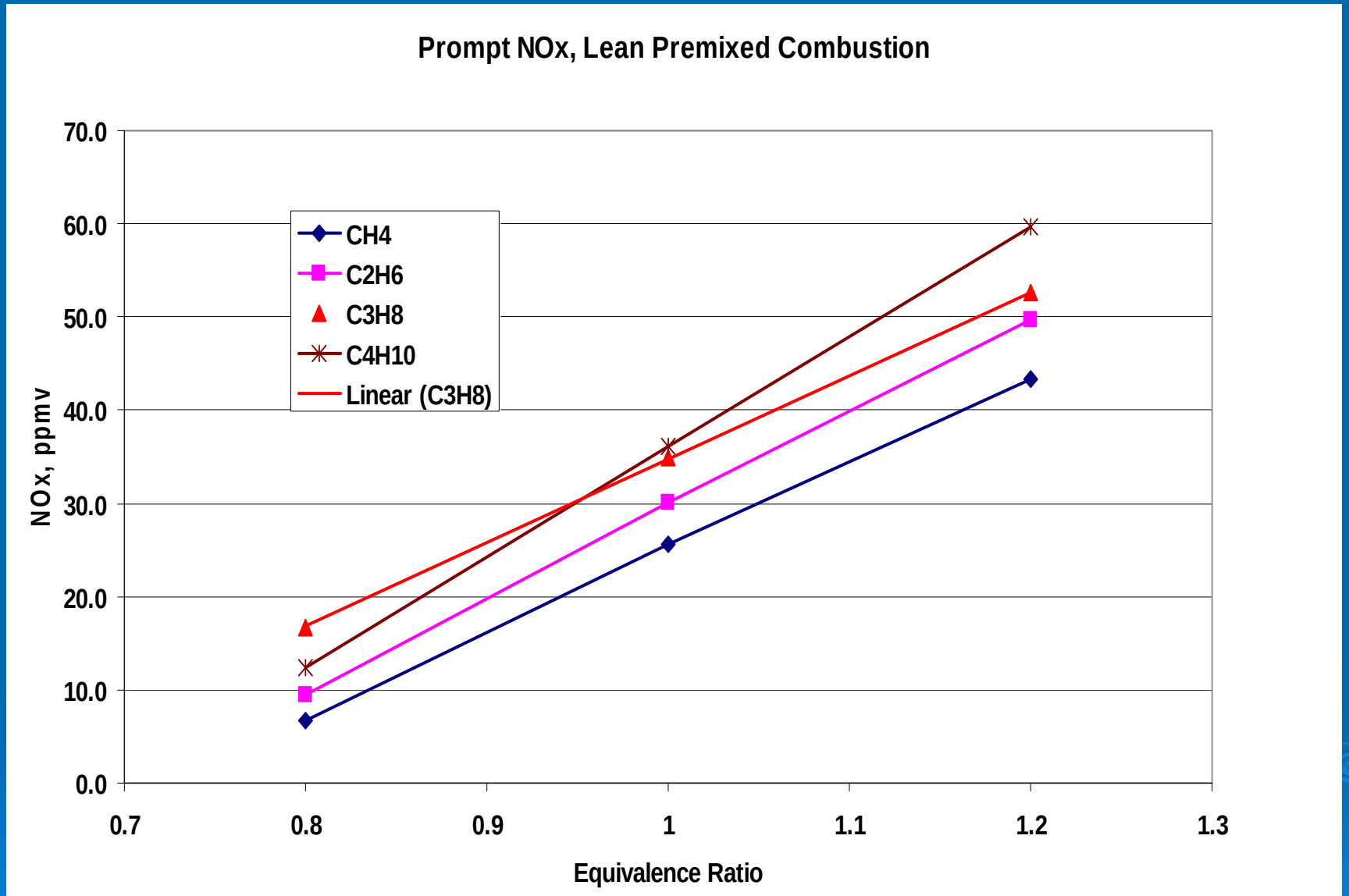
- Wobbe Index expected to be important for devices without fuel/air controls
- Non-Wobbe effects expected to dominate in devices with fuel/air controls or operating at very low NOx levels (i.e., at low temperatures)

Wobbe Effects on NOx

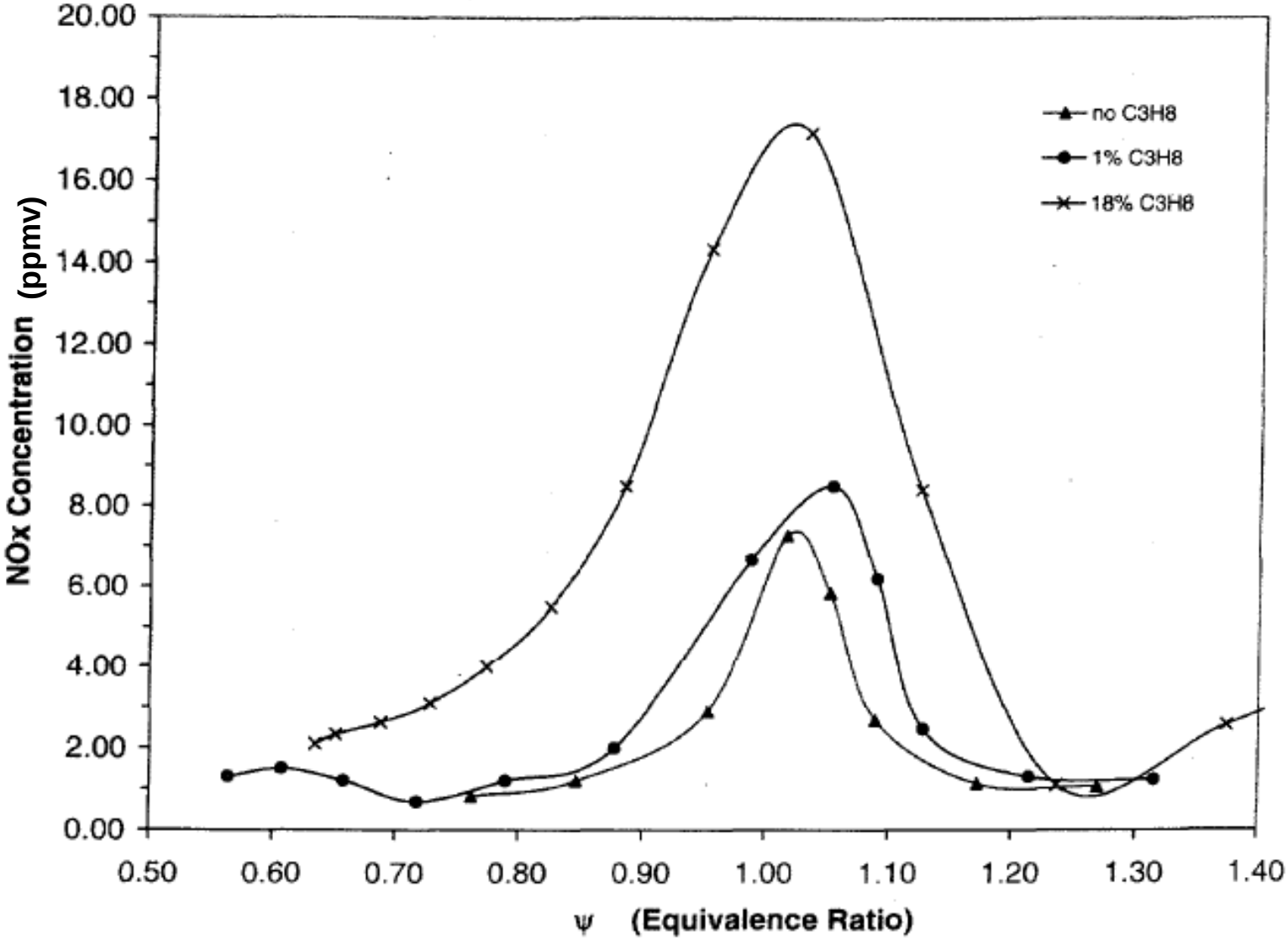


Source: Southern California Gas Company, Gas Quality and Research Study, Appendix G

