Ryan Kenny

Joint Workshop, December 3, 2015

Discussion Objectives

- Technical Progress
- Deployments
- Critical Barriers
- Opportunities to Boost Commercialization

CA's Major Environmental Goals

- LCFS: 10% GHG reduction by 2020; 30% by 2030;
- Federal NOx reduction attainment goals: 70% by 2023 / 80% by 2031;
- 40% GHG reduction by 2030;
- 50% petroleum reduction by 2030;
- 80% GHG reduction by 2050;
- Significant Reduction: Short-lived Climate Pollutants (black carbon and methane)

California Heavy-Duty Truck Statistics

4 – % of Trucks on CA Roads

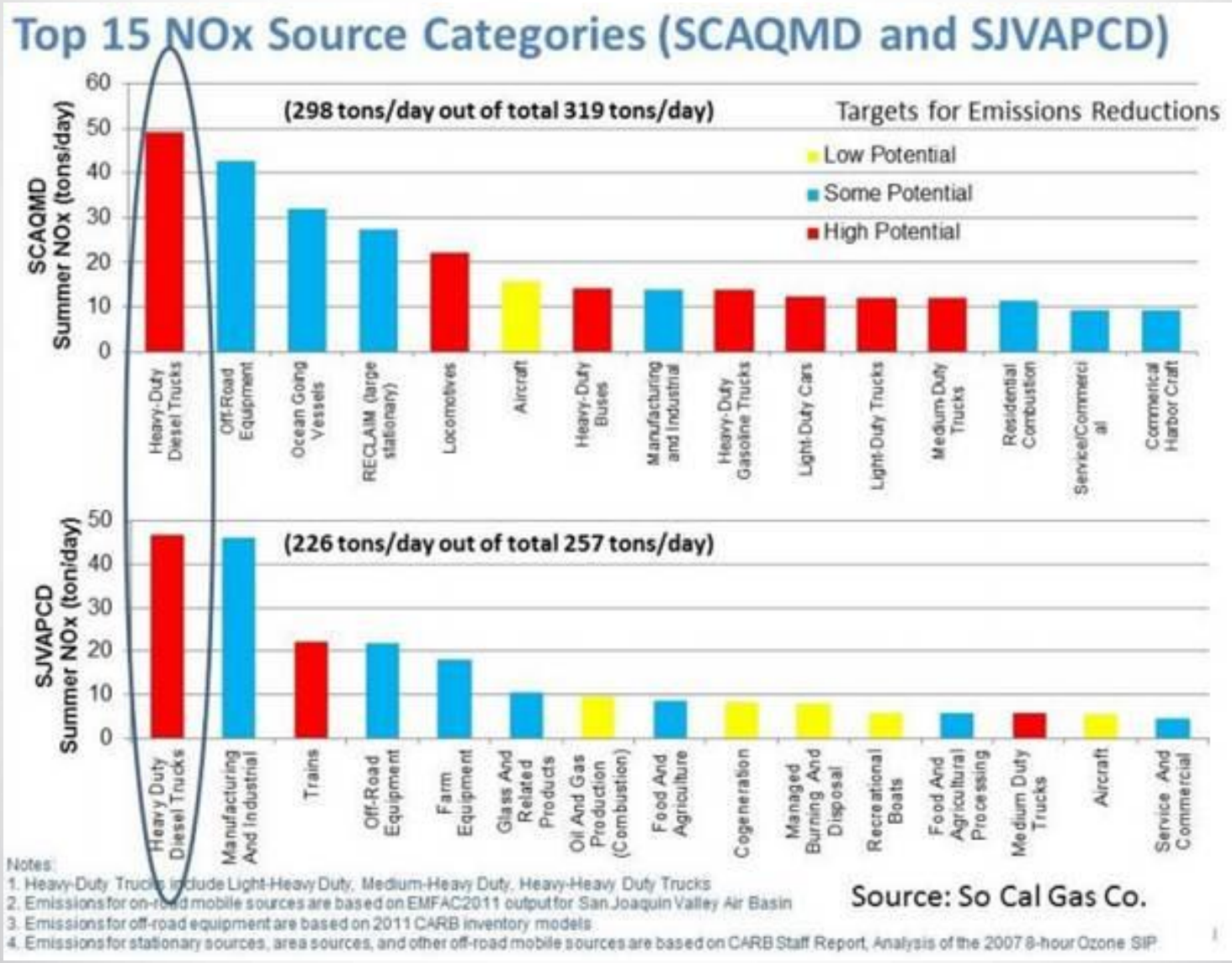
57 – % of NOx from CA highway vehicles

49 – % of PM from CA highway vehicles

21 – % of Statewide GHG emissions

1 – NOx Emission Source Rank in South Coast and San Joaquin Valley

Heavy-Duty Class 7-8 Trucks Matter for NOx



How Will Goals Be Met?

