Lower Carbon Technologies

International Transport Forum Expert Workshop
June 28-29, 2018

Dr. Michael Traver

Commercial Transport Fuels Research

where energy is opportunity™

where | Aramco Locations and Connections

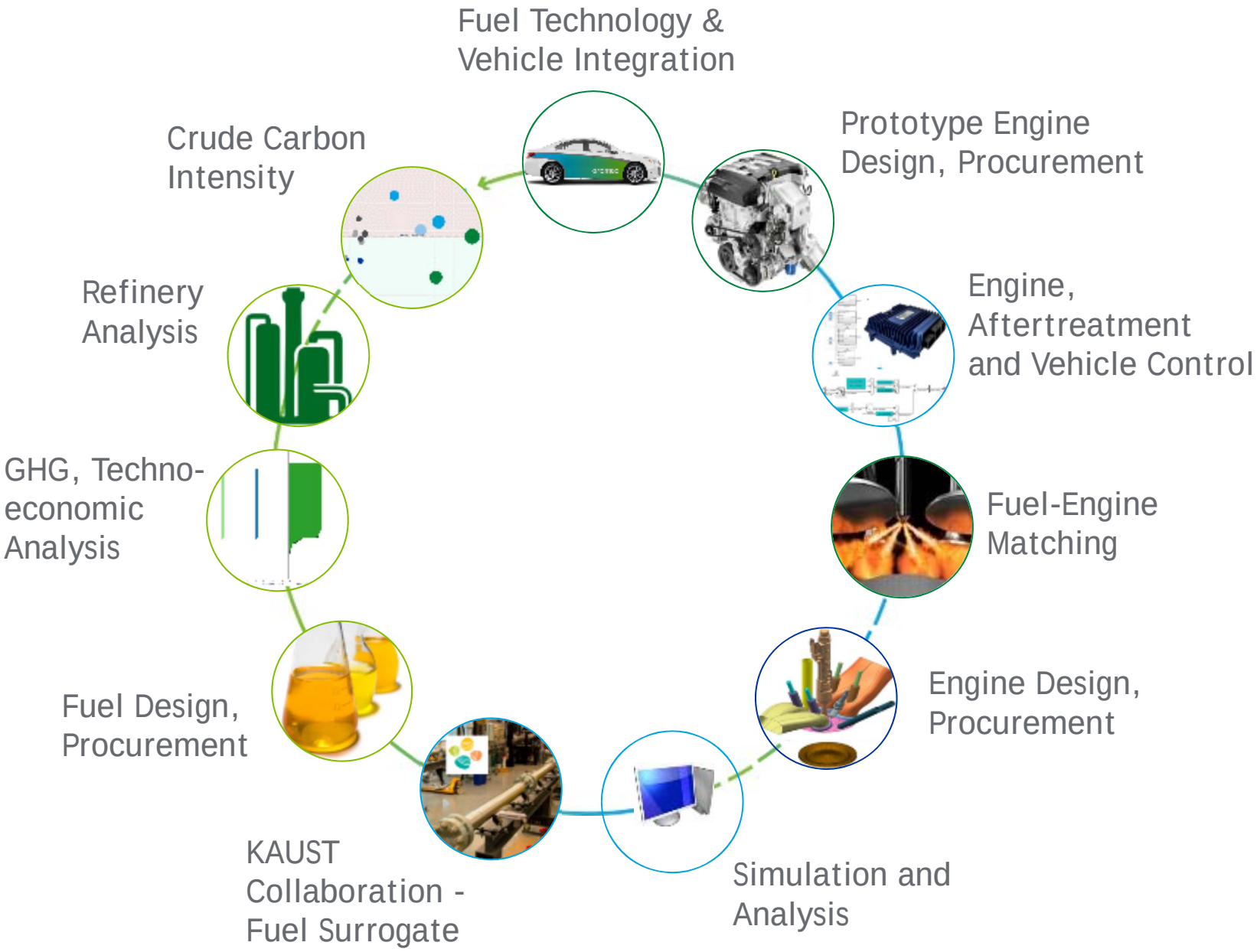
3 R&D centers connected with relevant stakeholders

Dhahran

Detroit

Paris

how | Aramco's Fuel Technology Activities

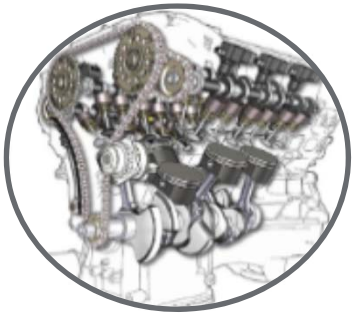


how | Fuel Technology Research Focus

Our fuels technology program is aimed at improving the efficiency of current and future engines, and reducing the overall environmental impact, cost and complexity of engine systems.

