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Natural Gas Pathways to Achieve Air Quality Goals

Presentation to
CEC-IEPR Workshop on Transportation
April 10, 2014

Natural Gas: A Foundational Fuel

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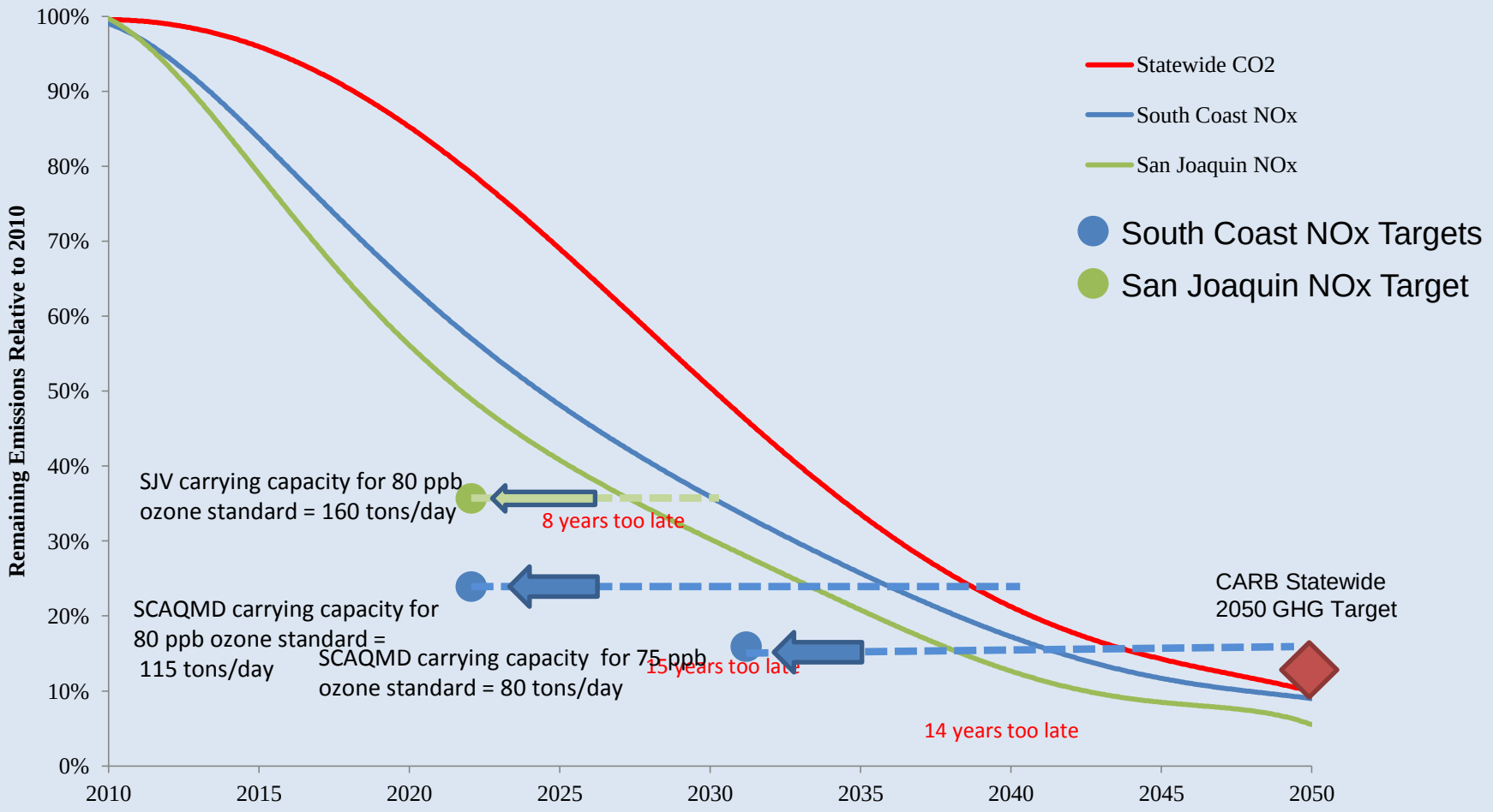
- ✓ Abundant
- ✓ Affordable
- ✓ Domestic

Overview

- Natural Gas technology is relatively mature offering the opportunity to achieve significant emissions reductions in the near term
- Low natural gas prices will aid adoption as an economic decision
- Tanks and fuel systems are the largest contributors to vehicle cost differential – both will come down significantly over the next 10 years
- A variety of technology advances and increasing blends of Renewable Natural Gas will allow NG solutions to meet NOx and GHG goals over the mid and long term

Current Glide Paths Miss Emissions Goals



Source:
Curves based on CARB Vision for clean air Scenario 3 in CARB vision model, available at http://www.arb.ca.gov/planning/vision/vision.htm