- Battery Electric Trucks?
- Fuel Cell Trucks?
- Hybrid Trucks?
- Low-NOx Trucks?

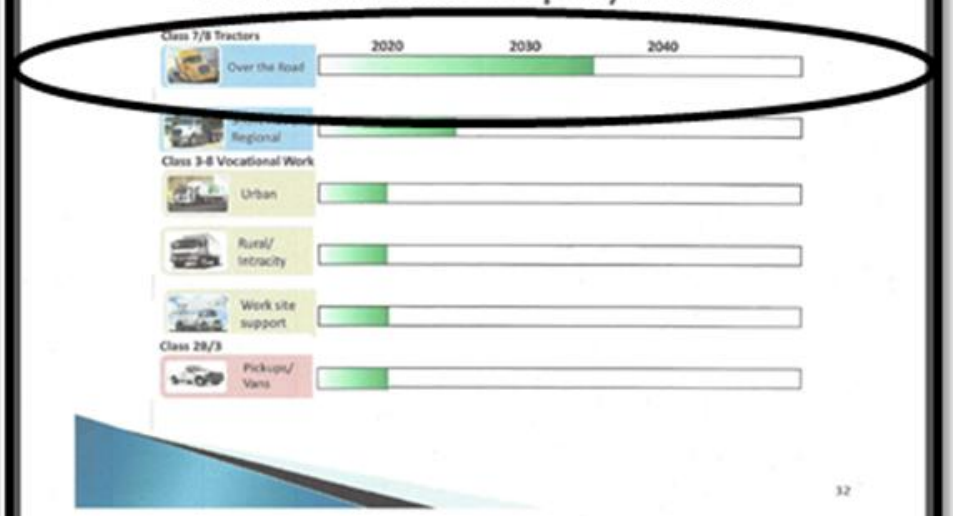
ARB Hybrid Tech Assessment - 2035

Heavy-Duty Hybrid Vehicles
Technology Assessment

September 2, 2014
Sacramento, California

California Environmental Protection Agency
Air Resources Board

Advanced Tech MD/HD Applications
Potential Pilot Deployments



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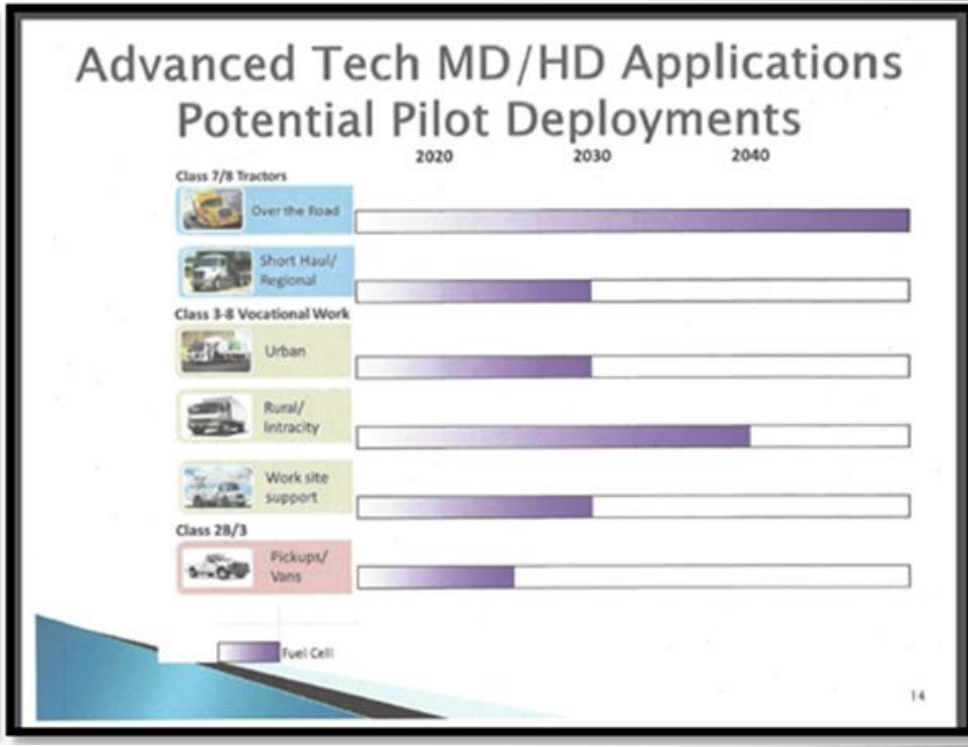
ARB Fuel Cell Tech Assessment - 2050



