

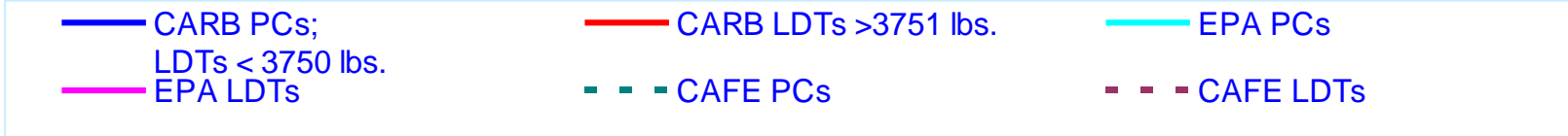
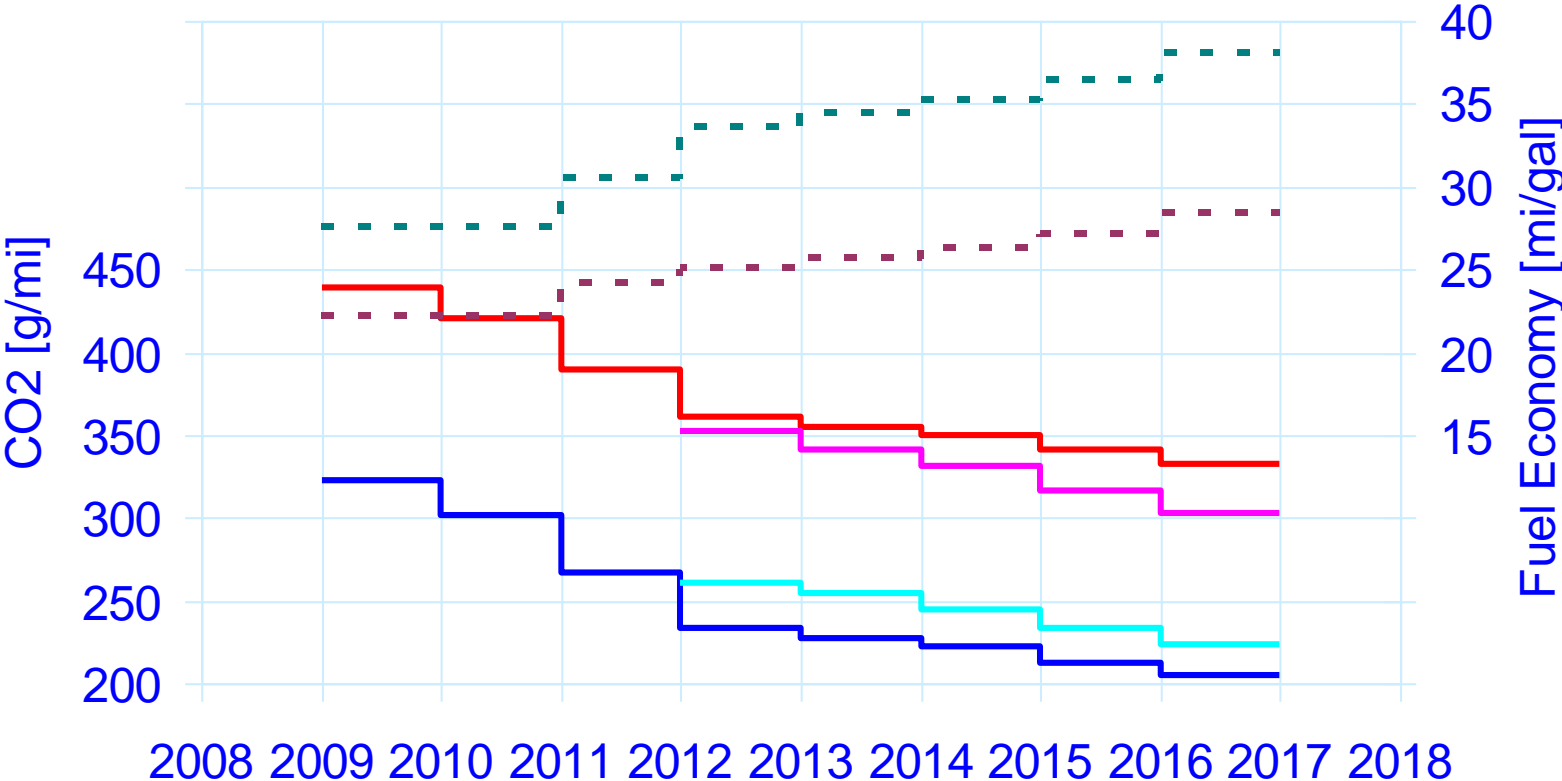
Update on Project SABRE - a Downsized High BMEP Direct Injection Engine and Lotus Range Extender Engine - a Different Approach to Maximum Efficiency

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Lotus Engineering



LOTUS
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Greenhouse Gas Emissions - Standards