Natural Gas in Reducing Emissions

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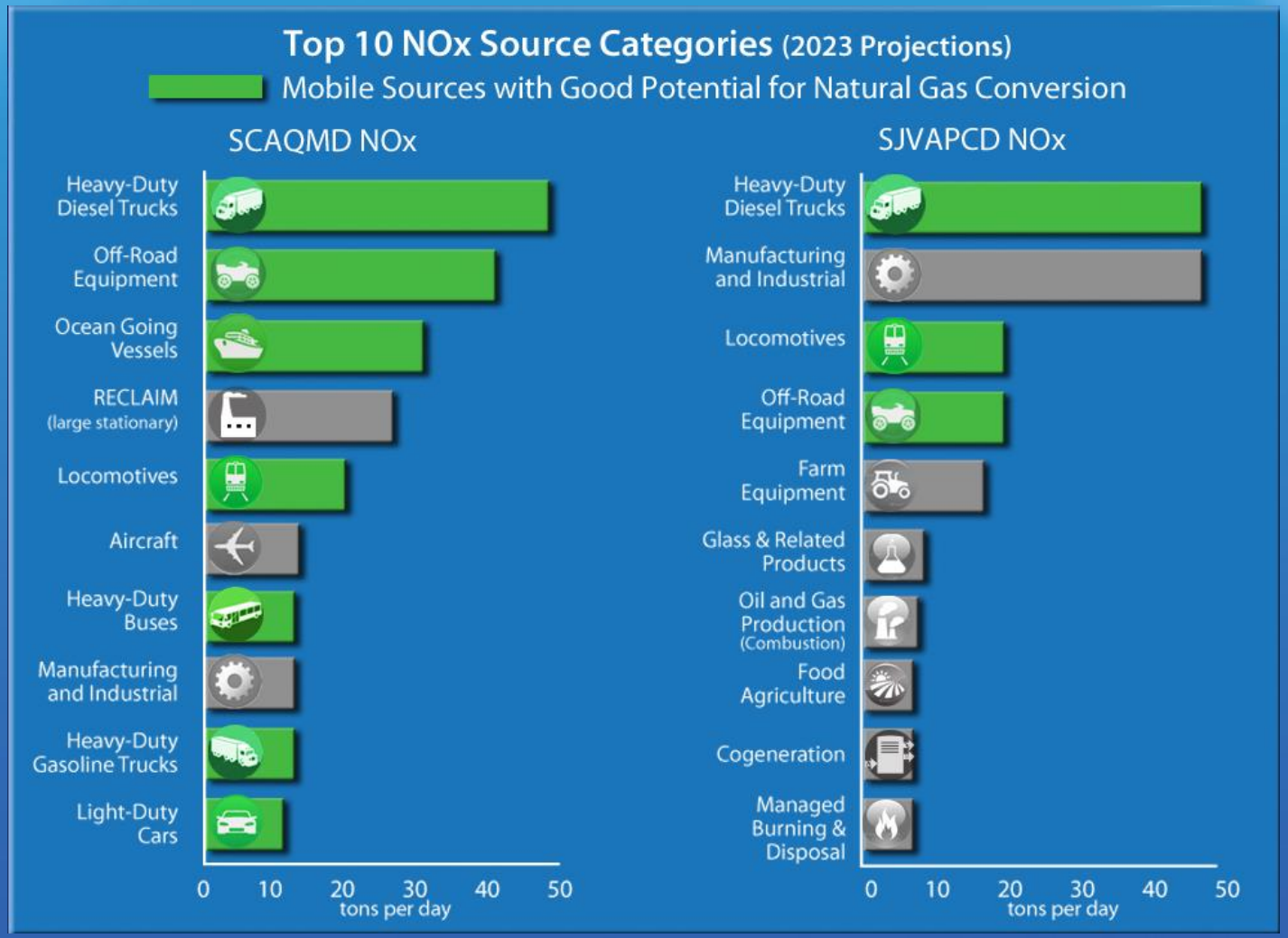

