Review of Advance ICE Technology

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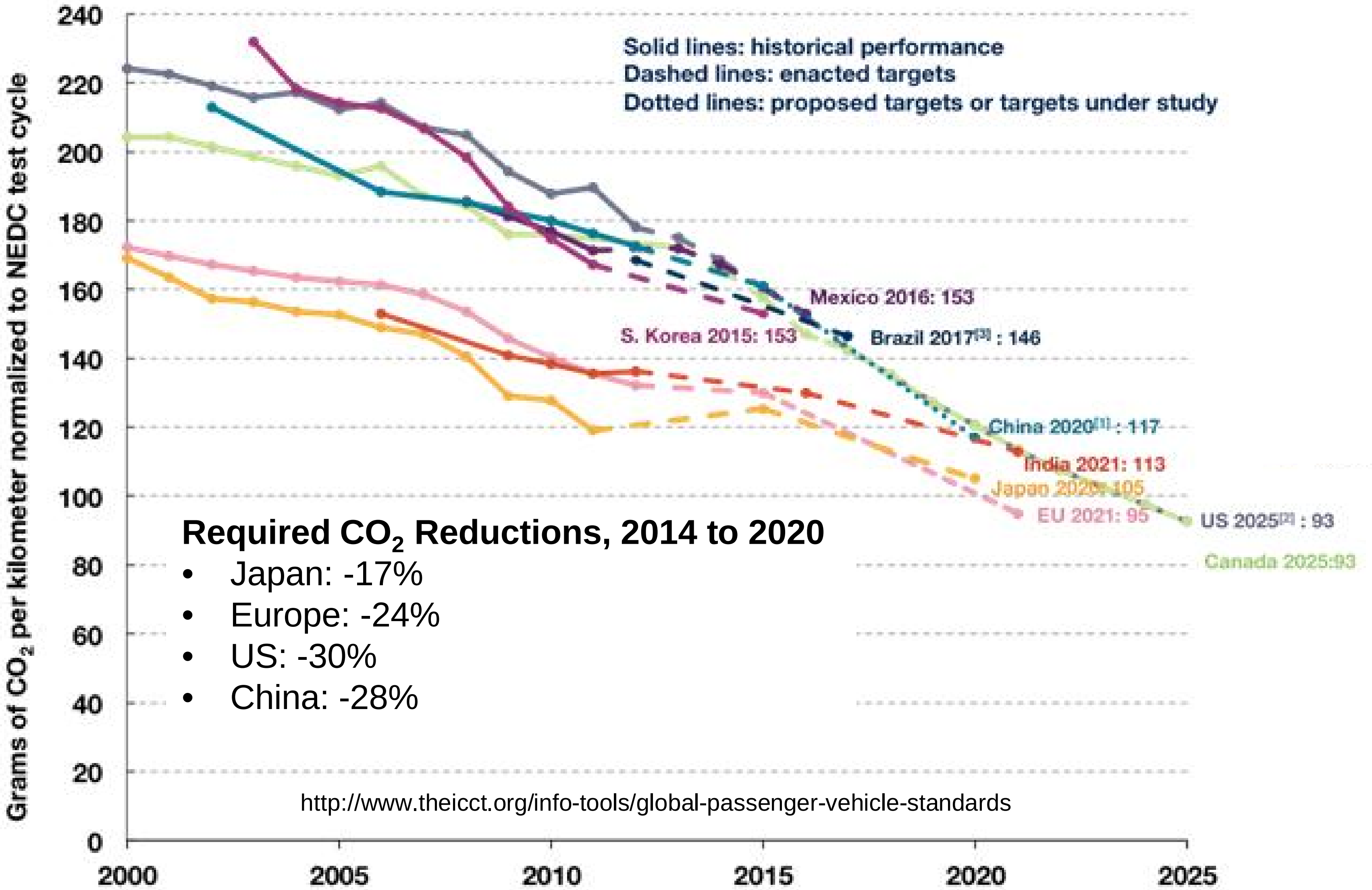
Summary

- GHG regulations are compared for LD and HD
  - LD: Resistance at EU2020 (US2025) level
  - HD: US tightest with next round coming
  - Fuels will likely be plentiful and stable in pricing
- Engines are up to the challenge for the next 10-15 yrs
  - LD: Up to 30% GHG reductions vs. GDI
  - HD: 20% reductions from today
- Aftertreatment challenge is high efficiency at low temperature
  - Significant gap: Oxidation catalysts for LTC and NG

Major LDV automotive markets are moving to ~100 g/km CO_2. Nominally 25-30% reductions from today by 2020.



Required CO_2 Reductions, 2014 to 2020

- Japan: -17%
- Europe: -24%
- US: -30%
- China: -28%

http://www.theicct.org/info-tools/global-passenger-vehicle-standards

Other countries are pursuing HD GHG standards. All are looking at the engine. None are looking at the trailer.

