Reducing Greenhouse Gas Emissions From Light-Duty Motor Vehicles

Presented to
California ARB Workshop
April 20, 2004

Stephen Brueckner
AVL Powertrain Engineering, Inc.

Outline

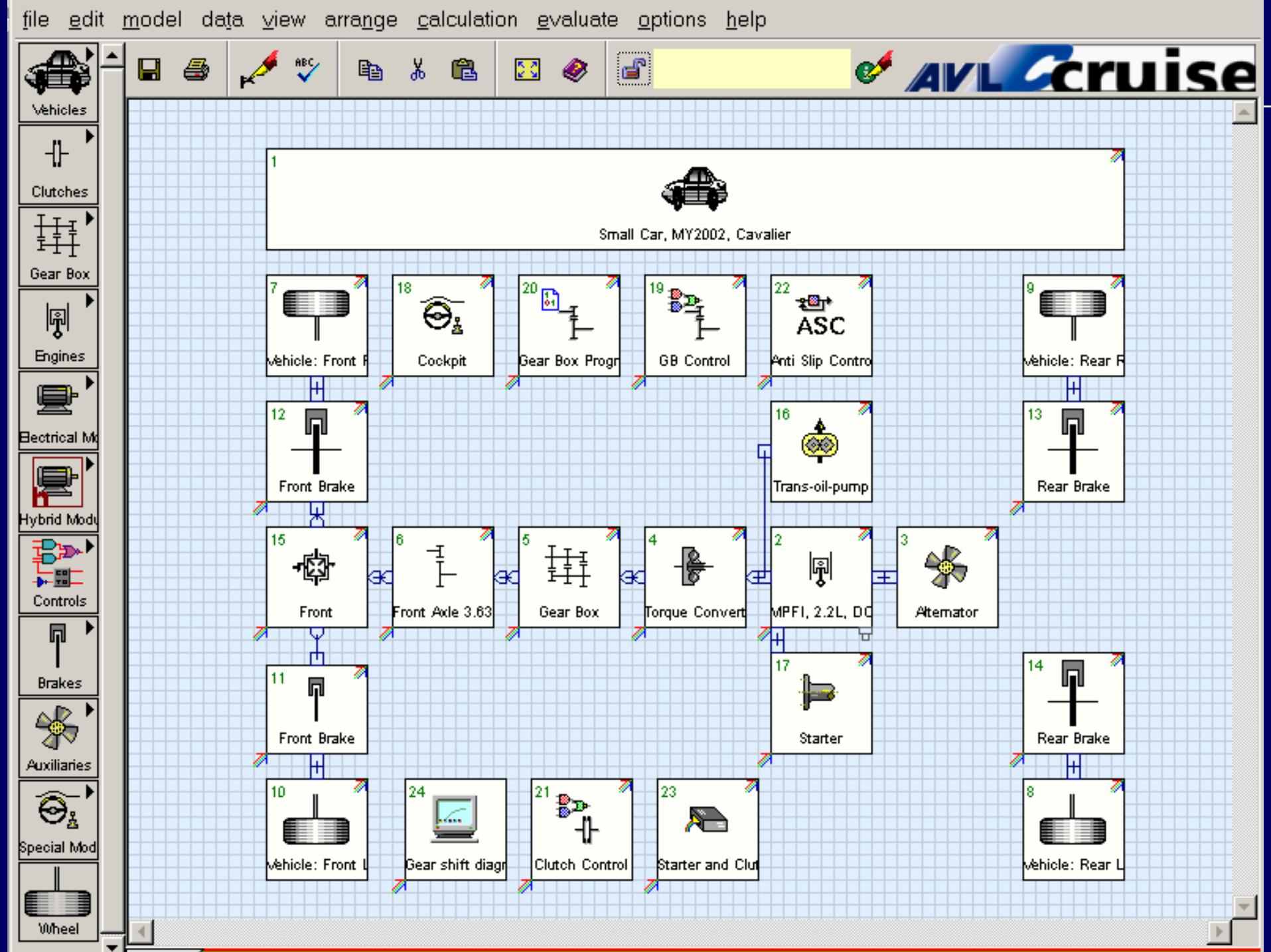
- Who is AVL?
- CRUISE Modeling Process
- Task 1 - Assessment of Individual Technologies
- Task 2 - Assessment of Technology Combinations

The Company

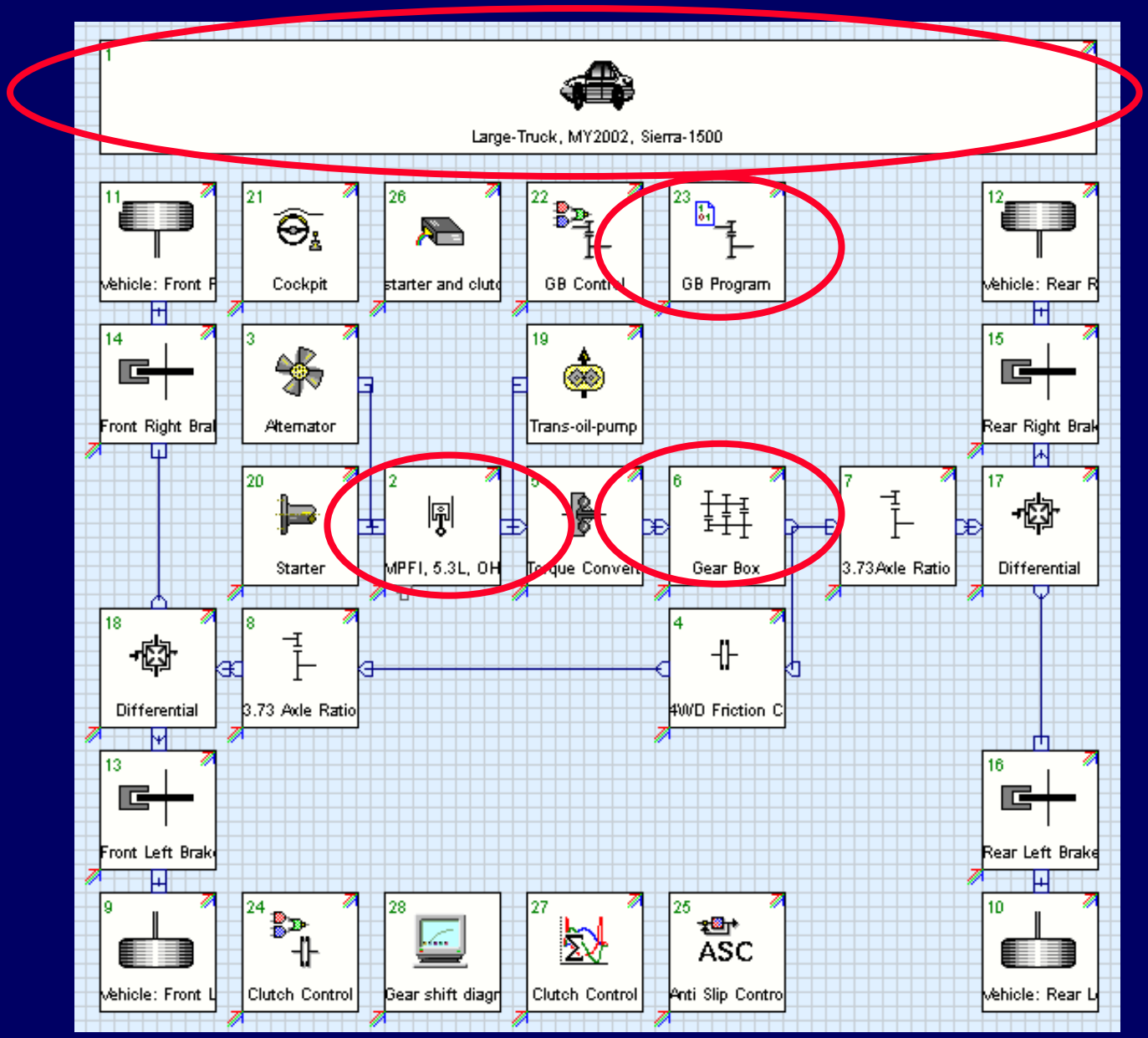
The world's largest independent company providing powertrain systems engineering and the manufacture of powertrain test systems and instrumentation.

CRUISE Modeling Process

- Who is AVL?
- **CRUISE Modeling Process**
- Task 1 - Assessment of Individual Technologies
- Task 2 - Assessment of Technology Combinations


file edit model data view arrange calculation evaluate options help
AVL cruise
Vehicles
Clutches
Gear Box
Engines
Electrical Mo
Hybrid Modu
Controls
Brakes
Auxiliaries
Special Mod
Wheel
1
Small Car, MY2002, Cavalier
7
Vehicle: Front R
18
Cockpit
20
Gear Box Progr
19
GB Control
22
ASC
Anti Slip Contro
9
Vehicle: Rear R
12
Front Brake
16
Trans-oil-pump
13
Rear Brake
15
Front
6
Front Axle 3.63
5
Gear Box
4
Torque Convert
2
MPFI, 2.2L, DO
3
Alternator
11
Front Brake
17
Starter
14
Rear Brake
10
Vehicle: Front L
24
Gear shift diagr
21
Clutch Control
23
Starter and Clut
8
Vehicle: Rear L

CRUISE Vehicle Model - Large Truck



CRUISE Vehicle Model Parameters

Vehicle - Small Car, MY2002, Cavalier

Vehicle

Author: AVL

Comment: Small Car, MY2002, Cavalier

Notice 1: 4 Speed AT, FWD

Notice 2: 3.63

Notice 3:

Date of Development: 18. Jul 2003 14:08:27

Gas Tank Volume: 14.1 USAgallon

Pressure Difference Engine/Environment: 0.0 mbar

Temperature Difference Engine/Environment: 0.0 K.