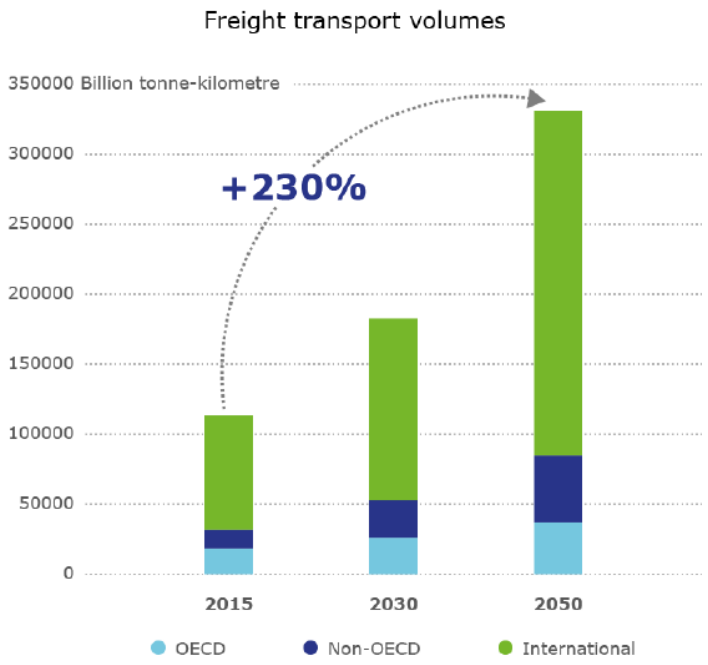
key elements:

- Holistic Approach to Innovation
- Beyond Well-to-Wheels
- Great Engineering Practices
- Technology Integration and Demonstration

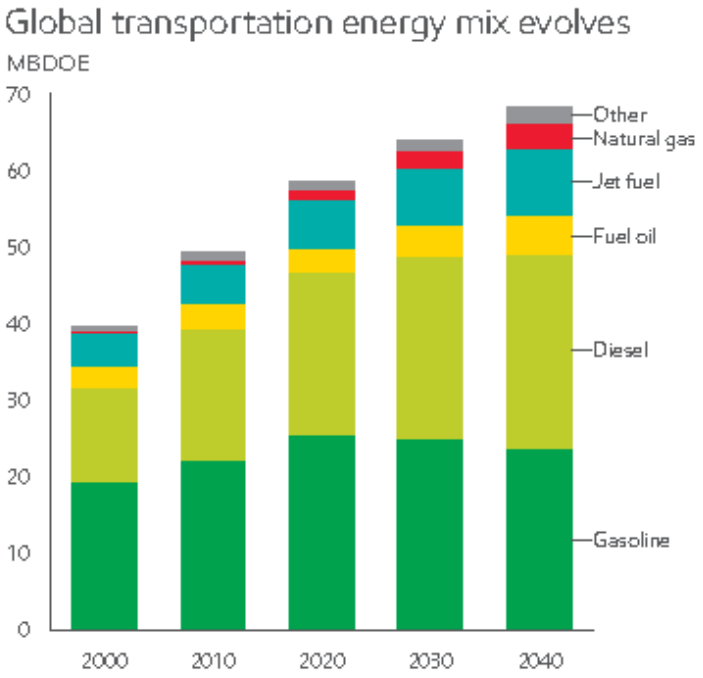


why | Future Demand

- Global economic growth drives increase in commercial demand



International Transport Forum Transport Outlook 2017



ExxonMobil 2017 Outlook for Energy: A View to 2040

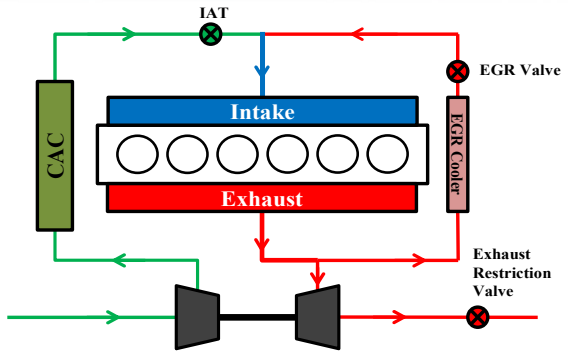
➔ **Decarbonizing the commercial sector presents a large challenge, but there are opportunities**

Heavy Duty Gasoline Compression Ignition

HD GCI | Test Engine

- Modern heavy duty highway diesel engine that can be installed in all major truck brands – non-road variant also available