Country/ Region	Regulation Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Japan	Fuel economy						Phase 1 regulation implemented starting MY 2015						
United States	GHG, Fuel efficiency	Standard proposal	Final rule			Regulation implemented starting MY 2014 (mandatory DOT program starts MY 2016)	Phase 2 development					Phase 2 implementation	
China	Fuel consumption	Test procedure finalized	Industry standard proposal	Industry standard implemented	National standard adopted		Regulation implemented starting MY 2015					Next phase national standard	
European Union	CO_2 test procedure	Technical studies			Impact assessment		Test procedure finalized			Policy implementation for CO_2 reporting			
Canada	GHG, fuel efficiency			Standard proposal	Final rule		Regulation implemented					Phase 2	
Korea	Fuel efficiency	Technical studies			Impact assessment		Test procedure finalized	Policy implementation					
Mexico	Fuel efficiency						Proposal			Regulation implemented			
California	End-user purchase requirements		Requirements for new tractors, trailers		Additional reqs. for existing tractors and trailers (<MY 2010)				Additional reqts. for existing trailers and reefers (<MY 2010)				

EUROPE
- Diesel price – ~1.2-1.7 €/L ($6-8+/gal) drives technology/operational efficiency
- Speed – 88 kph/55 mph speed limit
- Aero – Cab over engine
- Tires – Supersingles / LRR widely used
- Idle – Rarely idle even at truck stops

UNITED STATES
- Diesel price – ~0.8 €/liter (~$4/gal)
- Speed – High highway speed (~65 mph)
- Distance – long daily, annual distances
- Length/weight restrictions vary by state
- High engine idling

CHINA
- Diesel price – ~1 €/liter (~$5/gal)
- Speed – Typically lower speed (~43 mph)
- Weight – Generally significantly higher gross weight (108k lbs+ vs 80k lbs US)
- Euro IV engines, 50 ppm S

JAPAN
- Diesel price – ~1.2 €/liter (~$6/gal)
- Shorter distance for intercity driving
- Grade is important

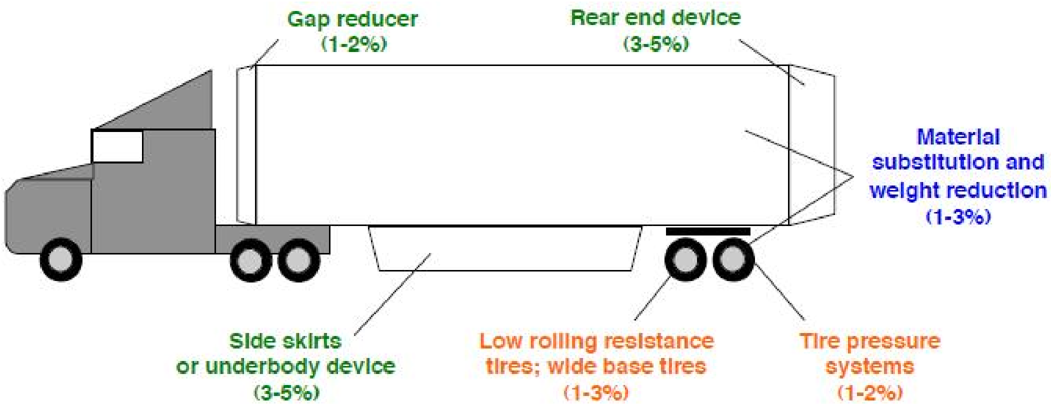
OTHERS
- Situations all vary greatly…

	Japan	U.S., Canada	China	EU #
Engine	Yes	Yes Separate engine standard	Yes	Yes
Transmission	Somewhat	Optional; by demonstration outside of standard protocol	Yes	Yes
Hybridization	Unclear	By demonstration outside of standard protocol	Yes	Yes
Aerodynamic drag, rolling resistance	No	Yes	Yes*	Yes
Trailer	No	No	No	No

** Option to use default values*

 # Refers to ongoing government research and testing protocols; No standards in place

US EPA is investigating more HD CO_2 reductions for 2020+



ICCT, SAE Gov&Ind 1-14

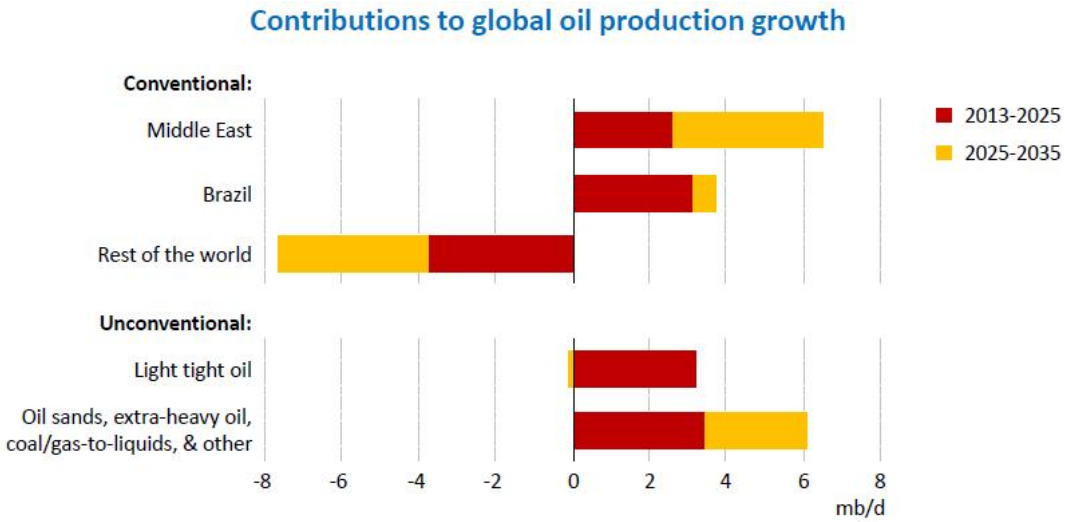
- 80% of van trailers made by 3 companies
- 2.5 to 3 trailers per truck
- Skirts: $900
  Boat tails: $1300

- Exploratory stage now
- NPRM by March 2015
- Final Rule by March 2016

- Looking at improving metrics
- Watching DOE 50% BTE progress
- Significant trailer reductions – new regs
- Hybrids? Alt fuels and separate standards? N_2O?