Options For Reducing GHGs

■ Higher Efficiency Engines

- ▮ Gasoline

- ▮ Diesel

■ Hybridization

■ Battery Electric Vehicles

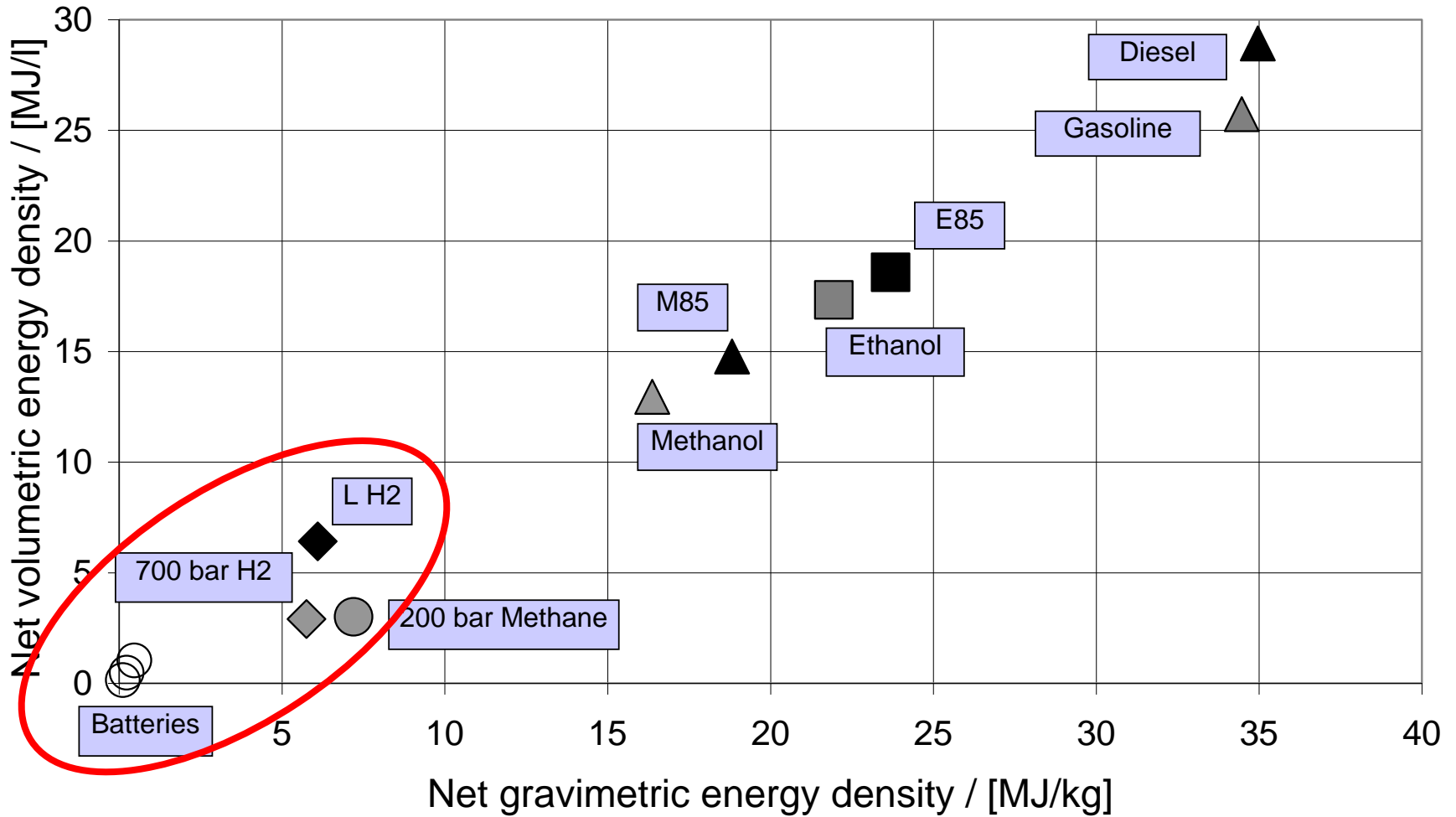
■ Hydrogen Fuel Cell Vehicles

■ Low Carbon Fuels

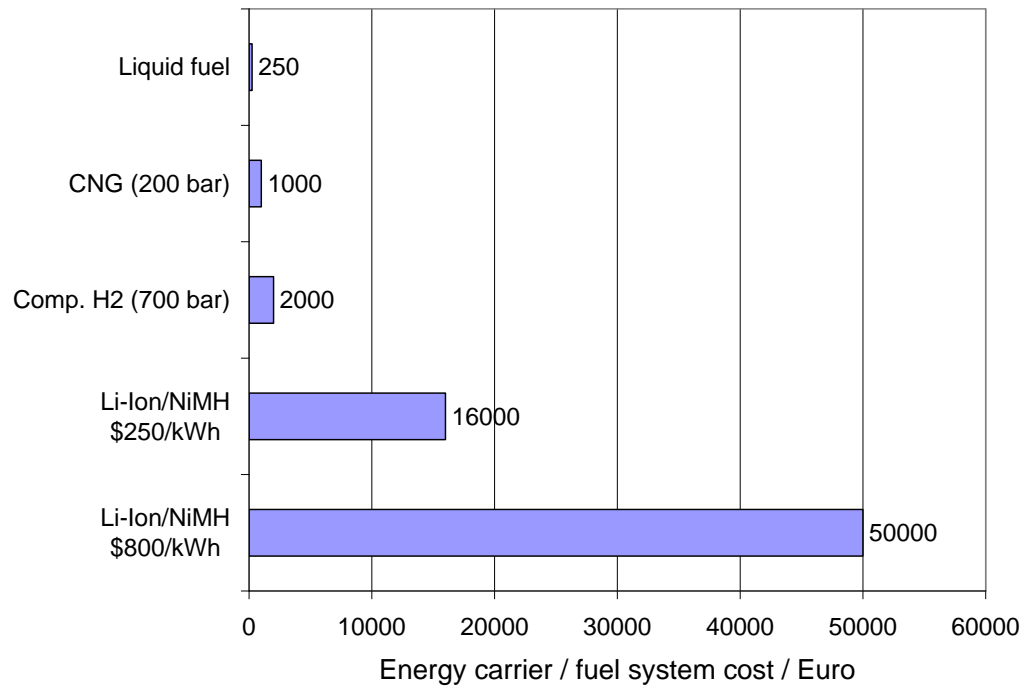
- ▮ Gaseous

- ▮ Liquid

Fuels and Energy Carriers



System Costs



Tata Nano

- For Equivalent Range, Electrical Storage is Very Expensive
- Increased Use of Scarce Materials Won't Lower Prices
- Unaffordable Low Carbon Vehicles Won't Reduce CO₂
- Hybridization Can Help to Reduce Total System Cost

Hybridization A Necessity But What Kind

- Type:
 - ≡ Electric, Hydraulic, Flywheel, . . .
- Architecture:
 - ≡ Parallel, Series, Combined
- Degree:
 - ≡ Mild, Strong, Full, . . .
- Battery Electric Vehicle Derivatives
 - ≡ Plug-In, Range Extended, . . .



The SABRE Concept

The vehicle: CO₂ Emissions < 140 g/km and fun-to-drive

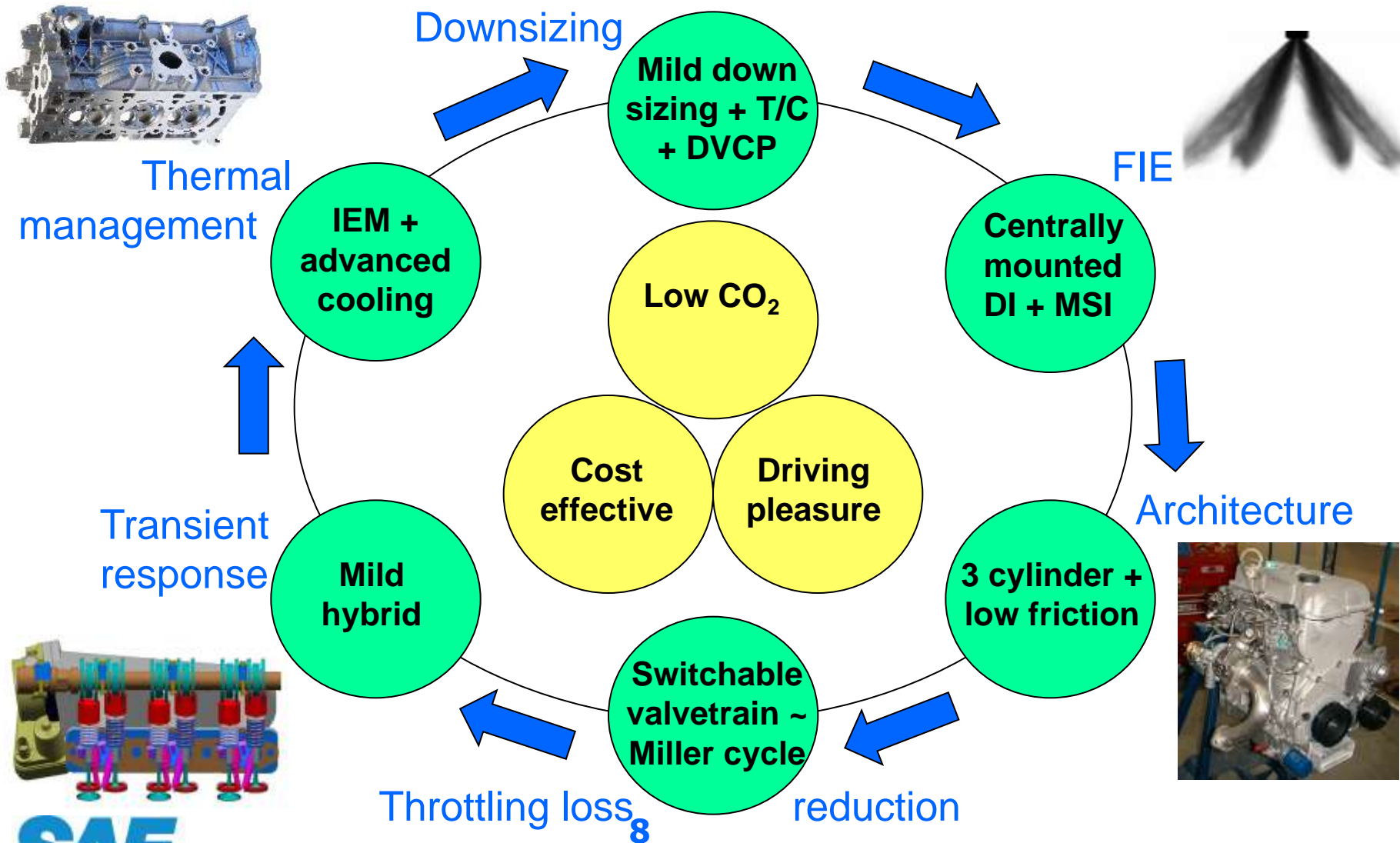
- Family Size Vehicle
- High Volume Model and Market Segment