Distance from Hitch to Front Axle: 2944.0 mm

Wheel Base: 2644.0 mm

Height of Support Point at Bench Test: 100.0 mm

Load Dependent Characteristics

Distance of Gravity Center in: <mm>

Height of Gravity Center in: <mm>

Height of

Wheel Pressure Front Axle in: bar

Wheel Pressure Rear Axle in: bar

Nominal Weight

Curb Weight: 2676.0 lb.mass

Gross Weight: 3176.0 lb.mass

Air Coefficient

Frontal Area: 2.04 m^2

Drag Coefficient: 0.36

Lift Coefficient Front Axle: 0.01

Lift Coefficient Rear Axle: 0.01

Vehicle

Total Driving Resistance

Lateral Dynamics Vehic

Cold Start Correction c

Pre-defined Temperatu

CRUISE Vehicle Model Parameters (2)

Vehicle - Small Car, MY2002, Cavalier

Total Driving Resistance

Author: AVL

Comment: EPA coefficients for Cavalier

Notice 1:

Notice 2:

Notice 3:

Date of Development: 18. Jul 2003 14:08:27

Reference Vehicle for Driving Resistance

Frontal Area: m^2

Drag Coefficient:

Weight: kg

Resistance Function

Constant Part: 27.9 lbf

Linear Part: 0.3677 lbf/mph

Quadratic Part: 0.01743 lbf/mph^2

Resistance Table

Vehicle

Total Driving Resistance

Lateral Dynamics Vehic

Cold Start Correction c

Pre-defined Temperatu

CRUISE Vehicle Model Parameters (3)

Vehicle Class	Small Car	Large Car	Minivan	Small Truck	Large Truck
Vehicle Modeled	Cavalier	Taurus	Town & Country	Tacoma	Sierra
Wheelbase [mm]	2644	2756	3030	3096	3645
Curb weight [lbm]	2676	3336	4107	3540	4919
Equiv. Test Weight [lbm]	3000	3625	4500	4250*	5500*
Gross Weight [lbm]	3176	3836	4700	5100	6400
EPA coefficient A [lbf]	27.90	30.19	36.16	47.89	29.80
EPA coefficient B [lbf/mph]	0.3677	0.6723	0.8909	0.32911	1.9928
EPA coefficient C [lbf/mph^2]	0.01743	0.01323	0.01812	0.03463	0.02435

CRUISE Engine Model

Engine - MPFI, 5.3L, OHV

Engine

Author: Russell Truemner
Comment: MPFI, 5.3L, OHV
Notice 1: gasoline
Notice 2: MPFI Tech V04 Maps
Notice 3:
Date of Development: 05. Nov 2003 16:42:58

Engine Type: Gasoline
Charger: Without
Engine Displacement: 5.3 l
Conversion to different Displacement...
Engine Working Temperature: 90.0 C
Number of Cylinders: 8
Number of Strokes: 4
Inertia Moment: 0.18 kg*m^2
Response Time: 0.1 s
Maximum Speed: 6000.0 1/min

Fuel Type

Idle
Speed: 550.0 1/min
Consumption: <l/h>
Emission NOX: kg/h
Emission CO: kg/h
Emission HC: kg/h
Emission Soot: kg/h

Friction Mean Effective Pressure (FMEP)

Nominal Temperature: 90.0 C
Equivalent Mass: 16.45 kg

Engine
Comments
Cooling Characteristic
Fuel Consumption Map
NOx Emission Map
CO Emission Map
HC Emission Map
Full Load Characterist
Motoring Curve

CRUISE Engine Model (2) - Full Load Curve

Engine - MPFI, 5.3L, OHV

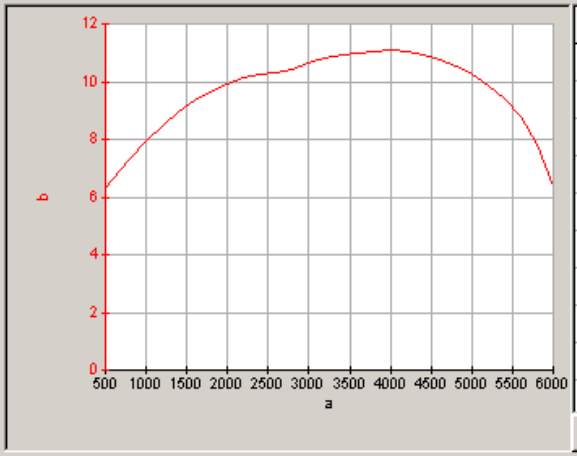
Full Load Characteristic

Comment

Test Environment

Air Pressure bar Temperature C Absolute Humidity kg/m^3

a = Speed <1/min> b = BMEP <bar>



a	b
500.0	6.32
800.0	7.34
1000.0	7.94
1200.0	8.47
1400.0	8.93
1600.0	9.33
1800.0	9.66
2000.0	9.92
2200.0	10.12

update

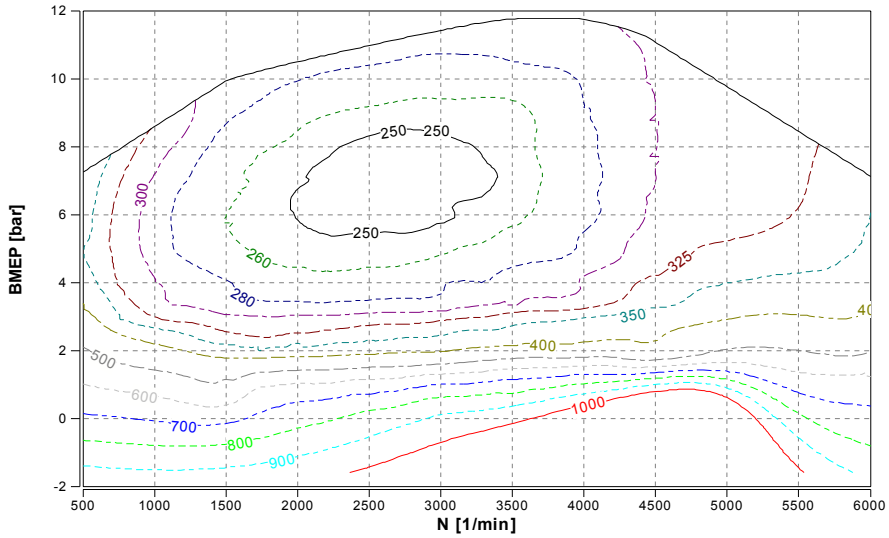
Full Load Reduction

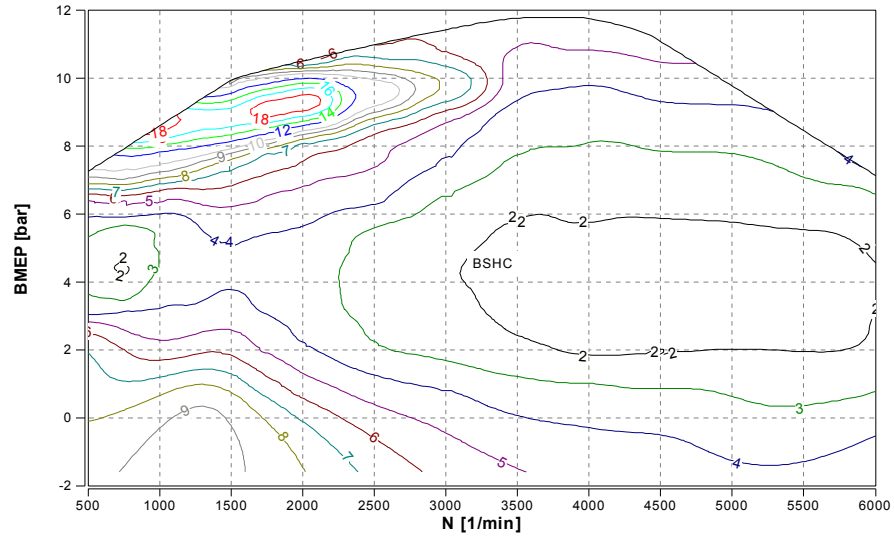
Reduction Factor

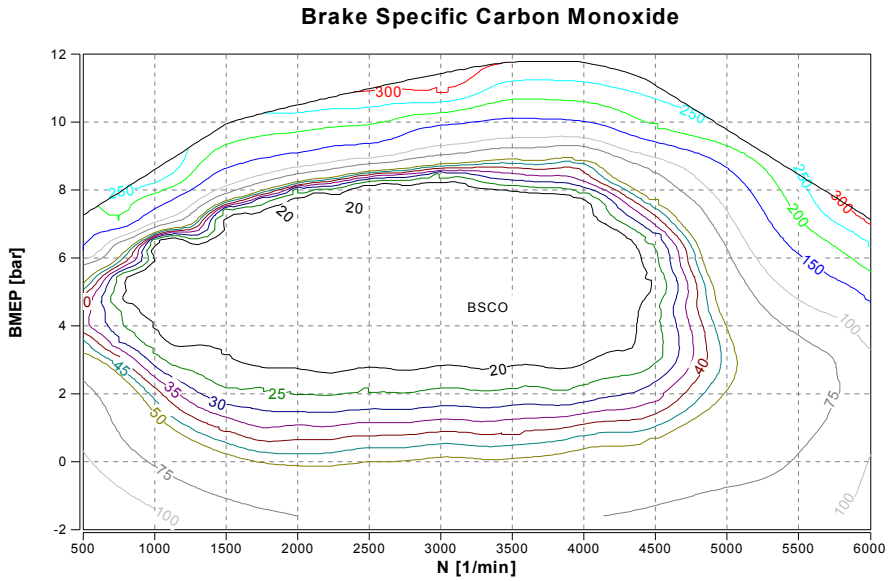
Full Load Reduction Characteristic

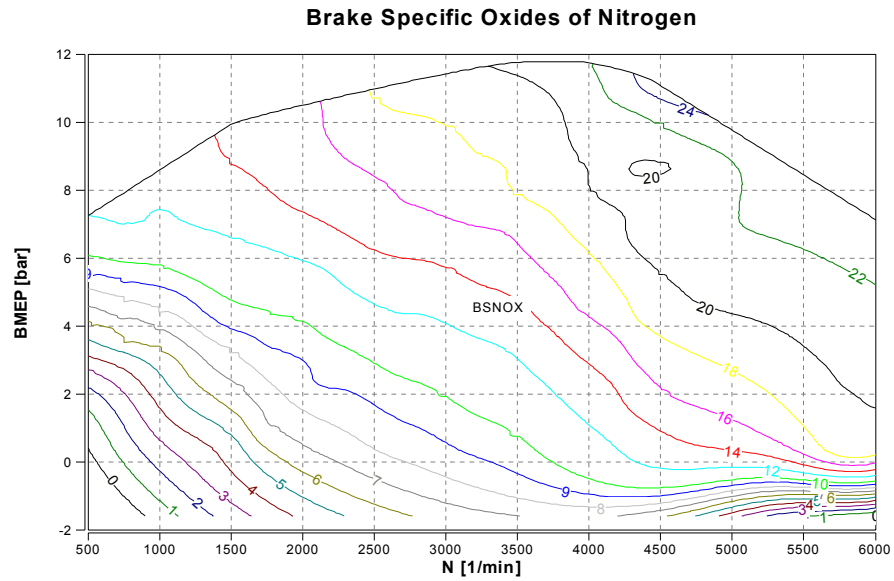
Engine
Comments
Cooling Charact
Fuel Consumptio
NOx Emission M
CO Emission Ma
HC Emission Ma
Full Load Characte
Motoring Curve

