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Spark versus Compression Ignition in a New Energy Environment

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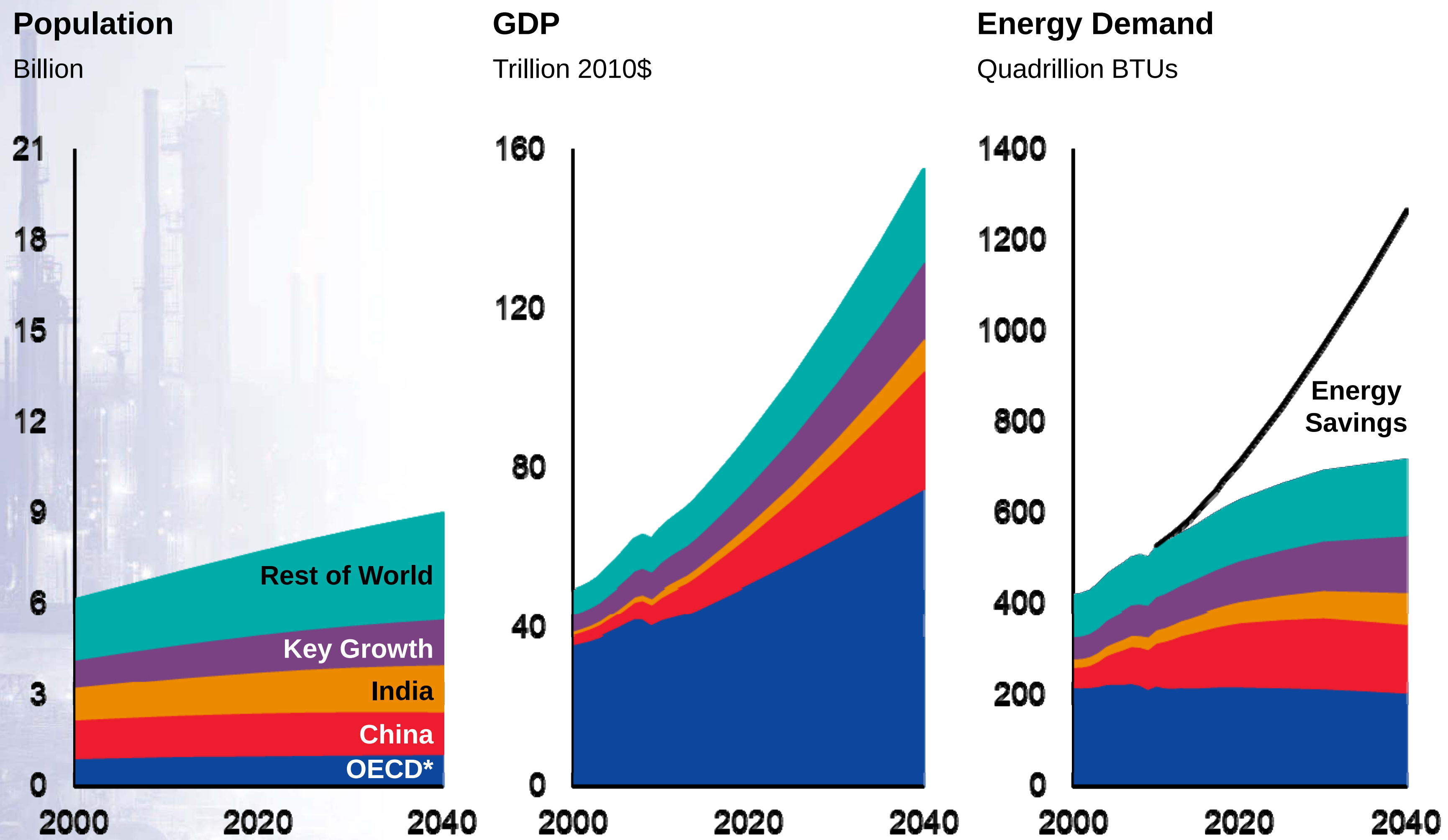
Global Progress Drives Demand



*Mexico and Turkey included in Key Growth countries

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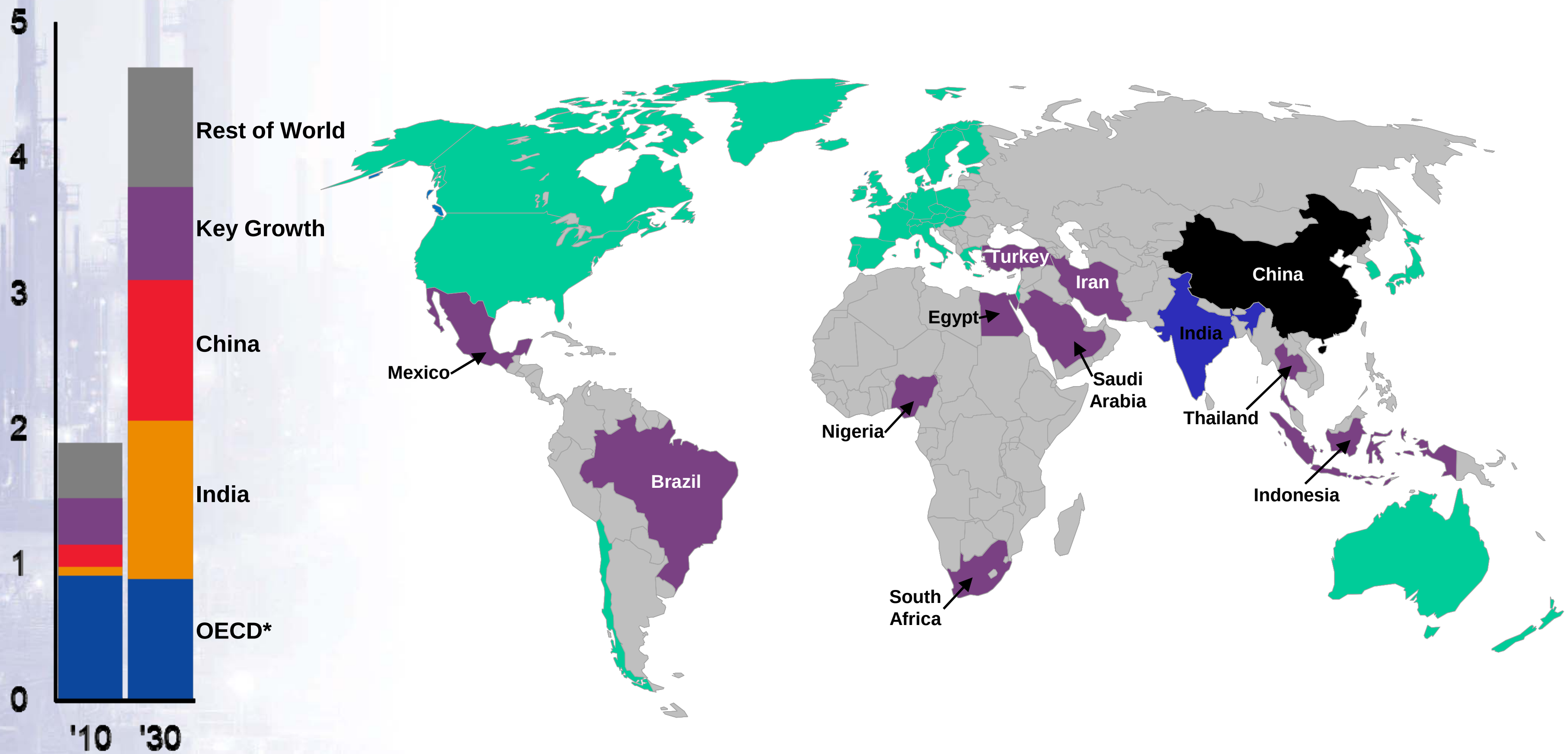
The Middle Class Continues to Grow