The Engine: Affordable High Technology Concept

- Downsizing concept with 1.5 l 3-cylinder engine, single stage, fixed geometry turbocharger, performance equal to 2.2l 4-cylinder engine
- Homogeneous DI concept
- Solenoid multi-stream injectors (MSI) in central position
- Variable valve actuation (switching tappets)
- Integrated exhaust manifold
- **Mild Hybrid** for Stop-Start, brake energy recovery and transient torque assist



SABRE Design Philosophy



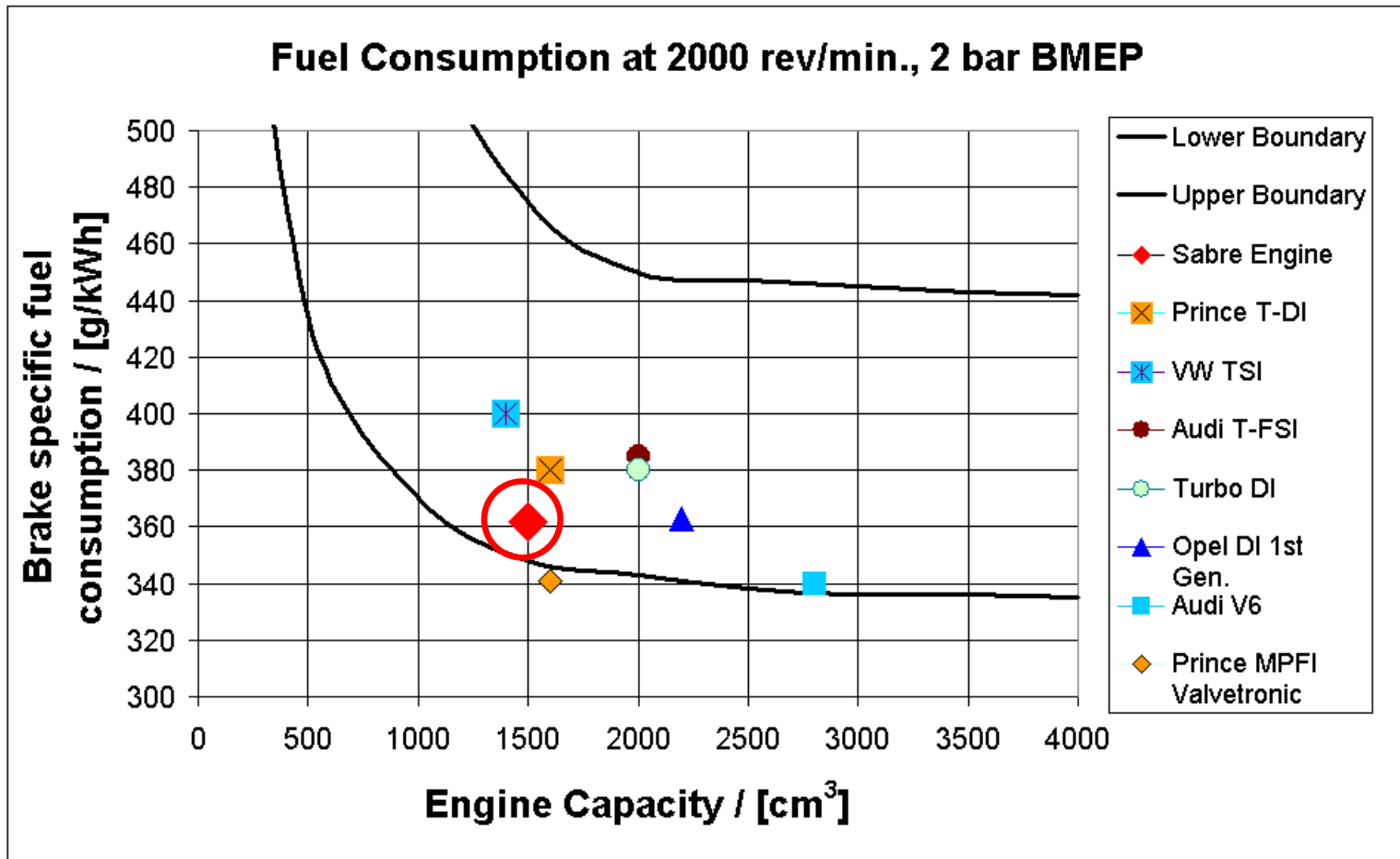
SABRE Design Features

- Mild Downsizing
- 3 Cylinders
 - ≡ Large Cylinder Diameter
 - ≡ Low Friction
 - ≡ Improved Turbocharging
- Central Direct Injection
- Two Step Cam and Dual Cam Phasers
- Integrated Exhaust Manifold