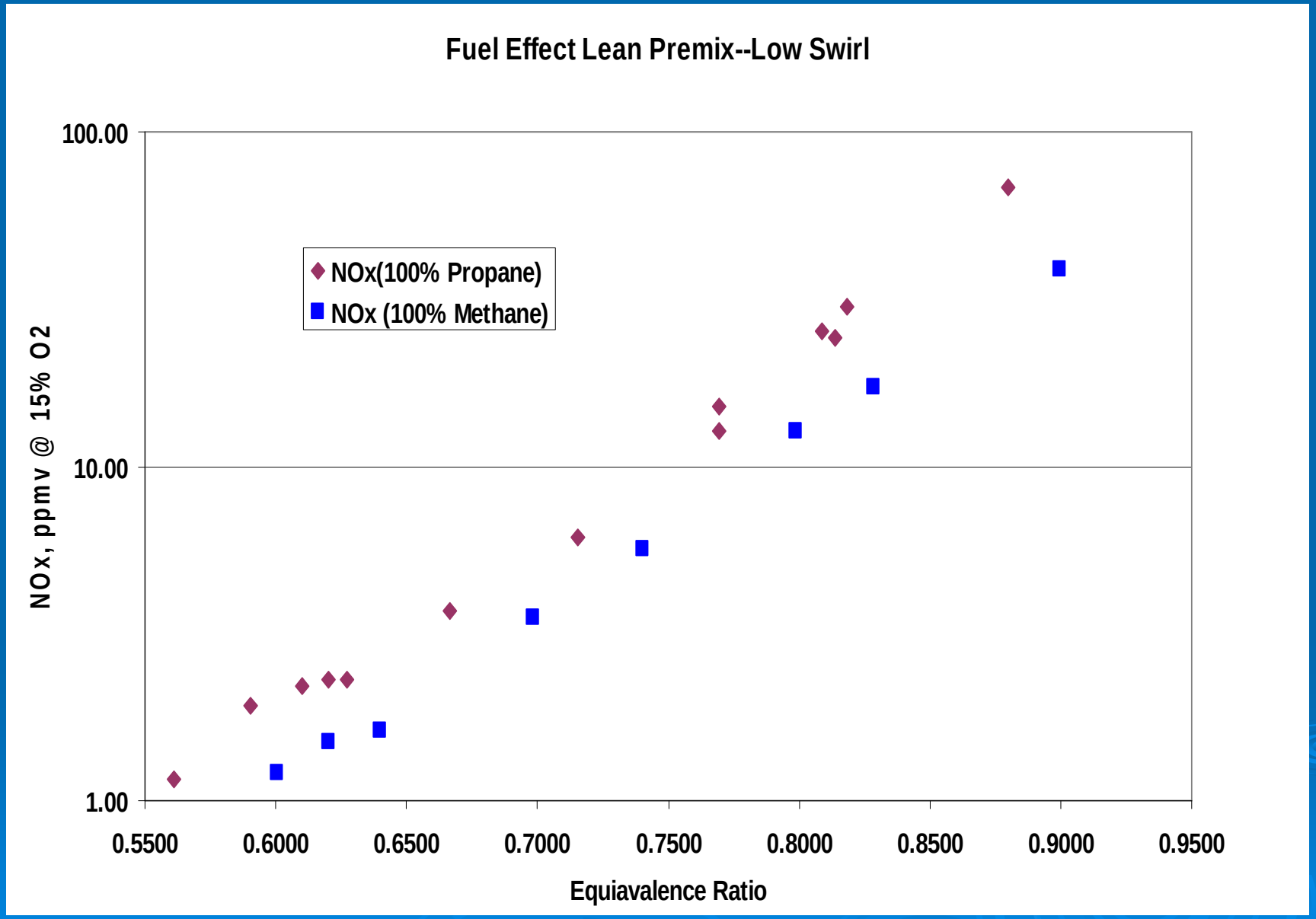
Non-Wobbe Effects on NOx



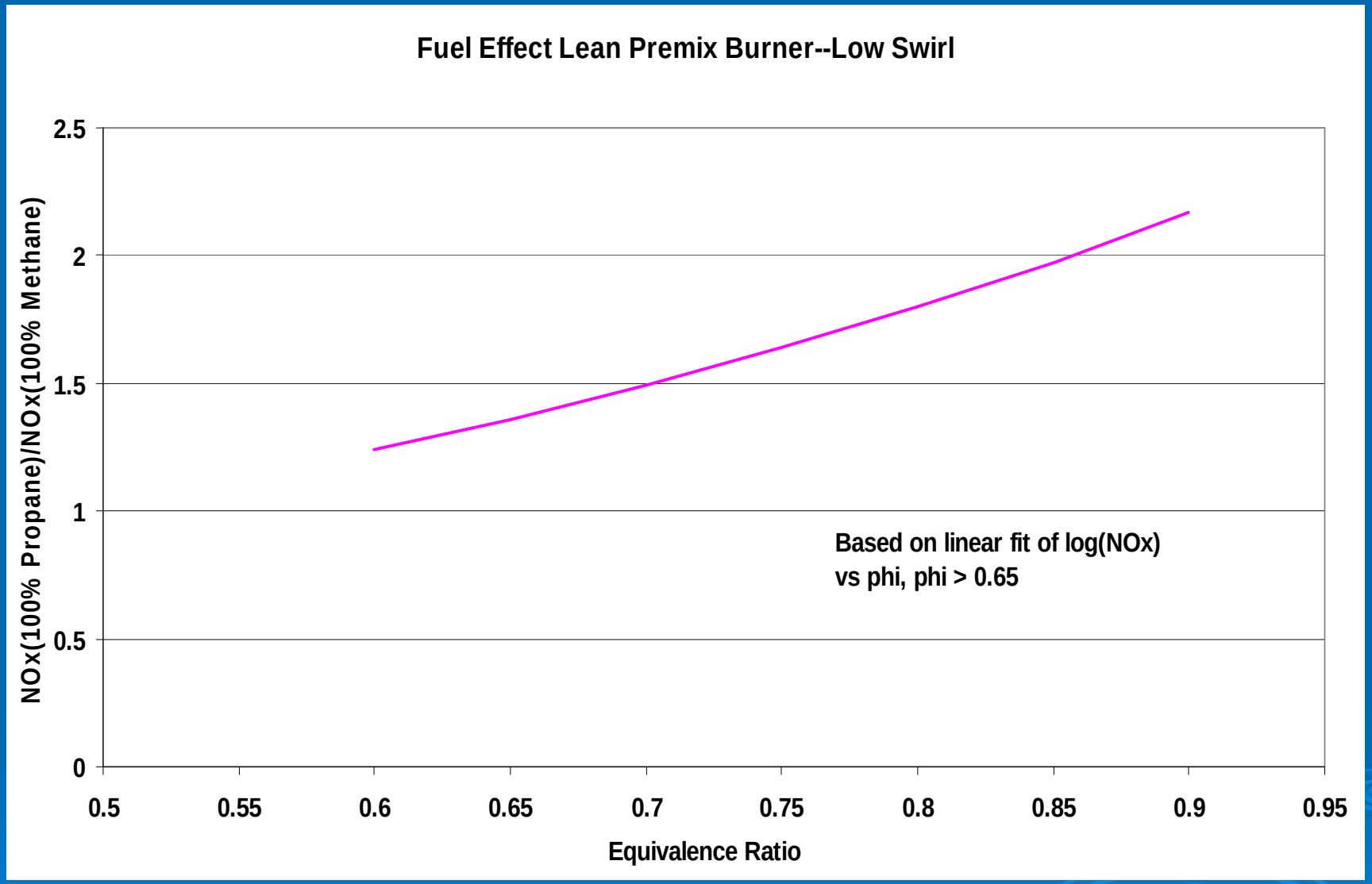
Replotted from Bachmaier F. et al., Combust. Sci. Tech., 7, 77 (1973)



Source: Clark Atlanta University Dept. Of Engineering



Replotted from: Littlejohn, D. & Cheng, R.K. Proceedings of the Combustion Institute, 31, 3155-3162, 2007.



