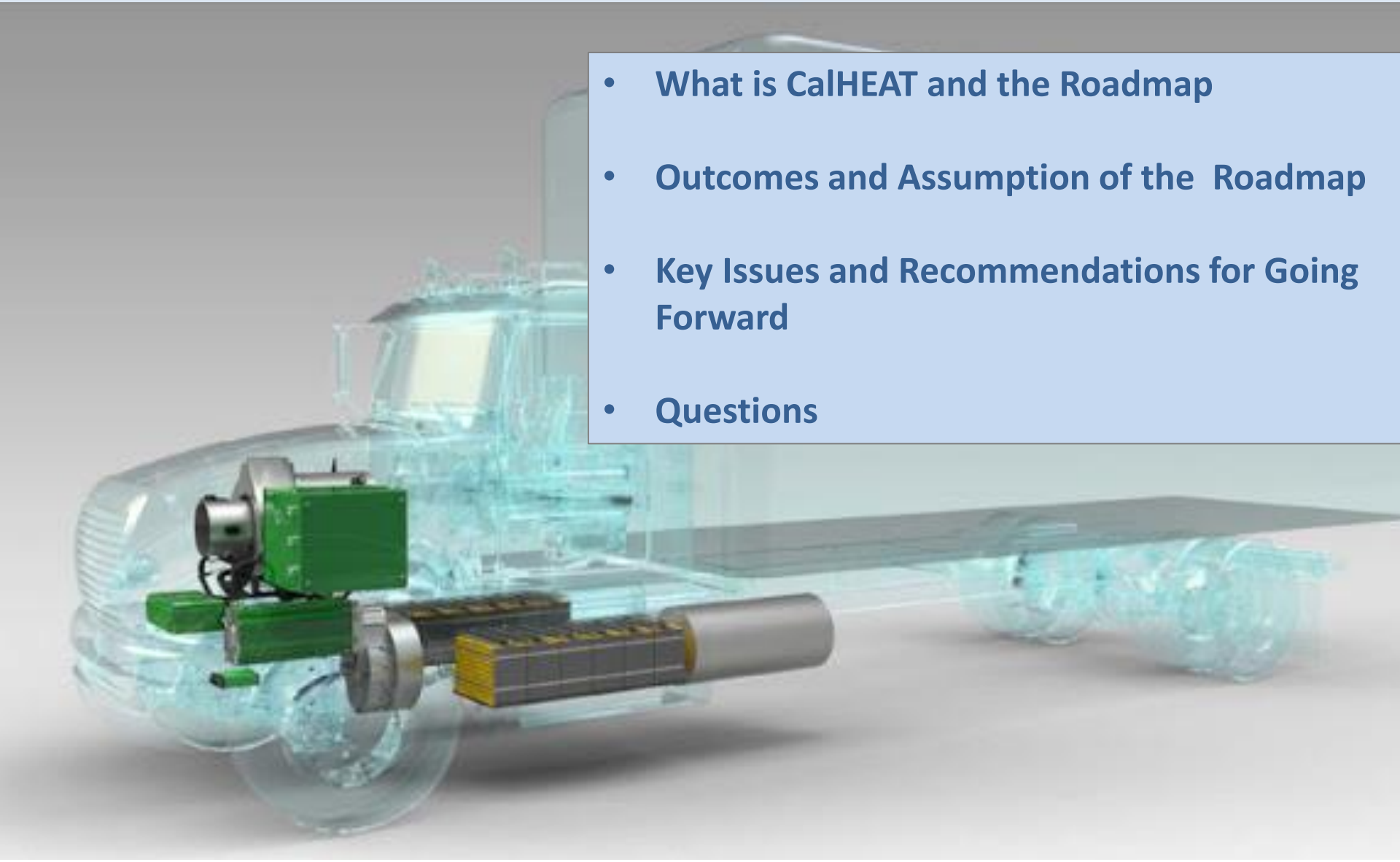
CalHEAT Research and Market Transformation Roadmap for Medium and Heavy Duty Trucks

Joint Lead Commissioners Workshop on Transportation Energy

July 31, 2013 -Fred Silver-VP CALSTART

Agenda



- What is CalHEAT and the Roadmap
- Outcomes and Assumption of the Roadmap
- Key Issues and Recommendations for Going Forward
- Questions

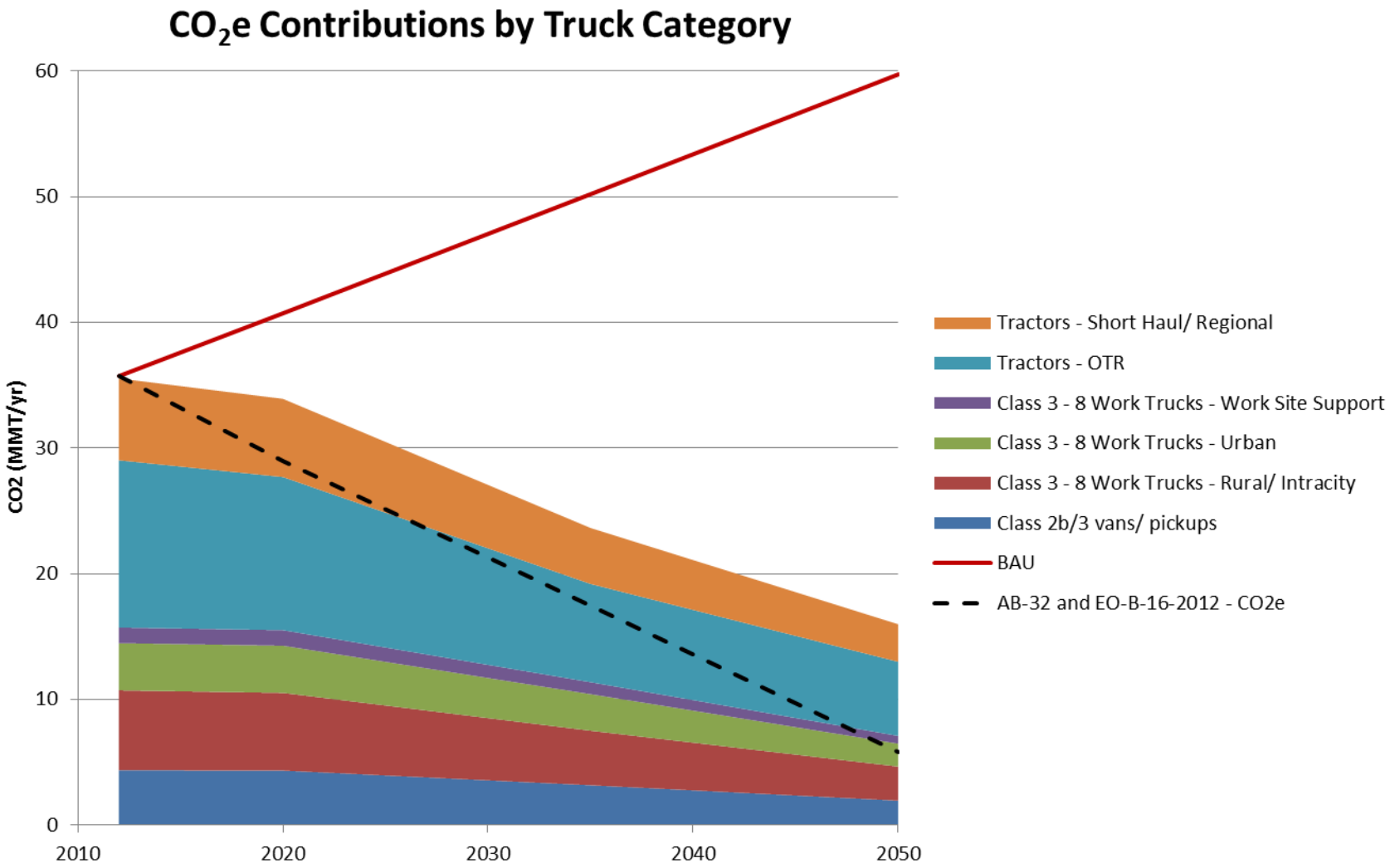
What is CalHEAT?