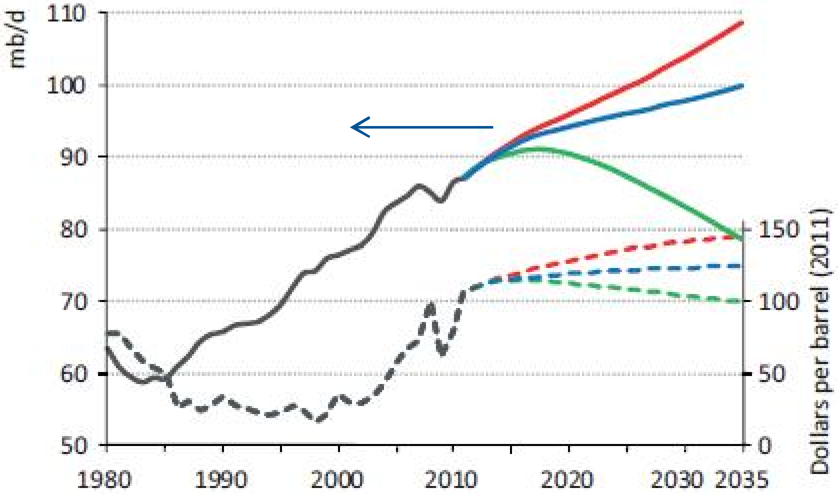
Fuels

Liquid transportation fuel source base will diversify. Although demand will still increase, the shift in production and flows to the Americas will stabilize fuel prices.



75% of the new growth in oil production to 2025 will come from the Western Hemisphere.

