MEETING the CO_2 CHALLENGE
DEER 2002

Doug Graham
Chief Program Engineer, Light Duty Diesel Engines

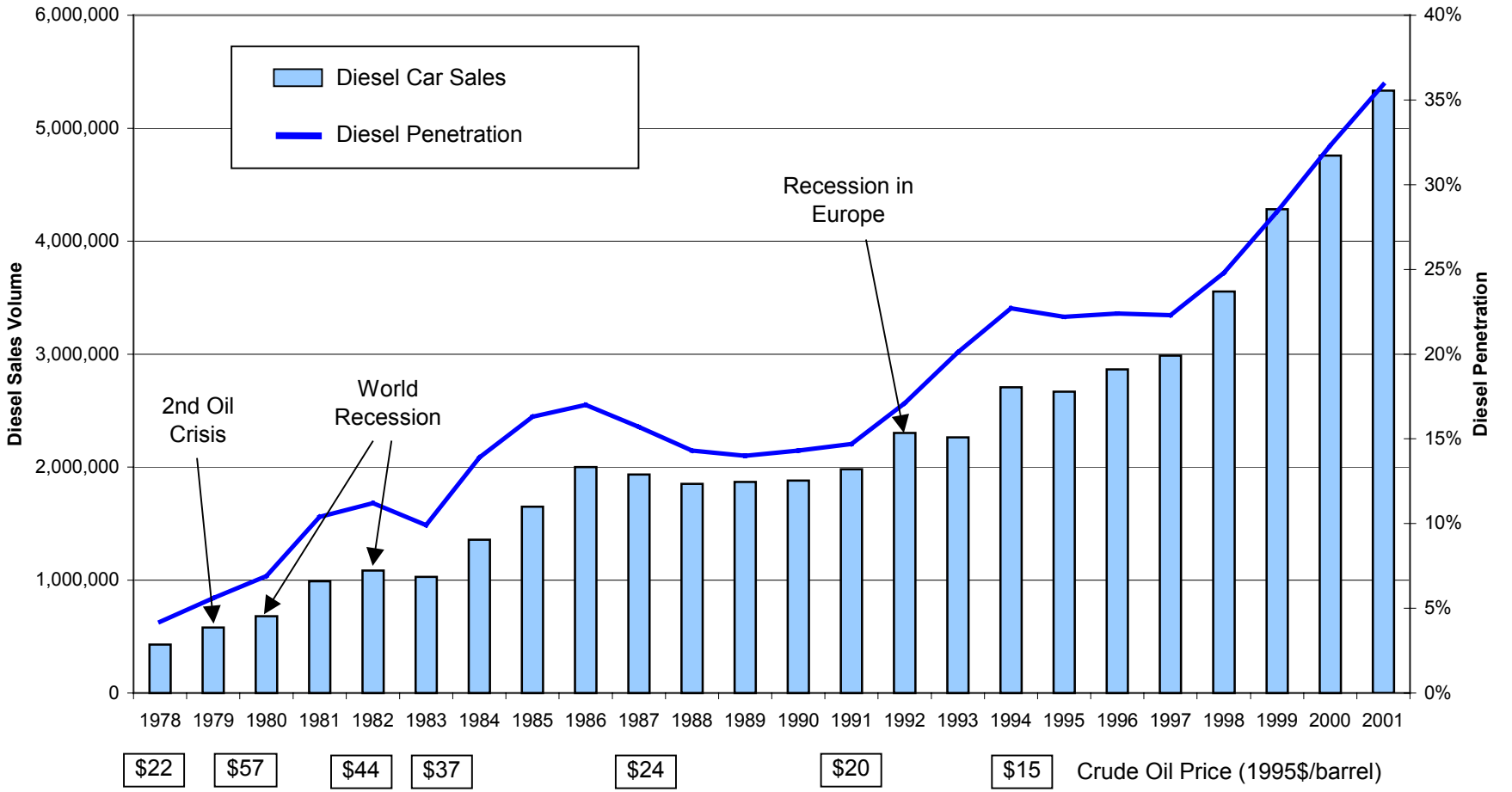
CO_2 Reduction / Challenge

- Fleet Based
  - Conversion to diesel
- Engine Based
  - Engine downsizing, right-sizing
  - Increased specific output
  - Advanced boosting
  - Pmax management
  - Energy management
    - Integrated Starter Generator
    - Electric ancillaries for friction reduction
  - Lightweight engines
- Vehicle Based
  - Hybrid systems--regenerative braking
  - Energy management
- Customer Value

Diesel Penetration is Increasing Rapidly

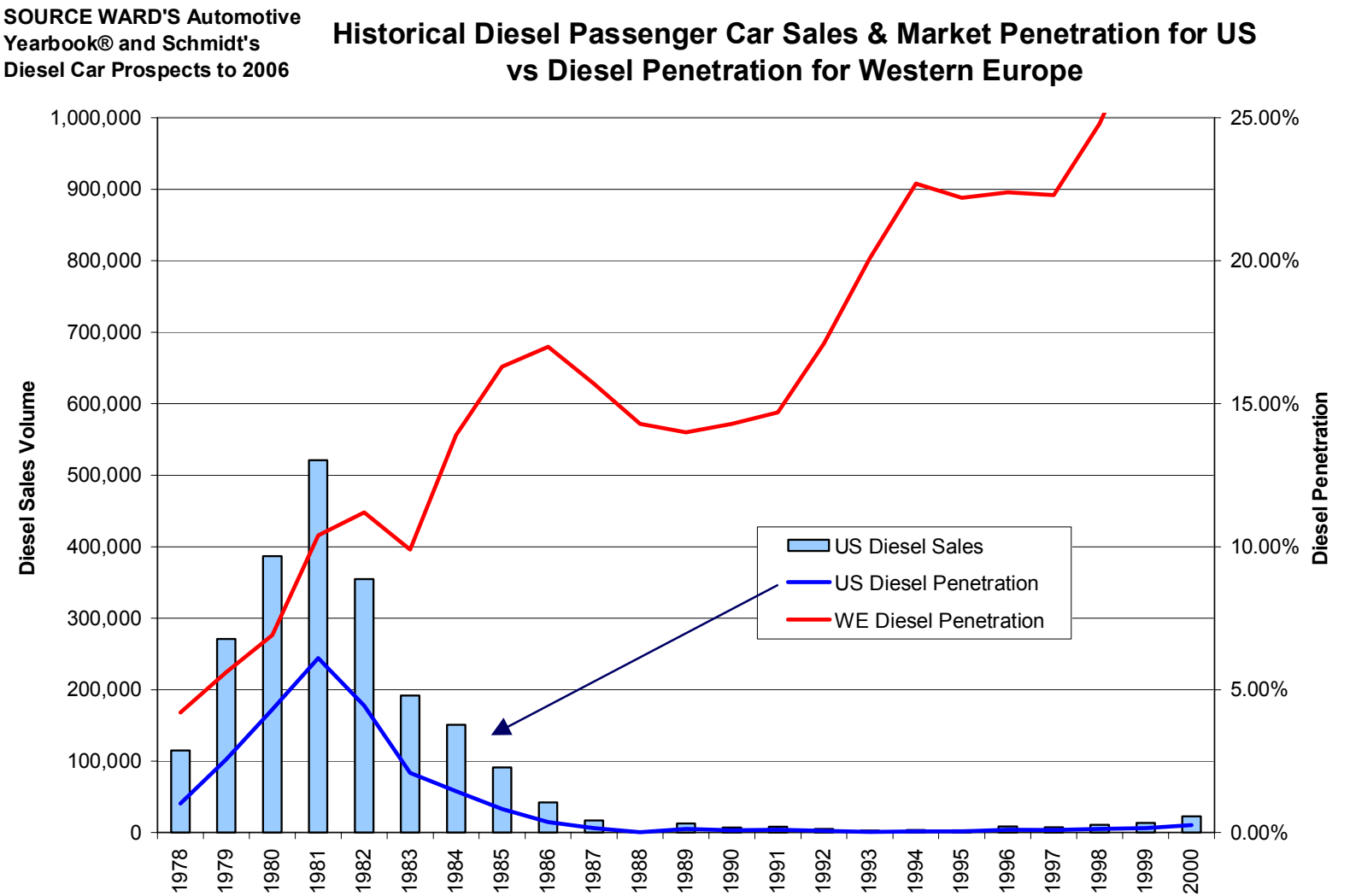
SOURCE data from Schmidt's Diesel Car Prospects to 2006