Potential for rapid increase in the N-ZEV Fleet

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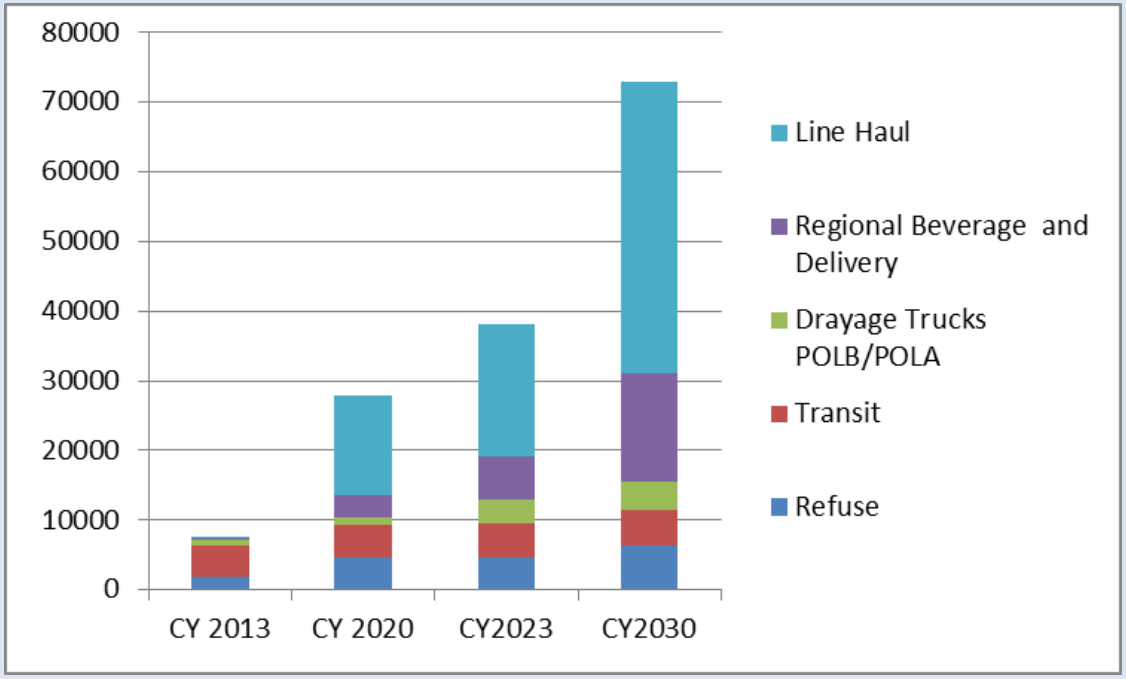
SoCal Regional NG HDV Adoption Firecast Scenario

Market Share Scenarios	CY2013	CY2020	CY2023	CY2030
Refuse	28.0%	55.5%	53.2%	62.4%
Transit	68.8%	68.8%	68.8%	68.8%
Drayage POLA / POLB	6.9%	6.9%	21.5%	22.1%
Regional / Beverage / Delivery	0.2%	5.5%	10.5%	24.5%
Line Haul	0.2%	8.7%	11.1%	21.3%
Total	4.0%	10.9%	14.5%	24.6%



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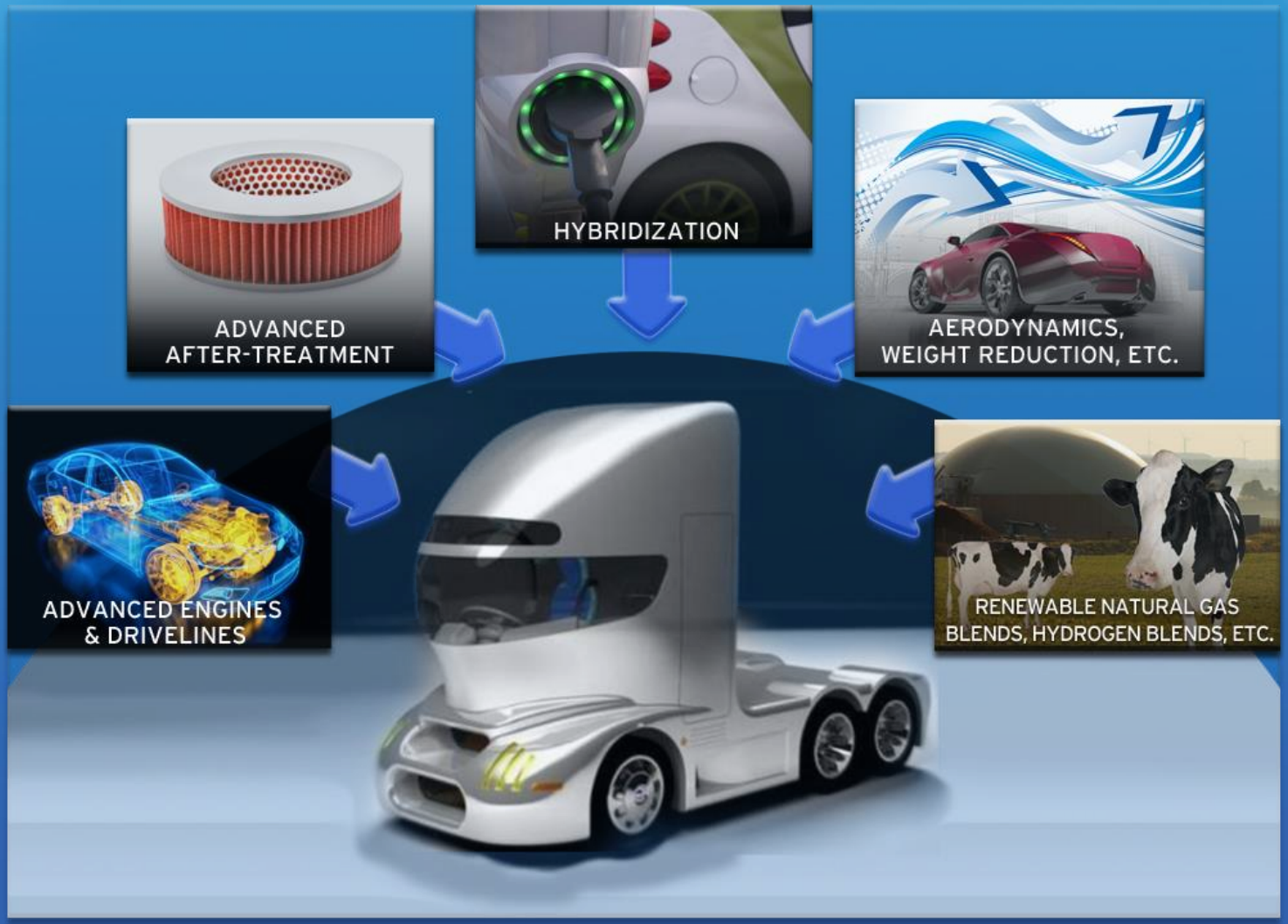
Five Strategies to Further Reduce NOx and GHG Emissions from NGVs