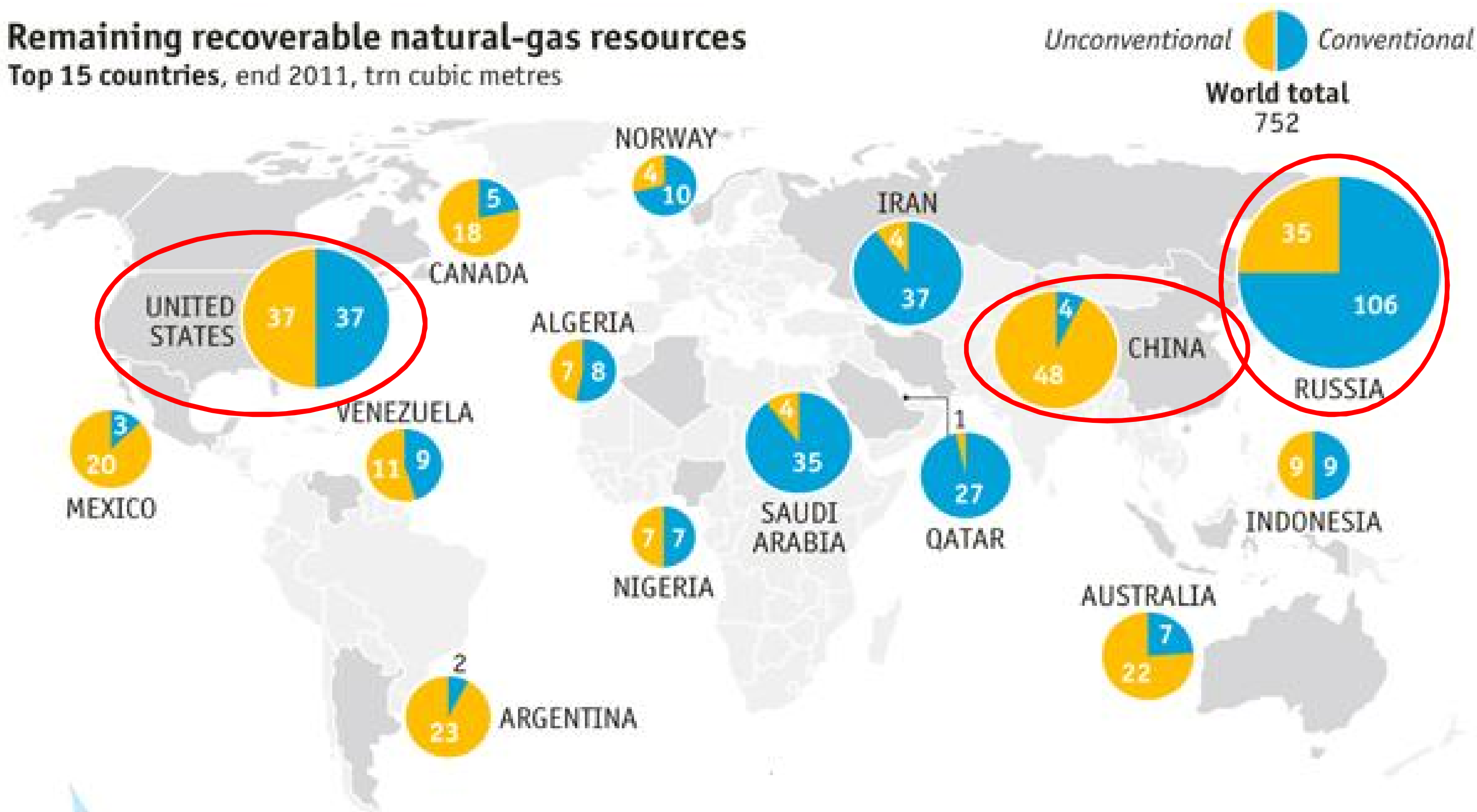
IEA 2013 Outlook



This shift to unconventional liquids could stabilize oil price and level.

IEA 2012 Review

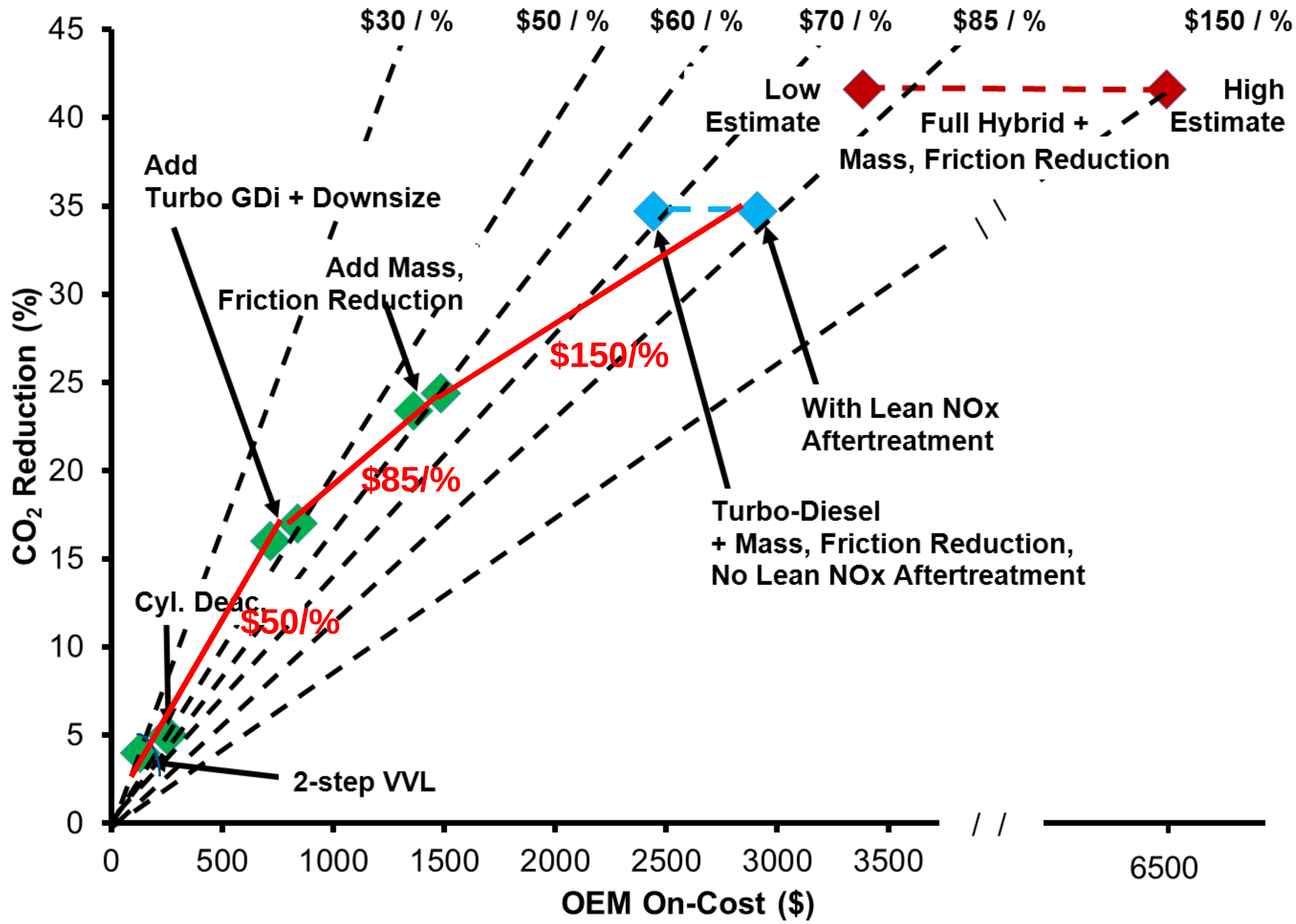
New natural gas extraction methods have increased gas reserves by >80%. Largest impact in US and China.



Fracking has increased the NG reserves by >80%, with the largest increases coming in China, US, and Russia.

