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COMPARISON OF UNREGULATED EMISSIONS FROM CNG BUSES WITH AND WITHOUT AFTER-TREATMENT TECHNOLOGIES

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CARB Vehicle Emissions Research

- Physiochemical and Toxicological Properties of Vehicle Emissions
  - **CNG Buses** and HDD Trucks (**2001, 2002)**
  - HDD Trucks with Retrofits (DOC, DPF and SCR) (2008)
  - **CNG Buses Compliant with 2010 Emissions Standards (2010)**
  - HDDT Truck Compliant with 2010 Emissions Standards (ongoing)
  - Light Duty Passenger Vehicle with Gasoline, CNG, E85, Diesel (ongoing)
- Particulate Measurement Programme (PMP)
- Light-Duty Gasoline Vehicle (LDGV) High-PM Emitters
- On-Road Vehicle Emissions Measurements with Remote Sensing Devices (RSD)
- On-Road Measurement of Light-Duty Gasoline and Heavy-Duty Diesel Vehicle Emissions

More detailed information from *http://www.arb.ca.gov/research/veh-emissions/veh-emissions.htm*

Comparison Of Unregulated Emissions From CNG Buses

- Lean-Burn
  - Spark ignition
  - Open/closed-loop combustion control
- Lean-Burn + Oxidation Catalyst (OxC)
  - Spark ignition
  - Closed-loop combustion control
  - Control HC and CO emissions by OxC
- Stoichiometric + Three-Way Catalyst (TWC)
  - Spark ignition
  - Closed-loop combustion control
  - Control NOx and HC emissions by TWC