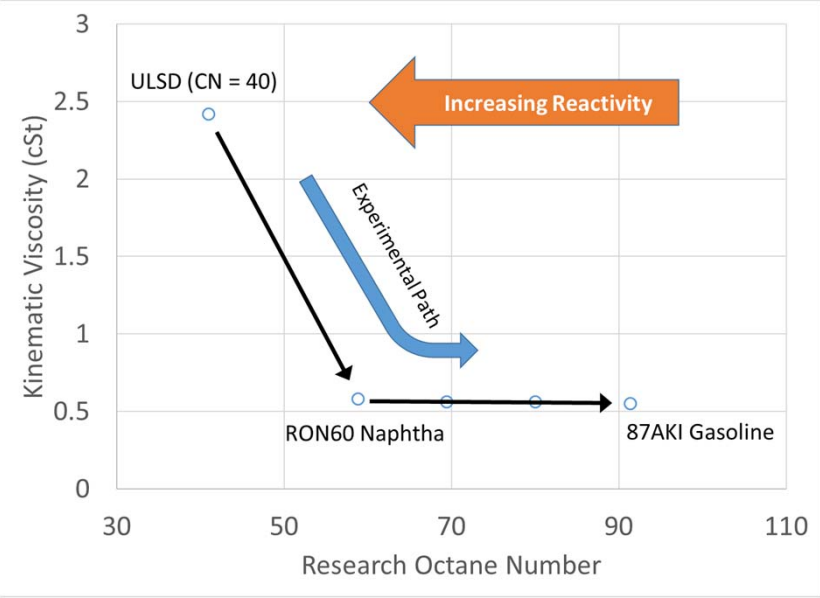
Displacement Volume	**14.9 L**
Number of Cylinders	6
Bore	137 mm
Stroke	169 mm
Compression Ratio	18.9, variants at 17.3 & 15.7
Diesel Fuel System	2500 bar common-rail
Air System	single-stage VGT high pressure cooled EGR loop charge air cooler
Engine Ratings	450 hp @ 1800 rpm 1750 lb-ft @ 1000 rpm



➔ **Aramco purchased a 2013MY Cummins ISX 15L 450hp engine as a research test bed**

HD GCI | Fuel Characteristics

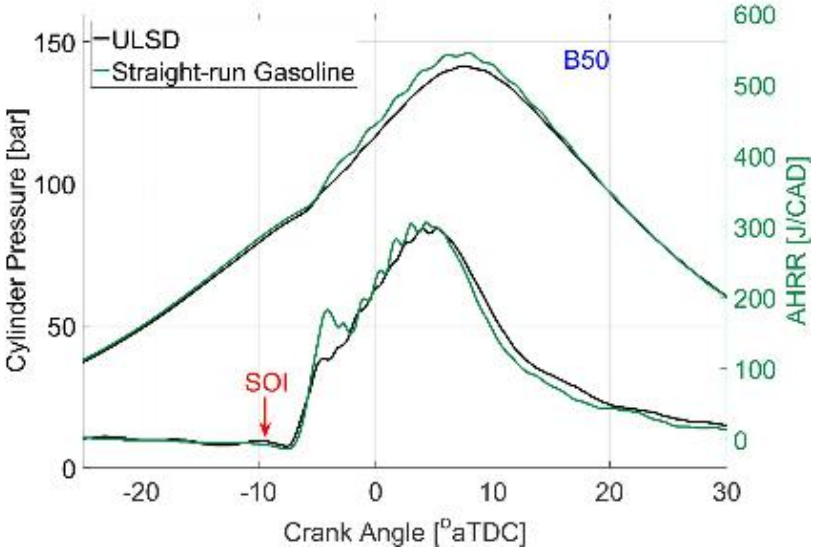
- Opportunities exist in engine-fuel optimization for heavy-duty engines
- Gasoline Range Fuels offer beneficial H:C ratio

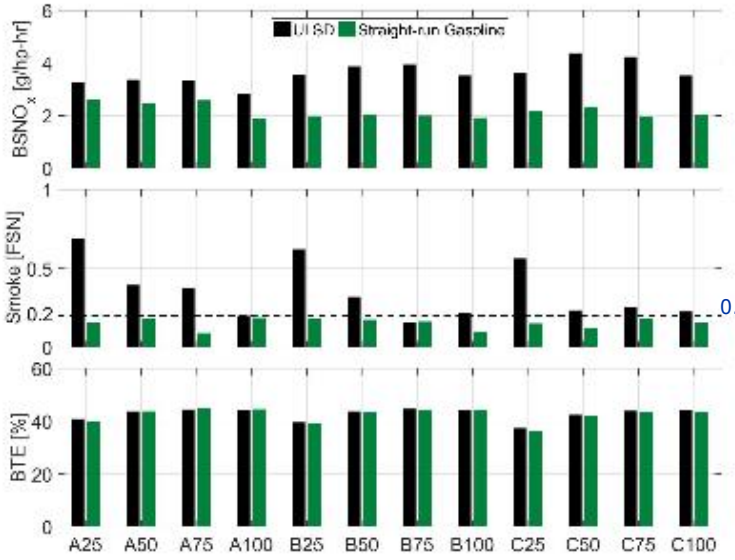


		Test Fuels				
		ULSD	RON60 Gasoline	RON70 Gasoline	RON80 Gasoline	RON91 Gasoline
IBP	°C	158	41	40	37	34
T10	°C	209	71	62	57	51
T50	°C	254	98	91	88	83
T90	°C	**305**	**124**	**127**	**133**	**151**
FBP	°C	336	141	169	184	198
Density at 15.56 °C	g/mL	**0.853**	**0.714**	**0.717**	**0.724**	**0.733**
Kinematic viscosity	cSt	**2.42**	**0.59**	**0.57**	**0.56**	**0.55**
Aromatics	vol%	29.0	9.1	13.7	19.7	25.7
Olefins	vol%	1.5	0.4	3.0	5.6	10.4
Saturates	vol%	69.5	90.5	83.4	74.7	63.9
Sulfur	ppm	5.9	19.3	8.2	6.2	3.0
H/C ratio	-	1.822	2.124	2.058	1.981	1.854
Cetane Number (CN)		**41.2**	**34.1**	**29.8**	**25.9**	**20.4**
RON	-	-	56.0	69.4	80.0	91.4
MON	-	-	55.1	67	74.9	84.6
AKI	-	-	55.6	68.2	77.4	88.0
Lower heating value	MJ/kg	42.76	44.112	43.623	43.58	43.42