CRUISE Engine Model (3) - Sample Engine Maps









CRUISE Transmission Model - 4 Speed Automatic

Gear Box

Gear Ratio

a = Gear <->
b = Transmission Ratio <->
c = Inertia Moment In <kg*m^2>
d = Inertia Moment Out <kg*m^2>
e = Number of Teeth Input <->
f = Number of Teeth Output <->

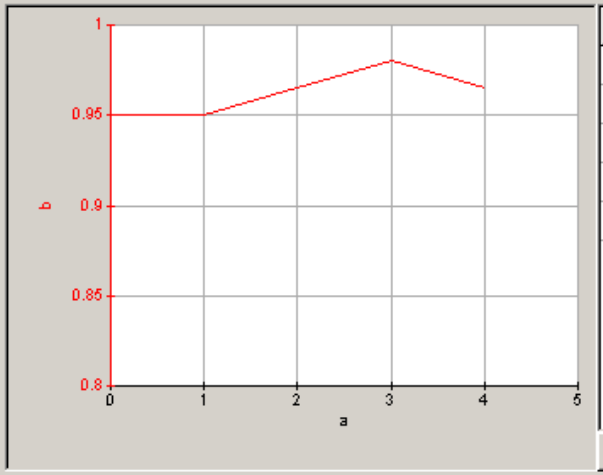
a	b	c	d	e	f
0	1.0	0.005	0.005	10	10
1	3.06	0.005	0.005	50	153
2	1.625	0.005	0.005	16	26

Gear Box
Gear Ratio
Efficiency & Torque Loss

Gear Box

Efficiency fixed

a = Gear <->
b = Efficiency <->



a	b
0	0.95
1	0.95
2	0.965
3	0.98
4	0.965

update

Gear Box
Gear Ratio
Efficiency & Torque Loss

CRUISE Gear Box Control Program - Sample Shift Curves

Gear Box Program - GB Program

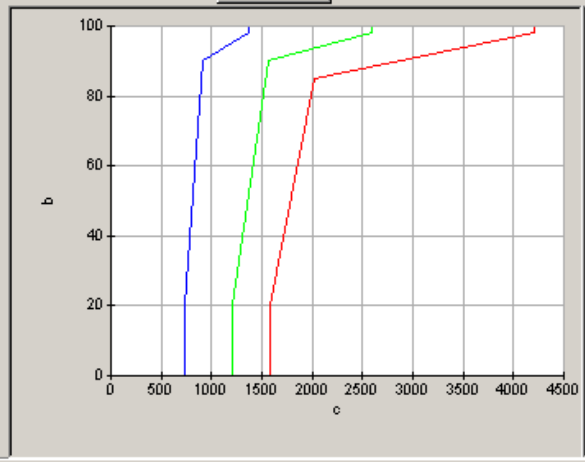
Shifting Program

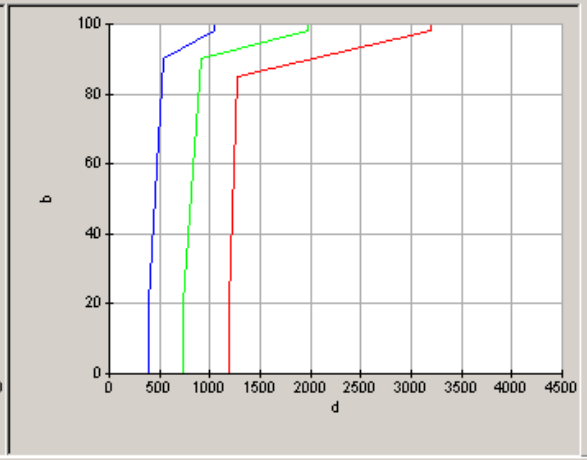
a = Gear <-> b = Load Signal <%>

c = Speed Upshifting <1/min> d = Speed Downshifting <1/min>

a	b	c	d
1	0.0	739.0	393.0
1	20.0	739.0	393.0
1	90.0	909.0	539.0
1	98.0	1373.0	1046.0
1	100.0	1373.0	1046.0
2	0.0	1200.0	740.0
2	20.0	1200.0	740.0
2	90.0	1573.0	905.0
2	98.0	2585.0	1969.0

update





Gear Box Program

Shifting Program

Optimized Shifting Program

CRUISE Vehicle Simulation Tasks

[SC MY2002_Small_Car_4AT-]

file object view calculation evaluate options help

NDF: SC.prj

AVL cruise

Project	GHG Reductio
Settings	<->
Vehicle	<->
Folder	<->
Variations	<->
Cycle Run	FTP 75
Cycle Run	HWFET
Cycle Run	US06
Folder	<->
Variations	<->
Full Load Acceleration	<->
Full Load Acceleration	0-60 MPH
Full Load Acceleration	50-70 MPH
Folder	<->
Variations	<->
Climbing Performance	<->
Folder	<->
Variations	<->
Constant Drive	<->
Constant Drive	Max Velocity
Folder	<->
Variations	<->
Brake/Coast/Thrust	<->

Cycle Run: run

Cycle Run

Author:

Comment:

Notice 1: FTP 75

Notice 2:

Notice 3:

Date of Development: 02. Apr 2004 11:43:51

Name: FTP75

- [x] Output of Text Report
- [x] Output of Presentation Diagrams
- [ ] Output of MS-Exports

Cold Start

Cycle dependent input data, defined in the component "Vehicle"

- [ ] Cold Start Correction
- [ ] Pre-defined Temperature Curve

Corresponding Cycle:

Simulation 1

Roadway

without Cornering

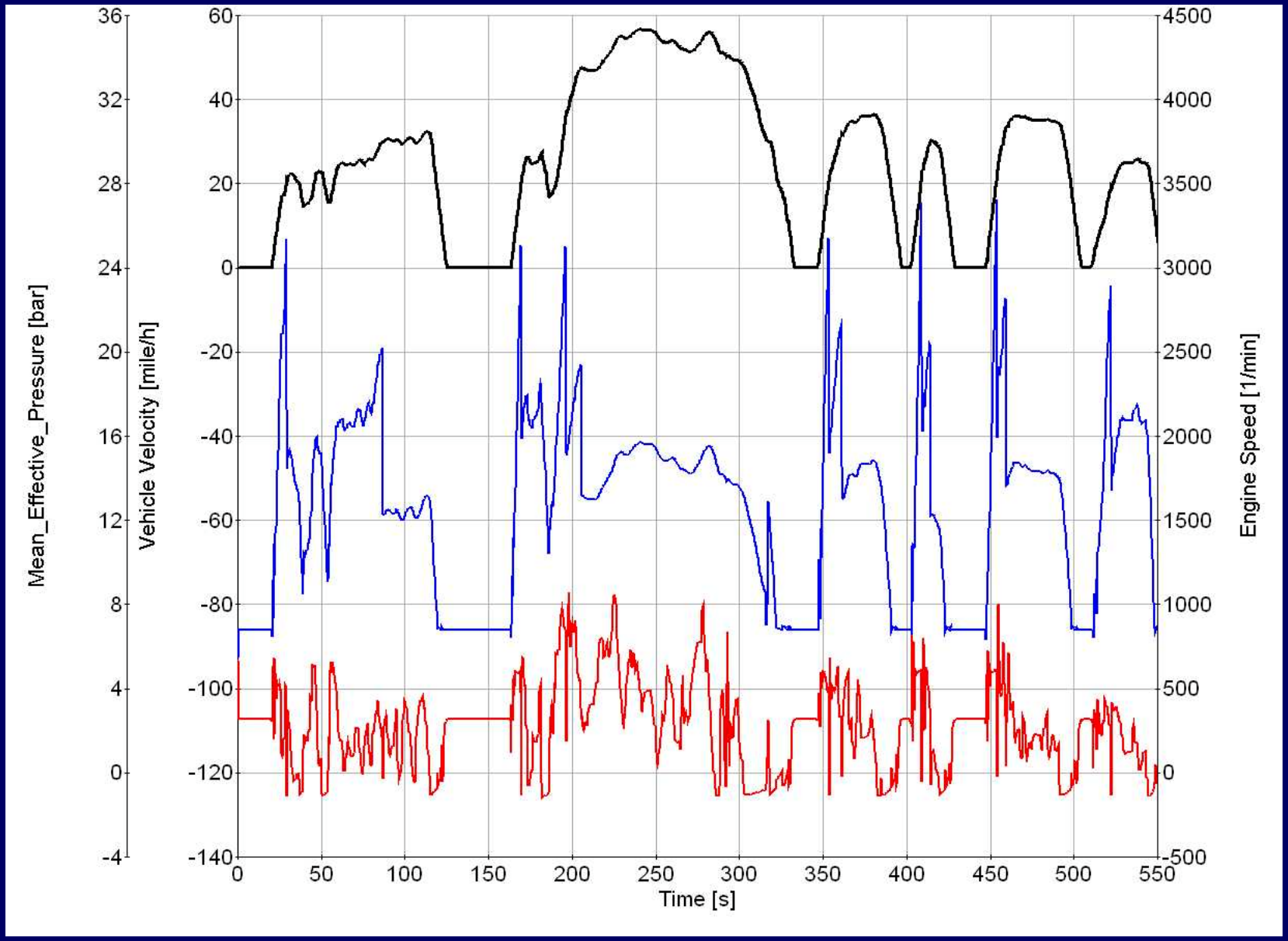
without Slip

Gear Selection Upshifting: According to Speed

Gear Selection Downshifting: According to Speed

- [ ] Tiptronic

CRUISE Vehicle Simulation
Sample Output



Task 1 - Assessment of Individual Technologies

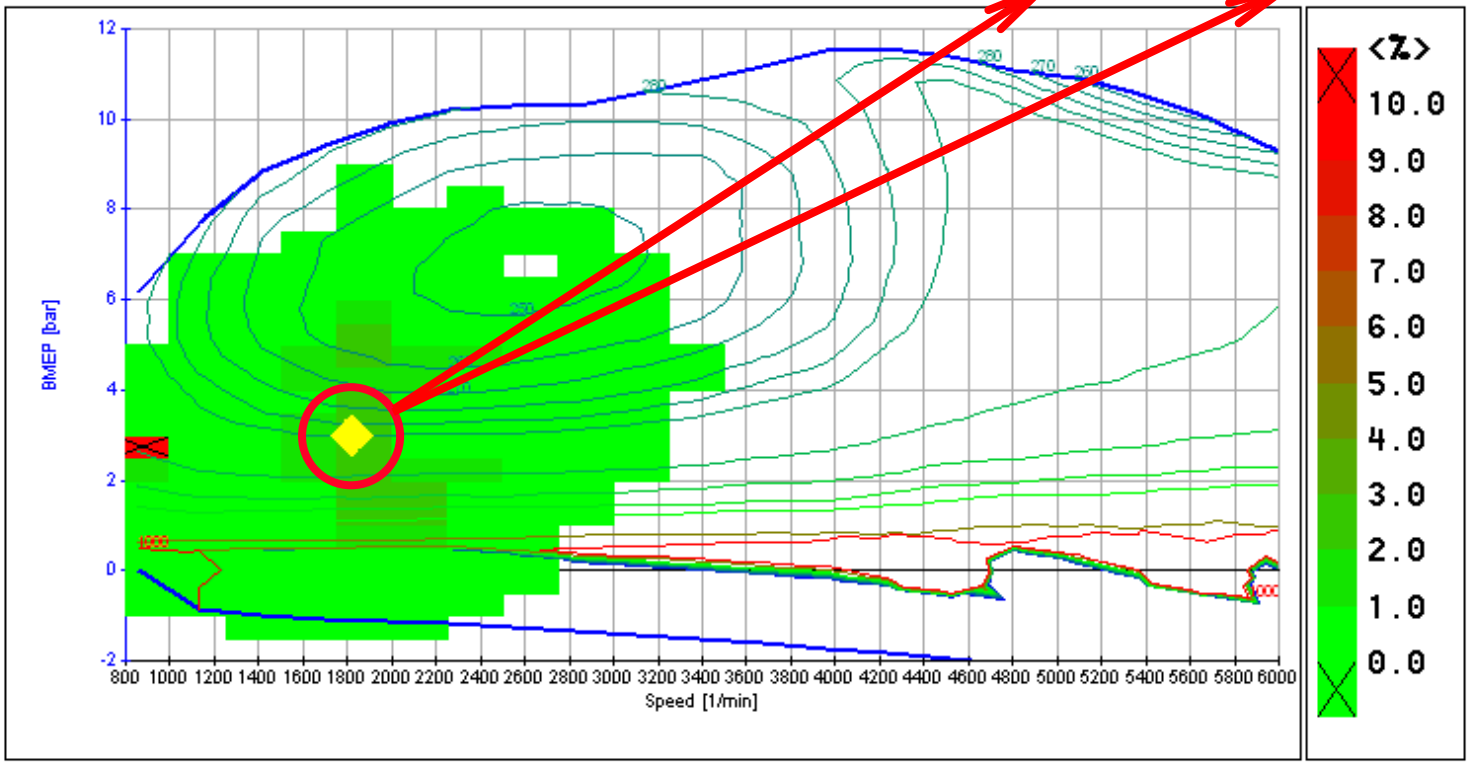
- Who is AVL?
- CRUISE Modeling Process
- **Task 1 - Assessment of Individual Technologies**
- Task 2 - Assessment of Technology Combinations

CRUISE Vehicle Simulation Output - "Single Point" Determination

FTP75 - Distribution of Fuel Consumption in Spec. Consumption Map [g/kWh]

Vehicle Class	Small Car, MY2002, Cavalier
Engine Technology Description	MPFI, 2.2L, DOHC
Driveline Technology Description	4 Speed AT, FWD

Speed	BMEP
[1/min]	[bar]
1819.13	3.14

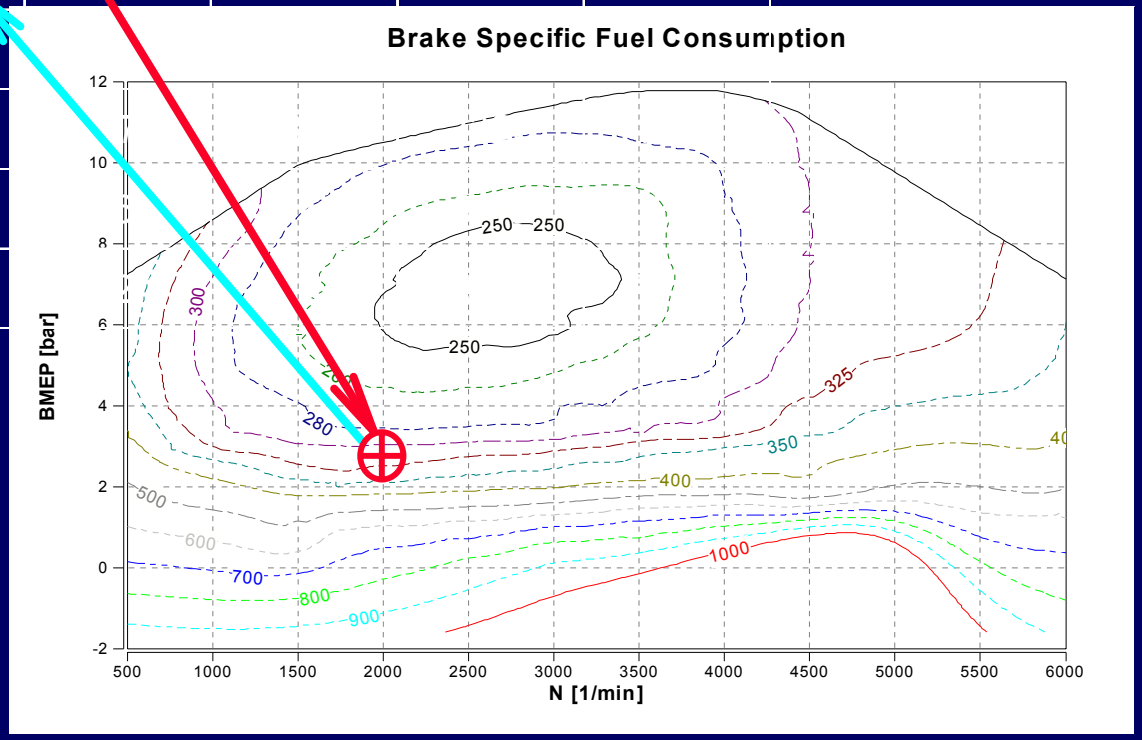


CRUISE Vehicle "Single Point" Matrix

2002 Mule Vehicle Data	Small Car	Large Car	Minivan	Small Truck	Large Truck
FTP 75 Cycle					
Engine Speed [1/min]	1995	2038	1864	1950	1483
Engine Load [bar]	2.74	2.13	2.95	2.72	2.74
CO_2 [g/mi]	319.9	382.9	426.0	456.0	534.8
Highway Cycle					
Engine Speed [1/min]	2188	2179	1837	2325	1526
Engine Load [bar]	3.19	2.63	3.69	3.45	3.70
CO_2 [g/mi]	204.4	242.3	276.0	350.9	391.4

CRUISE "Single Point" Engine Technology Assessment

2002 Mule Vehicle Data	Small Car	Large Car	Minivan	Small Truck	Large Truck
FTP 75 Cycle					
Engine Speed [1/min]	1995	2038	1864	1950	1483
Engine Load [bar]	2.74	2.13	2.95	2.72	2.74
CO_2 [g/mi]	319.9	382.9	426.0	456.0	534.8
Highway Cycle					
Engine Speed [1/min]	2188				
Engine Load [bar]	3.19				
CO_2 [g/mi]	204.4				



Individual Technologies Reduction in Combined CO_2 Emissions

Engine Technology	Small Car	Large Car	Minivan	Small Truck	Large Truck
Cam Phaser - Single (Intake Cam)	-2%	-1%	-1%	-1%	-2%
Cam Phaser - Single (Exhaust Cam)	-2%	-3%	-2%	-2%	-3%
Cam Phaser - Dual	-3%	-4%	-2%	-3%	-4%
Cam Phaser - Coupled	-3%	-4%	-2%	-2%	-4%
Variable Valve Lift - Discrete	-4%	-4%	-3%	-4%	-4%
Variable Valve Lift - Continuous	-5%	-6%	-4%	-5%	-5%
Camless Valve Actuation - Electromagnetic	-11%	-11%	-11%	-11%	-11%
Camless Valve Actuation - Electrohydraulic	-11%	-16%	-11%	-13%	-12%
Turbocharging	-6%	-8%	-6%	-6%	
Cylinder Deactivation	-3%	-6%	-5%	-6%	-4%
Variable Charge Motion (CBR)	-3%	-4%	-2%	-3%	-4%
Variable Compression Ratio	-7%	-7%	-7%	-7%	-7%
GDI Stochiometric	0%	-1%	1%	1%	0%
GDI Lean Burn Stratified	-6%	-9%	-4%	-5%	-8%
Gasoline HCCI	-4%	-6%	-3%	-4%	-5%
Diesel – HSDI	-20%	-22%	-24%	-27%	-23%
Diesel – Advanced Multi-Mode	-13%	-15%	-18%	-21%	-17%

Individual Technologies
Reduction in Combined CO_2 Emissions (2)

Drivetrain Technology	Small Car	Large Car	Minivan	Small Truck	Large Truck
5-Speed Automatic	-2%	-1%	-1%	-1%	-1%
6-Speed Automatic	-3%	-3%	-3%	-3%	-2%
6-Speed Automated Manual	-8%	-7%	-8%	-8%	-5%
5-Speed Manual	-2%			-1%	
Continuously Variable Transmission (CVT)	-4%	-3%	-4%		
42-Volt 10 kW ISG (Start Stop)	-7%	-4%	-4%	-4%	-5%
42-Volt 10 kW ISG (Motor Assist)	-10%	-6%	-6%	-6%	-5%

Note: Full CRUISE Vehicle Simulations Performed on Each Technology

Individual Technologies
Reduction in Combined CO_2 Emissions (3)

Other Vehicle Technology	Small Car	Large Car	Minivan	Small Truck	Large Truck
Electric Power Steering (EPS)	-1%				-1%
Electro-Hydraulic Power Steering (E-HPS)	-1%				-1%
Improved Alternator (Higher efficiency)	-1%				0%
Electric Water Pump (EWP)	0%				0%
Electric Oil Pump (EOP)	0%				0%
Electric Accessories	-3%				-2%
Variable Displacement AC Compressor	-10%	-9%	-7%	-9%	
Aerodynamic Drag Coefficient **(% CO_2 / % Cd)**	0.1649				0.1917
Mass Reduction **(% CO_2 Change / % Mass Change)**	0.5269				0.5708
Lower Tire Rolling Resistance **(% CO_2 / % TRR)**	0.1798				0.2036