= Low Cost Available Technologies

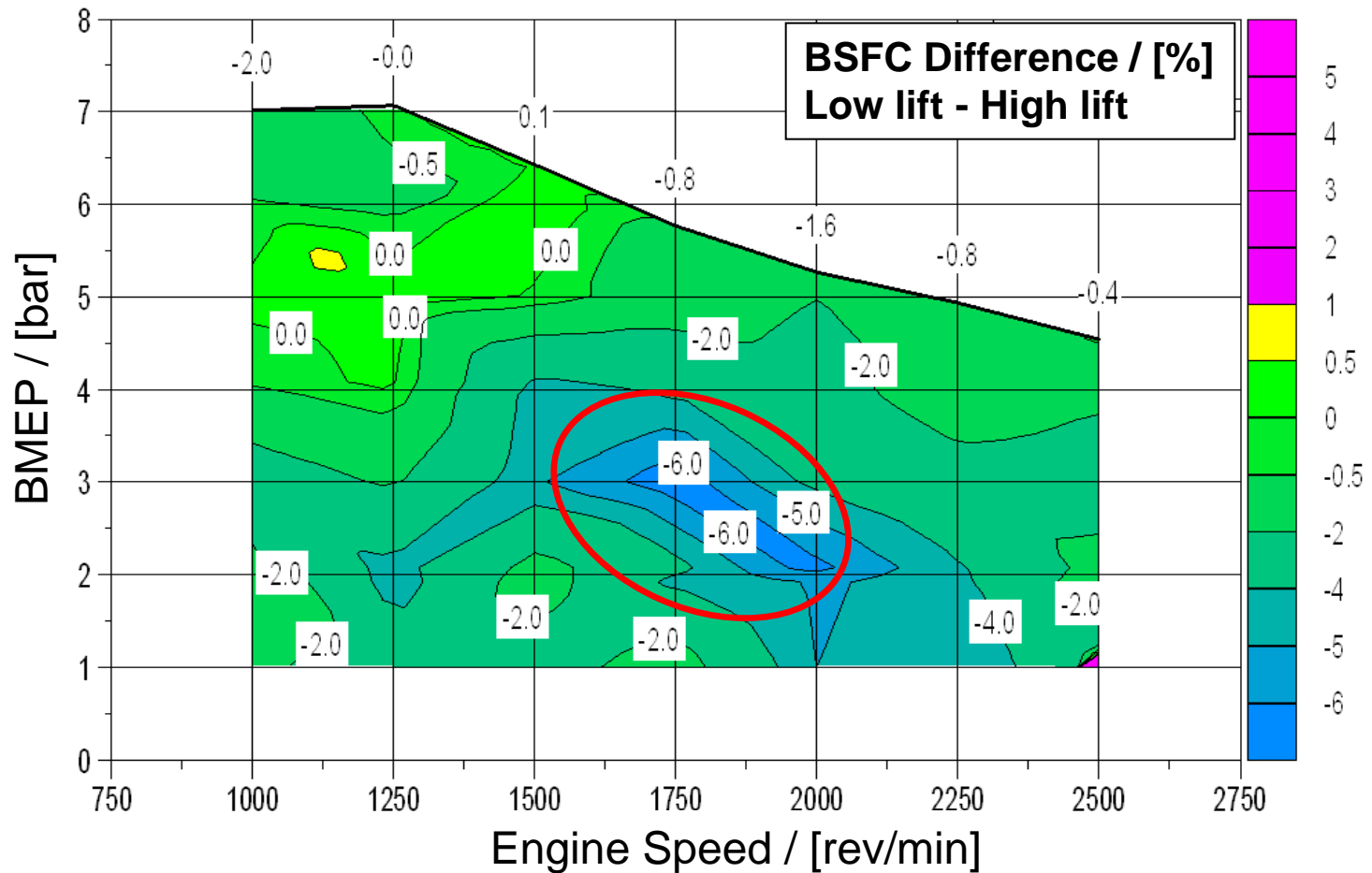
SABRE Results

Part Load Fuel Consumption



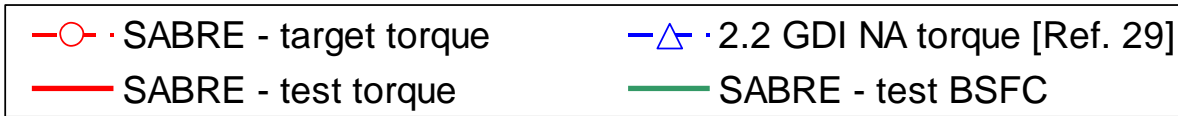
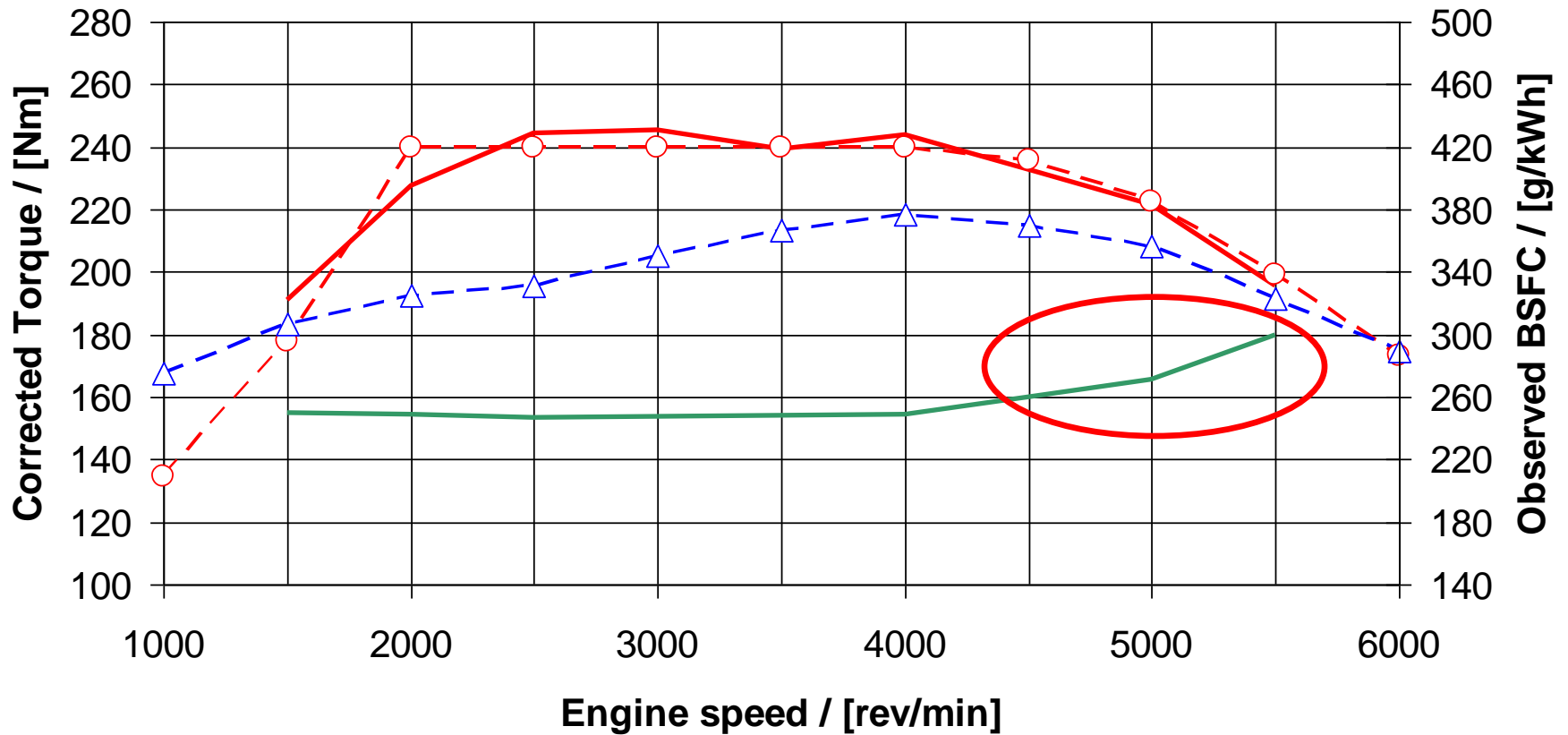
SABRE Results (2)