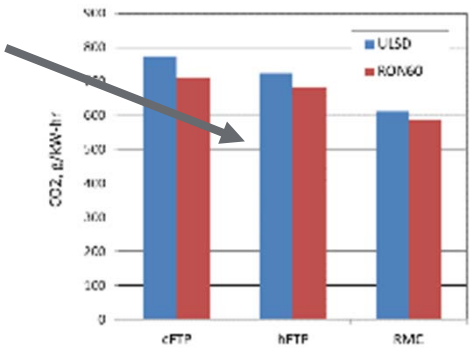
➔ **Aramco is exploring fuel chemistry and combustion as a means to lower CO_2 emissions**

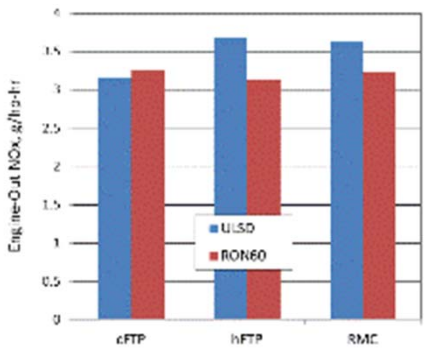
HD GCI | "Drop-in Fuel" Mixing-Controlled Combustion

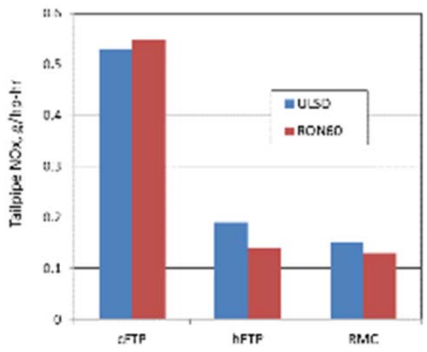




-7% CO_2

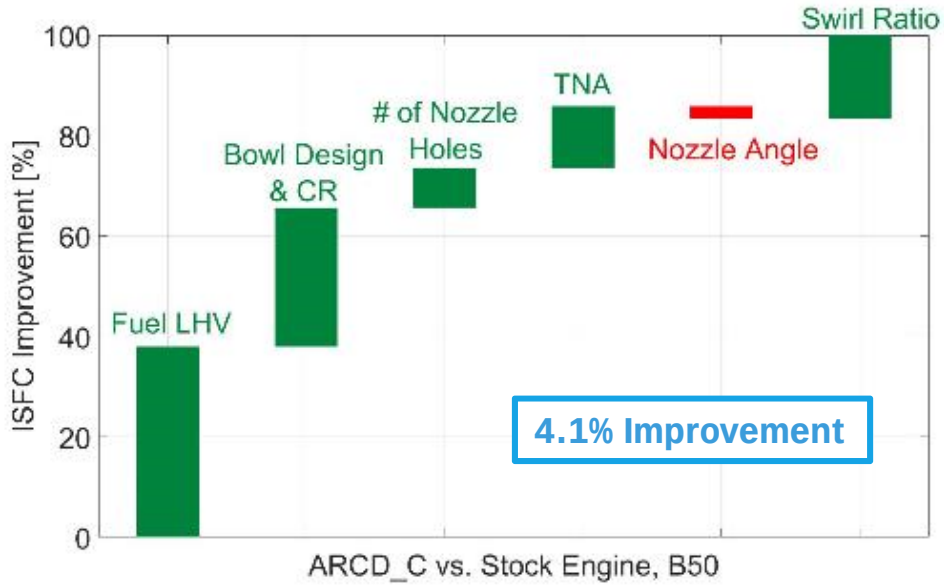






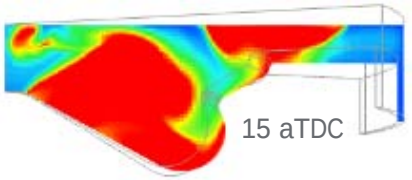
➔ **Lower engine-out emissions and EPA2010 compliant with light-end straight-run gasoline**

HD GCI | Efficiency Improvement Potential – Aramco Design



Fuel consumption improvement at B50:

- **2.6% improvement compared to stock engine with RON60 Gasoline**
- **4.1% improvement compared to stock engine with ULSD**



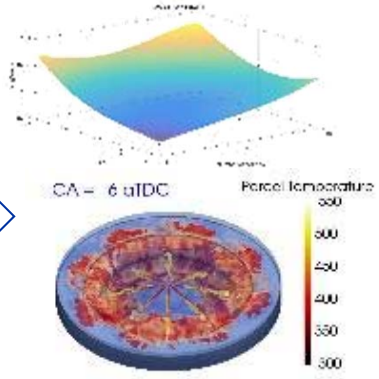
Enhanced fuel-air mixing in pocket and central region