WESTERN EUROPE
Historical Diesel Passenger Car Sales & Market Penetration

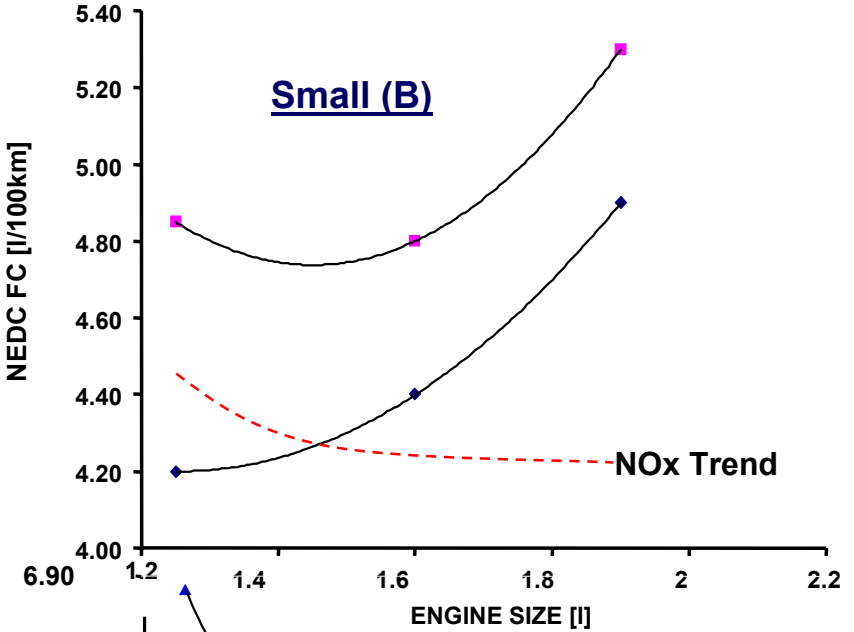


Light Duty Diesel In The USA

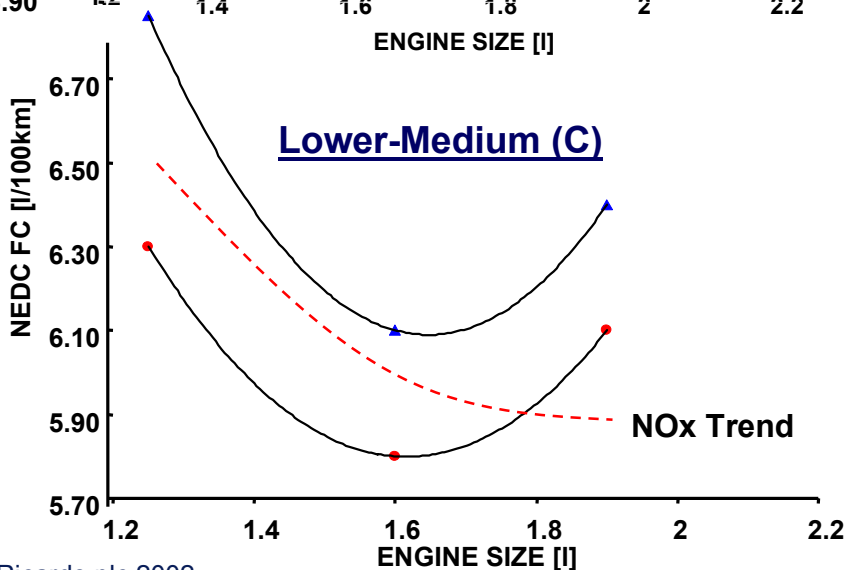
SOURCE WARD'S Automotive Yearbook® and Schmidt's Diesel Car Prospects to 2006

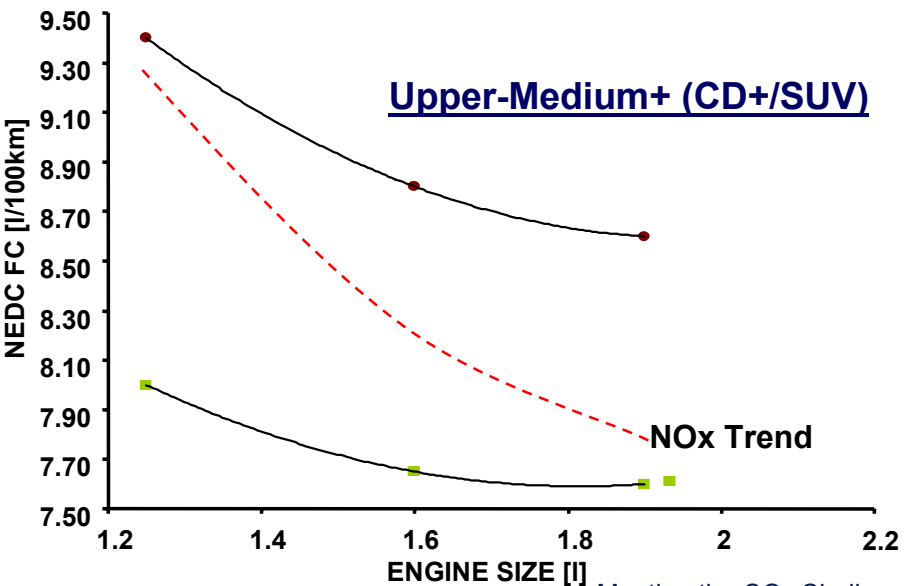


Downsizing vs "Right-Sizing"