- State center for research, development, demonstration and commercialization of advanced, efficient truck technologies and systems
- Initial funding by California Energy Commission
- Operated by CALSTART, a CA-based non-profit

Purpose of CalHEAT

- To drive and coordinate accelerated research, development and demonstration of cleaner, more efficient medium- and heavy-duty vehicles (M-HDVs)
- Enable commercialization of M-HDVs that enable State of California to meet its climate protection, air pollution, and energy security goals

CO2 Reduction from Roadmap



CalHEAT Truck Technology Roadmap

- Pathways for staged technology/market milestones to 2020
- Identifies needed actions to achieve milestones:
  - R&D
  - Demonstrations
  - Incentives and policies
- Leverage technology developments across platforms
- Roadmap is based on expected structure of market, applicability, ability to implement and benefits of technologies and approaches based on research
- Roadmap charts course of what's needed to meet 2020 goals (given California's multiple needed) as well as drive solutions needed beyond 2020

Technical Advisory Group	• Direct Technical inputs into the Transformation Roadmap • Technical and Industry Experts HTUF -OEMS -Fleets
Advisory Council	• Assist with strategic direction with a focus on the Transformation Roadmap • Govt Agencies, Visionaries, NGO's and Industry Associations.
Steering Committee	• Provide guidance, review and potentially contribute to the Annual Research Plan • Demonstration and Funding Partners

Advisory Council and Steering Committee Members

- Reynaldo Gonzalez, Program Engineer Public Interest Energy Research California Energy Commission
- Jack Broadbent-Executive Officer- Bay Area Air Quality Management District
- Seyed Sedriden, Air Pollution Control Officer, San Joaquin Air Pollution Control District
- Doug Failing- Executive Director Highway Programs, Los Angeles County MTA
- Mark Duvall, Manager, Technology Development-Electric Power Research Institute
- Erik White- Assistant Division Chief –California Air Resources Board Mobile Source Control Division
- Jack Kitowski-Chief Freight Transportation Branch- California Air Resources Board
- Joe Calavita- HVIP Program Manager- California Air Resources Board
- Rick Cameron/Heather Tomley Director of Environmental Planning Port of Long Beach (Advisory)
- Rose Siengsubcharti/Allyson Teramoto Environmental Specialist Associate, Port of Long Beach (Steering)
- Jeffrey Reed Director of Emerging Technologies SoCal Gas
- Ben Machol - Manager Clean Energy & Climate Change Office US Environmental Protection Agency Region 9
- Christopher Patton, Environmental Affairs Officer Port of Los Angeles
- Kerry Cartwright Dir Goods Movement Port of Los Angeles
- Felix Oduyemi Senior Program Manager, Smart Grid Policy & Planning Southern California Edison
- Terry Penney, Laboratory Program Manager — Vehicle Technologies, National Renewable Energy Laboratories
- Paul Skalny, Managing Director and CTO - Venture Management Services
- Michael Roeth -Executive Director-North American Council for Freight Efficiency
- Doyle Sumrall -Senior Director of Business Development, Nati'l Truck Equp. Assoc.
- Ben Sharpe - International Council on Clean Transportation
- Connie Burek -Solutions Specialist, Heavy Equipment & Truck-IBM Global Business Services

CalHEAT Technical Advisory Group

Mark Howerton	Allison Transmission Inc
Darren Gosbee	Navistar Hybrid
Philip Schnell	AVL Powertrain Engineering
Jan Hellaker	Volvo Group
Dave Mazaika	Quantum Technologies
Joe Vollmer	Sturman Industries
Patric Ouellette	Westport Innovations
Jim Mancuso	Azure Dynamics
Mike Mekhiche	BAE Systems
Rudy Smalling	Cummins Inc
Vincent Duray	Eaton Corp
Dan Bowermaster	Electric Power Research Institute
John Duffy	Kenworth Truck Company
Mihai Dorobantu	Eaton Transmissions
Tim Carmichael	Cal Natural Gas Vehicle Coalition
Tony Greszler	Volvo Group
John LeGrandeur	Amerigon
Mark Greer	Altec
Dennis DePazza	Terex
Michael Britt	United Parcel Service
Joe Gold	Frito-Lay NA
Jordan Smith	Southern California Edison
Terry Penney	National Renewable Energy Labs
Doyle Sumrall	National Truck Equipment Assoc
Marc Wiseman	Ricardo Inc
Mike Simon	Transpower
Alan Welch	Westport Innovations
Mike Stark	Freightliner Custom Chassis
Gordon Excel	Cummins Westport
Dave Bryant	Daimler Trucks North America
Michele Duhadway	Bosch Rexroth
Jon Koszewnik	Achates Power
John Liputz	Westport Light Duty NA
Abas Goodarzi	US Hybrid
Jim Kesseli	Brayton Energy
Jeffrey Reed	Sempra

6 Truck Categories – Based on Tech Applicability

Class 7/8 Tractors

Over the Road

- Younger Trucks; High Annual VMT
- Mostly higher average speed, highway driving

Short Haul/ Regional

- Between cities; Drayage; Day Cabs
- Includes second use trucks; trucks with smaller engines

Class 3-8 Vocational Work Trucks

Urban

- Cargo, freight, delivery collection
- Lower VMT; Lower Average speed; Lots of stop start

Rural/ Intracity

- Cargo, freight, delivery collection
- Higher VMT; Higher Avg speed; Combined urban/ highway