Design space:

- Bowl geometry and CR
- Injector Design - # of holes, total nozzle area, and nozzle inclusion angle
- Fuel Injection Timing
- Charge (swirl) motion

One wave of 256 doe cases
32 x 256 = 8192 cores

2000 simulations using MIRA supercomputer



➔ **4% better fuel consumption calculated with optimized combustion system**

HD GCI | GCI Hardware Performance: SET 12 Modes

SET 12-mode composite results	BTE [%]	BSFC [g/kWh]	BSFC Delta [%, vs. RON60 stock]	NOx [g/kWh]	Soot [g/kWh]	CO_2 [g/kWh]	CO_2 Delta [% vs. ULSD]
ULSD 18.9CR	42.6	197.7	-	4.6	0.037	627.4	
RON60 18.9CR	42.1	194.1	-	4.6	0.013	603.4	*3.8*
RON60 BowIC 8Holes TNA1.5 SwR2.0	42.5	192.3	*0.9*	4.5	0.046	597.9	*4.7*
RON60 BowIC 8Holes TNA1.0 SwR1.0	42.5	192.1	*1.0*	4.5	0.029	597.0	*4.8*
RON60 BowIE 9Holes TNA1.3 SwR1.0	42.8	190.2	*1.6*	4.5	0.084	591.7	*5.7*

- Up to 1.6% BSFC improvement was attained through lower heat transfer loss and faster combustion
- Higher soot emissions need to be addressed in future design refinement activity
- CFD model correlates reasonably well on efficiency, but soot prediction is lacking.
  - o Plume-to-plume interactions → full geometry simulations to understand interaction
  - o Soot formation vs. soot oxidation → Evaluation and calibration of different soot model options

→ Further CO_2 reduction possible with optimized combustion design

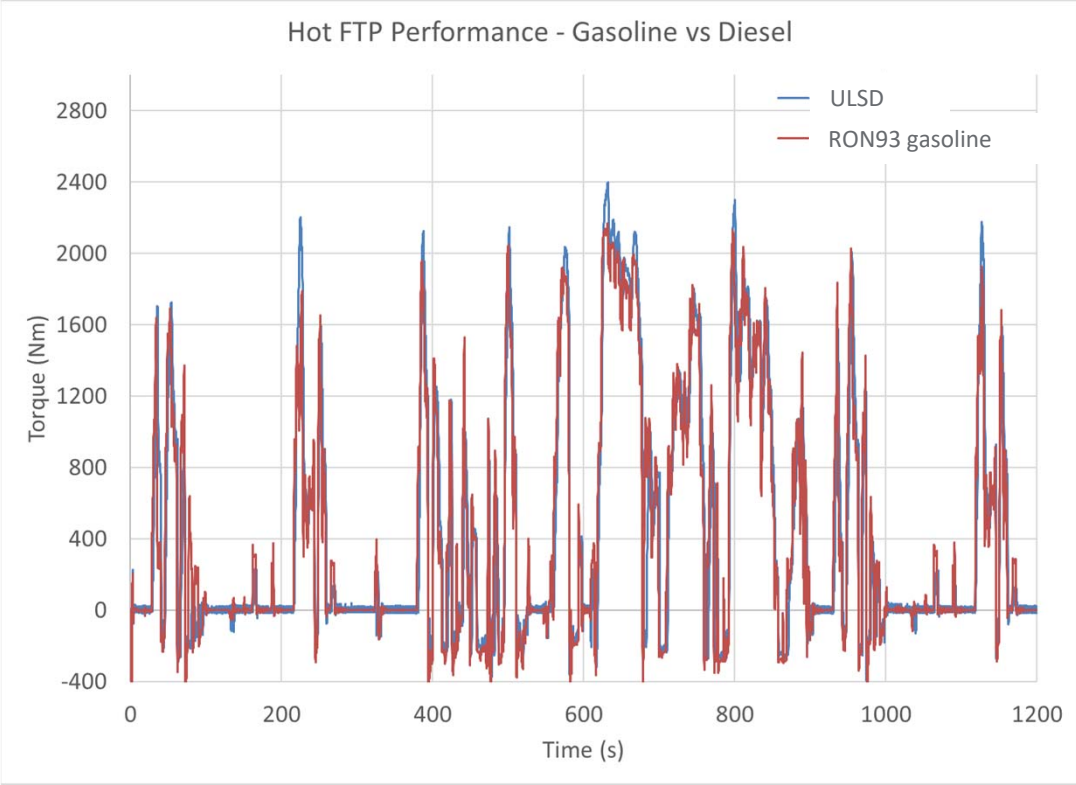
HD GCI | Mixing-Controlled Combustion with Market Gasoline

- Split injection strategy
- E0 RON 93 gasoline
- Production hardware
- Production AT configuration

	hFTP RON93
EO NOx	3.118 g/kWh
TP NOx	0.177 g/kWh
Conv Eff.	94.5%

TP CO_2	ULSD	RON93
g/kWh	728	699

-3% CO_2



➔ **Demonstrated EPA2010 NOx emissions compliance on market gasoline over hot FTP**

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Low Carbon Technology Demonstrator