NOx Reduction Pathway

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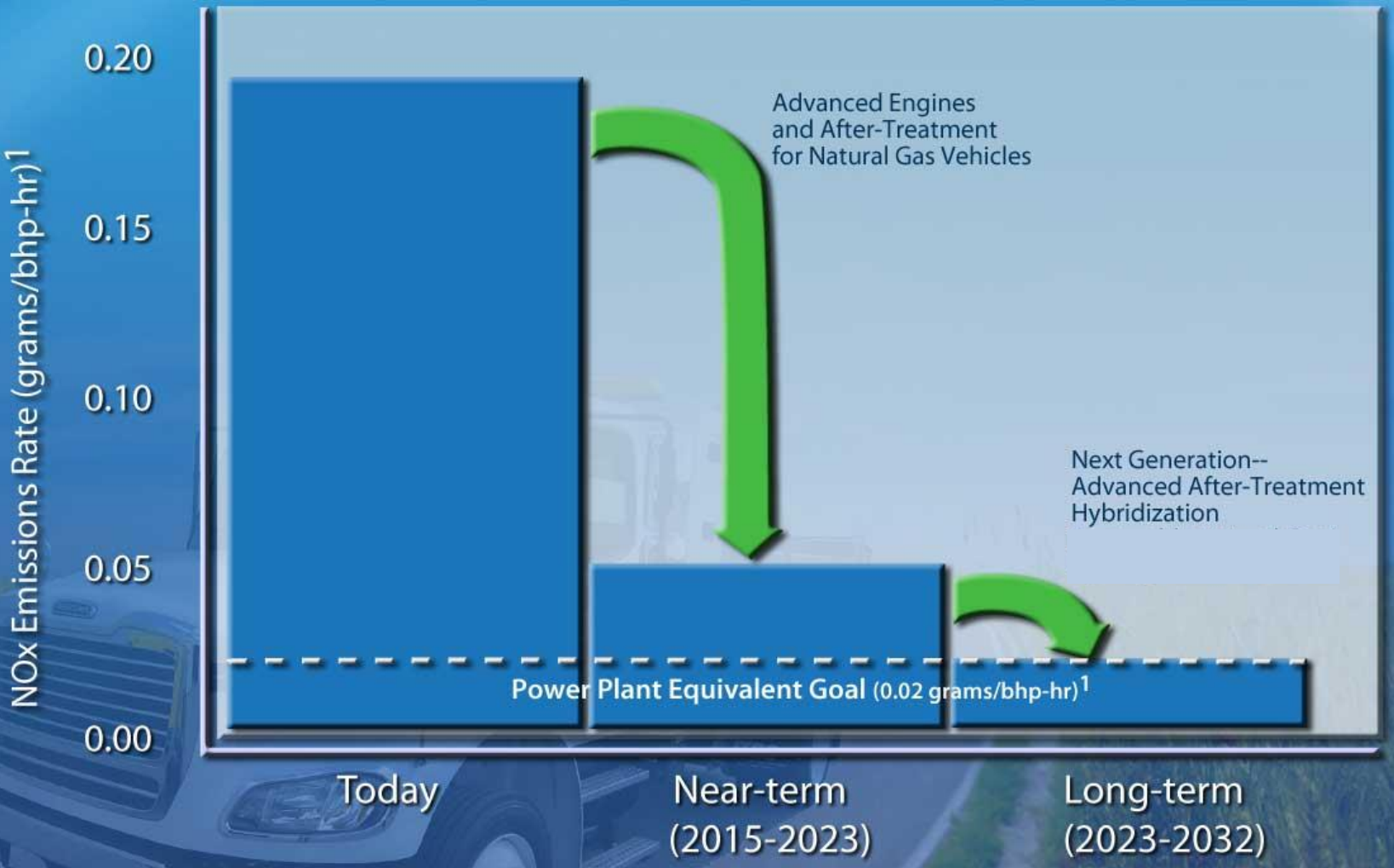