Work site support

- Utility trucks, construction, etc.
- Lots of idle time; Lots of PTO use

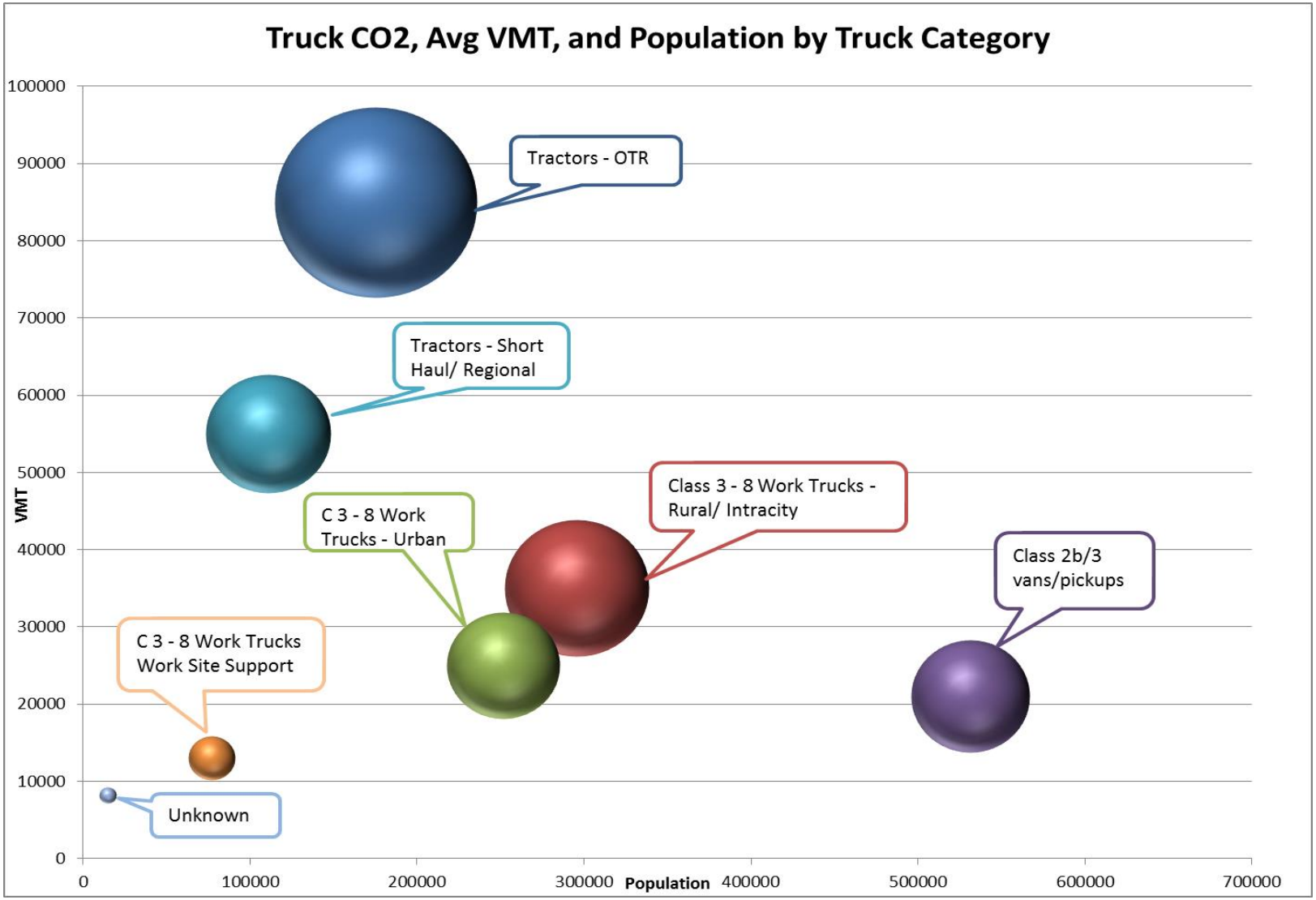
Class 2B/3

Pickups/ Vans

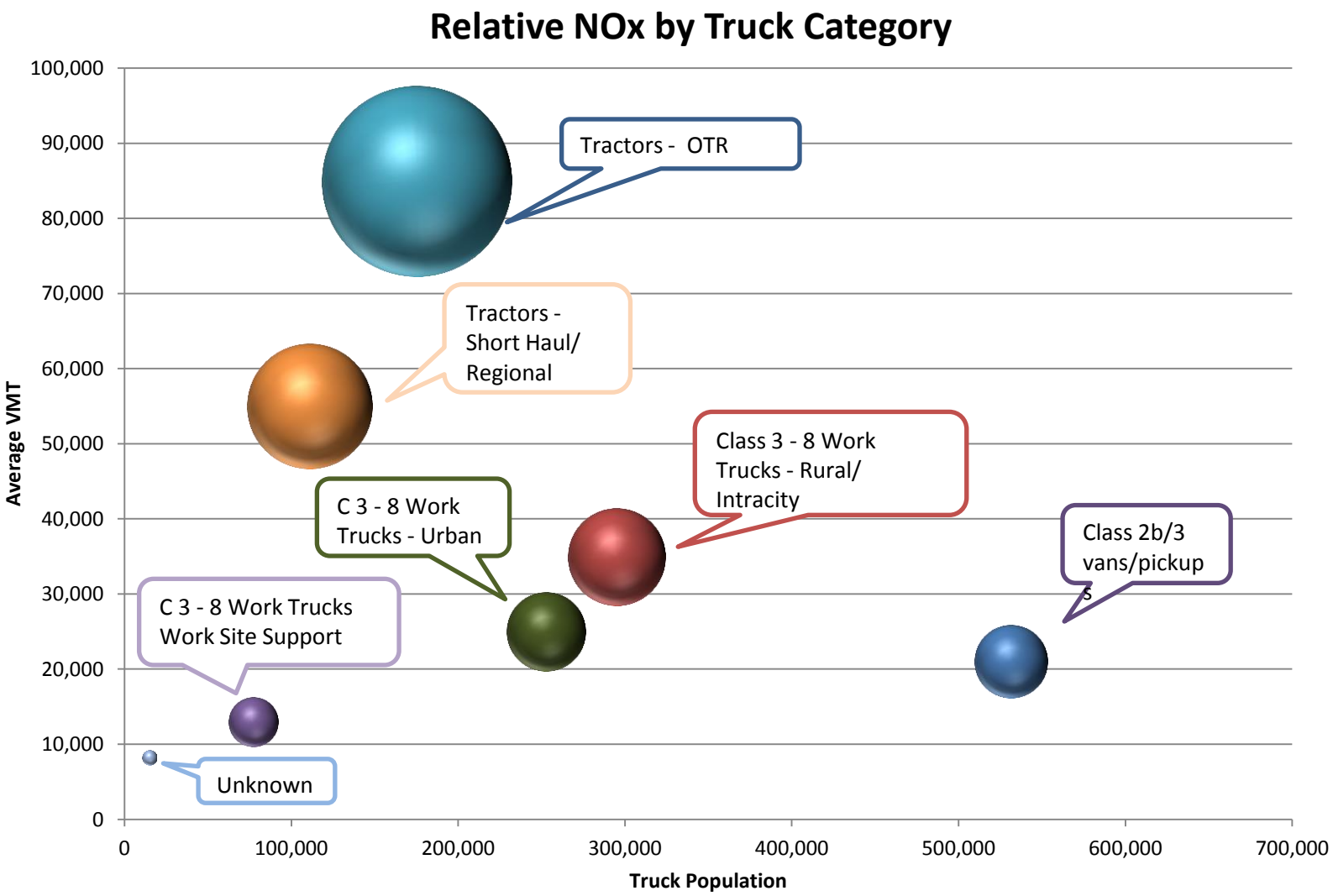
- Commercial use; Automotive OEMs & volumes