Note: Full CRUISE Vehicle Simulations Performed on Each Technology

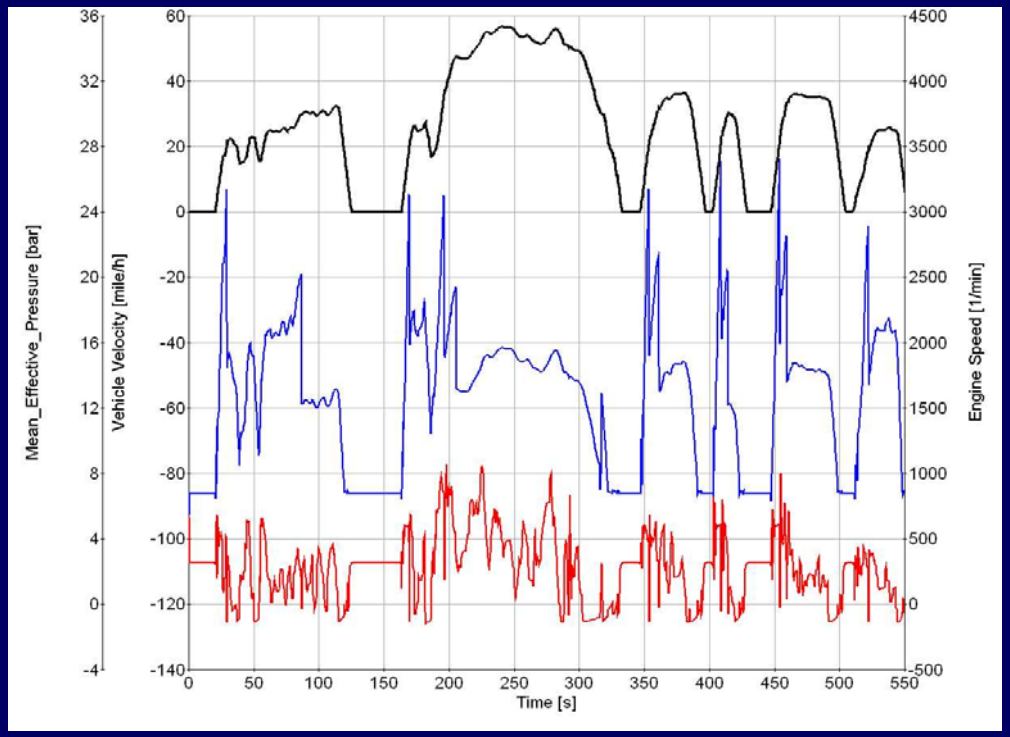
Task 2 - Assessment of Technology Combinations

- Who is AVL?
- CRUISE Modeling Process
- Task 1 - Assessment of Individual Technologies
- **Task 2 - Assessment of Technology Combinations**

2009 MY Vehicle Data Assumptions

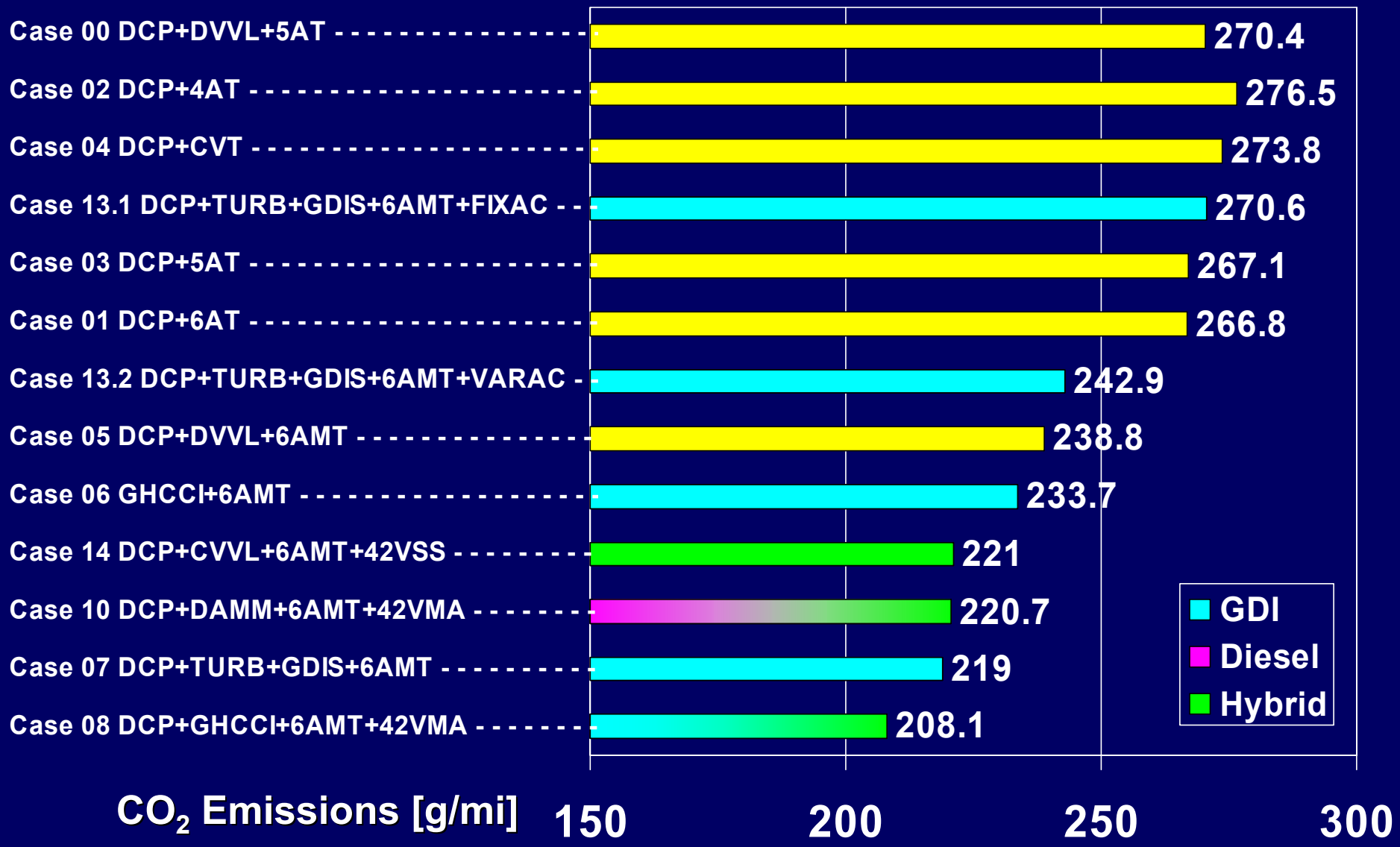
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Equivalent Test Weight [lbm]					
2002 MY	3000	3625	4500	4250	5500
2009 MY	3152	3625	4500	4250	5500
% Change	5.1%	0.0%	0.0%	0.0%	0.0%
0-60 MPH Time [s]					
2002 MY	8.74	8.07	10.48	9.99	8.86
2009 MY	8.08	7.24	9.18	9.23	7.97
% Change	-7.6%	-10.3%	-12.4%	-7.6%	-10.0%
Specific Power [kW/l]					
2002 MY	47.3	49.7	40.6	41.8	40.2
2009 MY	49.5	51.3	46.0	43.8	42.8
% Change	4.7%	3.2%	13.3%	4.8%	6.5%
Combined CO_2 [g/mi]					
2002 MY	277.9	329.2	376.4	425.7	492.6
2009 MY	270.4	306.5	351.0	385.5	464.6
% Change	-2.7%	-6.9%	-6.7%	-9.4%	-5.7%

Simulation of Combined Technologies

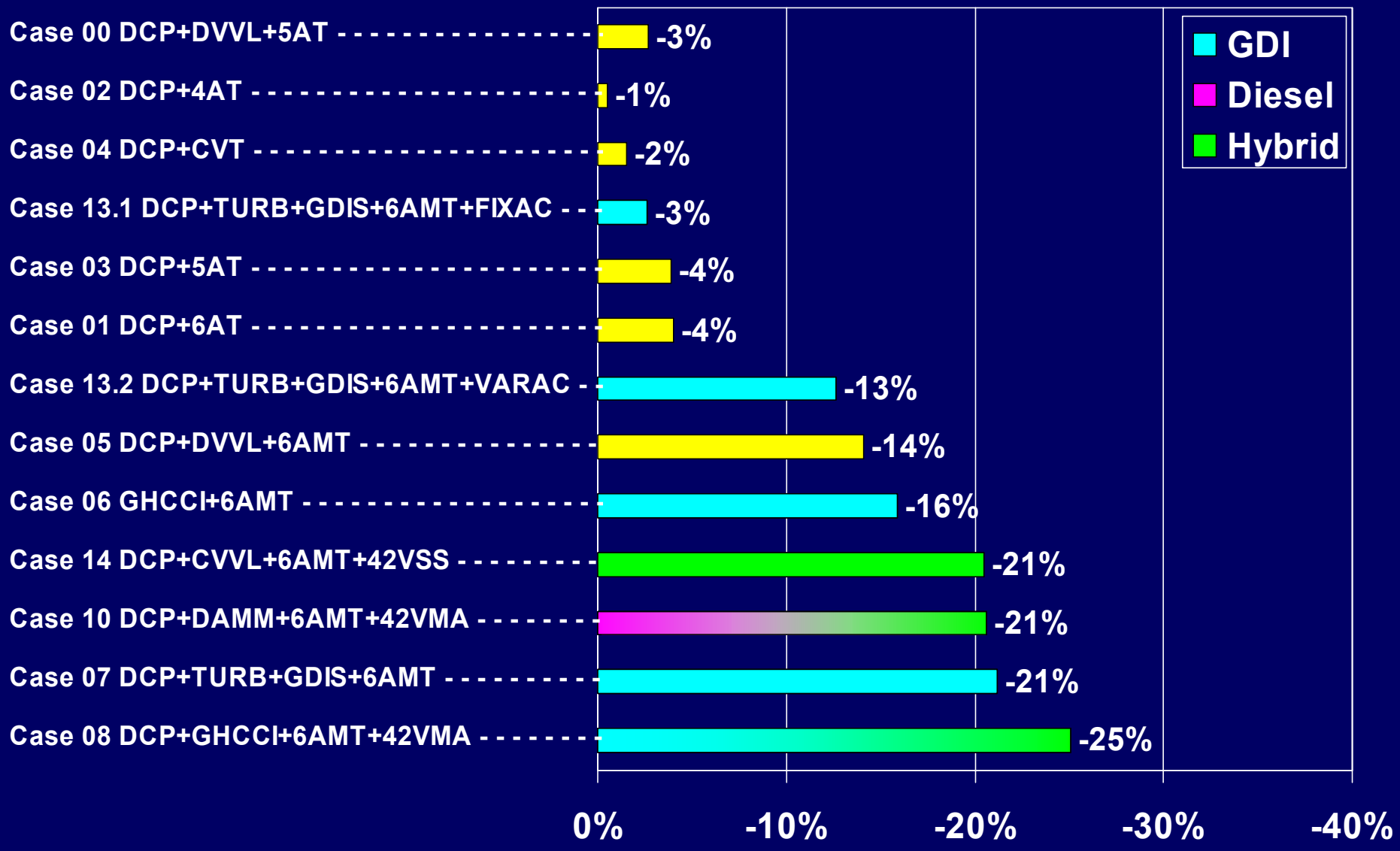


- Selection of Modeled Technologies
- Engine Maps and Full Load Curves Selected
- Engine Displacement and Final Drive Ratio Adjusted to Match 2009 Baseline Performance Levels
- Drivetrain and Engine Selection Determine Engine Operating Point
- CO_2 Emissions a Function of Operating Point and Engine Maps