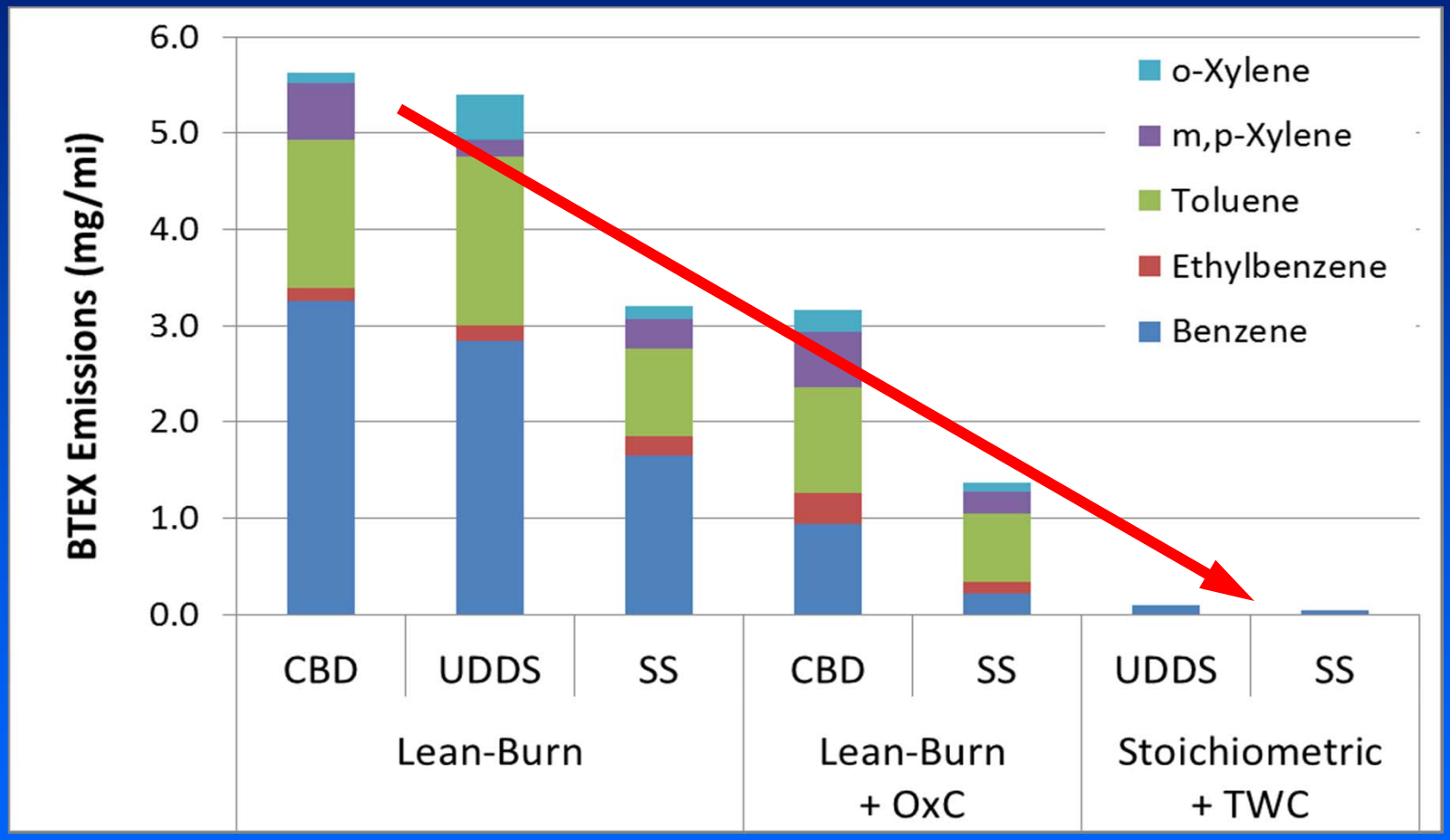
Test Facilities and Tested Buses

- ARB Heavy-Duty Emissions Testing Laboratory in Los Angeles, CA

- WVU Transportable Heavy-Duty Vehicle Emissions Laboratory Stationed at Stockton, CA

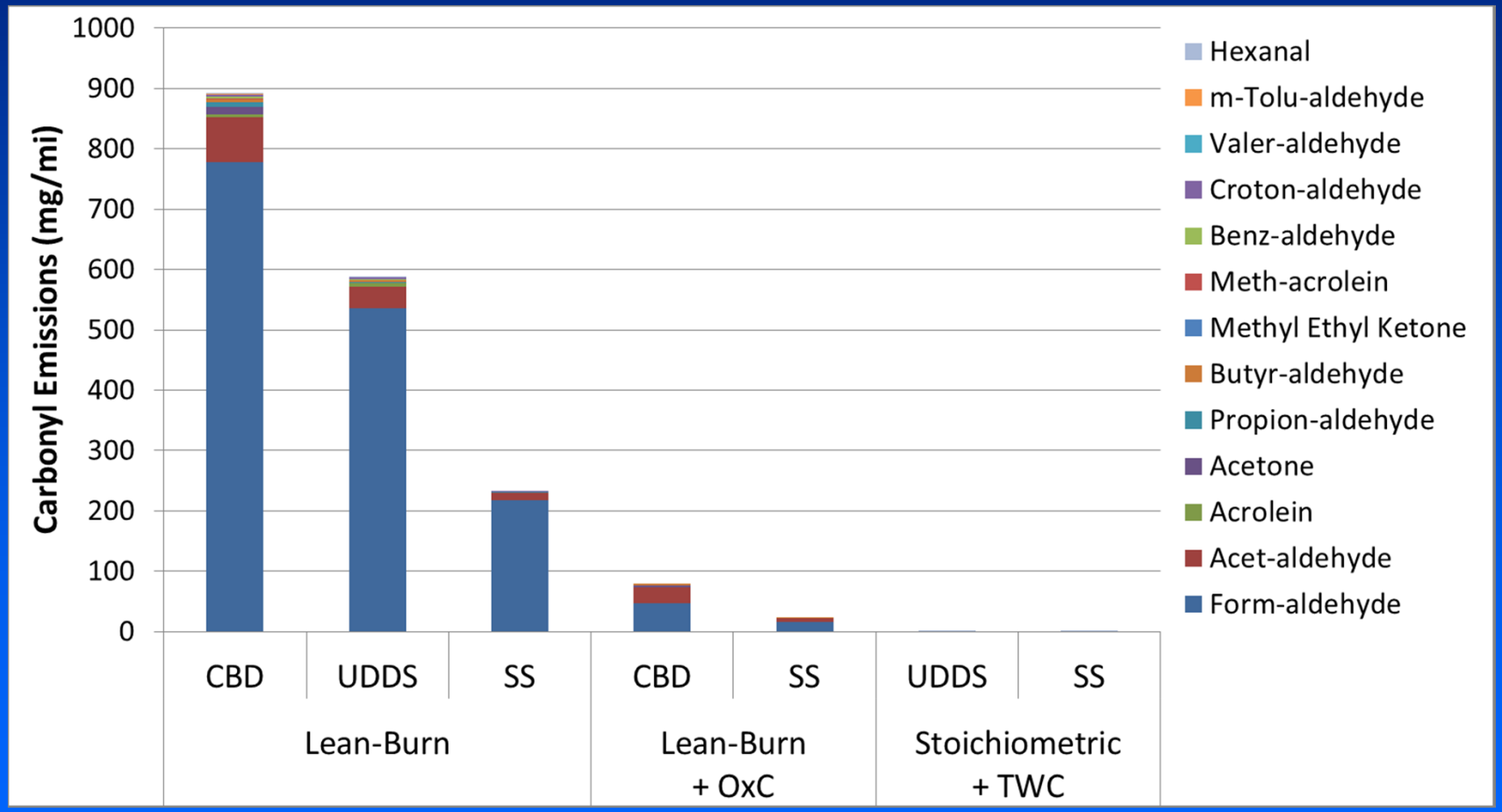
Engine + After-Treatment	Bus	Engine Maker	Engine Model	Engine Model Year	After-Treatment	Test Cycle	Test Date
Lean-Burn	CNG-1	Detroit Diesel	S50G	2000	N/A	CBD, UDDS, SS	March, 2001
	CNG-1	Detroit Diesel	S50G	2000	N/A		June, 2001
	CNG-1	Detroit Diesel	S50G	2000	N/A		
Lean-Burn + OxC	CNG-1	Detroit Diesel	S50G	2000	OxC (Retrofitted)	CBD, SS	May, 2002
	CNG-2	Cummins	C-Gas Plus	2001	OxC (OEM)		
Stoichiometric + TWC	CNG-3	Cummins	ISLG 280	2007	TWC	UDDS, SS	March, 2010
	CNG-4	Cummins	ISLG 280	2007	TWC		