Where We Are: Truck Categories, 2010 Populations and CO2e Emissions

Vehicle Category	Truck Population	% Population	Average VMT	CO2e (MMT/yr)	% CO2e
Tractors - OTR	175,000	12%	85,000	12.9	38%
Tractors - Short Haul/ Regional	111,000	8%	55,000	6.3	18%
Class 3 - 8 Work - Urban	253,000	17%	25,000	3.6	11%
Class 3 - 8 Work - Rural/ Intracity	295,000	20%	35,000	6.1	18%
Class 3 - 8 Work - Work Site	77,000	5%	13,000	0.8	2%
Class 2b/3 vans/pickups	531,000	36%	21,000	4.2	12%
Unknown	15,000	1%	8,192	0.1	0%
Total	1,457,000	100%	34,255	34.0	100%



Area of circle: CO_2e *x* axis: truck population in CA *y* axis: avg. annual VMT



Area of circle: NOx ***x* axis: truck population in CA** ***y* axis: avg. annual VMT**

Technology Strategies

Advanced Electrification

- Hybrid-electric
- Electrified accessories
- Full electric powertrains
- Electrified Power take-off (PTO)
- Plug-in hybrid-electric
- External power to electric powertrain for ZEV Corridors
- AF/Hybrid Combinations

Engine and Driveline Efficiency

- Hydraulic hybrid
- Optimized engines for alternative fuel (AF)
- Energy recovery
- Engine efficiency improvements
- Alternative power plants and combustion cycles
- Transmission and driveline improvements

Chassis, Body, and Roadway Systems

- Light weighting
- Aerodynamics
- Lower rolling resistance
- Intelligent vehicle technologies, e.g. forecasting, adapting
- Corridors and platooning
- Longer, heavier single trucks

Hybrid Electric

Technology

Stage 1 economic goal: Lifetime ROI
Stage 1 performance goals may include:
- Demonstrate hybrid functionality
- Commercially available
- Fuel economy improvement of 20 to 30%

Stage 1 technical characteristics may include:
No engine off at idle, no electric accessories

Stage 2 builds off Stage 1...
Stage 2 economic goal: ROI 5 years w/o incentives
Stretch goal: ROI 2-4 years
Stage 2 technical characteristics may include:
- Engine off at idle
- Electric accessories (may not show up until Stage 3)
- Improved design and integration (most important)
- Fuel economy gain of 30-50% (can be sacrificed for low cost system)
- Alternatively a simpler, light hybrid approach with strong ROI
- Capable of meeting CA OBD

Stage 3 builds off Stage 2...

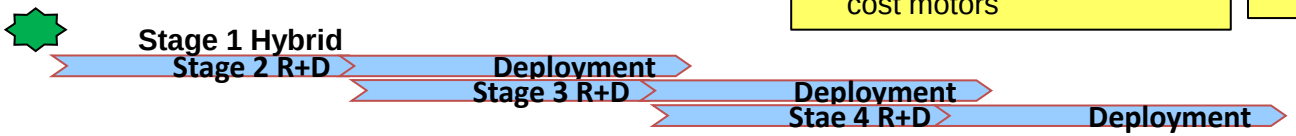
Stage 3 economic goal: ROI 3-5 years

Stage 3 technical characteristics may include:
- Optimized engine system and integration
- Increase energy storage to 5 kWh; design to take advantage of greater energy storage; better regen; greater idle capacity
- CARB OBD compliant
- Much larger electric motors (>65 kW), especially for series architecture; reduced cost motors

Stage 4 builds off Stage 3...

Stage 4 economic goal: ROI 2-4 years

Stage 4 technical characteristics may include:
- Emergence of OTR hybrid-electric trucks as ROI decreases further and payback is within initial ownership of OTR tractors
- Enhanced performance from further enlarged energy storage capacity



Actions

Stage 2 Action Items (draft list):
- SAE standardization of OBD interfaces (J1939)
- **Pre-commercial demonstration** support to hybrid driveline developers to improve design & integration (3 x $4m per platform direct); requires ARB OBD compliance
- Create pull for e-accessories through requirements of solicitations
- **Deployment Incentive** support for Stage 2 hybrids; start when Stage 2 hybrids are commercially available (3yrs, lower per-vehicle incentive than today)

Stage 3 Action Items (draft list):
- **R&D** prototype project for hybrid-specific optimized engines and combustion cycles for hybrid applications Integrate battery, electric motor and power electronics advancements from other pathways (lower cost, improved performance)

Stage 4 Action Items (draft list):
- **Pre-commercial demonstration** funding for the more-electric OTR hybrid truck