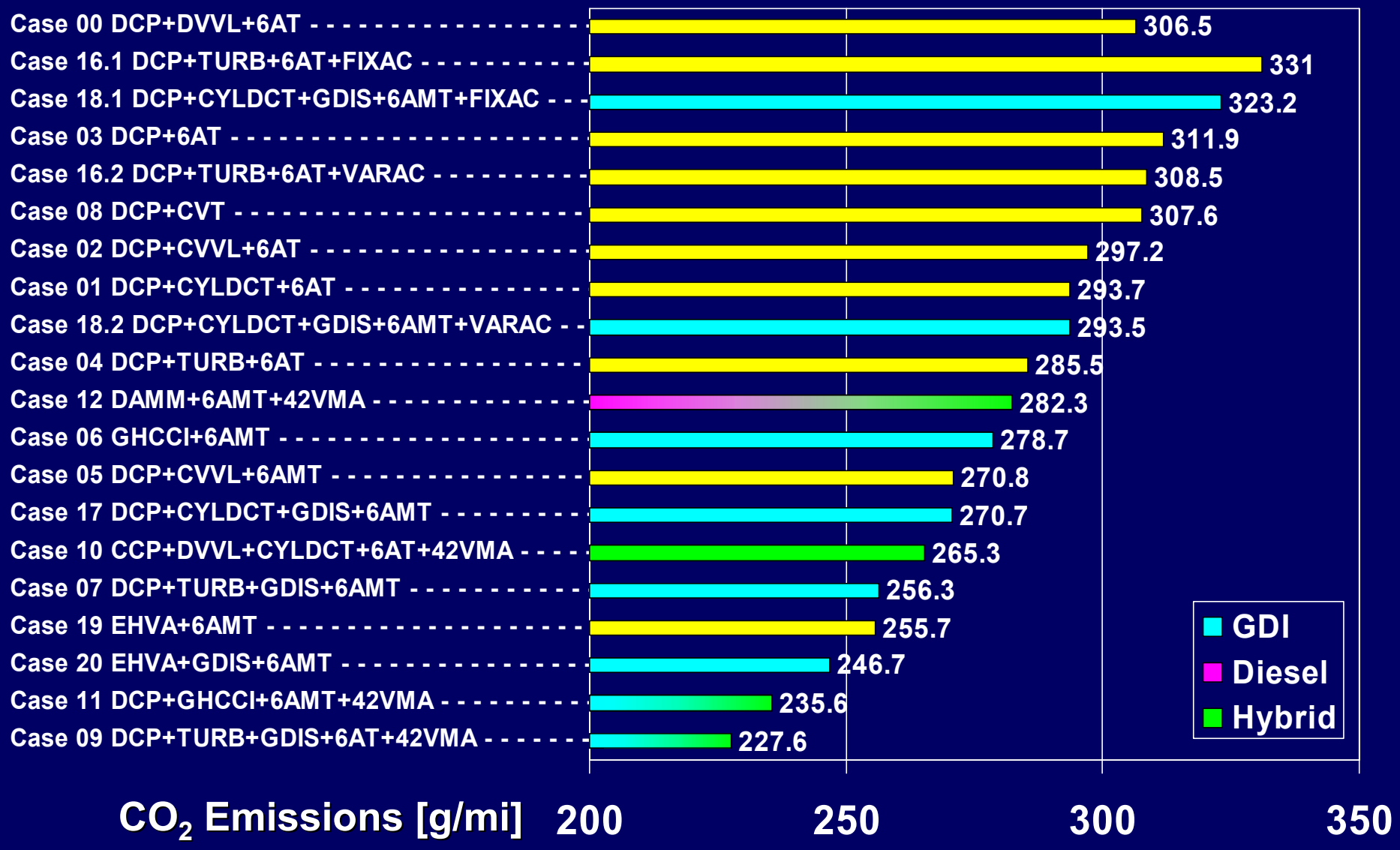
Small Car Combined CO_2 Emissions



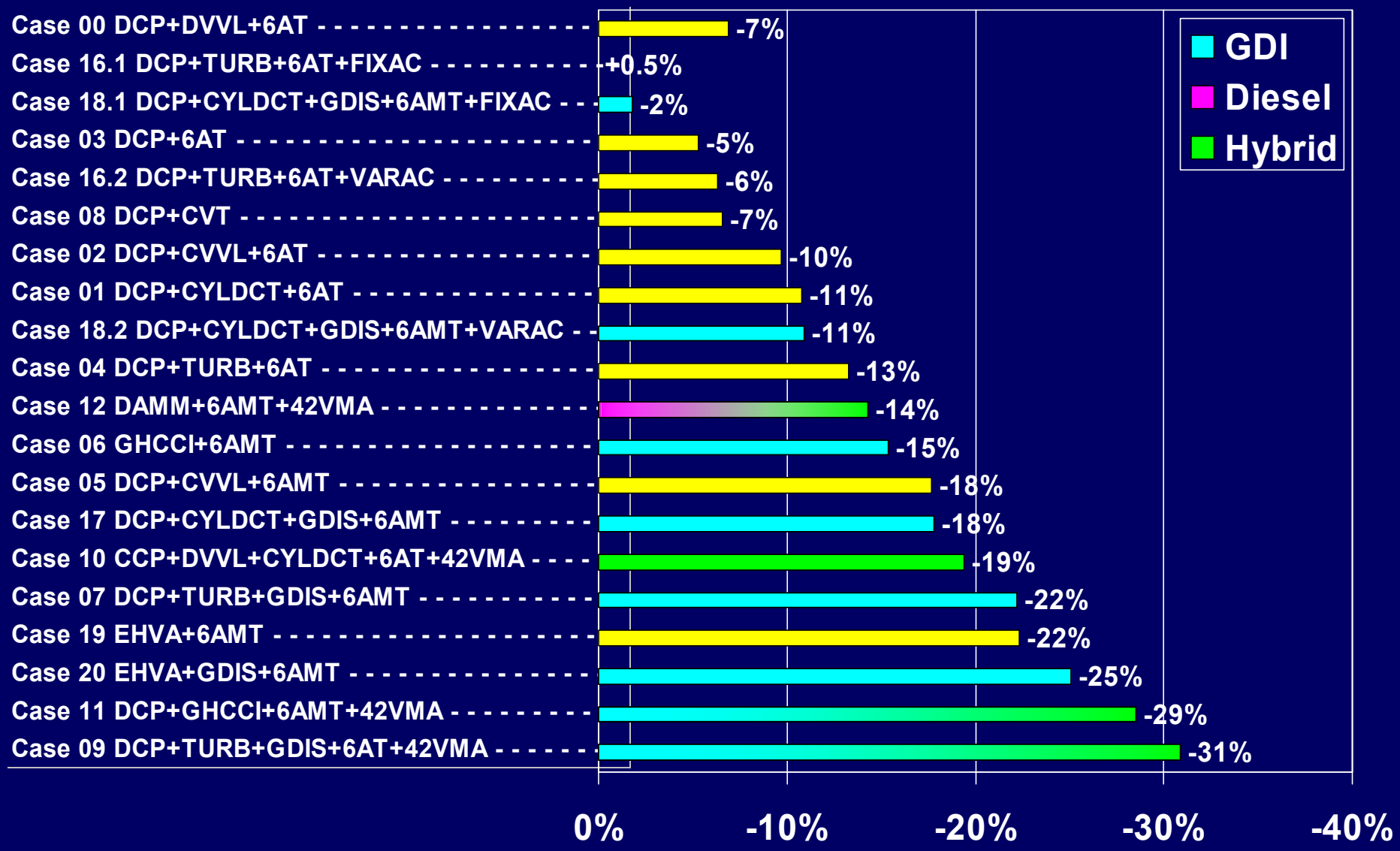
Small Car Reduction in Combined CO_2 Emissions



