Honeywell

Gasoline Engine Turbocharging & Rightsizing

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California Air Resource Board
Technology Assessment Workshop
CO_2 Emission Reduction - Cost & Feasibility Analysis
Climate Change Emissions - Light Duty Vehicles
Sacramento, CA
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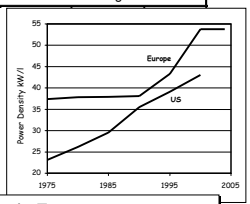
Benefits/feasibility (% CO_2 Reduction)
- Over 12 years of production data
- Methodical comparison by world class experts
- Experiments on two US SUVs

Cost
- Direct approach to rightsizing
- Engine family rationalization

Customer Acceptance
- Turbo gasoline in Europe
- European turbo gasoline imports in the US

Engine	2.2L L4	3.0L V6	3.4L V6	3.3L V6	5.3L V8
Cam/Valve	DOHC 4V	DOHC 4V	DOHC 4V	OHV 2V	OHV 2V
Vehicle	Cavalier	Taurus	Tacoma	Town & C	Sierra
0-60 mph (sec)	8.08	7.24	9.23	9.18	7.97
Curb Weight	2762	3380	3714	3980	4826
Power kW	109	154	140	149	213
**** (L)**	**1.8**	**2.6**	**2.3**	**2.5**	**3.6**
** State of the Art European Engine - Production Vehicle/Engine Data					

- **Baseline engines oversized compared to European average**
- **Potential rightsizing by using state of the art**
- **MAJOR rightsizing by TURBOCHARGING**



Technology in Use in Europe

Production vehicle data from 1992 to 2004

5-12% CO_2 Reduction

Methodical, comparison by world class experts

15-21%

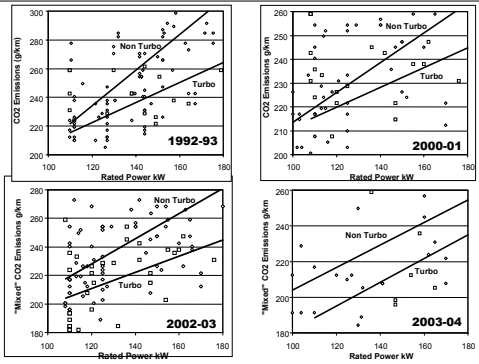
Experimental US SUVs

5-18%

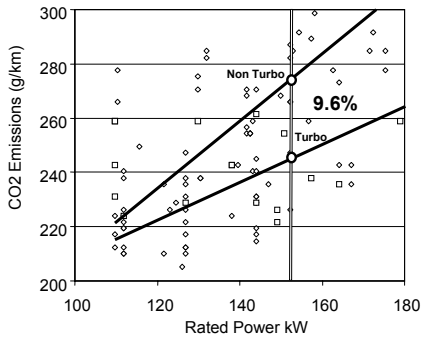
5 to 20% CO2 Reduction

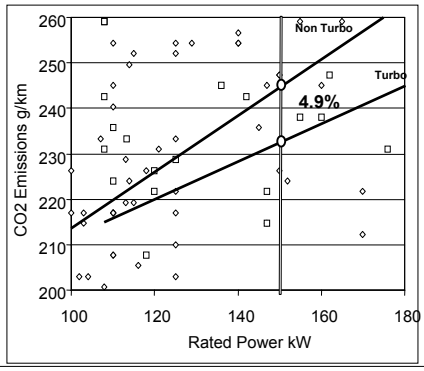
- **All production engines/vehicles in family sedan range - sports cars excluded**
- **Manufacturer certification data from published sources**
  - All data INCLUDED in mathematical linear fit
  - Graph display sized for visibility
  - Some data fell off the chart but is part of linear fit
- **Hundreds of non-turbo and tens of turbocharged vehicles in the data base**

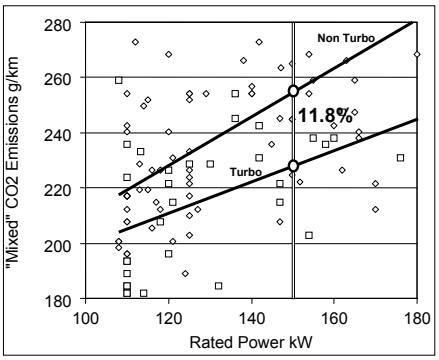
Benefits Measured over a Long Period and on Large Sample Production Vehicles

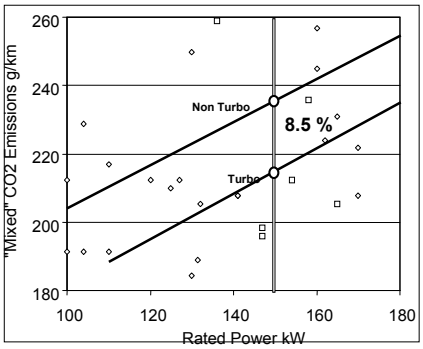


Less CO2 Emissions with Turbo Engines on All Model Years

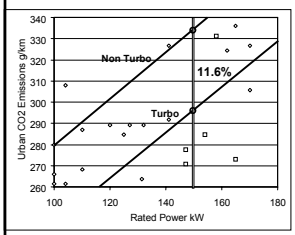


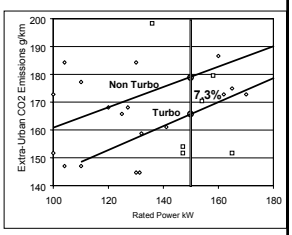






Urban & Extra-Urban Emissions

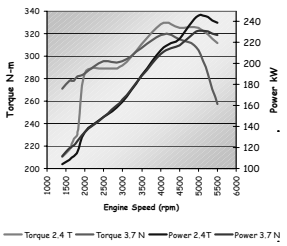




CO2 Reduction in Both Driving Cycles

Organization	Rightsizing (%)	CO2 Reduction	Reference	Remarks
AVL	29	15	SAE 2002-01-0236	Turbocharged, CBR, Miller Cycle Simulation
IFP	40	20	SAE 2003-01-0542	Stoichiometric DI. Engine Data - Vehicle Simulation
FEV	40	18	SAE 2001-01-3192 SAE 2002-01-1103	Vehicle Data. Variable Compr. Ratio Additional Benefits (9%).
Ricardo	30	21	SAE 2004-01-0036	Engine Data - Vehicle Simulation. Lean Boost DI