2012 2014 2016 2018 2020

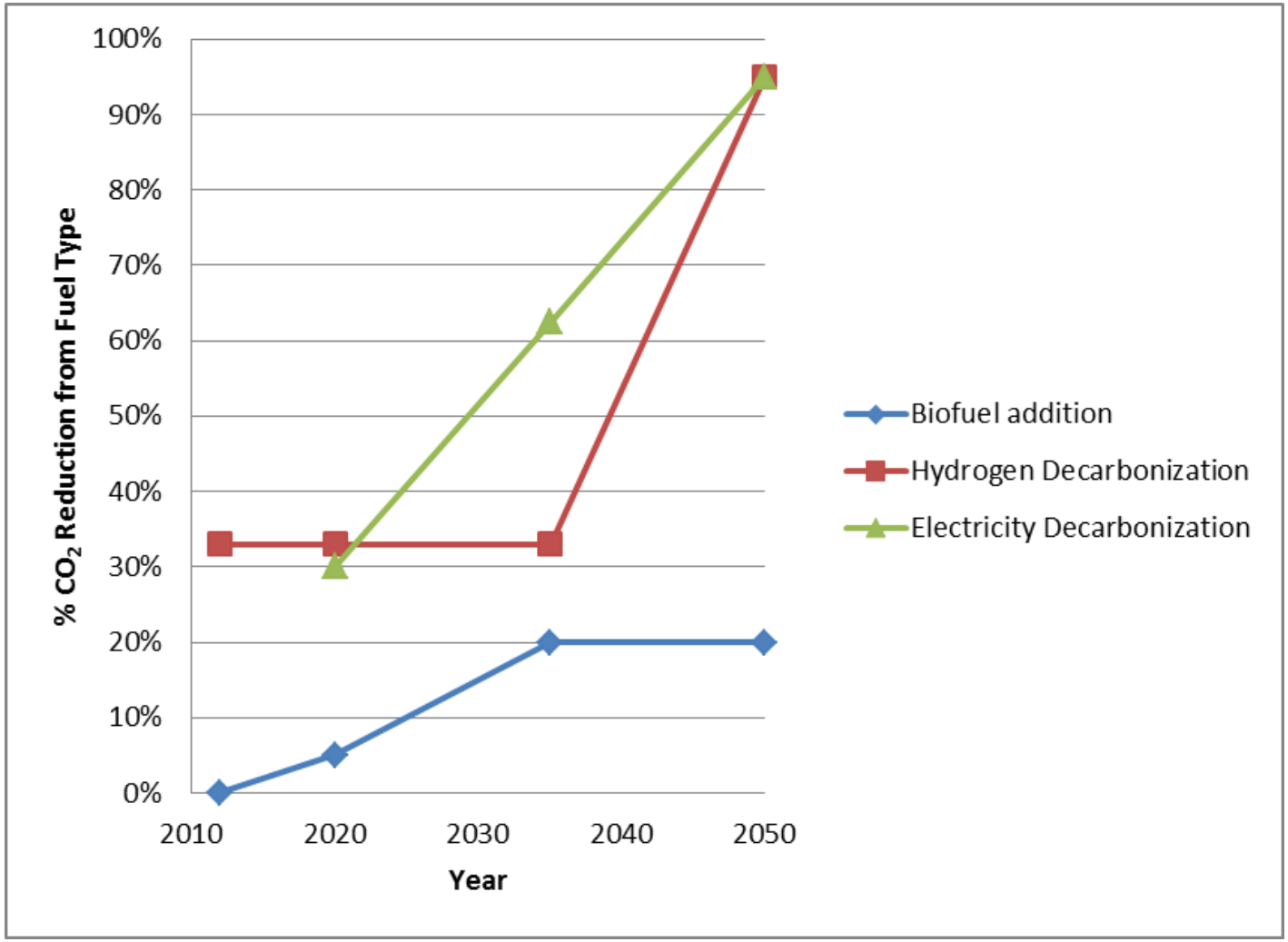
Technology Actions

CalHEAT uses five types of actions to accelerate technology solutions in the market

Studies	R&D	Pilot Demo	Precomm. Demos	Deploy. Incentives
Includes business case or technology feasibility studies.	Research and Development is a component or systems development activity for drivetrain systems and software.	A pilot demonstration is the full integration into a truck of a newly developed component or system to evaluate performance.	Pre-commercial demonstrations involve 1 to 50 trucks to evaluate performance in the field. Further system refinement precedes commercial production.	Incentives for early deployment (when a supplier sells a commercial product in the marketplace)

CO2 Reduction Methodology

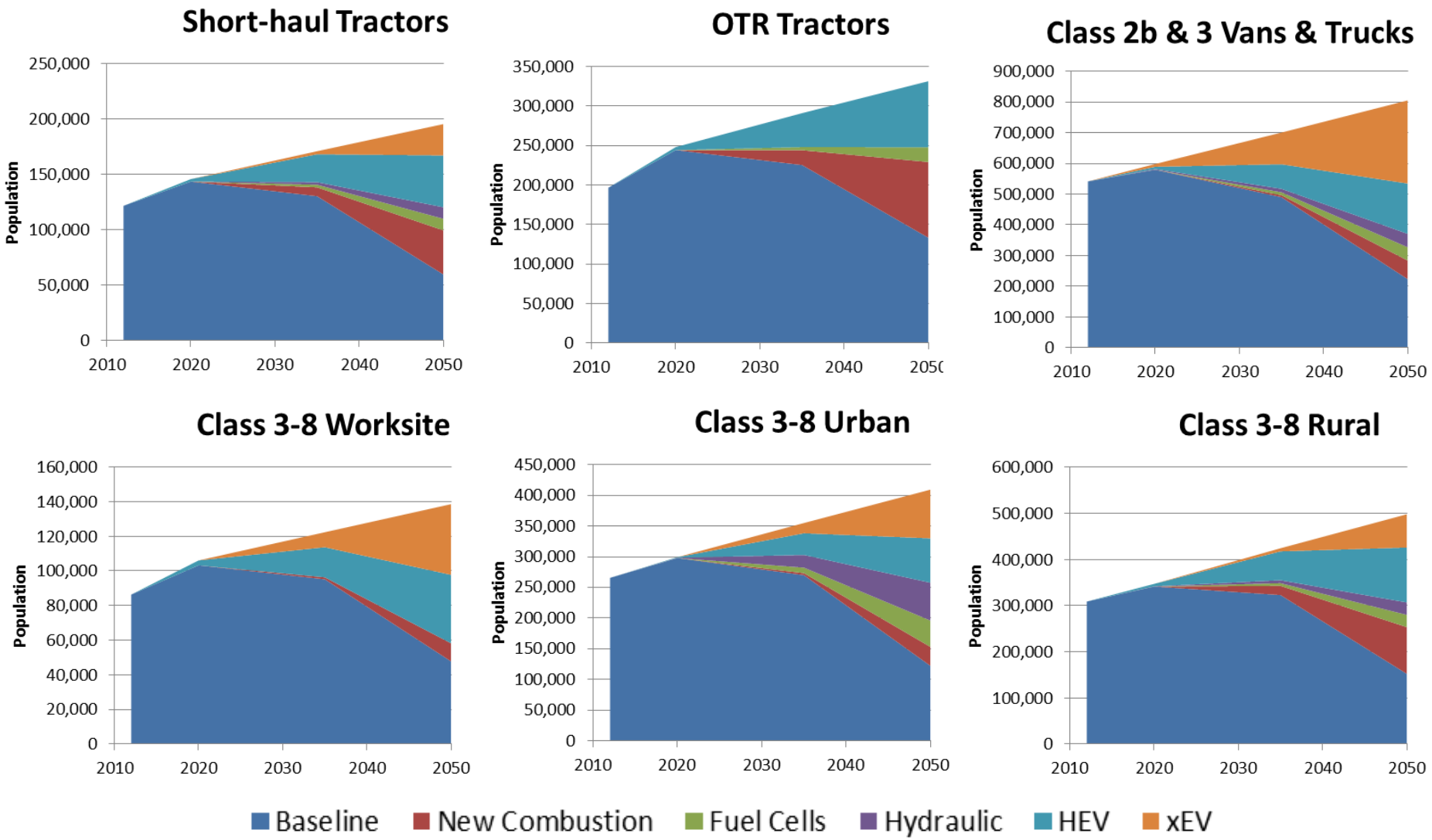
- Fuels accounted for some of CO2 reduction…