Middle Class per The Brookings Institution

Billion People



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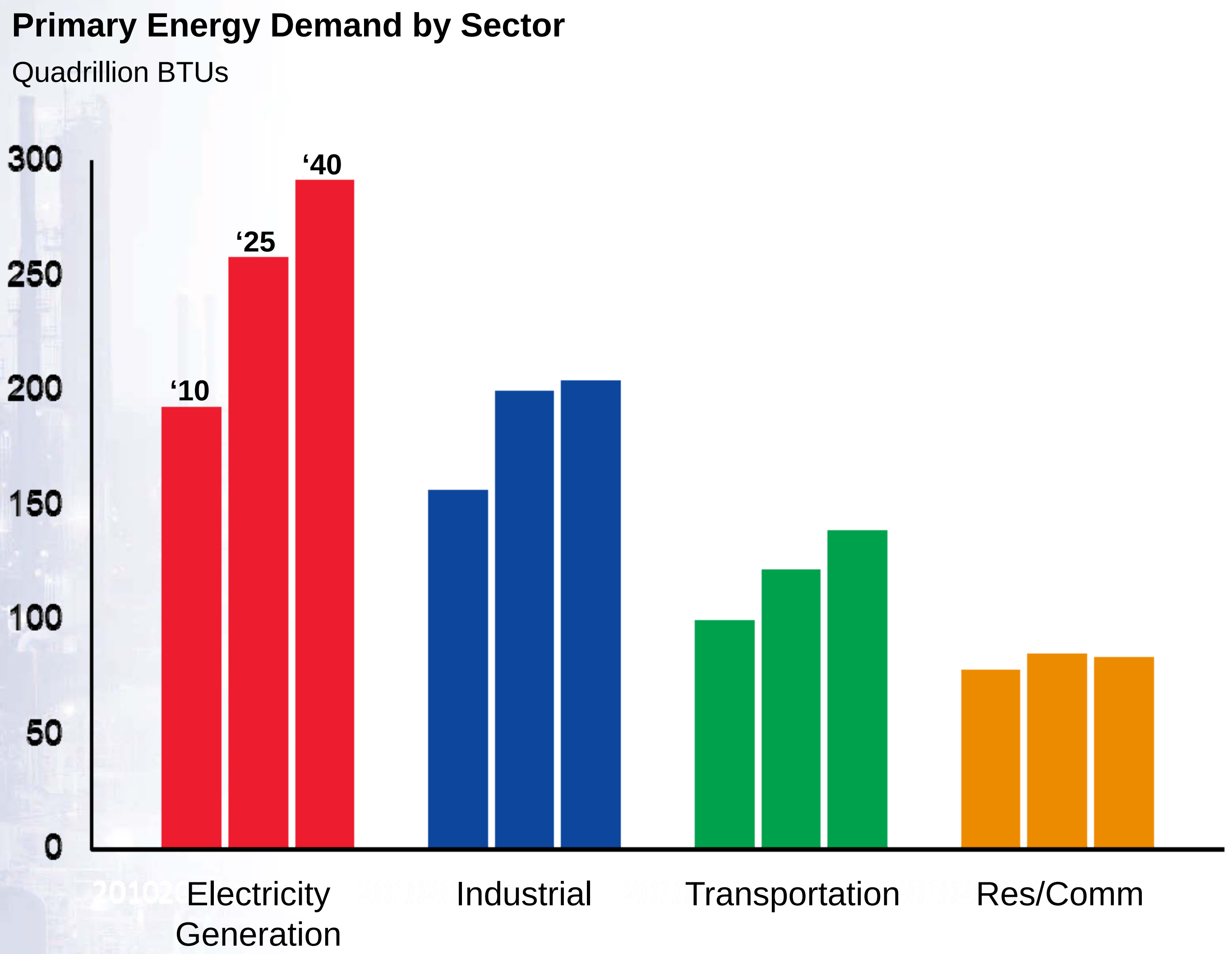
Electricity Generation Leads Growth



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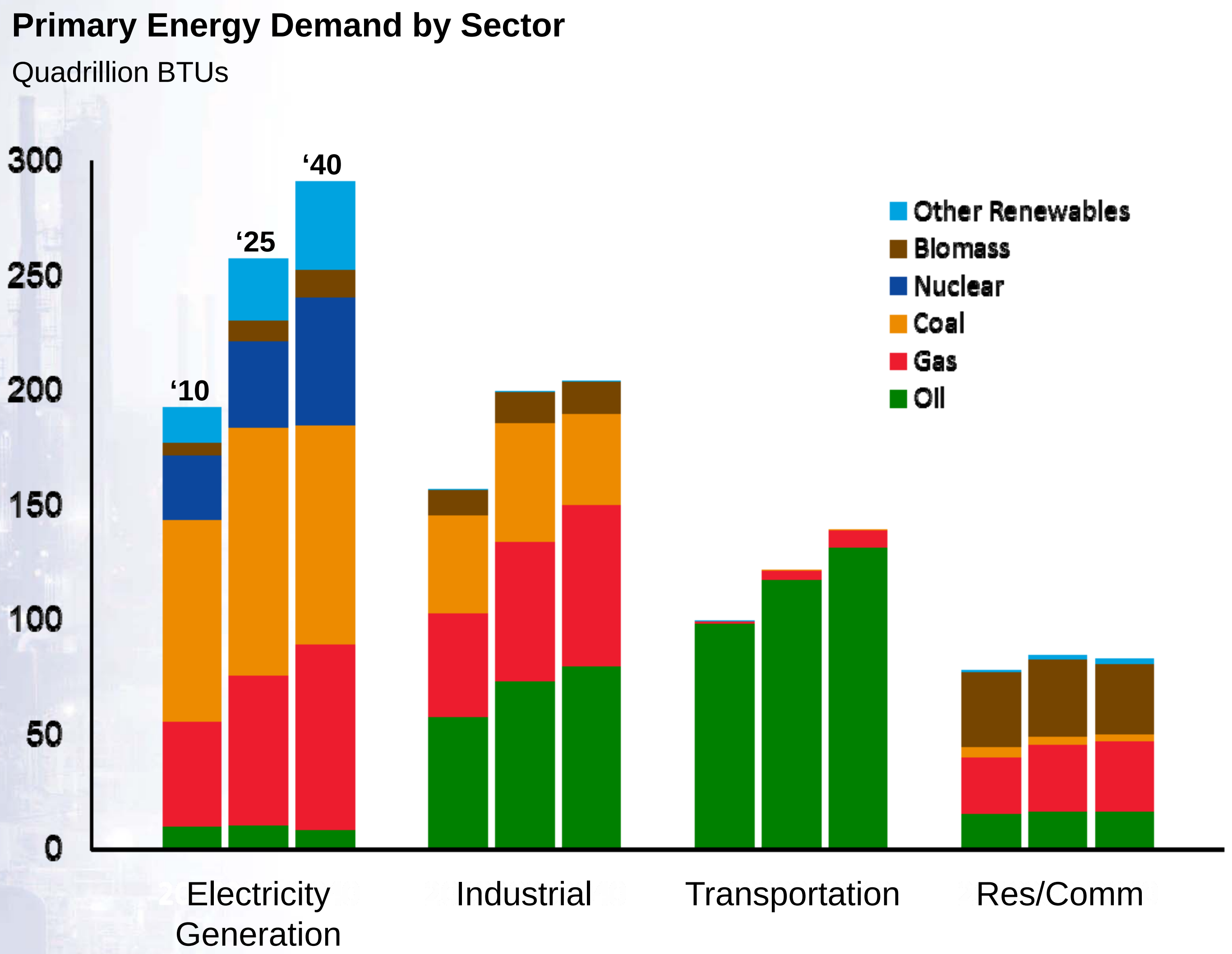
Electricity Generation Leads Growth