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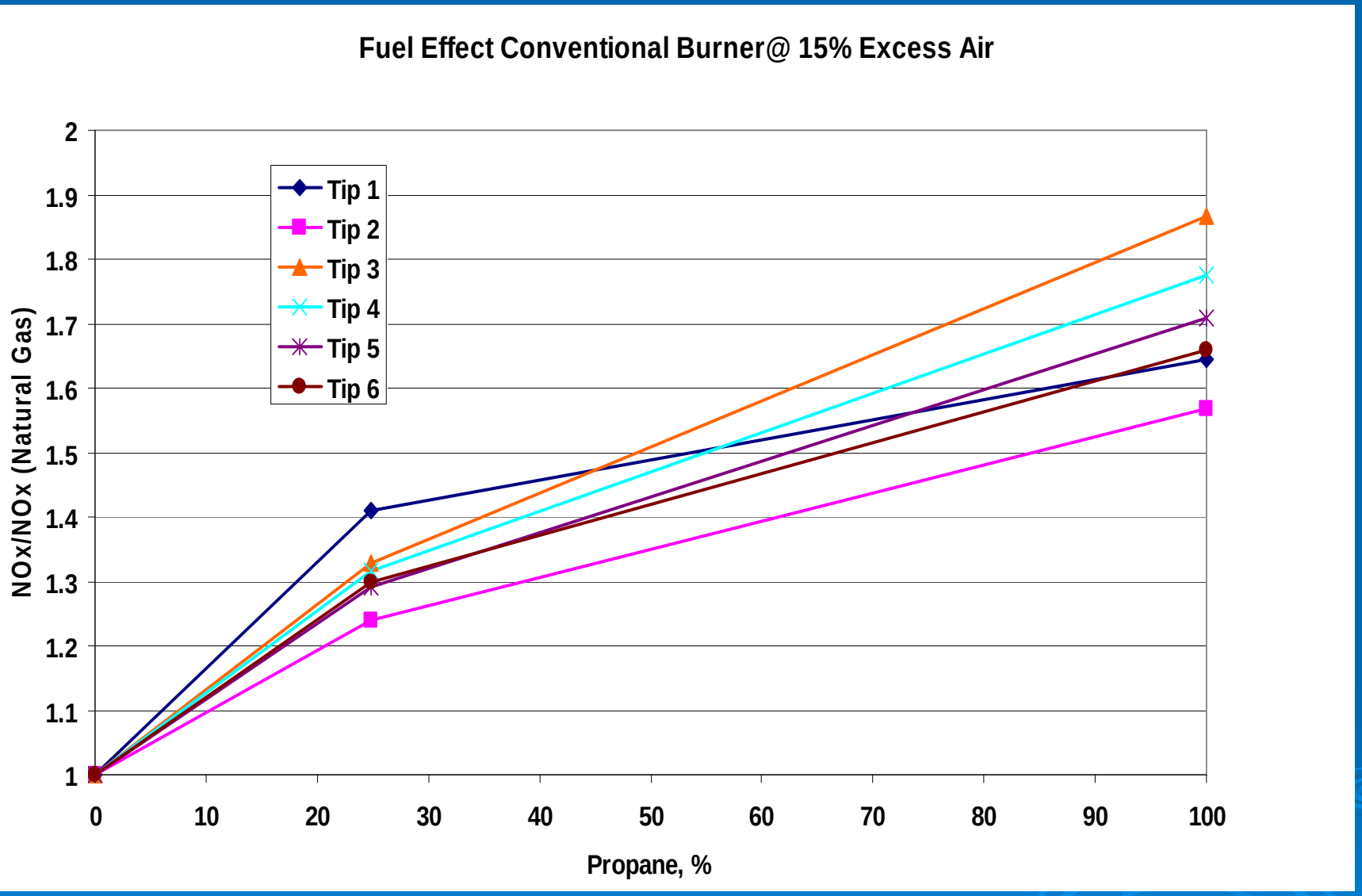


Replotted from Baukal, Jr, C. E.. and Colannino, J. "Pollutant Emissions," Chapter 6, in Baukal, Jr, C .E. and Schwartz, R. E., eds., John Zink Combustion Handbook, CRC Press, 2001.

Other Data with Non-Wobbe NOx Emission Increases

- Micro Turbine, Hack, R. L., and McDonnel, V. G., 2008
- 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
- Turbine test combustor, Straub, D. et al., 2007.

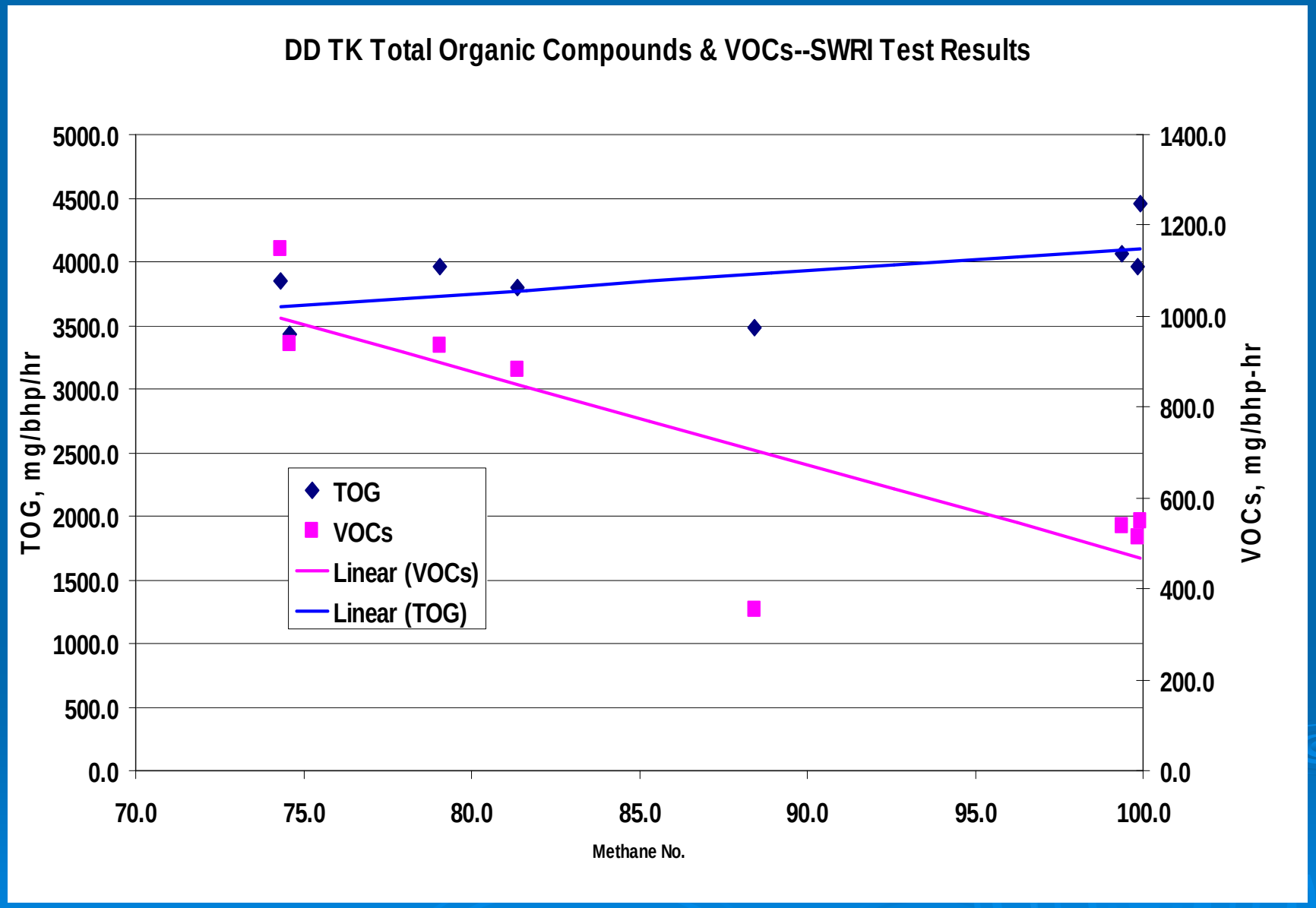
Conclusions—Characterizing NOx Emissions