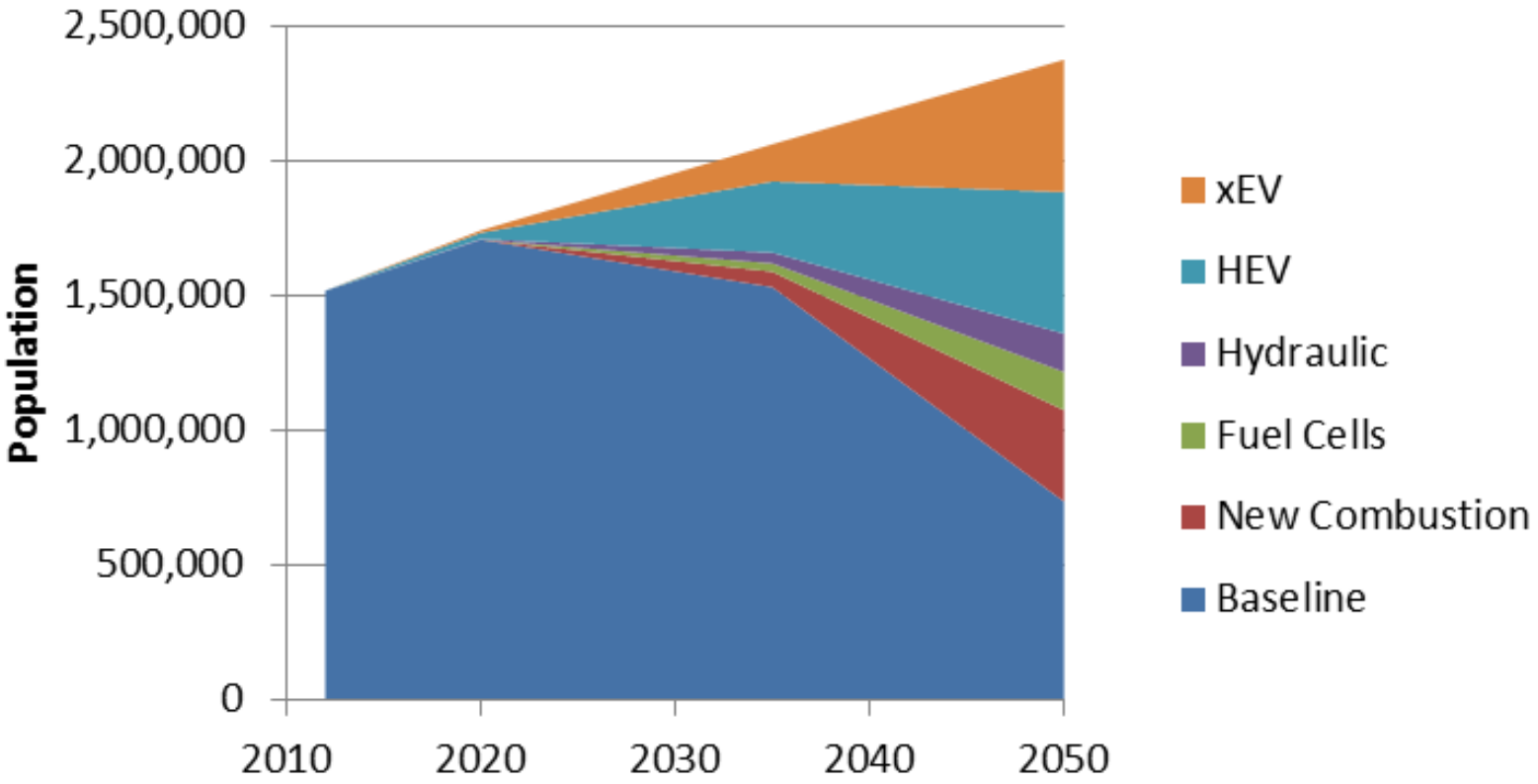
Technology Evaluation Grouping

Baseline	**Energy recovery** **Engine efficiency improvements** **Transmission and driveline improvements** **Light weighting** **Aerodynamics** **Lower rolling resistance** **Intelligent vehicle technologies, e.g. forecasting, adapting** **Corridors and platooning** **Longer, heavier single trucks**
New Combustion	**Alternative power plants and combustion cycles**
Fuel Cells	**Alternative power plants / Alt fuels**
Hydraulic	**Hydraulic hybrid**
HEV	**Hybrid-electric** **Electrified accessories** **Electrified Power take-off (PTO)**
xEV	**Full electric powertrains** **Plug-in hybrid-electric** **External power to electric powertrain for ZEV Corridors**