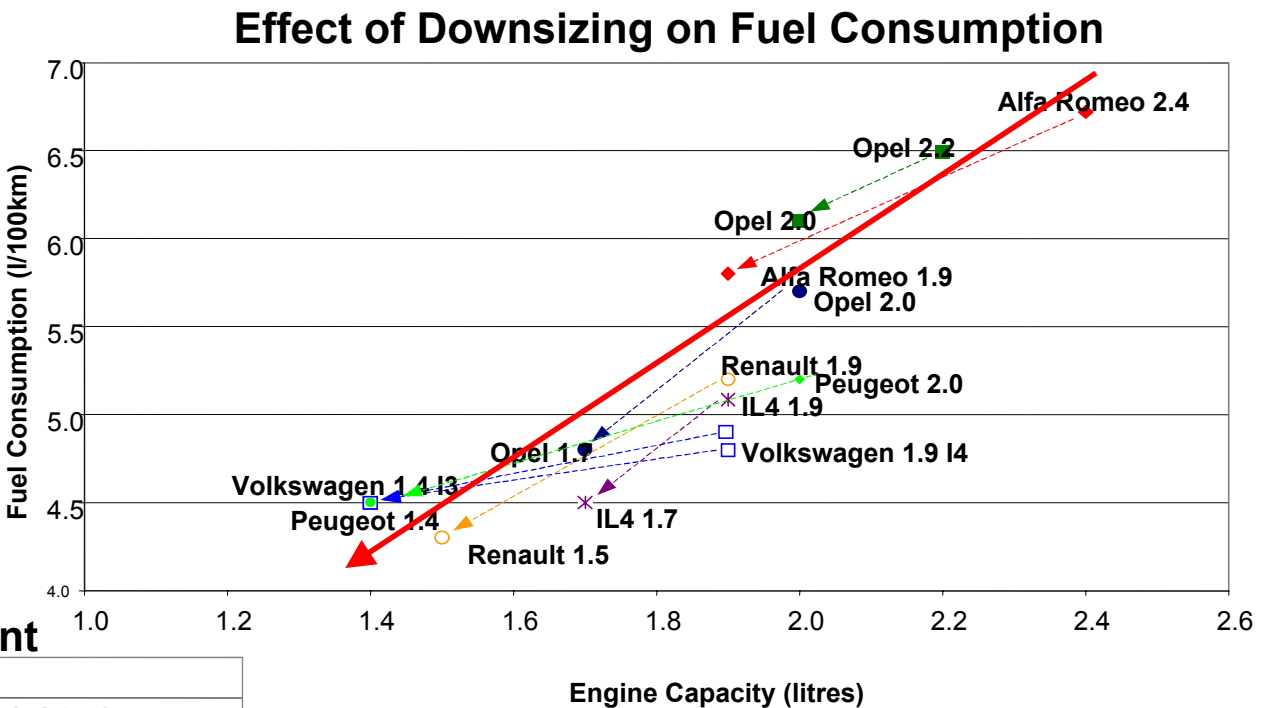
- Smaller engines have lower friction
- Too-small engines must have shorter transmission gearing to meet driveability requirements
- Smaller engines average higher cycle BMEP and higher cycle NOx.
- Smaller engines have higher exhaust temperatures which help catalysts.

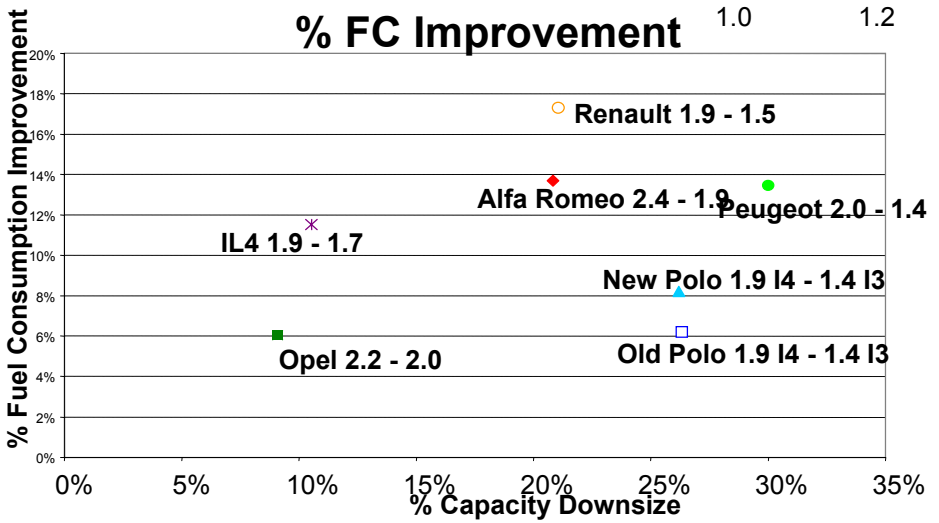




"Real-World" Downsizing

- real-world applications are demonstrating the real effects of downsizing
- same vehicles with smaller engines



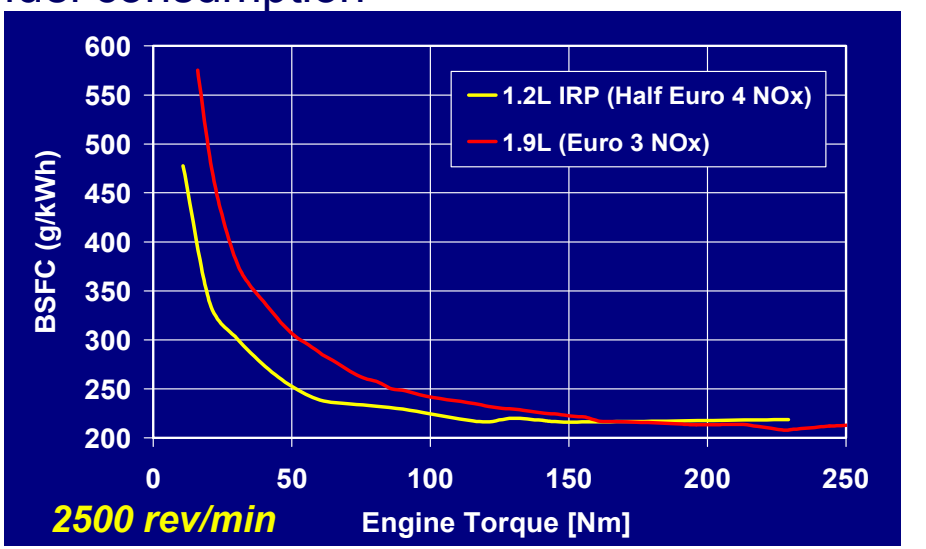


- Practical examples show:

  8% fuel consumption benefit for about 10% engine downsize

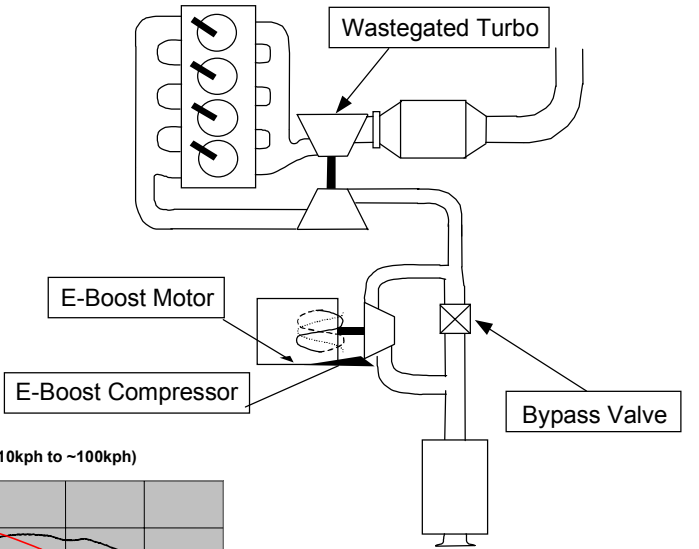
Downsizing brings many Benefits

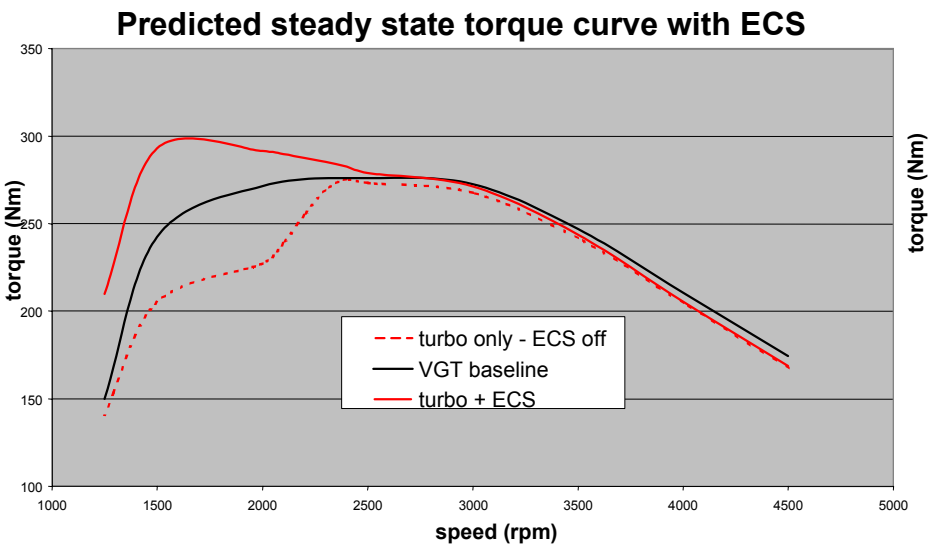
- Downsizing offers attractive benefits of:
  - Fuel consumption - more efficient engine operation
  - NVH - less excitation
  - Packaging
  - Crash improvements
- Downsizing is now a proven approach:
  - Eg: Renault Clio @ c.80CV 1.9dCi → 1.5 dCi → 1.2dCi??
  - increasing power density and reducing fuel consumption
- Issues
  - Low speed driveability
  - cost

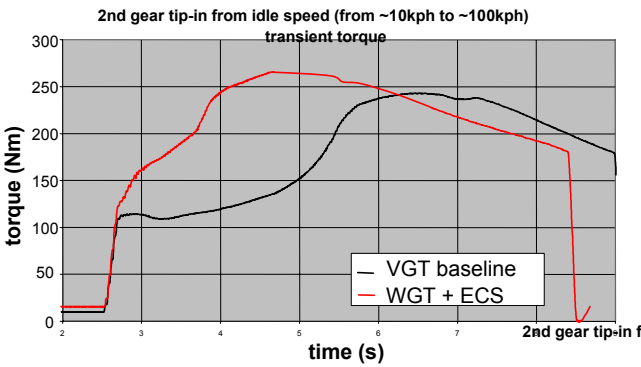


E-boost Application

- ~ 2 litre common rail TCA diesel in C/D class vehicle
- Objective: maintain rated power while enhancing low speed torque and driveability
- Turbo specification changed from VGT to wastegate machine with turbine match optimized for rated power
- 40% torque boost at low speeds