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

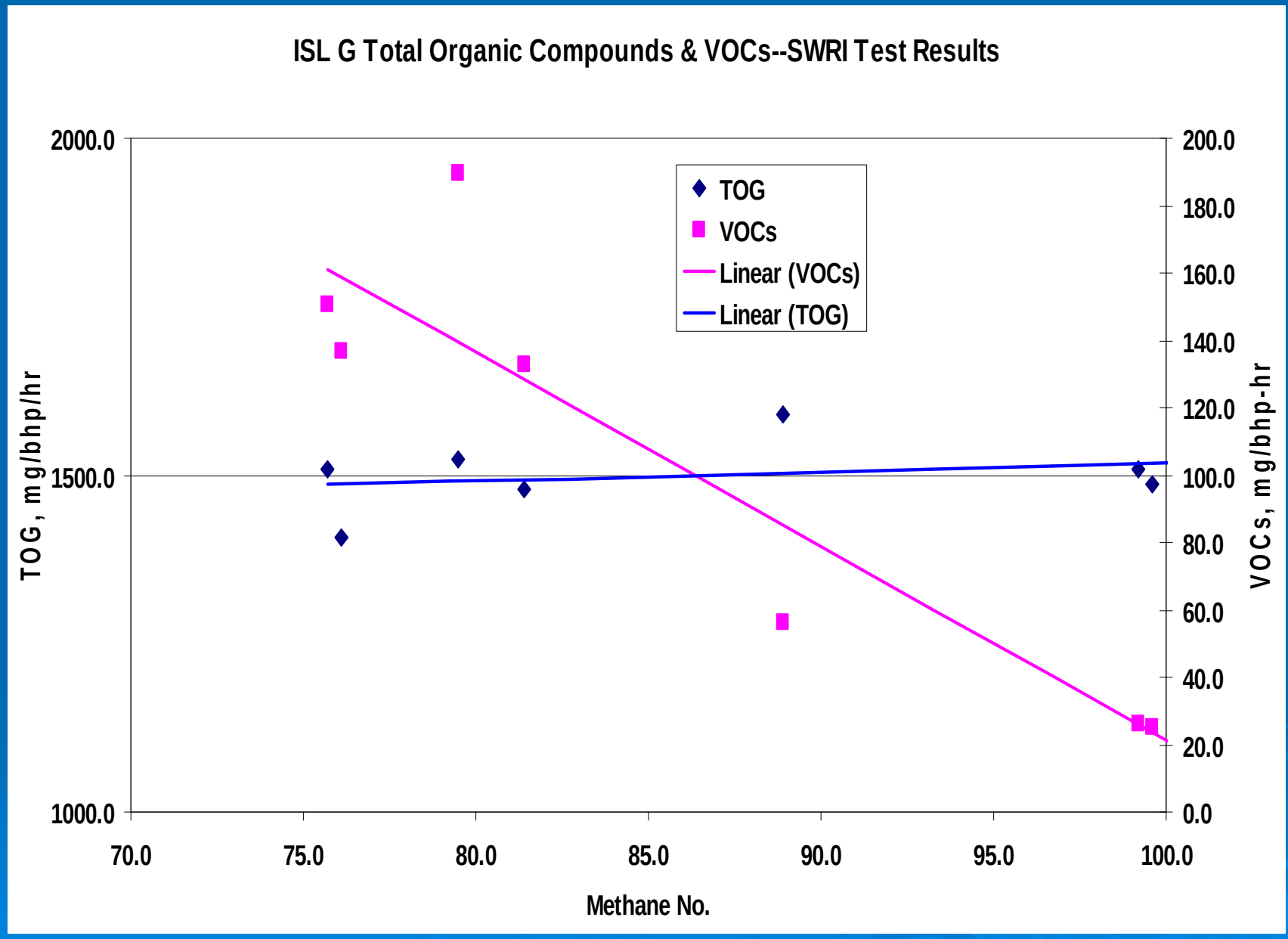
Characterizing VOC Emission Impacts

Characterizing VOC Combustion Emissions

- *Very limited testing (SWRI on engines)*
- *Increase in emissions expected to be related NMHC in fuel*
- *Ethane ⇒ ethene and acetylene*
- *Propane & Butane ⇒ 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.