Recent Engine Developments

Cost of CO_2 reductions range from $30-50/percent for 5-15% reductions to $60-$85/percent for up to 40% reductions



Baseline Vehicle: 4-cyl. DOHCMPFI with Dual Independent Cam Phasing
Data Source: 2011 National Research Council and Delphi Internal

LD CO_2 reduction strategies are at various stages of development and effectiveness

	CO_2 Reduction	Emissions Issues	Status
GDI base	0	PN	Implemented
Downsize GDI, 18 →24 bar BMEP	5%	PN	Implementing
Spark assist CI gasoline	5-10%	-	Research
Stratified GDI	5-8%	PN	Implementing
Cylinder de-activation	5-8%	-	Implementing
Homogeneous Lean SI	5-10%	Lean NOx	Development
RCCI	15%	LT HC+CO	Research
d- and c-EGR	10-20%	Cold start, low load	Development
Lean-burn GDI	11-25%	Lean NOx, PN	Implementing
Light-duty diesel	15-20%	Lean NOx	Implemented
GDCI	15-25%	Lean NOx, LT HC	Adv Eng
2-stroke opposed piston	20-30%	Lean NOx	Adv Eng

DOE SuperTruck program participants at >48% BTE.

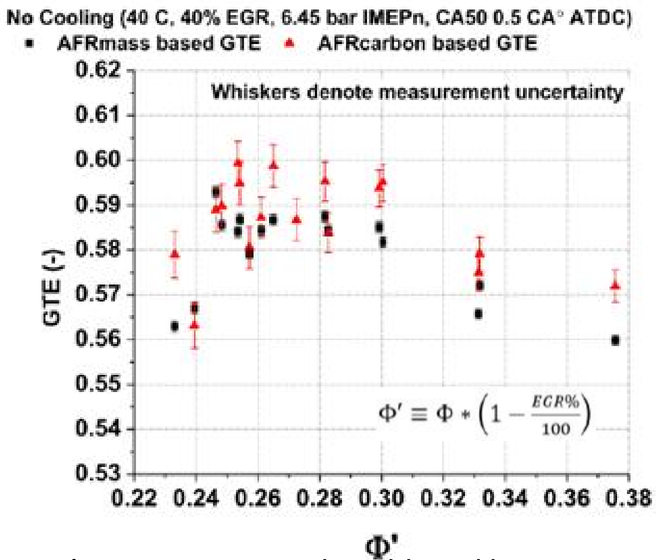
Common themes. Differences: Downspeeding, VVA, Turbocompounding

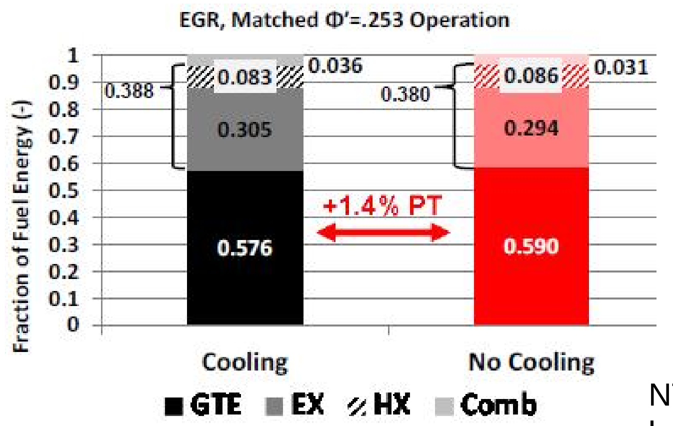
	BTE, May 2013	50% BTE Approach	55% BTE Possibilities
Cummins	51.1%	Combustion - CR, bowl, FIE, calibr Gas Flow - EGR flow, turbo improve Parasitics - seals, pumps, piston, lube WHR - EGR, exhaust, oil, water	Optimization Fuels
Daimler	48.1%	Combustion - PCP, bowl, FIE, calib Turbo – low Δp Parasitics - cylinder, lube WHR - EGR	Engine Optimization Turbocompounding WHR
Volvo	48%	Combustion – cyl geom, FIE, D.sp., EAT Air Management Parasitics – cooling and lube cicuits WHR – Gen 1 Rankine + turbocompound Other – DCT, idle reduction, axles (DS)	Combustion Pumping WHR Fuels
Navistar	48.2%	Combustion – PCP, FIE Parasitics – base comp., lube, cooling WHR – electric turbocompounding Variable Valve Actuation	Fuels More turbocomp More VVA

From DOE Peer Review, 5/13

HD RCCI NTE approaching 55% (60% GTE).

Transient response shown in LD platform. Robust to changes in intake temperature and pressure.





Univ. WI SAE 2013-01-0279

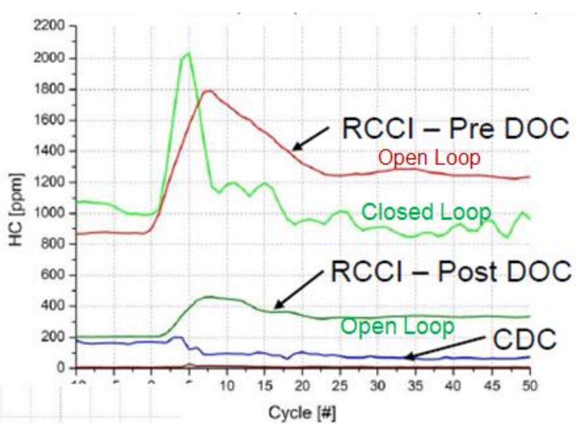
	GTE (%)	IMEPg (bar)	NTE (%)	IMEPn (bar)
Experiment	59.1	6.82	55.0	6.27
Model, HX =0 100% comb. η	62.4	7.12	58.5	6.85
Model, HX =0 100% comb.η, 0% EGR	63.4	7.23	61.0	6.95

94% of theor.