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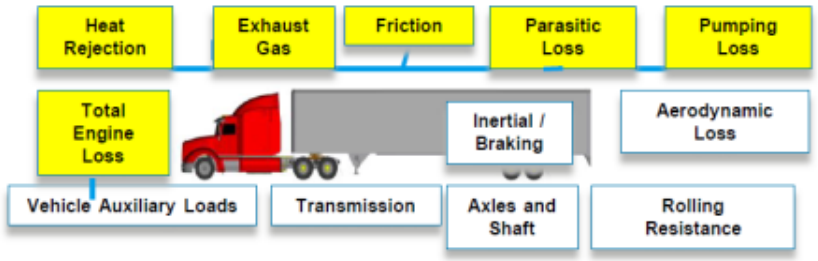
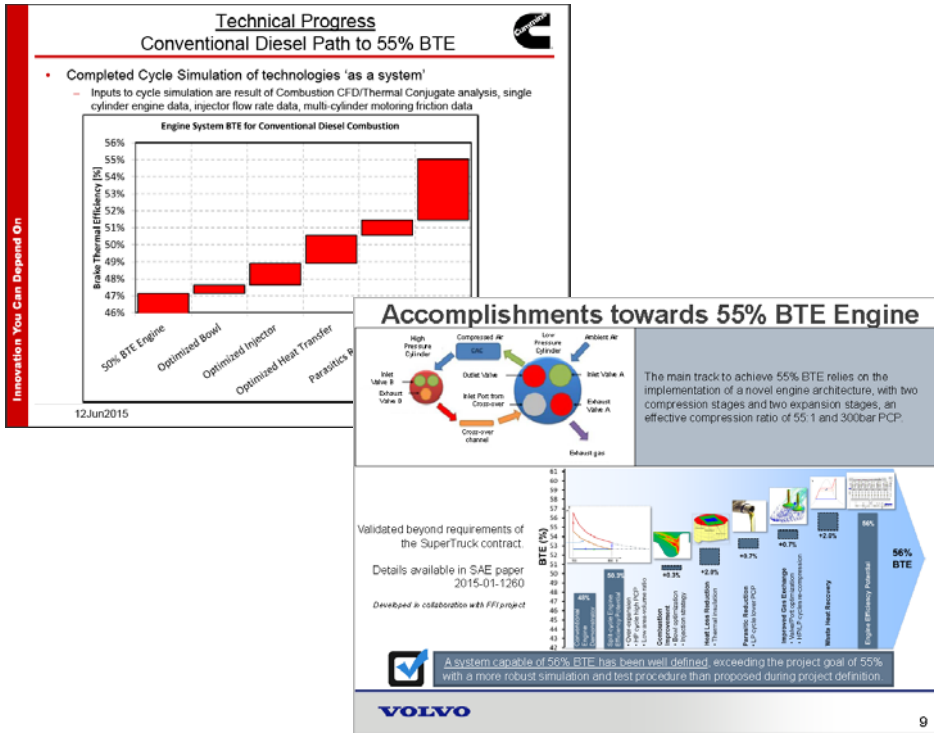
Low Carbon Tech | Motivation

- Global commercial vehicle contribution to GHG emissions expected to grow larger in future while regulations are tightening
- Significant research ongoing to improve the efficiency of the engine, driveline and vehicle
- Impact of each technology remains in the low single digit percentage improvement range
    - Engine efficiency ~ 5%
    - Friction ~1-3%
    - Waste Heat Recovery ~2-3%



EPA/NHTSA UPDATE ON PHASE II GHG AND FUEL EFFICIENCY RULES FOR MEDIUM AND HEAVY DUTY VEHICLES, 2015.



CO_2 Capture Technology offers high relative GHG reduction potential:

40-50%

➔ **Carbon capture technology has the potential to significantly reduce mobile CO_2 emissions**