GHG Reduction Pathway

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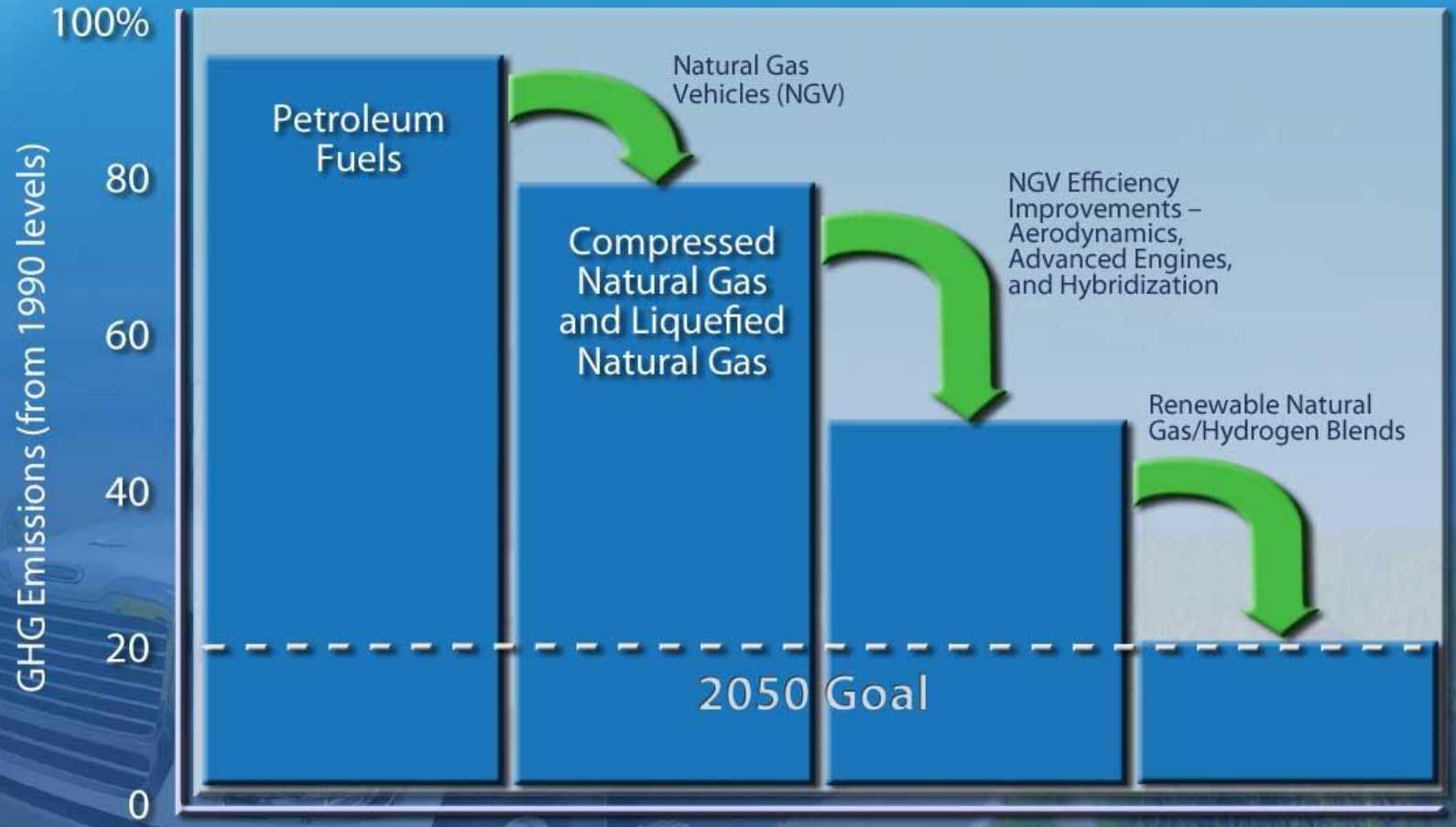