BTEX Emissions

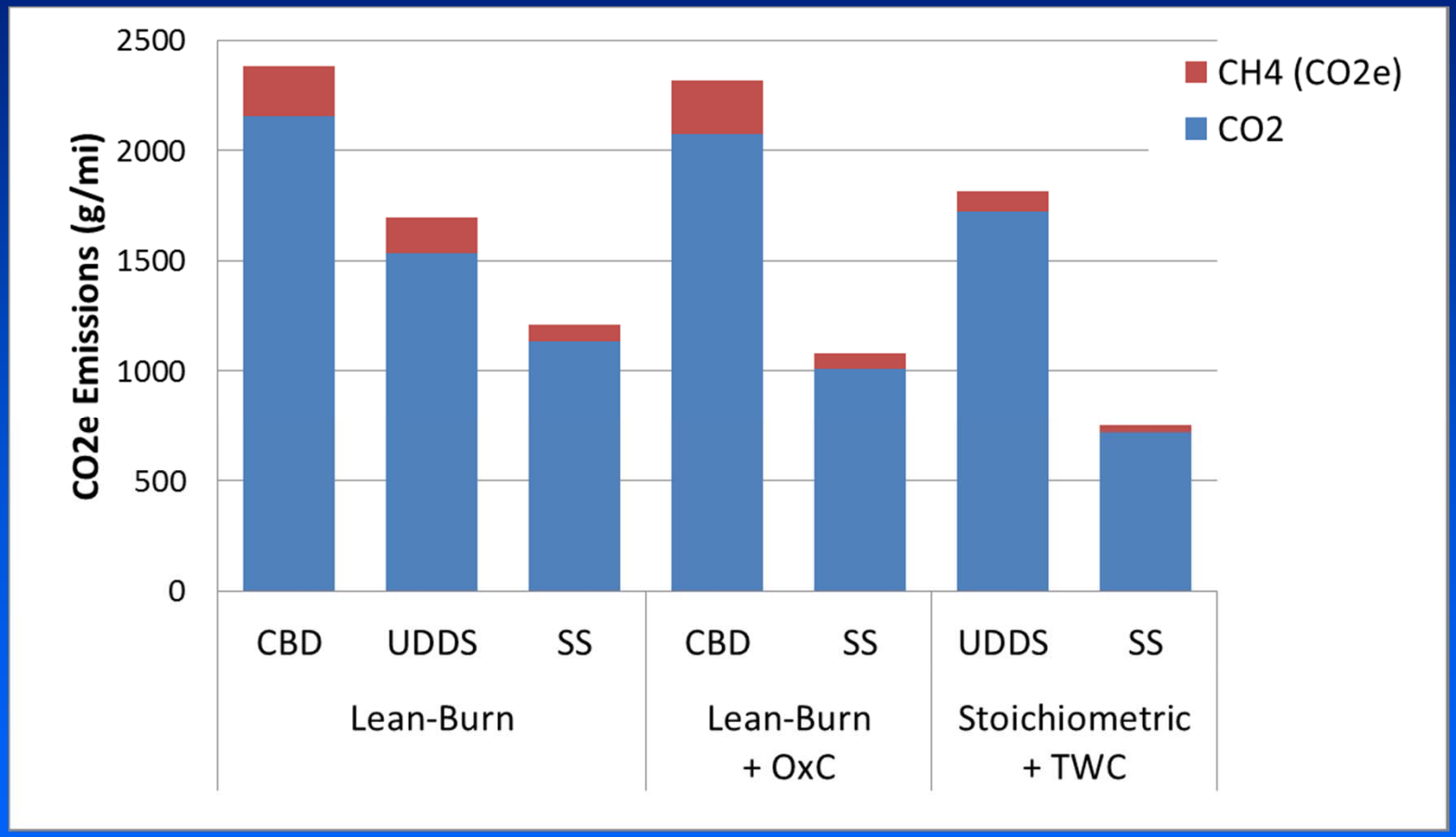


Note, Steady State (SS) cruise with 55mph for Lean-Burn and Lean-Burn+OxC, and 45mph for Stoichiometric+TWC