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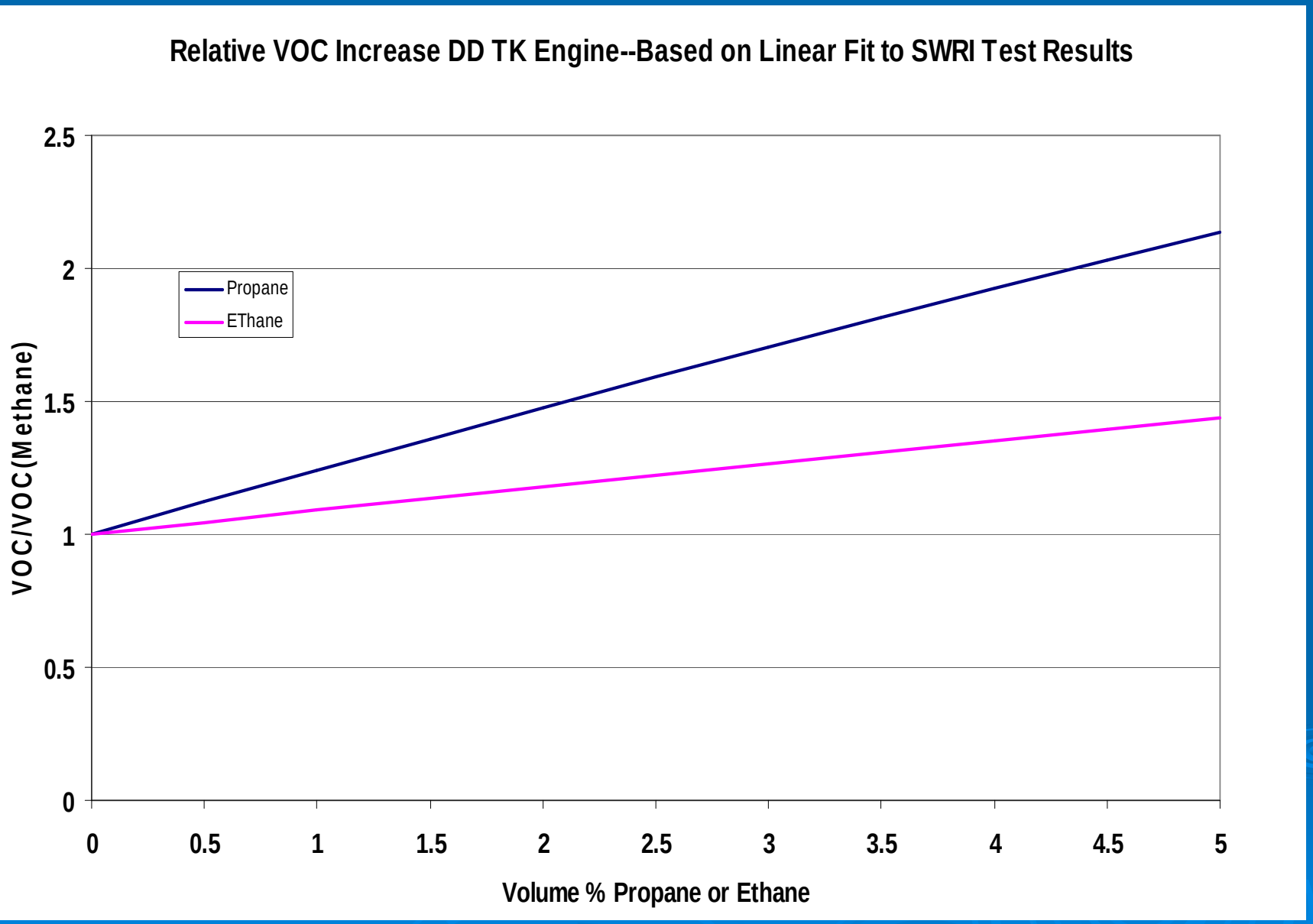
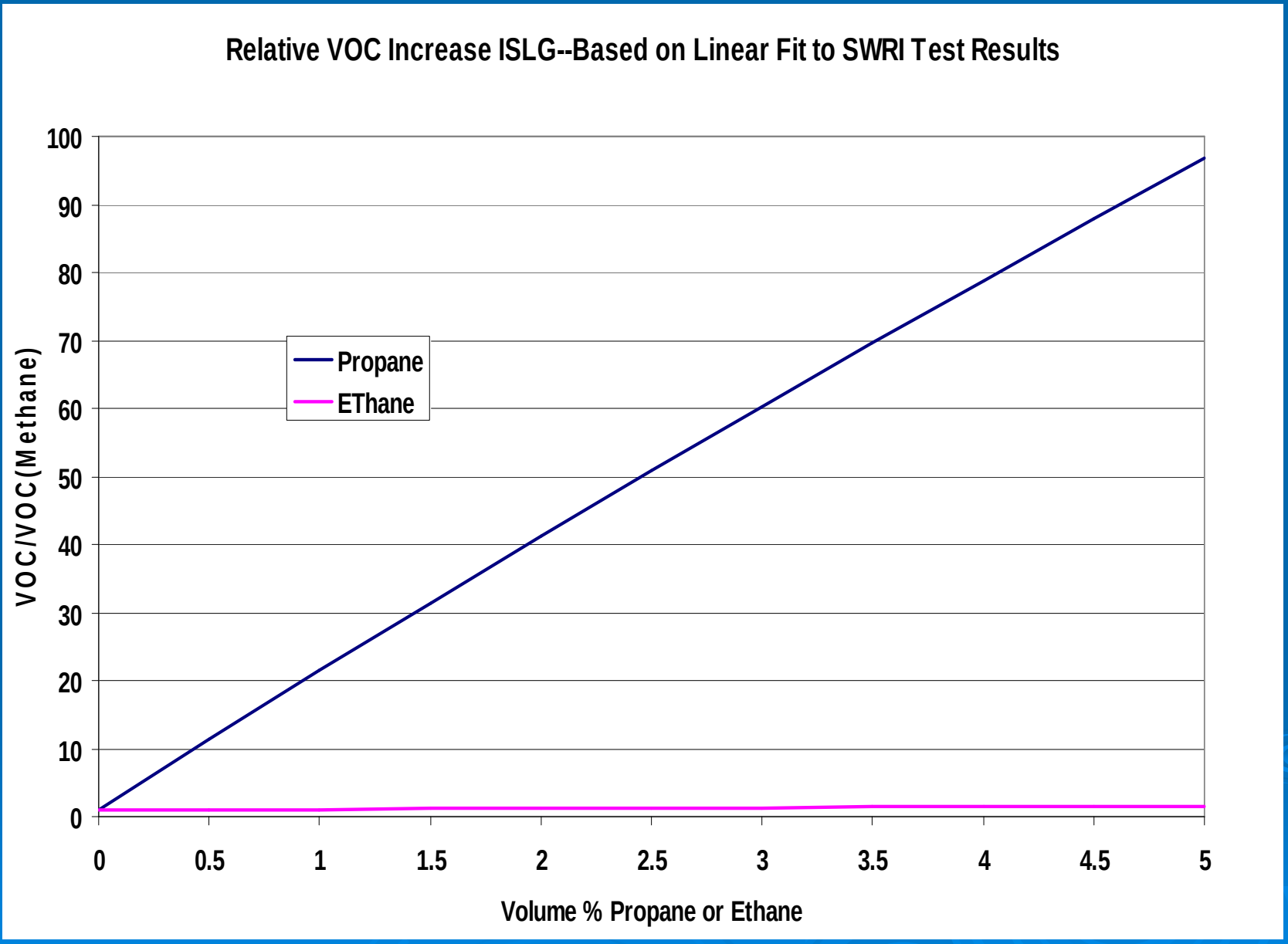


Based on fit of data from SwRI Heavy-Duty Natural Gas Engine Study, 2009.

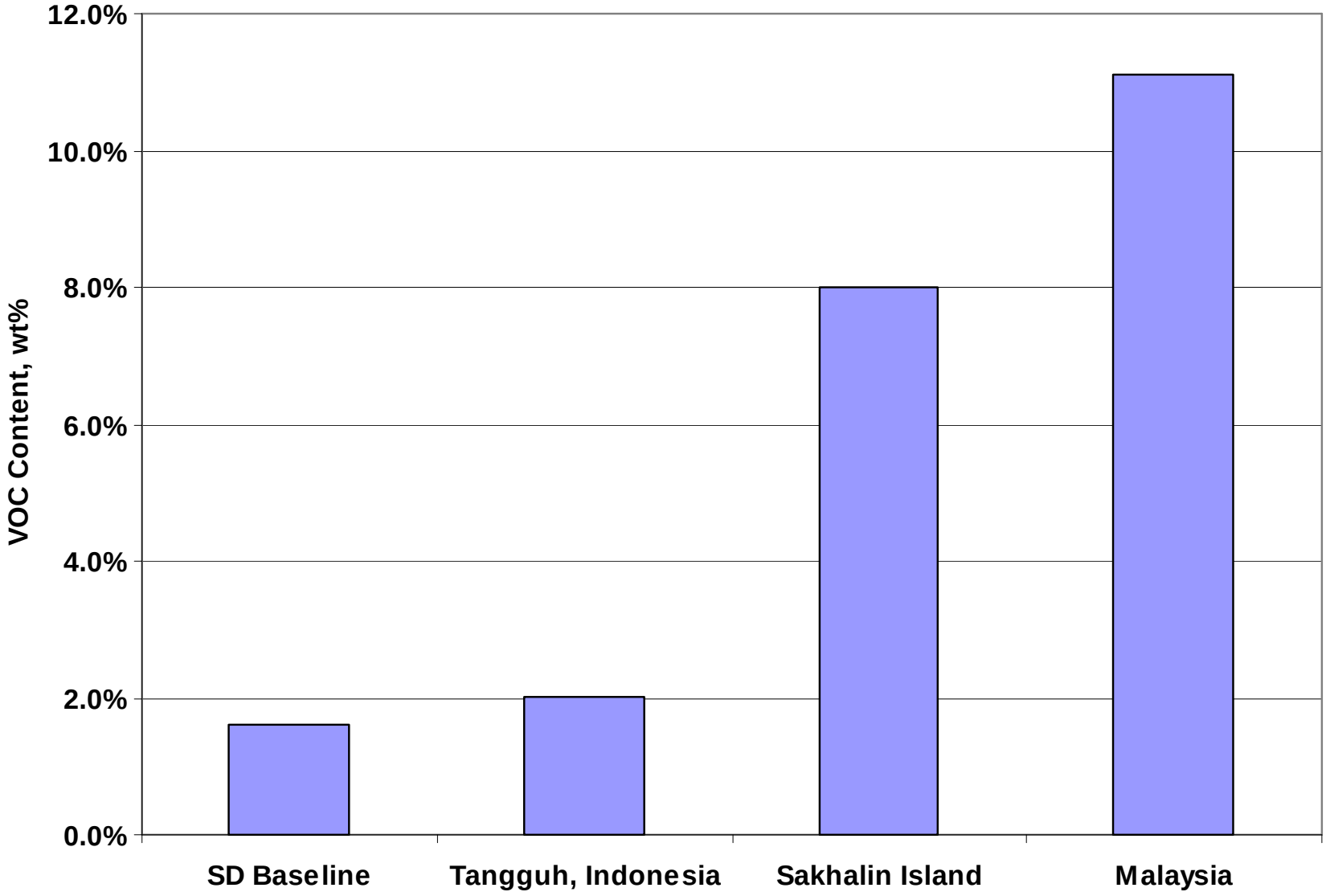


Plot of data from SwRI Heavy-Duty Natural Gas Engine Study, 2009.