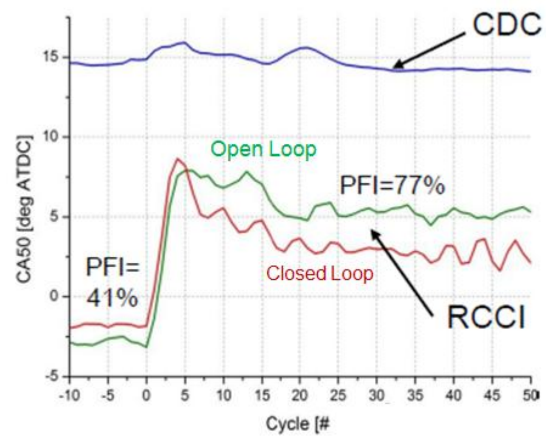
NTE is estimated at 55%. Est. heat losses in GT Power by matching to data.

Close to 60% GTE is achieved by removing oil jet cooling of piston, new bowl design, and going to CR=18.7:1

Univ WI, SAE HEE Symp. 4/13

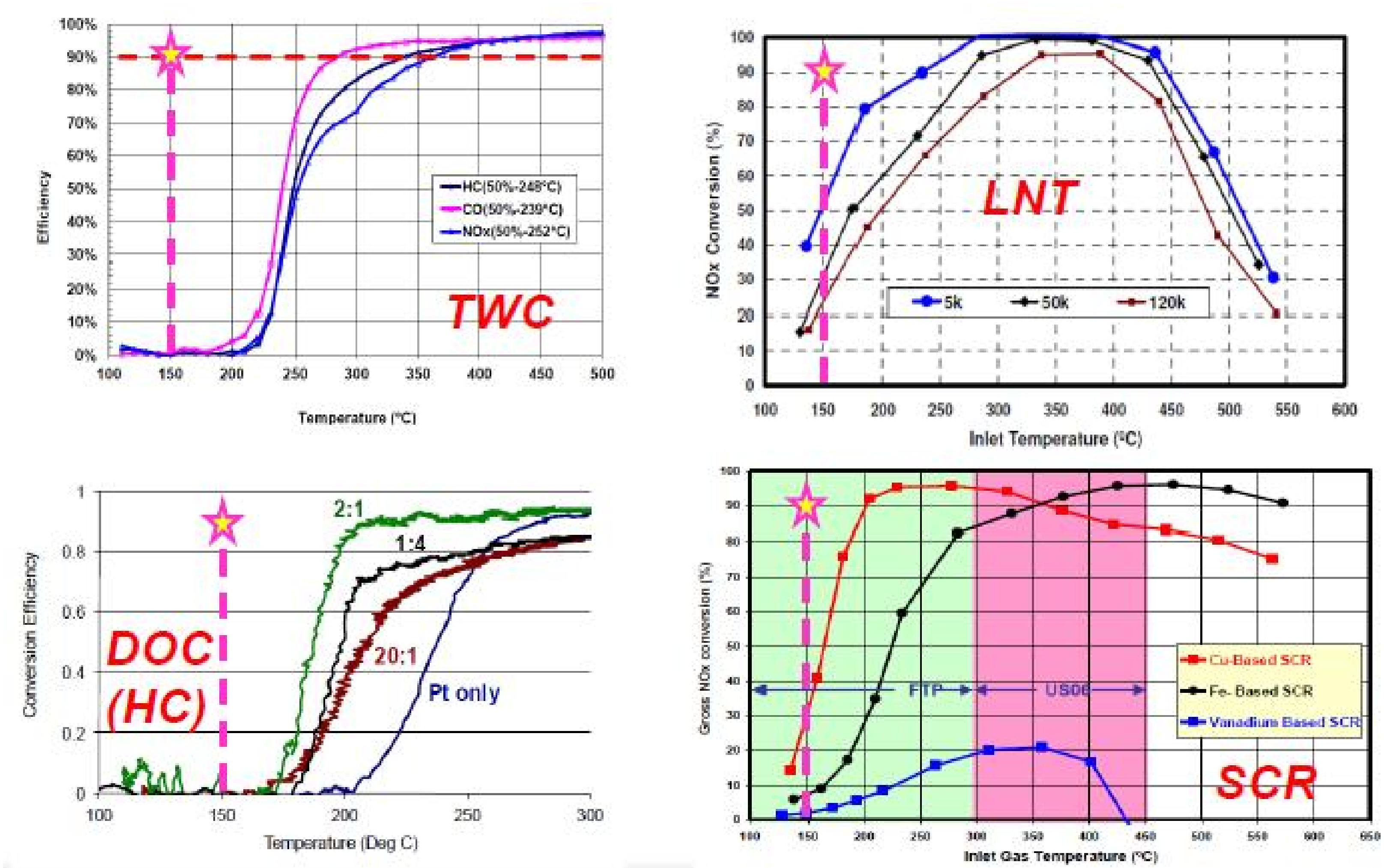


Transient data on 1.9 liter LD engine shows good closed-loop control. 1 → 4 bar BMEP