Carbonyl Emissions

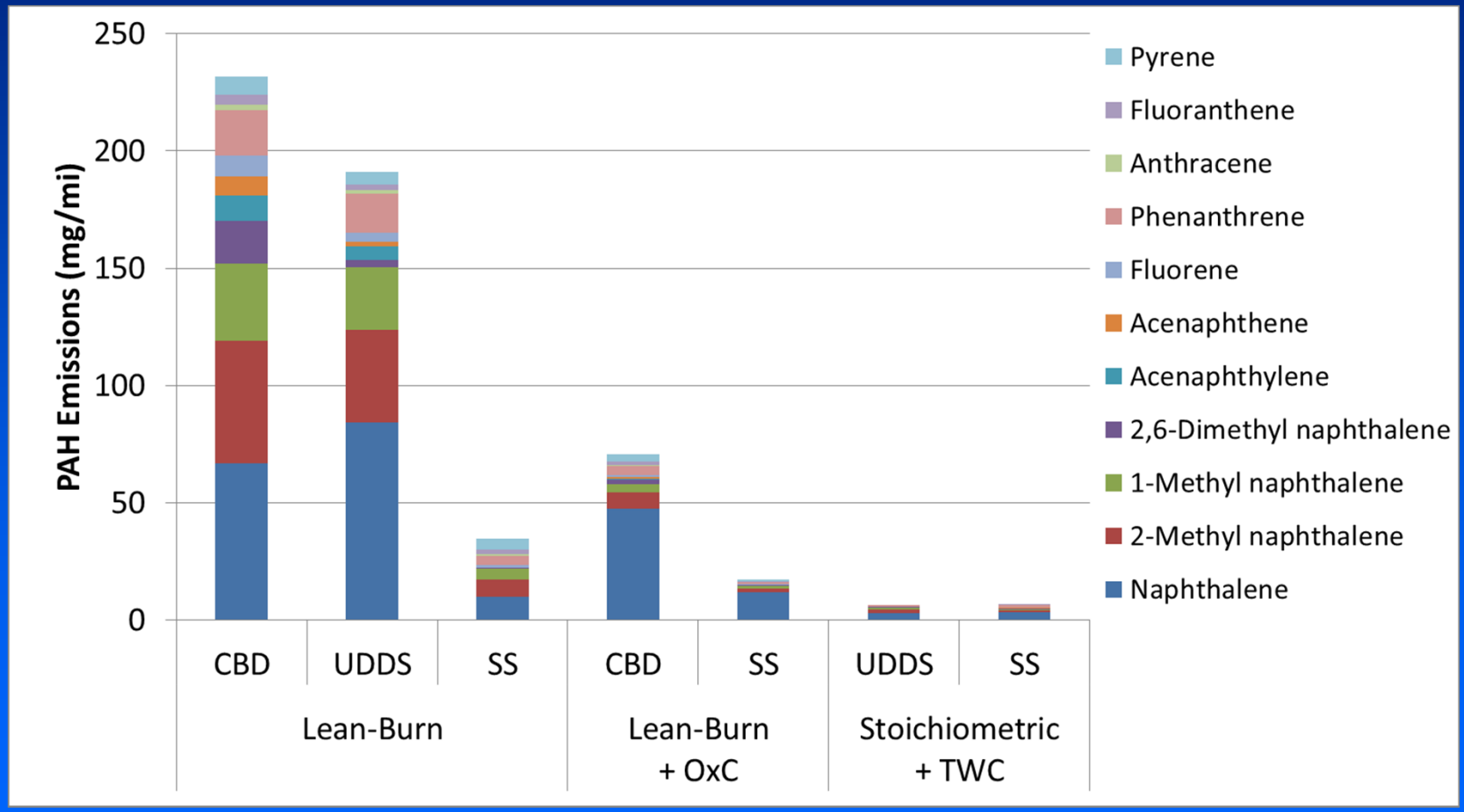


GHG Emissions

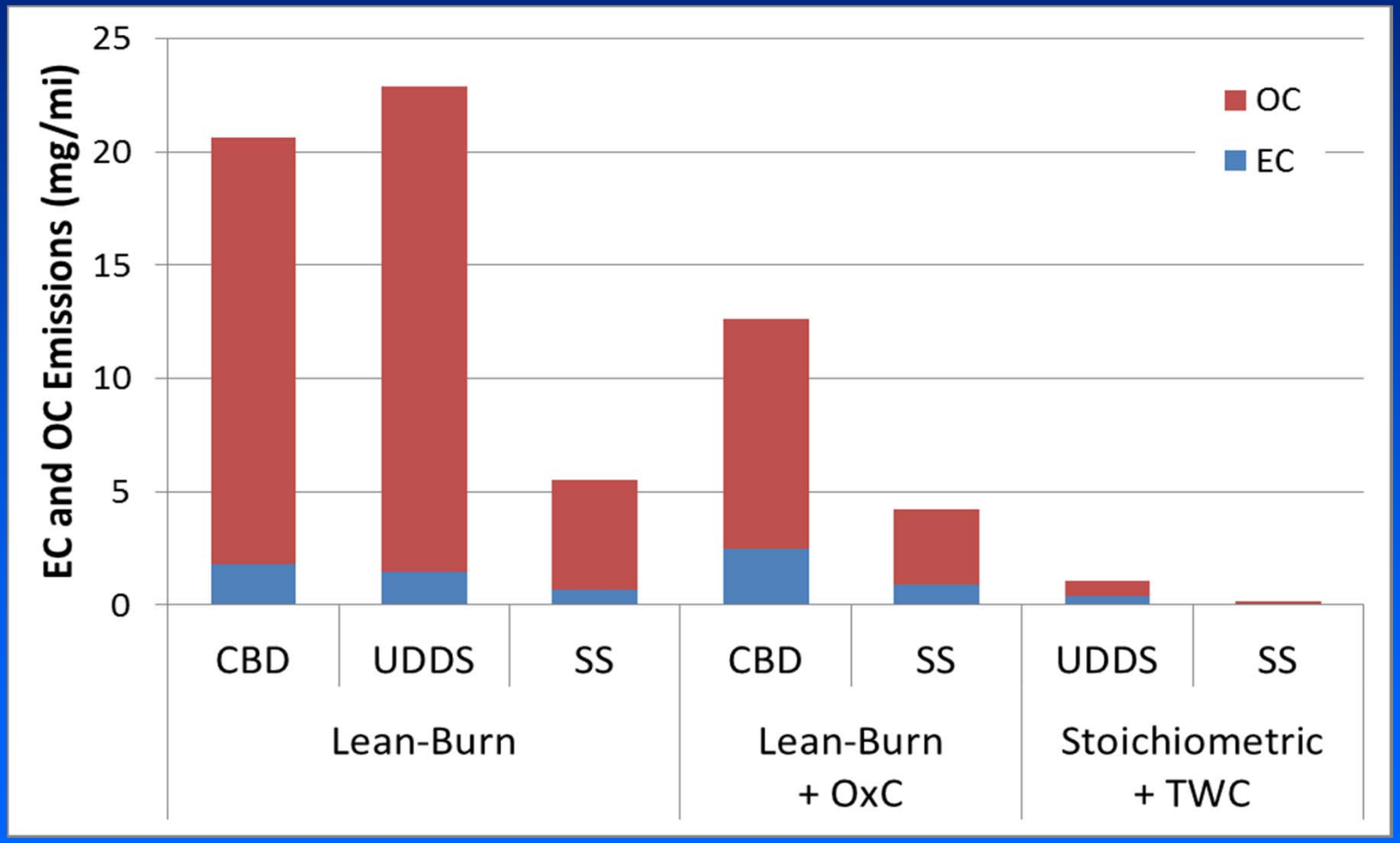


Note, GWP of 25 applied to CH4 emissions

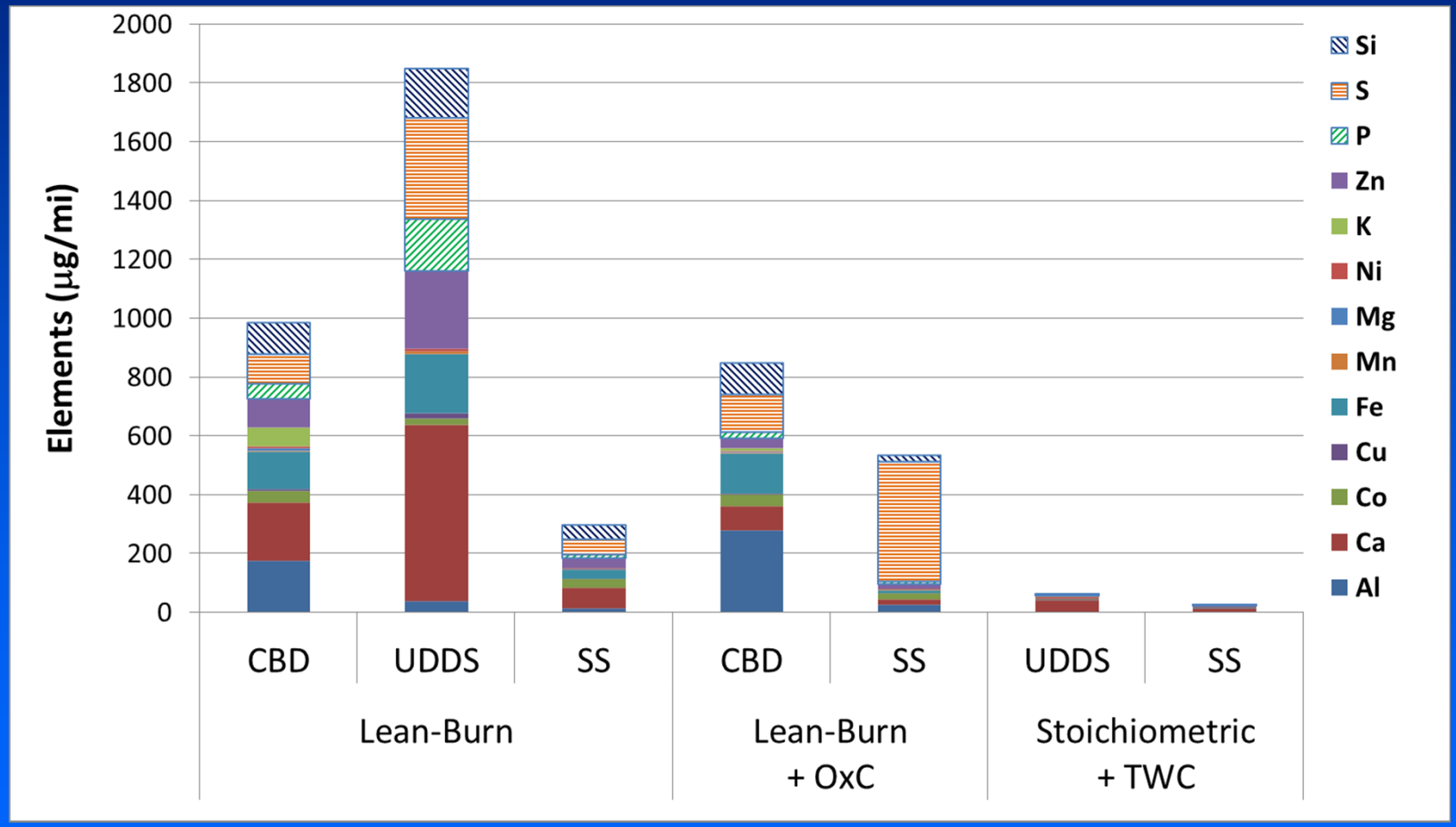
PAH Emissions



EC and OC Emissions



Elements


Elements (µg/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
CBD
UDDS
SS
CBD
SS
UDDS
SS
Lean-Burn
Lean-Burn + OxC
Stoichiometric + TWC
Si
S
P
Zn
K
Ni
Mg
Mn
Fe
Cu
Co
Ca
Al

Conclusions

- Stoichiometric combustion with three-way catalyst is the most efficient technology to reduce unregulated emissions from CNG buses
  - Many emission components were under the detection limits
- For in-use lean-burn CNG bus fleet, oxidation catalyst would be effective to reduce unregulated emissions, especially form-aldehyde

Related Publications

