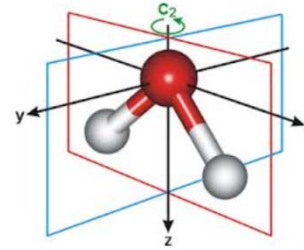
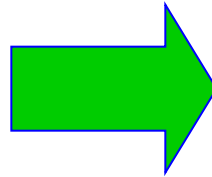


BACK TO THE FUTURE:

*Lessons Learned from California's 1990s Methanol Program
and Renewed Interest in Petroleum Reduction*



By Paul Wuebben

Senior Director of Renewable Fuels

CARBON RECYCLING INTERNATIONAL

2015 European Methanol Forum

Brussels, Belgium

October 13 + 14, 2015



Carbon Recycling International



Outline

- ▶ CA Methanol Experience
- ▶ Governor's and CARB's GHG + Energy Priorities
- ▶ Next Steps in Methanol Transition
- ▶ Conclusions



Summary of CA Fuel Methanol Program

- ▶ 17,000⁺ M85 FFVs sold to public without restriction
- ▶ Max fuel volume throughput: 7.5 M liters / month
- ▶ 10 OEMs involved
- ▶ Station deployment: 60⁺
- ▶ 7 oil company branded stations



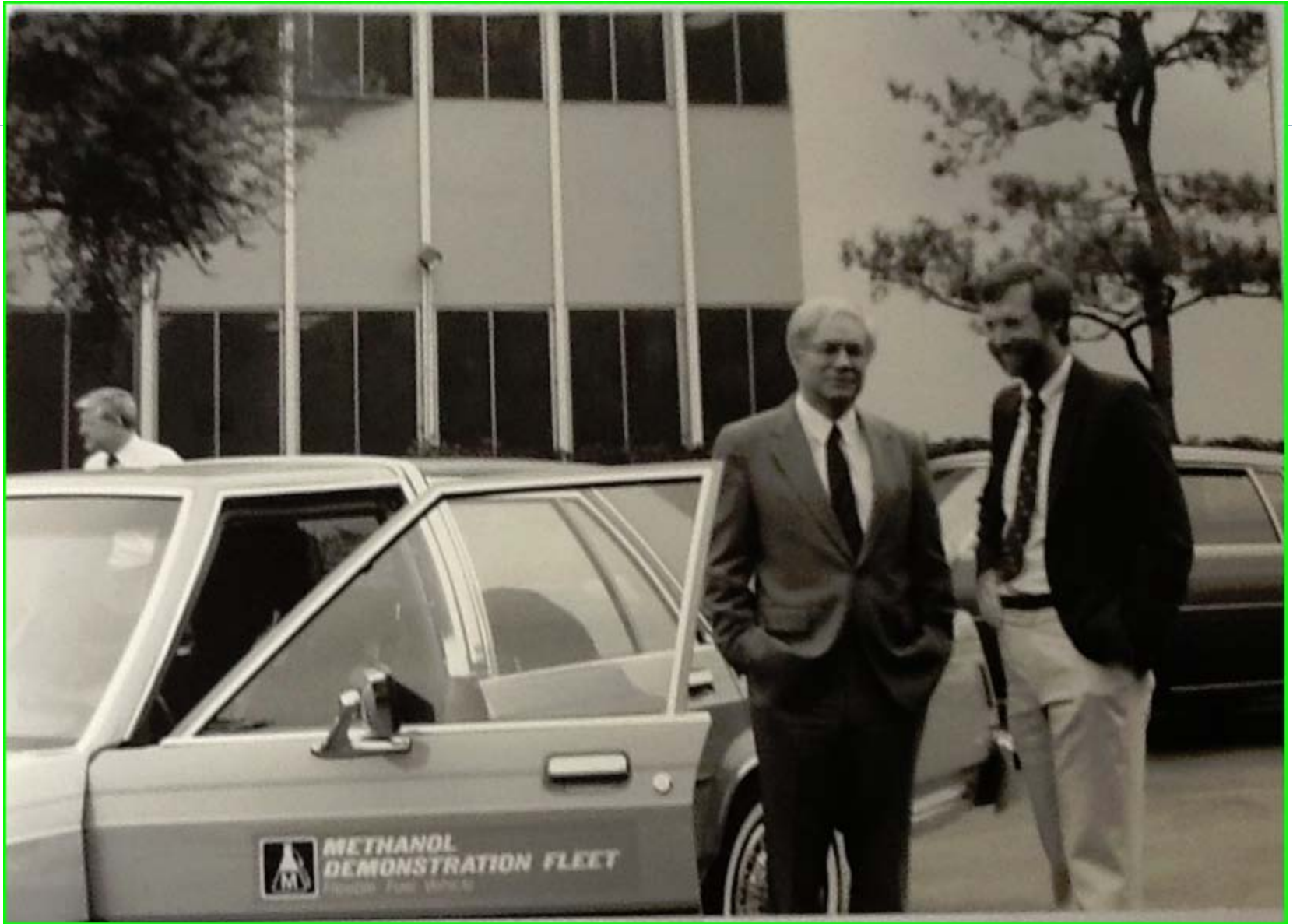
CA Legacy:

World's 1st M-85 FFV OEM Production

- ▶ Ford *
- ▶ GM
- ▶ Chrysler
- ▶ Toyota
- ▶ Nissan
- ▶ Honda
- ▶ VW
- ▶ Volvo
- ▶ Mitsubishi
- ▶ Mercedes

**** From 1996 through 1998, Ford offered the Taurus, then the nation's highest volume passenger car, for \$385 LESS than its gasoline counterpart.***

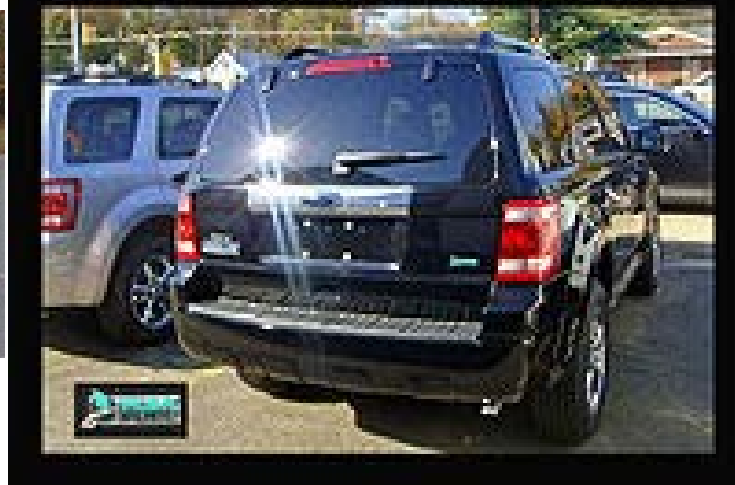
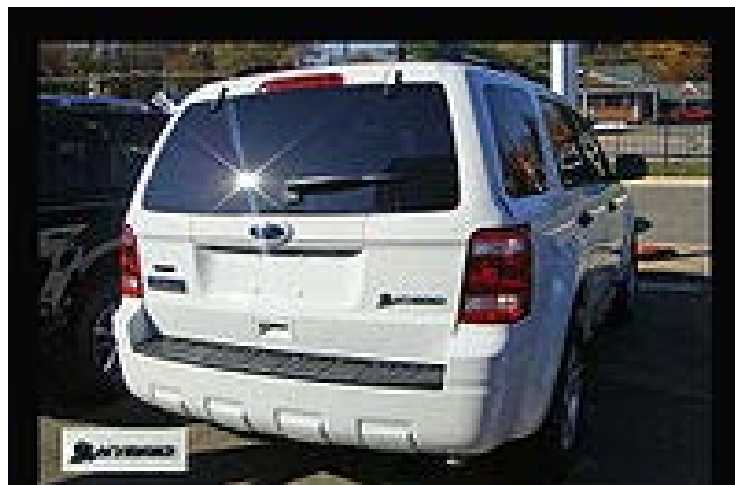




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Over 14 million in U.S.
as of 2014



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Oil Companies Offering M-85 in CA - 1990s:

- ▶ ARCO (*now BP*)
- ▶ Texaco (*now Chevron*)
- ▶ Mobil (*now Exxon*)
- ▶ Chevron
- ▶ Shell
- ▶ Exxon
- ▶ Ultramar (*now Shell*)



Specific Methanol Technology Highlights

- ▶ **World's 1st M85 FFV** demonstration
 - ▶ *With Roberta Nichols, Ford Motor Co.*
- ▶ **World's 1st “gasoline tolerant” M85 FFV**
 - ▶ *With Gordon Alardyce, Chrysler*
- ▶ **World's 1st FFV with high CR**
 - ▶ *Achieved gasoline-equivalent COP, Volvo*
- ▶ **World's 1st methanol bus retrofit**
 - ▶ *With Glen Short, ICI (with Avocet)*