Common Denominator - Boosting/Rightsizing
Methodical Development Gives 15-20% CO2 Reduction



	Baseline	Rightsized	Difference (%)
Engine Displacement (L)	3.7	2.4	35
CO_2 - City Cycle (g/km)	329	311	5.5
CO_2 - Hwy Cycle (g/km)	255	233	8.6

	Baseline	Rightsized	Difference (%)
Engine Displacement (L)	3.0	2.0	33
CO_2 - City Cycle (g/km)	285	233	18
CO_2 - Hwy Cycle (g/km)	214	190	11

- **No optimization**
- **No special control of regulated urban emission (conventional 3-way catalyst)**
- **No durability/towing capability**
- **Just an exploratory investigation**
- **Advanced turbo technology - still to come**

5 to18% CO_2 Reduction on First Trials - Potential for Refinement

Two approaches to Rightsizing

Direct "across the board" rightsizing

$300 Cost REDUCTION

Engine family rationalization

More Cost Reduction Possible

Cost-Benefit Analysis Turns into Benefit-Benefit Analysis

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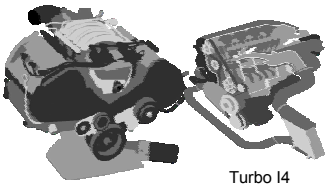
- Across the board rightsizing by 35-40%
- Stay with baseline engine technology
- Vee configuration converted to in line
- Contractor went through detailed parts differences, supplier prices, OEM cross checks to estimate costs and add up



Naturally Aspirated V6

Turbo I4

- Camshafts, valves, keepers, lash adjusters, pistons, rings etc.

  Direct cost reduction $700
- Variable geometry turbo, charge air cooler, plumbing, engine upgrades etc.

  Cost $400
- **Net $300 REDUCTION**

$300 Net Cost Reduction at Equal Performance

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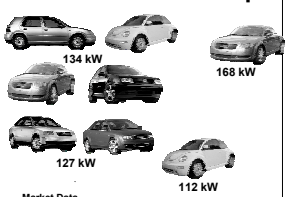
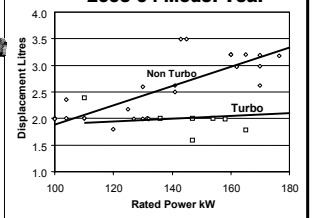
Actual Production Example



Market Data

Turbo Engine	Power (kW)	Equivalent Non-Turbo	CO2 Reduction	Mass Reduction
(L)	(kW)	(L)	(%)	(kg)
1.8	112	2.4	8	-
1.8	127	2.8	11	5-20
1.8	134	3.0	17	30-50
1.8	168	3.2	4	30-50

2003-04 Model Year



- **Capital cost, common parts, inventory reduction**
- **Warranty reduction, service costs**
- **Development cost reduction**
- **Production flexibility**

Further Cost Reduction Potential

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Turbo gasoline in Europe

- **15% gasoline powered cars turbocharged currently - projected to grow to 25% by 2010**

European Turbo Gasoline Imports in the US

- **32% of European gasoline powered cars imported in US are turbocharged**

Europe is Paving the Way - US Consumers Embrace it

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- **Saab 9-3, 9-5, Aero**
- **MazdaSpeed Protégé**
- **Dodge SRT- 4**
- **PT Cruiser Turbo**
- **Beetle Turbo**
- **Volvo XC90**
- **Subaru WRX**
- **Audi A4 1.8T**
- **Passat 1.8T**
- **Jetta 1.8T**
- **Porsche Cayenne**

Turbo Gasoline

- **Same or better performance than larger displacement naturally aspirated engine with 10 - 20% less CO_2**

15% of gasoline engines in Europe 25% in 2010

Turbo is a Growing Differentiator & Brand Equity Builder

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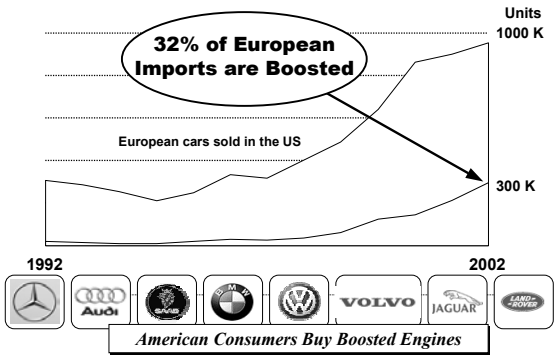

American Consumers Buy Boosted Engines

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Benefits/feasibility (% CO_2 Reduction)

- 15-20% reduction in emissions possible with proper development

Cost

- $300 net cost reduction with simple rightsizing
- Further cost reduction with engine family rationalization

Customer Acceptance

- 32% "acceptance" already demonstrated in the US

Rightsizing / Turbocharging is a Proven & Available Solution

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