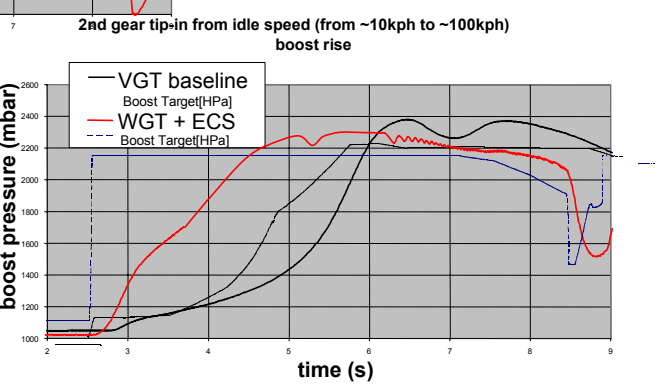


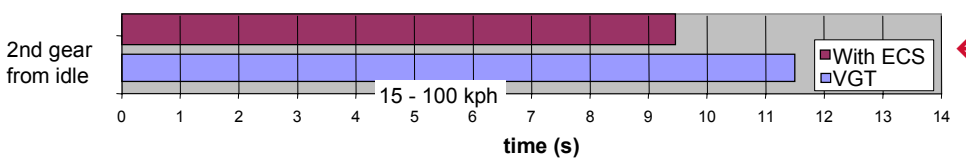




← 2nd gear tip-in transient torque

→ 2nd gear tip-in boost rise

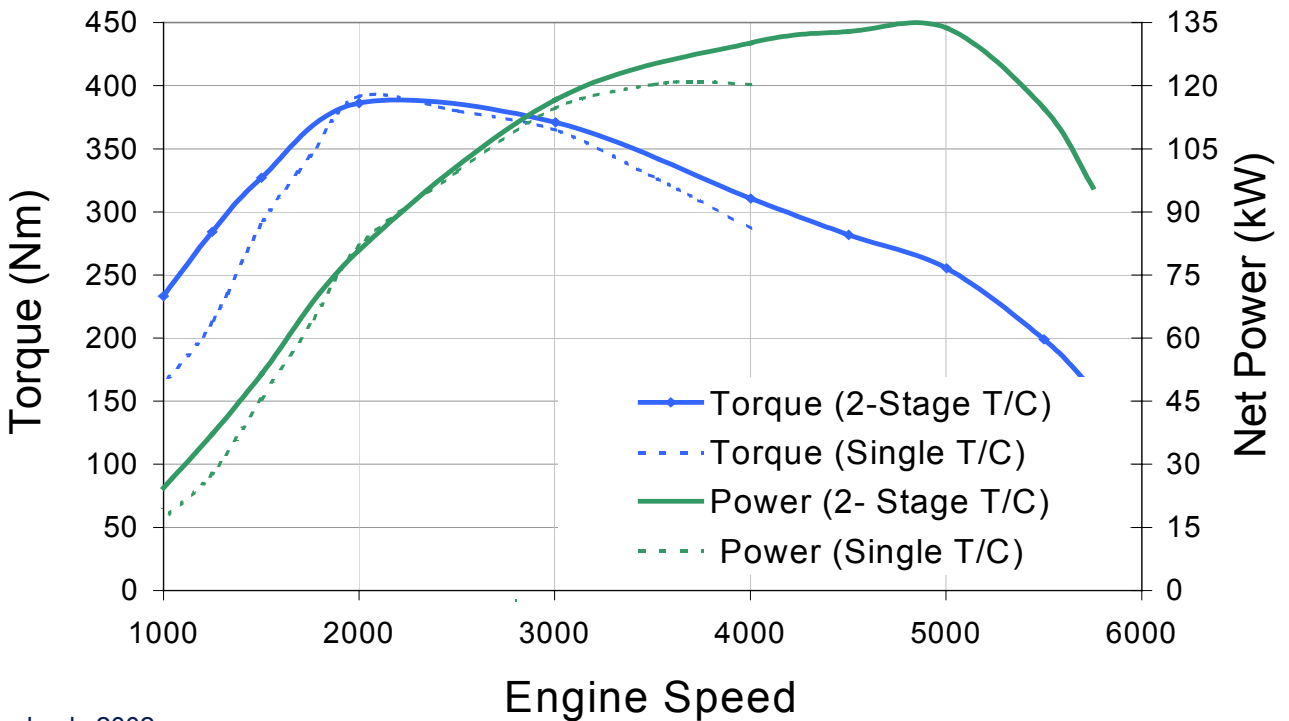


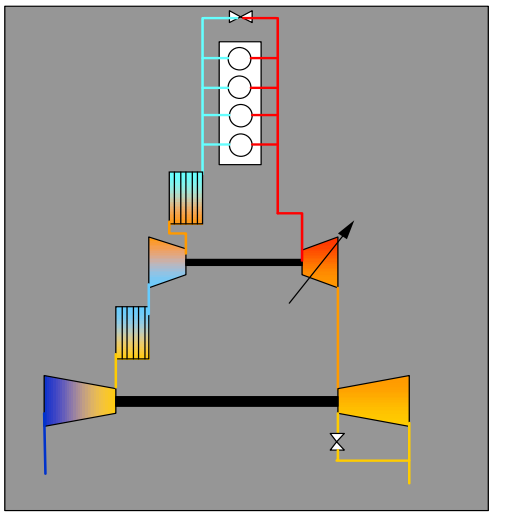


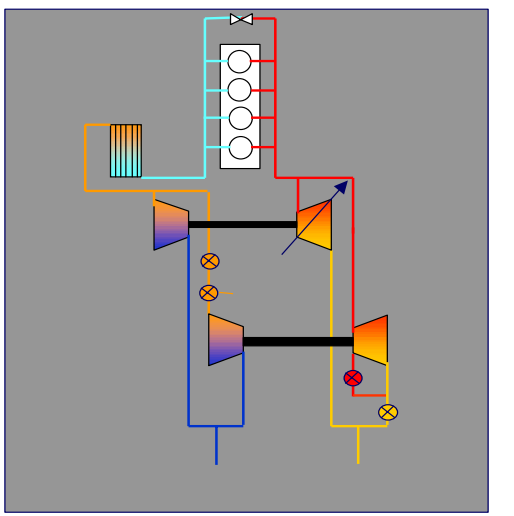
← time 15-100kph

70 kW/l Twin Boost & Hi-Speed

- Case study: 90BHP/litre with excellent transient response and low speed torque
- Two stage and sequential systems to be simulated and compared
- Two stage turbocharger tested on low compression ratio engine up to 5800 rev/min
- 90 BHP/lit achieved at 160 bar Pmax @ 5000 rev/min







Performance with Lowest Pmax

C/R reduction issues:

Cold start & running

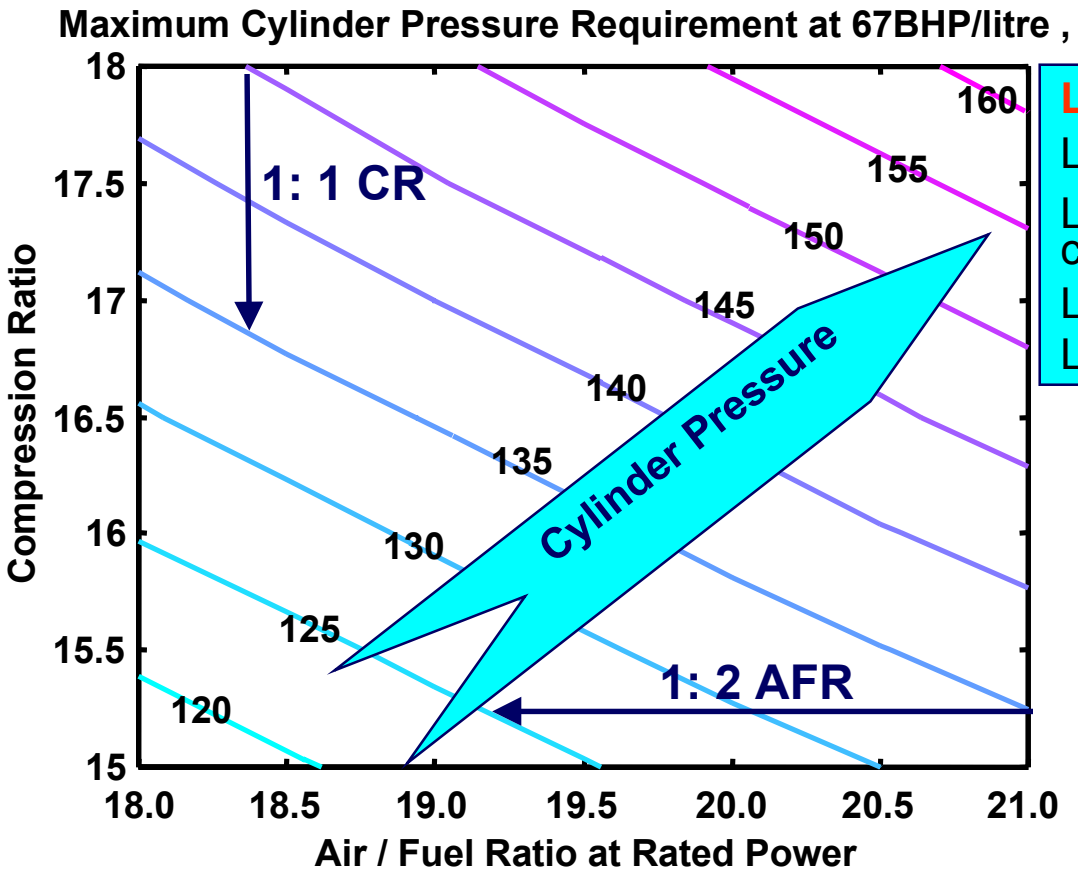
C/R reduction enablers:

42V ISG

Inlet air heating

E-boost

V V T



Low Pmax:

Low weight & cost

Low friction -low fuel consumption

Low reciprocating mass

Low NVH

- **Study uses validated WAVE engine model**
  - **AFR, CR, SOC**

Lowest Pmax

A/F reduction issues:

Smoke, exhaust temp, thermal loading

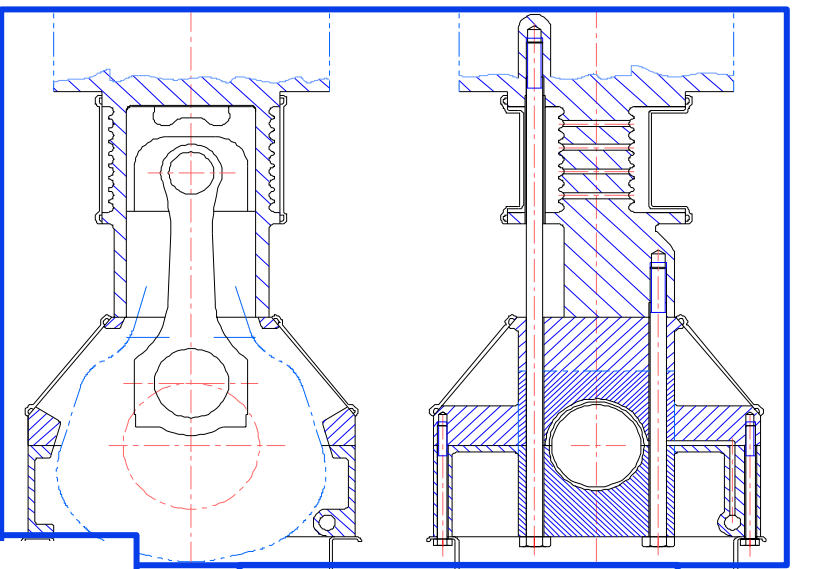
A/F reduction enablers:

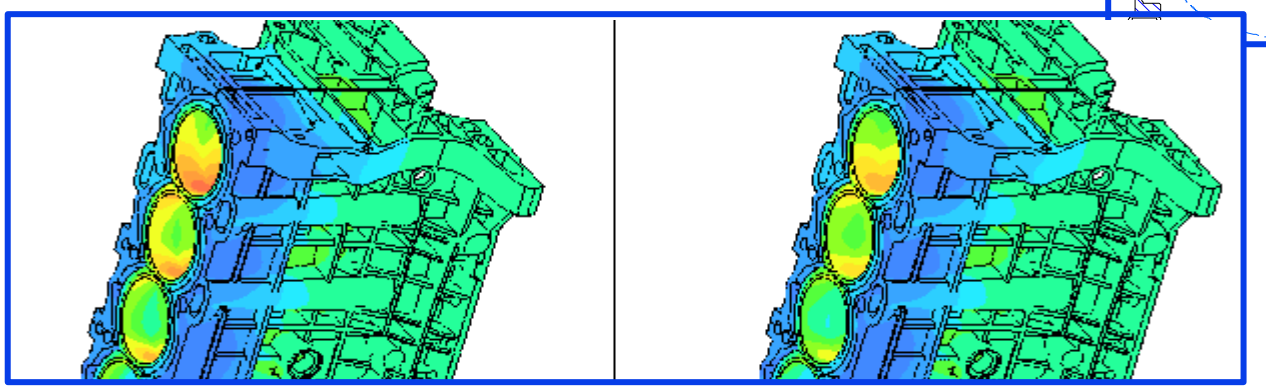
High pressure FIE, DPF, high temp materials

Lightweight Engines will be All-Alloy Structure

- Aluminium parent bore
  - Spray coated bores
  - Potential for reduced interbores
    - no tolerance issues
    - no cooling at moderate ratings
- Higher ratings and further weight reduction
  - Need for novel structures
  - Research ongoing

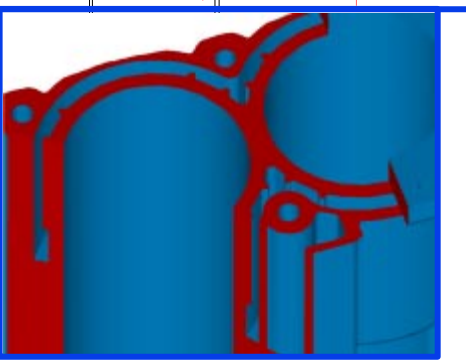
Novel structures research





Cast-in iron liner : 207 C

Parent bore : 189 C



Patented ribs control bore distortion

Hybrids:
The Ricardo *i*-MoGen Car

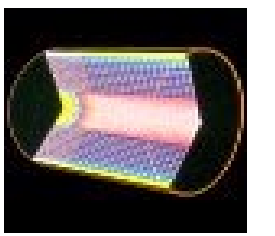
Advanced Diesel 1.2L, 100 BHP

Family Hatchback 1300kg (Future 1150kg?)

Integrated "Supervisor" Control System

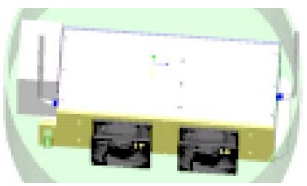
42v, 6 Kw Mild Hybrid (FMED / ISA)

Emission Control: Electric heated Particulate Trap Passive DeNOx Catalyst



Electric Ancillaries

Bin 8 Emissions Results



NiMH 42v Batteries (spare wheel well)

Competitive NVH & Driveability

0-60 mph (0-100kph) < 10 seconds

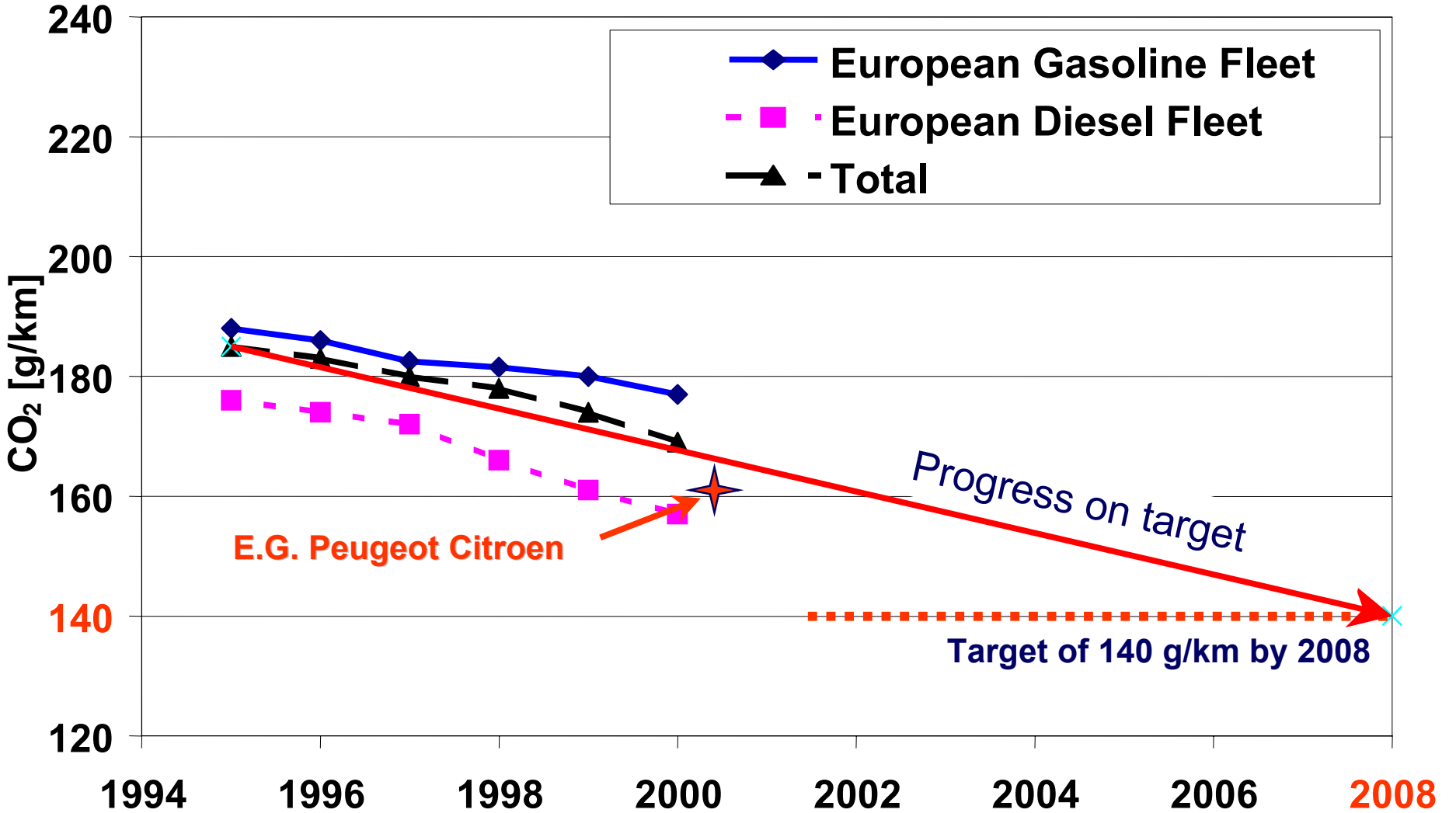
<4 l / 100 km
70 mpg (uk)
56mpg (us)