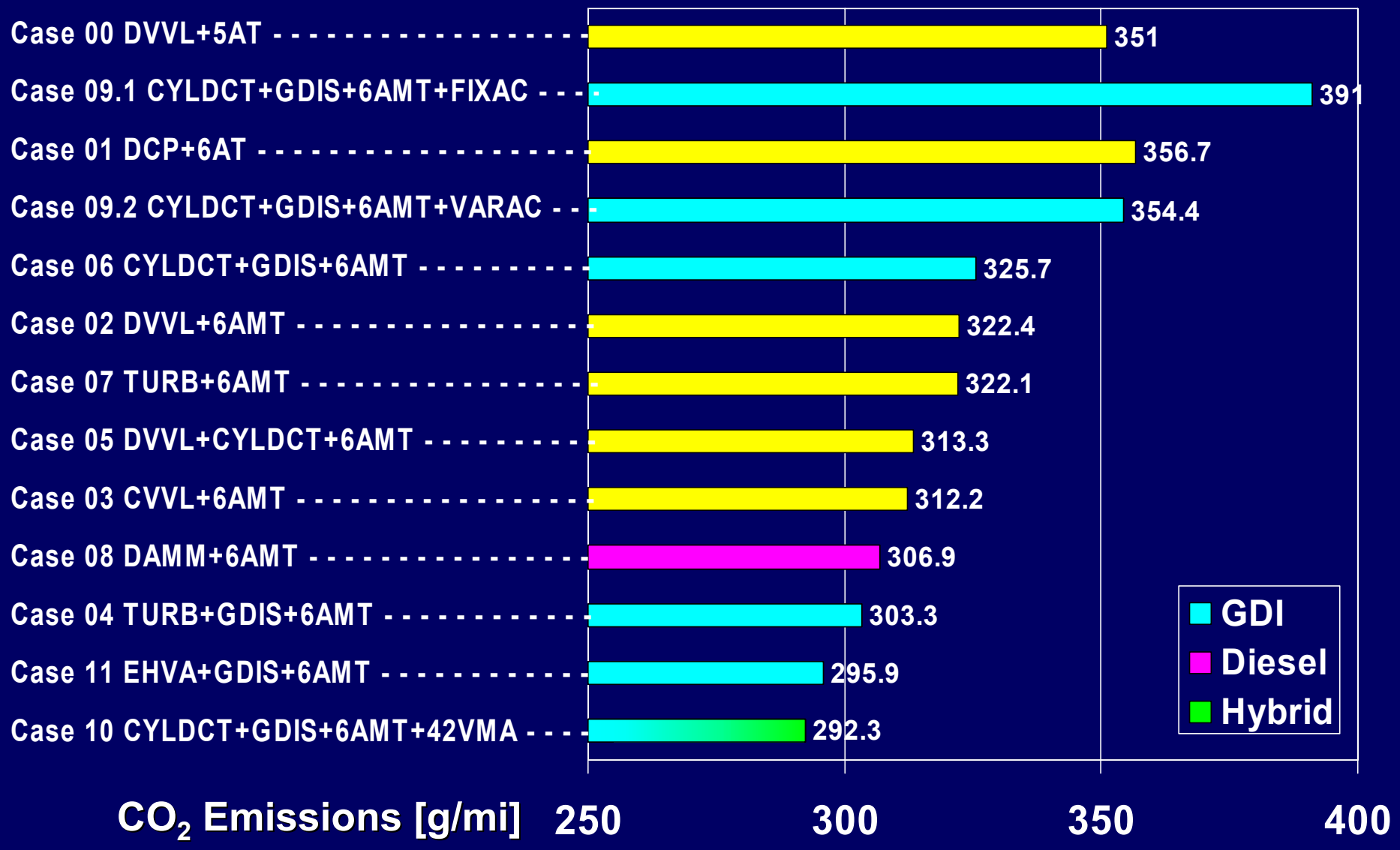
Large Car Combined CO_2 Emissions



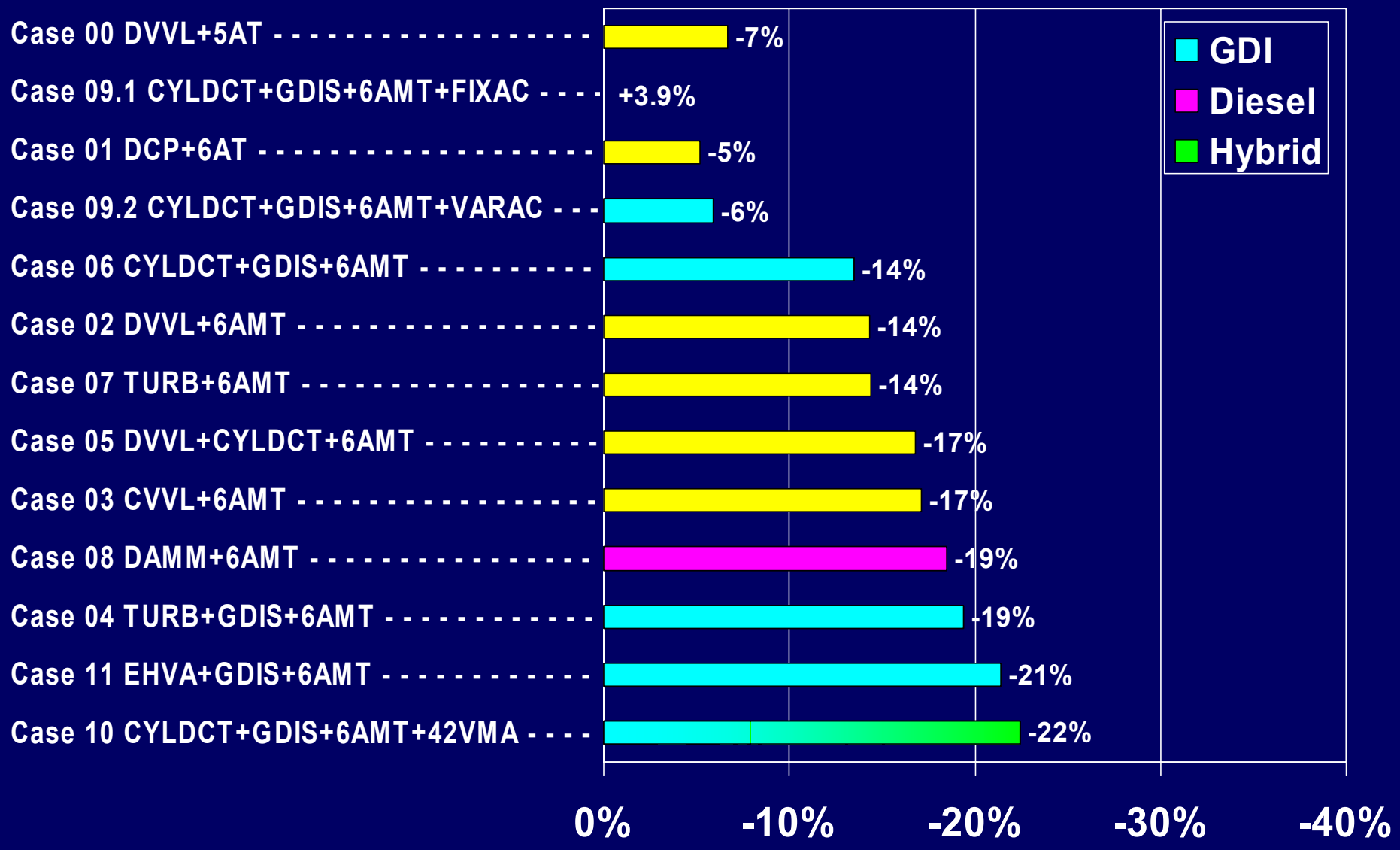
Large Car Reduction in Combined CO_2 Emissions