Roadmap for NOx Reductions from Natural Gas HDVs

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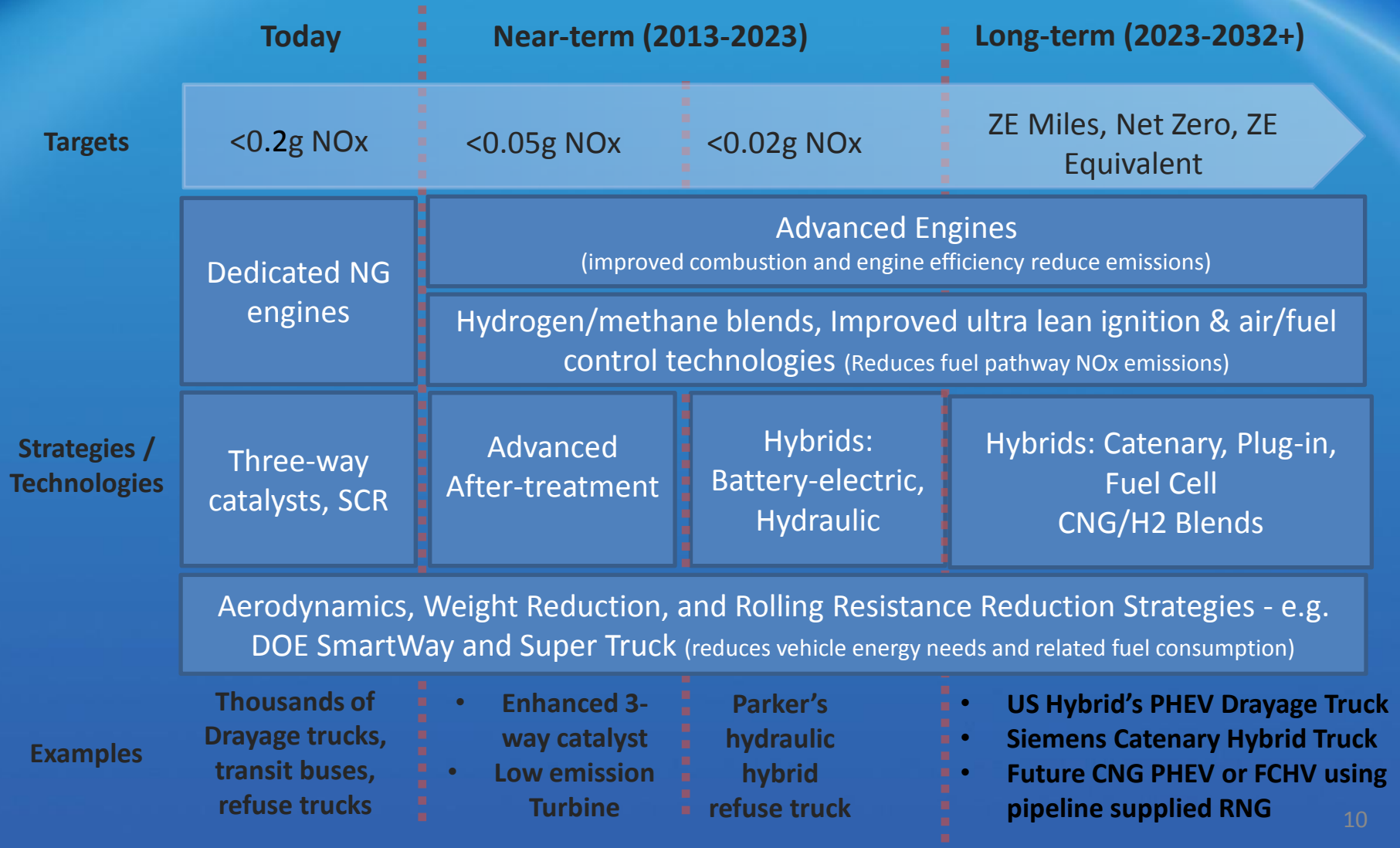