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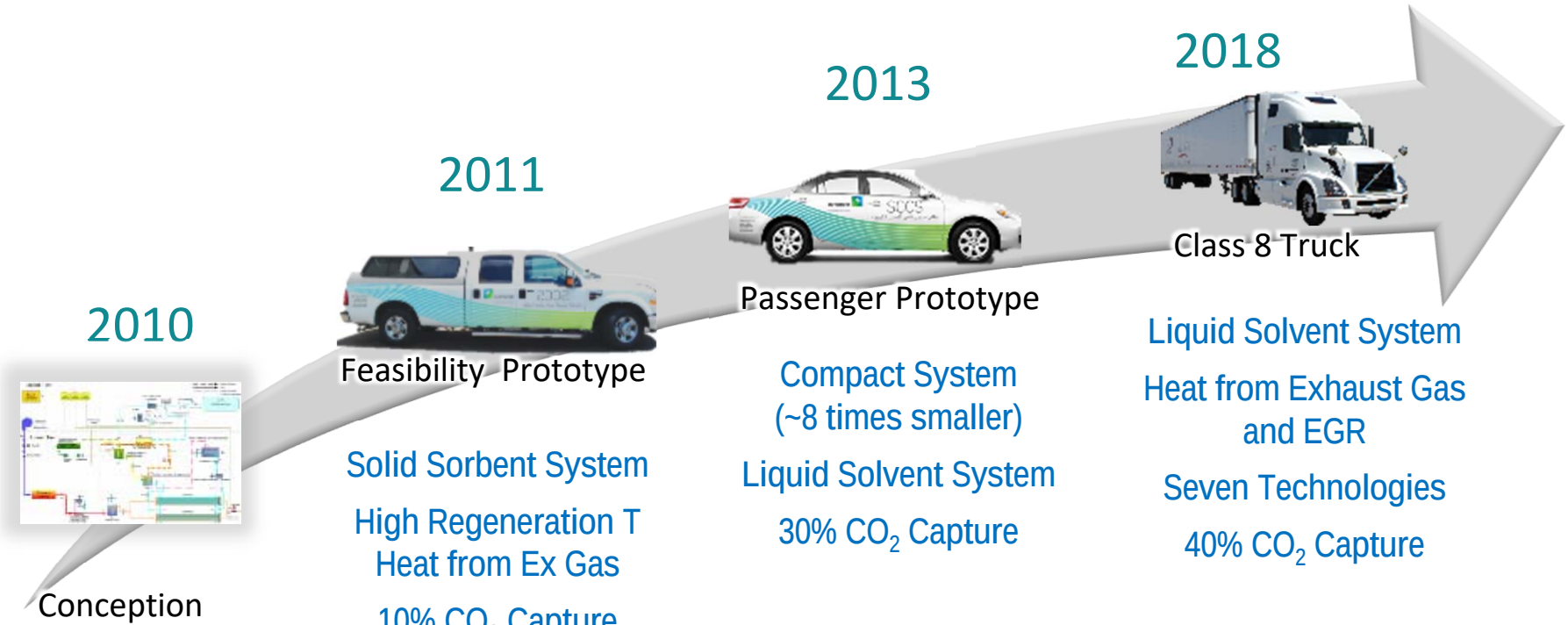
Low Carbon Tech | Project Milestones



➔ **Continuous improvement in capture rates**

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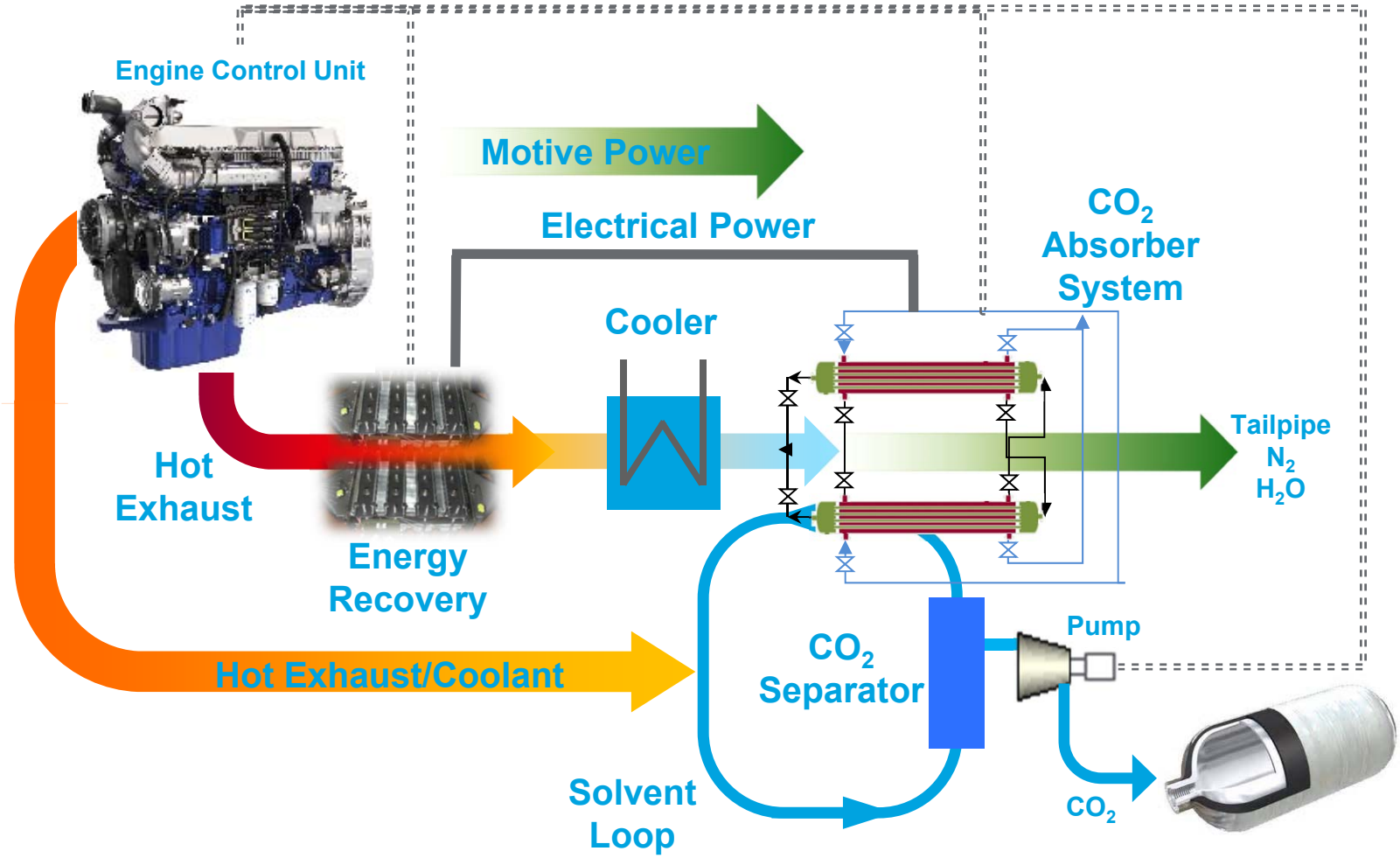
Low Carbon Tech | Carbon Capture System Overview