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



Transmission and Distribution Emission Estimates

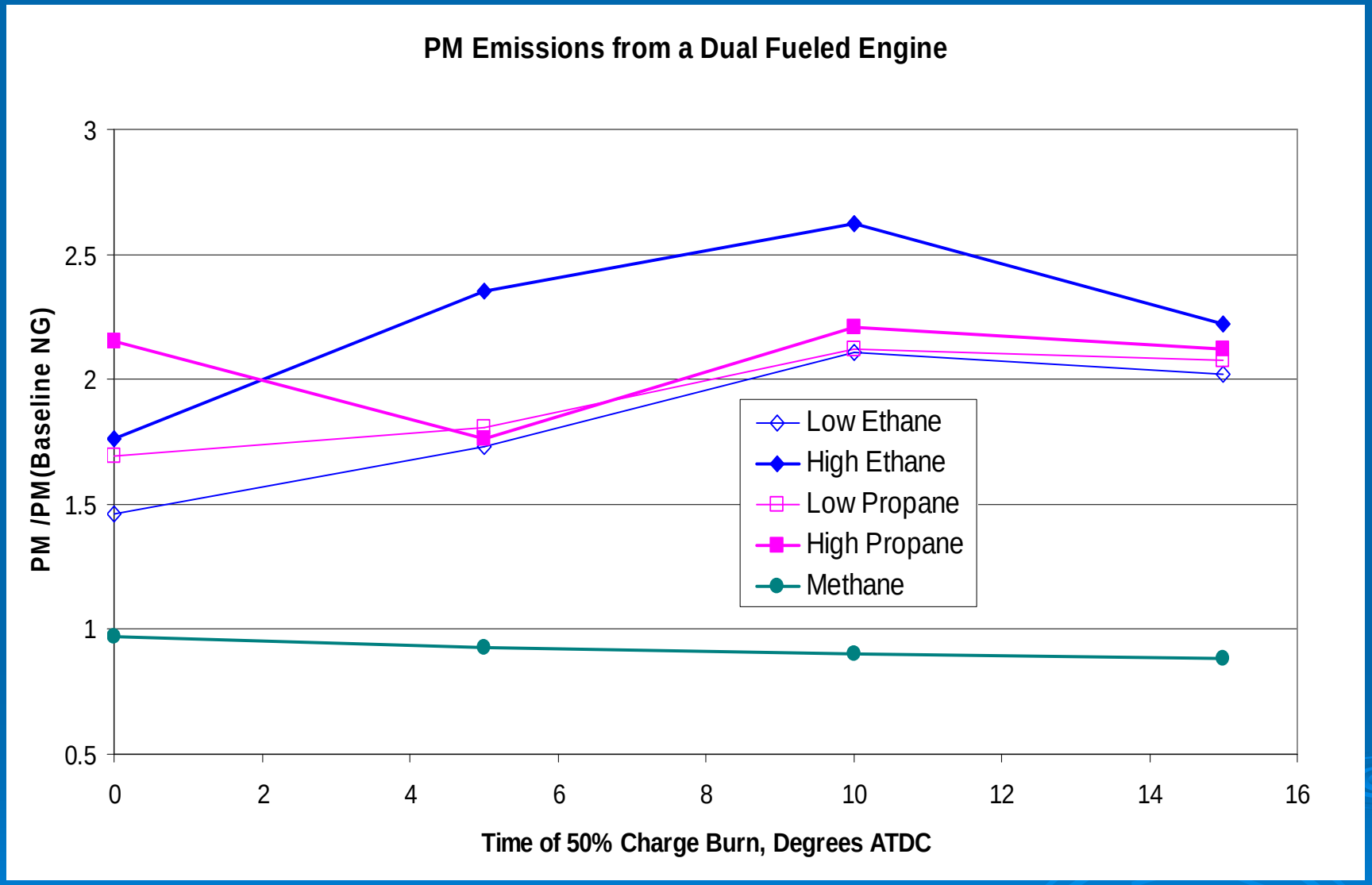
- Current estimate relies on AGA and INGAA emission factors ultimately based on data collected in the 1990s
- Updated emission factors may be useful in refining emission estimates

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*



Replotted from data in McTaggert-Cowan, et al., Fuel, 89, 752-759, 2010.