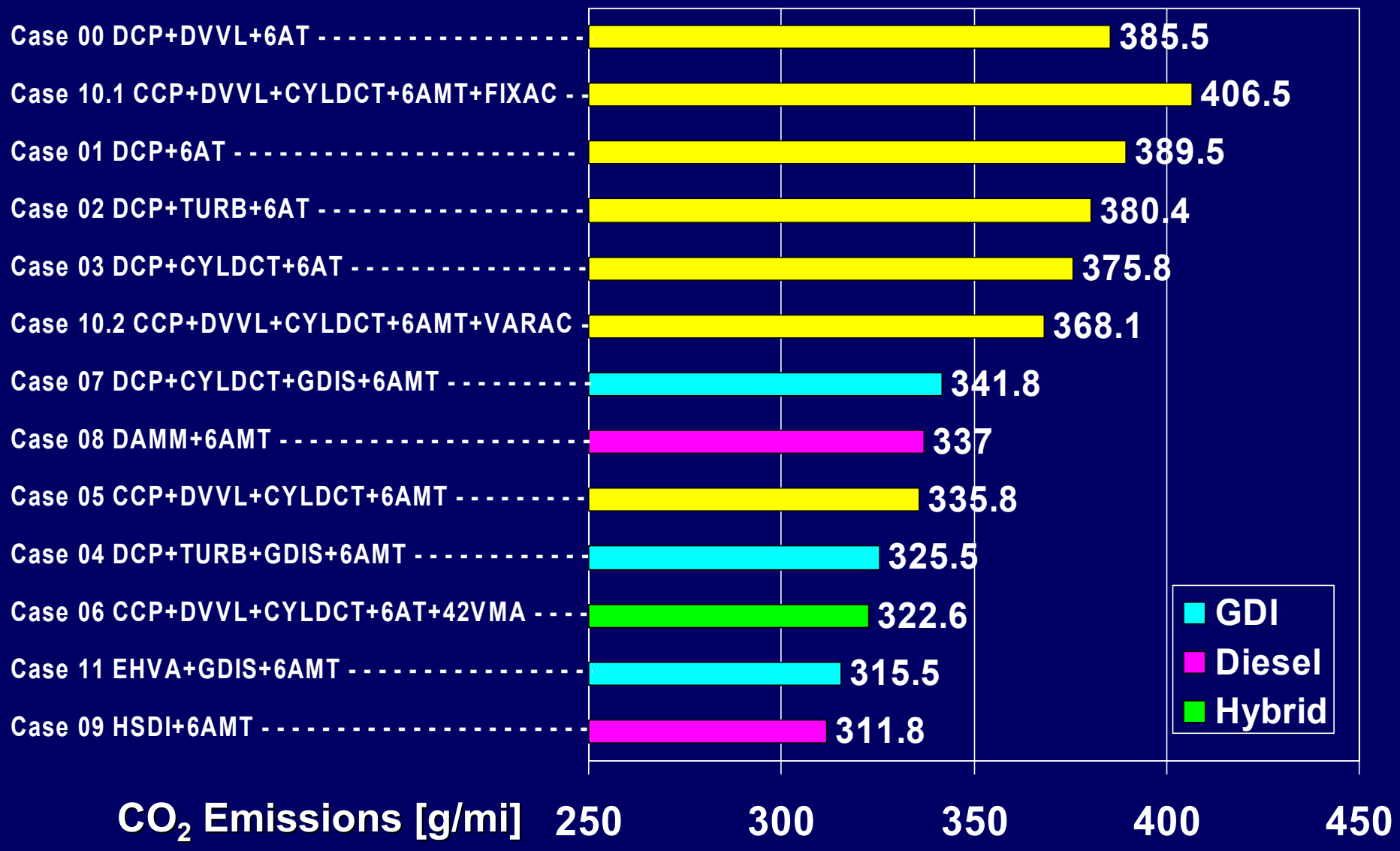
Minivan Combined CO_2 Emissions



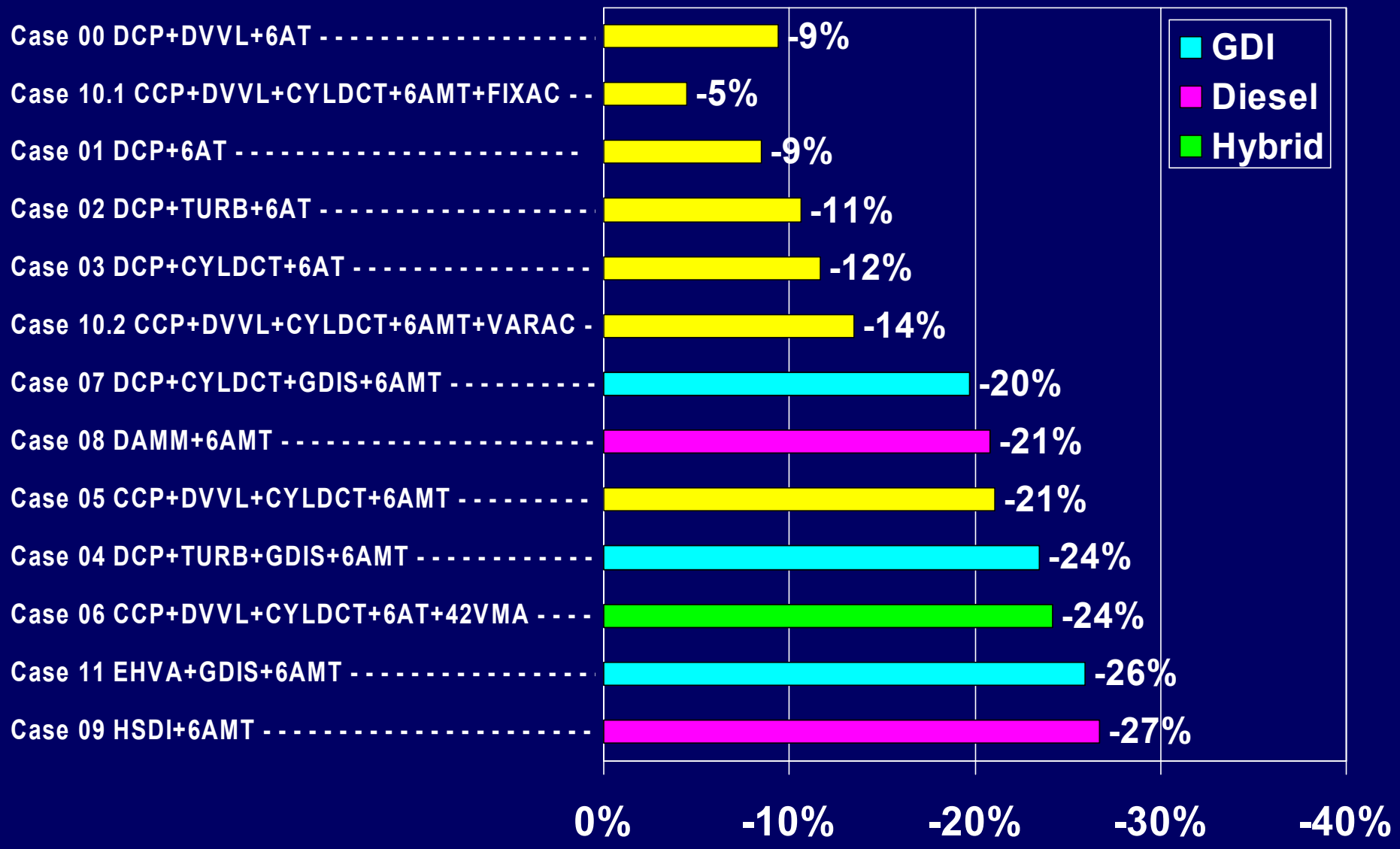
Minivan Reduction in Combined CO_2 Emissions



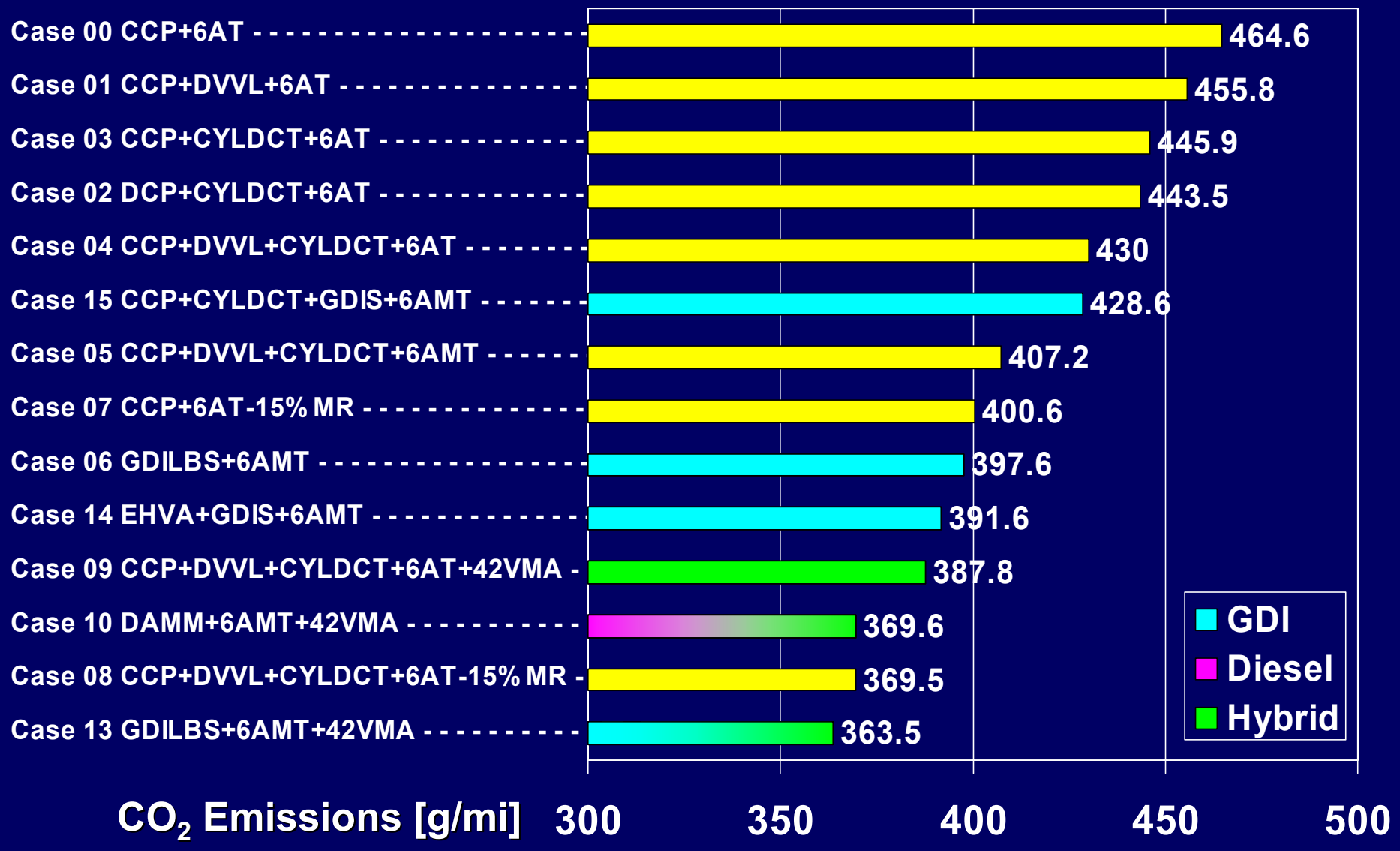
Small Truck Combined CO_2 Emissions



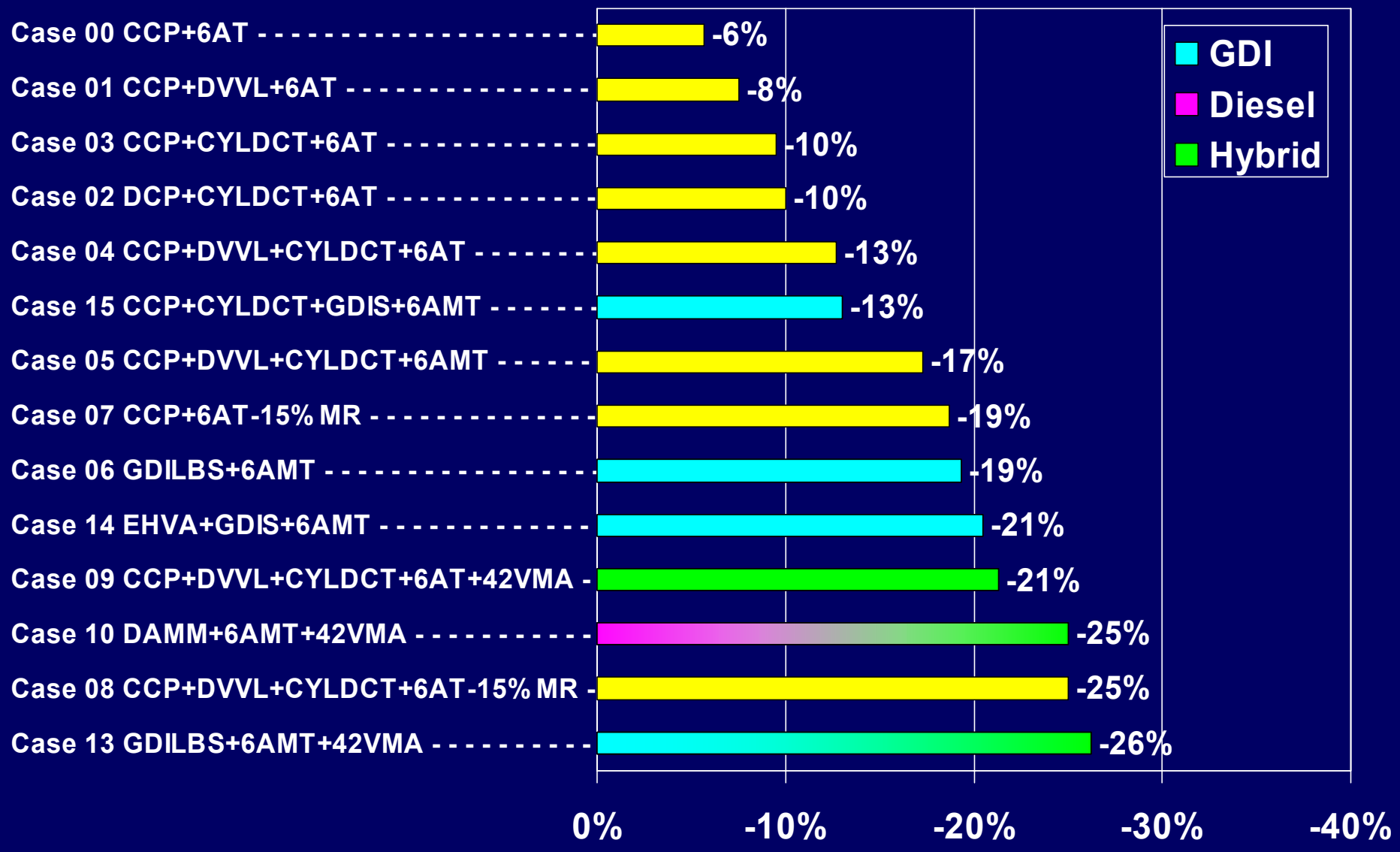
Small Truck Reduction in Combined CO_2 Emissions



Large Truck Combined CO_2 Emissions



Large Truck Reduction in Combined CO_2 Emissions



Contact Information:

Stephen R. Brueckner

AVL Powertrain Engineering, Inc.

47519 Halyard Drive

Plymouth, Michigan 48170-2438

Phone: (734) 414-9630

Fax: (734) 414-9690

E-Mail: stephen.brueckner@avlna.com