Technology Adoption Rates

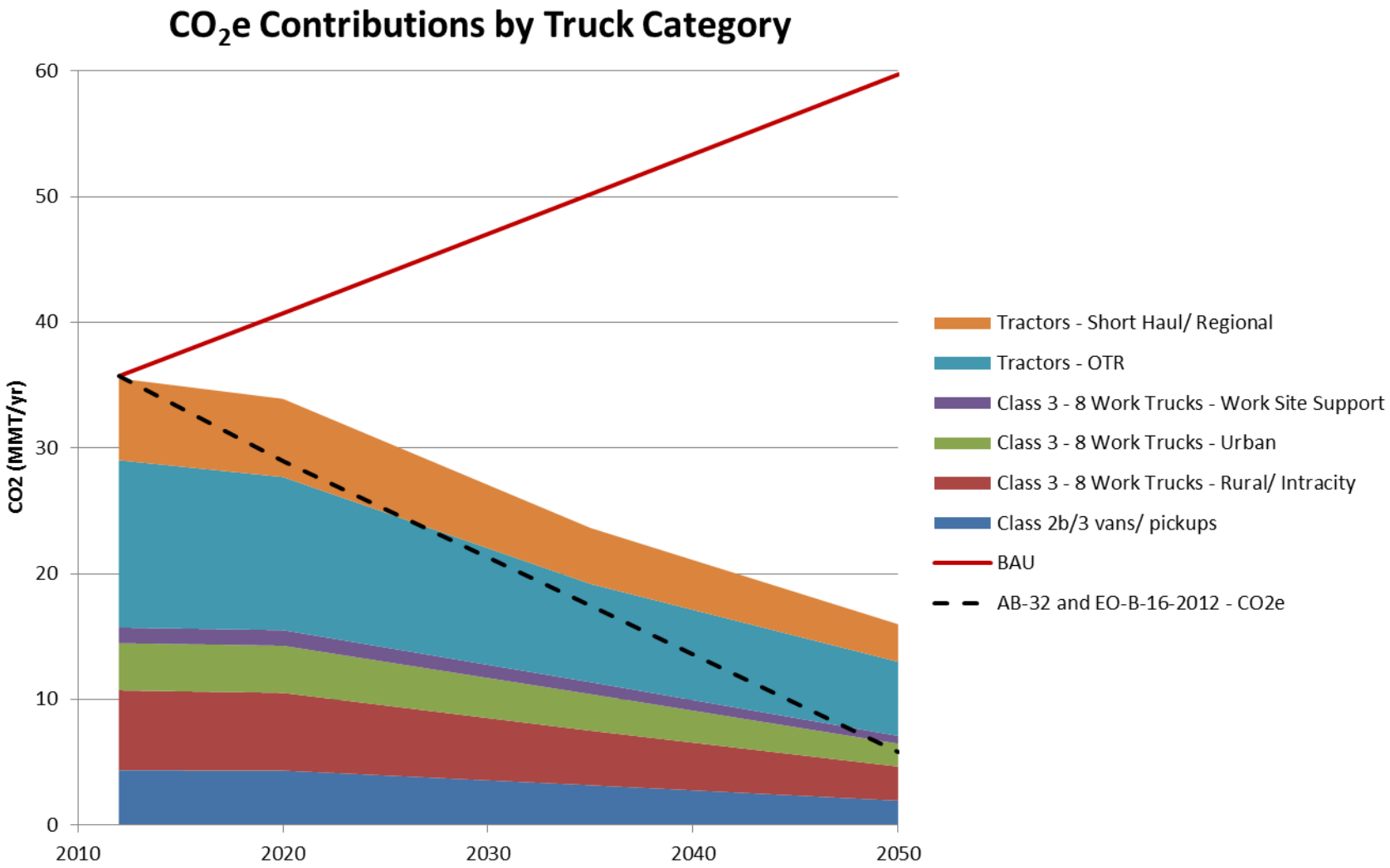


Technology Adoption



All Truck Categories

CO2 Reduction from Roadmap



A Most Critical Assumption

- Roadmap assumes greater than two times fuel economy improvement standards to be established by EPA/NHTSA under phase 2 Federal Truck Regulations 2018
  - Phase two standards are under development now
  - Without fuel economy regulations of two times, GHG from medium and heavy trucks likely to slide by ten years+ due to lack of industry investment

General Make up of the 2050 M-HD Truck Solution to Support 2050 GHG Target Reduction

- Growth Areas
  - Nearly 45% of truck 2050 inventory will include significant electrification of the vehicles
    - Pure EV
    - Plugin Electric Hybrid and Dual mode vehicles for the ZE corridor I-710 Los Angeles Ports
    - Hybrid
    - Fuel Cell Range Extension
    - Electrified Accessories and Electric Power Takeoff

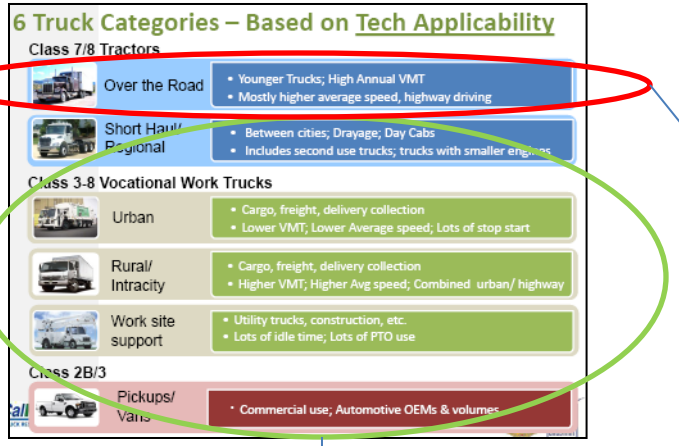
General Make up of the 2050 M-HD Truck Solution to Support 2050 GHG Target Reduction

- Growth Areas
  - 4% Hydraulic Hybridization- mostly refuse and delivery vehicles
  - 15-20% New combustion technologies including opposed piston engines, camless-digitally controlled engines and turbines

General Make up of the 2050 M-HD Truck Solution to Support 2050 GHG Target Reduction

- Diminishing Growth
  - Baseline Conventional Engine Technology still a robust 35-40 %
  - Include advanced engine efficiency technology derived from Waste heat recovery , general engine efficiency improvements combined with well integrated transmission and driveline efficiency improvements

Need for More Action on Commercialization of Lower GHG Solutions for Over the Road Trucks



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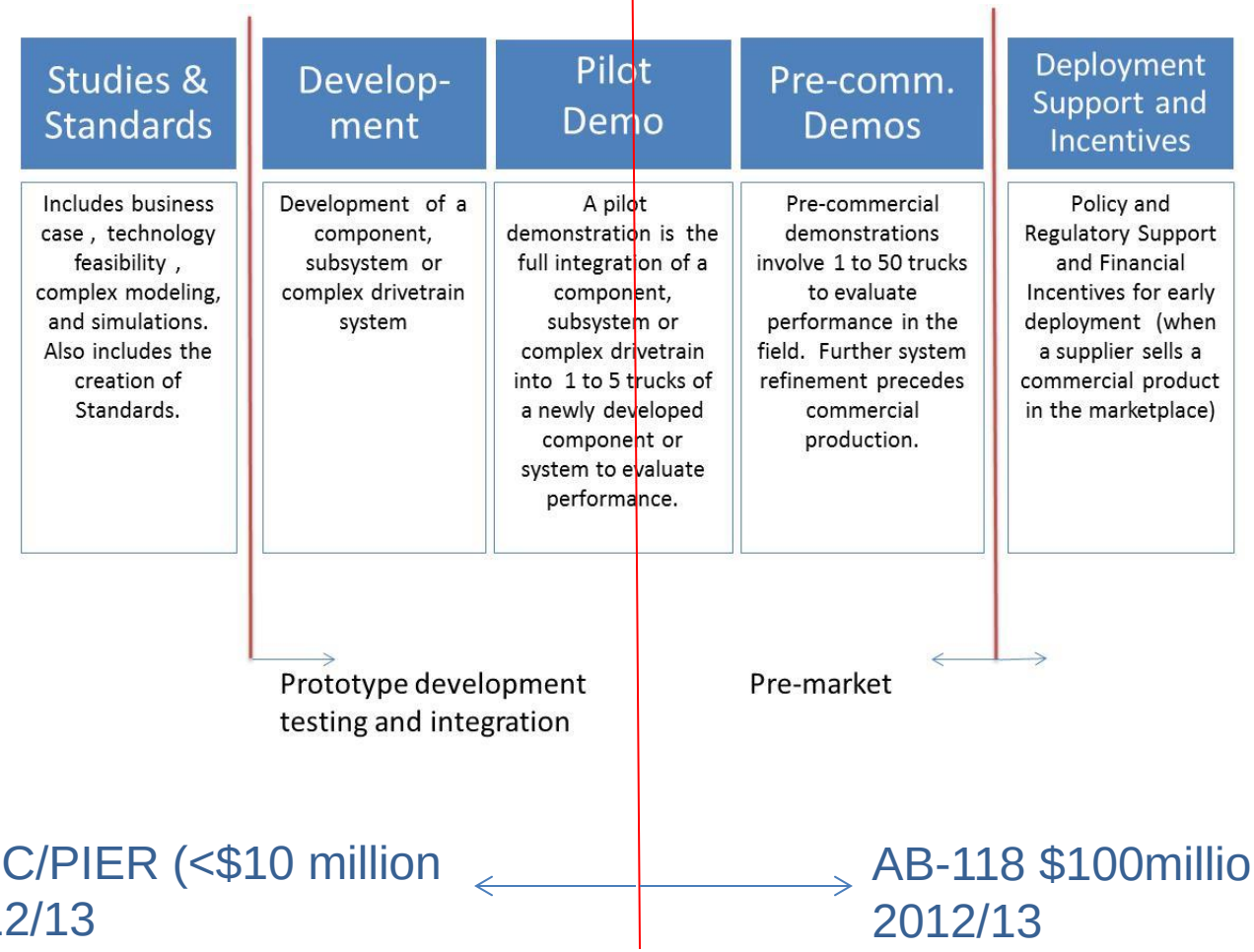
Demo Commercialization Momentum Occurring