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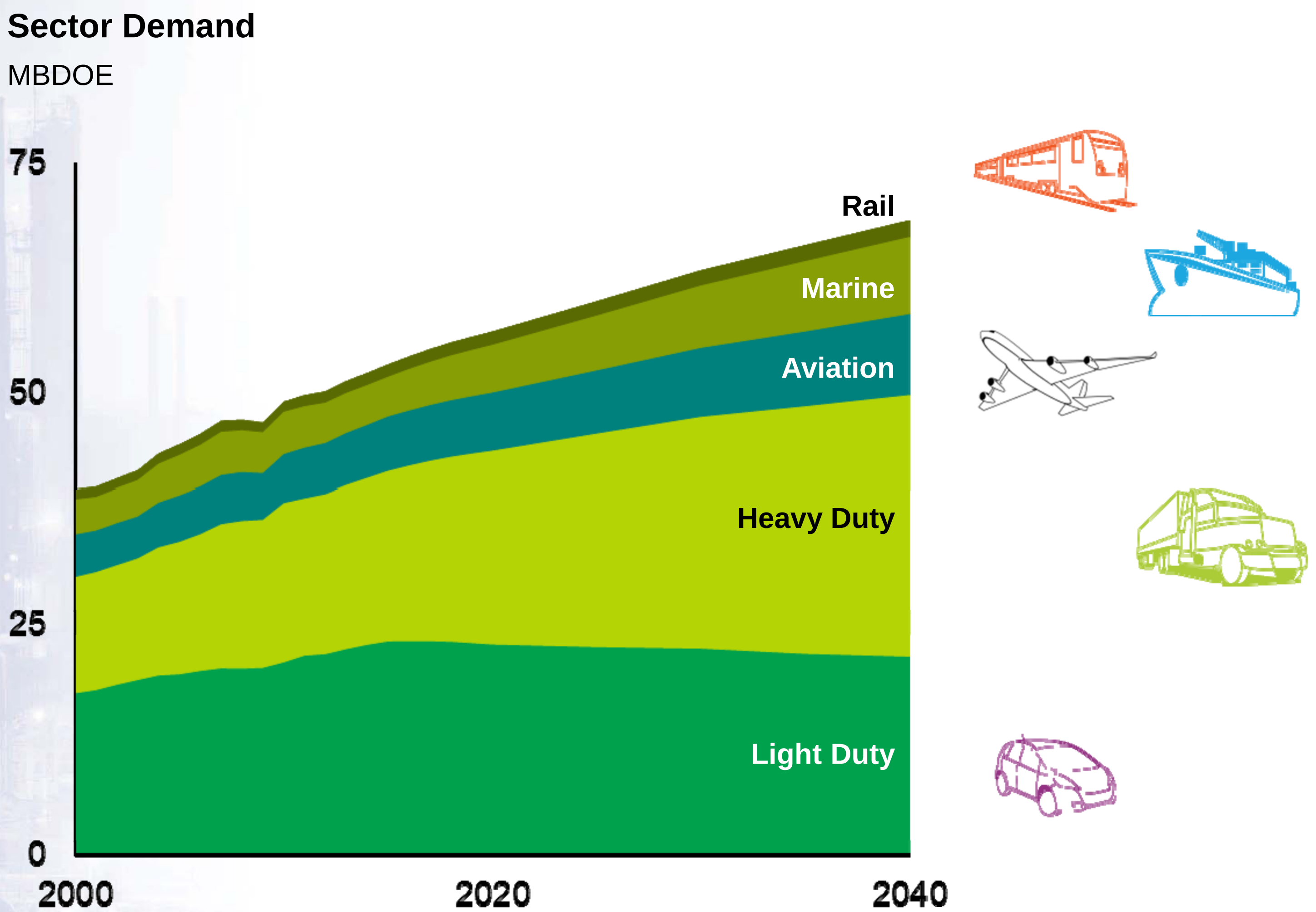
Transportation Demand



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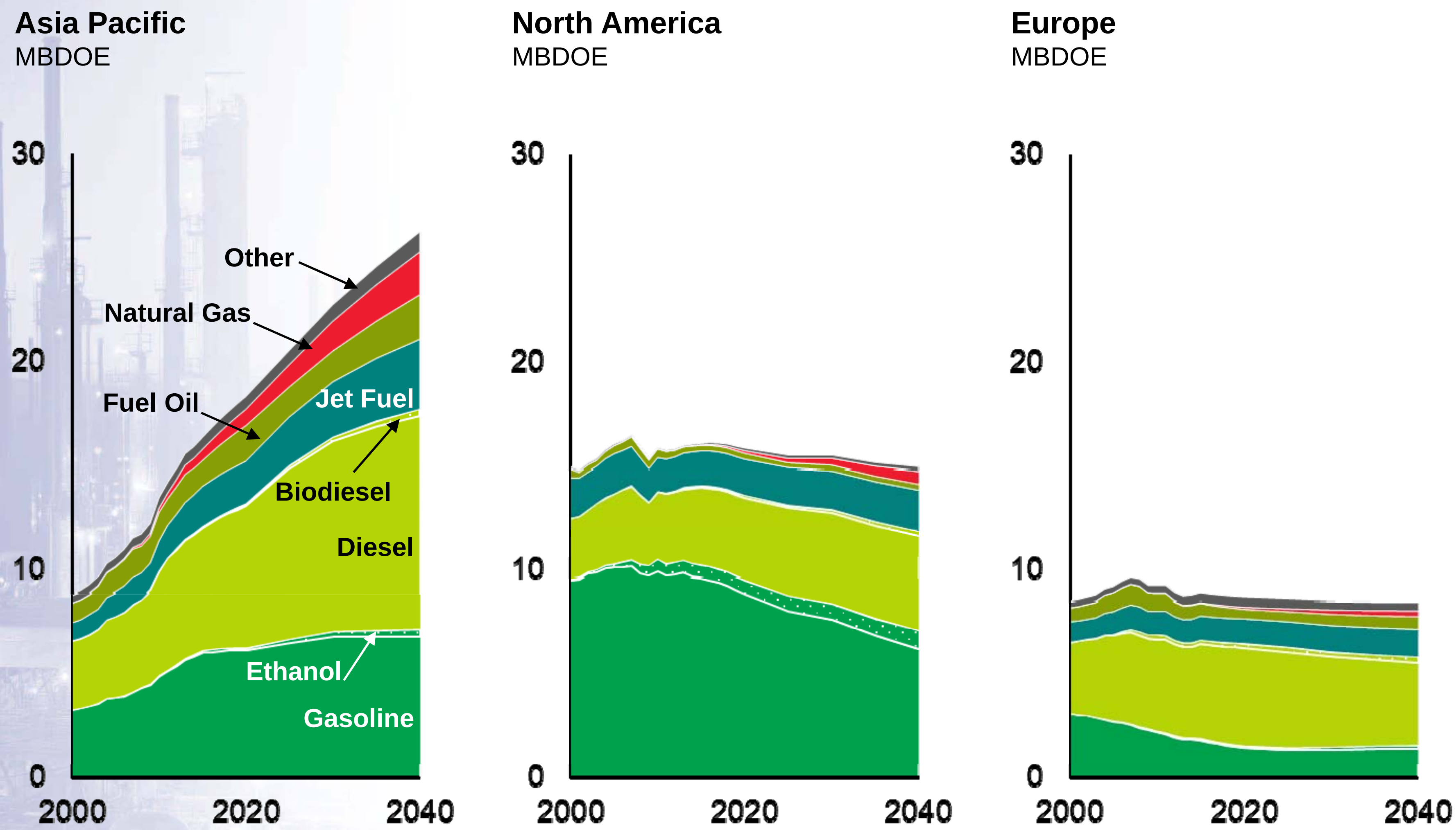
Transportation Fuel Mix by Region