➔ System harvests available energy from exhaust and coolant to drive separation process

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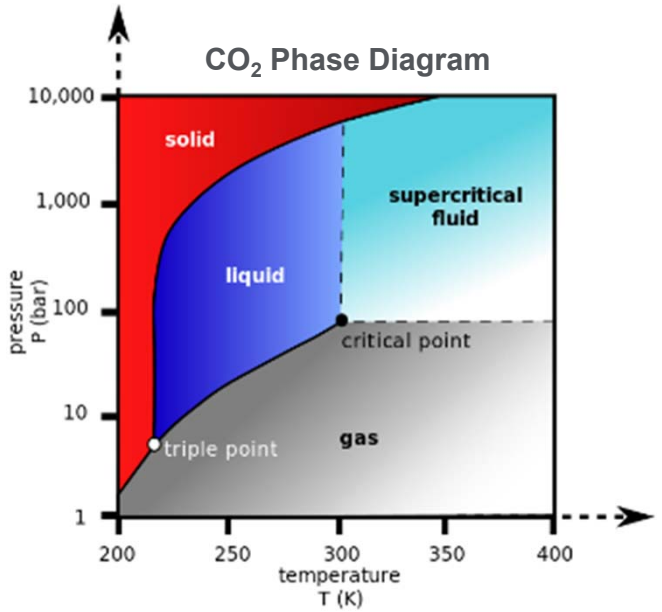
Low Carbon Tech | Carbon Capture Volume

- For 40% CO2 capture, volume of CO_2 = 1.12 gal/gal fuel at 298K & **110** bar

- Assuming a total fuel capacity of 200 gallons:
  - **Volume of CO2: 225 gallons or 850 liters**
  - **Weight of CO2: 1490 lb or 675 kg**
  - Tank sizes: 9.1-18.4” in diameter and up to 120” long
  - Three 75 gals-CO_2 tanks required (pictured)



➔ **Tank volume is high, but not infeasible**

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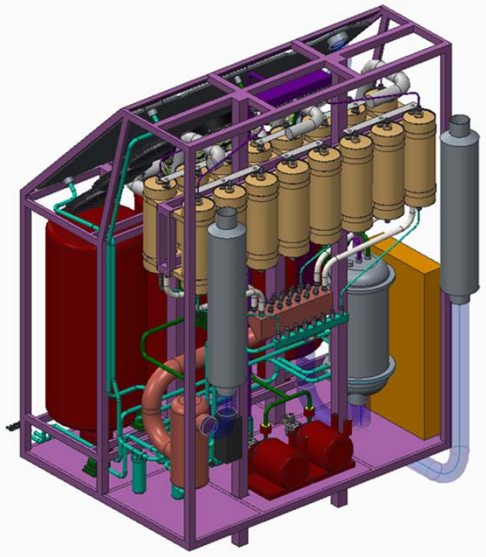
Low Carbon Tech | Vehicle Technologies



Concept Package for Mobile Carbon Capture System

D13 Engine with Turbocompounding

Target is 50% CO_2 Reduction below Baseline Vehicle

Single Wide Tires with Advanced Rubber Formulation

Liftable Non-Driven Axle

Diesel Engine Converted to Run GCI on reduced friction lubricants

➔ **Tech Demonstrator Combines Multiple Technologies to Achieve Low CO_2 Footprint**

Low Carbon Tech | Vehicle Technologies

Technology	Fuel Savings	CO_2 Reduction	Other Benefits	Interactions with other Technologies
Gasoline Compression Ignition: • **No hardware change needed**	0%	3% - 7%	Lower Soot /Similar NOx	Low CO2 Concentration: 3-4%
Waste Heat Recovery: • **Turbo-compounding**	2%	2%	Lowers exhaust temperature	Reduced exhaust cooler size
Low Rolling Resistance: • **Single-wide tires** • **Liftable 6x2 Axle**	5% 3%	5% 3%		
Lubricants: • **Reduced friction in Engine & Powertrain**	2%	2%		
CO_2 Capture	-2%	40%		Energy needed to compress CO_2
Total:	10%	55-59%		

Technologies not included: Aerodynamics, APU, Down-speeding, Automated manual transmission

➔ **Overall system stack-up projects to >50% CO_2 reduction compared to baseline vehicle.**

thank you

Question & Answers

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