Roadmap for GHG Reductions from Natural Gas HDVs

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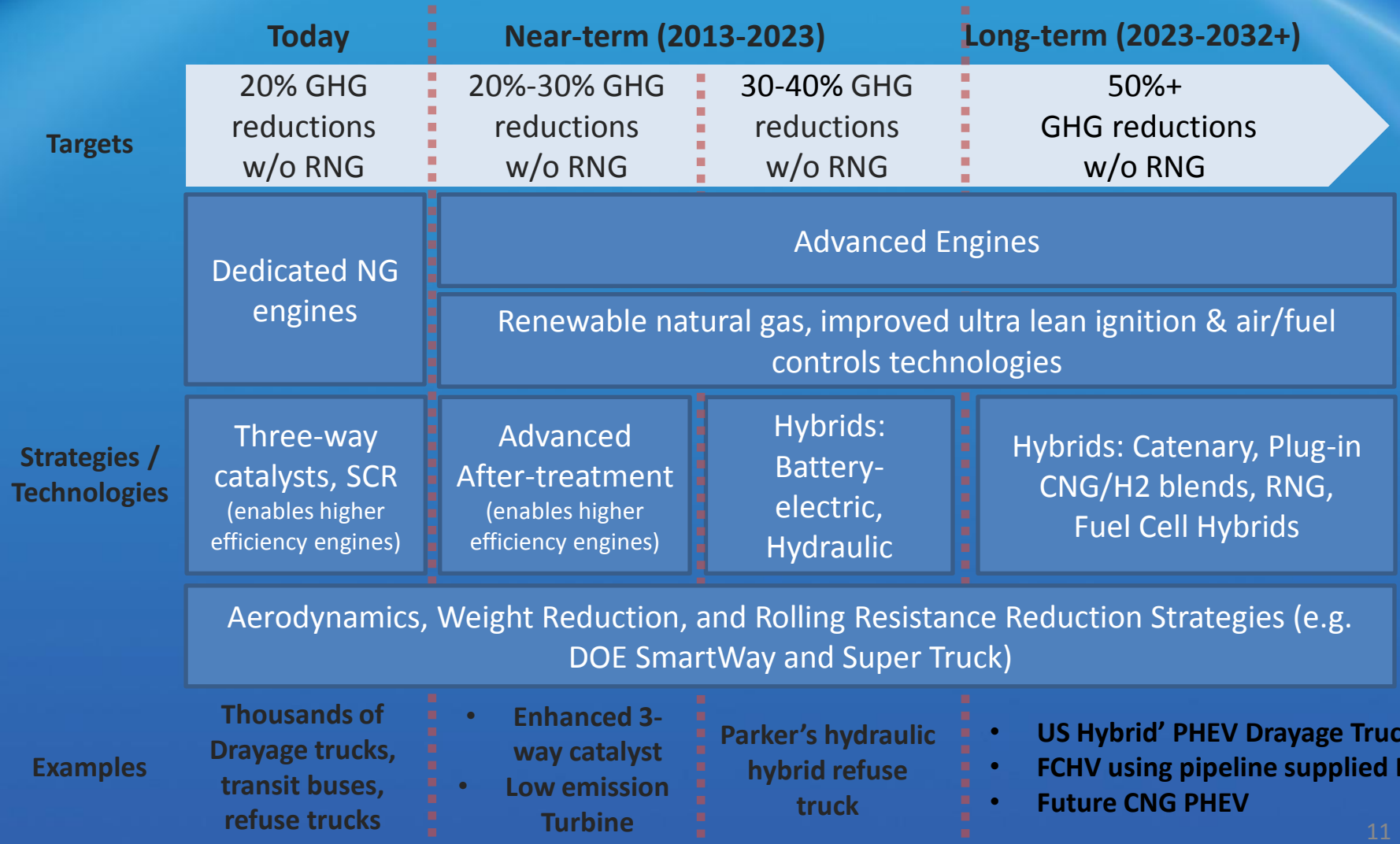

Siting Natural Gas Infrastructure in Proximity to Other Fleets Can Accelerate Emission Reductions:

Ports Example

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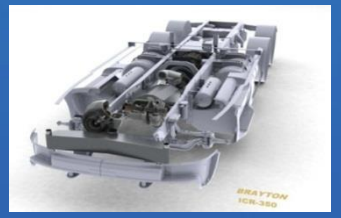
Putting the Strategies Together in a Pathway Example: Long Haul Truck

Today		By 2023		By 2032
Spark Ignition + EGR+TWC •<0.20 g NOx •~40% efficiency	• **Engine Efficiency Improvements** • **Lower NOx Emissions Targets**	•<0.05 g NOx •~40-45% efficiency	**New Engines (Gas Turbine)** **Near Zero Emissions Target** **Aero, Weight, Tires** **Renewable NG + H2 blending**	**Near Zero Emission Gas Turbine** •<0.02 g NOx •~55% efficiency
Benefits • Available today • ~20% GHG benefits vs. diesel		**Benefits** • 75% NOx reductions • ~30% GHG reductions		**Benefits** • Power plant-equivalent NOx emissions • Up to 50% less GHG without RNG blending



Putting the Strategies Together in a Pathway Example: Drayage/Short Haul Truck

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Today		By 2023		By 2032
Spark Ignition + EGR+TWC •<0.20 g NOx •~35-37% efficiency	•New Engines Sizes •Improved engines / after-treatment •Hybridization	**SI & Compression Ignition + Heat Recovery** •<0.05 g NOx •~45% efficiency	**Engine Efficiency Improvements** **Near Zero Emissions Target** **CNG-Hybrid (Extended all-electric range)** **Aero, Weight, Tires** **Hydrogen Blending**	**Zero Emission NG/H_2 Hybrid** •<0.02 g NOx •~55% efficiency
Benefits • Available today • ~20% GHG benefits vs. diesel		**Benefits** • Zero emission miles possible • 75% NOx reductions • 30%+ GHG reductions		**Benefits** • >70 zero emission miles per day • 50% + GHG reductions • Supports H2 fueling infrastructure dev