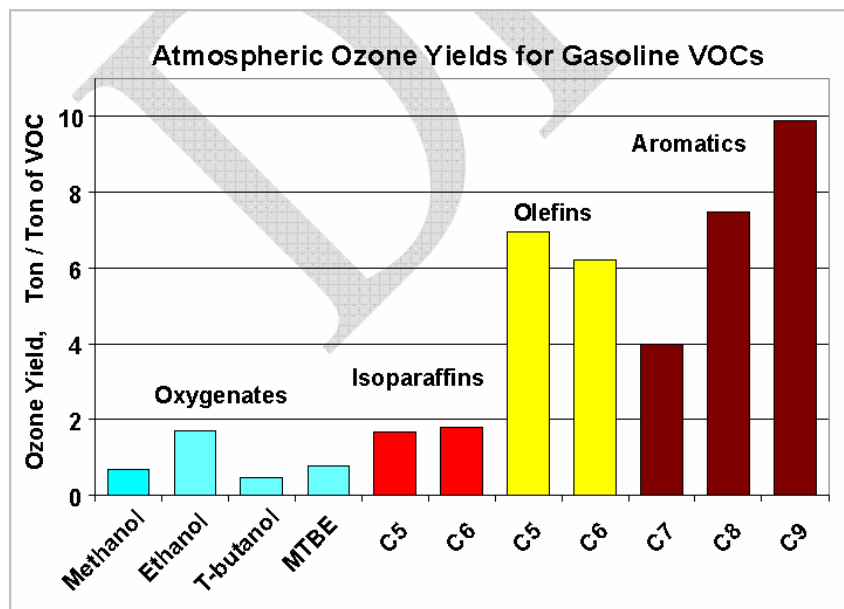


Technical Issues Successfully Addressed as a Result of the CA Methanol Program

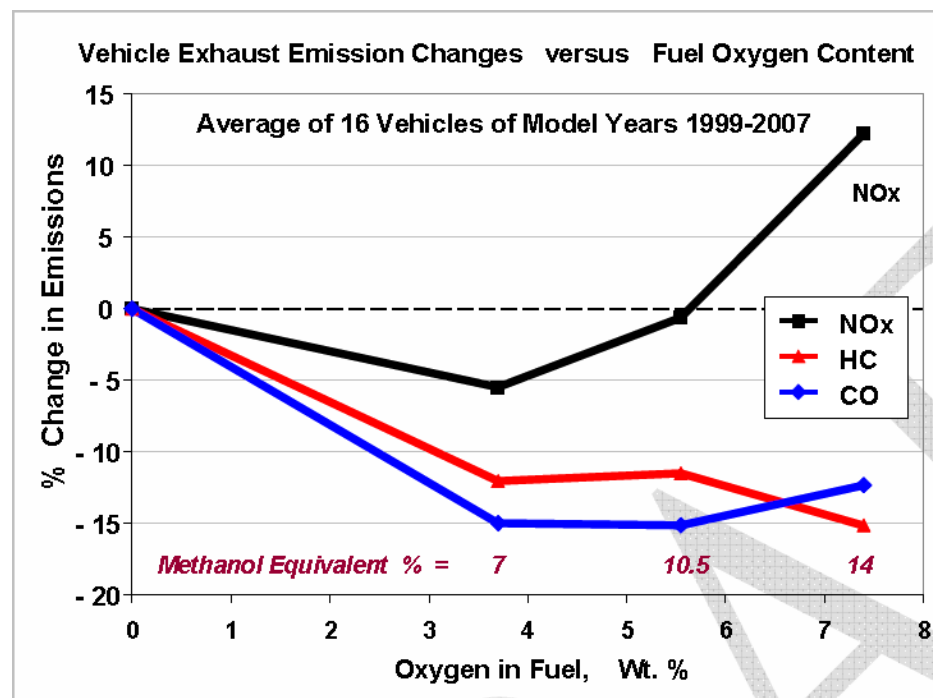
- ▶ Octane Effects
- ▶ Blending Vapor Pressure
- ▶ Distillation Properties
- ▶ Water Solubility
- ▶ Vehicle Emission Impacts
 - ▶ *e.g., HCHO standard adopted and easily complied with via close coupled catalysts*
- ▶ Toxicity of Vapors
- ▶ Risk Mitigation
 - ▶ *e.g., flame arrestors, anti-siphoning devices*
- ▶ Material Compatibility in FFVs
 - o Neat Methanol
 - o Methanol Gasoline Blends



Methanol Was Shown to Provide Ozone Reactivity and Emission Reduction Benefits Compared to Gasoline



**Ozone Reactivity Associated
With Specific Fuel Components**
(applicable to FFVs)



**Methanol Low Level Blend
Effects in Non-FFVs**

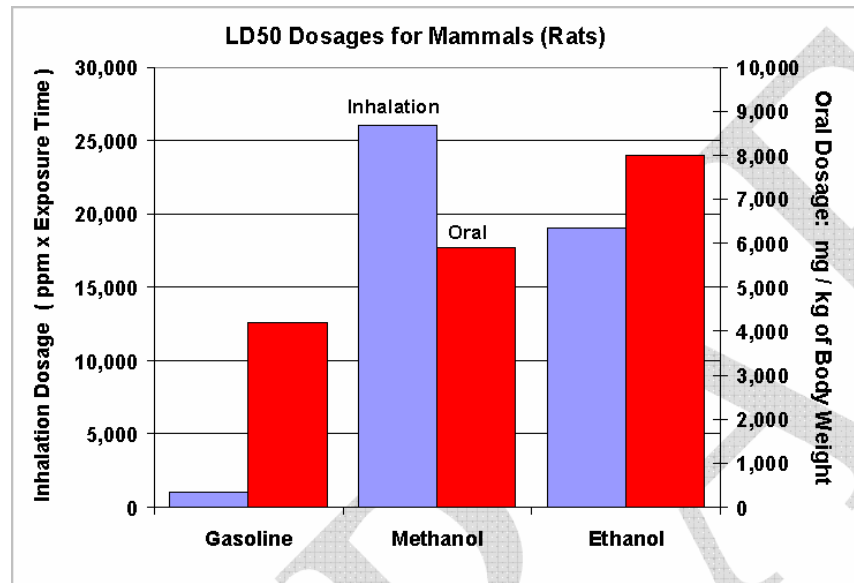


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Methanol Was Shown to Provide Health and Ecosystem Benefits Compared to Gasoline

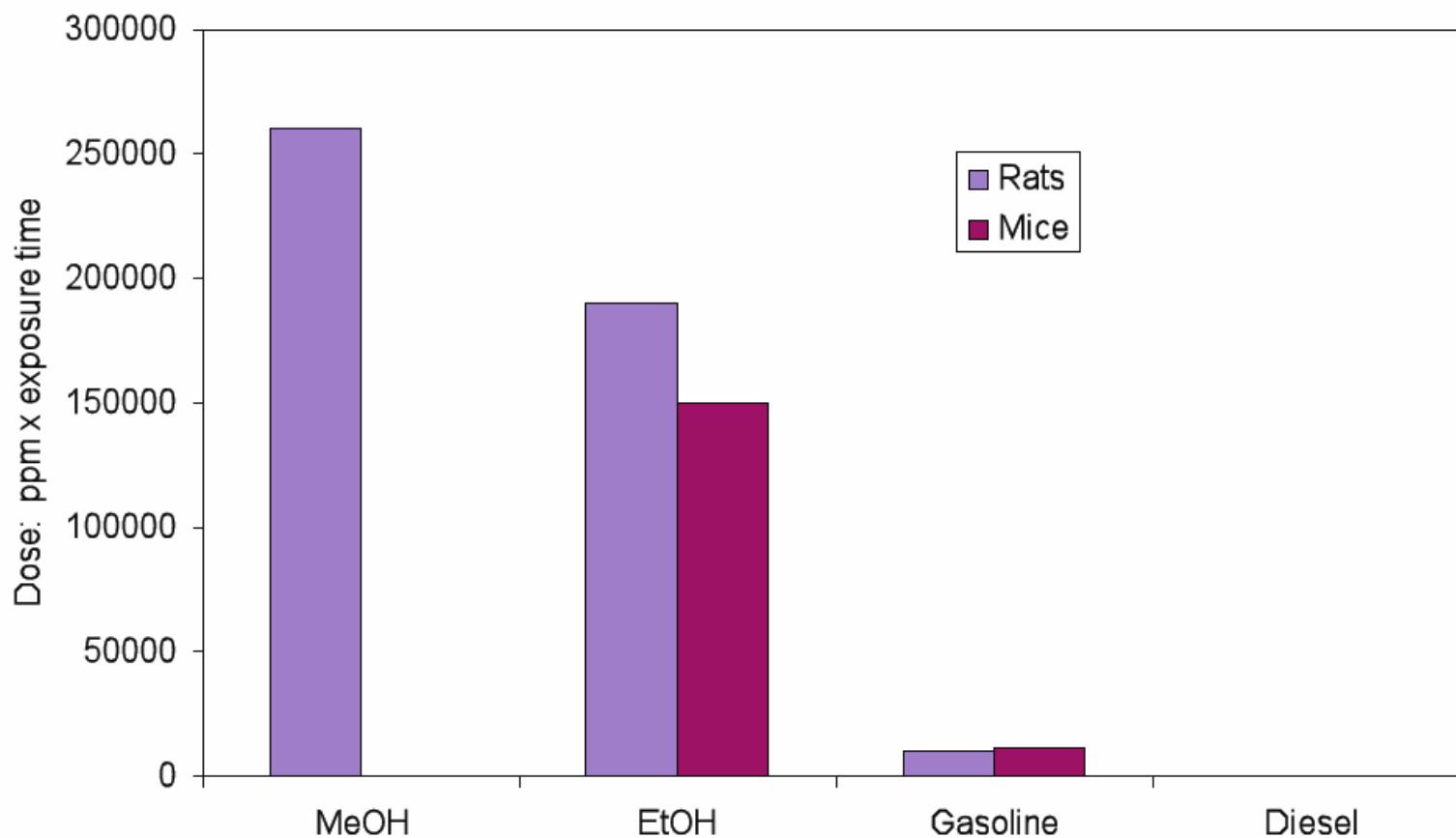
Environmental Half-Lives in Days				
	Soil	Air	Surface Water	Ground Water
Methanol	1 - 7	3 - 30	1 - 7	1 - 7
Ethanol	0.1 - 1	0.5 - 5.1	0.25 - 1	0.5 - 2.2
Benzene	5 - 16	2 - 21	5 - 16	10 - 720
Toluene	4 - 22	0.4 - 4.3	4 - 22	7 - 28