Effect of Two Step Cam on Part Load Fuel Consumption



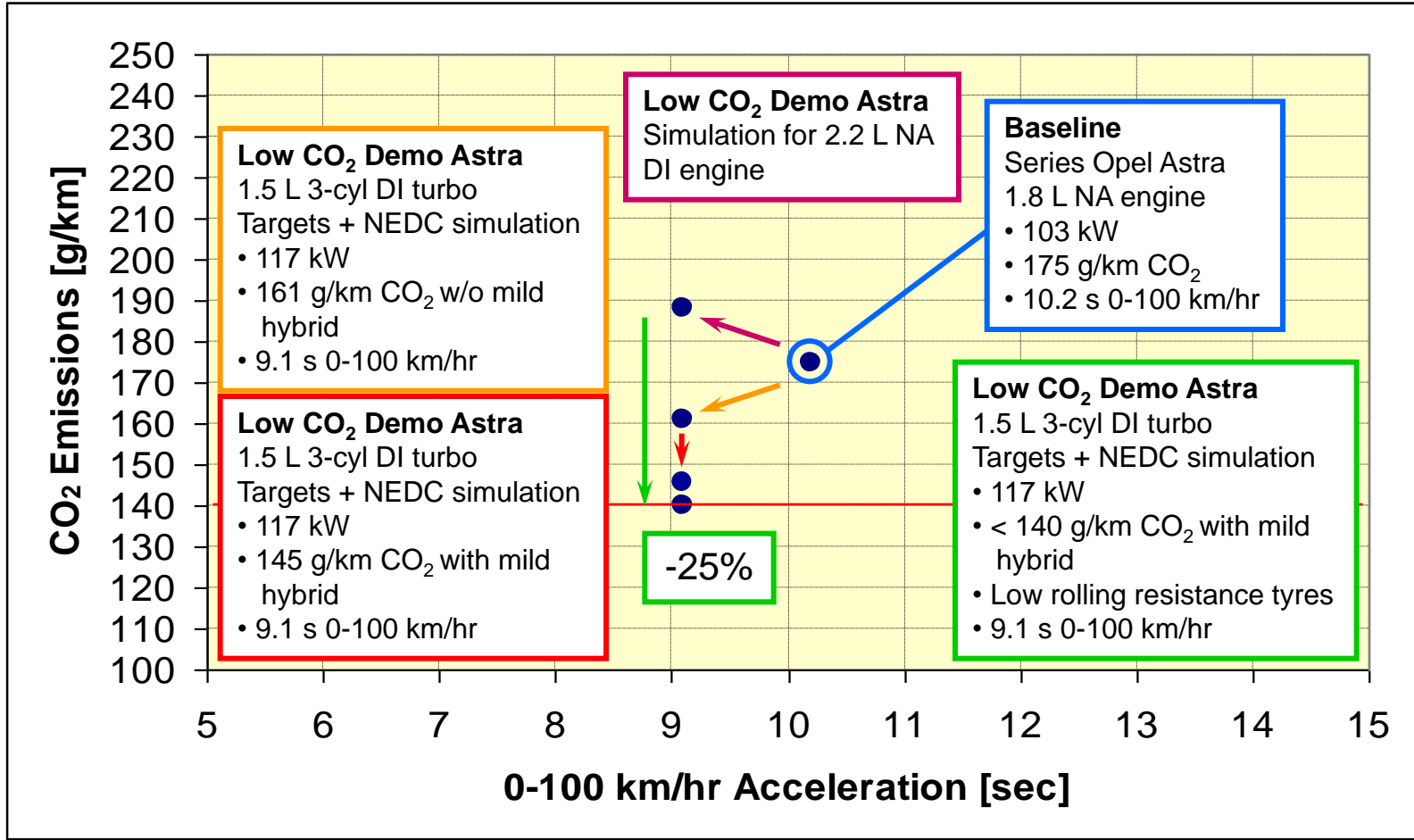
SABRE Results (3)