Powershift Automated Manual Transmission (Concept only)

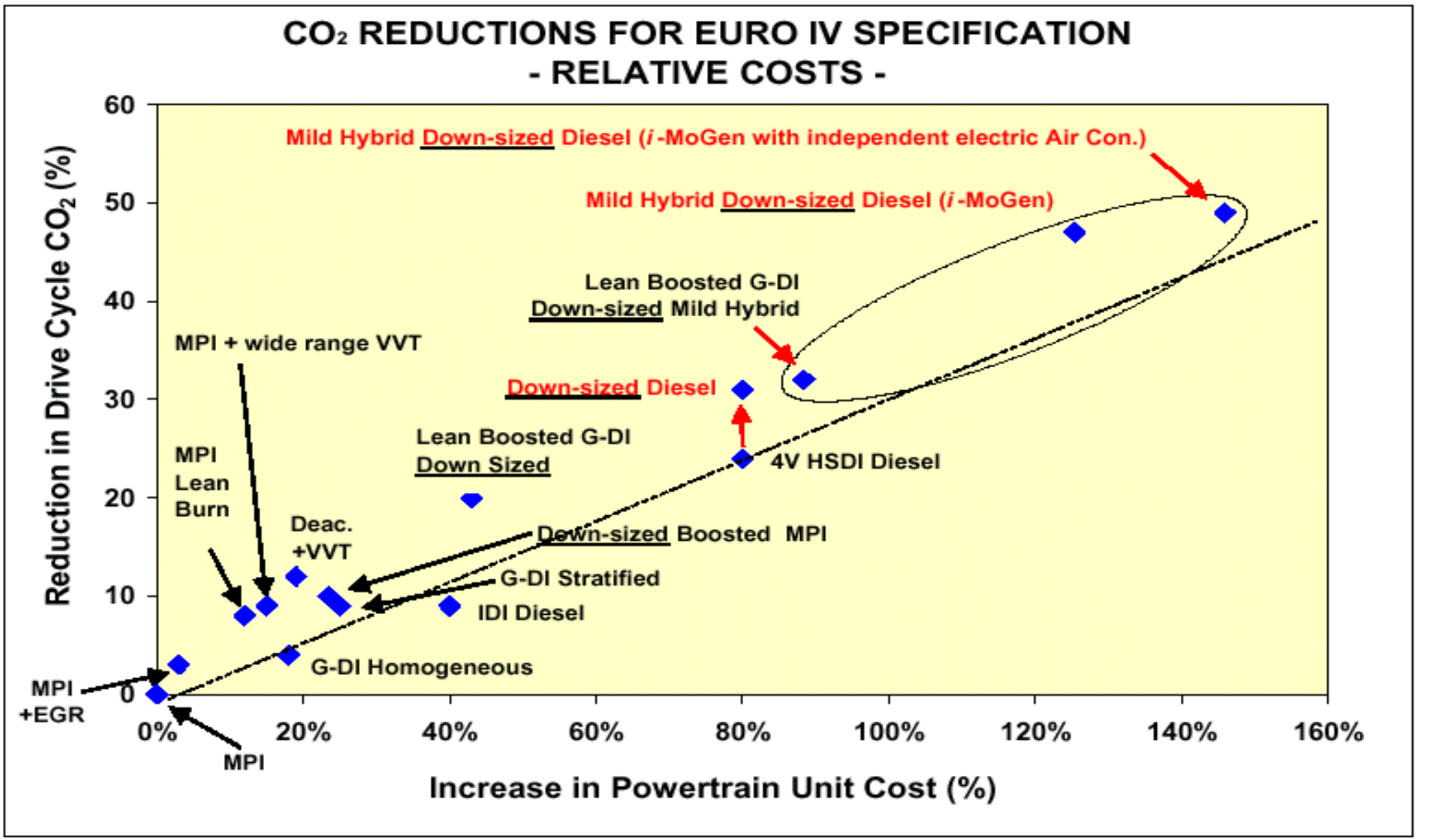
i-MoGen

Intelligent Motor Generator

European Progress on CO_2



The Cost of Reduced CO_2



Customer Value--Diesel

- Reduced impact on the environment
- Increased vehicle range
- Reduced operating cost
- Higher resale value
- Improved driveability

Benefits of New Diesel Technology

- Advanced FIE and turbocharging have resulted in diesel engines being:
  - More powerful
  - Higher torque
  - More fuel efficient
  - Quieter
  - Cleaner
  - More fun to drive
  - More widely accepted

European Diesels Are Better

BMW 320d vs 318i (2.0 Valvetronic)		
bhp	150	vs 140
lb-ft	243	vs 140
0-60:	8.9	vs 9.1
50-75:	7.5	vs 9.2
US mpg:	55	vs 39