Methanol as an alternative transportation fuel in the US: Options for sustainable and/or energy-secure transportation, MIT, Nov 2010

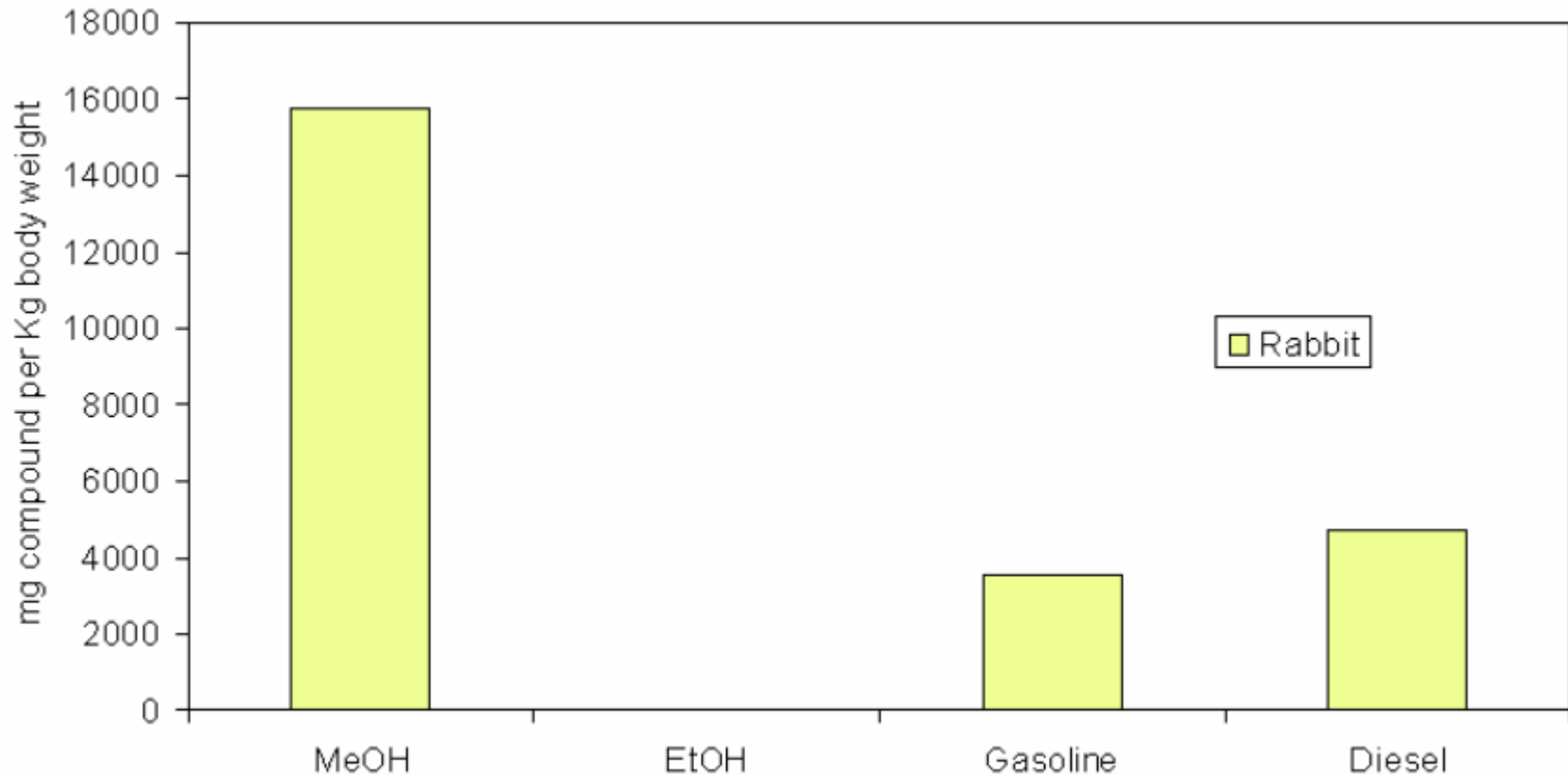


Inhalation Toxicity (LD_{50}):

Gasoline + Diesel MUCH Worse than Methanol

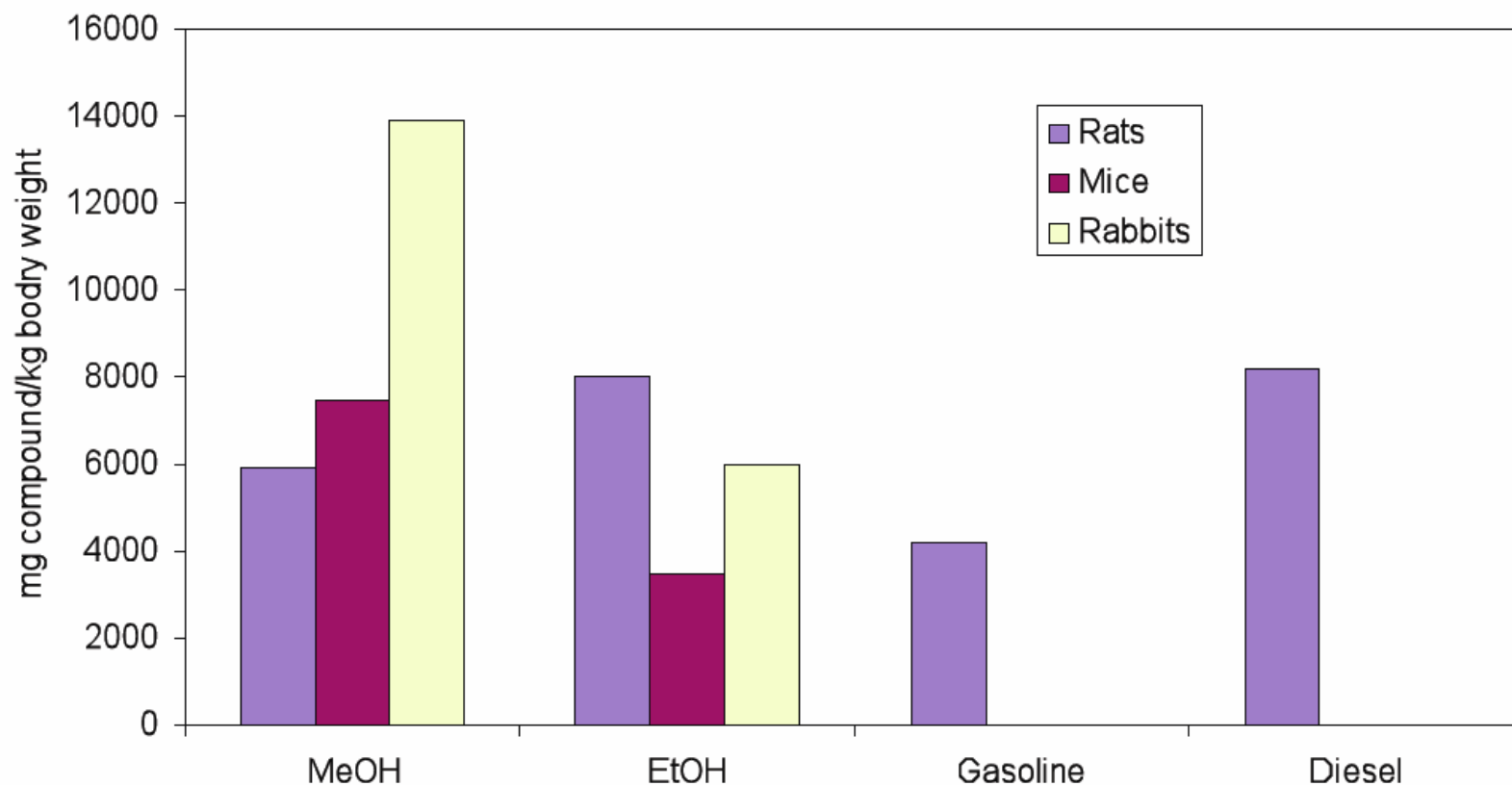


Dermal Toxicity (*LD50*): *Methanol Superior than Either Gasoline or Diesel*



Oral LD50 Toxicity:

Gasoline Worse than Methanol



Example of Mature HCHO Control Using Well-Established Catalyst Technology

Mercedes FFV C 240 and C 320 2005 MY Certification *						
	NMOG (g/mi)		NOx (g/mi)		HCHO (mg / mile)	
	50K Cert.	50k standard	50K Cert.	50k standard	50K Cert.	50k standard
E-85	0.043	0.1	0.01	0.14	0.4	15
RFG2 (w / MTBE)	0.028	0.1	0.04	0.14	0.3	15
ARB Cert level	LEV / ULEV					
EPA Cert level	Bin 8					

Table Source: South Coast Air Quality Management District



Diesel Particulate:

50 x More Potent Cancer Risk Than HCHO

Comparative Toxicities of Selected Toxic Compounds from Vehicle Sources	
Toxic Air Contaminant	Inhalation Cancer Unit Risk ($\mu\text{g}/\text{m}^3$) ⁻¹
Benzene	2.2×10^6
Diesel PM	3.0×10^4
Formaldehyde	6.0×10^6

Source: California Air Resources Board, Consolidated Table of OEHHA/ARB Approved Risk Assessment Health Values, March 2005;
<http://www.arb.ca.gov/toxics/healthval/healthval.htm>



Carbon Recycling International



September 23, 2015



Dan Morain

Editorial page editor, political affairs columnist and editorial writer

A lonely voice speaks out again

HIGHLIGHTS

Paul Wuebben long had warned about the dangers of widespread use of diesel engines

California regulators saw an opportunity to reduce greenhouse gas emissions

Now, Volkswagen's too-good-to-be-true claims have turned out to be just that



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METHANOL USE IN TRANSPORTATION:

- ▶ Toxicity of methanol, ethanol, gasoline and diesel are comparable
- ▶ Morbidity effect from methanol ingestion is far greater than gasoline or ethanol
 - ▶ *Affects Central Nervous System and can cause blindness*
- ▶ In 2000, there were 11 deaths in the U.S. from 2,000 methanol exposures
- ▶ ***In the CA Fuel Methanol Program, with over 200 million miles of consumer experience, there was not a single documented harmful event.***
- ▶ Existing commercial products contain significant amounts of methanol (e.g., windshield washer fluid)



Methanol in transportation

Environmental impact

- Consequence of methanol spills
 - Half lives of methanol in soil, air and water longer than ethanol
 - Decays much faster than hydrocarbons
- Water soluble
 - Can migrate in the subsurface water, but decays within a few days (1-7 days)



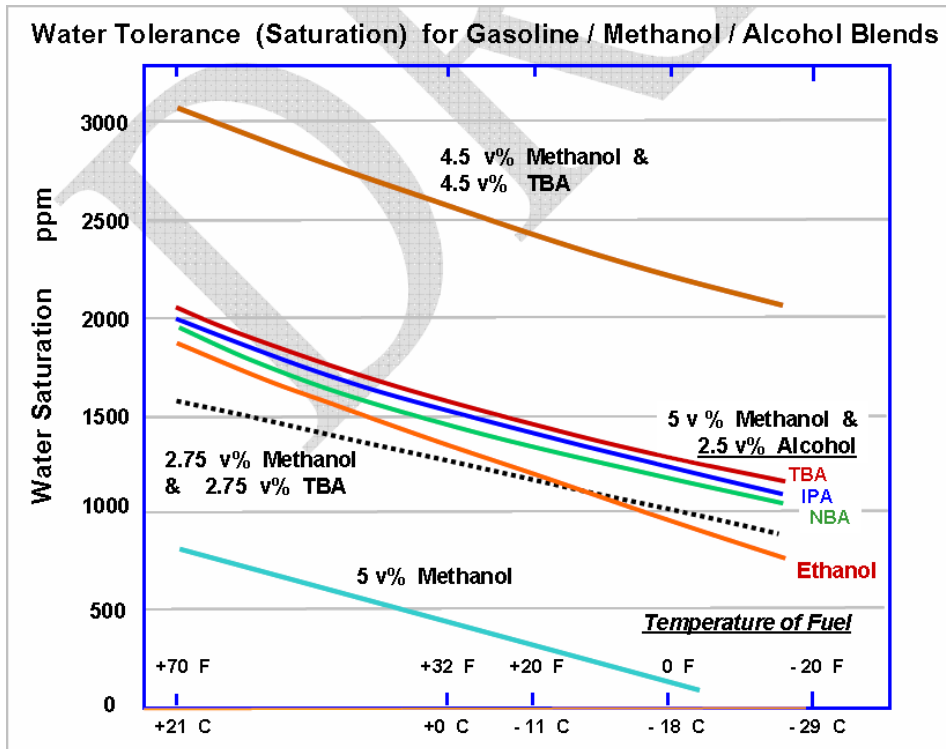
Methanol in transportation

Safety

- **Methanol safety characteristics:**
 - Hard to ignite (much harder than gasoline and ethanol, comparable to diesel)
 - Lower radiant heat (lower flame temperatures)
 - Burns without smoke that obscure the objects for rescuers
 - Can be put out with water
 - However, methanol is nearly invisible in direct sunlight
- **Fuel of choice in several racing categories:** IRL (1996-2006), CART (1979-2007), drag racing, Monster Truck racing



Materials and Phase Separation Were Carefully Considered



Material Compatibility of Commonly Used Materials with Gasoline / Methanol / Co-solvent Blends

Recommended	Not Recommended
Metals	
Aluminum	Galvanized metals
Carbon Steel	
Stainless Steel	
Bronze	
Elastomers	
Buna-N TM *	Buna-N TM *
Flurel TM	
Fluorosilicone	
Neoprene*	Neoprene*
Polysulfide Rubber	
Viton TM	
Polymers	
Acetal	Polyurethane
Nylon	Alcohol-based pipe dome
Polyethylene	
Teflon TM	
Fiberglass-reinforced	
TM – Trade mark * Okay for hoses and gaskets but not seals	
Source: Storage and Handling of Gasoline-Methanol / Cosolvent Blends API 1627 Recommended Practices, 1986	



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Relevant Question:

- ▶ It was recently disclosed that Chevron dewatered their entire pipeline distribution system in the mid-1990s to accommodate methanol distribution. This was the first and last time that an entire refiner's distribution system was made compatible for an alternative fuel not derived from petroleum.
- ▶ ***Are there any technical barriers to repeating that transition in this decade?***

NO



Reasons that “Orphaned” Opportunities Were Left Unrealized in the mid-1990s

- ▶ Low oil price environment very challenging...
- ▶ “Romance of the number zero” ZEV ideology
 - ▶ *Even though BEVs are 2nd car niche vehicles in reality...*
- ▶ Lack of adequate public education
- ▶ Distorted U.S. ethanol policies
 - ▶ *Now resolved with repeal of the VEETC*
- ▶ Limited number of “fuel methanol” champions
- ▶ China’s methanol efforts were not mature at that time
- ▶ Demographics of 5 billion population were less onerous than 7+
- ▶ **Renewable Methanol from recycled CO₂ emissions not demonstrated at that time...**