Full Load Performance

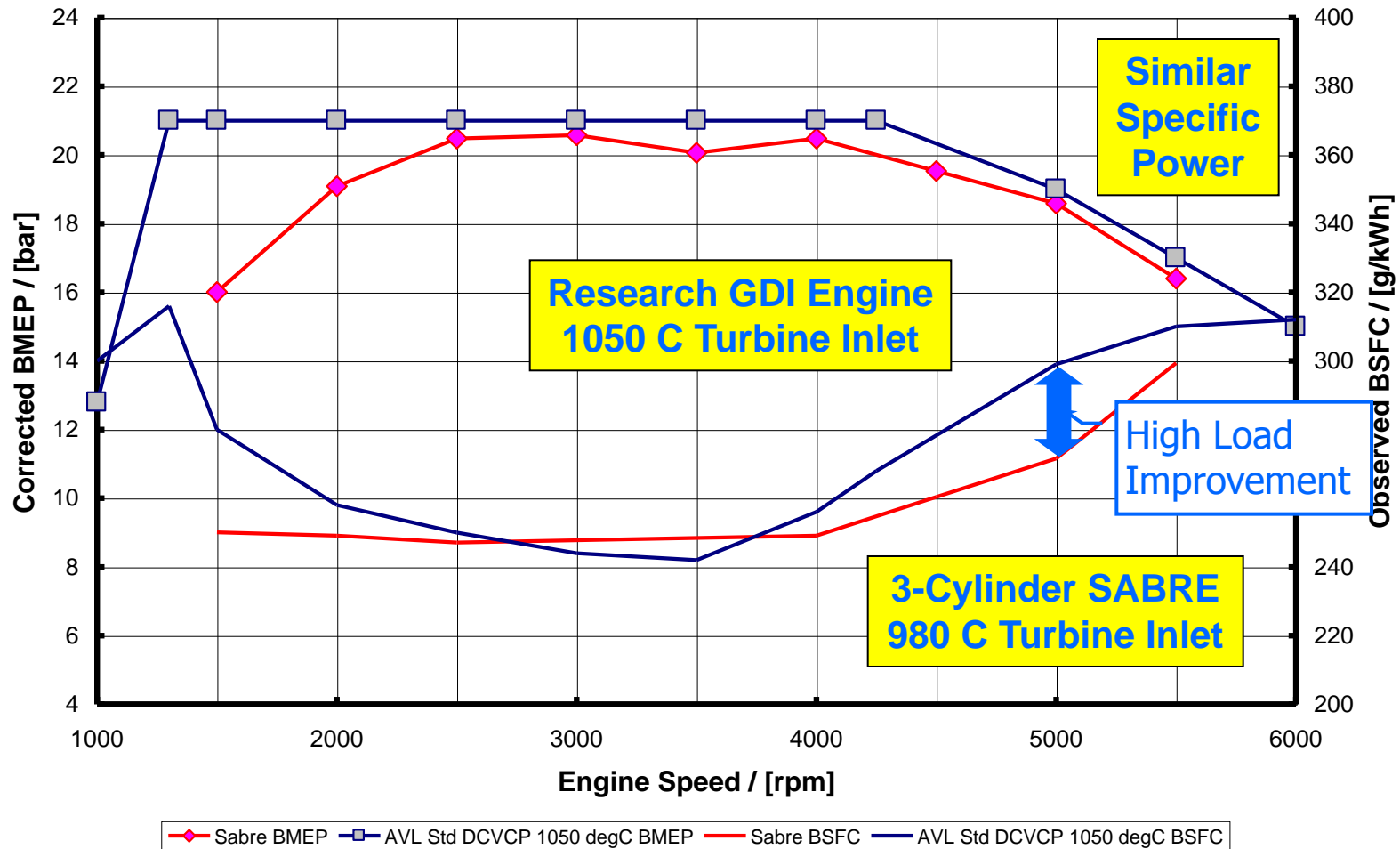


Low CO₂ Concept Vehicle Results

Positioning of System Concept Car: Low CO₂ Emissions versus Fun-to-Drive



Comparison to Other Downsized Engines

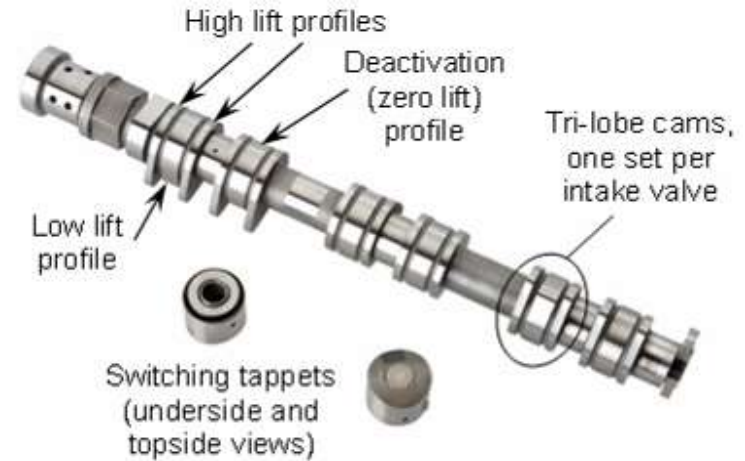


SABRE Summary

- Cost Effective, Affordable Technology Concept
- Known, Current Production Technologies:
 - ≡ Switching Tappets
 - ≡ Single Stage, Fixed Geometry Turbocharger
 - ≡ Cam Phasers
 - ≡ Solenoid Injectors
 - ≡ Integrated Exhaust Manifold

Plus:

- Homogeneous DI Concept (no Lean NO_x Aftertreatment)
- 3-Cylinder Configuration (Parts Count, Weight, and Cost Reduction)
- Mild Hybrid for Stop-Start, Regenerative Braking and Transient Torque Assist



A Synergistic Combination of Technologies to Achieve Low CO_2

Another High Efficiency Option



SABRE



**Range
Extender**

Range Extender Requirements

- Single Speed Engine
- High Thermal Efficiency/Low Fuel Consumption
- IC Engines Are Most Efficient if Operated at Single Speed/Load
- Low Technology Content for Lowest Cost
- Minimum Package Size
- Low Part Count
- Minimum Weight
- Automotive Reliability



Options for Range Extender Engines

Gen-Set Type SI engines

- Pros: Inexpensive
- Cons: Low Efficiency, High Emissions, Not Durable



Motorcycle SI engines

- Pros: High Power Density, Light Weight
- Cons: Low Efficiency, High Emissions, Not Durable, Expensive, NVH

Diesel – Existing Automotive Architecture

- Pros: High Efficiency, Durable
- Cons: High Cost, Complex Exhaust Aftertreatment, Expensive, Heavy



Gasoline – Existing Automotive Architecture

- Pros: Inexpensive, Low Emissions, Durable
- Cons: Lower Efficiency, Heavy, Excess Technology (Higher Cost)



Options for Range Extender Engines (2)

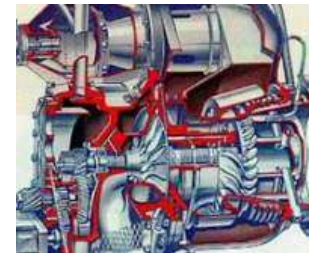
Rotary Engines

- Pros: Power Density, Weight, Package Size
- Cons: Low Efficiency, Not Durable, Cost



Gas Turbines

- Pros: Power Density, High Efficiency, Multi-Fuel
- Cons: Expensive, Package Size, Heavy



Fuel Cells

- Pros: Zero Emissions, High Efficiency
- Cons: Very Expensive, Hydrogen Refueling, Package Size, Heavy, Maturity