NEAR ZERO ENGINE WITH RNG

California Environmental Protection Agency
Air Resources Board

CUMMINS INC.

EXECUTIVE ORDER A-021-0630
New On-Road Heavy-Duty Engines
Page 1 of 2 Pages

Pursuant to the authority vested in the Air Resources Board by Health and Safety Code Division 26, Part 5, Chapter 2; and pursuant to the authority vested in the undersigned by Health and Safety Code Sections 39515 and 39516 and Executive Order G-14-012;

IT IS ORDERED AND RESOLVED: The engine and emission control systems produced by the manufacturer are certified as described below for use in on-road motor vehicles with a manufacturer's GVWR over 14,000 pounds. Production engines shall be in all material respects the same as those for which certification is granted.

MODEL YEAR	ENGINE FAMILY	ENGINE SIZES (L)	FUEL TYPE [1]	STANDARDS & TEST PROCEDURE	INTENDED SERVICE CLASS [2]	ECS & SPECIAL FEATURES [3]	DIAGNOSTIC [6]
2016	GCEXH0540LBJ	8.9	CNG/LNG	Diesel	MHDD	TBI, TC, CAC, ECM, EGR, TWC, HO2S	EMD+

PRIMARY ENGINE'S IDLE EMISSIONS CONTROL [5]	ADDITIONAL IDLE EMISSIONS CONTROL [5]
30g	N/A

ENGINE (L)	ENGINE MODELS / CODES (rated power, in hp)
8.9	ISL G 320 / 4835;FR95347 (320), ISL G 300 / 4835;FR95350 (300), ISL G 280 / 4835;FR95353 (280)
8.9	ISL G 260 / 4835;FR95356 (260), ISL G 250 / 4835;FR95358 (258)

* =not applicable; GVWR=gross vehicle weight rating; 13 CCR xyz=Title 13, California Code of Regulations, Section xyz; 40 CFR 86.abc=Title 40, Code of Federal Regulations, Section 86.abc; L=liter; hp=horsepower; kw=kilowatt; hr=hour;

1 CNG/LNG=compressed/liquefied natural gas; LPG=liquefied petroleum gas; E85=85% ethanol fue; MF=multi fuel a.k.a. BF=bi fuel; DF=dual fuel; FF=flexible fuel;

2 L/M/H HDD=light/medium/heavy heavy-duty diesel; UB=urban bus; HDO=heavy duty Otto;

3 ECS=emission control system; TWC/OC=three-way/oxidizing catalyst; NAC=NOx adsorption catalyst; SCR-U / SCR-N=selective catalytic reduction – urea / – ammonia; WU (prefix) =warm-up catalyst; DPF=diesel particulate filter; PTOX=periodic trap oxidizer; HO2S/O2S=heated/oxygen sensor; HAFS/AFS=heated/air-fuel-ratio sensor (a.k.a., universal or linear oxygen sensor); TBI=throttle body fuel injection; SFI/MFI=sequential/multi port fuel injection; DGI=direct gasoline injection; GCARB=gaseous carburetor; IDI/DDI=indirect/direct diesel injection; TC/SC=turbo/super charger; CAC=charge air cooler; EGR / EGR-C=exhaust gas recirculation / cooled EGR; PAIR/AIR=pulsed/secondary air injection; SPL=smoke puff limiter; ECM/PCM=engine/powertrain control module; EM=engine modification; 2 (prefix)=parallel; (2) (suffix)=in series;