California's Latest Initiatives



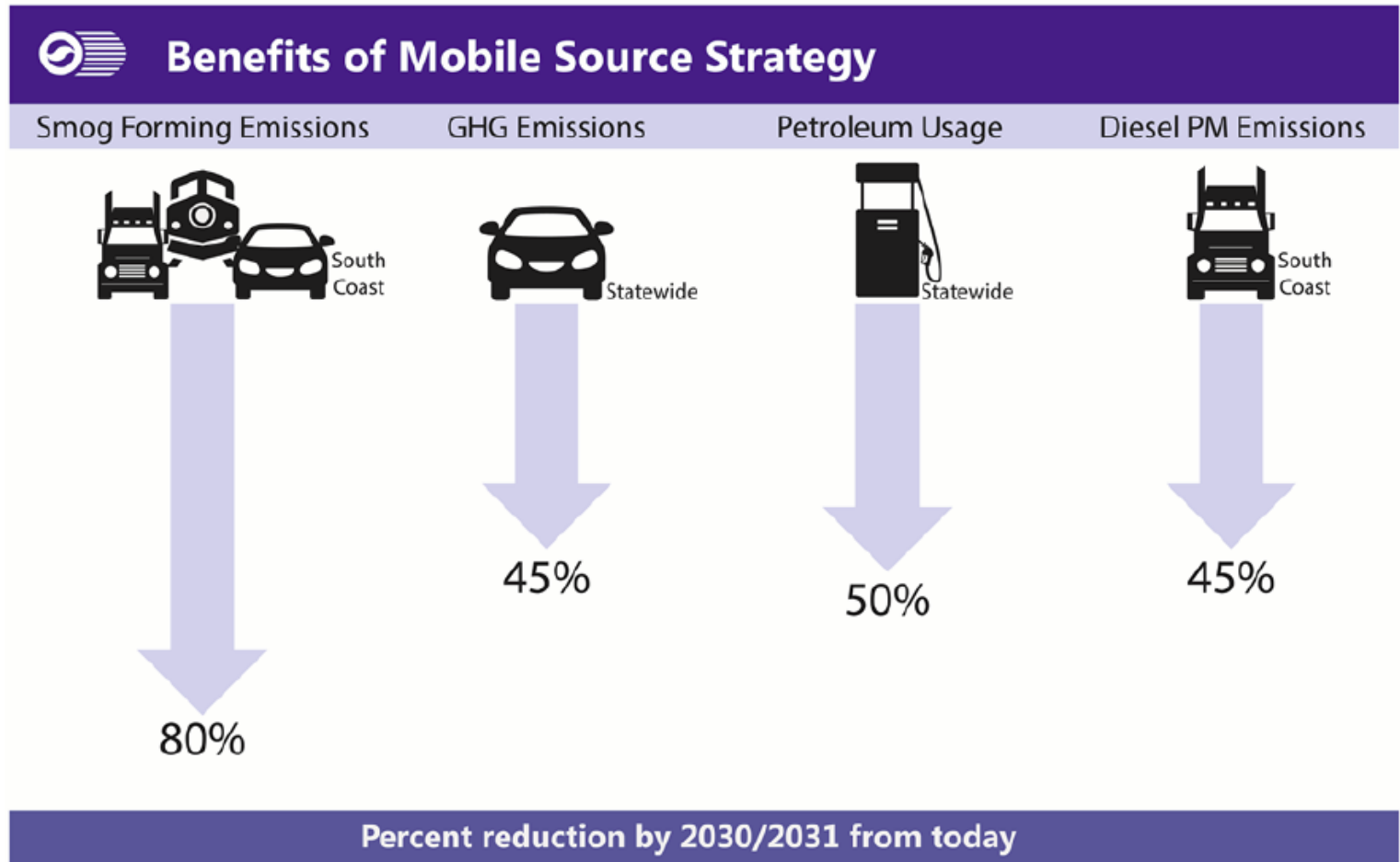
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California's Energy / GHG Challenges

- ▶ CO₂ concentrations already @ 400 ppm threshold
- ▶ Severe drought raising public awareness of GHGs
- ▶ Governor's commitment to 50% reduction in petroleum use by 2030
- ▶ **Growing skepticism regarding “clean diesel”**
- ▶ Pace of electric drive and H₂ fuel cell vehicles slower than needed
- ▶ Compliance with new federal ozone standard
- ▶ Disproportionate public health impact from port / marine activities

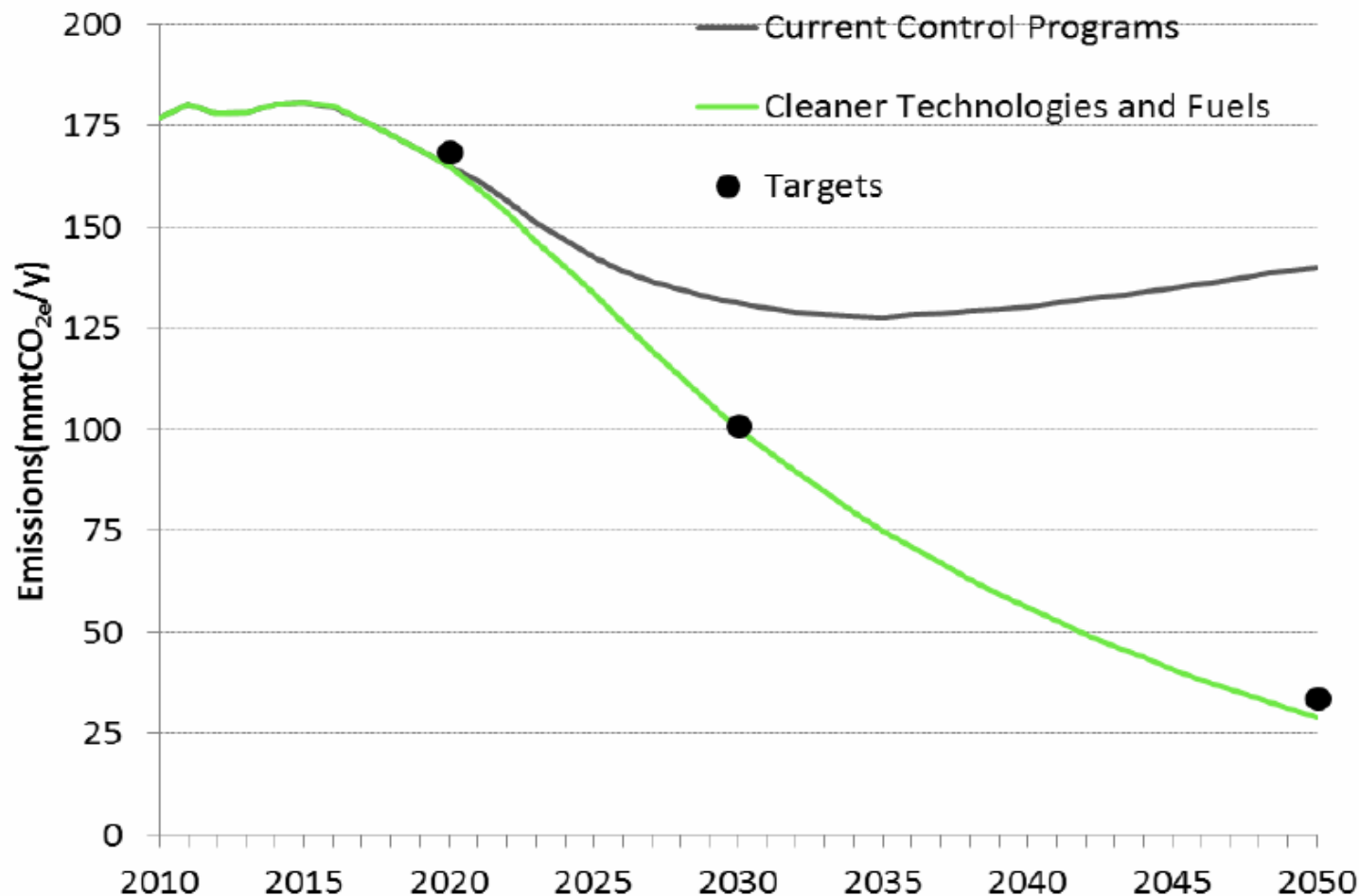


CALIFORNIA'S RECENT INITIATIVES:

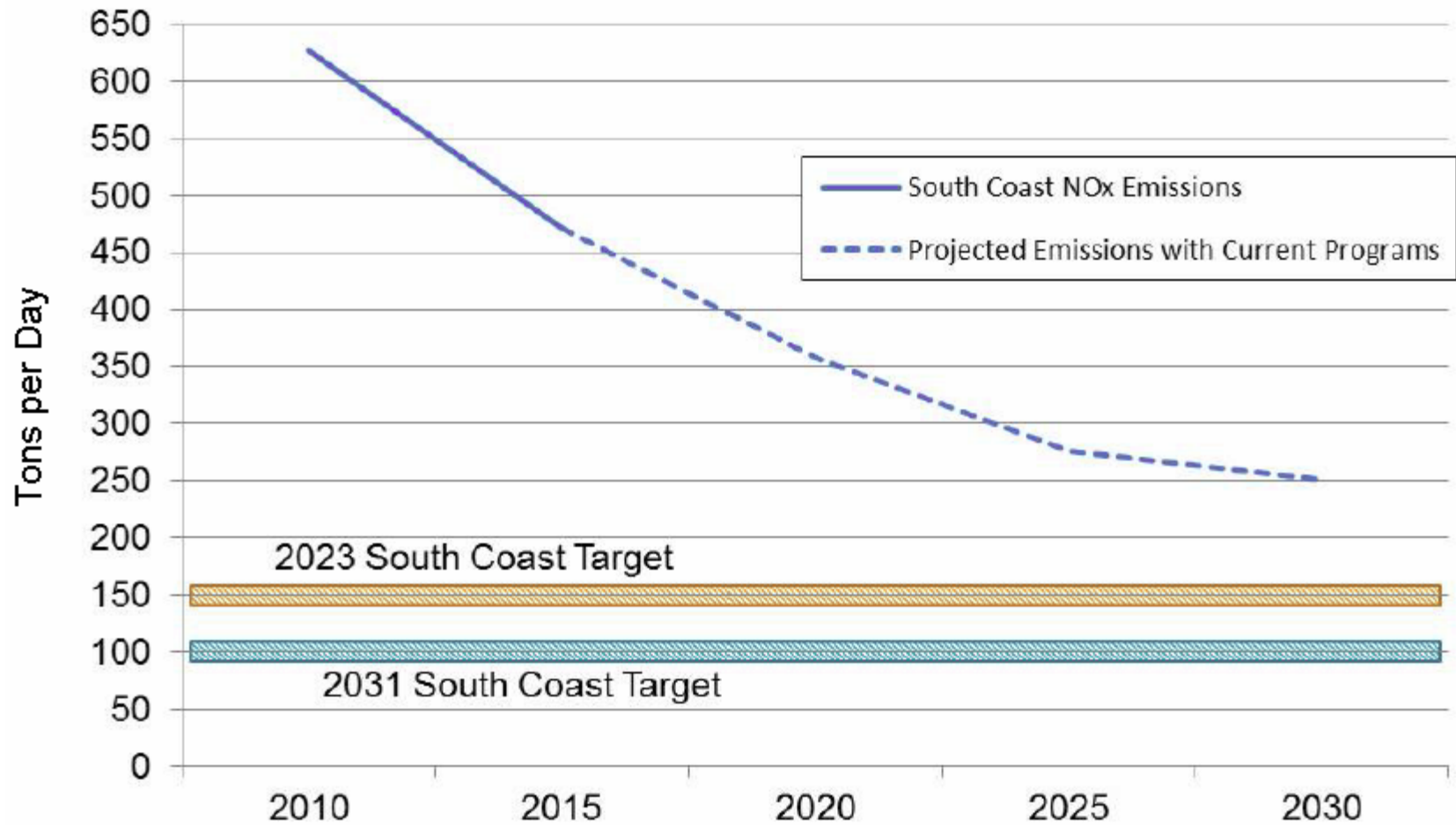


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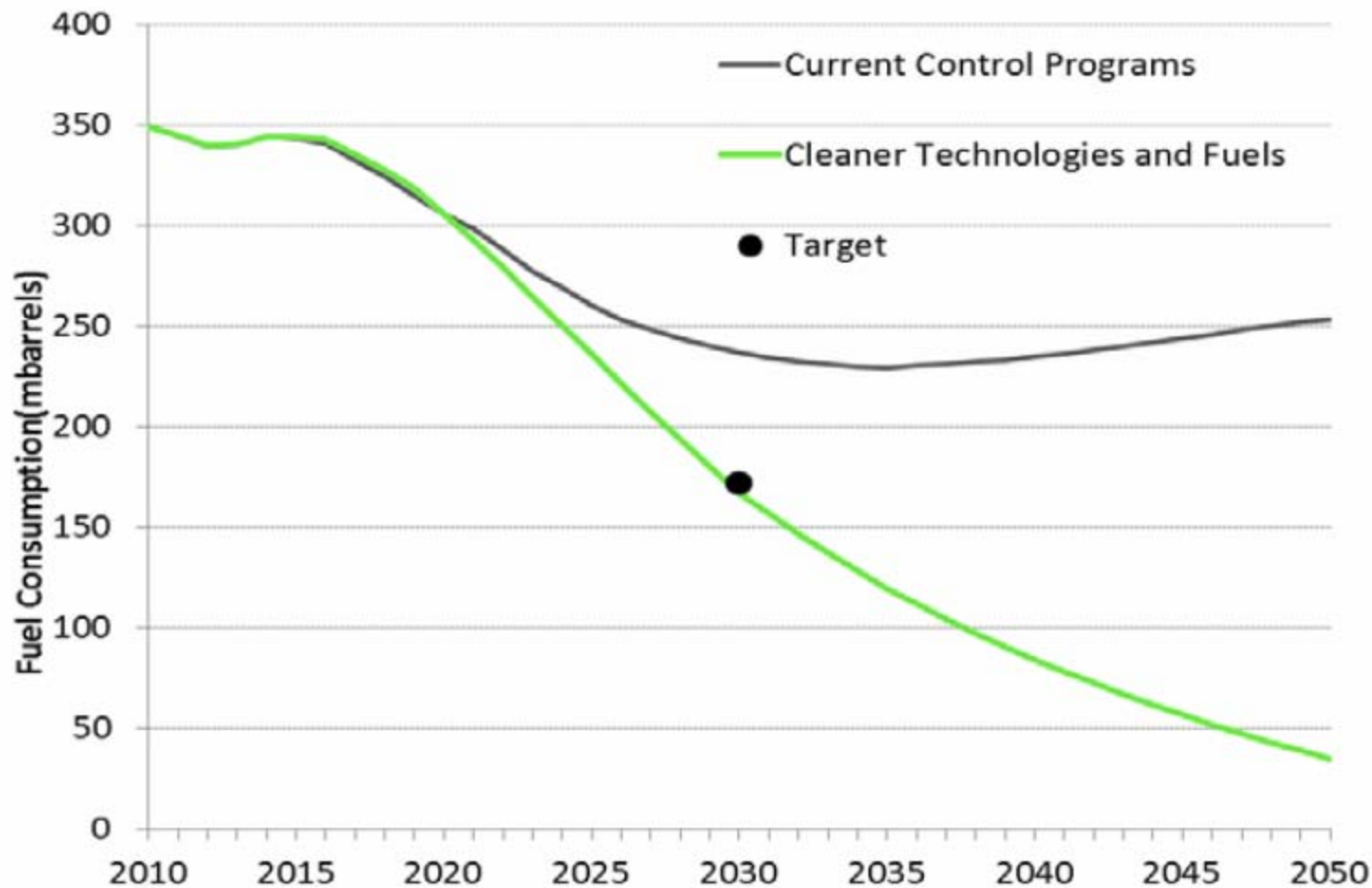
California On-Road GHG Emission Reductions



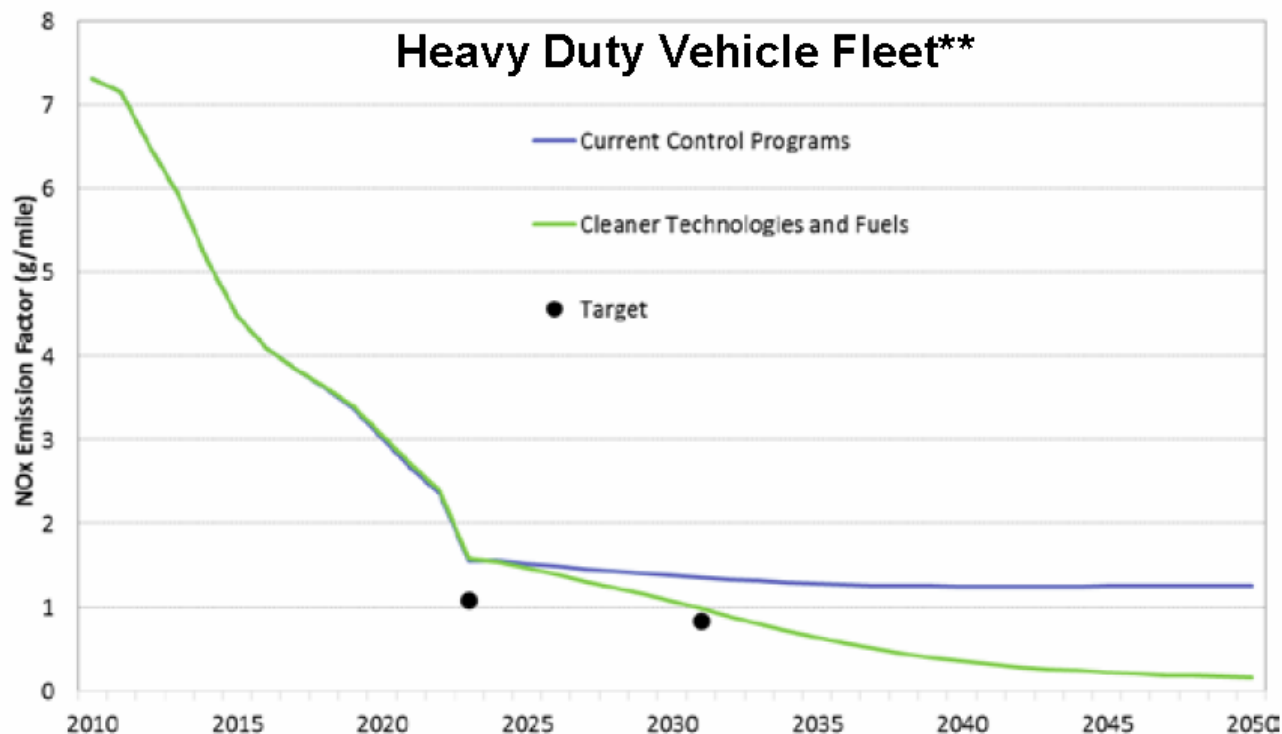
CA South Coast NOx Emission Trends



California Petroleum Reduction Trends



California Heavy Duty Vehicle Fleet**



*In-use fleet average NOx emissions reflect natural turnover rates for light and heavy duty vehicles.