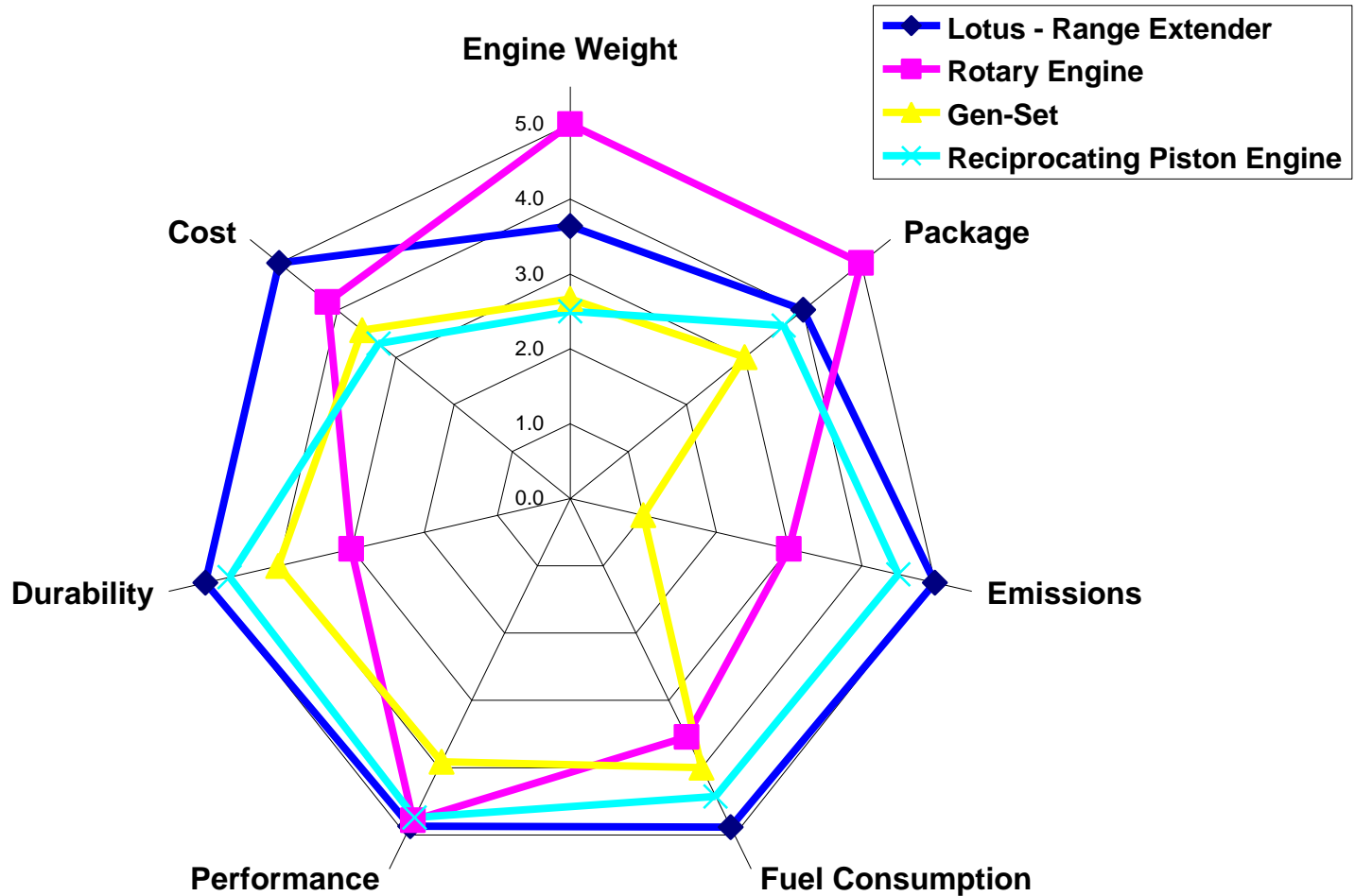


Dedicated Automotive SI Range Extender

- Pros: Inexpensive, Efficient, Durable
- Cons: Requires A New Engine Philosophy



Comparison of Range Extender Options



Lotus Range Extender Concept

- 3-Cylinder Engine
- Aluminum Monoblock Construction
- Integrated Exhaust Manifold
- Very High Efficiency
- Very Low Friction
- Low Emissions (High Cranking Speed From Integrated Generator)
- Low Cost Technology
- Reduced Part Count and Cost
- Reduced Mass
- Reduced Radiant Heat
- Improved NVH Performance
- Simple Aftertreatment and Control



Lotus Range Extender Key Features

3-Cylinders

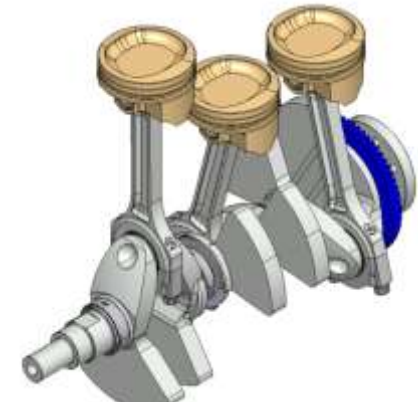
- Low Friction
- Breathing Advantages
- Reduced Part Count
- Low Cost

Monoblock With IEM

- Reduced Part Count
- Low Cost
- Higher Reliability

Low Rated Speed

- 2 Valves per Cylinder
- Component Downsizing, Lightweighting
- Low Friction
- Low Technology
- Low Cost



Strong Synergies

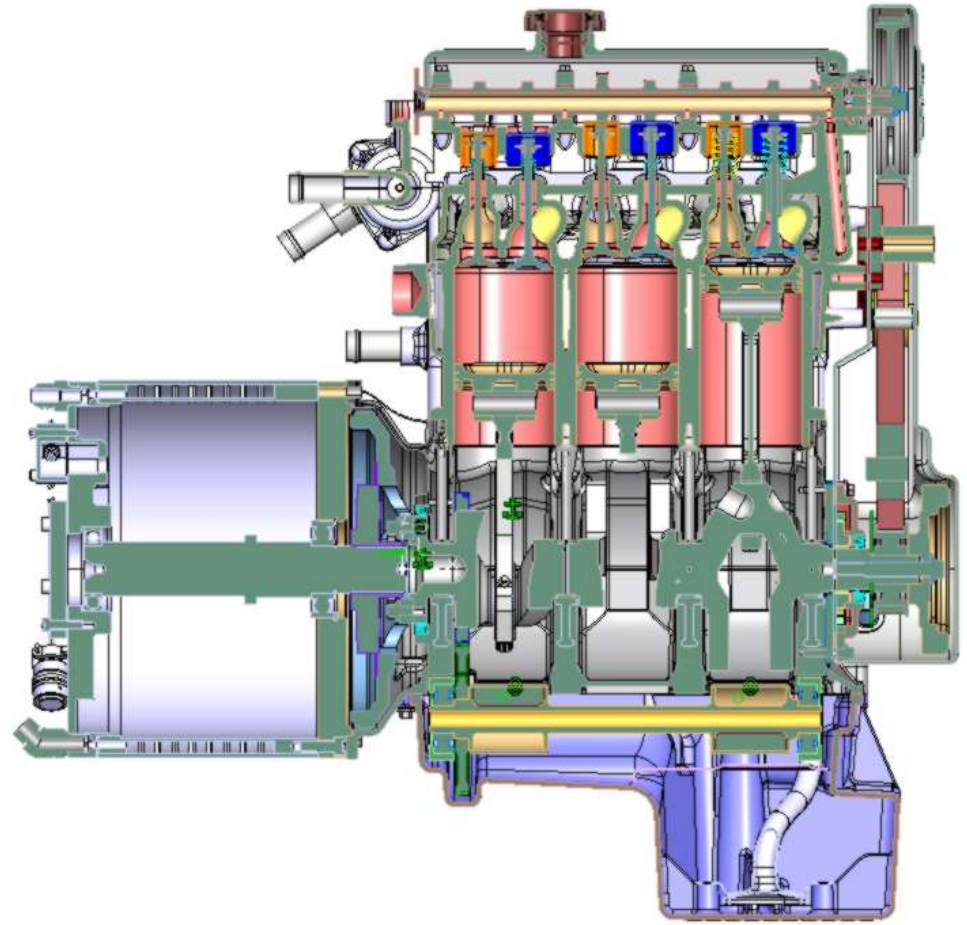
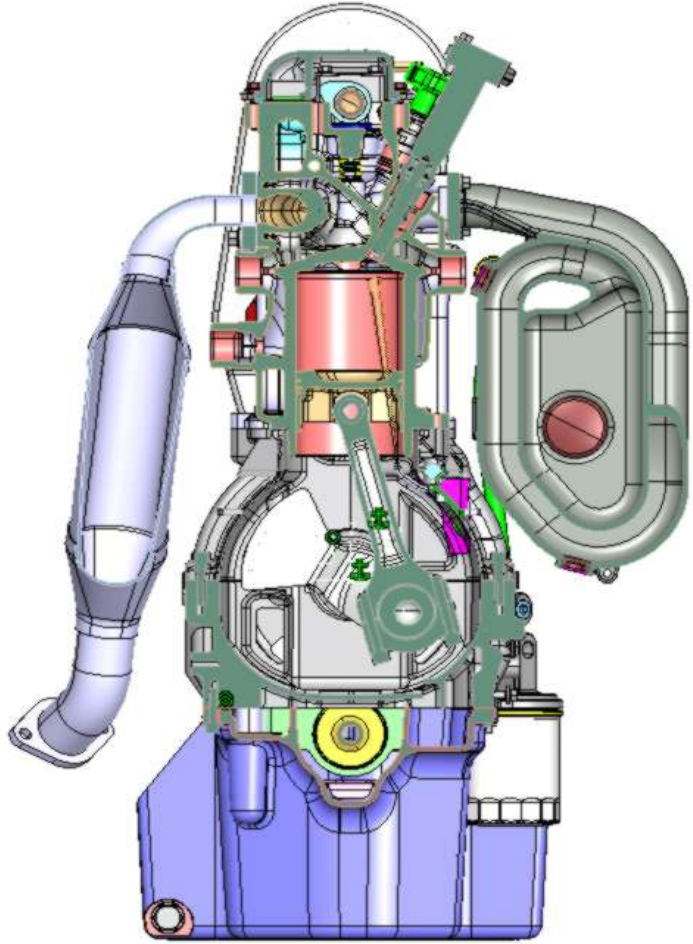