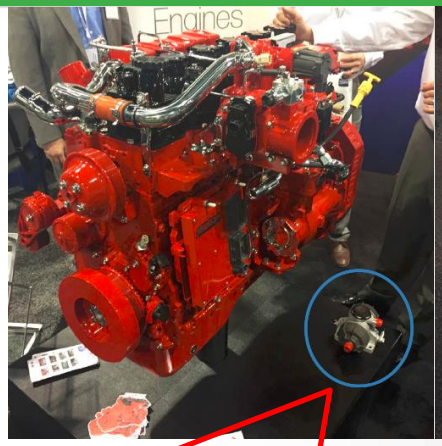
5 ESS=engine shutdown system (per 13 CCR 1956.8(a)(5)(A)(1)); 30g=30 g/hr NOx (per 13 CCR 1956.8(a)(6)(C)); APS =internal combustion auxiliary power system; ALT=alternative method (per 13 CCR 1956.8(a)(6)(D); Exempt=exempted per 13 CCR 1956.8(a)(5)(B) or for CNG/LNG fuel systems; N/A=not applicable (e.g., Otto engines and vehicles);

6 EMD=engine manufacturer diagnostic system (13 CCR 1971); OBD=on-board diagnostic system (13 CCR 1971.1);

Following are: 1) the FTP exhaust emission standards, or family emission limit(s) as applicable, under 13 CCR 1956.8; 2) the SET and NTE limits under the applicable California exhaust emission standards and test procedures for heavy-duty diesel engines and vehicles (Test Procedures); and 3) the corresponding certification levels, for this engine family. "Diesel" CO, SET and NTE certification compliance may have been demonstrated by the manufacturer as provided under the applicable Test Procedures in lieu of testing. (For flexible- and dual-fueled engines, the CERT values in brackets [ ] are those when tested on conventional test fuel. For multi-fueled engines, the STD and CERT values for default operation permitted in 13 CCR 1956.8 are in parentheses.). [4]

in g/bhp-hr	NMHC		NOx		NMHC+NOx		CO		PM		HCHO	
	FTP	SET	FTP	SET	FTP	SET	FTP	SET	FTP	SET	FTP	SET
STD	0.14	0.14	0.02	0.02	*	*	15.5	15.5	0.01	0.01	*	*
CERT	0.01	0.000	0.01	0.004	*	*	1.5	0.3	0.001	0.000	*	*
NTE	0.21		0.03		*		19.4		0.02		*	

4 g/bhp-hr=grams per brake horsepower-hour; FTP=Federal Test Procedure; SET= Supplemental emissions testing; NTE=Not-to-Exceed; STD=standard or emission test cap; FEL=family emission limit; CERT=certification level; NMHC/HC=non-methane/hydrocarbon; NOx=oxides of nitrogen; CO=carbon monoxide; PM=particulate matter; HCHO=formaldehyde



Closed Crankcase Reduces 70+% of Methane Emissions

90+% NOx reduction is power plant equivalent in emissions.

RNG blends can provide GHG benefits of up to -34% CI value.

ARB Says Low-NOx Most Feasible to Solve

"Based on ARB Staff's technology assessment, the most viable approach to meeting the 2031 and 2030 goals is low-NOx trucks" powered by a minimum of a 55% renewable fuel blend.

"…approximately 400K internal combustion trucks with NOx emissions 90 percent cleaner than today's standards" are needed

"ARB will develop a low-NOx standard in California, and petition U.S. EPA to establish new federal emission standards for heavy-duty engines.