** Heavy duty vehicle fleet weighted by vehicle class and vehicle miles travelled.



Implementation Milestones and Schedule:

Proposed Strategy	Implementation Steps	Date
Identify and secure funding for incentive based and other innovative funding programs for accelerated deployment of zero and near-zero off-road equipment	<i>Phase 1:</i> Identify funding needs and potential sources	2015 + (annually)
	<i>Phase 2:</i> Pursue actions to secure funding	
	<i>Phase 3:</i> Implement funding/incentive programs	
Develop regulatory strategies for deployment of zero-emission technologies in off-road equipment applications as appropriate	<i>Phase 1:</i> Evaluation of technology and prototype demonstrations	2015 – 2023
	<i>Phase 2:</i> Development of regulatory strategies	2022 – 2025
	<i>Phase 3:</i> Measure implementation	2027 – 2031
Evaluate potential for emission benefits from operational efficiencies, and intelligent transportation systems and quantify and develop mechanisms to provide SIP reductions as appropriate	<i>Phase 1:</i> Evaluation of approaches and potential for emission reductions	2016 – 2023
	<i>Phase 2:</i> Demonstration of systems	2020 – 2025
	<i>Phase 3:</i> Quantification of emission reductions and mechanisms for incorporating into SIP	2025 – 2031



Where Can Methanol Play a Role in California + EU for LDVs?

On-Road Light-Duty

- Increased ZEV sales coupled with expansion of necessary infrastructure
- More stringent engine performance standards and increased fuel efficiency
- Requirements to ensure durability of passenger vehicle technologies
- Incentive funding to achieve further ZEV deployment beyond vehicle regulations
- Electricity grid representing 50 percent renewable energy generation
- Increased use of renewable fuels
- Reductions from passenger vehicle miles traveled and intelligent transportation systems



GEM Fuel “Elegance”

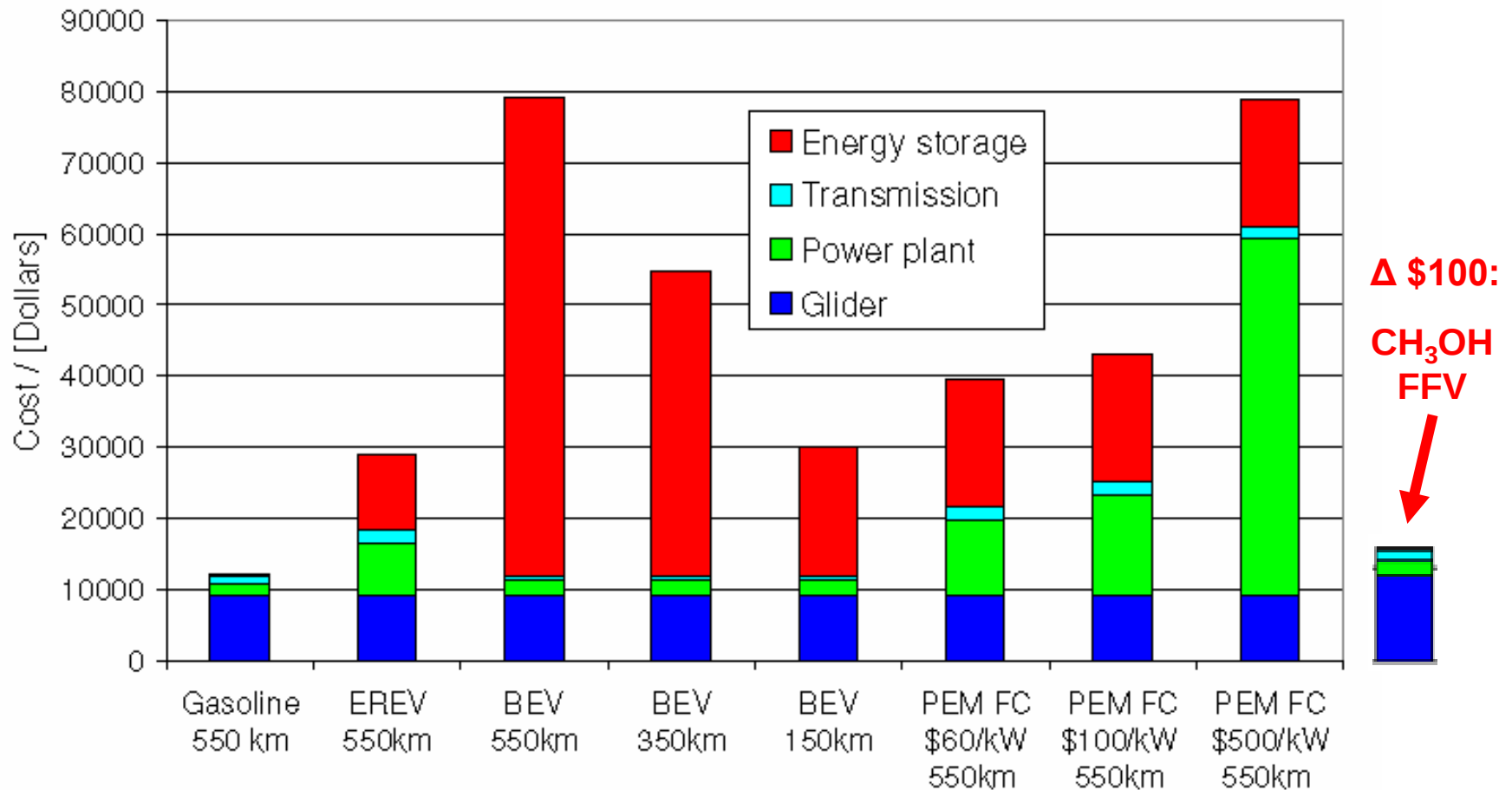
- Same AFR
- Same Gravimetric LHV
- Same Volumetric LHV
- Same Octane
- Same Heat of Vaporization
- Same O₂ Sensor Output
- & All Lower CI than Gasoline

Fuel	E85	Equivalent Binary Blend of Gasoline and Methanol	Change (%)
GEM Component Ratios	G15 E85 M0	G42.64 E0 M57.36	-
Stoichiometric AFR	9.74	9.74	0
Density (kg/l)	0.78	0.77	+0.78
Gravimetric LHV (MJ/kg)	29.07	29.30	-1.28
Volumetric LHV (MJ/l)	22.71	22.50	-0.92
Carbon Intensity (gCO ₂ /l)	1633.5	1619.4	-0.86
Carbon Intensity (gCO ₂ /MJ)	71.92	72.00 *	~

* NG based CH₃OH



The Lowest Cost Path to Scalable + Sustainable Mobility:



Where Can Methanol Play a Role in California + EU for HDVs?