Diesels are offered in all types of vehicles

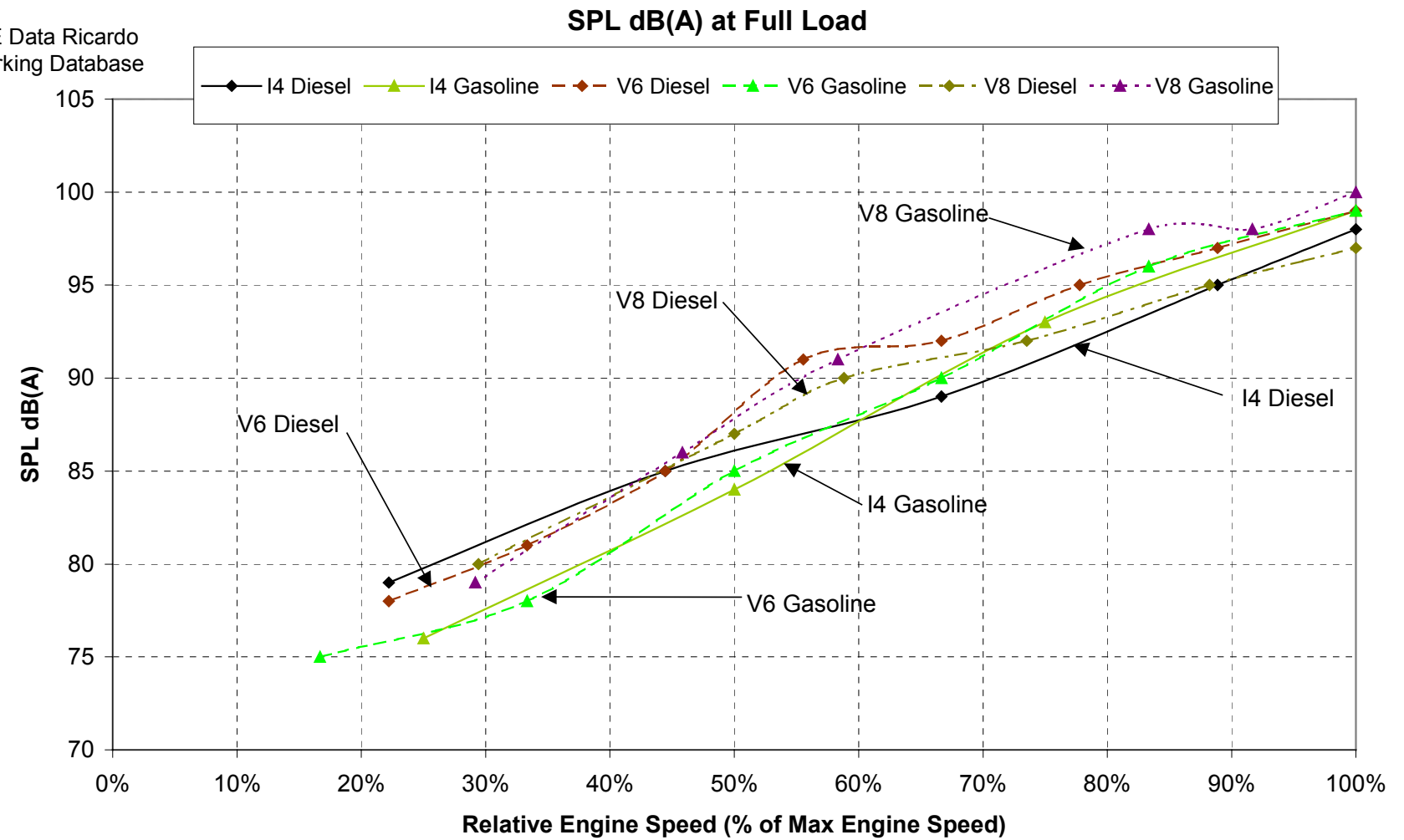
- Alfa Romeo 156
- Mercedes C-Class Sport Coupe
- Peugeot 406 Coupe
- Renault Vel Satis
- BMW Z9 Concept Car
- Volkswagen D1

Ford Focus 1.8TDCi		vs 1.8
bhp	115	vs 115
lb-ft	207	vs 116
0-60:	9.8	vs 9.5
50-70:	8.5	vs 12.7
US mpg:	55	vs 40

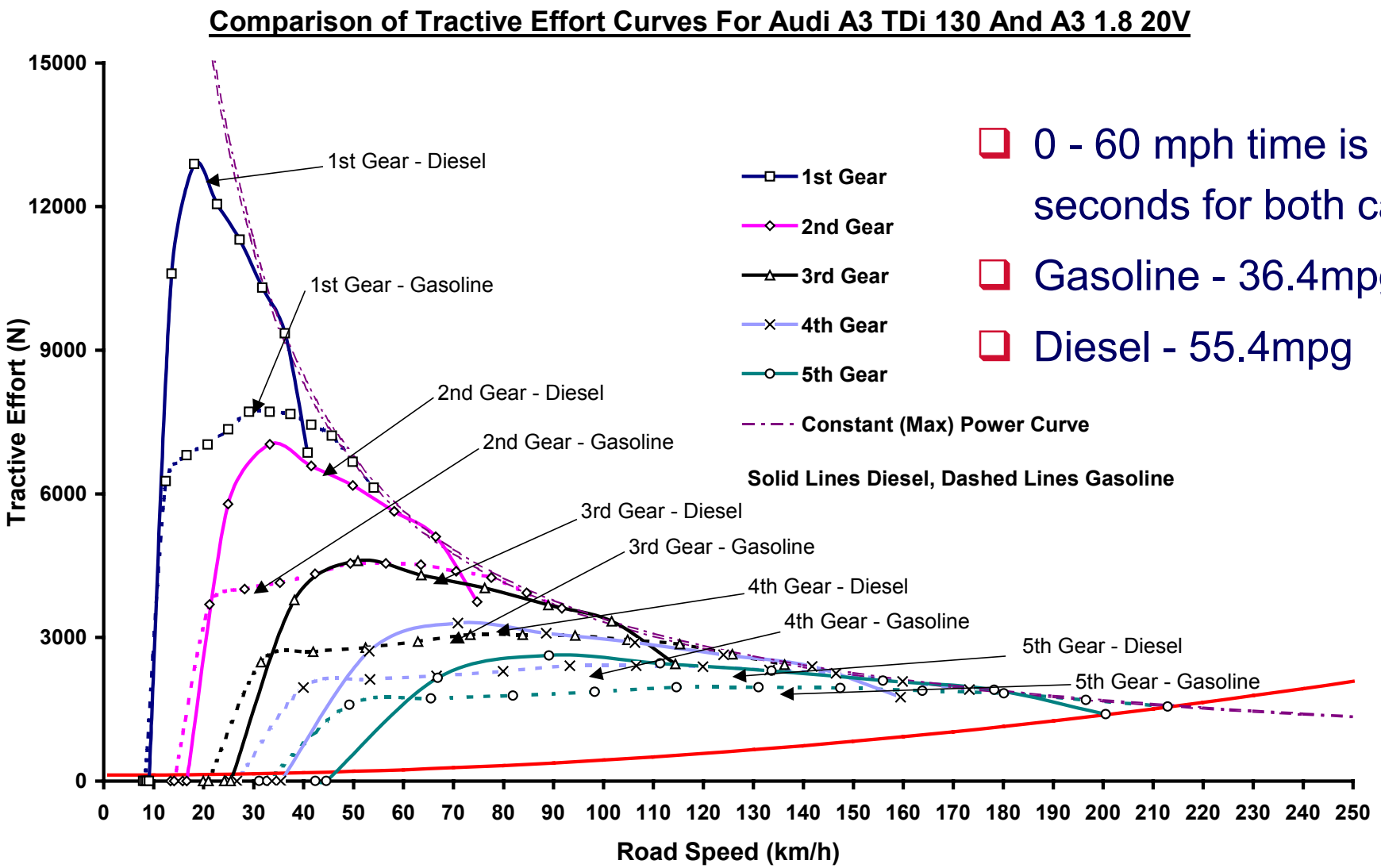
'The TDCi is quiet, economical and has enough pace to make the 1.8 gasoline feel a little sluggish - Autocar 10/01'

Diesels are Quiet

SOURCE Data Ricardo Benchmarking Database



Diesels Feel Good to Drive



- 0 - 60 mph time is 10.1 seconds for both cars
- Gasoline - 36.4mpg
- Diesel - 55.4mpg

Conclusions

- Major reductions in CO_2 emissions are possible
  - More diesels in the fleet
  - Advanced, down-sized engines
  - Hybrid technology
    - CO_2 reductions of up to 50% (iMoGen CO_2 is 48% lower than MPI gasoline on NEDC)
- Significant cost increases are likely
  - Powertrain cost increase of 150+ % is possible (with hybrid), lower with increased volumes
- With high performance diesels, perceived customer value has become competitive
- The Challenge: Maintain current favorable customer value in the face of new emissions regulations