0.02 NOx HD NAT GAS ENGINE LINE

NEAR ZERO EMISSIONS

- 0.02 g/bhp-hr NOx
- Same as a battery electric truck plugged into a brand new modern combined cycle natural gas power plant (i.e. “power plant equivalent”)

ISL G (9L)

ISB (6.7L)

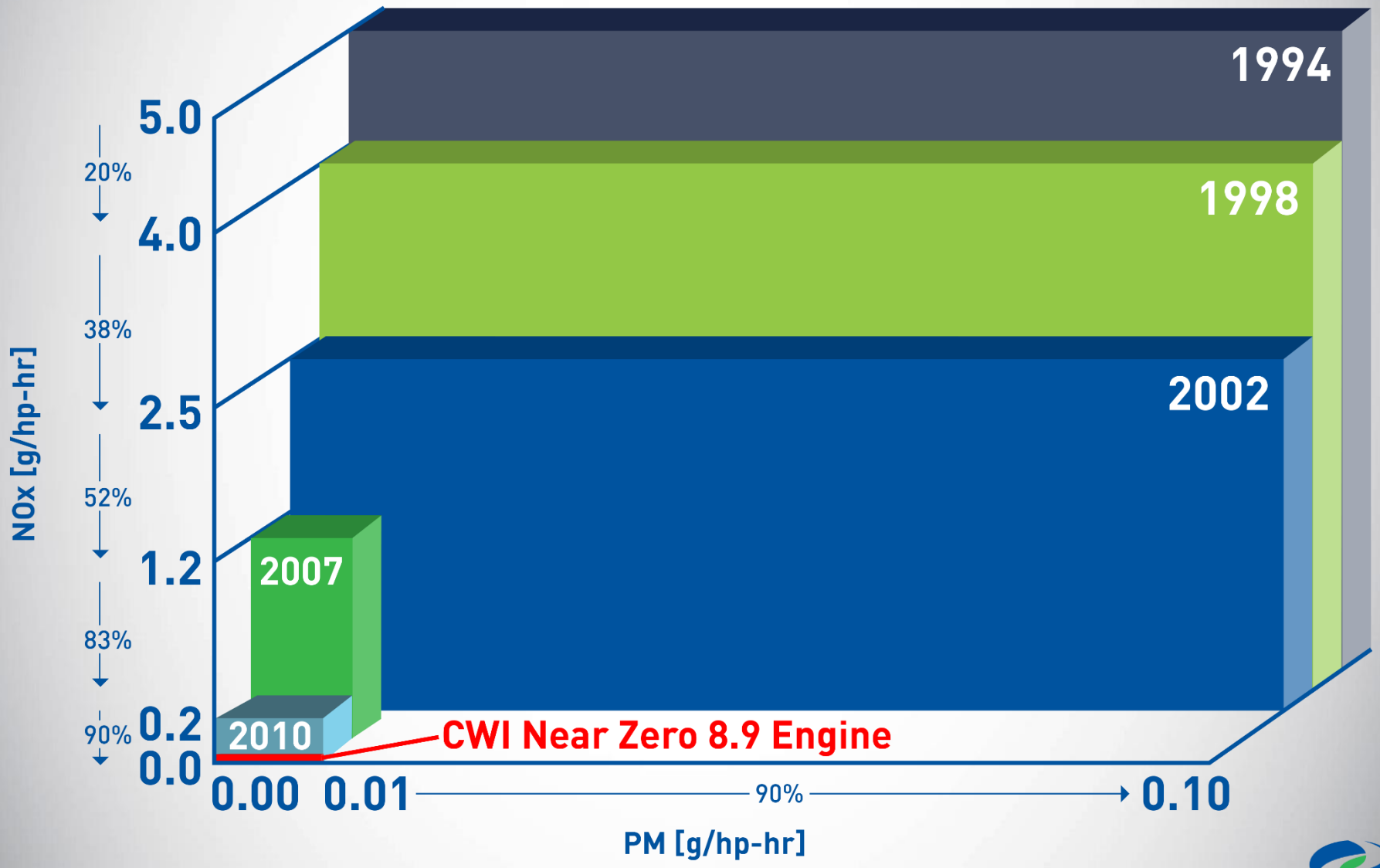
ISX (12L)

2015----------2016----------2017----------2018

CW.02 NOx Engine

- Closed crankcase lowers methane emissions by 70+% from today;
- 90% reduction in NOx compared to current diesel engines;
- Power plant equivalent;
- Immediate relief to regions, especially disadvantaged communities, struggling to reduce GHG emissions and ozone from transportation;
- Renewable natural gas blends + engines will further drive down GHG;
- Most technically feasible way to reduce levels of ozone, particulate matter, carbon, and petroleum fuels.