Lotus Range Extender Specification Summary

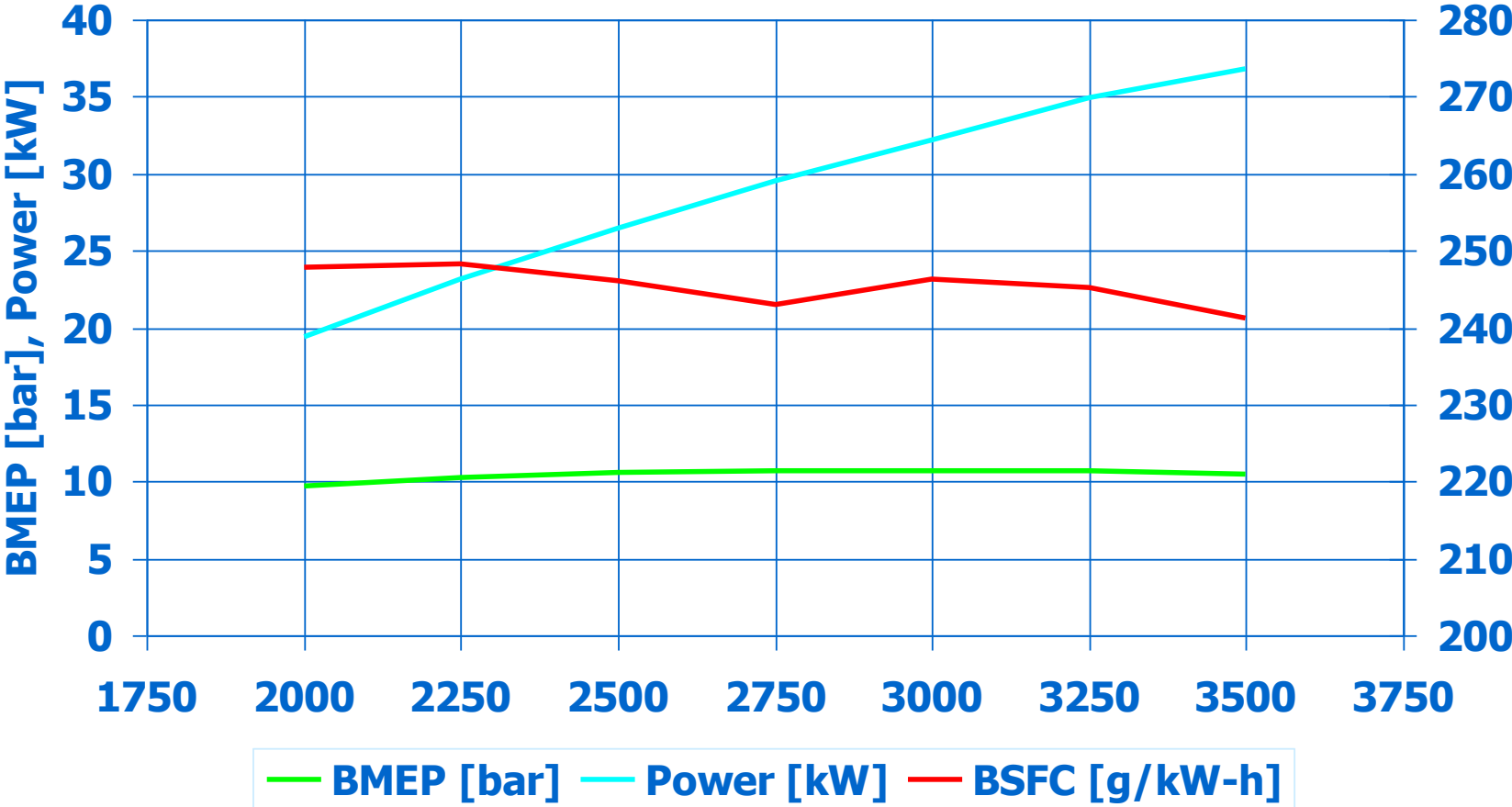


General	1.2 l 3-Cylinder With 2 Valves per Cylinder, SOHC
Bore X Stroke	75mm X 90mm
Construction	Monoblock With Integrated Exhaust Manifold All Aluminum Balance Shaft (Optional)
Maximum Power	38 kW (51 Bhp) At 3500 Rpm
Max BMEP	11.2 Bar
Peak Torque	107 Nm At 2500 Rpm
Maximum Speed	3500 Rpm (4000 Rpm Protected)
Fuel System	Port Fuel Injection, Lotus EMS
Fuel	Regular ULG / Ethanol / Methanol
Estimated Dry Weight	50 kg With Balancer Shaft and Oil Cooler Generator – 40 kg

Lotus Range Extender - Engine Sections



Lotus Range Extender Initial Results



Summary

- Two Approaches to Low CO₂
 - ▮ High Technology for Mild Parallel Hybrid
 - ▮ Low Cost, Low Technology for Range Extended Electric Vehicle
- Both Optimized for Their Respective Applications
- Both Would **Fit** Behind the Back Seat

	SABRE	Lotus Range Extender
Application	Mild Parallel Hybrid	Range Extended EV
Displacement [l]	1.5	1.2
Cylinder Configuration	I-3	I-3
Engine Architecture	Integrated Exhaust Manifold	Monoblock + IEM
Valvetrain	4 Valve/Cylinder, DOHC, 2 Step Cam Dual Phasers	2 Valve/Cylinder, SOHC
Aspiration	Single Stage Turbocharger	Natural Aspiration
Fuel Injection	Central Direct Injection, Multi-Hole Solenoid	Port Fuel Injection
Power [kW @ RPM]	117 @ 5000	38 @ 3500
Maximum BMEP [bar]	20.0	11.2

Thanks



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