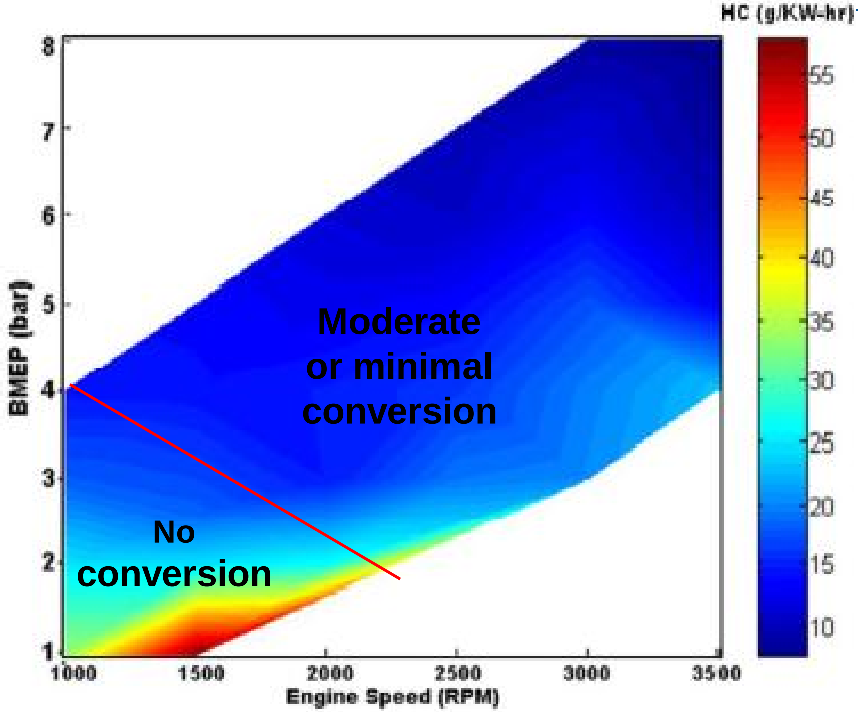
Also: Not as sensitive to changes in intake temperature and pressure as HCCI or PPC.

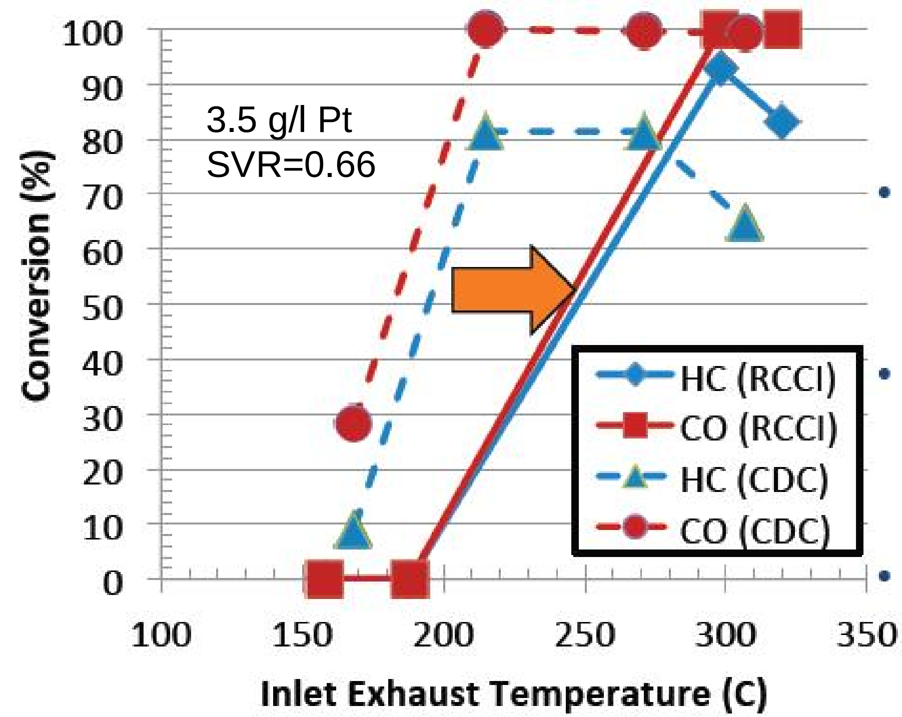
USCAR emissions challenge – T90 at 150C



Slide from ORNL, AMR 5/13; Chrysler USCAR workshop 11/12

RCCI is being looked at for its high efficiency. HC and CO control are major challenges.