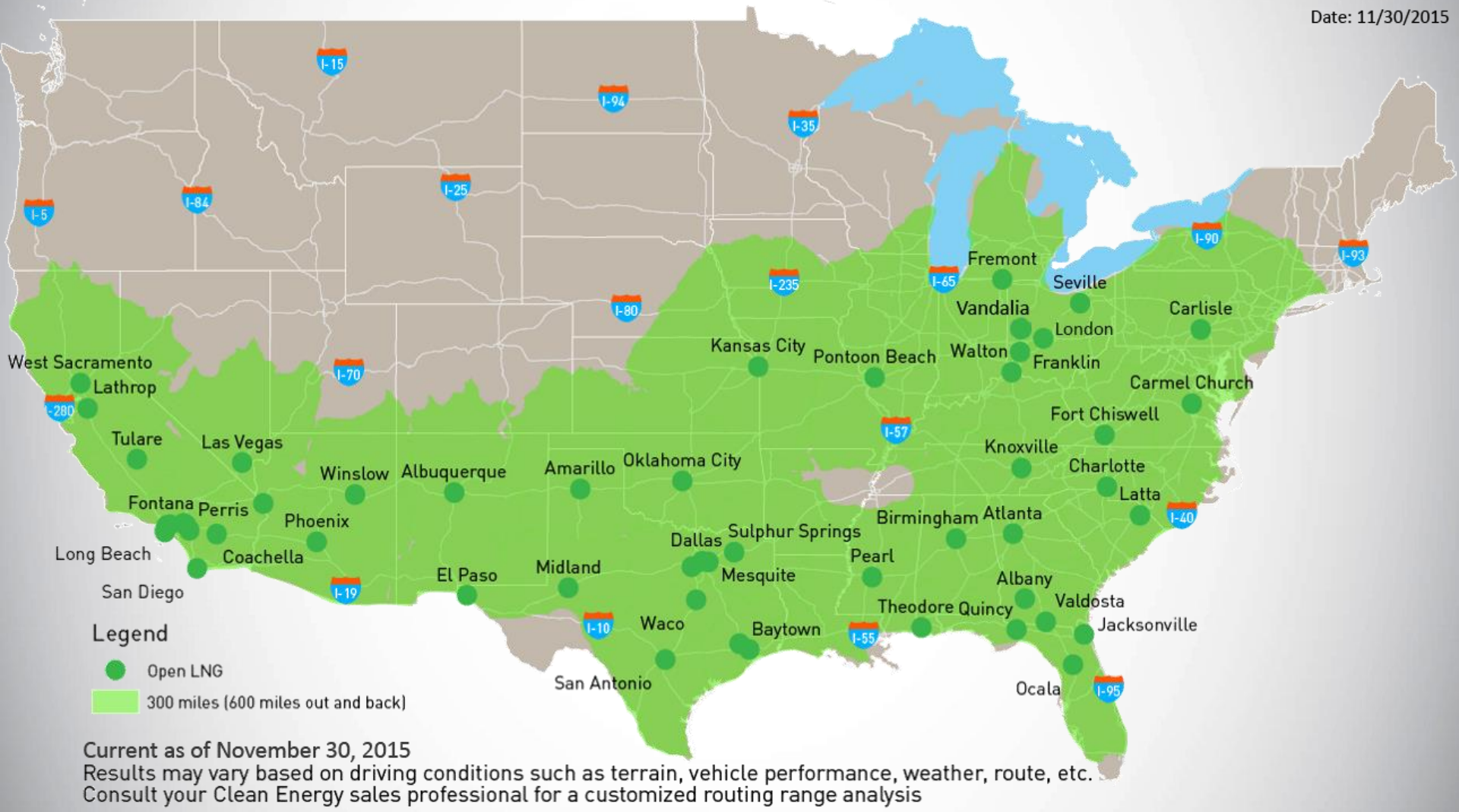
0.02 NOx HD NG ENGINES



CA Public Policy Answer

- Alternative Fuel Vehicle Incentives
- Technology Neutral
- Policy Environment Inflection Point – From “If” to “How Much” and “From Where?”

ENGINES + FUEL
ANGH LNG – 600 Miles of Range December2015



Current as of November 30, 2015
Results may vary based on driving conditions such as terrain, vehicle performance, weather, route, etc.
Consult your Clean Energy sales professional for a customized routing range analysis