A lack of momentum in developing and demonstrating Hi-Efficiency Solutions to address the 38% Problem

Technology Development

- Enabling technologies will be key for cost effective electric vocational work trucks and Class 8 OTR trucks
  - i.e. DC-DC converters , Aux motor drives, Waste heat recovery etc.
  - These enabling technologies need development and pilot demonstration funding

A Need for More Investment in Development and Pilot Demonstrations



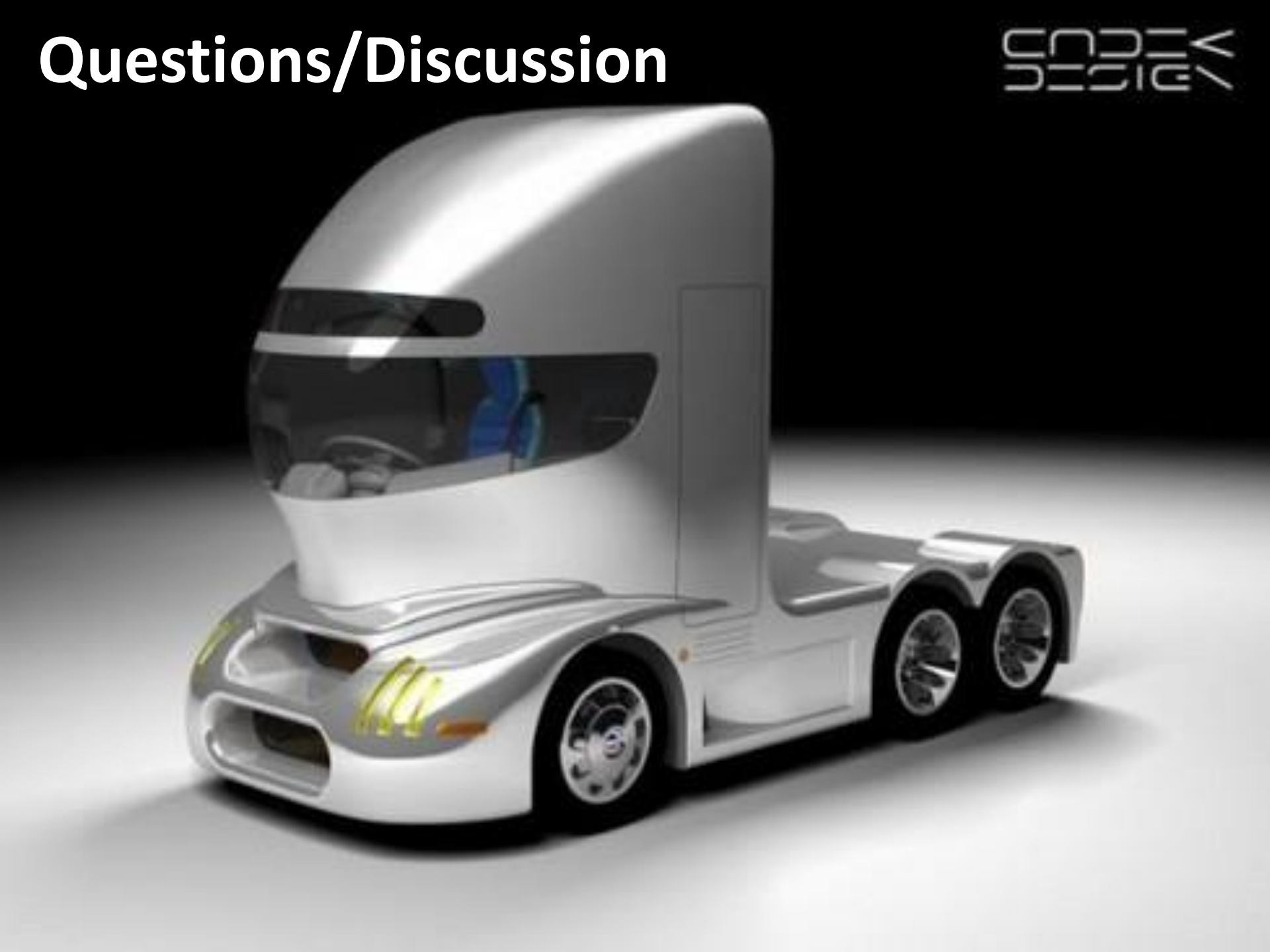
+ Several High level Follow-on Recommendations

- Perform additional research on new focus areas that have significant impacts on the roadmap but were not necessarily a focus of the initial CalHEAT work
  - Biofuel Availability and Projections for Medium and Heavy Duty Vehicles.
    - Update forecasts for potential production of renewable natural gas, renewable diesel and bio-diesel.
    - Develop and implement a Bio-Fuel Adoption Plan
  - Best Policies, Technologies and Practices in Reducing Vehicle Miles Traveled
    - (VMT). State predictions for VMT are significant and can easily contribute up to 25 million metric tons of CO2 per year by 2050.
    - Work with CalHEAT and CAlTrans to Develop and implement action plan for Intelligent vehicles leading to reduced VMT.

Development and Research – Top Issues

- Develop a Center for Class 8 Truck Focus in SJ Valley because of size of challenge
  - 38% of C02 while 12% of the vehicles
  - Would work with fleets who operate thru the central valley
  - Center could focus on
    - Use of CNG to provide lower Nox and C02
    - Greater electrification of the powertrain i.e. solid-state waste heat recovery-hotel load electrification and electrifies auxiliaries
- Implementation of the CalHEAT roadmap
  - Technology forums similar to the CALHEAT Forums to keep the industry moving forward
  - Maintain Advisory Council and Steering Committee to arrange and plan the technical interchange and dialogues of the greatest benefits

Questions/Discussion



CalHEAT TRUCK RESEARCH CENTER

www.calheat.org