- Ayala, A., Kado, N., Okamoto, R., Holmen, B., Kuzmicky, P., Kobayashi, R. & Stiglitz, K. *Diesel and CNG heavy-duty transit bus emissions over multiple driving schedules: regulated pollutants and project overview.* SAE Technical Paper 2002-01-1722, **2002**
- Ayala, A., Gebel, M., Okamoto, R., Rieger, P., Kado, N., Cotter, C. & Verma, N. *Oxidation catalyst effect on CNG transit bus emissions.* SAE Technical Paper 2003-01-1900, **2003**
- Okamoto, R., Kado, N., Ayala, A. & Kobayashi, R. *Unregulated emissions from compressed natural gas (CNG) transit buses configured with and without oxidation catalyst.* Environ. Sci. Technol, **2006**, Vol. 40, pp. 332-341
- Kado, N., Okamoto, R., Kuzmicky, P., Kobayashi, R. & Ayala, A. *Emissions of toxic pollutants from compressed natural gas and low sulfur diesel-fueled heavy-duty transit buses tested over multiple driving cycles*. Environ. Sci. Technol, **2005**, Vol. 39, pp. 7638-7649
- Gautam, M., Thiruvengadam, A., Carder, D., Besch, M., Shade, B., Thompson, G. & Clark, N. *Testing of volatile and nonvolatile emissions from advanced technology natural gas vehicles*. West Virginia University. **2011**; available at *http://www.arb.ca.gov/research/apr/past/07-340.pdf*
- Seungju Yoon et al., (2012). Comparison of Gaseous and Particulate Emissions from CNG Buses with and without After-Treatment Technologies, Oxidation and Three-Way Catalysts. *in preparation*
- Seungju Yoon et al., (2012). Comparison of VOC, Carbonyls and PAH emissions from CNG Buses with and without After-Treatment Technologies, Oxidation and Three-Way Catalysts. *in preparation*
- Arvind Thiruvengadam et al., (2012). Issues on Three-Way Catalyst Applied to CNG Buses. *in preparation*