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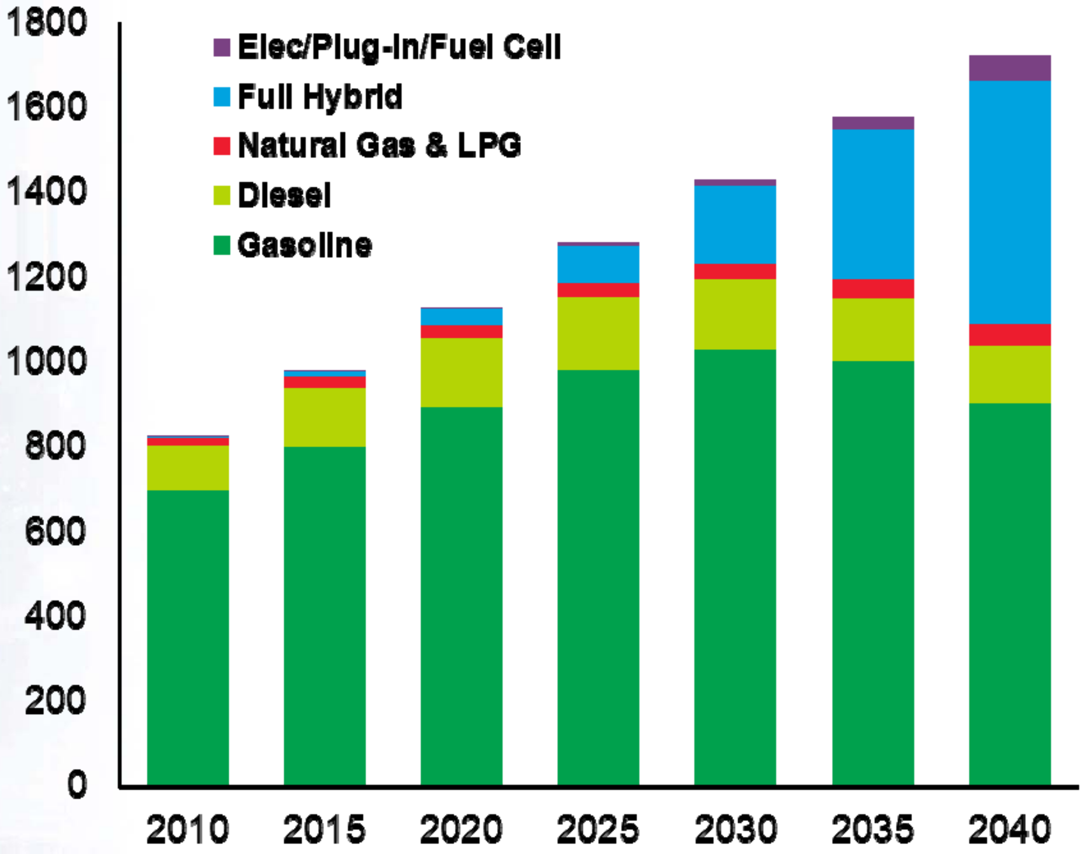
Light Duty Vehicles

Fleet by Type

Million



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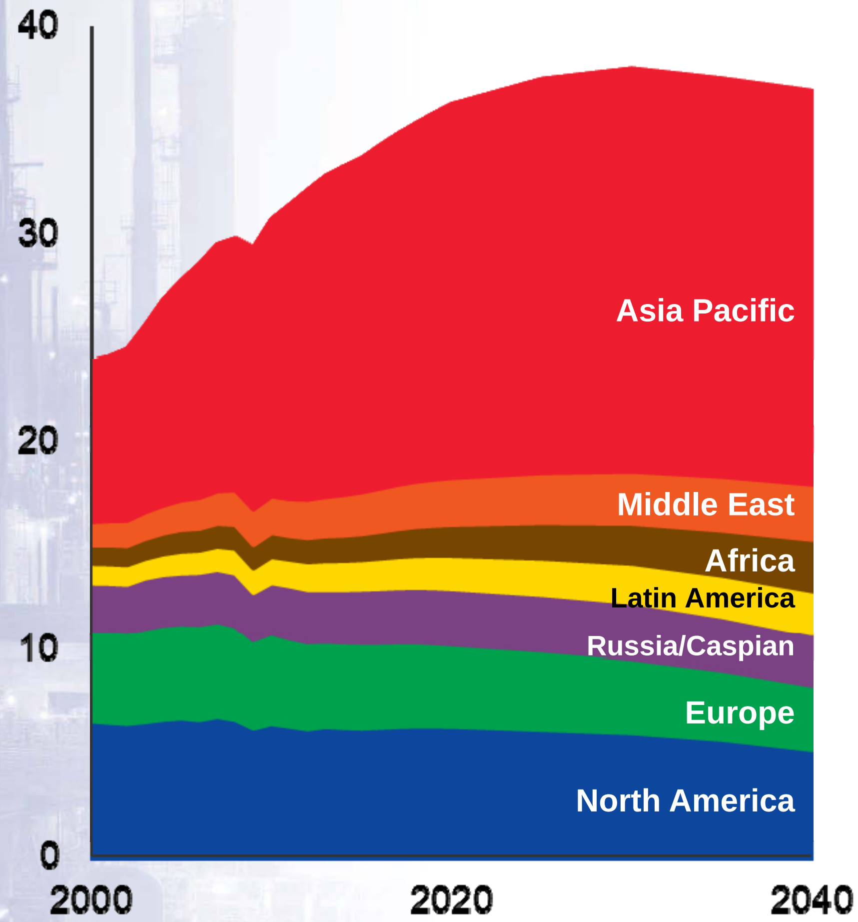
CO_2 Emissions Plateau

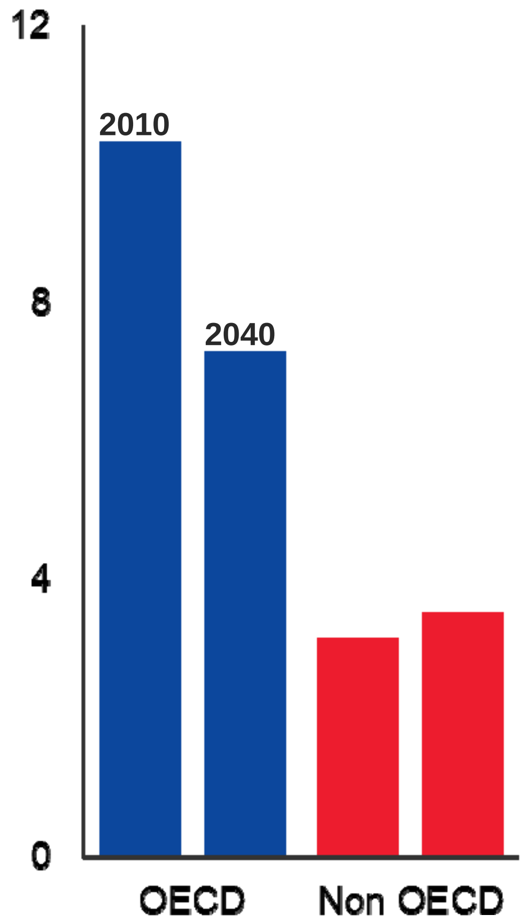
Energy-Related CO_2 Emissions by Region

Billion Tonnes



Emissions per Capita

Tonnes / Person



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Background to Advanced Diesel Studies