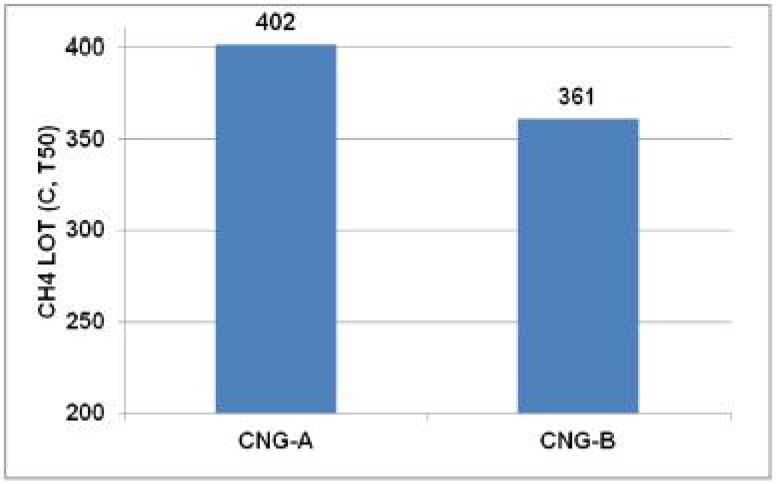


LD RCCI HC exceeds 10 g/kW-hr over whole operating range. Reference: T2B5 ~ 0.2 g HC/kW-hr (>98% efficiency needed)

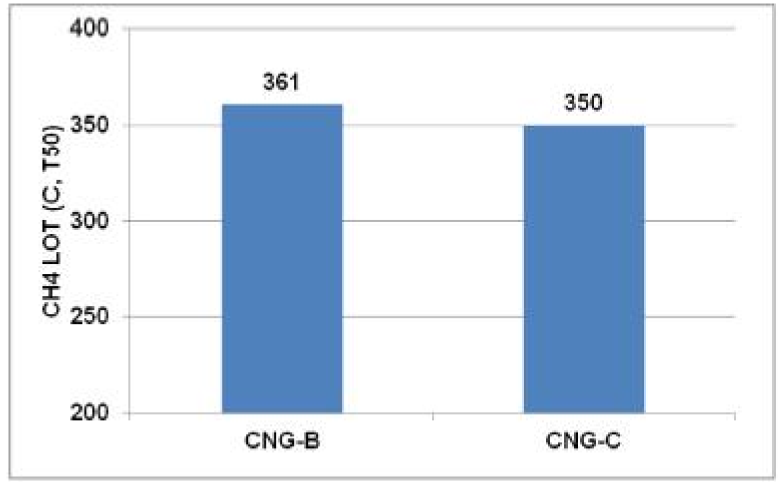
ORNL, CLEERS 4/13 and SAE 2013-01-0289

Improvements to a methane oxidation catalyst drop the T50 from 402C down to 317C. Stability improved.

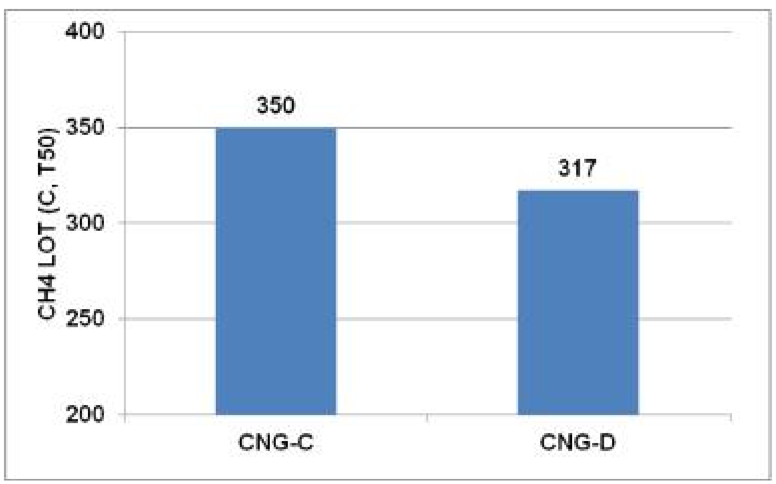
Heesung, SAE 2013-01-2591



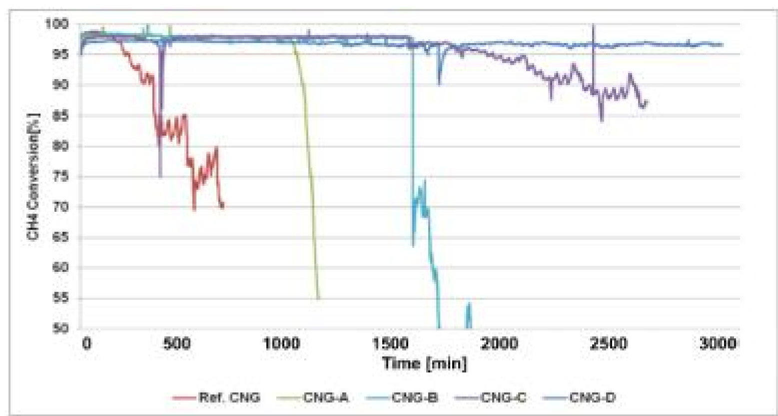
Dispersing and stabilizing the Pd dropped CH4 T50 from 402 to 361C.



Adding an optimized OSC dropped CH4 T50 from 361 to 350C.



Using promoters to improve the electronic properties of the Pd drops T50 from 350 to 317C.



Durability is improved to 38 hrs vs 4 hrs in a steady state test at 450C

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