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*

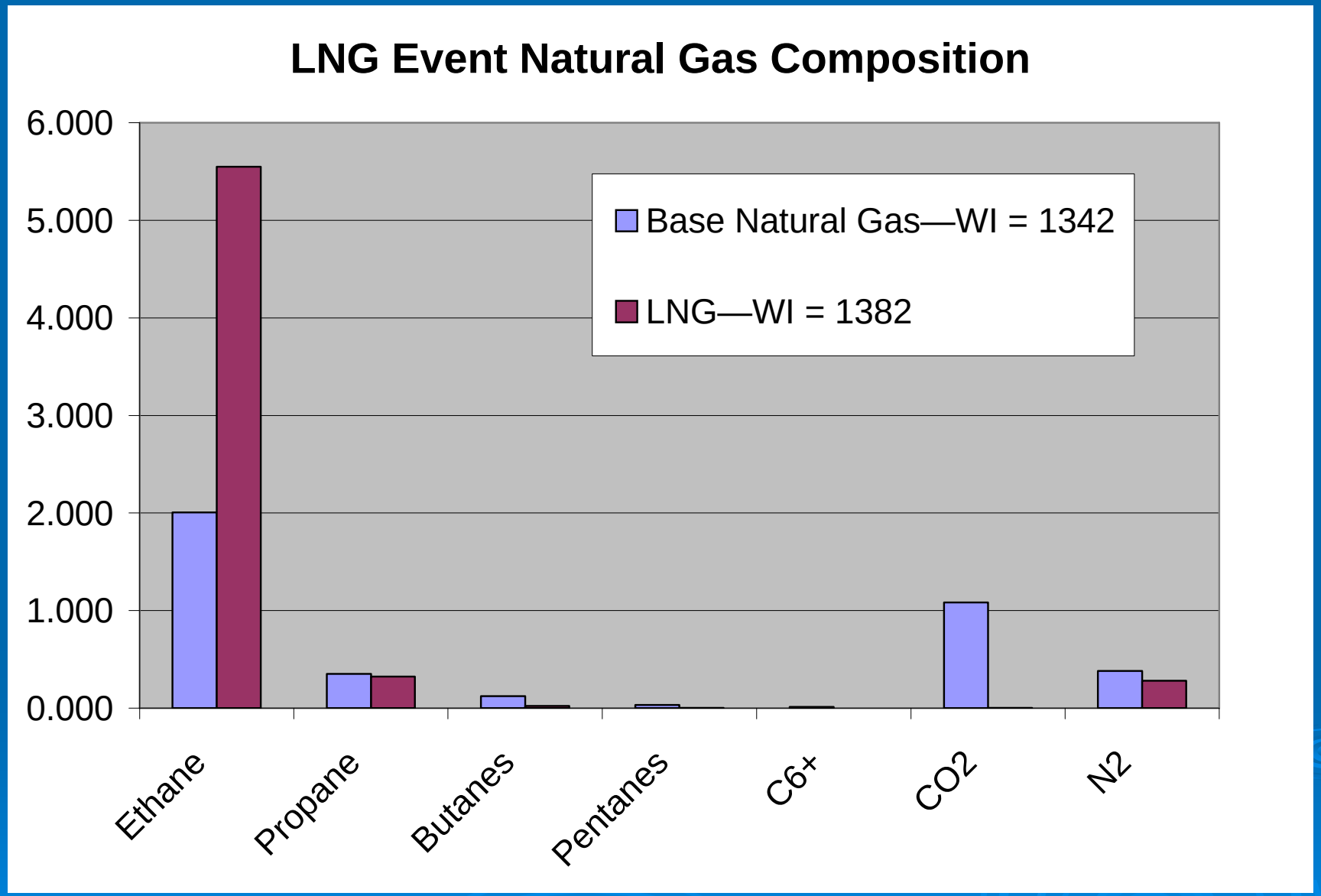
Testing Comments

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
6.000
5.000
4.000
3.000
2.000
1.000
0.000
Base Natural Gas—WI = 1342
LNG—WI = 1382
Ethane
Propane
Butanes
Pentanes
C6+
CO2
N2

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 exceedances of NOx limits*
  - **Lean burn engine—tuning resolved**
  - **Boiler—2 ppmv, but exceeded by 1 ppmv on base gas**

SWRI Engine Testing

Engine	Engine Type	Controls	Status When Procurred
Cummins ISL G	Rich-Burn	3-Way Catalyst	New
Cummins C Gas Plus	Lean-burn	Oxidation Catalyst	New
Cummins C Gas	Lean-burn	Oxidation Catalyst	New
Detroit Diesel TK	Lean-burn	None	Used
John Deere 6081H	Lean-burn	Oxidation Catalyst	Used—about 15% Life

Natural Gas Vehicle Engines In-Use Emission Increase

- In use emission increases need to be considered when using test results on new engines to estimate actual emission increases

Engine	Emissions Relative to New Emissions @ 435,000 miles	
	NOx	NMHCs
HHD Lean-Burn	1.07	1.20
LHD Rich-Burn	5.58	5.43

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

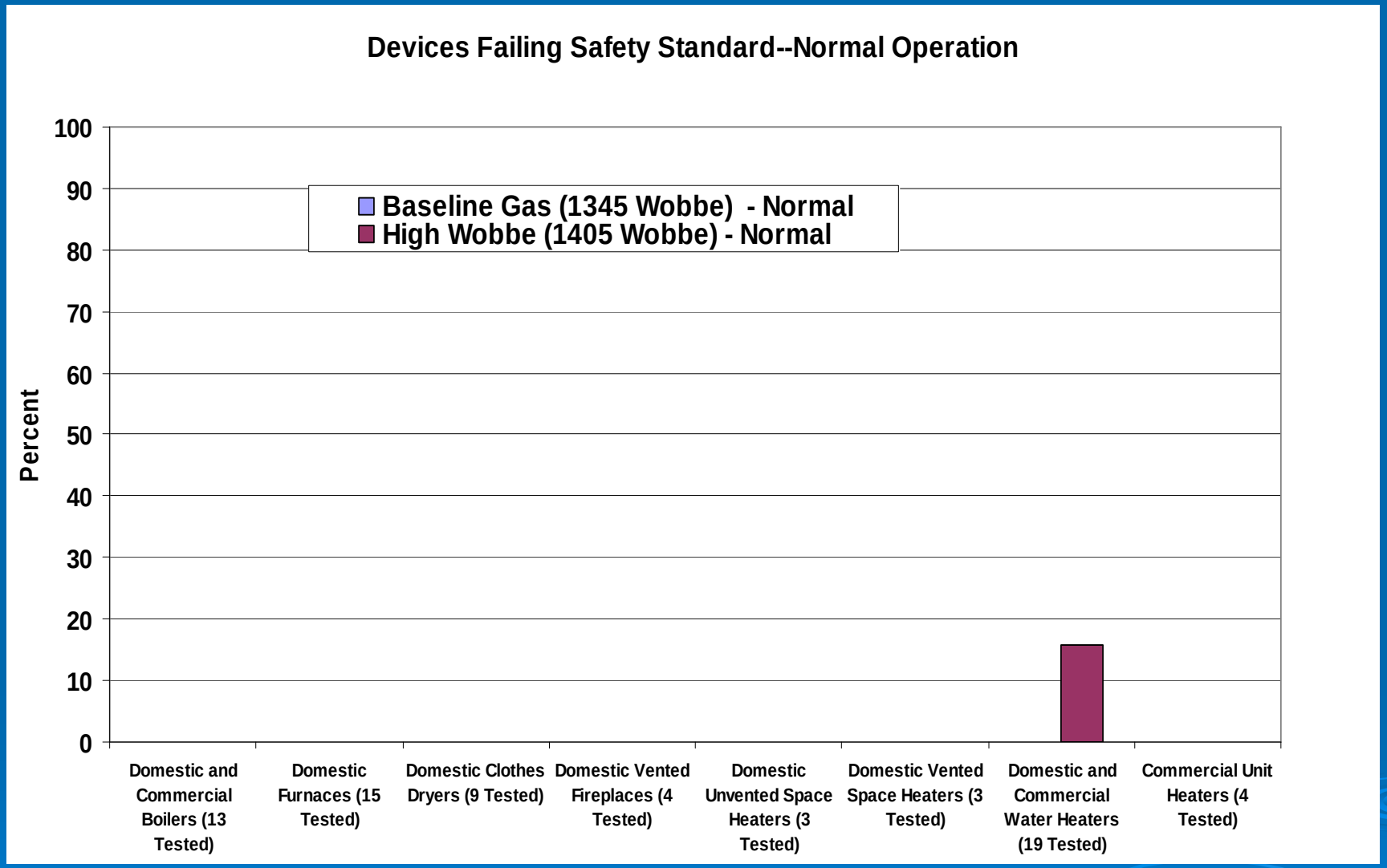
- *AHRI— an industry organization for appliance manufacturers—tested a large number (about 80) currently manufactured appliances*
- *Measured CO levels for WI increase slightly higher than generally expected increase from LNG in CA (4.5% vs. 4%)*
- *Used industry standard safety test procedures*