- Europe's diesel/gasoline demand ratio is continuing to increase:
  - Continuing consumer demand for personal mobility
  - More dieselization of the light-duty (LD) fleet
  - More heavy-duty demand for freight transport
  - Europe is importing diesel and jet fuel/kerosene and exporting gasoline
- Euro 6 (2014) emissions limits will lower NOx and PM emissions with new requirements anticipated for 'real-world driving' performance
  - Adding cost and complexity to LD diesel vehicles
- EU mandates will require better fuel consumption from LD vehicles
  - 130g CO_2/km from 2012; 95g CO_2/km by 2020
  - 43 to 47 MPG_{US} from 2012; 58 to 65 MPG_{US} by 2020
  - 'Systems' approach needed to capture improvements from entire engine/vehicle
- Renewables mandated to achieve 10% energy content in road fuels by 2020
  - Vehicle technology must be robust to a diverse fuel and biofuel mix

CONCAWE / FEV / RWTH Work on Advanced CI

- Extensive studies previously completed on bench engine and demo vehicle
  - Diesel engine optimised for low temperature combustion (LTC)
  - Closed Loop Combustion Control (CLCC) important
  - Bench engine operated successfully on diesel, diesel /gasoline, naphthas, gasoline Primary Reference Fuels having low cetane numbers (DCN 30)
  - Demonstrator vehicle achieved CO_2, NOx/PM, and combustion noise targets over the New European Driving Cycle on various fuels
  - Advanced diesel engines found to tolerate a wide range of fuels
- Concawe publications related to advanced combustion studies:
  - Literature review: Advanced combustion for low emissions and high efficiency (Report 4/08)
  - Part 1: Impact of engine hardware on HCCI combustion (SAE 2008-01-2405 and Report 9/10
  - Part 2: Impact of fuel properties on HCCI combustion (SAE 2008-01-2404 and Report 10/10)
  - Part 3: Advanced combustion in a demonstrator vehicle (SAE 2010-01-0334)
  - Exploring a Gasoline Compression Ignition (GCI) Engine Concept (SAE 2013-01-0911)
  - Modelling a Gasoline Compression Ignition (GCI) Engine Concept (SAE 2014-01-1305)
  - Modelling the Low-Load Performance of an Advanced Compression Ignition Engine Running on European Market Gasoline (TRA 2014:20165)
  - Exploring a Gasoline Compression Ignition (GCI) Engine Concept (Report 13/14)

For CONCAWE reports, see www.concawe.org

What Fuel for Advanced CI Engines?

	Will work in advanced CI engines?	Already available at retail stations?	Helps rebalance diesel/gasoline demand ratio?
Diesel (EN590)	✓	✓	✗
Kerosene	✓	✗	✗
Blends of diesel and gasoline	✓ *Evaporative emissions and flashpoint?*	? *New mixing dispensers at retail stations?*	? *Depends on performance and market uptake?*
New lower cetane fuel	✓	✗	?
Gasoline (EN228)	? *Evaporative emissions?*	✓	✓

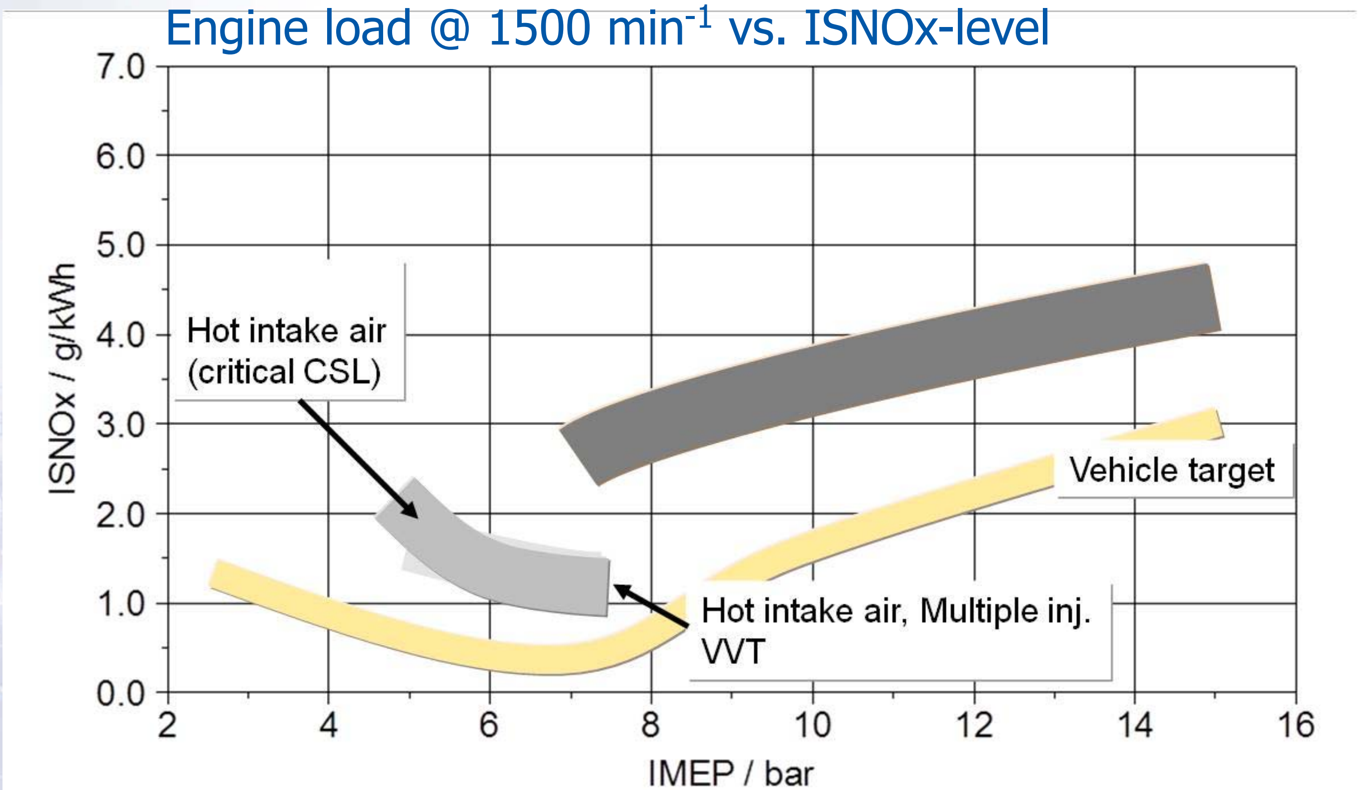
- Challenge with pump gasoline is its resistance to ignite
- Can Variable Valve Timing and combustion assistance aid low load operation?

Advanced Diesel Bench Engine Specifications

	Units	Bench Engine
Benchmark	[-]	Euro 6
Displacement	[cm^3]	390
Stroke	[mm]	88.3
Bore diameter	[mm]	75
Compression Ratio (CR)	[-]	19:1
Valves per cylinder	[-]	4
Maximum peak pressure	[bar]	220
Fuel injection system specifications	[-]	Bosch Piezo Common Rail System
Maximum injection pressure	[bar]	2000
Hydraulic Flow Rate (HFR)	[cm^3/30s at 100bar]	310
Nozzle hole diameter	[µm]	109
Number of spray holes	[-]	8
Spray Cone Angle	[°]	153
Charging	[-]	Max. 3.8 bar absolute