Extending the Pathways to The Ports Natural Gas for Cargo Handling Equipment

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Today		By 2023		2032+
Spark Ignition + EGR+TWC •<0.20 g NOx •~35-37% efficiency	•Improved engines / after-treatment (following on-road development)	**Compression Ignition + Heat Recovery** •<0.05 g NOx •~40% efficiency	**Engine Efficiency Improvements** **Near Zero Emissions Target** **CNG-Hybrid** **Hydrogen Blending**	**Zero Emission NG Plug-in Hybrid** •<0.02 g NOx •~55% efficiency
Benefits • Available today • ~20% GHG benefits vs. diesel		**Benefits** • 75% NOx reductions • 30%+ GHG reductions		**Benefits** • ZE miles possible • Eliminate idling • 90% NOx reductions • 70% + GHG reductions

Extending the Pathways to Off Road Locomotives

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Today	2013-2015	2015-2023	2023-2032	2032+

Existing Tier 2 Locomotive
•5.5 g NOx

- **New engine options (HPDI, dynamic gas blending)**
- **LNG Tender Car**

- **Tier 2 LNG Retrofits (<**3 g NOx)
- **Tier 4 LNG Newbuilds** (<1.3 g NOx)

Solid Oxide Fuel Cell Technology

Near Zero Emissions Target

Renewable NG blending

NZ-Emission Natural Gas Fuel Cell Locomotive
•<0.02 g NOx
•>60% efficiency

Ongoing RD&D for LNG fuel systems and engine conversions

Benefits
- Tier 2: 45% NOx reductions
- Tier 2 and 4: 20% GHG reductions vs Tier 2 diesel

Benefits*
- 98% + NOx reductions vs Tier 2 diesel
- 55%+ GHG reductions vs Tier 2 diesel w/o RNG

Extending the Pathways to The Ports
LNG for Marine Vessels

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Today	2013-2015	2015-2018	2018-2023	2032+

Existing Tier 1 & 2 Vessels

- **Ongoing RD&D for LNG fuel systems and vessel retrofits.**
- **Development of LNG bunkering standards and infrastructure**

- **1,000 ppm fuel sulfur limit for marine vessels in ECAs**
- **IMO Tier 3 NOx standards**

- **Tier 1& 2 LNG retrofits**
- **Tier 3 LNG new builds**
- **First LNG work boats, ferries, short sea shipping vessels deployed**

Benefits
- Up to 90% NOx reductions
- 98%+ PM and SOx reductions
- 20%+ GHG reductions

Tankers

Container Ships

Tug boats (new builds)

Expanded LNG bunkering

Vessel hydrodynamics

Vessel size increases

High penetration of LNG into marine vessel fleet – estimated at 10,000+ vessels

Benefits
- **NOx, PM, and SOx reductions beyond IMO Tier 3**
- **GHG reductions of up to 70%**

Numerous RNG and Related H2 Pathways Being Pursued

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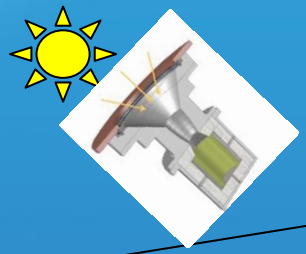
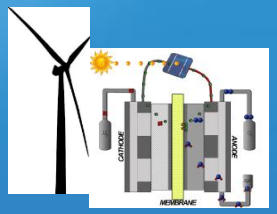
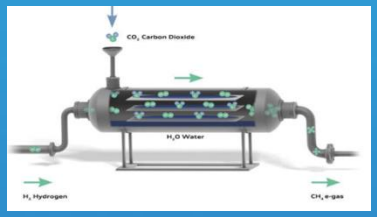
Solar Thermal Catalytic H2 Production
0.6% Energy Loss
TRL = 2



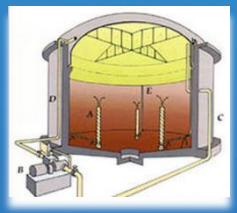


Renewable P2G H2 Production
33% Energy Loss
TRL = 9

Gasification
22% Energy Loss
TRL = 7



Methanation
20% Energy Loss
TRL = 7



Anaerobic Digester
3% Energy Loss
TRL = 9

CO2

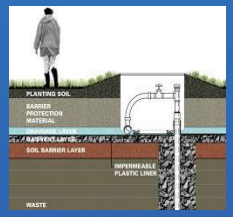
$CH4/CO_2$ Separation
Pressure Swing Adsorption
Amine Scrubbing
Water Scrubbing
Membrane
3% Energy Loss
TRL = 8

Compression, Odorization, Quality Control & Injection
0.6% Energy Loss
TRL = 9

Dry / Woody

Wet

Organic Matter



Landfill Biogas Collection

WWTP Biogas Collection

Current cost range $10 - $41/ MMBtu + transportation

Technology Development Priorities

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- Natural Gas Engine (and Turbine Drive) Development
- Next generation after-treatment
- Mild hybrids for accessories and fuel economy (tailored to duty cycle)
- Low-cost storage tanks (3600 psi and lower-pressure sorbent systems) – note that this is synergistic w/ FCV
- Low-cost compression systems including lower-capacity systems (small fleets… home refueling)
- Renewable Natural Gas pathways