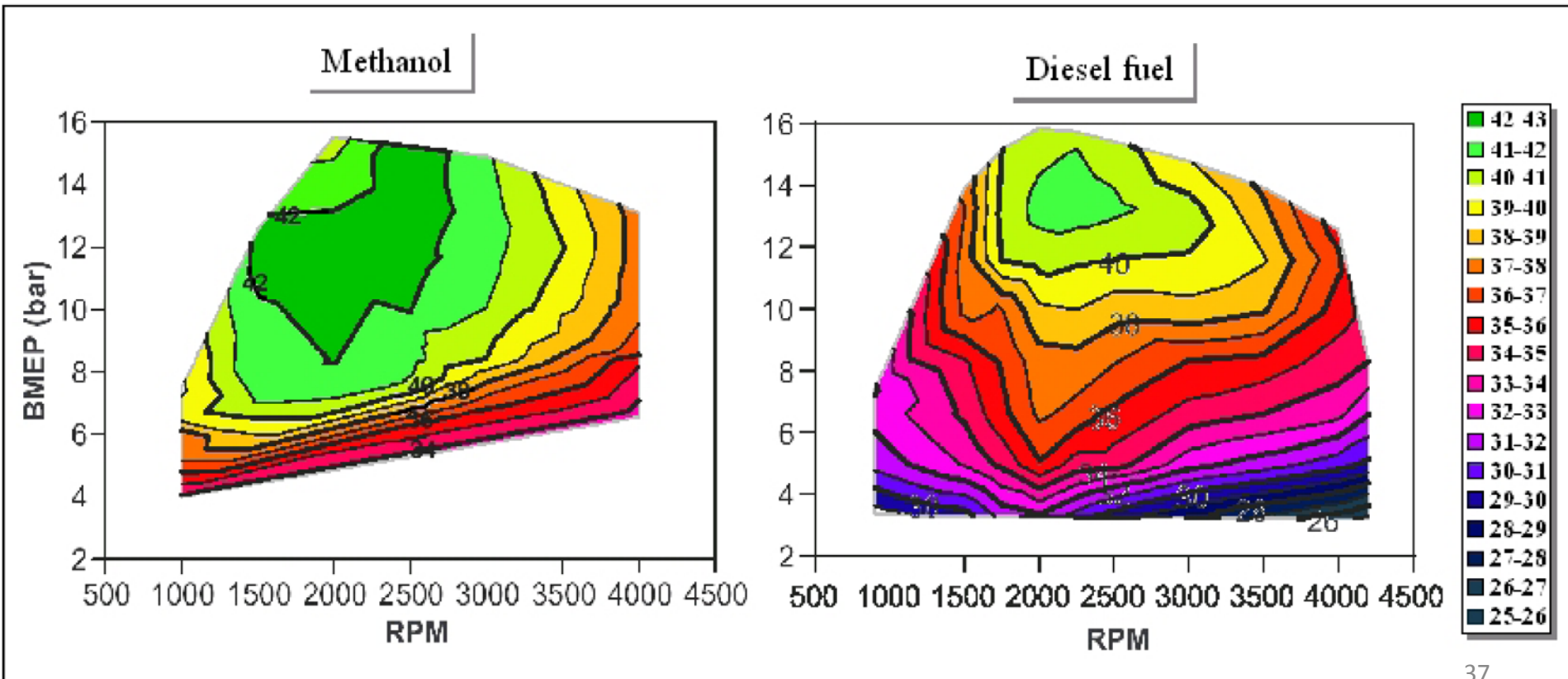
On-Road Heavy-Duty

- 
- More stringent engine performance standards reflecting technology 90 percent cleaner than today's standards and increased fuel efficiency
- 
- Deployment of ZEV technologies into focused heavy-duty applications such as transit buses and last mile delivery
 - Requirements to ensure durability of heavy-duty vehicle technologies
- 
- Incentive funding to achieve further deployment of cleanest engine technologies
 - Increased freight transport system efficiencies and use of intelligent transportation systems
 - Increased use of renewable fuels



The Full Potential of Methanol has Not Been Fully Leveraged

EPA VW 1.9l TDI Conversion:
Spark Ignited Methanol, + 19:1 CR



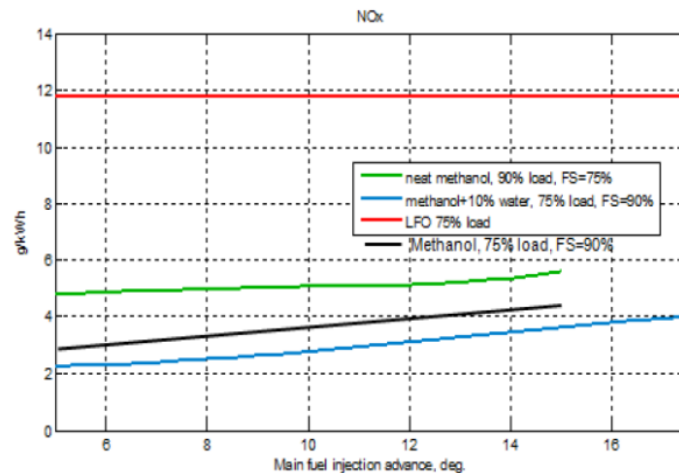
Where Can Methanol Play a Role in California + EU in the Marine Segment ?

Off-Road Federal and International Sources

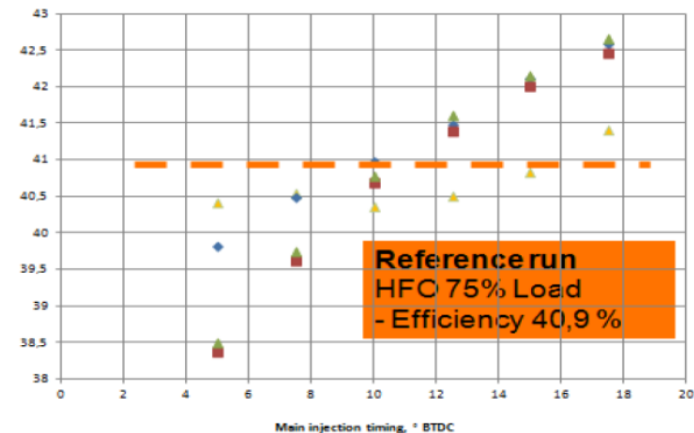
- Call for federal and international action to set more stringent standards for ocean going vessels, locomotives, and aircraft
- Cleaner technologies for older locomotives
- Decreased emissions from ocean going vessels at berth
- Increased freight transport system efficiencies
- Incentive funding to achieve further deployment of cleanest engine technologies
- Increased use of renewable fuels



Stena Germanica Methanol Conversion



Reduced NOx (-70%)



Same efficiency as diesel



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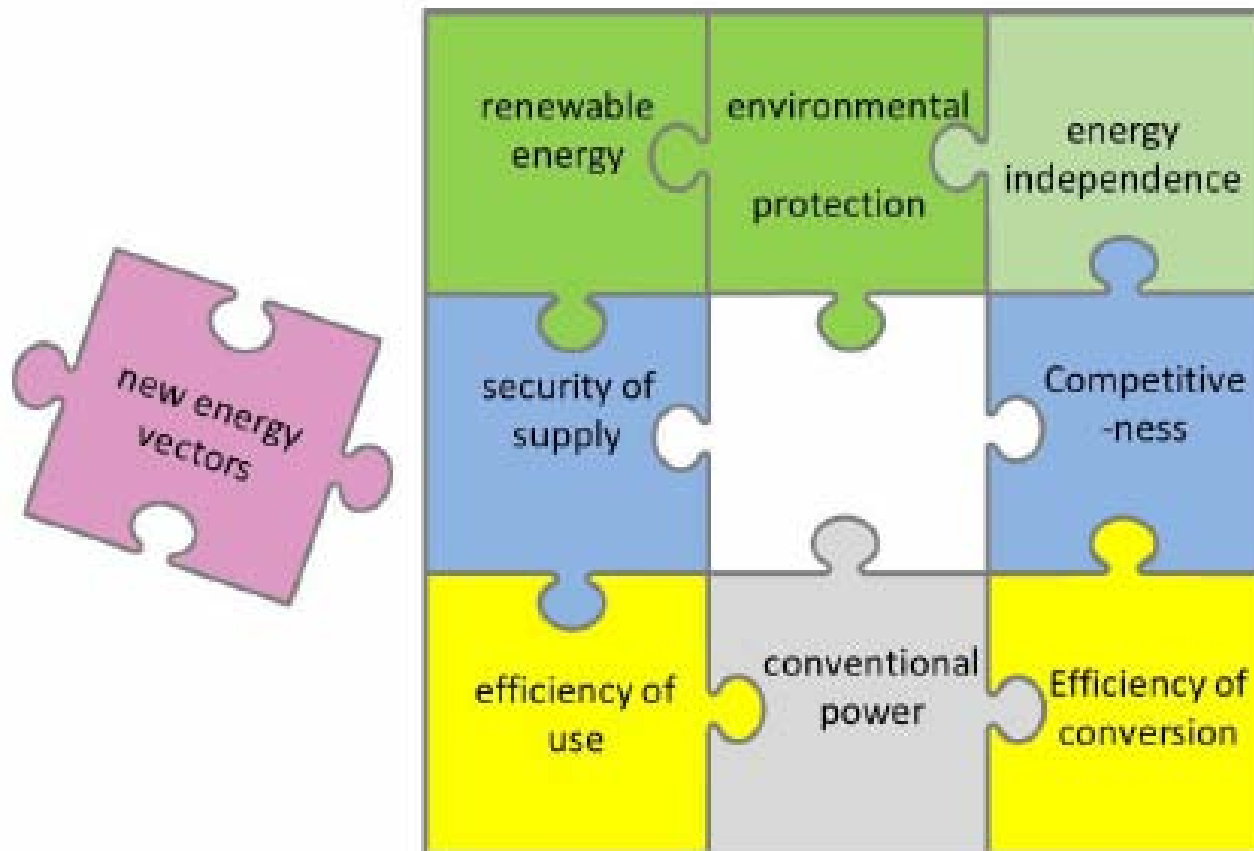
What's Different This Time?

- ▶ Global population: 7 B rather than 5 B
 - ▶ *China, India, Indonesia demographics + growth*
- ▶ California 1st to target 50% petroleum reduction by 2030
- ▶ **OEMs need non-diesel + high octane engine efficiency gains!**
- ▶ Fuel cell infrastructure costs are becoming transparent
- ▶ Oil prices of \$50 - \$100 rather than < \$20
 - ▶ *Petroleum supply vulnerabilities growing*
- ▶ Ethanol “Biofuel Limit” reached @ 15 B gallons
 - ▶ *U.S. ethanol price distortion (VEETC) now ended*



Fuel Methanol Has a Significant Role To Play –

Let's Put All Its Strengths Together !



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Thank You For This Opportunity...!



Paul@cri.is



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