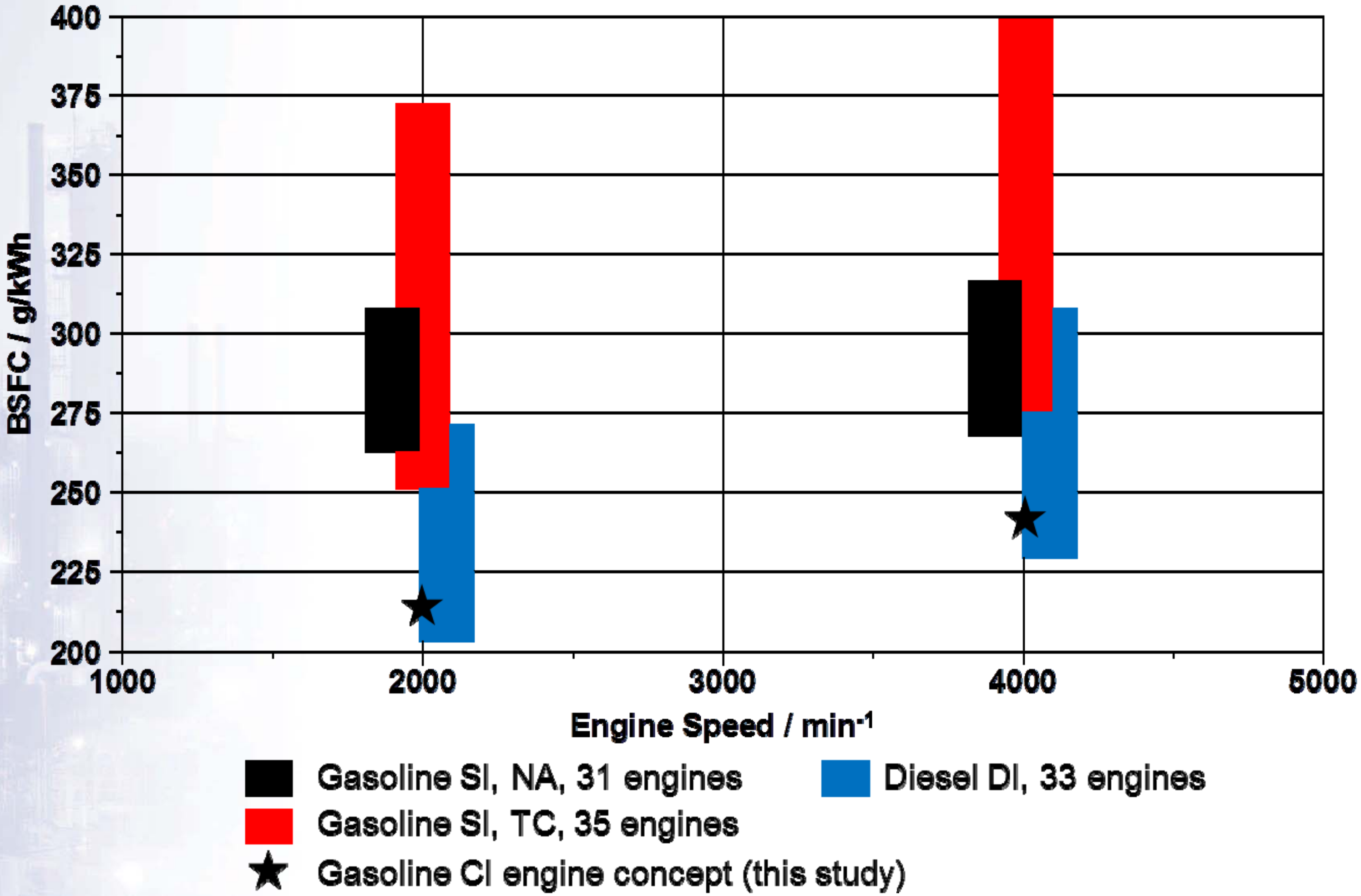
- 19:1 CR and pilot injection enabled gives better combustion at full load
- Success criterial low NOx, lowest posible PM/HC/CO, FC/noise similar to diesel

Stable Operation Achieved over Wide Range



- Stable operation was achieved over a large part of the operating range with good fuel consumption and acceptable CSL (noise)
- NOx emissions were higher than desired with limits on EGR rate
- Fuel's ignition resistance (low CN) prevented more improvement

Fuel Consumption Better than Gasoline Engines



- Comparison of the measured fuel consumption of the GCI engine and state of the art SI and CI engines (MY 2012 - benchmarked by FEV)

Lower load operation: What else can be done?

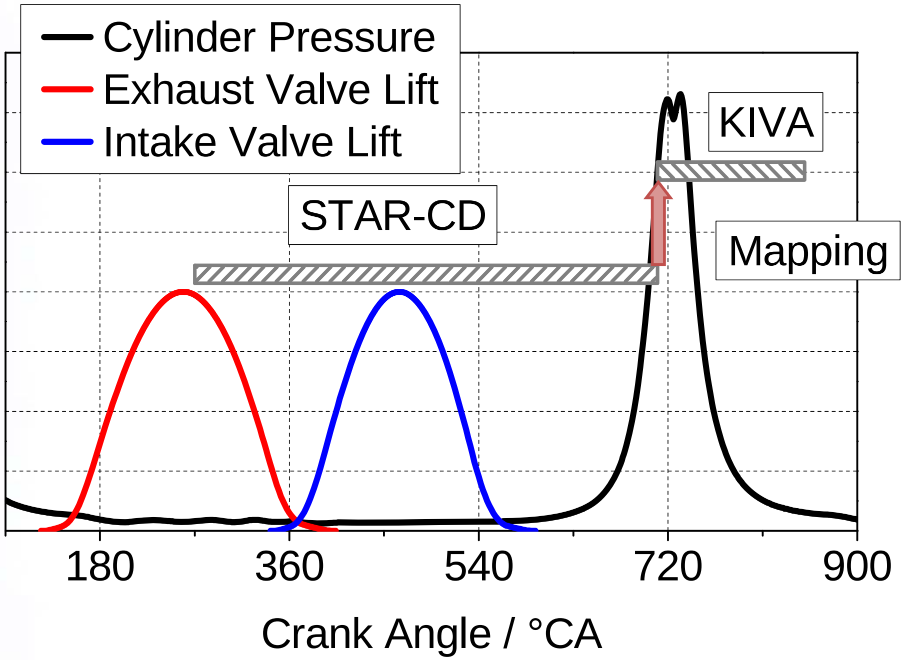
- With the objective of using market gasoline as the primary fuel:
  - More complex cam profile allowing a more flexible variable valve timing (VVT) arrangement
  - Use of a supercharger as well as a turbocharger to increase the boost pressure at low load
  - Use of an advanced ignition source (glow plug, spark plug, or laser) to initiate combustion and assist at lower loads
  - Use of Variable Compression Ratio (VCR)
  - Dual-fuelling operation

- All these options add complexity and cost ➔ benchmarking of potential improvements against the cost and efficiency of aggressively downsized and boosted SI engines would be needed