AHRI Testing

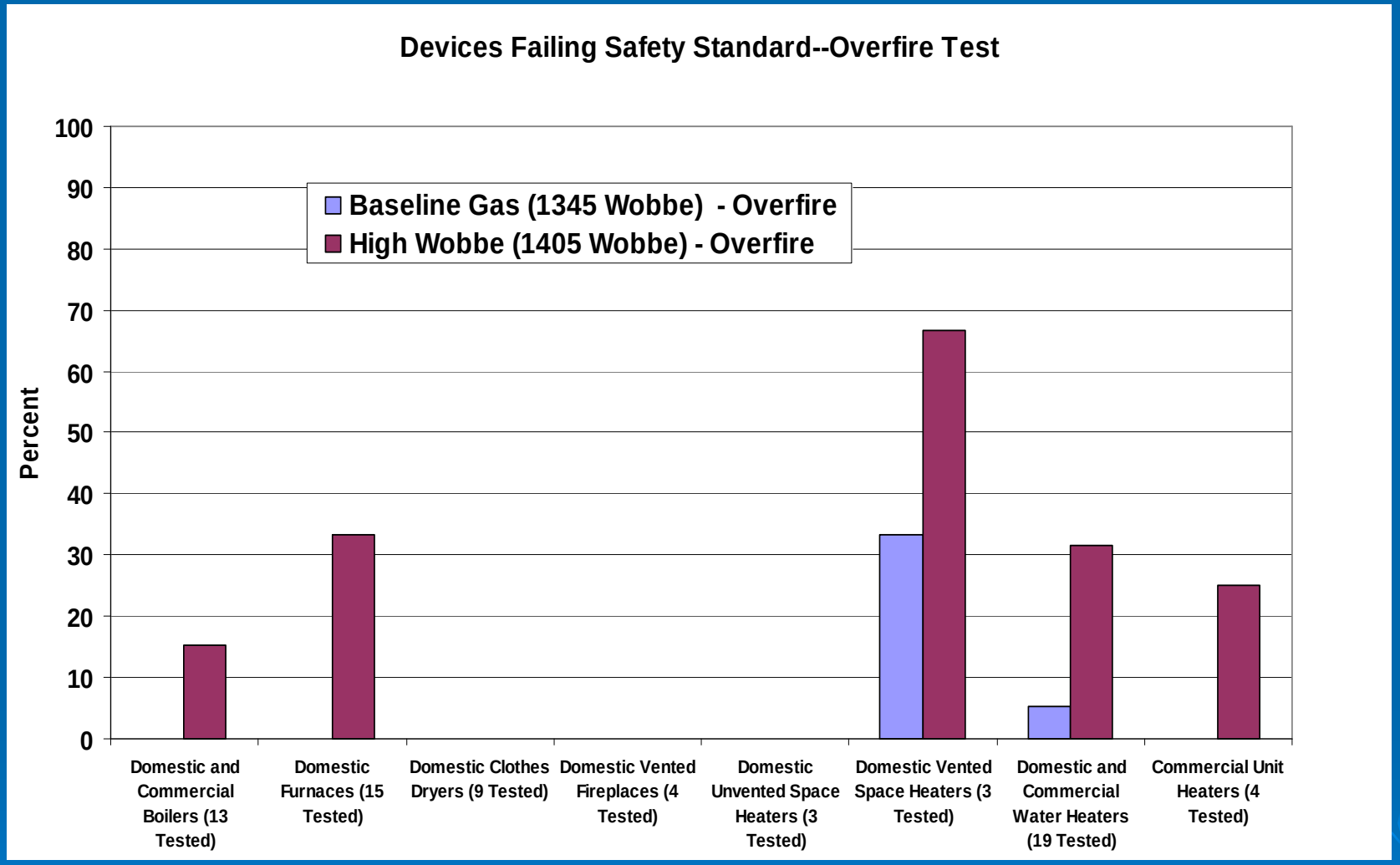
- *Standard appliance test procedures challenges appliance with overfiring*
- *Overfiring test provides a margin of safety to account for:*
  - Gas quality variation, ambient condition changes, manufacturing variations, poor maintenance, etc.

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*



Data taken from Williams, T.A., "MANUFACTURER TESTING OF U. S. APPLIANCES ON LNG COMPOSITIONS AND Other Gases, AGA, October, 2009. Based on unpublished data unpublished AHRI Program "Gas Interchangeability Testing Report, prepared by Gas Consultants, Inc., May 2009.



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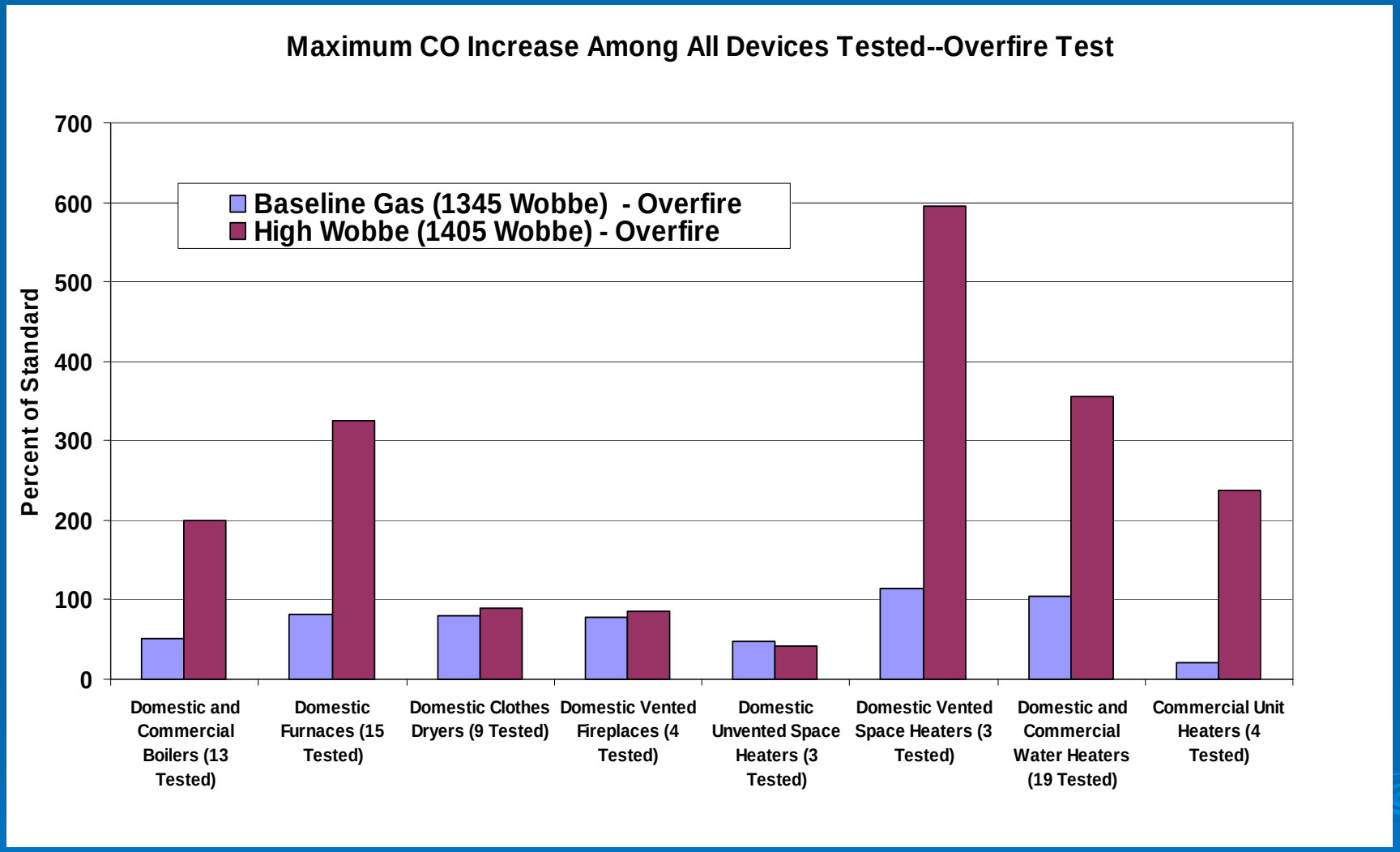

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Uncertaintities

- *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

Category	NOx, tpd	VOC, tpd
Gas Transmission & Distribution	0	>5
District Inventoried Combustion Sources	0.12	0.27
Residential Appliances	0.07	0.05
Unpermitted Commercial & Industrial Equipment	0.35	0.03
Transit & School Busses, 2010	0.13	0.06
Transit & School Busses, Future	≈ 0	0.14
TOTAL, 2010	0.67	5.41

Peak Summer Day Emission Increase

Category	NOx, tpd	VOC, tpd
Gas Transmission & Distribution	0	>5
District Inventoried Combustion Sources	0.17	0.50
Residential Appliances	0.03	0.03
Unpermitted Commercial & Industrial Equipment	0.33	0.02
Transit & School Busses, 2010	0.15	0.07
Transit & School Busses, Future	≈ 0	0.16
TOTAL	0.68	5.62

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 soleley 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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