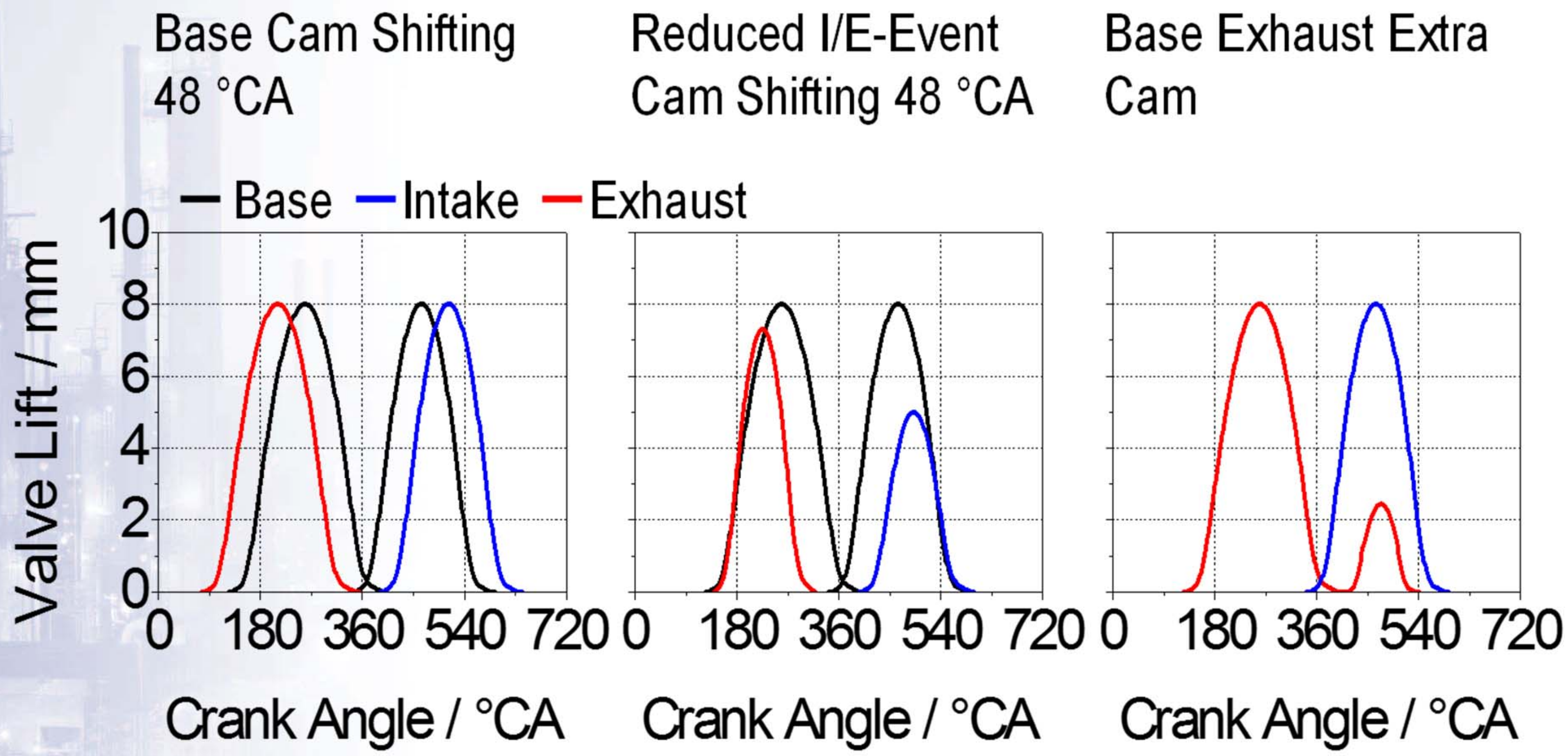
- Additional cost would also be incurred in adding an evaporative emissions control system to a Gasoline CI (GCI) concept

Modelling Methodology

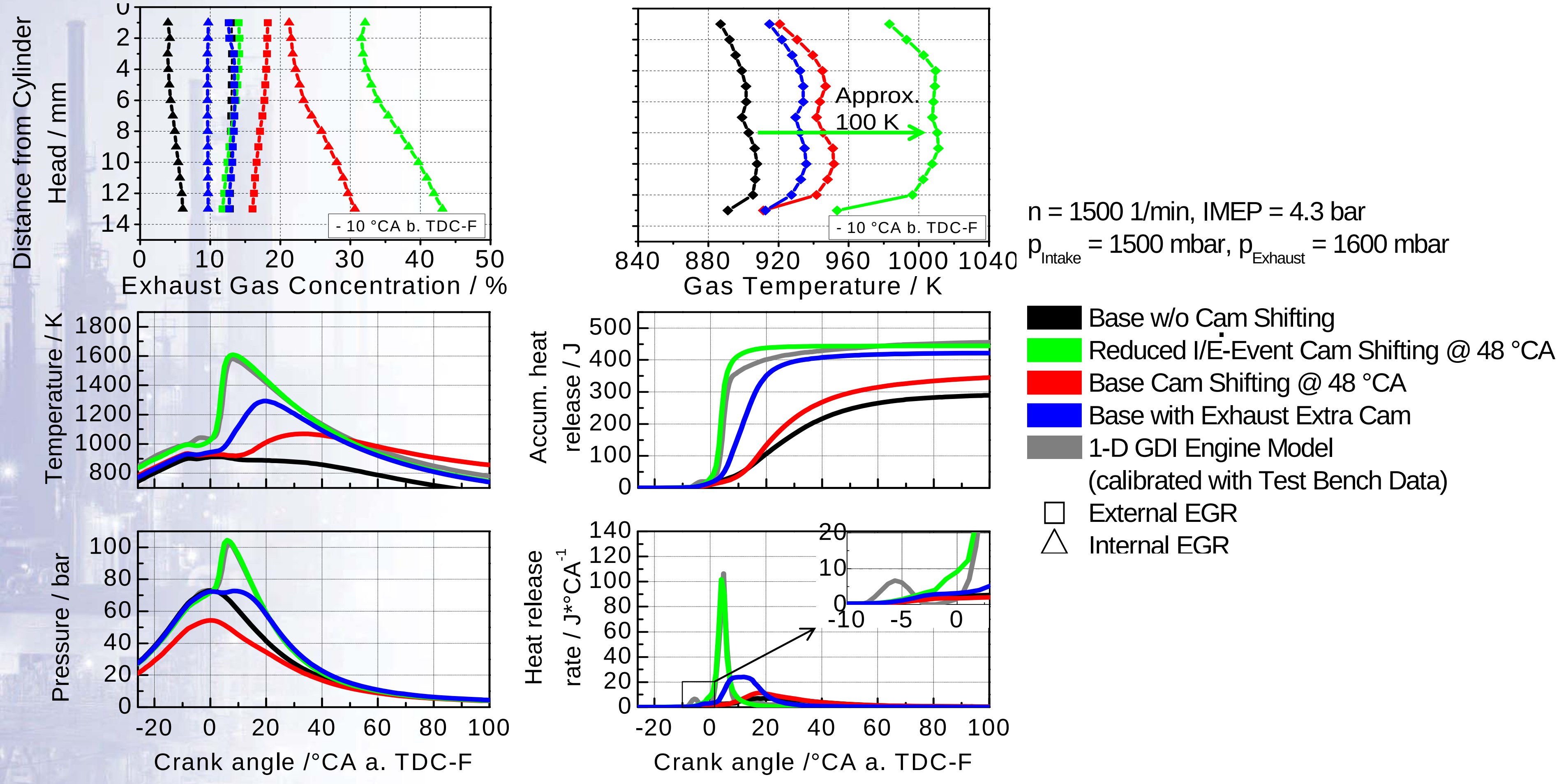
- Gas exchange and turbulent non-reacting flow
  - Modelled using STAR-CD
  - 1x 10^6 grid mesh containing inlet/outlet ports, piston, cylinder head and walls
  - 1D simulation (GT-Power) provided T + P boundary conditions for CFD model.
- Combustion
  - Modelled using KIVA 3V with Engine Research Center (ERC) model extensions
  - Segment of the ω-shaped piston bowl of approximately 50 000 cells



VVT Strategies Simulated

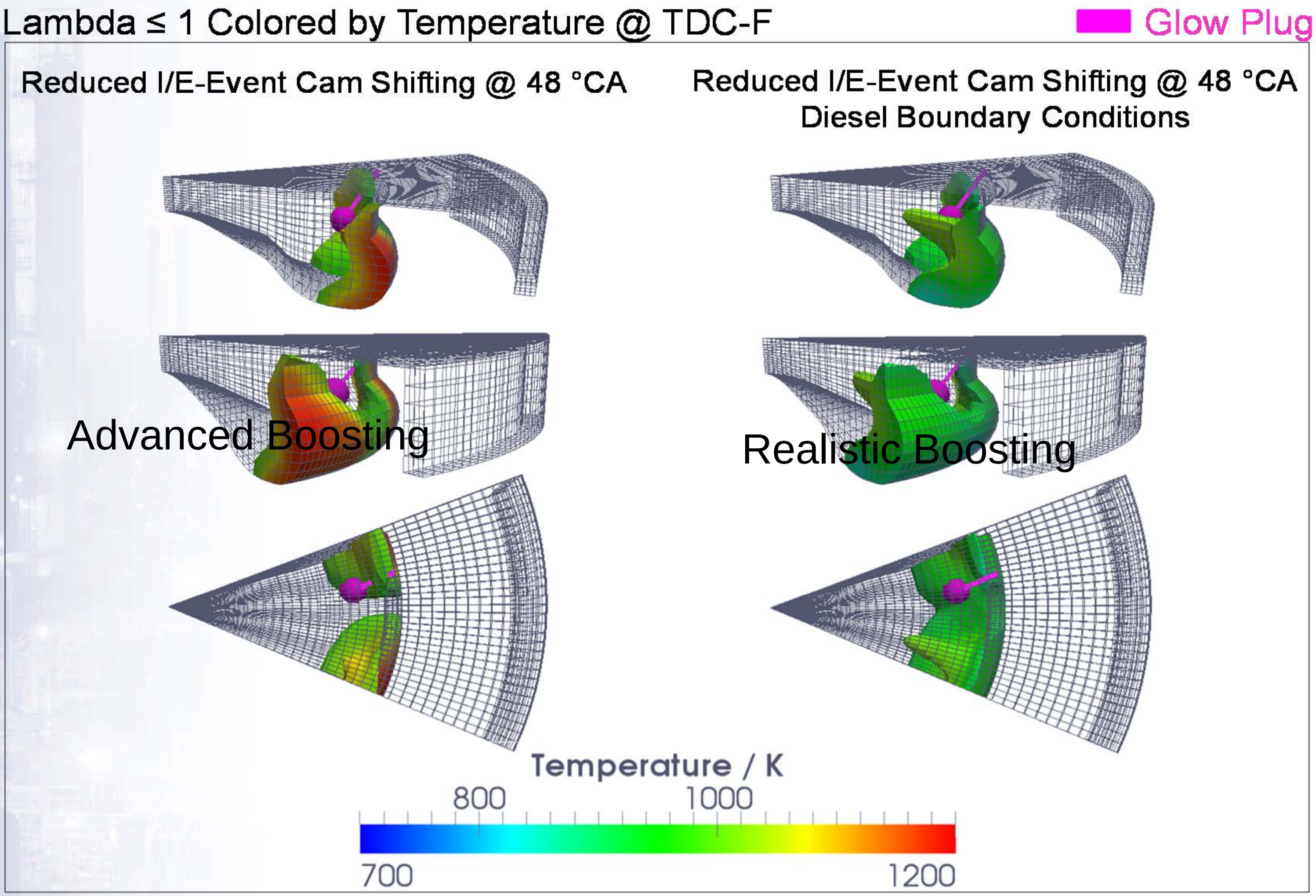


VVT can increase gas temperature by 100K



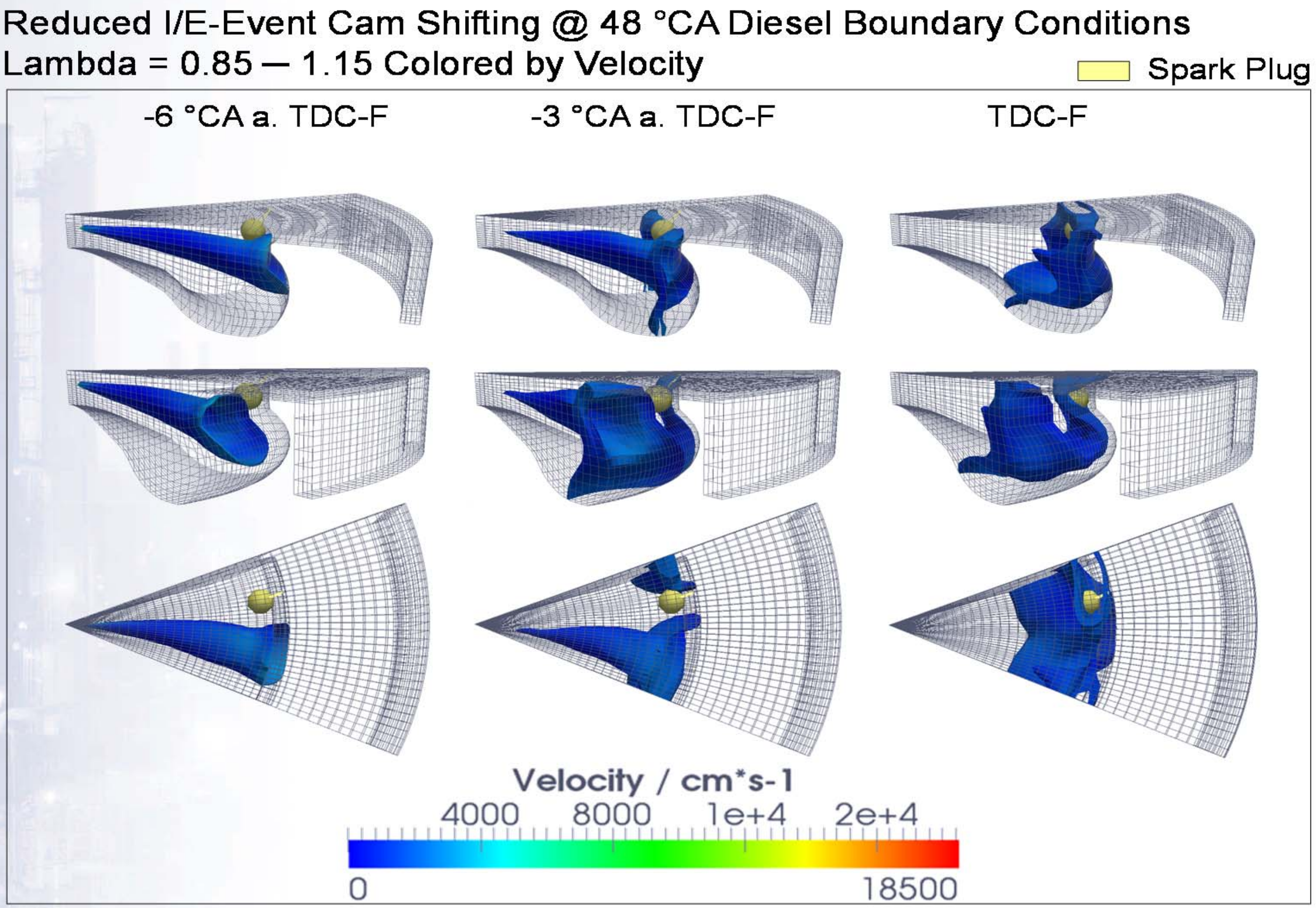
KIVA Results – Effect of realistic boost pressure
(1500rpm, 4.3 bar IMEP, Nozzle cone angle = 153°)

- In most promising VVT configuration, combustion assistance needed (glow plug)



Simulating spark plug assist

(1500rpm, 4.3 bar IMEP, Nozzle cone angle = 160°)



- Nozzle Cone Angle of 160° and nozzle protrusion > 1.5 mm found to be optimal to ensure ignitable mixture around spark location.

Summary

- Increasing dieselization of the market due to increased commercial transportation amongst other factors is increasing pressure on the diesel/gasoline demand from refineries
- Running a higher volatility fuel such as gasoline in a diesel engine has been shown to give some emissions and fuel economy benefits
- Previous Concawe work has shown that running market gasoline in a compression ignition engine is achievable over a large part of the speed/load range by applying common optimization techniques
- Modelling work shows that advanced VVT strategies can increase in-cylinder gas temperature, enhancing gasoline's ignitability at low loads especially in the presence of advanced boosting
- The most promising VVT strategy and nozzle configurations give an ignitable mixture in the vicinity of the glow
  - Spark plug ignition also possible with wider nozzle cone angle and nozzle protrusion>1.5mm
- Increasing interest in GCI as a viable technology which could help solve future supply issues as well as meet future regulation needs

Acknowledgements

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